# Incorporation of Eurocode 8 in the Netherlands

## Incorporation of Eurocode 8 and Induced Seismicity For Earthquake Engineering in the Netherlands

DOOR: BROUWER, J.W.R., VOLKER WESSELS STEVIN GEOTECHNIEK

In 2004, the Dutch Normalisation Institute (NEN) approved on Euro Code 8. Little discussion was held within the Dutch code committee on the contents of this item. The topic of earthquake loading is in general not well known by Dutch engineers. Furthermore, the Ministry of Housing, Spatial Planning and Environment will possibly decide 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.

Currently, a Dutch study group has been formed and investigates:

- the suitability of EC8 approach for Dutch conditions;
- seismic engineering approaches adopted in Belgium and Germany;
- the models that can be used to incorporate induced earthquakes measured in the North of the Netherlands;
- the implication of these measurements for the remaining parts of the Netherlands;
- the possibility to establish a uniform engineering approach for sensitive structures like LNG plants, nuclear power plants and storage facilities.

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

### TECTONIC SEISMICITY IN THE NEHTERLANDS

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.

On average about 10 tectonic earthquakes are detected annually in the Netherlands. Most of them have a magnitude smaller than ML= 2.5 and are

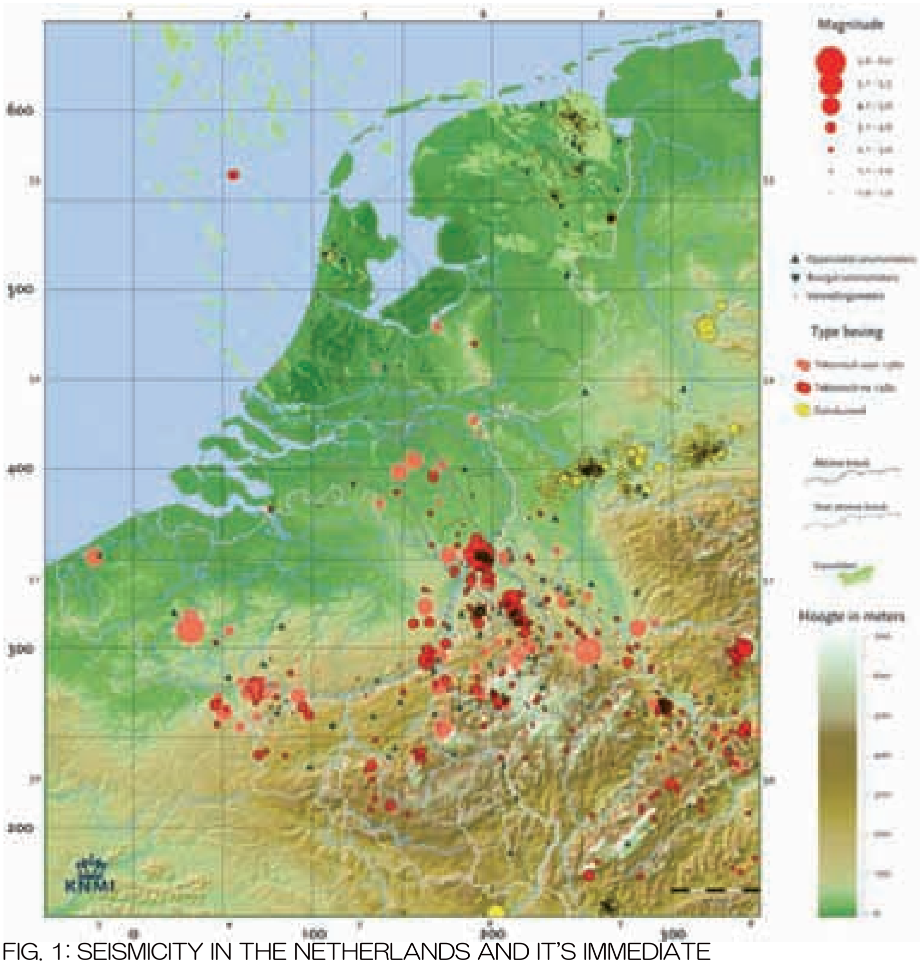


FIG. 1: SEISMICITY IN THE NETHERLANDS AND IT'S IMMEDIATE SURROUNDINGS IN THE PRIOD OF 1900-2004. RED CIRCLES INDICATE NATURAL TECTONIC EARTHQUAKES, YELLOW CIRCLES INDUCED EVENTS.

not felt by people. The largest observed earthquake occurred near Roermond in 1992 (ML = 5.8). The focal depth of the earthquakes is around 15 km.

**Seismic hazard map based on tectonic seismicity**

De Crook (1996) performed the latest seismic hazard study for the Netherlands, based on the earthquake catalogue up to 1993.

Figure 2 shows the map of seismic hazard zones in the Netherlands based on this study. This map is used 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. Ground motions are used instead of Intensities, which is more convenient for engineering purposes and can be compared with actual measurements.

## CURRENT NATIONAL CODE 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 values for earthquake loading on building structures. 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. 3. This figure shows intensities according to the modified Mercalli scale with return periods of 5000 years. 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.

There is a big need to update the current map. First of all (also) a map for return periods of 475 years 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. Acceleration is the only important parameter in design practice.

## INDUCED SEISMICITY

**General**

The Netherlands contains 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.

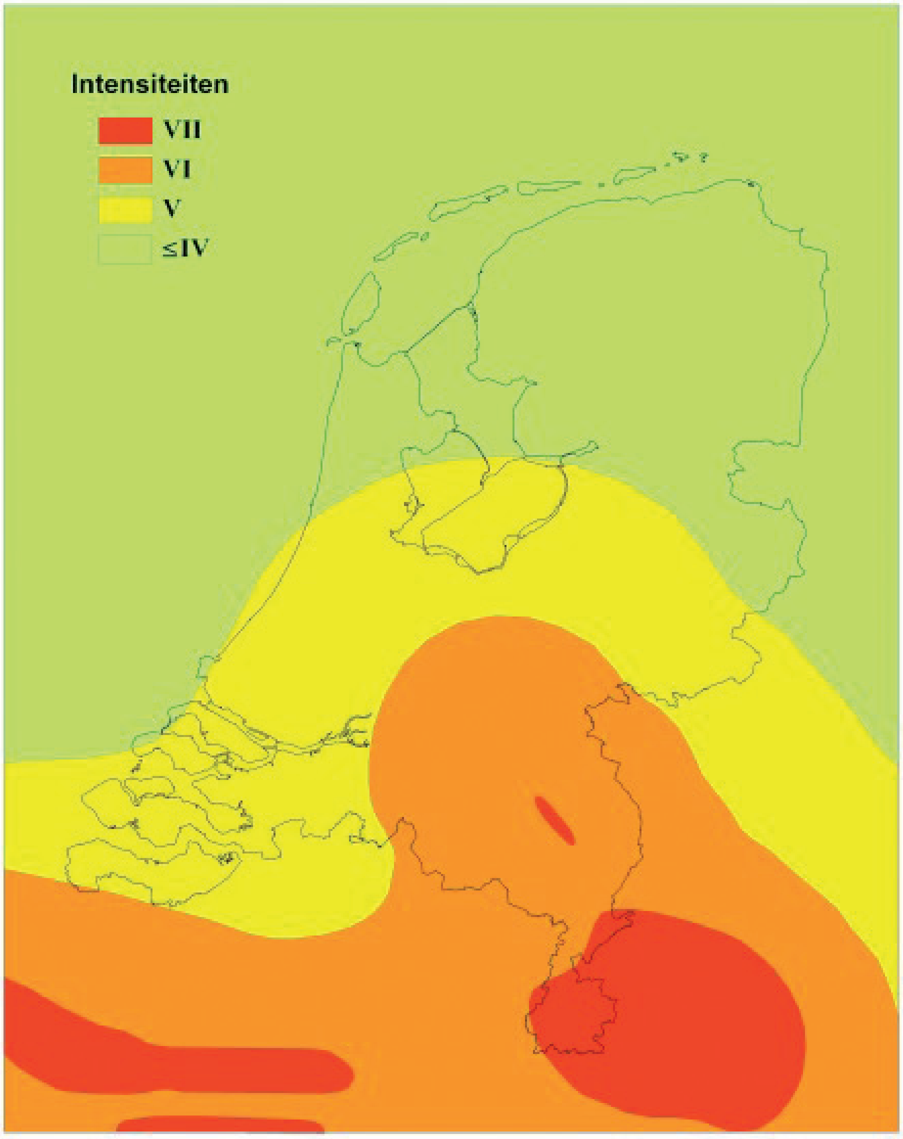


FIG. 2: CURRENTLY AVAILABLE HAZARD ZONATION IN THE NETHERLANDS. THE GROUND ACCELERATIONS DOR ZONES A, B, C AND D ARE 10, 22, 50 AND 100 CM/S2, RESPECTIVELY, FOR RETURN PERIODS OF 475 YEARS.

From 1986 to July 2009 625 induced events are recorded with magnitudes ranging from ML = 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.

In general, small earthquakes (ML≤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 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. 4).

The response spectrum of induced events are thus very different from the usual ones applied for tectonic events. The observed accelerations may potentially be damaging to special industrial structures.

### Seismic risk

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. 5.

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).

## 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 direct 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

Induced seismicity generally occurs in and around gas reservoirs, usually

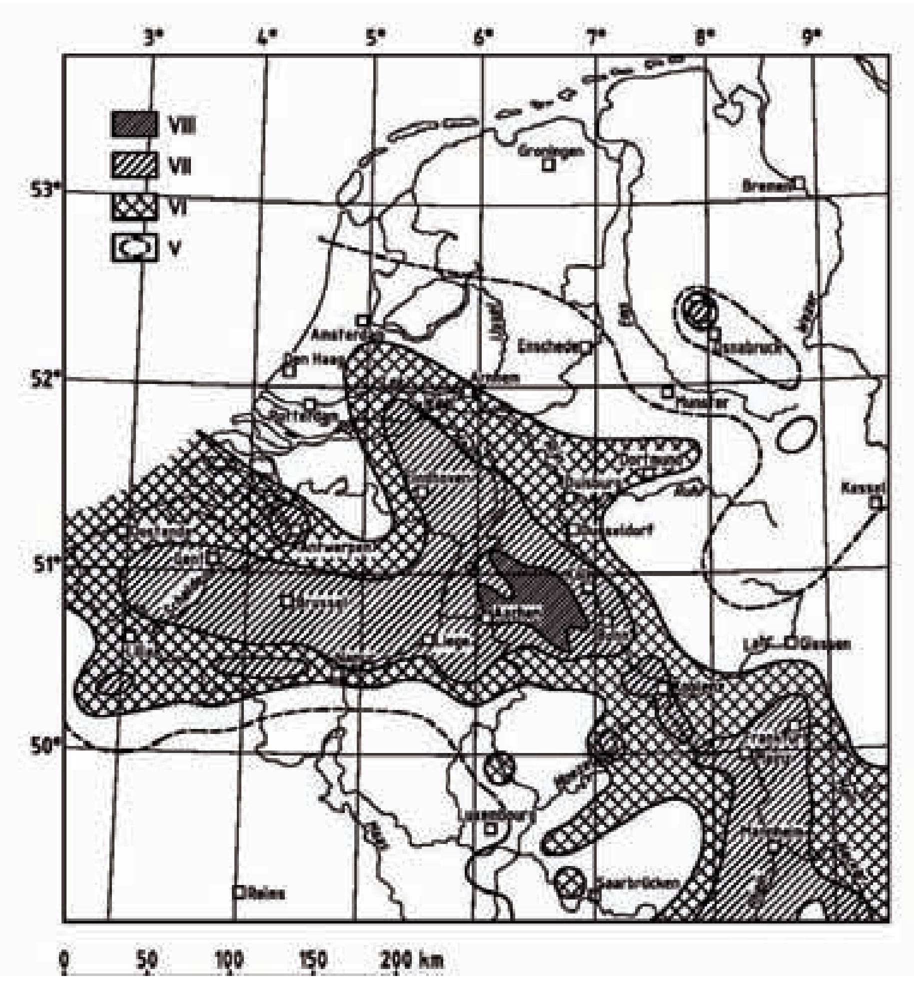


FIG. 3: CURRENT AVAILABLE SEISMIC HAZARD ZONATION FOR RETURN PERIODS OF 5000 YEARS SPECIFIED IN INTENSITIES (NNI, 2007).

around 2-3 km depth, whereas the tectonic seismicity mostly occurs at depths around 15-20 km. While there is a 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. In the period 1994-2004 only four events in the Bergermeer field near Alkmaar, North-Holland, all with ML > 2.9 were observed. As we currently lack a specific model explaining such behaviour 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.

**Results and discussion**

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 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. A clear division between these two types of seismicity in the application of EC8 is required.

## APPLICATION OF EC8 IN THE NETHERLANDS

**Dutch approach and needs**

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 quay walls and dams officially fall outside the scope of EC8, although many parts may be useful.

In geotechnical engineering the relation between earthquakes and the possibility of liquefaction is a major topic. Dutch design codes or rules are not suitable for these problems and very often international standards are applied.
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

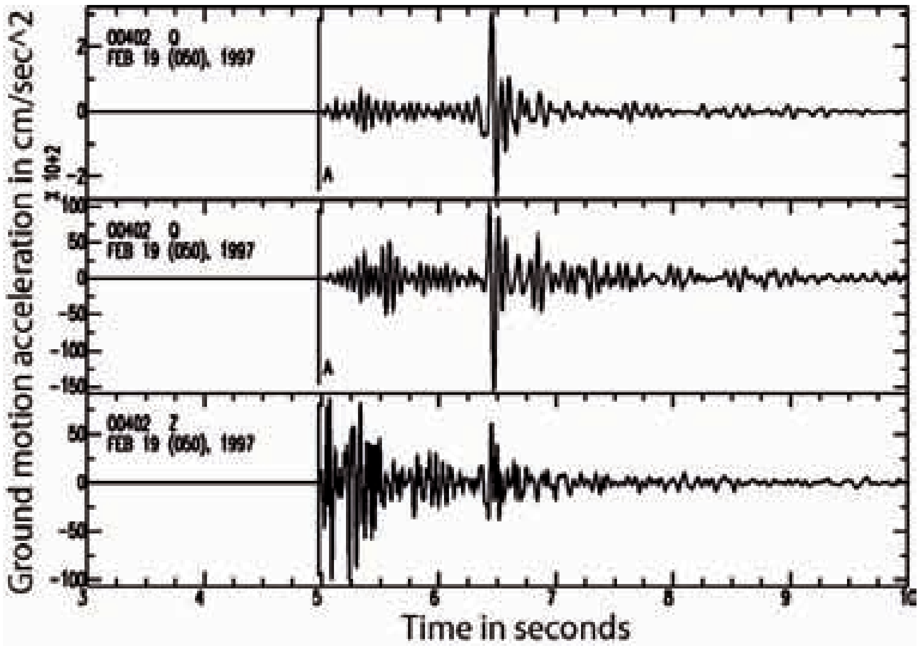


FIG. 4: THE GROUND ACCELERATION AS OBSERVED BY THE KNMI AT ABOUT 2 KM EPICENTRAL DISTANCE OF AN ML = 3.4 ONDUCED EARTHQUAKE IN 1997. THE FIGURE DEPICTS THE RADIAL, TRANSVERSE AND VERTICAL COMPONENT REPECTIVELY.

earthquakes will most likely lead to very conservative designs.

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

- determination of peak ground accelerations for tectonic earthquakes at all locations;
- guidelines for the application of EC8 for induced seismicity;
- translation of induced seismicity measurements from the northern part of The Netherlands to the other relevant parts of the country;
- information about 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.

**Opposition against EC8**

As previously stated, wind loading is considered governing over earthquake loading for normal structures. 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 misunderstanding as was proved in the past with simple 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 (where wind loading is obviously not a topic) in the province of Limburg where tectonic seismicity is a well known phenomenon.
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?

Conditions for introduction in the Netherlands

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. Up to now, NEN standards are agreements between parties: 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

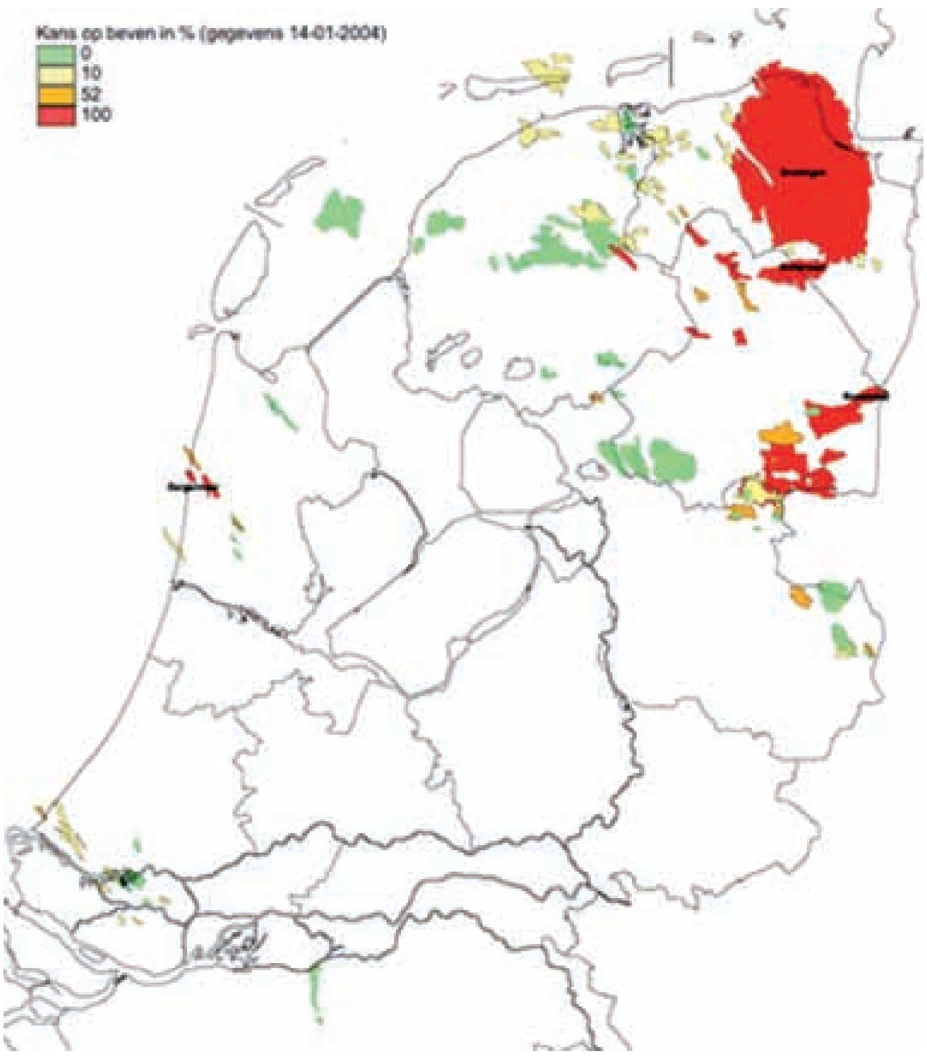


FIG. 5: PROBABILITY OF OCCURRENCE OF INDUCED EARTHQUAKES IN GAS FIELDS IN THE NETHERLANDS

(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.

**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.

The risks involved with Liquid Natural Gas (LNG) installations are also considered extremely high. The European guidelines NEN-EN 1473 (CEN, 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.

In the Rotterdam port area also a number of gas and/or oil exploration sites are present 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 South-western part of the Netherlands due to the gas extraction but this cannot be excluded completely.

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. Currently, seismic loads from induced earthquakes are generally not incorporated in design.

## ACTIONS TO BE TAKEN

The following actions must be taken to enable smooth introduction of EC8 in the Netherlands:
- official translation and publication of EC8, to establish easier access and familiarity about this code;
- preparation of a national annex to EC8. This annex should consist of zonation maps for tectonic and induced seismicity;
- 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. 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;
- preparation of a communication plan for the use of EC8 and its national annex in the Netherlands to ensure the knowledge to all engineers.

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 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 incorporated.

## CONCLUSIONS

Induced seismicity is a phenomenon which is typical for the Northern part of The Netherlands but may also occur on other locations in the future. This phenomenon requires further study;

The introduction of EC8 and the preparation of a national annex 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; and has to coincide with national annexes from neighbouring countries.

References:

- 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.
- Dost, B., T. van Eck and H. Haak [2004], Scaling peak ground acceleration and peak ground velocity recorded in The Netherlands, Bolletino di Geofisica, 45, 153-168.
- 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 between hydrocarbon reservoir properties and induced seismicity in the Netherlands, Engineering Geology, 84, pp. 99-111