Fifth International Conference on
Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics
and Symposium in Honor of Professor I.M. Idriss
May 24-29, 2010 • San Diego, California

The meaning of Eurocode 8 and Induced Seismicity For Earthquake Engineering in the Netherlands

Brouwer, J.W.R.
Volker Wessels Stevin Geotechniek
Woerden, The Netherlands

Van Eck, T., and Goutbeek, F.H.
Royal Netherlands Meteorological Institute
De Bilt, The Netherlands

Vrouwenvelder, A.C.W.M.
Delft University of Technology
Delft, The Netherlands

ABSTRACT

The Netherlands is one of the few European countries where seismic loading is not a dominant part of the national codes. Only for very special structures, earthquakes are regarded as a separate loading case. Until now, Eurocode 8 (EC8) is not part of Dutch building laws nor is there an official Dutch translation. Tectonic seismicity mainly occurs in the southern part of The Netherlands. The Dutch code NEN 6702 has a zonation map which shows horizontal peak accelerations of 0.01g to 0.1g for a return period of 5000 years. However, this seismic zonation map is yet not coherent with the EC8 National Annexes for Belgium and Germany.
Induced seismicity due to the exploitation of natural gas is mainly observed in the northern part of The Netherlands. Induced earthquakes in the Netherlands have been observed at shallow depths with magnitudes up to M_L = 3.5. Recorded strong accelerations are usually short in duration but have incidentally reached 0.3g.
Currently, a study group is investigating the suitability of EC8 approach for Dutch conditions, the different seismic engineering approaches in Belgium and Germany, the implication of induced seismicity and a uniform engineering approach for sensitive structures, adopting (seismic) risk assessment.

INTRODUCTION

In 2004, the Dutch Normalisation Institute (NEN) approved on section 1 through 6 of EC8. Little discussion was held within the Dutch code committee on the contents of this item. The topic of earthquake loading is in general not very well known by Dutch engineers and practioners. Furthermore, the Ministry of Housing, Spatial Planning and the Environment (Dutch: VROM) possibly decides not to incorporate EC8 in the Dutch building laws. This means that in the Netherlands there will be no legal obligation to apply EC8 for the design of structures.

This approach leads to certain practical issues:
- in the southern part of The Netherlands (province of South Limburg) structures are not designed using EC8 whilst engineers in adjacent areas in Belgium and Germany are bound to use that code, due to either insurance or legal obligations;
- currently, two LNG terminals in Rotterdam are designed or under construction; one terminal is designed adopting induced earthquake loading due to gas exploration (this phenomenon will be explained later in this article), the other one is designed only for tectonic seismicity;
- adopting the EC8 approach in combination with induced seismicity may lead to very conservative designs when applied to small structures.

Currently, a Dutch study group has been formed and investigates the following questions:
- is the EC8 approach suitable for Dutch conditions (tectonic and induced seismicity);
- what seismic engineering approaches are used in Belgium and Germany;
- what models can be used to incorporate the induced earthquakes measured in the North of the Netherlands;
- what is the implication of induced earthquake measurements in the North of the Netherlands for the remaining parts of the Netherlands, where minor gas and oil fields are explored or will be explored in the future;
- can we establish uniform engineering approaches for sensitive structures like LNG plants, nuclear power plants and storage facilities, adopting (seismic) risk assessment.

The ultimate goal will be the introduction of EC8 into Dutch (geotechnical) design practice in a uniform way that coincides with current practice as well as practice in adjacent areas or countries. This implies also that a national annex has to be generated which contains guidelines for specific Dutch (soil) conditions and phenomena.

TECTONIC SEISMICITY IN THE NETHERLANDS

Tectonic earthquakes in the Netherlands are concentrated in the southeastern part of the country, mainly in the province of Limburg. This part of the Netherlands is part of the Rhine Graben System, which extends from the Alps into Germany and finally into the Netherlands as the Roer Valley Graben. The major faults in the Netherlands are the Peel Boundary fault and the Feldbiss fault, both trending northwest-southeast into Germany. These faults are the borders of the Roer Valley Graben.

Seismicity in the Northern part of Belgium and the eastern part of Germany (extension of the Roer valley) will have some impact on the seismic hazard in The Netherlands, notably the provinces Limburg, Brabant and Zeeland.

Figure 1 shows an overview of seismicity in The Netherlands over a period of about 100 years.

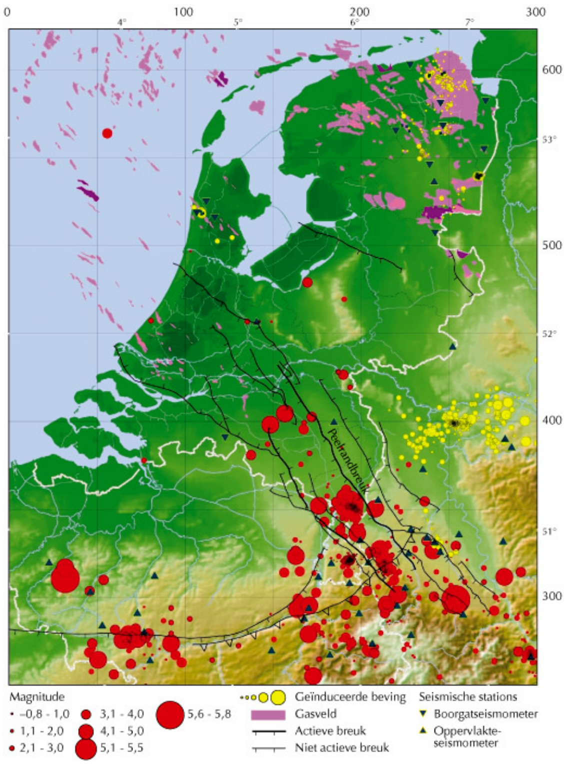

Fig. 1: Seismicity in the Netherlands and its immediate surroundings in the period of 1900-2004. Red circles indicate natural tectonic earthquakes, yellow circles are induced events identified by the KNMI. The earthquakes have been scaled according to magnitude. The black lines indicate faults and the purple fields are oil and gas fields. Blue triangles represent seismic stations.

On average about 10 tectonic earthquakes are detected annually in the Netherlands. Most of them have a magnitude smaller than M_L= 2.5 and are not felt by people. The largest observed earthquakes occurred near Roermond in 1992 (M_L=5.8) and near Uden in 1932 (M_L=5.0). The magnitudes of all other observed earthquakes were smaller than 4.5. The focal depth of the earthquakes is around 15 km.

Figure 2 shows a detailed map of the Roermond earthquake.

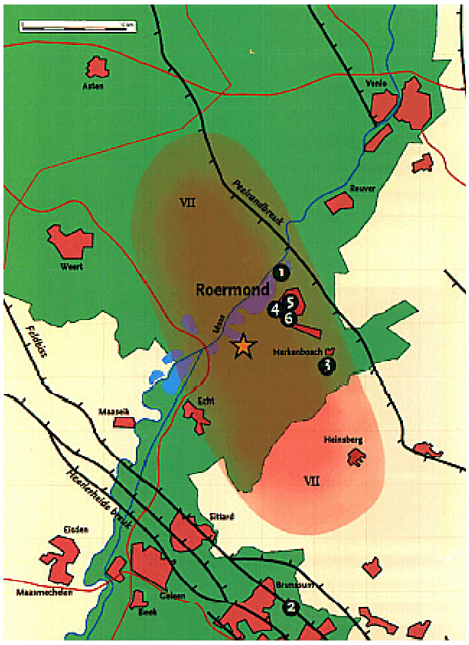

Fig. 2: detailed location Roermond earthquake The location of the Peel Boundary fault and the Feldbiss fault are clearly visible.

Figure 3 shows velocity versus times series for the Roermond earthquake measured at the BUG station in Bochum. The length of this signal is 100 seconds, which is much longer than the signals due to induced earthquakes, see figures 8 and 9.

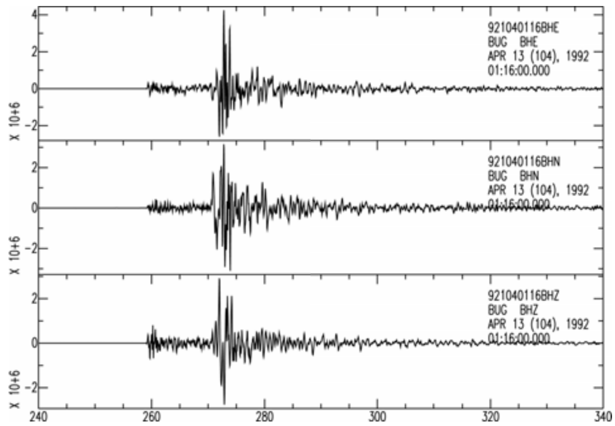

Fig. 3: Velocity time series for Roermond earthquake as recorded at station BUG (Bochum) in Germany (GR seismograph network) for the Roermond 1992 event at 100 kilometers epicentral distance from the site.

Seismic hazard map based on tectonic seismicity

De Crook (1996) carried out the latest seismic hazard study for the Netherlands, based on the earthquake catalogue up to 1993. The study is performed using intensities to determine the seismic hazard, and afterwards the Intensities are translated to peak ground accelerations.

Fig. 4Figure 4 shows the map of seismic hazard zones in the Netherlands based on this study. The ground accelerations for the zones A, B, C and D are 0.01g, 0.022g, 0.05g and 0.1g respectively for a return period of 475 years. This map is in use as the current hazard zonation map in the Netherlands. An update of this study using a revised and extended catalogue of earthquakes and new ground motion prediction relations is being prepared at the KNMI. The new ground motion relations use ground motion instead of Intensities, which is more convenient for engineering purposes and can be compared with actual measurements.

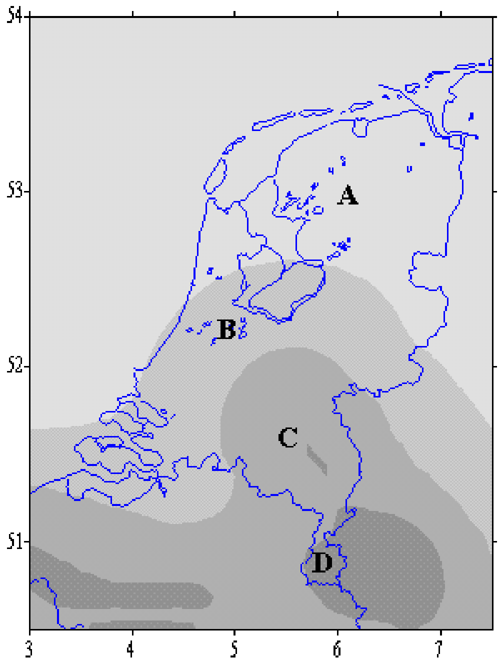

Fig. 4: Currently available hazard zonation in The Netherlands. The ground accelerations for the zones A, B, C and D are 10, 22, 50 and 100 cm/s², respectively, for return periods of 475 years (De Crook, 1996).

CURRENT NATIONAL CODES WITH RESPECT TO SEISMICITY

In the Netherlands, there is no legal obligation to design building structures with respect to earthquake loading. Dutch design code NEN 6702 does not specify representative values for earthquake loading on building structures in the text itself. In practice, wind loading is considered governing when compared to earthquake loading.

For special projects, where the client has specified that earthquake loading should be considered, the code presents a zonation map in the clarification text which is presented in *Fig. 5*. This figure shows intensities according to the modified Mercali scale with return periods of 5000 years. Furthermore, the code links these intensities to horizontal accelerations. Above values are meant as guidance and are not part of the main text but only given in the clarification text and are therefore not obligatory.

However, a set of design accelerations is not sufficient to determine effective loads on structures, including dynamic and nonlinear effects. To bridge that gap reference is made to EC8.

Regardless the status of the map there is a large need to update it. First of all (also) a map for return periods of 475 years as recommended now by Eurocode is required. Furthermore, the maps should not show any discontinuities at the borders with Belgium and Germany. Finally, the notion of intensities according to the Mercalli scale should be omitted. Accelerations in [m/s^2] is the only thing that matters in design practice.

For the determination of earthquake loading to constructions, NEN 6702 code only makes a small reference in the clarification text to EC8. Further guidelines on the behavior of structures to seismic loading are not given.

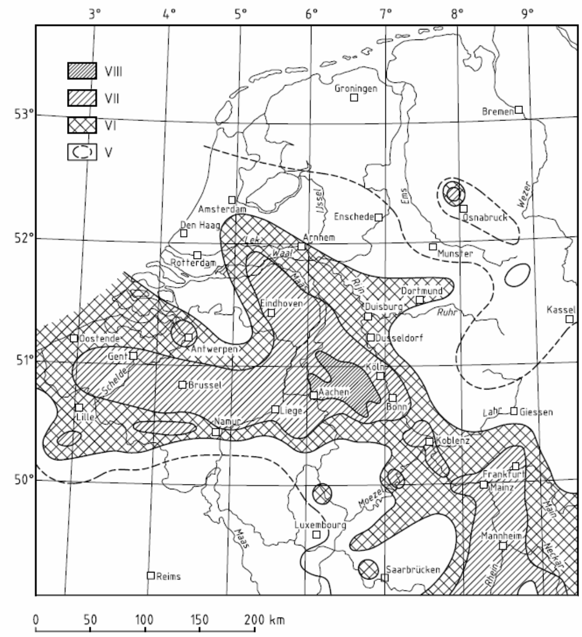

Fig. 5: Current available seismic hazard zonation for return periods of 5000 years specified in intensities (NNI, 2007).

CURRENT APPROACH IN ADJACENT AREAS

Most European countries already use EC8 and have prepared national annexes or are in the progress of doing so. For The Netherlands, especially the approach in adjacent countries of Belgium and Germany are of importance.

Belgium

The Belgium national annex (BIN, 2002) for EC8 shows a zonation map with Peak Ground Accelerations (PGA) for a return period of 475 years:

- Seismic zone 0: no significant acceleration
- Seismic zone 1: PGA = 0.05 g
- Seismic zone 2: PGA = 0.10 g

The map is shown in *Fig.* 6 and shows that partly there is a similarity with the seismic hazard zonation as shown in fig. 4 but for a large area there are distinctions between the Dutch and Belgian approach. For example: the western part of the province of Brabant and the province of Zeeland has a PGA of 0.022g according to the Dutch zonation and the Belgian adjacent areas have a PGA of 0.10g according to the Belgian zonation.

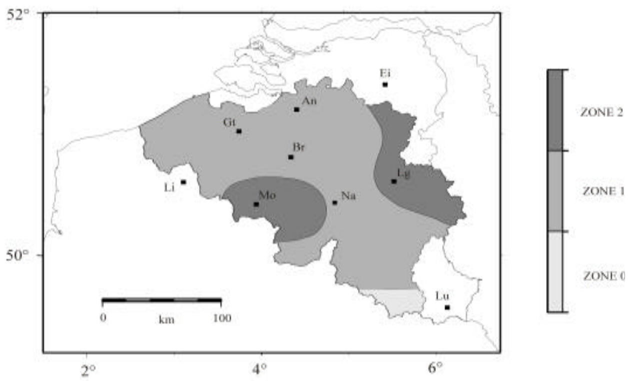

Fig. 6: Seismic zonation map for Belgium (BIN, 2002).

Germany

In Germany DIN 4149 is still in force for seismic design. This code, however, follows exactly the Eurocode EN 1998 text. In the areas close to the Dutch border in Limburg we have the EMS intensities V to VII (for a 475 years of return period as shown in fig. 7). This corresponds reasonably well with the KNMI estimates. In Germany, however, taking into account seismic loads is mandatory and the loads have effect on the structural dimensions and details.

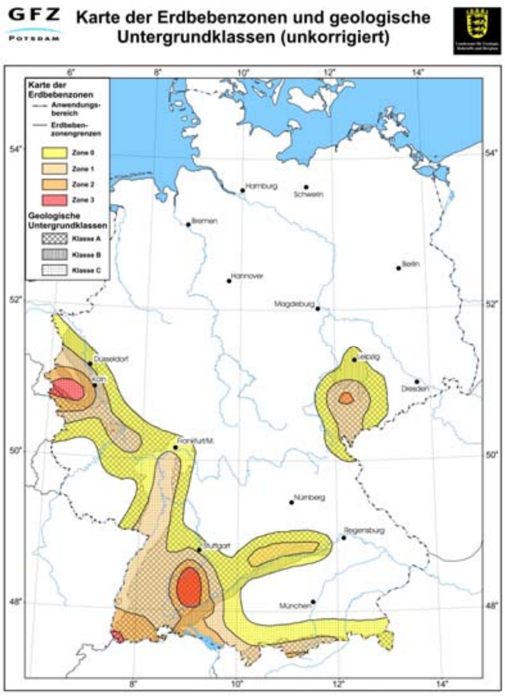

Fig 7 Seismic zonation in Germany including regional site responses (DIN, 2005).

INDUCED SEISMICITY

General

The Netherlands contains a number of large on-land natural gas reservoirs of various sizes. Since 1960 gas has been extracted from these gas fields and in 1986 the first induced earthquake was detected. Since then a steady rate of seismicity is observed, distributed over several fields. The KNMI monitors the area with a network of seismic sensors in shallow (200m) boreholes and accelerometers. From 1986 to July 2009 625 induced events are recorded with magnitudes ranging from M_L = -0.8 to 3.5. Most of the felt earthquakes are of general annoyance to the local population, but some of them have caused minor damage, such as cracks in buildings.

These small and shallow events occur at a steady rate most probably due to the steady rate of gas extraction, which is to continue in the next decades. It is therefore expected that events will also occur in the next decades. The induced events are related to differential movement along pre-existing zones of weaknesses in the vicinity of the gas reservoir layers. Currently the largest activity is observed in and near the Groningen reservoir, the largest onshore gas field in north-western Europe.
One of the other places in the world where small earthquakes due to gas extraction occur is the Lacq gas field in France. Also here research has been done to model the seismicity and to correlate production rate and stress change (Feignier and Grasso, 1990).

In general, small earthquakes ($M_L \leq 3.5$) are considered irrelevant in seismic risk analysis. However, these induced events occur at shallow depths (<4 km) compared to tectonic earthquakes (usually depths > 10 km) and cause short, but strong ground motions (Van Eck et al., 2006). This motion is usually of short duration, about one cycle, but the amplitude may exceed 0.3g (see Fig. 8 and 9).

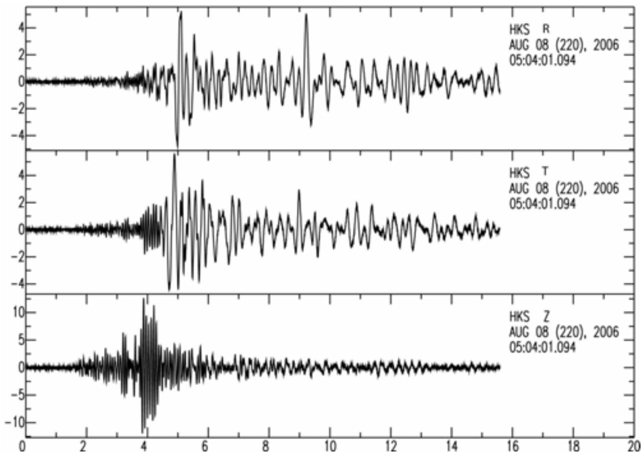

Fig. 8: Three component acceleration time series for a magnitude M_L = 3.5 induced earthquake recorded at 9.0 kilometers epicentral distance (amplitudes are in milli g). The components are the radial, transverse and the vertical component, respectively. The time is given in seconds, the ground acceleration amplitude in cm/s^2.

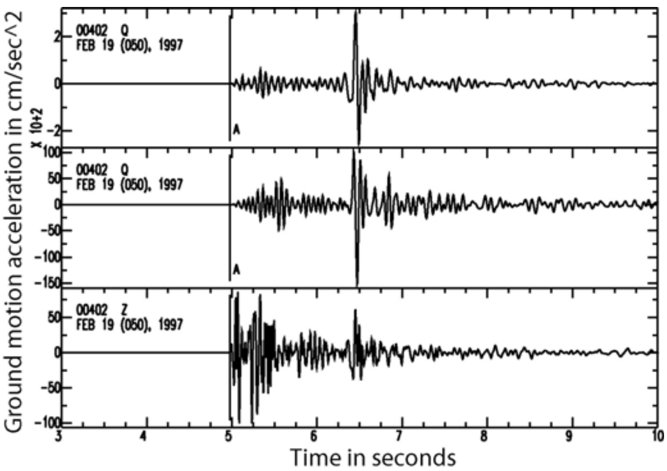

Fig 9: *The ground acceleration as observed by the KNMI at about 2 km epicentral distance of an M_L = 3.4 induced earthquake near Roswinkel on 19/2/1997. The figure depicts the radial, transverse and vertical component respectively. The time is given in seconds, the ground acceleration amplitude in cm/s^2*

The response spectrum of induced events are thus very different from the usual ones applied for tectonic events. Light damage has been observed in several occasions and observed accelerations may potentially be damaging to special industrial structures. We consequently propose special attention to such shallow induced events in the Dutch National Annex to EC8.

<u>Seismic risk</u>

In the Netherlands we observe both gas fields with significant activity and fields with a long extraction history but no induced seismicity. Van Eijs et al (2006) performed a systematic parameter analysis, including both geological information and extraction information and found a statistical relation between some of the parameters and the seismicity. Their result, the probability of the occurrence of an induced earthquake in a gas field is given in Fig. 10.

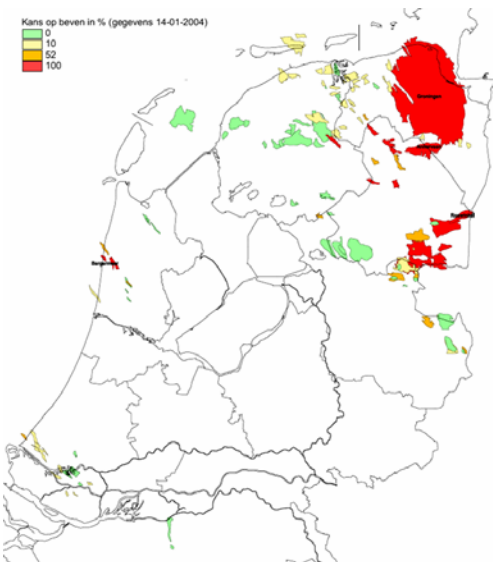

Fig. 10: Probability of occurrence of induced earthquakes in gas fields in The Netherlands.

This study was combined with a generalized probabilistic seismic hazard analysis to determine the expected peak ground motions, acceleration or velocity in a seismic active field (van Eck et al., 2006). As more data is being gathered a revision of this study is being considered.

HAZARD ANALYSIS

As a first approximation a standard probabilistic seismic hazard approach (Cornell, 1969) has been used to obtain the probabilities of exceedance of ground motion at specific sites. The motivation for this approach lies in the stationary seismicity, probably as a result of a stable rate of gas exploration. In this approach statistical models of the seismicity distribution and the frequency-magnitude distribution are used in combination with a ground motion prediction equation to obtain the probability of exceeding a certain ground motion for a specific site. The analysis is repeated for a large number of grid points (sites) at the surface above and in the d irect vicinity of the gas fields. The method is more appropriate for tectonic seismicity, but provides a fairly good first approximation of the hazard above the gas fields in the northern part of the Netherlands..

Seismicity distribution model

The induced seismicity occurs generally in and around the gas reservoirs, usually around 2-3 km depth, whereas the tectonic seismicity mostly occurs at depths around 15-20 km. Although we have strong indication that most seismicity is associated with existing faults, we are currently unable to identify precisely the active faults. Consequently, the best seismicity model is currently a homogeneous distribution of the seismicity at 2.5 km depth in the direct vicinity of a reservoir that has been identified as being seismically active.

Frequency-magnitude model

The frequency of occurrence versus size of all induced seismic events converges nicely to an exponential distribution (Van Eck et al, 2006). Local deviations do exist however. We observed, for example, in the period 1994-2004 only four events in the Bergermeer field near Alkmaar, North-Holland, all with $M_L > 2.9$. No other smaller events were observed. As we currently lack a specific model explaining such behavior we use a general statistical frequency-magnitude model determined using all induced events in the northern part of the Netherlands.

Attenuation relation

Peak ground velocity or peak ground acceleration is the most convenient parameter to characterize seismic hazard. The amplitude can be predicted for a given magnitude and distance using a basic equation, which describes the geometrical spreading and attenuation. Over the last decade many ground motion estimation equations have been empirically determined using tectonic data of larger and deeper earthquakes. Few consider smaller events and are suitable as best estimate for use in this analysis. Dost et al (2006) determined an attenuation relation for our region of interest using accelerometer and seismometer observations from small and shallow events in the Netherlands. However, this relation is currently based on relatively few events.

Results and discussion

We found that the seismic hazard estimates, using PGA or PGV, due to induced events in the northern part of the Netherlands are high compared to the hazard of tectonic events. For example, above the Groningen gas field we expect that peak velocity values of 20 and 30 mm/s may be exceeded with a 10 % probability in 1 and 10 years, respectively. Above some smaller gas fields (3-4 km2) we expect values around 35 and 60 mm/s, respectively. Although high, these values are in agreement with observations. Among the few acceleration observations we observed ~34 mm/s above a smaller gas field with relatively shallow seismicity at around 2 km depth.

These values exceed the vibration guidelines of the Dutch Building Research (SBR). However, the strong ground motions are usually of high frequency and very short duration, about one cycle. Consequently, the response spectra of the induced earthquakes differ significantly from those of tectonic earthquakes and we propose therefore a clear division between these two types of seismicity in the application of EC8.

Recently, the KNMI monitoring network has been extended with five extra borehole stations to improve detection and with six extra accelerometers to provide an extended database for ground motion estimation at the surface. Accelerometers have also proven valuable to identify focal mechanisms, location and event depth.

APPLICATION OF EC8 IN THE NETHERLANDS

Dutch approach and needs

For geotechnical engineering, sections 1 and 5 of EC8 are most important. The scope of EC8 is limited to, in the case of an earthquake, the protection of human life, to limit damage and sustain structures that are important for the protection of citizens. Special structures, such as nuclear power stations, offshore structures, LNG terminals and large dams officially fall outside the scope of EC8, although many parts of the Eurocode may be useful.. Furthermore, EC8 contains provisions that are complementary to those laid down in the other Eurocodes.

In fact, the structure of EC8 relates well to arrangements of Geotechnical Categories (GC) which are used in Dutch NEN codes for many years:

GC1: light and simple structures, for which the behaviour can be predicted relatively easily based upon local knowledge;

GC2: structures not part of GC1; generally most structures without special risks, subsoil conditions or loading involved;

GC3: special structures that can not be classified in GC1 or GC2, based on loads, risks or other aspects.

The codes are specifically written for Geotechnical Category 2 (GC2). Geotechnical Category 3 (GC3) structures are inn many cases special structures like large quay walls, petrochemical plants, (nuclear) storage facilities, etc. where additional client requirements apply. EC8 can therefore be seen as a minimum package of demands which are applicable for special structures.

In geotechnical engineering the relation between earthquakes and the possibility of liquefaction is a major topic. Flow liquefaction for example, is a well known phenomenon where instability of (under water) slopes consisting of loose to medium sands is frequently observed. But also cyclic liquefaction is a possible threat under seismic conditions, either tectonic or induced.
Dutch design codes or rules are not suitable for these problems and very often international standards have to be applied in order to assess these topics.

The use of EC8 for the design of (geotechnical) structures in case of tectonic earthquakes in the Netherlands seems feasible. Application of the EC8 approach and accompanying design response spectra to model induced earthquakes will most likely lead to very conservative designs.

From a geotechnical point of view, the following requirements can be stated:

- A geotechnical engineer has to be able to determine for each location the peak acceleration accelerations for tectonic earthquakes;
- guidelines for the application of EC8 for induced seismicity are required;
- translation of induced seismicity measurements from the northern part of The Netherlands to the other relevant parts of the country;
- information about the ground movements instead of response spectra alone.

As Dutch designers generally use the Cone Penetration Test (CPT) to assess soil parameters, all input parameters used in EC8 should be based on CPT cone resistance. The national annex to EC8 should allow to use this information, which is specific for Dutch geotechnical design practice.

<u>Opposition against EC8</u>

The study group focuses on the question how EC8 will be applied and appreciated in Dutch building practice, given the fact that at this moment there is no legal obligation to use EC in Dutch building laws.

In general Dutch engineers believe that for normal structures, wind loading is always governing over earthquake loading. This is also the background for Dutch design code NEN 6702 as explained above. When wind loads have been incorporated, earthquake loading is no longer regarded, except sometimes for special structures as mentioned in the previous section. This a total misunderstanding as has been proved in the past with simple hand calculations. Earthquake loading can be important in The Netherlands and neglecting this when wind loads have been incorporated can lead to unsafe designs.

Despite this, EC8 has not been applied in the recent design for a large highway tunnel in the city of Maastricht, in the province of Limburg where tectonic seismicity is a well known phenomenon (see section on tectonic seismicity). Wind loading is obviously not a topic for a fully underground structure.
The general feeling is that incorporation of earthquakes in the design will lead to very conservative design and a dramatic rise of building costs. Furthermore, fear of the unknown is another factor which bothers Dutch engineers: why should we incorporate dynamic loads while this has never been done before and the current approach has never led to damage of any importance?

The knowledge about earthquakes and the implications for (geotechnical) structures was, until a few years ago, very limited in the Netherlands. As more engineering firms and contractors are working in foreign countries, where earthquake loading is part of the engineering practice for years, the knowledge of and experience on this subject is growing in The Netherlands.

<u>Conditions for introduction in the Netherlands</u>

EC8 will be only used in the Netherlands if it contains useful information for Dutch building practice which covers the Dutch situation. The most important condition is that EC8 may not lead to a rise of building costs, except for projects where safety is really jeopardised.

In fact the actual use of EC8 is determined by the participants in the market. This is a situation well known for: NEN standards are agreements between parties, i.e. that if all parties are willing to support the content, EC8 will be used in engineering practice. It is expected that, however, an intensive information campaign is required.

As for all Eurocodes, composing a National Annex to EC8 is allowed. This annex may deal with the following aspects:

- determination of national parameters;
- application of specific national data , as seismic zonation for tectonic and induced seismicity;
- a choice between several design methods stated in EC8 has to be made (only when alternatives are allowed);
- application of Cone Penetration Test results as input parameter rather than SPT N values.
- certain informative annexes from EC8 may be declared normative (when applicable);
- adding references to additional information which may help (geotechnical) designers, as long as this does not contradict EC8 rules.

EC8 has specific rules for what provisions national choices can be made. Naturally, the Dutch national annex has to comply with these rules.

High-risk structures in the Netherlands

The International Atomic society obliges the member states to take account of the occurrence of earthquakes in the design of nuclear installations. For the design of a treatment and storage facility in Zeeland (municipality of Borssele) for the Central Organisation for Radioactive Waste (COVRA), only tectonic seismicity was taken into account.

The risks involved with Liquid Natural Gas (LNG) installations are also considered extremely high. Currently, several plants are being under construction or in the design phase in the Netherlands.
The European guidelines NEN-EN 1473 (NEN, 2007) for the installation and equipment for liquid natural gas require hazard estimates in terms of an Operational Based Earthquake (OBE) for a return period of 475 years and a Safe Shutdown Earthquake (SSE) for a return period of about 5000 years.

For a plant at the Eemshaven situated above the main gas field in the province of Groningen, an extensive study was conducted by the Dutch institutes TNO and KNMI towards the effects of seismic loading on the structures due to an induced earthquake.

In the Rotterdam port area however, including seismic loads from induced earthquakes in the design is not a straight forward and logical decision.

Fig.11: gas (green) and oil (red) fields in the Rotterdam area

Figure 11 shows a number of gas and/or oil exploration sites in the greater Rotterdam area which are either already in production or maybe active in the (near) future. They may be capable of induced seismicity. Compared to the fields in the northern part of the Netherlands, the size and amount of the gas fields are relative small. Up to now no events have occurred in the southwestern part of the Netherlands due to the gas extraction but this cannot be excluded completely.

For one LNG plant in this region, only loads from tectonic earthquakes were incorporated in design while induced seismicity was totally disregarded. For the design of another one, the approach was to perform the analyses on the dataset of earthquakes that occurred in the northern part of the Netherlands. The assumption was also made that if earthquakes are going to occur in the Rotterdam area, they will have similar characteristics. This is of course a conservative but safe approach which has are considerable (cost) impact on the design of the structure.

Currently, a reliable quantification of the probability of induced seismicity in this region is not possible at this time. There are no local records of any seismicity available. A reliable qualification of this hazard is therefore difficult due to too many unknown parameters. This topic requires further investigation and study.

ACTIONS TO BE TAKEN

The study group proposes the following actions to enable smooth introduction of EC8 in the Netherlands:

- first the official translation and publication of part 1 of EC8 on a very short term, followed by the translation of the other parts, to establish easier access, experience and familiarity about this code;
- prepare a national annex to EC8. This annex should consist of zonation maps for tectonic and induced seismicity. A seismic zone per city, as stated in the Belgium national annex, should be considered; the use of example calculations may help understand the nature of earthquake engineering;
- seismic zones should be in line with Belgian and German national annexes to avoid irregularities;
- create additional provisions for the geotechnical design for typical Dutch problems, such as the induced earthquakes in the North of the Netherlands. For the determination of response spectrum for this type of earthquakes, further research is needed;
- further research as to what extent the above mentioned measurements for induced earthquakes should be extrapolated to other oil and gas field in other parts of the Netherlands;
- set up a communication plan for the use of EC8 and its national annex in the Netherlands to ensure the knowledge to all engineers.

The above mentioned actions should first be taken by the current study group. The results should be tied in to the various NEN committees.

The proposed actions could lead to an approach where structures in the highest safety class (for the provinces of Limburg and Brabant) incorporation of earthquake loading is an obligatory and that for other parts of The Netherlands earthquake loading has to be considered as part of general risk assessment. In this way, also induced earthquake loading can be part of the national codes as well.

CONCLUSIONS AND REMARKS

Preliminary conclusions by the study group are as follows:

- Induced seismicity is a phenomenon which requires further study;
- guidelines are required on how to approach and model induced seismicity for the northern part and also for the remaining of The Netherlands.
- a national annex to EC8 is vital for Dutch engineering practice and has to be generated as soon as possible;
- the national annex has to provide rules for tectonic as well as induced seismicity;
- the national annex has to coincide with national annexes from Belgium and Germany;
- much effort is needed to introduce the EC8 national annex to Dutch engineering practice.

ACKNOWLEDGEMENTS

The authors wish to thank all the members of the preliminary CUR EC8 committee for their input in the discussion about this topic and a special thanks to the chairman of this committee, Mr. G. Hannink, for his effort to put together the introductory statements.

REFERENCES

BIN [2002], NBN-ENV 1998-1-1: 2002 NAD-E/N/F, Belgische toepassingsrichtlijn Eurocode 8: Ontwerp en dimensionering van aardschokbestendige structuren – Deel 1-1: Algemene regels – Aardschokken en algemene richtlijnen voor structuren.

CEN, NEN-EN 1998-1 [2004], Eurocode 8: design of structures for earthquake resistance.

CEN, NEN-EN 1473:2007 [2007], Installation and equipment for liquefied natural gas. Design of onshore installations

Cornell, C.A., [1960], Engineering seismic risk analysis, Bull. Seismol. Soc. Am., 58, 1503-1606.

Crook, Th. de, [1996], A seismic zoning map conforming to Eurocode 8, and practical earthquake parameter relations for the Netherlands, Geologie en Mijnbouw, 75, pp 11-18.

DIN [2005], DIN 4149:2005-04 (D): Bauten in deutschen Erdbebengebieten - Lastannahmen, Bemessung und Ausführung üblicher Hochbauten.

DIN [2009], DIN EN 1998-1/NA, National Annex - National determined paramters - Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings.

Dost, B., T. van Eck and H. Haak [2004], Scaling peak ground acceleration and peak groud velocity recorded in The Netherlands, Bolletino di Geofisica, 45, 153-168.

Feignier, B. and J.R. Grasso [1990], Seismicity induced by gas production: I. Correlation of focal mechanisms and dome structure, Pure and Applied Geoph., 134, 405-426.

NNI, NEN 6702:2007 [2007], Technical principles for building structures - TGB 1990 - Loadings and deformations.

Van Eck, T., F. Goutbeek, H. Haak en B. Dost [2006], Seismic hazard due to small-magnitude, shallow-source, induced earthquakes in The Netherlands, Engineering Geology, 87, pp. 105-121.

Van Eijs, R.M.H.E., F.M.M. Mulders, M. Nepveu, C.J. Kenters and B.C. Scheffers [2006], Correlation betweesn hydrocarbon reservoir properties and induced seismicity in the Netherlands, Engeneering Geology, 84, pp. 99-111