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NORTH SEA : IMPROVEMENTS IN PREDICTION OF STRONG GROUND MOTION

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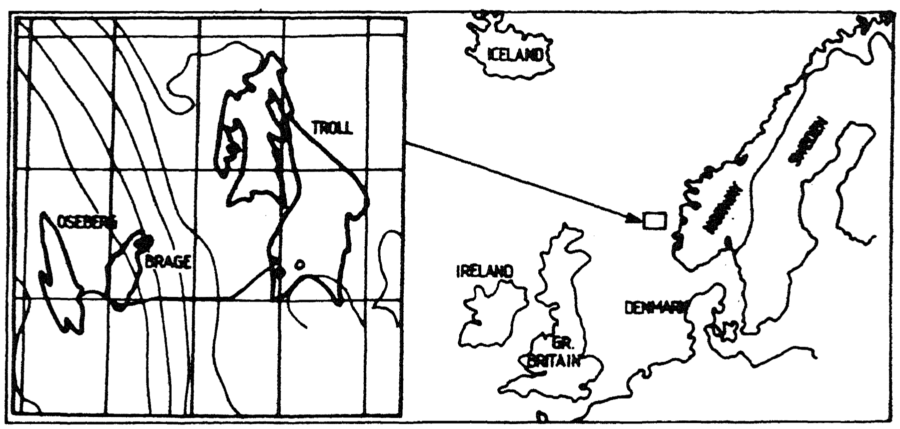
SUMMARY

Improvements in prediction of strong ground motion is demonstrated through reference to earthquake hazard and exposure analyses carried out for three adjacent oil and gas fields in the Norwegian sector of the North Sea in 1983 to 1987. The following areas are discussed: general methodology, historic and instrumental databases, seismotectonic modelling, attenuation relationships, hazard analyses, effects of local soil conditions. General tendency towards lower critical strong ground motion. Further, the effects of local soil conditions require more attention. Areas that need particular improvements are briefly outlined.



INTRODUCTION

Earthquake loads were not regarded as a major consern during the design and building of the early platforms in the North Sea. As exploration moved into deeper waters the platforms grew bigger, topside loads increased and the structures becoming more sensitive to low frequency environmental loads. Combined with advances in design tools it became aparent that earthquake loads, despite relative low recurrance could have significant effects on local parts of the structure.

This increased interest in earthquake loading also led to industry sponsored establishment of new seismic arrays and a seabottom seismograph in the norwegian sector of the North Sea, resulting in improved seismological data.

In order to improve the fidelity of the predicted earthquake loads for a given platform more extensive hazard and exposure analyses were initiated. Three oil and gas fields west of Norway have been under development by Norsk Hydro in this periode. In 1983 the Oseberg Project contracted Woodward-Clyde Consultants, San Fransisco together with Det norske Veritas to establish appropriate earthquake design loads.

Two years later, in 1985 the deepwater Troll field was at a feasability develpoment stage and NORSAR (Norwegian Seismic Array) was contracted to develop the design criteria for earthquake loads. In 1987 the Brage project ordered similar services from Dames & Moore, San Fransisco. At the same time the northern part of the Oseberg Field was ready for development and Geomatrix Consultants of California were requested to review the 1983 study and present updated load criteria. By comparing the four studies and their results it has been possible to evaluate development trends over the periode 1983 - 1987.

Each of the four studies are briefly presented, highlighting the basic approach and methodology, specific advances, results and problems. Finally the results are compared, trends are discussed and areas requiring further attention are mentioned.

OSEBERG FIELD STUDY 1983

The Oseberg Field study represented the first major effort in the norwegian sector of the North Sea to apply a consistent probabalistic approach together with a Bayseyan methodology (logic tree) to treat the uncertainties of all major input parameters.

The inherent uncertainties associated with natural phenomena such as earthquakes are associated with time and location of the occurrence of earthquakes and the level of severity of the resulting ground motions. Additional uncertainties relate mainly to seismic source characterization parameters that are specific to the region due to scarcity and incompleteness of the geological and seismological data. Only a limited amount and quality of deep seismic profiles were available at the time limiting the significance of geophysical input.

Although the Viking Graben had been subject to extensive petroleum related geological investigations during the past decade the local tectonic structures and processes were largely unknown.

The basic seismotectonic concept was that of reactivation of pre-existing faults. The seismotectonic modelling consisted of a zonation model and modelling of uniform faults as well as individual local faults.

Further, records of seismic activity in the area were scarce. The instrumental records were highly inaccurate and small, the historical records of litle help due to the 110 km distance from the norwegian west coast. The attenuation relationships used were modified western U.S. with little corrolation with local conditions other than a qualitative assessment. The effects of the local soil conditions were accounted for in the selection of attenuation relationships. The combination of these elements resulted in a rather conservative estimate of earthquake hazard. The consistent probabalistic approach combined with the logic tree methodology was, however a useful tool in identifying areas that needed an improved reliability and accuracy. These were:

*re-assesment of historical earthquake catalogue
*establishment of seismic array along the western coast and on the sea bottom
*improved modelling techniques to account for absence of major faults.

The results in terms of strong ground motion are:
*PGAmax=0.26g and 0.048g respectively for exceedance probabilities of 10^{-4} and 10^{-2}.
*PSV(horiz.)=0.45 and 0.06 m/s respectively for exceedance probabilities of 10^{-4} and 10^{-2}, both at 5% damping and a periode of 2 seconds.

TROLL FIELD STUDY 1985

This study was conducted as part for the work to qualify the prototype platforms for the 330 meter water depth, soft soil area at Troll. These platforms are sensitive to low periode environmental forces with theirt natural response periods in the range of 2 to 5 seconds.

With the experience from the Oseberg study in mind the study focused particularly on utilizing new microseismic data, increased understanding of the local geological history and a reassessment of the instrumental and historical earthquake catalogues.

The geological study attempted to find evidence of potentially active faults relevant to the earthquake hazard in the Troll area.

A regional overview was obtained through the study a dense net of seismic reflection survey lines. Local information was obtained through site surveys and high resolution sparker data. Onshore regions were studied for signs of neotectonics. Seven faults of tectonic significance were identified. Of these only the Øygarden Fault was of significance as demonstrated by the hazard analysis.

The seismological evaluation involved the parallel use of historical earthquake data and recent seismicity. Both were extended and improved. A catalogue of several hundred North Sea earthquakes (1980-1984) showed an activity that was consistent with historical seismicity. An activity rate of one Ms=5.6 every 100 years with the b-value of 1.2 was found. The highest activities were found along the coast and in the Viking Graben.

Computation of the earthquake hazard was carried out in a two-step process. First the hazard is computed up to the bedrock outcrop reference level underneath the platform location. Secondly the effects of the local soil is included.

The first part of the process consisted of three elements: modelling of the seismic sources, modelling of the wave attenuation and computation of the hazard at the location by computer programs. The source modelling was split in area sources (tectonic regions) and individual fault sources. The attenuation was estimated on the basis of real acceleration records from comparable regions in Europe and the United States due to lack of local records. The selected records were filtered and the attenuation relationships modified for differences in macroseismic intensity decay. Using the Bayesian approach (logic tree) uncertainties in the input parameters were included and confidence levels estimated for the final results.

The second part of the process accounting for the local soil conditions and sea water depth were studied by linear and non-linear one-dimentional wave propagation models. Thus local amplification influencing the characteristics of the earthquake motions were taken care of.

The following figures are taken from the recommended response spectra and motions:

*PGAmax=0.27 and 0.06 g for exceedance probabilities of 10^{-4} and 10^{-2}

*PSV(horiz.)=0.6 and 0.17 m/s for probabilities of exceedance of 10^{-4} and 10^{-2} respectively, both at 5% damping and periode 2 seconds.

The major problem areas of this study were associated with the following main topics:

- the southern European database refers to a rather different tectonic and geological environmnent. Is it possible to adjust for such major differences when applying data to the North Sea region? This relates particularly to attenuation relationships.

- the general approach of defining ground motions in terms of "rock" motion and adjusting for local soil conditions afterwards. This process has the advantage of having more high quality strong motion recordings than recordings on similar soft soil conditions. However, the modification process for the local soil conditions tend to misrepresent the long periode motions that are of such importance in this study.

BRAGE FIELD STUDY 1987

The basic approach applied in this study was similar to those used in the two preceeding studies. Seismologic and geologic information was used to develop a seismic zonation while seismicity information was used to develop statistical estimates of seismic activity rates. Attenuation was developed as a function of earthquake magnitude, distance and other factors. These three factors (zonation, activity and attenuation) were used as input parameters in determining the probabalistic contribution of each zone to the overall seismic hazard. The developed uniform hazard spectra were representative for a rock or firm soil, not taking into account the possible effects of the local soil conditions. Relevant time histories were then modified to match the target spectra. Effects of soil non-linearities and estimates of time histories within the soil column were studied with a finite element program and a finite difference program. Potential liquifaction was also studied.

Both geolgy and seismology indicated that the contribution to seismic activity in the Brage area would best be represented through seismic zonation rather than modelling of individual faults. This distinguishes the Brage study from the other studies referred in this article. The model was also extended to include the Oseberg Field as well as the Troll Field, thus allowing a direct comparison of the results.

The results indicate that the seismic hazard is somewhat lower than estimated for the neighbouring fields studied earlier. This is primarily due to two factors: recent microseismicity from the new Western Norwegian Network indicate such trends. New attenuation relationships were developed in a consistent manner particularly for this aera. The reports still concludes that the major uncertainty associated with this study is associated with attenuation and that the results must be regarded as average values. The report strongly recommends additional research on this topic.

The figures below are taken from the recommended load criteria:

*PGAmax=0.18 and 0.02 g for exceedance probabilities of 10^{-4} and 10^{-2}.

*PSV(horiz.)=0.1 and 0.06 m/s for exceedance probabilities of 10^{-4} and 10^{-2} respectively, both at 5% damping and a periode of 2 seconds.

*The modell also included the Troll and Oseberg fields and allowed a comparison with results obtained in the two previous studies:

-Oseberg PGAmax at 10^{-4} =0.22g (previous study 0.26g)
at 10^{-2} =0.03g (" " 0.05g)
-Troll PGAmax at 10^{-4} =0.25g (" " 0.28g)
at 10^{-2} =0.03g (" " 0.06g)

The reductions may in part be due to the area zonation model's insensitivity to effects of local faults modelled specifically in the other studies. However, the attenuation relationships applied have also contributed to the lower numbers.

The main problem areas of this study were:

- attenuation relationships are based on a general mean of weighted relationships relevant for three comparable regions(western North America,Japan/other subduction zones and central/east USA.How representative are the applied relationships for the study area?

- the choise to model "bedrock outcrop" motion underneath the platform site and then modify for effects of local soil and water depth has the same limitation as for the Troll study.The choic of method was due to very limited strong motion recordings made on the typical silty soils found at Brage.

- the seismic soursce model applied using zonation only allows the study of a larger area but also limits the accuracy of the results when including areas where local faulting plays a significant role.

OSEBERG FIELD 1987

In early 1987 development of the northern part of the Oseberg Field,called "phase 2",was ready for structural design.The improvements made since the original study in 1983 in the seismicity catalogue for the North Sea,better geophysical profiles and improved understanding of long periode attenuation called for a review and potential revision of the original study.An evaluation of the report concluded that the study and design criteria would benefit from application of the new data and information available.

The primary object of the revision of the study was to incorporate the new data and the improvements in methodology to identify sources of uncertainty and present updated earthquake loads.

On the basis of the observed seismicity distribution as well as tectonic similarity the regional zonation for the source model was modified.Each zone was defined in terms of individual recurrence parameters and relative confidence levels.Ground motion attenuation was redeveloped.Near field ground motion levels were modelled similar to those observed in the western USA.The rate of attenuation with distance was modelled significantly lower than originally.This implies that at a distance of 100 km from an earthquake ground motion may be 50 to 100% greater in the North Sea than in the western USA.The range reflects the difference between the two models used in 1987.

The three original source models were adjusted in terms of detailed charachterization parameters.

The seismicity data indicated a higher rate of small earthquakes and a smaller rate of larger eartrhquakes compared to the 1983 data.

Results from the new study show equal or somewhat grater hazard for peak acceleration and significantly lower hazard for spectral velocity(ref. 2 sec. periode).The reason for these effects are:

- as smaller magnitude events tend to dominate the hazard for peak acceleration the combination of somewhat higher recurrence frequency and median ground motion levels tend to give higher peak acceleration hazard.
- the present study predicts slightky higher ground motion levels for events of magnitude 4 to 5.
- previous overestimation of small magnitude spectral ordinates was corrected combined with a the somewhat higher frequency of large magnitude events.This resulted in a significantly lower hazard for long periode motions.

Considering the dominant periode of.of natural response of the planned platform of 2 to 4 seconds it was agreed to revise the seismic design criteria.Typical numerical examples of the above:

*PGAmax increased from 0.26 to 0.30 g for 10^{-4} exceedance probability but reduced from 0.048 g to 0.04 g for 10^{-2} .

*PSV(horiz.) for 10^{-4} fell from 0.45 to 0.28 m/s and from 0.06 to 0.02 m/s for 10^{-2} exceedance probability.

EVALUATION

Geology: the detailed study of the tectonic related geologic features in the area concerned has significantly improved the understanding of the historical background for the present seismicity. In terms of relative contribution in the process of total improvement the gains in this field do not seem to have resulted in major changes in the process of establishing earthquake load criteria.

Seismology: major improvements have been achieved through the improvements in the historical and instrumental databases. A major contribution has been the establishment of the new seismic network along the west coast of Norway with its large and accurate recordings of primarily microseismic data. This has led to improved seismicity maps, improved focal depth evaluations and improved accuracy in determination of epicentra.

Attenuation: this is still the most sensitive and at the same time uncertain facor in the process of establishing earthquake criteria. The attempts that have been made have mostly served to uncover the complexity and uncertain nature of this factor. This is the area where most research is required.

Recurrence rates: large improvements have been achieved in the periode concerned, mostly due the improvements in the seismic data.

Hazard analysis: the basic approach has not changed although the process has been refined.

Effects of local soil: the experience from the three fields is that method of accounting for the local effects of soil conditions and water column depends on the nature of these parameters. Firm and uniform soil conditions combined with shallow water may be taken care of in the selection of appropriate attenuation relationships. With increasingly soft and deep soil conditions as well as increasing water depths these effects must be studied separately. The bedrock hazard and motions are calculated as a first step, then modelling the soil and water column and analysing their influences.