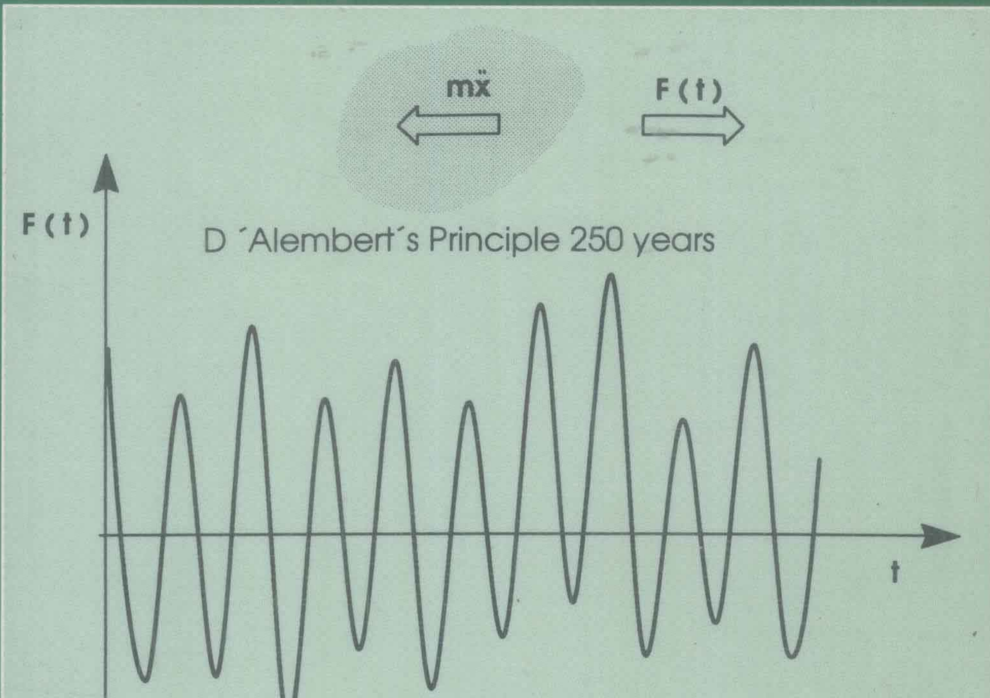
STRUCTURAL DYNAMICS

EURODYN '93

VOLUME 1



T. Moan et al., editors

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Structural Dynamics

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VOLUME 1
Earthquake engineering / Soil structure interaction / Blast loading / Impacts / Basic dynamics

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STRUCTURAL DYNAMICS – EURODYN '93
VOLUME 1

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Preface

The field of structural dynamics was founded through the pioneering works of Newton in his 'Principia' (1686), D'Alembert's 'Traité de Dynamique' (1743), Euler's 'Methodus inveniendi lineas curvas ...', (1744) and others. Yet, the developments in this field are more exciting than ever, partly because of researchers desire to know the laws of nature and man-made structures, and the need to deal with the behaviour of new structures subjected to seismic, wind, wave, traffic, mechanical impact and other actions. Dynamic effects have become increasingly important for the serviceability and safety of engineering structures such as buildings, bridges, offshore platforms, vehicles and other structures.

Today, structural dynamics analysis is carried out with tools based on differential or variational formulations and continuum and fracture mechanics. The stochastic nature of loads and nonlinear structural behaviour are accounted for. Laboratory and in-service investigations in conjunction with system identification provide the basis to develop and validate theoretical models both for the structure and the material properties.

Following the successful first EURODYN conference organized by Professor Krätzig and his colleagues in Bochum in 1990, the aim of this second conference is to provide a forum for engineers, researchers, university teachers and other professionals for discussing recent developments in dynamics of structures. The aim is to stimulate the exchange of information between various disciplines in science and engineering and various fields of application. This gathering is particularly intended to advance closer co-operation within Europe. However, we appreciate the interest shown in the conference by our colleagues outside Europe and the exchange of information with them.

These proceedings contain papers contributed from 35 nations which form the basis for the conference.

Finally, I would like to thank Professor Krätzig and his colleagues for initiating the EURODYN conference; our sponsors; and A.A. Balkema Publishers for pleasant cooperation in producing these proceedings.

Torgeir Moan
NTH
March 1993

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1 Earthquake engineering

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A comparison of seismic wave attenuation between intraplate Norway and plate margin areas

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ABSTRACT: A detailed recent study of seismic wave attenuation characteristics in Norway has made it possible to compare more closely the difference in this respect between plate interiors and the tectonically much younger areas of the plate margins. It is showed that the latter areas generally attenuate the waves much faster at large distances, which is expected because the rocks there have much lower quality factors. What is more important, however, is the quantitative demonstration in this work of the relative importance of the near-field region and in particular of how seismic attenuation models may differ with respect to the way the resulting ground motions scale with earthquake magnitude.

1 INTRODUCTION

The idea that it could be possible to approach scientifically the problem of estimating the potential danger from future earthquakes came into the world as a result of the 1906 San Francisco earthquake. California has since then served as an important center for earthquake engineering research, and it is only during the last few decades that these efforts have become a world-wide concern.

By the end of the 1960's the new concept of plate tectonics, which revolutionized the geosciences, influenced decisively also the methods and means for estimating seismic potentials for the different parts of the world. The new global tectonics as it was developed initially modelled the interior of the plates as rigid bodies, concentrating on the processes and dynamics at the plate margins.

During the 1980's an increasing awareness of the seismic potentials in the interior of plates developed, exemplified by the discovery of some very large (above magnitude 8) intraplate earthquakes. Fig. 1 shows that earthquakes are quite frequent also in Fennoscandia, even though the largest there in historical times have been below 6 in magnitude (Bungum et al., 1991).

The question of whether the basic generic processes might be different for interplate and intraplate earthquakes is still a subject of much research, while a clearer difference in this respect is found in the way in which the earthquake waves carries the energy and thereby the damage potential out from the focus.

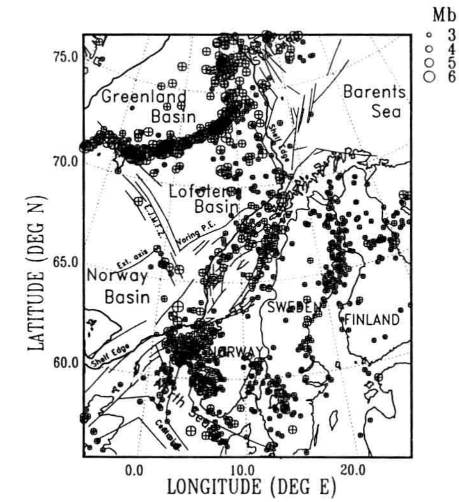

Fig. 1 Seismicity of Norway and surrounding areas, 1955-1989. From Bungum et al. (1991).

While earthquake risk estimation includes a consideration of the vulnerability of structures, the evaluation of earthquake hazard focuses directly on the probability for a certain earthquake related ground motion to occur at a particular site within a certain time period (Reiter, 1990). Such hazard is now normally estimated probabilistically, even in plate margin areas where deterministic methods dominated earlier, and this is done by integrating contributions to the ground motion from earthquake sources over a large area surrounding the site.

The state-of-the-art methodologies for seismic hazard estimation includes an earthquake source model that defines the occurrence rates of particular earthquake magnitudes near and around the site (where some construction may be planned), this is combined with a wave attenuation model which defines the ground motion at a given distance from an earthquake of a particular magnitude, and allowance is finally made for possible modifications of the wave field related to the local soil conditions at the site.

It is important to note here that the commonly used expression 'wave attenuation model' is somewhat misleading as such a model not only describes the attenuation with distance but also the absolute level of the seismic excitation from particular size (magnitude) earthquakes, including the areas near the focus. The purpose of this study is to demonstrate how such attenuation models may differ between intraplate (Norway) and plate margin (California) areas, and to investigate how this influences the seismic hazard potentials.

2 METHODOLOGY

The foundations for engineering seismic hazard analysis were established by Cornell (1968), who recognized the need for seismic design to be based on a method which properly accounted for the intrinsic uncertainties associated with earthquake phenomena.

The model for the occurrence of ground motions at a specific site in excess of a specified level is assumed to be that of a Poisson process. This follows if the occurrence of earthquakes is a Poisson process, and if the probability that any one event will produce site ground motions in excess of a specified level is independent of the occurrence of other events. The probability that a ground motion level z is exceeded at a site in unit time is thus expressed as $P(Z > z) = 1 - exp[-\nu(z)]$, where $\nu(z)$ is the mean number of events per unit time in which Z exceeds z. With several seismic sources, described through particular model parameters, the mean number of events per unit time in which the ground motion level z is exceeded can then be expressed specifically, involving functions that model the inherent stochastic uncertainty in the frequency and location of earthquakes, and in the attenuation of the seismic waves. Besides this natural uncertainty, there is also an element of uncertainty associated with the variability of model parameters. This source of uncertainty is accounted for by regarding these parameters as random variables, whose discrete values are assigned weights reflecting their likelihood.

The recurrence rate of earthquakes is assumed to follow the cumulative Gutenberg-Richter relation $\log N(M) = a - bM$, where $N(M)$ is the (annual) number of events with magnitude greater or equal then M, and a and b are parameters.

The self-similarity of earthquakes indicated by this power law appears with few exceptions to hold quite well within a fairly large magnitude range. For the very largest magnitudes some truncation of this distribution is of course needed, by introducing the concept of maximum magnitude.

With the specification of the occurrence of an event of magnitude M_i on a source, at a site-source distance of R_j, the probability of exceedance of ground motion level z needs to be defined. From studies of strong-motion records, a log-normal distribution is found to be generally consistent with the data, with the mean having a form such as:

$$lnZ = c_1 + c_2M_i + c_3lnR_j + c_4R_j + ln(\varepsilon) \qquad (1)$$

where Z is the ground motion variable, c_1 to c_4 are empirically determined constants, and $ln(\varepsilon)$ is a normally distributed error term with expectance zero and a standard deviation which also can be estimated from the recorded data.

Seismic hazard computations now regularly employs a logic-tree formalism by which weighted, discrete distributions are input for the principle seismological and geological variables. For each terminal node of the logic-tree branches that stem from source n, having model parameters $S_n(m)$, a probability weight function $P[S_n(m)]$ is computed, and used to construct the probability distribution of the random variables $\nu_n(z)$, the mean number of events per unit time in which the level z of ground motion is exceeded, and hence the sum $\nu(z) = \Sigma\nu_n(z)$. The probability distribution of $\nu(z)$ is close to lognormal for real seismic hazard problems of any complexity (Kulkarni et al., 1984), and estimates of its mean and variance allow confidence levels for the exceedance to be computed efficiently.

3 TEST MODELS

It is well known from numerous studies that the anelastic attenuation, represented by the c_4 term in equation (1), is much stronger in the tectonically younger plate margin areas than in intraplate areas. Physically, this term is expressed as $c_4 = -\pi f[\beta Q(f)]^{-1}$, where $Q(f)$ is a frequency dependent quality factor and β is wave velocity (Dahle et al., 1991). This difference is demonstrated very clearly in Fig. 2, where the fully drawn lines represent an intraplate (Norwegian) PGA attenuation model selected for this test (Bungum et al., 1992) and the dashed lines a plate margin (Californian) model selected for comparison (Joyner and Boore, 1982). The curves in both cases are given for magnitudes ranging from 4.0 to 7.0, and the sudden drop in the Californian model at 300-400 km is caused by the difference in anelastic attenuation. For a more detailed account of this difference, see Alsaker et al. (1991).

However, the most striking difference between the two models, which are derived using quite different methods, is not in terms of anelastic attenuation but rather in the way in which the modelled ground motion scales with earthquake magnitude, reflecting differences in the c_2 parameter in equation (1). It is seen that the curves are not much different at magnitudes around 6, while the Norwegian model predicts much lower ground motions around magnitude 4, and greater around magnitude 7.

A similar difference, but much smaller this time, is seen between the models for 0.2 Hz pseudo-relative velocity (PSV) in Fig. 3, where differences in $Q(f)$ now are negligible because of the much longer wavelengths involved. We have chosen to conduct the testing for PGA (normally tied to 40-50 Hz) and 0.2 Hz PSV, representing the highest and lowest frequency for which one normally estimates a seismic loading (equal-probability) spectrum.

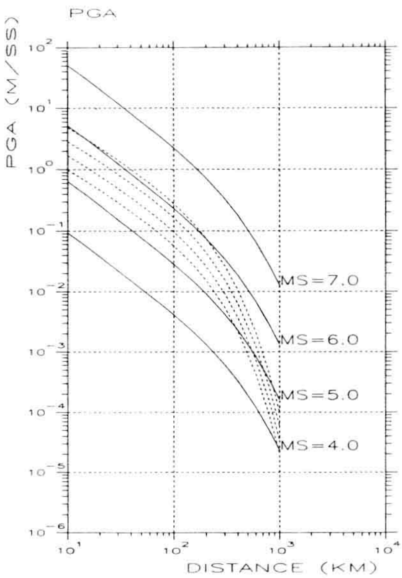

Fig. 2 Seismic wave attenuation models developed by for Norway (Bungum et al., 1992, fully drawn lines) as compared to California (Joyner and Boore, 1982, dotted lines). Ground motion is peak ground acceleration (PGA) in m/s^2, and the relations are plotted for source-site distances between 10 and 1000 km, for magnitudes of 4, 5, 6 and 7.

In testing the effects of these two models we have defined a very simple source model as shown in Fig. 4, consisting of a narrow linear zone of seismicity along the Mid-Norway continental margin, with five test sites located at distances between 100 and 500 km. The source zone has, for test purposes, been assigned a seismicity which is somewhat higher that what we normally should expect in that area.

4 RESULTS

Using the models for seismic sources and wave attenuation defined above, we find hazard curves, i.e., expected ground motion vs. annual exceedance probability, as shown in Fig. 5 for PGA at 100 km and in Fig. 6 for 500 km. The PGA results for the whole profile from 100 to 500 km are given in Fig. 7, for annual exceedance probabilities of 10^{-4}, 10^{-3} and 10^{-2}, respectively, corresponding to return times of about

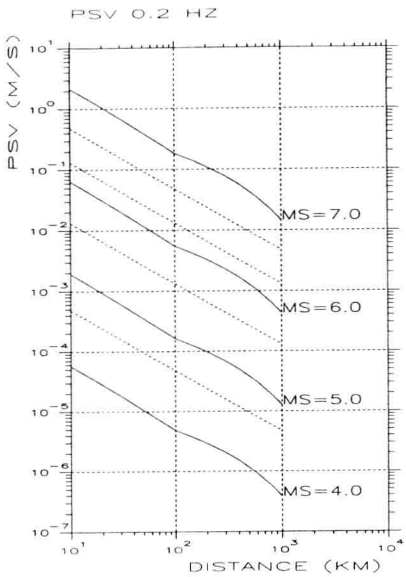

Fig. 3 Same as for Fig. 2, except that the ground motion parameter now is pseudo-relative velocity (PSV), in m/s.

10,000, 1,000 and 100 years. For 0.2 Hz PSV similar hazard curves are given in Fig. 8 for 100 km, and in Fig. 9 for 500 km.

The hazard curves in Figs. 5-6 and Figs. 8-9 are all for expected ground motion, which because of the skewness of the distribution corresponds to a confidence level of between 55 and 60%, dependent on the details of the models used. The way the uncertainties are treated then allows estimates to be evaluated at any desired confidence level, such as 90%, even though what is most commonly used is to estimate the expectance plus/minus one standard deviation. What confidence level and exceedance probability to use are questions which the owner and/or the regulatory authority have the responsibility to resolve.

Fig. 5 shows that the two models give about the same ground motion at 100 km at an exceedance probability of 10^{-2}/year, but with much higher Norwegian values at 10^{-4}/year. These results are reasonable in view of the wave attenuation differences in Fig. 2, knowing that the 10^{-4}/year results are dominated by less frequent larger (magnitude 5-7) earthquakes, while the 10^{-2}/year results are influenced primarily by more frequent and smaller (below magnitude 6) earthquakes. This also explains the relative steepness of the California curve in Fig. 5, reflecting the smaller differences in Fig. 2 between the different magnitudes for the California model (dashed lines).

At 500 km (Fig. 6) the same effects are seen, except that the absolute differences between Norway and California now are much larger, related to the earlier discussed differences in anelastic attenuation. The resulting hazard would normally be negligible when using a Californian attenuation model, while the Norwegian model still would give a hazard that could be of importance at that distance for particularly sensitive structures.

A summary of PGA results for the five distances between 100 and 500 km (see Fig. 4) are shown in Fig. 7, for the two attenuation models and for exceedance probabilities of 10^{-4}, 10^{-3} and 10^{-2}/year (labelled 1, 2 and 3, respectively). It is seen there, as we saw also in Figs. 5-6, that the main difference occurs first of all for the lowest exceedance probabilities (10^{-4}/year), where the ground motions and also the uncertainties are much larger. The main lesson from Fig. 7, however, is that the earthquake hazard

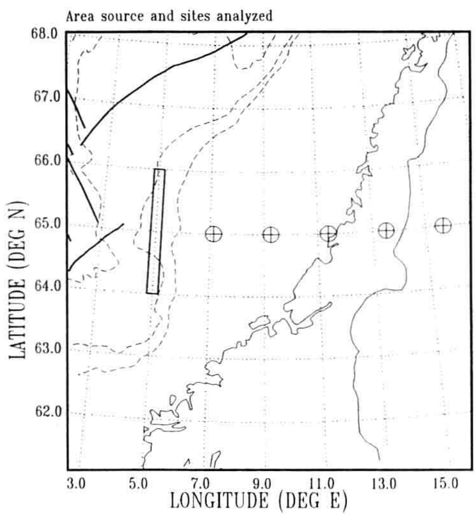

Fig. 4 Earthquake source model used (for test purposes only) in this analysis, represented by a narrow linear zone of seismicity along the continental margin of Mid-Norway, where Fig. 1 reveals a certain concentration of seismicity. The circles indicate theoretical sites located at the same latitude at distances from 100 to 500 km from the center of the source zone.