Prognosis of DS1 –Building Damage Groningen Field update for Production Profile GTS - raming 2021

February 2021

[redacted]

Contents

1 Damage Assessment

1.1 Classification of Building Damage; Building Damage States

European Seismological Commission, EMS-1998

The EMS-98, European Seismological Commission, 1998 (Ref. 1) document provides guidelines for estimation of the intensity of an earthquake based on the damage assessment of buildings.

Damage of buildings is assessed on the basis of a damage classification. This is provided for two main categories: unreinforced masonry buildings (URM) and reinforced concrete (RC) buildings. Figure 2 describes the 5 distinguished damage grades for both main categories. The description of the damage states in this figure are purely qualitative. For instance, “negligible to slight damage” is termed DS1, “moderate damage” DS2, “substantial to heavy damage" DS3”. The EMS scale relates DS1 to “hairline cracks in very few walls”, DS2 to “cracks in many walls” and DS3 to “large and extensive cracks in most walls”. The qualitative descriptions of the building damage states form a very useful, practical and generally accepted and applied classification system for building damage.

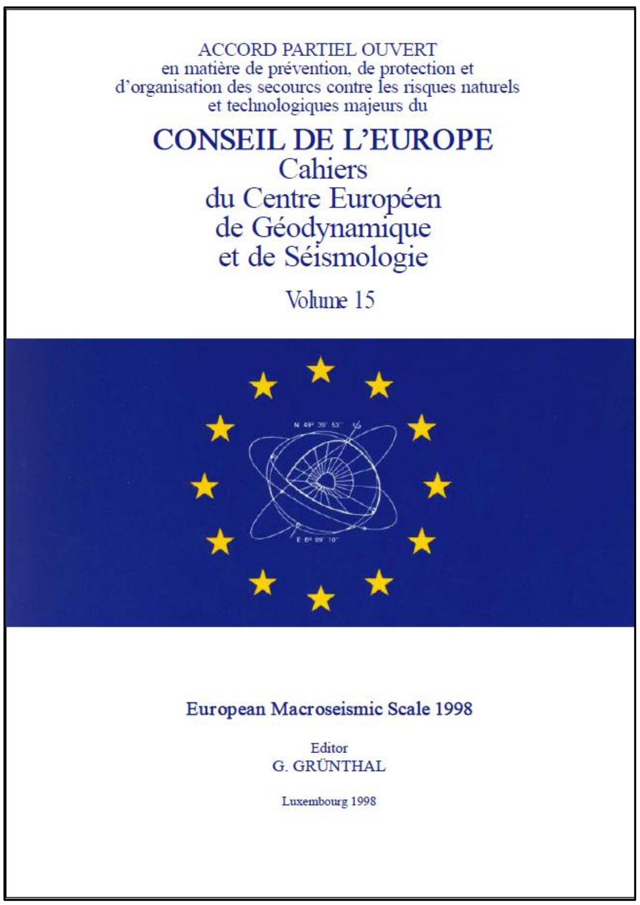


Figure 1 Cover of the “European Macroseismic Scale 1998, EMS-98”by the European Seismological Commission (G. Grünthal), 1998.

Classification of damage to masonry buildings	
	**Grade 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.
	**Grade 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.
	**Grade 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).
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** Serious failure of walls; partial structural failure of roofs and floors.
	**Grade 5: Destruction** **(very heavy structural damage)** Total or near total collapse.

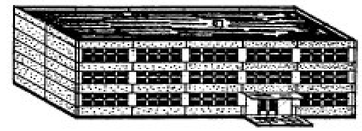
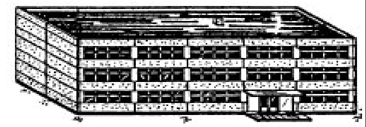
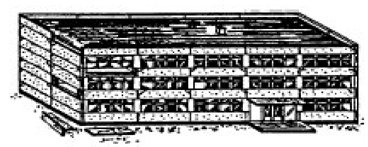
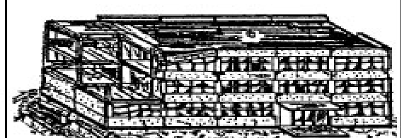
Classification of damage to buildings of reinforced concrete	
	**Grade 1: Negligible to slight damage** **(no structural damage,** **slight non-structural damage)** Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills.
	**Grade 2: Moderate damage** **(slight structural damage,** **moderate non-structural damage)** 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.
	**Grade 3: Substantial to heavy damage** **(moderate structural damage,** **heavy non-structural damage)** Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of conrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels.
	**Grade 4: Very heavy damage** **(heavy structural damage,** **very heavy non-structural damage)** 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.
	**Grade 5: Destruction** **(very heavy structural damage)** Collapse of ground floor or parts (e. g. wings) of buildings.

Figure 2 Classification of damage to masonry buildings (left) and classification of damage to reinforced concrete buildings (right). Illustration taken from EMS-98, European Seismological Commission, 1998 (Ref. 1).

1.2 Forecast for Damage State 1 (DS1) aesthetic damage

The report "Methodology Prognosis of Building Damage and Study and Data Acquisition Plan for Building Damage" (Assessment of Hazard, Building Damage and Risk based on Production Scenario Basispad Kabinet for the Groningen field, Jeroen Uilenreef, Jan van Elk and Assaf Mar-Or, NAM, July 2018.

2), issued February 2017, describes the studies program into building damage and the methodology for forecasting building damage. The building damage assessment of November 2017 (Ref. 3) contains an introduction into the classification of damage states and into the Monte Carlo method used for forecasting building damage and fatality risk.

This section presents the forecast of building damage level DS1 resulting from production profile "GTS-raming 2021" and is similar to the forecast provided last years for "GTS-raming 2020" and "GTS-raming 2019". The higher damage states DS4 and DS5 are relevant for risk and have been addressed in a the report by TNO on the SRA 2021. For the assessment of DS1 building damage, empirical methods based on analysis of historical damage data are used.

The approach to forecast DS1 based on observed damage from historical earthquakes is described in section 8 of the report "Induced Seismicity in Groningen, Assessment of Hazard, Building Damage and Risk – November 2017" (**Error! Reference source not found.**3, pages 168-173). An update of that work has been prepared In June 2018 (Ref. 4, pages 9-11).

This section describes a further update and incorporates the latest information and knowledge available in the following areas:

- Updated empirical GMPE, following recalibration of KNMI G0 accelerometer stations (Ref. 5).
- Recalibrated DS1 fragility curves based on the updated empirical GMPE.
- Production from the Groningen field "GTS-raming 2021"
- Exposure database V7.1 (EDB)

1.3 Earthquake catalogue of events

For the forecast, a range of possible future realizations is needed that adequately represent the anticipated earthquake distribution, both in terms of magnitude and location in the field. These have been generated stochastically, using the hazard tool for the Operational Strategy based on the average temperature demand profile. These are the same profiles as used for the full Hazard and Risk Assessment. In the Monte Carlo simulation process, repeated random sampling of a set of input distributions is used to create a probabilistic distribution output. So-called 'synthetic earthquake catalogues' (i.e. event locations and magnitudes for the period gas-year 2021/2022 to 2030/2031) are generated from the input probability distributions of total seismic moment, number of events and event epicentres. This forecast uses events between M_L = 1.8 and 4.0.

1.4 Exposure model

The exposure database (EDB V7.1 Ref. 6 and 7) is an extract of a project database and consists mainly of the building typology classifications and several other building related attributes, including the population, arranged per building. In addition to its use as input into the Hazard and Risk Modelling, the EDB deliverable also provides the necessary information to assign the TNO typologies to all 266,852 Buildings ("Basisregistratie adressen en gebouwen (BAG)" from the Kadaster) in the area considered for damage forecast. The area of interest is the same for the Hazard and Risk Assessment and is based on the Groningen gas field outline. The extract boundary for the EDB V7.1 is a 5 km buffer around the gas field outline.

Table 1 shows how the different type of buildings present in the Groningen building stock have been assigned to the typologies used by TNO.

TNO typologie	EDB V7.1	Number of Buildings
Not categorised / Secondary "Niet gecategoriseerd"	Buildings with zero population	111,346
Farms "Boerderijen"	All buildings with system URM1F	3,937
High Rise Buildings "Hoogbouw"	Gutter height >10m	4,661
Low Rise Buildings before 1940 "Laagbouw voor 1940"	Remaining year of construction before 1940	39,306
Low Rise Buildings after 1940 "Laagbouw na 1940"	Remaining year of construction after 1940	107,602

Table 1 Assignment of EDB V7.1 typologies to the typologies used in the TNO Kalibratiestudie.

Although it has been recognized that secondary buildings, representing ca. 40% of all buildings mainly consisting of sheds, garages and other small normally unoccupied buildings, could also incur damage, they have been excluded from the forecast because damage data/reports are unavailable for such structures. A previous sensitivity analysis, with assumed fragility function like Low Rise buildings after 1940, shows that secondary buildings may perhaps add up to ca. 60% additional damage cases.

Due to the absence of damage observations in the earlier TNO studies, fragility function for Low Rise buildings after 1940 have also been assigned to all High-Rise buildings. This is believed to be a conservative assumption.

1.5 Results

Figure 3 shows results of the DS1 damage forecast in the form of an annual F/N curve for the Groningen field area, one per gas-year, shown for the period 2021-2031. The median forecast (P50 or 50%) is indicated together with the 80% confidence interval (10% to 90%). Each building in the exposure area was assigned with a relevant typology. It was assumed that any resulting building damage is repaired after the event and before the next one (instant repair). The figure shows that in gas-year 2021-2022 a ca. forty percent chance that more than 100 buildings will be damaged with aesthetic damage (DS1) (due to all earthquakes in that year smaller than ML=4). In gas-year 2030-2031 there is a fifty percent chance that more than 10 buildings will be damaged with aesthetic damage.

Figure 4 shows the Mean and P50 for the DS1 damage forecast per gas-year for the period 2021-2031. Due to the skewed distribution of building damage the mean number of damaged buildings is considerably higher than the P50.

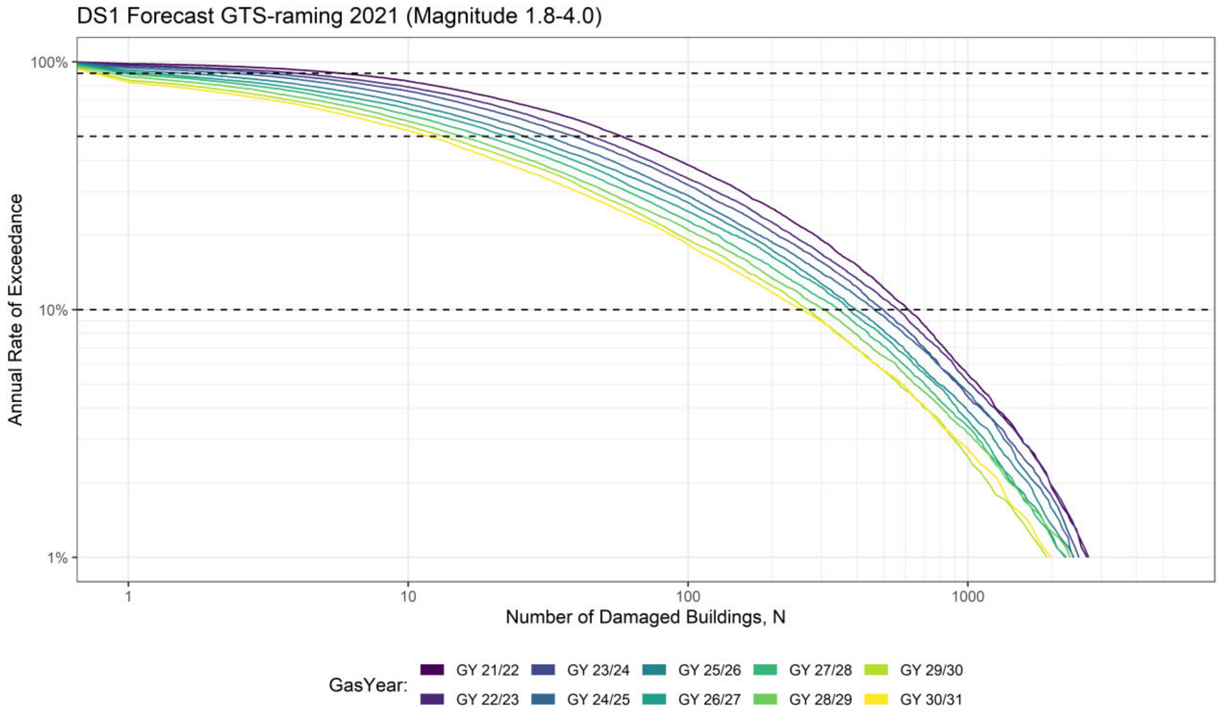


Figure 3 *DS1 Forecast per gas-year for period 2021-2031 based on the middle branch of the M_{max} distribution, shown for "GTS-raming 2021" average temperature demand profile.*

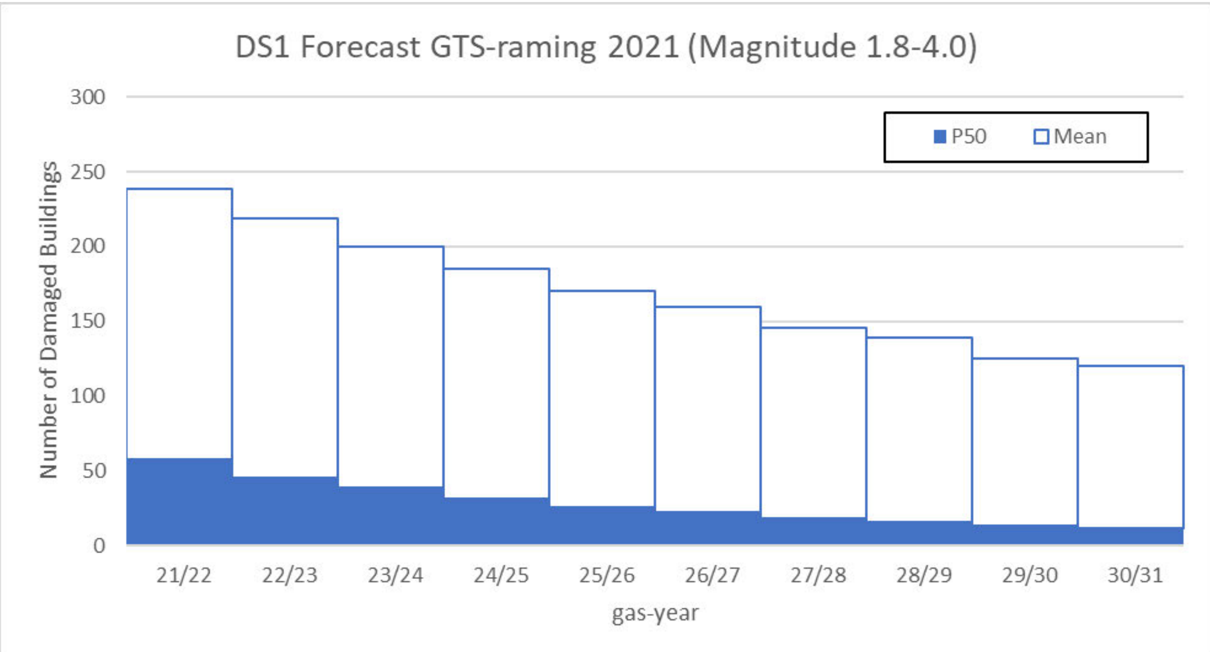


Figure 4 *Mean and P50 DS1 Forecast per gas-year for period 2021-2031 based on the middle branch of the Mmax distribution, shown for "GTS-raming 2021" average temperature demand profile.*

2 References

All reports referenced in this section prepared by NAM can be downloaded from the webpage "onderzoeksrapporten" on www.nam.nl.

Ref. 1 *European Seismological Commission (G. Grünthal), European Macroseismic Scale 1998, EMS-98, 1998*

Ref. 2 *Methodology Prognosis of Building Damage and Study and Data Acquisition Plan for Building Damage, Nederlandse Aardolie Maatschappij BV (Jan van Elk, Jeroen Uilenreef and Dirk Doornhof), 30 January 2017*

Ref. 3 *Assessment of Hazard Building Damage and Risk for Induced Seismicity in Groningen - 2017, Jan van Elk, Dirk Doornhof, NAM, Nov 2017.*

Ref. 4 *Assessment of Hazard, Building Damage and Risk based on Production Scenario Basispad Kabinet for the Groningen field, Jeroen Uilenreef, Jan van Elk and Assaf Mar-Or, NAM, July 2018.*

Ref. 5 *Updated Empirical GMPEs for PGV from Groningen Earthquakes – March 2019, Julian J Bommer, Peter J Stafford and Michail Ntinalexis, March 2019*

Ref. 6 *Exposure Database V7 - Data Documentation, Technical Report & Postprocessing to produce the v7 Exposure Model, NAM, March 2020*

Ref. 7 *Exposure Database V7.1 – Cover Note, February 2021*