KEM Innovation/Research Question (max. 4 pages + annex)

TITLE ***Evaluating, validating and improving the site-amplification component of the Groningen Seismic Risk Model***

Objective

Local site amplification in the Groningen areas is an important factor influencing the damage potential. Site amplification is observed to be spatially highly variable, due to the complex geological setting especially of the shallow subsurface (e.g., loosely packed sands, peat and "knipklei"). While the existing Groningen seismic risk model has implemented a detailed layer of local site amplification, in parts based on micro-zonation measurement, independently evaluating and validating this model, also against the most recent data observed with the densified seismic observation network, are important goals. The objectives of this project are thus:

1) To evaluate the site amplification model, its sensitivities and the quality and resolution of the data available to constrain it.
2) To validate how well the model performed again the most recent data, thus evaluating its forecasting skill.
3) To propose measurements and improvements to the model that would reduce the uncertainty in prediction local ground motions.

State of the art, background

Natural gas in the Netherlands is produced in many onshore and offshore gas fields. The Netherlands has one of the largest onshore as field of the world in Groningen. This gas field has produced for many decades. Associated to these gas extraction activities, induced earthquakes as well as subsidence are occurring. The earthquakes magnitude and frequency has been increasing up to 2015, and the largest events have caused damage to building. The observed damage patters as well as the observed ground motions are spatially strongly variable and in detail difficult to forecast, a fact difficult to explain to the public and raised during the MEA/NCG knowledge platform meetings (see annex II of the KEM Research Framework)

In the probabilistic seismic risk assessment that has been carried by NAM out for Groningen, site response was an important layer of the model, embedded in the Ground Motion Prediction Equation (GMPE) part of the model train (see references for details of the model). As part of the model building, there have been substantial efforts undertaken to understand and constrain the local site amplification, in parts based on measurements of shallow seismic velocities and then extrapolating based on geological knowledge. However, the most recent seismic recordings especially at new sites that have become available as part of the seismic network densification in Groningen, have not yet been used to validate and improve the site response module. There may also be alternative approaches available in the literature and applied in other places that may need to be considered. There are a number of places where ground motions do not well fit the predictive model, raising concerns about the general validity of the model. Finally, the relative importance of non-linear effects and upscaling to stronger ground motions needs to be explored.

Research Question

We expect the following research questions to be addressed:

Question 1: Evaluation of the existing site amplification model by NAM.

Based on literature review and comparison with other such models worldwide for natural or induced earthquakes, assess to what extend the existing model represent the state of the art and describe it strength and weaknesses. This evaluation should also specifically address the following concerns raised in the past:

- *The response of the Froombosch earthquake deviates from other earthquake signatures by its relative high PGA. Does site response offer an explanation?*
- *In Groningen are we encounter heavy sea clay ("Knipklei"), which can contain over pressured groundwater. Is this adequately represented in the existing model? Is there a specific relationship known or under development between earthquake – knipklei/ site response – damage?*
- *Are research results available which indicate that the effect of surface water bodies (ditches, canals) close to buildings can cause extra damage, caused by the fact they have different PGA's?*
- *Optionally, Is it possible that for slightly larger events "lateral spreading" (in combination with liquefaction) occurs? This has been observed in the Meuse levees as a result of the Roermond earthquake. If so, what effect can be expected for infrastructures and buildings in Groningen?*

Question 2: Model validation against independent data

Using the data collected after the site amplification model was calibrated, test in a quantitative sense how well the different ground motion parameters (PGA, PGV, spectral, ...) are forecasted by the model. A residual analysis should analyse the spatial patterns and thus identify, if possible, geological/geotechnical conditions where the model performs well or poorly. This should then lead also to a recommendation if and how future validation of the data against the model (or models) may lead to improved uncertainty quantification and ultimately scientific and societal acceptance. It is also possible to collect selectively additional data in order to validate the model.

Question 3: Recommendation for future improvements

Based partially on the results of Questions 1 and 2, suggest recommendations for future model generation and data collection, including permanent instrumentation and field campaigns. These recommendations could ideally be backed up by scenario modelling, and sensitivity analysis using existing 1D linear (GMPE), nonlinear site responses or full wave nonlinear codes on representative 3D varying Groningen geological (peat, loosely packed sand, "knipklei"/sea clay) and topographical conditions (ditches, canals and levees, "terpen"). Relevant questions include:

- *How sensitive is the local seismic network in Groningen to detect the locally varying shallow geological or topographical factors? Is the current observation network e.g. of accelerometers fit for purpose, i.e. is it designed and sufficiently localised keeping in mind the complex and heterogeneous subsurface?*
- *The shallow subsurface geology is complex and heterogeneous. How useful would a grid with a higher density of CPT/Borehole observation be to decrease uncertainties?*

Deliverables expected and expected use

- Report on question 1 (month 3)
- Report on question 2 (month 6)
- Report on question 3 (month 9)

The reports will open-access, note that peer reviewed publication of the results is encouraged.

Timeline

Duration 9 months.

Expected use

The deliverables will be used as:

(i) better ability to answer questions raised by scientists and the general public
(ii) input for improving Groningen seismic risk assessment model
(iii) input for potentially improving the current ranking system to determine the required level of strengthening to be applied to buildings and infrastructure at different locations