Towards a harmonized macroseismic database for Belgium

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Abstract: The resurgence of macroseismic data investigations over the last decades has highlighted its importance and versatility in the broader field of seismology. Macroseismic data in Belgium are plenty thanks to systematic and thorough macroseismic surveys, starting from the beginning of the 20th century. Collection and processing procedures, however, have changed significantly throughout the years. From addressing authoritative residents directly to request earthquake impact information through postal services and their classification in custom intensity scales in the early 20th century, to the online collection of testimonies and automatic intensity value calculations of today. Procedural developments occurred continuously and slowly and are not well documented. To encourage and facilitate macroseismic investigations, the Royal Observatory of Belgium strives towards a harmonized macroseismic database for Belgium.

Keywords: Macroseismology, intensity, macroseismic survey, earthquake impact

1. Introduction

The people's experiences and observations of building damage were the only available sources to characterize an earthquake for a long time. This changed in the late 19th - early 20th century, with the development of instrumental seismometers. In Belgium, the first seismometer became operational in 1898 in Uccle, Brussels. The very first instrumentally-recorded earthquake that had its epicentre within Belgian territory, took place on November 12, 1908 in Poulseur, Liège, but was only recorded by the foreign seismic station of Aachen, Germany (Sieberg, 1908). This event was also the first for which a thorough macroseismic study has been conducted by Lohest and De Rauw (1908) (Somville, 1936). It was not until 29 March 1911 that the first event within Belgium was recorded by the Uccle station (Camelbeeck, 1993; Camelbeeck *et al.*, 2022). With these achievements, seismological research within Belgium started flourishing at the start of the 20th century.

Macroseismic investigations claimed a leading role in the characterization of Belgian seismicity during most of the 20th century. With the realization of the modern seismic network in the 1980's (Camelbeeck, 1993), macroseismic data was no longer required for locating earthquakes and macroseismology lost some of its prominence in the field of seismology. Nonetheless are macroseismic investigations still relevant today, with multiple crucial applications. These include the characterisation of site effects, seismic hazard investigations, the rapid determination of the shaking distribution to constrain automated ShakeMap estimations and as stand-alone intensity observations for response planning.

At the Royal Observatory of Belgium (ROB), the leading seismological research and monitoring institution of Belgium, macroseismic data have been carefully collected and are compiled into a significant macroseismic database. However, collecting and processing methodologies underwent significant developments that have influenced the data. These developments are not readily available in the current state of the ROB database and do not facilitate its use for further investigations. Camelbeeck *et al.* (2022) recently revised the macroseismic data of the events that have taken place in the coal mining area of the Hainaut province in Belgium. In this paper, we explain the evolution of macroseismic data gathering, complemented with a summary of all macroseismic investigations and the current state of the ROB macroseismic database within all of Belgium, similarly to the work of Sira *et al.* (2021)

for France. With this information, advancements can be made to achieve a harmonized Belgian macroseismic database in the near future, from the start of the 20th century.

2. Macroseismic data collection and analysis

In Belgium, macroseismic investigations can be separated into three main types. The first data type is made up of early 20th century macroseismic investigations. These were conducted by different authors from different academic institutions, which collected and processed macroseismic data each in their own way. Next to these early investigations, the ROB archives contain many official macroseismic questionnaires, distributed by the ROB itself to the mayors of earthquake-affected Belgian communes, dating back until 1932. These macroseismic investigations collected and processed data in a more systematic manner and are the second data type. They make up the vast majority of data in the ROB's macroseismic database. In 2002, the ROB launched the online *'Did You Feel It'* (DYFI) questionnaire, following the example of the USGS (Wald *et al.*, 1999), which is the third main type of macroseismic investigations in Belgium. This allowed citizens to report their experience of an earthquake online, resulting in a significant increase in the total amount of received reports. In addition to these three types of macroseismic investigations, also other sources were used including (i) letters from individuals sent to the ROB, (ii) press reports, (iii) investigations conducted by other scientific institutions and (iv) epicentral macroseismic surveys on site. In Table 1, all events since the 20th century for which at least 10 communal macroseismic intensity data points are available in the current version of the ROB macroseismic database are listed, together with their earthquake parameters, the number of macroseismic intensity data points (IDPs), the questionnaire type and the source of the data or previous publications of the data. In this paper an IDP is defined as a macroseismic intensity value for a specific locality for a single event. The events that have taken place in the coal area of the Hainaut province in the 20th century and their macroseismic data have been taken from Camelbeeck *et al*. (2022).

2.1. The evolution of macroseismic data collection

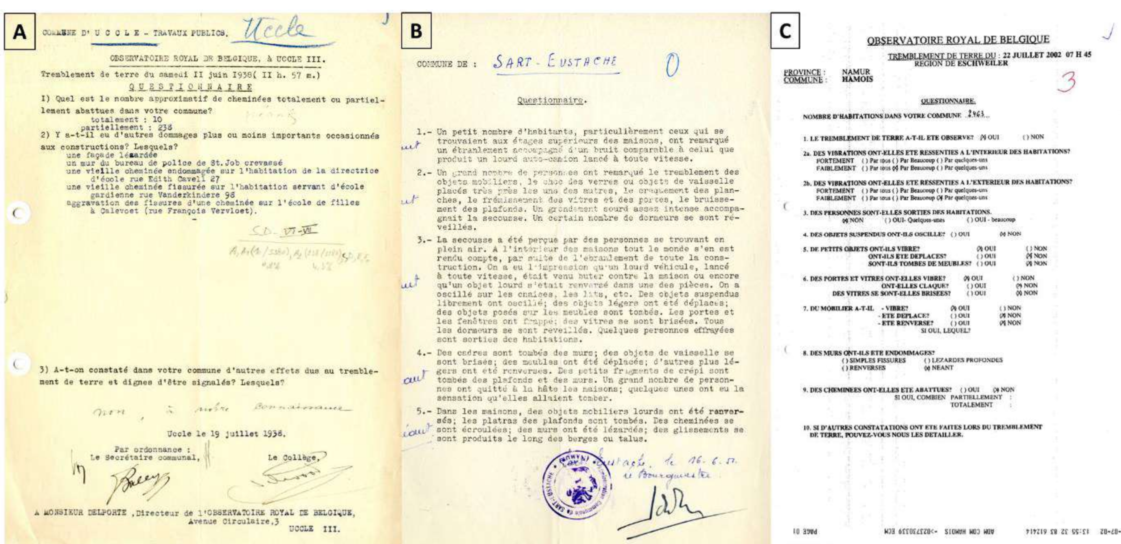
According to Somville (1936), the very first macroseismic study in Belgium, truly worthy of the name, is the study of the Poulseur 12 November 1908 earthquake by Lohest and De Rauw (1908). While this statement on itself is up for discussion, as macroseismic investigations within Belgium had already been performed in the 19th century (e.g. Egen, 1828; Nöggerath, 1828; De Munck, 1887), the publication by Lohest and De Rauw (1908) truly started the careful and consistent collection of macroseismic data in Belgium, which is still in process today. To collect macroseismic data, Lohest and De Rauw (1908) sent out questionnaires in two waves, addressed to prominent inhabitants of communities, such as school teachers, priests or other authoritative residents. The first wave of questionnaires were addressed to widely spaced localities, allowing a rough reconstruction of the total extent of the macroseismic field. The second wave then addressed all localities within the established macroseismic field. The questionnaires themselves consisted of only a few questions, asking for the time, duration and location of the event(s), to which extent the population has felt the earthquake, possible damages and other effects such as inhabitant- and animal reaction. The authors also conducted field surveys at the most impacted localities which endured limited damages (estimated EMS98 intensity V). Each locality was assigned an intensity value on a custom intensity scale. These methodologies applied by Lohest and De Rauw (1908) can be considered as the foundation of all future macroseismic investigations within Belgium and have largely been copied for the macroseismic investigation during the following two decades (e.g. Lohest and Anten, 1921; Fourmarier and Legraye, 1926; Fourmarier and Somville, 1926; Fourmarier, 1926).

Table 1. Events for which macroseismic data are available for Belgium in the ROB macroseismic database since the 20th century. This list is limited to events with at least 10 communal macroseismic intensity data points (IDPs). The felt events of the 2008-2010 seismic swarm in Court-Saint-Etienne (30 events with at least 10 communal macroseismic IDPs, Van Noten et al. 2015) are combined. M: Magnitude (M_L: local magnitude determined from Belgian station recordings; M_S: surface-wave magnitude determined from European station recordings; M_{WH}: equivalent M_W determined from macroseismic data using the formula from Camelbeeck et al. (2022); M_W: moment magnitudes determined from Camelbeeck (1985)). IMAX: maximum observed intensity; IDPs: number of macroseismic IDPs on the communal level in the Belgian catalogue; QTYPE: Questionnaire type (E20C: early 20th century macroseismic investigations; ROBque: official ROB questionnaires; DYFI: Did You Feel It? online inquiry; Cam22: data from Camelbeeck et al. (2022).

DATE	NAME	LAT	LON	M	IMAX	IDPS	QTYPE	SOURCE(S)
1908-11-12	POULSEUR	50.46	5.64		VI	79	E20C	Lohest and De Rauw (1908)
1911-04-12	CUESMES	50.44	3.92	3.1 M_{WH}	IV	22	CAM22	Cambier (1911), Camelbeeck *et al.* (2022)
1911-06-01	RANSART	50.45	4.46	3.8 M_S	VI	53	CAM22	Cambier (1911), Camelbeeck *et al.* (2022)
1911-06-03	GOSSELIES	50.46	4.45	4.4 M_L	VII	16	CAM22	Camelbeeck *et al.* (2022)
1920-01-17	HORNU	50.44	3.82	3.7 M_L	VI	12	CAM22	Capiau (1920), Camelbeeck *et al.* (2022)
1921-02-20	STEMBERT	50.53	5.89	4 M_L	V	33	E20C	Lohest and Anten (1921)
1921-05-19	GERAARDSBERGEN	50.80	3.95	4 M_L	V	47	E20C	Fourmarier and Somville (1926)
1925-02-23	BILZEN	50.88	5.52	4.1 M_L	VI	106	E20C	Fourmarier and Legraye (1926)
1926-01-05	SIEGBURG-ZULPICH (DE)	50.73	6.62	4.4 M_S	V	270	E20C	Fourmarier (1926)
1928-01-14	KALTERHERBERG (DE)	50.50	6.10	3.7 M_S	VI	132	E20C	Fourmarier and Somville(1928)
1932-11-20	UDEN (NL)	51.61	5.47	4.5 M_S	VII	702	ROBque	
1938-06-11	ZULZEKE-NUKERKE	50.73	3.62	5.0 M_S	VII	1496	ROBque	Somville (1939)
1940-01-07	LA LOUVIERE	50.47	4.17	3.5 M_{WH}	V	17	CAM22	Camelbeeck *et al.* (2022)
1949-04-03	HAVRE-BOUSSOIT	50.46	4.08	4.3 M_S	VII	134	CAM22	Charlier (1951), Camelbeeck *et al.* (2022)
1951-03-14	EUSKIRCHEN (DE)	50.63	6.78	5.3 M_S	VIII	1493	ROBque	
1951-09-07	THEUX	50.70	5.86	3.9 M_S	VI	584	ROBque	
1952-10-21	QUAREGNON	50.43	3.88	3.1 M_{WH}	IV	21	CAM22	Camelbeeck *et al.* (2022)
1952-10-22	FRAMERIES	50.42	3.90	2.8 M_{WH}	III	11	CAM22	Camelbeeck *et al.* (2022)
1952-10-27	QUAREGNON	50.43	3.87	3.5 M_{WH}	V	45	CAM22	Camelbeeck *et al.* (2022)
1953-01-06	COURT-SAINT-ETIENNE	50.62	4.60	3.4 M_S	VI	234	ROBque	
1953-08-28	COURT-SAINT-ETIENNE	50.62	4.60	3.4 M_L	VI	151	ROBque	
1953-08-30	VIELSALM	50.37	5.93		VI	87	ROBque	
1954-01-06	ZUTENDAAL	50.93	5.57		V	16	ROBque	
1954-07-10	FLENU	50.44	3.90	3.5 M_{WH}	V	44	CAM22	Camelbeeck *et al.* (2022)
1956-04-21	CHASTRES	50.58	4.63		VI	30	ROBque	
1960-06-25	KINROOI	51.18	5.68	4 M_L	V	96	ROBque	Ahorner and Van Gils (1963)
1963-03-10	GENK-AS	50.97	5.53	3.5 M_L	V	149	ROBque	
1965-12-15	STREPY-BRACQUEGNIES	50.45	4.12	4.0 M_W	VII	99	CAM22	Camelbeeck *et al.* (2022), Van Gils (1966)
1965-12-21	ANS-VOTTEM	50.65	5.53	4.3 M_L	VII	288	ROBque	Van Gils (1966)
1966-01-16	MORLANWELZ-MARIEMONT	50.46	4.24	2.7 M_L	IV	25	CAM22	Camelbeeck *et al.* (2022), Van Gils (1966)
1966-01-16	MORLANWELZ-MARIEMONT	50.47	4.26	3.5 M_W	V	41	CAM22	Camelbeeck *et al.* (2022), Van Gils (1966)
1966-01-16	MORLANWELZ-MARIEMONT	50.46	4.26	4.0 M_W	VII	120	CAM22	Camelbeeck *et al.* (2022), Van Gils (1966)
1967-03-28	CARNIERES	50.46	4.28	4.1 M_W	VII	143	CAM22	Camelbeeck *et al.* (2022)
1968-08-12	LA LOUVIERE	50.46	4.21	3.6 M_W	V	29	CAM22	Camelbeeck *et al.* (2022)
1968-08-13	LA LOUVIERE	50.46	4.21	3.9 M_W	VI	59	CAM22	Camelbeeck *et al.* (2022)
1968-09-23	MORLANWELZ-MARIEMONT	50.46	4.23	3.2 M_W	V	25	CAM22	Camelbeeck *et al.* (2022)
1968-09-23	HAINE-SAINT-PIERRE	50.47	4.22	3.0 M_W	IV	25	CAM22	Camelbeeck *et al.* (2022)
1970-11-03	MARCHIENNE-AU-PONT	50.41	4.41	3.6 M_W	V	31	CAM22	Camelbeeck *et al.* (2022)
1971-02-18	KONINGSBOSCH (NL)	51.05	5.95	4.5 M_L	V	424	ROBque	
1972-02-17	CANTONS DE L'EST	50.60	6.10	3.1 M_L	IV	26	ROBque	
1976-10-24	GIVRY	50.36	4.02	4.2 M_L	VI	95	CAM22	Camelbeeck *et al.* (2022)
1982-03-02	NE of SITTARD (NL)	51.01	5.91	3.7 M_L	V	19	ROBque	
1982-05-22	N of MAASEIK	51.12	5.80	3.7 M_L	V	16	ROBque	
1982-09-14	CARNIERES	50.44	4.24	3.4 M_L	IV	18	CAM22	Camelbeeck *et al.* (2022)
1983-11-08	LIEGE	50.63	5.52	4.6 M_S	VII	461	ROBque	Camelbeeck and De Becker (1984), Francois *et al. (1986)*
1983-11-08	LIEGE	50.61	5.50	3.5 M_L	V	34	ROBque	
1984-07-09	HEERS	50.75	5.35	3.6 M_L	IV	37	ROBque	
1987-03-22	REGION DE DOUR	50.41	3.82	2.6 M_L	IV	12	ROBque	Francois *et al.* (1989)
1988-10-17	GULPEN (NL)	50.81	5.92	3.4 M_L	IV	129	ROBque	Francois *et al.* (1989)
1988-12-27	SPRIMONT	50.54	5.69	3.5 M_L	IV	71	ROBque	
1992-04-13	ROERMOND (NL)	51.15	5.94	5.3 M_W	VII	2021	ROBque	Camelbeeck *et al.* (1992), Haak *et al.* (1995)
1992-06-13	OKEGEM-NINOVE	50.82	4.06	2.4 M_L	IV	45	ROBque	
1992-08-29	BARBENCON-BEAUMONT	50.20	4.29	2.6 M_L	V	24	ROBque	
1995-06-20	LE ROEULX	50.51	4.11	4.5 M_L	V	1838	ROBque	
1996-07-23	SPA	50.48	5.89	3.8 M_L	IV	289	ROBque	
2001-06-23	VOERENDAAL (NL)	50.88	5.92	3.9 M_L	IV	62	ROBque	
2002-07-22	ESCHWEILER - ALSDORF (DE)	50.89	6.21	4.6 M_W	VI	1003	ROBque/DYFI	Camelbeeck *et al.* (2003)
2008-2010	COURT-SAINT-ETIENNE (30)			$\leq$ 3.2 M_L	IV	591	DYFI	
2009-08-05	ZUTENDAAL	50.92	5.56	2.7 M_L	IV	10	DYFI	
2011-08-02	VELDEGEM	51.07	3.15	2.4 M_L	III	27	DYFI	
2011-09-08	GOCH (DE)	51.67	6.16	4.3 M_L	VI	236	DYFI	Van Noten *et al.* (2017)
2015-05-22	RAMSGATE (UK)	51.36	1.27	4.1 M_L	V	193	DYFI	Van Noten *et al.* (2017)
2018-05-25	KINROOI	51.18	5.69	3.1 M_L	IV	88	DYFI	

Fourmarier and Legraye (1926) applied the methodology from Lohest and De Rauw (1908), but included an additional isoseismal map, which was the result of the macroseismic study of Oscar Somville, the first section head of seismology at the Royal Observatory of Belgium. Somville applied different methodologies for his macroseismic investigations, such as addressing the local authorities of the municipalities directly and using internationally recognised macroseismic intensity scales. In the following years and decades, the Royal Observatory of Belgium became the only institution within Belgium to conduct macroseismic surveys, with a few sporadic exceptions (e.g. Francois *et al.*, 1986; Francois *et al.*, 1989). For the first macroseismic investigations conducted as a collaboration between the ROB and other institutions (e.g. Fourmarier and Somville, 1926; 1928; 1933), not much is known about the applied methodologies. Mostly due to the limited information given in the publications of their work, constituting mainly of describing the isoseismal maps, but also because the questionnaires themselves are missing from the ROB archives.

From the official questionnaires that are available in the ROB archives, significant differences exist between them, possibly affecting intensity determination through time. For many events, the macroseismic datasets of the ROB have never been published, resulting in a lack of information pertaining to the applied methodologies. The earliest inquiry available in the ROB archives pertain to the Ms 4.5 Uden 20 November 1932 event in The Netherlands. This questionnaire consisted of a description of 5 classes that represented increasing intensity values. On this form, the recipients indicated the description of possible earthquake effects that matched with the experiences and testimonies of the inhabitants. The following questionnaire available in the ROB archives was sent out after the Ms 5.0 Zulzeke-Nukerke 1938 earthquake, the largest Belgian event in the 20th century. This questionnaire consisted of only three questions, solely focusing on damages, of which the most important question was the number of collapsed chimneys. For the events in the following years to decades, the ROB macroseismic survey evolved slowly and consisted mainly of closed-ended questions, asking for the occurrence of specific effects, as is still the case today (Figure 1).


A

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

OBSERVATOIRE ROYAL DE BELGIQUE, À UCCLE III.

Tremblement de terre du samedi II juin 1938(II h. 57 m.)

QUESTIONNAIRE

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

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

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.

B

COMMUNE DE : SART-EUSTACHE 0

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 craquement des planches, le frémissement des vitres et des portes, 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 sur 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 reveillés. 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. Des 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.

C

OBSERVATOIRE ROYAL DE BELGIQUE

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

PROVINCE : NAMUR
COMMUNE : HAMOIS

QUESTIONNAIRE.

NOMBRE D'HABITATIONS DANS VOTRE COMMUNE 2463

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.

Fig. 1 – Examples of official ROB macroseismic questionnaires. **A:** Questionnaire of the Ms 5.0 Zulzeke-Nukerke 1938 event, solely focused on damages. **B:** Questionnaire for the Ms 5.3 Euskirchen (DE) 1951 event. Recipients were asked to indicate the descriptions that matched the earthquake effects in the community. Identical to the questionnaire of the Ms 4.5 Uden (NL) 1932 event. **C:** Questionnaire for the Mw 4.6 Alsdorf-Eschweiler (DE) 2002 event. Last questionnaire sent by the ROB, consisting of closed-ended questions.

For most events, the radius in which the official questionnaires were sent out was based on provincial district borders (e.g. Van Gils, 1966). An exception seems to be the questionnaire for the Ms 4.5 Uden (NL) 1932 event, for which random communes had been chosen in the more distant provinces of Belgium. It is unclear which selection criteria (e.g. distance, population density) were followed to decide to which communes the surveys were sent. For the Ms 5.0 Zulzeke-Nukerke 1938 event, which solely focused on requesting knowledge about damages, questionnaires were sent to only about half of the Belgian communes because of this, even though the event was strongly felt all throughout the country. For smaller events that only affected parts of the country, the reasoning on what the spatial extent of the investigations are based, are unknown. Publications often only mention having contacted the affected regions or the most shaken communes, but on what this information is based, is unclear.

The online collection of macroseismic data in Belgium started in 2002. The Belgian DYFI questionnaire is based on the DYFI? questionnaire of Wald *et al.* (1999) after Dengler and Dewey (2000). The questionnaire did not change since its launch, with the exception of a single question on the audible noise content, which was added in 2008 (Lecocq *et al.*, 2009). The ROB DYFI is provided in four languages: English, Dutch, French and German. Since 2011, the ROB and the BNS (erdbebenstation Bensberg) of the University of Cologne share the same questionnaire, allowing the collection of transfrontier macroseismic data (Lecocq *et al.*, 2009). The DYFI inquiry allows for the fast and automatic collection of macroseismic data, but during its existence, the largest event recorded within Belgium did not exceed M_L 3.2 (Court-Saint-Etienne, 2008). Because of this, the amount of collected IDPs from the DYFI system remains rather limited, despite its large potential.

2.2. Data processing and analysis

2.2.1. Intensity values assignments

Intensity values in Belgium have always been assigned to the communal level, on a similar scale as the collection of data. Due to the large number of communes in Belgium during most of the 20th century, the number of macroseismic intensity data were large and detailed. In 1977, however, large-scale mandatory mergers decreased the total number of communes from 2359 to 596. This drastically reduced the spatial resolution of the collected macroseismic data. With the launch of the online DYFI inquiry, more accurate data is again available since 2002, allowing more spatially detailed investigations.

For most of the early 20th century events, earthquake intensity values are not reported in a published international macroseismic scale, but in custom intensity scales specifically created for a single event, after the example of Lohest and De Rauw (1908). For example, Lohest and Anten (1921) list the intensity of localities of the 20th of February 1921 earthquake in eastern Belgium in four custom intensity classes: 1) localities which experienced the highest shaking, 2) localities where the majority of inhabitants felt the earthquake, 3) localities where the earthquake was felt by only a few people and 4) localities where the earthquake was not felt. The sources or questionnaires on which these values are based were not published and building vulnerability at that time are not available, rendering intensity reassignments to EMS-98 problematic. One could reassign an entire class to several intensity values on the EMS-98 scale, as currently done for the ROB database, but this results in large uncertainties and displays unnaturally large intensity value gaps (e.g. reassigning class 1 to EMS-98 results to intensity V-VI, while reassigning class 2 would give intensity IV).

Assigning intensity values based on the official questionnaires of the ROB is highly dependent on the type of the questionnaire itself and the actual questions. For the Ms 4.5 Uden (NL) 1932 earthquake questionnaire version, in which the recipients were requested to indicate the appropriate descriptions from a list of macroseismic intensities and their defining characteristic effects on the population and infrastructure, many returned with indicated sentences spread out over multiple classes. This allows for many interpretations and dubious intensity assignments. For the Ms 5.0 Zulzeke-Nukerke 1938 event, the questionnaire did not include any questions that allow assigning values below intensity V, and hence individual letters sent to the ROB were used for assigning intensity values to the communes without damage. Assigning EMS-98 intensity values to the official ROB questionnaires is a possibility as they are readily available in the archives, and has been done for most larger events of the 20th century (e.g. Ms 5.0 Zulzeke-Nukerke 1938 and Ms 4.6 Liège 1983). Unfortunately, assigning vulnerability classes to damaged buildings is not a possibility, as this data was not requested in any of the official questionnaires.

For the online DYFI data, EMS-98 intensity values are based on the original algorithm of Wald *et al.* (1999), by scoring and weighting individual questions and calculating a decimal community intensity (CDI) value. In the ROB current practice, addresses are geocoded and intensities are aggregated into size-adaptable grid cells (e.g. Van Noten *et al.*, 2017).

3. Summary of the present state of the Belgian macroseismic database

The ROB macroseismic database contains ~15,000 macroseismic intensity data points on the communal level since 1900. Since the launch of the official ROB questionnaires, available in the ROB archives starting from 1932, the amount of macroseismic data increased significantly (Figure 2). The event with the most IDPs available is the M_W 5.3 Roermond 1992 earthquake in The Netherlands, despite the large-scale fusion of communes that took place in 1977. This is because ROB questionnaires are addressed to the sub-municipalities as well. These sub-municipalities do not have any administrative functions and will be answered by the main municipality, often resulting in exact copies for all sub-municipalities within a single main commune. The launch of the DYFI system allows collecting large datasets of macroseismic data very quickly. Communal intensity values are only calculated and integrated into the database when a commune reaches at least 3 testimonies. For less testimonies, only a "Felt" sign is indicated for the commune. The 2002 Alsdorf-Eschweiler (DE) M_W 4.6 event is the only event for which two separate datasets are available (official ROB questionnaire intensity values and DYFI intensity values).

The maximal communal intensity value reported within Belgium in the 20th and 21st centuries is intensity VII, which has been reached 73 times for 8 separate events. The main damaging earthquakes are the 1938 Zulzeke-Nukerke Ms 5.0 event (52 times intensity VII, 439 times intensity VI) and the 1983 Liège Ms 4.6 event (12 times intensity VII, 28 times intensity VI). Other events that reached intensity VII are shallow earthquakes located in the coal area of the Hainaut province with a limited extent of the macroseismic field (Camelbeeck *et al.*, 2022).

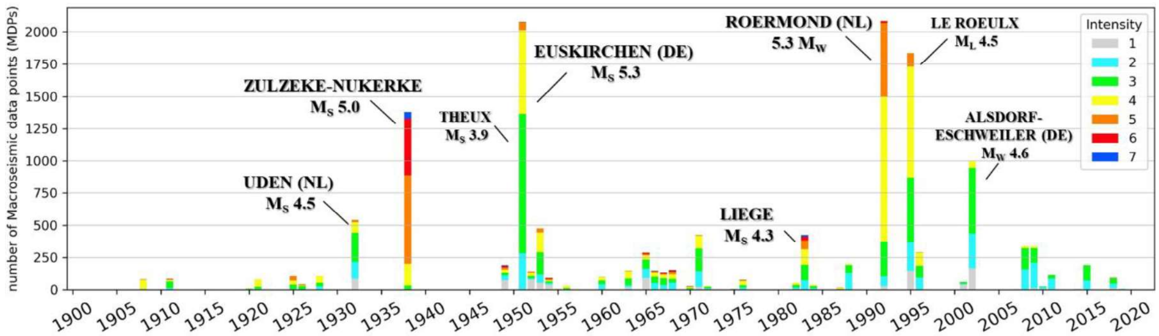


Fig. 2 – Number of yearly macroseismic intensity data points within Belgium in the ROB database for events in the 20th and 21st centuries.

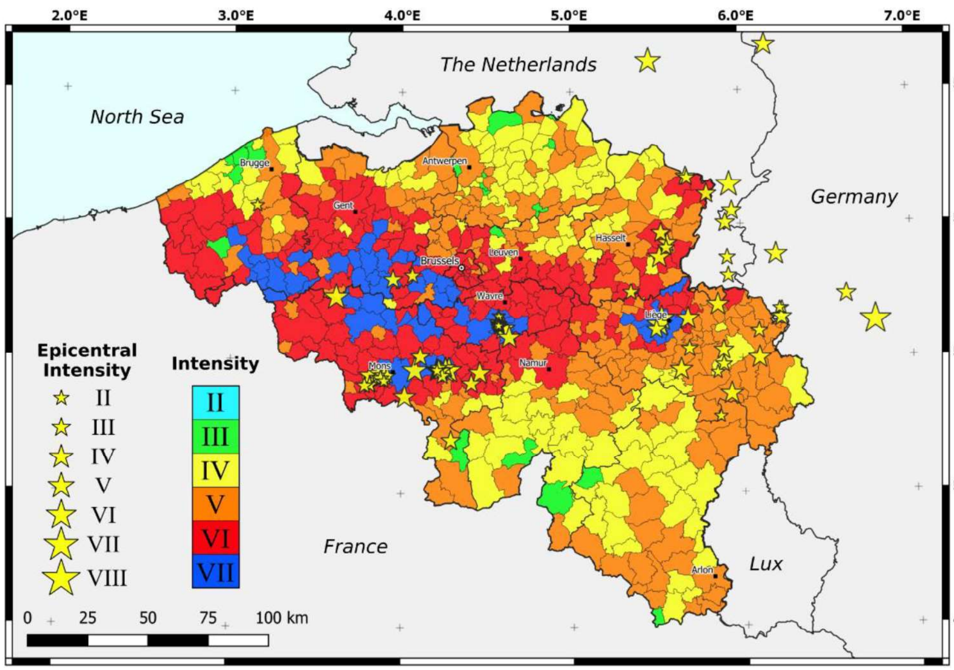


Fig. 3 – Maximal Belgian communal intensities in the ROB database for events in the 20th and 21st centuries.

Figure 3 summarizes the ROB macroseismic data and thus the earthquake impact on Belgium since the beginning of the 20th century. The areas with the largest experienced earthquake impact, i.e. the highest intensity values (values VI and VII), are situated in a rectangular zone from east to west throughout central Belgium. It has to be noted that although this data represents a large time period of ~120 years, it is not representative of the maximal possible ground motion in the country. Historical seismic research has shown the existence of large earthquakes, with estimated magnitudes exceeding M_W 6.0, causing widespread damage all over the country (Alexandre *et al.*, 2008).

4. Applications of Belgian macroseismic data.

Despite the existence of a permanent seismic network in Belgium, macroseismic data remains an important source of information. The population creates a much denser network than the instrumental network, allowing earthquake ground motion characterization in all populated places. A homogenized macroseismic database can be used for the creation of attenuation laws of multiple regions within Belgium, with highly different attenuation characteristics as observed from macroseismic maps. Other applications of macroseismic data include:

characterization of earthquake parameters, site effects investigations, seismic hazard and risk studies, supporting the creation of ShakeMaps and informing the public. These applications form part of the current PhD work of the first author.

5. Conclusion and perspectives

Thorough contemporaneous macroseismic investigations started in Belgium at the onset of the 20th century. Through time, macroseismic surveys evolved continuously towards more detailed, systematic and semi-automatic procedures. The ROB macroseismic database consists of ~15,000 Belgian communal intensity values distributed over more than 100 events during the past 120 years. The maximal intensity VII has been observed 73 times over 8 different events. The development of a historical intensity database is required to achieve a better representation of maximal earthquake damage impact.

The ongoing harmonization of this modern macroseismic database allows and facilitates further seismological research. Mapping the developments and evolutions of macroseismic surveys through time and their effects on determined intensity values will also allow harmonizing cross-border intensity datasets in the future.

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