Evaluating Ground Motion Prediction Equations Currently Used for the North Sea with Consideration of Induced Seismicity

Christopher Brooks[1] *, John Douglas[1]

[1] University of Strathclyde, Glasgow, UK
* christopher.brooks@strath.ac.uk

Introduction

Whilst natural seismicity is regarded as moderate within the North Sea and thus often of minimal consideration with regards to seismic hazard, induced seismicity in this area has recently become of interest to the scientific and engineering communities as well as oil and gas companies operating within the area (e.g. Ottemöller et al., 2005). This was following the occurrence of the M_L 4.2, shallow earthquake in the Ekofisk field in 2001 and smaller events in the Valhall and other fields.

There have been several probabilistic seismic hazard assessments (PSHAs) undertaken for the North Sea region. The output of these analyses conventionally takes the form of contour maps of horizontal peak ground acceleration for a specified annual probability of exceedance. The most recent appraisal of PSHA for the North Sea (see EQE International Ltd., 2002) computed a composite map of these various seismic hazard assessments in the North Sea. This composite map was deemed suitable until more extensive analysis had been undertaken. This appraisal does mention that the 2001 Ekofisk event was a significant development since the publication of previous PSHAs, and how this M_L 4.2 earthquake occurred in the central North Sea, a region previously considered one of low seismicity. Consequently, past PSHAs of the North Sea could be less adequate than suggested by this appraisal, especially when one considers the compelling evidence for further induced earthquakes of a similar or greater size as the 2001 Ekofisk event in other parts of Europe. A key piece of such evidence is the link between increased hydrocarbon production or fluid injection and an associated uptake in seismicity in the North Sea (Grasso, 1992). Therefore, an updated PSHA considering induced seismicity in the North Sea is necessary.

A key input which differs amongst the various PSHAs for the North Sea is the ground motion prediction equations (GMPEs) chosen. Such models predict ground motion intensity measures (IMs) such as PGA, peak ground velocity (PGV) and response spectral acceleration (SA) as a function of magnitude and distance (and often other parameters). The GMPEs chosen have a strong influence on the hazard maps. Within the most recent PSHA for the North Sea (Bungum et al., 2002; EQE International, 2002), a combination of the stochastic-model GMPE of Toro et al. (1997) and the empirical GMPE of Ambraseys et al. (1996)'s are used in a logic tree formulation. Bungum et al. (2002) note of how their selection of these GMPEs was hampered by a lack of readily available ground-motion records against which to check their applicability. Consequently, the approach taken was to select a GMPE derived for eastern North America due to its assumed tectonic relevance for north-western Europe (Toro et al., 1997) and combine it with the Europe-derived Ambraseys et al. (1996) GMPE.

Since this 2002 study there are considerably more ground motion records available for the North Sea. A portion of which could represent induced earthquakes. Consequently, an opportunity has presented itself to evaluate whether predictions from existing GMPEs match the observed ground motions. Our study will help improve PSHA in the North Sea. GMPEs which best fit the observations are considered for further adjustment to better predict the seismic hazard within the North Sea.

Method and Results of GMPE Evaluation

The preliminary database used within this investigation was provided by Dr Dino Bindi (GFZ Potsdam), and was extracted from the European Integrated Data Archive (EIDA) containing broadband and strong-motion data. This dataset covered the entirety of north-western Europe, and thus contained many records of events not of interest to this investigation, which were consequently removed. To remove potentially erroneous ground-motion records from the dataset we carried out an initial residual analysis.

Following this initial filtering of the dataset, more detailed residual analysis was undertaken using the Python/OpenQuake-based *gmpe-smtk* toolkit developed by Dr Graeme Weatherill (GFZ Potsdam). The toolkit en-

abled quick and effective comparison of the ground motion records from the EIDA database with numerous GMPEs, thus providing an efficient method of selecting the most appropriate GMPEs for the North Sea region. The fit of each GMPE was determined for several ground motion IMs including PGA, PGV and SA (e.g. fig. 1.0).

A significant result that should also be noted is that comparison of the PGA hazard contour maps computed from Bungum et al. (2002)'s study and those we obtain using GMPEs that better fit the available data suggest that the hazard maps of Bungum et al. (2002) are over-predicting the hazard. However, it should be noted that this is only an early result based on a database dominated by records from considerable distances (>100km) and small magnitudes (M<4) and hence further analysis is required.

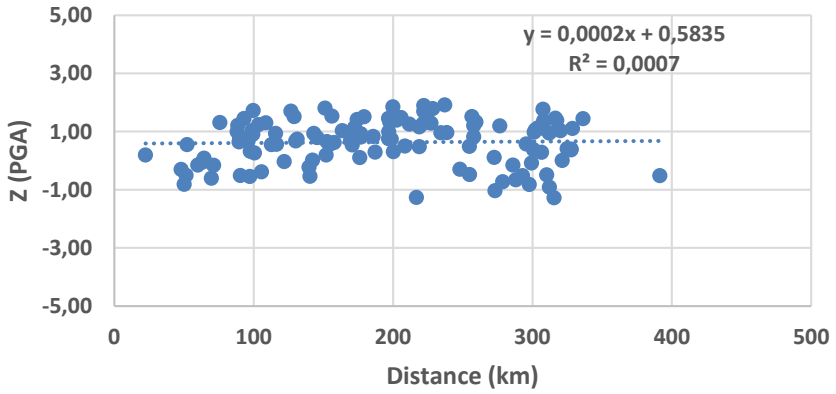

Fig. 1: PGA Residual analysis of the North Sea Data Subset with respect to distance using the GMPE of Akkar et al. 2014 (R_{hyp}-variant)

Conclusions

Following extensive residual analysis for each ground motion IM considered, each GMPE was assigned a score so as to rank them based on their overall fit to the North Sea dataset. No single GMPE was found to provide an overall good fit to the North Sea ground motion records. Therefore, it was concluded that the development of GMPE specifically for the North Sea region using the stochastic method is the best option for improving PSHA within the North Sea with respect to induced seismicity. This method will use the North Sea data subset to derive parameters for a stochastic North Sea point-source model. Computational simulations will then be undertaken using this point-source model, resulting in the development of a stochastic-method GMPE for the North Sea.

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