TC 13 'Aardbevingsbestendig Ontwerpen' van Bouwen met Staal

Typologie gebouwen in Groningen

In deze notitie is informatie verzameld over de gebouwpopulatie in Oost-Groningen die aan aardbevingen ten gevolge van de gaswinning blootgesteld wordt en voor een deel in aanmerking komt voor te treffen maatregelen om de kans op slachtoffers tot een aanvaardbaar minimum te beperken. De uit de Arup-rapporten beschikbare informatie die in deze notitie is opgenomen omvat:

1 een overzicht van de beschouwde klassen II, II en IV (indeling uit de Eurocode 8) gebouwen die binnen het initiële implementatiescenario vallen (gebouwen die naar de huidige inzichten en inschattingen op termijn beoordeeld en mogelijk versterkt moeten worden), zie bijlage 1. Het gaat om ca. 42.300 (II), ca. 500 (III), resp. ca. 100 (IV) gebouwen en > $8 \cdot 10^6$ m^2 GBO (grotendeels in II; > 800.000 m^2 in III en > 500.000 m^2 in IV. De tabel met de aantallen is op p. 2 te vinden; op p. 3 de kaartjes met de verdeling van de klasse III en IV gebouwen in het gebied.

2 een overzicht van de type bouwwijze, zie bijlage 2. Figuur 17 op p. 4 geeft in staafdiagrammen de procentuele verdeling van de bouwwijze. Geput is hierbij uit een uitgebreide database. Blauw betreft het eerste studiegebied (15 km rondom Loppersum) en rood het uitgebreide studiegebied (waar bijvoorbeeld de stad Groningen geheel in valt). Metselwerk (URM1 t/m 12) is het dominante constructiemateriaal (90 % in de eerste studie; 70 à 80 % in de uitgebreide), met beton (RC) als tweede met ca. 5 %. Hout en staal ca. 1 %. Tabel A.2 op p. 5 geeft een nadere uitsplitsing per constructiemateriaal naar bouwwijze (vrijstaand, half-vrijstaand, flexibele en stijve schijven, etc.), leeftijd (< 1920; 1920-1969; ≥ 1970) en aantal bouwlagen (1/2 en ≥ 3). Het kaartje op p. 6 geeft de verdeling in kleurtjes van de verschillende bouwwijzen over het gebied.

3 een overzicht van de bouwwijzen en upgradingopties, § 3.1 en Annex C van Arup's 'Structural Upgrading Study' zijn integraal opgenomen, zie p. 7 e.v.

Nadere (hier niet opgenomen) info:

- Arup's 'Seismic Risk Study – Earthquake Secenario-Based Risk Assessment' geeft in § 4.8 'fragility functions' voor de verschillende bouwwijzen, waarin het % gebouwen met schade in de vijf klassen (DS1 'slight', DS2 'moderate', DS3 'extensive', DS4 'complete', DS5 'collapse') als functie van de PGA (peak ground acceleration). In HS 5 zijn daarmee vervolgens statistische analyses van de schadeomvang en aantallen slachtoffers gedaan; in HS 6 en annex D voor een aantal locaties en aardbevingssterkten. De 'fragility functions' moeten in de toekomst op basis van nieuwe kennis en inzichten verbeteren en een betere onderbouwing geven van de te treffen maatregelen.
- Arup's 'Structural Upgrading Study' geeft in § 4.4 maatregelen om de gebouwen te versterken, onderscheiden naar niveau van de maatregelen (level 1 gaat over voorkomen van afvallende schoorstenen en opstaande muurtjes; level 2 over koppelen van wanden en vloeren; level 3 over het verstijven van flexibele wand- en vloerschijven; level 4 t/m 7 zijn ingrijpendere maatregelen).

Bijlage 1 Analyse van aantallen en typen gebouwen

Overzicht gebouwen die binnen het initiële implementatiescenario 'N' vallen						
Klasse II met PGA > 0,3g						
Klasse III met PGA > 0,25g	zie Fig. 11 page A4					
Klasse IV met PGA > 0,2g	zie Fig. 10 page A2					
Building	Description, examples	Number of buildings	Number of adresses	Mean surface area [m2]	GBO [m2] herleid	
Table 3 Class II buildings						
Detached		15.600	15.600	177	2761200	
Semi-detached		8.100	8.100	120	972000	
Terraced		13.800	14.500	107	1476600	
Flat and apartment		600	5.500	83	49800	
Commercial and Industrial		700	800	724	506800	
Agricultural		1.000	1.000	903	903000	
Miscellaneous		2.500	2.000	400	1000000	
Total Class II		42.300	47.500	169	7148700	7669400
Table 4 Class III buildings						
Residential	Housing for target groups, e.g. elderly		688		176000	
Shopping	Large shopping buildings		52		71000	
Sports			20		70000	
Education	Primary schools, secondary schools		124		199000	
Horeca	Hotels, restaurants		7		26000	
Offices			11		7000	
Industrial	Factories, storage		49		134000	
Health	Nursing homes		20		44000	
Prisons etc			1		3000	
Meeting functions	House of prayer, day care, large bars		127		85000	
Other	Cultural, transformation house		35		10000	
Total Class III		504	1134		825000	
		uitsplitsing 504, zie Table 8 Page A5				
Table 5 Class IV buildings						
Ambulance posts		3			350	
Fire stations		16			8000	
Police stations		10			12000	
Hospitals		2			470000	
Power plants		4			?	
NAM gas distribution station	>	20			?	
Transformer, switching and distribution stations	>	17			?	
Total Class IV	>	72		>	490350	
TOTAAL II, III en IV	>	42.876		>	8.464.050	
Arup Project Title: Groningen 2013 Implementation Study						
Sources used: Location of emergency services (Imergis, December 2012) and production facilities (BAG & Hoogspanningsnet						

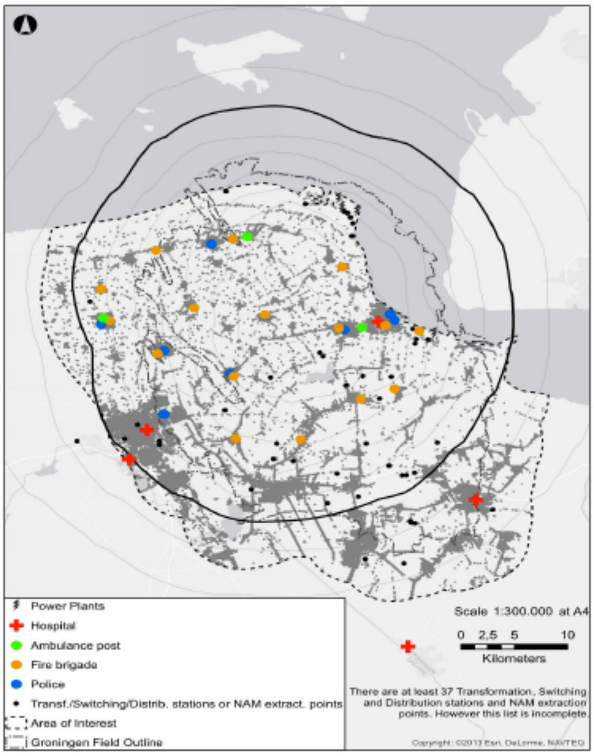

Figure 10 Class IV buildings

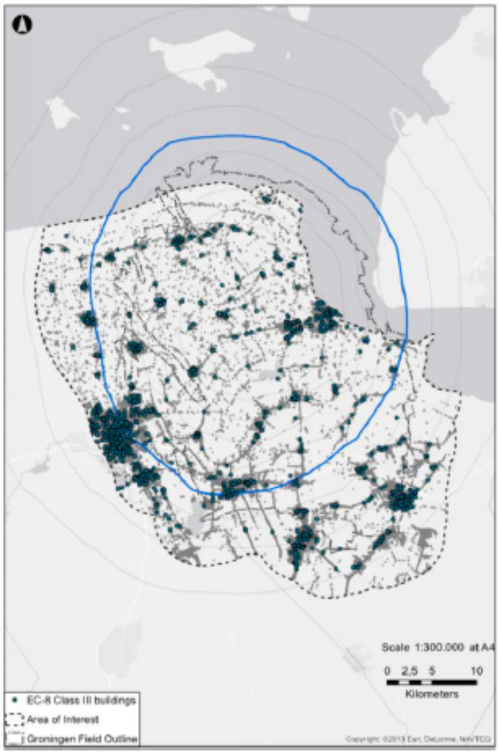

Figure 11 Class III buildings.

Bijlage 2: Type bouwwijze

Bron: Arup's Seismic Risk Study, 29-11-2013. Fig. 17 geeft de % verdeling van de constructiewijze in de database in het initiële studiegebied (blauw) en in het uitgebreide studiegebied (rood), met URM = metselwerk, RC = beton, W = hout, S = staal.

3.5 Building Type

A building type classification is assigned to each building. The estimated construction material (e.g. unreinforced masonry, reinforced concrete, timber, steel) is an important component of this classification, together with the estimated number of floors, and building age. The definitions of the building typologies for the risk assessment are classified in the Table A.2 in Appendix A for the initial and extended database and a summary is shown in Figure 17. The figure shows the proportions of the buildings in the two databases (y-axis), and the actual numbers as labels for each bar on the histogram.

Unreinforced masonry is the dominant building type in the region, estimated to comprise approximately 90 % of the building stock of the initial building database (within 15 km radius) and 75% to 80% of the preliminary extended building database. The second largest building material type is reinforced concrete which comprises around 5% of the building stock in the initial building database (within 15 km radius) and 4% in the preliminary extended database. Wood and steel frame buildings comprise less than 0.5% of the building stock.

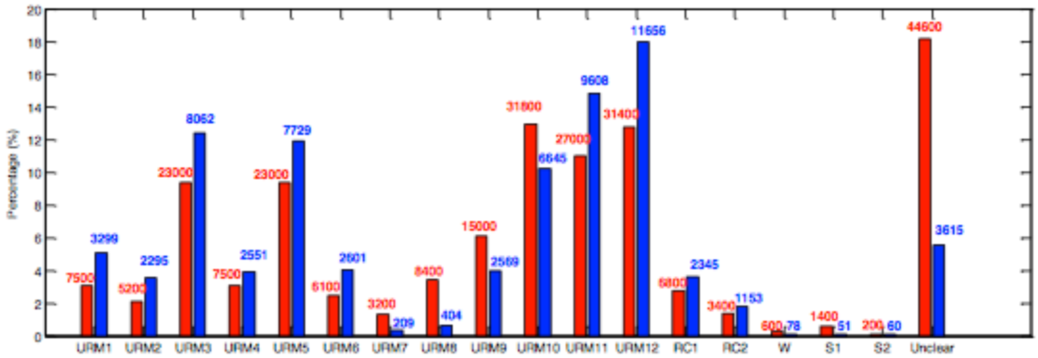

Figure 17 Building typology distribution in study area.

The geographical distribution of the building types are shown in Figure A.3 in Appendix A.

Table A.2 Building typologies for risk assessment and distribution in the initial study area (15 km radius database) and the extended study area.

Material	Building typology	Building type	Age	Storeys /Height	15 km database Sub-total	15 km database Total (%)	Extended database Sub-total	Extended database Total
Unreinforced masonry	Detached/villa/semi-detached, flexible diaphragms	URM1	Pre 1920	1-2	3,299 (5.03%)	57,628 (89%)	7,500 (2.40%)	189,100 (77%)
		URM2		≥3	2,295 (3.5%)		5,200 (2.10%)	
		URM3	1920-1969	1-2	8,062 (12.4%)		23,000 (9.30%)	
		URM4		≥3	2,551 (3.9%)		7,500 (3%)	
	Detached/villa/semi-detached, rigid diaphragms	URM5	Post 1970	1-2	7,729 (11.9%)		23,000 (9.30%)	
		URM6		≥3	2,600 (5%)		6,100 (2.50%)	
	Terraced house, flexible diaphragms	URM7	Pre 1920	1-2	209 (0.3%)		3200 (1.3%)	
		URM8		≥3	404 (0.6%)		8400 (3.4%)	
		URM9	1920 - 1969	1-2	2,569 (4%)		15,000 (6.1%)	
		URM10		≥3	6,645 (10.2%)		31,800 (13%)	
	Terraced house, rigid diaphragms	URM11	Post 1970	1-2	9,608 (14.8%)		27,000 (11%)	
		URM12		≥3	11,656 (18%)		31,400 (12%)	
Reinforced concrete	Concrete bearing wall, rigid diaphragms	RC1	Post 1980	1-3	2,345 (3.6%)	3,498 (5.40%)	6,800 (3%)	10,200 (4%)
		RC2	Post 1970	≥4	1,153 (1.8%)		3,400 (1%)	
Wood	Wooden barns of all ages (with possible non-bearing masonry façade)	W	All	All	78 (0.1%)	78 (0.1%)	600 (0.2%)	600 (0.2%)
Steel	Lightweight steel frame structures (e.g. industrial, building footprint larger than 200 m2)	S1	Post 1960	<15 m	51 (0.1%)	111 (0.20%)	1400 (0.6%)	106 (1%)
	Other steel buildings (steel offices, residential)	S2	Post 1960	>15 m	60 (0.10%)		200 -0.10%	
Unclear	Objects with unknown functions or under construction	UNCL	All	All	3,262 (5%)	3,262 (5%)	44,600 (18%)	3,311 (18%)
Other	To be ignored: (Electricity poles, demolished and non-existing buildings, caravans, docking bays, defence buildings)	OTHER	All	All	353 (0.5%)	353 (0.5%)		
				TOTAL	**64,931**		**246,100**	

A3 Building Type

Each building is assigned a building type classification. A combination of datasets, surveys by Arup and others and GIS tools such as Google Street View have been used to assign the building typologies. The definition of the building typologies are summarised in Table A.2, for the 15 km dataset and for the preliminary extended database.

Figure A. 3 illustrates the geographical distribution of the dominant buildings typologies for a 250m x 250m grid square. It can be seen that unreinforced masonry buildings are distributed across the entire region with reinforced concrete buildings only being the predominant type in discrete locations within Groningen city area, Eemshaven industrial area and associated with other urban areas. There are very few grid squares within the study area where wood is the dominant building type.

It should be noted that there is no pre-existing dataset on construction material type for the region and therefore compilation of this information required the most effort and includes the highest level of uncertainty and will therefore be subject to change as additional information becomes available.

It should be emphasised that it is not always possible to accurately determine the building construction type from the outside. Entry to buildings is not always possible or practical. For buildings where a construction type could not be determined, two or more building types have been assigned to the same building with a weighting factor assigned where the building type is more likely to be one building type than another based on the distribution of building types of the same age and usage in adjacent areas.

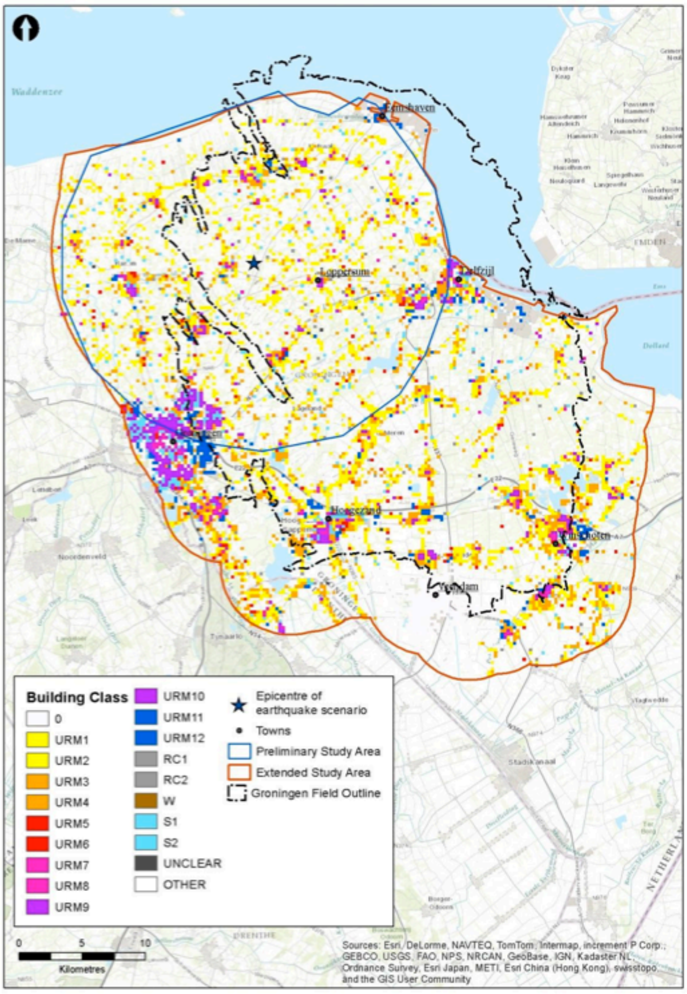

Figure A. 3 Distribution of building type within extended study area.

3 Scope of Study

The purpose of this section is to define the scope of the study in terms of the characterisation of the building stock in the Groningen region and the analysis studies for buildings and building elements.

This study assesses the performance of selected buildings representing typical, damaged, historical, and other buildings. To date, 16 buildings have been assessed:

- Eight typical buildings of six sub-typologies:
  - terraced house
  - semi-detached house
  - detached house
  - labourer's cottage
  - mansion
  - villa
- Four damaged buildings;
- One historic church; and
- Three other buildings:
  - one school
  - two utility buildings

3.1 Building Typologies

Typical building types are representative for a significant proportion of the building stock, while unique buildings are one of a kind. Lessons learned from the study of typical and unique buildings will be captured in the design rules and protocols.

The study area, shown in Figure 14 is centred northeast of Groningen and represents a 5km band beyond the extent of the Slochteren gas field. In this area of approximately 1475km², some 275,000 premises exist, all with different functions, shapes and sizes.

Buildings have been categorised in four main building typologies:

- **Typical buildings** – including houses, represent the largest proportion of buildings and can be divided into a number of sub-typologies representative of the majority of the total building stock in the region. Eight different buildings have been assessed based on covering a representative sample of the most common typologies in the area.
- **Damaged buildings** – potentially have an increased seismic risk and may need prioritization. Four specific buildings have been assessed to date, including assessments of the existing condition of each.
- **Historic heritage buildings** – require specific and sensitive upgrading measures to preserve their visual appearance. One church has been assessed; and
- **Other buildings** – are a mixed group with different materials or combinations of materials structural typologies. Schools, hospitals and utility buildings fall into this category. One school and two utility buildings have been assessed to date.

Building typologies 1, 3 and 4 have specific sub-typologies.

3.1.1 Typical buildings

Initially, the description of Typical buildings was defined by the type of houses located within a radius of around 15 km from the centre of the heavy seismic event indicated in Figure 15. The type of houses consists primarily of two storey high unreinforced masonry houses. Recently the seismic study area has been expanded and includes more urban areas, which comprised multi-storey buildings. This category of buildings has not been included in the above described typologies.

Based on the GIS database, which contains information about 275,000 individual buildings in the area of interest, a system was developed to categorise all of these buildings based on their age, height and expected material of construction. These categories were used in both studies, although in slightly different ways.

The Seismic Risk Study (see Table 8) identified 19 building typology categories, which were selected based on information that could be readily found from existing databases for the area. Buildings typologies were distinguished by building material, age, number of storeys and type (only detached, semi-detached and terraced houses were distinguished). These typologies were selected to allow empirical fragility functions (based on statistics collected in previous international earthquakes) to be assigned to typologies. Twelve of the typologies contain unreinforced masonry buildings, two typologies contain reinforced concrete buildings and the other five typologies contain steel buildings, timber buildings or buildings from which the structural material is unclear.

Since unreinforced masonry is the most common construction material for houses and is the most vulnerable construction material in case of seismic events, the structural upgrading study focusses on this construction material. The buildings assessed within this structural upgrading strategy study are selected based on an initial inspection of building stock and are considered representative for the typologies in the region. There is not a one-to-one correlation between buildings considered in the Seismic Risk Study and those considered in this study. Nevertheless, Table 8 shows a mapping between the Seismic Risk Study categories and the selected buildings for the Structural Upgrading Study.

Table 8 Building Typologies – Seismic Risk Study (RA) & Structural Upgrading Study References.

Typology RA	Type	Floor	Period	Storeys	Structural upgrading Sub-typologies
URM 1	Detached / Semi-detached	Flexible diaphragms	Pre 1920	1-2 storeys	T3a, T4, T5
URM 2				≥ 3 storeys	T6
URM 3			1920 – 1960	1-2 storeys	T2a, T3a, T4, T5
URM 4				≥ 3 storeys	T6
URM 5		Rigid diaphragms	Post 1960	1-2 storeys	T3b
URM 6				≥ 3 storeys	T2b
URM 7	Terraced buildings	Flexible diaphragms	Pre 1920	1-2 storeys	-
URM 8				≥ 3 storeys	-
URM 9			1920 – 1960	1-2 storeys	-
URM 10				≥ 3 storeys	-
URM 11		Rigid diaphragms	Post 1960	1-2 storeys	
URM 12				≥ 3 storeys	T1

Based on the GIS database and site visits to the region common sub-typologies were identified for the structural upgrading study and are summarised below:

For the terraced buildings, T1, the sub-typology believed to be the most common comprises concrete floors at ground, first and attic levels with cavity walls founded on piles.

Similarly, for the semi-detached buildings, sub-typology T2b with concrete floors; cavity walls and piled foundations is believed to be the most common. A more detailed breakdown of sub-typologies of typical buildings can be found in Appendix C.

Based on the database of buildings in the region the most common sub-typologies were identified and are summarised below. One example each of types 1 – 8 in Table 9 have been studied as part of the Typical Buildings study.

Table 9 Characteristics of Typical Buildings.

Nr	Type		Image	Floor	Note
1	T1	Terraced house		Concrete	80% of the terraced houses built after 1960. Concrete was introduced as a building material for regular houses around 1953. Therefore it is assumed that primarily concrete floors are used for terraced houses.
2	T2a	Semi-detached		Wood	
3	T2b	Semi-detached		Concrete	65% of the semidetached houses built after 1960. Therefore it is assumed that primarily concrete floors are used for semi-detached houses.
4	T3a	Detached		Wood	50% of the detached houses built after 1960. At least 40% of all detached houses will have wooden floors only. The other 60% may contain wooden floors, concrete floors or both.
5	T3b	Detached		Concrete	
6	T4	Labourers cottage		Wood	Typical building found in rural areas in the neighbourhood of farms
7	T5	Mansion		Wood	Typical square building found in towns and villages in the region
8	T6	Large masonry villa		Wood	Large masonry residence containing a ground level and at least 2 stories. Richly decorated with ornaments and generally well maintained.

3.1.2 Damaged buildings

Damaged buildings are buildings where damage has been reported in the past and where a damage survey has been conducted. These buildings are, according to the damage reports, in a 'critical condition'.

The four buildings studied in this phase have been selected by NAM. The location of these four buildings is shown in Figure 14 below. Damaged buildings assessed in this part of the study included a large old house which has had several alterations and extensions; a farmhouse constructed in two phases and two timber-framed barns.

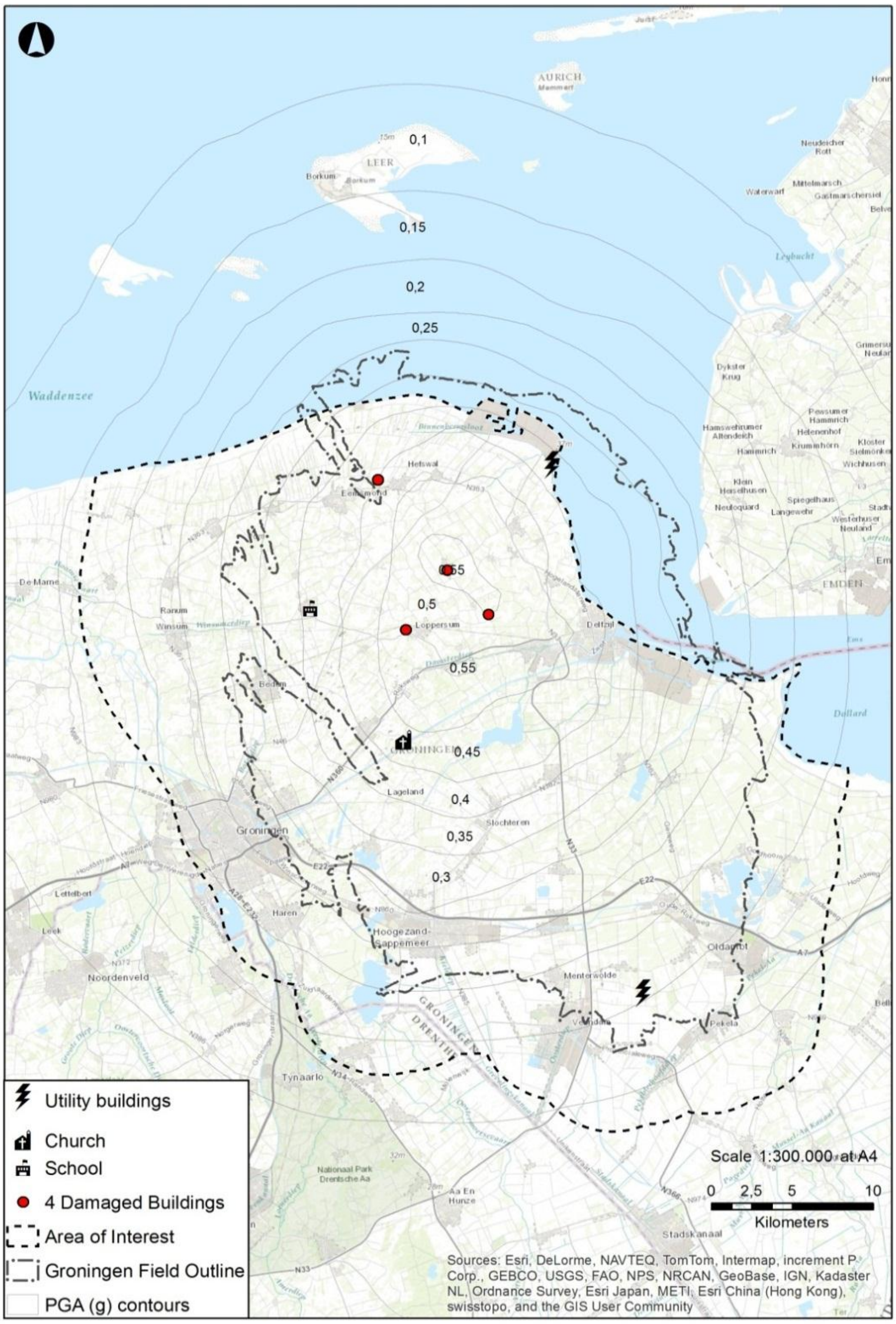

Figure 14 Hazard map with investigated building locations (contours according to Figure 6)

3.1.2.1 Pre and post-upgrading seismic evaluation

For each of the damaged buildings, a pre-upgrading seismic assessment has been undertaken on the basis that sufficient ties and diaphragm action were present to distribute seismic effects – in anticipation that these would be needed to provide adequate seismic resistance.

For the buildings investigated to date, the design of upgrading measures has been provided that does not significantly alter the mass or stiffness of the building. Therefore the overall seismic behaviour from an analysis perspective will not significantly change as a result of the structural upgrading measures. In case the mass or stiffness don change due to the structural upgrading measures, post-upgraded seismic evaluation will be necessary and for the post-upgraded buildings the same analysis and design procedure is followed as for the pre-upgraded building.

3.1.3 Historical buildings

Historical buildings provide special civic amenity. They often comprise large masonry elements attracting high seismic loads and use different structural systems than domestic-scale buildings. Therefore, the assessment methodology can be different from smaller-scale buildings.

The selection and development of upgrading measures involves specific consideration to maintain the appearance.

One historical church building has been assessed to date.

3.1.4 Other buildings

Other Buildings is a category used to capture important buildings not covered by the other categories. The following buildings have been assessed:

- **The school** is particularly important because of the large congregation of children and staff during the day. By their nature, schools tend to comprise a series of extensions built at different times using different construction methods. Therefore they have a certain complexity for seismic assessment;
- **Utility building 1** is an electricity transformer enclosure; and
- **Utility building 2** is a pair of adjacent structures used for gas distribution. There is a particular requirement to allow the roof to detach in the event of a gas explosion.

Structural upgrading measures for the utility buildings have been assessed on the basis that the buildings should be operational immediately after the design seismic event (currently a PGA of 0.25g) and to ensure minimal disruption to operation during implementation of the upgrading measures.

Appendix C

Typical Building Typology Photographs

Table 6 Typicals - Characteristics

Nr	Typology		Image	Foundations	Ground Floor	1st Floor	Attic	Walls	Party Walls
1	T1	Terraced		Piles	Concrete	Concrete	Concrete	Cavity	Cavity
2	T2a	Semi-detached		Strip Footing	Timber	Timber	Timber	Cavity	Solid
3	T2b	Semi-detached		Strip Footing	Concrete	Concrete	Concrete	Cavity	Solid
4	T3a	Detached		Strip Footing	Timber	-	Timber	Solid	-
5	T3b	Detached		Strip Footing	Concrete		Concrete	Cavity	-
6	T4	Labourer's cottage		Strip Footing	Timber	-	Timber	Solid	-
7	T5	Mansion		Strip Footing	Timber	-	Timber	Solid	-
8	T6	Large masonry villa		Strip Footing	Timber	Timber	Timber	Solid	-

Table 7 Terraced - Sub-typologies

Nr	Sub-typology		Image	Foundations	Ground Floor	1st Floor	Attic Floor	Walls	Party Walls
1	T1	Terraced		Stepped brockwork	Timber	Timber	Timber	Solid	Solid
2	T1	Terraced		Stepped brockwork	Timber	Timber	Timber	Solid	Cavity
3	T1	Terraced		Strip footing	Concrete	Concrete	Concrete	Solid	Cavity
4	T1	Terraced		Strip footing	Concrete	Concrete	Concrete	Cavity	Cavity
5	T1	Terraced		Strip footing	Timber	Concrete	Timber	Solid	Cavity
6	T1	Terraced		Strip footing	Timber	Concrete	Timber	Cavity	Cavity
7	T1	Terraced		Strip footing	Timber	Timber	Timber	Solid	Cavity
8	T1	Terraced		Strip footing	Timber	Timber	Timber	Cavity	Cavity
9	T1	Terraced		Wooden piles	Timber	Timber	Timber	Solid	Solid
10	T1	Terraced		Wooden piles	Timber	Timber	Timber	Solid	Cavity
11	T1	Terraced		Wooden piles	Timber	Timber	Timber	Cavity	Solid
12	T1	Terraced		Wooden piles	Timber	Timber	Timber	Cavity	Cavity
13	T1	Terraced		Modern piles	Concrete	Concrete	Concrete	Solid	Solid
14	T1	Terraced		Modern piles	Concrete	Concrete	Concrete	Solid	Cavity
15	T1	Terraced		Modern piles	Concrete	Concrete	Concrete	Cavity	Solid
16	T1	Terraced		Modern piles	Concrete	Concrete	Concrete	Cavity	Cavity

Table 8 Semi-detached - sub-typologies

Nr	Sub-typology		Image	Foundations	Ground Floor	1st Floor	Attic Floor	Party Walls	Façade Walls
1	T2	Semi-detached		Stepped brockwork	Timber	Timber	Timber	Solid	Solid
2	T2a	Semi-detached		Stepped brockwork	Timber	Timber	Timber	Solid	Cavity
3	T2b	Semi-detached		Strip footing	Concrete	Concrete	Concrete	Solid	Cavity
4	T2	Semi-detached		Strip footing	Concrete	Concrete	Concrete	Cavity	Cavity
5	T2	Semi-detached		Strip footing	Concrete	Concrete	Timber	Solid	Cavity
6	T2	Semi-detached		Strip footing	Concrete	Concrete	Timber	Cavity	Cavity
7	T2	Semi-detached		Strip footing	Timber	Concrete	Timber	Solid	Cavity
8	T2	Semi-detached		Strip footing	Timber	Concrete	Timber	Cavity	Cavity
9	T2	Semi-detached		Strip footing	Timber	Timber	Timber	Solid	Cavity
10	T2	Semi-detached		Strip footing	Timber	Timber	Timber	Cavity	Cavity
11	T2	Semi-detached		Wooden piles	Timber	Timber	Timber	Solid	Solid
12	T2	Semi-detached		Wooden piles	Timber	Timber	Timber	Solid	Cavity
13	T2	Semi-detached		Wooden piles	Timber	Timber	Timber	Cavity	Solid
14	T2	Semi-detached		Wooden piles	Timber	Timber	Timber	Cavity	Cavity
15	T2	Semi-detached		Modern piles	Concrete	Concrete	Concrete	Solid	Solid
16	T2	Semi-detached		Modern piles	Concrete	Concrete	Concrete	Solid	Cavity
17	T2	Semi-detached		Modern piles	Concrete	Concrete	Concrete	Cavity	Solid
18	T2	Semi-detached		Modern piles	Concrete	Concrete	Concrete	Cavity	Cavity