# The Belgian Macroseismic Database: Creation, Validation, and its Implications for Engineering Seismology

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# The Belgian Macroseismic Database: Creation, Validation, and its Implications for Engineering Seismology


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Thesis Submitted in Fulfilment of the Requirements of the Degree of Doctor in Engineering Sciences and Technology

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# The Belgian Macroseismic Database: Creation, Validation, and its Implications for Engineering Seismology

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# Summary

For the average citizen in Belgium, earthquakes are perceived as distant events, unlikely to ever affect their daily lives or warrant concern. This perception is supported by the relative absence of significant seismic activity in Belgium over the past 30 years. Such inactivity is not unusual, as Belgian intraplate seismicity is characterized by low to moderate diffuse seismicity with long periods of inactivity. Occasionally, however, large(r) earthquakes have occurred and are likely to occur again, causing damage throughout vast regions in Belgium.

Since 1985, Belgium's instrumental seismic network has been significantly expanded which improved the detection accuracy and earthquake coverage across the country. Due to Belgium's low to moderate seismicity, however, the number of recorded earthquakes remains **limited and unrepresentative** of the long-term seismic activity. To achieve a more comprehensive assessment of the seismic hazard, an additional source of information on the impact of earthquakes is required. This gap can be addressed using **macroseismic intensity data.**

Macroseismic intensity is the classification of the severity of ground shaking at a specific location. It is based only on the observed shaking effects on people and its surroundings. Since the start of the 20$^{th}$ century, the Royal Observatory of Belgium (ROB) has collected an extensive amount of macroseismic data on felt events, offering a rich database which summarizes the impact of seismic events on Belgium. Up until now, however, this wealth of information was not readily available, no comprehensive compilation of collected macroseismic data was provided and information on it was limited and scattered throughout various research papers and projects. Consequently, the main objectives of this PhD research are **to facilitate and promote the use of Belgian macroseismic data** in future applications towards seismic hazard assessments and real-time impact monitoring. This was accomplished through:

1) The publication of the **Belgian Traditional Macroseismic (BTM) database**, a comprehensive compilation of 20th-century macroseismic data including 23,950 intensity data points (IDPs) for 80 felt events (Neefs et al. 2024a, 2024b).
2) The publication of the **Belgian Online Macroseismic (BOM) database**, providing a first compilation of online collected macroseismic intensity data since 2002, with 1,220 IDPs for 39 felt events.
3) Illustrating the potential of Belgian macroseismic data, through an evaluation of the predictions provided by the most recent Belgian seismic hazard model with observed intensities, and through an evaluation of the performance of various Intensity Prediction Equations (IPEs) on the observed intensity attenuation rate.

The macroseismic **survey methodologies** that provided the data incorporated in the BTM and BOM databases are described in detail in this dissertation: from small-scale improvised surveys to the systematic mass-distribution of communal questionnaires and the online volunteer-based "Did You Feel It?" inquiries which, in practice, have replaced traditional macroseismic surveys in Belgium. These various macroseismic methodologies and sources are subjected to a **critical review of their quality**, illustrating the considerable extent of their associated uncertainties. To ensure the continuation of

the collection of both traditional and online macroseismic surveys and to reduce their uncertainties in the future, new survey methodologies are suggested.

Both databases combined provide a detailed summary of the **impact of 125 years of seismic activity** on Belgium. The maximum intensity registered is intensity 7 on the European Macroseismic Scale (EMS-98), with widespread damage in the affected localities where this intensity was observed. The earthquakes with the largest impact on Belgium in this time span are the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake, the $M_L$ = 5.1 Liège 1983 earthquake and the recurring shallow, small to moderate and triggered earthquakes in the Hainaut coal basin throughout most of the 20th century.

The information in the BTM and BOM databases allow evaluating possible limitations on the current seismic hazard assessment of Belgium. This evaluation indicates that the predicted values align with the macroseismic observations, providing **a validation of the Belgian seismic hazard map**. However, as only limited data on local site effects from seismic station locations and their unconstrained share in amplification effects was used, large-scale site effects mapping is needed to extrapolate these finding throughout Belgium.

Finally, the performances of various selected IPEs are compared with observed intensity attenuation rates. This evaluation illustrates that earthquake source depths are the main variable that determines IPE performances. Several IPEs are suggested to model the attenuation rates of Belgian earthquakes: the IPE by Camelbeeck et al. (2022) is best fit for shallow earthquakes, with focal depths lower than 10 km, even outside the Hainaut coal basin for which this IPE was developed. For deep(er) earthquakes, with focal depths equal to or greater than 10 km, the "*chi-square regression"* model by Stromeyer and Grünthal (2009) and the *"French stable continental region"* by Bakun and Scotti (2006) provide the best attenuation rates.

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# 1. Introduction

## 1.1. Macroseismology

### 1.1.1. Macroseismic intensity

An earthquake is the result of a sudden release of accumulated stress along a fault within the earth's lithosphere. This release of energy is accompanied by the generation of seismic waves that propagate through the earth in all directions. When these waves reach the surface, they shake the ground and everything on it. Seismic instruments record these waves, allowing for a very accurate determination of the ground motion. However, these instruments have not always been available, as dense regional seismic networks started to develop since the 1960's and 1970's only (Lay and Wallace 1995). Even within these regions with dense modern seismic networks, gaps in the instrumental coverage to characterize local ground motions remain. Apart from seismic instruments, also people are able to register ground motions; from the slightest vibrations felt while being seated on the couch to being forcefully thrown to ground, or from the gentle swaying of a chandelier to the collapse of an entire appartement building wall. These perceptions and observations of the earthquake effects on our surroundings do not allow for an accurate quantitative measure, but they can serve as indicators of the approximate strength of shaking. The more severe the observed effects, the stronger the ground movement. Seismologists can say with great confidence that if an earthquake caused masonry buildings to collapse in location A, while only few people felt the same earthquake in location B, that the ground movement in location A was greater than location B.

To more easily identify and compare the severity of earthquake effects between different locations, values are assigned to observed earthquake effects, i.e. macroseismic intensities. **Macroseismic intensity** is an integer value that represents a specific degree of earthquake shaking. Instead of describing the full impact an earthquake had to a location, as for example: *"many people were frightened by the earthquake and ran to the streets, a few even lost their balance and fell. Books, flowerpots and small ornaments were displaced or thrown to the ground, while chairs and tables were displaced. Cracks formed in the walls of some buildings and even a few chimneys collapsed"*, a single intensity value can be attributed to this location that summarizes the range of the earthquake effects that were observed, e.g.: "*6*". Intensity values were traditionally depicted as roman numerals to emphasise their integer nature. Nowadays, roman numerals are much harder to process digitally, and Arabic numerals are more often used. Macroseismic intensity is purely a descriptive parameter and does not rely on physical measurements. The term 'macroseismic' pertains to only the perceptible effects of an earthquake and strictly excludes instrumental seismic data.

### 1.1.2. Macroseismic intensity scales

An intensity value should always be expressed on a specific macroseismic intensity scale. Most intensity scales are arbitrarily defined classifications of ground shaking. Each degree on an intensity scale consists of a set of earthquake effects that are all equivalent to the same severity of shaking. Each earthquake effect included on a macroseismic scale is seen as a diagnostic for a specific intensity. For example, a few frightened people trying to run outdoors, is considered a diagnostic for intensity 5 on the European Macroseismic scale (EMS-98, Grünthal 1998). If no one runs outdoors, intensity is likely to be 4 or lower, while if most or all run outdoors, intensity is likely to be intensity 6 or higher. It should be stressed, that classifying an intensity degree based on a single observation is considered bad practice, and a decision should be made by comparing all available observations with the diagnostics of the chosen intensity scale, to provide the best fit. To maximise the applicability of an intensity scale, earthquake effects included in each degree should concern everyday things that are commonly found in a wide variety of environments. Each effect can be attributed to one of the following four sensors: 1) people and animals, 2) objects, 3) buildings and 4) the natural environment. These sensors are chosen as their response to the earthquake helps measuring/identifying the strength of shaking. With increasing degrees of intensity, different sensors become more important. At low intensities, people's perceptions and effects on small, everyday objects are the main sensors. At higher intensities, buildings, and the degree of damage they endured, are often the only usable sensors. If everyone loses their balance and all objects are thrown to the ground, the sensors 'people' and 'objects' can be considered as saturated. The natural environment is not commonly used as a sensor, as it is often seen as less reliable than the other sensors (Grünthal 1998) but can be of use in sparsely or unpopulated areas or at the highest intensities (Michetti et al. 2007).

Throughout the last 150 years, hundreds of intensity scales have been developed and published, with even more to come (e.g. Wald et al. 2024). Fortunately, only a handful of scales have been commonly used. The most impactful macroseismic intensity scales are discussed chronologically in the following paragraphs.

The first widely adopted internationally intensity scale is the **Rossi-Forel scale** (de Rossi 1883; Forel 1884). This scale was developed in agreement between the Italian Michele Stefano de Rossi and the Swiss Francois Alphonse Forel, as a compromise between both scientist's individual scales which were developed prior to the Rossi-Forel scale (de Rossi 1874; Forel 1881). Before the Rossi-Forel scale, multiple intensity scales had already been in use, but none were used by anyone other than their authors (Gisler et al. 2008). Others were designed to classify earthquake effects for individual earthquakes only (Davison 1927). The Rossi-Forel scale is the first one with general approval and was used to compare the impact of earthquakes all over the world on an internationally approved scale. The scale consists of 10 intensity degrees and contains many elements that are still used in modern intensity scales (**Table 1**).

***Table 1 :*** *The Rossi-Forel scale (de Rossi 1883; Forel 1884), translated from French to English by Davison (1921) from Forel (1884).*

| Intensity | Definitions of the Rossi-Forel scale (de Rossi 1883; Forel 1884) |
|---|---|
| **1** | Recorded by a single seismograph, or by some seismographs of the same pattern, but not by several seismographs of different kinds; the shock felt by an experienced observer. |
| **2** | Recorded by seismographs of different kinds; felt by a small number of persons at rest. |
| **3** | Felt by several persons at rest; strong enough for the duration or direction to be appreciable. |
| **4** | Felt by several persons in motion; disturbance of movable objects, doors, windows; creaking of floors. |
| **5** | Felt generally by everyone; disturbance of furniture and beds; ringing of some bells. |
| **6** | General awakening of those asleep; general ringing of bells; oscillation of chandeliers, stopping of clocks; visible disturbance of trees and shrubs; some startled persons leave their dwellings. |
| **7** | Overthrow of movable objects, fall of plaster, ringing of church bells, general panic, without damage to buildings. |
| **8** | Fall of chimneys, cracks in the walls of buildings. |
| **9** | Partial or total destruction of some buildings. |
| **10** | Great disasters, ruins, disturbance of strata, fissures in the earth's crust, rock-falls from mountains. |

The Italian Giuseppe **Mercalli** is a well-known name in the world of macroseismology and many intensity scales have been named after him. Mercalli is the author of two separate scales, that are both modifications from the Rossi-Forel scale. His first scale (Mercalli 1883) was a simplified version of the Rossi-Forel scale, with only 6 degrees. The second scale (Mercalli 1902) consists of 10 degrees and extends the definitions, including more diagnostics for each degree than what was included in the original scale (**Table 2**). This second version included names for each degree and was generally considered as an improvement to the Rossi-Forel scale and found favour with its users (Davison 1921). The name Mercalli is often used as a synonym to macroseismic intensity and other common incorrect remarks can be found on this figure, such as claiming Mercalli to be the inventor of macroseismic intensity scales (Musson et al. 2010).

***Table 2 :*** *The Mercalli scale (Mercalli 1902), translated from Italian to English by Davison (1921). The names of each degree are added in bold.*

| Intensity | Definitions of the Mercalli scale (Mercalli 1902) |
|---|---|
| **1** | **Instrumental shock**, reported by seismic instruments only. |
| **2** | **Very slight**, felt only by a few people in a perfectly quiet condition, especially on the upper floors of houses, or by very sensitive and nervous people. |
| **3** | **Slight**, felt by several people, but by few relatively to the number of inhabitants in a given place, said by them to have been hardly felt, without causing any alarm, and in general without their recognizing it as an earthquake until it was known that others had also felt it. |
| **4** | **Moderate**, not felt generally, but by many people indoors, though by few on the ground floor, without causing alarm, but with shaking of windows, crystals, creaking of floors, and slight oscillation of suspended objects |
| **5** | **Rather strong**, felt generally indoors, but by few outside, with waking of those asleep, with alarm of some people, rattling of doors, ringing of bells, rather large oscillation of suspended objects, stopping of clocks. |
| **6** | **Strong**, felt by everyone indoors, and by many with alarm and flight into the open air; fall of objects in houses, fall of plaster, with some cracks in badly built houses. |
| **7** | **Very strong**, felt with general alarm and flight from houses, sensible also outdoors, ringing of church bells, fall of chimneypots and tiles, cracks in numerous buildings, but generally slight. |
| **8** | **Ruinous**, felt with great alarm, partial ruin of some houses and frequent and considerable cracks in others, without loss of life or only with a few cases of personal injury. |
| **9** | **Disastrous**, with complete or nearly complete ruin of some houses and serious cracks in many others, so as to render them uninhabitable; a few lives lost in different parts of populous places. |
| **10** | **Very disastrous**, with ruin of many buildings and great loss of life, cracks in the ground, landslips from mountains, etc. |

The **Cancani scale** (1904) by the Italian Adolfo Cancani can hardly be called a macroseismic intensity scale, but it had a significant impact on the development of most major intensity scales ever since. Cancani did not name his scale after himself but published it as the Forel-Mercalli scale. Naming a new intensity scale after the authors of a previous intensity scale has occurred on multiple occasions in the history of intensity scales, with the consequence that publications sometimes refer to the wrong scale. To limit confusion, it is much better to refer to a new scale by its author, wherever possible (Davison 1921; Musson et al. 2010). Cancani (1904) attributed to each intensity value quantitative ground acceleration value ranges. He reckoned that intensity 10 corresponded to a maximum of 2500 mm/s², and to be able to include stronger earthquakes, such as experienced in Japan or South America where ground acceleration could reach 10 000 mm/s², two additional values were necessary. The Cancani scale only provides the names of each degree and its corresponding ground acceleration value range. Without any descriptive definitions of the earthquake effects, it is not usable as a macroseismic intensity scale (**Table 3**). Nonetheless, most authors of new intensity scales followed the proposal by Cancani (1904) and included twelve degrees in their scales.

***Table 3 :*** *The Cancani scale (Cancani 1904), translated from French to English.*

| Intensity | Name | Acceleration (mm/s$^2$) |
|---|---|---|
| **1** | Instrumental | 0 - 2.5 |
| **2** | Very slight | 2.5 - 5 |
| **3** | Slight | 5 - 10 |
| **4** | Sensible or moderate | 10 - 25 |
| **5** | Rather strong | 25 - 50 |
| **6** | Strong | 50 - 100 |
| **7** | Very strong | 100 - 250 |
| **8** | Ruinous | 250 - 500 |
| **9** | Disastrous | 500 - 1000 |
| **10** | Very disastrous | 1000 - 2500 |
| **11** | Catastrophic | 2500 - 5000 |
| **12** | Very catastrophic | 5000 - 10000 |

The next major development was the intensity scale by the German August Sieberg (1912), who greatly expanded the number of diagnostics included with each degree (SI 10.1.1). The **Sieberg scale** was the first to incorporate the different strengths of buildings around the world, which was influenced by his experience as a professional architectural engineer and his many visits to earthquake sites. The extensiveness of the Sieberg scale also made it much more complex to apply and could lead to consistency issues, as the many diagnostics described for a single intensity degree could be linked to slightly different degrees of ground shaking. Sieberg (1912) called his scale a further development of the scale of Mercalli (1902), in accordance with Cancani's (1904) suggestion. In a later version, Sieberg (1923) slightly modifies his scale, mainly focussing on intensity degrees 6 and 7 (Musson et al. 2010), and becomes known as the Mercalli-Cancani scale as formulated by Sieberg or the **Mercalli-Cancani-Sieberg (MCS-23) scale**. The MCS-23 scale has had a major influence on many later macroseismic intensity scales (Musson and Cecić 2012).

Wood and Neumann (1931) modified and condensed the MCS-23 scale (Sieberg 1923), and they decided to call their scale the **Modified Mercalli intensity scale of 1931** (**MM-31**; SI 10.1.2). This scale was widely adopted, in particular in the United States of America (Hough 2025). Instead of combining the various diagnostics in a coherent text, this scale lists a multitude of possible earthquake effects for each intensity degree. Doing so, many details are lost to its users that nuanced the diagnostics of the MCS-23 scale (Musson et al. 2010). Wood and Neumann also provided a shortened version of their scale, outlining the principal features of each intensity degree. When Charles Richter suggested his own macroseismic scale, he realized that calling it the Richter scale was not an option. The 'Richter scale' is widely used as a synonym for the local magnitude scale ($M_L$). Instead, Richter decided to call his macroseismic intensity scale the **Modified Mercalli intensity scale of 1956** (**MM-56**; Richter 1958), causing even more confusion. To avoid confusion here and for the sake of consistency, the Modified Mercalli intensity scale of 1931 by Wood and Neumann (1931) will be referred to as the **Wood-Neumann scale**. The Modified Mercalli intensity scale of 1956, however, will not be referred to as the Richter scale here, but as the MM-56 scale, as there is no need to invent yet another name and add to the confusion. The year of publication or development is added to a scale if multiple versions of it have been published.

The **MM-56 scale** reduces the complexity of the Wood-Neumann scale by taking out many of its diagnostics. Especially the lower intensities have been limited to only a few diagnostics for each intensity degree. The MM-56 scale is also the first to introduce a qualitative approach to describe damage to buildings, by defining four different classes of masonry buildings based on their perceived vulnerability to lateral forces (**Table 5**). Damage to buildings is thus defined in function of these classes. Intensity 8 on the MM-56 scale has, for example: 'Partial collapse to masonry C', 'some damage to masonry B' and 'none to masonry A'. Medvedev et al. (1964) applied a similar qualitative classification in their new scale to assess the strength of different buildings, based mainly on its construction materials. The **Medvedev-Sponheuer-Kárník intensity scale of 1964** (**MSK-64**; SI 10.1.3) was based on the work of Sieberg (1923), Wood and Neumann (1931) and an earlier scale from Medvedev himself, and it introduced a classification of five classes of damage (slight, moderate, severe, destructive and total collapse). Next to this qualitative approach, the MSK-64 scale included a quantitative approach, by attributing rough percentages to terms that have been used frequently throughout all macroseismic intensity scales before: *'Single'* or *'few'* equals to about 5%, *'many'* to about 50% and *'most'* to about 75%.

In the MSK-64 scale, earthquake effects are arranged according to the different sensors, which Medvedev et al. (1964) define as: a) Persons and surroundings; b) Structures of all kinds; and c) Nature. This scale was widely adopted in Europe, but after a while, seismologists and engineers were adopting unofficial modifications while practicing the scale. This need for new improvements, especially for new construction techniques, is what led to the establishment of the 1998 **European Macroseismic Scale** (**EMS-98**; Grünthal 1998). The EMS-98 resembles the MSK-64 scale in many ways: it includes a classification on building strength or vulnerability and a classification of damage degrees, as well as quantitative definition of terms such as 'few', 'many' and 'most'. The improvement with the EMS-98 (SI 10.1.4) is due to the inclusion of new types of buildings (such as earthquake-resistant design buildings), extensive guidelines, illustrations and application examples to reduce misapplication, but also general improvements to increase the clarity of the scale. This scale fundamentally advanced the science of macroseismology and became widely adopted by many European countries, where it is the most common scale in use nowadays. Currently, efforts are made to define yet a new intensity scale: the **International Macroseismic Scale** (**IMS**; Wald et al. 2024). The IMS aims to expand and adjust the vulnerability class and damage degree tables from the EMS-98 by incorporating new structures and damage degrees that are not well represented in their current form. Wald et al. (2024) focus primarily on New Zealand and the United States of America but aim to leave a paper trail by documenting and standardizing their process for new regional or national implementations, thereby advancing slowly towards a truly international macroseismic scale.

All these previous macroseismic scales, except for the Cancani scale, are examples of arbitrary scales: the transition from one intensity degree to another is arbitrarily defined by its authors, who decide what diagnostic becomes associated with what degree. Absolute scales, such as the Cancani scale, are classifications of intensities based on instrumental recordings. The most well-known example is the **'Japan Meteorological Agency' (JMA) scale** (JMA 2009), an originally seven-degree scale that defines its intensities by peak ground acceleration ranges. Each intensity on the JMA scale is provided with earthquake observations that are considered diagnostics for each range. Routine practice in Japan is to determine intensities based primarily on strong-motion instruments, and the scale can be seen as a guide to what effects might have taken place at the location of said instrument (Musson and Cecić 2012).

Many arbitrary scales are, perhaps surprisingly, not widely different to one another. In fact, most arbitrary scales discussed previously are twelve-degree scales and are practically interchangeable: the differences between assigned intensities by different experts that are provided with the same macroseismic information, are greater than the differences between the same expert assigning intensities on different scales (Musson et al. 2010). These similar twelve-degreed intensity scales (e.g. Sieberg scale, MCS-23, Wood and Neumann scale, MM-56, MSK-64, EMS-98) are part of the same group, called the *Cancani family*, after Cancani's proposal in 1904 (Cancani 1904; Musson et al. 2010). One could question the need for new intensity scales within the Cancani family after learning this fact. Yet their goal was never to change the definitions of what each intensity degree meant, but to improve the procedure of intensity assignments. Intensity scale changes took place in the form of improvements towards applicability (e.g. the inclusion of different construction materials for buildings or increasing/reducing the number of diagnostics), consistency (e.g. including building vulnerability classifications to express that not all buildings need the same intensity to suffer a certain amount of damage), or minimizing the influence of subjective bias (e.g. quantitatively defining terms such as few, many and most). To illustrate this evolution, certain selected diagnostics for intensity 5 from four different Cancani family scales are provided in **Table 4** for comparison.

***Table 4 :*** *Comparison of selected diagnostics for intensity 5 from four different Cancani family scales. Although these scales are practically interchangeable, large differences exist between them. With time, the definition of diagnostics become much more detailed. MCS-23: Mercalli-Cancani-Sieberg scale (Sieberg 1923); MM-56: Modified Mercalli scale of 1956 (Richter 1958); MSK-64: Medvedev-Sponheuer-Kárník scale (Medvedev et al. 1964); EMS-98: European macroseismic Scale (Grünthal 1998).*

| Intensity 5 | MCS-23 | MM-56 | MSK-64 | EMS-98 |
|---|---|---|---|---|
| **felt by _** | all indoors<br>many outdoors | people outdoors | all indoors<br>~50% outdoors | >50% indoors<br><20% outdoors |
| **_ sleeping people are awakened** | all | Sleepers wakened<br>(no quantifier) | ~50% | 10-60% |
| **hanging objects _** | oscillate | move | swing considerably | swing considerably |
| **small unstable objects _** | fall | displaced<br>or upset | may be overturned<br>or shifted | may be shifted<br>or fall down |
| **damage** | - | - | Fine cracks in plaster, fall of small pieces of plaster in buildings in fieldstone, rural structures, adobe houses or clay houses are possible | Negligible to slight damage (such as hair-line cracks in very few walls, fall of small pieces of plaster, fall of loose stones from upper parts of buildings in very few cases) occurs to less than 20% of the buildings of vulnerability class A and B (such as rubble stone, fieldstone, adobe, simple stone or unreinforced masonry structures). |

***Table 5 :*** *The Modified Mercalli intensity scale of 1956 (Richter 1958) or MM-56. Damage vulnerability classes are defined as:* ***Masonry A:*** *Good workmanship, mortar, and design; reinforced, especially laterally, and bound together by using steel, concrete, etc.; designed to resist lateral forces.* ***Masonry B:*** *Good workmanship and mortar; reinforced, but not designed in detail to resist lateral forces.* ***Masonry C:*** *Ordinary workmanship and mortar; no extreme weaknesses like failing to tie in at corners, but neither reinforced nor designed against horizontal forces.* ***Masonry D:*** *Weak materials, such as adobe; poor mortar; low standards of workmanship; weak horizontally.*

| Intensity | Definitions of the Modified Mercalli intensity scale of 1956 or MM-56 (Richter 1958) |
|---|---|
| **1** | Not felt. Marginal and long period effects of large earthquakes. |
| **2** | Felt by persons at rest, on upper floors, or favourably placed. |
| **3** | Felt indoors. Hanging objects swing. Vibration like passing light trucks. Duration estimated. May not be recognised as an earthquake. |
| **4** | Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. In the upper range of 4, wooden walls and frame creak. |
| **5** | Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing, close, open. Shutters, pictures move. Pendulum clocks stop, start, change rate. |
| **6** | Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, etc., off shelves. Pictures off walls. Furniture moved or overturned. Weak plaster and masonry D cracked. Small bells ring (church, school). Trees, bushes shaken (visibly, or heard to rustle). |
| **7** | Difficult to stand. Noticed by drivers of motor cars. Hanging objects quiver. Furniture broken. Damage to masonry D, including cracks. Weak chimneys broken at roof line. Fall of plaster, loose bricks, stones, tiles, cornices (also unbraced parapets and architectural ornaments). Some cracks in masonry C. Waves on ponds; water turbid with mud. Small slides and caving in along sand or gravel banks. Large bells ring. Concrete irrigation ditches damaged. |
| **8** | Steering of motor cars affected. Damage to masonry C; partial collapse. Some damage to masonry B; none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed piling broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes. |
| **9** | General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. (General damage to foundations.) Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground. In alluvial areas sand and mud ejected, earthquake fountains, sand craters. |
| **10** | Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Large landslides. Water thrown on banks of canals, rivers, lakes, etc. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly. |
| **11** | Rails bent greatly. Underground pipelines completely out of service. |
| **12** | Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air. |

### 1.1.3. Macroseismic surveys

Unlike the magnitude, which provides the strength of an earthquake through a single value, the impact of an earthquake is not commonly expressed by a single parameter. Although the maximum intensity (**Imax**) does provide an upper limit to the degree of damage that one can expect, it does not provide any indication on the extent of the impact on the affected region. It is thus important to investigate and assess the experienced intensities of an earthquake throughout the different localities. This investigation is done through macroseismic surveys. A **macroseismic survey** consists of two parts: collecting and processing macroseismic information. The result of a macroseismic survey consists most of the time of a list of **intensity data points** (IDPs). IDPs are the core data of macroseismic information and each IDP is the result of the combination of an intensity value on a certain intensity scale, attributed to a specific location and earthquake.

As one relies on the experience of individuals to assess macroseismic intensity values, one should realize that individual testimonies of an earthquake within a single locality can greatly vary. A person jogging through the forest with music blasting through her headphones might not even realize that an earthquake just struck the city, while someone 100 metres further might be running to the streets, fearing that his house would collapse. It is generally known that one's situation and activity can influence the perception of ground movement (Sbarra et al. 2012a, 2014). It is, therefore, important to realize that macroseismic intensity values should not be based on individual testimonies, but rather on a multitude of testimonies and observations. This is also made clear from the quantitative terms used in the diagnostics of most macroseismic intensity scales, such as 'few', 'many' and 'most'. Instead, a comparison should be made between all acquired observations of earthquake effects as a whole and the different degrees of the considered intensity scale, to come to the best fit between both. It is important to not assign intensities to individual reports and taking their average, as macroseismic intensity is not based on average or median effects, but on the sub-maximum effects observed (Brüstle et al. 2020). As a hypothetical example, an earthquake hits a small town late at night where all inhabitants are fast asleep. In the morning, when everyone is interviewed on their experience of the earthquake, 30 percent of the people indicate to have been woken up due to the shaking of their bed, china and glass clattering together or doors and windows swinging open or shut, while 70 percent indicates to have felt nothing at all. If intensity values are assigned to every single testimony and an average is taken, the resulting macroseismic intensity would be intensity 2, as 70 percent of the intensities would be equal to 1. Instead, if the overall testimonies are compiled and the European macroseismic scale (EMS-98) is applied, an intensity value of 5 would be the most likely conclusion.

All available macroseismic information should thus be considered together for each locality. This is, of course, also dependent on the size of the locality or place. The common procedure is to assign individual intensities to villages or small cities, while larger cities are split up into different districts (Grünthal 1998; Musson and Cecić 2012). In general, the more testimonies available for a single locality, the higher the reliability of the assigned intensity for this locality. Often enough, however, not enough information is available to reliably assign a single value. In this case, one can opt to assign the range of possible intensities, e.g. 4-5. These intensity ranges should rather be regarded as an indicator of uncertainty, than as an intermediate intensity value, i.e. 4.5. If the available macroseismic information is not sufficient to distinguish between more than two values, greater ranges could be assigned, e.g. 4-6, although in this instance, most experts prefer to not include these data or indicate it simply as 'felt'. In such case, when no intensity value or intensity range is identified, some prefer to designate these points as **Macroseismic Data Points** (MDPs).

MDPs are commonly used for historical earthquake research, where often only limited information is found on the impact of an earthquake to a location in the written record. Common historical macroseismic sources such as private correspondence, repair bills, church registries or memoirs only provide sporadic indications on certain sensors. these are often unsuited to assign reliable intensity values to. Instead of attributing a 'felt' intensity to these sources, many historians prefer the use of more detailed annotations, such as 'weakly felt', 'strongly felt', 'minor damage' or 'major damage' (Ambraseys and Melville 1982; Alexandre and Vogt 1994; Alexandre and Alexandre-Delamotte 2024). Historical macroseismic sources should always be evaluated with the necessary historical criticism and are therefore preferably carried out by professional historians (§2.1.5). For earthquakes in the recent past, historical research is not always needed and new macroseismic information can be collected through testimonial recollection of certain major events (Marreiros et al. 2023).

When an earthquake strikes, however, macroseismic surveys are preferably held as soon as possible. People's memories of earthquake effects details fade quickly, indications of damage can be cleared or patched up within the day, or accumulated damage from aftershocks render it impossible to assess the effect of individual events. This collection of macroseismic information can occur through different processes. Here below, four different groups of macroseismic surveys are discussed: 1) the open public request, 2) the public request with questionnaire, 3) the targeted questionnaire and 4) the field survey.

1) The most simple and cost-effective procedure is launching a request for macroseismic information to the general public through a radio or television broadcast, or a small advert in a newspaper. This procedure, **the open public request**, was common in many West European countries in the 20$^{th}$ century (e.g. Somville 1939a; Rothé 1941; Ahorner and Van Gils 1963; Dost et al. 2025). These general requests to the public often result in a large quantity of responses in a short period of time. The downside of this procedure, however, is that the seismologist has to read and process all the letters, which are often full of unnecessary details, obscure handwriting or unclear indications on their location at the time of the earthquake. If phone calls are accepted, multiple people should be on duty to accept the incoming requests to write down these testimonies.

2) To reduce the processing time, a questionnaire can be provided to the public, so that seismologists or other experts can limit the acquired information to what they consider useful. This **public request with questionnaire** was traditionally done by including them in the newspaper advert (e.g. Musson 1992; examples in Tertulliani et al 2018). Nowadays, however, many national (or regional) seismological institutions provide a questionnaire online on their website (Wald et al. 1999b; Musson 2006; Lecocq et al. 2009; Sbarra et al. 2010). The online questionnaire revolutionized the macroseismic survey in multiple ways as the collection rate and total responses reach unprecedented values. The best-known example of online macroseismic surveys, is the United States Geological Survey's (USGS) **'Did You Feel It?'** ("DYFI?") inquiry (Dengler and Dewey 1998; Wald et al. 1999b). Most responses to the "DYFI?" inquiry are received within the hour (Wald et al. 2011; Quitoriano et al. 2020), and the number of responses received for a single event can skyrocket to mindboggling heights. For the $M_W$ = 4.8 Tewksbury 2024 earthquake, 183,787 "DYFI?" responses were acquired (Boyd et al. 2024).

Most of the macroseismic data of 21st century earthquakes originate from online enquiries, as it is a very practical and cost-efficient procedure, that requires little to no time to collect and process an enormous amount of data.

3) Instead of providing macroseismic questionnaires freely available to everyone, to allow for as many responses as possible, questionnaires are also **targeted to specific individuals or entities**. These targeted individuals are either enthusiastic volunteers that can be addressed after an earthquake (De Rubeis et al. 2009), people with certain social standing in their community, such as teachers, clergy or even the local police (Lohest and De Rauw 1909; Lohest and Anten 1920), public officials (Neefs et al. 2024a) or notifications can be sent to people who downloaded an earthquake alert app (e.g. LastQuake; Bossu et al. 2017). These people or institutions can be sent macroseismic questionnaires and are requested to provide useful information of the earthquake effects in their locality. These questionnaires are no longer intended to represent the observations or experiences of individual people, but the answers should reflect the earthquake effects experienced throughout the community, as there will often be only one questionnaire for each locality. These macroseismic surveys with targeted questionnaires generally require a bit more planning and effort than public requests. Note that maintaining a network of volunteers to provide macroseismic information of an earthquake is different from volunteer sampling, as long as this network was composed before the earthquake for which information is requested.

4) A last method to perform a macroseismic survey is the **field survey**. Field surveys consist of experts visiting the impacted area and making observations themselves. By carefully interviewing people and making observations of the damage, a very accurate determination of the intensity can be achieved. Field surveys require plenty of preparation and training and, as a result, are often only conducted in case significant damage has been reported. Due to the complexity of assigning higher intensity values, in which the damage degree and vulnerability of the building must be determined, field surveys are also the preferred option in case of significant damage.

Which procedure is chosen to collect macroseismic information is often a reflection of the seismicity of the area as well as the responsible institution's available resources. In places with low seismic activity, often only limited resources are available to the experts, which must rely on more simple methodologies in the case of an earthquake. On the other hand, whenever a significant earthquake strikes a region with low seismic activity, said event is likely to be studied in much more detail than if the same event took place in a region with higher seismic activity. Each procedure has its advantages and disadvantages and there often is a trade-off between ease of collection and ease of processing. Targeted questionnaires are for example much easier to process, as often only a single form will be available for each locality. These questionnaires provide, in theory, a full summary of what earthquake effects have been observed said locality. Of course, with targeted questionnaires, one also needs to maintain a network of respondents to send the questionnaire to, estimate the limits of the macroseismic field to decide which localities should be addressed and which not, create well-designed questionnaires, etc. An exception to this trade-off, are the public requests through online questionnaires. Once the procedure has been fully implemented, both the collection as the processing of the data requires little to no action, which is in great contrast to the other more traditional procedures.

### 1.1.4. Intensity data presentations

To clearly visualize the impact of an earthquake, macroseismic surveys have included different methods to represent the intensity data on a map. Common practice throughout most of the 20th century was to publish isoseismal maps. Isoseismals are contour lines of equal macroseismic intensity and bound areas with similar experienced shaking intensity. The number of isoseismals presented on a map varies based on the maximum observed intensity and on the completeness of the data. Isoseismals for lower intensity values are often not drawn due to an insufficient number of reports from those localities. Applying collection procedures that do not include self-selection biases allows to visualize the full extent of the felt area or macroseismic field (§4.1).

The drawing of isoseismal lines is characterized by subjective preferences such as varying degrees of smoothness and extrapolation by the authors. This results in the low reproducibility of this method, with sometimes large differences between two isoseismal maps for the same event (**Figure 1**). To counter this subjectiveness, multiple algorithms and techniques have been proposed to ensure reproducible results (e.g. De Rubeis et al. 1992; Pettenati et al. 1999; Schenkova et al. 2006).

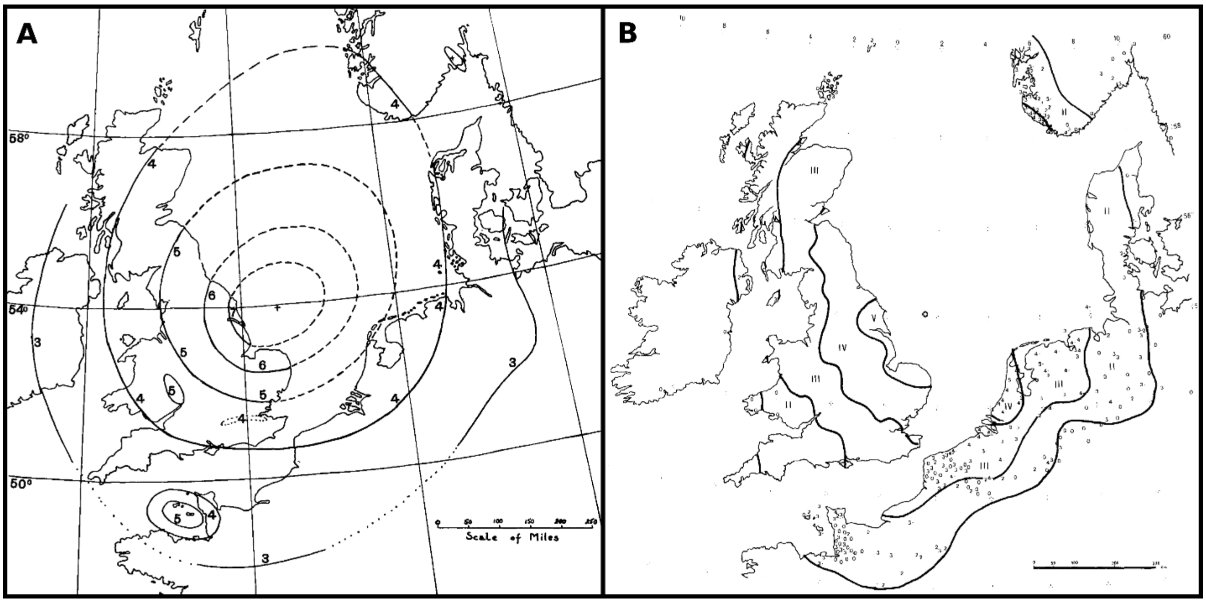



***Figure 1.*** *Isoseismal maps with varying degrees of smoothing and extrapolation employed for the $M_S$ = 5.5 Doggerbank 1931 earthquake in the North Sea.* ***A)*** *Isoseismal map on the MCS scale by Versey (1938) with high degree of smoothing and extrapolating isoseismal line across the North Sea.* ***B)*** *Isoseismal map on the MSK-64 scale by Ambraseys (1985) with lower degree of smoothing and extrapolation, closely outlining the intensity value distributions.*

The main purpose of presenting intensity data is to visualize the overall impact of an earthquake. Whether the map is intended to inform the general public of the impact of the earthquake, or to investigate local site effects on a much smaller scale, the varying levels of smoothing and extrapolation applied by the author should reflect this purpose. In the last few decades, however, many macroseismic applications require individual data points as input (e.g. Bakun and Wentworth 1997; Gasperini et al. 1999; Musson and Jiménez 2008). As a result, intensity data presentations also shifted from isoseismal maps towards maps displaying the raw intensity data or IDPs (**Figure 2**). These maps are often less clear in portraying the impact of an earthquake, but do not suffer from reproducibility issues as no processing of the data is required. Intensity values can be represented by either plotting the intensity degrees (**Figure 1B**) or intensity symbols on the map, or by using colour scales (e.g. **Figure 2**).

The development of conversion equations between macroseismic intensity and instrumental parameters, such as Peak Ground Velocity (PGV) and Peak Ground Acceleration (PGA), allow mapping the impact of an earthquake without using macroseismic intensity data. These instrumentally derived seismic intensities, or simply instrumental intensities, are based on calibrations between the instrumental parameters and macroseismic intensity (e.g. Atkinson and Kaka 2007; Worden et al. 2012). These instrumental intensities thus do not equal to macroseismic intensities but can be seen as approximations of the actual impact. The major advantage of instrumental intensity is the ability to automatically generate maps processed in near real-time, called **ShakeMap** (Wald et al. 1999a; Worden et al. 2018; Worden et al. 2020), that can be used to aid and improve rapid earthquake response. Online collected macroseismic data are incorporated into the generative process of ShakeMap as a major source of ground motion data, and also to provide constraints to the model (e.g. Wald et al. 2006; Bossu et al. 2023).

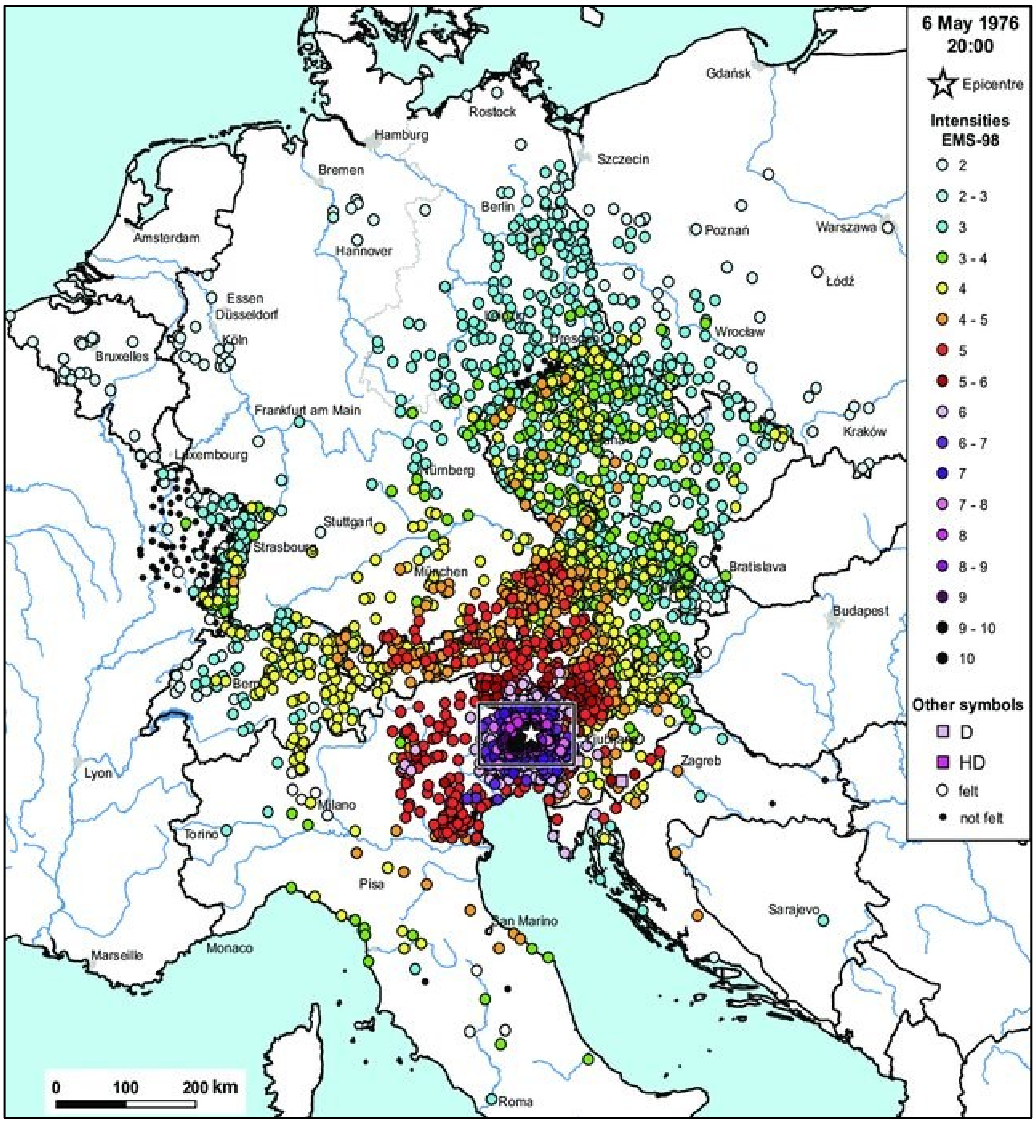



***Figure 2.*** *Intensity data points from various European countries for the $M_W$ = 6.4 Friuli 1976 earthquake. Intensity values are commonly represented by a colour scale. IDP density and distribution are clearly visible due to the unprocessed display of the raw data, revealing the application of different procedures to collect data between the countries. Figure taken from Tertulliani et al. (2018).*

### 1.1.5. Applications

At a first glance, macroseismic data possess a number of drawbacks: it is a qualitative parameter that cannot always be measured objectively and quantitatively; it is partially reliant on subjective experiences of the general population that vary based on their situational conditions at the time of the earthquake (Sbarra 2012a, 2014); different data collection and processing procedures can lead to varying results (Boatwright and Phillips 2017; Sbarra et al. 2020). These are all significant disadvantages that do not apply to instrumental data, and as a result, instrumental parameters provide greater precision and objectivity. Nonetheless, macroseismic data have been used consistently in a wide range of applications, often complementing instrumental datasets. This is primarily due to its simple, descriptive nature, which allows estimating the ground shaking intensity of an earthquake throughout the impacted area, without the need for costly seismic instruments and their maintenance. The macroseismic sensors required to assess earthquake shaking intensity (i.e. objects, people, buildings), do not require any installation, as these are deliberately chosen to be common features in all urban and rural environments. Because of this, macroseismic data have the potential to extend beyond the spatial and temporal capabilities of instrumental data.

As a result, macroseismic data are essential to many seismic hazard studies that aim to expand earthquake catalogues further back in time by providing constraints on earthquake source parameters, such as epicentral locations, focal depths or magnitudes (Ambraseys 1985; Levret et al. 1994; Hinzen and Oemisch 2002; Camelbeeck et al. 2022; Dost et al. 2025), or to constrain the ground motion attenuation in regions with no or few strong motion records (Villani et al. 2019; Vanneste et al. 2024). In contrast to instrumental data, macroseismic intensities allow for much greater resolutions that can be used to recognize local and regional site effects (Sousa and Oliveira 1997; Sbarra et al. 2012b).

The strength of Macroseismic intensity as a parameter, is that it provides a direct correlation between an earthquake and its impact on the people and the built environment. This allows seismic risk studies to estimate the potential economic and fatality losses of an earthquake based on past events, or as an aid to governments and disaster response agencies in the event of a severe earthquake (Wald et al. 2010; Riedel et al. 2014). This direct correlation with the impact of an earthquake, in combination with the simple descriptive and qualitative characteristics, offers a tool with great potential to communicate the impact of an earthquake to the general public. Unfortunately, macroseismic intensity is not well known with the general public, and mainstream media prefer to refer to the better-known parameter of magnitude to characterize the impact of an earthquake on the local population. While the magnitude is generally a good indication of the strength of an earthquake, its impact is dependent on a number of other factors, such as the distance to the epicentre, the focal depth, local or regional geological conditions, or even its frequency content. All these earthquake characteristics are incorporated into the macroseismic intensity. Using macroseismic maps, clear visualisations can be provided to illustrate the severity of the impact of earthquake throughout the affected areas. While scientific maps are often too complex for the public, with little or no attention to the aesthetics of the figure, media outlets can use these data to provide much more pleasing and clear images, but without the same level of detail (**Figure 3**). The recognition of an earthquake as a natural disaster by a government, a requisite for reimbursements in some countries, including Belgium, is often based on macroseismic intensity values.

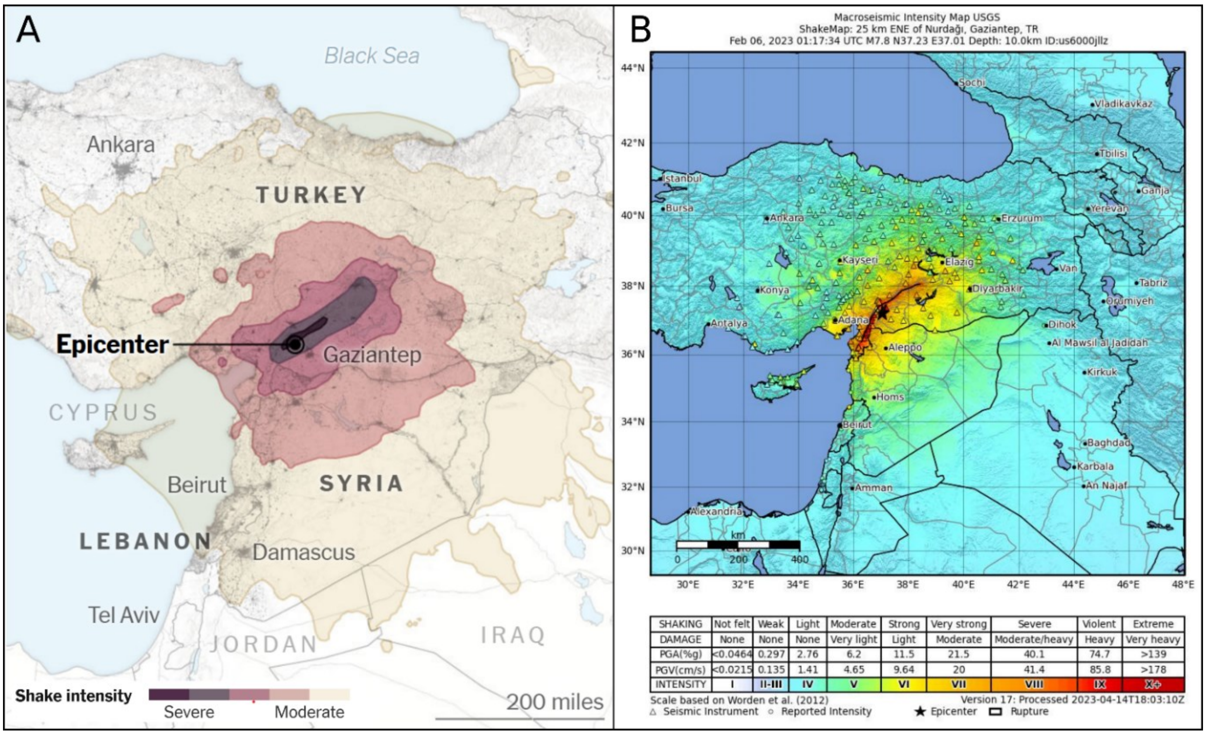



***Figure 3.*** *Examples of macroseismic maps of the $M_W$ = 7.8 Kahramanmaras 2023 earthquake, intended for:* ***A)*** *the general public (Robles et al. 2023),* ***B)*** *academics (USGS 2023).*

## 1.2. Belgian seismicity

### 1.2.1. Overview

Belgium is situated on the Eurasian plate, located far from the edges of the tectonic plate. In an intraplate region, seismic deformation rates are relatively low, resulting in a low, or low to moderate seismic activity in Belgium, which is both spatially and temporarily diffuse (Verbeeck et al. 2009). Only within the Roer Valley Graben, situated in the border region with the Netherlands and Germany (**Figure 4**), continuous seismic activity is observed (§1.2.2).

The largest instrumentally recorded earthquake in Belgium, is the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake, causing damage throughout large parts of the country (**Figure 5**). The $M_L$ = 5.0 Liège 1983 earthquake, the second largest recorded earthquake in Belgium, inflicted heavy damage to the city of Liège and its suburbs. These two earthquakes are the only 20$^{th}$ century events in Belgium that resulted in casualties directly caused by earthquake damage, with each incident claiming two lives (Vanneste et al. 2009; Camelbeeck and Plumier 2023). Indirectly, Belgian earthquakes have also caused casualties, either by cardiac arrest (e.g. $M_L$ = 4.1 Bilzen 1925 earthquake, Fourmarier and Legraye 1926) or due to carbon monoxide poisoning caused by earthquake-inflicted damage to chimneys ($M_L$ = 5.0 Liège 1983 earthquake, Camelbeeck and Plumier 2023). Larger events occurred across the border in the Roer Valley Graben, i.e. the $M_L$ = 5.8 Roermond 1992 earthquake in the Netherlands and the $M_L$ = 5.8 Euskirchen 1951 earthquake in Germany, both causing only limited damage in Belgium (Camelbeeck et al. 1992; Neefs et al. 2024b).

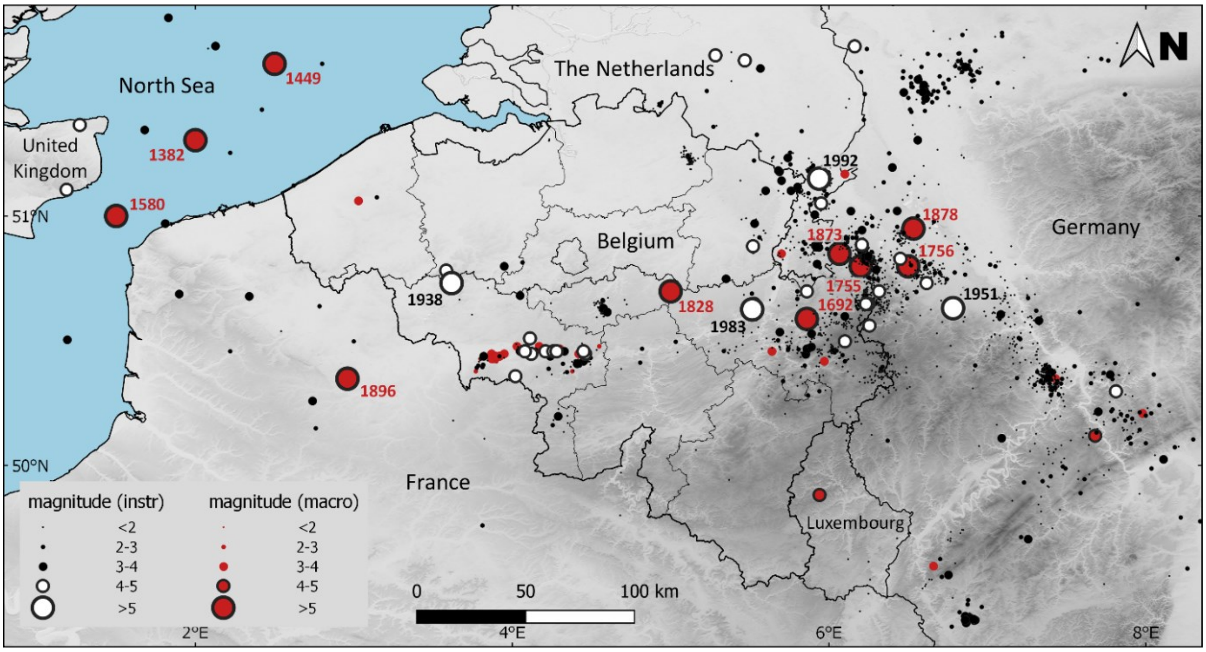



***Figure 4****. Earthquake magnitude and distribution of instrumentally recorded (black and white) and historical (red) felt events. Instrumental magnitudes are provided in the local magnitude ($M_L$) scale. Magnitudes of historical events are provided either in $M_S$ or $M_W$ and are derived from macroseismic data. Earthquakes with magnitudes ≥ 5 are provided with their year of occurrence.*

The total number of earthquake casualties in Belgium since the 20$^{th}$ century is almost negligible in comparison to other natural disasters like floods or heavy storms, where individual events regularly exceed the cumulative casualties caused by earthquakes during the last century. Recent examples of such events are, for example, the 2021 Eifel-Ardennes flood event which claimed 39 casualties in

Belgium (Paelinck and Dumarey 2022) or the 2011 Pukkelpop storm with 5 casualties (Verbruggen 2021). The impact of earthquakes on the Belgian population is primarily economic: The 1938 Zulzeke-Nukerke and the 1983 Liège earthquakes resulted in 17,550 collapsed chimneys in Belgium (Somville 1939b) and 16,000 damaged buildings in the region of Liège (García Moreno and Camelbeeck 2013), respectively. In the Hainaut coal basin, shallow, low to moderate magnitude earthquakes repeatedly caused similar damage to the built environment as to both the 1938 and 1983 events, but significantly more localized (Camelbeeck et al. 2022). Camelbeeck et al. (2025) demonstrates that this localized seismicity was triggered by extensive coal mining activity in the area. With the cease of coal mine activities in the 1970's, the seismic activity in the area strongly diminished.

Historically, larger earthquakes have impacted Belgium. The largest known earthquake to have struck the country is the Verviers 1692 earthquake, with estimated macroseismic $M_W$ between 6 and 6.25, and inflicted widespread damage from Kent in England to the Rhineland in Germany and Champagne region in France (Alexandre et al. 2008). Other significant historical earthquakes are the 1382 North Sea and the 1580 Dover Strait earthquakes with both macroseismic estimated magnitudes of $M_S$ = 6.0 (Melville et al. 1996; Camelbeeck et al. 2007), the 1640 Aachen earthquake with estimated $M_W$ = 5.5, the 1755 Aachen earthquake with estimated macroseismic $M_W$ = 5.2, the 1756 Düren earthquake with estimated macroseismic $M_W$ = 5.7 and the 1828 Central Belgium earthquake with estimated macroseismic $M_W$ = 5.1 (Camelbeeck et al. 2021). In comparison to the historical record, the maximum observed magnitudes in the 20$^{th}$ century remained limited (**Figure 6**). The seismicity in Belgium of the first quarter of the 21$^{st}$ century exhibits remarkably low activity, as not a single $M_L \geq 4.0$ earthquake occurred on Belgian territory.

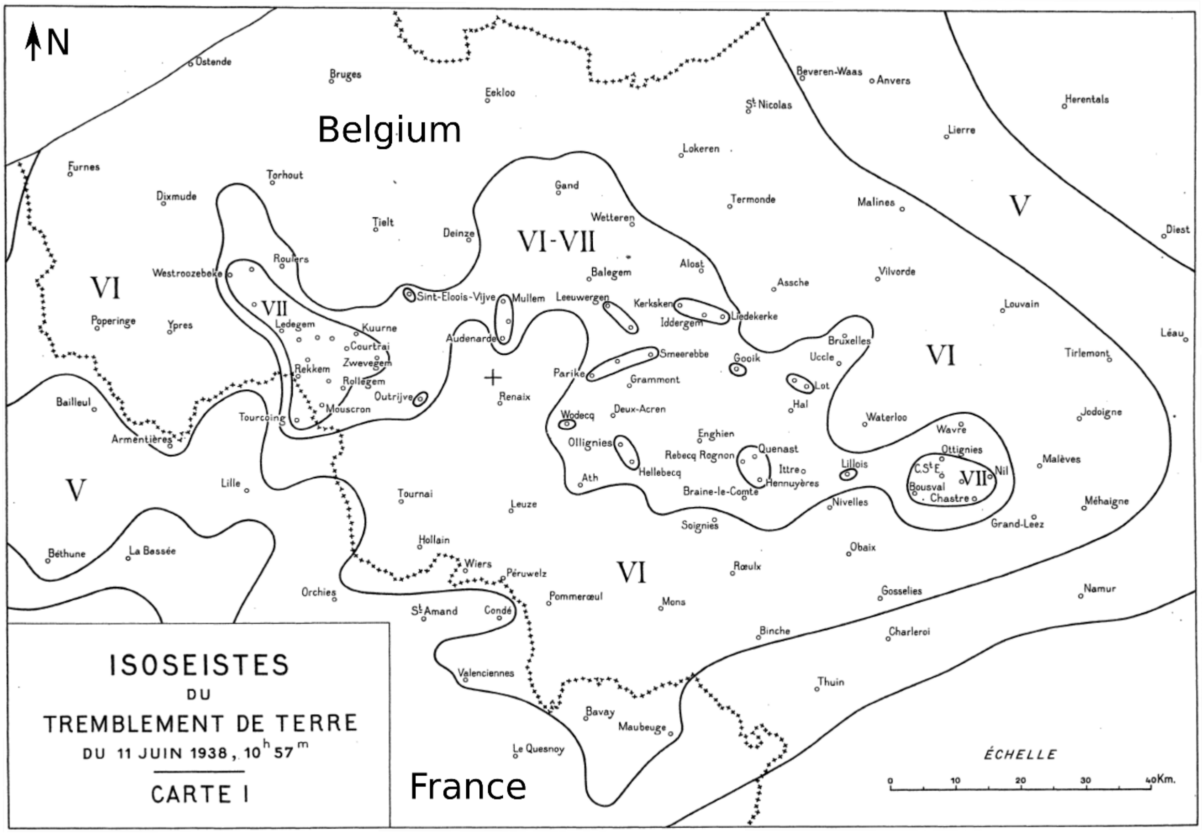



***Figure 5**. Isoseismal map by Somville (1939b) of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake. The earthquake's impact was primarily marked by the widespread collapse of chimneys. In total, 17,550 collapsed or partially destroyed chimneys were reported to the ROB (Somville 1939b).*

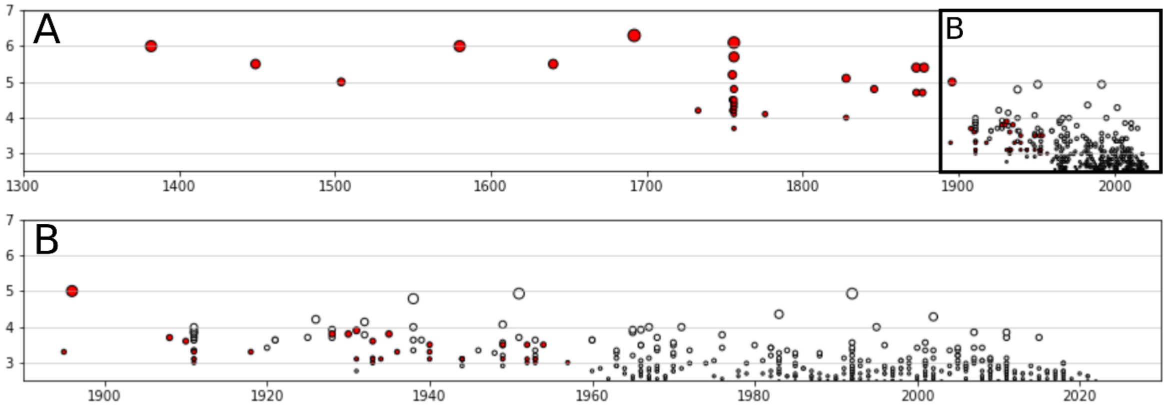



***Figure 6.** A) Earthquake magnitudes based on macroseismic data (red) and instrumental data (white and black), that have occurred between latitudes 49 - 52° N and longitudes 1 - 8°E, similar to the extent shown in **Figure 4**. All magnitudes have been converted to $M_W$, with $M_W = M_S$ and $M_W = 0.722\ M_L + 0.743$ (Reamer and Hinzen 2004). B) Zoom of the earthquake activity of the 20th and 21st centuries. Source: Royal Observatory of Belgium earthquake catalogue.*

### 1.2.2. Seismotectonic zonation model and seismic hazard

Due to Belgium's low to moderate seismic activity, identifying and characterizing active faults remains difficult, even in modern times. Only in the Roer Valley Graben, that exhibits a more continuous and higher tectonic deformation rate (yet still well below 1mm/year) in comparison to other regions in NW Europe, earthquakes can be linked to individual faults. To describe the diffuse Belgian seismicity, the seismotectonic zonation model of Verbeeck et al. (2009) is applied. Within each zone, the seismicity is considered homogeneously distributed. The model consists of 14 zones that cover the whole of Belgium and its surrounding countries, so that all earthquakes with a possible impact on Belgium are included (**Figure 7**). The zonation model borders are not only drawn around clusters of seismicity, but are defined by geological structures, geophysical properties, geomorphology, fault type and orientation. The most active zones of the Verbeeck et al. (2009) model and their seismicity are discussed in the following paragraphs. Focal depth and maximum magnitude parameters for each zone are given in **Table 6**.

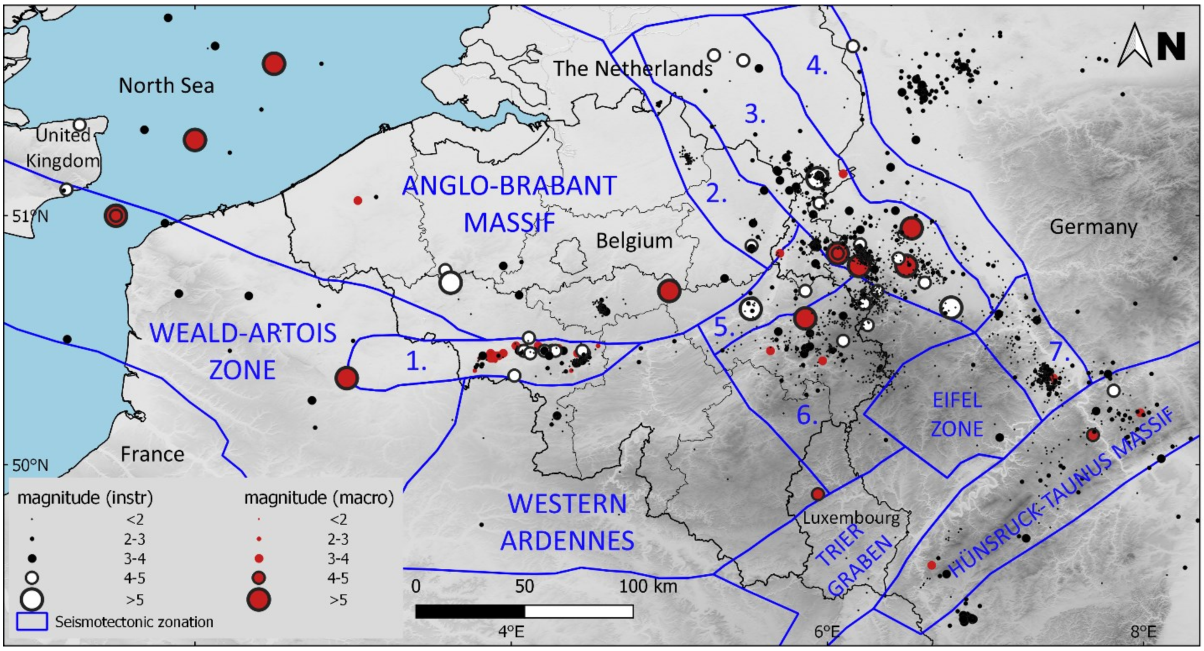



***Figure 7.*** *Seismotectonic zonation model by Verbeeck et al. (2009), displayed in blue: 1. Mons-Orchies basin, 2. Eastern Campine zone, 3. Roer Valley Graben, 4. Peel-Venlo zone, 5. Liège-Gulpen zone, 6. Eastern Ardennes, 7. Neuwied basin. The Verbeeck et al. (2009) includes a 14$^{th}$ zone, i.e. the West Netherlands basin, located to the north of the Anglo-Brabant massif and Roer Valley Graben. This basin displays no significant seismic activity.*

The **Roer Valley Graben** (RVG) is the central graben of the Lower Rhine Graben (LRG), an active rift system on the border region between Belgium, the Netherlands and Germany. The LRG consists of northwest-southeast orientated normal faults extending over 200 km. These faults separate a series of subsiding grabens and horsts in the LRG and have gone through several periods of activation since the Late Oligocene (Geluk et al. 1994). The LRG is part of the European Cenozoic rift system that extends from the Alps to the North Sea. Vertical displacement rates range up to 0.07 mm/year (Vanneste et al. 2013).

***Table 6 :*** *Zones of the seismotectonic zonation model of Verbeeck et al. (2009). Focal depth values indicate estimates of the source depth of the seismogenic layer for each zone. Observed $M_S$ max values are the largest recorded or estimated surface-wave magnitude ($M_S$) values of known earthquakes that took place within each zone. Evaluated $M_S$ max values indicate the considered maximum $M_S$ possible for each region, based on palaeoseismic observations and geological evidence, or the lack thereof. For zones with lower maximum magnitudes, the evaluated $M_S$ max is the observed $M_S$ max, increased by 0.5 magnitude units. This table is based on Verbeeck et al. (2009) and Vanneste et al. (2009).*

| Seismotectonic zone | Focal depth (km) | Observed $M_S$ max | Evaluated $M_S$ max |
|---|---|---|---|
| Roer Valley Graben | 5-20 | 5.7 | 6.7 |
| Eastern Ardennes | 10 | 6.3 | 6.3 |
| Anglo-Brabant massif | 10-25 | 6.0 | 6.0 |
| Weald-Artois zone | 10 | 6.0 | 6.0 |
| Hunsrück-Taunus massif | 10 | 4.8 | 5.3 |
| Liège-Gulpen zone | 5 | 4.7 | 5.2 |
| Mons-Orchies basin | 5 | 4.3 | 4.8 |
| Eastern Campine zone | 4-20 | 4.3 | 4.8 |
| Neuwied basin | 10 | 3.5 | 4.0 |
| Western Ardennes | 10 | 3.4 | 3.9 |
| Peel-Venlo zone | 4-20 | 3.4 | 3.9 |
| Eifel zone | NA | 2.9 | 3.4 |
| Trier graben | NA | 1.4 | 1.9 |

As one of the most seismically active regions in continental Northwest Europe, the RVG displays the highest and most consistent rate of activity. The largest earthquakes since the start of instrumental seismic measurements are:

1) $M_L = 5.8$ Roermond earthquake (1992-04-13)
2) $M_L = 5.8$ Euskirchen earthquake (1951-03-14)
3) $M_L = 5.1$ Uden earthquake (1932-11-20)

Six more earthquakes with $4.0 \leq M_L < 5.0$ were recorded in the RVG. Historically, seven earthquakes took place in the RVG with estimated $M_S \geq 5.0$ (Leydecker 2004). The strongest known event is the Düren earthquake (1756-02-18; Meidow 1995) with estimated macroseismic magnitudes $M_L = 6.1$ (Meidow 1995), $M_L = 6.4$ (Hinzen and Oemisch 2001) or $M_S = 5.7$ (Camelbeeck et al. 2007). This event was the most devastating in a series of earthquakes in the area from 1755 to 1760, with at least 240 documented felt earthquakes (Leydecker 2004). Other historically documented strong earthquakes in the RVG in Germany are the $M_S = 5.4$ Tollhausen earthquake in 1878, $M_S = 4.7$ Herzogenrath earthquakes in 1873 and 1877, the $M_S = 5.2$ Aachen earthquake in 1755 and the $M_S = 5.5$ Aachen earthquake in 1640.

Palaeoseismic investigations on the Bree fault scarp in northeastern Belgium provided evidence of a palaeoearthquake with up to 1 meter of vertical displacement (Vanneste et al. 2001). This palaeoearthquake possibly extended along a rupture length of 28 kilometres, which Camelbeeck et al. (2007) estimated to have $M_S = 6.7$ (**Table 6**), based on the empirical relation of Wells and Coppersmith (1994).

The second most active seismotectonic zone in Belgium, are the **Eastern Ardennes**. Instrumental seismicity did not exceed M = 5, however, as the largest recorded events are the $M_L$ = 4.5 Eifel-Eicherscheid earthquake (1911-05-30), the $M_L$ = 4.4 Kalterherberg earthquake (1928-01-14) and the $M_L$ = 4.3 Eifel-Raeren earthquake (1911-09-06). Yet, the Eastern Ardennes zone has produced the largest known earthquake in Belgium, with an estimated macroseismic $M_S$ = 6.3, i.e. the 1692-09-18 Verviers earthquake (Alexandre et al. 2008). The 1692 Verviers earthquake is suspected to have ruptured the Hockai fault zone, a SSE-NNW orientated fault zone with a total length of 40 km, marked by scattered geomorphological indices (Lecocq 2011; Vanneste et al. 2018; Camelbeeck et al. 2020). The Hockai fault zone is considered to be seismically active with many recorded microearthquakes (e.g. ~500 microearthquakes recorded during the 1989-1990 Hautes-Fagnes seismic swarm; Camelbeeck 1993). No other large (M>5) historical or even prehistorical earthquakes are known in the area. One should note that the determination of historical epicentres, such as the Verviers 1692 earthquake, are characterized by large uncertainties.

The **Anglo-Brabant massif** is a Lower Palaeozoic massif in the subsurface of the central and northern part of Belgium and extents to the west below the North Sea and up until the Anglia basin in the United Kingdom. Sparse outcrops of the massif in Belgium are located only in incised river valleys on its southern rim, as it is covered by Cretaceous chalk and soft Cenozoic sediments (Van Noten et al. 2022). The thickness of these sediments quickly increases towards the north, with depths up to a 1000 m at the Belgium-Netherlands border (Legrand 1968). Seismic activity in the Anglo-Brabant massif is concentrated on its southern rim and is considered low to moderate (Camelbeeck et al. 2007). The largest instrumentally recorded earthquake is the $M_L$ = 5.6 Zulzeke-Nukerke earthquake (1938-06-11), followed by the $M_L$ = 4.5 Le Roeulx earthquake (1995-06-20) and the $M_L$ = 4.1 Ramsgate earthquake (2011-22-05). The Anglo-Brabant massif also experienced two distinct periods of seismic swarm activity since the instrumental period. On 5 January 1953, the seismic sequence started with a $M_L$ = 4.0 earthquake and was followed by two earthquakes with $M_L$ = 3.6 and $M_L$ = 3.4 on August 28 (Van Noten et al. 2015b). The sequence lasted until 1957. From 2008 until 2010, the same area experienced another seismic sequence. This revival of the seismic sequence resulted only in a maximum $M_L$ = 3.2 over 239 recorded events, of which 60 have been reported felt (Van Noten et al. 2015b; §3.2). Larger events occurred before the 20th century, with the estimated macroseismic $M_W$ = 5.1 Central Belgium earthquake (1828-02-23), and the North Sea earthquakes of 1382 and 1449, with estimated macroseismic $M_S$ = 6.0 and $M_S$ = 5.5, respectively.

Looking at a seismic hazard map for Belgium (**Figure 8**), it is not the Roer Valley Graben, the Anglo-Brabant massif or the Eastern Ardennes that exhibits the highest seismic hazard, but a small zone at the French border in southwestern Belgium. This zone is the **Hainaut coal basin** and is part of the seismotectonic zone of the Mons-Orchies basin. From the late 19th century up until the late 20th century, the Hainaut coal basin has witnessed a series of damaging events of low to moderate magnitude ($M_L \leq 4.6$) and shallow focus (< 6 km) (Camelbeeck et al. 2022). This period of seismic activity coincides with the history of industrial coal mining in the region and has recently been confirmed as triggered seismicity (Camelbeeck et al. 2025). No earthquakes are known to have occurred before the late 19th century. Following the cease of industrial mining activities in the late 20th century, only very minor seismicity is observed. The largest events in the Hainaut coal basin are the $M_L$ = 4.6 Havré-Boussoit earthquake (1949-04-03) and the $M_L$ = 4.5 Carnières earthquake (1967-03-28). At least 6 other earthquakes occurred with $M_L \geq 4.0$ in the 20th century. Despite the relatively low magnitudes, the shallow focal depth of the earthquakes caused significant local damage. In a similar geological context, the **Liège coal basin** has also experienced shallow low to moderate seismic activity, notably the $M_L$ = 5.0 Liège earthquake (1983-11-8) and the $M_L$ = 4.3 Ans-Vottem earthquake (1965-12-21). Both events have also been linked to the coal mining activities in the past, but no conclusive evidence has been provided so far. The Liège coal basin is part of the Liège-Gulpen seismotectonic zone.

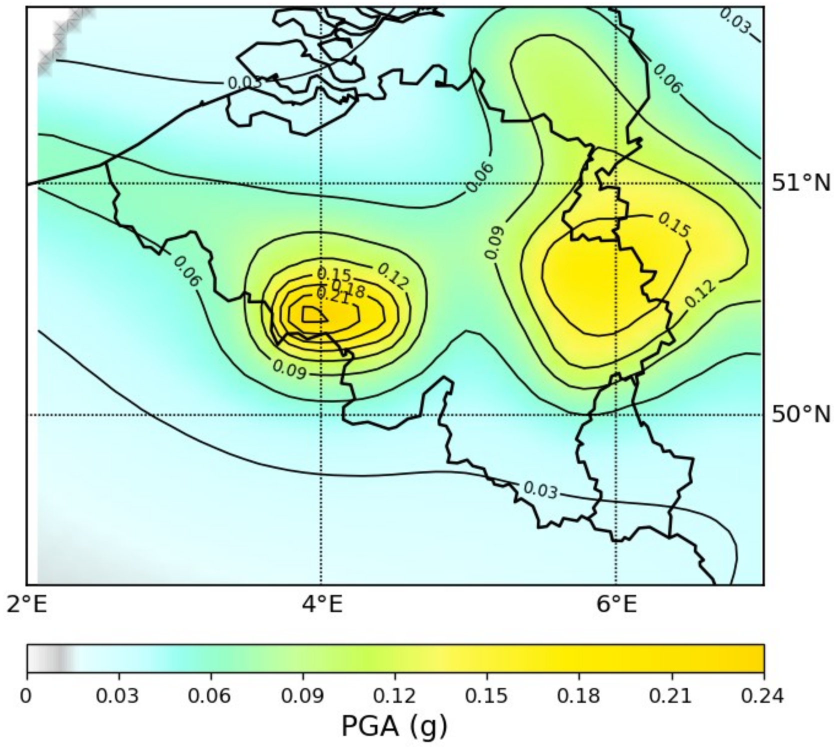



***Figure 8.*** *Seismic hazard map for Belgium from the SHARE project (Woessner et al. 2015) by Vanneste et al. (2024). 10% probability peak ground acceleration (PGA) exceedance in 50 years. The Hainaut coal basin at the French border in southwestern Belgium exhibits the largest seismic hazard in Belgium.*

Other seismotectonic zones display only low seismic activity or are located further with a very low probability of impacting the Belgian population. An exception to this could be the **Weald-Artois zone**. This zone is marked by a weak instrumental seismic activity. Few earthquakes with $M_L \geq 3.0$ have been recorded here, with the largest event being the $M_L$ = 4.3 Folkestone earthquake (2007-04-28). The $M_S$ = 6.0 (Melville et al. 1996) Dover strait earthquake (1580-04-06) proves, however, that the Weald-Artois zone displays a potential for future large earthquakes.

The seismotectonic zonation model described here, or other models that have been proposed in the past for Belgium (e.g. *GSHAP zonation*, Grünthal et al. 1999; *model 2*, Leynaud et al. 2000; *two-zone model*, Verbeeck et al. 2009), can be used to perform seismic hazard assessments. These result in the creation of **seismic hazard maps** (e.g. **Figure 8**) that depict the estimated probability that shaking will exceed a specific value during a certain time interval (Stein et al. 2015a). The recommended time interval provided by Eurocode 8 is 475 years, which equates to a 10% probability to exceed the depicted value in 50 years. Seismic hazard maps are widely used for policy decisions to decide on the required building codes within different regions. Localities with a higher chance of strong shaking should be built to better withstand earthquake ground motion.

The probabilities depicted in seismic hazard models are estimated by evaluating the past seismicity. In regions with low deformation rates, as is the case in Belgium, the known seismicity reflects only the short-term earthquake record (Swafford and Stein 2007). The Belgian seismic record likely fails to capture the typical large earthquake recurrence interval and thus the expected maximum magnitudes of future earthquake are fairly uncertain, possibly underestimated, and could occur at unexpected locations (Stein et al. 2015b). Additionally, the attenuation models used to predict the gradual decrease of ground shaking with distance are based on data that are not necessarily adapted to the Belgian geological and seismological context (Camelbeeck et al. 2022; Vanneste et al. 2024).

### 1.2.3. Seismic monitoring

The **Royal Observatory of Belgium (ROB)** is a Belgian federal scientific research institute that belongs to the Federal Public Planning Service Science Policy (BELSPO). Scientific research focuses on the planet Earth and other, near and distant objects in space. Scientists at the ROB are involved in astronomy, astrophysics, geophysics, seismology, space geodesy and solar physics. Apart from these scientific fields, the ROB also provides a range of public services including date and time service, management of the Belgian seismological network, gravimetric measurement, permanent monitoring of solar activity, space meteorological outlooks, the dissemination of information on a variety of astronomic phenomena and public outreach.

The ROB's department of Seismology-Gravimetry is the only seismological institution in Belgium and is tasked to develop and maintain a network of seismic stations covering the Belgian territory to monitor the national and regional seismicity. When an earthquake strikes, the ROB is the authoritative organization and responsible for the determination of earthquake source parameters, such as the epicentral coordinates, the focal depth and the magnitude. It also collects macroseismic data for each felt or potentially felt event through its public "DYFI?" inquiry, available to anyone on their website. In the case of a more significant earthquake, the ROB also collects macroseismic data through communal questionnaires that are distributed to the local authorities of Belgian municipalities. Updated source parameters and impact maps are provided to the national crisis centre and are used for the planning of disaster response agencies. If the source parameters pass a predefined threshold (**Table 7**) in one of the three Belgian regions, the earthquake can be categorised as a natural disaster, allowing the affected residents to request reimbursements for damage. Threshold parameters differ between the regions because of local geology and history.

***Table 7 :*** *Local magnitude ($M_L$) and macroseismic intensity on the European Macroseismic Scale (EMS-98) requirements to allow for the recognition of an earthquake as a natural disaster, throughout the three Belgian regions. The Flemish Region does not provide a minimum intensity requirement. The Flemish disaster relief fund will, however, consult the ROB and its assessment of macroseismic intensity values to determine the likelihood of reported insurance claims can be linked directly with to the earthquake (Vlaams Rampenfonds, pers comm). For the Walloon Region and the Brussels-Capital Region, an earthquake is recognized as a natural disaster if both magnitude and intensity conditions are met.*

| Region | Magnitude | Intensity | Decree |
|---|---|---|---|
| Flemish | $M_L \geq 5.0$ | - | 2019/04/30, Flemish Government |
| Walloon | $M_L \geq 4.0$ | EMS-98 ≥ 7 | 2016/05/26, Walloon Government |
| Brussels-Capital | $M_L \geq 4.0$ | EMS-98 ≥ 7 | 2019/04/25, Brussels-Capital Government |

The Royal Observatory of Belgium also maintains and updates the national earthquake catalogue and a macroseismic intensity dataset. The **ROB earthquake catalogue** lists every known event in Belgium with its parameters. The **ROB macroseismic intensity dataset** is a collection of Belgian macroseismic IDPs. These two documents are the most important sources on Belgian seismicity. They have never been officially published in their entirety but are available on request and through online INSPIRE initiatives. The ROB earthquake catalogue, and its parameters, is the result from a wide variety of analyses of both instrumental and macroseismic data. It is a dynamic catalogue, with multiple re-evaluations of its parameters. As new data and more sophisticated procedures become available, the accuracy of the parameters can be improved (e.g. Van Noten et al. 2015a; Camelbeeck et al. 2022, 2025; Vanneste and Onvani 2024). The majority of earthquake source parameters referenced in this work are sourced from the ROB earthquake catalogue. When other source parameters are used, a reference to the source of these parameters is provided. In contrast, the macroseismic intensity dataset is a static document, with very few updates or re-evaluations of its data. Only in case of a new felt earthquake, the dataset gets complemented with new data.

## 1.3. Thesis objectives and outline

This PhD thesis, which is a collaboration between the Royal Observatory of Belgium (ROB) and the Université catholique de Louvain (UCLouvain), investigates the impact of earthquakes on Belgium over the past 125 years, with the purpose of providing validated data for structural engineering applications. The results of this study can be used as a reference for future investigations in the field of engineering seismology.

The primary objective of engineering seismology is to provide reliable estimates of ground motion parameters that characterize the seismic forces that can impact the building environment in a specific region. This is achieved through performing seismic hazard assessments, which form the scientific foundation for earthquake-resistant design and are used to guide building codes. Seismic hazard assessment attempt to approximate the probability and severity of earthquake-induced ground shaking over a certain time period. To be able to attain accurate assessments of the seismic hazard, large quantities of ground motion data are required. In regions like Belgium, however, where only low to moderate seismic activity occurs and the modern seismic network was established only 40 years ago, such data is sparse. To extent the ground motion database of the Belgian seismicity both temporally and spatially, macroseismic intensity data can be consulted. At the Royal Observatory of Belgium (ROB), macroseismic intensity data have been collected extensively throughout Belgium from the 20$^{th}$ century onwards. Unfortunately, this rich source of ground motion data is often neglected as information on how macroseismic data was gathered throughout the period of interest is scattered in reports, scarce publication or in written archives of the ROB and was not summarised.

To facilitate and promote the use of Belgian macroseismic data, this PhD project first focusses on a comprehensive compilation and a critical review of macroseismic data in Belgium. Up until now, Belgian macroseismic intensity data has always been presented as homogeneous, while in reality, macroseismic collection procedures have varied immensely throughout the last century. This observation triggered a detailed investigation on the history of macroseismic surveys in Belgium in the first five chapters of this thesis.

The first chapter (§1) introduced the general concepts of macroseismology (§1.1), such as the definition of macroseismic intensity (§1.1.1), the evolution of macroseismic intensity scales and their gradual improvements towards the applicability, consistency and objectivity (§1.1.2), the most common procedures of collecting and processing macroseismic data through various types of macroseismic surveys (§1.1.3), as well as the most important data presentation methods (§1.1.4) and other applications of macroseismic data (§1.1.5). These are the basic concepts of macroseismology that need to be understood to fully comprehend the content of this PhD work. As this work discusses the impact of Belgian seismicity and the validity of current seismic hazard assessments for Belgium using macroseismic data, the Belgian seismic activity, its different seismotectonic zones and seismic hazard assessments are also discussed in this introductory chapter (§1.2).

In the second chapter (§2), all applied Belgian macroseismic surveys are investigated and, for the first time, their complete evolution is documented in great detail: from small-scale ad-hoc improvised surveys (§2.1.1, §2.1.2), to the mass distribution of collective questionnaire versions sent to local authorities (§2.1.3), or the individual questionnaires publicly available online on the *seismology.be* website (§2.1.6).

The macroseismic data that resulted from these surveys are provided and discussed in the third chapter (§3). These data are subdivided into a traditional database (1900-2002, §3.1) and an online database (≥2002, §3.2). The main focus of this chapter, and of this PhD project in general, is to clarify the use of Belgian traditional macroseismic data. In contrast to the traditional data, the more recently developed online macroseismic data procedure is much better documented, with only slight differences throughout its existence. Likewise, the revival of studying historical macroseismic data in the late 1970's and early 1980's, is much better documented and accessible than the applied traditional procedures. Consequently, only simplified databases are provided for the historical and online Belgian macroseismic data.

In the fourth chapter (§4), the quality of the traditional (§4.1) and online (§4.3) macroseismic data are evaluated. An evaluation on the correlation between both data types is also provided (§4.4), as well as an automatic procedure to determine the consistency of the traditional data (§4.2). In §4.5, a new procedure is proposed in an attempt to counter the current deficiencies of the Belgian traditional and online macroseismic surveys and to ensure the continued application of traditional communal surveys in the future.

With the newly provided macroseismic databases, the fifth chapter (§5) summarizes the impact of seismicity on the Belgian population and the built environment since the 20$^{th}$ century. The Belgian Traditional Macroseismic (BTM) database compiles Belgian data collected through traditional surveys (§5.1), while the Belgian Online Macroseismic (BOM) database provides Belgian macroseismic data collected through online surveys (§5.2). With a 125-years period of continuous macroseismic observations in Belgium, the necessary data is provided to evaluate the limitations on the current seismic hazard assessment of Belgium (§5.3.2). These assessments apply various published ground motion prediction equations that are not necessarily adapted to the Belgian geological and seismological context. With macroseismic intensity data, a parameter is provided that reflects the true experienced impact of Belgian seismicity, and with which the predictions of the seismic hazard model are compared.

A sixth chapter (§6) applies the BTM database to evaluate the performance of existing ground shaking models or intensity prediction equations (§6.3), after introducing attenuation modelling (§6.1) and describing the characteristic intensity attenuation throughout Belgium (§6.2).

This PhD research has contributed to three peer-reviewed scientific articles, along with the Belgian traditional macroseismic database, all published during the course of the PhD. The majority of the results have been presented on various international scientific conferences and results were discussed by peers. Neefs et al. (2024a) has been incorporated into the first chapters (§2, §3, §4, and §5), but has been expanded upon considerably. These chapters culminate in the publication of the Belgian macroseismic database/MIDOP, freely available online (Neefs et al 2024b). The co-authored Vanneste et al. (2024) and Dost et al. (2025) papers are not fully covered in this dissertation. Both publications provide clear examples of applications that are made possible through new and updated macroseismic data. In Vanneste et al. (2024), a reassessment of the seismic hazard of the Hainaut coal basin is provided by applying new ground motion prediction equations that better fit the attenuation rates observed in macroseismic intensity data. Dost et al. (2025) provides an evaluation of the source parameters of the $M_L = 5.1$ Uden 1932 earthquake in the Netherlands, which was made possible through updated intensity datasets.

This dissertation aims to provide an all-inclusive summary and review of macroseismic data in Belgium, a crucial source of seismic data which is still neglected too often. Excluded from this dissertation, is the discussion of the macroseismic data collected through historical research, as this work should be left to professional historians (Ambraseys 1983; Alexandre and Alexandre-Delamotte 2024).

# 2. Belgian Macroseismic Surveys

Each macroseismic survey procedure is inherent to a set of advantages and biases, and the chosen procedure will affect the quantity and quality of the macroseismic data. In Belgium, a variety of different macroseismic surveys have been applied: ROB communal macroseismic surveys, ROB “Did You Feel It?” online inquiry, University of Liège surveys, historical research, open public requests, newspaper articles and field surveys. None of this information on survey procedures and their associated biases were represented in the ROB intensity database and the database was displayed as a homogeneous list of IDPs instead. Neefs et al. (2024a) assigned a source type to each Belgian IDP for the traditional events and made the data public for all (Neefs et al. 2024b). For this to be possible, a thorough investigation on the evolution of macroseismic data collection and processing procedures in Belgium was conducted.

We distinguish three different types of macroseismic data in Belgium, based on the applied macroseismic surveys: **traditional surveys, online surveys and historical research.** Both traditional and online surveys are contemporaneous surveys that are conducted as soon as possible after the occurrence of an earthquake. A single procedure is responsible for all Belgian online macroseismic surveys (the “Did You Feel It?” inquiry, §2.1.6), while a large variety of traditional surveys have been applied throughout the 20$^{th}$ century. The term ‘traditional’ refers here to how macroseismic surveys were conducted before the use of the internet. Belgian traditional surveys have been processed manually by many individuals with each their subjective criteria to assess intensities and their interpretation of the data. This allows for a relatively large heterogeneity within the traditional survey data. Online survey data are processed automatically and there is no possibility for variations within the dataset. The Belgian online macroseismic data procedure has remained homogeneous throughout the 21$^{st}$ century, and its data can thus be considered homogeneous. Historical research concerns earthquakes for which contemporary surveys were not conducted or were not sufficient. Historical Belgian earthquakes have been investigated by professional historians since the 1980s (§2.1.5).

## 2.1. Evolution of Belgian data collection procedures

### 2.1.1. Early contemporaneous macroseismic investigations

There are few known contemporary scientific publications on the effects of earthquakes in Belgium before the 20th century. A remarkable exception are the works of the Prussian scientists Egen (1828) and Nöggerath (1828), which each separately conducted a macroseismic survey of the 23 February 1828 earthquake in Central Belgium with estimated macroseismic $M_W = 5.1 \pm 0.3$ (Camelbeeck et al. 2021). The work of Egen (1828) can be considered the first attempt to devise an intensity scale (Davison 1927), as well as the first display of a macroseismic map with intensities (**Figure 9**; Günther 1897; Gisler et al. 2008). The work of Nöggerath (1828) will lay the foundation to develop the official Prussian macroseismic survey through standardizes questionnaires in its early stages that continued up to the late 19th century (Knuts et al. 2018). While the practices in Prussian territory consisted of private and official governmental correspondence with impacted localities or conducting field surveys, their data collection procedure for Belgian and Dutch localities were limited to newspaper reports.

The 23 February 1828 Central Belgium earthquake is the only known event for which macroseismic investigations were conducted in Belgium that included the assignment of intensities. Other contemporary scientific publications of earthquake effects up to the end of the 19th century reported macroseismic observations of various impacted Belgian localities (e.g. Von Lasaulx 1874, 1878; Lancaster 1897), but without the attempt to classify or visualize the various degrees of intensity experienced at the degree of detail as done by Egen (1828). De Munck (1887) did make detailed maps of the total felt extent of the Havré earthquakes in 1887, which are seen as the starting point of the coal mining-triggered seismicity in the Hainaut region (Camelbeeck et al. 2022, 2025). These 1887 earthquakes, however, were felt only very locally within the small village of Havré and can hardly be considered as a full-scale macroseismic investigation.

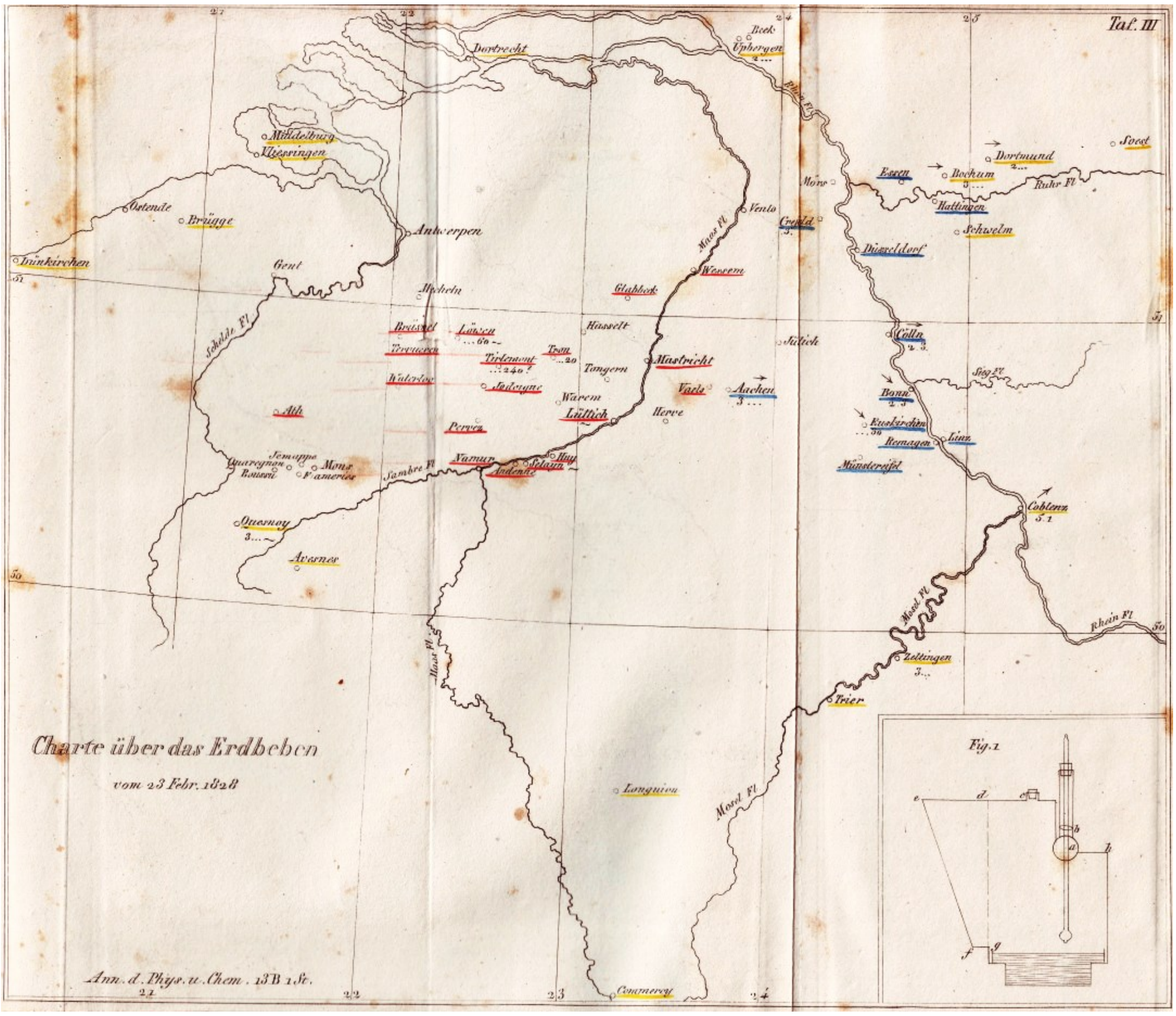



***Figure 9.*** *The first macroseismic map of an earthquake with the first attempt to devise an arbitrary scale of seismicity by the Prussian mathematician Peter Nikolaus Caspar Egen (1828). The 23 February 1828 earthquake in Central Belgium is the largest earthquake in Belgium in the 19th century with an estimated macroseismic* $M_W = 5.1 \pm 0.3$ *(Camelbeeck et al. 2021). Coloured underlined localities indicate the intensity grades of the earthquake: grades 5 and 6 (red), grades 3 and 4 (blue), grades 1 and 2 (yellow). Egen scale of intensity (translated by Davison 1927):* **Grade 1** – *Only very slight traces of the earthquake are sensible*. **Grade 2** – *A few persons, under favourable conditions, feel the shock; glasses close together jingle, small plants in pots vibrate; hanging bells are not rung.* **Grade 3** – *Windows rattle, house-bells are rung; most persons feel the shock*. **Grade 4** – *Slight movement of furniture; the shock in general so strong that it is felt by everyone.* **Grade 5** – *Furniture shaken strongly, walls are cracked, only a few chimneys thrown down, the damage caused being insignificant.* **Grade 6** – *Furniture shaken strongly; mirrors, glass and china vessels broken; chimneys thrown down, walls cracked or overthrown.*

### 2.1.2. First traditional surveys

From the beginning of the 20th century, macroseismic studies became much more prevalent in Belgium. The first macroseismic survey conducted in the 20th century on Belgian territory was performed by Lohest and De Rauw (1909, L&DR) for the 1908 Poulseur earthquake with estimated macroseismic $M_W = 3.7$. This event is also the first earthquake in Belgium with an instrumental record (Sieberg 1908). In practice, L&DR's collection procedure strongly resembles those by Egen (1828), roughly 90 years earlier; data were gathered mainly through private correspondence and a field survey. L&DR sent a total of 180 letters in two waves to a set of predetermined individuals, which consisted of mainly schoolteachers and a few priests. The first wave of letters was addressed to localities at large distances from each other to roughly define the total extent of the macroseismic field or the felt radius. Later, a second wave was sent to all localities within the full extent of the macroseismic field. This resulted in a dense dataset of localities to which intensity values were assigned. Despite the existence of internationally recognised macroseismic scales at the time (i.e. Rossi-Forel scale, de Rossi 1883; Mercalli scale, Mercalli 1902; Cancani scale, Cancani 1904), the authors designed a new scale. This scale was tailored specifically to the macroseismic data that was acquired, in a similar manner as Egen (1828). The custom scale defined only three degrees, with an additional subdivision of the first degree (**Table 8**).

***Table 8 :*** *Custom intensity scale defined by Lohest and De Rauw (1909), used to classify the earthquake effects of the 1908 Poulseur earthquake. Intensity degrees have been translated from French.*

| Intensity | Definitions of the custom scale by Lohest and De Rauw (1909) |
|---|---|
| 1 | a) The earthquake was not felt, or incorrect responses were provided with respect to timing or duration of the event.<br>b) The earthquake was perceived by only one or two people. |
| 2 | The earthquake was perceived by most. |
| 3 | The earthquake caused damage including ruptured walls, breaking of windows or other objects, rockfalls occurred. |

The field survey performed resulted in the observation of only very limited damage: A single wall was cracked, windowpanes and other objects have been broken in Remouchamps and Aywaille, and in Poulseur a small rockfall occurred in a quarry and a worker was almost knocked over. L&DR provided a list of the localities and the assigned intensities, including the respondent's name and occupation. The publication also included an isoseismal map delineating areas of equal intensity for degrees 2 and 3 (**Figure 10**).

A similar methodology was carried out by Lohest and Anten (1921) and Fourmarier and Legraye (1926) for the $M_L = 4.0$ Stembert 1921 earthquake and the $M_L = 4.1$ Bilzen 1925 earthquake, respectively. Lohest and Anten (1921) refrain from describing their procedure and only refer to the methodology used in L&DR. They provide a list of IDPs and an isoseismal map that delineates only the two highest intensity degrees. The intensity scale used here is practically identical to the one used by L&DR (**Table 8**), apart from reclassifying 1a and 1b into two separate degrees, resulting in four degrees in total. They also inverted the scale, so that the highest number on the scale corresponds to the lowest intensity and vice versa. Fourmarier and Legraye (1926) provide a very detailed description of the various parameters of the 1925 Bilzen earthquake such as the timing, duration, number of aftershocks, direction of propagation and instrumental record of the event. Comprehensive descriptions of macroseismic observations for many localities are also included. For the applied methodology, the authors also refer to the one used in L&DR. An important difference from previous macroseismic surveys by L&DR and Lohest and Anten (1921) is the use of a much more detailed intensity scale in Fourmarier and Legraye (1926), which more closely resembles the internationally recognized intensity scales at the time, such as the Mercalli-Cancani-Sieberg (MCS-23) scale (Sieberg 1912, 1923). Their scale included multiple diagnostics for different sensors and consisted of five degrees (**Figure 11**). A "not felt" degree was not included, and the scale remained inversed, with intensity 1 defined as the highest intensity. Unfortunately, no list of IDPs was provided for this event.

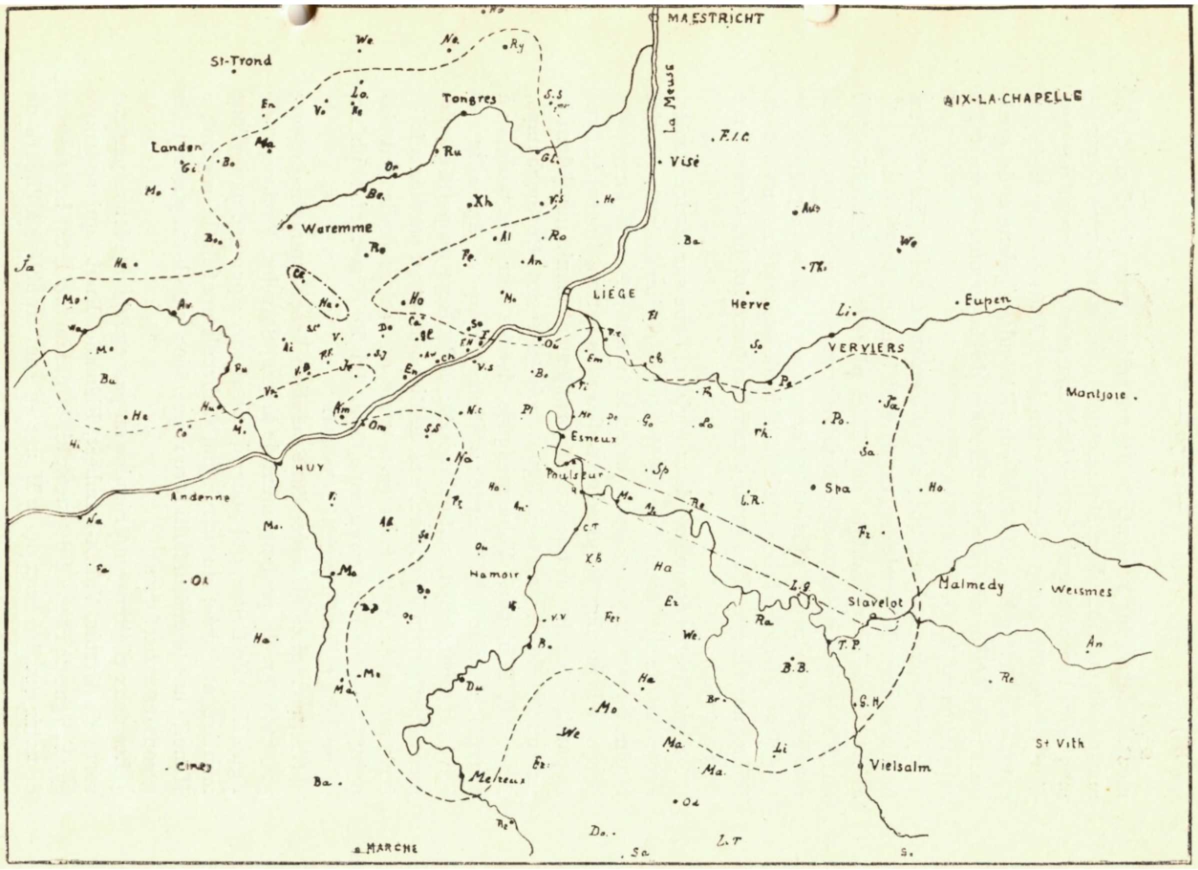



***Figure 10.*** *Isoseismal map of the 1908 Poulseur earthquake with estimated macroseismic* $M_W$ *= 3.7 by Lohest and De Rauw (1909). Dashed lines indicate the isoseismal for degree 2, while the dash-dotted lines indicate the isoseismal for degree 3. Solid lines indicate rivers.*

Two small-scale macroseismic studies were performed in the early 20th century for earthquakes in the Hainaut coal basin. Cambier (1911) described observations from various localities that originated from local newspaper articles concerning earthquakes occurring throughout the year 1911 in the region of Charleroi. Although the study refrains from assigning intensity values to any location, an isoseismal map for the $M_L$ = 4.1 earthquake on June 1st is provided that delineates two zones: the epicentral zone and the extent of felt reports of the event. Cornet (1911) conducted a macroseismic survey of the 1911 Mons-Wasmuel earthquake with estimated macroseismic $M_W$ = 3.1 (Camelbeeck et al. 2022). Although at least five events with higher magnitudes took place in the Hainaut coal basin that year, a detailed macroseismic survey was conducted for this event only. Cornet (1911) addressed 150 schoolteachers, priests, engineers or other individuals with professions of high social status at the time, from localities far exceeding the extent of those reported in the newspapers. The event itself was only felt by a few people and a maximum intensity of 3 on the Rossi-Forel scale was assigned to the event (de Rossi 1883). No list of IDPs was provided. Camelbeeck et al. (2022) assigned a maximum intensity of 4 on the EMS-98 (Grünthal 1998), based on a review of the data and newspaper articles.

In addition to these early 20th-century macroseismic studies, ROB seismologists often published short paragraphs about local earthquakes in the periodical “Ciel et Terre” from the “Société Royale Belge d’Astronomie”. These short articles contained only limited macroseismic information with either descriptions of individual testimonies or the maximum intensity value of an earthquake (e.g. Lagrange 1911a, b, c, 1925, 1931; Somville 1931).

### 2.1.3. ROB communal questionnaire surveys

#### *2.1.3.1. Concept*

Parallel to the survey of Fourmarier and Legraye (1926), O. Somville of the Royal Observatory of Belgium (ROB) conducted a survey of the same Bilzen 1925 event. This work was included in Fourmarier and Legraye (1926), who briefly described Somville's methodology. His isoseismal map of the event was provided as an attachment (**Figure 11**). This is, to our knowledge, **the earliest macroseismic survey performed by the ROB**, and it lays the groundwork for all subsequent ROB communal surveys in the 20th century. These are the main and often only macroseismic surveys for earthquakes in Belgium since the 1930s. Until recently, the $M_L$ = 5.1 Uden 1932 earthquake in the Netherlands (Dost et al. 2025) was regarded as the first event for which a macroseismic survey was conducted by the ROB, because the questionnaires of this survey are the oldest available in the ROB archives. There are, however, four earthquakes with ROB macroseismic surveys for which the responses to the questionnaires were not preserved, three of which took place before 1932. Except for the Bilzen 1925 event, these surveys involved collaborations between P. Fourmarier and O. Somville: the $M_L$ = 4.0 Geraardsbergen 1921 earthquake (Fourmarier and Somville 1926); the $M_L$ = 4.4 Kalterherberg 1928 earthquake (Fourmarier and Somville 1930); and the Diksmuide 1933 earthquake (Fourmarier and Somville 1933) with estimated macroseismic $M_W$ = 3.6. Important to note, is that while the Bilzen 1925 earthquake is the oldest communal macroseismic survey by the ROB, the oldest earthquake for which a communal ROB survey was conducted is the 1921 Geraardsbergen earthquake, five years after the earthquake took place (Fourmarier and Somville 1926).

Macroseismic surveys conducted by the ROB differ from those performed by others earlier in the 20th century, as ROB questionnaires were distributed to the local authorities of Belgian municipalities rather than to individuals. The municipal level is the smallest administrative subdivision and governs local interests and concerns. The municipal scale provides a great resolution without needing to maintain a network of volunteers while also reducing the time needed to process the data afterwards, as all observations for each municipality would already be compiled on a single sheet of paper. The downside, however, is that the degree of thoroughness with which a municipality conducts the survey is not known and is likely highly variable. The extent of the distribution of questionnaires is mostly based on higher-level administrative subdivisions, such as provinces or arrondissements. This often resulted in the distribution of questionnaires far outside the perceptibility radius and many negative or "not felt" responses in the ROB archives. ROB questionnaires were only sent to Belgian municipalities, and ROB macroseismic surveys only rarely included data from abroad. The ROB macroseismic enquiries or their questionnaires are often labelled as official, due to the governmental nature of the ROB as a scientific institution and the local authorities of the Belgian municipalities. This term on itself does not make them more valuable than any other form of macroseismic data.

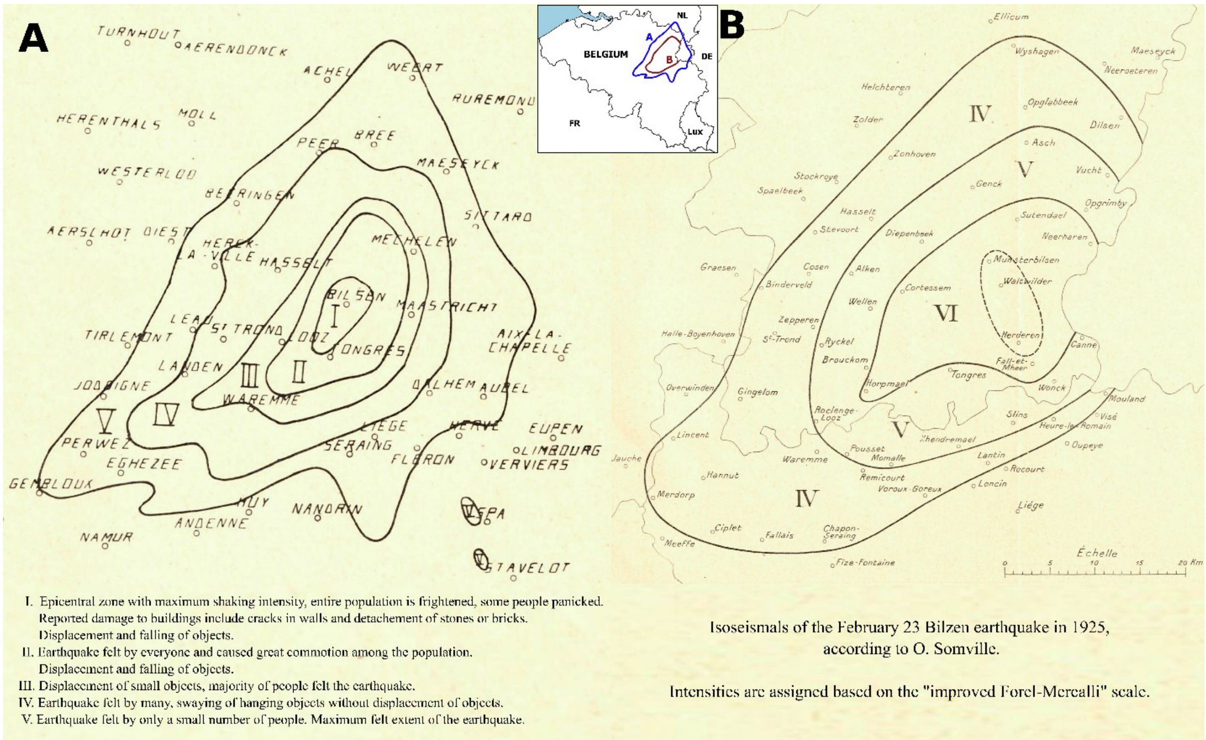
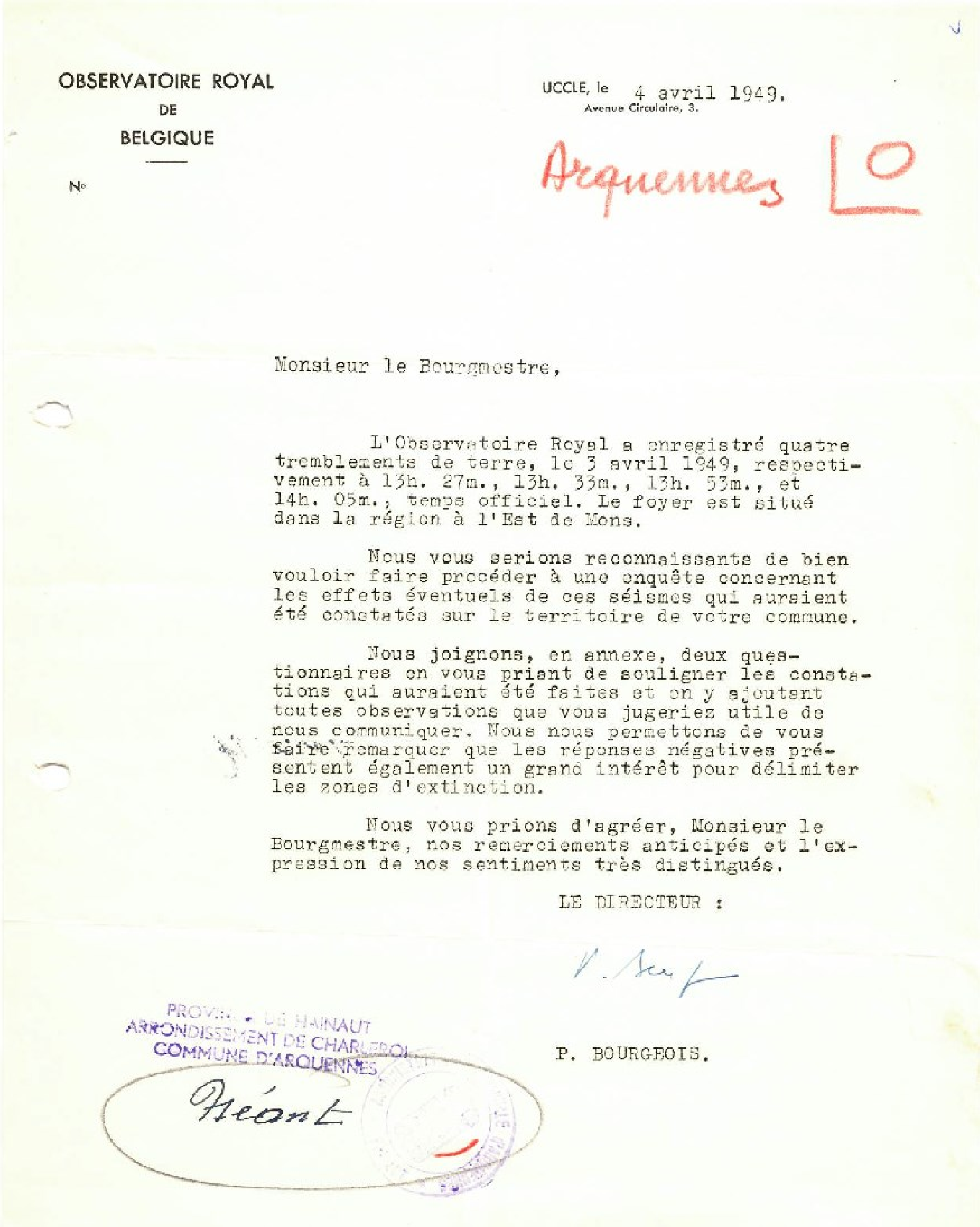



***Figure 11**. Isoseismal maps of the 1925-02-23 Bilzen earthquake with estimated $M_W$ = 4.1. A) Cross-border isoseismal map by Fourmarier and Legraye (1926). The custom macroseismic scale is provided below the map and was translated from French to English. Note that this scale is inverted, with intensity 1 as the highest intensity. B) Isoseismal map for Belgium from the macroseismic survey by O. Somville of the ROB (Fourmarier and Legraye 1926). This map is based on intensities assigned according to the "Improved Forel-Mercalli scale". This scale correlates best with the Rossi-Forel scale (de Rossi 1883). The inset map indicates the location of the outer isoseismals of both versions.*

The Royal Observatory of Belgium organized macroseismic enquiries from 1925 until 2002 for at least 60 earthquakes. Questionnaires were addressed to the local authorities of Belgian municipalities and accompanied by a short cover letter signed by the ROB director (**Figure 12**). This note informed the recipient of the preliminary earthquake parameters (i.e. timing and epicentral region) and encouraged the investigation of observed effects caused by the earthquake in their municipality. These observations could then be used to respond to the attached macroseismic questionnaire. It did not, however, provide any guidelines on how such an investigation should be held, nor did it explain the purpose of the inquiry. The note explicitly stated that negative answers are also of great interest for determining the limit of perceptibility of the earthquake, as well as the possibility to include any additional observations.



OBSERVATOIRE ROYAL
DE
BELGIQUE

N°

UCCLE, le 4 avril 1949.
Avenue Circulaire, 3.

Arquennes LO

Monsieur le Bourgmestre,

L'Observatoire Royal a enregistré quatre tremblements de terre, le 3 avril 1949, respectivement à 13h. 27m., 13h. 33m., 13h. 53m., et 14h. 05m., temps officiel. Le foyer est situé dans la région à l'Est de Mons.

Nous vous serions reconnaissants de bien vouloir faire procéder à une enquête concernant les effets éventuels de ces séismes qui auraient été constatés sur le territoire de votre commune.

Nous joignons, en annexe, deux questionnaires en vous priant de souligner les constations qui auraient été faites et en y ajoutant toutes observations que vous jugeriez utile de nous communiquer. Nous nous permettons de vous faire remarquer que les réponses négatives présentent également un grand intérêt pour délimiter les zones d'extinction.

Nous vous prions d'agréer, Monsieur le Bourgmestre, nos remerciements anticipés et l'expression de nos sentiments très distingués.

LE DIRECTEUR :

P. BOURGEOIS.

PROVINCE DE HAINAUT
ARRONDISSEMENT DE CHARLEROI
COMMUNE D'ARQUENNES

Néant

***Figure 12.*** *Example of a cover letter signed by the ROB director of that time that accompanied the ROB questionnaires. This letter informed the recipient of the preliminary earthquake source parameters (i.e. timing and epicentral region) and encouraged the investigation of observed earthquake effects in their municipality. These observations could then be used to respond to the attached macroseismic questionnaire.*

### 2.1.3.2. Questionnaire versions

The ROB questionnaires were written either in Dutch or in French and always consisted of only a single-sided page. Examples of the different versions of the questionnaires in French and Dutch are enclosed in the supplementary information (SI 10.2). The use of the word 'intensity' was intentionally avoided in all correspondence to avoid influencing the recipient. At least six different versions of the ROB questionnaire exist, each with various degrees of detail and types of questions (**Table 9**). The oldest macroseismic questionnaires available in ROB archives are those for the $M_L$ = 5.1 Uden 1932 earthquake in the Netherlands (Dost et al. 2025). The macroseismic surveys that were conducted in collaboration between the ROB and the University of Liège (Fourmarier and Somville 1926, 1930, 1933) and by the ROB alone (in Fourmarier and Legraye 1926), are not available in the ROB archives. No descriptions are given in the publications on these questionnaires and thus not much is known about their content, but it is considered probable that a different version was used for at least some of these studies (§2.2).

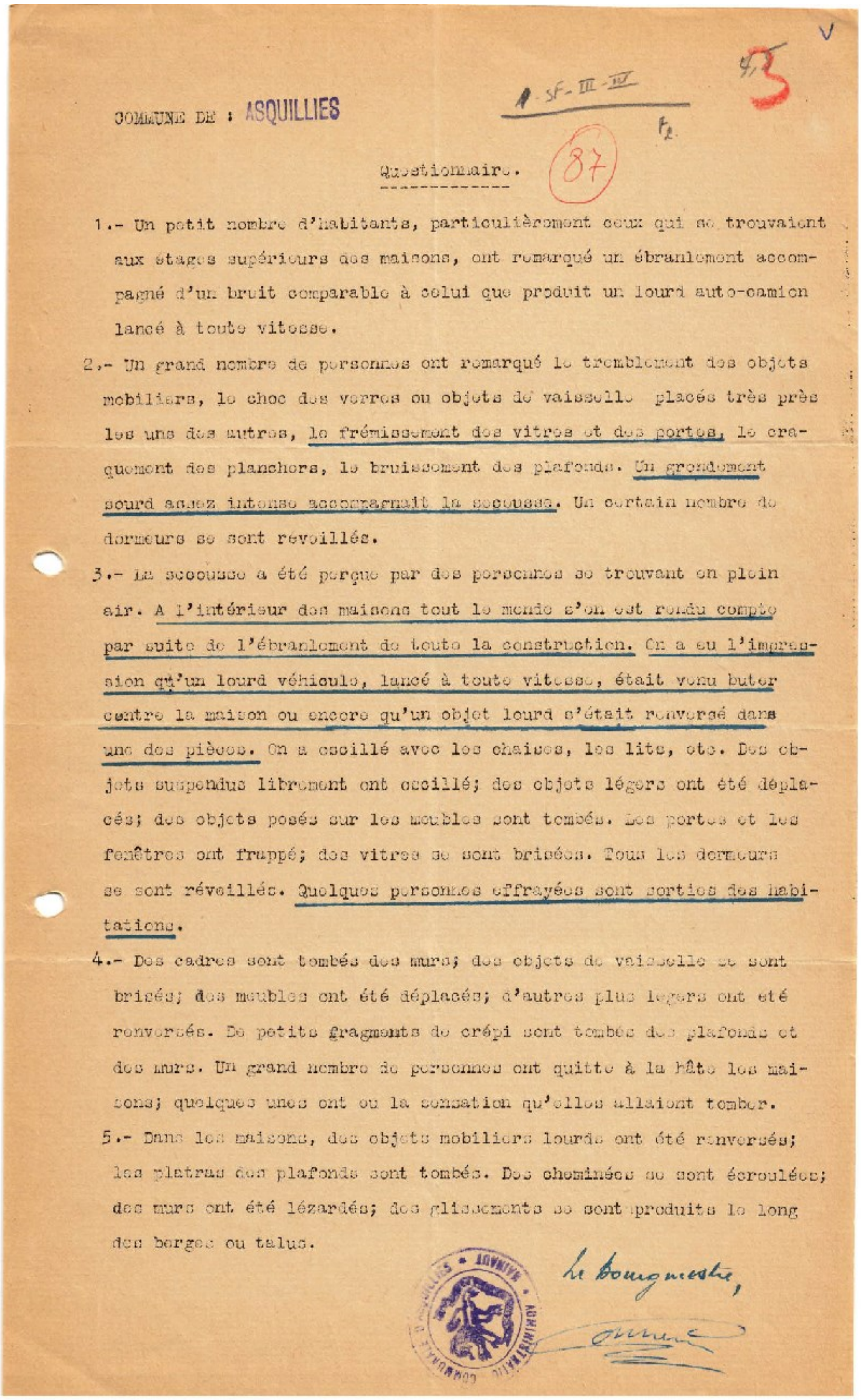
***Table 9*** **:** *Summary of the different questionnaire versions distributed by ROB and available in the ROB archives. The 'Forms' column indicates the number of questionnaires digitized for each version and does not equal the number of IDPs assigned to localities. Little is known about the contents of the first ROB questionnaires.*

| Version | Time range | Events | Intensity range | Questions | Forms | Type |
|---|---|---|---|---|---|---|
| v1 | 1932-1951 | 3 | 1-7 | 31* | 2343 | Check what applies |
| v2 | 1938 | 1 | 5-7 | 3 | 1304 | Open-ended |
| v3 | 1951-1953 | 2** | 1-7 | 27 | 677 | Closed-ended |
| v4 | 1952-1987 | 42** | 1-7 | 37 | 10252 | Closed-ended |
| v5 | 1988-1996 | 7 | 1-7 | 9 | 6183 | Multiple-choice |
| v6 | 2001-2002 | 2 | 1-7 | 20 | 565 | Multiple-choice |

** In v1, 31 diagnostics are included in the questionnaire. ** For the ML=4.0 Court-Saint-Etienne 1953 earthquake, v3 was distributed to Dutch-speaking municipalities, while v4 was distributed to French-speaking municipalities.*

The oldest macroseismic questionnaires available in ROB archives are those for the $M_L$ = 5.1 Uden 1932 earthquake in the Netherlands (Dost et al. 2025). This first version (v1; **Figure 13**) lists five classes with full-sentence descriptions of macroseismic observations that correspond to the diagnostics of the degrees in the Somville scale (Somville 1936; §2.2, SI 10.1.5). The first class on the questionnaire is a combination of degrees 2 and 3 on the Somville scale, while classes 2 to 5 correspond to degrees 4 to 7. In total, 31 different observations are listed on questionnaire v1, of which the recipients were asked to underline those observed in their municipality.

A second version (v2) of the ROB questionnaire was distributed only for a single event, the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake. This version was designed to meet the damaging character of this earthquake and was reduced to only deal with observations of damage. Only three open-ended questions were included: *"What is the approximative number of chimneys damaged partially or completely in your municipality?"*, *"Was there any other significant damage to buildings? Please describe"* and *"Are there any other effects caused by the earthquake in your municipality that are worth reporting?"*. Although the earthquake was felt throughout Belgium, the distribution of the questionnaire was limited to only about half of the Belgian municipalities, as it was only intended for municipalities that could have suffered damage.



COMMUNE DE : ASQUILLIES

Questionnaire.

1.- Un petit nombre d'habitants, particulièrement ceux qui se trouvaient aux étages supérieurs des maisons, ont remarqué un ébranlement accompagné d'un bruit comparable à celui que produit un lourd auto-camion lancé à toute vitesse.

2.- Un grand nombre de personnes ont remarqué le tremblement des objets mobiliers, le choc des verres ou objets de vaisselle placés très près les uns des autres, le frémissement des vitres et des portes, le craquement des planchers, le bruissement des plafonds. Un grondement sourd assez intense accompagnait la secousse. Un certain nombre de dormeurs se sont reveillés.

3.- La secousse a été perçue par des personnes se trouvant en plein air. A l'intérieur des maisons tout le monde s'en est rendu compte par suite de l'ébranlement de toute la construction. On a eu l'impression qu'un lourd véhicule, lancé à toute vitesse, était venu buter contre la maison ou encore qu'un objet lourd s'était renversé dans une des pièces. On a oscillé avec les chaises, les lits, etc. Des objets suspendus librement ont oscillé; des objets légers ont été déplacés; des objets posés sur les meubles sont tombés. Les portes et les fenêtres ont frappé; des vitres se sont brisées. Tous les dormeurs se sont réveillés. Quelques personnes effrayées sont sorties des habitations.

4.- Des cadres sont tombés des murs; des objets de vaisselle se sont brisés; des meubles ont été déplacés; d'autres plus légers ont été renversés. De petits fragments de crépi sont tombés des plafonds et des murs. Un grand nombre de personnes ont quitté à la hâte les maisons; quelques unes ont eu la sensation qu'elles allaient tomber.

5.- Dans les maisons, des objets mobiliers lourds ont été renversés; les platras des plafonds sont tombés. Des cheminées se sont écroulées; des murs ont été lézardés; des glissements se sont produits le long des berges ou talus.

Le Bourgmestre,

***Figure 13**. Example of an ROB questionnaire (version 1). This questionnaire consists of a list of descriptions of earthquake effects in five classes. These classes correspond roughly to the degrees in the Somville scale (§2.2.1.).*

A short-lived third version (v3) was used for only two macroseismic surveys, i.e. the $M_L$ = 4.1 Theux 1951 earthquake and the $M_L$ = 4.0 Court-Saint-Etienne 1953 earthquake. Starting from v3, ROB questionnaires consist dominantly of closed-ended yes-or-no questions and are ordered roughly from low to increasingly higher intensity diagnostics. While v3 was indeed used for the $M_L$ = 4.0 Court-Saint-Etienne 1953 earthquake, it was only distributed to the Dutch-speaking municipalities. For the French-speaking municipalities, a fourth version was already in use since the 1952 Quaregnon earthquake with an estimated macroseismic $M_W$ = 3.1. This v4 is quite similar to v3, it mostly uses closed-ended yes-or-no questions that are ordered from increasingly higher intensity diagnostics, but v4 is more detailed, increasing the number of questions from 27 to 37. Version 4 is the most detailed questionnaire of the ROB and has been used extensively for 44 different events over 35 years.

With the introduction of a fifth version (v5), the ROB questionnaires are shortened significantly. It consists of only 9 questions, including a question to enquire about the total number of residential buildings in the municipality. From now on, macroseismic observations are no longer arranged by increasing intensity as in previous versions but are ordered based on the different sensors they relate to. Version 5 also includes multiple-choice questions, explicitly providing the possible answers. The sixth version (v6) of the ROB questionnaire continues in a similar style as v5 but extends the number of questions again to 20. While in theory v6 is still active today, it has not been used for over 20 years and has been used only twice, i.e. for the $M_L$ = 3.9 Voerendaal 2001 earthquake and the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake.

### 2.1.4. Other traditional sources

Other than the macroseismic surveys performed through the distribution of standardized questionnaires by the ROB and the University of Liège (i.e. the early 20$^{th}$ century surveys by mainly M. Lohest and P. Fourmarier, as well as the work of François et al. (1986, 1989)), macroseismic data was also collected through other procedures. Following an event, the ROB would receive **letters** from people who felt the earthquake, reporting their experience and their observations. This could be on request, through an appeal to the public on radio, newspapers or television, resulting in many responses, as was the case for the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake (for which a total of 2271 letters were received); alternatively, these responses could be spontaneous actions, which generally led to much fewer letters. In some cases, people took up the phone and called to the ROB (e.g. Camelbeeck 1983). Not much is known about how often this occurred, for which events or how this information was processed, but few notes of these phone calls are present in the ROB database.

**Field surveys** are often considered to be the most qualitative sources of macroseismic data, as the evaluators do not have to rely on observations made by others. They typically occur only in the case of significant damage and only in the most heavily impacted localities. The number of field surveys conducted in Belgium, however, is limited to only a few cases. These surveys are quite basic, without proper quantification of the various damage grades and other diagnostics. Internal unpublished documents report single-day visits to multiple affected localities, quickly describing certain examples of macroseismic observations, either with or without pictures of the inflicted damage. The majority of these surveys were also conducted for events which only caused very limited damage such as the $M_L$ = 4.0 Court-Saint-Etienne 1953 earthquake with a maximum intensity of 5 or the 1954 Flénu earthquake with an estimated macroseismic $M_W$ = 3.5 and a maximum intensity of 5-6. These surveys cannot be compared to highly detailed surveys, such as those conducted by the "Macroseismic Intervention Group" (GIM) in France and its overseas territories (Sira 2015; Schlupp et al. 2021). A slight exception to this is the field survey by Bernard and Van Gils (unpublished) on the $M_L$ = 4.6 Havré-Boussoit 1949 earthquake, in which the number of damaged buildings and the type of damage are described shortly. The Belgian Calamity Fund also received letters describing the damage to 16,000 individual buildings caused by the impact of the $M_L$ = 5.0 Liège 1983 earthquake. These letters were sent by residents of the city of Liège and neighbouring municipalities. This information, unfortunately, was never used to assign macroseismic intensities but may still be available in the paper records and archives (García Moreno and Camelbeeck, 2013).

Another common source of macroseismic data are **newspaper articles**. These are especially useful for older events in the early to mid-20th century, as the existence of many local and regional newspapers at that time reported on macroseismic observations in detail with clear specifications of the localities in which they occurred. From the 1970s onwards, newspapers in Belgium no longer provide detailed descriptions of macroseismic observations separately for different localities individually and have become less useful as macroseismic sources.

### 2.1.5. Historical research

For a long time, our knowledge of historical seismicity was based on earthquake catalogues compiled by numerous seismologists or geologists without any knowledge on the necessary historical criticism (e.g. Karl Ernst Adolf Von Hoff, Alexis Perrey or Robert Mallet). Sources were not cited or there was no distinction between historical sources that were written contemporary with the occurrence of the facts or later works (Alexandre and Alexandre-Delamotte 2024). Unsurprisingly, this led to many fake and duplicated earthquakes as well as numerous parametric catalogues of earthquakes with unaccountable values for epicentre, coordinates or maximum intensity. Multiple compilations of historical earthquakes have been published for Belgium (e.g. Torfs 1862; Lancaster 1901), as well as parametric catalogues (e.g. Van Gils and Zaczek 1978).

The publication of these uncritical works continued up until the late 20$^{th}$ century. It was Ambraseys et al. (1983) who finally recommended a critical review of the sources available for historical seismology and to collaborate with professional historians. Since then, a series of regional critical studies have been performed by historians, including for Belgium (Alexandre 1985, 1989; Alexandre 1994; Melville et al. 1996), while other works focus on single major events (e.g. Alexandre et al. 2008; Kusman et al. 2010; Knuts et al. 2015; Camelbeeck et al. 2021; Alexandre and Alexandre-Delamotte 2024).

As the collection of macroseismic data was (mostly) not organized at the time of the facts on a national level, there also is not much reason to assemble separate national historical databases. Around the late 19$^{th}$ and early 20$^{th}$ century, various countries started collecting macroseismic data within their borders. As a result, collection and processing procedures, while evolving through time, were mostly identical throughout their territory. For historical earthquakes, with the exception of a few events, no macroseismic surveys were conducted, and the creation of national databases would thus not be of interest. Instead, the Archive of Historical Earthquake Data ("AHEAD") was created (Albini et al. 2013; Locati et al. 2014; Rovida and Locati 2015). AHEAD is a European database for historical earthquakes from 1000 to 1899 and provides macroseismic intensity data and parametric catalogues, but also a digital library of digitised papers and books. It marks identified fake events or earthquakes of which the authenticity is yet to be determined. AHEAD can be seen as the status of the available research of historical seismology in Europe, including Belgium.

### 2.1.6. "Did You Feel It?"

The Belgian online macroseismic survey was first launched on the 22nd of July 2002 by the ROB, in response to the $M_W$ = 4.6 Eschweiler-Alsdorf earthquake, just across the border in Germany (Camelbeeck et al. 2003). This Belgian online survey is called the "Did You Feel It?" ("DYFI?") inquiry and is almost an exact copy of the identically named United States Geological Survey (USGS) inquiry (Wald et al. 1999b). Only few small differences between both versions exist, e.g. the Belgian inquiry includes a question on the perceived noise during the earthquake, while the USGS inquiry includes a question on the length of the building in which the respondent resided at the time of the earthquake. Next to English, the original language of the inquiry, the ROB also provides the questionnaire in the three official languages of Belgium: Dutch, French and German. Through the online inquiry (seismology.be), anyone with internet access can easily report their individual perception and observations of the earthquake, within a few minutes. It consists of standard macroseismic questions, such as the location (geographically) and situation (e.g. indoors or outdoors, floor level, asleep or awake) of the respondent at the time of the earthquake and the perception or observation of several common diagnostics that are used in modern macroseismic intensity scales. Responses to the questions are grouped by locality and intensity values are automatically calculated (§2.3). The complete questionnaire, in its current form, is provided in the supplementary information (SI 10.3).

Very limited changes have been made to the "DYFI?" inquiry since its launch, more than two decades ago. A small change to the inquiry was made in 2009 to include a question pertaining to the noise of the earthquake, as many respondents to the online inquiry for events of the 2008-2010 Walloon Brabant seismic swarm reported to have not felt any shaking, but indicated to have heard a sound related to the earthquake (Van Noten et al. 2015a). Since 2011, the ROB and the Erdbebenstation Bensberg (BNS) from the university of Cologne share the same "DYFI?" inquiry and its macroseismic data. From 2016 onwards, the ROB and the Bureau Central Sismologique Français (BCSF) collaborate to transfer reports to the ROB "DYFI?" inquiry for French earthquakes in near real-time (Van Noten et al. 2017).

## 2.2. Traditional ROB macroseismic data processing

### 2.2.1. Assessment of intensity values

It is not exactly known how intensities were assigned by the ROB, other than comparing the questionnaires to the macroseismic scales in use at the time. Were there certain guidelines in place to guarantee consistent assignment of intensities over time or did each expert rely on their subjective assessments? Given that there is no evidence of the former in any published or unpublished documents, the latter is more likely. An important exception to this is the **"chimney rule"**, which has been used consistently at the ROB to distinguish between intensities 5, 6 and 7. This rule is based on the percentage of partly damaged or completely collapsed chimneys. If this number exceeds 10% for a single municipality, intensity 7 is assigned. Between 1 and 10%, intensity 6 is assigned, and intensity 5 when between 0 and 1% of the chimneys in a municipality are damaged. This rule was first introduced by Somville (1939b) for the macroseismic survey of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake. Although the chimney rule is quite simplistic in comparison to modern practices, as it does not consider the vulnerability of the building stock or other types of damage, the use of statistical values to assign intensities is similar to current practices and was adopted only much later in popular intensity scales. The use of the chimney rule survived to the present day: Camelbeeck et al. (2022) assume that, in the Hainaut coal basin, the building stock consists of 50% vulnerability A and 50% vulnerability B (according to the classification in EMS-98) and that the highest grade of damage only occurred to the vulnerability A buildings. With these assumptions, the chimney rule would indicate intensity 7 according to the EMS-98 if more than 10% of the chimneys in a locality were damaged or collapsed. The authors recognize the simplistic nature of this rule but state to have no other option due to a lack of other useful data from the ROB questionnaires.

### 2.2.2. Applied intensity scales

Various macroseismic intensity scales have been used in Belgium to assign intensity values to. Identifying the correct intensity scale of an IDP is of great importance to correctly assess the severity of ground shaking experienced at that location and to allow conversions of the values between intensity scales (§3.1.3.3). The first Belgian traditional macroseismic surveys established custom-designed intensity scales, which were provided in full (e.g. Lohest and De Rauw 1909; Fourmarier and Legraye 1926). ROB macroseismic studies consistently reported the use of recognized international macroseismic scales. Unfortunately, it is not always clear which macroseismic scale ROB seismologists intended to reference.

The names given to newly published macroseismic intensity scales or modifications to earlier scales are notoriously confusing (Musson et al. 2010), with the implication that macroseismic publications often refer to the wrong scale. The first ROB macroseismic publications mention the use of "l'échelle Forel-Mercalli améliorée à 12 degrés" (or "the improved Forel-Mercalli scale with 12 degrees", Fourmarier and Legraye 1926; Fourmarier and Somville 1926), which sometimes was also nicknamed as "the international intensity scale". The Forel-Mercalli scale was proposed by Cancani (1904) and is the first 12-degree scale. The Forel-Mercalli scale (further referred to as the Cancani scale) only consisted of titles, without providing any diagnostics for each degree in his scale. The Cancani scale was thus never usable as it was proposed (Musson et al. 2010). The next major macroseismic scale proposed, which can thus be considered as "the improved Forel-Mercalli scale with 12 degrees", was the Sieberg scale (Sieberg 1912). The definitions of "the improved Forel-Mercalli scale with 12 degrees" for degrees 4 and 5, as provided by Fourmarier and Somville (1926), do not match the lengthy descriptions of the Sieberg scale at all, but match very well with the degrees of the Rossi-Forel scale (de Rossi 1883; **Table 10**). Fourmarier and Somville (1930) drop the "improved" from the Forel-Mercalli scale (or Cancani scale), further indicating that they likely meant to refer to Cancani (1904), who only proposed to extend the scale from 10 degrees to 12.

***Table 10 :*** *Comparison of the diagnostics of degrees 4 and 5 between the "Improved Forel-Mercalli scale with 12 degrees", as mentioned in Fourmarier and Somville (1926; 1930) and Fourmarier and Legraye (1926), and the Rossi-Forel scale (de Rossi 1883). Both scales are practically identical.*

| degree | Improved Forel-Mercalli scale with 12 degrees* | Rossi-Forel scale** |
|---|---|---|
| **4** | Shaking observed by people in motion, weakly felt outside, more noticeable inside; shaking of movable objects, doors, windows; creaking of floors. | Felt by several persons in motion; disturbance of movable objects, doors, windows; creaking of floors. |
| **5** | Shaking observed in general by the whole population; shaking of heavier objects, furniture, beds; ringing of a few bells. | Felt generally by everyone; disturbance of furniture and beds; ringing of some bells. |

* *translated to English from Fourmarier and Somville (1926).*

** *as translated by Davison (1921).*

In 1932, the ROB macroseismic survey for the $M_L$ = 5.1 Uden earthquake used in its questionnaire another macroseismic scale. An almost identical scale to this version in the ROB questionnaire was provided by Somville (1936). Somville (1936) refers to this scale as the Mercalli-Cancani scale with 12 degrees by Sieberg (1917, providing a French translation of the Sieberg scale). The scale provided by Somville (1936) only provides the first seven classes in French and modified the scale to be suitable for Belgian earthquakes, which mainly entailed a strongly reduction of the definitions of the Sieberg scale and only few changes were implemented. Due to these modifications, one could no longer refer to this scale as the Sieberg or MCS-23 scale. Instead, the scale provided in Somville (1936) will be referred to as the **Somville scale** (SI 10.1.5), as, to our knowledge, he was the first and only to formulate this version. Somville (1936) also titles his scale as “the Mercalli intensity scale”, without mentioning Mercalli anywhere else throughout the publication. While Mercalli’s scale (1902) does resemble certain diagnostics from the Somville scale, it does more closely resemble the Sieberg scale. The name Mercalli has been seen by many, wrongfully so, as a synonym to macroseismic intensity and could have been the reason for the inclusion of the name.

Oddly enough, Fourmarier and Somville (1933) still mention the use of “the international intensity scale”, which in earlier publications was a synonym for “the improved Forel-Mercalli scale with 12 degrees” (Fourmarier and Legraye 1926; Fourmarier and Somville 1926) and thus the Rossi-Forel scale, a year after the first known use of the Somville scale. The fact that different macroseismic scales were used for the first ROB macroseismic surveys of which no original questionnaires are available, and those for which they are available, strongly indicates that these early ROB questionnaires would have differed from the version 1 questionnaires.

Subsequent Belgian macroseismic publications are few but generally refer to the MCS-23 scale in some way (e.g. Somville 1939b; Charlier 1944; Ahorner and Van Gils 1963), while likely the Somville scale was the scale in use. Van Gils (1966) introduces the MSK scale (Medvedev et al. 1964) in Belgian macroseismic surveys, whereas the EMS-98 was adopted in 2002 by Camelbeeck et al. (2003) and is still in use today.

## 2.3. DYFI aggregation

Macroseismic data collected through the online “DYFI?” inquiry of the ROB-BNS are processed automatically to assign macroseismic intensities. This procedure is identical to the one described by Wald et al. (1999b). Out of the 23 macroseismic questions of the ROB version of the “DYFI?” online inquiry, only eight are used to calculate macroseismic intensity. Each response to one of these questions is assigned a numerical value (SI 10.3), which are then averaged by location (e.g. main municipalities, sub-municipalities, zip codes, grid cells; §2.4). Responses that do not answer a particular question (as opposed to answering “none”) do not count in the computation of the corresponding index. Subsequently, a weighted sum is taken of these eight indexes for each location to determine the community weighted sum (CWS). The CWS is defined by (1) (Dengler and Dewey 1998):

$$\begin{aligned} CWS = 5 * felt\ index + motion\ index + reaction\ index + 2 * stand\ index + 5 \\ * shelf\ index + 2 * picture\ index + 3 * furniture\ index + 5 \\ * damage\ index \end{aligned} \tag{1}$$

The weights in this equation have been subjectively chosen to gradually increase CWS values with increasing intensity values. To scale CWS values to macroseismic intensity values to the Modified Mercalli scale (MM-93; Stover and Coffman 1993), Dengler and Dewey (1998) also provided a formula to calibrate between CWS and USGS assigned intensities from single postal questionnaires (2):

$$CDI = 3.3 + 0.13 * CWS \tag{2}$$

where CDI stands for community decimal intensity. This formula is the result of a linear regression between USGS assigned MM-93 intensity values from single postal questionnaires. CDI can thus be considered as the DYFI equivalent for macroseismic intensity. The decimal nature of CDI can be considered both a benefit, due to its possibility for greater resolutions, and an obstacle, as there is no such thing as intermediate macroseismic intensity values by definition. A common resolution is to round the CDI value to the closest integer value, i.e. the macroseismic intensity or MI.

The correlation between CDI and MM-93 intensity values was based only on data of the $M_W$ = 6.7 Northridge 1994 earthquake in Southern California. To extent the link between CDI and MM-93 intensity values to all felt earthquakes, Wald et al. (1999b) provided a new correlation based on three earthquakes in the same region (3):

$$\begin{aligned} CII &= 3.4 \ln(CWS) - 4.38 \quad (CWS \geq 6.53) \\ &= 2 \quad\quad\quad\quad\quad\quad\quad\quad\; (CWS < 6.53) \end{aligned} \tag{3}$$

where CII stands for community internet intensity. This improved equation is also used for the “DYFI?” inquiry at the ROB. At the ROB, the aggregation of the eight different indexes by location does not occur automatically. Instead, CWS and CII values are assigned to individual reports and are stored as such in the Belgian online macroseismic database at the ROB. This resulted in an often mistake to average the CWS values of individual responses in each location, instead of first aggregating all responses to then provide a single CWS value (Neefs and Van Noten 2023). Aggregated submissions to the “DYFI?” inquiry with a negative response to the felt-question are assigned with CII = 1. After the original publication by Wald et al. (1999b), literature started referring to (3 as the CDI (e.g. Wald et al. 2011; Saunders et al. 2024; Hough 2024). To be consistent with literature, this work will follow this evolution, and this equation will be referred to as the CDI value.

## 2.4. Presentation of intensity data and resolutions

Throughout the 20th century, the presentation of intensity data of earthquakes affecting Belgium was done almost exclusively through isoseismal maps. From the first traditional surveys by M. Lohest and P. Fourmarier (**Figure 10**, **Figure 11**), to the ROB communal surveys at the end of the century (e.g. Camelbeeck and De Becker 1984; Haak et al. 1994). Belgian isoseismal maps are generally characterized by high degrees of smoothing. Extrapolating isoseismals was often not needed, because of the high density of data available in Belgium for most events and the ROB mostly limited its macroseismic surveys to Belgium. Only limited examples can be given where intensity data points are plotted directly on the map in the 20th century (e.g. **Figure 14**, Ahorner and Van Gils 1963; François et al. 1989; Haak et al. 1994). These are all the result from collaborations between the ROB and other institutions from within our outside Belgium.

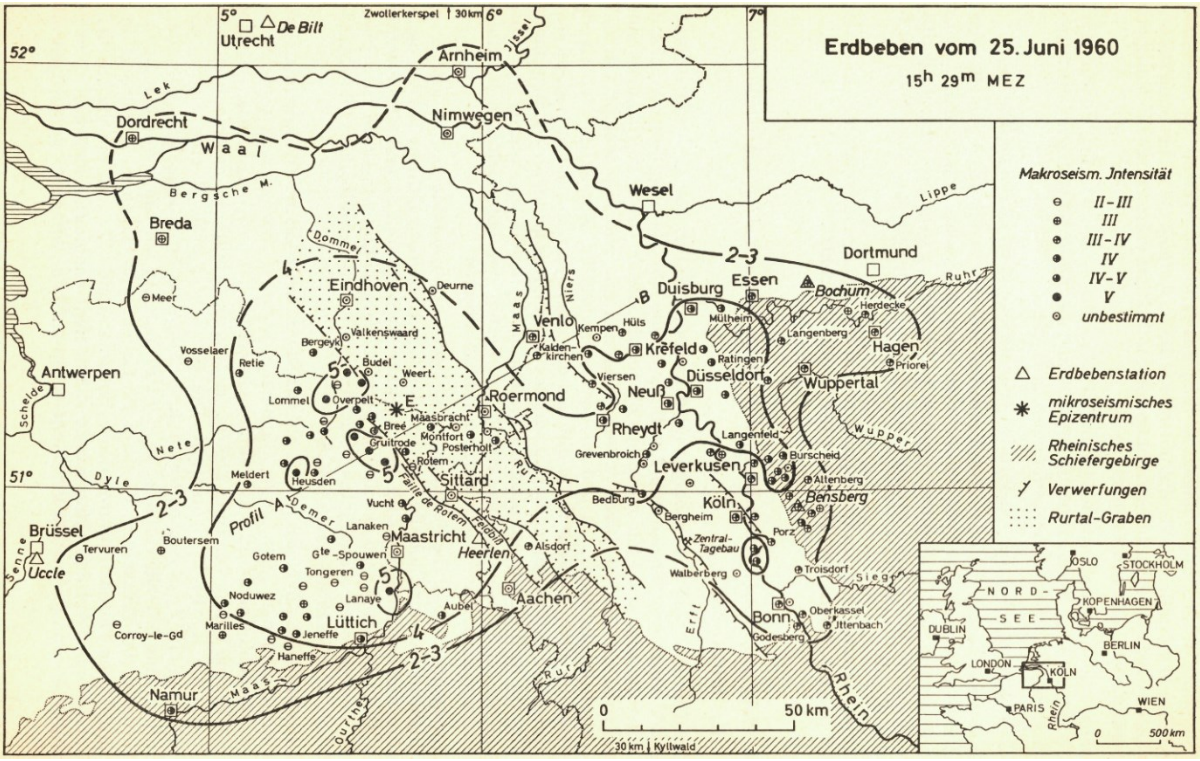



*Figure 14. Isoseismal map of the $M_L$ = 4.0 Bilzen 1960 earthquake by Ahorner and Van Gils (1963). This map displays both isoseismal lines as well as individual intensity data point symbols, shown as circles with different coloured in proportions to indicate the intensity values.*

In contrast, isoseismal maps of Belgian 21st century earthquakes are inexistent. This is no surprise, as the limited seismic activity during the last two decades resulted in very few notable events (§1.2.1) and besides two events in the first two years of the century, all macroseismic data in Belgium was collected by the online "DYFI?" inquiry. Applying a subjective manual interpretation to an otherwise automatic procedure would make little to no sense. Drawing bold definitive isoseismal lines on a map seems particularly counter-effective when these same maps are automatically updated with every new submission of a DYFI report. Instead, online collected macroseismic data have been presented consistently on the ROB's website as automatically generated IDP maps (e.g. $M_L$ = 3.1 Kinrooi 2018 earthquake). Up until 2021, aggregation of the responses by location of the data did not occur and intensities were calculated by averaging individual response CWS values within the same location.

From 2021 onwards, the procedure has been modified and aggregation of the data by location is now correctly calculated and presented for all events since the launch of the online inquiry in 2002.

Two different intensity colour scales are in use at the ROB. One is used more commonly for online macroseismic data maps, while the other is used mainly for traditional macroseismic data (**Figure 15**). The latter (**Figure 15B**) is a copy of a discrete version of the USGS' colour scale (**Figure 15C**, Wald et al. 1999b; Wald et al. 2011), widely adapted by many other institutions all over the world, while the first (**Figure 15A**) was first introduced by Camelbeeck et al. (2003). There is no known argumentation on why these two different scales exists, but the online version (**Figure 15A**) is likely the result of the limited colour contrasts between two consecutive values as used in **Figure 15B**. As maximum intensity values for Belgian earthquakes only rarely exceed intensity 5, the low contrast between these values limited the comprehensiveness of these maps. The online colour scale version deals with this accordingly by introducing sharper contrasts between each consecutive value.

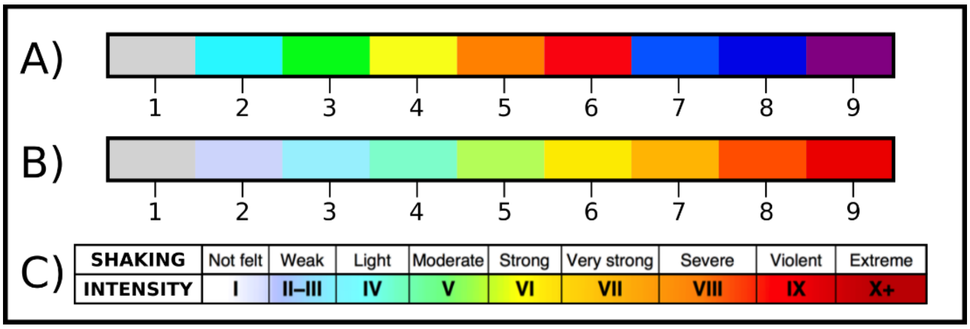



***Figure 15**. Colour palettes used to indicate intensity values for IDP map presentations. **A)** Discrete ROB colour scale commonly used for online DYFI macroseismic data. **B)** Discrete ROB colour scale mainly used for ROB traditional macroseismic data. **C)** Continuous colour scale from the USGS' for map presentations that make use of decimal intensities (Wald et al. 1999b; Wald et al. 2011). A discrete version of this continuous scale is often used as well.*

Belgian macroseismic intensity data are almost exclusively processed on the municipal scale, i.e. the smallest and lowest administrative level of Belgium. Representing Belgian data as points is thus theoretically incorrect, as observations are used spanning its entire territory. This disconnect between the data and its point representation is enhanced even more due to the strong ribbon development, present all throughout the more populated regions in Belgium. As an alternative, Belgian macroseismic maps of IDPs are often presented by colouring the entire area of a municipality (**Figure 16**). This representation also provides a more complete view of the dataset, as it shows clearly for which municipalities no data has been received. For most of the 20th century, the Belgian municipalities are perfectly in line with most guidelines that discuss good resolution for macroseismic data (e.g. Musson and Cecić 2012). A slight divergence would be some of the largest Belgian cities, such as Antwerp, Ghent and Liège, as these could benefit from a division into several city districts. The largest Belgian municipalities area-wise, such as Mol (115 km²), Geel (110 km²), Lommel (102 km²) and Genk (88 km²) in northeast Belgium, could also benefit from an additional subdivision. Throughout the 20$^{th}$ century, however, the number of municipalities decreased strongly, from a maximum of 2675 municipalities in 1929 (Vrielinck 2000) to 565 at the time of writing. This decrease in the number of municipalities was most pronounced in the 1960's and 1970's due to government-imposed mergers, from a total of 2585 to only 596 municipalities. In 2025, the number of Belgian municipalities was lowered to 565, and additional mergers between Belgian municipalities are likely to occur in the future.

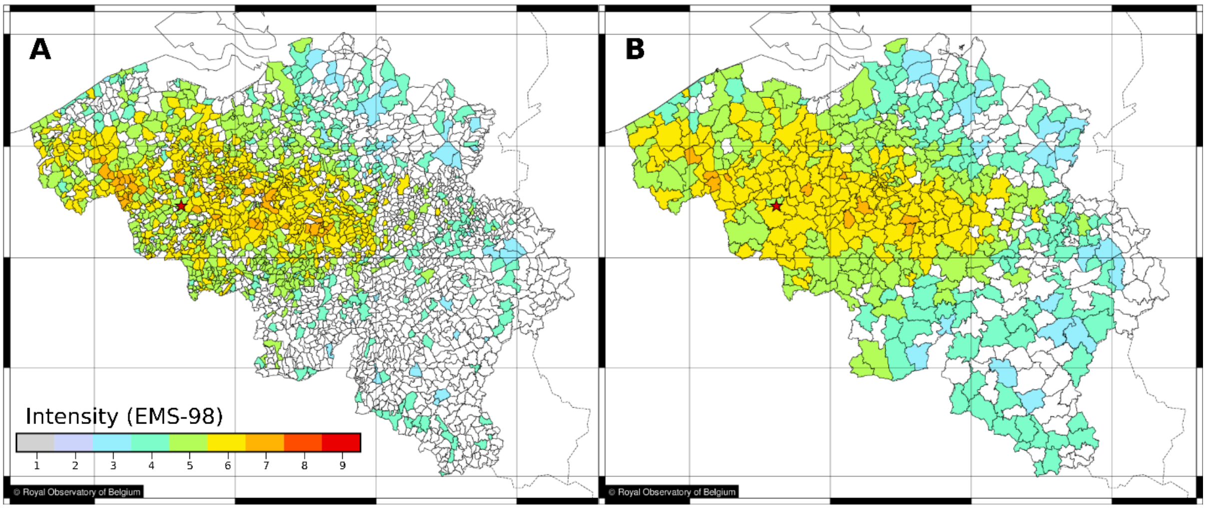



***Figure 16.*** *Polygon intensity presentations of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake by colouring in the entire municipality's area in its corresponding intensity value colour for A) all Belgian sub-municipalities, and B) main municipalities.*

As a result of the mergers, the current municipalities do no longer align with the optimal resolution for macroseismic surveys, as multiple towns are grouped together and cities become even larger by incorporating smaller neighbouring municipalities into their territory. The former dissolved municipalities still exist in name, sometimes with small territorial exchanges between neighbouring towns or cities, as sub-municipalities. Local governance, however, does no longer exist in these former municipalities, and ROB communal questionnaires could only be addressed to the merged municipalities, i.e. the main municipalities. Consequently, this caused a significant drop in resolution of the traditional macroseismic data (**Figure 16**). The online collection of data through the "DYFI?" inquiry does again allow for greater resolutions. If the respondent the inquiry decides to voluntarily provide street level data, rooftop quality data can be achieved through geocoding (Van Noten et al. 2017).

In this work, two distinct scales are commonly referenced to describe the resolution of the macroseismic data. The **main municipal scale** reflects the resolution of the Belgian municipalities on 1 January 2002. It consists of 589 municipalities with an average area of 52 km². The **sub-municipal scale** reflects the higher resolution of Belgian municipalities on 1 January 1961, before the large-scale mergers in the 1960s and 1970s. The sub-municipal scale consists of 2585 municipalities with an average area of 12 km².

## 2.5. Chapter conclusions

The history of conducting macroseismic surveys in Belgium is rich, but has never before been properly documented. This chapter presented a comprehensive overview of the history and current state of macroseismic surveys in Belgium since the start of the 20th century. Throughout the 20th century, Belgium surveys show a progression from sporadic, individual efforts to more systematic and institutionalized methodologies. Since the first true macroseismic survey in Belgium by Lohest and De Rauw (1909), macroseismic data collection has been marked by the development of custom intensity scales tailored to individual earthquakes and the publication of highly heterogeneous data, with notable inconsistencies between surveys.

The Royal Observatory of Belgium's (ROB) involvement, particularly with its municipal questionnaire surveys, represent a significant institutionalization of macroseismic data collection, allowing for more homogeneous data. Unlike early 20th century surveys, which were often driven by individual scientific initiatives, the ROB introduced a more systematic and nationwide approach. Its methodology significantly enhanced spatial coverage and ensured that macroseismic surveys were conducted consistently for earthquakes across the country. Nonetheless, the use of six different versions of the ROB questionnaire over time introduced a degree of procedural variability, contributing to residual heterogeneity within the dataset. This evolution ultimately culminated in a transition to digital data collection in the 21st century with the introduction of the "Did You Feel It?" online inquiry—yet another fundamentally different approach that further diversifies the procedural landscape of Belgian macroseismic data.

All these various survey methodologies apply a range of spatial resolutions, respondent types, levels of control over data quality, and intensity scales. Many of the conducted surveys also lack documentation. This methodological diversity of macroseismic surveys, complemented with various other macroseismic data sources such as letters, newspaper articles and the sporadic field surveys, inherently comprises the consistency of the Belgian macroseismic data. Any use of the Belgian macroseismic data must account for its fragmented origin, rather than viewing this data as a uniform and homogeneous body of information.

# 3. Belgian Macroseismic Data

## 3.1. The Belgian Traditional Macroseismic database

### 3.1.1. BTM database structure

With the **Belgian Traditional Macroseismic (BTM) database**, two new tables on the macroseismic history of Belgium in the 20th century are presented: 1) the Belgian Traditional Macroseismic **earthquake catalogue** (abbreviated to 'BTM catalogue') and 2) the Belgian Traditional Macroseismic **intensity dataset** (abbreviated to 'BTM dataset'). The BTM catalogue summarizes the summary macroseismic and source parameters of felt earthquakes in Belgium, while the BTM dataset lists all intensity data points (IDPs) of the events included in the BTM catalogue. The IDPs in the BTM dataset and the events in the BTM catalogue are linked through earthquake identifiers ('id_earth').

The BTM catalogue is limited to the 20th century, except for two earthquakes in 2001 and 2002, as these were the last traditional macroseismic surveys in Belgium. The BTM dataset is confined to IDPs located within Belgium. This limitation results from the federal character of the ROB, which has primarily collected data only from within the country. While the ROB is in possession of IDPs from neighbouring countries for certain events, these were not included as their origins are mostly unknown. Instead, the BTM database should be set side by side with similar initiatives abroad (e.g. Sira et al. 2021; Locati et al. 2022; Martin et al. 2022).

To complete the BTM database, a search for additional felt events without prior IDPs in the original ROB intensity database, was performed. Available sources in the ROB archives and online repositories consisted of old seismological and macroseismic publications and newspaper articles. A small number of IDPs from previously collected but unprocessed historical research (i.e. ≤ 1911; Camelbeeck et al. 2009) were also included to the BTM database. In total, seven new events were added which had no IDPs available in the ROB macroseismic database. All these events occurred before World War II, as afterwards, ROB macroseismic surveys were conducted even for very small events (e.g. $M_L$ = 2.5 De Panne-Koksijde 1968 or $M_L$ = 2.4 Okegem-Ninove 1992) or non-seismic events (e.g. Brussel 1956-11-19, presumed sonic boom; Knokke 1959-09-09, detonation of the "Empire Blessing", a sunken British WWII ammunition ship off the Belgian coast).

The intensity data of the ROB has never been published in its entirety. Only recently, a large subset of this database was published for the first time (Camelbeeck et al. 2022). Nonetheless, IDPs from the ROB were used in multiple publications (e.g. Ambraseys 1985; Nguyen et al. 2004; Stromeyer and Grünthal 2009), as they were shared upon request. The lack of a centrally available source of data and accompanying metadata resulted in several problems, such as the existence of different versions or subsets of the data that now show considerable differences from current ROB data (e.g. Hinzen and Oemisch 2001) or the withdrawal of Belgian IDPs from certain datasets (e.g. Bakun and Scotti 2006). The BTM database is now provided as a centralized and publicly available database through the interactive website generated with the Macroseismic Intensity Data Online Publisher (MIDOP, Locati and Cassera 2010; **Figure 17**, Neefs et al. 2024b). This database will be updated whenever new data becomes available, either from new events in the future or from newly discovered macroseismic sources of past events. The Belgian traditional macroseismic database on MIDOP could potentially also be complemented with the Belgian online macroseismic database (§3.2) in the near future.

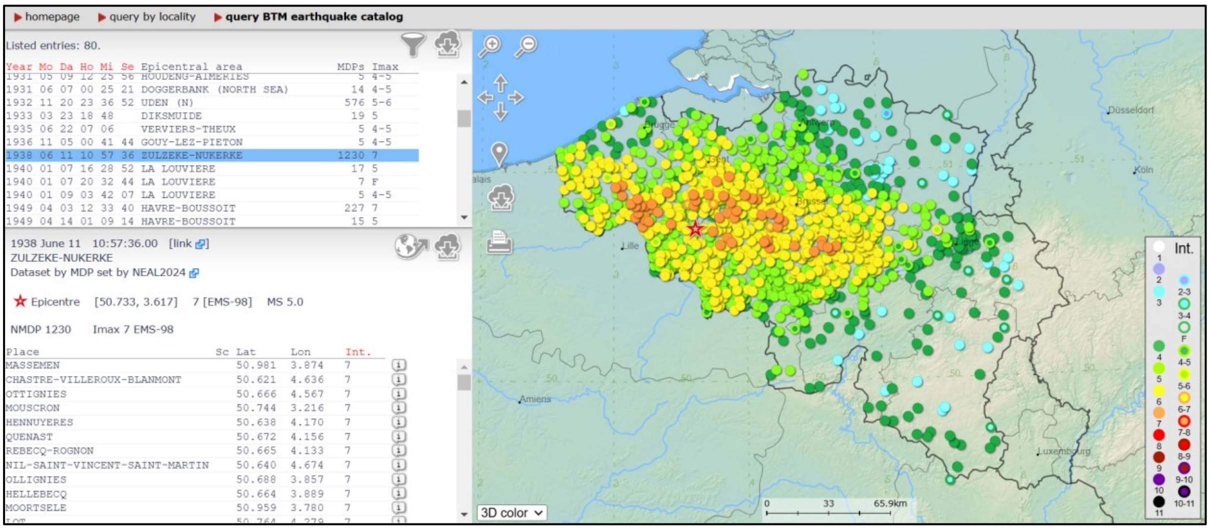



***Figure 17***. *The BTM Database has been published online with MIDOP (Locati and Cassera 2010) and can be consulted on [https://seismologie.be/midop/index.htm](https://seismologie.be/midop/index.htm) (Neefs et al. 2024b). The example above shows the impact of the 1938 earthquake.*

### 3.1.2. The Belgian Traditional Macroseismic earthquake catalogue

The BTM earthquake catalogue starts in 1908, coinciding with the divide between historical macroseismic research, the onset of more continuous and consistent scientific reporting of earthquakes in Belgium, and the onset of continuous instrumental recording. It includes all earthquakes for which traditional macroseismic surveys have been performed in Belgium. Additionally, felt events for which other macroseismic sources are available, such as newspaper articles or individual letters, have also been included, provided that at least two IDP were available for the event. There are felt earthquakes for which insufficient macroseismic sources are available for assigning IDPs (e.g. the aftershocks of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake), for which macroseismic information is confined to a single locality (e.g. Fleurus 1904, La Louvière 1952) or which have documented IDPs just across the Belgian border (e.g. $M_S$ = 3.3 Maastricht 1918, $M_S$ = 3.8 Roermond 1935). The BTM catalogue currently consists of 80 felt events (**Table 11**) and can be extended if new macroseismic data from 20th-century events are discovered.

The BTM catalogue provides new macroseismic information collected during the PhD project and is complemented with parameters from the ROB earthquake catalogue. Many of its parameters such as the date, time, location/name and source parameters, such as epicentral coordinates, hypocentral depth and various magnitudes, are copied to the BTM earthquake catalogue. The earthquake identifiers in the BTM catalogue coincide with those in the ROB earthquake catalogue to ensure the relation between both. Date and time parameters are given in UTC. The name of the event corresponds to the name of the town closest to the epicentre or the two closest localities if the epicentre is situated close to their borders (e.g. Zulzeke-Nukerke).

The ROB earthquake catalogue is not homogeneous as the source parameters it contains were obtained from various analyses of both instrumental and macroseismic data. The ROB earthquake catalogue is constantly updated and improved, and parameters are revised as new data and more sophisticated procedures become available (e.g. Camelbeeck et al. 2022, 2025; Vanneste and Onvani 2024). Analyses to determine source parameters are not always published, and the origin of certain values is not known with certainty, especially for early 20$^{th}$ century events. As a result, the precision and accuracy of source parameters can vary significantly.

Data quality has changed over time with the evolution of seismic networks in Belgium and in neighbouring countries. Most location parameters are based on measurements of the arrival times of seismic phases on seismograms recorded by these stations. Until 1958, the number of stations was not sufficient to locate local earthquakes with a precision better than 10 km (Camelbeeck 1993). The epicentral coordinates of small ($M < 4$) events had to be estimated with the help of macroseismic data using the procedure of Bakun and Wentworth (1997) or were based on visual estimations from isoseismal maps (Camelbeeck 1993); the corresponding focal depths were estimated with empirical macroseismic attenuation equations (Van Gils and Zaczek 1978; Camelbeeck et al. 2022). From the end of the1970s, epicentral locations and hypocentral depths could be determined with a precision of 2 and 5 km, respectively. Since the deployment of a modern digital network with more than 20 stations in 1985, location precision has further improved. Three different magnitude scales are used to express earthquake size: local magnitude ($M_L$), surface-wave magnitude ($M_S$) and moment magnitude ($M_W$). $M_L$ is the routinely determined magnitude for instrumentally recorded earthquakes and is based on amplitude measurements, either on paper records or digital waveforms. $M_S$ is based on the period and amplitude of surface waves. $M_W$ was determined from displacement spectra for the three largest earthquakes since 1983 and based on coda-wave duration for several earthquakes in the 1960s in the Hainaut region. For earthquakes before the 1960s, $M_W$ was estimated from macroseismic data (Bakun and Wentworth 1997).

The focus of the BTM catalogue is, however, on the new macroseismic parameters. The maximum intensity (Imax) denotes the highest intensity value in the BTM database for the event. For earthquakes with an epicentre in other countries, the highest reported intensity value outside Belgium is provided in brackets. Half-degree values are given for events that have an intensity range as their maximum intensity value (e.g. 6.5 for 6–7). The number of intensity data points (IDPs) represents the total count of IDPs available in Belgium. In the BTM database, there is no distinction between IDPs and Macroseismic data points (MDPs) and the term “IDP” is used as an equivalent to MDP, thus including felt data points. The “Qual” parameter represents a source quality value, indicated by a letter: fair (A), poor (B) or bad (C). These categories represent the degree of uncertainty associated with the various macroseismic sources on which the IDPs are based (§4.1). Other included parameters are the ROB questionnaire version (qROB), the availability of other source types such as letters sent by individuals (letters), newspaper articles (press), field surveys (field) or publications of macroseismic surveys specific to the event (pub) and a reference to (un)published scientific sources with valuable macroseismic information (references). These summary macroseismic parameters are new or updated and not (yet) included in the general ROB earthquake catalogue. The seismotectonic source regions, based on the seismotectonic model of Verbeeck et al. (2009), have also been included. **Table 11** presents the most essential parameters of the BTM catalogue. The full BTM catalogue can be consulted in the supplementary information (SI 10.4).

***Table 11 :*** *Simplified version of the Belgian Traditional Macroseismic (BTM) earthquake catalogue. Non-macroseismic parameters are copied directly from the ROB earthquake catalogue.* ***$M_L$:*** *local magnitude;* ***$M_S$:*** *surface-wave magnitude;* ***$M_W$:*** *moment magnitude;* ***IDPs:*** *number of intensity data points available in the BTM dataset;* ***Imax:*** *maximum intensity in Belgium, higher Imax values reported abroad are added in brackets;* ***Qual:*** *source quality value indication based on the IDP source types (A: fair; B: poor; C: bad);* ***References:*** *reference to (un)published scientific sources with valuable macroseismic information. The full BTM catalogue with all parameters can be consulted in the supplementary information (SI 10.4)*

| id_earth | date | UTC time | name | lat | lon | depth | $M_L$ | $M_S$ | $M_W$ | IDPs | Imax | Qual | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 445 | 1908-11-12 | 09:14:-- | POULSEUR | 50.46 | 5.64 | | | | 3.7 | 168 | 5 | C | Lohest and De Rauw (1909) |
| 446 | 1910-11-07 | 00:40:-- | HAUTES FAGNES | 50.65 | 6.23 | | | | 3.6 | 2 | 3.5 | C | Lagrange (1911a) |
| 447 | 1911-03-29 | 0:05:43 | RANSART | 50.46 | 4.47 | | 3.6 | | | 4 | 6 | C | Cambier (1911), Camelbeeck et al. (2022) |
| 449 | 1911-04-12 | 16:15:-- | MONS-WASMUEL | 50.44 | 3.92 | 2.4 | | | 3.1 | 94 | 4 | C | Cornet (1911), Camelbeeck et al. (2022) |
| 451 | 1911-05-30 | 19:43:25 | EIFEL-EICHERSCHEID (DE) | 50.65 | 6.23 | | 4.5 | 4.0 | | 6 | 5 (5.5) | C | |
| 465 | 1911-06-01 | 22:51:58 | RANSART | 50.45 | 4.46 | 4.3 | 4.2 | 3.8 | | 55 | 6 | C | Cambier (1911), Camelbeeck et al. (2022) |
| 466 | 1911-06-03 | 14:35:54 | RANSART | 50.46 | 4.45 | 1.4 | 4.4 | | | 16 | 7 | C | Camelbeeck et al. (2022) |
| 470 | 1911-09-06 | 13:54:13 | EIFEL-RAEREN | 50.70 | 6.32 | | 4.3 | 3.7 | | 14 | 4.5 (5) | C | |
| 476 | 1920-01-17 | 03:11:04 | HORNU | 50.44 | 3.82 | 1.6 | 3.7 | | | 12 | 6 | C | Capiau (1920), Camelbeeck et al. (2022) |
| 477 | 1921-02-20 | 16:17:35 | STEMBERT | 50.53 | 5.89 | | 4.0 | | 3.5 | 56 | 4.5 | C | Lohest and Anten (1921) |
| 478 | 1921-05-19 | 02:41:41 | GERAARDSBERGEN | 50.80 | 3.95 | | 4.0 | | 3.5 | 48 | 4.5 | C | Fourmarier and Somville (1926) |
| 480 | 1925-02-23 | 21:32:58 | BILZEN | 50.88 | 5.52 | | 4.1 | | 3.8 | 131 | 5.5 | C | Fourmarier and Legraye (1926) |
| 481 | 1926-01-05 | 23:37:19 | SIEGBURG-ZUELPICH (DE) | 50.73 | 6.62 | | 4.8 | 4.4 | | 70 | 5 | C | Fourmarier (1926, 1928) |
| 485 | 1928-01-14 | 00:17:35 | KALTERHERBERG (DE) | 50.50 | 6.10 | | 4.4 | 3.7 | 4.0 | 105 | 4.5 | C | Fourmarier and Somville (1930) |
| 488 | 1931-05-09 | 12:25:56 | HOUDENG-AIMERIES | 50.47 | 4.15 | 0.6 | 2.8 | | | 5 | 4.5 | C | Camelbeeck et al. (2022) |
| 490 | 1931-06-07 | 00:25:21 | DOGGER BANK (North Sea) | 53.95 | 1.40 | | | 5.5 | | 14 | 4.5 (5.5) | C | Somville (1931), Lagrange (1931). |
| 492 | 1932-11-20 | 23:36:52 | UDEN (NL) | 51.61 | 5.47 | | 5.1 | 4.5 | | 576 | 5.5 (7) | B | Van Dijk (1933, 1934), Dost et al. (2025) |
| 500 | 1933-03-23 | 18:48:-- | DIKSMUIDE | 51.06 | 3.03 | | | | 3.6 | 19 | 5 | C | Fourmarier and Somville (1933) |
| 504 | 1935-06-22 | 07:06:-- | VERVIERS-THEUX | 50.50 | 5.82 | | | | | 5 | 4.5 | C | |
| 505 | 1936-11-05 | 00:41:44 | GOUY-LEZ-PIETON | 50.47 | 4.30 | 2.2 | | | 3.3 | 5 | 4.5 | C | Camelbeeck et al. (2022) |
| 509 | 1938-06-11 | 10:57:36 | ZULZEKE-NUKERKE | 50.73 | 3.62 | 19.0 | 5.6 | 5.0 | | 1230 | 7 | B | Somville (1939a, b), Charlier and Poncelet (1940) |
| 517 | 1940-01-07 | 16:28:52 | LA LOUVIERE | 50.47 | 4.17 | 1.5 | | | 3.5 | 17 | 5 | C | Camelbeeck et al. (2022) |
| 518 | 1940-01-07 | 20:32:44 | LA LOUVIERE | 50.47 | 4.20 | | | | 3.1 | 7 | F | C | Camelbeeck et al. (2022) |
| 519 | 1940-01-09 | 03:42:07 | LA LOUVIERE | 50.48 | 4.17 | 2.8 | | | 3.3 | 5 | 4.5 | C | Camelbeeck et al. (2022) |
| 534 | 1949-04-03 | 12:33:40 | HAVRE-BOUSSOIT | 50.46 | 4.08 | 2.2 | 4.6 | 4.3 | | 227 | 7 | B | Bernard and Van Gils (unpublished), Charlier (1951), Marlière (1951), Camelbeeck et al. (2022) |
| 538 | 1949-04-14 | 01:09:14 | HAVRE-BOUSSOIT | 50.46 | 4.07 | 3.7 | | | 3.5 | 15 | 5 | C | Marlière (1951), Camelbeeck et al. (2022) |
| 539 | 1949-04-14 | 05:12:21 | HAVRE | 50.46 | 4.06 | 2.4 | 3.8 | | | 21 | 6 | C | Marlière (1951), Camelbeeck et al. (2022) |
| 544 | 1951-03-14 | 09:46:59 | EUSKIRCHEN (DE) | 50.63 | 6.78 | | 5.8 | 5.3 | | 2269 | 6 (8) | B | Van Gils and De Bruyn (unpublished) |
| 545 | 1951-09-07 | 23:06:48 | THEUX | 50.70 | 5.86 | 13.0 | 4.1 | 3.9 | | 1856 | 5 | A | |
| 547 | 1952-10-21 | 21:15:-- | QUAREGNON | 50.43 | 3.88 | 2.9 | | | 3.1 | 140 | 4 | A | Camelbeeck et al. (2022) |
| 548 | 1952-10-22 | 07:--:-- | FRAMERIES | 50.42 | 3.90 | 3.0 | | | 2.8 | 134 | 4 | A | Camelbeeck et al. (2022) |
| 549 | 1952-10-27 | 06:11:-- | QUAREGNON | 50.43 | 3.87 | 3.5 | | | 3.5 | 145 | 5 | A | Camelbeeck et al. (2022) |
| 550 | 1953-01-06 | 23:58:44 | COURT-SAINT-ETIENNE | 50.62 | 4.60 | | 4.0 | 3.4 | | 236 | 5 | A | Van Gils and Bernard (unpublished) |
| 553 | 1953-06-11 | 00:22:21 | BOUSSOIT | 50.46 | 4.08 | | | | 3.1 | 16 | 4.5 | A | |
| 555 | 1953-08-28 | 00:06:16 | COURT-SAINT-ETIENNE | 50.62 | 4.60 | | 3.4 | | | 256 | 5 | A | |
| 556 | 1953-08-30 | 23:35:30 | VIELSALM | 50.37 | 5.93 | | | | | 121 | 5 | A | |

***Table 11 :** continued*

| id_earth | date | UTC time | name | lat | lon | depth | $M_L$ | $M_S$ | $M_W$ | IDPs | Imax | Qual | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 557 | 1953-09-15 | 23:55:-- | QUAREGNON | 50.45 | 3.87 | | | | 3.1 | 82 | 5 | A | |
| 558 | 1954-01-06 | 03:35:-- | ZUTENDAAL | 50.93 | 5.57 | | | | | 16 | 4 | A | |
| 562 | 1954-07-10 | 17:18:21 | FLENU | 50.44 | 3.90 | 3.3 | | | 3.5 | 92 | 5.5 | A | Bernard (unpublished), Camelbeeck et al. (2022) |
| 567 | 1955-10-02 | --:--:-- | SAIVE | 50.65 | 5.68 | | | | | 27 | 5 | A | |
| 569 | 1956-04-21 | 22:47:07 | CHASTRES | 50.58 | 4.63 | | | | | 31 | 4 | A | |
| 578 | 1960-06-25 | 14:29:13 | KINROOI | 51.18 | 5.68 | 12.5 | 4.0 | | | 655 | 5 | A | Ahorner and Van Gils (1963) |
| 580 | 1963-03-10 | 05:51:30 | GENK-AS | 50.97 | 5.53 | | 3.5 | | | 176 | 5 | A | |
| 582 | 1965-12-15 | 12:07:14 | STREPY-BRACQUEGNIES | 50.45 | 4.12 | 2.7 | 4.4 | | 4.0 | 500 | 7 | A | Van Gils (1966), Camelbeeck et al. (2022) |
| 586 | 1965-12-21 | 10:00:02 | ANS-VOTTEM | 50.65 | 5.53 | 7.2 | 4.3 | | | 423 | 6 | A | Van Gils (1966) |
| 587 | 1966-01-16 | 00:13:18 | MORLANWELZ-MARIEMONT | 50.46 | 4.24 | 2.6 | 2.7 | | | 917 | 4.5 | A | Van Gils (1966), Camelbeeck et al. (2022) |
| 588 | 1966-01-16 | 06:51:34 | MORLANWELZ-MARIEMONT | 50.47 | 4.26 | 3.3 | 3.8 | | 3.5 | 894 | 5 | A | Van Gils (1966), Camelbeeck et al. (2022) |
| 589 | 1966-01-16 | 12:32:50 | MORLANWELZ-MARIEMONT | 50.46 | 4.26 | 2.1 | 4.4 | | 4.0 | 894 | 7 | A | Van Gils (1966), Camelbeeck et al. (2022) |
| 597 | 1967-03-28 | 15:49:25 | CARNIERES | 50.46 | 4.28 | 3.0 | 4.5 | | 4.1 | 725 | 7 | A | Camelbeeck et al. (2022) |
| 603 | 1968-08-12 | 07:26:41 | LA LOUVIERE | 50.46 | 4.21 | 2.3 | 3.7 | | 3.6 | 30 | 5 | A | Camelbeeck et al. (2022) |
| 604 | 1968-08-13 | 16:17:28 | LA LOUVIERE | 50.46 | 4.21 | | 3.6 | | 3.6 | 23 | 6 | A | Camelbeeck et al. (2022) |
| 605 | 1968-08-13 | 16:40:40 | LA LOUVIERE | 50.46 | 4.21 | | 2.8 | | 3.0 | 17 | 5 | A | Camelbeeck et al. (2022) |
| 606 | 1968-08-13 | 16:57:14 | LA LOUVIERE | 50.46 | 4.21 | 2.3 | 4.1 | | 3.9 | 59 | 6 | A | Camelbeeck et al. (2022) |
| 607 | 1968-09-23 | 04:08:12 | MORLANWELZ-MARIEMONT | 50.46 | 4.23 | 2.8 | 3.0 | | 3.2 | 58 | 5 | A | Camelbeeck et al. (2022) |
| 608 | 1968-09-23 | 05:47:16 | HAINE-SAINT-PIERRE | 50.47 | 4.22 | 2.4 | 2.9 | | 3.0 | 58 | 4 | A | Camelbeeck et al. (2022) |
| 609 | 1968-12-27 | 23:45:05 | DE PANNE-KOKSIJDE | 51.12 | 2.62 | | 2.5 | | | 26 | 4.5 | A | |
| 612 | 1970-11-03 | 08:45:59 | MARCHIENNE-AU-PONT | 50.41 | 4.41 | 2.3 | 3.9 | | 3.6 | 69 | 5 | A | Camelbeeck et al. (2022) |
| 615 | 1971-02-18 | 23:41:23 | KONINGSBOCH (NL) | 51.05 | 5.95 | | 4.5 | | | 947 | 5 (5-6) | A | Ahorner and Schwarzbach (unknown) |
| 618 | 1972-02-17 | 04:03:29 | CANTONS DE L'EST | 50.60 | 6.10 | | 3.1 | | | 86 | 4 | A | |
| 622 | 1975-01-23 | 05:42:-- | VIELSALM | 50.28 | 5.87 | | 2.6 | | | 55 | 3 | A | |
| 627 | 1976-10-24 | 20:33:28 | GIVRY | 50.36 | 4.02 | 5.5 | 4.2 | | | 192 | 6 | A | Camelbeeck et al. (2022) |
| 638 | 1982-03-02 | 01:27:26 | NE of SITTARD (NL) | 51.01 | 5.91 | 10.0 | 3.7 | | | 133 | 4 (5) | A | |
| 640 | 1982-05-22 | 06:00:02 | N of MAASEIK | 51.12 | 5.80 | 14.0 | 3.7 | | | 135 | 4 | A | |
| 641 | 1982-09-14 | 19:24:34 | CARNIERES | 50.44 | 4.24 | 3.5 | 3.4 | | | 138 | 4 | A | Camelbeeck et al. (2022) |
| 648 | 1983-08-04 | 07:08:26 | CHARLEROI | 50.42 | 4.45 | | 3.2 | | | 147 | 3.5 | A | Camelbeeck (1983), Camelbeeck et al. (2022) |
| 649 | 1983-08-09 | 01:32:36 | CHARLEROI | 50.42 | 4.45 | | 3.3 | | | 136 | 4 | A | Camelbeeck (1983), Camelbeeck et al. (2022) |
| 651 | 1983-11-08 | 00:49:34 | LIEGE | 50.63 | 5.52 | 5.8 | 5.0 | 4.6 | 4.7 | 684 | 7 | A | Camelbeeck and De Becker (1984), De Becker and Camelbeeck (1985), Ahorner et al. (1985), Ahorner (1985), Houtgast (1985), Phillips (1985), François et al. (1986), Camelbeeck et al. (2013), Garcia Moreno and Camelbeeck (2013) |
| 654 | 1983-11-08 | 02:13:22 | LIEGE | 50.61 | 5.50 | 4.2 | 3.5 | | | 185 | 4 | A | De Becker and Camelbeeck (1985) |
| 662 | 1984-07-09 | 23:19:01 | HEERS | 50.75 | 5.35 | | 3.6 | | | 77 | 4 | A | |
| 736 | 1987-03-21 | 14:47:24 | REGION DE DOUR | 50.41 | 3.82 | 7.0 | 2.5 | | | 119 | 4 | A | Camelbeeck (1988), François et al. (1989) |
| 740 | 1987-03-22 | 21:05:35 | REGION DE DOUR | 50.41 | 3.82 | 7.0 | 2.6 | | | 106 | 4 | A | François et al. (1989) |
| 829 | 1988-10-17 | 19:39:54 | GULPEN (NL) | 50.81 | 5.92 | 23.5 | 3.4 | | | 414 | 4 | B | François et al. (1989) |
| 830 | 1988-12-27 | 11:53:12 | SPRIMONT | 50.54 | 5.69 | 17.1 | 3.5 | | | 479 | 4 | B | |
| 987 | 1992-04-13 | 01:20:02 | ROERMOND(NL) | 51.15 | 5.94 | 19.0 | 5.8 | 5.4 | 5.3 | 2089 | 6 (7) | B | Camelbeeck et al. (1992), Haak et al. (1994), Pappin et al. (1994), Maurenbrecher and De Vries (1995) |
| 1040 | 1992-06-13 | 18:01:35 | OKEGEM-NINOVE | 50.82 | 4.06 | 2.2 | 2.4 | | | 409 | 4 | B | |
| 1044 | 1992-08-29 | 09:22:26 | BARBENCON-BEAUMONT | 50.20 | 4.29 | 7.0 | 3.6 | | | 139 | 5 | B | |
| 1108 | 1995-06-20 | 01:54:47 | LE ROEULX | 50.51 | 4.11 | 24.4 | 4.5 | | | 1905 | 5 | B | |
| 1114 | 1996-07-23 | 22:30:21 | SPA | 50.48 | 5.89 | 16.8 | 3.8 | | | 648 | 4 | B | |
| 1306 | 2002-07-22 | 05:45:04 | ESCHWEILER-ALSDORF (DE) | 50.89 | 6.21 | 16.4 | 4.9 | | 4.6 | 500 | 4 (6) | B | Camelbeeck et al. (2003) |
| 1529 | 2001-06-23 | 01:40:03 | VOERENDAAL (NL) | 50.88 | 5.92 | 6.8 | 3.9 | | | 59 | 4.5 | B | |

### 3.1.3. The BTM intensity dataset

#### *3.1.3.1. The BTM intensity dataset content*

The BTM dataset is a reviewed and updated version of the original ROB macroseismic intensity dataset and is limited to IDPs located in Belgium for the events listed in the BTM catalogue. Each IDP requires at least three components: (1) the location, (2) the time and date of the earthquake, and (3) an intensity value on a defined macroseismic intensity scale. The locations of the IDPs in the BTM dataset are defined by the name of the locality and its coordinates, which are extracted from the ROB localities database consisting of cities, city districts, towns, villages and hamlets in Belgium. As the ROB questionnaires were distributed only on a municipal level, the municipalities make up the majority of the BTM dataset and define the resolution of the data. The ROB Belgian localities database was also subjected to a full review as multiple errors in the linked names and coordinates were discovered. Information on the timing of an IDP is not available directly in the BTM dataset but all IDPs are provided with an earthquake identification number ("id_earth") that refers to an event in the BTM catalogue that includes the time and date of the earthquake. The third component, the intensity value, is the most complex component. Intensity values in the BTM dataset are the result of a manual evaluation of the macroseismic sources by expert judgement and range from 1 (not felt) to 7 (damaging) on the EMS-98 (Grünthal 1998). Although multiple modifications have been proposed for the definitions of EMS-98 intensity degrees (e.g. Sbarra et al. 2014, 2020), intensity assessment were made with the original diagnostics by Grünthal (1998), as this information is more readily available. All IDPs are presented with minimum and maximum values. A difference between both values, i.e. an intensity range, indicates an uncertainty during the assignment process, either by a lack of information or by ambiguity in the data. Intensity ranges have been limited to only spanning two degrees maximally (e.g. intensity 6-7) and should not be interpreted as half-degree values. If the uncertainty is too high and the resulting intensity value would span more than two degrees, it is marked as felt (F) instead. The full BTM dataset can be consulted in Neefs et al. (2024a, 2024b) The full summary of intensity values by event is listed in **Table 12**.

In total, the BTM database contains 23,950 IDPs distributed across the Belgian territory. The maximum intensity 7 (EMS-98) was observed for seven different events, five of which had their epicentre in the Hainaut coal basin. **Figure 18** provides a histogram of all intensity values in the BTM database, while **Figure 19** shows the chronological evolution. The "not felt" IDPs (I=1) make up a large fraction of the total number of IDPs, with 11,546 IDPs or ~48% of all IDPs in the BTM database. This large quantity of intensity 1 values is the result of the wide distribution area of the ROB questionnaires which was often much larger than the extent of the felt radius of the event.

***Table 12 :*** *Full summary of intensity values of the IDPs in the BTM database*

| Id_earth | date | F | 1 | 2 | 2-3 | 3 | 3-4 | 4 | 4-5 | 5 | 5-6 | 6 | 6-7 | 7 | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 445 | 1908-11-12 | | 78 | | 5 | | | 74 | 5 | 6 | | | | | 168 |
| 446 | 1910-11-07 | | 1 | | | | 1 | | | | | | | | 2 |
| 447 | 1911-03-29 | 1 | | | | | | | | | 2 | 1 | | | 4 |
| 449 | 1911-04-12 | | 71 | 2 | 3 | 15 | 2 | 1 | | | | | | | 94 |
| 451 | 1911-05-30 | | | | | 2 | 1 | 1 | 1 | 1 | | | | | 6 |
| 465 | 1911-06-01 | | | | | 2 | | 30 | | 17 | 2 | 4 | | | 55 |
| 466 | 1911-06-03 | 11 | | | | | | 2 | | 1 | | 1 | | 1 | 16 |
| 470 | 1911-09-06 | 4 | | 1 | 1 | 5 | | | 3 | | | | | | 14 |
| 476 | 1920-01-17 | 9 | | | | | | | | 1 | | 2 | | | 12 |
| 477 | 1921-02-20 | | 22 | | | 4 | 1 | 24 | 5 | | | | | | 56 |
| 478 | 1921-05-19 | | | | 6 | 11 | | 25 | 6 | | | | | | 48 |
| 480 | 1925-02-23 | 12 | | 6 | | 34 | | 23 | 22 | 28 | 6 | | | | 131 |
| 481 | 1926-01-05 | | 28 | | | 28 | | 4 | 1 | 9 | | | | | 70 |
| 485 | 1928-01-14 | | | 24 | | 30 | | 27 | 24 | | | | | | 105 |
| 488 | 1931-05-09 | 4 | | | | | | | 1 | | | | | | 5 |
| 490 | 1931-06-07 | 2 | | | | 1 | 6 | 4 | 1 | | | | | | 14 |
| 492 | 1932-11-20 | 4 | 85 | 94 | 40 | 61 | 177 | 63 | 37 | 14 | 1 | | | | 576 |
| 500 | 1933-03-23 | 1 | | | | 2 | | 7 | 3 | 6 | | | | | 19 |
| 504 | 1935-06-22 | 2 | | | | | 1 | 1 | 1 | | | | | | 5 |
| 505 | 1936-11-05 | | | | | | | | 5 | | | | | | 5 |
| 509 | 1938-06-11 | | | | 1 | 38 | 9 | 189 | 16 | 447 | 16 | 459 | 3 | 52 | 1230 |
| 517 | 1940-01-07 | | | | 2 | 6 | 5 | 3 | | 1 | | | | | 17 |
| 518 | 1940-01-07 | 7 | | | | | | | | | | | | | 7 |
| 519 | 1940-01-09 | | | | | 2 | | 2 | 1 | | | | | | 5 |
| 534 | 1949-04-03 | | 94 | 24 | 3 | 35 | 1 | 32 | 8 | 13 | 6 | 7 | 2 | 2 | 227 |
| 538 | 1949-04-14 | 7 | | | | | | 6 | | 2 | | | | | 15 |
| 539 | 1949-04-14 | 12 | | | | | | | 2 | 3 | 2 | 2 | | | 21 |
| 544 | 1951-03-14 | | 637 | 140 | 14 | 869 | 35 | 497 | 15 | 59 | | 3 | | | 2269 |
| 545 | 1951-09-07 | | 1222 | 148 | 14 | 272 | 10 | 183 | | 7 | | | | | 1856 |
| 547 | 1952-10-21 | | 119 | 2 | 1 | 12 | 2 | 4 | | | | | | | 140 |
| 548 | 1952-10-22 | | 122 | 1 | 1 | 8 | 1 | 1 | | | | | | | 134 |
| 549 | 1952-10-27 | | 102 | 6 | | 12 | 4 | 11 | 2 | 8 | | | | | 145 |
| 550 | 1953-01-06 | | 259 | 25 | 18 | 84 | 11 | 79 | 5 | 14 | | | | | 495 |
| 553 | 1953-06-11 | | 13 | | 1 | | 1 | | 1 | | | | | | 16 |
| 555 | 1953-08-28 | | 96 | 27 | 1 | 71 | | 49 | | 12 | | | | | 256 |
| 556 | 1953-08-30 | | 84 | 2 | | 10 | | 20 | 1 | 4 | | | | | 121 |
| 557 | 1953-09-15 | | 78 | | | 2 | | | | 2 | | | | | 82 |
| 558 | 1954-01-06 | | 9 | 2 | | 2 | | 3 | | | | | | | 16 |
| 562 | 1954-07-10 | | 48 | 11 | | 7 | 1 | 9 | 2 | 12 | 2 | | | | 92 |
| 567 | 1955-10-02 | | 15 | | 1 | 3 | 2 | 5 | | 1 | | | | | 27 |
| 569 | 1956-04-21 | | 1 | 2 | | 9 | | 19 | | | | | | | 31 |
| 578 | 1960-06-25 | | 543 | 44 | 9 | 34 | | 24 | | 1 | | | | | 655 |
| 580 | 1963-03-10 | | 36 | 18 | 2 | 54 | 1 | 61 | | 4 | | | | | 176 |
| 582 | 1965-12-15 | | 401 | 23 | | 30 | 6 | 17 | | 19 | | 2 | | 2 | 500 |
| 586 | 1965-12-21 | | 202 | 79 | 7 | 74 | 8 | 31 | | 17 | 4 | 1 | | | 423 |
| 587 | 1966-01-16 | | 892 | 3 | 1 | 13 | 4 | 2 | 2 | | | | | | 917 |
| 588 | 1966-01-16 | | 851 | 17 | 1 | 8 | 2 | 12 | 1 | 2 | | | | | 894 |
| 589 | 1966-01-16 | | 774 | 37 | | 42 | 2 | 22 | 1 | 12 | | 3 | | 1 | 894 |
| 597 | 1967-03-28 | | 582 | 40 | | 56 | 3 | 22 | 1 | 10 | | 9 | | 2 | 725 |
| 603 | 1968-08-12 | | | 6 | | 3 | 1 | 12 | | 8 | | | | | 30 |
| 604 | 1968-08-13 | | | 10 | | 5 | | 3 | | 3 | | 2 | | | 23 |
| 605 | 1968-08-13 | | | 8 | | 6 | | 1 | | 1 | | | | | 16 |
| 606 | 1968-08-13 | | | 18 | | 9 | | 10 | | 17 | 1 | 4 | | | 59 |
| 607 | 1968-09-23 | | 32 | 11 | | | 4 | 9 | 1 | 1 | | | | | 58 |
| 608 | 1968-09-23 | | 33 | 13 | | 5 | 2 | 5 | | | | | | | 58 |
| 609 | 1968-12-27 | | 23 | | | | 1 | 1 | 1 | | | | | | 26 |
| 612 | 1970-11-03 | | 37 | 6 | | 9 | 3 | 5 | | 9 | | | | | 69 |

***Table 12*** *: continued*

| id_earth | date | F | 1 | 2 | 2-3 | 3 | 3-4 | 4 | 4-5 | 5 | 5-6 | 6 | 6-7 | 7 | total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 615 | 1971-02-18 | | 530 | 125 | 9 | 191 | 14 | 112 | 3 | 2 | | | | | 986 |
| 618 | 1972-02-17 | | 59 | 10 | | 11 | 1 | 5 | | | | | | | 86 |
| 622 | 1975-01-23 | | 51 | 2 | | 2 | | | | | | | | | 55 |
| 627 | 1976-10-24 | | 117 | 17 | | 18 | 1 | 30 | | 7 | | 2 | | | 192 |
| 638 | 1982-03-02 | | 114 | 6 | | 6 | | 7 | | | | | | | 133 |
| 640 | 1982-05-22 | | 118 | 7 | | 5 | 1 | 4 | | | | | | | 135 |
| 641 | 1982-09-14 | | 120 | 1 | 1 | 8 | 1 | 7 | | | | | | | 138 |
| 648 | 1983-08-04 | | 144 | | | | 3 | | | | | | | | 147 |
| 649 | 1983-08-09 | | 132 | | | | 1 | 3 | | | | | | | 136 |
| 651 | 1983-11-08 | | 264 | 54 | 3 | 123 | 6 | 122 | 8 | 65 | | 26 | 2 | 11 | 684 |
| 654 | 1983-11-08 | | 146 | 26 | | 9 | | 4 | | | | | | | 185 |
| 662 | 1984-07-09 | | 40 | 13 | | 13 | | 11 | | | | | | | 77 |
| 736 | 1987-03-21 | | 113 | 1 | | 1 | | 4 | | | | | | | 119 |
| 740 | 1987-03-22 | | 85 | | | 10 | | 11 | | | | | | | 106 |
| 829 | 1988-10-17 | | 276 | 81 | | 51 | 1 | 5 | | | | | | | 414 |
| 830 | 1988-12-27 | | 404 | 58 | | 13 | | 4 | | | | | | | 479 |
| 987 | 1992-04-13 | | 49 | 66 | | 244 | 3 | 1145 | 1 | 564 | | 16 | | | 2088 |
| 1040 | 1992-06-13 | | 362 | 25 | | 9 | | 13 | | | | | | | 409 |
| 1044 | 1992-08-29 | | 115 | 4 | | 11 | | 7 | | 2 | | | | | 139 |
| 1108 | 1995-06-20 | | 179 | 222 | 2 | 524 | 1 | 866 | 3 | 108 | | | | | 1905 |
| 1114 | 1996-07-23 | | 355 | 93 | | 97 | | 103 | | | | | | | 648 |
| 1306 | 2002-07-22 | | 151 | 52 | 75 | 156 | 48 | 18 | | | | | | | 500 |
| 1529 | 2001-06-23 | | 31 | 3 | 7 | 1 | 13 | 2 | 2 | | | | | | 59 |
| **Total intensities** | | **76** | **11545** | **1716** | **229** | **3488** | **402** | **4118** | **192** | **1520** | **42** | **544** | **7** | **71** | **23950** |

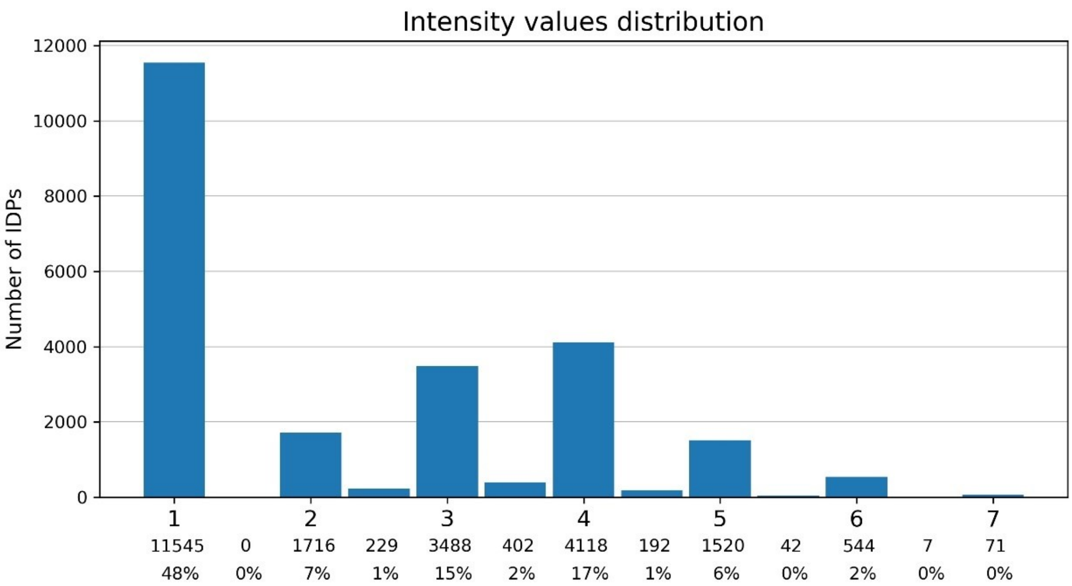



***Figure 18****. Distribution of intensity values in the BTM database. Intermediate values correspond to IDPs with intensity ranges.*

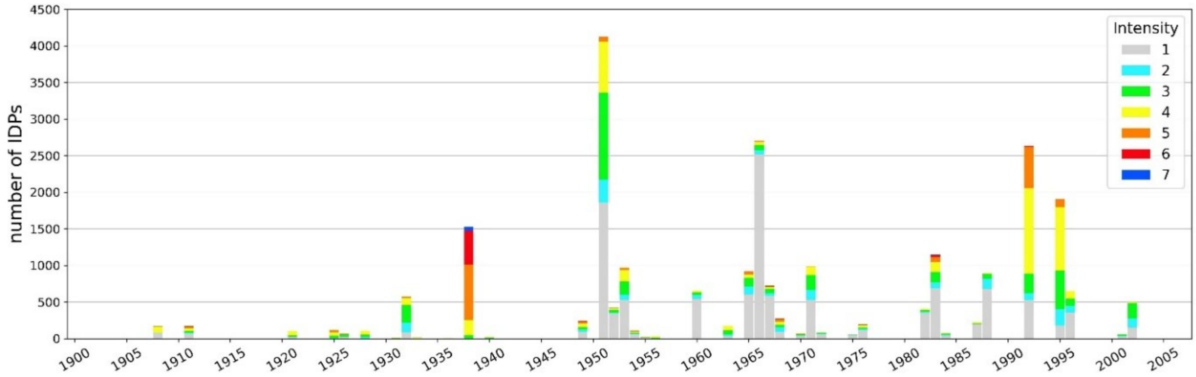



***Figure 19***. *Chronological summary of the EMS-98 intensities in the ROB BTM database. Intermediate values are rounded down.*

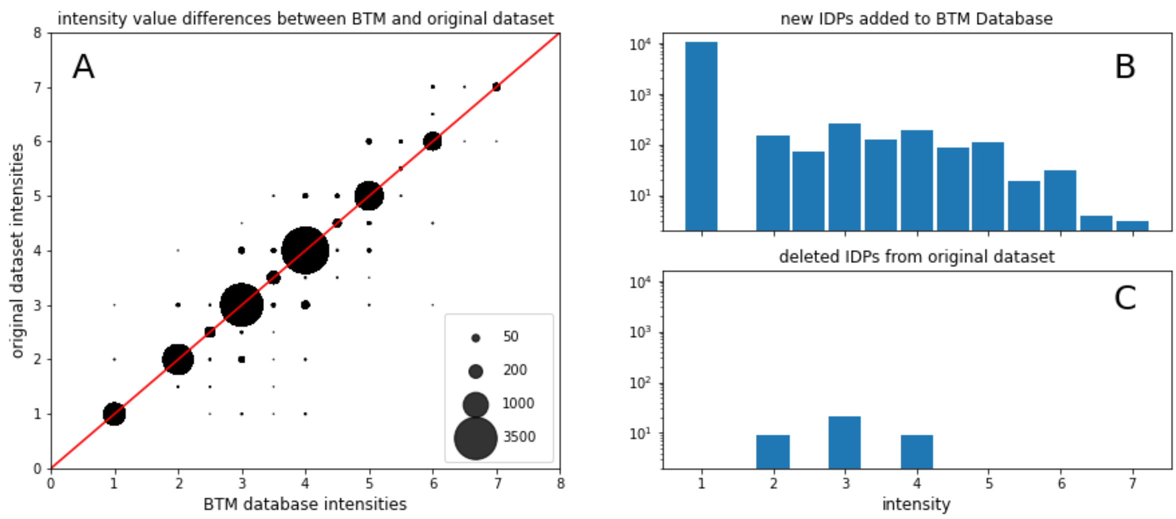



***Figure 20.*** *A) Overview of the changes made to the intensity values for the IDPs that are both present in the BTM database and in the original IDP dataset. B) Intensity values of newly added IDPs to the BTM database. C) Intensity values of IDPs that are no longer present in the BTM database.*

A dataset of IDPs was already available at the ROB. This ROB intensity dataset is a compilation of data that has been gradually expanded over time, by multiple individuals with varying levels of expertise, using different intensity scales and based on different types of sources. Recently, Camelbeeck et al. (2022) reviewed and documented all intensity data from the Hainaut coal basin and added new IDPs from numerous documented sources. In comparison, the BTM database encompasses all events with traditional macroseismic data in Belgium, for all seismotectonic regions, including the Hainaut coal basin. Changes between both datasets are sparse and discussed in Vanneste et al. (2024). The dataset used in Vanneste et al. (2024) is a subset of the BTM dataset.

Out of the 23,950 total IDPs in the BTM database, 13,018 are new or modified IDPs as a result of revisiting unprocessed or previously missed source documents in the ROB archives (e.g. unprocessed ROB questionnaires, letters and old publications or unpublished documents) and a few newspaper articles that were consulted through the newspaper databank of the Brussels Royal Library (www.kbr.be/belgicapress). This number includes the data collected by Camelbeeck et al. (2022) in the coal-mining area in the Hainaut province (1396 IDPs). 10,914 or ~85% of the new IDPs and thus the large majority of these are intensity 1 values (not felt). These are mainly based on unprocessed negative ROB questionnaires, which were previously not included in the ROB database for many events. **Figure 20** shows the difference between the re-evaluations of the IDPs and the original dataset, the number of new IDPs added to the BTM database, and the number of IDPs from the original dataset that are no longer present in the BTM database. IDPs were only removed if macroseismic observations were found to be attributed to the wrong locations in case of identical or similar name locations.

Additionally, source types were assigned to each IDP in the BTM dataset. The discerned source types are the different ROB questionnaire versions (§2.1.3.2), letters from individuals sent to the ROB, newspaper articles, field surveys and references to macroseismic publications. Although IDPs can be based on multiple sources, each IDP has been assigned only a single source type, i.e. the source type with the highest perceived quality (§4.1). The ROB questionnaires are the main source of IDPs in the BTM database. From 1932 until 2002, the procedure resulted in ~94% of the total or 22,617 IDPs from 56 events. Macroseismic surveys performed by other institutes (752 IDPs or ~3%), letters from individuals (445 IDPs or ~2%), newspaper articles (130 IDPs or ~0.5%) and field surveys (6 IDPs or <0.01%) make up only a small percentage. Macroseismic publications of Belgian earthquakes rarely include IDP lists and instead provide only isoseismal maps. The drawing of isoseismal maps is a subjective process involving varying degrees of smoothing and extrapolation of the data (Musson and Cecić 2012). Although retrieving IDPs from an isoseismal map is not recommended and results in large uncertainties, this practice was still applied for a few events (i.e. id_earth 478, 480, 481, 485, 500) due to a lack of other available sources. The following paragraphs explain the process and strategy that was used to review the existing IDPs based on the available sources.

#### *3.1.3.2. Reassigning intensity values*

If the original macroseismic data are available, applying conversions between two scales are to be avoided and new intensity values should be reassigned to the desired intensity scale based on the original source data (Ambraseys 1983; Grünthal 1998; Musson et al. 2010). The BTM dataset is dominantly based on original sources (i.e. ~ 97%), collected through various ROB macroseismic surveys. Of these original sources, most are ROB questionnaires (~ 96%), while individual letters (~ 3%), newspaper articles (~ 1%) and field surveys (< 0.1%) make up only a small portion. Most of the BTM dataset can thus be re-evaluated and does not need to rely on conversion diagrams between scales.

Certain events of the ROB intensity dataset had their IDPs already re-evaluated in the past. Unfortunately, there are no records of this work, for which events this was done, by whom, when, or to which intensity scale. What is known, is that the ROB-conducted macroseismic surveys consistently used 12-degree intensity scales of the Cancani family: the Mercalli-Cancani-Sieberg (MCS-23) scale, the Somville scale (Somville 1936), the Medvedev-Sponheuer-Karník (MSK-64) scale (Medvedev et al. 1964) and the European Macroseismic scale (EMS-98; Grünthal 1998). Musson et al. (2010) state that: *"Differences between seismologists in assessing intensity with the same scale are greater than differences assessed by the same seismologist using different scales, for scales within the Cancani family"*. Considering this and the knowledge that re-evaluations were already performed for certain unknown events in the near past, large differences between the original IDPs and the EMS-98 re-evaluations were not expected. Consequently, all questionnaires and other available original sources of small events (i.e. < 50 IDPs) were revisited and re-evaluated. For larger events, only the IDPs with the highest intensities, outliers and randomly sampled lower intensities were selected for review. This review consisted of a manual re-evaluation of the data to assign new EMS-98 intensities based on personal judgement.

For most of the events, the difference between the EMS-98 re-evaluations and the original dataset were insignificant (<1 intensity value) and can be attributed to subjective difference between experts. The original intensity values of all IDPs of these events remained unchanged and were copied to the BTM dataset. If an event shows significant differences (≥1 intensity value) for at least 10% of the total reviewed IDPs, the complete dataset of the event was re-evaluated, and the reassigned values replaced the original values in the BTM dataset. Such re-evaluations of the full dataset only occurred for a few events (i.e. id_earth 586, 603, 606, 651, 1529). Overall, the changes made to the intensity values have been limited to only ~3% of the common IDPs of the original and BTM datasets (**Figure 20**). The use of the chimney rule (Camelbeeck et al. 2022) as the main strategy to distinguish the higher intensities (I≥5) was continued here as well, as quantitative damage to chimneys is the only consistent high intensity data source available in ROB questionnaires. If other available data do not agree with the result of the chimney rule, deviations from the rule are allowed, or intensity ranges are assigned instead, to reflect this uncertainty.

#### *3.1.3.3. Intensity scale conversions*

The BTM dataset includes 752 IDPs from macroseismic surveys that were carried out by other institutes and for which the source data were not available to perform re-evaluations. Conversions of the intensity values were thus required from their original scale to EMS-98. These IDPs originate from macroseismic publications, often providing descriptions of the diagnostics used to assess the intensity value at certain localities. The level of detail used in describing these diagnostics varies from very extensive (e.g. Fourmarier and Legraye 1926) to the bare minimum (e.g. Fourmarier 1926). Conversions between the intensity scale from the publications to EMS-98 were performed theoretically, based on the descriptions provided for each intensity degree in both scales. The extensive macroseismic descriptions of earthquake effects in certain publications aided these conversions considerably. IDP conversions between two scales without the original source data are associated with large uncertainties, and the events for which this was performed are consequently flagged in the BTM catalogue with a low source quality level (§4.1). For all 752 IDPs in the BTM dataset for which the original sources were not available, references to the publications from which these were sourced are provided (Neefs et al. 2024a, 2024b).

## 3.2. The Belgian Online Macroseismic database

The Belgian Online Macroseismic (BOM) database represents the seismic impact on Belgium since its launch on July 22nd, 2002, until the end of 2024. This online data is collected through the "Did You Feel It?" ("DYFI?"; Lecocq et al. 2009) inquiry on the seismology.be website of the Royal Observatory of Belgium and is based on the USGS procedure of the same name (Wald et al. 1999b; §2.1.6, §2.3). Unlike the traditional macroseismic data, the "DYFI?" inquiry collects testimonies from individual volunteers. Because of this, the structure of the BOM database slightly differs to that of the BTM database. The BOM database consists of three main tables: 1) the **BOM input data**, 2) the **BOM earthquake catalogue**, and 3) the **BOM intensity dataset**. In similar fashion to the BTM database, the BOM database is limited to Belgian data; while earthquakes that occurred in adjacent regions in neighbouring countries are included in the BOM earthquake catalogue if they impacted the Belgian population, the BOM input data and BOM earthquake catalogue are limited to Belgium only. The BOM database provides an overview of the results of more than 20 years of the "DYFI?" inquiry in Belgium, as well as a useable IDP list of the most significant events during this period. The BOM database is the first version of the online macroseismic data and has never been shared before on such broad scope. Because of European privacy regulations, the BOM input data cannot be shared publicly. Instead, only the processed BOM earthquake catalogue and BOM intensity dataset are shared.

The **BOM input data** consists of the individual responses to all the questions of the "DYFI?" questionnaire (SI 10.3) in Belgium: personal data (i.e. name, email address, phone number, language of the questionnaire), location data (street, city, zip code, province, country), earthquake timing (date and time of the earthquake), and macroseismic information (i.e. situation of the observer and the observed earthquake effects). Since 2002 up until 2024, a total of 26,369 responses have been received for 246 recorded earthquakes and other non-seismic events, such as controlled explosions (mainly quarry blasts) and sonic booms. Of these responses, 3052 reports are spontaneous submissions that were received during a time of no recorded seismicity. With an increased number of visitors on the seismology.be website and multiple "DYFI?" submissions in a short time span, an inquiry will be opened, and the public will be invited to fill in this form (Lecocq et al. 2009). These 3052 reports are all isolated submissions and are thus highly likely to be associated with other sources of tremors than seismic activity.

In recent years, the "DYFI?" inquiry of the ROB has experienced an increase in spam. As for example, a small earthquake ($M_L$ = 2.4) on January 3rd, 2025, on the border between the Netherlands and Germany, resulted in 2 genuine responses, and 102 spam responses. To filter out unwanted data, a score from 0 to 100 is assigned to each induvial response, called the 'fiability' (which is likely a mistranslation or adaption from the French 'fiabilité', meaning reliability). This scoring procedure is in use since the launch of the inquiry (Camelbeeck et al. 2003) and was originally aimed to reject incoherent responses. For example, the fiability score is reduced significantly if the respondent said to not have felt the earthquake but at the same time answered it was difficult to stand because of it. Nowadays, similar responses are no longer possible, as many follow-up questions are automatically skipped when the respondent indicates to have not felt the earthquake. Even though it is not its intended purpose, the fiability score assigned to each response is used to filter out spam. This is far from optimal, however, as some spam manages to attain high fiability scores, while at the same time, genuine responses are marked with low scores due to questionable scoring mechanisms (e.g. 10 points are deducted for not providing any email address and the existence of the email address needs no verification). There is no viable solution to filter out all the spam based on the responses alone, as the answers of certain spam reports are undiscernible from genuine reports, and additional mechanisms should be set in place to prevent these submissions. To filter out many spam responses from the BOM input data, as well as incoherent responses from during the early years of the inquiry, responses with fiability scores equal to 0 are rejected. As one of the only required responses to be able to submit a report with the “DYFI?” application, the zip code can also be used to filter out additional spam by only accepting real Belgian zip code values. The eventual, filtered BOM input data includes a total of **22,821 individual reports** for **166 recorded seismic events**.

Out of the 166 recorded seismic events in the BOM input data for which responses have been collected from the Belgian population, only 74 events received 10 or more individual reports. Due to the unreliable nature of individual reports, the **BOM earthquake catalogue** is limited to events with at least 50 individual responses. This leaves a total of 21,670 individual reports for 39 earthquakes, with local magnitudes ($M_L$) ranging between a remarkably low 0.7 and 4.9 (**Table 13**). In fact, 19 out of the 39 events in the BOM catalogue have a magnitude lower than $M_L = 2.0$. Every single one of these small events are part of the Brabant-Wallon seismic swarm that took place in Central Belgium on the southern side of the Anglo-Brabant massif between July 2008 and January 2010. The numerous responses collected from these low magnitude events, however, indicated to have more often only heard the event (Van Noten et al. 2015a, b). In total, 30 out of the 39 events in the BOM catalogue are part of this seismic swarm (i.e. all Court-Saint-Etienne, Ottignies and Louvain-La-Neuve events), with a maximum $M_L = 3.2$.

***Table 13 :*** *The Belgian Online Macroseismic (BOM) earthquake catalogue. Earthquake source parameters are copied from the ROB earthquake catalogue.* ***Reports:*** *the number of individual reports in the BOM input data;* ***IDPs:*** *number of intensity data points available in the BOM intensity dataset;* ***Imax:*** *maximum intensity of the IDPs in the BOM intensity dataset.*

| Nr. | id_earth | date | UTC time | name | lat | lon | depth | ML | MW | reports | IDPs* | Imax* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1306 | 2002-07-22 | 05:45:04 | ESCHWEILER - ALSDORF (DE) | 50.89 | 6.21 | 16.4 | 4.9 | 4.6 | 6073 | 413 | 4.5 |
| 2 | 2975 | 2007-11-25 | 03:10:20 | LA GLEIZE | 50.45 | 5.85 | 16.7 | 3.1 | | 65 | 5 | 3 |
| 3 | 3068 | 2008-07-12 | 17:47:18 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 6.3 | 2.2 | | 331 | 17 | 3 |
| 4 | 3069 | 2008-07-13 | 13:45:49 | COURT-SAINT-ETIENNE | 50.63 | 4.58 | 5.5 | 3.2 | | 1493 | 79 | 3.5 |
| 5 | 3070 | 2008-07-14 | 01:33:58 | DOUR | 50.40 | 3.79 | 3.4 | 2.6 | | 104 | 8 | 3.5 |
| 6 | 3096 | 2008-08-09 | 14:18:56 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.66 | 4.57 | 8.2 | 2.2 | | 74 | 9 | 2.5 |
| 7 | 3098 | 2008-08-09 | 18:31:41 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 8.5 | 2.2 | | 173 | 13 | 3 |
| 8 | 3165 | 2008-09-12 | 05:08:55 | OTTIGNIES-COURT-SAINT-ETIENNE | 50.63 | 4.57 | 5.3 | 2.2 | | 514 | 18 | 3 |
| 9 | 3167 | 2008-09-13 | 01:14:17 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.62 | 4.58 | 5.5 | 2.6 | | 1127 | 34 | 3.5 |
| 10 | 3169 | 2008-09-18 | 20:57:24 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.64 | 4.57 | 6.6 | 0.9 | | 68 | 5 | 2 |
| 11 | 3171 | 2008-09-27 | 16:41:32 | OTTIGNIES-COURT-SAINT-ETIENNE | 50.64 | 4.56 | 7.3 | 1.6 | | 107 | 9 | 3 |
| 12 | 3175 | 2008-10-06 | 06:14:15 | COURT-SAINT-ETIENNE | 50.64 | 4.56 | 6.4 | 1.8 | | 79 | 7 | 2.5 |
| 13 | 3204 | 2008-10-30 | 19:12:29 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.63 | 4.57 | 5.5 | 1.5 | | 147 | 8 | 3 |
| 14 | 3225 | 2008-12-20 | 20:53:08 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.63 | 4.57 | 6.3 | 2.4 | | 853 | 19 | 3 |
| 15 | 3232 | 2008-12-29 | 03:27:55 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.62 | 4.57 | 5.6 | 1.7 | | 128 | 11 | 2.5 |
| 16 | 3239 | 2009-01-15 | 12:02:24 | COURT-SAINT-ETIENNE | 50.63 | 4.58 | 4.7 | 1.9 | | 77 | 7 | 2.5 |
| 17 | 3250 | 2009-02-08 | 19:33:02 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.4 | 1.6 | | 158 | 10 | 2 |
| 18 | 3252 | 2009-02-21 | 13:21:21 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 5 | 2 | | 298 | 14 | 2.5 |
| 19 | 3254 | 2009-02-23 | 19:31:42 | COURT-SAINT-ETIENNE | 50.63 | 4.56 | 5.6 | 1.3 | | 55 | 4 | 2 |
| 20 | 3257 | 2009-02-25 | 07:26:37 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.3 | 1.6 | | 82 | 9 | 2 |
| 21 | 3273 | 2009-03-03 | 03:23:32 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.6 | 2.8 | | 1580 | 41 | 4 |
| 22 | 3274 | 2009-03-03 | 19:25:20 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 5 | 0.8 | | 121 | 9 | 4 |
| 23 | 3276 | 2009-03-05 | 04:21:42 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 5.9 | 1.7 | | 277 | 12 | 3 |
| 24 | 3285 | 2009-03-12 | 07:31:03 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.4 | 1.4 | | 61 | 7 | 2.5 |
| 25 | 3288 | 2009-03-12 | 10:42:22 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.3 | 1.8 | | 125 | 9 | 2 |
| 26 | 3289 | 2009-03-12 | 15:12:47 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.5 | 1.3 | | 64 | 7 | 2.5 |
| 27 | 3299 | 2009-03-26 | 14:30:28 | COURT-SAINT-ETIENNE | 50.63 | 4.56 | 6.4 | 1.3 | | 89 | 9 | 2 |
| 28 | 3301 | 2009-03-26 | 19:42:55 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.7 | 2.3 | | 874 | 22 | 4 |
| 29 | 3302 | 2009-03-27 | 17:46:27 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 6.2 | 1.3 | | 66 | 6 | 2 |
| 30 | 3426 | 2009-07-12 | 05:29:34 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 5.3 | 1.8 | | 283 | 14 | 3 |
| 31 | 3501 | 2009-08-05 | 21:18:36 | ZUTENDAAL | 50.92 | 5.56 | 11.2 | 2.7 | | 117 | 10 | 3.5 |
| 32 | 3552 | 2009-12-26 | 06:50:13 | COURT-SAINT-ETIENNE | 50.63 | 4.58 | 5.8 | 2.5 | | 802 | 22 | 3.5 |
| 33 | 3555 | 2009-12-31 | 03:16:45 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 5.8 | 1.3 | | 104 | 9 | 3 |
| 34 | 3560 | 2010-01-06 | 22:04:49 | COURT-SAINT-ETIENNE | 50.63 | 4.57 | 5.4 | 0.7 | | 93 | 9 | 2.5 |
| 35 | 4565 | 2011-08-02 | 18:37:08 | VELDEGEM | 51.07 | 3.15 | 6.9 | 2.4 | | 570 | 15 | 2.5 |
| 36 | 4580 | 2011-09-08 | 19:02:50 | GOCH (DE) | 51.67 | 6.16 | 10 | 4.3 | | 763 | 73 | 3 |
| 37 | 5329 | 2015-05-22 | 01:52:17 | RAMSGATE (UK) | 51.36 | 1.27 | 15 | 4.1 | | 1969 | 183 | 3.5 |
| 38 | 6625 | 2018-05-25 | 22:43:27 | KINROOI | 51.18 | 5.69 | 16.6 | 3.1 | | 1656 | 61 | 4 |
| 39 | 17540 | 2022-11-16 | 08:59:07 | DESSEL | 51.23 | 5.12 | 5 | 2.1 | | 50 | 3 | 3.5 |

* parameters 'IDPs' and 'Imax' are based on aggregation of the input data on the main municipal scale. Aggregating the data over other scales or resolutions results in different values for both parameters.

Other large earthquakes in the broad vicinity of Belgium since the launch of the “DYFI?” inquiry, such as the $M_L$ = 5.4 Rambervillers 2003 earthquake in the French Vosges, the $M_L$ = 4.8 Lincolnshire 2008 earthquake or the $M_L$ = 4.3 Folkestone 2007 earthquake, have only been felt sporadically, and consequently have not been included in the BOM earthquake catalogue. The most recent event, the $M_L$ = 2.1 Dessel 2022 earthquake, is the only induced event on the list. This earthquake is linked to the Balmattum deep geothermal powerplant in the northeast of the country. The $M_L$ = 2.1 Dessel 2019 earthquake was the first induced event linked to the geothermal powerplant to have been reported felt. As it only resulted in 43 submissions to the ROB “DYFI?” inquiry, this event also did not make the BOM earthquake catalogue.

The BOM earthquake catalogue (**Table 13**) includes the same earthquake source parameters as the BTM database (**Table 11**). The macroseismic parameters consist of the number of individual reports received with the “DYFI?” inquiry (*reports*), the number of intensity data points (*IDPs*) in the BOM intensity dataset and the maximum intensity for each earthquake (*Imax*). IDPs in the BOM database are the result of aggregating submissions by the main Belgian municipalities (§2.3). Because of the high unreliability associated with individual responses, only IDPs based on at least three responses are included in the BOM earthquake catalogue and BOM intensity dataset. The number of IDPs for each earthquake in the BOM earthquake catalogue thus reflects the number of main municipalities with three or more submissions in the BOM input data. The main municipal scale (§2.4) was chosen for the BOM database to ensure a sufficient number of submissions per IDP. Applying higher resolutions results in the rejection of many IDPs due to an insufficient number of reports for each. The maximum intensity (*Imax*) of an earthquake responds to the maximum CDI value acquired for a Belgian municipality. CDI values ((3) are rounded to the nearest half integer, to provide a similar resolution as the traditional IDPs in the BTM database. Aggregation of the data using another resolution, such as the sub-municipal scale, Belgian zip codes or grid cells with custom dimensions, will impact the macroseismic parameters of the events in the BOM earthquake catalogue, i.e. the number of IDPs and the Imax. The use of grid cells is a popular method to aggregate online macroseismic data that allows customizing the resolution to specific needs or based on the density of the data (Van Noten et al. 2017; Quitoriano et al. 2020).

***Table 14 :** Full summary of intensity values of the IDPs in the BOM intensity dataset.*

| Nr. | id_earth | date | 1 | 2 | 2-3 | 3 | 3-4 | 4 | 4-5 | total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1306 | 2002-07-22 | 5 | 130 | 76 | 125 | 61 | 12 | 4 | 413 |
| 2 | 2975 | 2007-11-25 | | 3 | | 2 | | | | 5 |
| 3 | 3068 | 2008-07-12 | | 9 | 3 | 5 | | | | 17 |
| 4 | 3069 | 2008-07-13 | | 38 | 19 | 18 | 4 | | | 79 |
| 5 | 3070 | 2008-07-14 | | 1 | 1 | 4 | 2 | | | 8 |
| 6 | 3096 | 2008-08-09 | | 8 | 1 | | | | | 9 |
| 7 | 3098 | 2008-08-09 | | 9 | 2 | 2 | | | | 13 |
| 8 | 3165 | 2008-09-12 | | 9 | 7 | 2 | | | | 18 |
| 9 | 3167 | 2008-09-13 | | 7 | 7 | 12 | 8 | | | 34 |
| 10 | 3169 | 2008-09-18 | | 5 | | | | | | 5 |
| 11 | 3171 | 2008-09-27 | | 7 | 1 | 1 | | | | 9 |
| 12 | 3175 | 2008-10-06 | | 6 | 1 | | | | | 7 |
| 13 | 3204 | 2008-10-30 | | 6 | 1 | 1 | | | | 8 |
| 14 | 3225 | 2008-12-20 | | 8 | 6 | 5 | | | | 19 |
| 15 | 3232 | 2008-12-29 | | 10 | 1 | | | | | 11 |
| 16 | 3239 | 2009-01-15 | | 5 | 2 | | | | | 7 |
| 17 | 3250 | 2009-02-08 | | 10 | | | | | | 10 |
| 18 | 3252 | 2009-02-21 | | 12 | 2 | | | | | 14 |
| 19 | 3254 | 2009-02-23 | | 4 | | | | | | 4 |
| 20 | 3257 | 2009-02-25 | | 9 | | | | | | 9 |
| 21 | 3273 | 2009-03-03 | 1 | 9 | 7 | 10 | 12 | 2 | | 41 |
| 22 | 3274 | 2009-03-03 | | 7 | 1 | | | 1 | | 9 |
| 23 | 3276 | 2009-03-05 | | 11 | | 1 | | | | 12 |
| 24 | 3285 | 2009-03-12 | | 4 | 3 | | | | | 7 |
| 25 | 3288 | 2009-03-12 | | 9 | | | | | | 9 |
| 26 | 3289 | 2009-03-12 | | 5 | 2 | | | | | 7 |
| 27 | 3299 | 2009-03-26 | | 9 | | | | | | 9 |
| 28 | 3301 | 2009-03-26 | | 8 | 6 | 7 | | 1 | | 22 |
| 29 | 3302 | 2009-03-27 | | 6 | | | | | | 6 |
| 30 | 3426 | 2009-07-12 | | 11 | 2 | 1 | | | | 14 |
| 31 | 3501 | 2009-08-05 | | 3 | 3 | 3 | 1 | | | 10 |
| 32 | 3552 | 2009-12-26 | | 7 | 7 | 7 | 1 | | | 22 |
| 33 | 3555 | 2009-12-31 | | 6 | 2 | 1 | | | | 9 |
| 34 | 3560 | 2010-01-06 | 1 | 6 | 2 | | | | | 9 |
| 35 | 4565 | 2011-08-02 | | 13 | 2 | | | | | 15 |
| 36 | 4580 | 2011-09-08 | | 46 | 15 | 12 | | | | 73 |
| 37 | 5329 | 2015-05-22 | | 34 | 48 | 73 | 28 | | | 183 |
| 38 | 6625 | 2018-05-25 | | 26 | 18 | 13 | 3 | 1 | | 61 |
| 39 | 17540 | 2022-11-16 | | | | 2 | 1 | | | 3 |
| | **Total intensities** | | **7** | **516** | **248** | **307** | **121** | **17** | **4** | **1,220** |

Finally, the **BOM intensity dataset** is the collection of IDPs for the events in the BOM earthquake catalogue (SI 10.5). In total, this table contains 1,220 IDPs on the main municipal scale and Intensity values range from 1 to 4.5 (**Table 14**; **Figure 21**; SI 10.5). The BOM intensity dataset IDPs are not EMS-98 values but rather approximations to the Modified Mercalli scale (MM-93; Stover and Coffman 1993; Wald et al. 1999b). The low maximum intensity value of only 4.5 can be linked to a relatively quiet period of Belgian seismicity (§1.2.1).

Even though the number of not-felt intensities (CDI = 1) in the BOM intensity dataset is confined to only 7 IDPs, the number of negative responses to the 'felt' question adds up to 3982 submissions or 17% of the total submissions in the BOM input data. With the aggregation of the data, however, at least three negative submissions are required to constitute an IDP and a single positive submission within the aggregated data renders the CDI value to 2 or more. At the early stages of the ROB "DYFI?" inquiry, it was possible to submit a questionnaire with the 'felt' question unanswered. Because of this, a CDI value of 1 is only assigned to a data point if the sum of the 'felt', 'reaction' and 'motion' indexes is equal to zero. The 'other-felt' index, i.e. if other people nearby have felt the earthquake, is sometimes used to distinguish among the lowest intensities from a single response by obtaining information of the fraction of people that felt the earthquake (Wald et al. 1999b). The 'other-felt' question would, if answered, overwrite the 'felt' answer. This question, however, is not designed for negative responses to the 'felt' question, as answering 'No other person felt it' to the 'other-felt' question, would be translated to a net positive value (either 0.33 or 0.36 based on the source). Implementing the 'other-felt' index only to the positive 'felt' submission, would thus skew the data towards lower CDI values. Because of this issue and the requirement of at least three submissions per IDP, the 'other-felt' index is not used in the BOM database.

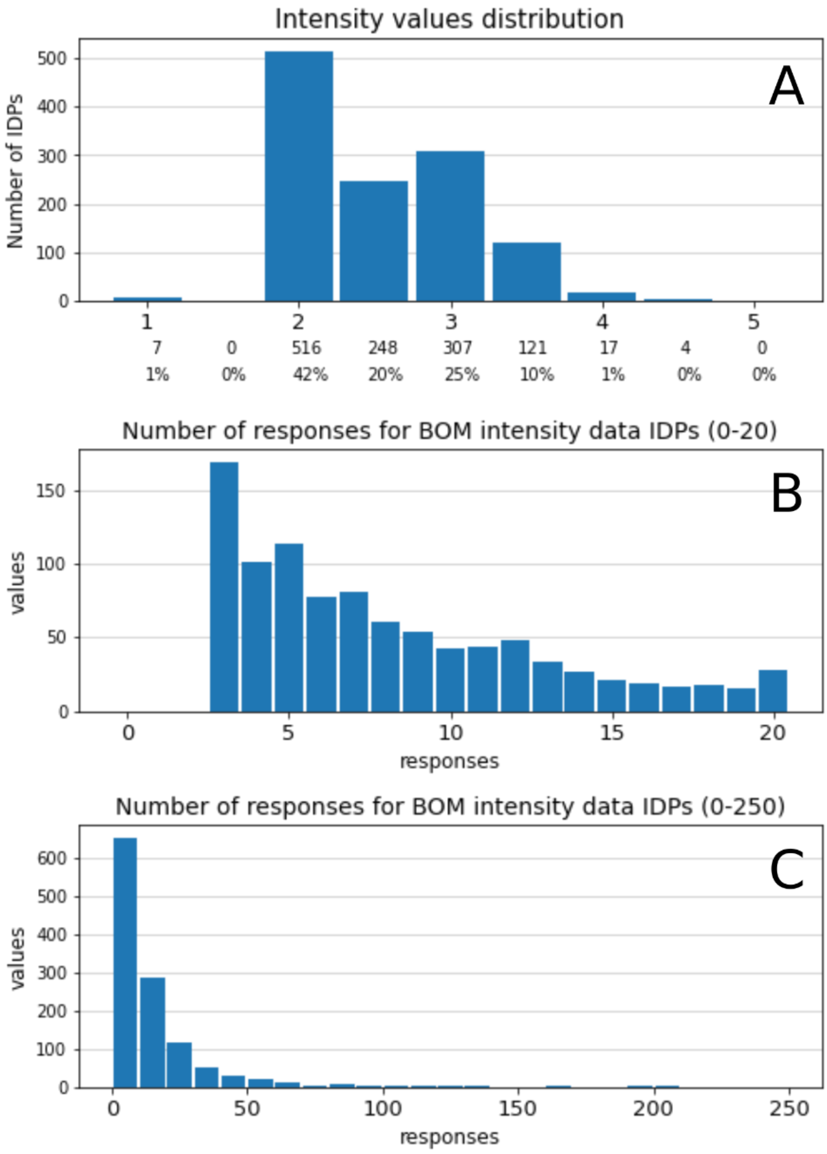



***Figure 21.*** *A) Distribution of intensity values in the BOM intensity dataset. B and C) Number of responses for BOM intensity dataset IDPs.*

## 3.3. Chapter conclusions

For the first time, a comprehensive summary of Belgian macroseismic data is presented in this chapter, from the start of the 20th century up until the present. The macroseismic data is presented through two separate databases:

the Belgian Traditional Macroseismic (BTM) database comprises an earthquake catalogue of 80 felt events in Belgium during the 20th century, along with 23,950 intensity data points (IDPs) contributing to the BTM intensity dataset.

the Belgian Online Macroseismic (BOM) database extends to the 21st century, capturing macroseismic data collected via the “Did You Feel It?” (“DYFI?”) inquiry since 2002. With 39 felt events and 21,670 individual responses, resulting in a total of 1,220 IDPs, the BOM database demonstrates the value of online public participation in macroseismic surveys with high numbers of reports for relatively small events, especially during a period of relative seismic quiescence in Belgium.

This chapter emphasized the longstanding efforts of Belgian seismologists to compile macroseismic observations and maintain a national repository of intensity data. Despite Belgium’s low to moderate seismicity and the challenges that accompany it, such as a low public awareness and sparse reporting for smaller events, Belgium possesses a rich, though fragmented macroseismic data record. By assembling and structuring the Belgian Traditional Macroseismic (BTM) and Belgian Online Macroseismic (BOM) databases, this chapter demonstrates the consolidation of legacy macroseismic data and contemporary online testimonies into coherent and usable datasets. This consolidation not only preserves valuable historical records (since 1900), but also ensures their utility for future seismic studies.

Data collection procedures in Belgium lacked uniformity throughout the 20th century. The BTM database consists of intensity datapoints determined through ROB questionnaires, letters, newspaper articles and old macroseismic publications, with each their own variations in collection methodologies, scale usage and documentation. These inconsistencies have hindered both the completeness and comparability of the data. This chapter, however, shows that through critical reassessment, systematic database construction and methodological transparency, such data can still be effectively integrated into modern seismological frameworks.

Citizen-based macroseismic surveys, such as “DYFI?” inquiry, while innovative and scalable, also require more stringent quality control mechanisms if they are to supplement traditional surveys reliably. The growing reliance on online macroseismic data, without established filtering protocols or controlled environments, poses a long-term risk to the data quality in Belgium.

# 4. Belgian intensity data quality and homogeneity

## 4.1. Quality of Belgian traditional macroseismic data

Despite the variety in data collection procedures, no investigations have been performed to review the Belgian traditional macroseismic data or to re-evaluate them in light of modern practices. In the social sciences, determining the quality of a survey comes down to two main criteria (Stoop and Harrison 2012):

1) Is the studied sample representative of the target population? (§4.1.1)
2) Does the collected information represent the concepts of interest? (§4.1.2)

Although macroseismic surveys are not social sciences surveys, these two broad criteria still hold up well for any survey. In the following sections, these criteria will be discussed for the ROB questionnaire versions and other source types included in the BTM intensity dataset. The overall quality associated with the different source types are then provided with a quality indicator (§4.1.3). As responses to the ROB questionnaires are the source of ~94% of the IDPs in the BTM database, their quality defines a large part of the quality of the database.

### 4.1.1. Representation of the survey target population

Sampling first requires a definition of the target population. For macroseismic surveys, the target population covers all considered sensors over the total macroseismic field or maximum felt extent of an earthquake. With EMS-98, the macroseismic intensity scale used for the BTM database, the considered sensors are people, ordinary objects and buildings (Grünthal 1998). A representative sample is one that considers the different aspects or conditions influencing the response of a sensor during an earthquake. For people, this depends on their situation during the earthquake: were they indoors or outdoors, in rest or in motion, ground floor or upper floors, etc. (Sbarra et al. 2014). Conditions such as weight and stability must be considered for objects, while for buildings, the focus is on the different vulnerability classes (SI 10.1.4). A good macroseismic survey should investigate the earthquake effects on all three main sensor classes, for each different aspect or condition of the macroseismic sensors that could influence its response. For example, if only testimonies are collected from people that were in particularly receptive positions, assigned intensity values would be considerably overestimated. This is an example of sample selection bias, as the selected sample is not representative of the intended population.

Sample selection bias is a very common occurrence with macroseismic surveys that make use of public requests, also called volunteer sampling, as people "volunteer" to participate to the survey. People tend to volunteer their observations of earthquakes more often if they perceived it. Consequently, "not felt" reports are rather uncommon with volunteer sampling surveys (Boatwright and Phillips 2017; Sbarra et al. 2020). This is also noticeable in the BTM dataset, as only ~1% of the IDPs based on the letters that were sent to the ROB (§2.1.4) have I = 1. Although this lack of not felt reports here is not surprising at all, as the public requests for macroseismic data were sometimes specifically targeted at only those who have felt the earthquake (**Figure 22**).

Public request surveys also tend to be biased by the population density, with few or no responses from less populated areas (Wald et al. 2011). This becomes evident when examining the number of letters received for each city or town for a particular earthquake in the BTM earthquake catalogue. Sometimes, more than 100 letters are received for a single city (e.g. 156 letters from the city of Brussels for the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake), where the number of letters from towns and rural villages were often limited to a single one, or none at all. This bias is not reflected in the BTM database. Letters were only consulted in case there was no response to the ROB questionnaire available for a given municipality. When the letters were used to assign intensity values, the rural village with one or two letters and the city with 100 or more letters available, both resulted in a single IDP. Only in the sparsely populated region of southern Belgium, fewer IDPs are based on letters. This, however, can also be attributed to the lower seismic activity in the region (§1.2.2).


DE TOESTELLEN VAN HET OBSERVATORIUM TE UKKEL DOOR DEN SCHOK BUITEN GEBRUIK GESTELD

Het Observatorium te Ukkel deelde omstreeks 1 uur mee, dat de aldaar ingebruik zijnde toestellen voor het opnemen van aardschokken, door de aardbeving buiten gebruik werden gesteld.

Het observatorium vraagt ook aan degenen die den schok hebben gevoeld en bijzondere waarnemingen hebben kunnen doen, er den uitslag van mee te deelen, vooral in verband met de hevigheid van den schok, de verplaatsing van meubelen en de kracht van de waargenomen geluiden.

***Figure 22.*** *Newspaper clipping from "Het Laatste Nieuws" (12/06/1938) in which the ROB publicly requests for macroseismic information on the* $M_L$ *= 5.6 Zulzeke-Nukerke 1938 earthquake. The request specifically targets people who have felt the earthquake: 'The observatory requests to those who have felt the earthquake to report their observations, specifically concerning the intensity of the shock, the movement of furniture and the strength of the perceived sounds'.*

Open public requests (§1.1.3), such as the letters received from individuals by the ROB, also have the disadvantage of incomplete data. Because there is no specific set of questions provided to the respondents, they often only provide information on the observations that were most noteworthy to them personally. These observations, however, often only relate to a few macroseismic sensors, disregarding all other useful observations to establish a macroseismic intensity. This impacts the accuracy of the assigned intensity, as the shared information will often be limited to only the most severe observations. Similarly, this tendency to only report on the most severe effects of an earthquake is also present in the media (Hough and Pande 2007), resulting in an overestimation of the intensity values that are based on newspaper articles. While generally considered the most qualitative procedure of performing a macroseismic survey, field surveys conducted by the ROB lacked thoroughness and were only organized for very few events with limited damage (§2.1.4). Little information is provided on the quality of the field surveys conducted by other institutions than the ROB (e.g. Lohest and De Rauw 1909).

To avoid the sample selection bias, the population density bias, the incomplete data and the tendency of people to only focus on the most severe observations, the ROB conducted targeted macroseismic surveys (§1.1.3), i.e. the ROB questionnaire. The ROB questionnaire did not target specific people but instead targeted the local authorities of Belgian municipalities in their entirety. By doing so, no sampling is applied, and the total target population is considered. In practice, this means that the ROB questionnaire relies on the local authorities to conduct a macroseismic investigation in their municipality. Local authorities have the tools to conduct thorough macroseismic investigations. They have access to useful information such as the total population and the number of buildings in the municipality, and they have the manpower to survey macroseismic observations through the local police force or gendarmerie. This illustrates the potential strength of this sampling strategy. The issue, however, lies with the uncertainty of how thoroughly the survey was conducted. For most of the ROB questionnaire responses, this information is lacking, as this was not requested. Answers to the questions of the ROB questionnaire could thus be based on a well-conducted survey with a large sample or on a single person's experience and observations. With volunteer sampling, the number of individuals or households that collaborated to the assigned intensity value is at least known, simply by counting the number of submissions received.

As the ROB questionnaire is only targeted to the municipal authorities, the number of Belgian municipalities determine the resolution of the macroseismic data. Due to the government-imposed large-scale mergers in Belgium that occurred in the 20$^{th}$ century (§2.4), this resolution decreased significantly. Attempts were made to negate this loss in resolution by providing each main municipality with multiple questionnaires, i.e. one for each sub-municipality that now falls under the jurisdiction of the main municipality. This approach, however, resulted in a multitude of identical questionnaire responses from the sub-municipalities (Haak et al. 1994) and cannot be considered separate IDPs.

### 4.1.2. Representation of concepts of interest

To assign intensity values on the EMS-98, a specific set of information is required, i.e. diagnostic information. The diagnostics criteria are sensor specific: e.g. the percentage of people who felt the earthquake inside and outside, the percentage of people who saw or heard objects fall from shelves in large numbers, or the number of buildings of vulnerability class B that suffered damage of grade 2 or higher. The more information available on the various EMS-98 diagnostics, the more accurate an intensity value can be assigned and thus the higher the quality. The different versions of the ROB questionnaire vary significantly in the number of included questions (**Table 9**; SI 10.2). In general, one could say that the more extended versions will allow for a better assessment, as more information would be available. With shorter versions, often insufficient information is available to distinguish between intensity degrees. The availability of information on all EMS-98 diagnostics for each ROB questionnaire version is summarized in **Table 15**.

The most detailed ROB questionnaire version that includes the most EMS-98 diagnostics is the version 1 questionnaire, i.e. the oldest version. This, however, does not make v1 the best ROB questionnaire version, as the design and structure are also of great importance. The version 1 questionnaire simply provides a full macroseismic scale (the Somville scale; §2.1.3; §2.2.2). The "check what applies" format of v1 allows for more ambiguity than closed-ended questions, as multiple contradictory diagnostics can be selected and may elicit multiple response modes (i.e. indicating whole classes, individual diagnostics, modifying the meaning of diagnostics, etc.). Repeating similarly looking diagnostics throughout the questionnaire at different sections (e.g. "A few people were awakened", "everyone was awakened"), cause repetitiveness and possible confusion (Gideon 2012). Not including the full range of possible observations also causes confusion (e.g. what does one indicate if more than a few people were awakened but not all?). Poor question formatting, such as polling for multiple diagnostics in a single multiple-choice question, as used in v5, introduces additional ambiguity, as this can lead to confusion and incomplete responses. Ambiguity can also be introduced due to poor phrasing of the questions: a positive answer to "Have people left their homes?" in v6 does not necessarily align with the EMS-98 diagnostic of frightened people fleeing their homes.

Apart from v1, the most detailed questionnaire versions are v3 and v4. Both versions are very similar in concept and lay-out, with v4 including only slightly more diagnostics than v3. The simple yes-or-no questions provide a much more straightforward design, which is easier to process and interpret. V5 and v6 do include fewer diagnostics, again allowing for more uncertainty in the assessment of intensity values. These versions do, however, group together questions based on which sensor they request information from, instead of being arranged by increasing intensity as with previous versions. This new lay-out greatly improves the readability of the questionnaire for the respondents (Gideon 2012). Due to the damage-focused design of the v2 questionnaire and its limited number of questions, only intensities 5 to 7 could be assigned with the use of the "chimney rule" (§2.2.1). Only if other observations were provided in question three, lower intensities could be assigned as well. Due to the damaging nature of the event and the wording used on the questionnaire itself, however, most recipients did not consider observations other than damage to buildings to be worth reporting.

With communal questionnaires, where a single form is used to inquire on the earthquake effects across an entire municipality, it is essential to indicate the number of occurrences or at least provide some quantitative description on how common each earthquake effect was. The lack of quantitative data on each observation results in ambiguous information, which in its turn results in less accurate intensity assignments. For example, the observations of people fleeing their homes is a diagnostic of several intensity values on the EMS-98. A small percentage of people fleeing their homes (<15%) is a diagnostic for intensity 5. If, instead, most people (>50%) flee their homes, the intensity is likely to be defined as 7 or higher. When no quantitative information is given on the number or percentage of people that fled their homes, the intensity could be assigned any intensity starting from 5. Also, if only an inconsiderable number of people fled their homes, e.g. two or three people in a medium-sized city, this observation can be answered positively on the questionnaire. Due to its low rate of occurrence, however, it is of little importance to the overall experience of the city, and the actual intensity could be even lower than 5. The EMS-98 includes quantitative terms for most of its diagnostics regarding effects on people and for all diagnostics relating to building damage (SI 10.1.4). Some of the 'effects on people' diagnostics included in the scale, as well as all the diagnostics related to effects on objects and nature, are not provided with quantitative terms. It can be important to request this information when using communal questionnaires, however, in case diagnostics were observed only in isolated instances. In this case, the observation is not representative for the municipality and should be disregarded. Quantitative information on the occurrence of earthquake effects, is thus of great importance for the determination of intensity values. Consequently, it is extremely regrettable that for all ROB questionnaire versions, only few of its questions are provided with quantitative terms (**Table 15**).

The only consistently requested quantitative data throughout the ROB questionnaire versions, are the number of collapsed or partially damaged chimneys, in order to apply the "chimney rule". Only since v5, however, information was requested on the number of residential buildings present in the municipalities. Before v5, outdated data was used to calculate the percentage of collapsed and partially damaged chimneys. The last ROB questionnaire version, i.e. v6, did include more quantitative terms, but only for questions related to the effects on people (SI 10.2). Because of this lack of quantitative data that was provided by the ROB questionnaire versions, assigning intensities occurred by comparing the ranges of occurrence of the various earthquake effects that were observed or not. For example, if a response to the questionnaire reports that people were awakened (starting from EMS-98 intensity 4), no damage occurred (damage can take place from either EMS-98 intensity 5 or 6), and nobody ran outside (starting from EMS-98 intensity 5), one can conclude that the intensity should be 4. This comparison of observations to the descriptions of the various intensities on a specific scale is a very common procedure to establish an intensity value, with or without quantitative data. If, however, it turns out that only people residing in high buildings were awakened, while everyone else slept through the event, the intensity would likely be reduced to 3, and perhaps even to 2.

Assigning intensity values based on the ROB questionnaire responses thus occurs with the assumption that the earthquake effects indicated on the forms are typical observations throughout the municipality, representative for the severity of the experienced shaking. From correspondence between the ROB and the municipalities, it has become obvious that this is often not the case (e.g. people stating that a certain earthquake effect should have been indicated as observed in their municipality, because someone they know informed them it occurred to another person). Furthermore, the cover letter provided together with the questionnaire does not state that the respondent should only indicate the observations that were representative of the entire municipality.

Additionally, no information on the vulnerability of buildings is requested in any ROB questionnaire version and data on the damage grades are sparse. Most questionnaire versions distinguish between damaged and collapsed chimneys, which can indicate the difference between damage grades 2 and 3, respectively. The chimney rule relies on the assumption that the building stock consists of 50% vulnerability A and 50% vulnerability B. Progressing throughout the 20th century, this assumption becomes less likely as building techniques improve and consequently decreasing the vulnerability. As the average age of the building stock can vary significantly between municipalities, the average vulnerability of buildings between municipalities can also vary significantly. The vulnerability is, for example, higher in municipalities that saw a surge in newly constructed buildings in the late 19th and early 20th century due to large-scale industrial activities (Camelbeeck et al. 2014).

***Table 15*** **:** *EMS-98 diagnostics occurrence in the various ROB communal questionnaire versions. The checkmarks for each version indicate the presence of a question that enquires about said EMS-98 diagnostic. The diagnostics are subdivided into 1) effects on humans, 2) effects on objects and nature and 3) damage to buildings. Red checkmarks indicate that the questionnaire version provides information to help quantify the occurrence of said diagnostic.*

| **Effects on people** | | v1 | v2 | v3 | v4 | v5 | v6 |
|---|---|---|---|---|---|---|---|
| **People** | perceive the earthquake indoors | ✓ | | | | ✓ | ✓ (red) |
| | perceive the earthquake outdoors | ✓ | | | | ✓ | ✓ (red) |
| | are awakened | ✓ | | | ✓ | | |
| | flee outdoors | ✓ | | | ✓ | ✓ | ✓ (red) |
| | lose their balance | ✓ | | | | | |
| **People describe their experience as** | swaying or light trembling | ✓ | | ✓ | ✓ | | ✓ (red) |
| | moderate vibration | ✓ | | ✓ | ✓ | | |
| | strong shaking or rocking of the whole building | ✓ | | | ✓ | | ✓ (red) |
| **Effects on objects and nature** | | **v1** | **v2** | **v3** | **v4** | **v5** | **v6** |
| **Hanging objects** | swing slightly | | | | | | |
| | swing moderately | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | swing considerably | ✓ | | ✓ | ✓ | | |
| **China and glasses** | rattle or clatter together | ✓ | | ✓ | ✓ | | |
| | break | ✓ | | ✓ | ✓ | | |
| **Woodwork** | creaks | ✓ | | ✓ | ✓ | | |
| **Windows and doors** | rattle | ✓ | | ✓ | ✓ | | ✓ |
| | swing open or shut | ✓ | | | | | ✓ |
| | windowpanes break | ✓ | | ✓ | ✓ | | ✓ |
| **Furniture** | shakes visibly | ✓ | | ✓ | ✓ | ✓ | ✓ |
| | shifts | ✓ | | ✓ | ✓ | | ✓ |
| | overturns | ✓ | | | ✓ | ✓ | ✓ |
| Small, top-heavy and/or precariously supported objects shift or fall | | ✓ | | ✓ | ✓ | | ✓ |
| Small objects of ordinary stability fall | | ✓ | | ✓ | ✓ | | |
| Objects fall from shelves in large numbers | | | | | | | |
| Heavy objects fall to the ground | | | | ✓ | | | |
| Animals indoor are uneasy | | | | | | | |
| Farm animals are frightened | | | | | | | |
| Liquids oscillate or spill from well-filled containers | | | | | | | |
| Liquids splash from containers, tanks and pools | | | | | | | |
| **Damage to buildings** | | **v1** | **v2** | **v3** | **v4** | **v5** | **v6** |
| **Walls** | hair-line cracks in very few walls | | | | ✓ | | |
| | Cracks in many walls | ✓ | | ✓ | | ✓ | ✓ |
| | large and extensive cracks in most walls | | | | ✓ | ✓ | ✓ |
| | serious failure of walls | | | | | ✓ | ✓ |
| **Plaster** | fall of small pieces | ✓ | | ✓ | ✓ | | |
| | fall of fairly large pieces | ✓ | | ✓ | ✓ | | |
| **Chimneys** | partial collapse | ✓ | ✓ (red) | ✓ | ✓ (red) | ✓ (red) | ✓ (red) |
| | fracture at the roofline | | ✓ (red) | ✓ (red) | ✓ (red) | ✓ (red) | ✓ (red) |
| **Roofs** | roof tiles detachment | | | | | | |
| | structural failure of roofs and floors | | | | | | |
| **Other** | Fall of loose stones from upper parts of buildings | | | ✓ | ✓ | | |
| | failure of individual non-structural elements | | | | | | |
| | total or near total collapse | | | | | | |

### 4.1.3. Macroseismic source-based quality indicators

As discussed in the previous two sections, the accuracy of the assigned intensity values primarily depends mainly on how the macroseismic data was collected. To provide each earthquake in the BTM catalogue (**Table 11**) with a quality indicator, a macroseismic source-based quality letter is assigned to each event, i.e. A (fair), B (poor) or C (bad). These indicators are based on the quality of the macroseismic information and the degree of uncertainty they are associated with (**Table 16**).

***Table 16 :*** *Quality indicators and the corresponding levels of uncertainty associated with different original sources of information. No quality level is provided for the field survey because it is not the main macroseismic source for any of the events in the BTM database.*

| source type | uncertainty | quality indicator |
|---|---|---|
| v1 | high | B |
| v2 | high | B |
| v3 | moderate | A |
| v4 | moderate | A |
| v5 | high | B |
| v6 | high | B |
| letters | very high | C |
| newspaper articles | very high | C |
| field survey | low | - |
| no original sources | very high | C |

Field surveys are considered the most qualitative source, providing the least amount of uncertainty for establishing an intensity degree. All information is gathered, firsthand, by experts on the field. Unfortunately, field surveys in Belgium were rather limited, both in number of actually performed field surveys and the extent of the surveys, and very few IDPs in the BTM intensity dataset could be based on them (§2.1.4; §3.1). Out of all the ROB questionnaire versions, v3 and v4 are associated with the least amount of uncertainty. This is primarily because of the large number of questions included in these versions. Because of the unoptimized designs, the absence of vulnerability degrees and the lack of quantitative data requested with these versions, the uncertainty of the intensity degrees established from these versions are still considerable. Other questionnaire versions are associated with higher uncertainties, either due to the limited number of questions included in them (v2, v5, v6), poor design (v1, v5) and a drop in resolution because of the municipality mergers (v5 and v6). Intensities established based on letters are associated with very high uncertainties, due to the self-selection bias and the low average of number of reports available for each municipality. Very high uncertainties are also attributed to intensities established on what newspaper articles reported, as well as for unavailable sources, as intensity scale conversions were required for these and the accuracy of the IDPs of these sources are often low (e.g. derived from isoseismal maps).

If multiple source types are available to establish a single IDP, the source type with the lowest associated uncertainty is provided in the BTM intensity dataset (see supplementary information in Neefs et al. 2024a). The uncertainties associated with each source type, as provided by **Table 16**, reflect the average uncertainty, and variations occur within each source type. While one questionnaire of v3 only answered every other question, for example, another v3 questionnaire could have provided a detailed description for each residential quarter of the municipality, provided by the police officers that were charged with the inquiry. Similarly, the number of letters received for each municipality could vary strongly. Because of these variations, the average uncertainties associated with each source type are not explicitly copied for each IDP in the BTM intensity dataset. Because each event included in the BTM earthquake catalogue is predominantly based on one specific source type, however, the average quality of this source type can be directly associated with the overall quality of the macroseismic data for each event.

## 4.2. The influence of subjective bias

Next to the discussion on the quality of the collected macroseismic information in the previous section (§4.1), establishing an intensity value also contains an element of subjectivity (Musson et al. 2010). Two experts using an identical scale and the same macroseismic information can still end up with different assessments of the intensity degree. During the evaluation of the Belgian traditional macroseismic data, it was regularly observed that identical responses to a ROB questionnaire were assigned different intensity values. These differences could reflect additional macroseismic sources that are no longer available. As there is no evidence that indicates to the existence of such supplementary sources, these inconsistencies are more likely the result of variations in the subjective interpretations of the individuals assigning the macroseismic intensity values. Subjective differences in the assigned intensity degrees based on identical macroseismic information are generally attributed to one of the following factors:

1) the macroseismic scale
2) the expert
3) the macroseismic data

Some macroseismic scales are better in reducing disagreements between users, while others allow for more ambiguity. Consequently, **not all macroseismic scales are equal** (Musson et al. 2010). Earlier macroseismic scales, for example, often did not provide quantitative terms for the diagnostics attributed to the different intensity degrees. The Modified Mercalli scale of 1956 (MM-56) by Richter (1958) has a diagnostic "felt indoors" for intensity 3, while the Somville scale includes the diagnostic "chimneys collapse" for intensity 7. Because these diagnostics lack expected distributions, different users of the scale may interpret them differently, depending on whether the effects impact a few, many or most cases. As most scales do provide quantitative terms to the various diagnostics included, the lack of definitions provided to these terms also gives ambiguous results. If an earthquake effect took place in 10% of the households in a specific locality, one expert could have associated this number with 'few', while another would associate it with 'many'. This difference in subjective interpretation of these quantifiers could lead to differences in the assigned intensity. Similarly, a scale could provide multiple diagnostics for a single intensity degree that do not represent the same level of shaking. This consistency issue can also be the cause of subjective differences, when the interpretation of which diagnostic represents best a certain intensity degree do not match between different experts.

Subjective differences between assigned intensities can also result from a **lack of expertise** on the individual's part. A common reoccurring and erroneous practice with inexperienced users of macroseismic scales is to assign intensities based on the highest effect reported, instead of the effects most representative of the experienced shaking. This practice is certain to result in differences in assigned intensity degrees between two individuals (Musson et al. 2010). The absence of clear guidelines for most scales also increases the likelihood of their misapplication.

The third factor that can lead to subjective differences, is the macroseismic data. When tasked to assign intensities based on **incomplete data**, the resulting values are likely to differ between experts. As discussed in section 4.1, the lack of quantitative terms provided for most of the questions included in the ROB questionnaire versions will result in confusion and varying interpretations of the data. One might reason that as the form indicated that people ran outdoors, the intensity should be at least 5. Another individual could reason that since there are no other earthquake observations that align with intensity 5, the number of people running outdoors could be negligible, and the experienced shaking is best described by intensity 4. Others might even attribute intensity 4-5.

Disagreements on the assigned intensities among experienced users are likely to persist, even when applying the least ambiguous scale and with complete data. This is because macroseismic intensity scales impose an integer-based classification on the effects of a continuous parameter, i.e. ground motion. Subjective differences between experts can be eliminated by removing expert judgment altogether and using automated algorithms instead, that attribute intensity values to each data point in a consistent manner. This is commonly applied with online macroseismic collection inquiries, for which the submissions are instantaneous and automatically processed to intensity values. There are two general approaches to develop these algorithms. The regression approach is based on a calibration between traditional manual assignments and the scores attributed to several key questions from the online inquiry. This is the approach applied by both the USGS and ROB "DYFI?" online inquiries (§2.1.6; §3.2). The other approach is an expert approach and is based on emulating the thought process of a seismologist through the algorithm (e.g. Musson 2006; Tosi et al. 2007; Sbarra et al. 2010; Goded et al. 2018, Dost et al. 2025). Macroseismic data can also be collected through thumbnail-based questionnaire (Bossu et al. 2017; Sira 2018). These use small, simplified images (thumbnails) to help respondents describe the effects of an earthquake in a faster and more intuitive way.

Throughout the first decade of the 21st century, most ROB questionnaire responses of all versions have been digitized by various student workers. This was done by manually entering the responses to each question of each questionnaire. The existence of this data allows for the development of algorithms to attribute intensity values consistently. Consequently, this data can be compared to the manual assignments of intensity values to assess the consistency of these intensities and to evaluate the subjective differences. Because each ROB questionnaire version consists of a different set of questions, as well as different modes to answer these questions, algorithms must be developed for each version separately. At the time of writing, algorithms have only been developed for versions 1 and 6 and have been included in Dost et al. (2025) and Neefs and Van Noten (2023), respectively. Although these versions are rather limited in the number of forms and events available (**Table 9**), they can already provide some useful insights in the subjective influence on the attribution of intensity values based on the ROB questionnaire responses.

As a regression approach is not suited for the intended purpose, as the regression would incorporate any possible subjective bias, an expert approach was chosen for both v1 and v6. As both versions are quite different to each other, different procedures have been applied to develop the script. Note that the results of the algorithms based on the expert approach still includes a subjective factor, as the script emulates the subjective thinking process of the developer of the script. It is not the intention of these scripts to assess the intensity as accurately as possible, however, but to assess the intensities consistently throughout all questionnaire forms. That said, the algorithms have been modified and tweaked rigorously so that the results align as close as possible with my (i.e. Ben Neefs') personal intensity assignments based on manual evaluations. The algorithm for questionnaire version 1 only attributes integer intensity values to the questionnaire responses, while the algorithm for questionnaire version 6 also includes intensity ranges (e.g. 3-4). This evaluation only includes IDPs from the BTM intensity dataset that mention either v1 or v6 as its source.

For the **v1 questionnaire** (10.2), the developed algorithm evaluates the data separately for each municipality, starting from the highest considered intensity to the lowest, i.e. from intensity 7 to 2 (Dost et al. 2025). If the reported effects in a municipality meet the requirements for an intensity value, the algorithm assigns this value to the municipality and starts evaluating the next one. If the requirements are not met, it evaluates the possibility of lower intensity values, until one of the requirements of an intensity value are met. If the requirements of none of the intensity degrees are met, no intensity value is assigned. Questionnaire responses that reported negatively to all questions are assigned intensity 1. Considered diagnostics for intensity 7, for example, include the collapse of chimneys, cracking of walls and the fall of plaster from the ceiling. Not all diagnostics are as conclusive, and as a result, different weights have been assigned to the diagnostics in each intensity value.

For the **v6 questionnaire** (10.2), the algorithm categorizes the questions into five classes: 'weakly felt', 'strongly felt', 'weak effects on object', 'strong effects on objects' and 'damage' (Neefs and Van Noten 2023). If a question has been answered positively, the score of the corresponding class increases. To assign an intensity value certain thresholds need to be met. The higher the intensity value, the higher the threshold. For intensities 5 to 7, the classes 'strongly felt', 'strong effects to objects' and 'damage' are considered, while for intensities 2 to 4, the 'weakly felt' and 'weak effects to objects' are used. Similarly to the algorithm of the v1 questionnaire, the v6 algorithm proceeds from assessing each form from the highest intensity, to the lowest.

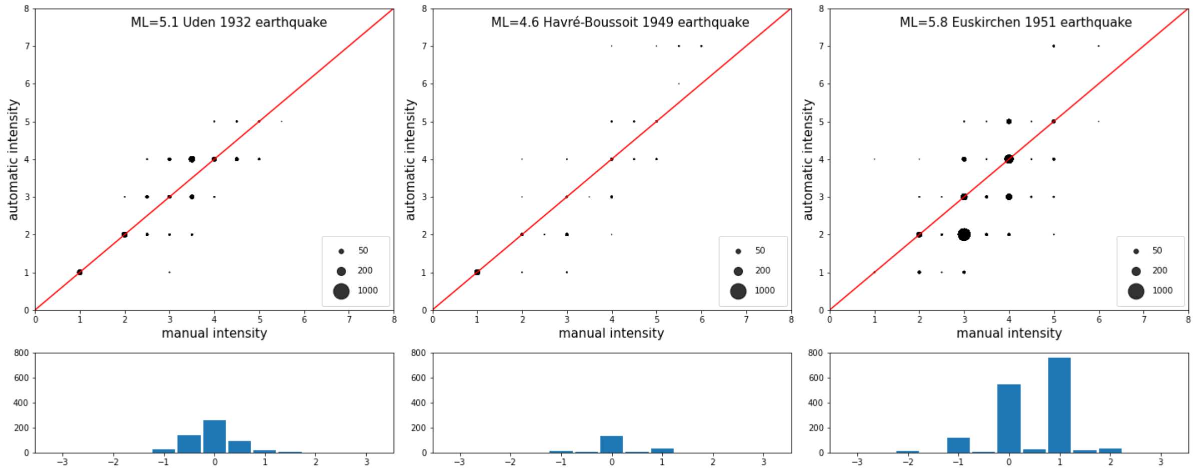



***Figure 23.*** *Comparison between manually assigned intensities in the BTM database and the algorithmic assigned intensities based on a consistently performing algorithm. The three graphs show the individual data of each earthquake that used the v1 questionnaire. The histograms below show the residuals between the manual and the algorithmic intensities.*

The results of the comparison between the manually assigned intensity values and the intensities assigned by the algorithm are provided in **Figure 23** for the v1 questionnaire and in **Figure 24** for the v6 questionnaire. Intensity values that are identical between both procedures lie on the 1:1 line (red diagonal line). Datapoints above the red line indicate a higher intensity value assigned to the IDP by the algorithm, while the manually assigned intensity values are higher below the red line.

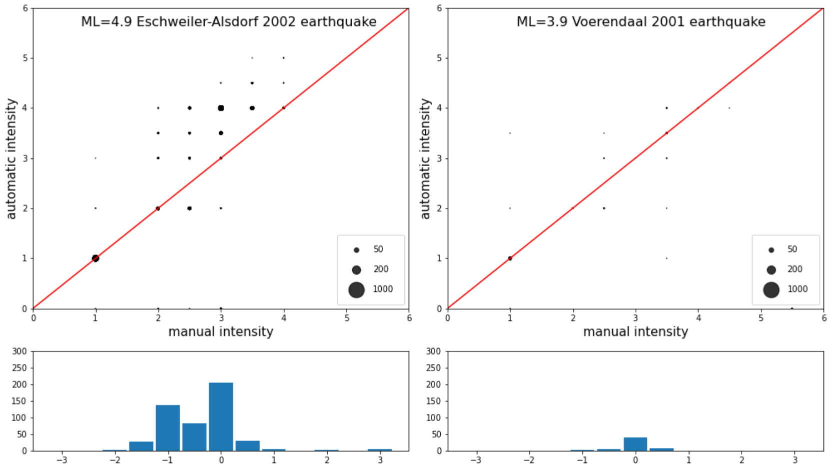



***Figure 24.*** *Comparison between manually assigned intensities in the BTM database and the algorithmic assigned intensities based on a consistently performing algorithm. The two graphs show the individual data of both earthquakes for which the v6 questionnaire was used. The histograms below show the residuals between the manual and the algorithmic intensities.*

For the v1 questionnaire, the first two events presented in **Figure 23**, the $M_L$ = 5.1 Uden 1932 and the $M_L$ = 4.6 Havré-Boussoit 1949 earthquakes, show a good correlation, with most datapoints falling on the 1:1 line or close to it. As the algorithm for the v1 questionnaire does not assign intensity ranges, while the manual assignments do, differences between both intensities up to 0.5 are to be expected. From the histogram of the third event, the $M_L$ = 5.8 Euskirchen 1951 earthquake, the algorithm seems to underpredict intensity values with respect to the manual assignments. From the graph, it becomes clear that this is mainly due to a single datapoint with coordinates (3,2), where the algorithm consistently attributed intensity 2 to these questionnaire responses, the manual assignment assigned these forms with intensity 3. All these forms (n = 611) show very similar responses, they indicated to agree with the earthquake observations provided in the first class of the v1 questionnaire. The first class of the v1 questionnaire reads as follows: *"Few residents, particularly those residing on upper floors, noticed shaking and rumbling like that caused by a speeding truck"*. This sentence is, in fact, an amalgamation of the description of intensity 2 and intensity 3 of the Somville scale (SI 10.1.5), where the first part of the sentence *"Few residents, particularly those residing on upper floors"* can be found in intensity degree 2, while the second part of the sentence *"noticed shaking and rumbling like that caused by a speeding truck"* can be found in intensity degree 3. When respondents indicate this full sentence, this hints at an intensity of either 2, 3 or 2-3. An argument can be made for all three options. What is more significant, is the fact that for the $M_L$ = 5.8 Euskirchen 1951 earthquake, the manual assignments indicate this response as an intensity 3, while for the $M_L$ = 5.1 Uden 1932 earthquake, the same response was provided with an intensity 2. Because of the ambiguity in the design of the questionnaire, and thus incomplete data, the subjective interpretation by the expert results in inconsistencies in the assignment of intensity values.

For the v6 questionnaire, the comparison of the manually assigned intensities and the intensities assigned by the algorithm do show considerable differences for the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake (**Figure 24**). The algorithm assigns significantly higher intensity values than the manual assignments. No such differences are observed with the $M_L$ = 3.9 Voerendaal 2001 earthquake, but this event only has a limited dataset (n = 59). As the algorithm also relies on subjective interpretations of the data by a single individual, other experts at the ROB were consulted and they all shared similar interpretations as those incorporated in the algorithm. The manual assignments are thus most likely due to a lack of expertise on the side of the individual that made the original manual assignments, although the incompleteness of the data certainly also plays a role.

The comparison between the algorithms and the manual assignments of both v1 and v6 questionnaires show two other remarkable and recurring differences. A first observation is that, based on the data on the graphs, the algorithm assigns higher maximum intensity values than the manual assignments. This is the case for the $M_L$ = 4.6 Havré-Boussoit 1949, $M_L$ = 5.8 Euskirchen 1951 and $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquakes. For the last event, this is in line with the general increase of all intensity values. For the first two events, the maximum intensity is increased from intensity 6 to intensity 7. A single IDP even increases from intensity 4 from the manual assignments to intensity 7 using the algorithm. The graphs on **Figure 23** and **Figure 24** only include IDPs from the BTM intensity dataset that report either v1 or v6 as their source. Because of this, the maximum intensity (i.e. intensity 7) of the $M_L$ = 4.6 Havré-Boussoit 1949 earthquake evaluated from the manual assignments, is not included in the graph as this was based on data from a field survey. A second observation is that for some IDPs, there is a disagreement to assign intensity 1, i.e. not-felt, between the manual and the algorithmic procedure. Considering that intensity 1 can only be assigned if there are no observations, this should not be the result of subjective differences.

Both remarks can be (partly) linked to the digitization of the questionnaires. If a municipality did not provide any responses to the questionnaire questions, but instead provided a short description of what earthquake effects did take place, the manual assignment can take this description into account. The algorithm only receives negative responses to all questions and consequently assigns intensity 1. If the answers provided do not fit the structure of the digital data, differences between the manual and algorithmic assignments are inevitable. The digitalization process consisted of manual data entry of thousands of questionnaire forms. It is to be expected that errors will occur during this process. Errors such as accidentally skipping a questionnaire form, a response to a single question or attributing the wrong response to a question have been observed sporadically. This, evidently, also causes a disagreement between both intensity assignment methods.

The increase of the maximum intensities assigned by the algorithm in comparison with the manual assignments cannot (entirely) be attributed to the digitalization process. In a first instance, it is difficult to assess the intensity of higher intensities without any data on the quantity of damaged buildings or their respective vulnerabilities. The algorithm assumes that, if the earthquake effect has been indicated as observed on the questionnaire response, it interpreted this as being a representative observation throughout the municipality. This reasoning was not followed during the manual assignment. Even more, although every question related to damage was answered positively on the questionnaire response, the manual assignments could attribute intensities as low as intensity 4 to these responses. This is for example the case for the municipality of Cambron-Casteau for the $M_L$ = 4.6 Havré-Boussoit 1949 earthquake. The response to the questionnaire from Cambron-Casteau could certainly be considered dubious. The municipality is surrounded by municipalities that reported no damage, which are assigned intensities from only 2 to 4, and many other municipalities in its vicinity have even reported to have not felt the earthquake at all. It is also located at a significantly greater epicentral distance than the other municipalities that also reported damage. Yet, discarding the information from the questionnaire without proof that outliers such as Cambron-Casteau are genuine exaggerations, however, is discouraged, as it introduces subjective bias.

Due to the limited information acquired from the responses to the ROB communal questionnaires, each intensity value is only based on a few questions from a single questionnaire. If the responses do not align with one's expectations of what the intensity should be, based on data from neighbouring municipalities or reports in the press, it is easy to discard the provided data as unreliable or not representative of the overall impact on the municipality. This not only occurs with the highest intensity values, but on all levels of the intensity scale. This effect is also strengthened by the ambiguous data provided by the questionnaire responses, due to a lack of quantitative information. As a small range of intensity values can truthfully be assigned to a single response to a questionnaire, the intensity value that best fits the neighbouring municipalities can be assigned to reduce the heterogeneity of the macroseismic map.

This comparison between manually assigned intensities in the BTM database and algorithmic assessments illustrates the impact of subjective bias. This bias arises from incomplete datasets, allowing for multiple reasonable interpretations, as well as the differing expertise of experts. The results in this subchapter suggest that a standardized algorithmic approach can significantly enhance consistency in intensity assignments. Further development of algorithms for other questionnaire versions will provide a more comprehensive understanding of subjective biases and their effects on macroseismic intensity assessments.

## 4.3. Quality of Belgian online macroseismic data

Unlike the BTM database, which exhibits a high variability in macroseismic survey methodology procedures, the BOM database is characterized by a nearly constant data collection procedure throughout its existence. Since its launch, only minor changes have been made to the "Did You Feel It?" (DYFI?) inquiry, such as adding a noise-related question, making the 'felt' question mandatory, and disabling responses about the earthquake's nature for 'not felt' responses (e.g. 'how would you best describe the ground shaking?'). These minor changes have not affected the answers of the inquiry, allowing for a consistent evaluation of the entire BOM database's overall quality.

One of the major advantages of online macroseismic data collection tools over traditional surveys is their rapid response rate. For example, the USGS "DYFI?" inquiry typically collects 60 to 90 % of entries within the first hour (Quitoriano et al. 2020). In Belgium, a much slower collection rate is observed with the ROB "DYFI?" inquiry, as 60 to 90% of the entries are typically only collected within the first 24 hours. This slower collection rate in Belgium is caused by two distinct waves of submissions commonly observed for earthquakes in the BOM earthquake catalogue (**Figure 25**). The first wave immediately occurs after the earthquake, as individuals who felt the event promptly submit their experiences. The second wave is the result of media coverage revolving around the earthquake, which prompts additional submissions to the "DYFI?" inquiry. This second wave can include submissions from people who did not initially recognize their experience as the result of seismic activity or from people unaware of the inquiry until hearing about it on the news. This second wave is thus dependent on media coverage and is absent for many small earthquakes that do not attract widespread attention (**Figure 25**).

Compared to the traditional ROB questionnaire surveys, which suffer from reduced resolutions due to the large-scale municipal mergers, the "DYFI?" inquiry offers a significant improvement in macroseismic data resolution. Although respondents are only required to provide their zip code, this already presents an advancement over the main municipality resolution of the traditional ROB questionnaire surveys (**Figure 26**). This advancement, however, still falls short of the ideal sub-municipal resolution, as the zip codes of many towns and cities within a main municipality are identical. Fortunately, more than 90% of the submissions in the BOM input data provide a street address, enabling geocoding with rooftop-level accuracies (Van Noten et al. 2017). Consequently, geocoded addresses can be aggregated into custom-sized grid cells, with resolutions as high as 1 km$^2$ (e.g. Quitoriano et al. 2020). To ensure a sufficient number of data points within each data cell, larger grid sizes up to 100 km$^2$ are often used (Van Noten et al. 2017).

The availability of the "DYFI?" questionnaire in four languages also allows residents of neighbouring countries to respond to the online inquiry as well. Its reach outside of Belgium is rather limited, however, as all neighbouring countries have similar initiatives to collect online macroseismic data (e.g. franceseisme.fr; knmi.nl; gd.nrw.de). Only in West-Germany, a large number of submissions are received, thanks to the collaboration between the ROB and the University of Cologne (Erdbebenstation Bensberg). The work in this PhD only discusses the online macroseismic data collected from Belgium.

Online macroseismic inquiries are typically based on the volunteer sampling principle (or self-selection). This principle is known to underrepresent both negative (not-felt) submissions and lower population density areas (e.g. Mak and Schorlemmer 2016; Boatwright and Phillips 2017). The ROB

"DYFI?" inquiry is no exception to these flaws. The number of intensity 1 values in the BOM intensity dataset is very low (**Table 14**) and there is a clear correlation between the number of submissions from a municipality and its population (**Figure 27**). The fraction of 'not-felt' submissions to the "DYFI?" inquiry are significantly higher than those of other similar online inquiries (e.g. 17% in the BOM input data vs <1% for the USGS "DYFI?" inquiry; Boatwright and Phillips 2017), even without additional initiatives to collect these data, as for example is done with the Italian online inquiry (Sbarra et al. 2010). The 17% of the BOM input data is still significantly lower than that of the BTM database, with 48% intensity 1 IDPs.

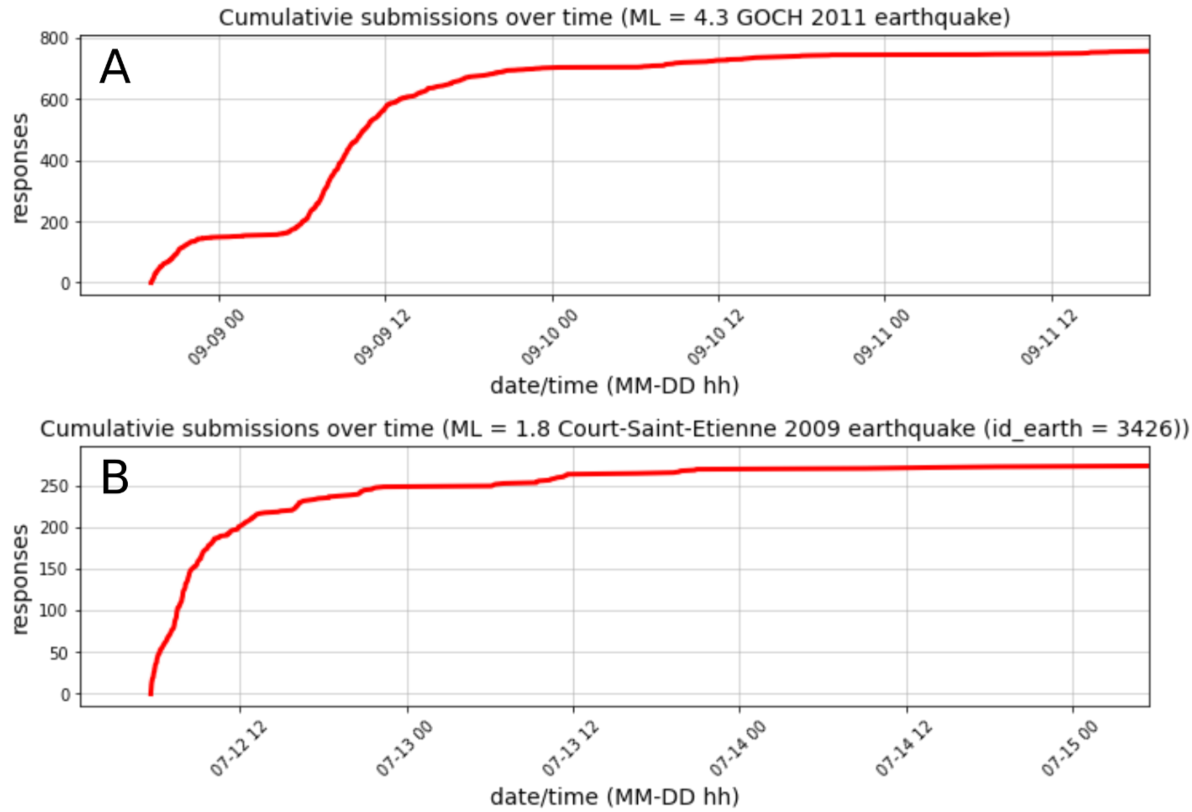



***Figure 25.*** *Cumulative "DYFI?" submissions over a time span of 3 days for A) The $M_L$ = 4.3 Goch 2011 earthquake and B) the $M_L$ = 1.8 Court-Saint-Etienne 2009 earthquake (id_earth = 3426). The 2011 Goch earthquake (21:02 local time) received less than 200 responses in Belgium during the first 12 hours. After a day of broadcasting the occurrence of an earthquake on various media channels, ~600 more responses were submitted. The much smaller $M_L$ = 1.8 Court-Saint-Etienne 2009 earthquake (07:29 local time) was not covered by the media and, consequently, received no significant amount of additional submission after the first few hours.*

The community decimal intensity (CDI) values derived from the aggregation of responses submitted through the ROB "DYF?" inquiry are commonly equated to EMS-98 intensity values (Camelbeeck et al. 2003; Van Noten et al. 2017; Neefs and Van Noten 2023). The scoring procedure of the online "DYFI?" inquiry, as originally introduced by Wald et al. (1999b), was calibrated by comparing manually assigned intensities from traditional postal questionnaires based on the MM-93 scale with online submissions. As the ROB version of the "DYFI?" inquiry retained this scoring procedure without significant modifications, its CDI scores should be regarded as MM-93 intensities rather than EMS-98 intensities. As both scales are part of the Cancani family (§1.1.2, Musson et al. 2010), however, no significant concerns are raised on this equalisation of the two scales.

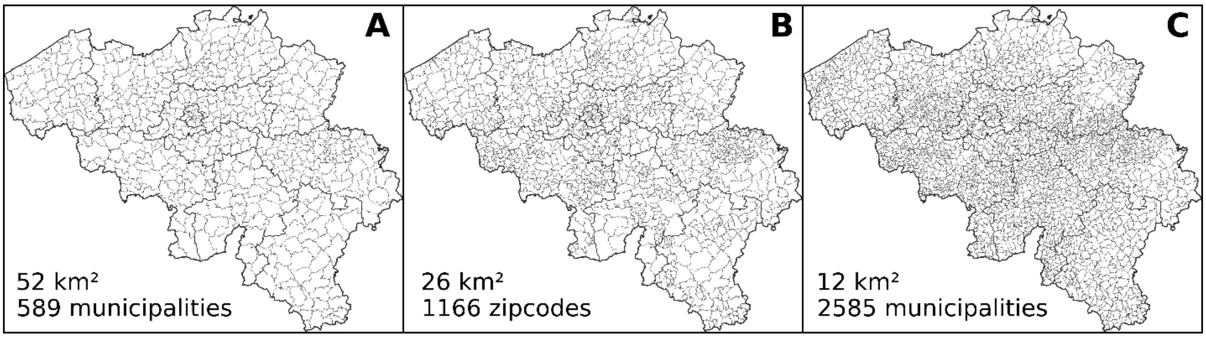



***Figure 26.*** *The three administrative resolutions of Belgium and their average surface area. A) the main municipal resolution, B) the zip code resolution, and C) the sub-municipal resolution.*

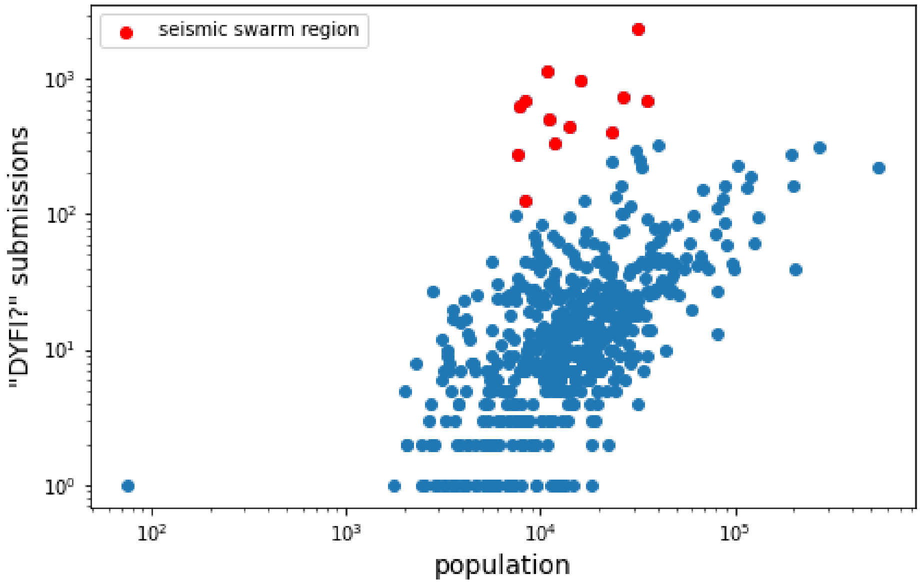



***Figure 27.*** *Municipality population versus the number of submissions in the BOM input data per municipality. There is a correlation between the population of a municipality and the number of submissions per municipality received with the "DYFI?" inquiry of the ROB. The red data points represent the municipalities within a 10 km radius of the Brabant-Wallon 2008-2010 seismic swarm.*

The calibration between CDI values and MM-93 intensities, however, presents certain challenges. Dengler and Dewey (1998) first introduced the community weighted sum (CWS, (1)) and CDI (2) equations. This calibration is based on a comparison of two macroseismic datasets for the $M_W$ = 6.7 Northridge California 1994 earthquake, i.e. 6000 telephone surveys of randomly selected individuals and the manually determined MM-93 intensities based on traditional USGS postal surveys (Dewey et al. 1995). The weights of the different indexes in the CWS equation were subjectively chosen so that the scores assigned by the telephone surveys would match the range of the traditionally assigned intensities. Wald et al. (1999b) later adopted the CWS equation but recalibrated the relation between CWS and intensity with a new CDI equation (3), based on online "DYFI?" submissions (800+ responses), collected of the same Northridge 1994 earthquake and two other large earthquakes in Southern California (130 responses).

A first significant issue is that the calculation of CDI values is entirely based on data from strong earthquakes in Southern California. Camelbeeck et al. (2003) adopted the procedure and applied it in Belgium, implicitly assuming that the calibrations established by Dengler and Dewey (1998) and Wald et al. (1999b) would also be valid in a Belgian context. There are various reasons why this assumption might not be valid, ranging from differences in demographic composition to variations in earthquake awareness. Mak and Schorlemmer (2016), for example, discuss a variety of factors that influence why people respond to an online macroseismic inquiry. It is easy to imagine how the Belgian population, with minimal experience with seismic events, might respond more strongly to a moderate earthquake compared to Californians, who encounter moderate and large earthquakes multiple times throughout their lives. This heightened reaction in Belgium would directly impact the 'reaction' index, which contributes to the CWS value and thus the resulting CDI score.

Secondly, while Dengler and Dewey (1998) performed telephone surveys from randomly selected individuals, the online "DYFI?" inquiry relies on volunteers. This results into a self-selection bias, with the well-known results of acquiring fewer submissions from people who did not feel the earthquake and from lower population density areas (Mak and Schorlemmer 2016; Boatwright and Phillips 2017). The fraction of 'not-felt' submissions to the ROB "DYFI?" inquiry are significantly higher than those of other similar online inquiries (17% in the BOM input data vs <1% for the USGS "DYFI?" inquiry; Boatwright and Phillips 2017), even without additional initiatives to collect these data, as for example is done with the Italian online inquiry (Sbarra et al. 2010). The 17% of the BOM input data is still significantly lower than that of the BTM database, with 48% intensity 1 IDPs.

While Wald et al. (1999b) does take into account the lack of negative responses with the online inquiry with its recalibrated CDI equation (3), telephone surveys also tend to have more complete answers, while submissions to the "DYFI?" inquiry tend to lack information on one or more of the indexes used in the CWS equation (Sbarra et al. 2020; Hough and Bilham 2024). As Wald et al. (1999b) adopted the CWS equation fully, this incompleteness of the data consequently influences the CWS score towards lower values and thus also the CDI value, especially for IDPs with few responses (Hough and Bilham 2024; Hough 2024).

Thirdly, CDI values are merely a calibration between the CWS values and traditional intensities. They cannot be classified as actual intensity values, as they are not defined on a macroseismic scale. The CDI does not consider the situation of an observer or the vulnerability of a building in case of damage. Many parameters that can be used to determine intensity values are simply not requested in the online inquiry (SI 10.3; **Table 15**), while other parameters that are been collected are simply not used to determine the CDI value. Instead, only 5 parameters or indexes are used, assigned with subjectively determined weights. These indexes also do not all correlate equally strongly with macroseismic intensity (Hough 2024). This disconnection between the CDI values and expert-based intensity values can, however, result in difference up to multiple integer values for the same town or city (§4.4). Plotting the different index scores, calculated from the BOM input data to create the CDI values for the BOM intensity dataset on the main municipal scale, over the CDI values (**Figure 28**) shows a positive correlation for the 'motion' and 'reaction' indexes only. A weak positive correlation can be seen for the 'felt' index. The lack of a correlation with any of the other indexes is to be expected given the low CDI values in the BOM intensity dataset (<5).

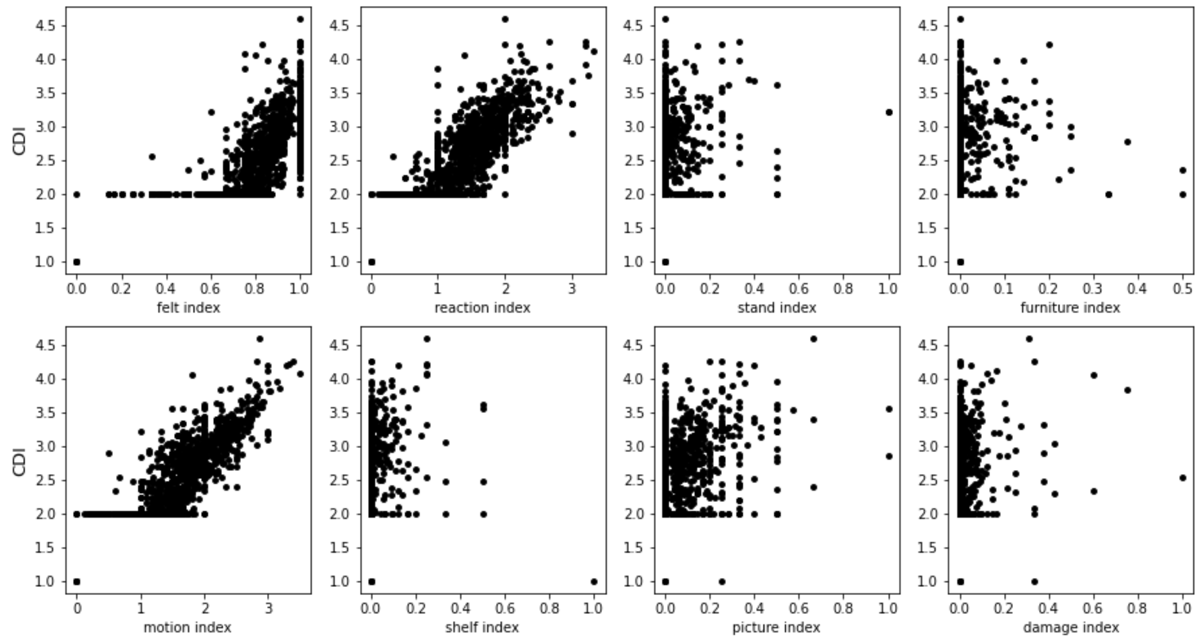



***Figure 28.*** *The different indexes on which the CDI values of the BOM intensity dataset are based upon. There is a positive relation between the CDI values and the reaction and motion indexes, and a very weak correlation with the felt index. The lack of correlation between the other indexes and the CDI is related to a lack of CDI data higher than 4.5.*

These issues related to calibration-based algorithms stem mostly from a lack of parallel traditional manually assigned intensity datasets. Because of the general ease of online macroseismic data procedures, traditional procedures have been abolished in many countries quickly after the introduction of online collection inquiries (Wald et al. 2024). This resulted in very few parallel macroseismic datasets of earthquakes with both traditional and online collected datasets, on which the calibration between the two can rely on. In Belgium, there is only one such event, i.e. the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake. Because of this, many seismological institutions employ expert-based algorithms to determine intensity values from online collected macroseismic data (e.g. Musson 2006; Tosi et al. 2007; Sbarra et al. 2010; Goded et al. 2018), instead of algorithms based on calibrations. These have the advantage of being more closely related to a macroseismic scale of choice and could be considered as actual macroseismic intensities.

## 4.4. Online-traditional intensity data correlation

The “Did You Feel It?” (DYFI?) procedure was optimised to align online inquiry responses with traditionally assigned intensities for California specifically (Dengler and Dewey 1998; Wald et al. 1999b; §4.3). In this subchapter it is evaluated if this procedure also aligns with the traditionally assigned intensities in Belgium. There is only one event for which both traditional and DYFI? intensities are available, i.e. the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake. Camelbeeck et al. (2003) provided a visual comparison (**Figure 29**) and observed two main differences:

1) The online “DYFI?” macroseismic map provides more homogeneous results.
2) The online “DYFI?” macroseismic map likely provides a better overview of the macroseismic field or felt area of an earthquake.

Both observations are attributed to the lack of effort in accurately reporting the earthquake effects in their municipality for the traditional ROB communal questionnaire surveys. Camelbeeck et al. (2003) consider the online macroseismic intensity to be more accurately representing the experienced shaking, given enough submissions are collected for each municipality. They also note that the number of municipalities that are assigned intensity 4 is significantly lower with the online intensity data in comparison to the traditional data.

Since the publication by Camelbeeck et al. (2003), no traditional ROB questionnaire surveys have been conducted anymore. Instead, Belgian macroseismic data in Belgium has only been collected through the “DYFI?” inquiry, with the assumption that these online data more accurately depict the experienced shaking than the traditional data. The quality of both traditional macroseismic surveys (§4.1, §4.2) and online surveys (§4.3) in Belgium have been discussed in detail earlier. From these discussions, it became evident that both data types have their shortcomings. Furthermore, Neefs and Van Noten (2023) showed that the data used by Camelbeeck et al. (2003) for the comparison between both datatypes was not correctly processed. The traditional intensities had been significantly underestimated, and the online intensity data was not properly aggregated. The new datasets developed by Neefs and Van Noten (2023) are shown in **Figure 30**. The newly traditional intensity dataset is the result of the v6 questionnaire algorithm, which provides a consistent attribution of intensity values to the responses of the questionnaire based on an expert-approach (§4.2). Whereas the original traditional intensity dataset by Camelbeeck et al. (2003) only depicted a few municipalities with intensity 4, the revised traditional dataset in this work has more municipalities with intensity 4 and even a few with intensities 4-5 and 5. The large number of intensity 4 values in the revised traditional dataset may look inflated, but all questionnaires from these municipalities indicated that 1) many people felt the earthquake or at least a few people felt it outside, and 2) multiple effects were observed such as the swinging, shaking, vibrating, rattling or moving of objects (Neefs and Van Noten 2023). The updated online intensity data is reprocessed by aggregating all responses received for each municipality (§2.3, §3.2). Similarly to Camelbeeck et al. (2003), only municipalities with 3 or more responses are included on the macroseismic map with revised data. Visually, only few limited changes can be observed from a comparison between the online macroseismic intensity map by Camelbeeck et al. (2003; **Figure 29b**) and the revised online intensity dataset (**Figure 30b**).

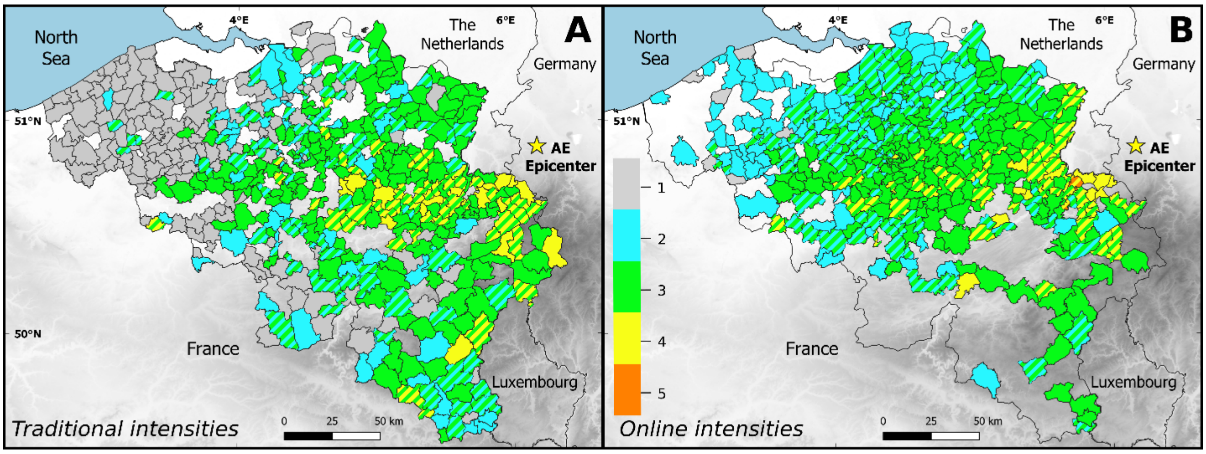



***Figure 29.*** *The macroseismic maps of the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake based on A) the traditional ROB questionnaires and B) the online "DYFI?" inquiry. These datasets were used by Camelbeeck et al. (2003) to visually compare both methodologies. The Camelbeeck et al. (2003) maps did not use shaded colouring to illustrate intensity ranges and instead provided the lower bound for the traditional intensities and rounded to the nearest integer for the CDI scores provided by the online intensity data. To be consistent with other maps in this work, shaded intensities are used. The online intensity map only includes municipalities with at least three submissions to the "DYFI?" inquiry.*

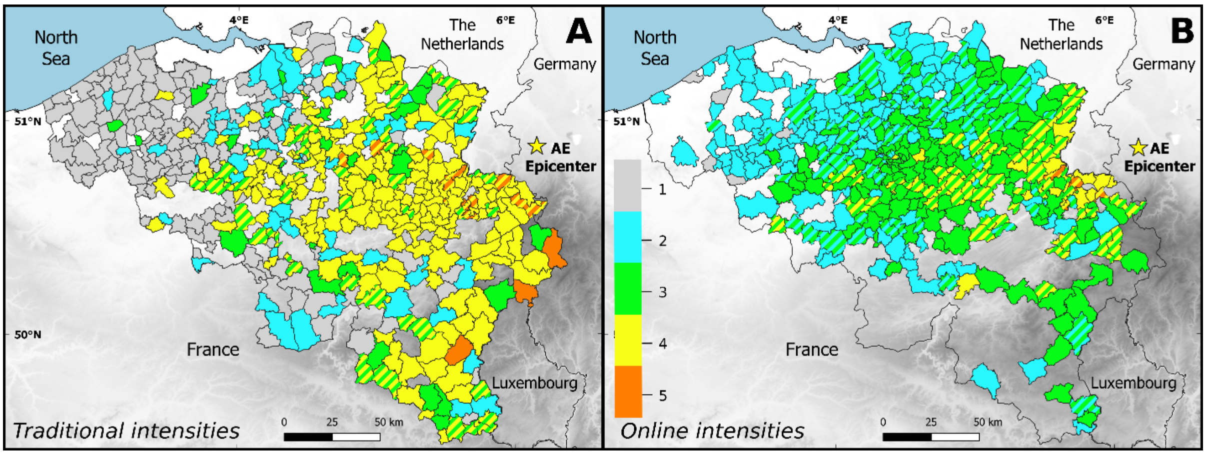



***Figure 30.*** *The revised developed macroseismic maps of the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake based on a) traditional ROB questionnaires and B) the online "DYFI?" inquiry. The traditional intensities are the result of an automated algorithm written from an expert approach. The online intensity map only includes municipalities with at least three submissions to the "DYFI?" inquiry and responses have been aggregated by the municipalities before calculating intensity values.*

A visual comparison between both revised datasets for the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake (**Figure 30**) depicts a sharp contrast with very few similarities. Only for the Belgian intensity data closest to the epicentre, the intensity values of both datasets, i.e. intensity 4 and 4-5, are comparable. Outside of this area, the traditional intensities are higher than the online intensities. Only where the traditional dataset attributes intensity 1, the intensity of the online dataset is consistently higher. The observations made by Camelbeeck et al. (2003) for the original datasets remain true for the revised datasets. The online intensity data provides more homogeneous results and provides a better image of the total felt macroseismic field. The number of municipalities with intensity 4 is also much higher for the traditional data than for the online data.

In **Figure 31**, another approach is used to compare the different intensity datasets. The comparison between the **original traditional dataset** with manual intensity evaluation of the ROB communal questionnaires and the **revised traditional dataset** using an algorithmic approach (**Figure 31a**) has already been discussed in §4.2. The correlation between the **original online datasets**, by averaging the intensities attributed to individual "DYFI?" submissions within each municipality, and the **revised online dataset**, using an aggregation procedure within each municipality, is high (**Figure 31b**). This strong correlation indicates that aggregation within a municipality, as opposed to averaging intensities attributed to individual submissions, results in only a slight increase in intensity values above 3 and a slight decrease in values below 3. **Figure 31c** shows a comparison between the **original traditional** and the **original online datasets** by Camelbeeck et al. (2003), while **Figure 31d** provides a comparison between the **revised traditional** and **revised online datasets**. Between the original datasets, a very weak correlation is visible, while no trend is visible in the comparison of the revised datasets. The comparisons show that for traditional intensities below 3, the online datasets provide higher values (above the 1:1 line), which can be attributed to the erroneous reporting by the municipalities that nobody, or only very few people, felt the earthquake. For traditional intensities above 3, online intensities are lower. This discrepancy is much more difficult to explain. The "DYFI?" is known to attract submissions from people that felt the earthquake. 76% of the IDPs in the BOM intensity dataset have a felt index of at least 0.7. This means that at least 70% of the submissions of each of these IDPs have reported to have felt the earthquake. This is also illustrated by the felt index in **Figure 28**. As there are barely any IDPs in the BOM intensity dataset that equal or surpass intensity 4, 76% is thus considered high. The EMS-98 defines that for intensity 4, 10-60% have felt shaking indoors. This data hence suggests an overestimation of ROB "DYFI?" inquiry at lower intensities values (I < 5), yet they are still lower than the traditional intensities.

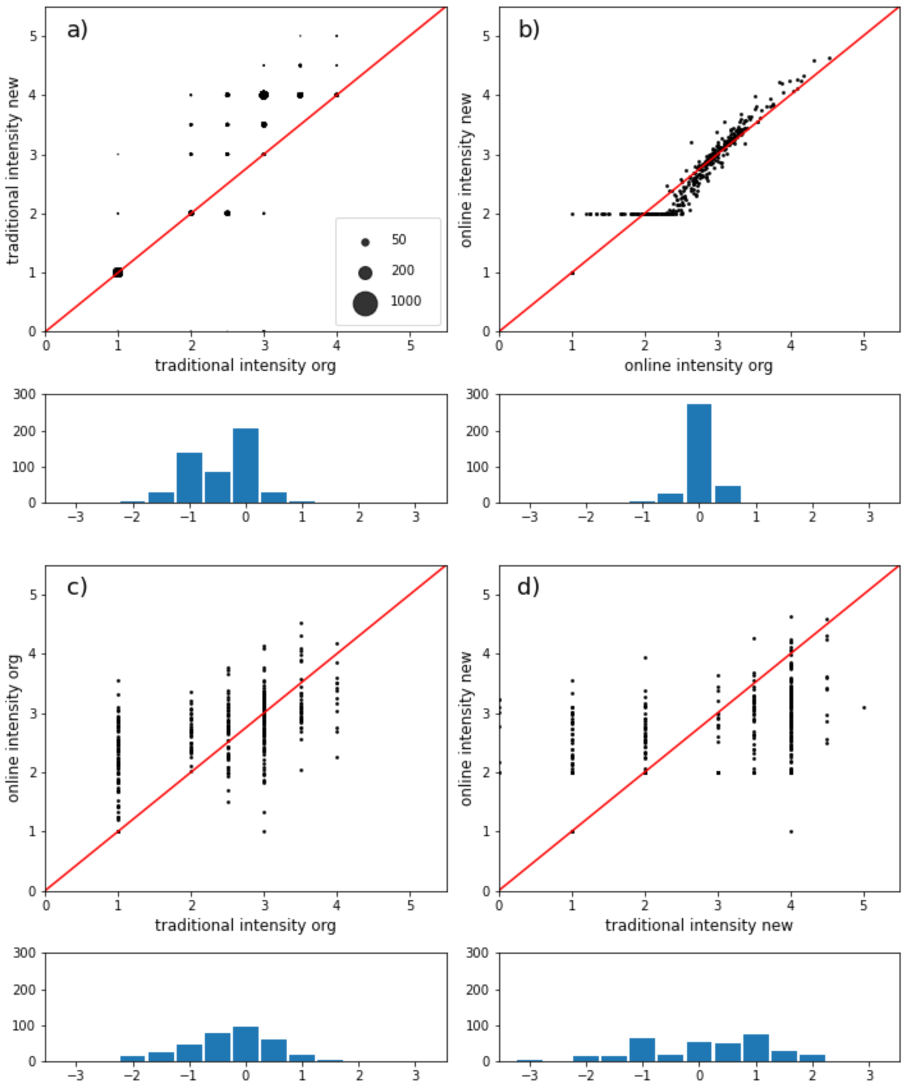



***Figure 31.*** *Comparison of the Belgian macroseismic datasets for the $M_L = 4.9$ Eschweiler-Alsdorf 2002 earthquake. Histogram values show the distribution of differences between the x-axis dataset and the y-axis dataset values. The red diagonal line indicates the 1:1 line or the line of equality. Different graphs present a comparison between* ***a)*** *the original (org) traditional intensity dataset by Camelbeeck et al. (2003) and the revised traditional dataset using an algorithmic approach (§4.2);* ***b)*** *the original online intensity dataset by Camelbeeck et al. (2003), averaging intensities attributed to individual submissions, and the revised online intensity dataset, using an aggregation procedure;* ***c)*** *the original traditional intensity and online datasets by Camelbeeck et al. (2003);* ***d)*** *the revised traditional and online intensity datasets.*

A distinct difference between the revised traditional and online datasets, is the low number of intensity 4 values. Inverting equation (3), a community weighted sum (CWS) (2) of at least 11.7 is needed for the procedure to assign intensity 4 to a municipality. The CWS includes 8 different indexes (SI 10.3). At intensity 4, it is unlikely to receive positive responses to the stand, furniture or damage indexes. As a positive score is only attributed to the shelf index if objects topple or fall down, the shelf index unlikely contributes to the CWS for intensity 4. This means that only the stand, motion, reaction and picture indexes contribute to the CWS. Following the diagnostics outlined in the EMS-98 for intensity 4, the maximum score attainable would be 12, comprising 5 points from the felt index, 3 from the motion index, 2 from the reaction index and 2 from the picture index. This already includes the higher percentage of felt submissions with online inquiries, as strictly following the EMS-98 would result in a maximum of only 2.5-3 points from the felt index. In ideal circumstances, municipalities that experienced intensity 4 shaking could indeed be attributed the correct intensity by the "DYFI?" procedure, but only if all submissions provide these optimal responses. In practice, it is very unlikely that all submissions would adhere to these ideal responses. Depending on the number of submissions received for a municipality, a single not felt response, which would be completely expected at intensity 4, could significantly decrease the CWS score and result in a lower intensity value.

A comparison between the original online datasets of Camelbeeck et al. (2003) and the revised online dataset with the CWS values determined for each IDP is presented in **Figure 32**. For both datasets, the CWS increases much slower with intensity than suggested by the regression of equation (3). This is also visible in the original datasets used by Wald et al. (1999b) to calibrate traditional intensities with the CWS values (**Figure 33**). Average CWS scores for traditional intensities from 2 to 4 increase significantly slower than what the regression equation (solid line) indicates. This indicates that the CWS and/or CDI equations are unoptimized for lower intensity values. Similar findings have been formulated by Hough and Bilham (2024) and Hough (2024). At these lower intensity values, the percentage of people who felt the earthquake is the main indicator to distinguish between intensities. Unfortunately, this percentage parameter is not reliably sampled through the online "DYFI?" inquiry.

The discrepancy between revised traditional and online intensities for the ML = 4.9 Eschweiler-Alsdorf 2002 earthquake suggests that the correlation between "DYFI?" CDI values and traditional intensities is more complex than previously assumed. No clear correlation is observed, but it should be noted that the analysis is limited to a single event with intensities below 5. Adjusting the CWS scoring algorithm or CDI equation for Belgium would require more data across multiple events. While the "DYFI?" inquiry is shown to have its limitations in Belgium, the revised traditional dataset is also influenced by reporting inconsistencies and a limited ROB communal questionnaire. Both methodologies are further evaluated and discussed in the following subchapter (§4.5).

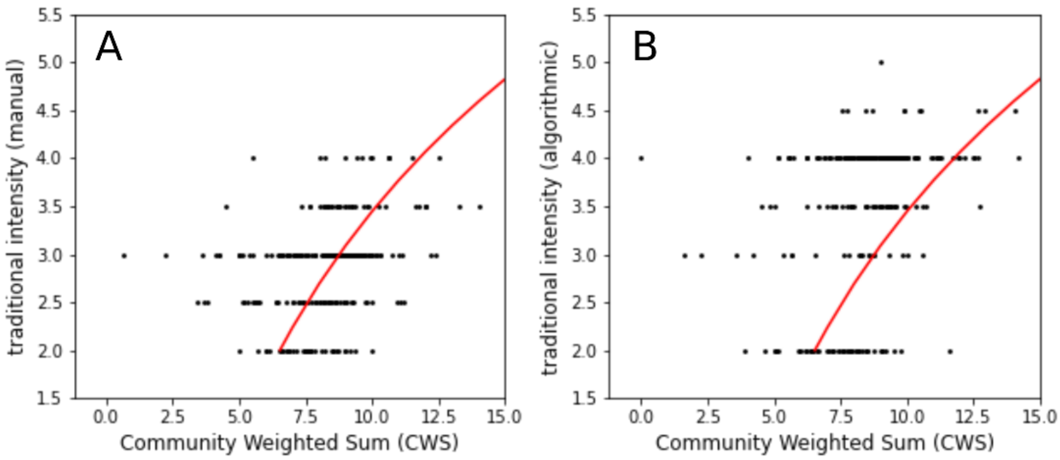



***Figure 32.*** *Comparison of the community weighted sum (CWS) and the traditional intensity data of the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake of: A) the original dataset by Camelbeeck et al. (2003); B) the revised dataset. The average CWS values of the traditional intensities (black dots) increase much slower than what the regression between CWS and CDI suggests (red solid line).*

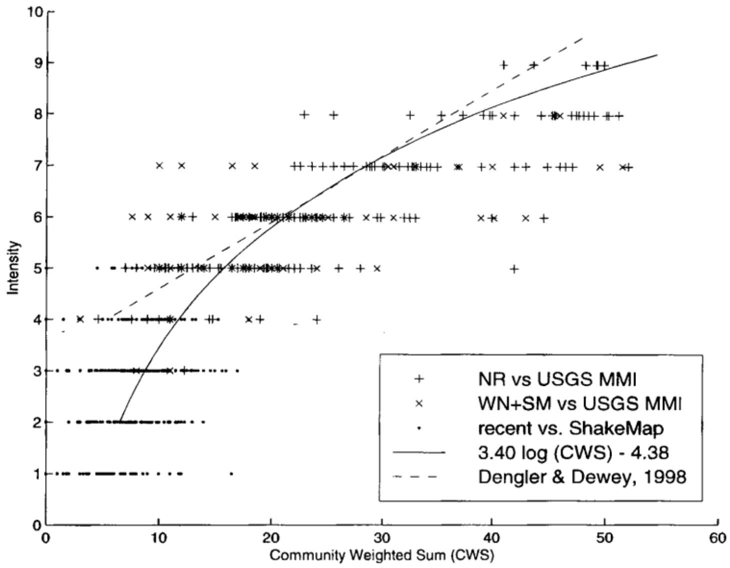



***Figure 33.*** *Regression of the community weighted sum (CWS) versus observed and instrumental intensities (solid line). Data for higher intensities are USGS Modified Mercalli intensities for the same communities from the 1994 Northridge (NR), 1991 Sierra Madre (SM), and 19987 Whittier Narrows (WN) earthquakes as labelled. Lower intensities data (dots) are from ShakeMap Instrumental intensities for recent earthquakes (Wald et al. 1999a). The dashed line shows the linear fit to the CWS data collected by Dengler and Dewey (1998) versus USGS Modified Mercalli intensities for the Northridge earthquake. Figure and caption taken from Wald et al. (1999b).*

## 4.5. The future of Belgian macroseismic data

### 4.5.1. The online macroseismic inquiry

Through traditional communal questionnaires and the "Did You Feel It?" inquiry, the ROB has collected macroseismic intensity data using two distinct methodologies. Although both are theoretically active, traditional macroseismic data collection has not taken place for over two decades. As a result, the online inquiry has been the only source of macroseismic data in Belgium since 2002. The lack of traditional surveys can partly be attributed to the seismic quiescence during the 21st century, as no earthquakes larger than $M_L$ = 3.2 took place in Belgium. The strongest event to occur within Belgian borders in the last 20 years, i.e. the $M_L$ = 3.2 Court-Saint-Etienne 2008 earthquake, had only a limited impact on the country. Before the launch of the "DYFI?" inquiry, however, at least 12 traditional surveys have been conducted for comparable or even smaller magnitude events, as low as $M_L$ = 2.4 (**Table 11**). This means that in practice indeed the online inquiry has replaced traditional communal questionnaires.

As Camelbeeck et al. (2003) found a strong correlation between both data types, online macroseismic intensities were deemed more accurate. The greater accuracy, ease of collection, and cost-effectiveness of the online inquiry contributed to the decline of traditional ROB questionnaires. The conclusion of a strong correlation between the two datatypes was based on flawed, however, raising concerns about the DYFI? inquiry's ability to accurately determine experienced macroseismic intensity for Belgium (§4.4).

There is no doubt that collecting macroseismic data online, with a consistent and instantaneous automatic intensity procedure, is of great value to any institution tasked with monitoring the seismicity of a region. The number of responses received from small earthquakes in Belgium, such as those of the Brabant-Wallon seismic swarm, would be unimaginable with traditional procedures. For moderate events, the quantity and rate at which the responses are collected through the "DYFI?" inquiry are also unparalleled by any traditional survey: 2271 letters received from individuals for the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake against 6073 individual submissions to the "DYFI?" inquiry for the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake. If, however, the intensity values derived through the online inquiry do not match the actual experienced macroseismic intensities, it is highly recommended to carry out traditional communal surveys as well.

The original USGS "DYFI?" procedure by Wald et al. (1999b), of which the ROB "DYFI?" is an almost identical copy, is based on large earthquakes in California. This could explain the discrepancy at the lower end of the macroseismic intensity scale, as observed for the $M_L$ = 4.9 Eschweiler-Alsdorf 2002 earthquake (§4.4). Another possible explanation is that, for the same experienced ground motions, distinct populations from different regions could show discrepancies in the responses provided. Californians might, for example, react differently than Belgians to a moderate earthquake (§4.3). At higher intensities (intensity 5 to 7), the "DYFI?" procedure might correlate more strongly with traditional intensities in Belgium. Due to a lack of data, however, no statements can be made on this.

As there is only one event for which both traditional and online intensity data are available, establishing a regression between the two data types, similarly to the calibration by Wald et al. (1999b) but for Belgium specifically, is not likely to provide meaningful results. For this purpose, it would be beneficial to have had traditional data for more events in Belgium, regardless of their limited impact on the population and building stock. The continuation of the traditional macroseismic surveys will allow for constructing more meaningful regressions. Given Belgium's low seismic activity, retrieving enough data might take a considerable number of years. Another option would be to shift from the regression-based approach of the "DYFI?" to an expert-based approach. This approach does not need any data in advance, as it can be directly correlated to the diagnostics of a macroseismic intensity scale. Due to the sampling bias towards people that felt the earthquake, open online requests for macroseismic data do not allow to accurately quantify the degree of the population that felt the earthquake, which is essential to distinguish between the lower intensity values. Nonetheless, this approach proved to be quite popular, as many seismological institutions have developed expert-based algorithms to determine intensity values from online collected macroseismic data. In fact, Belgium is one of the few countries in the world to use a regression-approach in their online macroseismic survey.

An argument to stay with the "DYFI?" procedure in Belgium, is that it is a globally applied survey. In the case of a large event that spans multiple countries, the "DYFI?" survey by the USGS allows for a homogenized procedure across national borders. This, however, does not imply that the resulting intensities are equivalent to each other, as the provided values are not correlated to any specific macroseismic intensity scale. A value of 4 in one region could thus, theoretically, be the same as intensity 5 in another region. For this reason, it is recommended to determine macroseismic intensity as accurately as possible using expert-based approaches, tailored to each region individually.

### 4.5.2. A new communal macroseismic questionnaire

The decline of traditional macroseismic surveys in Belgium is not solely due to the launch of the "DYFI?" inquiry or the relative seismic quiescence in the 21st century. The effectiveness of the ROB communal questionnaire was already decreasing since the late 20th century. Large-scale municipal mergers in the 1960s and 1970s significantly reduced the resolution of the surveys (§2.4) and v5 and v6 questionnaires introduced fewer questions than before, increasing uncertainty in intensity assignments. Moreover, the ROB questionnaires failed to incorporate key developments. Van Gils (1966), for example, stated that he processed the ROB communal questionnaires in the spirit of the MSK-64 scale. This scale introduced a quantitative classification of damage and other observations, separates the diagnostics based on the different sensors, and defines various damage grades and a reworked vulnerability classification from the Modified Mercalli scale of 1956 (Richter 1958). The v4 questionnaire in use at this time and which was introduced in 1952, however, remained the same as before until 1988. Even with the introduction of the v5 ROB questionnaire in 1988, the only concept partly introduced from the MSK-64 scale is the separation of diagnostics based on the different sensors. The same can be said for the introduction of the v6 ROB questionnaire and the EMS-98. While v6 was introduced shortly after the publication of the EMS-98, none of the concepts of this new scale (or the ones from the MSK-64 scale) were introduced in the questionnaire, even though intensities are said to be assigned to EMS-98 (Camelbeeck et al. 2003). Additionally, increased uncertainty over respondents' efforts to accurately represent earthquake effects and the time and cost intensive procedures associated with traditional surveys, further contributed to the decline of ROB traditional communal questionnaire.

Despite these flaws, the continuation of communal macroseismic surveys in Belgium is still recommended, as it will allow providing a better correlation with online macroseismic data. Either to test the validity of the "DYFI?" procedure for Belgium, adjust the USGS "DYFI" scoring equations, or assess the correlation with a new expert-based approach. Simultaneously, a separate procedure to assess macroseismic intensity independently from a volunteer-based approach is necessary, as enough submissions for each locality cannot be guaranteed. For larger earthquakes that could potentially qualify as a natural disaster, macroseismic intensity is one of the requisites to request reimbursements (**Table 7**). It is therefore crucial that such assessments are not based solely on a limited number of volunteer submissions that are known to be highly unreliable in low numbers (Wald et al. 2006; Atkinson and Wald 2007). At the same time, the review of forms in this study clarified that the continuation of the v6 questionnaire will not provide macroseismic data with a consistently high quality. Instead, the design of a **new procedure** and a **new questionnaire** are suggested.

As the online collection of macroseismic data already provides a rapid summary of the impact of an earthquake and the modern instrumental seismic network characterizes the earthquake parameters, there no longer is any urgency to rapidly collect traditional macroseismic data. Consequently, a new traditional ROB survey should focus on providing **high-quality data** with as little uncertainty as possible. This can be achieved through a more extensive questionnaire with proper quantification of the diagnostics and the provision of a more comprehensive cover letter to the responsible administration of the Belgian municipalities.

With communal macroseismic questionnaires, the responsibility for accurately conducting a macroseismic survey is entrusted to local authorities. Therefore, the cover letter should not only outline the earthquake source parameters and the survey's purpose but also provide **clear guidelines** on best practices for conducting macroseismic surveys. These guidelines should include core concepts of macroseismic surveys, such as collecting observations of earthquake effects separately for each town and ensuring that a representative sample of residents is surveyed across all areas of a town/municipality. Ideally, the desired resolution of the observations, which is similar to the sub-municipal scale (§2.4), can directly be communicated to each municipality separately. Additionally, to maintain a **quality control** on the provided data, the respondent should indicate or describe the actions taken to complete the survey, e.g. approximate number of interviews taken by the police, letters to the administration, reports from the firemen, local volunteering, etc.

There is little reason to distribute paper questionnaires and instead, local authorities should be contacted through their official email addresses or on an online platform, similarly to the procedure in France (e.g. Schlupp et al. 2021). This saves unnecessary costs and time on the postal service and the printing of papers and also allows providing supplementary information when this is requested. As this would no longer make these macroseismic surveys "traditional", the continuation of the communal aspect of the survey is of much greater importance to ensure consistency with earlier ROB questionnaire surveys. Web-based communal surveys also provide the possibility to automatically process submitted responses consistently. Distributing the questionnaire to the local Belgian municipal authorities is still considered to be the best option, despite the sharp decrease in resolution. In some countries, a network of volunteers is maintained which can be contacted in the case of an earthquake (Tosi et al. 2007; Goded et al. 2018). Such networks, however, require significant maintenance which is difficult to organise in regions with low seismic activity such as Belgium. However, the ROB could benefit from the rise of social media to organise volunteering.

The design of the questionnaire should be significantly modified in comparison with all previous versions. With web-based surveys, an **adaptive questionnaire** can be developed that is based on previously provided answers. It is, for example, irrelevant to request information on the observed damage or how often people lost their balance, when the previous response was that most people were not aware of the occurrence of an earthquake. Before the start of the questionnaire, an initial question could be provided that aims to roughly estimate the intensity. This could, for example, be based on **thumbnail pictures** (Bossu et al. 2017; Sira 2018). Based on the thumbnail response, a questionnaire and a set of guidelines could be automatically provided that is most suited to clarify the intensity estimate. In this case, the respondents are not overwhelmed with unnecessary information or irrelevant questions.

The questions should not only ask if certain earthquake effects occurred but also quantify their frequency. A proposed design is outlined in **Table 17**, **Table 18** and **Table 19**, ensuring the collection of detailed quantitative data. The categories **'few'**, **'many'** and **'most'** align with the EMS-98 quantitative terms, with the original ranges by Grünthal (1998; SI 10.1.4) simplified to **<10%**, **≤ 50%** and **>50%**. Additionally, the **'very few'** category has been introduced to distinguish sporadic reports from more commonly observed effects. The distinction between **'N/A'** (not applicable) and **'none'** clarifies whether an observation was impossible to make or simply did not occur. For instance, if an earthquake happened during the day and none of the interviewed individuals were asleep, 'N/A' should be selected. If some were asleep but none were awakened by the tremors, however, the appropriate response is 'none'.

***Table 17 :*** *Proposed design of a new communal questionnaire for the questions related to the perception and experience of an earthquake.*

| **How many people** | **N/A** | **none** | **very few (<1%)** | **few (<10%)** | **many (≤50%)** | **most (>50%)** |
|---|---|---|---|---|---|---|
| felt the earthquake inside? | | | | | | |
| felt the earthquake outside? | | | | | | |
| were awakened? | | | | | | |
| ran outdoors frightened? | | | | | | |
| lost their balance? | | | | | | |

***Table 18 :*** *Proposed design of a new communal questionnaire for the questions related to the experienced ground shaking of an earthquake.*

| **People described their experience as** | **N/A** | **none** | **very few (<1%)** | **few (<10%)** | **many (≤50%)** | **most (>50%)** |
|---|---|---|---|---|---|---|
| a light trembling or swaying | | | | | | |
| a moderate vibration | | | | | | |
| strong shaking or rocking of the whole building | | | | | | |

***Table 19 :*** *Proposed design of a new communal questionnaire for the questions related to the effects on objects.*

| **Effects on objects** | | **N/A** | **none** | **very few (<1%)** | **few (<10%)** | **many (≤50%)** | **most (>50%)** |
|---|---|---|---|---|---|---|---|
| **hanging objects** *lamps, chandeliers, pictures, plants, etc.* | swing slightly | | | | | | |
| | swing moderately | | | | | | |
| | swing considerably | | | | | | |
| **Small objects** *kitchenware, small ornaments* | rattle / clatter together | | | | | | |
| | topple over or fall | | | | | | |
| **Heavy objects** | topple over or fall | | | | | | |
| **windows and doors** | rattle | | | | | | |
| | swing open or shut | | | | | | |
| | windowpanes break | | | | | | |
| **furniture** | shakes visibly | | | | | | |
| | shifts | | | | | | |
| | overturns | | | | | | |

Providing accurate quantitative data on earthquake damage through a questionnaire is challenging, as it requires assessing both the vulnerability of buildings in a locality and quantifying the degree of damage sustained by each vulnerability class. Expecting respondents to classify buildings by vulnerability and assign damage levels accordingly, however, is impractical.

Apart from masonry buildings, the EMS-98 guidelines also include a description of the damage degrees in reinforced concrete buildings (SI 10.1.4). Applying these damage descriptions, however, might require observations from people with a more technical or engineering background, which might not be present in all municipalities. This would contribute to the uncertainty when computing the communal intensity values and should be mentioned on the forms. No standardized damage degrees are available for other types of constructions, such as steel and timber, but these are likely to be included in an update of the EMS-98 (Wald et al. 2024). If this detailed information is needed for all types of buildings, expert-led macroseismic field surveys would be the appropriate approach.

The more feasible method in Belgium is to request quantitative damage data exclusively for masonry buildings (**Table 20**). Masonry structures are the predominant construction type in Belgium, found even in the smallest towns and hamlets. By focusing only on masonry buildings, respondents are spared from complex assessments of structural damage across different building types, while still providing a clear overview of overall damage within a locality. Additionally, open-ended questions could be included to document observations of damage to other types of buildings.

***Table 20*** *: Proposed design of a new communal questionnaire for the questions related to damage to masonry buildings. The descriptions of the different damage grades are from the EMS-98 guidelines (Grünthal 1998; SI 10.1.4).*

| **Damage to masonry buildings** | **N/A** | **none** | **very few (<1%)** | **few (<10%)** | **many (≤50%)** | **most (>50%)** |
|---|---|---|---|---|---|---|
| **Grade 1**: small cracks in very few walls, small pieces of plaster fall | | | | | | |
| **Grade 2**: cracks in many walls, fall of fairly large pieces of plaster, partial collapse of chimneys | | | | | | |
| **Grade 3**: large, extensive cracks in most walls, roof tiles detach, chimneys fracture at the roof line, failure of individual non-structural elements | | | | | | |
| **Grade 4**: Serious failure of walls, partial structural failure of roofs and floors | | | | | | |
| **Grade 5**: Total or near total collapse | | | | | | |

## 4.6. Chapter conclusions

The macroseismic intensity value assigned to each intensity datapoint in the BTM and BOM database is only as reliable as the applied survey methodology to collect and process the data. Both traditional survey procedures and the “DYFI?” online inquiry allow for many uncertainties in the evaluation of the macroseismic data.

For traditional survey procedures, uncertainty levels have been assigned based on the available quantity of macroseismic observation and the representativeness of the provided data, ranging from bad to fair. The manual evaluation of the data collected through traditional surveys also introduced the risk of subjective bias in influencing the assessment of the intensity values. The semi-automatic “DYFI?” inquiry provides many benefits, but the quality of the data remains questionable, as the calculation procedure is based on an empirical correlation for a very limited number of earthquakes in a very constrained geographical area.

The generally low quality of Belgian macroseismic data is further evidenced by a large discrepancy between the results of the traditional and online datasets for the only event for which both procedures were applied simultaneously. As macroseismic intensity is based on the experiences and observations made by individuals, which on turn have to be communicated to and interpreted by other individuals or an automated script, the associated low quality to this data is not surprising. Macroseismic intensity data is, inherently, a subjective parameter. Even though the more modern macroseismic intensity scales have made significant efforts to increase the quality and reliability of macroseismic intensity data (e.g. the European macroseismic scale of 98 by Grünthal 1998 or the international macroseismic scale by Wald et al. 2024), the data received through macroseismic surveys will always only provide a certain aspect of the impact of an earthquake to a certain community. Only when extensive field surveys are conducted, and macroseismic observations can be considered complete and of high quality, one can safely assume a high reliability of the data.

Nevertheless, there remains significant potential to improve the quality of macroseismic data in future surveys. By requesting more detailed information during the data collection phase, substantial improvements can be made. Several such recommendations have been discussed in this chapter and are encouraged for application in future Belgian surveys. For example, the continued use of traditional communal macroseismic surveys in Belgium through the implementation of a newly proposed questionnaire. These communal surveys would also generate parallel datasets to the online procedure, allowing for better constraint of the strengths and weaknesses of each approach and ultimately improving data quality for future events.

Despite the limitations and high uncertainty associated with Belgian macroseismic data, the BTM and BOM databases remain invaluable for engineering seismology applications. In many cases, they represent the only available sources of information and still offer a detailed picture of earthquake impacts in Belgium, even if those data come with considerable uncertainties.

# 5. The seismic impact on Belgium since the 20th century

## 5.1. The BTM database

The BTM database summarizes the full impact of seismic activity on Belgium over the course of a century. The BTM catalogue contains 80 felt events that occurred from 1908 to 2002, with magnitudes ranging from $M_L$ = 2.4 (Okegem-Ninove 1992) to $M_S$ = 5.5 (Dogger Bank 1931). The latter had only a limited impact in Belgium with a maximum intensity of 4-5 because of the large distance between its epicentre and Belgium (~300 km). The earthquakes with the largest impact on the country were the $M_S$ = 5.0 Zulzeke-Nukerke 1938, $M_S$ = 4.6 Liège 1983 and $M_S$ = 5.4 Roermond 1992 earthquakes. Most events in the BTM catalogue can be assigned to one of the following four source zones (**Figure 34**): 1) the Roer Valley Graben (RVG) in the border region between the Netherlands and Germany, 2) the Hainaut and Liège coal basins, 3) the Eastern Ardennes in the east and 4) the Palaeozoic Anglo-Brabant massif (ABM).

With 37 felt events, the Hainaut coal basin experienced the most frequent seismic activity in Belgium in the 20th century. Intensive coal mining activity in the region is demonstrated to have triggered these events (Camelbeeck et al. 2022, 2025; Vanneste et al. 2024) and the activity in the region is characterised by low-to-moderate magnitudes ($M_W \leq 4.1$) and shallow focal depths (<6 km). Their shallowness, in combination with strong absorption in the upper crust, results in the fast attenuation of the ground motion with distance. These events were thus only slightly felt outside of the Hainaut coal basin. Within the boundaries of the basin, however, intensities of up to 7 have been reported for five separate events and thousands of buildings were damaged within a very confined and densely populated area. Camelbeeck et al. (2022) provide a detailed description of the Hainaut seismicity and its impact. Similar, but less frequent, low-to-moderate, shallow seismicity is observed in the Liège coal basin, with only four events in the BTM catalogue. Nonetheless, the seismic impact of the region is significant, as the $M_L$ = 5.0 Liège 1983 earthquake was one of the most damaging events in Belgium in the 20th century. The Liège coal basin is part of the Liège-Gulpen seismotectonic zone, following the model of Verbeeck et al. (2009). Designating the events in the Liège coal basin as mining-triggered is much more ambiguous because of its proximity to the active seismic regions of the Roer Valley Graben and the Eastern Ardennes. Thirteen events took place in the Eastern Ardennes with magnitudes up to $M_L$ = 4.5. With a maximum intensity of only 5, these events had a relatively low impact on the Belgian population in the 20th century.

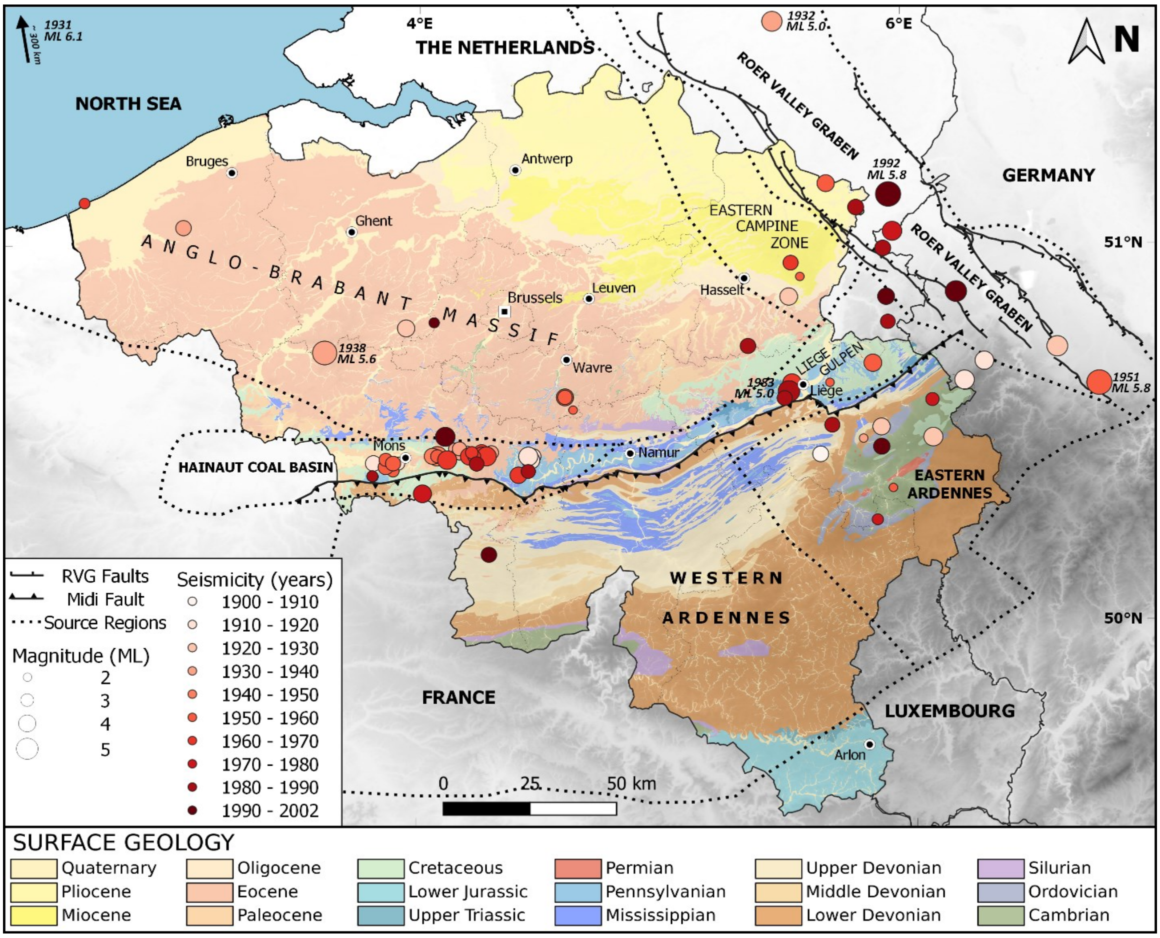



***Figure 34.*** *Overview of felt events in the BTM catalogue. The main active seismic regions in Belgium in the 20th century are 1) the Roer Valley Graben, which spans the border region of Belgium, the Netherlands and Germany and is indicated by the main graben faults 2) the Hainaut coal basin, 3) the Eastern Ardennes and 4) the Anglo-Brabant massif.*

The earthquake with the largest impact on Belgium during the 20th century was unmistakably the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake, inflicting damage to large parts of the country and with a maximum intensity of 7. This event had its epicentre in the Anglo-Brabant massif. In total, ten earthquakes in the BTM catalogue are attributed to the ABM, with only the 1938 event strong enough to cause significant damage. Earthquakes with larger magnitudes, up to $M_L$ = 5.8, occurred in the Roer Valley Graben. Out of the 11 felt events in the graben that are included in the BTM catalogue, only two had their epicentre in Belgium, on the border with the Netherlands. The impact of RVG earthquakes on Belgium in the 20th century was relatively limited to a maximum intensity of 6, but intensity 7 values have been reported just across the border ($M_L$ = 5.8 Roermond 1992; Haak et al. 1994). Only five events in the BTM catalogue are not attributed to one of the four main source zones. One had its epicentre at a large distance from Belgium (i.e. $M_S$ = 5.5 Dogger Bank 1931), another took place in the Western Ardennes, which rarely experiences seismicity, and three others are located just north of Liège and west of the RVG in the Eastern Campine zone. This zone acts as a transition zone between the RVG and the ABM. Vanneste et al. (2017) slightly modified the seismotectonic zonation model of Verbeeck et al. (2009) by expanding the Roer Valley Graben to a Background Roer Valley Rift System zone that includes the Eastern Campine zone and the eastern part of the Liège-Gulpen zone or the Gulpen zone.

With the recently demonstrated triggered nature of the seismicity in the Hainaut coal basin (Camelbeeck et al. 2025) and the highly suspected triggered seismicity in the Liège coal basin, industrial coal mining activities significantly contributed to the seismic impact on Belgium in the 20th century. The third coal basin in Belgium that has seen extensive coal mining exploitation, has not been associated with triggered seismicity. The three earthquakes that took place within the seismotectonic Eastern Campine zone, however, are closely located to the coal mining sites. These are the $M_L$ = 4.1 Bilzen 1925, the Zutendaal 1954 (no known magnitude) and $M_L$ = 3.5 Genk-As 1963 earthquakes. With a maximum intensity of 5-6 and magnitude of $M_L$ = 4.1, the impact on the area is much smaller than that caused by larger events that occurred in the nearby Roer Valley Graben. As very little is known about these events (no focal depths are available for any of the three events) and the proximity to the active system of the Roer Valley Graben, the suggestion that these events could be triggered by coal mining activities is purely speculative.

The maximum observed intensity in Belgium for each locality in the BTM intensity dataset is provided in **Figure 35**. This representation includes some more remote or isolated localities such as hamlets, abbeys, old castles or even hunter's cabins. For such localities, there is often only a single IDP available, and consequently its maximum intensity is highly likely to be underreported. Mergers between municipalities occurred on multiple occasions throughout the time span of the BTM catalogue and affected the spatial resolution of the ROB questionnaires. For simplicity, the content of the BTM database is only presented at the sub-municipal scale and the main municipal scale (§2.4). The maximum observed intensities in the BTM database are presented in **Figure 36** and **Figure 37**, for the sub-municipal scale and main municipal scale, respectively. Note that for all these visualisations of the maximum observed intensity, the true maximum experienced intensity may be higher than presented. for most events, certain localities lacked macroseismic information, preventing the attribution of intensity values. As the main municipal scale almost always encompasses multiple sub-municipalities (4.3 sub-municipalities on average), this chance is much higher for the individual IDPs and sub-municipal scale than it is for the main municipal scale. This is also clearly evidenced by the numerous lower intensity values on **Figure 35** and **Figure 36** that are surrounded by much higher intensity values. While the main municipal scale is much less likely to underestimate the maximum experienced intensity within the main municipality and consequently reducing the heterogeneity of the map, it also significantly overestimates the total area over which these maximum intensities have been observed. As most of the sub-municipalities were abolished in the 1960s and 1970s, they often also lack data for more recent events, increasing the chance that the sub-municipal scale misrepresents the actual maximum experienced intensity.

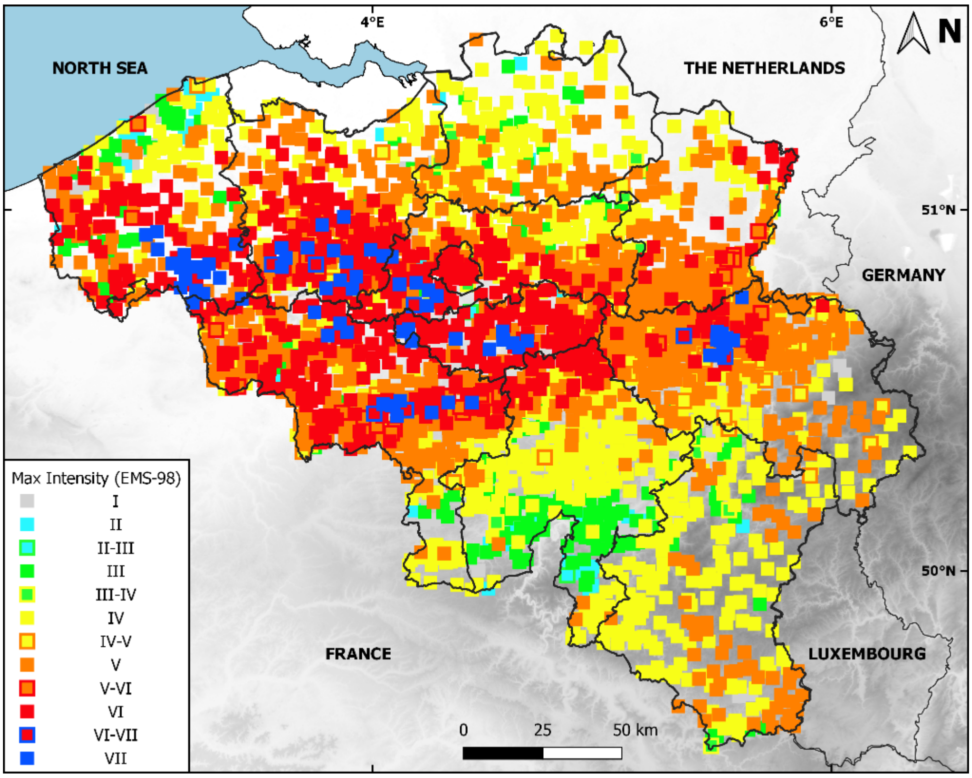



***Figure 35.*** *Maximum observed intensity in the BTM database for each locality.*

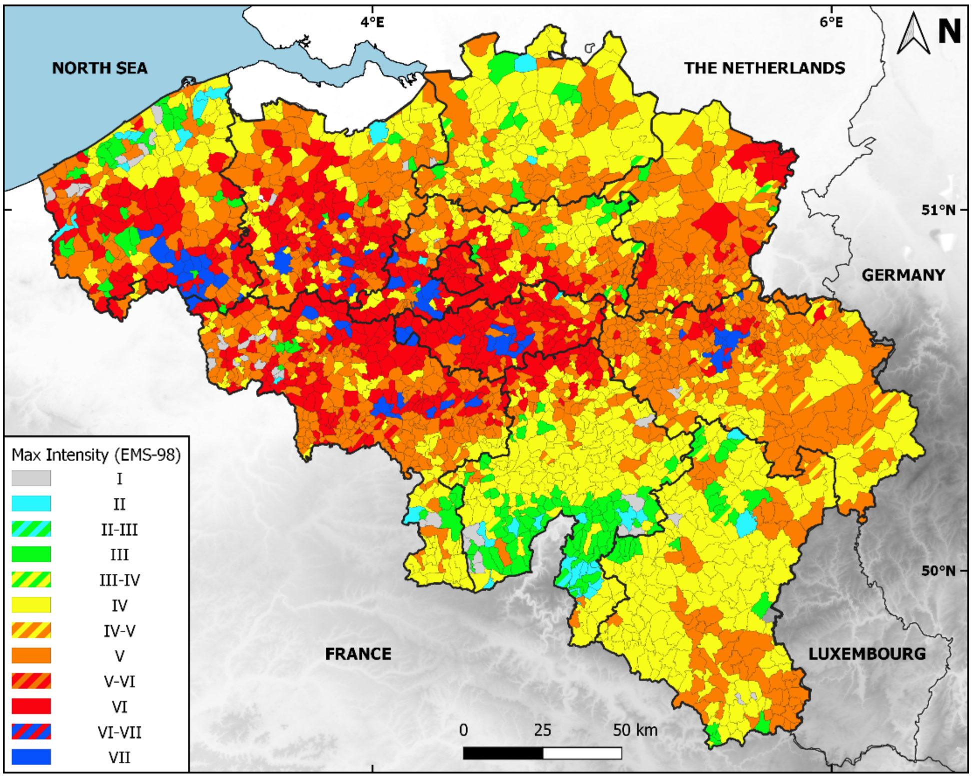



***Figure 36.*** *Maximum observed intensity in the BTM database on the sub-municipal scale.*

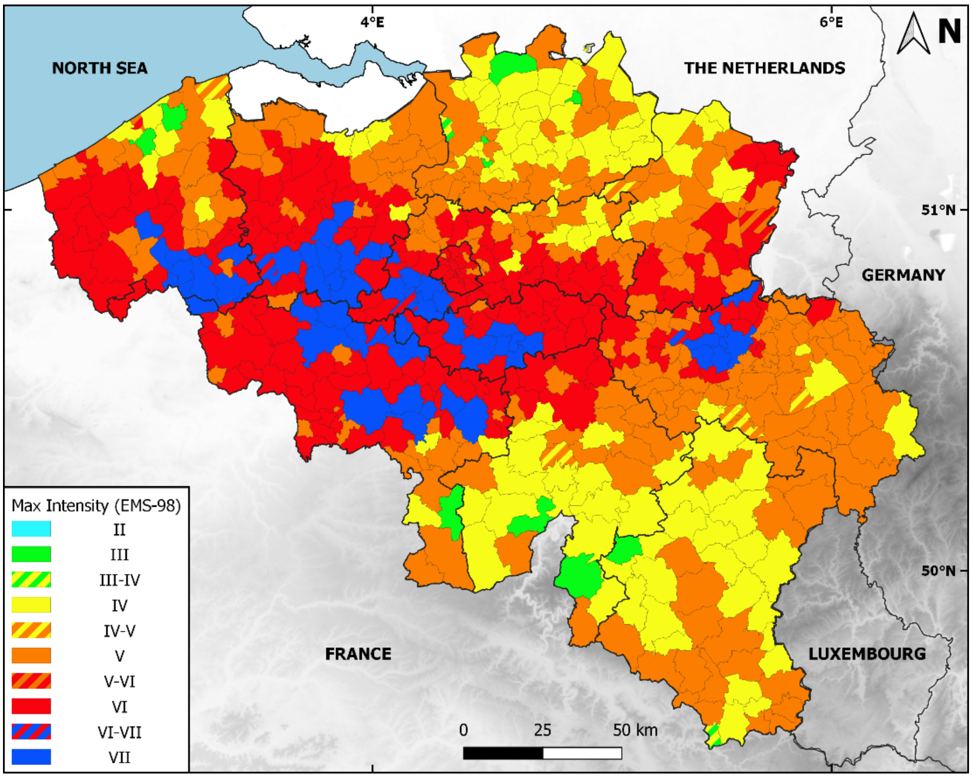



***Figure 37.*** *Maximum observed intensity in the BTM database on the main municipal scale.*

The IDPs with a maximum intensity of 7 in Belgium are concentrated in the Hainaut coal basin, around the Liège coal basin and on the southern edge of the Anglo-Brabant massif from the west to the centre of the country. These highest intensities are the result of only a few larger earthquakes. In **Figure 38**, the source regions responsible for the maximum intensity on the main municipality scale are shown. Only three events account for 73% of all main municipalities, with the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake having the largest impact in western and central Belgium and the $M_L$ = 5.8 Roermond 1992 earthquake dominating the eastern part. The $M_L$ = 5.0 Liège 1983 earthquake had a smaller but still prominent impact on the city of Liège and its surroundings. The impact radius of the Hainaut coal basin events is small, even though multiple events reach the maximum intensity 7. The Eastern Ardennes events had only a limited impact on Belgium in the 20th century.

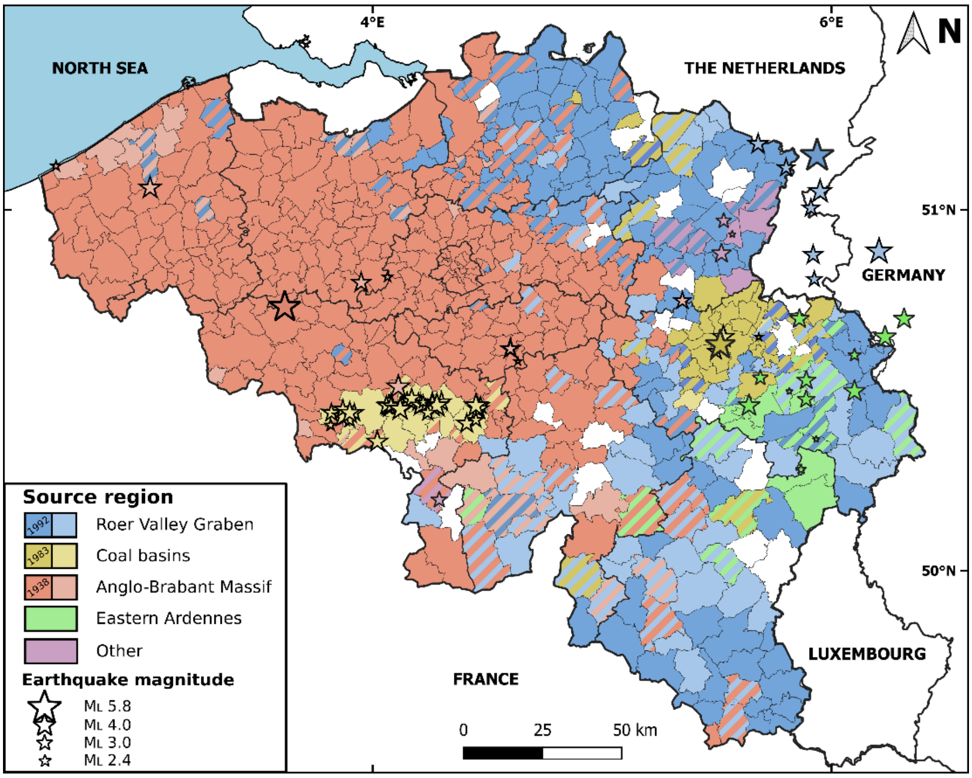



***Figure 38.*** *Source regions of the maximum observed intensity in each municipality. The maximum observed intensities of the three most impactful earthquakes are highlighted in slightly darker colours than those inflicted by other events within the source region. These events include the $M_L$=5.8 Roermond 1992 earthquake (RVG, blue), the $M_L$=5.0 Liège 1983 earthquake (shallow seismicity in coal basins, yellow) and the $M_L$=5.6 Zulzeke-Nukerke 1938 earthquake (Anglo-Brabant massif, red). Shaded areas indicate that two different source regions inflicted the maximum observed intensity. Municipalities in white indicate that earthquakes from three or more source regions inflicted the maximum observed intensity.*

As the maximum observed intensities in Belgium are dominated by just a few events, **Figure 39** displays the number of earthquakes for which I ≥ 5 has been reported for the Belgian municipalities. This representation is interesting as it shows the cumulative impact on a region due to recurrent seismicity. The municipalities La Louvière and Morlanwelz-Mariemont (east of the city of Mons) in the Hainaut coal basin were impacted most frequently, with 13 and 17 earthquakes with I ≥ 5, respectively. More broadly, an east-west oriented belt of more numerous occurrences of I ≥ 5 extends across the centre of the country, from the Hainaut coal basin to the Dutch German border region. Maps of maximum intensity and number of occurrences of a given intensity level can be used to study the influence of surface geology on earthquake ground motion (site amplification) and to check the validity of probabilistic seismic hazard maps (e.g. Salditch et al. 2020).

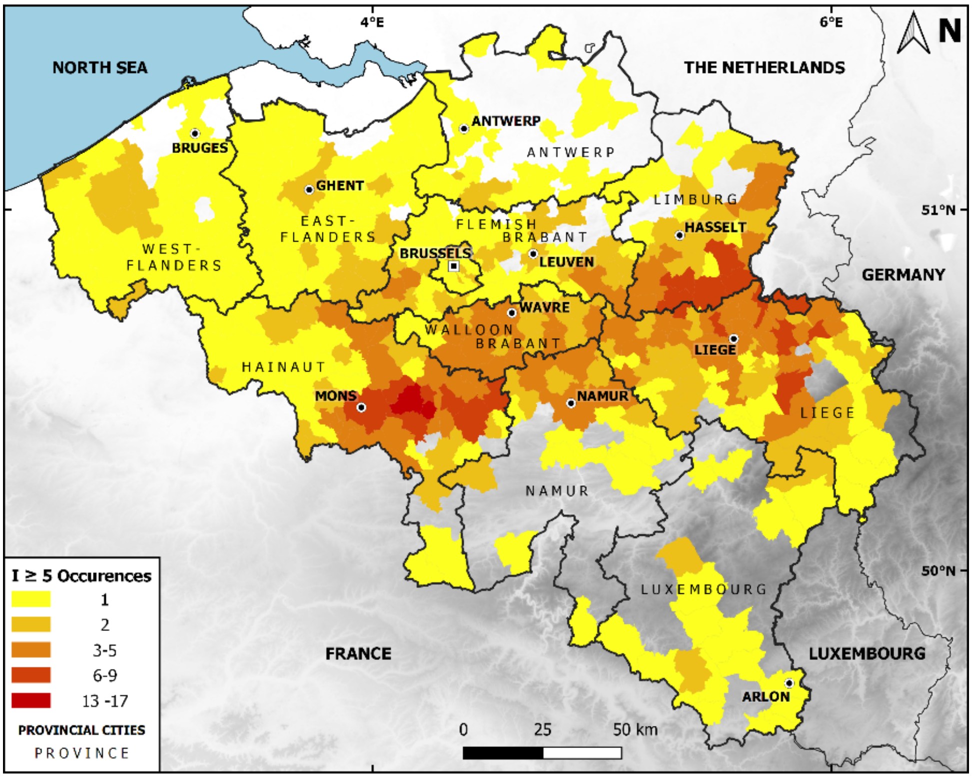



***Figure 39.*** *Number of occurrences of intensity 5 or higher in the main Belgian municipalities.*

## 5.2. The BOM database

In a similar manner to how the BTM database summarizes the impact of seismic activity on Belgium in the 20th century, the BOM database summarizes its impact on Belgium in the first quarter of the 21st century. The BOM earthquake catalogue consists of 39 felt events that occurred from 2002 to 2022, with magnitudes ranging from $M_L = 0.7$ to $M_L = 4.9$. The 2008–2010 Walloon-Brabant seismic swarm accounts for 30 events, making it the dominant feature of the catalogue. The three largest events in the catalogue all occurred outside the Belgian borders, however, namely the $M_L = 4.9$ Eschweiler-Alsdorf 2002 (which is also included in the BTM database), the $M_L = 4.3$ Goch 2011 and the $M_L = 4.1$ Ramsgate 2015 earthquakes. The online macroseismic data and the seismic impact of the last two have been studied in detail by Van Noten et al. (2017). The largest earthquake to occur on Belgian territory during the first quarter of the 21st century is the $M_L = 3.2$ Court-Saint-Etienne 2008 earthquake. The felt seismicity in the BOM earthquake catalogue is displayed in **Figure 40**.

With a maximum intensity in the BOM intensity dataset of 4-5, the seismic impact was very limited. The maximum intensity for each main municipality provided by the BOM database is given in **Figure 41**. Not only is the maximum intensity low, but most regions in Belgium did not even exceed intensity 3. Comparing the maximum intensities of the BOM database with those of the BTM database on the main municipal scale, not a single municipality has exceeded the intensity that is had experienced in the 20th century. These low intensities, however, could potentially be biased by the "DYFI?" procedure and its inability to effectively distinguish between low intensity values (§4.4). The lack of macroseismic data in the southern regions of Belgium is mainly caused by its low population density, which has resulted in significantly less submission for these municipalities through the "DYFI?" inquiry.

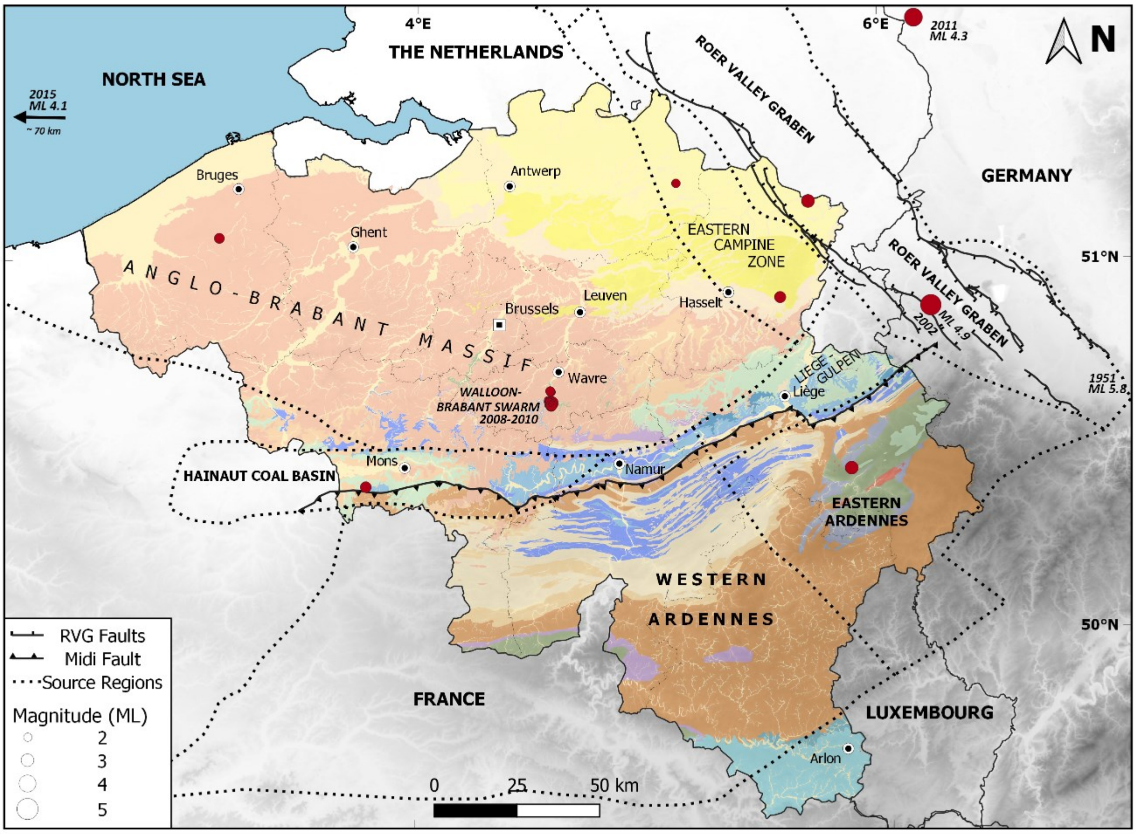



***Figure 40.*** *Overview of felt events in Belgium in the BOM database during the first quarter of the 21st century.*

Most notably, is the decrease in seismic activity in the 21st century in comparison to the 20th century. While a felt earthquake occurred, on average, every 3 years in the basin during the 20th century, only a single one was perceived in the last ~25 years, i.e. the $M_L$ = 3.4 Dour 2008 earthquake. This is a continuation of a trend that started around the 1970s, coinciding with the stop of mining operations in the area. For Belgium as a whole, the timespan covered by the BOM database is not nearly sufficient to provide insights in the long-term seismicity of Belgium. The limited activity recorded does not mean that seismic activity throughout Belgium shows a decreasing trend. On average, an earthquake with magnitude 4 or greater occurs every 3-6 years in Belgium and surrounding areas, while an earthquake of magnitude 5 or greater occurs every 30-50 years (e.g. Camelbeeck et al. 2007; Vanneste et al. 2009). While the number of magnitude 4 earthquakes included in the BOM database is certainly less than what would occur on average, it is not indicative of a major change in the seismicity. Especially considering the BOM database does only include earthquakes with more than 50 submissions to the "DYFI?" inquiry, which has excluded events such as the $M_L$ = 5.4 Rambervillers 2003 and $M_L$ = 4.3 Folkestone 2007 earthquakes in France and the United Kingdom, respectively.

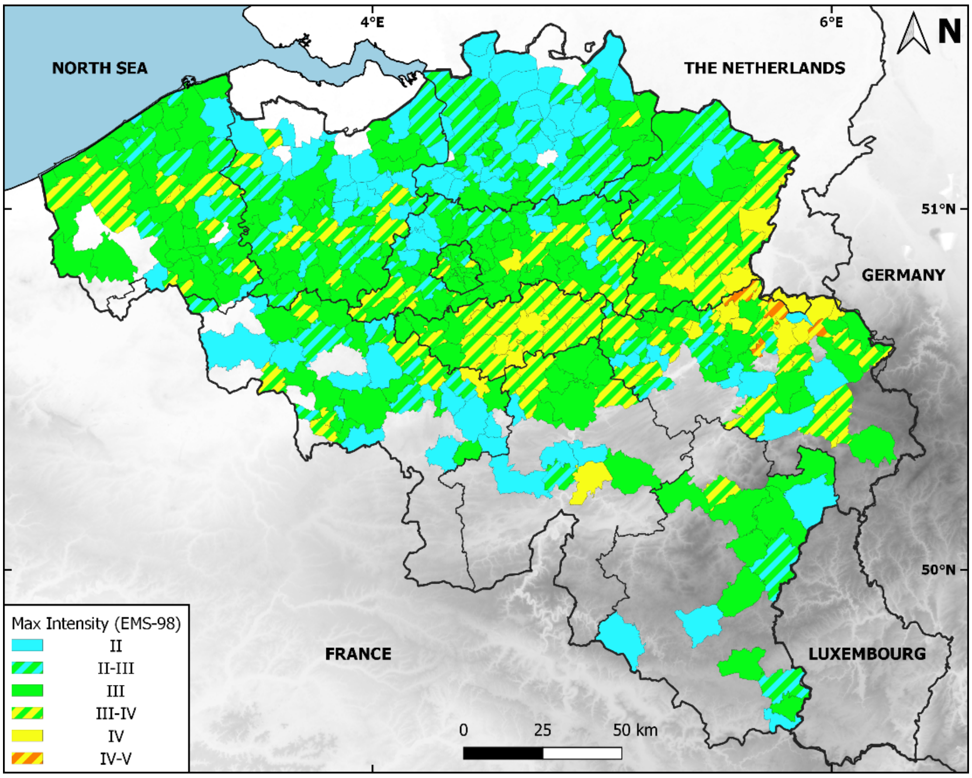



***Figure 41.*** *Maximum observed intensity in the BTM database on the sub-municipal scale.*

## 5.3. Belgian seismic hazard

### 5.3.1. Introduction and seismic hazard assessment uncertainties

National seismic hazard maps, such as the Belgian seismic hazard map in **Figure 42**, play a crucial role in the determination of the design codes of structures in seismic regions. Higher seismic hazard levels indicate a greater likelihood of stronger ground motions, necessitating more robust building designs. In Belgium, design codes for constructions are formulated by the European standard EN 1998-1, also referred to as Eurocode 8 (EC8; CEN 2004), along with its national annex (Bureau de Normalisation 2011). This standard is the only regulation addressing seismic hazard in Belgium, except for specific rules governing nuclear installations. EC8 provides guidelines to ensure new constructions minimize risks to human life and economic losses. Its design principles rely heavily on seismic hazard maps with a 475-year return period, meaning there is a 10% probability of exceeding the predicted ground motion values within 50 years, i.e. the typical lifespan of buildings and infrastructure. These hazard maps, in turn, are derived from historical earthquake records, selected seismic source models, and ground motion attenuation models, each of which carries inherent uncertainties.

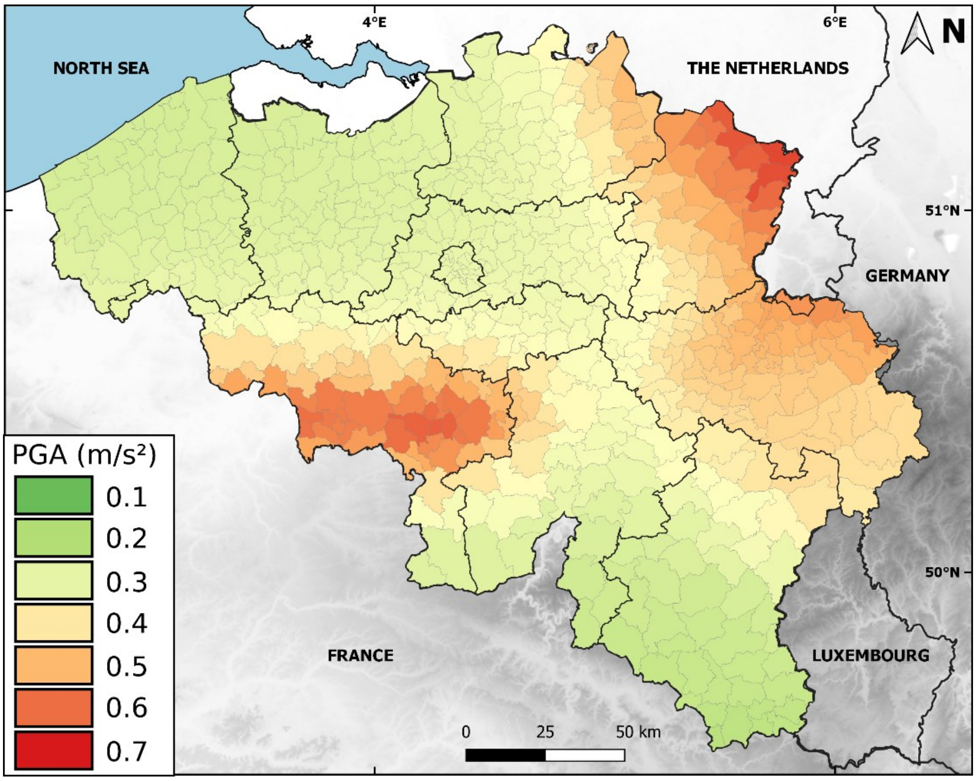



***Figure 42.*** *Mean seismic hazard map with a 475-year return period in peak ground acceleration (PGA) for standard rock conditions ($V_{S30}$ ~800m/s). Each municipality has a 10% probability of exceeding the PGA depicted in 50 years. Data provided by Kris Vanneste et al. (2017).*

The earthquake record for Belgium, based on both instrumental and historical data (~1,000 years), is too short to capture the recurrence intervals of large events, which can span tens of thousands of years. Palaeoseismic investigations in northeastern Belgium have provided evidence of surface-rupturing earthquakes during the Holocene and late Pleistocene, with magnitudes reaching up to $M_W$ = 7.0 (Camelbeeck and Meghraoui 1998; Vanneste et al. 1999, 2001; Camelbeeck et al. 2007, 2014). Additionally, there are significant uncertainties in determining the hypocentral location and magnitude of historical earthquakes.

The seismic source models used in the most recent Belgian hazard map (Vanneste et al. 2017; **Figure 42**) are adaptations of the seismotectonic zonation model by Verbeeck et al. (2009), with minor modifications to the two-zone model. This two-zone model (Verbeeck et al. 2009) differentiates between the Roer Valley Graben (zone 1), where fault activity is ongoing and relatively continuous, and the surrounding area (zone 2), where seismic activity is more diffuse and can occur anywhere. Zone 2 is a single, large region covering most of Belgium. Given the limited earthquake record and the small number of known active faults, the model simplifies seismicity as homogeneously diffuse within each zone. The ground motion attenuation models used in the Belgian seismic hazard map rely on accelerometric data from other regions, which may not be well suited to Belgium's geological and seismological context. This limitation has recently been illustrated for the Hainaut coal basin Camelbeeck et al. (2022) and Vanneste et al. (2024).

Seismic hazard maps provide the probabilistic hazard at bedrock level. They do not take into account local site effects, caused by the sediments overlaying the bedrock. These sediments can significantly amplify ground motion and the experienced shaking, leading to areas with increased damage in comparison to other regions located on bedrock sites. Several studies have shown that local site effects considerably increased sustained losses during past events in Belgium. Nguyen (2004) illustrated that the thickness of the sedimentary cover overlaying the Anglo-Brabant massif could be correlated to the damage distribution of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake. Where the thickness of the sedimentary cover is larger, the seismic wave energy in the high-frequency range (~3-10 Hz) is attenuated more strongly before reaching the surface. Low-rise buildings, which are mainly impacted by higher frequencies, endured less damage at localities with larger sedimentary cover thicknesses (50 m and more; Nguyen et al. 2004; Camelbeeck et al. 2014). Larger buildings, such as churches and castles, are affected by lower frequencies (~1 Hz). These lower frequencies, which are only produced by larger earthquakes (M > ~5.5), have been less modified in their propagation through poorly consolidated sedimentary covers. Churches and other buildings have been observed to sustain significant damage at localities where low-rise buildings where less or barely impacted (Meidow and Ahorner; Camelbeeck et al. 2014). Case studies have also shown the impact of local site effects on the distribution of damage in Belgium, such as the observed damage in the city of Ath, which experienced a higher density of observed damage in certain areas during the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake (Rosset et al. 2007; Barszez 2007).

### 5.3.2. Seismic hazard evaluation

Seismic hazard models include multiple uncertainties that could lead into a deviation of the predicted ground motion from its true values. This renders the question of how accurate the predicted values provided in **Figure 42** truly are. In contrast, macroseismic data provides a detailed summary on the observed seismic impact at the surface. Within macroseismic data, amplification effects are already incorporated, no attenuation models are required to interpolate to regions with no available data and the data is not affected by possible large uncertainties in the determination of the hypocentral parameters of historical events, which are readily incorporated in the seismic hazard prediction model.

The BOM database does not include any IDPs for which the maximum observed intensity exceeds the maximum observed intensity in the BTM database for a single Belgian main municipality. As a result, the maximum observed intensity on the main municipal scale of the BTM database, i.e. **Figure 37**, can be used as the maximum observed intensity for both databases. To compare maximum intensities with the predicted seismic hazard peak ground acceleration (PGA) values in m/s² from **Figure 42**, the data first needs to be converted with a ground-motion-to-intensity conversion equation (GMICE). GMICE are empirical models that correlate instrumentally-measured ground motion parameters with the attributed macroseismic intensity at the same locality through various regression techniques. Multiple GMICE have been developed based on the available data in specific regions and are available in literature, with each their respective regional seismicity and intensity attribution procedures. As there are no GMICE designed for Belgium, a model developed for another region must be chosen. Vanneste et al. (2024) recently compared multiple GMICE with Belgian macroseismic data in the Hainaut region and concluded that the GMICE from Atkinson and Kaka (2007), developed for the central United States, provided the best results. Consequently, this GMICE will also be used here to convert the predicted PGA values from the seismic hazard map to macroseismic intensity values. The GMICE of Atkinson and Kaka (2007) is characterized by equations:

$$Intensity = 2.65 + 1.39 * \log_{10} PGA \qquad (\log_{10} PGA \leq 1.69) \tag{4}$$

$$Intensity = -1.91 + 4.09 * \log_{10} PGA \qquad (\log_{10} PGA \geq 1.69) \tag{5}$$

with PGA values in cm/s², a standard deviation of 1.01 intensity units and intensity defined on the Modified Mercalli scale. As explained earlier, differences between the intensities attributed by different experts on the same scale are greater than the differences between intensities attributed on different macroseismic scales of the 12-degree Cancani family (e.g. EMS-98 and MM-93) by the same expert (Musson et al. 2010). Therefore, the assumption is made that equations (4) and (5) are identical for intensities defined on the EMS-98. This empirical relationship between intensity and PGA is illustrated in **Figure 43**.

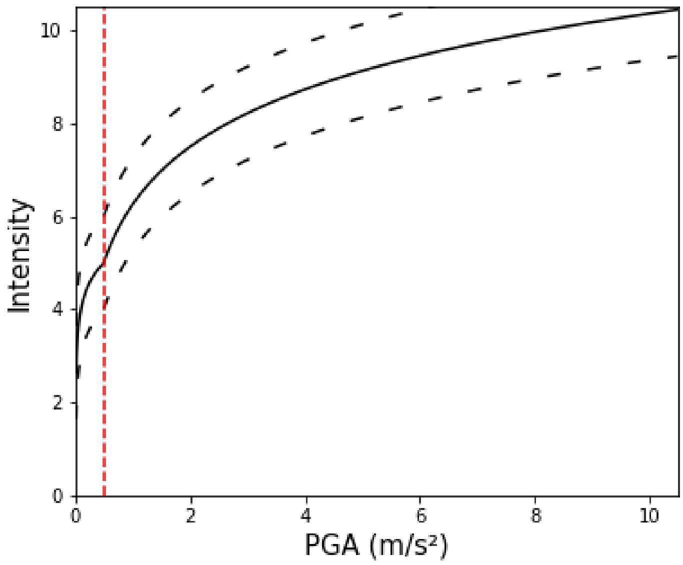



***Figure 43.*** *Empirical relationships between instrumental peak ground acceleration (PGA) and macroseismic intensity as formulated by Atkinson and Kaka (2007) for the central United States. The black dashed lines illustrate the standard deviation of 1.01 intensity units. The red dashed line indicates log PGA (cm/s²) = 1.69 at intensity = 5.*

With the aid of GMICE, macroseismic intensity values can thus be converted into ground motion parameters such as peak ground acceleration. **Figure 44** provides a maximum PGA map for Belgium converted from the maximum observed intensities in the BTM and BOM database on the sub-municipal scale. These converted values can be interpreted as the maximum observed PGA over a 125-year period across Belgium. It is, however, important to note that the converted PGA values are based on an empirical equation, and the actual ground accelerations experienced may differ substantially from those shown in **Figure 44**.

The maximum converted PGA values in Belgium during this 125-year period do not exceed 1.5 m/s². Localities with PGA values exceeding 1.0 m/s² are limited and correspond to the intensity 6-7 and 7 values in the BTM database. The majority of these higher values are associated with the impact of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake at incised river valleys (i.e. Dyle, Senne, Scheldt, Dender and Lys rivers) where the distance between the surface and the top of the Anglo-Brabant Massif is reduced (§6.2). PGA values between 0.5 and 1.0 m/s² correspond to intensity 5-6 and 6, most of which are also associated to the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake. The spatial distribution of the PGA values is predominantly determined by the thickness of the sedimentary cover overlying the Anglo-Brabant Massif, increasing from south to north. As the regional geology is a major factor in the distribution of damage in this part of the country, any deep event (i.e. close to or greater than the focal depth of the 1938 earthquake of 19 km) that takes place in the Anglo-Brabant Massif in Belgium in the future with $M_W \geq 5.0$, is likely to result in a similar damage distribution as observed during this Zulzeke-Nukerke event, independent of the location of the epicentre. For more shallow events, the distribution of damage would be limited to the vicinity of the epicentre.

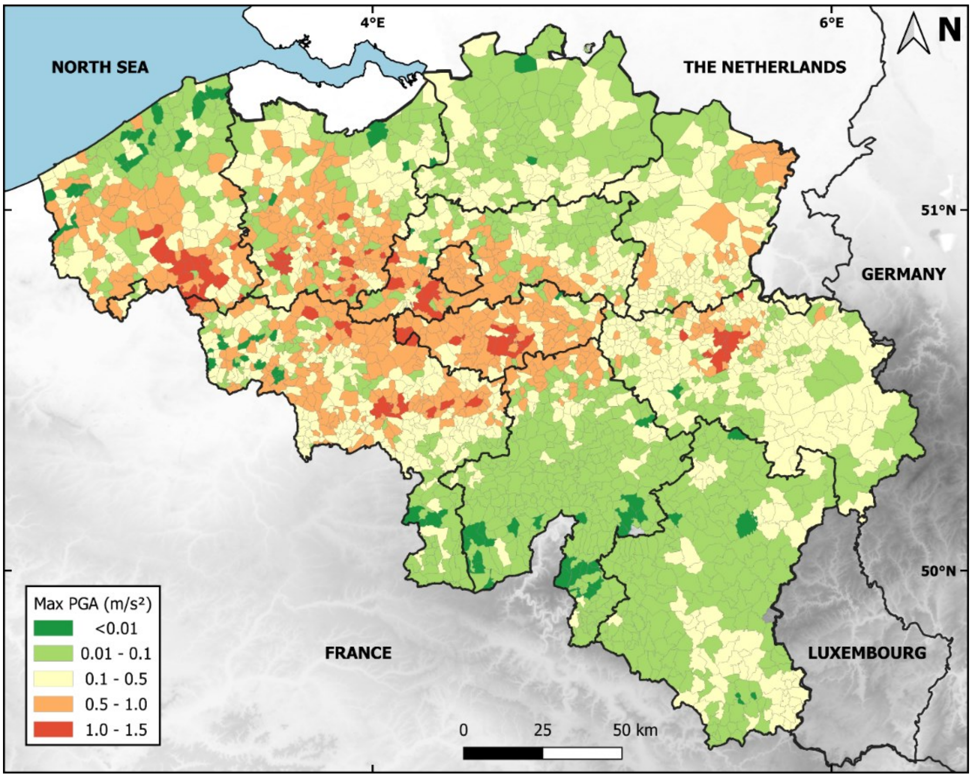



***Figure 44.*** *Maximum peak ground acceleration (PGA) from converted macroseismic intensity values of the BTM database on the sub-municipal scale. Conversion from macroseismic intensity to PGA was done following the GMICE of Atkinson and Kaka (2007).*

A visual comparison between **Figure 44** and **Figure 42** reveals significant discrepancies, both in the spatial distribution of the most severe affected municipalities and in the reported values. Such differences between the observed macroseismic intensity map and the seismic hazard assessment model, however, do not necessarily imply that the hazard model is inadequate. The observed macroseismic intensities are derived from a limited time period (i.e. 125 years) and therefore do not capture the full range of long-term seismicity that the seismic hazard model by Vanneste et al. (2017) aims to represent. As a result, the observed macroseismic intensities reflect localized or rare events (e.g. the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake) rather than the broader statistical behaviour of seismic hazard over extended timeframes. For this reason, it is ill-advised to use maps based on observations from a limited timeframe that does not reflect the long-term seismicity (such as **Figure 36**, **Figure 37** or **Figure 44**) as a means to determine the seismic hazard. Additionally, the observed macroseismic intensity map inherently incorporates site-specific amplification effects due to local geological and soil conditions, which can significantly enhance observed ground shaking. In contrast, the seismic hazard map typically presents values for a reference rock site condition and does not account for such local amplification, which further contributes to the discrepancy between the two representations.

The macroseismic data provided by the BTM and BOM databases can, however, be used to evaluate the coherence with the most recent seismic hazard map (Vanneste et al. 2017; **Figure 42**). The Poisson probability (p) used in seismic hazard maps represents the likelihood that earthquake shaking will exceed a specified level within a given time period (t), based on the assumption that earthquakes occur randomly in time with an average recurrence interval (T). This probability is derived from the

Poisson distribution, assuming that earthquake occurrences are independent events with a constant average rate. It is calculated as:

$$p = 1 - e^{\frac{-t}{T}} \qquad (6)$$

For an observation period t of 50 years and a return period T of 475 years, the probability of exceedance is 10%. The BTM and BOM databases span a combined observation period of 125 years, from 1900 until 2024. Maintaining the return period of 475 years, the probability of exceedance according to equation (6) is 23%. When comparing the observed with the predicted intensities, 23% of the observed values should thus exceed the predicted values of the seismic hazard model. A significant discrepancy between the observations (i.e. the macroseismic data) and the seismic hazard map could suggest that the model and the methods used to create the model are flawed (Geller 2011).

Converting the predicted PGA values from the Belgian seismic hazard model of Vanneste et al. (2017) for the main municipalities with the GMICE of Atkinson and Kaka (2007), results in intensities with a limited range from 4.5 and 5.5. **Figure 45a** provides a comparison of these values with the maximum observed intensities from the BTM database. The maximum observed intensities display a much wider range, from intensity 3 to intensity 7. For an effective seismic hazard model, all data points would be positioned closely to the 1:1 line. This is clearly not the case here, as the predictions of the Belgian seismic hazard model provide both significant underestimations (above the 1:1 line), as well as significant overestimations (below the 1:1 line). According to equation (6), the exceedance rate for an observation period of 125 years and a return period of 475 years, should be ~23%. The exceedance ratio derived from the comparison, however, surpasses this value with a ratio of 73%. This hints to a significant underestimation of the hazard model, or at least for the seismicity experienced during the period from 1900 to 2024.

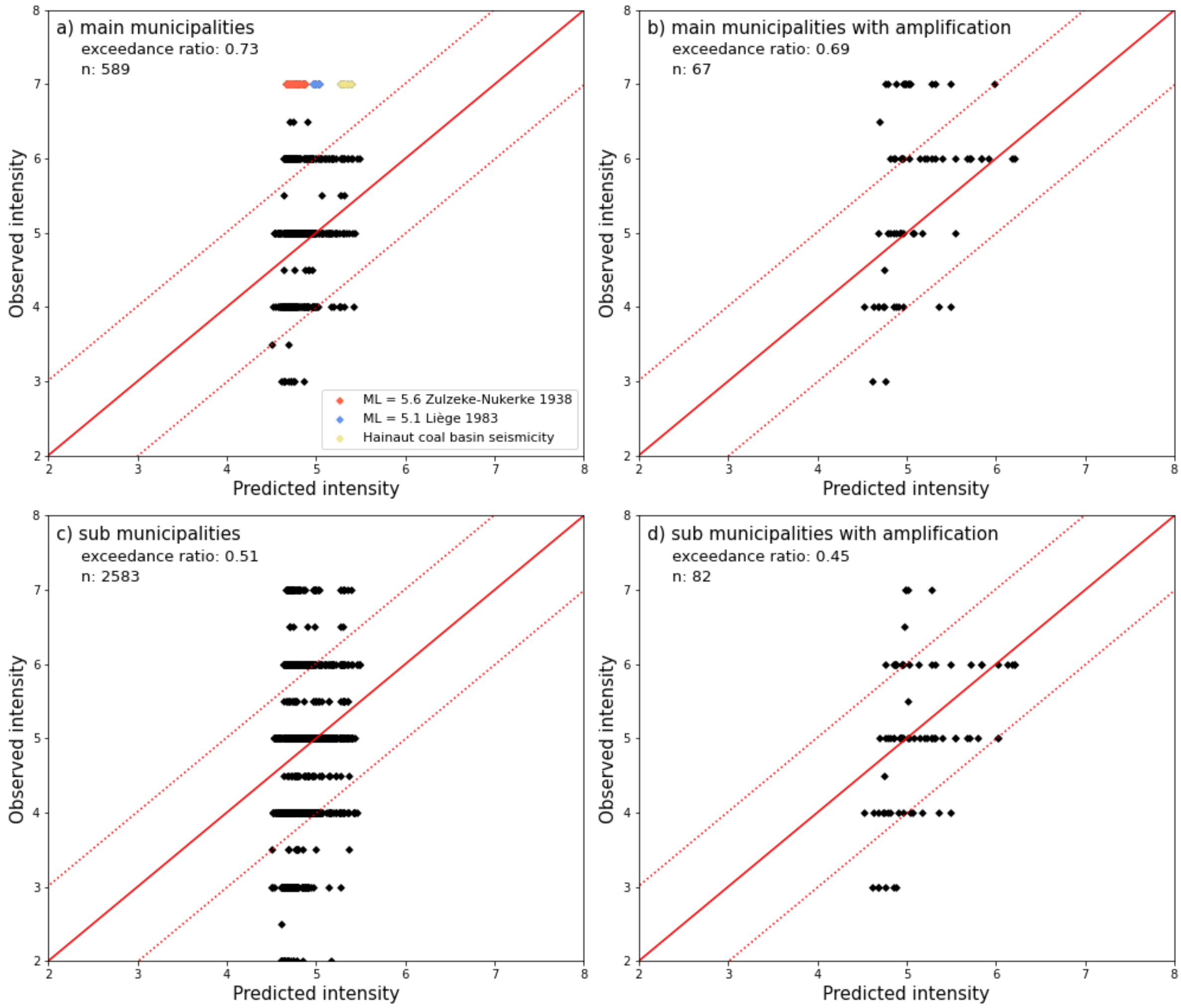



***Figure 45.*** *Comparison between the predicted intensities of the Belgian seismic hazard model and the observed maximum intensity in the BTM and BOM databases. Predicted intensities result from applying the GMICE of Atkinson et al. (2007) to the predicted PGA values of Vanneste et al. (2017) for Belgian municipalities. Dashed red lines indicate the uncertainty of the GMICE. a & c) Comparison between predicted intensities and observed intensities on the main (a) municipal scale and the (c) sub-municipal scale; b-d) predicted intensities accounting for amplification due to site effects and observed intensities on the main (b) and sub-municipal (d) scale.*

Municipalities that experienced an Imax of 7 are shown in **Figure 45a**, based on the earthquakes or regional seismic activity responsible for these values. The Hainaut coal basin seismicity resulted in higher observed intensities than what is predicted by the hazard model (yellow data points in **Figure 45a**). The observation period includes nearly all known seismicity in the Hainaut coal basin. Due to the triggered nature of this seismic activity in response to the extensive coal mining activity from the late 19th century to the late 20th century, as recently demonstrated by Camelbeeck et al. (2025), it does not conform to the time-independence criteria required for the application of Poisson probability distributions. Seismicity in the Hainaut coal basin does not occur randomly over time and could potentially be considered as a (past) transient phenomenon for the publication of future Belgian seismic hazard maps (Vanneste et al. 2024; Camelbeeck et al. 2025). Consequently, this can explain the exceedance of the observed intensities in comparison the predicted intensities for the region.

Larger discrepancies between observed and predicted values, however, are seen for other regions. The observed intensity 7 values of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake are lower than the predicted values for the Anglo-Brabant massif. Although the Belgian earthquake record includes several larger earthquakes that took place within the Anglo-Brabant massif, the corresponding observed intensities plot on the lower end of the intensity range. In the 20th century, the largest events are the damaging $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake and the widely felt but not damaging $M_L$ = 4.5 Le Roeulx 1995 earthquake. Historical seismicity also includes the estimated macroseismic $M_W$ = 5.1 Central Belgium 1828 earthquake and the 1382 and 1449 earthquakes with estimated macroseismic magnitudes $M_S$ = 6.0 and 5.5, respectively. Seismic activity in the Anglo-Brabant massif is considered diffuse, and seismicity may occur anywhere within this large seismotectonic zone, even though seismicity seems to be concentrated around the southern rim of the massif.

This diffuse seismicity is not only associated to the Anglo-Brabant massif, but it is characteristic for stable continental regions in general. For Belgium, this includes all zones of the Verbeeck et al. (2009) seismotectonic model, except for the Roer Valley Graben. In stable continental regions, large and moderate earthquakes occur on fault zones that present little Quaternary activity (Stein 2007). Camelbeeck et al. (2018) consequently argues that the seismic activity outside of the Roer Valley Graben occurs episodically and clustered in some areas and is interrupted by long periods of inactivity, typically lasting tens to hundreds of thousand years. From this viewpoint, the observation that most seismic activity in the Anglo-Brabant massif occurred on its southern rim, is of little importance, and coincides better with the rather homogeneous predicted intensity values throughout the zone. In extension, the limited predicted intensity range (x-axis in **Figure 45**) is also caused by the second selected source model, the two-zone model which considers the seismic hazard to be homogeneous throughout most of Belgium.

A possible explanation for the underprediction of the Belgian seismic hazard model in comparison with the highest observed maximum macroseismic intensities, is that amplification is not considered in the hazard model, while it is inherently incorporated in the macroseismic data. Eurocode 8 regulations require to take into account the site effects caused by the local soil conditions, for which a soil classification has been provided based on the average shear wave velocity of the first 30 m ($V_{S30}$). **Table 21** provides the $V_{S30}$ values and soil amplification factors (S) for various ground type classes. The soil amplification factors provided are from the Belgian National Annex (Bureau de Normalisation 2011), which follows the type-2 reference spectra provided by EC8.

***Table 21 :*** *Eurocode 8 soil or ground type classification.* $V_{S30}$ *– the average shear wave velocity in the upper 30m of the soil profile; S – soil factors used in the Belgian National Annex.*

| Ground type | Description of stratigraphic profile | $V_{S30}$ (m/s) | S |
|---|---|---|---|
| A | Rock or other rock-like geological formation | > 800 | 1 |
| B | very dense sand, gravel or very stiff clay deposits, at least several tens of metres in thickness | 360-800 | 1.35 |
| C | Deep deposits of dense or medium-dense sand, gravel or stiff clay with thickness from several tens to many hundreds of metres | 180-360 | 1.5 |
| D | Deposits of loose-to-medium cohesionless soil or predominantly soft-to-firm cohesive soil | < 180 | 1.8 |
| E | A soil profile consisting of a surface alluvium layer with Vs values of type C or D and thickness varying between about 5 m and 20 m, underlain by stiffer material with $V_S$ > 800 m/s | variable | 1.6 |

To evaluate whether local site effects could (partially) account for the underestimation of predicted peak ground acceleration (PGA) values compared to observed intensities, EC8 soil amplification factors are applied. Unfortunately, Belgium currently lacks comprehensive investigations into the spatial distribution of EC8 ground types or Vs30 values from which EC8 can be derived. The construction of reliable ground motion site effect maps requires the integration of extensive geological and geotechnical datasets. While abundant geological data are indeed available for Belgium and some geotechnical $V_{S30}$ measurements have been conducted in the recent past (e.g. EPOS-BE, Bruyninx et al. 2023), the process of transforming this information into a reliable site effect model is time-consuming and would extend far beyond the scope and objectives of this PhD research. Nonetheless, the creation of a detailed site effect map remains an important goal for future studies, as it would substantially improve the quality of seismic hazard assessments at the local scale.

Based on direct $V_{S30}$ measurements and indirect $V_{S30}$ derivations from geology, the ROB already established EC8 soil classes for all seismometer sites in Belgium (**Figure 46**). These EC8 soil classes can be used to determine the contribution of amplification at these sites, by multiplying the predicted PGA values of the municipalities with the corresponding soil factors. Consequently, these amplified values are converted again to macroseismic intensity values with the Atkinson and Kaka (2007) GMICE. The results of applying the amplification factor to the predicted values are shown in **Figure 45b**. This results into a slight shift towards higher predicted intensity values. This shift is best visible for the observed Imax 6 values. For the intensity 7 values, no shift towards higher predicted values can be observed. EC8 soil factor corrected predicted intensities (**Figure 45b)** only show a slight decrease in the exceedance ratio than without EC8 soil factor correction (**Figure 45a)**.

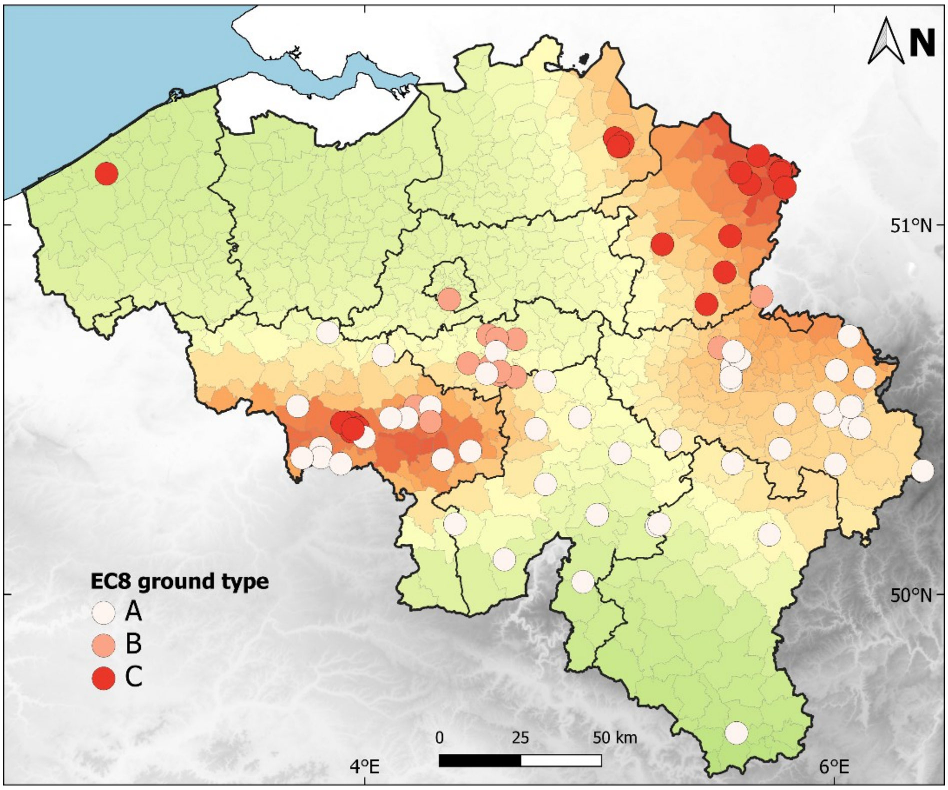



***Figure 46.** Eurocode 8 ground type classification and locations. Data from EPOS.BE site characterisation of the Belgian seismic stations (Bruyninx et al. 2023).*

Bruyninx et al. (2023) conducted measurements at the location of (former) Belgian seismic stations, which are preferably installed directly on the bedrock. These bedrock sites generally correspond to higher shear wave velocities and EC8 ground type A and thus includes no amplification factor (soil factor = 1). Only when no solid rock formations are available on the surface, such as in most of northern Belgium, seismic stations are installed on sedimentary deposits. Hence, in regions where both bedrock sites and sedimentary deposits are present, which is the case for most of southern Belgium, the simplification of taking the EC8 ground type of the seismic station site as representative for the municipality biases the interpretation. This simplification was done to facilitate the comparison between macroseismic intensity and amplification, but one should keep in mind that lower amplification factors still could be present in the considered municipalities. The stations that are not installed on the surface but at depth are not included here as they do also provide EC8 ground types at depth. These data points thus do not allow to evaluate the amplification factor of observed macroseismic intensities at the surface.

The comparison between predicted and observed intensities was so far only applied on the main municipal scale. The main municipal scale significantly increases the total area of the maximum observed intensity. The area covered by municipalities with observed intensity 6 or 7 is much higher on the main municipal scale (**Figure 37**) than on the sub-municipal scale (**Figure 36**). This contributes to higher observed macroseismic intensities in comparison to the predicted intensities of **Figure 45a** and **Figure 45b**. Applying the same procedure to the sub-municipalities, the underestimation of seismic hazard is less expressed, both for the predicted values (**Figure 45c)**, as for the EC8 corrected intensities (**Figure 45d)**. The exceedance ratios when using sub-municipalities with and without amplification, decreased to 45% and 51%, respectively. This is still a significant underestimation of the seismic hazard model in comparison to the observed intensities. Considering the large uncertainty on the GMICE (std dev = 1.01 intensity), however, only 20% and 18% exceed this uncertainty range for the sub-municipalities.

This evaluation of the seismic hazard model of Belgian macroseismic data has shown that, although the model incorporates significant uncertainties, it produces adequate results for the observed shaking from 1900 until 2024. The significant increase of the average observed maximum intensities in Belgian municipalities on the main municipal scale in comparison to the sub-municipal scale, provides much less favourable results. This also highlights that local site effects had a significant impact on the distribution of damage in the 20th century, with very localized increments of the observed macroseismic intensity. For this reason, the lack of data on these local site effects can be considered a major concern and the investigation of ground type classes or $V_{S30}$ analyses should be prioritised to highlight areas and regions with an increased potential for significant damage.

### 5.3.3. Site amplification using $V_{S30}$ estimates from topographic slope

Wald and Allen (2007) identified a correlation between site effect maps derived from geological and geotechnical data and maps representing topographic slope. In general, areas with steeper slopes correspond to regions where the bedrock is exposed or lies near the surface, indicating higher shear-wave velocities. Conversely, low-relief terrain typically coincides with sedimentary basins characterized by lower $V_{S30}$ values due to the presence of soft, unconsolidated material at the surface. Based on this relationship, Wald and Allen (2007) proposed the use of topographic slope as a practical and globally accessible proxy for estimating $V_{S30}$, particularly in regions where direct geophysical measurements are unavailable. This enables a much broader evaluation of the contribution of ground motion amplification to seismic hazard in Belgium than was possible with the data from Bruyninx et al. (2023).

A map of Belgium overlaid with a raster of $V_{S30}$ values derived from topographic slope data is presented in **Figure 47** (Allen and Wald 2007; Heath et al. 2020). The raster is composed of cells, with each cell covering an area of approximately 0.5 km². The $V_{S30}$ value for each sub-municipality is determined as the median $V_{S30}$ of all cells contained within its boundaries. These median values then correspond to a specific EC 8 soil class and corresponding soil factor, which can be multiplied by the predicted seismic hazard PGA values. **Figure 48** shows that including site effects based on topographic slope derived $V_{S30}$ values significantly shifts the predicted intensities to higher values, which reduces the exceedance ratio to 40%.

To evaluate this proxy, the $V_{S30}$ values derived through the topographic slope are compared with the EC8 ground type classes derived through direct $V_{S30}$ measurements that were performed in view of site characterisations of the Belgian seismic network by Bruyninx et al. (2023). Bruyninx et al. (2023) do not provide these $V_{S30}$ measurements explicitly but instead provide the EC8 ground type classes.

Comparing the distribution of established EC8 ground type classes with mean $V_{S30}$ values derived from the topographic slope (**Figure 47**) indicates that communes with steeper topographic slopes, such as those in the Belgian Ardennes in the southern part of the country, are generally associated with EC8 ground type A and hence higher shear wave velocities. A more direct comparison between the EC8 ground type classes of the Belgian seismic stations and the $V_{S30}$ value of only that cell at which this class was determined, however, demonstrates that the derived $V_{S30}$ values do no align with the defined thresholds by the EC8 classification (**Figure 49**). The spatial distribution of topographic slope $V_{S30}$ values for Belgium, as provided in **Figure 47**, does also not correlate with ground motion amplification caused by regional site effect observations from macroseismic intensity data (§6.2). To avoid introducing additional uncertainties into the Belgian seismic hazard evaluation based on macroseismic data, $V_{S30}$ values derived from topographic slope values are not used. Instead, local site effects are considered only at locations where EC8 ground type classes have been established through direct $V_{S30}$ measurements (i.e. the data from Bruyninx et al. 2023). Likewise, for engineering investigations into the amplification effect of a specific site, it is recommended to conduct a study to evaluate the geotechnical structure of the site and to not blindly rely on $V_{S30}$ values derived from topographic slopes.

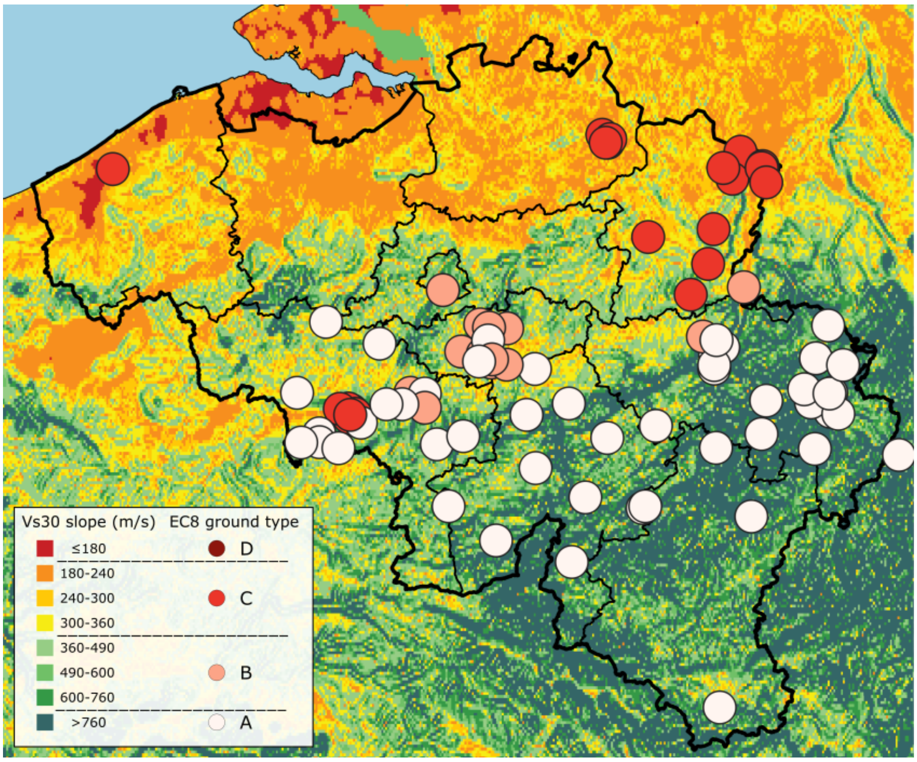



***Figure 47****. Eurocode 8 (EC8) ground type classification and locations of $V_{S30}$ measurements at Belgian seismic station sites (circles; EPOS-BE, Bruyninx et al. 2023) overlain on a $V_{S30}$ map derived from the topographic slope (Wald and Allen 2007; Heath et al. 2020). Areas with high $V_{S30}$ values inferred from topographic slope generally correspond to EC8 ground type A. In contrast, regions with lower slope-derived $V_{S30}$ values are more frequently associated with EC8 ground types B and C.*

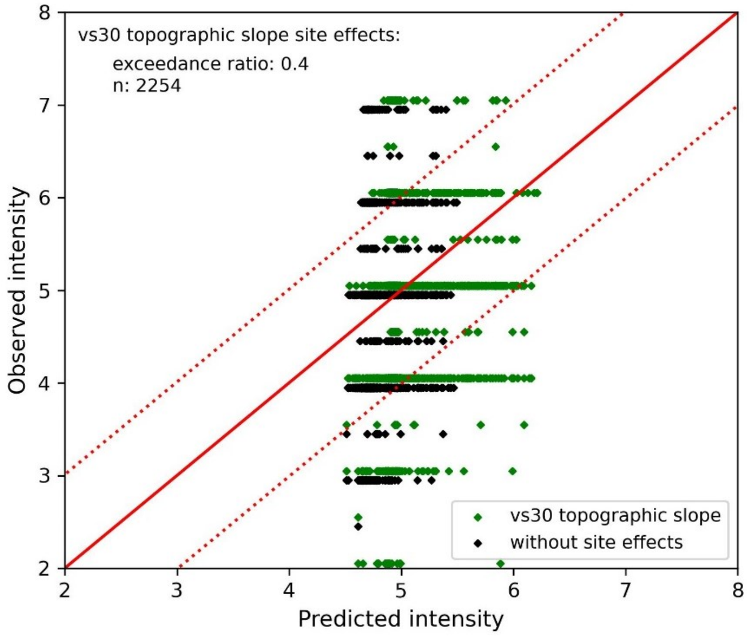



***Figure 48.*** *Comparison between the predicted intensities of the Belgian seismic hazard model and the observed maximum intensity in the BTM and BOM databases on the sub-municipal scale. Predicted intensities result from applying the GMICE of Atkinson et al. (2007) to the predicted PGA values of Vanneste et al. (2017) for Belgian sub-municipalities. Dashed red lines indicate the uncertainty of the GMICE. The green datapoints indicate sub-municipalities for which the predicted values have been multiplied with the corresponding soil factors based on the median $V_{S30}$ slope. Black datapoints indicate the same sub-municipalities without accounting for site effects in the predicted intensity.*

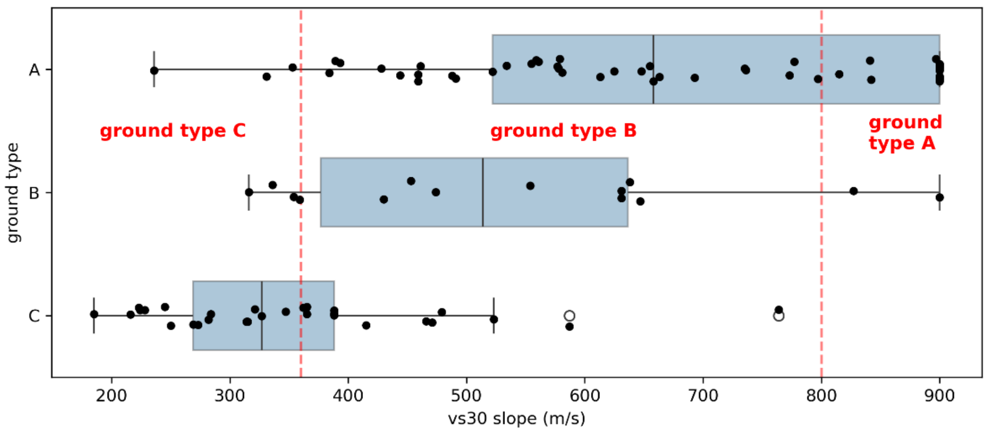



***Figure 49.*** *The black datapoints represent sites in Belgium where the shear wave velocity values for the first 30 metres ($V_{S30}$) are derived from topographic slope data (Wald and Allen 2007; Heath et al. 2020) on the x-axis, while the EC8 ground type classes, based on VS30 measurements (Bruyninx et al. 2023), are given on the y-axis. The dashed vertical red lines indicate the same EC8 ground type classes on the x-axis (i.e. type A: > 800 m/s; type B: 360-800 m/s; type C: 180-360 m/s). While a clear trend is observed in which the median topographic slope and associated VS30 decreases with increasing soil softness (y-axis, from ground type A, to B, to C), the topographic slope-based ground types do not align well with the ground types based on actual measurements. This is also shown by the broad range of the boxplot for ground type A, as well as the boxplot for ground type C, for which the interquartile range (blue area) spreads over topographic slope-derived $V_{S30}$ values, corresponding to both ground type B and C. This figure highlights the limitations and the potential for misclassification when using topographic slope as a proxy for $V_{S30}$ values.*

## 5.4. Chapter conclusions

In this chapter, a quantitative summary of the impact of 125 years of seismic activity on Belgium is provided. Two earthquakes have left a significant mark on the country during this timeframe: the $M_L = 5.6$ Zulzeke-Nukerke earthquake of 1938, which caused widespread damage, particularly to chimneys, from western to central Belgium; and the $M_L = 5.0$ Liège earthquake of 1983, which resulted in damage to 16,000 buildings in the highly urbanized area of Liège. The region most affected by seismic activity in Belgium is the Hainaut coal basin, where recurring shallow, small to moderate earthquakes that were triggered by coal mining activities, have repeatedly caused damage throughout the 20$^{th}$ century within a very confined area. With a relatively modest maximum intensity of 7 on the EMS-98 scale, Belgian seismicity has fortunately caused few fatalities since the early 20th century. Its impact on the country's rapidly expanding urban infrastructure, along with the increasing seismic risk and potential economic losses, however, should not be underestimated. The seismic impact on Belgium in the 21$^{st}$ century was almost negligible.

These macroseismic observations throughout the last 125 years also allow for the validation of the most recent seismic hazard map for Belgium (Vanneste et al. 2017), which provides probabilities on the exceedance of specific peak ground acceleration (PGA) values. By applying a ground-motion-to-intensity conversion equation, observed maximum intensities were converted into PGA values for each Belgian municipality, allowing for a direct comparison with seismic hazard map predictions. While visually, notable discrepancies can be observed between the observations from the macroseismic data and the predictive model, both spatially and in total value, taking in to account the probabilistic nature of the Belgian seismic hazard assessment, these discrepancies mostly vanished. The seismic hazard map by Vanneste et al. (2017) would thus have been a satisfactory model to predict the impact of seismic activity if it would have been developed at the start of the 20$^{th}$ century. This evaluation of the seismic hazard model demonstrated that 1) the higher resolution offered by the sub-municipal scale is crucial for accurately characterizing seismic impact in Belgium, and 2) the inclusion of amplification factors to instrumental ground motion parameters is essential for improving our understanding of the true extent of seismic effects across the region.

Unfortunately, the lack of data and research on local site effects in Belgium significantly obstructs the ability to map regions with significant amplification factors, which can be considered a major concern. While the topographic slope-derived $V_{S30}$ values do provide an indication of the dominant ground type classification in a region and thus its amplification and are certainly useable if no other data is available, its resolution and quality, however, is too low for more accurate characterizations.

# 6. Intensity attenuation modelling

## 6.1. Introduction to attenuation modelling

The energy released by an earthquake is transferred away from the hypocentre through seismic waves. While propagating through the earth and along its surface, these seismic waves distribute the energy over an increasingly bigger area. Consequently, the energy density decreases with increasing distance from the hypocentre, an intrinsic parameter of the Earth which is referred upon as the **geometric spreading factor**. During this process, heterogeneities in the earth's composition also cause **absorption** of energy, either by heat generation due to internal frictions (anelastic attenuation) or by the redirection of seismic waves due to scattering (elastic attenuation). These factors cause the decrease in seismic wave amplitude with increasing distance from the epicentre, generally referred to as **ground motion attenuation**. The attenuation rate is dependent on regional geological settings, and even smaller local-scale conditions such as sedimentary basins can cause significant amplification.

Modern seismic instruments can register ground motion and its attenuation with distance in high detail. Parameters such as peak ground velocity (PGV), peak ground acceleration (PGA), or spectral acceleration (SA) are used to characterize the severity of ground motion at specific locations and are used for the creation of ground motion attenuation relations, often referred to as ground motion prediction equations (GMPEs). These are empirical models with practical applications to engineers such as the creation of seismic hazard maps, building design coefficients, or early warning systems (Woessner et al. 2015; Allen and Melgar 2019). The creation of GMPEs, however, requires vast strong-motion datasets, which are often lacking in regions with lower seismic activity such as Belgium. Instead, GMPEs from data-rich areas are adopted (e.g. Villani et al. 2019; Vanneste et al. 2024) or adjusted to fit the local conditions (e.g. Campbell 2003).

Another source of ground motion data is macroseismic intensity data. While they are generally of less use to engineers, which generally desire reliable physical parameters, quantifying the attenuation of macroseismic data has a use for other audiences such as the public, insurance companies, local governments, or disaster response agencies (Musson 2005). As it provides a direct correlation between an earthquake and its impact on a community, macroseismic intensity data are much easier to comprehend for these audiences than, for example, PGA values. Also from a probabilistic hazard assessment approach, intensity attenuation models are extremely valuable as they can significantly extend the examined seismic history in comparison to only instrumental data. Attenuation relations can be developed directly from these data as **intensity prediction equations** (IPEs), or they can be used to evaluate GMPEs with the use of a ground-motion-to-intensity conversion equation (GMICE). As macroseismic intensity is not a measurement of a physical variable, however, correlations with instrumental parameters are strictly empirical.

Assuming a point source and a homogeneous medium, the attenuation of macroseismic intensity is classically formulated as equation (7) (Kövesligethy 1906; Jánosi 1907; Sponheuer 1960):

$$I_0 - I = km\, log\left(\frac{R}{h}\right) + \; k\alpha\, log(e)\,(R - h) \tag{7}$$

where I is the intensity at a hypocentral distance R and $I_0$ the epicentral intensity, with hypocentral distance equating to the focal depth h. Parameters m and α represent the geometric spreading and the material absorption factors, respectively. The parameter k varies between 2 and 5 and is the function of the supposed empirical relation between intensity and acceleration (Murphy and O'Brien 1977). For surface waves, *m = 1* and α should be determined regionally, but is typically in the range of 0.001 to 0.01 (Stromeyer and Grünthal 2009). As 'k', 'm' and 'α' cannot be determined separately, and the hypocentral distance R can be formulated in function of the focal depth h and the epicentral distance r, equation (7) can be written as:

$$I = \; I_0 - \; a\, log\sqrt{\frac{r^2 + h^2}{h^2}} - \; b\left(\sqrt{r^2 + h^2} - h\right) \tag{8}$$

with *a* = *km* and *b* = *kα log e*. Parameter *a* determines the near-field behaviour at small epicentral distances, while parameter b describes the far-field characteristics (**Figure 50**). The use of the epicentral intensity $I_0$ to indicate the source strength at epicentral distance R = 0, is somewhat problematic (Pasolini et al. 2008). IDPs are often not available at the location of the epicentre and could also be affected by local site amplification effects. In practice, instead of choosing the IDP closest to the epicentre, the maximum intensity value (Imax) of an earthquake is taken. This results in the overestimation of the actual source strength. Additionally, $I_0$ can be impossible to assess when the epicentre is located offshore and often requires more time to determine aften an earthquake than for example the magnitude.

Intensity attenuation can also be expressed as any function of magnitude and depth, avoiding the use of $I_0$ or $I_*$ altogether (9):

$$I = \; c + d\, M + e\, R + f\, \log{(R)} \tag{9}$$

with c, d, e and f representing constants and M the magnitude of the earthquake. As in equation (7), R is the hypocentral distance. This completely circumvents the use of $I_0$ or $I_*$ altogether but requires instrumental magnitude data for the considered events (Stromeyer and Grünthal 2009).

Both equations (8) and (9) can be fitted to a data set of macroseismic intensities with various regression techniques. The regression procedure presents some problems, however, due to the integer nature of intensity and a lack of spatial precision, as intensity values represent shaking intensity over a larger area and not a single point (Musson 2005). The general practice to deal with these issues during the regression procedure, is to regard the intensities as continuous variables and to provide specific coordinates to each IDP. These coordinates can be derived through different approaches, such as visual approaches, or by calculating the centroid or the centre of mass or a weighted centre based on population density data. If required, the results of the regression procedure can be rounded to integer values and the obtained value for the point data can be applied to an entire polygon (e.g. a municipality) again.

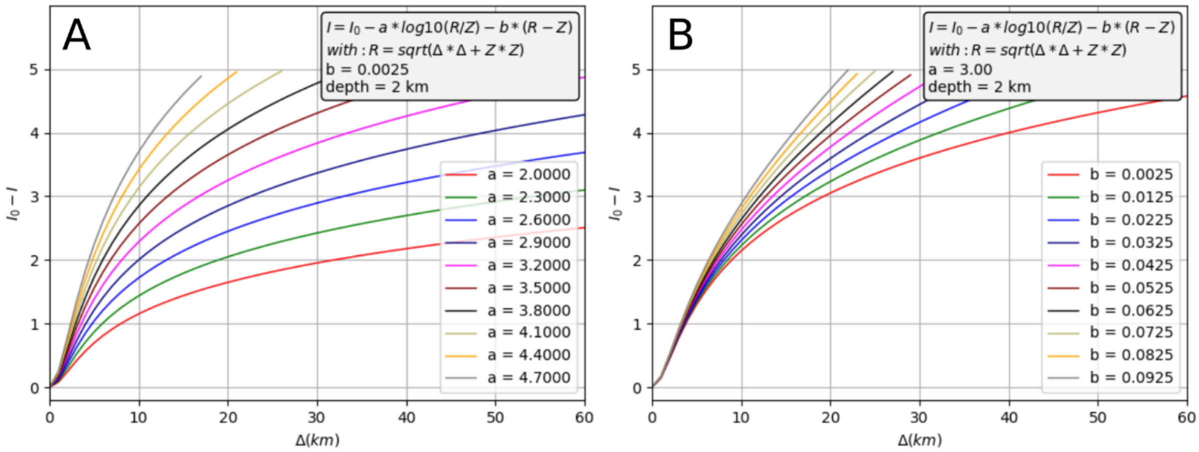



***Figure 50**. Intensity attenuation versus epicentral distance Δ. Theoretical visualisation of the influence of parameters a and b in equation (8) for an earthquake with a shallow focal depth (2 km). A) While keeping parameter b constant and parameter a variable, differences in intensity attenuation already start at very short epicentral distances. B) With parameter a constant and parameter b variable, intensity attenuation remains relatively constant at short epicentral distances and only deviates at larger distances.*

## 6.2. Belgian ground motion attenuation characteristics

Regional geological structures as well as local site effects lead to variations in the ground motion attenuation in Belgium. These variations in the ground motion attenuation rate become evident from visual observations of the distribution of macroseismic data alone (Neefs et al. 2021; **Figure 52**, **Figure 53**). The most peculiar observation of attenuation rate difference in Belgium, are the asymmetric macroseismic distribution patterns in the **Anglo-Brabant massif**, clearly visible from the macroseismic field derived for most felt earthquakes that affected the region. Even the damage distribution for the historical Central Belgium earthquake of 1828, with estimated macroseismic $M_W = 5.1 \pm 0.3$, showed these asymmetric patterns (Camelbeeck et al. 2021). In **Figure 51**, this asymmetric distribution of observed intensities is quantified for the $M_L = 5.6$ Zulzeke-Nukerke 1938 earthquake, with a difference of almost two intensity values for two opposite orientations, at greater epicentral distances.

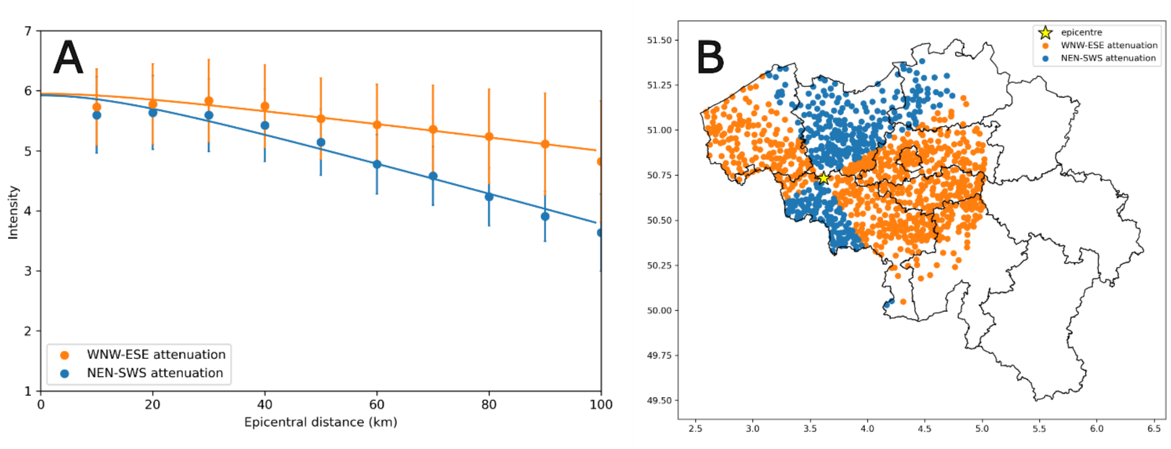



***Figure 51.*** *Anisotropic attenuation of intensity of the $M_L = 5.6$ Zulzeke-Nukerke 1938 earthquake. A: the intensity attenuates faster along the NNE-SSW orientation (blue) than along the WNW-ESE orientation (orange). The datapoints represent the average intensity in 10 km distance bins. B: Distribution of the datapoints used to create the attenuation graphs in A.*

While Somville (1939b) already took notice of the peculiar east-west oriented elongation of the isoseismals of the $M_L = 5.6$ Zulzeke-Nukerke 1938 earthquake (**Figure 5**), he provided no explanation on the origin of this phenomenon. Ahorner (1975) interpreted this elongation as an indication of strike-slip faulting along a right-lateral WNW-ENE-trending shear zone. Due to a lack of instrumental ground motion data of the event, however, no reliable fault plane solutions have been published for the event. Nguyen et al. (2004) did provide a convincing argument to explain the elongated east-west amplification: the authors demonstrated a correlation between the distribution of damage of the 1938 earthquake and the thickness of the soft sedimentary cover overlaying the Anglo-Brabant massif. Where the sedimentary cover is thicker, high-frequency seismic waves experience greater attenuation before reaching the surface. The asymmetric distribution of intensity values observed for seismic events such as the $M_L = 5.6$ Zulzeke-Nukerke 1938 earthquake has thus a geological origin. This is also visible for other events. Van Noten et al. (2017) demonstrated that the distribution of the intensity data of the $M_L = 4.1$ Ramsgate 2015 and $M_L = 4.3$ Goch 2011 earthquakes were clearly impacted by the thickness of the sedimentary cover, causing the macroseismic field to deviate from a concentric pattern. Where the thickness between the surface and the seismic bedrock depth was larger, only very few people reported to have felt these earthquakes (**Figure 54**). The seismic bedrock is defined as the interface with the highest acoustic impedance contrast between the soft sediments and the basement, which differs from the engineering bedrock, i.e. the interface where shear-wave velocity exceeds ~800 m/s. A progressive absorption of the high-frequency seismic energy is observed when the thickness of the sedimentary cover increases. The low-frequency content, however, is preserved throughout the sedimentary cover and is possibly even amplified when it matches the fundamental resonance frequency of the soil (Camelbeeck et al. 2014).

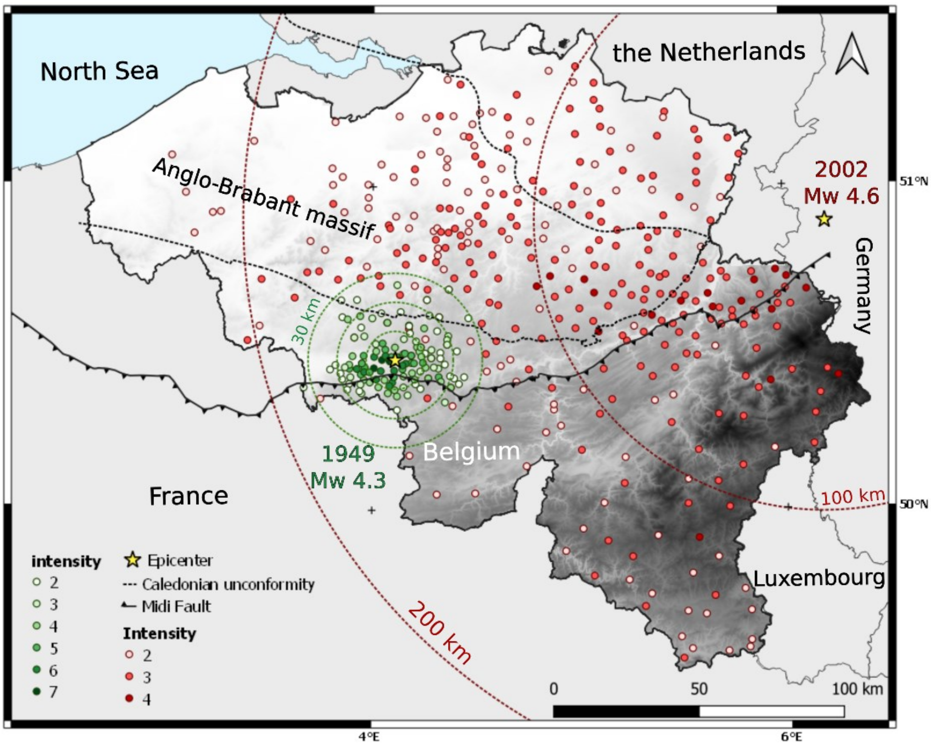



***Figure 52**. Macroseismic intensity data of the $M_W$ = 4.6 Eschweiler-Alsdorf 2002 earthquake in Western Germany (red) and the $M_W$ = 4.3 Havré 1949 earthquake in Belgium (green). Although both earthquakes had only a small difference in magnitude, the macroseismic field of both events is significantly different, with felt reports at much larger distances for the 2002 earthquake (>200 km) than the 1949 earthquake (~30 km). This large difference in the extent of the macroseismic field can partly be attributed to the difference in focal depths for the 1949 and 2002 earthquakes, i.e. 2.2 km and 16.4 km, respectively. Yet, it does not explain the full extent of this difference, as the high absorption rate in the Hainaut coal basin also plays a major role in its high attenuation rate (Camelbeeck et al. 2022). This figure was adapted from Neefs et al. (2021).*

In the **Hainaut coal basin** and the **Liège coal basin**, the intensity attenuation rate is much higher than elsewhere in Belgium. At first glance, this does not seem unusual, as from equation (8) and (9), lower focal depths (h) lead to higher attenuation terms, as already suggested by Charlier (1949) and Van Gils (1966). Camelbeeck et al. (2022) demonstrated that the attenuation rate is even much higher in the Hainaut coal basin than in other regions with similar focal depths and magnitudes. They associate this exceptional attenuation rate to the combination of a high fracturing degree in the frontal zone of a tectonic belt and the slow seismic propagation velocity of coal deposits. These same geological conditions are present in the Liège-Gulpen zone and similar attenuation characteristics could be applied, although this was never demonstrated. Multiple authors also mention the effect of the **Midi fault** (e.g. Charlier 1951; Van Gils and Zaczek 1978; Nguyen et al. 2004; Camelbeeck et al. 2022), a Variscan thrust fault crossing Belgium from east to west, and the Artois-Shear Zone in France (Van Noten et al. 2017) on the distribution of macroseismic intensity data. These fault zones act as seismic barriers, inhibiting the transfer of ground motion from north to south, and vice versa (e.g. **Figure 52**, **Figure 53**, **Figure 54**).

These regional variations, combined with low to moderate diffuse seismic activity, limit the precise characterisation of ground motion attenuation in Belgium. The number of parameters is high, but the available macroseismic data is insufficient to develop empirical models specifically adapted to Belgian conditions. The initial goal of this PhD to develop regional intensity prediction equations, was already quickly abandoned due to a lack of data. Only in the Hainaut coal basin, where recurrent seismic activity with consistent earthquake source properties has occurred within a confined area with uniform geological conditions, sufficient data is available to develop a tailored intensity prediction equation (Camelbeeck et al. 2022). To provide ground motion attenuation models for Belgium, existing models in literature must be evaluated. Vanneste et al. (2024) provided a rigorous evaluation of the applicability of various ground motion prediction equations in the Hainaut coal basin. For the other regions in Belgium, with less available data, various IPEs are evaluated on their correlation with the observed macroseismic intensity attenuation of the largest earthquakes incorporated in the BTM database (§6.3).

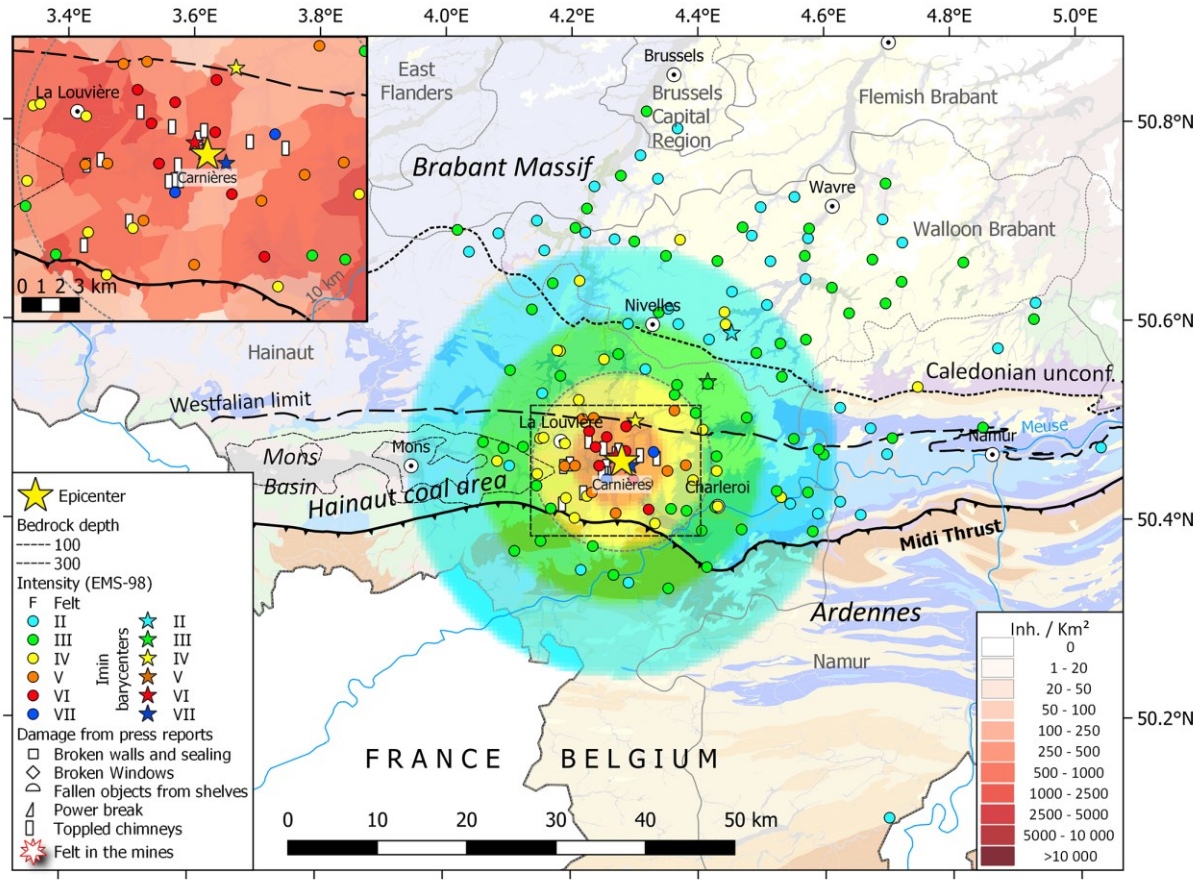



***Figure 53**. Macroseismic intensity data of the $M_W$ = 4.1 Carnières 1967 earthquake. The inset map in the top left of this figure shows the specific reported damage in press reports. The coloured concentric areas around the epicentre show the Hainaut coal basin attenuation model as developed in Camelbeeck et al. (2022). This model was developed the characterize the strong attenuation rate in the Hainaut coal basin specifically and should not be applied outside of its borders (between the Midi Thrust and the Westphalian limit). Note the asymmetric macroseismic field: this event was felt at much larger epicentral distances in the north, in the Anglo-Brabant massif, than it was felt in the south, in the Ardennes, or within the Hainaut coal basin itself. This figure was reproduced from Camelbeeck et al. (2022).*

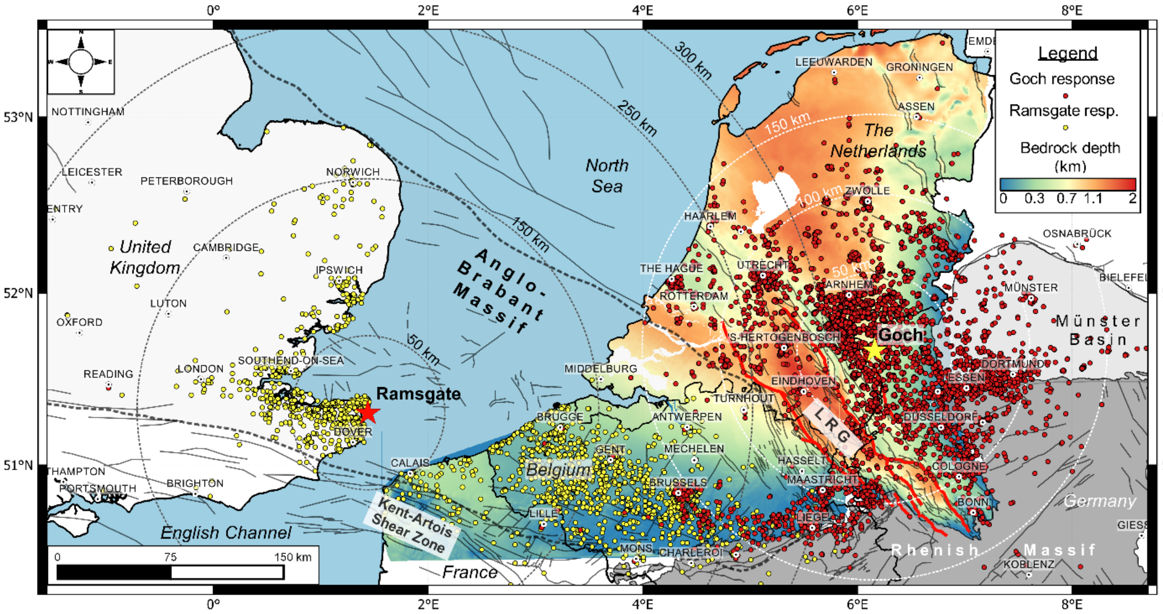



***Figure 54**. Felt reports of the $M_L$ = 4.3 Goch 2011 earthquake (red IDPs) and the $M_L$ = 4.1 Ramsgate 2015 earthquake (yellow IDPs), projected over a map of the seismogenic bedrock depth. Regions with deeper bedrock depths show an absence of felt responses, such as in northeast Belgium. This figure was reproduced from Van Noten et al. (2017).*

The intensity attenuation, i.e. the intensity decrease with increasing epicentral distance, visible in the BTM database is presented in **Figure 55** and **Figure 56**. In **Figure 55**, intensity versus distance is plotted for the entire BTM database (Fig. 50a) and for each seismotectonic source region individually, but only for those earthquakes that have an origin in the same seismotectonic region. **Figure 56** provides a different analysis and presents the intensity attenuation of all IDPs observed within a seismotectonic region. In the last figure, earthquakes that have an origin inside a certain seismotectonic zone, still can provide useful data to derive the attenuation in another seismotectonic zone. The high attenuation rate of the Hainaut coal basin and of the Liège-Gulpen zone are evident in **Figure 55d** and **Figure 55f**, respectively. These graphs show a high maximum intensity, with sharply decreasing intensity values with increasing epicentral intensity. The impact of events originating in other seismotectonic zones, however, is much less attenuated in the Hainaut and Liège-Gulpen zones (**Figure 56d** and **Figure 56f**). This can be explained by the selective attenuation of high-frequency seismic waves by the sedimentary cover in these basins. Only earthquakes that are large enough ($M_W$ > ~5), produce low frequency seismic waves that are preserved throughout the sedimentary cover.

The intensity attenuation of each seismic event in the BTM database is provided in the supplementary information (SI 10.6). The dataset of many of these events are limited, either in function of total IDPs available, or the maximum intensity observed. Camelbeeck et al. (2022) developed an IPE specifically for the Hainaut coal basin and consequently, these events will not be used, as it is already evidenced that existing IPEs were not able to adequately characterize its fast attenuation rate. The Hainaut coal basin IPE from Camelbeeck et al. (2022) will, however, be evaluated for other events in the BTM database.

If only events with at least 100 felt IDPs (intensity > 1) and a maximum intensity (Imax) of at least 5 (whether or not observed in Belgium) are considered, and seismicity from the Hainaut coal basin is excluded, only 15 events remain. These events are highlighted in the BTM earthquake catalogue in the supplementary information (SI 10.4). For these 15 events, the performance of existing IPEs is evaluated in the next subchapter.

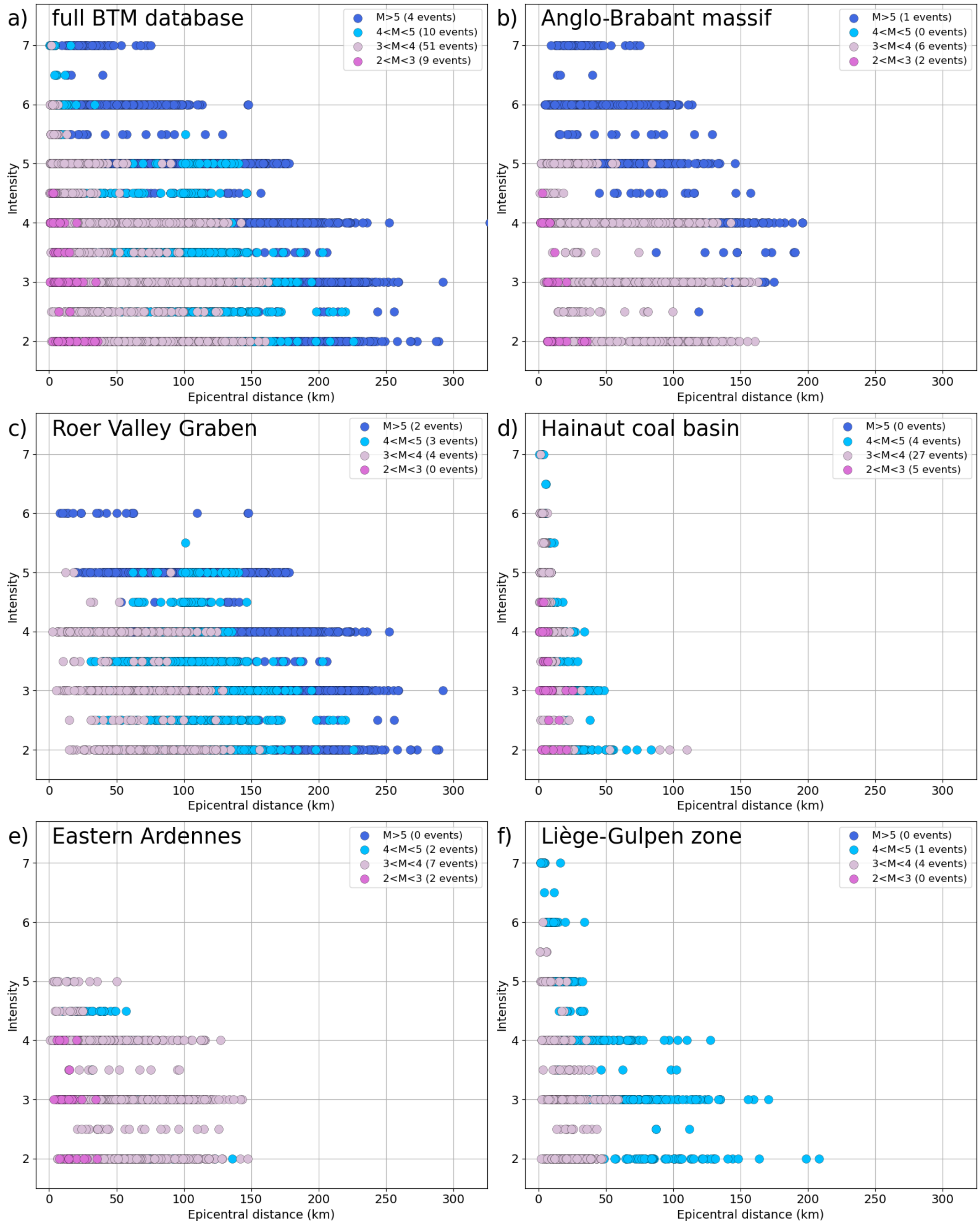



***Figure 55.*** *Epicentral distance and intensity of the IDPs that originated from seismicity in the different seismotectonic source zones. Intensity attenuation of seismicity that originated from the: a) full BTM database; b) Anglo-Brabant massif; c) Roer Valley Graben; d) Hainaut coal basin; e) Eastern Ardennes; f) Liège-Gulpen zone. Magnitude* $M = M_W = M_S = 0.722\ M_L + 0.743$ *(Reamer and Hinzen 2004).*

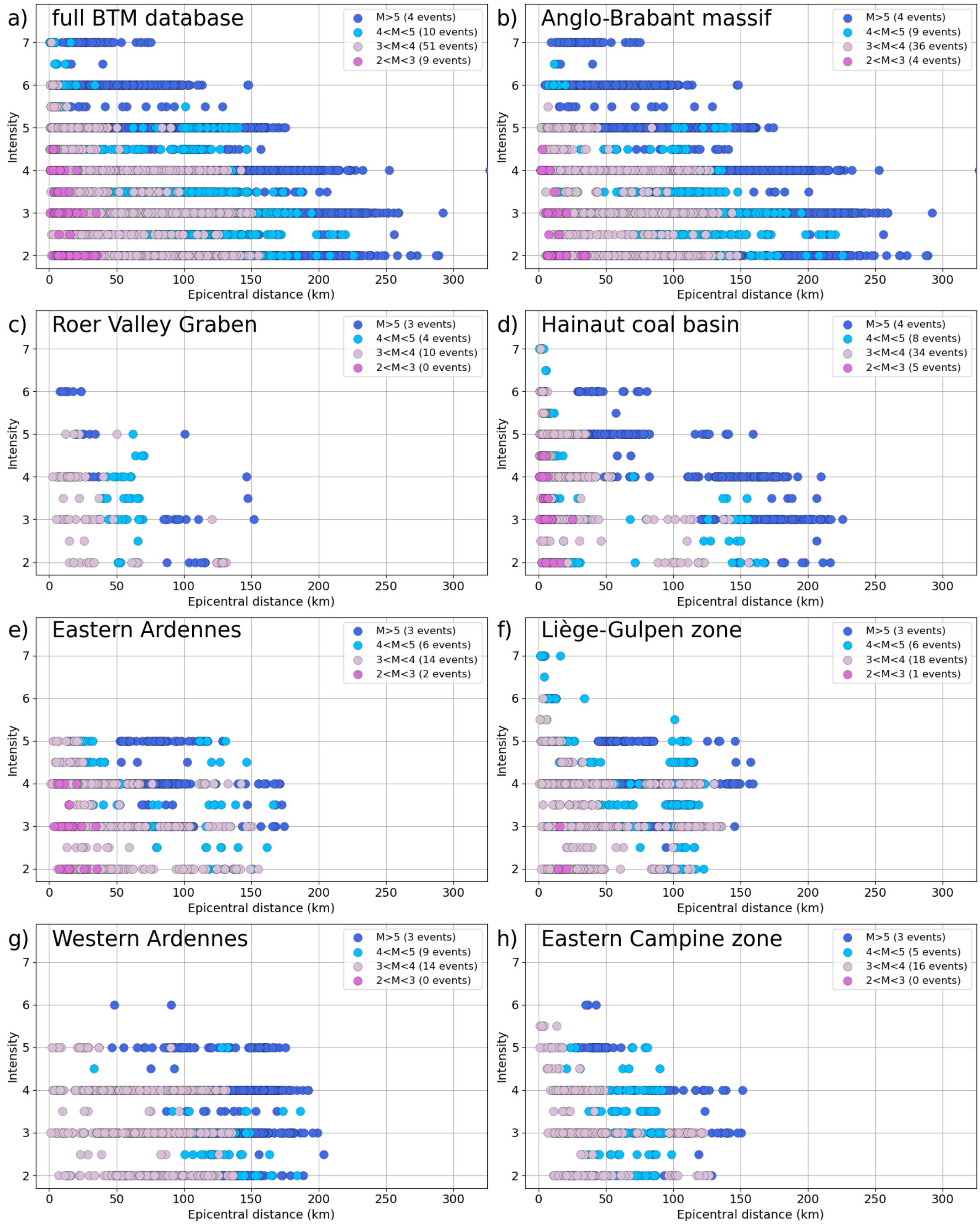



***Figure 56.*** *Epicentral distance and intensity of the IDPs located in the different seismotectonic source zones. Intensity attenuation of the experienced intensity in the: a) full BTM database; b) Anglo-Brabant massif; c) Roer Valley Graben; d) Hainaut coal basin; e) Eastern Ardennes; f) Liège-Gulpen zone; g) Western Ardennes; h) Eastern Campine zone. Magnitude* $M = M_W = M_S = 0.722\ M_L + 0.743$ *(Reamer and Hinzen 2004).*

## 6.3. IPE performance evaluation

Intensity prediction equations (IPEs) can be categorized into two types based on their input data. The first type, represented by equation (8), uses the epicentral intensity or intensity strength $I_0$ to estimate the rate of the attenuation with decreasing epicentral distance. The second type, represented by equation (9), relies on instrumentally derived earthquake source parameters to model intensity attenuation. These equations of the second type estimate the intensity distribution across the affected region and provide insights into the expected severity of shaking. They are particularly valuable for rapid post-earthquake assessments, as they allow for the estimation of intensity levels before macroseismic data can be fully collected. This capability is essential for applications such as generating ShakeMaps (Worden et al. 2020), which support emergency response and risk assessment. While both types of IPEs serve the same fundamental purpose, i.e. modelling the intensity attenuation of an earthquake, they both use different input data. Both types of IPEs are also useful for determining earthquake source parameters of historical earthquakes when instrumental data are unavailable or insufficiently reliable. They play a crucial role in reconstructing seismic catalogues, which in turn enhances seismic hazard assessment for a given region.

Numerous IPEs have been developed worldwide. However, only a few are applicable for the seismotectonic characteristics of Belgium. The IPEs selected to test their performance on Belgian macroseismic data are provided in **Table 22** and **Table 23**. These equations have been developed specifically for northwestern or Central Europe, with the exception of the Atkinson and Wald (2007) IPE, which was developed for the Central and Eastern United States. Out of the 80 events in the BTM database, only 15 have been selected for the evaluation of several IPEs (§6.2). A visual overview of these events individually and the comparison with the selected IPEs is provided in the supplementary information (SI 10.7).

***Table 22 :*** *Selected IPEs based on an epicentral intensity $I_0$ factor. The performance of these IPEs on Belgium macroseismic intensity data provided in the BTM database is tested. R = hypocentral distance (km) and h = focal depth (km).*

| IPE | equation | region | reference |
|---|---|---|---|
| amb85 | $I = I0 + 0.22 - 0.0024 * (R - h) - 2.85 * \log(\frac{R}{h})$ | Northwest Europe | Ambraseys et al. (1985) |
| SG09-wls | $I = I0 - 0.09 - 0.00126 * (R - h) - 2.8 * \log(\frac{R}{h})$ | Central Europe | Stromeyer and Grünthal (2009) |
| SG09-chi | $I = I0 - 0.11 - 0.00252 * (R - h) - 2.95 * \log(\frac{R}{h})$ | | |
| Cam22 | $I = I0 - 0.052 * (R - h) - 3.45 * \log(\frac{R}{h})$ | Hainaut coal basin | Camelbeeck et al. (2022) |

***Table 23 :*** *Selected magnitude-based IPEs for evaluating their performance on Belgian macroseismic intensity data provided in the BTM database. R = hypocentral distance (km), D = sqrt(R²+17²) and B = 0 when D ≤ 80 km or B = log(D/80) when D > 80 km.*

| **IPE** | **equation** | **region** | **reference** |
|---|---|---|---|
| HO01 | $I = -0.7374 + 1.2673 * Ml - 0.0184 * R$ | Northern Rhine area | Hinzen and Oemisch (2001) |
| BS06 | $I = 4.48 + 1.27 * Mw - 3.37 * log(R)$ | France | Bakun and Scotti (2006) |
| AW07 | $I = 11.72 + 2.36 * (Mw - 6) + 0.1155 * (Mw - 6)^2 - 0.44 * log(D) - 0.002044 * D + 2.31 * B - 0.479 * Mw * log(D)$ | Central and Eastern US | Atkinson and Wald (2007) |

Belgian macroseismic intensity data displays a wide spread of values, both in observed intensities at a given distance from the epicentre and in the median or average distance for each intensity class. This variability is illustrated in **Figure 57**, where observed intensities at an epicentral distance of 70 km range from intensity 3 to 7, while intensity 5 is recorded from the epicentral zone up to distances exceeding 100 km. Such high variability is primarily attributed to local site effects and regional geological conditions, which strongly influence ground motion attenuation and amplification (§5.3.2), as well as the low quality of Belgian macroseismic intensity data (§4.3). To mitigate this variability, intensity binning is applied by grouping observed intensities and determining the median distance for each intensity class (green points in **Figure 57**). A bin size of 0.5 intensity units is used, and only bins containing more than 10 IDPs are considered. No binning is applied to intensity 1, however, as its median distance is entirely dependent on sample distribution. The intensity binning for the $M_L$ = 5.1 Uden 1932 earthquake shows a reverse attenuation (SI 10.7), with the median intensity increasing with distance. This is attributed to amplification in the Liège and Hesbaye area, which is also observed for other events (Neefs et al. 2024b; **Figure 39**). This amplification is suggested to be linked to the shallow depth of Cretaceous formations (Dost et al. 2025). Consequently, the dataset of the $M_L$ = 5.1 Uden 1932 earthquake is discarded during the IPE performance evaluation.

The predicted attenuation rates of the selected IPEs are plotted over the BTM intensity data points in **Figure 57**. For epicentral intensity-based IPEs, the methodology of the epicentral intensity was tested based on two different procedures. The first procedure equalized the epicentral intensity to the maximum observed intensity. The second method determined the epicentral intensity as the average intensity of the five IDPs closest to the epicentre. For events that had their epicentre outside of Belgium, however, the five closest IDPs would already be at significant epicentral distances (i.e. up to epicentral distances of 40 km), which could hardly be considered as the epicentral intensity. Instead, to harmonize the procedure for all events, epicentral intensity was determined by the maximum intensity for all events.

To evaluate the performance of the selected IPEs, the root mean square error (rmse) between the intensity bins of the observations and the predictions of the IPEs at the median distance of each intensity class is computed. This provides the average difference between the predicted and observed values. A second parameter provides the trend of residuals with distances. This parameter is implemented to evaluate the differences between the residuals with varying epicentral distances. If an IPE underpredicts the intensity at lower epicentral distances, but overpredicts at higher epicentral intensities, the overall rmse could still be potentially limited and might score well in the evaluation. The trend is thus defined by the slope of the linear correlation of the residuals. In a perfect model, both parameters (rmse and trend) are equal to 0. If the trend is positive, the IPE attenuates slower than the observed intensities. If the trend is negative, the IPE attenuates faster than the observations. In **Figure 57**, which presents the attenuation of the 1938 $M_L$ = 5.6 Zulzeke-Nukerke earthquake, all IPEs apart from cam22, attenuate slower than the observed intensities.

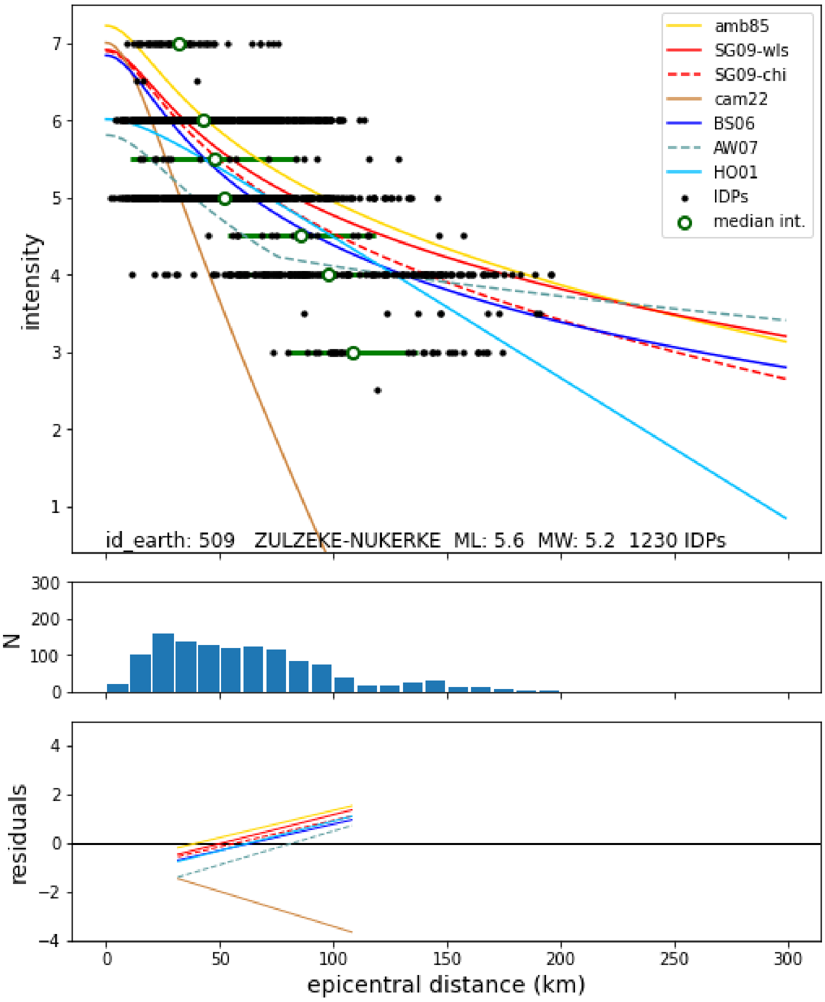



***Figure 57.*** *Intensity attenuation of the $M_L$ = 5.6 Zulzeke-Nukerke 1938 earthquake.*

Each IPE is ranked for its performance based on the computed rmse and trend parameters. The IPE with the closest rmse to 0 is awarded 'rmse ranking' 1, while the highest rmse value is given rank 7. The same ranking procedure occurs for the trend parameter, the 'trend ranking'. The overall ranking of the IPEs for each event individually is determined by the sum of both parameter rankings. The IPE with the lowest overall rank, is the best performing IPE for the specific earthquake. The rmse and trend parameters, as well as the rankings, are provided in the supplementary information (SI 10.8).

The IPE with the lowest rank across all events is the '*SG09-chi*' or the chi-square regression attenuation relation by Stromeyer and Grünthal (2009). The second-best performing IPE is the *'BS06'* or the French stable continental region model by Bakun and Scotti (2006). The worst performing model is the *'AW07'* or the central and eastern United States model by Atkinson and Wald (2007), which is based on "DYFI?" intensity data. The performances of all IPEs are provided in **Table 24**.

***Table 24 :*** *Performance scores of the selected IPEs across 14 selected events in the BTM database. The $M_L$ = 5.1 Uden 1932 earthquake was discarded from the computation of these scores. The score provided is the sum of the 'rmse ranking' and 'trend ranking' parameters across all selected earthquakes. The applied model in this performance evaluation is specified if multiple IPEs are provided in the given reference.*

| IPE | model | reference | Score |
|---|---|---|---|
| SG09-chi | chi-square method | Stromeyer and Grünthal (2009) | 60 |
| BS06 | French stable continental region | Bakun and Scotti (2006) | 96 |
| SG09-wls | weighted least squares method | Stromeyer and Grünthal (2009) | 114 |
| cam22 | - | Camelbeeck et al. (2022) | 119 |
| amb85 | - | Ambraseys (1985) | 124 |
| HO01 | - | Hinzen and Oemisch (2001) | 128 |
| AW07 | central and eastern United States | Atkinson and Wald (2007) | 143 |

Across the selected events, however, significant differences are visible between the performance of IPEs. While the *'cam22'* model scores much worse overall than for example the *'SG09-chi'* IPE, it is the best performing IPE in 5 out of the 14 selected events. It performs best with low to moderate magnitude earthquakes in the Anglo-Brabant massif (the $M_L$ = 4.0 and $M_L$ = 3.4 Court-Saint-Etienne earthquakes in 1953) and the Eastern Campine zone (the $M_L$ = 3.5 Genk-As 1963 and the $M_L$ = 4.1 Bilzen 1925 earthquakes). It is also the best performing IPE for the $M_L$ = 4.3 Ans-Vottem 1965 earthquake in the Liège coal basin. Although focal depths are only available for the Ans-Vottem 1965 earthquake, the strong correlation with the fast attenuating *'cam22'* IPE, which was developed for small to moderate, shallow earthquakes in the Hainaut coal basin, strongly suggests shallow focal depths for these events. Both Court-Saint-Etienne events were part of a seismic swarm that took place from 1953 to 1957 (§1.2.2). The same area experienced another seismic swarm from 2008 until 2010 (§1.2.2, §3.2), of which the focal depths could be determined to be ranging between 5 to 7 km (Van Noten 2015a, 2015b).

The other two source regions for which the *'cam22'* performs best, are associated with coal mining activities, the Liège coal basin and the Eastern Campine zone. The Liège coal basin is characterized by a similar geological context as the Hainaut coal basin. While the seismic activity that occurred in the Liège coal basin has not been demonstrated to be the triggered by the coal mining activities, a link between them can be suggested based on the spatial and timely correlation between both, as well as the shallow focal depths. While the *'cam22'* IPE shows the best performance for the $M_L$ = 4.3 Ans-Vottem 1965 event, it does not perform well for the $M_L$ = 5.0 Liège 1983 event. Zooming in into the data in **Figure 58**, it shows that *'cam22'* does perform well at short epicentral distances but fails at larger epicentral distances. The *'cam22'* IPE was only developed for IDPs within 15 km of the epicentre. At larger epicentral distances, IDPs of Hainaut seismicity are no longer located in the Hainaut coal basin, but either in the Anglo-Brabant massif or Western Ardennes. To avoid influencing the *'cam22'* with the much slower attenuation rate from these regions, the IDPS were discarded. The same argument could thus apply to the Liège coal basin and the $M_L$ = 5.0 Liège 1983 earthquake.

While the limited seismicity in the Eastern Campine zone is not commonly associated with a triggered or induced origin, the seismic activity can also be spatially and temporarily linked to coal mining activities. The well-performing *'cam22'* IPE suggests that this seismicity is likely also related to a shallow source, providing an argument to a triggered-based seismicity. The limited number of felt event (i.e. 4 over 125 years), however, does not provide sufficient data to make any significant claim on this statement. In recent years, induced seismicity occurred in the more northern part of the

Eastern Campine zone in Belgium (§3.2), indicating that the area is susceptible to human industrial activities at depth.

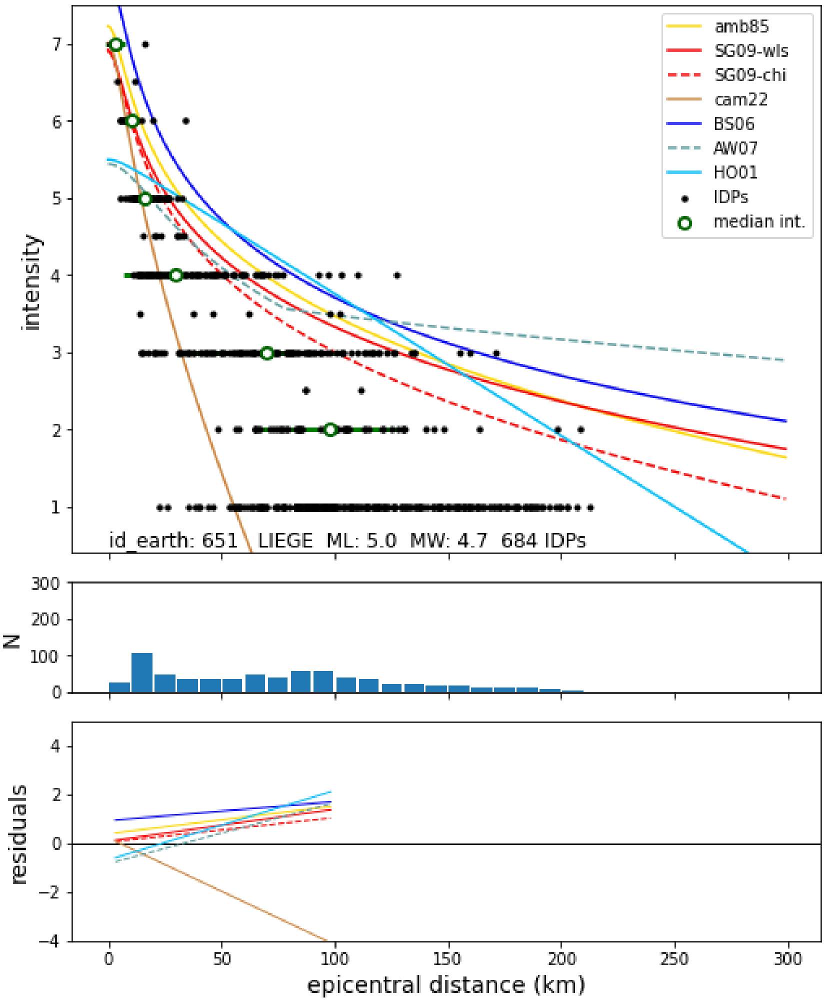



***Figure 58.*** *Intensity attenuation of the $M_L$ = 5.0 Liège 1983 earthquake.*

Outside of the Eastern Campine zone, the Liège coal basin and the low-magnitude earthquakes in the Anglo-Brabant massif, the *'SG09-chi'* IPE performs best across all other source regions, closely followed by the *'BS06'* IPE. In this analysis, epicentral intensity-based IPEs have a significant advantage over the magnitude-based IPEs, as the used maximum intensity already provides a good estimation of the observed intensity at the epicentre. The *'BS06'* IPE is a magnitude-based attenuation model, and consequentially its good performance, is remarkable. Unlike the epicentral intensity-based *'SG09-chi'* and *'cam22'* IPEs, the *'BS06'* IPE can be used to estimate the impact of future earthquakes in Belgium, with source regions in the Anglo-Brabant massif, the Roer Valley Graben and the Eastern Ardennes. It does seem to perform worse with more shallow earthquakes (<~10 km) and its bad performance for the $M_L$ = 5.8 Euskirchen 1951 earthquake in the Roer Valley Graben illustrates that it cannot be applied for all events.

Magnitude-based IPEs can be incorporated in ShakeMap simulations, together with instrumental data, GMPEs and macroseismic intensity data (Worden et al. 2020). To evaluate the impact of an earthquake, a good estimate of the epicentral or maximum intensity can significantly improve the emergency response support. To determine the performance of the selected magnitude-based IPEs, the predicted epicentral intensity is compared to the maximum observed intensity for the various events in the BTM database.

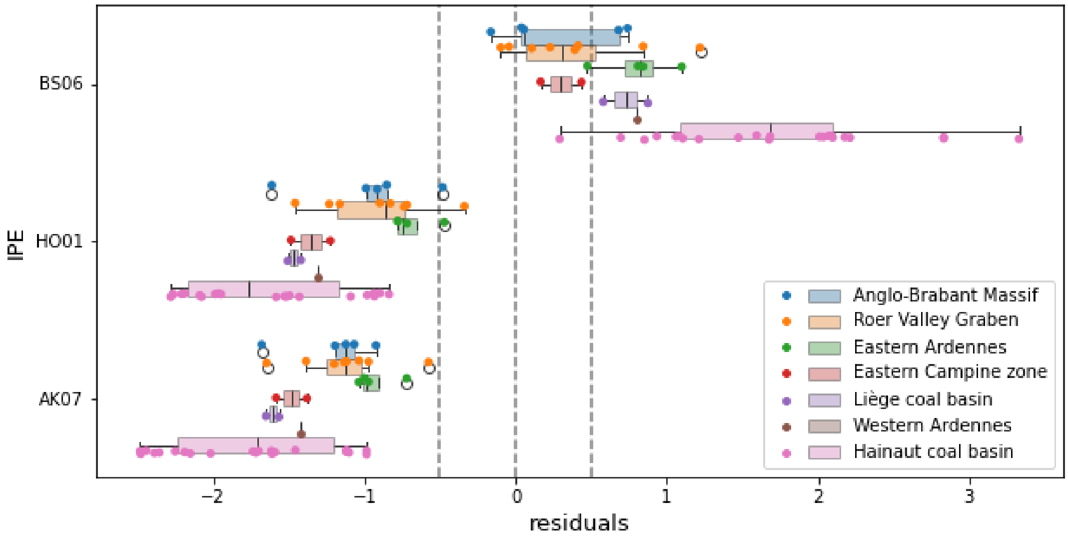



***Figure 59.*** *Residuals between the IPE predicted epicentral intensity and the observed maximum intensity provided by the BTM database for events with maximum intensity ≥ 5. BS06: French stable continental region IPE by Bakun and Scotti (2006); HO01: Hinzen and Oemisch (2001); AK07: Central and eastern United States IPE by Atkinson et al. (2007).*

Out of the three selected magnitude-based IPEs, the *'BS06'* IPE provides much better estimations of the maximum or epicentral intensity than the *'HO01'* and *'AK07'* IPEs (**Figure 59**). The *'BS06'* IPE consistently predicts slightly higher values than observed. For shallow earthquakes, however, it consistently provides larger overestimations of the maximum intensity for shallow earthquakes, such as the Hainaut and Liège coal basin earthquakes or the $M_L = 3.6$ Barbençon-Beaumont 1992 earthquake in the Western Ardennes with a focal depth of 7.0 km. All events that lie outside of the 0.5 uncertainty range bounds for the *'BS06'* IPE have no known focal depths, with exception of the Liège coal basin events and most of the Hainaut coal basin events. To compensate for these unknown depths, a fixed depth of 10 km was attributed, except for the Hainaut events which are given a fixed depth of 5 km. For events with a maximum intensity lower than 5, which are not included in **Figure 59**, *'BS06'* estimations of the maximum intensity are much less consistent. The *'BS06'* IPE thus provide good estimations of earthquakes felt in Belgium for moderate and deep events (> 10 km) and which have maximum intensities equal or greater than 5.

Although no intensity prediction equations are designed specifically for Belgium (with exception of the *'cam22'* IPE), this analysis shows that IPEs developed for other regions provide consistent results with the observed intensity attenuation. The *'cam22'* IPE by Camelbeeck et al. (2022) also provides good results for other shallow earthquakes (<~10 km). For moderate to deep earthquakes (> 10 km), the *'SG09-chi'and 'BS06'* IPEs provide a good correlation between observed and predicted intensity attenuation. The *'BS06'* IPE is of particular interest to estimate the impact of future earthquakes as it relies on instrumental source parameters that are much more rapidly determined than epicentral intensities. The *'BS06'* IPE also provides good estimates of the maximum intensity of an earthquake for events with moderate to deep earthquake focal depths in Belgium (>10 km). It should be noted, however, that during this analysis, the IPEs do not incorporate amplification effects based on geological or local site conditions and are only evaluated based on the average attenuation rate. For this reason, significant variations between observed and predicted intensity values are still likely to occur. To identify regions with amplification in Belgium, the residuals between observed and predicted intensity values from the best-performing IPEs in this analysis should be mapped and should be compared with instrumental data.

## 6.4. Chapter conclusions

Ground motion attenuation in Belgium is far from uniform, as it is strongly influenced by regional geological structures. The complex interplay of sedimentary cover thickness, fault structures, and focal depth introduces significant variability in the observed macroseismic intensity patterns across the country. Most notably are the anisotropic attenuation, most evidently observed within the Anglo-Brabant massif region, as well as the high attenuation rates in Hainaut and Liège coal basins. These variations in ground motion attenuation highlight the high spatial variability in seismic response, a factor that must be accounted for in future seismic hazard assessments for Belgium.

In spite of these variable ground motion attenuation rates throughout the country, as well as the insufficiently available macroseismic data, the development of Belgium specific intensity prediction equations (IPEs) remains out of reach. Only in the Hainaut coal basin, where seismicity was both frequent (i.e. during the 20$^{th}$ century) and spatially confined, it was possible to develop a tailored IPE, as was evidenced by Camelbeeck et al. (2022). For other regions within Belgium, the performance of various IPEs in literature were ranked. Three models stood out from the analysis. The chi-square regression attenuation relation by Stromeyer and Grünthal (2009) was found to offer the most consistent overall performance across different regions and event types, while the French stable continental region model by Bakun and Scotti (2006) showed significant potential for the application of rapid earthquake response tools in the near future for Belgium, such as the nation-wide development of ShakeMap, as the best performing magnitude-based model. While developed specifically for the Hainaut coal basin, the IPE by Camelbeeck et al. (2022) also performs well for shallow events in other regions within Belgium.

# 7. Conclusions and perspectives

This PhD dissertation significantly advances the study of macroseismology in Belgium by providing, for the first time, a comprehensive summary, compilation, and review of Belgian Macroseismic intensity data and survey methodologies. Through the systematic development and analysis of two new datasets, the Belgian Traditional Macroseismic (BTM) and Belgian Online Macroseismic (BOM) databases, this dissertation provides a unique, 125-year record of the seismic impact on Belgium. These datasets fill a long-standing gap in Belgian seismic research and provide a critical resource for future studies in engineering seismology, including seismic hazard assessments and the development of rapid earthquakes response tools.

The most prominent contribution of this work is **the creation and publication of two extensive, open-access Macroseismic databases**:

- the BTM database, comprising 23,950 validated intensity data points (IDPs) for 80 felt events during the 20th century. The BTM database compiles data from a wide range of traditional Macroseismic sources including ROB communal questionnaires, letters, newspaper articles, field surveys and various (un)published macroseismic studies.
- the BOM database, comprising 21,670 individual responses collected through the “Did You Feel It?” (DYFI?) inquiry since 2002. With 39 felt events and a total of 1,220 IDPs, the BOM database demonstrates the value of online public participation in macroseismic surveys, especially during a period of relative seismic quiescence in Belgium.

Together, these resources represent the most complete macroseismic dataset ever assembled for Belgium, covering 119 felt earthquakes and 25,170 IDPs. These databases set a new standard for seismic data archiving in the region and will serve as an essential basis for both real-time applications and long-term hazard modelling. The maps provided in this work further summarize the seismic impact on Belgium of the past 125 years.

A second major contribution lies in **the critical evaluation of traditional macroseismic survey methodologies**. This work introduces a data quality grading system that classifies events based on the reliability of their sources, i.e. “fair” (A), “poor” (B) or “bad” (C), and shows how subjective interpretation, methodological heterogeneity and incomplete data limit the accuracy of intensity assignments. It also demonstrates the impact of expert bias in manual evaluations, based on a direct comparison between algorithmic and traditional manual intensity assessments.

This analysis not only highlights the limitations of past practices but also proposes a path forward: an adaptive, web-based communal questionnaire designed to integrate the strengths of traditional surveys with the consistency of modern, standardized data collection.

This dissertation also offers a rare critique of the widely used calculation procedure for determining intensity values from the “Did You Feel It?” (DYFI?) online inquiry, highlighting its limitations when applied to low-to-moderate seismic regions such as Belgium. The validity of intensity values derived from DYFI’s Community Weighted Sum, which are based on a calibration with Californian data and may not accurately reflect true macroseismic intensity in different geological and cultural contexts.

A third key innovation is **the integration of macroseismic observations into seismic hazard validation and ground motion modelling**. By converting observed maximum intensities to peak ground acceleration (PGA) values, this study validates the most recent Belgian seismic hazard model. It shows that incorporating local site effects leads to a significantly better agreement between observed macroseismic data and predicted ground motion data.

This work has also identified the Stromeyer and Grünthal (2009) chi-square regression model and the Bakun and Scotti (2006) French stable continental region model as the most effective models to approximate Belgian ground motion attenuation. For shallow or mining-induced earthquakes, the Camelbeeck et al. (2022) Hainaut coal basin model was shown to be the most accurate. These findings provide a practical aid for future applications, including ShakeMap generation and rapid earthquake response tools.

The tools, datasets and insights developed in this dissertation pave the way for a new generation of macroseismic research in Belgium. They also provide a methodological blueprint for other regions with low or low-to-moderate seismic activity facing similar data limitations.

The next logical step after this research would be to map the residuals between the predictions of the best performing IPEs and the observations. This should provide constraints on the impact of ground motion amplification and highlight regions of amplification in Belgium and would provide a very useful source of information for seismic hazard assessments in the future. The best performing IPEs can also be applied to determine earthquake source parameters, as demonstrated for the $M_L$ = 5.1 Uden 1932 earthquake in Dost et al. (2025). The selection process for identifying the most suitable IPEs could be further refined by expanding the dataset to include additional IPEs, even from outside northwestern Europe, as well as incorporating a broader range of statistical parameters. This would allow for a more comprehensive and robust evaluation of IPE performance.

The extensive archive of macroseismic information has also not been fully explored. It still contains a substantial collection of letters detailing personal earthquake experiences that have not been processed. While individual letters often have high uncertainty, as their descriptions may not be representative of an entire area, the impact of larger earthquakes has generated a significant volume of correspondence from the public. In some cities, more than 100 letters were sometimes received, providing a more representative overview of the macroseismic effects experienced. Analyzing these letters could offer additional insights into the robustness of the intensity values derived from ROB communal surveys.

# 8. PhD Thesis Publications and Outreach

**PEER-REVIEWED PUBLICATIONS:**

**Neefs B**, Van Noten K, Vanneste K, Camelbeeck T (2024a). The Belgian traditional macroseismic (BTM) database of the twentieth century. Journal of Seismology. https://doi.org/10.1007/s10950-024-10266-9

Vanneste K, **Neefs B**, Camelbeeck T (2024). Testing the applicability of ground motion prediction equations for the Hainaut region (Belgium) using intensity data. Bulletin of Earthquake Engineering 22, 5321–5345. https://doi.org/10.1007/s10518-024-01958-1

Dost B, **Neefs B**, Van Noten K, Ruigrok E. (2025). The damaging 1932 Uden Earthquake in The Netherlands – revision of cross- border macroseismic data and its impact on source parameters. Journal of Seismology. https://doi.org/10.1007/s10950-024-10278-5

**DATASETS**

**Neefs B**, Van Noten K, Vanneste K, Camelbeeck T. (2024b). The Belgian Traditional Macroseismic (BTM) Database of the 20th Century [Data set]. https://doi.org/10.24414/2b5w-j029

Vanneste K, **Neefs B**, Camelbeeck T (2023). Macroseismic intensity data points for shallow 20th century earthquakes in the Hainaut coal area and the 1983 Liège earthquake (Belgium) (Version v2) [Data set]. Royal Observatory of Belgium. https://doi.org/10.5281/zenodo.10047233

**CONTRIBUTIONS TO (INTER)NATIONAL CONFERENCES**

Dost B, **Neefs B**, Van Noten K (2023). "Re-assessment of the Macroseismic Intensity Source Parameters for the ML 5.0 1932 Uden earthquake, the Netherlands". Talk presented at 8$^{th}$ International Colloquium on Historical Earthquakes, Palaeo-, Macroseismology and Seismotectonics on 2023-01-18

**Neefs B**, Van Noten K (2023). "Discrepancy Between Traditional and Online Intensities - Revisiting the Relation between two different Macroseismic Datasets in Belgium". 8th International Colloquium on Historical Earthquakes, Paleo-Macroseismology and Seismotectonics on 2023-09-18

**Neefs B**, Vanneste K, Camelbeeck T, Van Noten K (2023). "Ranking GMPEs using macroseismic intensity data of 20th century mining-triggered earthquakes". Talk presented at American Geophysical Union AGU 23 on 2023-12-14

**Neefs B**, Van Noten K (2022). "Modelling earthquake ground motion attenuation in Belgium with macroseismic intensity data". Talk presented at Belqua Workshop, Royal Academies of Science and the Arts of Belgium, Brussels, Belgium on 2022-03-29

**Neefs B**, Van Noten K, Camelbeeck T (2022) "Towards a harmonized macroseismic database for Belgium". Talk presented at 3rd European conference on earthquake engineering and seismology, Bucharest, Romania on 2022-09-07.

**Neefs B**, Van Noten K, Camelbeeck T (2021). "The complexity of modelling anisotropic intensity attenuation in Belgium". Talk presented at 37th General Assembly of the European Seismological Commission.

**Neefs B**, Van Noten K, Camelbeeck T (2021). "The Effects of Belgian Crustal Geology and its Sedimentary Cover on Macroseismic Intensity Attenuation". Talk presented at 7th INTERNATIONAL GEOLOGICA BELGICA MEETING 2021 on 2021-09-17

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# 10. Supplementary information

## 10.1. Intensity scales

### 10.1.1. The Sieberg scale (1912 version)

The Sieberg scale (1912) as translated by Davison (1921). This comprehensive scale greatly increased the number of diagnostics in comparison to its predecessors (de Rossi 1883; Forel 1884; Mercalli 1902).

| Intensity | Definitions |
|---|---|
| 1 | **Imperceptible.** The shock is not felt by anyone; only the records of seismometers adapted for earthquakes of near origin, or of sensitive seismoscopes give notice of it. |
| 2 | **Very slight.** Only a few people in perfect repose, especially those with sensitive nerves, feel the shock as a slight tremor or rocking. The shock is especially sensible on the upper floors of houses and very rarely on the ground floor. Also, the quiet of the night is favourable to its perception, if the observer is awake. |
| 3 | **Slight.** Even in densely populated districts, the shock is felt by only a few people as a shaking like that produced by the rapid passing of a wagon. Occasionally, the duration, and perhaps also the direction, of the movement can be detected. Many only realize afterwards, in talking with others, that there has been an earthquake. |
| 4 | **Moderate.** Of people in the open air, not many feel the earthquake. Indoors, many persons, but not all, recognize the trembling or slight rocking movement of furniture; glasses and crockery near together gently strike one another as they do when a heavily laden wagon is driven by on an uneven pavement; windows rattle; doors, joists, floors, and ceilings creak; liquids in open vessels are slightly moved. Alarm is hardly ever caused except in the case of people who have already become nervous and anxious through the experience of other earthquakes. In a few cases, sleepers awake. |
| 5 | **Rather strong.** Even during the busiest hours of the day, the earthquake is felt by many people in the open air. Indoors, the shaking of the whole building is generally noticed, the feeling being the same as when some heavy object (such as a sack or piece of furniture) falls in the house; or the observers move, together with chair, bed, etc., as in a ship on an agitated sea. Plants, the branches and weaker boughs of shrubs and trees sway visibly, as they do with a moderate wind. Freely hanging objects, such as curtains and lamps, but not heavy chandeliers, oscillate; small bells ring; the pendulums of clocks are stopped or swing more widely according as the direction of the shock is at right angles or parallel to the plane of oscillation; similarly, stopped pendulum clocks are set going; the striking spring of clocks sounds; electric lights fail to act when contact of the conducting wire is made; pictures rattle against the walls or are displaced; small quantities of liquid are spilt out of well-filled open vessels; ornaments, small standing frames fall and also objects leaning against the wall; even light furniture may be somewhat shifted from its place, rattling of furniture; doors and window-shutters open or shut; window-panes crack. Sleepers as a rule are awakened. A few people run into the open air. |
| 6 | **Strong.** The earthquake is felt by everyone with alarm, so that very many persons run into the open air, many thinking that they must fall. Liquids move violently, pictures fall from the walls, books, etc., from shelves, unless the direction of the shock is parallel to that of the walls; numerous vessels are broken; a few pieces of stable furniture are shifted or overturned; church bells and church clocks strike. In a few solidly built mid-European houses there are cracks in the plaster, which is detached here and there in fragments from the roof and walls. In poorly built houses, the damage is greater, but still not of a serious nature. |

7 **Very strong.** Considerable damage is done to furniture through the upsetting or breaking even of heavy pieces. Even large church bells strike. The surfaces of rivers, ponds, and lakes are disturbed, and the mud at the bottom stirred up. A few slips of sandy and gravelly coasts. The level of water in wells is changed. Notwithstanding their solid construction, many mid-European houses suffer moderate damage; there are slight fractures in walls, large pieces of plaster crumble down, tiles fall, pantiles are loosened and slip down. Chimneys are damaged by cracks and by the falling of weather moulding and stones; chimneys in bad condition break off at the roof and injure it. Badly fastened decorations fall down from towers and high buildings. In framework buildings, and especially in their partition walls, the damage to the plastering is great. Buildings that are badly built or out of repair suffer seriously in the same way; wooden fences, sheds, high enclosure walls, cottages and even churches, minarets of mosques, etc., in many country districts of southern Europe, fall down to a greater or less extent. Earthquake-proof buildings, such as most of the stone and wooden houses in Japan, and the wood and wattled buildings, which are used in such great quantities in tropical earthquake districts, remain quite undamaged.

8 **Ruinous.** The trunks of trees, of palms especially, sway as with a strong wind. Even the heaviest pieces of furniture are shifted some distance or overturned. Statues, etc., near the ground, such as those in churches, churchyards, public parks, etc., either rotate on their pedestals or fall. Stone enclosure-walls are split and thrown to the ground. Notwithstanding their solid construction, mid-European houses suffer serious damage, with gaping cracks in the masonry; in some cases, they collapse partly; most chimneys fall; church towers and factory chimneys especially so suffer, and, by their fall, neighbouring houses may be more seriously damaged as if by the action of the shock alone; exceptionally well-built factory chimneys are only fractured and displaced in their upper portions. Earthquake-proof buildings (such as those of Japan) show, slight damage, such as fractures, the crumbling of plaster, etc. (see degree 7, mid-European houses), and wooden houses crack considerably in their joints. Rotten posts of Malayan stake-huts break. Slight cracks in the ground near steep slopes and in damp soil; a few outflows of water carrying small quantities of sand or mud.

9 **Disastrous.** Solidly built houses of European construction are seriously damaged, so that a large number becomes uninhabitable, a few fall completely or nearly so. Framework buildings are displaced on their stone foundations, on account of which they are under certain conditions damaged. Earthquake-proof buildings made of stone show considerable damage, the walls of wooden ones reveal gaps and cracks, old wooden houses are loosened in their frames.

10 **Destructive.** Most stone and framework buildings are overthrown together with their foundations, even first-class brick walls show dangerous cracks, but the percentage of those of mid-European construction is larger than in the case of earthquake-proof buildings. Even well-built wooden houses and bridges suffer serious damage, a few are even demolished. Embankments, dams, etc., are more or less considerably damaged. Iron railway-lines are slightly bent. Conduit pipes (gas, water, etc.) in the ground are rent or compressed. Fissures and undulating folds are formed in the asphalt of the streets. Loose, and especially damp, ground shows fissures up to several decimetres in width; especially near water-courses, there may be parallel fissures from one-half to three-quarters of a meter wide. Not only does loose ground slide down from cliffs as landslips, but also rockslides fall into the valleys from the mountains, from the banks of rivers and even steep coasts whole parts break off, and on flat coasts masses of sand and mud are displaced, by which substantial changes in the form of the ground are wrought. The level of water springs is changed. From rivers, canals and lakes, water is thrown on to the banks.

11 **Catastrophe.** Stone buildings of whatever kind practically no longer stand. Even solid buildings of wood or wattling are only in a few cases able to survive, especially near lines of faulting. Bridge-buildings, though large and securely constructed, are destroyed by the breaking off of massive stone piers or fracture of iron shafts. Yielding wooden floors, however, are sometimes less damaged. Embankments and dams are quite torn asunder, frequently for long distances. Iron rails are strongly bent and compressed. The kind and amount of damage to roads depends on the nature of the foundations. Conduit pipes in the ground are completely severed and rendered useless. The most varied and very considerable morphological changes of the ground are noticed, which are closely defined by the nature of the ground; wide fissures and cracks are formed, the derangements in the horizontal and vertical directions being especially important in soft and watery ground. There is also the appearance in various forms of water carrying sand and mud. Landslips and rocks-falls are numerous.

12 **Great catastrophe.** No work of human hands remains standing. The derangements and transformations of the ground attain the grandest dimensions. Even in rocky ground, faults of considerable depth are formed, with great horizontal movements and numerous fissures. Dock cliffs break, rock-falls, landslips, collapse of riverbanks or shore are numerous and widespread. Underground and surface waters in consequence undergo the most various derangements; waterfalls are formed, lakes are dammed, rivers diverted, etc.

### 10.1.2. The Wood-Neumann scale

The Wood-Neumann scale (Wood and Neumann 1931), commonly known as the Modified Mercalli intensity scale of 1931.

| Intensity | Definitions |
|---|---|
| **1** | **Not felt** or, except rarely under especially favorable circumstances.<br>Under certain conditions, at and outside the boundary of the area in which a great shock is felt:<br>sometimes birds, animals, reported uneasy or disturbed;<br>sometimes dizziness or nausea experienced;<br>sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly. |
| **2** | **Felt indoors by few, especially on upper floors,** or by sensitive, or nervous persons.<br>Also, as in grade I, but often more noticeably:<br>sometimes **hanging objects may swing**, especially when delicately suspended;<br>sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly;<br>sometimes birds, animals reported uneasy or disturbed;<br>sometimes dizziness or nausea experienced. |
| **3** | **Felt indoors by several, motion usually rapid vibration.**<br>Sometimes not recognized to be an earthquake at first.<br>**Duration estimated** in some cases.<br>Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away.<br>**Hanging objects may swing slightly.**<br>Movements may be appreciable on upper levels of tall structures.<br>Rocked standing motor cars slightly. |
| **4** | **Felt indoors by many, outdoors by few.**<br>**Awakened few**, especially light sleepers.<br>**Frightened no one**, unless apprehensive from previous experience.<br>Vibration like that due to passing of heavy, or heavily loaded trucks.<br>Sensation like heavy body striking building, or falling of heavy objects inside.<br>**Rattling of dishes, windows, doors**; glassware and crockery clink and clash.<br>**Creaking of walls, frame**, especially in the upper range of this grade.<br>**Hanging objects-swung**, in numerous instances.<br>Disturbed liquids in open vessels **slightly.**<br>Rocked standing motor cars noticeably. |
| **5** | **Felt indoors by practically all, outdoors by many or most: outdoors direction estimated.**<br>**Awakened many,** or most.<br>**Frightened few** - slight excitement, a few ran outdoors.<br>Buildings trembled throughout.<br>**Broke dishes,** glassware, to some extent.<br>**Cracked windows** - in some cases, but not generally.<br>**Overturned vases, small or unstable objects**, in many instances, with occasional fall.<br>**Hanging objects, doors, swing** generally or considerably.<br>Knocked pictures against walls, or swung them out of place.<br>Opened, or closed, doors, shutters, abruptly.<br>**Pendulum clocks stopped**, started, or ran fast, or slow.<br>**Moved small objects, furnishings,** the latter to slight extent.<br>**Spilled liquids** in small amounts from well-filled open containers.<br>**Trees, bushes, shaken slightly.** |

**6** **Felt by all,** indoors and outdoors.
**Frightened many,** excitement general, some alarm, many ran outdoors.
**Awakened all.**
Persons made to move unsteadily.
**Trees, bushes, shaken slightly to moderately.**
Liquid set in strong motion.
Small bells rang - church, chapel, school, etc.
**Damage slight** in poorly built buildings.
**Fall of piaster** in small amount_
**Cracked plaster** somewhat, especially fine cracks **chimneys** in some instances.
**Broke dishes**, glassware, in considerable quantity, also some windows.
**Fall of knick-knacks, books, pictures.**
**Overturned furniture** in many instances.
**Moved furnishings** of moderately heavy kind.

**7** **Frightened all** - general alarm, all ran outdoors.
Some, or many, found it difficult to stand.
Noticed by persons driving motor cars.
**Trees and bushes shaken moderately to strongly.**
Waves on ponds, lakes, and running water.
Water turbid from mud stirred up.
Incaving to some extent of sand or gravel stream banks.
Rang large church bells, etc.
Suspended objects made to quiver.
**Damage negligible** in buildings of good design and construction, **slight** to moderate in well-built ordinary, buildings, **considerable** in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires etc.
**Cracked chimneys** to considerable extent, **walls** to some extent.
**Fall of plaster** in considerable to large amount, also some stucco.
**Broke numerous windows, furniture** to some extent.
Shook down loosened brickwork and tiles.
Broke weak chimneys at the roof-line (sometimes damaging roofs).
**Fall of cornices** from towers and high buildings.
Dislodged bricks and stones.
**Overturned heavy furniture**, with damage from breaking.
**Damage considerable** to concrete irrigation ditches.

**8** **Fright general** - alarm approaches panic.
Disturbed persons driving motor cars.
**Trees shaken strongly** - branches, trunks, broken off, especially palm trees.
Ejected sand and mud in small amounts.
Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring, and well waters.
**Damage slight** in structures (brick) built especially to withstand earthquakes.
**Considerable** in ordinary substantial buildings, partial collapse:
racked, tumbled down, wooden houses in some cases; threw out panel wails in frame structures, broke off decayed piling.
**Fall of walls.**
**Cracked, broke, solid stone walls seriously.**
**Wet ground** to some extent, also ground on steep slopes.
**Twisting, fall, of chimneys, columns, monuments,** also factory stacks, towers.
**Moved conspicuously, overturned, very heavy furniture.**

9 Panic general.
**Cracked ground conspicuously.**
**Damage considerable** in (masonry) structures built especially to withstand earthquakes:
threw out of plumb some wood-frame houses built especially to withstand earthquakes;
great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames;
serious to reservoirs; underground pipes sometimes broken.

10 **Cracked ground,** especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks.
Landslides considerable from river banks and steep coasts.
Shifted sand and mud horizontally on beaches and flat land.
Changed level of water in wells.
Threw water off banks of canals, lakes, rivers, etc.
**Damage serious** to dams, dikes, embankments.
Severe to well-built wooden structures and bridges, some destroyed.
Developed dangerous cracks in excellent brick walls.
Destroyed most masonry and frame structures, also their foundations.
Bent railroad rails slightly.
Tore apart, or crushed endwise, pipe lines buried in earth.
Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

11 Disturbances in ground many and widespread, varying with ground material.
Broad fissures, earth slumps, and land slips in soft, wet ground.
Ejected water in large amount charged with sand and mud.
Caused sea-waves ("tidal" waves) of significant magnitude.
**Damage severe** to wood-frame structures, especially near shock centers.
Great to dams, dikes, embankments, often for long distances.
Few, if any (masonry), structures remained standing.
Destroyed large well-built bridges by the wrecking of supporting piers, or pillars.
Affected yielding wooden bridges less.
Bent railroad rails greatly, and thrust them endwise.
Put pipe lines buried in earth completely Out of service.

12 **Damage total** - practically all works of construction damaged greatly or destroyed.
Disturbances in ground great and varied, numerous shearing cracks.
Landslides, falls of rock of significant character, slumping of river banks; etc., numerous and extensive.
Wrenched loose, tore off, large rock masses.
Fault slips in firm rock, with notable horizontal and vertical offset displacements.
Water channels, surface and underground, disturbed and modified greatly.
Dammed lakes, produced waterfalls, deflected rivers, etc.
Waves seen on ground surfaces (actually seen, probably, in some cases).
Distorted lines of sight and level.
Threw objects upward into the air.

### 10.1.3. The Medvedev-Sponheuer-Kárník scale

The Medvedev-Sponheuer-Kárník (MSK-64) scale (Medvedev et al. 1964).

| Types of structures (buildings) | |
|---|---|
| **Structure A** | Buildings in field-stone, rural structures, Adobe houses, clay houses. |
| **Structure B** | Ordinary brick buildings, buildings of the large block and prefabricated type, half timbered structures, buildings in natural hewn stone. |
| **Structure C** | Reinforced buildings, well-built wooden structures. |

| Classification of damage to buildings | |
|---|---|
| **Grade 1** | Slight damage: Fine cracks in plaster; fall of small pieces of plaster. |
| **Grade 2** | Moderate damage: Small cracks in walls; fall of fairly large pieces of plaster; pantiles slip off; cracks in chimneys; parts of chimneys fall down. |
| **Grade 3** | Heavy damage: Large cracks in walls; fall of chimneys. |
| **Grade 4** | Destruction: Gaps in walls; parts of buildings may collapse; separate parts of the building lose their cohesion; inner walls collapse. |
| **Grade 5** | Total damage: Total collapse of buildings. |

| Definition of quantity | |
|---|---|
| **Single, few** | About 5% |
| **Many** | About 50% |
| **Most** | About 75% |

| Arrangement of the scale | |
|---|---|
| **a** | Persons and surroundings |
| **b** | Structures of all kinds |
| **c** | Nature |

| Intensity | Definitions |
| --- | --- |
| **1** | *Not noticeable.*<br>a) The intensity of the vibration is below the limit of sensibility; the tremor is detected and recorded by seismographs only. |
| **2** | *Scarcely noticeable (very slight)*<br>a) Vibration is felt only by individual people at rest in houses, especially on upper floors of buildings. |
| **3** | *Weak, partially observed only*<br>a) The earthquake is felt indoors by a few people, outdoors only in favourable circumstances. The vibration is like that due to the passing of a light truck. Attentive observers notice a slight swinging of hanging objects. |
| **4** | *Largely observed*<br>a) The earthquake is felt indoors by many people, outdoors by few. Here and there people awake, but no one is frightened. The vibration is like that due to the passing of a heavily loaded truck. Windows, doors and dishes rattle. Floors and walls creak. Furniture begins to shake. Hanging objects swing slightly. Liquids in open vessels are slightly disturbed. In standing motor cars the shock is noticeable. |
| **5** | *Awakening*<br>a) The earthquake is felt indoors by all, outdoors by many. Many sleeping people awake. A few run outdoors. Animals become uneasy. Buildings tremble throughout. Hanging objects swing. Pictures knock against the wall or swing out of place. Occasionally pendulum clocks stop. Unstable objects may be overturned or shifted. Doors and windows are thrust open and slam back again. Liquids spill in small amounts from well-filled open containers. The sensation of vibration is like that due to a heavy object falling inside the building.<br>c) Slight waves on standing water; sometimes change in flow of springs. |
| **6** | *Frightening*<br>a) Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoors. A few persons lose their balance. Domestic animals run out of their stalls. In many instances dishes and glassware may break, books fall down, pictures move and unstable objects overturn. Heavy furniture may possibly move and small steeple bells may ring.<br>b) Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in some buildings of type A is of grade 2.<br>c) Cracks up to widths of 1 cm possible in wet ground; in mountains occasional land-slips; change in flow of springs and in level of well-water. |
| **7** | *Damaging*<br>a) Most people are frightened and run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving motor cars. Large bells ring.<br>b) In many buildings of type C damage of grade 1 is caused; in buildings of type B damage is of grade 2. Most buildings of type A suffer damage of grade 3, some of grade 4. In single instances land-slips of roadway on steep slopes; cracks in roads; seams of pipelines damaged; cracks in stone walls.<br>c) Waves are formed on water, and water is made turbid by mud stirred up. Water levels in wells change, and the flow of springs changes. Sometimes dry springs have their flow restored and existing springs stop flowing. In isolated instances parts of sandy or gravelly banks slip off. |

**8** *Destruction of buildings*
a) Fright and panic; also persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hanging lamps are in part damaged.
b) Most buildings of type C suffer damage of grade 2. Most buildings of type B suffer damage of grade 3, and most buildings of type A suffer damage of grade 4. Many buildings of type C suffer damage of grade 4, here and there of grade 5. Occasional breakage of pipe seams. Memorials and monuments move and twist. Tombstones overturn. Stone walls collapse.
c) Small land-slips in hollows and on banked roads on steep slopes; cracks in ground up to widths of several centimeters. Water in lakes becomes turbid. New reservoirs come into existence. Dry wells refill and existing wells become dry. In many cases change in flow and level of water.

**9** *General damage to buildings*
a) General panic; considerable damage to furniture. Animals run to and from in confusion and cry.
b) Many buildings of type C suffer damage of grade 3, some of grade 4. Many buildings of type B show damage of grade 4, a few of grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railway lines are bent and roadways damaged.
c) On flat land overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10 cm, on slopes and river banks more than 10 cm; furthermore a large number of slight cracks in ground; falls of rock, many landslides and earth flows; large waves on water. Dry wells renew their flow and existing wells dry up.

**10** *General destruction of buildings*
b) Many buildings of type C suffer damage of grade 4, some of grade 5. Many buildings of type B show damage of grade 5, most of type A have destruction category 5; critical damage to dams and dykes and severe damage to bridges. Railway lines are bent slightly. Underground pipes are broken or bent. Road pavement and asphalt show waves.
c) In ground, cracks up to widths of several dcm, sometimes up to 1 meter. Parallel to water courses occur broad fissures. Loose ground slides from steep slopes. From river banks and steep coast considerable landslides are possible. In coastal areas displacement of sand and mud; change of water level in wells; water from canals, lakes, rivers etc. thrown on land. New lakes occur.

**11** *Destruction*
b) Severe damage even to well-built buildings, bridges, water dams and railway lines; highways become useless; underground pipes destroyed.
c) Ground considerably distorted by broad cracks and fissures, as well as by movement in horizontal and vertical directions; numerous land slips and falls of rock. The intensity of the earthquake requires to be investigated specially.

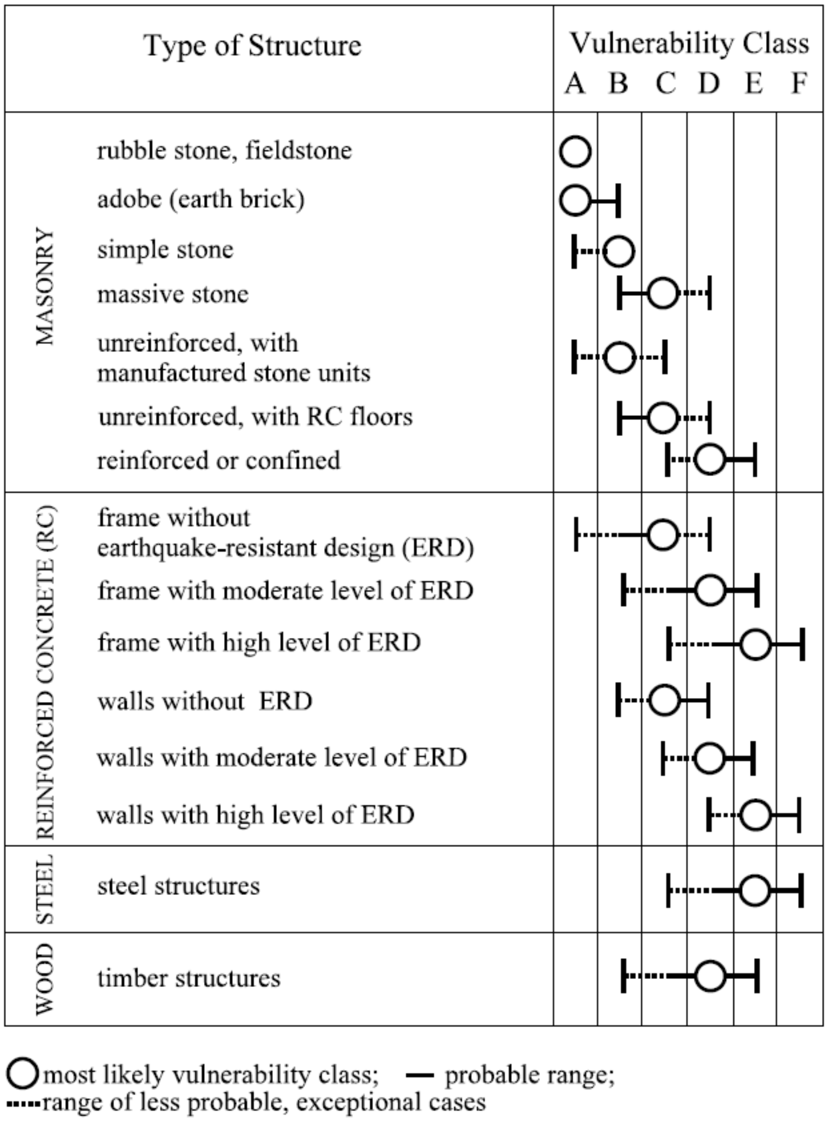
**12** *Landscape changes*
b) Practically all structures above and below ground are greatly damaged or destroyed.
c) The surface of the ground is radically changed. Considerable ground cracks with extensive vertical and horizontal movements are observed. Falls of rock and slumping of river banks over wide areas; lakes are dammed; waterfalls appear, and rivers are deflected.

### 10.1.4. The European Macroseismic scale (EMS-98) by Grünthal (1998)

| Damage grades | Masonry buildings | Buildings of reinforced concrete |
|---|---|---|
| **1. Negligible to slight damage** (no structural damage, slight non-structural damage) | Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases. | Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills. |
| **2. Moderate damage** (slight structural damage, moderate non-structural damage) | Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys. | Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels. |
| **3. Substantial to heavy damage** (moderate structural damage, heavy non-structural damage) | Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls). | Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels. |
| **4. Very heavy damage** (heavy structural damage, very heavy non-structural damage) | Serious failure of walls; partial structural failure of roofs and floors. | Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor. |
| **5. Destruction** (very heavy structural damage) | Total or near total collapse. | Collapse of ground floor or parts (e. g. wings) of buildings. |

| **Definition of quantity** | |
|---|---|
| **Few** | 0-20% |
| **Many** | 10-60% |
| **Most** | 50-100% |

| **Arrangement of the scale** | |
|---|---|
| **a** | Effects on humans |
| **b** | Effects on objects and nature |
| **c** | Damage to buildings |


Type of Structure
Vulnerability Class
A B C D E F
MASONRY
rubble stone, fieldstone
adobe (earth brick)
simple stone
massive stone
unreinforced, with manufactured stone units
unreinforced, with RC floors
reinforced or confined
REINFORCED CONCRETE (RC)
frame without earthquake-resistant design (ERD)
frame with moderate level of ERD
frame with high level of ERD
walls without ERD
walls with moderate level of ERD
walls with high level of ERD
STEEL
steel structures
WOOD
timber structures
most likely vulnerability class; probable range;
range of less probable, exceptional cases

| Intensity | Definitions of the European Macroseismic Scale (EMS-98; Grünthal 1998) |
|---|---|
| 1 | **Not felt**<br>**a)** Not felt, even under the most favourable circumstances.<br>**b)** No effect.<br>**c)** No damage. |
| 2 | **Scarcely felt**<br>**a)** The tremor is felt only at isolated instances (<1%) of individuals at rest and in a specially receptive position indoors.<br>**b)** No effect.<br>**c)** No damage. |
| 3 | **Weak**<br>**a)** The earthquake is felt indoors by a few. People at rest feel a swaying or light trembling.<br>**b)** Hanging objects swing slightly.<br>**c)** No damage. |
| 4 | **Largely observed**<br>**a)** The earthquake is felt indoors by many and felt outdoors only by very few. A few people are awakened. The level of vibration is not frightening. The vibration is moderate. Observers feel a slight trembling or swaying of the building, room or bed, chair etc.<br>**b)** China, glasses, windows and doors rattle. Hanging objects swing. Light furniture shakes visibly in a few cases. Woodwork creaks in a few cases.<br>**c)** No damage. |
| 5 | **Strong**<br>**a)** The earthquake is felt indoors by most, outdoors by few. A few people are frightened and run outdoors. Many sleeping people awake. Observers feel a strong shaking or rocking of the whole building, room or furniture.<br>**b)** Hanging objects swing considerably. China and glasses clatter together. Small, top-heavy and/or precariously supported objects may be shifted or fall down. Doors and windows swing open or shut. In a few cases window panes break. Liquids oscillate and may spill from well-filled containers. Animals indoors may become uneasy.<br>**c)** Damage of grade 1 to a few buildings of vulnerability class A and B. |
| 6 | **Slightly damaging**<br>**a)** Felt by most indoors and by many outdoors. A few persons lose their balance. Many people are frightened and run outdoors.<br>**b)** Small objects of ordinary stability may fall and furniture may be shifted. In few instances dishes and glassware may break. Farm animals (even outdoors) may be frightened.<br>**c)** Damage of grade 1 is sustained by many buildings of vulnerability class A and B; a few of class A and B suffer damage of grade 2; a few of class C suffer damage of grade 1. |
| 7 | **Damaging**<br>**a)** Most people are frightened and try to run outdoors. Many find it difficult to stand, especially on upper floors.<br>**b)** Furniture is shifted and top-heavy furniture may be overturned. Objects fall from shelves in large numbers. Water splashes from containers, tanks and pools.<br>**c)** Many buildings of vulnerability class A suffer damage of grade 3; a few of grade 4.<br>Many buildings of vulnerability class B suffer damage of grade 2; a few of grade 3.<br>A few buildings of vulnerability class C sustain damage of grade 2.<br>A few buildings of vulnerability class D sustain damage of grade 1. |

**8** **Heavily damaging**

**a)** Many people find it difficult to stand, even outdoors.

**b)** Furniture may be overturned. Objects like TV sets, typewriters etc. fall to the ground. Tombstones may occasionally be displaced, twisted or overturned. Waves may be seen on very soft ground.

**c)** Many buildings of vulnerability class A suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class B suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class C suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class D sustain damage of grade 2.

**9** **Destructive**

**a)** General panic. People may be forcibly thrown to the ground.

**b)** Many monuments and columns fall or are twisted. Waves are seen on soft ground.

**c)** Many buildings of vulnerability class A sustain damage of grade 5. Many buildings of vulnerability class B suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class C suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class D suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class E sustain damage of grade 2.

**10** **Very destructive**

**c)** Most buildings of vulnerability class A sustain damage of grade 5. Many buildings of vulnerability class B sustain damage of grade 5. Many buildings of vulnerability class C suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class D suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class E suffer damage of grade 2; a few of grade 3. A few buildings of vulnerability class F sustain damage of grade 2.

**11** **Devastating**

**c)** Most buildings of vulnerability class B sustain damage of grade 5. Most buildings of vulnerability class C suffer damage of grade 4; many of grade 5. Many buildings of vulnerability class D suffer damage of grade 4; a few of grade 5. Many buildings of vulnerability class E suffer damage of grade 3; a few of grade 4. Many buildings of vulnerability class F suffer damage of grade 2; a few of grade 3.

**12** **Completely devastating**

**c)** All buildings of vulnerability class A, B and practically all of vulnerability class C are destroyed. Most buildings of vulnerability class D, E and F are destroyed. The earthquake effects have reached the maximum conceivable effects.

### 10.1.5. The Somville scale (Somville 1936)

*The Somville scale as defined in Somville (1936). This scale is based on the French version of the MCS-23 scale (Sieberg 1917), strongly condensed and slightly modified to be better suited for Belgian earthquakes. Somville and others ROB seismologists refer to the MCS-23 scale, while using the scale given below.*

**Degré I.** – Secousse non ressenti par l'homme, signalée seulement par les séismographes.

**Degré II.** – Un petit nombre d'observateurs au repos et plus particulièrement ceux qui se trouvent aux étages supérieurs des maisons, ressentent une très légère secousse accompagnée d'un grondement sourd semblable à un coup de tonnerre lointain, à une explosion ou encore au roulement d'un train. Très souvent, on ne perçoit que le bruit. La tranquillité de la nuit est plus favorable à l'observation pour les personnes à l'état de veille.

**Degré III.** – Même dans les localités à forte population, le phénomène n'est remarque que par un petit nombre d'habitants sous forme de vibrations comparables à celles que produit un lourd auto-camion roulant à vive allure sur une route pavée. Parfois, on peut apprécier la durée et la direction du mouvement.

**Degré IV.** – Un grand nombre de personnes remarquent le tremblement des objets mobiliers et le choc des verres ou objets de vaisselle places très près les uns des autres. Les vitres frémissent, les portes et les planchers craquent, les plafonds bruissent. Les bruits qui accompagnent les vibrations sont plus intenses. Un certain nombre de dormeurs se réveillent.

**Degré V.** – La secousse peut être ressentie par des personnes se trouvant en plein air. A l'intérieur des maisons, chacun s'en rend compte par suite de l'ébranlement de toute la construction. On a l'impression qu'un objet très lourd est tombé dans une des pièces. On oscille avec les chaises, les lits, etc. Des objets suspendus librement se mettent à osciller ; des bibelots posés sur les meubles peuvent tomber ; des objets légers peuvent être déplacés ; portes et fenêtres frappent ; des vitres se brisent. Tous les dormeurs se réveillent. Quelques personnes effrayées sortent des habitations.

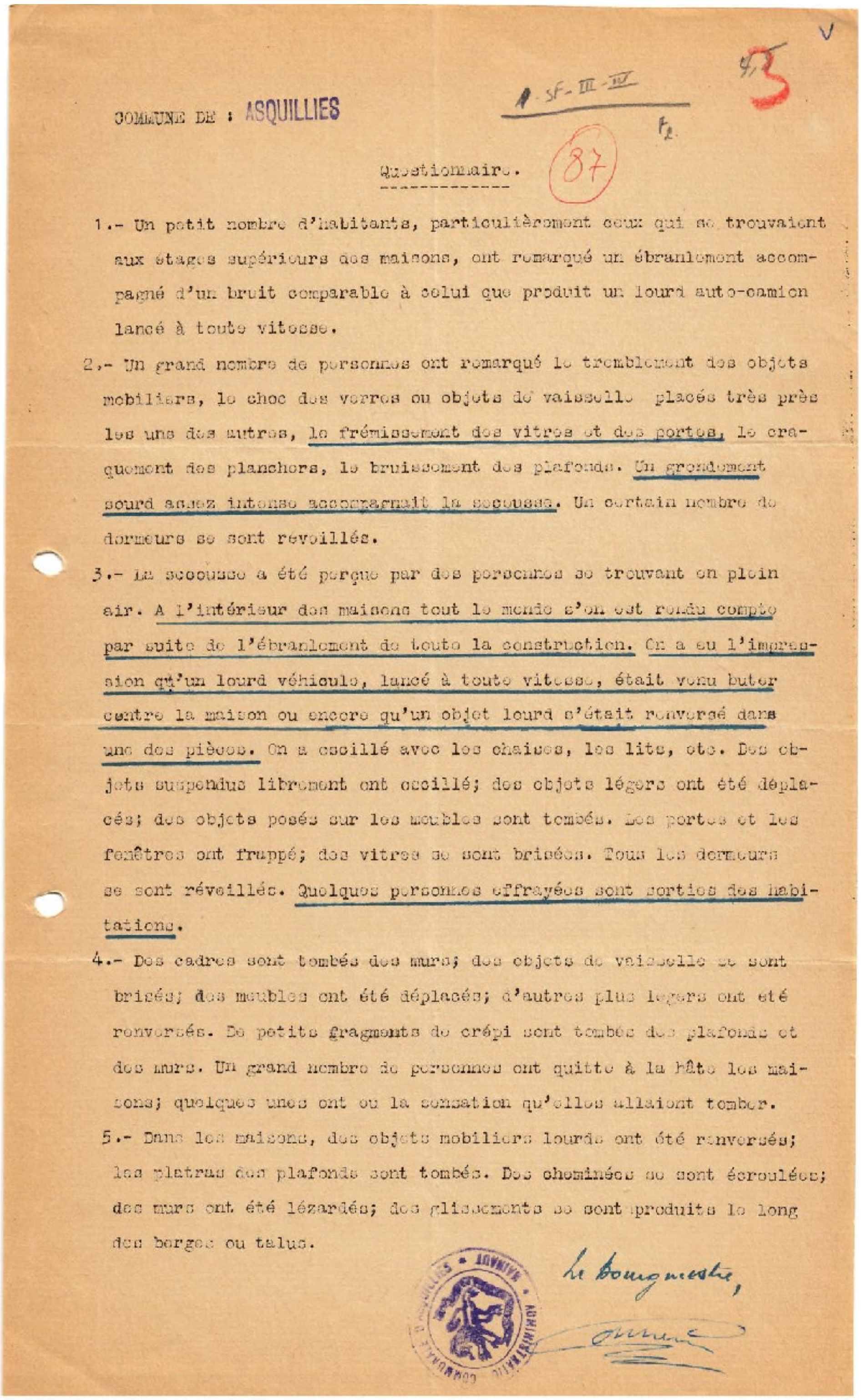
**Degré VI.** – Les cadres tombent des murs ; des objets de vaisselle se brisent ; des meubles sont déplacés, d'autres plus légers peuvent être renversés. De petits fragments de crépi tombent des plafonds et des murs. Un grand nombre des personnes quittent à la hâte les maisons ; quelques-unes ont la sensation qu'elles vont tomber.

**Degré VII.** – Des glissements peuvent se produire le long de certaines berges ou talus. Dans les maisons, des objets mobiliers lourds sont renversés. Chute des plâtras des plafonds et des murs. Des cheminées s'écroulent ; des murs peu résistants sont lézardés ; des ornements mal fixés se détachent des édifices élevés. Les bâtiments solidement construits restent intacts.

## 10.2. ROB questionnaire versions

*Examples of all questionnaire versions used by the ROB since 1932.*

**Version 1 - French**



COMMUNE DE : ASQUILLIES

1-SF-III-IV

Questionnaire.

1.- Un petit nombre d'habitants, particulièrement ceux qui se trouvaient aux étages supérieurs des maisons, ont remarqué un ébranlement accompagné d'un bruit comparable à celui que produit un lourd auto-camion lancé à toute vitesse.

2.- Un grand nombre de personnes ont remarqué le tremblement des objets mobiliers, le choc des verres ou objets de vaisselle placés très près les uns des autres, le frémissement des vitres et des portes, le craquement des planchers, le bruissement des plafonds. Un grondement sourd assez intense accompagnait la secousse. Un certain nombre de dormeurs se sont réveillés.

3.- La secousse a été perçue par des personnes se trouvant en plein air. A l'intérieur des maisons tout le monde s'en est rendu compte par suite de l'ébranlement de toute la construction. On a eu l'impression qu'un lourd véhicule, lancé à toute vitesse, était venu buter contre la maison ou encore qu'un objet lourd s'était renversé dans une des pièces. On a oscillé avec les chaises, les lits, etc. Des objets suspendus librement ont oscillé; des objets légers ont été déplacés; des objets posés sur les meubles sont tombés. Les portes et les fenêtres ont frappé; des vitres se sont brisées. Tous les dormeurs se sont réveillés. Quelques personnes effrayées sont sorties des habitations.

4.- Des cadres sont tombés des murs; des objets de vaisselle se sont brisés; des meubles ont été déplacés; d'autres plus légers ont été renversés. De petits fragments de crépi sont tombés des plafonds et des murs. Un grand nombre de personnes ont quitté à la hâte les maisons; quelques unes ont eu la sensation qu'elles allaient tomber.

5.- Dans les maisons, des objets mobiliers lourds ont été renversés; les platras des plafonds sont tombés. Des cheminées se sont écroulées; des murs ont été lézardés; des glissements se sont produits le long des berges ou talus.

Le Bourgmestre,

**Version 1 - Dutch**

SF-V

F2

3

1539

~~Maaseik~~

VRAGENLIJST

1.- Een gering getal inwoners, in 't bijzonder degenen die zich op de bovenste verdiepingen der huizen bevonden, hebben schokkingen en gerommel opgemerkt zooals door een snelvoorbijrijdenden vrachtwagen veroorzaakt,

2.- Een groot getal personen hebben ~~een schudding van meubels~~, een botsing van dichtbijelkaar staande glazen of ander keukengerief, de trilling van vensters en deuren, ~~het kraken van houten vloeren en zolderingen~~ vastgesteld. Een vrij hevig dof gerommel/ging met den schok gepaard. Een zeker aantal menschen werden uit hun slaap gerukt.

3.- ~~De schok werd door personen gevoeld, die zich buitenhuis bevonden.~~ Binnen de huizen werd ~~iedereen~~ hem de schok gewaar, door de schudding van het gansche gebouw. Men had den indruk dat een zware snelrijdende wagen tegen het huis kwam gereden of nog, dat een zwaar voorwerp in een der plaatsen was omgevallen, zelf dat het huis instortte. ~~Men schommelde op stoelen of in bed, enz. Vrije ophangende voorwerpen gingen aan 't slingeren; lichte voorwerpen werden verplaatst; voorwerpen vielen van meubels. Deuren en vensters sloegen; ruiten werden gebroken. Al de~~ Eenige menschen werden uit hun slaap gerukt. Enkele verschrikte personen liepen uit hun woningen.

4.- ~~Lijsten vielen van de wanden; keukengerief werd gebroken; meubels werden verschoven; kleine~~ meubels werden omgeworpen. ~~Kleine pleisterbrokken vielen van zolderingen en muren.~~ Een ~~groot~~ Klein aantal personen verlieten inderhaast hun woningen; ~~enkele hunner hadden het gevoelen dat zij gingen vallen.~~

5.- ~~In de woningen werden zware meubelstukken omgeworpen; de pleisterkalk viel van de zolderingen. Schoorsteenen stortten in; muren scheurden; verschuivingen langsheen hellingen en wegkanten deden zich voor.~~

---

**Version 2 - French**

COMMUNE D' U C C L E - TRAVAUX PUBLICS. Uccle

OBSERVATOIRE ROYAL DE BELGIQUE, à UCCLE III.

Tremblement de terre du samedi II juin I938( II h. 57 m.)

Q U E S T I O N N A I R E

I) Quel est le nombre approximatif de cheminées totalement ou partiellement abattues dans votre commune? néant

totalement : 10
partiellement : 238

2) Y a-t-il eu d'autres dommages plus ou moins importants occasionnés aux constructions? Lesquels?

une façade lézardée
un mur du bureau de police de St.Job crevassé
une vieille cheminée endommagée sur l'habitation de la directrice d'école rue Edith Cavell 27
une vieille cheminée fissurée sur l'habitation servant d'école gardienne rue Vanderkindere 98
aggravation des fissures d'une cheminée sur l'école de filles à Calevoet (rue François Vervloet).

SD - VI - VII

A, A1 (10 / 5580), A2 (238 / 5580), S, D, E, F
0,2% 4,3%

3) A-t-on constaté dans votre commune d'autres effets dus au tremblement de terre et dignes d'être signalés? Lesquels?

non, à notre connaissance

Uccle le 19 juillet 1938.

Par ordonnance :
Le Secrétaire communal,

Le Collège,

A MONSIEUR DELPORTE ,Directeur de l'OBSERVATOIRE ROYAL DE BELGIQUE,
Avenue Circulaire,3
UCCLE III.

**Version 2 - Dutch**

Dixmude Diksmuide

KONINKLIJKE STERRENWACHT VAN BELGIE, UKKEL III.

Aardbeving van Zaterdag II Juni I938 (II u.57 m.)

V R A G E N L I J S T

I) Welk is ongeveer het getal schouwen die geheel og gedeeltelijk verwoest werden in uwe gemeente? 50 tal

2) Is er andere aanzienlijke schade aan de gebouwen? (Korte beschrijving). Hier en daar lichte scheuring aan verbindingsmuren. Ook hier en daar schade aan puntgevels.

De schade mag niewel als betrekkelijk gering worden beschouwd ten overstaan van de hevigheid der aardschokken.

De aardbeving was onmiddelijk voorafgegaan door een gerommel gelijkende op een woest aanstormend onweder, doch iets doffer.

Quelques fissures légères à des murs mitoyens, aussi quelques dégats à des [illegible] pignons

Les dégats très minimes par rapport au grand tremblement de terre!

Tremblement précédé par roulement orage lointain étouffé.

3) Heeft men andere noemenswaardige feiten of gebeurtenissen waargenomen die in verband staan met de aardschokken? Welke zijn die feiten?

Uit bekomen inlichtingen blijkt dat de hoornbeesten in de weiden van Veurne-Ambacht, verschrikt waren en wild op hol sloegen. Duizenden visschen vertoonden zich aan de oppervlakte van het water.

Les bêtes à cornes d. les prairies de VA étaient effrayées et couraient d. les champs.

Des milliers de poissons se montraient à la surface de l'eau

SD VI

A, Av(50/160), C, D, E, G

5,3%

**Version 3 - French**

COMMUNE DE REMAGNE PROVINCE DE LUXEMBOURG

2141

QUESTIONNAIRE 1

F II / F3

1.- Avez-vous perçu des vibrations légères ? un bruit caractéristique (grondement, roulement, ...) ? quelques familles se sont rendues compte de vibrations légères.

2.- Avez-vous ressenti un ébranlement net ? non

3.- Avez-vous constaté l'oscillation de lustres ? non
l'oscillation de chaises ou de lits ? non
les craquements des plafonds ? non

4.- Avez-vous observé les vibrations des vitres et des portes, le choc des verres ou d'objets de vaisselle placés très près les uns des autres, le tremblement d'objets mobiliers (vases, bibelots, ...) l'oscillation de cadres suspendus au mur? non

5.- Avez-vous constaté le déplacement de bibelots, le déplacement d'objets légers, l'arrêt de pendules? Des objets sont-ils tombés des meubles ? Des cadres sont-ils tombés des murs ? non

6.- Avez-vous observé la chute de fragments de crépi ? non
Des objets légers (pots de fleurs, vases, ...) se sont-ils renversés ? non
Des meubles lourds (bahuts, poêles, ...) ont-ils vibrés ? non
Des meubles lourds se sont-ils déplacés ? non
Des cloches ont-elles sonné ? non
Avez-vous constaté le bris de vitres ou de vaisselle ?
Y a-t-il eu des murs lézardés, des chutes de platras ?
Avez-vous constaté une chute exceptionnelle d'une cheminée ou de quelques briques ?
Y a-t-il eu de nombreuses cheminées fendues, des objets lourds renversés, des cheminées écroulées ?
Quel pourcentage pour la commune ?
} non

Le Bourgmestre, f.f.
[signature]

ADMINISTRATION COMMUNALE DE REMAGNE (PROV. DE LUX.)

**Version 3 - Dutch**

609

Aan de heer Directeur van de Koninklijke Sterrenwacht
Ringlaan, nr 3, Ukkel,
naar aanleiding van zijn navraging in verband met de
eardschok waargenomen op 7 Januari 1953, te 0 u. 59 m.
te Dworp.

PROVINCIE : Brabant

GEMEENTE : D W O R P

1156 F-II-III F3

VRAGENLIJST.

1.- Hebt U lichte trillingen opgemerkt ? — ja
een gerommel waargenomen ? — ja

2.- Hebt U een schok waargenomen ? — neen

3.- Hebt U het slingeren van luchters, — ?
het schommelen op stoelen en in bedden, — ja
het kraken van zolderingen waargenomen ? — neen

4.- Hebt U het trillen van ruiten en deuren, — ja
het rinkelen van glazen of van dicht bij elkaar staand keukengerief — ja
het trillen van het mobilair (vazen, ....) — neen
het schommelen van tegen de muur hangende voorwerpen (kaders, enz.) — neen
waargenomen ?

5.- Hebt U de verplaatsing van het mobilair (vazen, enz.) — neen
de verplaatsing van lichte voorwerpen — neen
het stil vallen van uurwerken waargenomen ? — neen

Zijn er voorwerpen van meubles gevallen ? — neen

Zijn er kaders van de muren gevallen ? — neen

6.- Vielen er kleine pleisterbrokjes neer ? — neen

Zijn er lichte voorwerpen als vazen en bloempotten omgevallen ? — neen

Trilden de zware meubelstukken (kasten, kachels, enz.) ? — neen

Werden zware meubelstukken verplaatst ? — neen

Klopten de klokken ? — neen

Werd er glas- of vaatwerk gebroken ? — neen

Werden muren gescheurd ? — neen

Vielen er pleisterstukken van wanden of zolderingen ? — neen

Werd een schoorsteen of enkele stenen neergeworpen ? — neen

Werden veel schoorstenen gescheurd ? — neen

Werden zware voorwerpen omgeworpen ? — neen

Werden vele schoorstenen neergeworpen ? Welk percentage ? — neen.

Dworp, 9 Januari 1953.

Bij opdracht :
De Gemeentesekretaris,

[signature]

De Burgemeester,

[signature]

**Version 4 - French**

OBSERVATOIRE ROYAL DE BELGIQUE

COMMUNE :

PROVINCE : Alleur (1371) (33)

Tremblement de Terre du :

- 8 -11- 1983

1h 49m

QUESTIONNAIRE

1.- Quelques habitants ont-ils perçu :
des vibrations légères oui
un bruit caractéristique : grondement ou roulement non

2.- De nombreux habitants ont-ils perçu :
un ébranlement net de l'immeuble non
un fort grondement oui

3.- A-t-on observé :
l'oscillation de lustres ou d'objets suspendus librement oui
l'oscillation de chaises ou de lits oui
le craquement des plafonds oui
le réveil de dormeurs oui

4.- A-t-on observé ou constaté :
le frémissement de vitres et de portes non
le tremblement d'objets mobiliers (tables, vases, bibelots..) oui

5.- le choc de verres, de vaisselle dans les buffets oui
l'oscillation de cadres suspendus au mur oui
le craquement des planchers non
la chute de petits fragments de crépis des plafonds oui
un émoi des habitants (des personnes sortent des habitations)

6.- A-t-on constaté :
le déplacement de bibelots oui
le déplacement d'objets légers, lesquels ? oui
la chute de cadres pendus au mur oui
la chute d'objets légers posés sur des meubles polis ou un marbre
des vitres fêlées ou brisées non
des objets de vaisselle brisés. non

7.- Des objets légers (vases, pots de fleurs,..) se sont-ils renversés oui
Des meubles légers se sont-ils déplacés oui
Des meubles lourds (bahuts, poëles,..) ont-ils vibré oui
Des cloches ont-elles tinté non

8.- Des meubles lourds se sont-ils déplacés non
Des meubles légers se sont-ils renversés oui
Des portes ont-elles été déplacées sur leurs gonds non

9.- A-t-on constaté :
la chute de morceaux de platras des plafonds oui
des fissures dans les platras des murs oui
une chute exceptionnelle d'une cheminée en mauvais état non
une chute exceptionnelle de quelques briques non

10.- Y a-t-il eu plusieurs cheminées endommagées, combien ? ± 50.
plusieurs cheminées renversées, combien ? % pour la commune ?
non des chutes d'ornements de façades, de quelle importance
1 partie de quartier des lézardes profondes dans les murs (brique ? béton ?)
non des glissements le long des berges ou des talus, Importance ?

OBSERVATIONS COMPLEMENTAIRES :

N.B.- Si l'on n'a rien observé dans la commune, veuillez renvoyer ce questionnaire avec la mention "NEANT"; ces renseignements sont indispensables pour délimiter les zones de silence et la limite d'extinction.

**Version 4 - Dutch**

KONINKLIJKE STERRENWACHT VAN BELGIE

GEMEENTE : MARTENSLINDE

PROVINCIE : Limburg

Aardbeving van : 21 DEC. 1965

V R A G E N L IJ S T

1.- Enkele inwoners hebben lichte trillingen waargenomen,
een eigenaardig gedruis of gerommel opgemerkt
2.- Hebben vele inwoners het schokken van hun woning
een zwaar gerommel waargenomen ?
3.- Werd het slingeren van luchters of andere vrij opgehangen voorwerpen,
het schommelen op stoelen en bedden,
het kraken van zolderingen,
het ontwaken van slapende personen waargenomen ?
4.- Werd het trillen van ruiten en deuren
het lichtjes daveren van de huisraad (tafels, vazen, bibelots,..)
5.- het rinkelen van glazen of van dicht bij elkaar staand vaatwerk,
het schommelen van tegen de muur opgehangen voorwerpen (kaders..)
het kraken van plaketten,
het afvallen van kleine pleisterbrokjes
er onrust bij de bevolking (het buitenshuis lopen) waargenomen of
vastgesteld ?
6.- Werd de verplaatsing van bibelots (pronkstukjes,..)
de verplaatsing van lichte voorwerpen (welke ?),
het afvallen van tegen de muur opgehangen voorwerpen,
het vallen van lichte voorwerpen geplaatst op gepolijste meubels
of marmers,
het scheuren of breken van ruiten,
het breken van vaatwerk vastgesteld ?
7.- Werden lichte voorwerpen (vazen, bloempotten,..) omgeslagen ?
Werd het licht meubilair verplaatst ?
Hebben zware meubels (pronkkasten, kachels..) gedaverd ?
Klepten de klokken ?
8.- Werden zware meubels verplaatst ?
Werden lichte meubels omgeslagen ?
Werden deuren om hun hengsels (scharnieren) verplaatst ?
9.- Werd het afvallen van stukken uit het pleistergewelf,
het scheuren van het pleisterwerk op de muren,
bij uitzondering, het neerslaan van een bouwvallige schoorsteen,
het afvallen van stenen vastgesteld ?
10.- Werden verscheidene schoorstenen beschadigd en hoeveel ?
" " neergeslagen en hoeveel ?
Welk % voor de gemeente ?
diepe scheuren in de muren (van steen ? van beton ?)
grondverschuivingen langs oevers of hellingen vastgesteld ?
Hoe groot waren ze ?

BIJKOMENDE WAARNEMINGEN :

N.B. - Wanneer niets werd waargenomen in de gemeente, dient de vragenlijst teruggezonden te worden met de vermelding "NIHIL"; deze inlichting is noodzakelijk om de stiltezonen en het uitstervingsgebied te begrenzen.

GEMEENTEBESTUUR MARTENSLINDE PROVINCIE LIMBURG

Alles nihil

24-12-65

**Version 5 - French**

OBSERVATOIRE ROYAL DE BELGIQUE.

TREMBLEMENT DE TERRE DU : 13 Avril 1992 A 3h 20m

REGION DE ROERMOND

PROVINCE : LIEGE

COMMUNE : BASSENGE

QUESTIONNAIRE.

NOMBRE D'HABITATIONS DANS VOTRE COMMUNE ? ...320...

1. DES VIBRATIONS ONT-ELLES ETE RESSENTIES PAR LA POPULATION?

(X) FORTEMENT ( ) FAIBLEMENT
(X) PAR TOUS LES HABITANTS ( ) UNE PARTIE DE LA POPULATION
( ) QUELQUES PERSONNES ( ) A L'EXTERIEUR DES HABITATIONS
(X) A L'INTERIEUR DES HABITATIONS: QUEL ETAGE : ___
( ) NEANT

2. A T-ON OBSERVE UN EMOI DE LA POPULATION,(DES PERSONNES SORTENT DES HABITATIONS).
(X) OUI ( ) NON

3. DES OBJETS SUSPENDUS ONT-ILS OSCILLE?
(X) OUI ( ) NON

4. DU MOBILIER A-T-IL - VIBRE? (X) OUI ( ) NON
SI OUI, LEQUEL? bibelots petits meubles

- ETE RENVERSE? ( ) OUI (X) NON
SI OUI, LEQUEL?

5. DES MURS ONT-ILS ETE ENDOMMAGES?

( ) SIMPLES FISSURES ( ) LEZARDES PROFONDES
( ) RENVERSES (X) NEANT

6. DES CHEMINEES ONT-ELLES ETE ABATTUES? ( ) OUI (X) NON

SI OUI, COMBIEN PARTIELLEMENT =
TOTALEMENT =

7. SI D'AUTRES CONSTATATIONS ONT ETE FAITES LORS DU TREMBLEMENT DE TERRE, VEUILLEZ LES DETAILLER.

N.B.- SI L'ON N'A RIEN OBSERVE DANS LA COMMUNE, VEUILLEZ RENVOYER CE QUESTIONNAIRE AVEC LA MENTION ''NEANT''. CES RENSEIGNEMENTS SONT INDISPENSABLES POUR DELIMITER LA ZONE DE PERCEPTION ET LA LIMITE D'EXTENSION DU TREMBLEMENT DE TERRE.

MERCI.

P.S. METTRE UNE "X" DANS LA CASE CORRESPONDANTE.

**Version 5 - Dutch**

√

KONINKLIJKE STERRENWACHT VAN BELGIE

AARDBEVING VAN : 13 April 1992 om 3h 20m

STREEK VAN ROERMOND

PROVINCIE : ANTWERPEN

GEMEENTE : AARTSELAAR

VRAGENLIJST.

AANTAL WONINGEN IN UW GEMEENTE ? 5.165

1. WERDEN ER TRILLINGEN WAARGENOMEN DOOR DE BEVOLKING?

( ) *HEVIGE* ( ) *LICHTE*
(X) *GEHEEL DE BEVOLKING* ( ) *DEEL VAN DE BEVOLKING*
( ) *ENKELE PERSONEN* ( ) *BUITENSHUIS*
( ) *BINNENSHUIS: WELKE VERDIEPING* : ___
( ) *NIHIL*

2. WERD DE BEVOLKING ONRUSTIG, (NAAR BUITEN LOPEN)?
( ) *JA* (X) *NEEN*

IV-V

3. SLINGERDEN ER OPGEHANGEN VOORWERPEN? ( ) *JA* (X) *NEEN*

4. a) DAVERDE HET MEUBILAIR? (X) *JA* ( ) *NEEN*
*ZO JA, WELKE?*

b) KANTELDE HET MEUBILAIR? ( ) *JA* (X) *NEEN*
*ZO JA, WELKE?*

5. WERDEN ER MUREN BESCHADIGD?

( ) *GEBARSTEN* ( ) *GESPLETEN*
( ) *OMGEVALLEN* (X) *NIHIL*

6. WERDEN ER SCHOORSTENEN BESCHADIGD? ( ) *JA* (X) *NEEN*

*ZO JA, HOEVEEL* ( ) *GEDEELTELIJK* =
( ) *GEHEEL* =

7. INDIEN ANDERE VERSCHIJNSELEN WERDEN WAARGENOMEN TIJDENS DE AARDBEVING, GELIEVE DEZE HIERONDER TE OMSCHRIJVEN.

N.B.- *WANNEER NIETS WERD WAARGENOMEN IN DE GEMEENTE, DIENT DE VRAGENLIJST TERUGGEZONDEN TE WORDEN MET DE VERMELDING 'NIHIL'. DEZE INLICHTING IS NOODZAKELIJK OM DE STILTEZONE EN HET UITSTERVINGSGEBIED TE BEGRENZEN.*

DANK U.

P.S. *ZET EEN 'X' IN HET CORRESPONDERENDE VAK.*

**Version 6 – French**

# OBSERVATOIRE ROYAL DE BELGIQUE

TREMBLEMENT DE TERRE DU : **22 JUILLET 2002 07 H 45**
REGION DE **ESCHWEILER**

PROVINCE : **NAMUR**
COMMUNE : **HAMOIS**

3

**QUESTIONNAIRE.**

**NOMBRE D'HABITATIONS DANS VOTRE COMMUNE** ..2.463...

**1. LE TREMBLEMENT DE TERRE A-T-IL ETE OBSERVE?** (X) OUI ( ) NON

**2a. DES VIBRATIONS ONT-ELLES ETE RESSENTIES A L'INTERIEUR DES HABITATIONS?**
FORTEMENT ( ) Par tous ( ) Par Beaucoup ( ) Par quelques-uns
FAIBLEMENT ( ) Par tous (X) Par Beaucoup ( ) Par quelques-uns

**2b. DES VIBRATIONS ONT-ELLES ETE RESSENTIES A L'EXTERIEUR DES HABITATIONS?**
FORTEMENT ( ) Par tous ( ) Par Beaucoup ( ) Par quelques-uns
FAIBLEMENT ( ) Par tous ( ) Par Beaucoup (X) Par quelques-uns

**3. DES PERSONNES SONT-ELLES SORTIES DES HABITATIONS.**
(X) NON ( ) OUI- Quelques-unes ( ) OUI - beaucoup

**4. DES OBJETS SUSPENDUS ONT-ILS OSCILLE?** ( ) OUI (X) NON

**5. DE PETITS OBJETS ONT-ILS VIBRE?** (X) OUI ( ) NON
**ONT-ILS ETE DEPLACES?** ( ) OUI (X) NON
**SONT-ILS TOMBES DE MEUBLES?** ( ) OUI (X) NON

**6. DES PORTES ET VITRES ONT-ELLES VIBRE?** (X) OUI ( ) NON
**ONT-ELLES CLAQUE?** ( ) OUI (X) NON
**DES VITRES SE SONT-ELLES BRISEES?** ( ) OUI (X) NON

**7. DU MOBILIER A-T-IL - VIBRE?** (X) OUI ( ) NON
**- ETE DEPLACE?** ( ) OUI (X) NON
**- ETE RENVERSE?** ( ) OUI (X) NON
SI OUI, LEQUEL?

**8. DES MURS ONT-ILS ETE ENDOMMAGES?**
( ) SIMPLES FISSURES ( ) LEZARDES PROFONDES
( ) RENVERSES (X) NEANT

**9. DES CHEMINEES ONT-ELLES ETE ABATTUES?** ( ) OUI (X) NON
SI OUI, COMBIEN PARTIELLEMENT :
TOTALEMENT :

**10. SI D'AUTRES CONSTATATIONS ONT ETE FAITES LORS DU TREMBLEMENT DE TERRE, POUVEZ-VOUS NOUS LES DETAILLER.**

**Version 6 - Dutch**

# KONINKLIJKE STERRENWACHT VAN BELGIE

AARDBEVING VAN : **22 JULI 2002 om 07 H 45**
STREEK VAN ESCHWEILER

PROVINCIE : LIMBURG
GEMEENTE : **KORTESSEM**

3-4

**VRAGENLIJST .**

AANTAL WONINGEN IN UW GEMEENTE 3030

**1. WERD DE AARDBEVING WAARGENOMEN DOOR DE BEVOLKING ?**

**2a. WERDEN ER DOOR DE BEVOLKING BINNENSHUIS TRILLINGEN WAARGENOMEN ?**
HEVIGE ( ) Door iedereen ( ) Door velen ( ) Door slechts enkelen
LICHTE ( ) Door iedereen (X) Door velen ( ) Door slechts enkelen

**2b. WERDEN ER DOOR DE BEVOLKING BUITENSHUIS TRILLINGEN WAARGENOMEN ?**
HEVIGE ( ) Door iedereen ( ) Door velen ( ) Door slechts enkelen
LICHTE ( ) Door iedereen (X) Door velen ( ) Door slechts enkelen

**3. ZIJN ER MENSEN DIE HUN WONINGEN ONTVLUCHT ZIJN ?**
( ) NEEN (X) JA enkele ( ) JA veel

**4. ZIJN ER OPGEHANGEN VOORWERPEN BEGINNEN SLINGEREN ?** ( ) JA (X) NEEN

**5. ZIJN ER KLEINE VOORWERPEN BEGINNEN TRILLEN ?** ( ) JA (X) NEEN
**ZIJN ER KLEINE VOORWERPEN VERPLAATST ?** ( ) JA (X) NEEN
**ZIJN ER KLEINE VOORWERPEN VAN HET MEUBILAIR GEVALLEN ?** ( ) JA (X) NEEN

**6. ZIJN ER DEUREN EN VENSTERS BEGINNEN TRILLEN ?** ( ) JA (X) NEEN
**ZIJN ER DEUREN EN VENSTERS OPEN EN TOE GESLAGEN ?** ( ) JA (X) NEEN
**ZIJN ER VENSTERS GEBROKEN ?** ( ) JA ( ) NEEN

**7. DAVERDE HET MEUBILAIR ?** (X) JA ( ) NEEN
**IS ER MEUBILAIR VERPLAATST ?** ( ) JA (X) NEEN
**IS ER MEUBILAIR OMVERGEWORPEN ?** ( ) JA (X) NEEN
ZO JA, WELKE ?

**8. WERDEN ER MUREN BESCHADIGD ?**
(X) LICHTE BARSTEN ( ) DIEPE BARSTEN
( ) OMGEVALLEN ( ) NIHIL

**9. WERDEN ER SCHOORSTENEN BESCHADIGD ?** ( ) JA (X) NEEN
ZO JA, HOEVEEL GEDEELTELIJK :
VOLLEDIG :

**10. INDIEN ANDERE VERSCHIJNSELEN WERDEN WAARGENOMEN TIJDENS DE AARDBEVING, GELIEVE DEZE HIERONDER TE OMSCHRIJVEN.**

## 10.3. “Did You Feel It?” online inquiry by the ROB-BNS

The “Did You Feel It?” (“DYFI?”) inquiry by the Royal Observatory of Belgium and the University of Cologne (Erdbebenstation Bensberg) in its current form in English (2025). This online questionnaire is made up of five sections: personal information, date and approximate time of the earthquake (if not yet provided directly on the website), geographical location, situation during the earthquake and the macroseismic information questions. The macroseismic information questions are further subdivided into questions pertaining to the perception, the personal experience and the observed earthquake effects. Questions marked with * are required to submit the form. The “DYFI?” inquiry consists of a few open questions and a majority of multiple-choice questions. The options provided for multiple-choice questions or the provided format to which the response must adhere, are given with each question. Multiple-choice questions that allow the selection of multiple options are indicated with ‘check-all’. Some questions can only be answered when specific answers have been provided in previous questions. If other answers have been provided, the question is locked and cannot be answered. The required answers to unlock the question are provided with a superscript letter in parentheses to both the possibly locked question and its required answer(s) to unlock, e.g. [(a)]. The number of the questions that are used for the calculation of the Community Weighted Sum or CWS (1) are in red. The scores assigned to the answers to these questions are in brackets in red. If ‘No damage’ is selected for question 30, all other options for question 30 are locked. The answer with the highest score of question 30 is the score used as the damage index. The computations used to determine the CWS and communal decimal intensities (CDI) are described in §2.3.

## QUESTIONNAIRE FOR A NEW EVENT

Fields marked with * are required.

**Name**:

**E-mail**:

**Phone**:

## Date and time of the earthquake (approximate)

**Date***: DD-MM-YYYY (only dates within the past month, up to the current date, can be selected)

**Time***: hh:mm

## Your location when the earthquake occurred

**Street, Address**:

**Country***: (Please choose a country)

- Belgium
- France
- United Kingdom
- The Netherlands
- Germany
- Grand Duchy of Luxembourg

**Zip code***:

**City**:

## Your situation when the earthquake occurred

**What was your situation during the earthquake?**

- No answer
- Inside [(a)]
- Outside
- In stopped vehicle
- In moving vehicle
- Other [(c)]

**If you were inside, please select the type of building or structure [a]**

- No Building
- Family Home (b)
- Apartment Building (b)
- Office Building/School (b)
- Mobile Home with Permanent Foundation (b)
- Trailer or Recr. Vehicle with No Foundation (b)
- Other (b, c)

**If you know the floor, please specify it [b]**

- [-10 – 100]
- No answer

**If other, please describe [c]:**

## Perception of the earthquake

**Were you asleep during the earthquake?**

- No
- Yes, and I slept through it
- Yes, but I woke up

**Did you feel the earthquake?*** [felt index]

- No [0]
- Yes [1]

**Did you hear a noise?**

- No
- Yes, Light and brief noise
- Yes, Light and prolonged noise
- Yes, Strong and brief noise
- Yes, Strong and prolonged noise

**Did other persons nearby feel the earthquake?**

- No answer – Don't know – Nobody else nearby
- No other person felt it
- Some felt it, but most did not
- Most others felt it, but some did not
- Everyone or almost everyone felt it

## Your experience of the earthquake

**How would you best describe the ground shaking?** (d) [motion index]

- No description
- Not felt [0]
- Weak [1]
- Mild [2]
- Moderate [3]
- Strong [4]
- Violent [5]

**About how many seconds did the shaking last?** (d)

- No answer
- [1-60]

**How would you best describe your reaction?** (d) [reaction index]

- No answer – Don't remember
- No reaction - Not felt [0]
- Very little reaction [1]
- Excitement [2]
- Somewhat frightened [3]
- Very frightened [4]
- Extremely frightened [5]

**How did you respond?** (Select one.) (d)

- No answer – Don't remember
- Took no action
- Moved to doorway
- Ducked and covered
- Ran outside
- Other

**Was it difficult to stand or walk?** (d) [stand index]

- No answer - Did not try
- No [0]
- Yes, difficult to stand [1]
- Yes, I was fallen [1]
- Yes, I was forcibly thrown to the ground [1]

## Earthquake effects on the furniture and the buildings

**Did you notice the swinging or swaying of doors or hanging objects?** [d]

- No answer - Did not look
- No
- Yes, slight swinging
- Yes, violent swinging

**Did you notice creaking or other noises?** [d]

- No answer - Did not pay attention
- No
- Yes, slight noise
- Yes, loud noise

**Did objects rattle, topple over, or fall off shelves?** [shelf index]

- No answer - No shelves
- No [0]
- Rattled slightly [0]
- Rattled loudly [0]
- A few toppled or fell off [1]
- Many fell off [2]
- Nearly everything fell off [3]

**Did pictures on walls move or get knocked askew?** [picture index]

- No answer - No picture
- No [0]
- Yes, but did not fall [1]
- Yes, and some fell [1]

**Did any furniture or appliances slide, tip over, or become displaced?** [furniture index]

- No answer - No furniture
- No [0]
- Yes [1]

**Was a heavy appliance (refrigerator or range) affected?**

- No answer - no heavy appliance
- No
- Yes, some contents fell out
- Yes, shifted by inches/cm
- Yes, shifted by a foot or more (>30cm)
- Yes, overturned

**Were free-standing walls or fences damaged?**

- No answer - No walls
- No
- Yes, some were cracked
- Yes, some partially fell
- Yes, some fell completely

**Was there any damage to the buildings nearby you?** Check all that apply [damage index]

- ☐ No damage [0]
- ☐ Hairline cracks in walls [0.5]
- ☐ A few large cracks in walls [0.75]
- ☐ Many large cracks in walls [1]
- ☐ Ceiling tiles or lighting fixtures fell [1]
- ☐ Cracks in chimney [1]
- ☐ One or several cracked windows [0.5]
- ☐ Many windows cracked or some broken out [2]
- ☐ Masonry fell from block or brick wall(s) [2]
- ☐ Old chimney, major damage or fell down [2]
- ☐ Modern chimney, major damage or fell down [3]
- ☐ Outside wall(s) tilted over or collapsed completely [3]
- ☐ Separation of porch, balcony, or other addition from building [3]
- ☐ Building shifted over foundation [3]

**If you know the type (wood, brick, etc.) and/or the height (in floors) of building please indicate here:**

## Additional comments

**If you have some complementary observations, use the next box.**
**(Do not ask questions here. Use the email)**

## 10.4. The Belgian traditional macroseismic (BTM) earthquake catalogue

***Id_earth**: earthquake identification number; **date**: format YYYY-MM-DD; **UTC time**: format hh:mm:ss; **name**: epicentral location name; **lat**: latitude (WGS84); **lon**: longitude (WGS84); **depth**: focal depth (km); **$M_L$**: local magnitude; **$M_S$**: surface-wave magnitude; **$M_W$**: moment magnitude; **$M_W$ meth.**: data used to determine $M_W$ – macro (macroseismic data), coda (coda duration), spectral (spectral displacement); **source region**: seismotectonic region of the epicentre according to the model of Verbeeck et al. (2009); **IDPs**: number of intensity data points in the BTM dataset; **Imax**: maximum intensity in Belgium, higher Imax values reported abroad are provided in brackets (if applicable); **Qual**: source quality value indication based on the IDP source types; **qROB**: ROB questionnaire version; **letters**: availability of letters with individual testimonies; **press**: availability of newspaper articles reporting useful macroseismic observations; **field**: macroseismic field survey conducted; **pub**: existence of a published macroseismic survey; **References**: reference to (un)published scientific sources with valuable macroseismic information. The events used for the evaluation of IPEs (§6.3) are highlighted in bolt.*

| Nr. | id_earth | date | UTC time | name | lat | lon | depth | $M_L$ | $M_S$ | $M_W$ | $M_W$ meth. | source region | IDPs | Imax | Qual | qROB | letters | press | field | pub | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 445 | 1908-11-12 | 09:14:-- | POULSEUR | 50.46 | 5.64 | | | | 3.7 | macro | East. Ard. | 168 | 5 | C | | | | x | x | Lohest and De Rauw (1909) |
| 2 | 446 | 1910-11-07 | 00:40:-- | HAUTES FAGNES | 50.65 | 6.23 | | | | 3.6 | macro | East. Ard. | 2 | 3.5 | C | | | x | | | Lagrange (1911a) |
| 3 | 447 | 1911-03-29 | 0:05:43 | RANSART | 50.46 | 4.47 | | 3.6 | | | | Hain. | 4 | 6 | C | | | x | | | Cambier (1911), Camelbeeck et al. (2022) |
| 4 | 449 | 1911-04-12 | 16:15:-- | MONS-WASMUEL | 50.44 | 3.92 | 2.4 | | | 3.1 | macro | Hain. | 94 | 4 | C | | | x | | x | Cornet (1911), Camelbeeck et al. (2022) |
| 5 | 451 | 1911-05-30 | 19:43:25 | EIFEL-EICHERSCHEID (DE) | 50.65 | 6.23 | | 4.5 | 4.0 | | | East. Ard. | 6 | 5 (5.5) | C | | | x | | | |
| 6 | 465 | 1911-06-01 | 22:51:58 | RANSART | 50.45 | 4.46 | 4.3 | 4.2 | 3.8 | | | Hain. | 55 | 6 | C | | | x | | | Cambier (1911), Camelbeeck et al. (2022) |
| 7 | 466 | 1911-06-03 | 14:35:54 | RANSART | 50.46 | 4.45 | 1.4 | 4.4 | | | | Hain. | 16 | 7 | C | | | x | | | Camelbeeck et al. (2022) |
| 8 | 470 | 1911-09-06 | 13:54:13 | EIFEL-RAEREN | 50.70 | 6.32 | | 4.3 | 3.7 | | | East. Ard. | 14 | 4.5 (5) | C | | | x | | | |
| 9 | 476 | 1920-01-17 | 03:11:04 | HORNU | 50.44 | 3.82 | 1.6 | 3.7 | | | | Hain. | 12 | 6 | C | | | x | | | Capiau (1920), Camelbeeck et al. (2022) |
| 10 | 477 | 1921-02-20 | 16:17:35 | STEMBERT | 50.53 | 5.89 | | 4.0 | | 3.5 | macro | East. Ard. | 56 | 4.5 | C | | | | | x | Lohest and Anten (1921) |
| 11 | 478 | 1921-05-19 | 02:41:41 | GERAARDSBERGEN | 50.80 | 3.95 | | 4.0 | | 3.5 | macro | Ang-Br Mas. | 48 | 4.5 | C | ? | | | | x | Fourmarier and Somville (1926) |
| **12** | **480** | **1925-02-23** | **21:32:58** | **BILZEN** | **50.88** | **5.52** | | **4.1** | | **3.8** | **macro** | **East. Camp.** | **131** | **5.5** | **C** | **?** | | | | **x** | **Fourmarier and Legraye (1926)** |
| 13 | 481 | 1926-01-05 | 23:37:19 | SIEGBURG-ZUELPICH (DE) | 50.73 | 6.62 | | 4.8 | 4.4 | | | RVG | 70 | 5 | C | | | | | x | Fourmarier (1926, 1928) |
| 14 | 485 | 1928-01-14 | 00:17:35 | KALTERHERBERG (DE) | 50.50 | 6.10 | | 4.4 | 3.7 | 4.0 | macro | East. Ard. | 105 | 4.5 | C | ? | | | | x | Fourmarier and Somville (1930) |
| 15 | 488 | 1931-05-09 | 12:25:56 | HOUDENG-AIMERIES | 50.47 | 4.15 | 0.6 | 2.8 | | | | Hain. | 5 | 4.5 | C | | | x | | | Camelbeeck et al. (2022) |
| 16 | 490 | 1931-06-07 | 00:25:21 | DOGGER BANK (North Sea) | 53.95 | 1.40 | | | 5.5 | | | Other | 14 | 4.5 (5.5) | C | | | x | | | Somville (1931), Lagrange (1931). |
| **17** | **492** | **1932-11-20** | **23:36:52** | **UDEN (NL)** | **51.61** | **5.47** | | **5.1** | **4.5** | | | **RVG** | **576** | **5.5 (7)** | **B** | **v1** | **x** | | | | **Van Dijk (1933, 1934); Dost et al. (2025)** |
| 18 | 500 | 1933-03-23 | 18:48:-- | DIKSMUIDE | 51.06 | 3.03 | | | | 3.6 | macro | Ang-Br Mas. | 19 | 5 | C | ? | | x | | x | Fourmarier and Somville (1933) |
| 19 | 504 | 1935-06-22 | 07:06:-- | VERVIERS-THEUX | 50.50 | 5.82 | | | | | | East. Ard. | 5 | 4.5 | C | | | x | | | |
| 20 | 505 | 1936-11-05 | 00:41:44 | GOUY-LEZ-PIETON | 50.47 | 4.30 | 2.2 | | | 3.3 | macro | Hain. | 5 | 4.5 | C | | | x | | | Camelbeeck et al. (2022) |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 509 | 1938-06-11 | 10:57:36 | ZULZEKE-NUKERKE | 50.73 | 3.62 | 19.0 | 5.6 | 5.0 | | | Ang-Br Mas. | 1230 | 7 | B | v2 | x | | | x | Somville (1939a, b), Charlier and Poncelet (1940) |
| 22 | 517 | 1940-01-07 | 16:28:52 | LA LOUVIERE | 50.47 | 4.17 | 1.5 | | | 3.5 | macro | Hain. | 17 | 5 | C | | | x | | | Camelbeeck et al. (2022) |
| 23 | 518 | 1940-01-07 | 20:32:44 | LA LOUVIERE | 50.47 | 4.20 | | | | 3.1 | macro | Hain. | 7 | F | C | | | x | | | Camelbeeck et al. (2022) |
| 24 | 519 | 1940-01-09 | 03:42:07 | LA LOUVIERE | 50.48 | 4.17 | 2.8 | | | 3.3 | macro | Hain. | 5 | 4.5 | C | | | x | | | Camelbeeck et al. (2022) |
| 25 | 534 | 1949-04-03 | 12:33:40 | HAVRE-BOUSSOIT | 50.46 | 4.08 | 2.2 | 4.6 | 4.3 | | | Hain. | 227 | 7 | B | v1 | | x | x | x | Bernard and Van Gils (unpublished), Charlier (1951), Marlière (1951), Camelbeeck et al. (2022) |
| 26 | 538 | 1949-04-14 | 01:09:14 | HAVRE-BOUSSOIT | 50.46 | 4.07 | 3.7 | | | 3.5 | macro | Hain. | 15 | 5 | C | | | x | | x | Marlière (1951), Camelbeeck et al. (2022) |
| 27 | 539 | 1949-04-14 | 05:12:21 | HAVRE | 50.46 | 4.06 | 2.4 | 3.8 | | | | Hain. | 21 | 6 | C | | | x | | x | Marlière (1951), Camelbeeck et al. (2022) |
| 28 | 544 | 1951-03-14 | 09:46:59 | EUSKIRCHEN (DE) | 50.63 | 6.78 | | 5.8 | 5.3 | | | RVG | 2269 | 6 (8) | B | v1 | x | | x | | Van Gils and De Bruyn (unpublished) |
| 29 | 545 | 1951-09-07 | 23:06:48 | THEUX | 50.70 | 5.86 | 13.0 | 4.1 | 3.9 | | | East. Ard. | 1856 | 5 | A | v3 | x | | | | |
| 30 | 547 | 1952-10-21 | 21:15:-- | QUAREGNON | 50.43 | 3.88 | 2.9 | | | 3.1 | macro | Hain. | 140 | 4 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 31 | 548 | 1952-10-22 | 07:--:-- | FRAMERIES | 50.42 | 3.90 | 3.0 | | | 2.8 | macro | Hain. | 134 | 4 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 32 | 549 | 1952-10-27 | 06:11:-- | QUAREGNON | 50.43 | 3.87 | 3.5 | | | 3.5 | macro | Hain. | 145 | 5 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 33 | 550 | 1953-01-06 | 23:58:44 | COURT-SAINT-ETIENNE | 50.62 | 4.60 | | 4.0 | 3.4 | | | Ang-Br Mas. | 495 | 5 | A | v3/v4 | x | | x | | Van Gils and Bernard (unpublished) |
| 34 | 553 | 1953-06-11 | 00:22:21 | BOUSSOIT | 50.46 | 4.08 | | | | 3.1 | macro | Hain. | 16 | 4.5 | A | v4 | x | | | | |
| 35 | 555 | 1953-08-28 | 00:06:16 | COURT-SAINT-ETIENNE | 50.62 | 4.60 | | 3.4 | | | | Ang-Br Mas. | 256 | 5 | A | v4 | x | | | | |
| 36 | 556 | 1953-08-30 | 23:35:30 | VIELSALM | 50.37 | 5.93 | | | | | | East. Ard. | 121 | 5 | A | v4 | x | | | | |
| 37 | 557 | 1953-09-15 | 23:55:-- | QUAREGNON | 50.45 | 3.87 | | | | 3.1 | macro | Hain. | 82 | 5 | A | v4 | | | | | |
| 38 | 558 | 1954-01-06 | 03:35:-- | ZUTENDAAL | 50.93 | 5.57 | | | | | | East. Camp. | 16 | 4 | A | v4 | | | | | |
| 39 | 562 | 1954-07-10 | 17:18:21 | FLENU | 50.44 | 3.90 | 3.3 | | | 3.5 | macro | Hain. | 92 | 5.5 | A | v4 | | x | x | | Bernard (unpublished), Camelbeeck et al. (2022) |
| 40 | 567 | 1955-10-02 | --:--:-- | SAIVE | 50.65 | 5.68 | | | | | | Liège | 27 | 5 | A | v4 | | | | | |
| 41 | 569 | 1956-04-21 | 22:47:07 | CHASTRES | 50.58 | 4.63 | | | | | | Ang-Br Mas. | 31 | 4 | A | v4 | | | | | |
| 42 | 578 | 1960-06-25 | 14:29:13 | KINROOI | 51.18 | 5.68 | 12.5 | 4.0 | | | | RVG | 655 | 5 | A | v4 | x | | | x | Ahorner and Van Gils (1963) |
| 43 | 580 | 1963-03-10 | 05:51:30 | GENK-AS | 50.97 | 5.53 | | 3.5 | | | | East. Camp. | 176 | 5 | A | v4 | x | | | | |
| 44 | 582 | 1965-12-15 | 12:07:14 | STREPY-BRACQUEGNIES | 50.45 | 4.12 | 2.7 | 4.4 | | 4.0 | coda | Hain. | 500 | 7 | A | v4 | x | x | | x | Van Gils (1966), Camelbeeck et al. (2022) |
| 45 | 586 | 1965-12-21 | 10:00:02 | ANS-VOTTEM | 50.65 | 5.53 | 7.2 | 4.3 | | | | Liège | 423 | 6 | A | v4 | x | x | | x | Van Gils (1966) |
| 46 | 587 | 1966-01-16 | 00:13:18 | MORLANWELZ-MARIEMONT | 50.46 | 4.24 | 2.6 | 2.7 | | | | Hain. | 917 | 4.5 | A | v4 | x | x | | x | Van Gils (1966), Camelbeeck et al. (2022) |
| 47 | 588 | 1966-01-16 | 06:51:34 | MORLANWELZ-MARIEMONT | 50.47 | 4.26 | 3.3 | 3.8 | | 3.5 | coda | Hain. | 894 | 5 | A | v4 | x | x | | x | Van Gils (1966), Camelbeeck et al. (2022) |
| 48 | 589 | 1966-01-16 | 12:32:50 | MORLANWELZ-MARIEMONT | 50.46 | 4.26 | 2.1 | 4.4 | | 4.0 | coda | Hain. | 894 | 7 | A | v4 | x | x | | x | Van Gils (1966), Camelbeeck et al. (2022) |
| 49 | 597 | 1967-03-28 | 15:49:25 | CARNIERES | 50.46 | 4.28 | 3.0 | 4.5 | | 4.1 | coda | Hain. | 725 | 7 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 50 | 603 | 1968-08-12 | 07:26:41 | LA LOUVIERE | 50.46 | 4.21 | 2.3 | 3.7 | | 3.6 | coda | Hain. | 30 | 5 | A | v4 | x | x | | | Camelbeeck et al. (2022) |
| 51 | 604 | 1968-08-13 | 16:17:28 | LA LOUVIERE | 50.46 | 4.21 | | 3.6 | | 3.6 | coda | Hain. | 23 | 6 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 52 | 605 | 1968-08-13 | 16:40:40 | LA LOUVIERE | 50.46 | 4.21 | | 2.8 | | 3.0 | coda | Hain. | 16 | 5 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 53 | 606 | 1968-08-13 | 16:57:14 | LA LOUVIERE | 50.46 | 4.21 | 2.3 | 4.1 | | 3.9 | coda | Hain. | 59 | 6 | A | v4 | | x | | | Camelbeeck et al. (2022) |
| 54 | 607 | 1968-09-23 | 04:08:12 | MORLANWELZ-MARIEMONT | 50.46 | 4.23 | 2.8 | 3.0 | | 3.2 | coda | Hain. | 58 | 5 | A | v4 | | | | | Camelbeeck et al. (2022) |
| 55 | 608 | 1968-09-23 | 05:47:16 | HAINE-SAINT-PIERRE | 50.47 | 4.22 | 2.4 | 2.9 | | 3.0 | coda | Hain. | 58 | 4 | A | v4 | | | | | Camelbeeck et al. (2022) |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 56 | 609 | 1968-12-27 | 23:45:05 | DE PANNE-KOKSIJDE | 51.12 | 2.62 | | 2.5 | | | | Ang-Br Mas. | 26 | 4.5 | A | v4 | | | | | |
| 57 | 612 | 1970-11-03 | 08:45:59 | MARCHIENNE-AU-PONT | 50.41 | 4.41 | 2.3 | 3.9 | | 3.6 | coda | Hain. | 69 | 5 | A | v4 | x | x | | | Camelbeeck et al. (2022) |
| **58** | **615** | **1971-02-18** | **23:41:23** | **KONINGSBOCH (NL)** | **51.05** | **5.95** | | **4.5** | | | | **RVG** | **986** | **5 (5-6)** | **A** | **v4** | **x** | | | | **Ahorner and Schwarzbach (unknown)** |
| 59 | 618 | 1972-02-17 | 04:03:29 | CANTONS DE L'EST | 50.60 | 6.10 | | 3.1 | | | | East. Ard. | 86 | 4 | A | v4 | x | x | | | |
| 60 | 622 | 1975-01-23 | 05:42:-- | VIELSALM | 50.28 | 5.87 | | 2.6 | | | | East. Ard. | 55 | 3 | A | v4 | | | | | |
| 61 | 627 | 1976-10-24 | 20:33:28 | GIVRY | 50.36 | 4.02 | 5.5 | 4.2 | | | | Hain. | 192 | 6 | A | v4 | | | | | Camelbeeck et al. (2022) |
| 62 | 638 | 1982-03-02 | 01:27:26 | NE of SITTARD (NL) | 51.01 | 5.91 | 10.0 | 3.7 | | | | RVG | 133 | 4 (5) | A | v4 | | | | | |
| 63 | 640 | 1982-05-22 | 06:00:02 | N of MAASEIK | 51.12 | 5.80 | 14.0 | 3.7 | | | | RVG | 135 | 4 | A | v4 | | | | | |
| 64 | 641 | 1982-09-14 | 19:24:34 | CARNIERES | 50.44 | 4.24 | 3.5 | 3.4 | | | | Hain. | 138 | 4 | A | v4 | | | | | Camelbeeck et al. (2022) |
| 65 | 648 | 1983-08-04 | 07:08:26 | CHARLEROI | 50.42 | 4.45 | | 3.2 | | | | Hain. | 147 | 3.5 | A | v4 | x | | | | Camelbeeck (1983), Camelbeeck et al. (2022) |
| 66 | 649 | 1983-08-09 | 01:32:36 | CHARLEROI | 50.42 | 4.45 | | 3.3 | | | | Hain. | 136 | 4 | A | v4 | | | | | Camelbeeck (1983), Camelbeeck et al. (2022) |
| **67** | **651** | **1983-11-08** | **00:49:34** | **LIEGE** | **50.63** | **5.52** | **5.8** | **5.0** | **4.6** | **4.7** | **spectral** | **Liège** | **684** | **7** | **A** | **v4** | **x** | **x** | **x** | **x** | **Camelbeeck and De Becker (1984), De Becker and Camelbeeck (1985), Ahorner et al. (1985), Ahorner (1985), Houtgast (1985), Phillips (1985), Francois et al. (1986), Camelbeeck et al. (2013), García Moreno and Camelbeeck (2013)** |
| 68 | 654 | 1983-11-08 | 02:13:22 | LIEGE | 50.61 | 5.50 | 4.2 | 3.5 | | | | Liège | 185 | 4 | A | v4 | | | | | De Becker and Camelbeeck (1985) |
| 69 | 662 | 1984-07-09 | 23:19:01 | HEERS | 50.75 | 5.35 | | 3.6 | | | | Ang-Br Mas. | 77 | 4 | A | v4 | | x | | | |
| 70 | 736 | 1987-03-21 | 14:47:24 | REGION DE DOUR | 50.41 | 3.82 | 7.0 | 2.5 | | | | Hain. | 119 | 4 | A | v4 | | | | x | Camelbeeck (1988), Francois et al. (1989) |
| 71 | 740 | 1987-03-22 | 21:05:35 | REGION DE DOUR | 50.41 | 3.82 | 7.0 | 2.6 | | | | Hain. | 106 | 4 | A | v4 | x | | | x | Francois et al. (1989) |
| 72 | 829 | 1988-10-17 | 19:39:54 | GULPEN (NL) | 50.81 | 5.92 | 23.5 | 3.4 | | | | Liège | 414 | 4 | B | v5 | | x | | x | Francois et al. (1989) |
| 73 | 830 | 1988-12-27 | 11:53:12 | SPRIMONT | 50.54 | 5.69 | 17.1 | 3.5 | | | | East. Ard. | 479 | 4 | B | v5 | | | | | |
| **74** | **987** | **1992-04-13** | **01:20:02** | **ROERMOND(NL)** | **51.15** | **5.94** | **19.0** | **5.8** | **5.4** | **5.3** | **spectral** | **RVG** | **2088** | **6 (7)** | **B** | **v5** | | **x** | | **x** | **Camelbeeck et al. (1992), Haak et al. (1994), Pappin et al. (1994), Maurenbrecher and De Vries (1995)** |
| 75 | 1040 | 1992-06-13 | 18:01:35 | OKEGEM-NINOVE | 50.82 | 4.06 | 2.2 | 2.4 | | | | Ang-Br Mas. | 409 | 4 | B | v5 | | | | | |
| 76 | 1044 | 1992-08-29 | 09:22:26 | BARBENCON-BEAUMONT | 50.20 | 4.29 | 7.0 | 3.6 | | | | West. Ard. | 139 | 5 | B | v5 | | | | | |
| **77** | **1108** | **1995-06-20** | **01:54:47** | **LE ROEULX** | **50.51** | **4.11** | **24.4** | **4.5** | | | | **Ang-Br Mas.** | **1905** | **5** | **B** | **v5** | | **x** | | | |
| 78 | 1114 | 1996-07-23 | 22:30:21 | SPA | 50.48 | 5.89 | 16.8 | 3.8 | | | | East. Ard. | 648 | 4 | B | v5 | | | | | |
| **79** | **1306** | **2002-07-22** | **05:45:04** | **ESCHWEILER-ALSDORF (DE)** | **50.89** | **6.21** | **16.4** | **4.9** | | **4.6** | **spectral** | **RVG** | **500** | **4 (6)** | **B** | **v6** | | | | **x** | **Camelbeeck et al. (2003)** |
| 80 | 1529 | 2001-06-23 | 01:40:03 | VOERENDAAL (NL) | 50.88 | 5.92 | 6.8 | 3.9 | | | | Liège | 59 | 4.5 | B | v6 | | x | | | |

## 10.5. The Belgian online macroseismic (BOM) intensity dataset

The Belgian Macroseismic Online (BOM) intensity dataset consists of intensity data points in Belgium, collected with the “DYFI?” inquiry of the Royal Observatory of Belgium from 2002 until 2024. Each row represents an IDP, a combination of an intensity value (*int.*), a location in the form of the name of a Belgian main municipality and its coordinates, and an earthquake identifier number (*id_earth*) that corresponds to the events in the BOM earthquake catalogue, as well as the ROB earthquake catalogue. Only IDPs for earthquakes that are part of the BOM earthquake catalogue are included in the BOM intensity data. The numbers of responses (*resp.*), for each earthquake and main municipality combination, is at least three. CDI values from the “DYFI?” procedure have been rounded to the nearest half value (0.5).

| Nr. | id_earth | name | lat | lon | int. | resp. |
|---|---|---|---|---|---|---|
| 1 | 1306 | AARTSELAAR | 51.13 | 4.39 | 3 | 13 |
| 2 | 1306 | ANTWERPEN | 51.22 | 4.39 | 2 | 201 |
| 3 | 1306 | BOECHOUT | 51.16 | 4.49 | 2.5 | 9 |
| 4 | 1306 | BOOM | 51.09 | 4.36 | 2 | 6 |
| 5 | 1306 | BORSBEEK | 51.19 | 4.49 | 2 | 9 |
| 6 | 1306 | BRASSCHAAT | 51.29 | 4.49 | 3 | 24 |
| 7 | 1306 | BRECHT | 51.35 | 4.64 | 2 | 9 |
| 8 | 1306 | EDEGEM | 51.16 | 4.44 | 2.5 | 22 |
| 9 | 1306 | ESSEN | 51.46 | 4.45 | 2 | 4 |
| 10 | 1306 | HOVE | 51.15 | 4.47 | 2.5 | 7 |
| 11 | 1306 | KALMTHOUT | 51.38 | 4.48 | 2 | 9 |
| 12 | 1306 | KAPELLEN (ANTWERPEN) | 51.32 | 4.43 | 2.5 | 16 |
| 13 | 1306 | KONTICH | 51.13 | 4.44 | 2 | 22 |
| 14 | 1306 | LINT | 51.13 | 4.50 | 3 | 9 |
| 15 | 1306 | MORTSEL | 51.17 | 4.45 | 2.5 | 19 |
| 16 | 1306 | NIEL | 51.11 | 4.33 | 2 | 3 |
| 17 | 1306 | RANST | 51.19 | 4.56 | 2 | 14 |
| 18 | 1306 | RUMST | 51.08 | 4.42 | 2 | 16 |
| 19 | 1306 | SCHELLE | 51.13 | 4.34 | 3 | 11 |
| 20 | 1306 | SCHILDE | 51.23 | 4.58 | 3 | 11 |
| 21 | 1306 | SCHOTEN | 51.25 | 4.50 | 2.5 | 32 |
| 22 | 1306 | STABROEK | 51.33 | 4.36 | 2 | 9 |
| 23 | 1306 | WIJNEGEM | 51.23 | 4.52 | 2.5 | 8 |
| 24 | 1306 | WOMMELGEM | 51.20 | 4.52 | 2.5 | 13 |
| 25 | 1306 | WUUSTWEZEL | 51.39 | 4.59 | 2 | 5 |
| 26 | 1306 | ZANDHOVEN | 51.22 | 4.66 | 2.5 | 7 |
| 27 | 1306 | ZOERSEL | 51.27 | 4.71 | 2 | 12 |
| 28 | 1306 | ZWIJNDRECHT | 51.22 | 4.33 | 2 | 8 |
| 29 | 1306 | MALLE | 51.28 | 4.71 | 2 | 5 |
| 30 | 1306 | BERLAAR | 51.12 | 4.66 | 3 | 4 |
| 31 | 1306 | BONHEIDEN | 51.02 | 4.55 | 3 | 19 |
| 32 | 1306 | BORNEM | 51.10 | 4.23 | 2 | 18 |
| 33 | 1306 | DUFFEL | 51.09 | 4.50 | 2 | 5 |
| 34 | 1306 | HEIST-OP-DEN-BERG | 51.08 | 4.73 | 2.5 | 27 |
| 35 | 1306 | LIER | 51.13 | 4.57 | 2.5 | 27 |
| 36 | 1306 | MECHELEN | 51.03 | 4.48 | 3 | 82 |
| 37 | 1306 | NIJLEN | 51.16 | 4.67 | 2 | 13 |
| 38 | 1306 | PUTTE | 51.06 | 4.63 | 3 | 14 |
| 39 | 1306 | PUURS | 51.08 | 4.28 | 2 | 5 |
| 40 | 1306 | SINT-AMANDS | 51.05 | 4.20 | 3 | 3 |
| 41 | 1306 | SINT-KATELIJNE-WAVER | 51.07 | 4.53 | 2 | 27 |
| 42 | 1306 | WILLEBROEK | 51.06 | 4.36 | 2 | 9 |
| 43 | 1306 | ARENDONK | 51.32 | 5.09 | 2 | 7 |
| 44 | 1306 | BALEN | 51.17 | 5.17 | 2.5 | 14 |
| 45 | 1306 | BEERSE | 51.32 | 4.86 | 2.5 | 13 |
| 46 | 1306 | DESSEL | 51.24 | 5.11 | 3 | 8 |
| 47 | 1306 | GEEL | 51.16 | 4.99 | 2.5 | 32 |
| 48 | 1306 | GROBBENDONK | 51.19 | 4.74 | 2 | 7 |
| 49 | 1306 | HERENTALS | 51.18 | 4.84 | 2 | 21 |
| 50 | 1306 | HERSELT | 51.05 | 4.88 | 2 | 5 |
| 51 | 1306 | HULSHOUT | 51.07 | 4.79 | 2 | 4 |
| 52 | 1306 | KASTERLEE | 51.24 | 4.97 | 2 | 5 |
| 53 | 1306 | LILLE | 51.24 | 4.82 | 2 | 8 |
| 54 | 1306 | MEERHOUT | 51.13 | 5.08 | 2.5 | 6 |
| 55 | 1306 | MOL | 51.18 | 5.12 | 3 | 36 |
| 56 | 1306 | OLEN | 51.14 | 4.86 | 3 | 9 |
| 57 | 1306 | OUD-TURNHOUT | 51.32 | 4.98 | 3 | 6 |
| 58 | 1306 | RAVELS | 51.37 | 4.99 | 2 | 6 |
| 59 | 1306 | RETIE | 51.27 | 5.08 | 3 | 12 |
| 60 | 1306 | RIJKEVORSEL | 51.35 | 4.76 | 2 | 4 |
| 61 | 1306 | TURNHOUT | 51.32 | 4.95 | 2.5 | 32 |
| 62 | 1306 | VORSELAAR | 51.20 | 4.77 | 2 | 3 |
| 63 | 1306 | VOSSELAAR | 51.31 | 4.89 | 2 | 11 |
| 64 | 1306 | WESTERLO | 51.09 | 4.92 | 2.5 | 18 |
| 65 | 1306 | LAAKDAL | 51.08 | 5.02 | 2.5 | 10 |
| 66 | 1306 | ANDERLECHT | 50.84 | 4.31 | 3 | 29 |
| 67 | 1306 | AUDERGHEM | 50.82 | 4.43 | 3 | 31 |
| 68 | 1306 | BERCHEM-SAINTE-AGATHE | 50.86 | 4.30 | 3 | 12 |
| 69 | 1306 | BRUXELLES | 50.85 | 4.35 | 3 | 118 |
| 70 | 1306 | ETTERBEEK | 50.84 | 4.39 | 3 | 47 |
| 71 | 1306 | EVERE | 50.87 | 4.40 | 2.5 | 21 |
| 72 | 1306 | FOREST | 50.81 | 4.32 | 3 | 24 |
| 73 | 1306 | GANSHOREN | 50.87 | 4.31 | 3 | 10 |
| 74 | 1306 | IXELLES | 50.83 | 4.37 | 2.5 | 95 |
| 75 | 1306 | JETTE | 50.87 | 4.34 | 2.5 | 24 |
| 76 | 1306 | KOEKELBERG | 50.86 | 4.33 | 2 | 7 |
| 77 | 1306 | MOLENBEEK-SAINT-JEAN | 50.86 | 4.32 | 2 | 24 |
| 78 | 1306 | SAINT-GILLES | 50.83 | 4.35 | 2.5 | 26 |
| 79 | 1306 | SAINT-JOSSE-TEN-NOODE | 50.85 | 4.37 | 2.5 | 12 |
| 80 | 1306 | SCHAERBEEK | 50.86 | 4.37 | 2.5 | 60 |
| 81 | 1306 | UCCLE | 50.81 | 4.35 | 3 | 49 |
| 82 | 1306 | WATERMAEL-BOITSFORT | 50.81 | 4.40 | 3 | 17 |
| 83 | 1306 | WOLUWE-SAINT-LAMBERT | 50.85 | 4.43 | 3.5 | 53 |
| 84 | 1306 | WOLUWE-SAINT-PIERRE | 50.83 | 4.46 | 3 | 40 |
| 85 | 1306 | ASSE | 50.91 | 4.20 | 2 | 20 |
| 86 | 1306 | BEERSEL | 50.77 | 4.31 | 2.5 | 33 |
| 87 | 1306 | BEVER | 50.72 | 3.94 | 3.5 | 4 |
| 88 | 1306 | DILBEEK | 50.85 | 4.26 | 2.5 | 41 |
| 89 | 1306 | GALMAARDEN | 50.75 | 3.97 | 3.5 | 5 |
| 90 | 1306 | GOOIK | 50.80 | 4.12 | 3.5 | 6 |
| 91 | 1306 | GRIMBERGEN | 50.93 | 4.37 | 2.5 | 21 |
| 92 | 1306 | HAL | 50.74 | 4.24 | 3 | 51 |
| 93 | 1306 | HERNE | 50.72 | 4.03 | 3 | 8 |
| 94 | 1306 | HOEILAART | 50.77 | 4.47 | 3 | 13 |
| 95 | 1306 | KAMPENHOUT | 50.94 | 4.55 | 2 | 19 |
| 96 | 1306 | KAPELLE-OP-DEN-BOS | 51.01 | 4.36 | 2.5 | 8 |
| 97 | 1306 | LIEDEKERKE | 50.87 | 4.08 | 2 | 12 |
| 98 | 1306 | LONDERZEEL | 51.00 | 4.30 | 2.5 | 9 |
| 99 | 1306 | MACHELEN (VLAAMS-BRABANT) | 50.91 | 4.44 | 3 | 12 |
| 100 | 1306 | MEISE | 50.93 | 4.33 | 3 | 6 |
| 101 | 1306 | MERCHTEM | 50.96 | 4.23 | 2 | 10 |
| 102 | 1306 | OPWIJK | 50.97 | 4.19 | 2 | 5 |
| 103 | 1306 | OVERIJSE | 50.77 | 4.54 | 3 | 31 |
| 104 | 1306 | PEPINGEN | 50.76 | 4.16 | 3.5 | 4 |
| 105 | 1306 | SINT-PIETERS-LEEUW | 50.78 | 4.24 | 2.5 | 22 |
| 106 | 1306 | STEENOKKERZEEL | 50.91 | 4.51 | 3 | 9 |
| 107 | 1306 | TERNAT | 50.87 | 4.18 | 2.5 | 16 |
| 108 | 1306 | VILVOORDE | 50.93 | 4.42 | 2.5 | 27 |
| 109 | 1306 | ZAVENTEM | 50.89 | 4.47 | 3 | 36 |
| 110 | 1306 | ZEMST | 50.98 | 4.46 | 2.5 | 26 |
| 111 | 1306 | ROOSDAAL | 50.84 | 4.08 | 2.5 | 12 |
| 112 | 1306 | KRAAINEM | 50.86 | 4.47 | 3 | 12 |
| 113 | 1306 | LINKEBEEK | 50.77 | 4.34 | 2 | 7 |
| 114 | 1306 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 3 | 14 |
| 115 | 1306 | WEMMEL | 50.91 | 4.30 | 2.5 | 10 |
| 116 | 1306 | WEZEMBEEK-OPPEM | 50.84 | 4.49 | 3 | 12 |
| 117 | 1306 | LENNIK | 50.81 | 4.16 | 3 | 9 |
| 118 | 1306 | AFFLIGEM | 50.91 | 4.11 | 2.5 | 8 |
| 119 | 1306 | AARSCHOT | 50.98 | 4.83 | 3 | 25 |
| 120 | 1306 | BEGIJNENDIJK | 51.02 | 4.78 | 3 | 6 |
| 121 | 1306 | BEKKEVOORT | 50.94 | 4.97 | 2 | 3 |
| 122 | 1306 | BERTEM | 50.86 | 4.63 | 4 | 8 |
| 123 | 1306 | BIERBEEK | 50.83 | 4.76 | 3 | 16 |
| 124 | 1306 | BOORTMEERBEEK | 50.98 | 4.57 | 2.5 | 16 |
| 125 | 1306 | BOUTERSEM | 50.84 | 4.83 | 3.5 | 9 |
| 126 | 1306 | DIEST | 50.98 | 5.05 | 3 | 21 |
| 127 | 1306 | GEETBETS | 50.89 | 5.12 | 3 | 4 |
| 128 | 1306 | HAACHT | 50.98 | 4.64 | 3 | 18 |
| 129 | 1306 | HERENT | 50.91 | 4.67 | 3 | 32 |
| 130 | 1306 | HOEGAARDEN | 50.77 | 4.89 | 3 | 15 |
| 131 | 1306 | HOLSBEEK | 50.92 | 4.76 | 3.5 | 11 |
| 132 | 1306 | HULDENBERG | 50.79 | 4.58 | 3 | 15 |
| 133 | 1306 | KEERBERGEN | 51.00 | 4.63 | 3 | 14 |
| 134 | 1306 | KORTENAKEN | 50.91 | 5.06 | 3 | 3 |
| 135 | 1306 | KORTENBERG | 50.89 | 4.54 | 3 | 28 |
| 136 | 1306 | LANDEN | 50.76 | 5.08 | 3.5 | 25 |
| 137 | 1306 | LEUVEN | 50.88 | 4.70 | 3 | 209 |
| 138 | 1306 | LUBBEEK | 50.88 | 4.84 | 3 | 21 |
| 139 | 1306 | OUD-HEVERLEE | 50.84 | 4.66 | 3 | 23 |
| 140 | 1306 | ROTSELAAR | 50.95 | 4.71 | 2 | 11 |
| 141 | 1306 | TERVUREN | 50.82 | 4.51 | 3 | 23 |
| 142 | 1306 | TIENEN | 50.81 | 4.94 | 3.5 | 52 |
| 143 | 1306 | TREMELO | 50.99 | 4.71 | 2.5 | 14 |
| 144 | 1306 | ZOUTLEEUW | 50.83 | 5.10 | 3.5 | 10 |
| 145 | 1306 | LINTER | 50.80 | 5.06 | 2.5 | 6 |
| 146 | 1306 | SCHERPENHEUVEL-ZICHEM | 51.00 | 4.98 | 2.5 | 20 |
| 147 | 1306 | TIELT-WINGE | 50.94 | 4.90 | 3.5 | 9 |
| 148 | 1306 | GLABBEEK | 50.87 | 4.95 | 3 | 3 |
| 149 | 1306 | BEAUVECHAIN | 50.78 | 4.77 | 3.5 | 7 |
| 150 | 1306 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 3 | 34 |
| 151 | 1306 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 2.5 | 7 |
| 152 | 1306 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 3 | 8 |
| 153 | 1306 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 5 |
| 154 | 1306 | GENAPPE | 50.61 | 4.45 | 3 | 9 |
| 155 | 1306 | GREZ-DOICEAU | 50.74 | 4.70 | 3 | 15 |
| 156 | 1306 | INCOURT | 50.69 | 4.80 | 3.5 | 8 |
| 157 | 1306 | ITTRE | 50.65 | 4.26 | 3.5 | 3 |
| 158 | 1306 | JODOIGNE | 50.72 | 4.86 | 3.5 | 10 |
| 159 | 1306 | LA HULPE | 50.73 | 4.49 | 3 | 10 |

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|---|---|---|---|---|---|---|
| 160 | 1306 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3 | 5 |
| 161 | 1306 | NIVELLES | 50.60 | 4.32 | 3 | 18 |
| 162 | 1306 | PERWEZ | 50.62 | 4.81 | 2.5 | 8 |
| 163 | 1306 | RIXENSART | 50.71 | 4.54 | 3.5 | 22 |
| 164 | 1306 | TUBIZE | 50.69 | 4.20 | 3 | 9 |
| 165 | 1306 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 5 |
| 166 | 1306 | WATERLOO | 50.72 | 4.40 | 3.5 | 24 |
| 167 | 1306 | WAVRE | 50.72 | 4.61 | 3.5 | 22 |
| 168 | 1306 | CHASTRE | 50.61 | 4.64 | 3 | 7 |
| 169 | 1306 | HELECINE | 50.75 | 4.97 | 3 | 6 |
| 170 | 1306 | LASNE | 50.68 | 4.46 | 2.5 | 15 |
| 171 | 1306 | ORP-JAUCHE | 50.68 | 4.95 | 3 | 12 |
| 172 | 1306 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3 | 42 |
| 173 | 1306 | RAMILLIES | 50.66 | 4.89 | 3.5 | 4 |
| 174 | 1306 | REBECQ | 50.67 | 4.13 | 2.5 | 6 |
| 175 | 1306 | WALHAIN | 50.62 | 4.70 | 3.5 | 5 |
| 176 | 1306 | BEERNEM | 51.14 | 3.34 | 2 | 5 |
| 177 | 1306 | BLANKENBERGE | 51.32 | 3.13 | 2 | 5 |
| 178 | 1306 | BRUGGE | 51.21 | 3.23 | 2 | 17 |
| 179 | 1306 | DAMME | 51.25 | 3.28 | 2 | 3 |
| 180 | 1306 | TORHOUT | 51.07 | 3.10 | 2 | 3 |
| 181 | 1306 | ZEDELGEM | 51.14 | 3.14 | 1 | 6 |
| 182 | 1306 | KNOKKE-HEIST | 51.34 | 3.24 | 1 | 3 |
| 183 | 1306 | IEPER | 50.85 | 2.88 | 2 | 8 |
| 184 | 1306 | WERVIK | 50.78 | 3.05 | 1 | 4 |
| 185 | 1306 | ANZEGEM | 50.83 | 3.48 | 2 | 6 |
| 186 | 1306 | AVELGEM | 50.78 | 3.45 | 2 | 3 |
| 187 | 1306 | DEERLIJK | 50.85 | 3.36 | 2 | 5 |
| 188 | 1306 | HARELBEKE | 50.86 | 3.31 | 2 | 8 |
| 189 | 1306 | KORTRIJK | 50.83 | 3.27 | 2 | 18 |
| 190 | 1306 | KUURNE | 50.85 | 3.29 | 2 | 6 |
| 191 | 1306 | LENDELEDE | 50.89 | 3.24 | 2 | 3 |
| 192 | 1306 | MENEN | 50.80 | 3.12 | 2 | 5 |
| 193 | 1306 | WAREGEM | 50.89 | 3.43 | 2 | 20 |
| 194 | 1306 | WEVELGEM | 50.81 | 3.18 | 2 | 11 |
| 195 | 1306 | ZWEVEGEM | 50.81 | 3.33 | 2 | 5 |
| 196 | 1306 | OOSTENDE | 51.23 | 2.91 | 2 | 9 |
| 197 | 1306 | DE HAAN | 51.27 | 3.04 | 2 | 3 |
| 198 | 1306 | HOOGLEDE | 50.98 | 3.08 | 2 | 3 |
| 199 | 1306 | IZEGEM | 50.92 | 3.22 | 2 | 5 |
| 200 | 1306 | MOORSLEDE | 50.89 | 3.06 | 2 | 3 |
| 201 | 1306 | ROESELARE | 50.94 | 3.12 | 2 | 23 |
| 202 | 1306 | DENTERGEM | 50.96 | 3.42 | 2.5 | 3 |
| 203 | 1306 | PITTEM | 51.00 | 3.27 | 2 | 3 |
| 204 | 1306 | TIELT (WEST-VLAANDEREN) | 51.00 | 3.33 | 2 | 5 |
| 205 | 1306 | WIELSBEKE | 50.91 | 3.37 | 2 | 5 |
| 206 | 1306 | KOKSIJDE | 51.10 | 2.65 | 2 | 5 |
| 207 | 1306 | AALST (OOST-VLAANDEREN) | 50.94 | 4.04 | 2.5 | 45 |
| 208 | 1306 | DENDERLEEUW | 50.88 | 4.08 | 3 | 17 |
| 209 | 1306 | GERAARDSBERGEN | 50.77 | 3.88 | 2.5 | 24 |
| 210 | 1306 | HAALTERT | 50.90 | 4.01 | 2.5 | 14 |
| 211 | 1306 | HERZELE | 50.89 | 3.89 | 2.5 | 9 |
| 212 | 1306 | LEDE | 50.97 | 3.98 | 3 | 13 |
| 213 | 1306 | NINOVE | 50.84 | 4.02 | 2.5 | 29 |
| 214 | 1306 | SINT-LIEVENS-HOUTEM | 50.92 | 3.86 | 2 | 4 |
| 215 | 1306 | ZOTTEGEM | 50.87 | 3.81 | 3 | 11 |
| 216 | 1306 | ERPE-MERE | 50.93 | 3.98 | 2 | 11 |
| 217 | 1306 | BERLARE | 51.03 | 4.00 | 2 | 8 |
| 218 | 1306 | BUGGENHOUT | 51.02 | 4.20 | 2.5 | 7 |
| 219 | 1306 | DENDERMONDE | 51.03 | 4.10 | 2.5 | 24 |
| 220 | 1306 | HAMME (OOST-VLAANDEREN) | 51.10 | 4.14 | 2 | 6 |
| 221 | 1306 | LAARNE | 51.03 | 3.85 | 2 | 6 |
| 222 | 1306 | LEBBEKE | 51.00 | 4.13 | 2 | 7 |
| 223 | 1306 | WAASMUNSTER | 51.11 | 4.09 | 2 | 11 |
| 224 | 1306 | WETTEREN | 51.01 | 3.89 | 2 | 12 |
| 225 | 1306 | WICHELEN | 51.01 | 3.98 | 2.5 | 6 |
| 226 | 1306 | ZELE | 51.07 | 4.04 | 2 | 11 |
| 227 | 1306 | EEKLO | 51.19 | 3.57 | 2 | 5 |
| 228 | 1306 | KAPRIJKE | 51.22 | 3.62 | 2 | 3 |
| 229 | 1306 | MALDEGEM | 51.21 | 3.45 | 2 | 5 |
| 230 | 1306 | ZELZATE | 51.20 | 3.81 | 2 | 3 |
| 231 | 1306 | AALTER | 51.08 | 3.45 | 2 | 5 |
| 232 | 1306 | DEINZE | 50.98 | 3.53 | 2 | 8 |
| 233 | 1306 | DE PINTE | 50.99 | 3.65 | 2 | 6 |
| 234 | 1306 | DESTELBERGEN | 51.06 | 3.80 | 2.5 | 11 |
| 235 | 1306 | EVERGEM | 51.11 | 3.71 | 2 | 8 |
| 236 | 1306 | GAVERE | 50.93 | 3.66 | 2 | 6 |

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|---|---|---|---|---|---|---|
| 237 | 1306 | GENT | 51.05 | 3.72 | 2.5 | 137 |
| 238 | 1306 | LOCHRISTI | 51.10 | 3.83 | 2 | 8 |
| 239 | 1306 | LOVENDEGEM | 51.10 | 3.61 | 2 | 5 |
| 240 | 1306 | MELLE | 51.00 | 3.80 | 2 | 12 |
| 241 | 1306 | MERELBEKE | 50.99 | 3.75 | 2 | 17 |
| 242 | 1306 | NAZARETH | 50.96 | 3.60 | 1 | 3 |
| 243 | 1306 | OOSTERZELE | 50.95 | 3.80 | 2 | 7 |
| 244 | 1306 | ZULTE | 50.92 | 3.44 | 2.5 | 5 |
| 245 | 1306 | KRUISHOUTEM | 50.90 | 3.53 | 2 | 4 |
| 246 | 1306 | OUDENAARDE | 50.84 | 3.60 | 2 | 20 |
| 247 | 1306 | RONSE | 50.75 | 3.60 | 2.5 | 18 |
| 248 | 1306 | ZINGEM | 50.90 | 3.65 | 2 | 4 |
| 249 | 1306 | BRAKEL | 50.80 | 3.77 | 3 | 11 |
| 250 | 1306 | WORTEGEM-PETEGEM | 50.85 | 3.51 | 3 | 4 |
| 251 | 1306 | HOREBEKE | 50.83 | 3.69 | 2 | 4 |
| 252 | 1306 | MAARKEDAL | 50.80 | 3.65 | 2 | 6 |
| 253 | 1306 | BEVEREN-WAAS | 51.21 | 4.26 | 2.5 | 22 |
| 254 | 1306 | KRUIBEKE | 51.17 | 4.31 | 2 | 6 |
| 255 | 1306 | LOKEREN | 51.10 | 3.99 | 2 | 8 |
| 256 | 1306 | SINT-GILLIS-WAAS | 51.22 | 4.13 | 2 | 5 |
| 257 | 1306 | SINT-NIKLAAS | 51.16 | 4.14 | 2.5 | 22 |
| 258 | 1306 | STEKENE | 51.21 | 4.04 | 3 | 4 |
| 259 | 1306 | TEMSE | 51.12 | 4.21 | 3 | 17 |
| 260 | 1306 | ATH | 50.63 | 3.77 | 2 | 4 |
| 261 | 1306 | BELOEIL | 50.55 | 3.73 | 2.5 | 3 |
| 262 | 1306 | ELLEZELLES | 50.73 | 3.68 | 3 | 3 |
| 263 | 1306 | FLOBECQ | 50.74 | 3.74 | 3 | 4 |
| 264 | 1306 | FRASNES-LEZ-ANVAING | 50.68 | 3.56 | 3 | 3 |
| 265 | 1306 | CHAPELLE-LEZ-HERLAIMONT | 50.47 | 4.29 | 3 | 4 |
| 266 | 1306 | CHARLEROI | 50.41 | 4.44 | 2 | 24 |
| 267 | 1306 | CHATELET | 50.40 | 4.52 | 2 | 7 |
| 268 | 1306 | COURCELLES | 50.46 | 4.38 | 2 | 3 |
| 269 | 1306 | FLEURUS | 50.48 | 4.55 | 3 | 4 |
| 270 | 1306 | GERPINNES | 50.34 | 4.53 | 2 | 3 |
| 271 | 1306 | MANAGE | 50.50 | 4.23 | 2 | 5 |
| 272 | 1306 | PONT-A-CELLES | 50.51 | 4.36 | 2.5 | 5 |
| 273 | 1306 | SENEFFE | 50.53 | 4.26 | 3 | 5 |
| 274 | 1306 | LES BONS VILLERS | 50.52 | 4.48 | 2.5 | 3 |
| 275 | 1306 | FRAMERIES | 50.41 | 3.89 | 2 | 3 |
| 276 | 1306 | JURBISE | 50.53 | 3.91 | 2 | 4 |
| 277 | 1306 | MONS | 50.45 | 3.95 | 2.5 | 20 |
| 278 | 1306 | SAINT-GHISLAIN | 50.45 | 3.82 | 2.5 | 3 |
| 279 | 1306 | QUEVY | 50.37 | 3.96 | 2 | 3 |
| 280 | 1306 | MOUSCRON | 50.74 | 3.22 | 1 | 3 |
| 281 | 1306 | BRAINE-LE-COMTE | 50.61 | 4.14 | 3.5 | 3 |
| 282 | 1306 | ENGHIEN | 50.69 | 4.04 | 2 | 8 |
| 283 | 1306 | LA LOUVIERE | 50.48 | 4.19 | 2.5 | 9 |
| 284 | 1306 | LESSINES | 50.71 | 3.83 | 3 | 12 |
| 285 | 1306 | LE ROEULX | 50.50 | 4.11 | 3 | 3 |
| 286 | 1306 | SOIGNIES | 50.58 | 4.07 | 2 | 3 |
| 287 | 1306 | ECAUSSINNES | 50.56 | 4.18 | 2.5 | 4 |
| 288 | 1306 | THUIN | 50.34 | 4.29 | 2 | 5 |
| 289 | 1306 | HAM-SUR-HEURE-NALINNES | 50.32 | 4.39 | 3 | 5 |
| 290 | 1306 | PERUWELZ | 50.51 | 3.59 | 3.5 | 3 |
| 291 | 1306 | TOURNAI | 50.61 | 3.39 | 2 | 12 |
| 292 | 1306 | BURDINNE | 50.58 | 5.07 | 2 | 3 |
| 293 | 1306 | FERRIERES | 50.40 | 5.61 | 3.5 | 3 |
| 294 | 1306 | HERON | 50.55 | 5.10 | 3 | 5 |
| 295 | 1306 | HUY | 50.52 | 5.24 | 3 | 11 |
| 296 | 1306 | VERLAINE | 50.61 | 5.32 | 3.5 | 5 |
| 297 | 1306 | WANZE | 50.54 | 5.21 | 3.5 | 6 |
| 298 | 1306 | ANS | 50.66 | 5.52 | 3.5 | 24 |
| 299 | 1306 | AWANS | 50.66 | 5.46 | 2.5 | 6 |
| 300 | 1306 | AYWAILLE | 50.47 | 5.68 | 3.5 | 4 |
| 301 | 1306 | BASSENGE | 50.76 | 5.61 | 4.5 | 6 |
| 302 | 1306 | BEYNE-HEUSAY | 50.62 | 5.65 | 3.5 | 10 |
| 303 | 1306 | CHAUDFONTAINE | 50.59 | 5.65 | 3 | 11 |
| 304 | 1306 | DALHEM | 50.71 | 5.72 | 4 | 4 |
| 305 | 1306 | ESNEUX | 50.53 | 5.57 | 2 | 17 |
| 306 | 1306 | FLERON | 50.62 | 5.69 | 4.5 | 8 |
| 307 | 1306 | HERSTAL | 50.67 | 5.63 | 4 | 14 |
| 308 | 1306 | JUPRELLE | 50.71 | 5.53 | 3.5 | 6 |
| 309 | 1306 | LIEGE | 50.64 | 5.57 | 3 | 125 |
| 310 | 1306 | OUPEYE | 50.71 | 5.64 | 3 | 13 |
| 311 | 1306 | SAINT-NICOLAS | 50.63 | 5.54 | 2.5 | 7 |
| 312 | 1306 | SERAING | 50.60 | 5.51 | 3 | 32 |
| 313 | 1306 | SOUMAGNE | 50.61 | 5.75 | 2.5 | 7 |
| 314 | 1306 | SPRIMONT | 50.50 | 5.66 | 2 | 3 |
| 315 | 1306 | VISE | 50.73 | 5.70 | 3.5 | 8 |

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|---|---|---|---|---|---|---|
| 316 | 1306 | GRACE-HOLLOGNE | 50.64 | 5.50 | 2 | 6 |
| 317 | 1306 | BLEGNY | 50.67 | 5.73 | 3.5 | 11 |
| 318 | 1306 | FLEMALLE | 50.60 | 5.47 | 2.5 | 10 |
| 319 | 1306 | NEUPRE | 50.55 | 5.49 | 2.5 | 12 |
| 320 | 1306 | AMEL | 50.35 | 6.17 | 3 | 5 |
| 321 | 1306 | BAELEN | 50.63 | 5.97 | 3 | 4 |
| 322 | 1306 | DISON | 50.61 | 5.85 | 3 | 8 |
| 323 | 1306 | EUPEN | 50.63 | 6.03 | 3.5 | 8 |
| 324 | 1306 | HERVE | 50.64 | 5.79 | 3.5 | 16 |
| 325 | 1306 | JALHAY | 50.56 | 5.96 | 2 | 4 |
| 326 | 1306 | KELMIS | 50.72 | 6.01 | 4 | 6 |
| 327 | 1306 | MALMEDY | 50.43 | 6.03 | 3.5 | 3 |
| 328 | 1306 | PEPINSTER | 50.57 | 5.80 | 3.5 | 5 |
| 329 | 1306 | SPA | 50.49 | 5.86 | 3 | 7 |
| 330 | 1306 | STAVELOT | 50.39 | 5.93 | 3.5 | 6 |
| 331 | 1306 | STOUMONT | 50.41 | 5.81 | 2 | 3 |
| 332 | 1306 | THEUX | 50.54 | 5.81 | 3 | 8 |
| 333 | 1306 | VERVIERS | 50.59 | 5.86 | 3.5 | 29 |
| 334 | 1306 | WELKENRAEDT | 50.66 | 5.97 | 4.5 | 5 |
| 335 | 1306 | PLOMBIERES | 50.74 | 5.96 | 4 | 5 |
| 336 | 1306 | THIMISTER-CLERMONT | 50.66 | 5.88 | 4 | 10 |
| 337 | 1306 | CRISNEE | 50.72 | 5.40 | 3 | 4 |
| 338 | 1306 | DONCEEL | 50.65 | 5.32 | 3 | 3 |
| 339 | 1306 | FEXHE-LE-HAUT-CLOCHER | 50.67 | 5.40 | 4 | 3 |
| 340 | 1306 | HANNUT | 50.67 | 5.08 | 3.5 | 11 |
| 341 | 1306 | LINCENT | 50.71 | 5.03 | 2.5 | 3 |
| 342 | 1306 | REMICOURT | 50.68 | 5.33 | 3.5 | 7 |
| 343 | 1306 | WAREMME | 50.70 | 5.26 | 3 | 5 |
| 344 | 1306 | WASSEIGES | 50.62 | 5.01 | 3 | 3 |
| 345 | 1306 | AS | 51.01 | 5.58 | 3.5 | 9 |
| 346 | 1306 | BERINGEN | 51.05 | 5.22 | 3 | 31 |
| 347 | 1306 | DIEPENBEEK | 50.91 | 5.42 | 3.5 | 21 |
| 348 | 1306 | GENK | 50.96 | 5.50 | 3.5 | 54 |
| 349 | 1306 | GINGELOM | 50.75 | 5.14 | 3.5 | 12 |
| 350 | 1306 | HALEN | 50.95 | 5.11 | 3.5 | 7 |
| 351 | 1306 | HASSELT | 50.93 | 5.34 | 3 | 77 |
| 352 | 1306 | HERK-DE-STAD | 50.94 | 5.17 | 3 | 11 |
| 353 | 1306 | LEOPOLDSBURG | 51.12 | 5.26 | 2.5 | 17 |
| 354 | 1306 | LUMMEN | 50.99 | 5.19 | 3 | 17 |
| 355 | 1306 | NIEUWERKERKEN (LIMBURG) | 50.86 | 5.19 | 3.5 | 5 |
| 356 | 1306 | OPGLABBEEK | 51.04 | 5.58 | 2 | 7 |
| 357 | 1306 | SINT-TRUIDEN | 50.82 | 5.19 | 3 | 28 |
| 358 | 1306 | TESSENDERLO | 51.07 | 5.09 | 2.5 | 12 |
| 359 | 1306 | ZONHOVEN | 50.99 | 5.37 | 3 | 18 |
| 360 | 1306 | ZUTENDAAL | 50.93 | 5.57 | 3 | 14 |
| 361 | 1306 | HAM | 51.11 | 5.16 | 3 | 11 |
| 362 | 1306 | HEUSDEN-ZOLDER | 51.02 | 5.31 | 2.5 | 19 |
| 363 | 1306 | BREE | 51.14 | 5.60 | 3 | 11 |
| 364 | 1306 | DILSEN | 51.04 | 5.72 | 3 | 13 |
| 365 | 1306 | KINROOI | 51.14 | 5.74 | 3.5 | 6 |
| 366 | 1306 | LOMMEL | 51.23 | 5.31 | 2.5 | 23 |
| 367 | 1306 | MAASEIK | 51.09 | 5.79 | 3.5 | 21 |
| 368 | 1306 | NEERPELT | 51.23 | 5.43 | 2 | 12 |
| 369 | 1306 | OVERPELT | 51.21 | 5.43 | 2.5 | 6 |
| 370 | 1306 | PEER | 51.13 | 5.45 | 2 | 7 |
| 371 | 1306 | HAMONT-ACHEL | 51.25 | 5.55 | 2 | 9 |
| 372 | 1306 | HECHTEL-EKSEL | 51.15 | 5.39 | 2.5 | 10 |
| 373 | 1306 | HOUTHALEN-HELCHTEREN | 51.03 | 5.37 | 3.5 | 25 |
| 374 | 1306 | MEEUWEN-GRUITRODE | 51.09 | 5.59 | 3 | 12 |
| 375 | 1306 | ALKEN | 50.88 | 5.31 | 3.5 | 23 |
| 376 | 1306 | BILZEN | 50.87 | 5.52 | 3.5 | 50 |
| 377 | 1306 | BORGLOON | 50.80 | 5.34 | 4 | 12 |
| 378 | 1306 | HEERS | 50.76 | 5.30 | 3 | 7 |
| 379 | 1306 | HOESELT | 50.85 | 5.49 | 3 | 13 |
| 380 | 1306 | KORTESSEM | 50.86 | 5.39 | 3.5 | 6 |
| 381 | 1306 | LANAKEN | 50.89 | 5.65 | 3.5 | 36 |
| 382 | 1306 | RIEMST | 50.81 | 5.60 | 4 | 23 |
| 383 | 1306 | TONGEREN | 50.78 | 5.46 | 3.5 | 44 |
| 384 | 1306 | WELLEN | 50.84 | 5.34 | 3.5 | 13 |
| 385 | 1306 | MAASMECHELEN | 50.96 | 5.70 | 4 | 23 |
| 386 | 1306 | VOEREN | 50.73 | 5.84 | 4 | 7 |
| 387 | 1306 | ARLON | 49.68 | 5.82 | 2.5 | 7 |
| 388 | 1306 | AUBANGE | 49.57 | 5.81 | 2 | 4 |
| 389 | 1306 | MESSANCY | 49.59 | 5.82 | 3 | 3 |
| 390 | 1306 | BASTOGNE | 50.01 | 5.72 | 2.5 | 9 |
| 391 | 1306 | BERTOGNE | 50.08 | 5.67 | 3 | 3 |
| 392 | 1306 | HOUFFALIZE | 50.13 | 5.79 | 3 | 5 |
| 393 | 1306 | VIELSALM | 50.29 | 5.92 | 3 | 3 |
| 394 | 1306 | VAUX-SUR-SURE | 49.91 | 5.57 | 3 | 3 |
| 395 | 1306 | LA ROCHE-EN-ARDENNE | 50.18 | 5.58 | 3 | 5 |
| 396 | 1306 | MARCHE-EN-FAMENNE | 50.23 | 5.34 | 3 | 7 |
| 397 | 1306 | RENDEUX | 50.23 | 5.50 | 3.5 | 3 |
| 398 | 1306 | BOUILLON | 49.80 | 5.07 | 2 | 3 |
| 399 | 1306 | NEUFCHATEAU (LUXEMBOURG) | 49.84 | 5.43 | 2.5 | 3 |
| 400 | 1306 | HABAY | 49.73 | 5.64 | 3 | 3 |
| 401 | 1306 | ANHEE | 50.31 | 4.88 | 2 | 3 |
| 402 | 1306 | CINEY | 50.30 | 5.10 | 3 | 3 |
| 403 | 1306 | DINANT | 50.26 | 4.91 | 4 | 5 |
| 404 | 1306 | ONHAYE | 50.24 | 4.84 | 2.5 | 3 |
| 405 | 1306 | YVOIR | 50.33 | 4.88 | 2 | 4 |
| 406 | 1306 | ANDENNE | 50.49 | 5.10 | 3.5 | 8 |
| 407 | 1306 | EGHEZEE | 50.59 | 4.91 | 3 | 7 |
| 408 | 1306 | FLOREFFE | 50.44 | 4.76 | 3 | 5 |
| 409 | 1306 | NAMUR | 50.46 | 4.86 | 2.5 | 61 |
| 410 | 1306 | SOMBREFFE | 50.52 | 4.60 | 3 | 5 |
| 411 | 1306 | SAMBREVILLE | 50.45 | 4.62 | 2 | 5 |
| 412 | 1306 | GEMBLOUX | 50.56 | 4.69 | 3 | 21 |
| 413 | 1306 | FLORENNES | 50.25 | 4.60 | 2 | 3 |
| 414 | 2975 | SPRIMONT | 50.50 | 5.66 | 2 | 3 |
| 415 | 2975 | JALHAY | 50.56 | 5.96 | 2 | 3 |
| 416 | 2975 | SPA | 50.49 | 5.86 | 3 | 10 |
| 417 | 2975 | THEUX | 50.54 | 5.81 | 3 | 13 |
| 418 | 2975 | VERVIERS | 50.59 | 5.86 | 2 | 4 |
| 419 | 3068 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 12 |
| 420 | 3068 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 10 |
| 421 | 3068 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 36 |
| 422 | 3068 | GENAPPE | 50.61 | 4.45 | 2 | 35 |
| 423 | 3068 | JODOIGNE | 50.72 | 4.86 | 2 | 3 |
| 424 | 3068 | LA HULPE | 50.73 | 4.49 | 2 | 3 |
| 425 | 3068 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 26 |
| 426 | 3068 | NIVELLES | 50.60 | 4.32 | 2 | 5 |
| 427 | 3068 | RIXENSART | 50.71 | 4.54 | 3 | 8 |
| 428 | 3068 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 11 |
| 429 | 3068 | WATERLOO | 50.72 | 4.40 | 2 | 8 |
| 430 | 3068 | WAVRE | 50.72 | 4.61 | 3 | 17 |
| 431 | 3068 | CHASTRE | 50.61 | 4.64 | 2.5 | 23 |
| 432 | 3068 | LASNE | 50.68 | 4.46 | 3 | 12 |
| 433 | 3068 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2.5 | 64 |
| 434 | 3068 | WALHAIN | 50.62 | 4.70 | 3 | 10 |
| 435 | 3068 | GEMBLOUX | 50.56 | 4.69 | 2 | 17 |
| 436 | 3069 | ANDERLECHT | 50.84 | 4.31 | 2 | 10 |
| 437 | 3069 | AUDERGHEM | 50.82 | 4.43 | 3 | 34 |
| 438 | 3069 | BRUXELLES | 50.85 | 4.35 | 2 | 12 |
| 439 | 3069 | ETTERBEEK | 50.84 | 4.39 | 3 | 15 |
| 440 | 3069 | EVERE | 50.87 | 4.40 | 2 | 12 |
| 441 | 3069 | FOREST | 50.81 | 4.32 | 2 | 9 |
| 442 | 3069 | IXELLES | 50.83 | 4.37 | 2 | 27 |
| 443 | 3069 | JETTE | 50.87 | 4.34 | 3 | 8 |
| 444 | 3069 | MOLENBEEK-SAINT-JEAN | 50.86 | 4.32 | 3 | 4 |
| 445 | 3069 | SAINT-GILLES | 50.83 | 4.35 | 2.5 | 5 |
| 446 | 3069 | SAINT-JOSSE-TEN-NOODE | 50.85 | 4.37 | 3 | 4 |
| 447 | 3069 | SCHAERBEEK | 50.86 | 4.37 | 2 | 5 |
| 448 | 3069 | UCCLE | 50.81 | 4.35 | 2.5 | 28 |
| 449 | 3069 | WATERMAEL-BOITSFORT | 50.81 | 4.40 | 2 | 25 |
| 450 | 3069 | WOLUWE-SAINT-LAMBERT | 50.85 | 4.43 | 2 | 13 |
| 451 | 3069 | WOLUWE-SAINT-PIERRE | 50.83 | 4.46 | 2 | 19 |
| 452 | 3069 | BEERSEL | 50.77 | 4.31 | 2.5 | 20 |
| 453 | 3069 | HAL | 50.74 | 4.24 | 2 | 7 |
| 454 | 3069 | HOEILAART | 50.77 | 4.47 | 3 | 17 |
| 455 | 3069 | KAMPENHOUT | 50.94 | 4.55 | 3 | 3 |
| 456 | 3069 | OVERIJSE | 50.77 | 4.54 | 2.5 | 26 |
| 457 | 3069 | SINT-PIETERS-LEEUW | 50.78 | 4.24 | 2.5 | 10 |
| 458 | 3069 | VILVOORDE | 50.93 | 4.42 | 2 | 6 |
| 459 | 3069 | ZAVENTEM | 50.89 | 4.47 | 2.5 | 8 |
| 460 | 3069 | DROGENBOS | 50.79 | 4.32 | 2 | 3 |
| 461 | 3069 | KRAAINEM | 50.86 | 4.47 | 2 | 8 |
| 462 | 3069 | LINKEBEEK | 50.77 | 4.34 | 3.5 | 8 |
| 463 | 3069 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 2.5 | 22 |
| 464 | 3069 | WEZEMBEEK-OPPEM | 50.84 | 4.49 | 2 | 10 |
| 465 | 3069 | BERTEM | 50.86 | 4.63 | 3 | 4 |
| 466 | 3069 | BIERBEEK | 50.83 | 4.76 | 3 | 3 |
| 467 | 3069 | HOEGAARDEN | 50.77 | 4.89 | 2.5 | 4 |
| 468 | 3069 | HULDENBERG | 50.79 | 4.58 | 2 | 14 |
| 469 | 3069 | KORTENBERG | 50.89 | 4.54 | 2 | 7 |
| 470 | 3069 | LEUVEN | 50.88 | 4.70 | 2 | 6 |
| 471 | 3069 | OUD-HEVERLEE | 50.84 | 4.66 | 2 | 3 |
| 472 | 3069 | TERVUREN | 50.82 | 4.51 | 2 | 11 |

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|---|---|---|---|---|---|---|
| 473 | 3069 | TIENEN | 50.81 | 4.94 | 3 | 3 |
| 474 | 3069 | BEAUVECHAIN | 50.78 | 4.77 | 2.5 | 10 |
| 475 | 3069 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 54 |
| 476 | 3069 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 2 | 8 |
| 477 | 3069 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 3 | 29 |
| 478 | 3069 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3.5 | 43 |
| 479 | 3069 | GENAPPE | 50.61 | 4.45 | 2.5 | 50 |
| 480 | 3069 | GREZ-DOICEAU | 50.74 | 4.70 | 2.5 | 24 |
| 481 | 3069 | INCOURT | 50.69 | 4.80 | 2 | 16 |
| 482 | 3069 | ITTRE | 50.65 | 4.26 | 2 | 4 |
| 483 | 3069 | JODOIGNE | 50.72 | 4.86 | 2 | 15 |
| 484 | 3069 | LA HULPE | 50.73 | 4.49 | 2 | 21 |
| 485 | 3069 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3 | 33 |
| 486 | 3069 | NIVELLES | 50.60 | 4.32 | 2 | 30 |
| 487 | 3069 | PERWEZ | 50.62 | 4.81 | 2 | 15 |
| 488 | 3069 | RIXENSART | 50.71 | 4.54 | 2.5 | 64 |
| 489 | 3069 | TUBIZE | 50.69 | 4.20 | 2 | 5 |
| 490 | 3069 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 25 |
| 491 | 3069 | WATERLOO | 50.72 | 4.40 | 2 | 37 |
| 492 | 3069 | WAVRE | 50.72 | 4.61 | 3 | 66 |
| 493 | 3069 | CHASTRE | 50.61 | 4.64 | 3.5 | 34 |
| 494 | 3069 | HELECINE | 50.75 | 4.97 | 3 | 7 |
| 495 | 3069 | LASNE | 50.68 | 4.46 | 3.5 | 28 |
| 496 | 3069 | ORP-JAUCHE | 50.68 | 4.95 | 2.5 | 13 |
| 497 | 3069 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3 | 114 |
| 498 | 3069 | RAMILLIES | 50.66 | 4.89 | 3 | 7 |
| 499 | 3069 | WALHAIN | 50.62 | 4.70 | 3 | 24 |
| 500 | 3069 | FLEURUS | 50.48 | 4.55 | 2 | 4 |
| 501 | 3069 | PONT-A-CELLES | 50.51 | 4.36 | 2.5 | 4 |
| 502 | 3069 | LES BONS VILLERS | 50.52 | 4.48 | 2 | 15 |
| 503 | 3069 | BRAIVES | 50.63 | 5.15 | 2.5 | 5 |
| 504 | 3069 | GEER | 50.67 | 5.17 | 2 | 4 |
| 505 | 3069 | HANNUT | 50.67 | 5.08 | 2 | 10 |
| 506 | 3069 | WASSEIGES | 50.62 | 5.01 | 2 | 3 |
| 507 | 3069 | ANDENNE | 50.49 | 5.10 | 2 | 3 |
| 508 | 3069 | EGHEZEE | 50.59 | 4.91 | 2.5 | 24 |
| 509 | 3069 | NAMUR | 50.46 | 4.86 | 2 | 38 |
| 510 | 3069 | SOMBREFFE | 50.52 | 4.60 | 2.5 | 18 |
| 511 | 3069 | FERNELMONT | 50.56 | 4.99 | 2 | 8 |
| 512 | 3069 | JEMEPPE-SUR-SAMBRE | 50.47 | 4.67 | 2.5 | 13 |
| 513 | 3069 | LA BRUYERE | 50.53 | 4.82 | 2 | 18 |
| 514 | 3069 | GEMBLOUX | 50.56 | 4.69 | 3 | 57 |
| 515 | 3070 | BOUSSU | 50.43 | 3.79 | 3.5 | 22 |
| 516 | 3070 | DOUR | 50.40 | 3.78 | 3.5 | 24 |
| 517 | 3070 | FRAMERIES | 50.41 | 3.89 | 3 | 3 |
| 518 | 3070 | HENSIES | 50.43 | 3.68 | 2.5 | 5 |
| 519 | 3070 | MONS | 50.45 | 3.95 | 3 | 4 |
| 520 | 3070 | QUAREGNON | 50.44 | 3.87 | 2 | 6 |
| 521 | 3070 | SAINT-GHISLAIN | 50.45 | 3.82 | 3 | 3 |
| 522 | 3070 | COLFONTAINE | 50.41 | 3.85 | 3 | 21 |
| 523 | 3096 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 12 |
| 524 | 3096 | GENAPPE | 50.61 | 4.45 | 2 | 11 |
| 525 | 3096 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 5 |
| 526 | 3096 | RIXENSART | 50.71 | 4.54 | 2 | 3 |
| 527 | 3096 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 4 |
| 528 | 3096 | WAVRE | 50.72 | 4.61 | 2 | 4 |
| 529 | 3096 | CHASTRE | 50.61 | 4.64 | 2 | 5 |
| 530 | 3096 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 19 |
| 531 | 3096 | GEMBLOUX | 50.56 | 4.69 | 2 | 4 |
| 532 | 3098 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 4 |
| 533 | 3098 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 5 |
| 534 | 3098 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 15 |
| 535 | 3098 | GENAPPE | 50.61 | 4.45 | 2 | 18 |
| 536 | 3098 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 12 |
| 537 | 3098 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2.5 | 13 |
| 538 | 3098 | WATERLOO | 50.72 | 4.40 | 2 | 5 |
| 539 | 3098 | WAVRE | 50.72 | 4.61 | 2 | 10 |
| 540 | 3098 | CHASTRE | 50.61 | 4.64 | 2.5 | 13 |
| 541 | 3098 | LASNE | 50.68 | 4.46 | 2 | 9 |
| 542 | 3098 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 48 |
| 543 | 3098 | WALHAIN | 50.62 | 4.70 | 3 | 4 |
| 544 | 3098 | GEMBLOUX | 50.56 | 4.69 | 2 | 11 |
| 545 | 3165 | OVERIJSE | 50.77 | 4.54 | 2 | 6 |
| 546 | 3165 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 2.5 | 3 |
| 547 | 3165 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 14 |
| 548 | 3165 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 17 |
| 549 | 3165 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 57 |
| 550 | 3165 | GENAPPE | 50.61 | 4.45 | 2.5 | 52 |
| 551 | 3165 | LA HULPE | 50.73 | 4.49 | 2 | 5 |
| 552 | 3165 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 34 |
| 553 | 3165 | RIXENSART | 50.71 | 4.54 | 2 | 31 |
| 554 | 3165 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 18 |
| 555 | 3165 | WATERLOO | 50.72 | 4.40 | 2.5 | 14 |
| 556 | 3165 | WAVRE | 50.72 | 4.61 | 2 | 35 |
| 557 | 3165 | CHASTRE | 50.61 | 4.64 | 3 | 19 |
| 558 | 3165 | LASNE | 50.68 | 4.46 | 2.5 | 35 |
| 559 | 3165 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2.5 | 120 |
| 560 | 3165 | WALHAIN | 50.62 | 4.70 | 2 | 12 |
| 561 | 3165 | SOMBREFFE | 50.52 | 4.60 | 2 | 5 |
| 562 | 3165 | GEMBLOUX | 50.56 | 4.69 | 2 | 24 |
| 563 | 3167 | HOEILAART | 50.77 | 4.47 | 2 | 3 |
| 564 | 3167 | OVERIJSE | 50.77 | 4.54 | 2 | 7 |
| 565 | 3167 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 2.5 | 3 |
| 566 | 3167 | HULDENBERG | 50.79 | 4.58 | 3 | 4 |
| 567 | 3167 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 22 |
| 568 | 3167 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 3 | 3 |
| 569 | 3167 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 3 | 49 |
| 570 | 3167 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3.5 | 65 |
| 571 | 3167 | GENAPPE | 50.61 | 4.45 | 3.5 | 65 |
| 572 | 3167 | GREZ-DOICEAU | 50.74 | 4.70 | 2.5 | 16 |
| 573 | 3167 | INCOURT | 50.69 | 4.80 | 3 | 8 |
| 574 | 3167 | ITTRE | 50.65 | 4.26 | 3 | 4 |
| 575 | 3167 | JODOIGNE | 50.72 | 4.86 | 2 | 3 |
| 576 | 3167 | LA HULPE | 50.73 | 4.49 | 2 | 6 |
| 577 | 3167 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3.5 | 55 |
| 578 | 3167 | NIVELLES | 50.60 | 4.32 | 2 | 20 |
| 579 | 3167 | PERWEZ | 50.62 | 4.81 | 2.5 | 6 |
| 580 | 3167 | RIXENSART | 50.71 | 4.54 | 3 | 36 |
| 581 | 3167 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3.5 | 56 |
| 582 | 3167 | WATERLOO | 50.72 | 4.40 | 2.5 | 25 |
| 583 | 3167 | WAVRE | 50.72 | 4.61 | 3 | 93 |
| 584 | 3167 | CHASTRE | 50.61 | 4.64 | 3.5 | 48 |
| 585 | 3167 | LASNE | 50.68 | 4.46 | 3 | 38 |
| 586 | 3167 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3 | 202 |
| 587 | 3167 | WALHAIN | 50.62 | 4.70 | 3.5 | 38 |
| 588 | 3167 | FLEURUS | 50.48 | 4.55 | 2.5 | 4 |
| 589 | 3167 | LES BONS VILLERS | 50.52 | 4.48 | 2.5 | 8 |
| 590 | 3167 | EGHEZEE | 50.59 | 4.91 | 2.5 | 12 |
| 591 | 3167 | NAMUR | 50.46 | 4.86 | 2 | 15 |
| 592 | 3167 | SOMBREFFE | 50.52 | 4.60 | 3.5 | 26 |
| 593 | 3167 | FERNELMONT | 50.56 | 4.99 | 3 | 3 |
| 594 | 3167 | JEMEPPE-SUR-SAMBRE | 50.47 | 4.67 | 3.5 | 5 |
| 595 | 3167 | LA BRUYERE | 50.53 | 4.82 | 3 | 22 |
| 596 | 3167 | GEMBLOUX | 50.56 | 4.69 | 3 | 132 |
| 597 | 3169 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 14 |
| 598 | 3169 | GENAPPE | 50.61 | 4.45 | 2 | 10 |
| 599 | 3169 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 7 |
| 600 | 3169 | CHASTRE | 50.61 | 4.64 | 2 | 6 |
| 601 | 3169 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 21 |
| 602 | 3171 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 17 |
| 603 | 3171 | GENAPPE | 50.61 | 4.45 | 2 | 12 |
| 604 | 3171 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 9 |
| 605 | 3171 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2.5 | 7 |
| 606 | 3171 | WAVRE | 50.72 | 4.61 | 2 | 5 |
| 607 | 3171 | CHASTRE | 50.61 | 4.64 | 3 | 3 |
| 608 | 3171 | LASNE | 50.68 | 4.46 | 2 | 3 |
| 609 | 3171 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 40 |
| 610 | 3171 | WALHAIN | 50.62 | 4.70 | 2 | 4 |
| 611 | 3175 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 18 |
| 612 | 3175 | GENAPPE | 50.61 | 4.45 | 2.5 | 8 |
| 613 | 3175 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 8 |
| 614 | 3175 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 4 |
| 615 | 3175 | WAVRE | 50.72 | 4.61 | 2 | 3 |
| 616 | 3175 | CHASTRE | 50.61 | 4.64 | 2 | 4 |
| 617 | 3175 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 27 |
| 618 | 3204 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 28 |
| 619 | 3204 | GENAPPE | 50.61 | 4.45 | 2 | 26 |
| 620 | 3204 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 12 |
| 621 | 3204 | RIXENSART | 50.71 | 4.54 | 3 | 3 |
| 622 | 3204 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 7 |
| 623 | 3204 | WAVRE | 50.72 | 4.61 | 2 | 6 |
| 624 | 3204 | CHASTRE | 50.61 | 4.64 | 2.5 | 13 |
| 625 | 3204 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 45 |

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|---|---|---|---|---|---|---|
| 626 | 3225 | OVERIJSE | 50.77 | 4.54 | 2 | 6 |
| 627 | 3225 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 21 |
| 628 | 3225 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 2 | 3 |
| 629 | 3225 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 35 |
| 630 | 3225 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 103 |
| 631 | 3225 | GENAPPE | 50.61 | 4.45 | 3 | 75 |
| 632 | 3225 | GREZ-DOICEAU | 50.74 | 4.70 | 2 | 3 |
| 633 | 3225 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 47 |
| 634 | 3225 | NIVELLES | 50.60 | 4.32 | 2.5 | 5 |
| 635 | 3225 | RIXENSART | 50.71 | 4.54 | 2.5 | 33 |
| 636 | 3225 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3 | 48 |
| 637 | 3225 | WATERLOO | 50.72 | 4.40 | 2 | 22 |
| 638 | 3225 | WAVRE | 50.72 | 4.61 | 2.5 | 72 |
| 639 | 3225 | CHASTRE | 50.61 | 4.64 | 3 | 54 |
| 640 | 3225 | LASNE | 50.68 | 4.46 | 2 | 31 |
| 641 | 3225 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3 | 205 |
| 642 | 3225 | WALHAIN | 50.62 | 4.70 | 2.5 | 22 |
| 643 | 3225 | SOMBREFFE | 50.52 | 4.60 | 2 | 3 |
| 644 | 3225 | GEMBLOUX | 50.56 | 4.69 | 2.5 | 50 |
| 645 | 3232 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 5 |
| 646 | 3232 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 26 |
| 647 | 3232 | GENAPPE | 50.61 | 4.45 | 2 | 10 |
| 648 | 3232 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 15 |
| 649 | 3232 | RIXENSART | 50.71 | 4.54 | 2 | 4 |
| 650 | 3232 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 5 |
| 651 | 3232 | WAVRE | 50.72 | 4.61 | 2 | 3 |
| 652 | 3232 | CHASTRE | 50.61 | 4.64 | 2 | 12 |
| 653 | 3232 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 36 |
| 654 | 3232 | WALHAIN | 50.62 | 4.70 | 2.5 | 5 |
| 655 | 3232 | GEMBLOUX | 50.56 | 4.69 | 2 | 3 |
| 656 | 3239 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2.5 | 14 |
| 657 | 3239 | GENAPPE | 50.61 | 4.45 | 2 | 13 |
| 658 | 3239 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 5 |
| 659 | 3239 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 5 |
| 660 | 3239 | CHASTRE | 50.61 | 4.64 | 2 | 11 |
| 661 | 3239 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 15 |
| 662 | 3239 | GEMBLOUX | 50.56 | 4.69 | 2.5 | 8 |
| 663 | 3250 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 6 |
| 664 | 3250 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 3 |
| 665 | 3250 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 27 |
| 666 | 3250 | GENAPPE | 50.61 | 4.45 | 2 | 22 |
| 667 | 3250 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 12 |
| 668 | 3250 | RIXENSART | 50.71 | 4.54 | 2 | 8 |
| 669 | 3250 | WAVRE | 50.72 | 4.61 | 2 | 7 |
| 670 | 3250 | CHASTRE | 50.61 | 4.64 | 2 | 6 |
| 671 | 3250 | LASNE | 50.68 | 4.46 | 2 | 8 |
| 672 | 3250 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 53 |
| 673 | 3252 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 4 |
| 674 | 3252 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 10 |
| 675 | 3252 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 39 |
| 676 | 3252 | GENAPPE | 50.61 | 4.45 | 2.5 | 35 |
| 677 | 3252 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 23 |
| 678 | 3252 | RIXENSART | 50.71 | 4.54 | 2 | 7 |
| 679 | 3252 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 17 |
| 680 | 3252 | WATERLOO | 50.72 | 4.40 | 2 | 3 |
| 681 | 3252 | WAVRE | 50.72 | 4.61 | 2 | 20 |
| 682 | 3252 | CHASTRE | 50.61 | 4.64 | 2 | 19 |
| 683 | 3252 | LASNE | 50.68 | 4.46 | 2 | 16 |
| 684 | 3252 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 83 |
| 685 | 3252 | WALHAIN | 50.62 | 4.70 | 2 | 7 |
| 686 | 3252 | GEMBLOUX | 50.56 | 4.69 | 2 | 11 |
| 687 | 3254 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 11 |
| 688 | 3254 | GENAPPE | 50.61 | 4.45 | 2 | 6 |
| 689 | 3254 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 9 |
| 690 | 3254 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 18 |
| 691 | 3257 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 10 |
| 692 | 3257 | GENAPPE | 50.61 | 4.45 | 2 | 10 |
| 693 | 3257 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 13 |
| 694 | 3257 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 5 |
| 695 | 3257 | CHASTRE | 50.61 | 4.64 | 2 | 7 |
| 696 | 3257 | LASNE | 50.68 | 4.46 | 2 | 4 |
| 697 | 3257 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 18 |
| 698 | 3257 | WALHAIN | 50.62 | 4.70 | 2 | 4 |
| 699 | 3257 | GEMBLOUX | 50.56 | 4.69 | 2 | 5 |
| 700 | 3273 | AUDERGHEM | 50.82 | 4.43 | 2 | 3 |
| 701 | 3273 | UCCLE | 50.81 | 4.35 | 2 | 6 |
| 702 | 3273 | WATERMAEL-BOITSFORT | 50.81 | 4.40 | 3 | 7 |
| 703 | 3273 | BEERSEL | 50.77 | 4.31 | 2 | 8 |
| 704 | 3273 | HOEILAART | 50.77 | 4.47 | 3 | 12 |
| 705 | 3273 | OVERIJSE | 50.77 | 4.54 | 2.5 | 13 |
| 706 | 3273 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 2.5 | 8 |
| 707 | 3273 | HULDENBERG | 50.79 | 4.58 | 3 | 5 |
| 708 | 3273 | BEAUVECHAIN | 50.78 | 4.77 | 2 | 3 |
| 709 | 3273 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 66 |
| 710 | 3273 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 3 | 9 |
| 711 | 3273 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 3.5 | 43 |
| 712 | 3273 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 4 | 110 |
| 713 | 3273 | GENAPPE | 50.61 | 4.45 | 3.5 | 107 |
| 714 | 3273 | GREZ-DOICEAU | 50.74 | 4.70 | 3.5 | 12 |
| 715 | 3273 | INCOURT | 50.69 | 4.80 | 3 | 7 |
| 716 | 3273 | JODOIGNE | 50.72 | 4.86 | 2 | 5 |
| 717 | 3273 | LA HULPE | 50.73 | 4.49 | 2.5 | 14 |
| 718 | 3273 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3.5 | 88 |
| 719 | 3273 | NIVELLES | 50.60 | 4.32 | 2 | 15 |
| 720 | 3273 | PERWEZ | 50.62 | 4.81 | 3 | 9 |
| 721 | 3273 | RIXENSART | 50.71 | 4.54 | 3.5 | 62 |
| 722 | 3273 | TUBIZE | 50.69 | 4.20 | 2 | 4 |
| 723 | 3273 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3.5 | 62 |
| 724 | 3273 | WATERLOO | 50.72 | 4.40 | 2.5 | 61 |
| 725 | 3273 | WAVRE | 50.72 | 4.61 | 3.5 | 94 |
| 726 | 3273 | CHASTRE | 50.61 | 4.64 | 4 | 61 |
| 727 | 3273 | LASNE | 50.68 | 4.46 | 3.5 | 81 |
| 728 | 3273 | ORP-JAUCHE | 50.68 | 4.95 | 2.5 | 7 |
| 729 | 3273 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3.5 | 285 |
| 730 | 3273 | WALHAIN | 50.62 | 4.70 | 3.5 | 43 |
| 731 | 3273 | FLEURUS | 50.48 | 4.55 | 3 | 3 |
| 732 | 3273 | LES BONS VILLERS | 50.52 | 4.48 | 3 | 19 |
| 733 | 3273 | HANNUT | 50.67 | 5.08 | 1 | 3 |
| 734 | 3273 | EGHEZEE | 50.59 | 4.91 | 3 | 7 |
| 735 | 3273 | NAMUR | 50.46 | 4.86 | 3 | 11 |
| 736 | 3273 | SOMBREFFE | 50.52 | 4.60 | 3.5 | 31 |
| 737 | 3273 | FERNELMONT | 50.56 | 4.99 | 2 | 5 |
| 738 | 3273 | JEMEPPE-SUR-SAMBRE | 50.47 | 4.67 | 2.5 | 7 |
| 739 | 3273 | LA BRUYERE | 50.53 | 4.82 | 2 | 14 |
| 740 | 3273 | GEMBLOUX | 50.56 | 4.69 | 3.5 | 129 |
| 741 | 3274 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 4 | 4 |
| 742 | 3274 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 16 |
| 743 | 3274 | GENAPPE | 50.61 | 4.45 | 2 | 15 |
| 744 | 3274 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 11 |
| 745 | 3274 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 7 |
| 746 | 3274 | CHASTRE | 50.61 | 4.64 | 2 | 10 |
| 747 | 3274 | LASNE | 50.68 | 4.46 | 2 | 7 |
| 748 | 3274 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 32 |
| 749 | 3274 | GEMBLOUX | 50.56 | 4.69 | 2.5 | 4 |
| 750 | 3276 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 13 |
| 751 | 3276 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 31 |
| 752 | 3276 | GENAPPE | 50.61 | 4.45 | 2 | 27 |
| 753 | 3276 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 24 |
| 754 | 3276 | RIXENSART | 50.71 | 4.54 | 2 | 7 |
| 755 | 3276 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 17 |
| 756 | 3276 | WAVRE | 50.72 | 4.61 | 3 | 14 |
| 757 | 3276 | CHASTRE | 50.61 | 4.64 | 2 | 23 |
| 758 | 3276 | LASNE | 50.68 | 4.46 | 2 | 18 |
| 759 | 3276 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 59 |
| 760 | 3276 | WALHAIN | 50.62 | 4.70 | 2 | 10 |
| 761 | 3276 | GEMBLOUX | 50.56 | 4.69 | 2 | 24 |
| 762 | 3285 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 9 |
| 763 | 3285 | GENAPPE | 50.61 | 4.45 | 2 | 9 |
| 764 | 3285 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 4 |
| 765 | 3285 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2.5 | 6 |
| 766 | 3285 | CHASTRE | 50.61 | 4.64 | 2.5 | 5 |
| 767 | 3285 | LASNE | 50.68 | 4.46 | 2.5 | 3 |
| 768 | 3285 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 18 |
| 769 | 3288 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 20 |
| 770 | 3288 | GENAPPE | 50.61 | 4.45 | 2 | 10 |
| 771 | 3288 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 11 |
| 772 | 3288 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 3 |
| 773 | 3288 | WAVRE | 50.72 | 4.61 | 2 | 6 |
| 774 | 3288 | CHASTRE | 50.61 | 4.64 | 2 | 7 |
| 775 | 3288 | LASNE | 50.68 | 4.46 | 2 | 9 |

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|---|---|---|---|---|---|---|
| 776 | 3288 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 46 |
| 777 | 3288 | GEMBLOUX | 50.56 | 4.69 | 2 | 4 |
| 778 | 3289 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 12 |
| 779 | 3289 | GENAPPE | 50.61 | 4.45 | 2 | 9 |
| 780 | 3289 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 7 |
| 781 | 3289 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2.5 | 3 |
| 782 | 3289 | CHASTRE | 50.61 | 4.64 | 2 | 6 |
| 783 | 3289 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 21 |
| 784 | 3289 | GEMBLOUX | 50.56 | 4.69 | 2 | 3 |
| 785 | 3299 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 7 |
| 786 | 3299 | GENAPPE | 50.61 | 4.45 | 2 | 16 |
| 787 | 3299 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 7 |
| 788 | 3299 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 9 |
| 789 | 3299 | WAVRE | 50.72 | 4.61 | 2 | 5 |
| 790 | 3299 | CHASTRE | 50.61 | 4.64 | 2 | 8 |
| 791 | 3299 | LASNE | 50.68 | 4.46 | 2 | 4 |
| 792 | 3299 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 25 |
| 793 | 3299 | GEMBLOUX | 50.56 | 4.69 | 2 | 3 |
| 794 | 3301 | HOEILAART | 50.77 | 4.47 | 3 | 3 |
| 795 | 3301 | OVERIJSE | 50.77 | 4.54 | 2 | 6 |
| 796 | 3301 | HULDENBERG | 50.79 | 4.58 | 2 | 3 |
| 797 | 3301 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2 | 38 |
| 798 | 3301 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2.5 | 41 |
| 799 | 3301 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2.5 | 78 |
| 800 | 3301 | GENAPPE | 50.61 | 4.45 | 3 | 82 |
| 801 | 3301 | GREZ-DOICEAU | 50.74 | 4.70 | 2 | 10 |
| 802 | 3301 | LA HULPE | 50.73 | 4.49 | 2 | 10 |
| 803 | 3301 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3 | 42 |
| 804 | 3301 | NIVELLES | 50.60 | 4.32 | 2 | 5 |
| 805 | 3301 | RIXENSART | 50.71 | 4.54 | 2.5 | 35 |
| 806 | 3301 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3 | 37 |
| 807 | 3301 | WATERLOO | 50.72 | 4.40 | 2.5 | 30 |
| 808 | 3301 | WAVRE | 50.72 | 4.61 | 2 | 79 |
| 809 | 3301 | CHASTRE | 50.61 | 4.64 | 3 | 44 |
| 810 | 3301 | LASNE | 50.68 | 4.46 | 2.5 | 31 |
| 811 | 3301 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 3 | 193 |
| 812 | 3301 | WALHAIN | 50.62 | 4.70 | 3 | 19 |
| 813 | 3301 | LES BONS VILLERS | 50.52 | 4.48 | 4 | 5 |
| 814 | 3301 | SOMBREFFE | 50.52 | 4.60 | 2.5 | 8 |
| 815 | 3301 | GEMBLOUX | 50.56 | 4.69 | 2 | 57 |
| 816 | 3302 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 13 |
| 817 | 3302 | GENAPPE | 50.61 | 4.45 | 2 | 7 |
| 818 | 3302 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 7 |
| 819 | 3302 | CHASTRE | 50.61 | 4.64 | 2 | 4 |
| 820 | 3302 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 20 |
| 821 | 3302 | GEMBLOUX | 50.56 | 4.69 | 2 | 3 |
| 822 | 3426 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2 | 6 |
| 823 | 3426 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 32 |
| 824 | 3426 | GENAPPE | 50.61 | 4.45 | 2 | 27 |
| 825 | 3426 | LA HULPE | 50.73 | 4.49 | 2 | 3 |
| 826 | 3426 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 27 |
| 827 | 3426 | RIXENSART | 50.71 | 4.54 | 2 | 3 |
| 828 | 3426 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 16 |
| 829 | 3426 | WAVRE | 50.72 | 4.61 | 2 | 9 |
| 830 | 3426 | CHASTRE | 50.61 | 4.64 | 2 | 22 |
| 831 | 3426 | LASNE | 50.68 | 4.46 | 2 | 19 |
| 832 | 3426 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 80 |
| 833 | 3426 | WALHAIN | 50.62 | 4.70 | 2 | 6 |
| 834 | 3426 | SOMBREFFE | 50.52 | 4.60 | 2.5 | 3 |
| 835 | 3426 | GEMBLOUX | 50.56 | 4.69 | 2 | 22 |
| 836 | 3501 | DIEPENBEEK | 50.91 | 5.42 | 2.5 | 15 |
| 837 | 3501 | GENK | 50.96 | 5.50 | 2 | 9 |
| 838 | 3501 | HASSELT | 50.93 | 5.34 | 2 | 7 |
| 839 | 3501 | ZUTENDAAL | 50.93 | 5.57 | 2 | 3 |
| 840 | 3501 | BILZEN | 50.87 | 5.52 | 3 | 43 |
| 841 | 3501 | HOESELT | 50.85 | 5.49 | 3 | 9 |
| 842 | 3501 | KORTESSEM | 50.86 | 5.39 | 2.5 | 6 |
| 843 | 3501 | LANAKEN | 50.89 | 5.65 | 2.5 | 4 |
| 844 | 3501 | TONGEREN | 50.78 | 5.46 | 3 | 3 |
| 845 | 3501 | WELLEN | 50.84 | 5.34 | 3.5 | 4 |
| 846 | 3552 | HOEILAART | 50.77 | 4.47 | 2 | 7 |
| 847 | 3552 | OVERIJSE | 50.77 | 4.54 | 2 | 4 |
| 848 | 3552 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 19 |
| 849 | 3552 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2.5 | 22 |
| 850 | 3552 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 3 | 82 |

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|---|---|---|---|---|---|---|
| 851 | 3552 | GENAPPE | 50.61 | 4.45 | 3 | 50 |
| 852 | 3552 | LA HULPE | 50.73 | 4.49 | 2.5 | 8 |
| 853 | 3552 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 3 | 44 |
| 854 | 3552 | NIVELLES | 50.60 | 4.32 | 2 | 4 |
| 855 | 3552 | RIXENSART | 50.71 | 4.54 | 2.5 | 38 |
| 856 | 3552 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3 | 39 |
| 857 | 3552 | WATERLOO | 50.72 | 4.40 | 2 | 16 |
| 858 | 3552 | WAVRE | 50.72 | 4.61 | 2.5 | 45 |
| 859 | 3552 | CHASTRE | 50.61 | 4.64 | 3.5 | 56 |
| 860 | 3552 | LASNE | 50.68 | 4.46 | 2.5 | 30 |
| 861 | 3552 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2.5 | 166 |
| 862 | 3552 | WALHAIN | 50.62 | 4.70 | 3 | 28 |
| 863 | 3552 | LES BONS VILLERS | 50.52 | 4.48 | 2 | 5 |
| 864 | 3552 | NAMUR | 50.46 | 4.86 | 2 | 3 |
| 865 | 3552 | SOMBREFFE | 50.52 | 4.60 | 2 | 15 |
| 866 | 3552 | LA BRUYERE | 50.53 | 4.82 | 3 | 7 |
| 867 | 3552 | GEMBLOUX | 50.56 | 4.69 | 2.5 | 90 |
| 868 | 3555 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2.5 | 15 |
| 869 | 3555 | GENAPPE | 50.61 | 4.45 | 2 | 11 |
| 870 | 3555 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 11 |
| 871 | 3555 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3 | 3 |
| 872 | 3555 | WAVRE | 50.72 | 4.61 | 2 | 6 |
| 873 | 3555 | CHASTRE | 50.61 | 4.64 | 2 | 10 |
| 874 | 3555 | LASNE | 50.68 | 4.46 | 2 | 4 |
| 875 | 3555 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 27 |
| 876 | 3555 | GEMBLOUX | 50.56 | 4.69 | 2 | 9 |
| 877 | 3560 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2 | 19 |
| 878 | 3560 | GENAPPE | 50.61 | 4.45 | 2 | 12 |
| 879 | 3560 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2.5 | 7 |
| 880 | 3560 | VILLERS-LA-VILLE | 50.58 | 4.53 | 2 | 6 |
| 881 | 3560 | WAVRE | 50.72 | 4.61 | 1 | 3 |
| 882 | 3560 | CHASTRE | 50.61 | 4.64 | 2.5 | 11 |
| 883 | 3560 | LASNE | 50.68 | 4.46 | 2 | 3 |
| 884 | 3560 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 23 |
| 885 | 3560 | WALHAIN | 50.62 | 4.70 | 2 | 5 |
| 886 | 4565 | BEERNEM | 51.14 | 3.34 | 2 | 6 |
| 887 | 4565 | BRUGGE | 51.21 | 3.23 | 2 | 40 |
| 888 | 4565 | JABBEKE | 51.18 | 3.09 | 2 | 36 |
| 889 | 4565 | OOSTKAMP | 51.15 | 3.24 | 2.5 | 107 |
| 890 | 4565 | TORHOUT | 51.07 | 3.10 | 2 | 45 |
| 891 | 4565 | ZEDELGEM | 51.14 | 3.14 | 2 | 224 |
| 892 | 4565 | KORTEMARK | 51.03 | 3.04 | 2 | 8 |
| 893 | 4565 | GISTEL | 51.16 | 2.97 | 2 | 7 |
| 894 | 4565 | ICHTEGEM | 51.09 | 3.01 | 2 | 21 |
| 895 | 4565 | OUDENBURG | 51.18 | 3.00 | 2 | 5 |
| 896 | 4565 | HOOGLEDE | 50.98 | 3.08 | 2 | 3 |
| 897 | 4565 | LICHTERVELDE | 51.03 | 3.14 | 2.5 | 17 |
| 898 | 4565 | ROESELARE | 50.94 | 3.12 | 2 | 5 |
| 899 | 4565 | WINGENE | 51.06 | 3.28 | 2 | 16 |
| 900 | 4565 | ARDOOIE | 50.98 | 3.20 | 2 | 3 |
| 901 | 4580 | ANDERLECHT | 50.84 | 4.31 | 2 | 9 |
| 902 | 4580 | AUDERGHEM | 50.82 | 4.43 | 2.5 | 7 |
| 903 | 4580 | BRUXELLES | 50.85 | 4.35 | 2 | 15 |
| 904 | 4580 | ETTERBEEK | 50.84 | 4.39 | 3 | 6 |
| 905 | 4580 | FOREST | 50.81 | 4.32 | 3 | 6 |
| 906 | 4580 | IXELLES | 50.83 | 4.37 | 2 | 16 |
| 907 | 4580 | MOLENBEEK-SAINT-JEAN | 50.86 | 4.32 | 3 | 3 |
| 908 | 4580 | SCHAERBEEK | 50.86 | 4.37 | 2.5 | 14 |
| 909 | 4580 | UCCLE | 50.81 | 4.35 | 2 | 12 |
| 910 | 4580 | WATERMAEL-BOITSFORT | 50.81 | 4.40 | 2 | 3 |
| 911 | 4580 | WOLUWE-SAINT-LAMBERT | 50.85 | 4.43 | 2 | 11 |
| 912 | 4580 | WOLUWE-SAINT-PIERRE | 50.83 | 4.46 | 2 | 4 |
| 913 | 4580 | LEUVEN | 50.88 | 4.70 | 2 | 6 |
| 914 | 4580 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 6 |
| 915 | 4580 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2.5 | 4 |
| 916 | 4580 | JODOIGNE | 50.72 | 4.86 | 2 | 3 |
| 917 | 4580 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 3 |
| 918 | 4580 | PERWEZ | 50.62 | 4.81 | 2 | 3 |
| 919 | 4580 | RIXENSART | 50.71 | 4.54 | 2 | 10 |
| 920 | 4580 | WATERLOO | 50.72 | 4.40 | 2 | 9 |
| 921 | 4580 | WAVRE | 50.72 | 4.61 | 2 | 10 |
| 922 | 4580 | ORP-JAUCHE | 50.68 | 4.95 | 2 | 5 |
| 923 | 4580 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2.5 | 12 |
| 924 | 4580 | RAMILLIES | 50.66 | 4.89 | 2.5 | 6 |
| 925 | 4580 | BURDINNE | 50.58 | 5.07 | 2 | 3 |
| 926 | 4580 | VERLAINE | 50.61 | 5.32 | 2 | 3 |
| 927 | 4580 | VILLERS-LE-BOUILLET | 50.57 | 5.27 | 2 | 5 |

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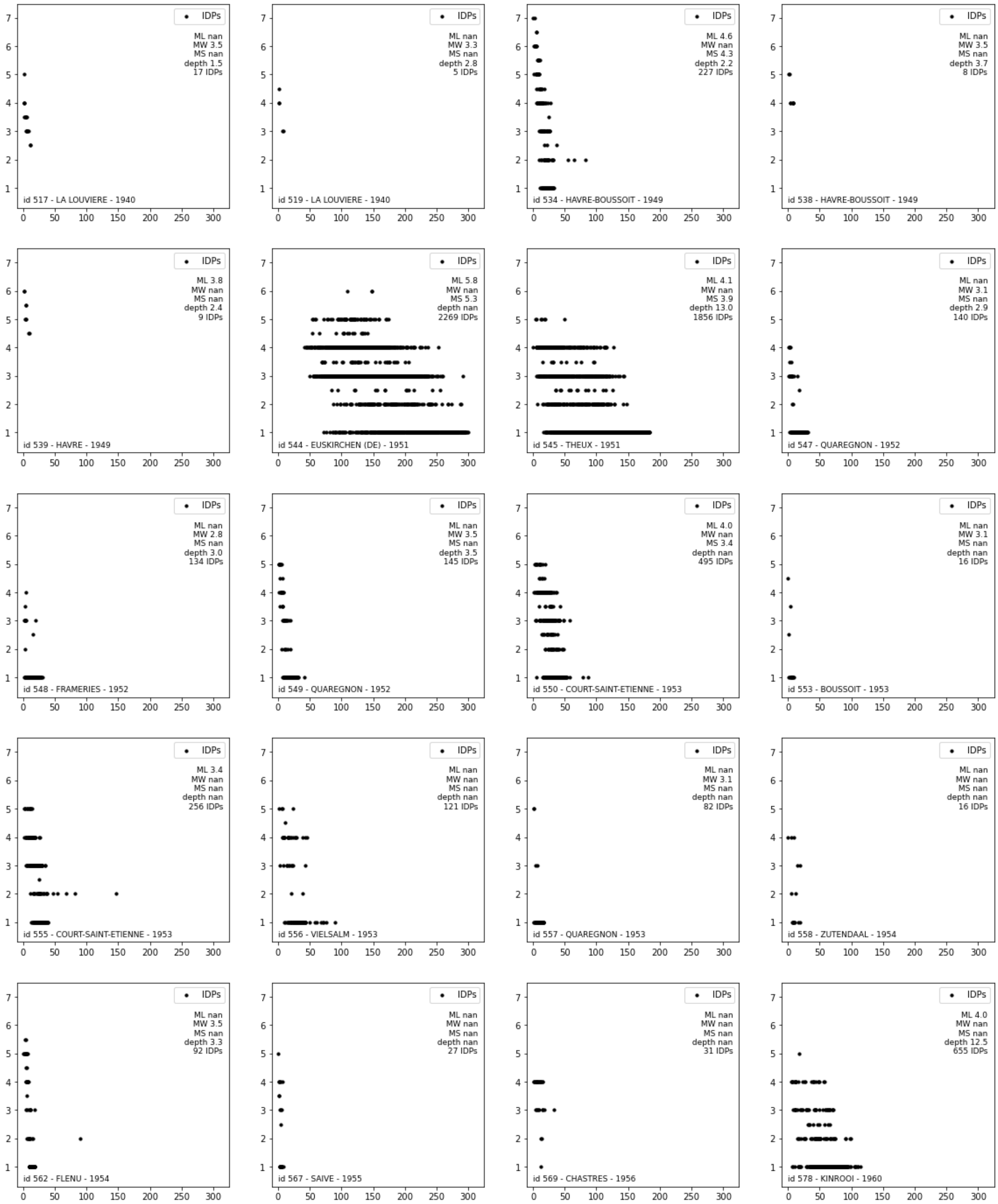
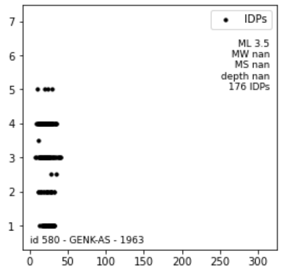
|---|---|---|---|---|---|---|
| 928 | 4580 | WANZE | 50.54 | 5.21 | 2 | 8 |
| 929 | 4580 | ANS | 50.66 | 5.52 | 3 | 9 |
| 930 | 4580 | AWANS | 50.66 | 5.46 | 2 | 10 |
| 931 | 4580 | AYWAILLE | 50.47 | 5.68 | 2 | 3 |
| 932 | 4580 | BASSENGE | 50.76 | 5.61 | 2 | 6 |
| 933 | 4580 | DALHEM | 50.71 | 5.72 | 2 | 3 |
| 934 | 4580 | ESNEUX | 50.53 | 5.57 | 2 | 5 |
| 935 | 4580 | HERSTAL | 50.67 | 5.63 | 2 | 12 |
| 936 | 4580 | JUPRELLE | 50.71 | 5.53 | 2 | 11 |
| 937 | 4580 | LIEGE | 50.64 | 5.57 | 2 | 132 |
| 938 | 4580 | OUPEYE | 50.71 | 5.64 | 2.5 | 10 |
| 939 | 4580 | SAINT-NICOLAS | 50.63 | 5.54 | 2 | 9 |
| 940 | 4580 | SERAING | 50.60 | 5.51 | 2 | 10 |
| 941 | 4580 | VISE | 50.73 | 5.70 | 2.5 | 13 |
| 942 | 4580 | GRACE-HOLLOGNE | 50.64 | 5.50 | 2.5 | 7 |
| 943 | 4580 | AUBEL | 50.70 | 5.86 | 2 | 9 |
| 944 | 4580 | DISON | 50.61 | 5.85 | 3 | 5 |
| 945 | 4580 | EUPEN | 50.63 | 6.03 | 2 | 12 |
| 946 | 4580 | HERVE | 50.64 | 5.79 | 2.5 | 8 |
| 947 | 4580 | JALHAY | 50.56 | 5.96 | 2 | 3 |
| 948 | 4580 | KELMIS | 50.72 | 6.01 | 3 | 4 |
| 949 | 4580 | LONTZEN | 50.68 | 6.01 | 3 | 4 |
| 950 | 4580 | RAEREN | 50.68 | 6.11 | 3 | 4 |
| 951 | 4580 | SPA | 50.49 | 5.86 | 2 | 3 |
| 952 | 4580 | STAVELOT | 50.39 | 5.93 | 2 | 3 |
| 953 | 4580 | VERVIERS | 50.59 | 5.86 | 2 | 9 |
| 954 | 4580 | WELKENRAEDT | 50.66 | 5.97 | 2.5 | 18 |
| 955 | 4580 | PLOMBIERES | 50.74 | 5.96 | 2 | 4 |
| 956 | 4580 | BERLOZ | 50.70 | 5.21 | 3 | 4 |
| 957 | 4580 | BRAIVES | 50.63 | 5.15 | 2 | 9 |
| 958 | 4580 | CRISNEE | 50.72 | 5.40 | 3 | 3 |
| 959 | 4580 | DONCEEL | 50.65 | 5.32 | 3 | 3 |
| 960 | 4580 | GEER | 50.67 | 5.17 | 3 | 4 |
| 961 | 4580 | HANNUT | 50.67 | 5.08 | 2.5 | 9 |
| 962 | 4580 | OREYE | 50.73 | 5.35 | 2.5 | 5 |
| 963 | 4580 | REMICOURT | 50.68 | 5.33 | 2 | 12 |
| 964 | 4580 | WAREMME | 50.70 | 5.26 | 2 | 23 |
| 965 | 4580 | FAIMES | 50.66 | 5.26 | 2 | 8 |
| 966 | 4580 | MAASEIK | 51.09 | 5.79 | 2 | 3 |
| 967 | 4580 | RIEMST | 50.81 | 5.60 | 2 | 4 |
| 968 | 4580 | TONGEREN | 50.78 | 5.46 | 2.5 | 7 |
| 969 | 4580 | GOUVY | 50.19 | 5.94 | 2 | 3 |
| 970 | 4580 | ANDENNE | 50.49 | 5.10 | 2 | 3 |
| 971 | 4580 | NAMUR | 50.46 | 4.86 | 2 | 12 |
| 972 | 4580 | FERNELMONT | 50.56 | 4.99 | 2.5 | 5 |
| 973 | 4580 | GEMBLOUX | 50.56 | 4.69 | 2 | 3 |
| 974 | 5329 | ANTWERPEN | 51.22 | 4.39 | 2.5 | 9 |
| 975 | 5329 | MECHELEN | 51.03 | 4.48 | 2 | 4 |
| 976 | 5329 | ANDERLECHT | 50.84 | 4.31 | 3.5 | 9 |
| 977 | 5329 | AUDERGHEM | 50.82 | 4.43 | 2.5 | 9 |
| 978 | 5329 | BERCHEM-SAINTE-AGATHE | 50.86 | 4.30 | 2.5 | 3 |
| 979 | 5329 | BRUXELLES | 50.85 | 4.35 | 2 | 10 |
| 980 | 5329 | ETTERBEEK | 50.84 | 4.39 | 2 | 12 |
| 981 | 5329 | EVERE | 50.87 | 4.40 | 2.5 | 6 |
| 982 | 5329 | FOREST | 50.81 | 4.32 | 2.5 | 11 |
| 983 | 5329 | IXELLES | 50.83 | 4.37 | 3 | 20 |
| 984 | 5329 | MOLENBEEK-SAINT-JEAN | 50.86 | 4.32 | 3.5 | 3 |
| 985 | 5329 | SAINT-GILLES | 50.83 | 4.35 | 3 | 7 |
| 986 | 5329 | SAINT-JOSSE-TEN-NOODE | 50.85 | 4.37 | 3 | 4 |
| 987 | 5329 | SCHAERBEEK | 50.86 | 4.37 | 2.5 | 14 |
| 988 | 5329 | UCCLE | 50.81 | 4.35 | 2 | 23 |
| 989 | 5329 | WATERMAEL-BOITSFORT | 50.81 | 4.40 | 2.5 | 14 |
| 990 | 5329 | WOLUWE-SAINT-LAMBERT | 50.85 | 4.43 | 2.5 | 13 |
| 991 | 5329 | WOLUWE-SAINT-PIERRE | 50.83 | 4.46 | 3 | 14 |
| 992 | 5329 | BEERSEL | 50.77 | 4.31 | 3 | 12 |
| 993 | 5329 | BEVER | 50.72 | 3.94 | 3.5 | 4 |
| 994 | 5329 | DILBEEK | 50.85 | 4.26 | 3 | 5 |
| 995 | 5329 | GALMAARDEN | 50.75 | 3.97 | 2.5 | 5 |
| 996 | 5329 | GOOIK | 50.80 | 4.12 | 2 | 4 |
| 997 | 5329 | GRIMBERGEN | 50.93 | 4.37 | 2 | 4 |
| 998 | 5329 | HAL | 50.74 | 4.24 | 2.5 | 13 |
| 999 | 5329 | HERNE | 50.72 | 4.03 | 3 | 5 |
| 1000 | 5329 | HOEILAART | 50.77 | 4.47 | 3 | 6 |
| 1001 | 5329 | LIEDEKERKE | 50.87 | 4.08 | 3 | 5 |
| 1002 | 5329 | PEPINGEN | 50.76 | 4.16 | 3.5 | 3 |
| 1003 | 5329 | SINT-PIETERS-LEEUW | 50.78 | 4.24 | 2.5 | 11 |
| 1004 | 5329 | ZEMST | 50.98 | 4.46 | 2 | 4 |
| 1005 | 5329 | ROOSDAAL | 50.84 | 4.08 | 2 | 5 |
| 1006 | 5329 | DROGENBOS | 50.79 | 4.32 | 2 | 3 |
| 1007 | 5329 | LINKEBEEK | 50.77 | 4.34 | 2 | 7 |
| 1008 | 5329 | SINT-GENESIUS-RODE | 50.75 | 4.35 | 2.5 | 4 |
| 1009 | 5329 | WEMMEL | 50.91 | 4.30 | 2.5 | 3 |
| 1010 | 5329 | LENNIK | 50.81 | 4.16 | 2.5 | 6 |
| 1011 | 5329 | AFFLIGEM | 50.91 | 4.11 | 2 | 9 |
| 1012 | 5329 | HULDENBERG | 50.79 | 4.58 | 2 | 3 |
| 1013 | 5329 | KORTENBERG | 50.89 | 4.54 | 3 | 3 |
| 1014 | 5329 | LEUVEN | 50.88 | 4.70 | 3 | 4 |
| 1015 | 5329 | TERVUREN | 50.82 | 4.51 | 2 | 6 |
| 1016 | 5329 | SCHERPENHEUVEL-ZICHEM | 51.00 | 4.98 | 2 | 3 |
| 1017 | 5329 | BRAINE-L'ALLEUD | 50.68 | 4.37 | 2.5 | 10 |
| 1018 | 5329 | BRAINE-LE-CHATEAU | 50.68 | 4.27 | 3 | 7 |
| 1019 | 5329 | CHAUMONT-GISTOUX | 50.68 | 4.72 | 2.5 | 6 |
| 1020 | 5329 | COURT-SAINT-ETIENNE | 50.64 | 4.57 | 2.5 | 13 |
| 1021 | 5329 | GENAPPE | 50.61 | 4.45 | 2 | 6 |
| 1022 | 5329 | GREZ-DOICEAU | 50.74 | 4.70 | 2.5 | 4 |
| 1023 | 5329 | ITTRE | 50.65 | 4.26 | 2 | 4 |
| 1024 | 5329 | LA HULPE | 50.73 | 4.49 | 3 | 3 |
| 1025 | 5329 | MONT-SAINT-GUIBERT | 50.63 | 4.61 | 2 | 6 |
| 1026 | 5329 | NIVELLES | 50.60 | 4.32 | 2 | 6 |
| 1027 | 5329 | PERWEZ | 50.62 | 4.81 | 3.5 | 4 |
| 1028 | 5329 | RIXENSART | 50.71 | 4.54 | 3 | 13 |
| 1029 | 5329 | TUBIZE | 50.69 | 4.20 | 2.5 | 16 |
| 1030 | 5329 | VILLERS-LA-VILLE | 50.58 | 4.53 | 3 | 5 |
| 1031 | 5329 | WATERLOO | 50.72 | 4.40 | 3 | 25 |
| 1032 | 5329 | WAVRE | 50.72 | 4.61 | 2 | 14 |
| 1033 | 5329 | CHASTRE | 50.61 | 4.64 | 2.5 | 10 |
| 1034 | 5329 | LASNE | 50.68 | 4.46 | 2.5 | 5 |
| 1035 | 5329 | ORP-JAUCHE | 50.68 | 4.95 | 2.5 | 3 |
| 1036 | 5329 | OTTIGNIES-LOUVAIN-LA-NEUVE | 50.67 | 4.57 | 2 | 20 |
| 1037 | 5329 | REBECQ | 50.67 | 4.13 | 2 | 5 |
| 1038 | 5329 | WALHAIN | 50.62 | 4.70 | 2.5 | 6 |
| 1039 | 5329 | BEERNEM | 51.14 | 3.34 | 2.5 | 8 |
| 1040 | 5329 | BLANKENBERGE | 51.32 | 3.13 | 2.5 | 14 |
| 1041 | 5329 | BRUGGE | 51.21 | 3.23 | 3 | 127 |
| 1042 | 5329 | JABBEKE | 51.18 | 3.09 | 3 | 9 |
| 1043 | 5329 | OOSTKAMP | 51.15 | 3.24 | 3 | 25 |
| 1044 | 5329 | TORHOUT | 51.07 | 3.10 | 3.5 | 10 |
| 1045 | 5329 | ZEDELGEM | 51.14 | 3.14 | 2.5 | 16 |
| 1046 | 5329 | ZUIENKERKE | 51.27 | 3.16 | 3 | 3 |
| 1047 | 5329 | KNOKKE-HEIST | 51.34 | 3.24 | 2.5 | 14 |
| 1048 | 5329 | DIKSMUIDE | 51.03 | 2.86 | 3.5 | 13 |
| 1049 | 5329 | HOUTHULST | 50.98 | 2.95 | 3.5 | 14 |
| 1050 | 5329 | KOEKELARE | 51.09 | 2.98 | 3 | 7 |
| 1051 | 5329 | KORTEMARK | 51.03 | 3.04 | 3 | 5 |
| 1052 | 5329 | IEPER | 50.85 | 2.88 | 3 | 6 |
| 1053 | 5329 | POPERINGE | 50.86 | 2.73 | 3 | 11 |
| 1054 | 5329 | WERVIK | 50.78 | 3.05 | 2 | 7 |
| 1055 | 5329 | ANZEGEM | 50.83 | 3.48 | 3.5 | 6 |
| 1056 | 5329 | DEERLIJK | 50.85 | 3.36 | 2.5 | 9 |
| 1057 | 5329 | HARELBEKE | 50.86 | 3.31 | 3 | 5 |
| 1058 | 5329 | KORTRIJK | 50.83 | 3.27 | 3 | 48 |
| 1059 | 5329 | KUURNE | 50.85 | 3.29 | 2.5 | 4 |
| 1060 | 5329 | LENDELEDE | 50.89 | 3.24 | 3 | 3 |
| 1061 | 5329 | MENEN | 50.80 | 3.12 | 3.5 | 13 |
| 1062 | 5329 | WAREGEM | 50.89 | 3.43 | 3 | 22 |
| 1063 | 5329 | WEVELGEM | 50.81 | 3.18 | 3 | 11 |
| 1064 | 5329 | ZWEVEGEM | 50.81 | 3.33 | 3 | 8 |
| 1065 | 5329 | BREDENE | 51.23 | 2.98 | 2.5 | 5 |
| 1066 | 5329 | GISTEL | 51.16 | 2.97 | 2.5 | 5 |
| 1067 | 5329 | ICHTEGEM | 51.09 | 3.01 | 3 | 12 |
| 1068 | 5329 | MIDDELKERKE | 51.19 | 2.82 | 3 | 13 |
| 1069 | 5329 | OOSTENDE | 51.23 | 2.91 | 2.5 | 27 |
| 1070 | 5329 | OUDENBURG | 51.18 | 3.00 | 2.5 | 4 |
| 1071 | 5329 | DE HAAN | 51.27 | 3.04 | 3 | 6 |
| 1072 | 5329 | HOOGLEDE | 50.98 | 3.08 | 3 | 5 |
| 1073 | 5329 | INGELMUNSTER | 50.92 | 3.25 | 3 | 3 |
| 1074 | 5329 | IZEGEM | 50.92 | 3.22 | 3 | 3 |
| 1075 | 5329 | LEDEGEM | 50.85 | 3.13 | 3 | 6 |
| 1076 | 5329 | LICHTERVELDE | 51.03 | 3.14 | 3.5 | 5 |
| 1077 | 5329 | MOORSLEDE | 50.89 | 3.06 | 3 | 3 |
| 1078 | 5329 | ROESELARE | 50.94 | 3.12 | 3 | 21 |
| 1079 | 5329 | STADEN | 50.97 | 3.01 | 2.5 | 4 |
| 1080 | 5329 | DENTERGEM | 50.96 | 3.42 | 3 | 5 |
| 1081 | 5329 | MEULEBEKE | 50.95 | 3.29 | 3.5 | 4 |
| 1082 | 5329 | RUISELEDE | 51.04 | 3.39 | 3.5 | 5 |
| 1083 | 5329 | TIELT (WEST-VLAANDEREN) | 51.00 | 3.33 | 2.5 | 14 |
| 1084 | 5329 | WIELSBEKE | 50.91 | 3.37 | 2.5 | 8 |
| 1085 | 5329 | WINGENE | 51.06 | 3.28 | 3 | 15 |

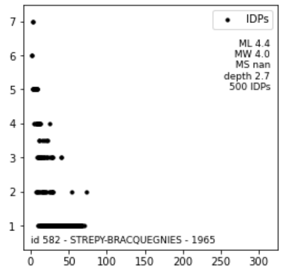
| Nr. | id_earth | name | lat | lon | int. | resp. |
|---|---|---|---|---|---|---|
| 1086 | 5329 | ARDOOIE | 50.98 | 3.20 | 3 | 3 |
| 1087 | 5329 | ALVERINGEM | 51.01 | 2.71 | 3 | 3 |
| 1088 | 5329 | DE PANNE | 51.10 | 2.59 | 3 | 7 |
| 1089 | 5329 | KOKSIJDE | 51.10 | 2.65 | 3 | 37 |
| 1090 | 5329 | NIEUWPOORT | 51.13 | 2.75 | 3.5 | 6 |
| 1091 | 5329 | VEURNE | 51.07 | 2.66 | 3.5 | 5 |
| 1092 | 5329 | AALST (OOST-VLAANDEREN) | 50.94 | 4.04 | 3.5 | 11 |
| 1093 | 5329 | DENDERLEEUW | 50.88 | 4.08 | 3 | 5 |
| 1094 | 5329 | GERAARDSBERGEN | 50.77 | 3.88 | 2.5 | 19 |
| 1095 | 5329 | LEDE | 50.97 | 3.98 | 3 | 7 |
| 1096 | 5329 | NINOVE | 50.84 | 4.02 | 3 | 15 |
| 1097 | 5329 | SINT-LIEVENS-HOUTEM | 50.92 | 3.86 | 3.5 | 3 |
| 1098 | 5329 | ZOTTEGEM | 50.87 | 3.81 | 2.5 | 11 |
| 1099 | 5329 | ERPE-MERE | 50.93 | 3.98 | 2.5 | 7 |
| 1100 | 5329 | DENDERMONDE | 51.03 | 4.10 | 3.5 | 3 |
| 1101 | 5329 | WAASMUNSTER | 51.11 | 4.09 | 3 | 3 |
| 1102 | 5329 | WETTEREN | 51.01 | 3.89 | 2 | 4 |
| 1103 | 5329 | EEKLO | 51.19 | 3.57 | 3.5 | 3 |
| 1104 | 5329 | AALTER | 51.08 | 3.45 | 2.5 | 16 |
| 1105 | 5329 | DEINZE | 50.98 | 3.53 | 2.5 | 17 |
| 1106 | 5329 | DE PINTE | 50.99 | 3.65 | 3 | 5 |
| 1107 | 5329 | DESTELBERGEN | 51.06 | 3.80 | 3 | 3 |
| 1108 | 5329 | EVERGEM | 51.11 | 3.71 | 2 | 6 |
| 1109 | 5329 | GAVERE | 50.93 | 3.66 | 3.5 | 7 |
| 1110 | 5329 | GENT | 51.05 | 3.72 | 3 | 164 |
| 1111 | 5329 | KNESSELARE | 51.14 | 3.41 | 3.5 | 7 |
| 1112 | 5329 | LOVENDEGEM | 51.10 | 3.61 | 2 | 3 |
| 1113 | 5329 | MELLE | 51.00 | 3.80 | 2.5 | 4 |
| 1114 | 5329 | MERELBEKE | 50.99 | 3.75 | 3 | 13 |
| 1115 | 5329 | NAZARETH | 50.96 | 3.60 | 2 | 8 |
| 1116 | 5329 | NEVELE | 51.03 | 3.55 | 2.5 | 7 |
| 1117 | 5329 | OOSTERZELE | 50.95 | 3.80 | 3.5 | 9 |
| 1118 | 5329 | SINT-MARTENS-LATEM | 51.02 | 3.64 | 2 | 4 |
| 1119 | 5329 | ZOMERGEM | 51.12 | 3.56 | 2 | 4 |
| 1120 | 5329 | ZULTE | 50.92 | 3.44 | 3 | 10 |
| 1121 | 5329 | KRUISHOUTEM | 50.90 | 3.53 | 2.5 | 7 |
| 1122 | 5329 | OUDENAARDE | 50.84 | 3.60 | 3 | 25 |
| 1123 | 5329 | RONSE | 50.75 | 3.60 | 2 | 7 |
| 1124 | 5329 | ZINGEM | 50.90 | 3.65 | 3.5 | 3 |
| 1125 | 5329 | BRAKEL | 50.80 | 3.77 | 3 | 5 |
| 1126 | 5329 | KLUISBERGEN | 50.78 | 3.52 | 3 | 3 |
| 1127 | 5329 | LIERDE | 50.82 | 3.85 | 3.5 | 7 |
| 1128 | 5329 | MAARKEDAL | 50.80 | 3.65 | 3 | 5 |
| 1129 | 5329 | ZWALM | 50.87 | 3.72 | 2 | 6 |
| 1130 | 5329 | SINT-NIKLAAS | 51.16 | 4.14 | 2.5 | 4 |
| 1131 | 5329 | ATH | 50.63 | 3.77 | 2.5 | 12 |
| 1132 | 5329 | BELOEIL | 50.55 | 3.73 | 3 | 4 |
| 1133 | 5329 | ELLEZELLES | 50.73 | 3.68 | 3.5 | 3 |
| 1134 | 5329 | FRASNES-LEZ-ANVAING | 50.68 | 3.56 | 3 | 7 |
| 1135 | 5329 | SENEFFE | 50.53 | 4.26 | 3.5 | 3 |
| 1136 | 5329 | MONS | 50.45 | 3.95 | 2.5 | 12 |
| 1137 | 5329 | SAINT-GHISLAIN | 50.45 | 3.82 | 3 | 3 |
| 1138 | 5329 | MOUSCRON | 50.74 | 3.22 | 2.5 | 13 |
| 1139 | 5329 | BRAINE-LE-COMTE | 50.61 | 4.14 | 2 | 4 |
| 1140 | 5329 | ENGHIEN | 50.69 | 4.04 | 2 | 11 |
| 1141 | 5329 | LESSINES | 50.71 | 3.83 | 3 | 11 |
| 1142 | 5329 | SILLY | 50.65 | 3.92 | 3 | 8 |
| 1143 | 5329 | SOIGNIES | 50.58 | 4.07 | 2 | 4 |
| 1144 | 5329 | ECAUSSINNES | 50.56 | 4.18 | 2.5 | 3 |
| 1145 | 5329 | PERUWELZ | 50.51 | 3.59 | 3 | 3 |
| 1146 | 5329 | TOURNAI | 50.61 | 3.39 | 2 | 25 |
| 1147 | 5329 | LEUZE-EN-HAINAUT | 50.60 | 3.62 | 2 | 4 |
| 1148 | 5329 | MONT-DE-L'ENCLUS | 50.74 | 3.50 | 2 | 7 |
| 1149 | 5329 | FAIMES | 50.66 | 5.26 | 3 | 3 |
| 1150 | 5329 | ARLON | 49.68 | 5.82 | 2 | 3 |
| 1151 | 5329 | EGHEZEE | 50.59 | 4.91 | 2.5 | 5 |
| 1152 | 5329 | NAMUR | 50.46 | 4.86 | 3 | 13 |
| 1153 | 5329 | SOMBREFFE | 50.52 | 4.60 | 3 | 5 |
| 1154 | 5329 | FERNELMONT | 50.56 | 4.99 | 2 | 3 |
| 1155 | 5329 | LA BRUYERE | 50.53 | 4.82 | 3 | 3 |
| 1156 | 5329 | GEMBLOUX | 50.56 | 4.69 | 2 | 6 |
| 1157 | 6625 | BALEN | 51.17 | 5.17 | 3 | 3 |
| 1158 | 6625 | UCCLE | 50.81 | 4.35 | 2 | 3 |
| 1159 | 6625 | DIEST | 50.98 | 5.05 | 2 | 3 |
| 1160 | 6625 | LANDEN | 50.76 | 5.08 | 2 | 5 |
| 1161 | 6625 | LEUVEN | 50.88 | 4.70 | 2 | 5 |
| 1162 | 6625 | GENT | 51.05 | 3.72 | 2 | 3 |
| 1163 | 6625 | VERLAINE | 50.61 | 5.32 | 3 | 4 |
| 1164 | 6625 | ANS | 50.66 | 5.52 | 3.5 | 4 |
| 1165 | 6625 | AWANS | 50.66 | 5.46 | 2.5 | 8 |
| 1166 | 6625 | BASSENGE | 50.76 | 5.61 | 3 | 9 |
| 1167 | 6625 | JUPRELLE | 50.71 | 5.53 | 4 | 5 |
| 1168 | 6625 | LIEGE | 50.64 | 5.57 | 2 | 5 |
| 1169 | 6625 | VISE | 50.73 | 5.70 | 3.5 | 3 |
| 1170 | 6625 | BERLOZ | 50.70 | 5.21 | 2.5 | 3 |
| 1171 | 6625 | BRAIVES | 50.63 | 5.15 | 2 | 5 |
| 1172 | 6625 | CRISNEE | 50.72 | 5.40 | 3 | 7 |
| 1173 | 6625 | GEER | 50.67 | 5.17 | 2 | 8 |
| 1174 | 6625 | HANNUT | 50.67 | 5.08 | 2 | 7 |
| 1175 | 6625 | OREYE | 50.73 | 5.35 | 3 | 14 |
| 1176 | 6625 | REMICOURT | 50.68 | 5.33 | 3 | 8 |
| 1177 | 6625 | WAREMME | 50.70 | 5.26 | 2.5 | 11 |
| 1178 | 6625 | FAIMES | 50.66 | 5.26 | 3.5 | 4 |
| 1179 | 6625 | AS | 51.01 | 5.58 | 2 | 28 |
| 1180 | 6625 | BERINGEN | 51.05 | 5.22 | 2 | 10 |
| 1181 | 6625 | DIEPENBEEK | 50.91 | 5.42 | 2 | 9 |
| 1182 | 6625 | GENK | 50.96 | 5.50 | 2.5 | 48 |
| 1183 | 6625 | GINGELOM | 50.75 | 5.14 | 2.5 | 7 |
| 1184 | 6625 | HASSELT | 50.93 | 5.34 | 2.5 | 23 |
| 1185 | 6625 | LEOPOLDSBURG | 51.12 | 5.26 | 2 | 7 |
| 1186 | 6625 | LUMMEN | 50.99 | 5.19 | 1 | 3 |
| 1187 | 6625 | OPGLABBEEK | 51.04 | 5.58 | 3 | 40 |
| 1188 | 6625 | SINT-TRUIDEN | 50.82 | 5.19 | 2 | 31 |
| 1189 | 6625 | TESSENDERLO | 51.07 | 5.09 | 2 | 7 |
| 1190 | 6625 | ZONHOVEN | 50.99 | 5.37 | 3 | 8 |
| 1191 | 6625 | ZUTENDAAL | 50.93 | 5.57 | 2 | 11 |
| 1192 | 6625 | HEUSDEN-ZOLDER | 51.02 | 5.31 | 2 | 7 |
| 1193 | 6625 | BOCHOLT | 51.17 | 5.58 | 2.5 | 55 |
| 1194 | 6625 | BREE | 51.14 | 5.60 | 2.5 | 64 |
| 1195 | 6625 | DILSEN | 51.04 | 5.72 | 2 | 34 |
| 1196 | 6625 | KINROOI | 51.14 | 5.74 | 2.5 | 55 |
| 1197 | 6625 | LOMMEL | 51.23 | 5.31 | 2.5 | 18 |
| 1198 | 6625 | MAASEIK | 51.09 | 5.79 | 3 | 136 |
| 1199 | 6625 | NEERPELT | 51.23 | 5.43 | 2.5 | 37 |
| 1200 | 6625 | OVERPELT | 51.21 | 5.43 | 2.5 | 9 |
| 1201 | 6625 | PEER | 51.13 | 5.45 | 2 | 12 |
| 1202 | 6625 | HAMONT-ACHEL | 51.25 | 5.55 | 2.5 | 25 |
| 1203 | 6625 | HECHTEL-EKSEL | 51.15 | 5.39 | 2 | 8 |
| 1204 | 6625 | HOUTHALEN-HELCHTEREN | 51.03 | 5.37 | 2 | 15 |
| 1205 | 6625 | MEEUWEN-GRUITRODE | 51.09 | 5.59 | 2.5 | 45 |
| 1206 | 6625 | ALKEN | 50.88 | 5.31 | 2 | 13 |
| 1207 | 6625 | BILZEN | 50.87 | 5.52 | 2.5 | 124 |
| 1208 | 6625 | BORGLOON | 50.80 | 5.34 | 2.5 | 19 |
| 1209 | 6625 | HEERS | 50.76 | 5.30 | 3 | 24 |
| 1210 | 6625 | HOESELT | 50.85 | 5.49 | 3 | 63 |
| 1211 | 6625 | KORTESSEM | 50.86 | 5.39 | 2 | 16 |
| 1212 | 6625 | LANAKEN | 50.89 | 5.65 | 2 | 59 |
| 1213 | 6625 | RIEMST | 50.81 | 5.60 | 3 | 96 |
| 1214 | 6625 | TONGEREN | 50.78 | 5.46 | 3 | 192 |
| 1215 | 6625 | WELLEN | 50.84 | 5.34 | 2 | 6 |
| 1216 | 6625 | MAASMECHELEN | 50.96 | 5.70 | 2 | 39 |
| 1217 | 6625 | ANDENNE | 50.49 | 5.10 | 2.5 | 3 |
| 1218 | 17540 | DESSEL | 51.24 | 5.11 | 3.5 | 19 |
| 1219 | 17540 | MOL | 51.18 | 5.12 | 3 | 20 |
| 1220 | 17540 | RETIE | 51.27 | 5.08 | 3 | 8 |

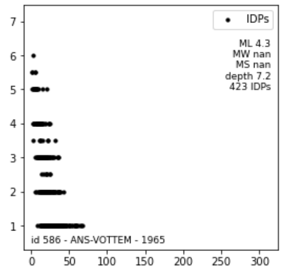
## 10.6. Intensity attenuation of individual events in the BTM database

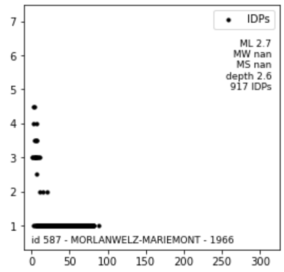
Decrease of intensity with increasing epicentral distance (km) of each event in the BTM database. Only the $M_S$ = 5.5 Dogger bank 1931 earthquake is not included as the IDPs of the event are located at epicentral distances greater than 300 km.

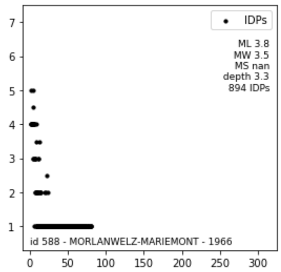

IDPs
ML nan MW 3.5 MS nan depth 1.5 17 IDPs
id 517 - LA LOUVIERE - 1940
ML nan MW 3.3 MS nan depth 2.8 5 IDPs
id 519 - LA LOUVIERE - 1940
ML 4.6 MW nan MS 4.3 depth 2.2 227 IDPs
id 534 - HAVRE-BOUSSOIT - 1949
ML nan MW 3.5 MS nan depth 3.7 8 IDPs
id 538 - HAVRE-BOUSSOIT - 1949
ML 3.8 MW nan MS nan depth 2.4 9 IDPs
id 539 - HAVRE - 1949
ML 5.8 MW nan MS 5.3 depth nan 2269 IDPs
id 544 - EUSKIRCHEN (DE) - 1951
ML 4.1 MW nan MS 3.9 depth 13.0 1856 IDPs
id 545 - THEUX - 1951
ML nan MW 3.1 MS nan depth 2.9 140 IDPs
id 547 - QUAREGNON - 1952
ML nan MW 2.8 MS nan depth 3.0 134 IDPs
id 548 - FRAMERIES - 1952
ML nan MW 3.5 MS nan depth 3.5 145 IDPs
id 549 - QUAREGNON - 1952
ML 4.0 MW nan MS 3.4 depth nan 495 IDPs
id 550 - COURT-SAINT-ETIENNE - 1953
ML nan MW 3.1 MS nan depth nan 16 IDPs
id 553 - BOUSSOIT - 1953
ML 3.4 MW nan MS nan depth nan 256 IDPs
id 555 - COURT-SAINT-ETIENNE - 1953
ML nan MW nan MS nan depth nan 121 IDPs
id 556 - VIELSALM - 1953
ML nan MW 3.1 MS nan depth nan 82 IDPs
id 557 - QUAREGNON - 1953
ML nan MW nan MS nan depth nan 16 IDPs
id 558 - ZUTENDAAL - 1954
ML nan MW 3.5 MS nan depth 3.3 92 IDPs
id 562 - FLENU - 1954
ML nan MW nan MS nan depth nan 27 IDPs
id 567 - SAIVE - 1955
ML nan MW nan MS nan depth nan 31 IDPs
id 569 - CHASTRES - 1956
ML 4.0 MW nan MS nan depth 12.5 655 IDPs
id 578 - KINROOI - 1960

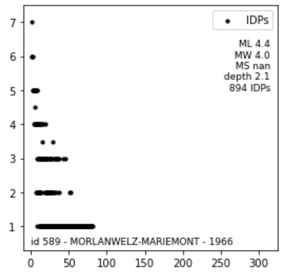

IDPs
ML 3.5
MW nan
MS nan
depth nan
176 IDPs
id 580 - GENK-AS - 1963

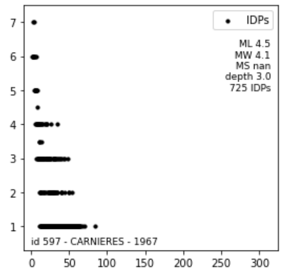

IDPs
ML 4.4
MW 4.0
MS nan
depth 2.7
500 IDPs
id 582 - STREPY-BRACQUEGNIES - 1965

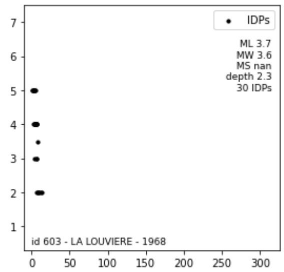

IDPs
ML 4.3
MW nan
MS nan
depth 7.2
423 IDPs
id 586 - ANS-VOTTEM - 1965

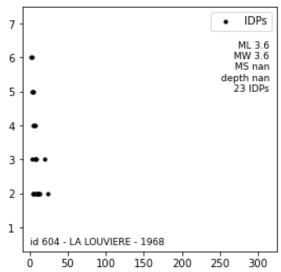

IDPs
ML 2.7
MW nan
MS nan
depth 2.6
917 IDPs
id 587 - MORLANWELZ-MARIEMONT - 1966

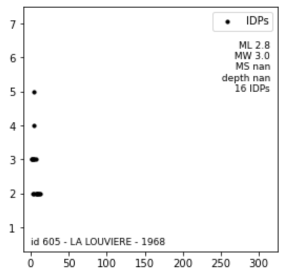

IDPs
ML 3.8
MW 3.5
MS nan
depth 3.3
894 IDPs
id 588 - MORLANWELZ-MARIEMONT - 1966

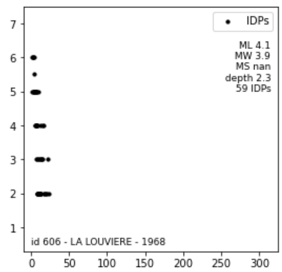

IDPs
ML 4.4
MW 4.0
MS nan
depth 2.1
894 IDPs
id 589 - MORLANWELZ-MARIEMONT - 1966

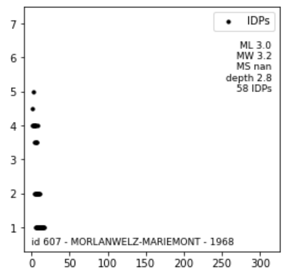

IDPs
ML 4.5
MW 4.1
MS nan
depth 3.0
725 IDPs
id 597 - CARNIERES - 1967

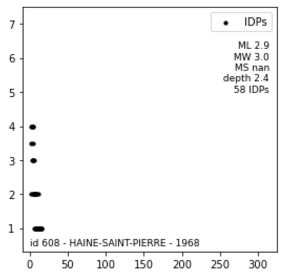

IDPs
ML 3.7
MW 3.6
MS nan
depth 2.3
30 IDPs
id 603 - LA LOUVIERE - 1968

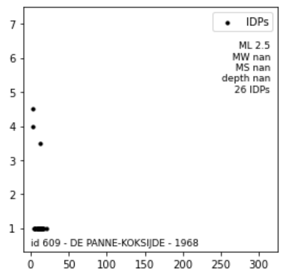

IDPs
ML 3.6
MW 3.6
MS nan
depth nan
23 IDPs
id 604 - LA LOUVIERE - 1968

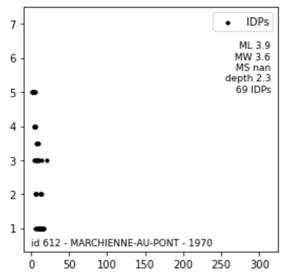

IDPs
ML 2.8
MW 3.0
MS nan
depth nan
16 IDPs
id 605 - LA LOUVIERE - 1968

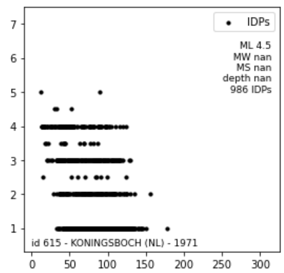

IDPs
ML 4.1
MW 3.9
MS nan
depth 2.3
59 IDPs
id 606 - LA LOUVIERE - 1968

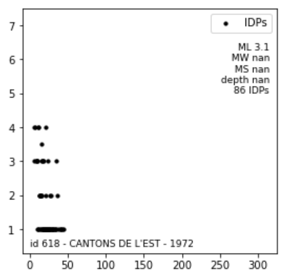

IDPs
ML 3.0
MW 3.2
MS nan
depth 2.8
58 IDPs
id 607 - MORLANWELZ-MARIEMONT - 1968

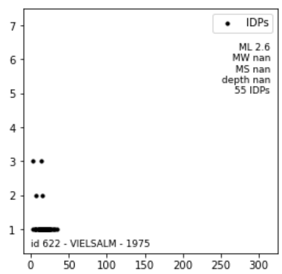

IDPs
ML 2.9
MW 3.0
MS nan
depth 2.4
58 IDPs
id 608 - HAINE-SAINT-PIERRE - 1968

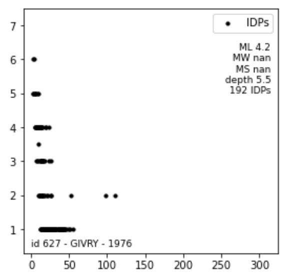

IDPs
ML 2.5
MW nan
MS nan
depth nan
26 IDPs
id 609 - DE PANNE-KOKSIJDE - 1968

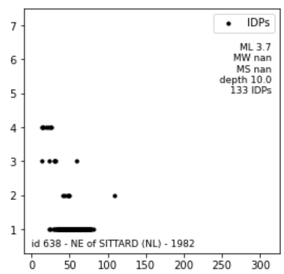

IDPs
ML 3.9
MW 3.6
MS nan
depth 2.3
69 IDPs
id 612 - MARCHIENNE-AU-PONT - 1970

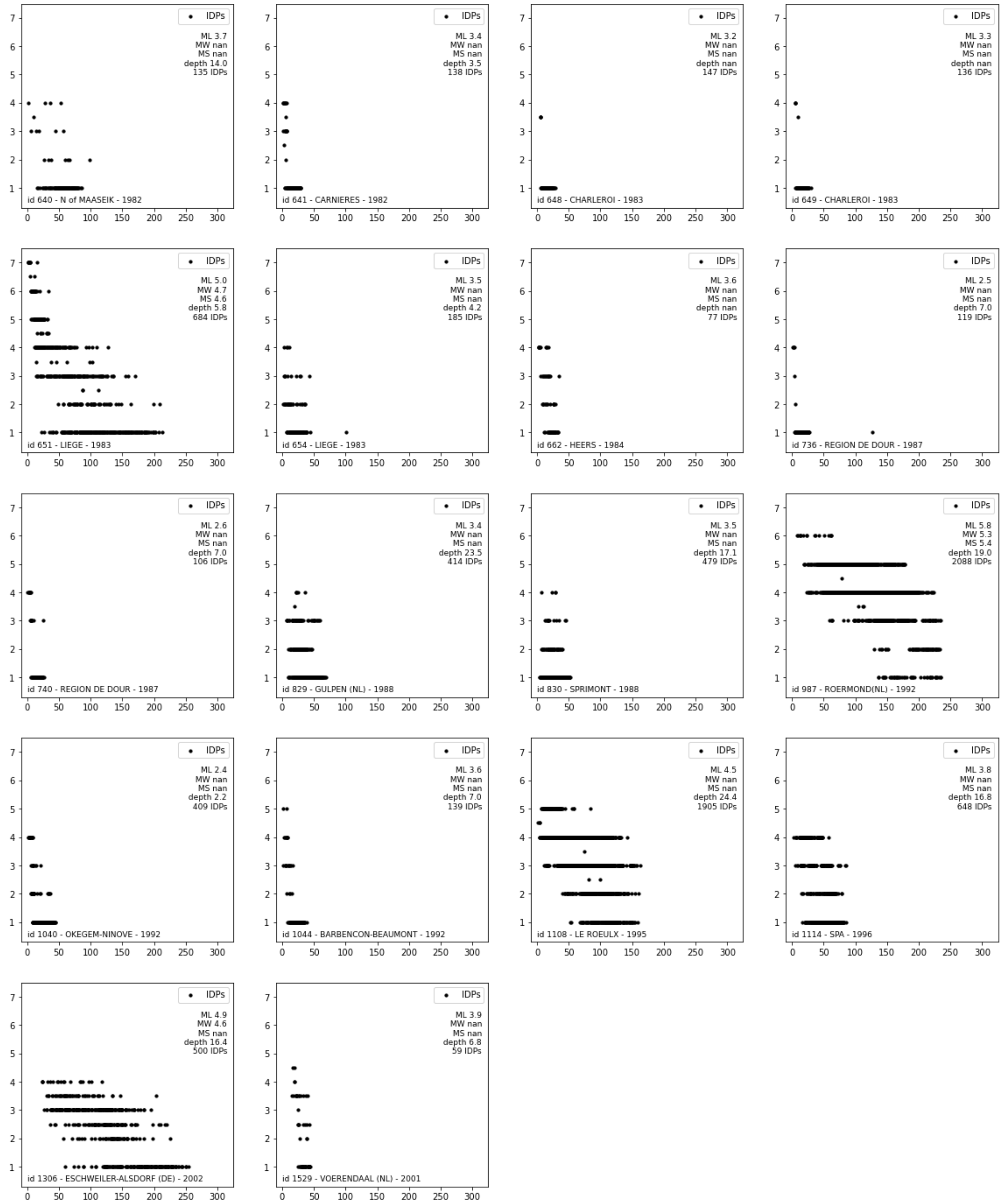

IDPs
ML 4.5
MW nan
MS nan
depth nan
986 IDPs
id 615 - KONINGSBOCH (NL) - 1971


IDPs
ML 3.1
MW nan
MS nan
depth nan
86 IDPs
id 618 - CANTONS DE L'EST - 1972


IDPs
ML 2.6
MW nan
MS nan
depth nan
55 IDPs
id 622 - VIELSALM - 1975

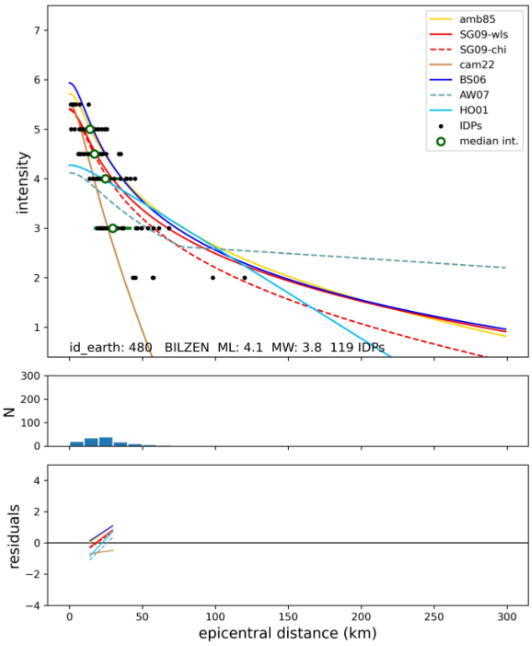

IDPs
ML 4.2
MW nan
MS nan
depth 5.5
192 IDPs
id 627 - GIVRY - 1976

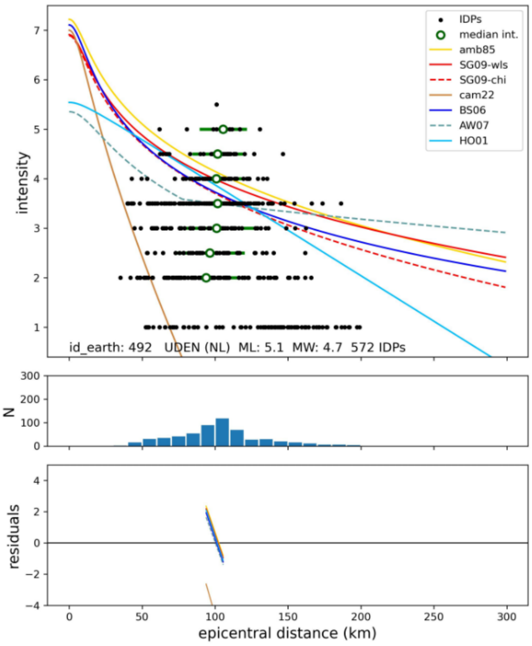

IDPs
ML 3.7
MW nan
MS nan
depth 10.0
133 IDPs
id 638 - NE of SITTARD (NL) - 1982

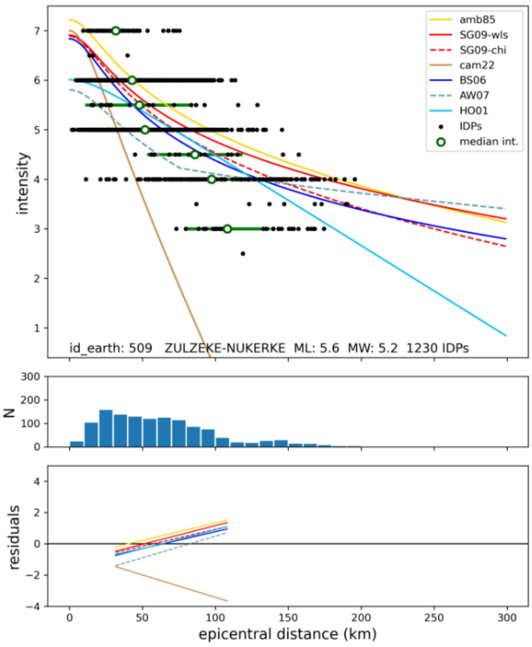

IDPs
ML 3.7 MW nan MS nan depth 14.0 135 IDPs
id 640 - N of MAASEIK - 1982
ML 3.4 MW nan MS nan depth 3.5 138 IDPs
id 641 - CARNIERES - 1982
ML 3.2 MW nan MS nan depth nan 147 IDPs
id 648 - CHARLEROI - 1983
ML 3.3 MW nan MS nan depth nan 136 IDPs
id 649 - CHARLEROI - 1983
ML 5.0 MW 4.7 MS 4.6 depth 5.8 684 IDPs
id 651 - LIEGE - 1983
ML 3.5 MW nan MS nan depth 4.2 185 IDPs
id 654 - LIEGE - 1983
ML 3.6 MW nan MS nan depth nan 77 IDPs
id 662 - HEERS - 1984
ML 2.5 MW nan MS nan depth 7.0 119 IDPs
id 736 - REGION DE DOUR - 1987
ML 2.6 MW nan MS nan depth 7.0 106 IDPs
id 740 - REGION DE DOUR - 1987
ML 3.4 MW nan MS nan depth 23.5 414 IDPs
id 829 - GULPEN (NL) - 1988
ML 3.5 MW nan MS nan depth 17.1 479 IDPs
id 830 - SPRIMONT - 1988
ML 5.8 MW 5.3 MS 5.4 depth 19.0 2088 IDPs
id 987 - ROERMOND(NL) - 1992
ML 2.4 MW nan MS nan depth 2.2 409 IDPs
id 1040 - OKEGEM-NINOVE - 1992
ML 3.6 MW nan MS nan depth 7.0 139 IDPs
id 1044 - BARBENCON-BEAUMONT - 1992
ML 4.5 MW nan MS nan depth 24.4 1905 IDPs
id 1108 - LE ROEULX - 1995
ML 3.8 MW nan MS nan depth 16.8 648 IDPs
id 1114 - SPA - 1996
ML 4.9 MW 4.6 MS nan depth 16.4 500 IDPs
id 1306 - ESCHWEILER-ALSDORF (DE) - 2002
ML 3.9 MW nan MS nan depth 6.8 59 IDPs
id 1529 - VOERENDAAL (NL) - 2001

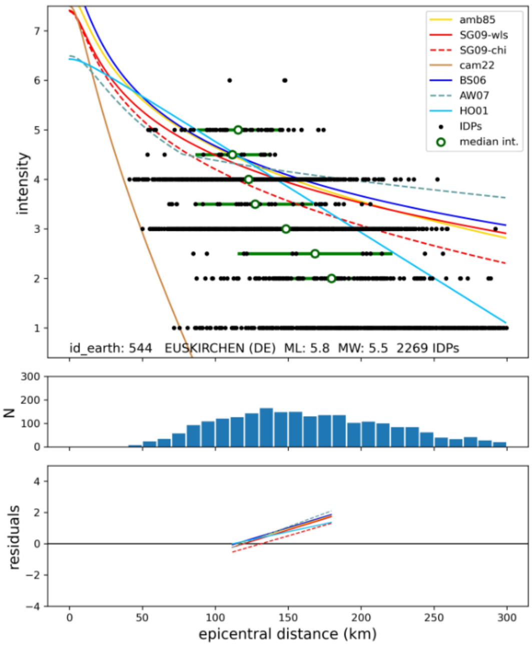
## 10.7. IPE evaluation plots

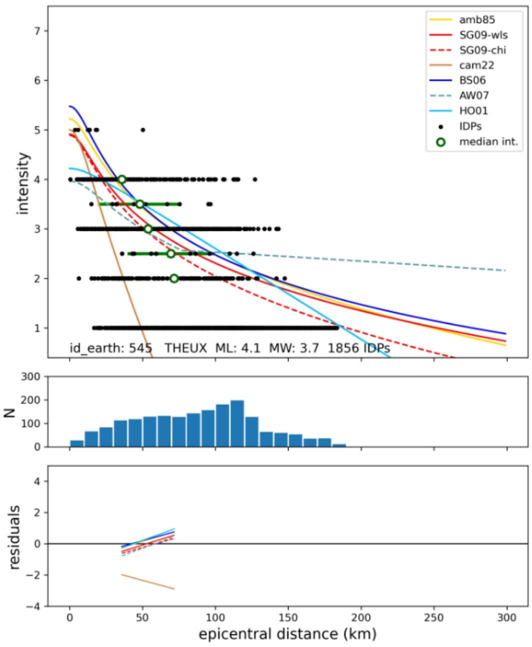
Comparison between macroseismic intensity data of selected events in the BTM database with existing intensity prediction equations. The histogram below each graph shows the number of IDPs (N) within 10 km bins. The lowest graph shows the trend between the IPE prediction and the observations (for both individual IDPs as well as for the intensity bins). Colours match the IPEs.

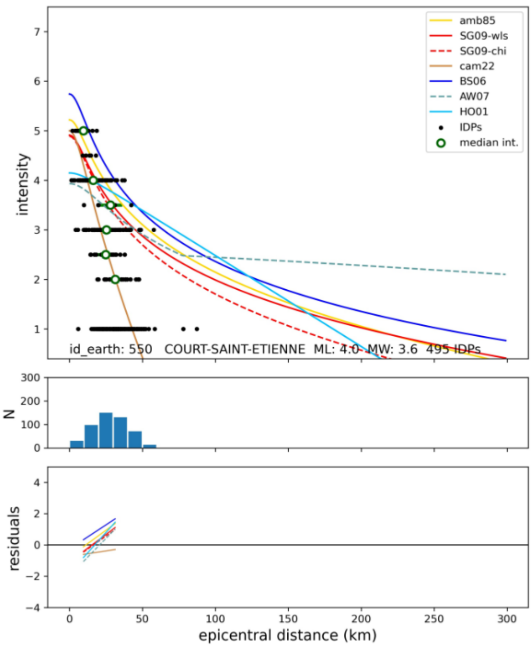


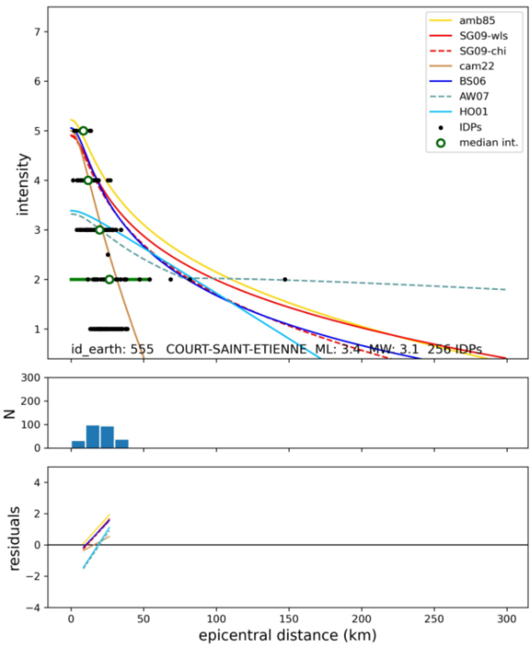



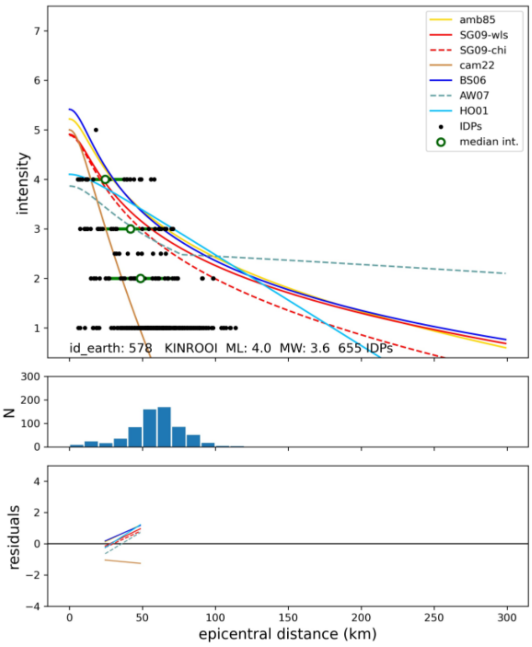



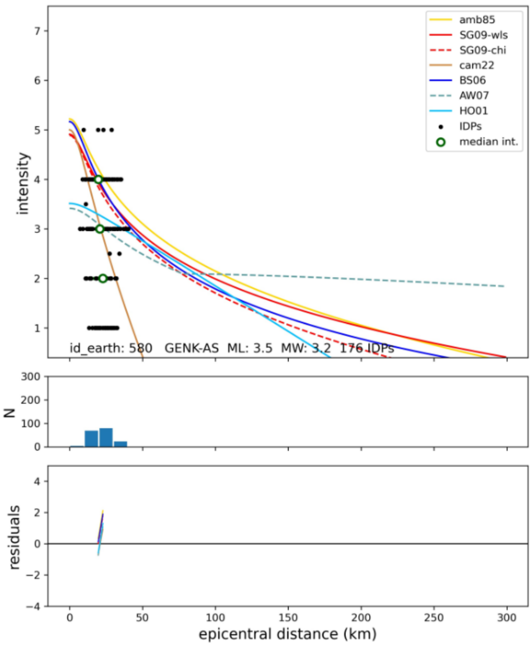

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 544 EUSKIRCHEN (DE) ML: 5.8 MW: 5.5 2269 IDPs
N
residuals
epicentral distance (km)

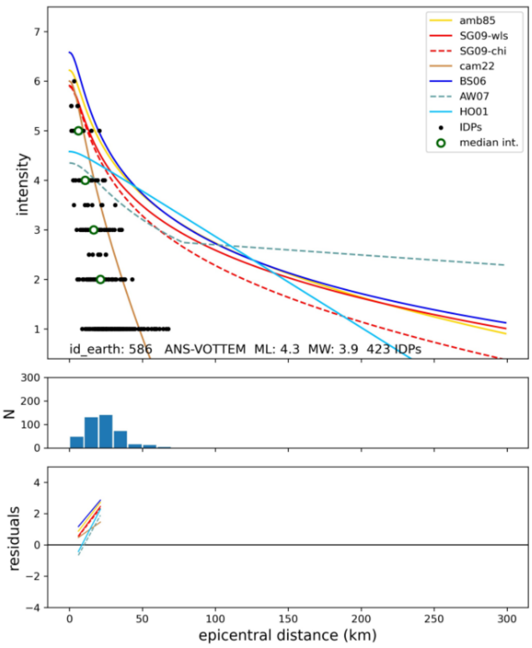

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 545 THEUX ML: 4.1 MW: 3.7 1856 IDPs
N
residuals
epicentral distance (km)

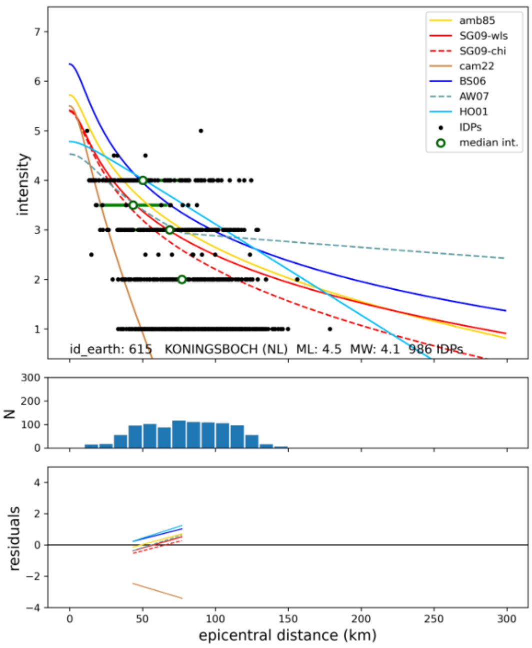

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 550 COURT-SAINT-ETIENNE ML: 4.0 MW: 3.6 495 IDPs
N
residuals
epicentral distance (km)

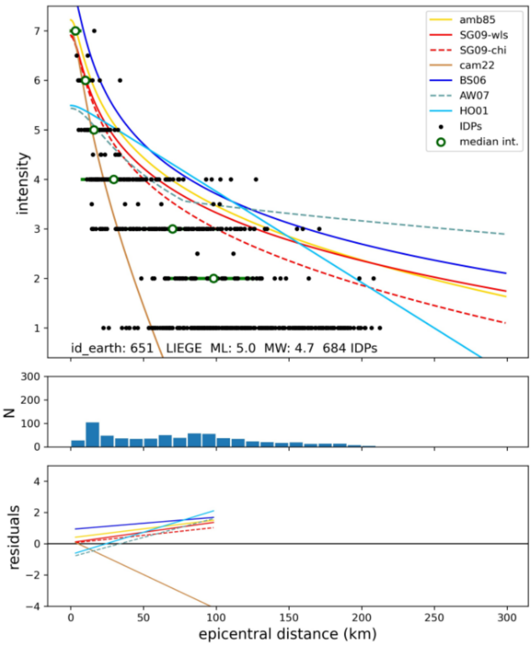

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 555 COURT-SAINT-ETIENNE ML: 3.4 MW: 3.1 256 IDPs
N
residuals
epicentral distance (km)

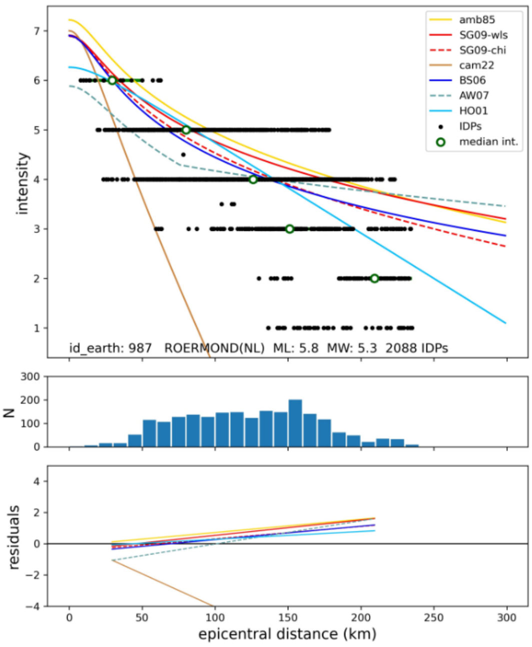

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 578 KINROOI ML: 4.0 MW: 3.6 655 IDPs
N
residuals
epicentral distance (km)

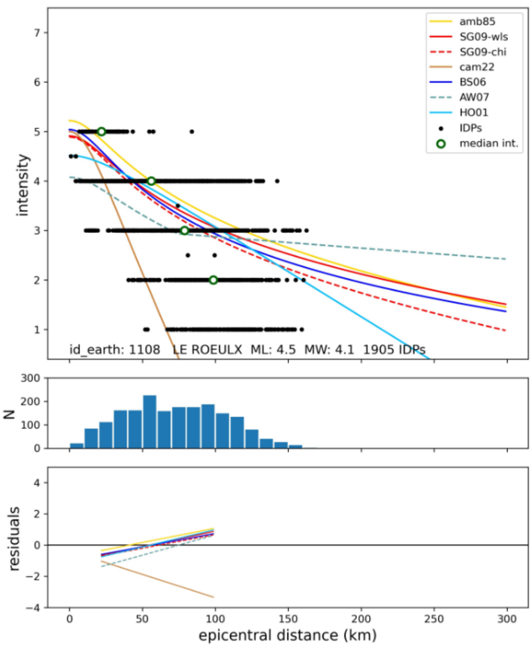

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 580 GENK-AS ML: 3.5 MW: 3.2 176 IDPs
N
residuals
epicentral distance (km)

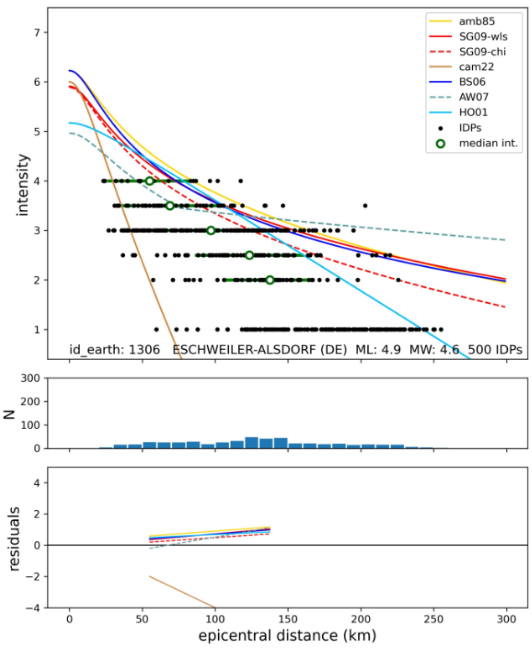

amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 586 ANS-VOTTEM ML: 4.3 MW: 3.9 423 IDPs
N
residuals
epicentral distance (km)


amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 615 KONINGSBOCH (NL) ML: 4.5 MW: 4.1 986 IDPs
N
residuals
epicentral distance (km)


amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 651 LIEGE ML: 5.0 MW: 4.7 684 IDPs
N
residuals
epicentral distance (km)


amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 987 ROERMOND(NL) ML: 5.8 MW: 5.3 2088 IDPs
N
residuals
epicentral distance (km)


amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 1108 LE ROEULX ML: 4.5 MW: 4.1 1905 IDPs
N
residuals
epicentral distance (km)


amb85
SG09-wls
SG09-chi
cam22
BS06
AW07
HO01
IDPs
median int.
intensity
id_earth: 1306 ESCHWEILER-ALSDORF (DE) ML: 4.9 MW: 4.6 500 IDPs
N
residuals
epicentral distance (km)

## 10.8. Ranking and scores IPE performances

| id_earth | source region | IPE | trend | rmse | trend ranking | rmse ranking | rank |
|---|---|---|---|---|---|---|---|
| 480 | East. Camp. | amb85 | 0.068 | 0.69 | 4 | 5 | 9 |
| 480 | East. Camp. | SG09-wls | 0.070 | 0.53 | 5 | 2 | 7 |
| **480** | **East. Camp.** | **SG09-chi** | **0.066** | **0.47** | **3** | **1** | **4** |
| **480** | **East. Camp.** | **cam22** | **0.013** | **0.62** | **1** | **3** | **4** |
| 480 | East. Camp. | BS06 | 0.062 | 0.72 | 2 | 7 | 9 |
| 480 | East. Camp. | AW07 | 0.092 | 0.71 | 6 | 6 | 12 |
| 480 | East. Camp. | HO01 | 0.101 | 0.65 | 7 | 4 | 11 |
| 492 | RVG | amb85 | 0.271 | 1.23 | 4 | 6 | 10 |
| 492 | RVG | SG09-wls | 0.270 | 1.15 | 2 | 5 | 7 |
| 492 | RVG | SG09-chi | 0.272 | 1.07 | 5 | 2 | 7 |
| 492 | RVG | cam22 | 0.323 | 4.83 | 7 | 7 | 14 |
| 492 | RVG | BS06 | 0.271 | 1.07 | 3 | 3 | 6 |
| **492** | **RVG** | **AW07** | **0.260** | **1.01** | **1** | **1** | **2** |
| 492 | RVG | HO01 | 0.275 | 1.12 | 6 | 4 | 10 |
| 509 | Ang-Br Mas. | amb85 | 0.022 | 0.93 | 3 | 5 | 8 |
| 509 | Ang-Br Mas. | SG09-wls | 0.024 | 0.83 | 4 | 4 | 8 |
| 509 | Ang-Br Mas. | SG09-chi | 0.022 | 0.73 | 2 | 2 | 4 |
| 509 | Ang-Br Mas. | cam22 | 0.029 | 2.62 | 7 | 7 | 14 |
| **509** | **Ang-Br Mas.** | **BS06** | **0.022** | **0.70** | **1** | **1** | **2** |
| 509 | Ang-Br Mas. | AW07 | 0.028 | 0.96 | 6 | 6 | 12 |
| 509 | Ang-Br Mas. | HO01 | 0.024 | 0.78 | 5 | 3 | 8 |
| 544 | RVG | amb85 | 0.028 | 1.00 | 4 | 4 | 8 |
| 544 | RVG | SG09-wls | 0.029 | 0.95 | 6 | 3 | 9 |
| 544 | RVG | SG09-chi | 0.027 | 0.76 | 3 | 1 | 4 |
| 544 | RVG | cam22 | 0.024 | 6.69 | 2 | 7 | 9 |
| 544 | RVG | BS06 | 0.028 | 1.04 | 5 | 5 | 10 |
| 544 | RVG | AW07 | 0.034 | 1.14 | 7 | 6 | 13 |
| **544** | **RVG** | **HO01** | **0.020** | **0.80** | **1** | **2** | **3** |
| 545 | East. Ard. | amb85 | 0.027 | 0.50 | 4 | 4 | 8 |
| 545 | East. Ard. | SG09-wls | 0.029 | 0.42 | 5 | 2 | 7 |
| **545** | **East. Ard.** | **SG09-chi** | **0.027** | **0.39** | **3** | **1** | **4** |
| 545 | East. Ard. | cam22 | 0.025 | 2.52 | 1 | 7 | 8 |
| 545 | East. Ard. | BS06 | 0.026 | 0.51 | 2 | 5 | 7 |
| 545 | East. Ard. | AW07 | 0.034 | 0.49 | 7 | 3 | 10 |
| 545 | East. Ard. | HO01 | 0.034 | 0.62 | 6 | 6 | 12 |
| 550 | Ang-Br Mas. | amb85 | 0.068 | 1.01 | 4 | 5 | 9 |
| 550 | Ang-Br Mas. | SG09-wls | 0.070 | 0.83 | 5 | 3 | 8 |
| 550 | Ang-Br Mas. | SG09-chi | 0.066 | 0.76 | 3 | 2 | 5 |
| **550** | **Ang-Br Mas.** | **cam22** | **0.014** | **0.61** | **1** | **1** | **2** |
| 550 | Ang-Br Mas. | BS06 | 0.061 | 1.29 | 2 | 7 | 9 |
| 550 | Ang-Br Mas. | AW07 | 0.095 | 0.85 | 6 | 4 | 10 |
| 550 | Ang-Br Mas. | HO01 | 0.104 | 1.03 | 7 | 6 | 13 |

| id_earth | source region | IPE | trend | rmse | trend ranking | rmse ranking | rank |
|---|---|---|---|---|---|---|---|
| 555 | Ang-Br Mas. | amb85 | 0.103 | 1.17 | 4 | 7 | 11 |
| 555 | Ang-Br Mas. | SG09-wls | 0.105 | 0.98 | 5 | 4 | 9 |
| 555 | Ang-Br Mas. | SG09-chi | 0.101 | 0.91 | 3 | 2 | 5 |
| **555** | **Ang-Br Mas.** | **cam22** | **0.050** | **0.39** | **1** | **1** | **2** |
| 555 | Ang-Br Mas. | BS06 | 0.095 | 0.93 | 2 | 3 | 5 |
| 555 | Ang-Br Mas. | AW07 | 0.137 | 1.06 | 6 | 6 | 12 |
| 555 | Ang-Br Mas. | HO01 | 0.143 | 1.05 | 7 | 5 | 12 |
| 578 | RVG | amb85 | 0.044 | 0.89 | 4 | 6 | 10 |
| 578 | RVG | SG09-wls | 0.046 | 0.71 | 5 | 3 | 8 |
| **578** | **RVG** | **SG09-chi** | **0.043** | **0.60** | **3** | **1** | **4** |
| 578 | RVG | cam22 | 0.009 | 1.19 | 1 | 7 | 8 |
| 578 | RVG | BS06 | 0.041 | 0.88 | 2 | 5 | 7 |
| 578 | RVG | AW07 | 0.057 | 0.63 | 6 | 2 | 8 |
| 578 | RVG | HO01 | 0.061 | 0.87 | 7 | 4 | 11 |
| 580 | East. Camp. | amb85 | 0.552 | 1.37 | 4 | 7 | 11 |
| 580 | East. Camp. | SG09-wls | 0.554 | 1.15 | 5 | 5 | 10 |
| 580 | East. Camp. | SG09-chi | 0.550 | 1.08 | 3 | 4 | 7 |
| **580** | **East. Camp.** | **cam22** | **0.497** | **0.68** | **1** | **1** | **2** |
| 580 | East. Camp. | BS06 | 0.545 | 1.19 | 2 | 6 | 8 |
| 580 | East. Camp. | AW07 | 0.578 | 0.79 | 6 | 2 | 8 |
| 580 | East. Camp. | HO01 | 0.585 | 0.84 | 7 | 3 | 10 |
| 586 | Liège | amb85 | 0.123 | 1.93 | 4 | 6 | 10 |
| 586 | Liège | SG09-wls | 0.125 | 1.67 | 5 | 5 | 10 |
| 586 | Liège | SG09-chi | 0.120 | 1.59 | 3 | 4 | 7 |
| **586** | **Liège** | **cam22** | **0.065** | **1.04** | **1** | **1** | **2** |
| 586 | Liège | BS06 | 0.112 | 2.11 | 2 | 7 | 9 |
| 586 | Liège | AW07 | 0.170 | 1.14 | 6 | 2 | 8 |
| 586 | Liège | HO01 | 0.180 | 1.38 | 7 | 3 | 10 |
| 615 | RVG | amb85 | 0.025 | 0.57 | 3 | 4 | 7 |
| 615 | RVG | SG09-wls | 0.027 | 0.52 | 4 | 2 | 6 |
| **615** | **RVG** | **SG09-chi** | **0.024** | **0.52** | **2** | **1** | **3** |
| 615 | RVG | cam22 | 0.028 | 2.98 | 5 | 7 | 12 |
| 615 | RVG | BS06 | 0.024 | 0.79 | 1 | 5 | 6 |
| 615 | RVG | AW07 | 0.030 | 0.56 | 7 | 3 | 10 |
| 615 | RVG | HO01 | 0.030 | 0.90 | 6 | 6 | 12 |
| 651 | Liège | amb85 | 0.011 | 0.94 | 3 | 3 | 6 |
| 651 | Liège | SG09-wls | 0.013 | 0.78 | 4 | 2 | 6 |
| **651** | **Liège** | **SG09-chi** | **0.010** | **0.60** | **2** | **1** | **3** |
| 651 | Liège | cam22 | 0.044 | 2.11 | 7 | 7 | 14 |
| 651 | Liège | BS06 | 0.008 | 1.26 | 1 | 6 | 7 |
| 651 | Liège | AW07 | 0.025 | 1.01 | 5 | 4 | 9 |
| 651 | Liège | HO01 | 0.028 | 1.21 | 6 | 5 | 11 |

| id_earth | source region | IPE | trend | rmse | trend ranking | rmse ranking | rank |
|---|---|---|---|---|---|---|---|
| 987 | RVG | amb85 | 0.008 | 1.05 | 3 | 6 | 9 |
| 987 | RVG | SG09-wls | 0.010 | 0.97 | 5 | 4 | 9 |
| 987 | RVG | SG09-chi | 0.008 | 0.72 | 2 | 2 | 4 |
| 987 | RVG | cam22 | 0.042 | 5.52 | 7 | 7 | 14 |
| 987 | RVG | BS06 | 0.009 | 0.74 | 4 | 3 | 7 |
| 987 | RVG | AW07 | 0.015 | 1.00 | 6 | 5 | 11 |
| **987** | **RVG** | **HO01** | **0.005** | **0.51** | **1** | **1** | **2** |
| 1108 | Ang-Br Mas. | amb85 | 0.018 | 0.70 | 3 | 5 | 8 |
| 1108 | Ang-Br Mas. | SG09-wls | 0.020 | 0.63 | 4 | 3 | 7 |
| 1108 | Ang-Br Mas. | SG09-chi | 0.018 | 0.55 | 2 | 1 | 3 |
| 1108 | Ang-Br Mas. | cam22 | 0.030 | 2.45 | 7 | 7 | 14 |
| **1108** | **Ang-Br Mas.** | **BS06** | **0.017** | **0.55** | **1** | **2** | **3** |
| 1108 | Ang-Br Mas. | AW07 | 0.026 | 0.83 | 6 | 6 | 12 |
| 1108 | Ang-Br Mas. | HO01 | 0.022 | 0.68 | 5 | 4 | 9 |
| 1306 | RVG | amb85 | 0.007 | 0.91 | 4 | 6 | 10 |
| 1306 | RVG | SG09-wls | 0.008 | 0.75 | 5 | 5 | 10 |
| **1306** | **RVG** | **SG09-chi** | **0.006** | **0.51** | **2** | **1** | **3** |
| 1306 | RVG | cam22 | 0.045 | 4.08 | 7 | 7 | 14 |
| 1306 | RVG | BS06 | 0.007 | 0.73 | 3 | 4 | 7 |
| 1306 | RVG | AW07 | 0.016 | 0.69 | 6 | 2 | 8 |
| 1306 | RVG | HO01 | 0.004 | 0.69 | 1 | 3 | 4 |

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For Belgian citizens, earthquakes are perceived as distant events, unlikely to ever affect their daily lives. Occasionally, however, large earthquakes have occurred and are likely to occur again, causing damage throughout vast regions in Belgium. Due to the low seismicity, the number of instrumentally recorded earthquakes remains limited and unrepresentative of the long-term seismic activity. This gap can be addressed using macroseismic intensity data, which provides a classification of the severity of ground shaking through observations of the effects of earthquakes on people on their surroundings.

In this PhD, damage and eyewitness reports from over a century have been compiled and analyzed. The result is the publication of the most comprehensive summary available of macroseismology in Belgium: from a summary of the conducted macroseismic surveys since the early 20th century, to a detailed overview of the spatial distribution and the impact of seismic activity on Belgium, as well as a critical review on the quality of this data. The publication of the Belgian macroseismic database represents a significant advancement for engineering seismology in Belgium, improving its earthquake preparedness. It enables a range of applications, some of which are demonstrated in this work: from the validation of the most recent Belgian seismic hazard model against observations, to the identification of the best performing intensity Prediction Equations that best represent ground shaking attenuation in Belgium.

*Neefs Ben (2025). The Belgian Macroseismic Database: Creation, Validation, and its Implications for Engineering Seismology. PhD thesis, Université catholique de Louvain.*