Report on the Autumn Symposium of the Ingeokring 2016: Geotechnical Earthquake Engineering.

Culture Centre Delft University of Technology, 18 November 2016

The symposium was very well attended. More people than the attendance limit, which was set at 100, were present. Apart from a considerable number of members of the Ingeokring, a large part of the audience existed of scientists and engineers that came especially for the subject matter. The symposium covered three groups of topics: Natural Earthquakes (Wenchuan 2008 disaster; Roermond 1992), Induced Earthquakes (focussed on the Groningen gas extraction induced seismic events) and Engineering Studies (modelling for engineering design and subsoil-structure interaction studies). It proved to be a very interesting afternoon, with a concentrated audience attentively following the presentations, and actively participating in the panel discussions.

At the start of the event, the Symposium Chairman, Dr. Carolina Sigaran-Loria, gave a short resume of the three papers that were not presented orally at the symposium:

Van Herpen & Karreman (Van Oord): *Field trial benchmark of shell correction factor for Dubai calcareous sand.* The minimum required relative density of calcareous sand fill for a marine breakwater was determined based on site-specific seismic analysis. Advanced numerical models were made to determine the minimum required density. The models were verified using the results of field tests conducted on a 6 m high sand bund.

De Jong et al. (Crux): *Understanding liquefaction risks in the Netherlands*. The Crux team performed cyclic triaxial tests to quantify the effects of fines content on liquefaction hazard potential from Groningen soils. They examine the effect of the initial isotropic consolidation of the Triaxial tests specimens in order to obtain the required density in the cells. They compare the assumption of isotropy with the anisotropic stress state found in-situ, and notice that this leads to an unrealistic quick onset of liquefaction in the tests. Further cyclic tests taking anisotropy into account are planned.

Tsinaris et al. (Aristotle Univ. Thessaloniki, Greece): *Experimental investigation of the dynamic properties of lightweight mixtures under cyclic loading.* Torsional resonant column and undrained cyclic triaxial tests have been executed on saturated mixes of coarse volcanic soil (pumice) with granulated rubber from recycled tires. The aim is to assess the dynamic response, deformations and resistance against liquefaction of varied percentages of rubber.

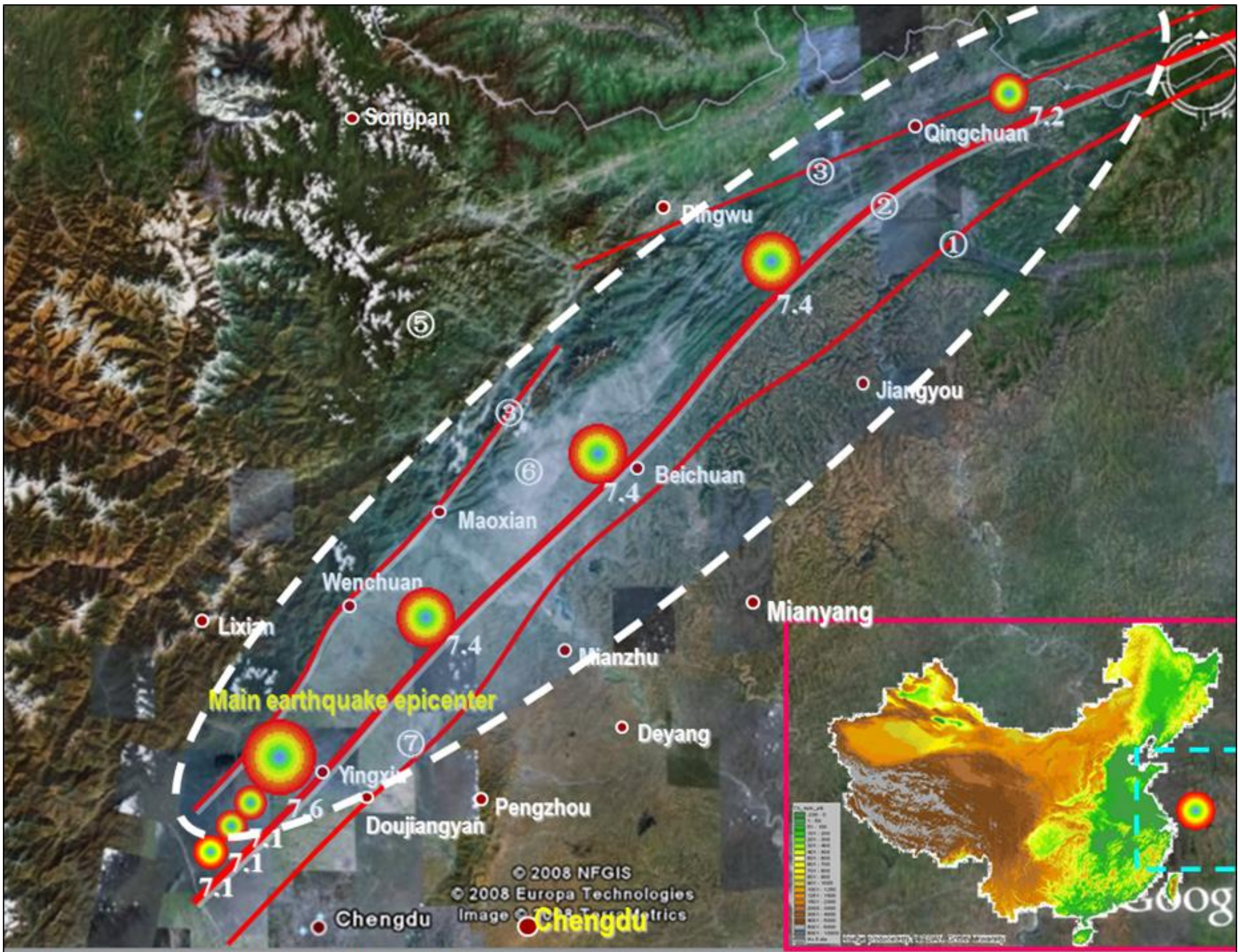
These papers will appear in the Ingeokring Newsletter of 2016, together with the papers presented at the Symposium. This Newsletter will be prepared and published early 2017, together with the delayed Newsletter of 2014-2015.

First Session

Keynote lecture: *Lessons learned for geotechnical earthquake engineering from the 2008 Wenchuan Earthquake (Ms 8.0).*

Niek Rengers (Chengu University, China; former Assoc. Professor at ITC, UTwente and TUDelft).

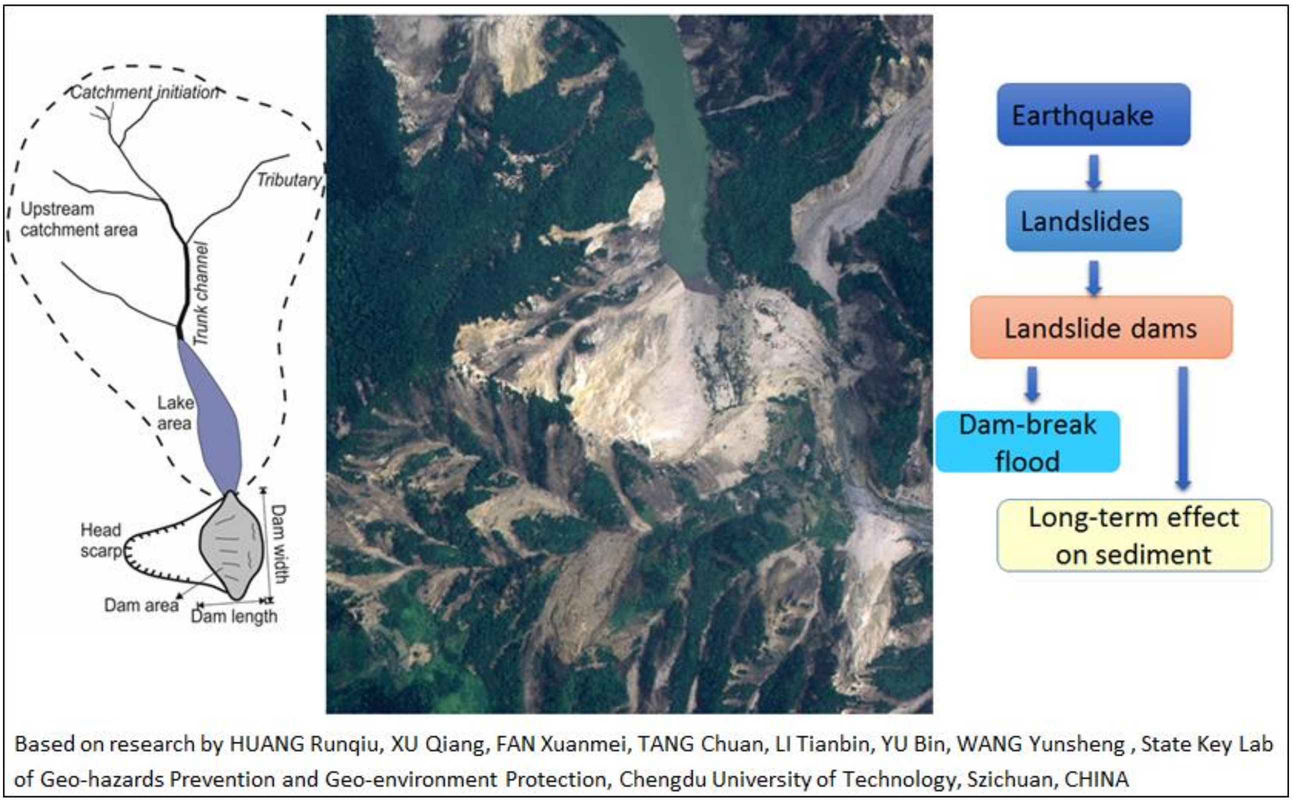
Niek Rengers, now retired, past President of the International Association of Engineering Geology (IAEG), former vice-rector of ITC, and for a long time an outstanding lecturer in Engineering Geology in Delft is since 2006 a visiting professor at Chengdu University in China. He gave an impressive lecture on the extensive research that is carried out at the State Laboratory of Geo-hazard Prevention at Chengdu to study the effects of the 2008 Earthquake near Wenchuan. This earthquake occurred along the Wenchuan-Maoxian thrust fault system where the Himalayan Indian subcontinent is thrusted over the Sichuan Basin. The depth of the quake was 12 km, the magnitude M 8.0. A series of heavy tremors occurred along a 300 km long section of the fault system, along the thrust fault with up to 3.5 m vertical displacements and, more to the north, with lower magnitude tremors, along a strike slip fault. The main shock lasted 1.5 minutes and reached peak ground accelerations of 1 to 2 g. The intensity of the earthquakes varied from VI to XI on the scale of Mercalli. Most damage occurred within a band of 5 km width parallel to the fault system. Approximately 90.000 people were killed, 30% of the casualties were due to co-seismic landslides and rock falls.



Based on research by HUANG Runqiu, XU Qiang, FAN Xuanmei, TANG Chuan, LI Tianbin, YU Bin, WANG Yunsheng , State Key Lab of Geo-hazards Prevention and Geo-environment Protection, Chengdu University of Technology, Szichuan, CHINA

Location of the major earthquakes and aftershocks of the Wenchuan earthquake (map by HUANG Runqiu).

Due to the setting in high mountainous terrain in the upper hanging wall section of the affected region the earthquakes caused a series of disastrous effects. Rock falls, landslides and debris flows were triggered and at more than 800 locations landslides caused damming of rivers. These landslide dams let to accumulating lakes behind them. The landslide material is easily eroded, resulting in debris flows, carrying sometimes enormous rock blocks, and covering buildings, villages and cities located downstream. The valleys are relatively narrow gorges that are incised into an old glacial landscape. The slides originated high up in the slopes of the old relief valley and the debris flowed into the narrow gorges. Niek showed slides of the devastation in the city of Beichuan, which was completely destroyed by debris flows.



Example of a landslide dam (map by HUANG Runqiu).

The effects of the earthquake were less intense in the Sichuan Basin, forming the lower, foot wall, block of the thrust fault system.

The study of the State Laboratory of Geohazard Prevention at Chengdu also examined damage to structures such as tunnels and dams. Tunnel portals were damaged by rock falls and landslides, but also inside tunnels the support had locally failed, when the tunnel was located near the epicentre of the earthquake. Many dams in the region are over 200m high concrete dams. The reinforced slopes at the side walls and the dams themselves had often withstood the earthquake. An example was shown of a rockfill dam that stayed intact, but its crest had settled for one meter due to the tremors. Different types of slope reinforcement had withstood the dynamic loading very well. A popular Chinese practice for slope stability is by driving piles along the unstable slope toe, and protecting the slope with a beam frame lattice of reinforced concrete. Methods such as this lattice with anchors and bolts performed well, while wire netting with bolts performed less well.

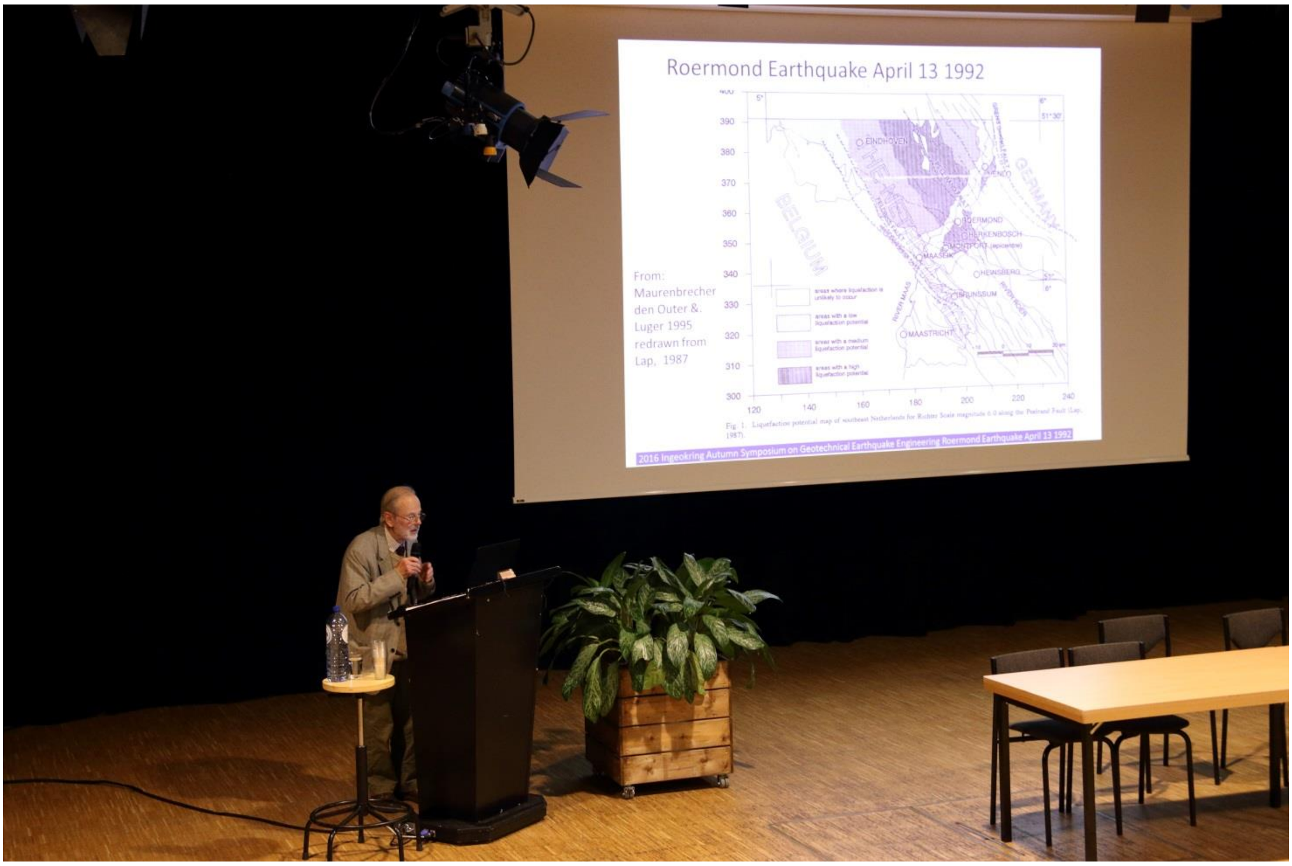
This lecture provided a good insight in the post-seismic hazards that remain after the earthquake. The first major sign of this were the debris flows that occurred several months after the earthquake in September 2008 after a period of heavy rainfall, when debris flows again covered the town of Beichuan. Debris flows are a normal feature in the region, but the fresh debris material from the earthquake needs less prolonged rainfall to become saturated and a lower peak rain intensity than was known from the area before the earthquake. This means, according the study, that for the coming 20 to 30 years, the hazard of sudden debris flows in the valleys will remain. Niek discussed the hazard and risk assessment study for relocation and planning, and the remedial and repair methods used. He finally ended an impressive lecture with a summary of the long list of lessons learned.

First session papers

Slob et al. (TEC): *New International Airport Mexico City*. A Dutch-Mexican consortium (TASANA) lead by NACO (RHDHV) is executing since February 2015 the design for all airside infrastructure (runways, taxiways, aprons, tunnels, drainage systems) for the new international airport of Mexico City. The airport will be built in an old marsh area on a subsurface of very soft sediments. Mexico City is known for its surface subsidence due to deep groundwater extraction, up to 20 cm/yr. Siefko Slob explained that the design has to accommodate the subsidence. The seismic hazard is one of the major challenges for the design. The main source of the hazard is the subduction zone at the Pacific coast. In 1985 the earthquake of M 8.1 caused lots of damage in Mexico City, with 40.000 casualties. A pragmatic approach to the seismic design was taken. A 3D subsurface model based on borehole and CPT data was the basis for the seismic response analysis. TEC carried out the determination of seismic design parameters, analysed the site-specific ground response using the model and analysed the impact of long-period surface waves on long structures using a novel approach.

Anita Laera et al.(PLAXIS): *Comparison between the simplified procedure and finite element analysis for liquefaction.* Anita Laera compared the semi-empirical simplified procedure (Idriss & Boulanger, 2014) with a FEM analysis implemented in 2D PLAXIS. Both methods were used to assess the liquefaction susceptibility of non-cohesive soil deposits (level ground geometry). The former is a simple and widely used analytical calculation method, while the second simulates the subsoil as a soil column (1D) made of finite elements through which a seismic wave propagates from bottom to top. The input in both cases was an earthquake signal and in-situ SPT $(N_1)_{60}$ values. Parameter calibration and calculation/modelling differed significantly in the two methods. The output was a factor of safety (FS), which converged in both approaches. Consequently, the FEM analysis was validated by the semi-empirical method.

Pieter Michiel Maurenbrecher (formerly TU Delft): *Retrospect on TU Delft Engineering Geology research related to the 1992 Roermond Earthquake.* On April 13th 1992 a 5.8 M earthquake occurred with the epicentre at 18 km depth beneath the village of Montfort, 15 km South of Roermond. The earthquake occurred on the Peelrand Fault. This fault is visible on the surface near Uden as a step in the landscape. This geomorphological feature is a remnant of the high magnitude earthquake occurring at Uden in 1932 (intensity VII on the MSK scale). This observation was a reason to set up an MSc study that should investigate all CPT data of the Geological Survey in a wide corridor along the Peelrand fault to make a liquefaction susceptibility map. This map was produced by Joris Lap in 1988. It appeared that the map predicted correctly where liquefaction has occurred around the hypocentre at Montfort. Liquefaction and slope movements were observed as far as 30 km away at Brunssummerheide very near to where the Heerlerheide Fault comes to the surface. Directly after the earthquakes and in the following years teams of students were led by Michiel Maurenbrecher, Prof. Price and a specialist in the study of earthquake induced structures in soils, Dr. Colin Davinport from the University of East Anglia. Object of the research was to study the damage caused by the earthquake. An inventory of damage to buildings was done. A church tower had collapsed. In dykes along the river Maas fissures and cracks had developed. At the Heksenberg tilted trees and downslope steps outlined a slope failure. The fault structures were mapped and pointed to failure of the upper sand layers due to a liquefied zone below at 8m depth. Sand boils occurring at Herkenbosch south of the town perimeter and north of the river Roer were reported to have sprayed sand fountains 1 m high during the quake. These structures were excavated to study the pathways of the liquefied sand.



Michiel Maurenbrecher during his presentation explaining the liquefaction susceptibility map made by Joris Lap.

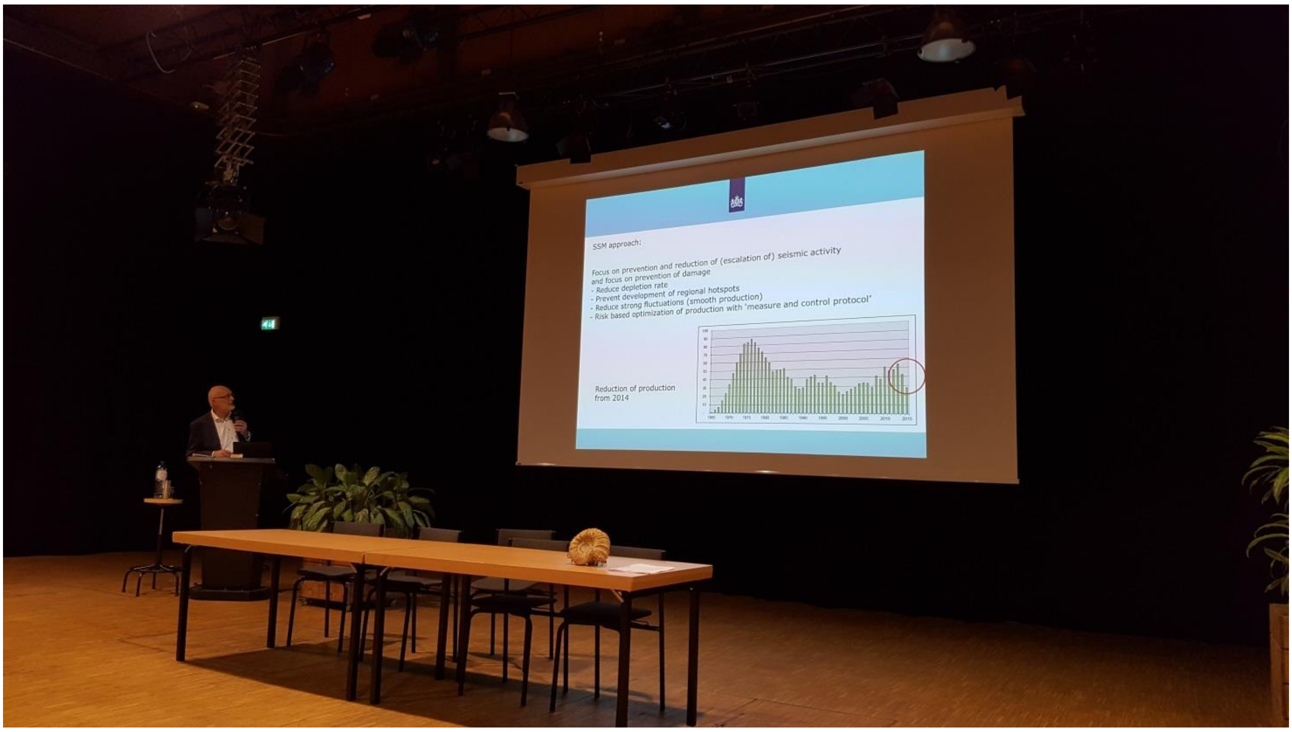
A video presentation by Dr. Jose Abell Mena (University of California Davis, USA and Universidad de los Andes, Chile): *Physics-based Earthquake-Soil-Structure Interaction for Near-field induced Seismic Events* was introduced by his co-author, Prof. Federico Pisano. Ground motions due to induced seismicity can be modeled using finite-fault models with low stress-drops. Produced seismic wave-field features a broad range of frequencies that are, however, skewed towards lower frequencies when compared with tectonic events. The response of structures to ground motions due to this type of excitation are amenable to modelling using a comprehensive near-field approach, which considers the source event explicitly. Considering source, path and the soil structure system explicitly is possible, even with modest computational resources. This provides the advantage that the effects of complex three-dimensional crustal structures (deep rock), local geology (shallow rock) and local site (soil) can be modeled simultaneously. The physics-based modelling method emphasizes the development of a sound earthquake-soil-structure model based on the most advanced method: the DRM domain reduction method developed by Bielak et al. (2003). The method is specifically designed for nuclear power plants. 3D modelling of the motions is possible. Especially in the high frequency domains an important difference of the results with 2D models is noted. Case by case you have to decide what type of modelling is best. According to Dr. Abell Mena the Groningen case is amenable for 3D modelling. It is particularly relevant for the assessment of flexible structures. “It is the most rational and comprehensive approach you can have, the state of the art at the moment.”

First panel discussion. From left to right Michiel Maurenbrecher, Niek Rengers, Anita Laera, Siefko Slob and Frederico Pisano.

Second Session

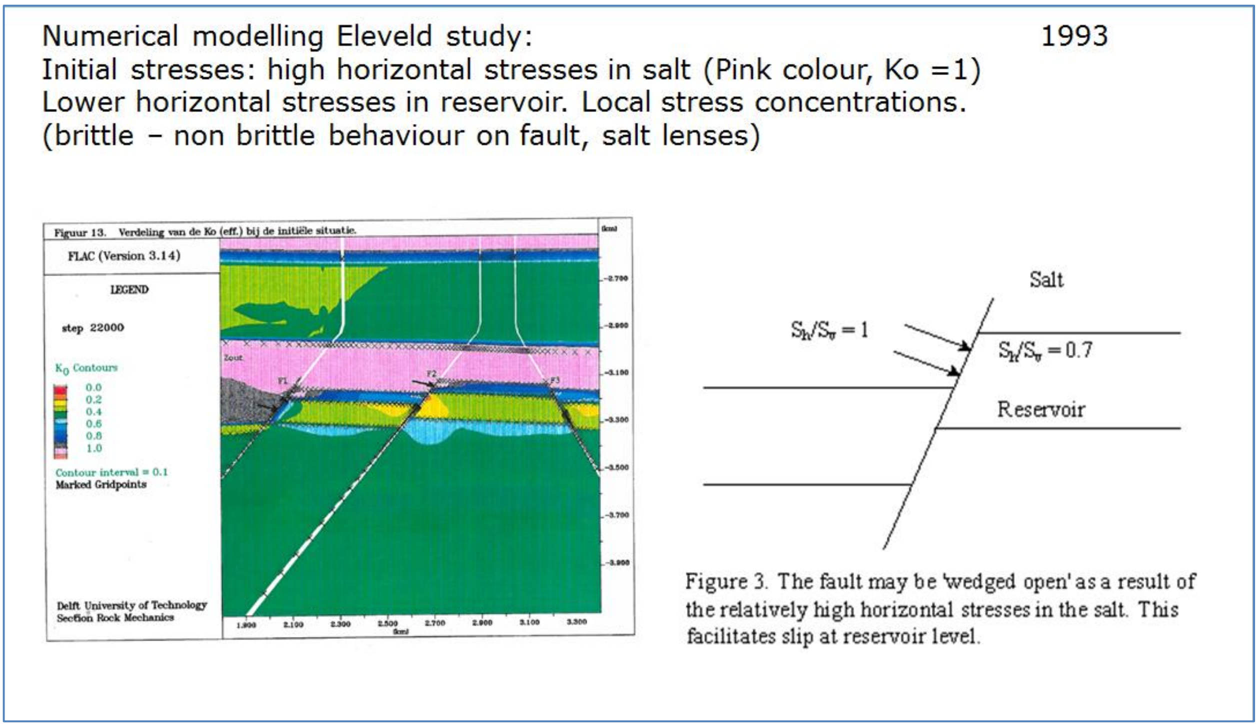
Keynote lecture: *Personal view on 30 years induced seismicity in The Netherlands 1986-2016*

Hans Roest (State Supervision of Mines, formerly TU Delft, Applied Earth Sciences)



Hans Roest is a former research scientist and lecturer of rock mechanics of the Mining Engineering Department of the TU Delft. He worked on the improvement of a huge true triaxial rock testing frame that was capable of testing rock blocks of considerable size (cubes of the order of 20 to 30 cm length). He developed a system using acoustic sensors to monitor the (microseismic) crack development in these rock blocks. In the early 1980’s the aim of the research was to control the fracture process in rock in underground mining and tunnelling to avoid explosive rock failure. A second objective was to study post-failure behaviour. Acoustic monitoring of microseismic events was amongst others done in South Limburg, in the room and pillar mines there, together with Roland Bekendam then PhD student and ir. Pöttgens of the State Supervision of Mines.

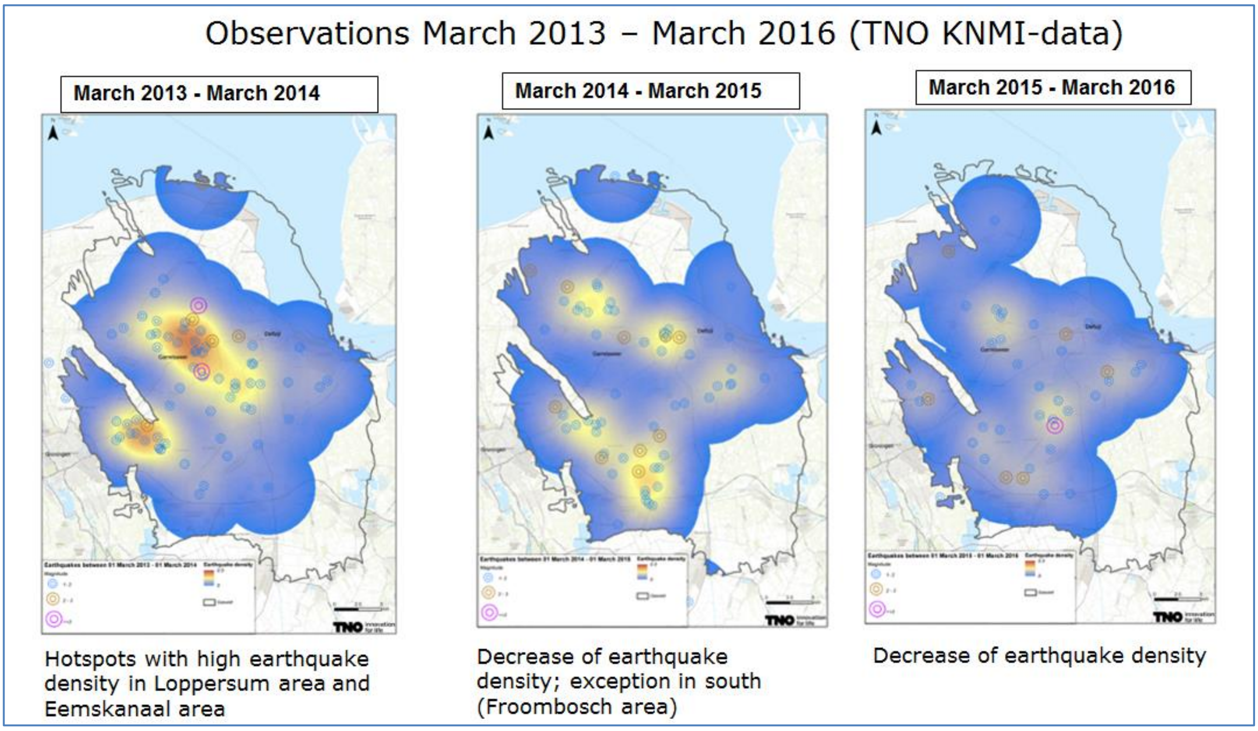
In 1986-1989 the first seismic events in Groningen occurred. Dr. Meent van der Sluis was one of the first people that made the connection of the subsurface structure in Groningen, characterized by saltdomes and faults, with the gas extraction by the NAM. His ‘’Bomijs” theory was ridiculed by the NAM, which refuted any connection of the earthquakes with the gas extraction. Prof. van Veen of the Petroleum Engineering Department at the TU Delft wrote a report stating that there was no relationship of the earthquakes with the gas extraction. In this period Hans started to use FLAC (Fast Lagrangian Analysis of Continua) to make models to see whether pressure depletion due to gas extraction will lead to slip along faults bounding the reservoir layer. In November 1990 on the ‘’Bodemdaling in Nederland’’ Symposium of the Ingeokring Hans presented the first results that showed that earthquakes of the Magnitudes that were measured indeed could be generated that way. Together with Wim Kuilman a great number of geometries were modelled with FLAC. The geometry generating the highest stresses was a depleting reservoir at the footwall of a normal fault. When a salt layer occurs above the reservoir layer, the models indicated intrusion of salt along the fault boundary. This was found in 1992-1993. Recently Professor Janos Urai, a well-known specialist in salt rock mechanics, confirmed the possibility of salt intrusions under these circumstances. In 1993 the Begeleidingscommissie Onderzoek Aardbevingen (BOA) published a report into which the connection of the earthquakes with the gas extraction was confirmed. Hans Roest and Wim Kuilman published the results of their FLAC study in the 1994 large ISRM Congress (International Society of Rock Mechanics) that was organised in Delft. In 1994 above the Bergermeer gasfield, near Alkmaar, 4 events with magnitudes up to M = 3.4 occurred. By that time the connection with the gas extraction was generally accepted. In 1995-1996 a report was published where the underground storage of gas in the reservoir layers was considered ‘’not advisable”.



Example of the outcome of a FLAC model (Study presented at the 1994 IRSM Congress in Delft).

In 2001 Hans Roest accepted a job at the State Supervision of Mines. From 2003 – 2008 increasing activity of the earthquakes in the Groningen area was experienced. In 2013 the State Supervision of Mines published a report stating that higher magnitudes of the earthquakes were to be expected. Hotspots of earthquake activity were situated near Loppersum, the city of Groningen and in the Eemskanaal area. Microseismic observations made clear that these were situated along faults due to the compaction of the reservoir.

Since 2014 it the production of gas is lowered. In 2016 the State Supervision of Mines published report that advises how to manage the gas field in the future. It shows that the tremors have reduced since the measures taken in 2014. The results of the TNO studies are also presented in this report: file:///D:/Users/pnve/Downloads/advies-sodm-winningsplan-groningen-2016.pdf



Distribution of the density of earthquakes (M ≥ 1.0) per year in the Groningen area (TNO study, source SDOM report 2016).

Important measures that are advised are: Try to avoid fluctuations in the winning (high gas production in winter, low in summer were the custom). Reduce the production to 24 BCM/year until a risk controlled optimization system for the production is developed. Aim is to come to a satisfactory risk management system, minimizing damage and nuisance. The planning is for 5 year periods. In the meantime Hans sees the following task for the State Supervision: "Analyse the data and try to explain the results!"

Second session papers

Vasileios Drosos et al. (Fugro, Turkey): *Comparison of site-specific response analyses and NPR9998 guidelines for projects in Groningen.* The effects of soil stratigraphy up to a depth of 30 m below ground level on site response to dynamic loading were analysed for various types of structures in the Groningen area. Time-domain nonlinear site response analyses were performed for several soil profiles to estimate the alteration of the seismic ground motion as it propagates from a competent soil horizon (i.e. corresponding to Vs_{30} of 300 m/s) to the ground surface. The estimated surface acceleration response spectra are compared to the code-based response spectra for "normal" or "special" soil conditions. It is shown that in several cases the code-based design response spectrum tends to overestimate the seismic load for a range of structural periods while at the same time it may underestimate the spectral response at the fundamental period of the soil profile. Vasileios showed that site specific response analysis can be used to determine the Cyclic Stress Ratio (CSR), mainly due to the soft soil profiles. Results can be used for soil structure interaction analysis. Kinematic and inertial forces are determined for the design of foundation elements.

Ger de Lange (Deltares): *Microzonation of site effects for the Groningen gas field*. Ger de Lange presented the results of a joint study with members working at Deltares, TNO Geological Survey, Shell, NAM, Virginia Tech USA, and Imperial College London. A "walk through" was made through the new study performed to assess the induced earthquake hazard and risk of the Groningen gas field. The subsoil's variability along an average depth of 800m was taken into account in the generation of a groundmodel that depicts the 3D zonation of the subsoil. The geomechanical and dynamic parameters of the subsoil were acquired by a series of shallow shear wave velocity surveys, seismic CPTs, MASW, fully logged boreholes, and existing seismic reflection surveys (Rayleigh waves). Using the micro-zonation map and the subsoil parameters, a total number of 700,000 site response calculations were executed using a 1D equivalent linear approach on a database of 108 Groningen specific excitations. The microzonation map and the site response analysis results fed a probabilistic seismic hazard and risk analysis for the Groningen area.

Onno Walta (Sweco): *Analysis method for earthquake resistance of underground pipeline structures*.
In recent years, the frequency and the severity of induced earthquakes in the Northern Netherlands have increased as a result of natural gas extraction. Questions are asked by the government and industry whether existing and new underground pipes withstand future earthquakes. A probabilistic method was developed to determine the failure probability of pipelines subjected to an earthquake wave passing through the subsurface. The method is consistent with the current standards of NEN 3650 series and the Eurocode. Onno Walta went through the modelling process, starting with an analysis of the stress distributions and concentrations that can occur in pipelines, joints and cross sections due to dynamic loading. Quasy-static FEM calculations were done in PLAXIS-2D and a critical analysis of the factors influencing the outcome of the calculations was given.

John Adrichem (Royal HaskoningDHV): *Recent advances in the modelling of soil-structure interaction in DIANA, the road towards fully coupled non-linear earthquake foundation design.* In earthquake engineering, an integral approach between the different engineering disciplines involved is essential to properly account for the greater inherent uncertainties and complexity of geo-structural behaviour when compared to static design. A higher degree of interaction between geotechnical specialists and structural designers is therefore required in the earthquake design process, especially when a significant degree of soil-structure interaction (SSI) is to be taken into account. John stressed that simplifications imply that you have to formulate boundary conditions, which have to be met. Dynamic response analyses incorporate the foundation system into the general dynamic model of the structure. In these analyses, also referred to as the soil-structure interaction analysis, the foundation system is commonly represented by a system of non-linear springs. The most comprehensive approach involves using finite element software to model the foundation soils and the structure, including the superstructure, embedded elements of the foundation system, and the surrounding soils. Consequently, these analyses require an even higher degree of interaction between geotechnical specialists and structural designers than already required in the usual seismic design. At this moment, numerous coupled Non-Linear Time History (NLTH) analyses have already been performed successfully, but there are still significant improvements to be made in order to be able to fully capture SSI in one model.

Final Session

Keynote lecture: *Development in seismic hazard assessment in the Netherlands*

Bernard Dost (KNMI, Royal Netherlands Meteorological Institute)

Bernard Dost gave an overview of the continuing study into the earthquakes induced by the gas extraction. Bernard works at the R&D group Seismology and Acoustics of the KNMI. Research is done in cooperation with an international research group (see the presentation by Ger de Lange of Deltares).

The approach of the probabilistic seismic hazard analysis is presented as a hybrid modelling frame:

SOURCE model=> Ground Motion Prediction Equation (GMPE) => HAZARD maps => VULNERABILITY=> CONSEQUENCES

Results are presented in the form of Peak Ground Acceleration (PGA) maps. Natural earthquakes produce stationary maps. Induced earthquakes are different. Induced seismic events occurred near Alkmaar, in the North Sea, at Roswinkel and in Groningen. The KNMI monitors the magnitudes and frequencies of the earthquakes. In the period 2014-2016, after the changes in gas extraction policy, the density of earthquakes changes. Since the quakes are a non-stationary process, it is not useful to produce yearly compilation maps, event-density maps for a 5 year period are more useful.

The expected M_{max}, the maximum magnitude probable, is M = 6.5. But this is a highly unlikely scenario. For a finite fault of width of 1 km and length of 20 km, the M_{max} = 4.9. For the next 5 years an M_{max} =5 is possible.

Much attention has been paid in the research to the development of the site specific GMPE. It appeared that the resulting PGA maps of the KNMI and the NAM compare well (GMPE version 1). Newer versions of the GMPE have been developed and are still being improved (V3 & V4).

In January 2014 KNMI used a network of 18 real time accelerometers placed in 6 boreholes. The observation network in Groningen will increase to 69 deep boreholes, 69 surface accelerometers, 4 boreholes with broadband sensors and 2 deep downhole arrays. The triggering threshold will then be events of Magnitude 0.5. The deep boreholes will go to reservoir level. This will give an improved deep depth coverage and a better resolution, both vertically and horizontally, for the determination of the depth location of quakes. More information can be found in the KNMI report on the modelling:

http://www.knmi.nl/kennis-en-datacentrum/publicatie/probabilistic-seismic-hazard-analysis-for-induced-earthquakes-in-groningen-update-2015

Bernard Dost participating in the second panel discussion led by Prof. Frederico Pisano (TU Delft)

Price Prize and activities 2017

At the end of the meeting the Professor Price Prize of 2016 was awarded to Hans Roest by the Board of the Ingeokring. Milcar Vijlbrief handed the Ammonite fossil to a surprized recipient. Peter Verhoef gave a congratulations speech, memorizing the value of the work that Hans has done the past 40 years and its relevance for society.

The main activities of the Ingeokring in 2017 will be:

The CPD (continuous professional development) course "*Rock mass Classification*". In spring a weekend workshop consisting of a symposium on the applications of RMR for design and fieldwork will be held in the Eifel under the leadership of Dr. Robrecht Schmitz, chairman of the Ingeokring.

Next year's Autumn Symposium will deal with data management under the work title *"5D-IT and Engineering Geology".* More information can be found on www.ingeokring.nl

Reported by Dr. Peter Verhoef, Boskalis Westminster