koninklijk nederlands meteorologisch instituut
royal netherlands meteorological institute

publication no 153

on earthquake risk for nuclear power plants

PROCEEDINGS OF THE E.S.C. SYMPOSIUM
IN LUXEMBOURG ON 20 - 22 OCTOBER 1975

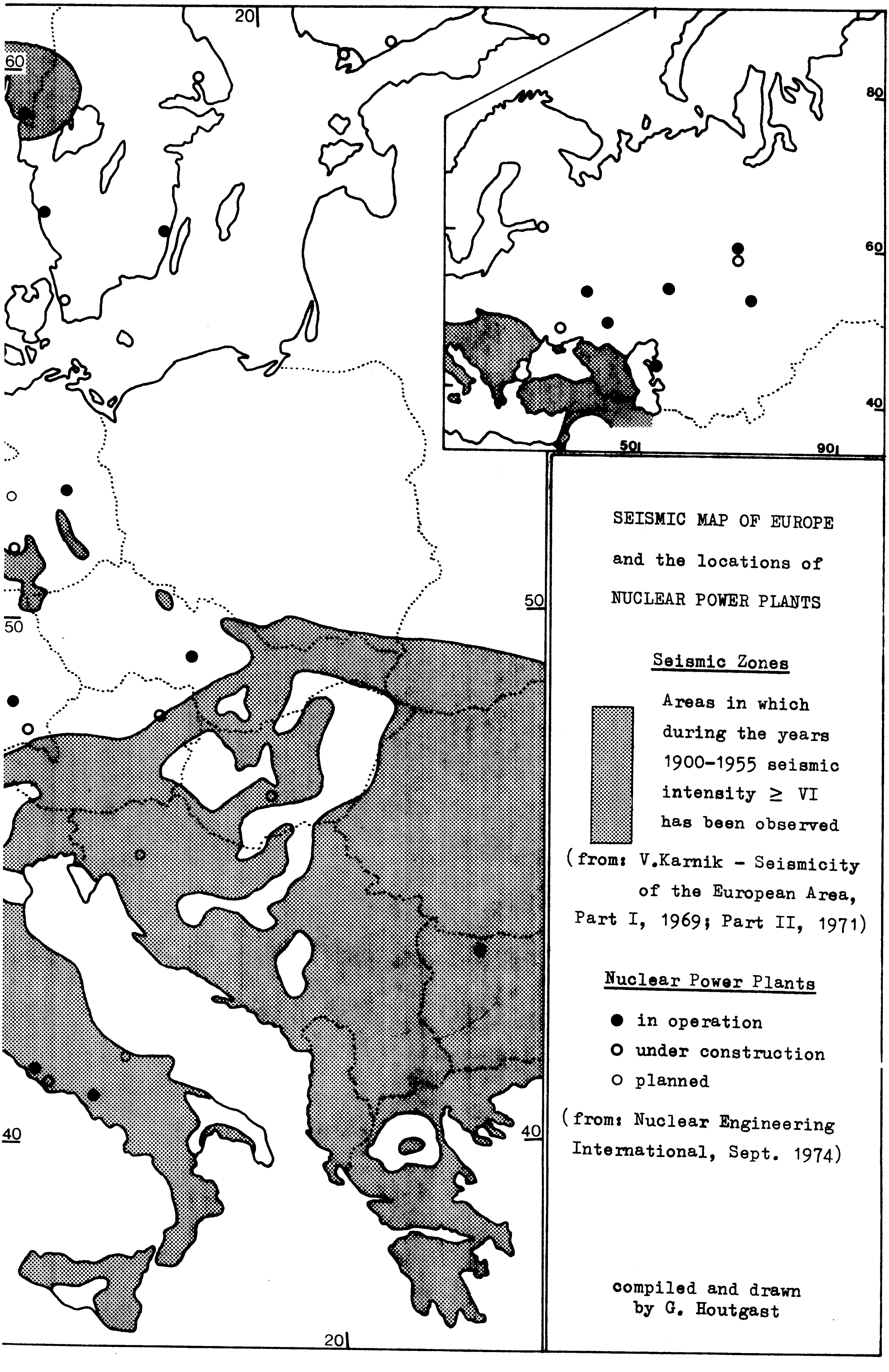
EDITED BY
A.R. RITSEMA

K.N.M.I.

de bilt - january 1976

ON EARTHQUAKE RISK FOR NUCLEAR POWER PLANTS


20
10
0
10
60
50
50
40
40
0
10



SEISMIC MAP OF EUROPE

and the locations of

NUCLEAR POWER PLANTS

Seismic Zones

▨ Areas in which during the years 1900–1955 seismic intensity ≥ VI has been observed

(from: V.Karnik - Seismicity of the European Area, Part I, 1969; Part II, 1971)

Nuclear Power Plants

- ● in operation
- **O** under construction
- ○ planned

(from: Nuclear Engineering International, Sept. 1974)

compiled and drawn
by G. Houtgast

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preface

One of the tasks of the Geophysical Division of the Royal Netherlands Meteorological Institute is to give advice in matters of seismicity. In the present era of design and construction of nuclear power plants, risk evaluation and analysis for earthquakes has become more necessary than ever. In the Netherlands this has lead to a more detailed study of local seismicity, and to the initiation of a close co-operation with seismic experts of neighbouring countries to remove some of the existing ambiguities in seismic zoning at the mutual national borders.

The study of seismic risks, especially in the absence of long series of seismic observations, is a problem common to many European countries. This was also reflected in the Symposium on Earthquake risk for nuclear power plants, held in Luxemburg on October 20-22, 1975, under auspices of the European Seismological Commission. The present Volume of the Publication Series of the Institute contains the Proceedings of this Symposium. It is supposed to give the work done locally an essential and wider perspective on European scale. Apart from our own interest in the matter, it is hoped that many colleagues from other countries in and outside Europe will profit from this publication.

The Proceedings are edited by Dr. A.R. Ritsema, convener of the Symposium, with the special aid, advice and assistence of Miss J.H.W.M. Vermeulen, P.A.S. Doets, G. Houtgast and J.J. Wittebol, all members of the Institute. The former Director in Chief, Dr. M.W.F. Schregardus, actively promoted the publication. The fact that the authors delivered in time print-ready manuscripts made publication possible within three months of the Symposium.

Dr. H.C. Bijvoet

Director in Chief

De Bilt, January 1976

ON EARTHQUAKE RISK FOR NUCLEAR POWER PLANTS

A Symposium of the

European Seismological Commission

PLACE: Institut Pédagogique, Walferdange, Luxembourg - DATE: 20-22 October 1975 - CONVENER: A.R. Ritsema - SECRETARY: J.M. van Gils - LOCAL ORGANIZATION: J.A. Flick - OPENING CEREMONY: welcome by Mr. P. Weber, attaché of the Minister of Culturel Affairs of Luxembourg; opening by Prof. St. Mueller, president of the European Seismological Commission - SESSION CHAIRMEN: A.R. Ritsema, A. López-Arroyo, P.L. Willmore, J. Hjelme - CHAIRMAN OPEN DISCUSSION: St. Mueller - EVENING PROGRAMS: reception by the burgomaster in the townhall of Walferdange; concert of the Quatuor "Ars Vocalis"; excursion to the Laboratoire Souterrain de Géodynamique.

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BIENVENUE WELCOME

Monsieur le Président,
Mesdames,
Messieurs,

C'est un grand honneur pour moi que de pouvoir vous souhaiter la bienvenue à Luxembourg au nom de Monsieur le Ministre des Affaires culturelles Robert Krieps qui assume la responsabilité de la recherche scientifique au sein du gouvernement luxembourgeois. Je tiens à remercier la Commission Séismologique Européenne d'avoir choisi notre pays pour tenir son symposium sur les risques séismiques pour les centrales nucléaires.

Etant donné le peu de spécialistes que nous avons dans le domaine de la géodésie et de la géophysique, le gouvernement luxembourgeois suivra avec beaucoup d'attention vos travaux durant ces deux jours et demi que durera votre réunion. En effet, vous n'ignorez sans doute pas que, bien que le Luxembourg ne possède pas de centrale nucléaire à l'heure actuelle, le problème posé par l'installation d'une telle centrale a cessé pour nous d'être un problème purement théorique depuis qu'est envisagée la construction d'une centrale nucléaire à Remerschen. Depuis que ce projet est connu, partisans et adversaires du nécléaire, scientifiques ou non scientifiques s'affrontent, avec des arguments aussi valables, me semble-t-il, d'un côté que de l'autre.

Vous devez donc être très conscients de la dimension sociale de votre recherche. Car vous êtes les premiers à pouvoir attirer l'attention de la collectivité sur les implications de vos travaux. Je n'ignore pas que la responsabilité sociale ou scientifique s'oppose ici dans une large mesure à la conception traditionnelle de la responsabilité scientifique: alerter la société au stade d'une recherche qui n'a pas encore définitivement abouti, c'est, en effet, aller au-delà de la stricte neutralité scientifique, c'est interpréter des résultats préliminaires à la lumière d'hypothèses peut-être fragiles. N'est-ce pas courir le risque d'être inutilement alarmant?

J'estime cependant que le silence serait plus coupable que l'erreur: les scientifiques que vous êtes ne front qu'attirer l'attention de la société sur une éventualité. La décision, elle, reste et doit rester fondamentalement une décision politique.

Il est donc incontestable qu'une éthique scientifique nouvelle qui paraît se dégager actuellement, faciliterait l'instauration du débat public indispensable pour que la société, dans son ensemble, se préparer à résoudre les problèmes que lui pose la science.

Voilà quelques réflexions qui pourraient constituer le back-ground de vos travaux et vous inciter peut-être à réfléchir sur l'élaboration de procédures qui permettraient d'informer le public des incidences des innovations technologiques, de solliciter ses réactions et de le faire participer au processus de décision.

Il ne me reste qu'à souhaiter un plein succès à vos travaux et à espérer que votre séjour au Luxembourg sera le plus agréable possible.

Je vous remercie.

M.P. Weber
Attaché du Ministre
des Affaires Culturelles
Luxembourg

OPENING ADDRESS

Professor Weber,
Ladies and Gentlemen,
Dear Colleagues,

It is a pleasure and a privilege for me to welcome you here in Walferdange on behalf of the European Seismological Commission and the Council of Europe. In particular I would like to bid my welcome to the representatives of the press, of the European Communities and of the government, the authorities and scientific societies of Luxembourg - our hosts here in Walferdange. We have invited you to attend and contribute to a special symposium entitled "Earthquake Risk for Nuclear Power Plants".

Over the past few years many seismologists have been confronted with official and unofficial requests to evaluate the seismic risk encountered in the design and construction of nuclear power plants. As we all know this problem has many different aspects - political, socio-economic and psychological ones - as well as scientific, technical and engineering ones. We will restrict our discussions at this meeting to the second group: the seismological, the geologic/tectonic, and in part to the soil and rock mechanical aspects of the problem, but the civil engineering aspects should, of course, not be forgotten.

The purpose of this symposium is to gain some insight into the present activities in this field in Europe and to become conscious of new developments in neighbouring disciplines which may be relevant to the problem. So in addition to a description, discussion and comparison of the methods presently used in seismic risk determination quite some time should be spent in a mutual personal exchange of information in order to arrive at some consensus on how to deal most effectively with the pending questions in the various European countries.

We should direct our efforts to come to an agreement about the most useful consistent criteria in assessing objectively the seismic risk involved in the design of nuclear power plants. We should explore systematically the possibilities - the information seismology can contribute to this problem -, and we should clearly define the needs of the engineer in this field. It is, therefore, highly desirable to have some constructive feedback from those of our colleagues present who are dealing with the practical aspects of design and construction. Utilizing all the available data we should then aim for producing a "Map of Seismic Risk in Europe", which would serve both the seismologist and the engineer in judging possible hazards.

The European Seismological Commission (ESC) considers this symposium only to be the beginning in its efforts to contribute to the study of the environment. I am sure that the results of our discussions will be of great value for the UNESCO Intergovernmental Conference to be held in Paris (10-19 February 1976). The subject will also be followed up at the 15th General Assembly of the ESC in Cracow/Poland at the end of September 1976, where a special symposium will be organized on "Seismic Hazard".

I would like to take this opportunity to express our sincere gratitude to the Luxembourg Ministry of Cultural Affairs for having made possible this meeting here in Walferdange. I would also like to thank our colleagues Dr. A.R. Ritsema and Mr. J.M. van Gils who have put a lot of time and effort into organizing this symposium - and last but not least many special thanks go to Mr. J. Flick, the local organizer here in Luxembourg, who is also the official delegate of the Working Party of Geodynamics in the Council of Europe.

Let us make the best use of this meeting, which judging by the number of participants seems to have just the optimum size. I hope that we all will benefit as much as possible while we are here, both professionally and personally.
Thank you very much.

20 October 1975

Stephan Mueller
President of the ESC

PROGRAM
of
LECTURES

Les Recherches de séismicité historique et la magnitude maximale à envisager en un site donné

J.P. ROTHÉ

Institut de Physique du Globe, Strasbourg

Résumé

Pour la France l'extrapolation du graphique fréquence-magnitude conduirait à des périodes d'apparition des séismes de grande magnitude en contradiction avec les données historiques, données dont on souligne l'intérêt. Chaque grande région géologique française peut être affectée d'un chiffre de magnitude maximale. A l'échelle des sites de centrales nucléaires il est possible de définir des intensités maximales historiques caractérisant des provinces séismotectoniques d'étendue limitée. Des indications sont données sur les recherches actuellement en cours en France dans ce domaine.

Introduction

Bien que la France soit un pays où le danger séismique est relativement faible plusieurs organismes s'attachent actuellement à définir et à préciser ce risque.

La Direction de la Protection Civile (Ministère de l'Intérieur) a constitué une commission "Sécurité en montagne et Risques naturels" formée elle-même de groupes de travail dont l'un a pour objectif l'étude des séismes et du volcanisme. L'un des buts de ce groupe de travail est de réviser et de faire adopter légalement les "Règles parasismiques 1969".

L'Electricité de France chargée de préparer les projets d'installation des Centrales nucléaires s'intéresse de plus en plus au risque séismique ; son service géologique et géotechnique étudie la séismicité historique des différents sites prévus et son service technique calcule les effets des séismes sur les constructions.

Le Service central de sûreté des installations nucléaires (Commissariat à l'Energie atomique) a lui-même constitué un groupe de travail pour l'élaboration d'une règlementation sur la prise en compte du risque séismique pour les réacteurs nucléaires. A la demande de ce Service le Bureau des Recherches géologiques et minières a été chargé de préparer une carte séismotectonique de France à 1 : 1.000.000 - échelle de la carte géologique de France - et pour certaines régions des cartes plus détaillées à l'échelle 1:250.000.

Le problème de la magnitude maximale

En tant que séismologues nous avons d'abord à répondre à la question suivante : dans un pays comme la France est-il possible de définir un certain nombre de provinces séismotectoniques considérées comme homogènes sur le plan de la géologie structurale et si oui pour chaque province séismotectonique quelle devra être l'intensité macroséismique maximale – ou la magnitude maximale – à envisager, le foyer du séisme de magnitude maximale étant susceptible de se produire au point le plus proche du site envisagé sur la structure tectonique ou sur la faille identifiée.

Cette première approche est inspirée du règlement préparé en 1971 par la Commission américaine de l'Energie atomique (Annexe A, Règles 10 CFR, part 100). Il convient d'ailleurs de remarquer que le Règlement américain a été fortement influencé par les conditions spéciales de la Californie où de grandes failles de coulissage sont susceptibles de jouer sur des centaines de kilomètres de longueur. La stricte application de ce Règlement à un pays comme la France ou même à l'Europe occidentale conduirait à des conséquences trop sévères sur le plan de la protection.

Le problème de la magnitude maximale pour une région donnée est particulièrement important à étudier. Certains chercheurs se basant sur la construction des graphiques fréquence-magnitude et sur le caractère linéaire de ces graphiques ont émis l'hypothèse que dans une région donnée il y aurait, si le temps est suffisamment long, la possibilité d'enregistrer un séisme de la magnitude la plus forte, de l'ordre de 8,5 par exemple. Quel serait alors ce temps et quelle serait la probabilité de l'apparition d'un tel séisme pendant la durée prévue pour la centrale nucléaire.

Pour la France on peut répondre que cette hypothèse est en opposition avec les données d'observation et les conceptions tectoniques. J'ai demandé à notre collègue roumain C. Radu, lors de son séjour à Strasbourg, d'examiner cette hypothèse. A partir des données instrumentales et des données macroséismiques nous avons établi pour la France et les régions immédiatement voisines une liste de 199 séismes de magnitude au moins égale à 4,1 et correspondant à la période 1901-1972.

La France a été divisée en cinq grandes régions géologiques :

1) Le socle hercynien dans le Massif central et dans le Massif armoricain ; le Bassin d'Aquitaine, aséismique, a été joint à cette région (au total 335.000 km^2, 32 séismes).

2) Les Pyrénées (108.000 km^2, 47 séismes).

3) Le Sud-Est de la France et les Alpes occidentales en Suisse et en Italie (184.000 km^2, 92 séismes).

4) L'Est de la France, le Fossé rhénan et ses bordures (46.000 km^2, 17 séismes).

5) Le Bassin parisien et le Nord de la France (146.000 km^2, 11 séismes).

Les séismes ont été classés en fonction de leur magnitude par intervalles de 0,1 degré de magnitude (M) d'une part et de 0,5 degré de magnitude (M) d'autre part. Cette dernière répartition est donnée dans le tableau suivant

Magnitude	France	Région séismique				
		1	2	3	4	5
4,1 - 4,5	117	13	31	55	11	7
4,6 - 5,0	56	14	11	23	5	3
5,1 - 5,5	15	3	2	8	1	1
5,6 - 6,0	8	2	3	3	-	-
6,1 - 6,5	3	-	-	3	-	-
	199	32	47	92	17	11

Pour chacune des régions et pour l'ensemble de la France M. Radu a calculé les coefficients a et b de la formule classique log n = a - b M. Les résultats détaillés de cette étude ont fait l'objet d'une publication (voir références).

Les résultats obtenus sont analogues à ceux établis par V. Karnik dans son travail sur la séismicité de l'Europe. La valeur la plus faible du coefficient b (0,75) correspond à la région la plus stable au point de vue tectonique, à savoir la zone hercynienne, résultat en accord avec les recherches de certains auteurs, Miyamura en particulier.

Pour l'ensemble de la France et pour 72 ans la fréquence cumulative pour une magnitude égale ou supérieure à M s'écrit log N = 5,66 - 0,82 M.

En extrapolant la droite fréquence-magnitude correspondant à l'ensemble de la France on trouverait que la période moyenne d'apparition de séismes de magnitude 8 1/2, 8, 7 1/2, 7 serait de 1429, 556, 217 et 85 ans en contradiction formelle avec les données d'observation au cours des 800 dernières années.

Intérêt des recherches historiques

L'intérêt des recherches historiques est particulièrement grand pour cette discussion ; aussi y attache-t-on actuellement de plus en plus de valeur. Pour la France, pour la période antérieure à 1900, on dispose d'une série de catalogue rédigés par Von Hoff (1840-1841), Perrey (1844), Mallet (1852-1854), Montessus de Ballore (1892). Cette documentation est complétée par plusieurs monographies régionales concernant les séismes de Bretagne, d'Anjou, de Normandie, du Bassin de Paris, de Lorraine, d'Alsace, d'Auvergne, etc .., monographies souvent publiées immédiatement après que des tremblements de terre destructeurs (1887, 1909) aient attiré l'attention des chercheurs français sur le phénomène séismique. Le dépouillement de ces données a permis à l'auteur d'établir un double fichier chronologique et géographique qui est la base des recherches actuelles sur la séismicité de la France.

Il convient de souligner que cette documentation historique, surtout lorsqu'elle est résumée dans des catalogues généraux, tel que le catalogue des séismes destructeurs publié par Milne en 1911, doit être soigneusement vérifiée par des recherches d'archives faites sur place dans les communes intéressées et en particulier dans les archives communales ou celles des congrégations religieuses. Il arrive que certaines destructions soient attribuées à des séismes alors qu'elles sont dues en réalité à des phénomènes météorologiques. Par ailleurs la proportion de bâtiments endommagés ou détruits est rarement indiquée. Aussi d'une manière générale a-t-on tendance à la lecture des catalogues résumés à attribuer aux séismes anciens des intensités trop fortes, ce qui conduit à fixer un risque trop élevé et par conséquent à entraîner pour les constructions des frais supplémentaires probablement inutiles.

Les recherches historiques fournissent une documentation de base précieuse. Est ce à dire que des surprises ne soient pas possibles ? On connaît aux Etats-Unis les exemples classiques des séismes de New-Madrid destructeurs en 1811 et 1812 dans la vallée du Missis-sipi et l'exemple encore plus étonnant du séisme de Charleston en 1886 sur la côte atlantique : ces deux régions, par leur histoire géologique pouvaient paraître peu dangereuses.

En France même on peut citer l'exemple de la région d'Aix-en-Provence : Montessus de Ballore qui était à la fois mathématicien et géologue considérait la Provence comme une région "pénéséismique", c'est-à-dire dépourvue de séismes fréquents et destructeurs, et il écrivait en 1906 dans sa "Géographie séismologique" : "Cette région n'a pas subi de mouvements suffisamment amples à une époque récente pour avoir constitué une région séismique"... Trois ans plus tard le 11 juin 1909 le séisme le plus important qui se soit produit en France détruisait plusieurs villages au voisinage d'Aix et faisait une quarantaine de victimes.

La recherche des causes de telles anomalies est très délicate mais serait certainement fructueuse.

La séismicité de la France

En utilisant la documentation disponible l'auteur (voir Références) a pu établir pour la France les quatre cartes schématiques suivantes :

a) carte des épicentres pour la période 1861-1960. On notera que cette carte présente le même aspect général que celle établie par Montessus de Ballore ou même que celles portant sur des périodes récentes beaucoup plus courtes.

b) carte des intensités maximales observées depuis 1021.

c) carte séismotectonique

d) carte des intensités maximales probables (ou carte des intensités maximales généralisées).

A partir de ces cartes, des données instrumentales et des renseignements historiques on peut chercher pour chacune des grandes régions séismotectoniques françaises envisagées plus haut à définir une magnitude maximale spécifique. Cette magnitude maximale dépend naturellement de l'histoire géologique de la région : l'activité séismique est plus forte dans le domaine hercynien que dans le domaine calédonien et elle est plus forte dans le domaine alpin que dans le domaine hercynien. A l'intérieur même de la zone alpine la magnitude des séismes dépasse la valeur 7 dans les Apennins en Italie où les phénomènes orogéniques sont très récents ; cette magnitude maximale reste voisine de 6 à 6 1/4 dans les Alpes occidentales où l'orogénie est plus ancienne.

Pour la France les données d'observation et les considérations séismotectoniques conduisent pour la magnitude maximale aux valeurs régionales suivantes :

	M	
Région 1 (Massifs hercyniens)	5 3/4	
Région 2 (Pyrénées)	6,0	
Région 3 (Sud-est et Alpes)	6 1/4	
Région 4 (fossés)	6,0	(en tenant compte du séisme de 1356 à Bâle).
Région 5 (Bassin Parisien ; Nord)	5 1/4	
France entière	6 1/4	

A l'intérieur même d'une région comme la région 3 (Sud-est de la France) il est possible d'envisager des subdivisions ; c'est le but du levé des cartes séismotectoniques à 1:250.000. Pour faire ce travail il convient d'utiliser à la même échelle la carte des épicentres, la carte des intensités maximales observées, les cartes d'isoséistes disponibles, les cartes d'anomalies magnétiques et gravimétriques, la carte des isobathes du socle, la carte géologique et la carte néotectonique (mouvements récents) et même la carte d'interprétation détaillée des cassures et fractures visibles sur les assemblages de photos par satellites.

On citera à titre d'exemple la feuille "Marseille" à 1:250.000, actuellement en cours d'achèvement au Bureau des Recherches géologiques et minières, carte qui représente une surface de 180 x 150 km et sur laquelle il est possible de distinguer sept provinces séismotectoniques, 4 d'entre elles avec une activité séismique importante et 3, au contraire, aséismiques. A chacune de ces provinces on peut affecter une intensité macroséismique maximale - ou une magnitude maximale. Le tracé exact des frontières entre les différentes provinces reste cependant souvent délicat et peut varier latéralement de quelques kilomètres. Dans le doute de l'appartenance d'un site déterminé à telle ou telle province il conviendra par prudence de choisir la province où la séismicité est la plus forte.

Cette intensité macroséismique maximale correspond à ce que le Service de sureté des installations nucléaires propose d'appeler le séisme maximal historique vraisemblable (SMHV). L'intensité du séisme majoré de sécurité (SMS) correspondra à celle du séisme historique majoré d'une unité :

$$I\ (SMS) = I\ (SMHV) + 1$$

On retrouve ainsi une analogie avec les séismes envisagés par le Règlement américain, le séisme opérationnel OBE (Operating basis earthquake) et le séisme de sécurité SSE (Safe shutdown earthquake).

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On Earthquake Risk for Nuclear Power Plants in a Non-Seismic Region

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Summary

Reports on earthquakes felt in Denmark have been analysed. In several cases the epicenter is located elsewhere. In some cases no location could be done, but no epicenter is definitly located here.

This makes the definition of Design Earthquake less suitable for studies on earthquake effects. Use of Calculated Risk is demonstrated, and the different steps in the procedure are discussed.

When a nuclear power plant is planned all possible interactions with the environments have to be evaluated. So also the impacts from possible earthquakes. For this reason the working groups planning power plants in Denmark have requested studies of design earthquakes for Danish power plants.

Denmark is situated between the seismically very quiet German lowlands and the more active Fennoscandia. Båth (1956) has published an Earthquake Catalogue for Fennoscandia 1891-1950. Miyamura (1962) has plotted the epicenters and magnitudes given by Båth in a very illustrative figure. No epicenters are located in Denmark - except on the island Bornholm in the Baltic. More material is found in the ISC catalogues. In figure 1 the epicenters given by ISC are plotted on a map of Denmark and southern Fennoscandia. The period covered is 7 years, from 1964 to 1970. Only a few of the earthquakes are assigned a magnitude and then only m_b-values. No M determinations have been given.

I Lehmann (1956) has reviewed all available information on earthquakes felt in Denmark. The first reported one is from 1073 A.D. In all she lists 50 earthquakes felt in Denmark during these 900 years. But about half of them have taken place during the last 100 years. Recently an earthquake with known epicenter off the coast was felt in northern Jutland. Comparing the extent of the felt area with those given in the old reports we found it is not necessary to suppose epicenters inside Jutland to explain the reported observations.

Based on these facts the answer concerning Jutland is: Earthquakes from the past have never had epicenters in Jutland itself and have never produced intensities above VII (Intensity VII has been reported once in these 900 years.

But recommended procedures imply knowledge of values like return periods, extreme values, design earthquakes, etc. Guidence should be found in a booklet distributed by the International Atomic Energy Agency, Vienna (1972). A fundamental concept in this guide is design earthquakes. The guide gives the following definition:

The regional design earthquake is the strongest earthquake which it is reasonable to expect in the general region where the site is located, neglecting features which are local to the specific site itself. The maximum acceleration, the maximum velocity and the vibration frequency content of the motion in the regional design earthquake are important characteristics in determing the effect of that earthquake on structures or items subjected to its motion.

This definition has not taken account of the depth of the earthquake nor the focal mechanism. Furthermore it contains some difficult words, which should be discussed in the following:

1) strongest earthquake

2) reasonable

3) the general region

The last clause is not defining anything, but it contains some considerations on the effect of earthquakes.

Our present knowledge of occurence of earthquakes allows us only to treat them as random events. Risks associated with random events have been investigated by A. Court (1952) who has introduced the calculated risk. In this context risk means simply the probability of an (unwanted) event.

The Poisson distribution tells us the probability for finding n events in a timeinterval t, when the mean frequency of the events is λ.

$$P_n(t) = \frac{(\lambda t)^n}{n!} e^{-\lambda t} \qquad (1)$$

The condition for this distribution to be valid is that the events are independent.

If we look for n=0, that is the event does not happen at all during t the probability is

$$P_0 = e^{-\lambda t} \qquad (2)$$

Then the probability of the opposite situation (at least one event during t) is:

$$r = 1-P_0(t)$$

With the distribution (2), the risk is

$$r = 1-e^{-\lambda t}$$

or

$$\lambda = \frac{-\log(1-r)}{t} \qquad (3)$$

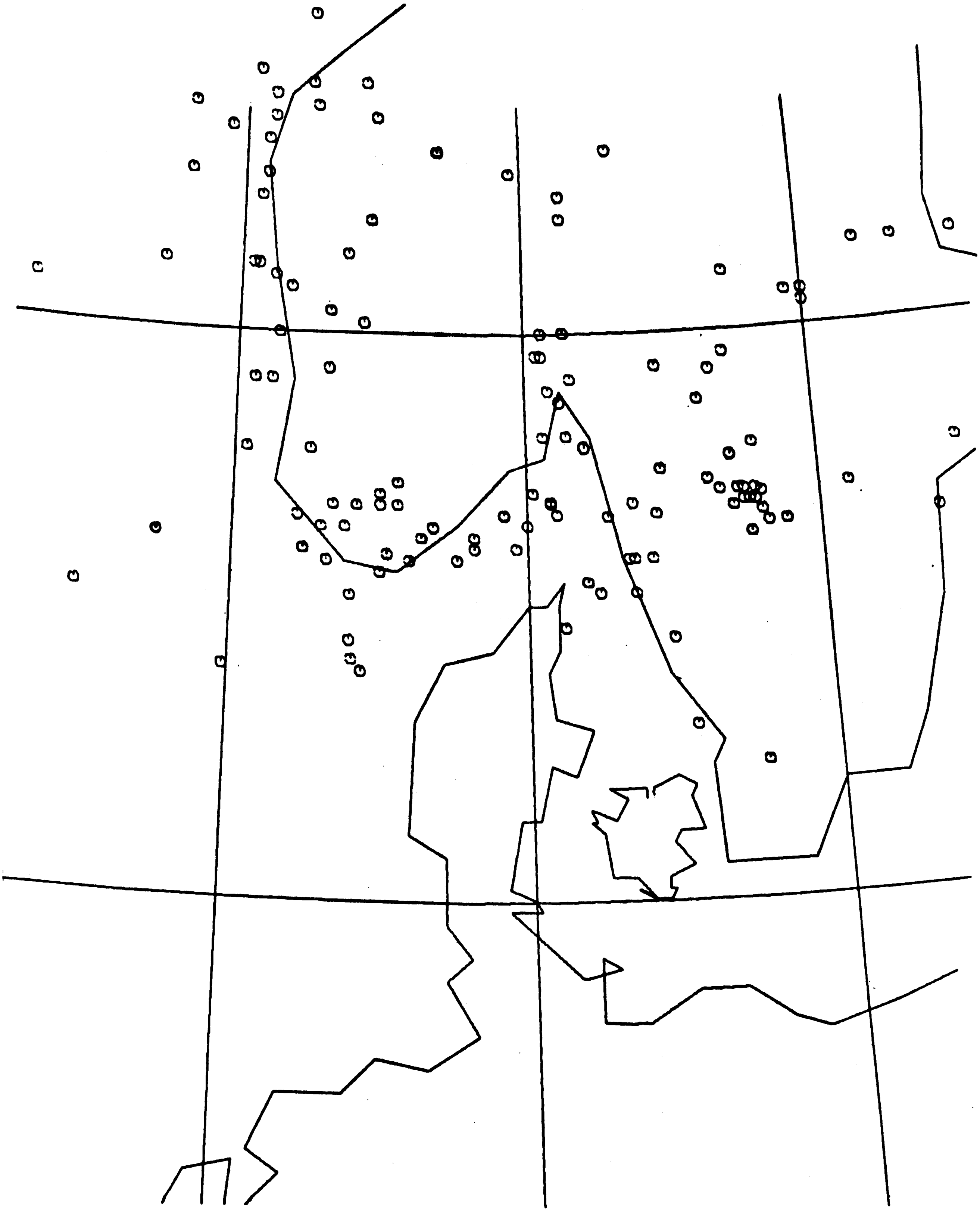

Figure 1. ISC 1964 - 70

This λ is the frequency we must design for, when t is the timeinterval to be considered (lifetime) and r is risk we can tolerate. The choice of t and r is governed by political economical, technical considerations (Gumbel).

Now we can give "reasonable" a meaning. We can regard events occuring with a mean frequency larger than the determined by (3) as those which are reasonable to expect. With this meaning of "reasonable" the strongest earthquakes are such which occur with the mean frequency λ.

But still we cannot determine a design earthquake, because the extent of the region in view is a problem. When the region only covers Jutland there are no earthquakes at all, but if the whole southern Fennoscandia is included, we will get a design earthquake which will occur only far from the sites in question.

The solution to this problem is simple. We are not at all interested in the size of the earthquakes. What is of real concern is the resulting impact on the structures to be designed and how often the different loads from earthquakes are expected to occur.

A more appropriate definition may then read as follows:

> The design value is the threshold for which the probability for surpassing it at least once during a chosen lifetime is the specified risk.

This is not the finite version. The word value should later be exchanged with a more descriptive one. But the effects from earthquakes are not well described by the present measures of impact. This question is still an open one.

Another point in this definition is very important. The design value is relative to the lifetime and the risk. In this way the word "reasonable" from the former definition has been replaced by these two quantities. Of cause, the values to be chosen for them must be reasonable too, but now it is clear we have made a choice.

Let me return to the measure of destructive power of the shakings. Intensity scales have for a long time been used to classify the amount of damage. Several improvements have been made to these scales, but they still consist of classes each describing in verbal forms different levels of damage. The intensities are the numbering of these classes. They do not constitute variables like the physical quantities we are used to. It is very difficult if not impossible to deduct from the intensity the dynamical behavior during an earthquake.

Another measure is the response spectra. The US Atomic Energy Commission has recommended some "standard" response spectra USAEC (1973).

The response spectrum is an example on a multivalued measure of earthquake effect. It has the drawback it cannot be calculated like other spectra by transformations because its definition includes determinations of maximum values of response motions. Then a reverse transformation is also impossible. We must hope that future developments will overcome this difficulty and provide us with a measure which has a more easy mathematics and still describe the impact on structures from earthquakes.

However! The US spectra are all relative to one single parameter: the maximum horizontal ground acceleration.

So in this case the design value to be determined by the calculated risk method is the maximum horizontal ground acceleration at the site of interest.

We know this quantity is not sufficient as a measure of damage. But it has been used in several investigations. And the dependence on magnitude and distance has been studied very much.

In figure 2 Q is the site of interest and $d\omega$ is an areaelement in an earthquake region. Let $\lambda_a d\omega$ be the frequency of occurrence of earthquakes which at Q induce horizontal accelerations greater than a specified value a.

This λ_a is the number of such earthquakes per areaunit and per timeunit. It is dependent of the distribution of earthquakes and of the damping between $d\omega$ and Q.

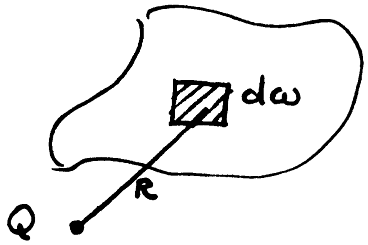

Figure 2

If we integrate over all areas with earthquakes we will get the frequency of cases where the acceleration at Q is greater than a

$$\Lambda_a = \int \lambda_a d\omega$$

The calculated risk is then

$$r = 1 - e^{-\Lambda_a t} \qquad \text{(cfr. 2)}$$

The important quantity in this procedure is λ_a. Normally λ_a is not determined directly, but it can be calculated from the distributions of earthquakes and the relations between acceleration and magnitude, distance and damping.

As an example, the distribution of earthquakes may be given by

$$\lambda_M = n e^{-\gamma M} \qquad (4)$$

where M is the magnitude and λ_M is the number of earthquakes larger than M.

The acceleration may be related to M and R, the distance from $d\omega$ to Q by

$$a = b_1 \, e^{b_2 M} R^{-b_3} \qquad (5)$$

Solving (5) for M we determine the magnitude corresponding to a. When this M is introduced in (4) we get the wanted

$$\lambda_a = n \left(\frac{b_1}{a}\right)^{\frac{\gamma}{b_2}} \cdot R^{-\gamma \frac{b_3}{b_2}}$$

The parameters n, b_1, b_2, b_3, and γ may vary in the different regions. If the assumed relations are oversimplifications λ_a cannot be given by an expression but only by numerical values.

The material in Båth's catalogue has been used to determine some values of λ_M in the regions surrounding Denmark. The results are given in table I.
The parameters in (5) are not known for Scandinavia, but Orphal and Lahoud (1974) who investigated ground motions in California found the values

$$b_1 = 6.6 \cdot 10^{-2} \text{ gravity}$$
$$b_2 = 0.40 \cdot \log_e 10$$
$$b_3 = 1.39$$

when M is local magnitude and R in km.

M	>2	>3	>4	>5
Western Norway	23	8.2	3.1	.34
Oslo Region	65	15.1	3.2	.80
Central Sweden	22	11.6	3.7	.47
Southcoast of Norway	8.1	1.8	.60	
Southern Sweden	14.5	4.1	1.35	

Table I: λ_M events/km^2 year$\cdot 10^6$

If the design acceleration is 50 $cm \cdot s^{-2}$, M is 6.7 already at a distance of 100 km. Båth's material does not allow estimation of λ_M for so large M.

The existing values of λ_M could be extrapolated by (4) if this distribution is valid also for large M, but G.M. Molchan et. al. (1970) have shown that a straight line representation of (4) bends with 80% confidence.

This work has shown low risk for even moderate acceleration but reliable figures can only be given when λ_M and the acceleration relations have been determined for Scandinavia.

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The Seismicity of Fennoscandia

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Summary

The systematic collection of macroseismic data on earthquake occurrence in Fennoscandia began in the 1880's. Prior to that time the macroseismic information is fragmentary and incomplete, although the essential data have been preserved at least for the largest earthquakes. Using the macroseismic and seismograph data available, we have investigated the seismicity for Fennoscandia covering the time interval 1497 to 1973. The earthquake activity is subdivided in 4 zones: Telemark-Vänern, Western Norway, Lappland and Bothnian zones which account for most of the reported seismic activity. There is some correlation between geological and geophysical information pertinent to the area and earthquake occurrence. The seismic activity of Fennoscandia is discussed in the framework of intraplate tectonics and the driving forces connected with the opening of the North Atlantic Ocean.

Introduction

The systematic collection of macroseismic data on earthquake occurrence in Fennoscandia began in the 1880's when the use of questionnaires was initiated, and prior to that time macroseismic data has been extracted from newspaper reports and similar sources. The oldest known report on seismic activity in Fennoscandia dates back to 1497 (Kjellén, 1903) when a relatively large earthquake was felt in Sweden, and the oldest reports for Norway and Finland date back to 1612 (Keilhau, 1836) and 1610 (Renquist, 1931), respectively. The classical analysis of available macroseismic observations is due to Båth (1956), who published an excellent earthquake catalogue for Fennoscandia covering the period 1891-1950.

Instrumental observations of Fennoscandian earthquakes date back to 1904 and 1905 when the first mechanical pendulum seismographs were installed in Uppsala and Bergen. In the period 1955-1965 the Fennoscandian seismograph network was expanded through the installation of modern, high-gain electromagnetic seismographs, and in 1971 another generation of instruments was introduced with the large aperture Norwegian Seismic Array (NORSAR). The Fennoscandian network of stations represents a vast improvement in the capability of monitoring the seismic activity in this area, albeit it is not considered adequate for seismo-tectonic studies of local earthquakes.

The available macroseismic observations have been used by Kjellén (1903), Kolderup (1913), Kvale (1960) and Båth (1953, 1972) for correlating the seismic activity with known tectonic features such as faults tied to Caledonian mountain folding, the uplift of Fennoscandian land masses during Tertiary times and the on-going glacial rebound. More recently, Husebye et al (in press) have made an extensive analysis of earthquake occurrence in Fennoscandia in the light of intraplate tectonics.

Earthquake Occurrence in Fennoscandia

For the time before 1890 the main macroseismic data sources in the case of Norway are the works of Keilhau (1835), Thomassen (1888) and Kolderup (1913). The corresponding macroseismic data for Sweden and Finland (e.g., see Kjellén, 1903, 1909; and Renquist, 1931) is less suitable for a systematic analysis, with the exception of the largest earthquakes. It should be pointed out that the seismic activity is relatively high in Norway, modest in Sweden and low in Finland. For the time period 1891-1950 the classical work is that of Båth (1956), his earthquake catalogue for this interval is both homogenous and of high quality. Only for the time since 1951 has the instrumental situation been such that one should be in a position to undertake a much more detailed study of the Fennoscandian seismicity, which is characterized by the relatively infrequent occurrence of small earthquakes. Strangely enough, macroseismic information here is still highly esteemed, simply because a comprehensive and systematic earthquake catalogue primarily based on local seismograph records has, to our knowledge, so far not been published. This is attributed to shortcomings of the local seismograph network, and we would here point to the large station separation, the poor azimuthal coverage for earthquakes in the coastal areas of Norway and the difficulties in obtaining original seismogram records, which are stored in three different countries. The most serious problem, however, is that of discriminating between the relatively few (tectonic) earthquakes and the very many artificial events from quarry blasts, naval activities in the adjacent waters, etc. These shortcomings of the seismograph network are, however, not critical for earthquakes with magnitude greater than 4.0-4.5, because these events are also recorded by stations outside Fennoscandia. Considering also that the macroseismic detectability for small and even moderate sized earthquakes is dependent on the population settlement, we believe that the most reliable and essential information, especially with respect to seismic hazards, can be found in a map containing only events with magnitude greater than or equal to 4.5 (Fig. 1).

A critical parameter in seismicity studies in the space-time relationship between the largest occurring earthquakes within the region under investigation. An interesting feature here is that most of the largest shocks ($M \geq 6$) are restricted to the period 1863-1913, while 3 other strong earthquakes took place between 1819 and 1836. There is no indication of spatial migration in the distribution of the largest earthquakes and

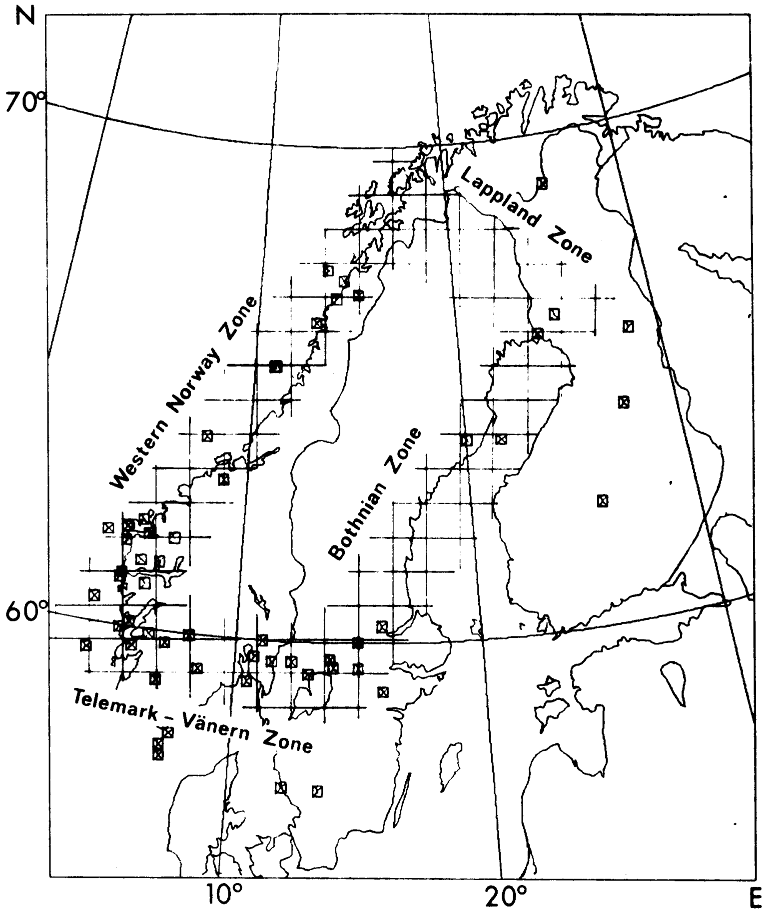

Fig. 1 Fennoscandian earthquakes for the time period 1497-1973 and with a magnitude M greater than 4.5. An outline is also given of the 4 seismicity zones defined in this paper. Note that the definition of the zones is based on much more seismicity data than is actually displayed in this figure.

and neither do we find any clear regularity in occurrence of large events in specific areas. In other words, the very largest earthquakes observed seem to be isolated phenomena. This points towards exceptionally long recurrence intervals, i.e., a large time lag between two large events occurring within a tectonically uniform area. As it is considered unlikely that any major earthquake occurring after 1600 are left unreported, the recurrence interval is probably larger than 350 years for earthquakes with magnitude M larger than 6.

Discussion and Interpretation

As of today, observed tectonic activity within plates, of which the seismicity of Fennoscandia is an example, remains largely unexplained. In this respect, recent progress in plate tectonics on mechanisms of stress accumulation in the lithosphere (Turcotte and Oxburgh, in press) and the relative importance of different plate driving mechanisms (Turcotte and Oxburgh, 1973; Solomon et al, 1975; Forsyth and Uyeda, 1975) are likely to give a better understanding of intraplate distribution of stresses. The usefulness of these modern concepts of plate tectonics have already been demonstrated in several studies of intraplate earthquakes, and this should be highly relevant to an improved understanding of the Fennoscandian seismicity (e.g., see Mendiguren, 1971; Forsyth, 1973; Sbar and Sykes, 1973; and Sykes and Sbar, 1973).

There are many sources of stress in the lithosphere. According to Forsyth and Uyeda (1975) the most important driving forces of plate motion are the mantle drag force, the ridge push and the slab pull. The latter is not relevant here as there are no subduction zones near the western part of the Eurasian plate, while the two former ones have to be considered in relation to the tectonic history of Fennoscandia. A significant phenomenon here is the north and northeasterly movement of Fennoscandia which took place following the breakup of Pangaea in Permian times. There are two tectonic aspects of this northward migration of Eurasia; first, effects of membrance stresses due to increasing principal radii of curvature (Turcotte, 1974), and secondly, either the asthenosphere is passively resisting the lithospheric movement, or the asthenosphere is dragging the lithosphere, an ambiguity which cannot be properly resolved as data on mantle flow rates are not available. The ridge push is an important plate driving force, and is physically explained in terms of the gravitational push exerted by the upwelling material at mid-oceanic ridges (Orowan, 1964; Forsyth and Uyeda, 1975). With the opening of the North Atlantic approx. 62 m.y.b.p. this force is likely to have created strong compressive stresses, possibly within Fennoscandia itself. Intraplate earthquake studies imply dominant horizontal stresses with maximum compression perpendicular to the oceanic ridge axis (Mendiguren, 1971; Forsyth, 1973; Sykes and Sbar, 1973). However, the stress distribution within Fennoscandia and in particular the Norwegian Sea is likely to be rather complex, in view of the 'twisting' of the North Atlantic and Arctic Ocean ridges (Aki and Husebye, 1974). The relatively abundant number of in situ stress measurements for Fennoscandia itself (Hast, 1969, 1973) also point towards a somewhat complicated stress pattern. In a critical review of the available data for this area, Ranalli and Chandler (1975) found that the principal compressive stress axis is roughly NW-SE in southern Fennoscandia, while in northern Fennoscandia the axis gradually changes towards a northerly direction.

The types of stresses discussed above are tied to past movements of the Eurasian plate and to the opening of the North Atlantic. In this respect we cannot ignore the possible stress effects due to loading and unloading of the lithosphere by the Tertiary oblique uplift of particularly western Norway, the sedimentation off the western coast and the most recent glacial episode in Fennoscandia. Remnant stress, i.e., stress locked in the rock during a previous episode of tectonic deformation, may also be of some importance for the present stress distribution within a certain region.

Evidence on tectonic movements such as locations of dominant fault lines is relatively scarce for Fennoscandia, with the exception of Finland where the picture is quite blurred (Tuominen et al, 1973; Kukkamäki, 1963). The trend direction patterns, however, are dominantly parallel and perpendicular to the Caledonian folding axis. Numerous seismic profiling, gravity and magnetic surveys have been undertaken in Fennoscandia (for general references see Der and Landisman, 1972; Massé and Alexander, 1974; Ramberg, 1975; and Åm, 1975) but this kind of information has seemingly no direct bearing on the seismic activity.

The seismicity pattern of Fennoscandia is somewhat diffuse, which is normal for intraplate earthquake occurrence (Sbar and Sykes, 1973). We found it convenient to subdivide the Fennoscandian earthquakes in 3 primary zones: namely, the western Norway zone, the Telemark-Vänern zone and the Bothnian zone; plus a weaker one called the Lappland zone (Fig. 1).

The western Norway seismicity belt is in northern Norway confined to the coastal area while the epicenters become more dispersed south of 64°N. The west coast area of Norway is relatively prominent seismically and also geophysically (Husebye et al, 1975). Also, in-situ stress measurements discussed by Ranalli and Chandler (1975) indicate a complex stress field in this area. A characteristic feature here is that this zone is within the Caledonides and its strike direction is parallel to the folding axis; this can be taken as evidence for the importance of remnant or locked-in stresses from the above mountain folding period. Another feature is that the epicenters are mainly confined to the coastal areas where the relief is very pronounced due to the Tertiary oblique uplift (Torske, 1972), which in turn may indicate additional loading stresses and/or zones of weakness. A geologic boundary line of faults in this area has been suggested (Holtedahl, 1933), although neither seismic profiles nor other geophysical observations are confirmative in this respect.

The Telemark-Vänern seismicity zone which represents a *geographical* envelope of earthquake epicenters in this area is typified by graben structures. The most prominent one is the Oslo Graben (for geological and geophysical descriptions, see Oftedahl, 1960; Ramberg, 1975; and Aki et al, 1975) which is the northern chain in Stille's (1925) Mittelmeer-Mjøsen zone. According to Lind (1971) the Lake Vättern area (58°N, 15°E) is a minor graben, while graben-like structures are also hypothesized in the Lake Vänern area (I. Ramberg, personal communication). A slight clustering of epicenters can be found around these graben structures, pointing towards a causal connection between these structures and earthquake occurrence, possibly through release of locked-in stresses. An alternative explanation is, however, that the orientation of the Telemark-Vänern belt is in fact tectonically significant.

The Bothnian seismicity belt, parallel to the Caledonian folding axis, goes from Lake Vättern to the northern end of the Gulf of Bothnia. The latter area has the most pronounced earthquake activity, and there may be a correlation between the relatively strong glacial uplift and the earthquake occurrence in this particular area (Kjellén, 1903; Båth, 1953). Also, this zone is characterized by block faulting (I. Ramberg, personal communication).

The Lappland seismicity zone is only weakly defined by the data available to us, but a series of earthquakes in 1973/74 was entirely within this zone (Porkka and Korhonen, 1975). It should also be noted this area always has been thinly settled, so the macroseismic information available would necessarily be scarce. Geophysical evidence in support of this zone is the pronounced Malangen-White Sea lineament based on Nimbus satellite imagery data (Tuominen et al, 1973) and the change in orientation towards a NS-direction of the in-situ stress measurements (Ranalli and Chandler, 1975).

The above seismic zones account for most of the seismic activity in Fennoscandia during the last five hundred years. The seismic activity is typical for intraplate earthquake occurrence, by neither exhibiting a too clear spatial zoning nor an obvious correlation with geological and geophysical information pertinent to the area. The likely reason for this is that Fennoscandia has been through several tectonic cycles, which in turn is reflected in the present complex stress distribution. Consequently, an improved understanding of the on-going seismic activity here and at the same time a better assessment of dominant stress sources requires more in-situ stress measurements. Equally important would be focal mechanism solutions for earthquakes occurring within Fennoscandia.

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Probability model for peak ground accelerations in Sweden

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read by O. Dahlman

Summary

From the statistical distribution of the earthquakes, estimated from observations, and from a relation between peak ground acceleration, earthquake magnitude and distance between site and hypocenter, the probabilities of exceeding given accelerations at the site can be computed. A conservative method of estimating the earthquake distribution around the site is discussed. The method is used to estimate the probable ground accelerations in the three biggest cities Stockhom, Gothenburg and Malmö. The computations show that the rare earthquakes having M>6, are the major contributors to the seismic risk.

1. Introduction

In this paper we present and apply a simple but general method of estimating the seismic risk in terms of probability of having peak ground accelerations exceeding a given level, or, equivalently, the accelerations that will be exceeded with a given probability.

In most low seismicity areas, as in Sweden, very little is known about the earthquake processes. The data, especially concerning the large and rare earthquakes, is often very meagre. At the same time these large earthquakes are important for the risk analysis. This means that the estimated probabilities will necessarily be uncertain. We want however to show how a straight forward probability computation works in a case study based on available knowledge of the earthquakes and of the wave propagation of the area. We will look at the seismic risk at three sites Stockholm, Gothenburg and Malmö, the three biggest cities in Sweden. In figure 1 we show the location of the sites together with the epicenters of observed earthquakes in Scandinavia during the period 1891-1950 (Båth, 1956).

2. Methods

2.1 The principle

We assume a very simple earthquake model where the earthquakes are completely described by 5 parameters, their epicenters (2 parameters), depths, magnitudes and times of occurrence. Furthermore we assume that the peak ground acceleration at the site due to a given earthquake is a function of only the earthquake magnitude and hypocentral distance from the surface site. If the function relating acceleration to magnitude and hypocentral distance is known together with the joint statistical distribution of the earthquake parameters the probability of exceeding an acceleration a_0 can be directly computed. This is done by integrating the joint frequency function over the volume of the 5-dimensional earthquake space containing the earthquakes giving acceleration greater than a_0 at the site. This volume is determined by the acceleration a_0, the relation between acceleration, magnitude and hypocentral distance and the time period we are talking about when discussing probability. The main problem with the method is the estimation of the earthquake distribution and the acceleration dependence on magnitude and distance.

2.2 Acceleration as a function of distance and magnitude

No relations between ground acceleration, distance and magnitude in Scandinavia have been published. Furthermore not one acceleration measurement in the epicentral area of a Scandinavian earthquake has been made. We thus have to rely on theoretical considerations and results from other regions. We have calculated the distance dependence for SH-waves using a crust model chosen in agreement with profile studies (Vogel, 1971) by a method outlined by Bullen (1963). The result is shown in figure 2. Note that the distance used is the hypocentral distance as then the same curve can be used for all source depths with good approximation.

As the definition of the magnitudes of the Scandinavian earthquakes introduced by Båth (1953) based on macroseismic observations roughly coincides with the Richter magnitude, we decided to use the magnitude dependence found by Guthenberg and Richter (1956)

$$\log a = C + 0.81M - 0.027M^2$$

where C is a constant.

This relation defines together with the distance dependence of figure 2 the variation of the ground acceleration due to distance and magnitude.

The level of our acceleration function remains to be determined, that means the value of the constant C. As the large earthquakes are the major contributors to the seismic risks we want to determine the constant from observations of a large Scandinavian earthquake ($M>6$). Due to the lack of direct acceleration measurements we have to use macroseismic observations. The observations of the large 1904 earthquake, $M = 6.5$ (Båth 1956), have been reported by Svedmark (1908). Estimating the modified Mercally intensity on bedrock from the reports and making use of the correlations between modified Mercalli intensity and peak ground acceleration found by Trifunac and Brady (1975) we can estimate the constant C. By this procedure we get the resulting function relating acceleration to magnitude and distance to fit the macroseismic observations of the largest shock for at least two hundred years, the 1904 earthquake. In figure 3 we have plotted the resulting relation between magnitude and distance for some bedrock acceleration levels.

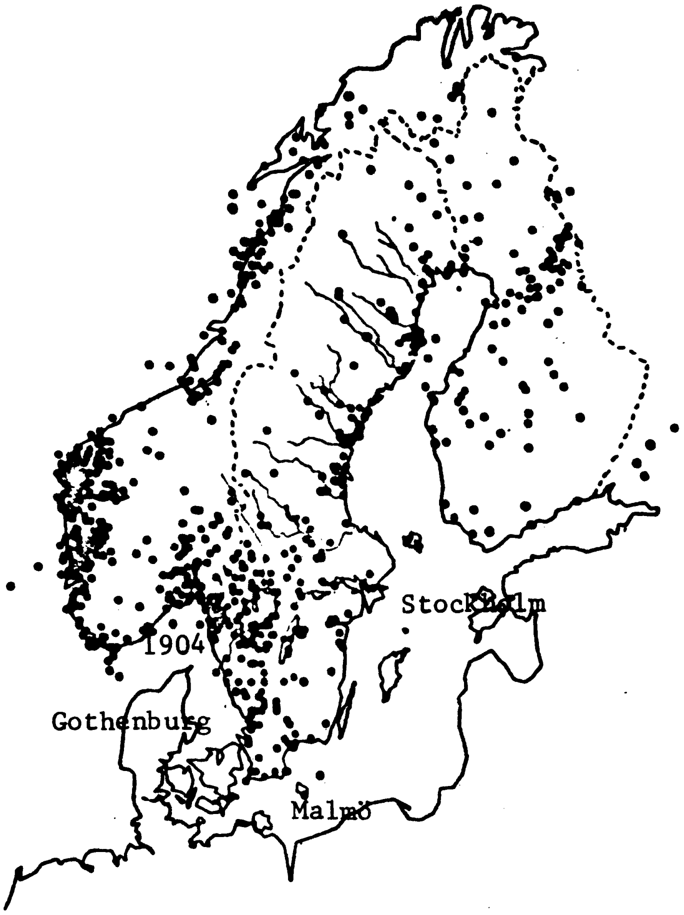

Figure 1. The epicenters of the earthquakes 1891-1950 based on macroseismic observations. The three sites for which the seismic risks have been calculated and the epicenter of the M=6.5 event of 1904 are also shown.

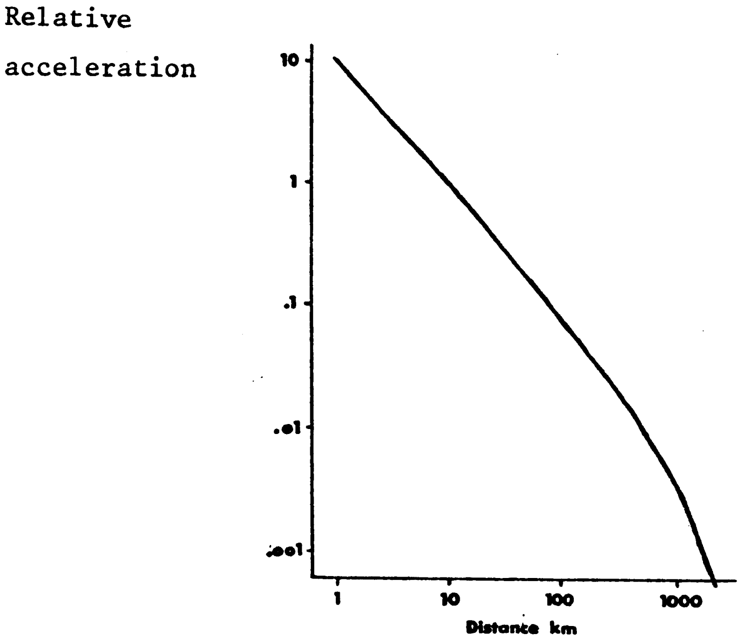

Figure 2. The theoretically achieved distance dependence of SH-waves using a Scandinavian crust and upper mantle model.

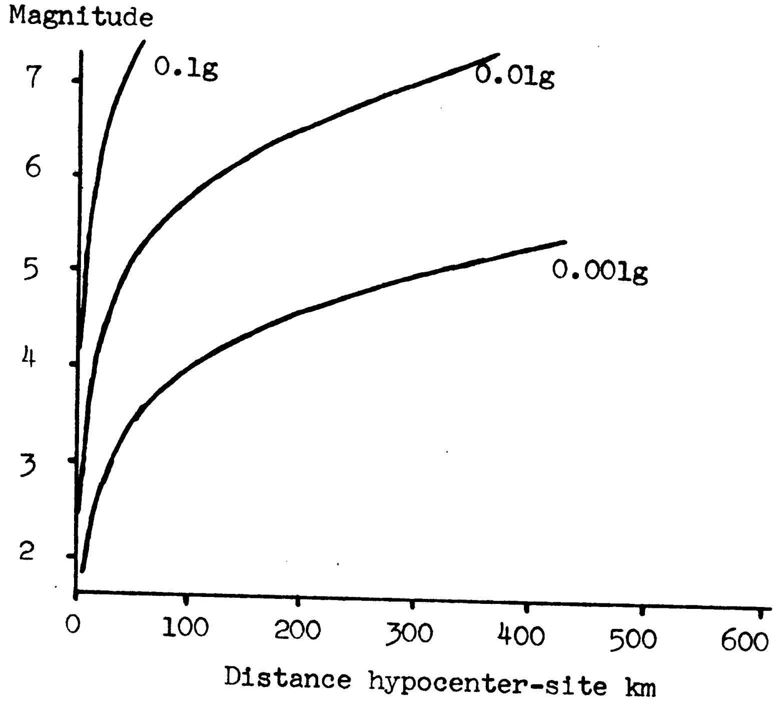

Figure 3. The relation between peak acceleration on bedrock, magnitude and hypocentral distance used in the calculations.

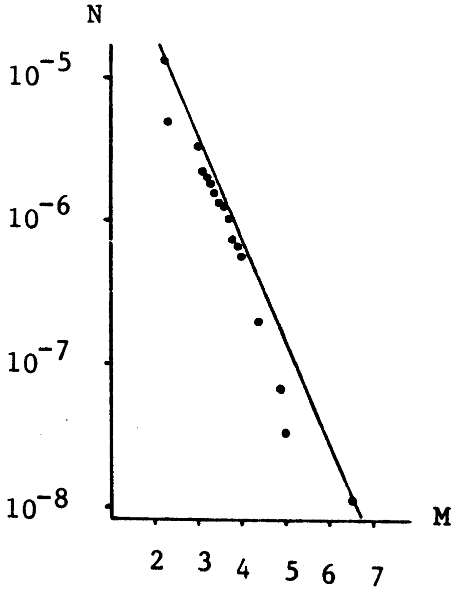

Figure 4. The resulting observed mean number of earthquakes , N, greater than M per year and square kilometer around the Stockholm site. For each magnitude value the points in the figure represent the highest value found for any radius around Stockholm assuming uniform distribution within the circle.

2.3 The earthquake distribution

The earthquake distribution is for $M<6$ estimated from the data by Båth (1956) covering the period 1891-1950 and for $M>6$ estimated from earthquakes observed during the period 1650-1975.

We assume epicenter, depth, magnitude and time of appearance to be independent variables. We can thus discuss these parameters one at the time.

Then we make the assumption that the distribution in time is a Poisson distribution with different mean value for different magnitudes.

The epicenter distribution is very essential when discussing seismic risks. For the sites discussed here we decided to use the following conservative estimate: Calculate for circles of different radius centered at the site the number of earthquakes with magnitude greater than M per year and square kilometer within the circle by using the earthquake catalogue. Take the highest value found for any radius less than 600 km and let this value represent the epicenter distribution around the site. This means that we assume a uniform epicenter distribution around the site. If we have no linear or point clustering close to the site this surely gives a conservative estimate. Note that for different magnitudes we can get different radii of the circles. In figure 4 we have plotted the resulting numbers of observed earthquakes per year and square km for different magnitudes around Stockholm.

As the earthquake data are based on macroseismically observed earthquakes, the non uniform population distribution means that small earthquakes may pass unobserved. In the calculations we want the acutal number of earthquakes and not only the observed number. This is achieved by taking the detection probability for the different magnitudes into account. Figure 5 shows the detection probability function used in the calculations. As the small magnitude earthquakes contribute very little to the seismic risk the results are very insensitive to variation of the curve of figure 5.

Finally we need the depth distribution. No depth determination based on close recordings have been made in Sweden. By using the macroseismic data of the earthquakes 1891-1950, the maximum intensity and the radius of perceptibility, together with the distance attenuation of figure 2 and the assumption that three intensity levels correspond to a factor 10 in acceleration (Trifunac and Brady, 1975) we estimated the depths of the earthquakes within 600 km of the site Stockholm. See figure 6. The calculations were made for two values of the rather uncertain value of I_1, the intensity limit of perception. In the figure we have also marked the uniform distribution between zero and 36 km depth used in the calculations.

2.4 The computations

As we for each magnitude assume a uniform distribution within the crust around the site the probability calculations are very simple. When calculating the probability of exceeding the acceleration value a_o at the site we determine for each magnitude M_i the volume of the upper 36 km of the crust within which the earthquake must be located to exceed a_o at the site. This volume multiplied by the number of earthquakes per year and volume unit gives then the number n_i of magnitude M_i earthquakes per year exceeding a_o. By summing the contributions from all magnitudes up to the assumed largest possible earthquake (in our case M = 6.8) we get the total number n of earthquakes per year exceeding a_o at the site. As we assume the earthquakes to be Poisson distributed in time the probability per year, p, of having one or more earthquakes giving acceleration a_o is given by

$$p = 1 - e^{-n}.$$

3. Results and discussion

The resulting relations between peak ground acceleration and the probability per year to exceed that acceleration is shown in figure 7. It turns out by the computations that the large earthquakes (M>6) are the major contributors to the seismic risks. For instance at Stockholm 80% of the probability of having 0.1 g peak acceleration is due to shocks of magnitude above 6.0.

The much higher risk level at Gothenburg is mainly due to that site's smaller distance to the 1904 earthquake with M = 6.5. The difference between Malmö and Stockholm is very much dependent on the M = 4.5 earthquake within some 40 km of Malmö in 1930.

The three relations of figure 7 are conservative estimates at each site. As a consequence of the conservativity these three relations can not be realistic at the same time. This is so because we make different assumptions about the epicenter distribution of the Scandinavian earthquakes when looking at the different sites. These different assuptions are inconsistent. The reason for making these assumptions is to get a reasonable conservative estimate at each site. If more knowledge about the earthquakes is available more consistant assumptions can be made at the different sites without loosing the conservativity.

However this inconsistency means that in general if one wants the probability of having a certain acceleration at any of several sites one have to make new estimates of the epicenter distribution and go through the computations to get consistency and a reasonable estimate of the probability.

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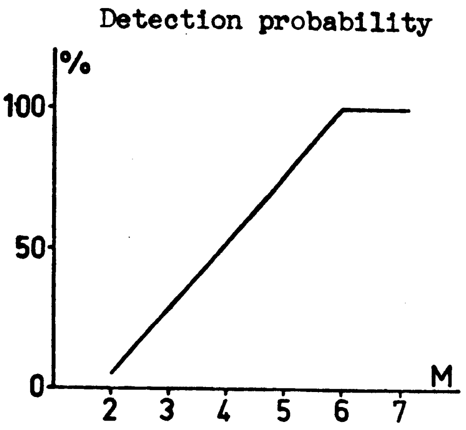

Figure 5. The detection probability used when estimating the real number of earthquakes from the observed number.

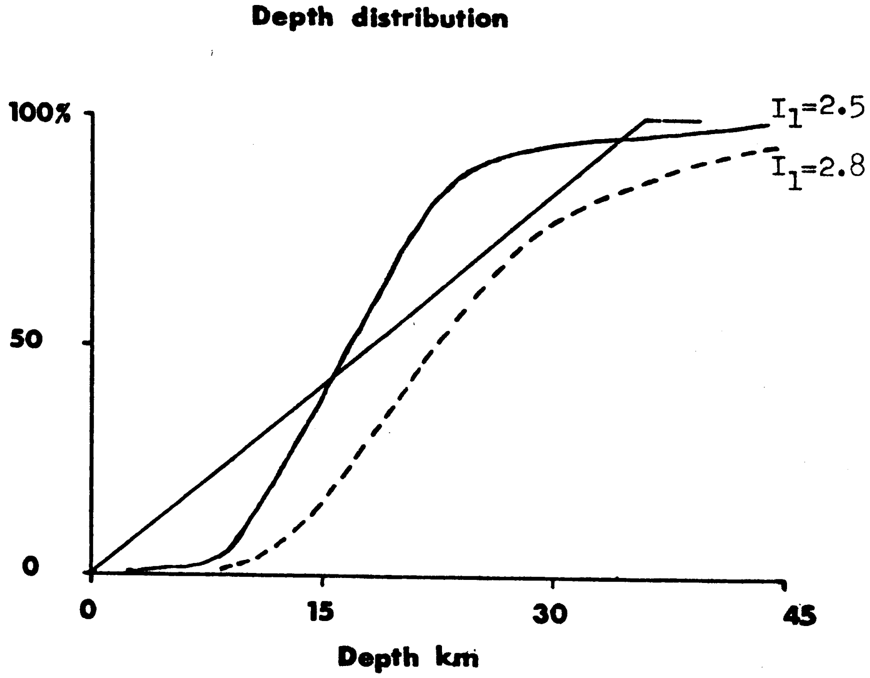

Figure 6. The depth distribution of the earthquakes within 600 km of Stockholm estimated from macroseismic observations. I_1 means the intensity value corresponding to the limit of perception. The uniform distribution between 0 and 36 km shown in the figure was used in the calculations.

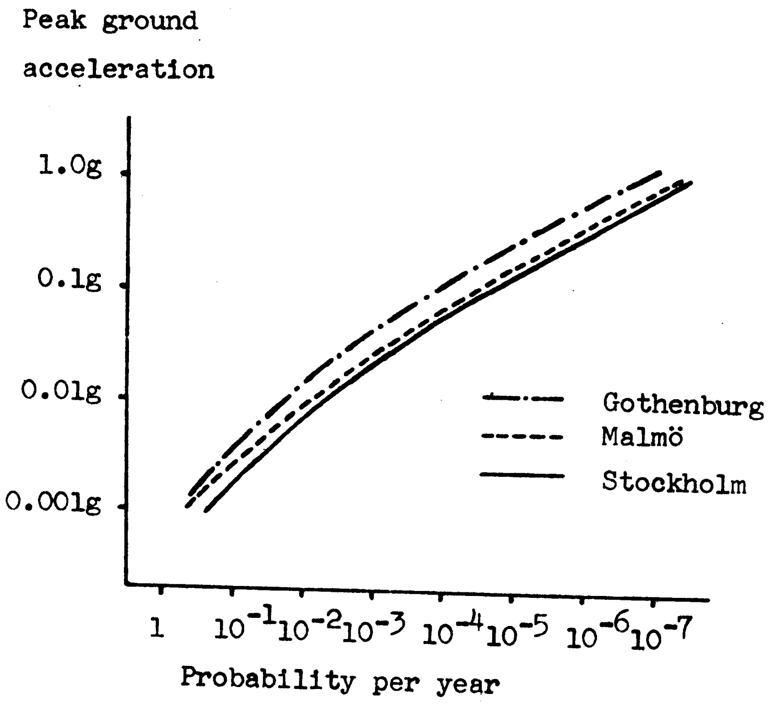

Figure 7. The resulting relations between peak bedrock acceleration and probability at the three sites.

The UK approach to hazard assessment

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Summary

This approach takes account of the limitation of total magnitude range for UK events, as revealed by Gumbel's Third Distribution, and derives an estimate of the combination of magnitude and distance which is most likely to produce any given value of intensity. It thereby avoids some of the problems of defining real hazards in terms of historical intensity, and of extrapolation to very long return periods.

The earthquake history of the United Kingdom since AD1800 has been processed (Lilwall 1976) to yield a map of earthquake epicentres, a map showing the estimated maximum intensities in the period under review, and a map of the maximum intensity to be expected over a 200-year return period. These maps show limited areas of relatively high activity which closely represent maxima of short-term hazard, but it is not clear how far the distribution of epicentres over the rest of the country can be linked to permanently active tectonic regions as compared with strain release distributed at random. In particular, it is not possible to say whether the areas which have suffered the least disturbance since 1800 are the ones which can be expected to remain aseismic in the future, or whether they are the ones in which the largest earthquakes are to be expected when release eventually takes place. The fact that two of the largest earthquakes on record have occurred in comparatively inactive areas tend to support the latter hypothesis.

The subsequent approach has therefore been to concentrate long-term statistical analysis on the whole history of background seismicity, regarded as a single population, by fitting the parameters of Gumbel's third distribution, (Gumbel 1958). In this approach, P is the probability that the largest known value of a parameter A is not exceeded in a time interval T. The observed extremes of A within each sampling interval are ranked in increasing order of magnitude, and the value of P for the j^{th} sample is given by

$$P(A_j) = j/(N+1)$$

where N is the total number of samples. Gumbel's theory then yields

$$P = \exp\left[-\left(\frac{W-A}{W-U}\right)^K\right]$$

where W,K and U are constants to be found from the distribution. In particular, we see that W is the limiting value of A.

On the assumption that the Gumbel distribution could represent the parameter P for the land area of Britain, Lilwall found W = 5.75 as the limiting value of m_b and calculated annual probabilities for events of lower magnitude within an epicentral distance d as follows:-

$m \geqslant 4.0 \qquad P = 4 \times 10^{-6}d^2$

$m \geqslant 4.5 \qquad P = 2 \times 10^{-6}d^2$

$m \geqslant 5.0 \qquad P = 7 \times 10^{-7}d^2$

$m \geqslant 5.5 \qquad P = 5 \times 10^{-8}d^2$

Clearly, the expectation of an event near the limiting value of m_b becomes highly unstable.

Lilwall used the relationship

$$I = -2.5 + 3.1m_b - 1.9\log_e D$$

to define the intensity in terms of a modified hypocentral distance D, where

$$D^2 = h^2 + d^2 + k^2,$$

h is the focal depth and k is an empirical factor (introduced by Esteva, 1967) which can allow for the lateral extent of the focal region. Eliminating D^2 for any given value of k, we can plot the annual probability of occurrence against earthquake magnitude m_b for any given value of I. Preliminary results are plotted in Fig 1.

If we assume that an earthquake of any magnitude can be represented by a point focus at the surface, we find that the curves all peak for a value of m_b of about 5.1. If the earthquakes are taken to have an average depth and extent for which $h^2 + k^2 = 500$, the probabilities of experiencing all intensities are depressed, and maximum hazards, particularly for higher values of intensity, occur for somewhat larger magnitudes.

The method is clearly extensible to other spatial distributions of earthquake foci. It has the advantage of transferring dependence to some extent from the exact definition of the concept of Intensity towards the situation in which an earthquake of given magnitude can be adopted as the one most likely to cause damage. This provides a relevant criterion for the selection of an appropriate strong-motion seismogram, to which techniques of spectral analysis in relation to resistance of proposed structures can be applied. In so far as the highest intensities are most likely to arise from the occurrence of the design earthquake in conjunction with very small values of D, return periods tend to infinity in an orderly manner as the volume available to the source tends to zero.

This work has been supported by the Natural Environment Research Council of the United Kingdom and is published by permission of the Director of the Institute of Geological Sciences.

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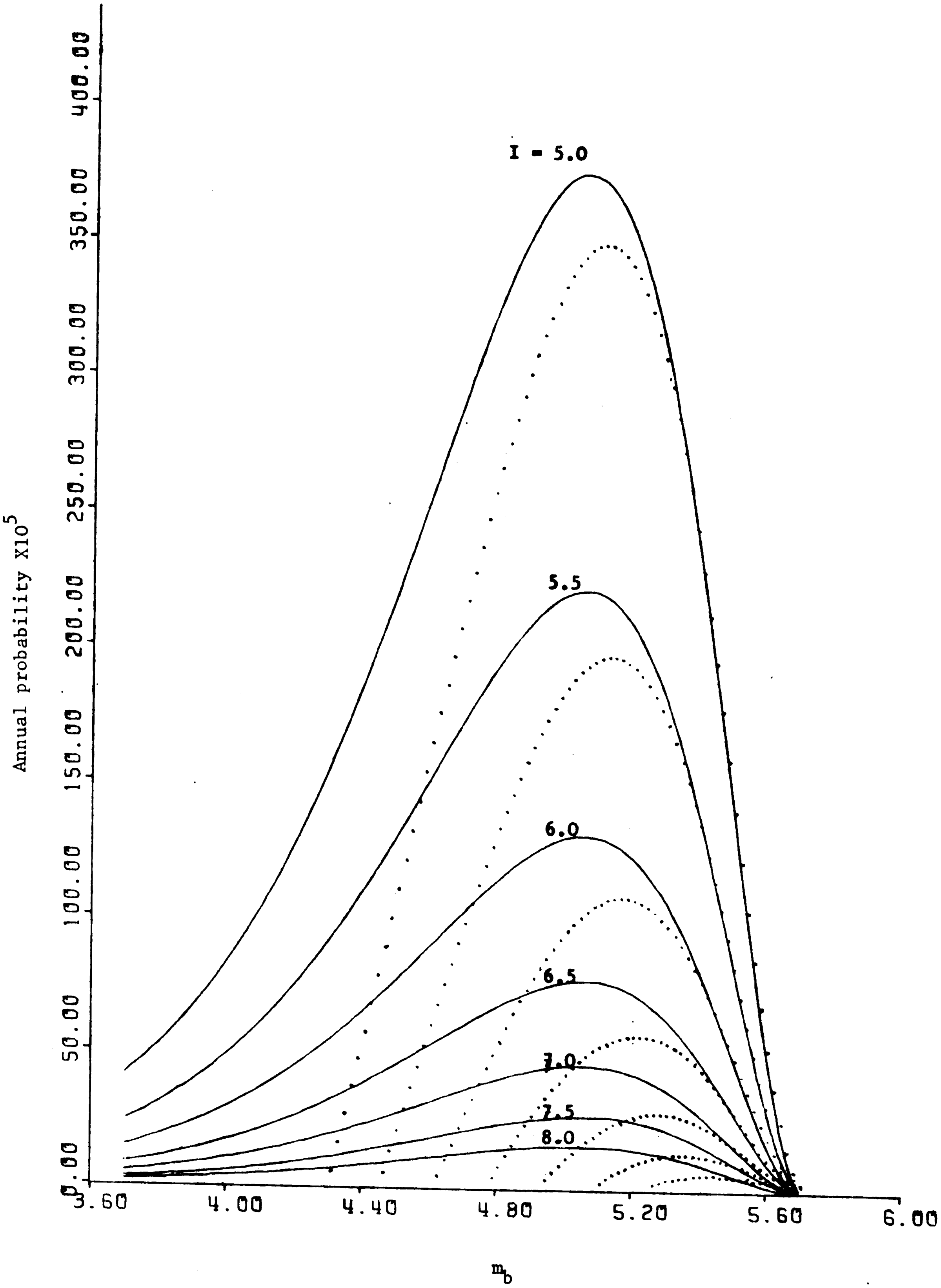

Fig 1. Expectation of earthquakes of magnitude $\geqslant m_b$, within the region for which m_b generates intensities $\geqslant$ I. Solid lines, surface point foci. Dotted lines, $h^2 + k^2 = 500$. The tendency for the dotted lines to rise above the solid ones at high magnitudes is probably a mechanical error in the plotter.

First draft of an earthquake zoning map of Northwest-Germany, Belgium, Luxemburg and the Netherlands

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Since several years seismological agencies are asked by national governments as well as by building contractors, to provide the seismic parameters of importance for the consideration of the safety of nuclear power plants. The answer to such requests involves a detailed study of historical events, of present-day records, of the tectonic environment and of the ground conditions, apart from the relevant theoretical background necessary for a correct interpretation of these data in terms of risk.

Seismic effects are tied to the regional seismo-tectonic system, which is not confined to areas within or outside national borders. This is the reason that, especially in the region concerned, international co-operation is a necessity. The realization of this need, in the course of 1975, led to successive work-meetings of the authors in Heerlen (Netherlands), Uccle (Belgium) and Bensberg (Germany) in order to reach homogeneity of the basic materials of the different countries. At these work-meetings the methods used were discussed, national catalogues were compared and brought into agreement, and uniformity in the presentation of micro- and macro-seismic data was established.

From earlier and present work it has become clear that the seismic activity in the region is localized along two main axes: one pointing to the West through Belgium near the Northern edge of the old Cambrian Brabant massif, and the other one in Northwest direction into the Netherlands following the tectonic graben of the river Roer. At the intersection of these two zones along the Northern edges of the Eiffel massif in Western Germany the seismicity is greatest.

As a conclusion of this joint study the construction and compilation of a series of seismic maps (scale 1:1.000.000), covering the domain inside of 49^{o}N to 54^{o}N and 1^{o}E to 10^{o}E, and an earthquake catalogue for the region are planned. The accompanying figure is a first draft of a seismic zoning map, giving an insight in the maximal intensity (MMS scale) that at any locality of the region may be reached. Apart from the known seismic data this map is also based upon the local trend and intensity of tectonic structures. Ground conditions have not been considered, which means that for any site in the region additional local studies have to be executed before a complete risk evaluation is possible.

It is the intention to produce the following types of maps:

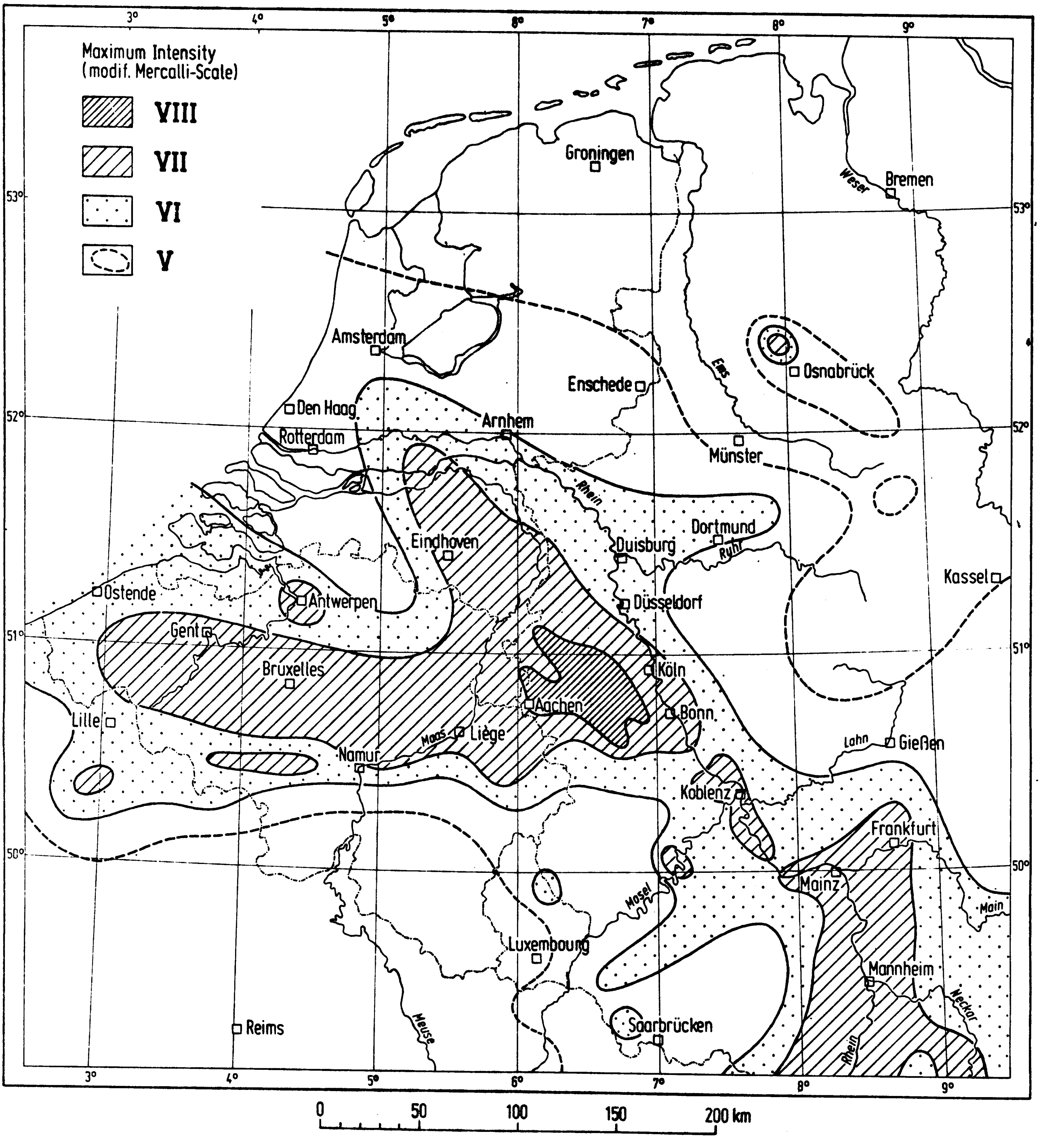
1. epicenter map of known earthquakes in the period 1500-1975 of magnitude $m > 4$, with an indication of magnitude and accuracy of location;
2. map of observed maximal intensities (MMS scale);
3. tectonic map with Quaternary (and Tertiary) faults, depth of base Pleistocene and outcrop of Paleozoic basement;
4. map of expected maximal intensities (MMS scale V-VIII) based on historical seismicity and tectonic structure (= seismic zoning map); and
5. map of recurrence periods or annual probabilities.

The catalogue will comprise the known earthquakes of the region with magnitude $\geq 3\frac{1}{2}$ and/or intensity $\geq$ V for the period 1500-1975.

An explanatory guide will be joined to maps and catalogue.

SEISMIC ZONING MAP OF NORTHWEST-GERMANY, BELGIUM, LUXEMBOURG AND THE NETHERLANDS

Compiled by L.Ahorner, J.M.van Gils, J.Flick, A.R.Ritsema and G.Houtgast 1975.



Probability distribution of earthquake accelerations for sites in Western Germany

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Abstract

Based on the observed earthquake activity in the period of 1750-1970 and the distribution of neotectonic structural activity (Ahorner 1970, 1975) a regional seismicity model has been established to calculate the earthquake risk for sites in Western Germany and the adjoining regions of Belgium, Luxembourg and the Netherlands by a computer program.

The calculation procedure makes use of Gumbel's extreme value theory (Gumbel 1967) and gives the recurrence intervals of various earthquake magnitudes for finite volume elements of seismoactive regions and, in interdependence herewith, the probability distribution of earthquake accelerations at the earth surface as a function of distance from the entirety of finite focal volumes.

Numerical calculations were made for more than 220 sites distributed regularly over an area of 160 000 square km. From the results, earthquake risk maps have been drawn, which give isolines of annual probabilities for earthquake accelerations higher than 100 and 300 cm/s^2 (Fig. 1).

The highest earthquake risk has been found in the western part of the Lower Rhine graben between Köln and Aachen, where two seismoactive zones, the Rhenish and Belgian earthquake zones, are intersecting. The probabilities for exceeding a distinct earthquake acceleration b near this intersection point are:

$$W\ (b \geq 100\ \text{cm/s}^2) = 4{,}0 \times 10^{-3} \text{ per year}$$

$$W\ (b \geq 200\ \text{cm/s}^2) = 5{,}8 \times 10^{-4} \text{ per year}$$

$$W\ (b \geq 300\ \text{cm/s}^2) = 1{,}4 \times 10^{-4} \text{ per year}$$

These results are in good agreement with more qualitative seismological concepts about earthquake risk which have been used up to now (Ahorner, Murawski & Schneider 1970, Ahorner, Flick, Van Gils, Houtgast & Ritsema 1975).

In spite of considerable uncertainties, which have been calculated numerically by Monte-Carlo simulation using random numbers, the presented methods and results will help to improve the earthquake risk analysis in regions with minor seismicity such as Central Europe on a consistent basis and will make possible comparisons with other risks.

The complete paper is in press in "Journal of Geophysics - Zeitschrift für Geophysik", Vol. 41: 581-594, Ahorner & Rosenhauer 1975.

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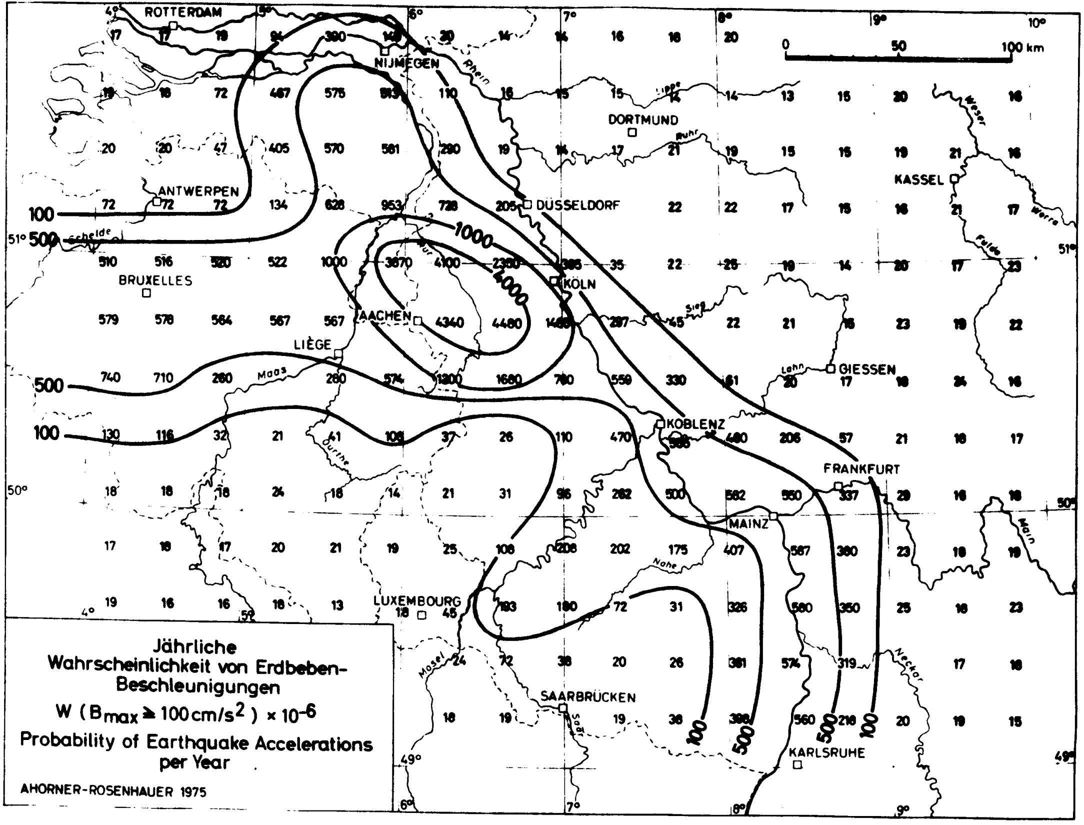

Figure 1. Earthquake Risk Map with annual Probabilities of Earthquake Accelerations higher than 100 cm/s^2.

SEISMIC RISK MAPS OF SWITZERLAND

Description of the Probabilistic Method and Discussion of Some Input Parameters

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Summary

The probabilistic model used in a seismic risk mapping project for Switzerland is presented. Some of its advantages and limitations are spelled out. In addition some earthquake parameters which should be carefully investigated before using them in a seismic risk analysis are discussed.

A probabilistic model for a seismic risk analysis

There is no doubt that the effects of potential earthquakes must be incorporated in the design of nuclear power plants. However, designing for earthquakes can be costly, and earthquakes are but one of the external hazards that have to be considered. The crucial question is, for which parameters values of an earthquake loading a particular plant should be designed.

A general design philosophy of choosing the largest possible or credible event as a design-basis is often impossible and rarely feasible. A balanced design strategy for all potential hazards should take into consideration the probabilities of various load levels, their effects on the plant and also the cost for protection. In such a strategy the optimal decision on the design value is always coupled with a decision on an acceptable probability, that this value will be reached or exceeded during the life-time of the plant. It should be clear, that such an approach is the only rational one, when dealing with loads of probabilistic nature.

If earthquakes are accepted as more or less random events, both with respect to time, location and size, then the effects of earthquakes at a particular site are of probabilistic nature. Methods which assign a "probable maximum" or a "maximum credible" earthquake to a particular site do not account for this probabilistic nature and therefore cannot be used in a balanced design strategy. A seismic risk analysis as described later offers the opportunity to assign probability values to each earthquake-intensity, for example, at a site, and has successfully been applied to single sites of proposed nuclear power plants.

An over-all seismic risk mapping project, using such a probabilistic seismic risk analysis, has been started a few months ago in Switzerland. Results, which cannot be expected before the end of 1976, will be in the form of different maps for different propabilities showing intensity isolines.

The purpose of seismic risk analysis is to establish a relationship between earthquake or ground motion parameters and a probability of occurrence for a specified time period at a particular site. In contrast to approaches of deterministic nature this kind of seismic risk analysis only yields a probability distribution for an earthquake intensity, for example, at a site and not a final design value. The latter has to be determined on the basis of an acceptable probability on which the regulatory authorities have to decide.

Seismic risk analysis must not be considered as an earthquake forecasting tool, but as a statistical evaluation and modelling of the observed earthquake history of a region and the observed relationships between various parameters. It allows to extrapolate the observations from a limited time period (say 200 - 1000 years) to time periods relevant for safety purposes (say 10 000 - 20 000 years) by assuming that the past is representative for the future. Considering the time periods of tectonic and geologic changes, this assumption seems not to be unreasonable. But it has to be pointed out, that this method cannot account for instance for sudden changes in the seismic activity of a region in the near future, when this region has been relatively quiet in the past.

The probabilistic model used here is in many respects a simplification of the actually observed behavior. It is primarily tied to the needs of engineers, whose interest usually focusses on the larger earthquakes. In this respect the model has been checked against real data and a reasonable fit has been observed. For more scientific use, however, the applicability has to be checked for each case.

The mathematics of the probabilistic model are described in detail in several papers by Cornell and Merz and others. It can shortly be summarzed as follows (see Figure 1). The region surrounding a site is divided into seismotectonic provinces. For computational reasons each province is again divided into a grid of smaller areas for which a constant distance to the site can be assumed. In a first step the probability is computed that an earthquake of particular intensity occurs in one of the small areas. For the occurrence of earthquakes in time a Poisson-model is used, which assumes independence between succeeding events and a constant average rate of occurrence. Even though the Poisson-model contradicts for instance the elastic (strain) rebound theory, it is an acceptable model for earthquakes of engineering interest (say Intensity V and larger). The probability distribution of the earthquake intensity is derived from the Gutenberg-Richter relationship between intensities and their frequency of occurrence, or similar relationships. Since indefinitely lare earthquakes are physically not possible, the probability distribution is truncated at an upper bound, which should reflect the largest earthquake, a seismotectonic province is able to produce. Of course, all parameters in this step can vary from province to province.

In a second step the probability distribution of the earthquake intensities at the site produced by the earthquake, assumed in the first step, are computed. A correlation between epicentral intensity or ground motion parameters and epicentral distance is used as transfer-function. Thereby an attenuation - correlation instead of a function seems to be more appropriate due to the considerable scatter of the observed data.

The seismic risk is finally obtained by integrating over all earthquake intensities and all areas. The results yield a smooth relationship between intensity and probability of occurrence, and are in the form of a type I extreme value distribution.

The seismic risk calculated by such a method is influenced by a number of parameters and parameter relationships, whose values and forms are known with various degrees of certainty. A change in the values of critical parameters can easily change the risk values in a significant way. So, the major problem of such an analysis is primarily not the statistical model, but the right choise of input-parameters. The difficulties can best be illustrated by picking out some special problems which are of more seismological nature.

Discussion of some earthquake parameters

Of the great numbers of earthquake parameters, magnitude, intensity, peak-acceleration, -velocity and -displacement are used most frequently to establish quantitative relationships between the "size" of an earthquake and its "destructiveness" at a certain site. The problem is that the seismologically determined measures for the size or energy-release of an earthquake (like magnitude or intensity) cannot be used directely by engineers for design-purposes. On the other hand, peak values are well defined in engineering practice, but very often only weakly dependent on magnitude or intensity, e.g.. Some special problems in this respect will be discussed later in this paper. It also can be put to question, if peak values - especially the most widely used peak acceleration - are indeed a relevant measure for the destructiveness of an earthquake. Despite the fact, that earthquake intensity is a qualitative and subjective measure, it probably is best related to what engineers want to know about the destructiveness of an earthquake. It also is the only information about historical events and therefore must play a central role in seismic risk evaluations which should take into account seismological earthquake-data of the past. In Switzerland a program is currently under way to compile all available data about historic earthquakes. Because of the basic difficulties and uncertainties, as described above, it was decided, that the first set of seismic risk maps will display the seismic risk in the most unchanged way, namely intensities versus probability of occurrence for a specified time-periode. It seems not to be advisable to convert intensities beforehand into other parameters. Conversion-inaccuracies and personal judgement would then be involved, without increasing the reliability of the data.

A cross check between relationships using magnitudes and intensities is inevitable as soon as instrumental data are available for recent times. In any case, the basic maps should show the original data interpreted as little as possible. From these maps, conversions into engineering parameters must be done.

From the engineering point of view, the peak acceleration is still the most useful ground-motion parameter. Besides that (or better because of that) most strong motion instruments produce accelerograms. Relationships between peak-acceleration and magnitude as well as intensities were investigated by many authors. In general they show great scatter and rather unclear correlation with ground-properties. Nevertheless a number of systematic relations could be derived for distances greater than several tenths of kilometers from the source. (Page et al 1975, Donovan 1973, Coulter et al 1973 Trifunac et al 1975). Despite of this , the question is still open, if peak acceleration is a characteristic value for the intensity of an earthquake. It seems to be more reasonable to relate it to the magnitude, since the definition of the latter is also based on maximum values of the amplitude in a seismogram. For design procedures, the maximum acceleration should probably better be taken merely as a sort of "anchor-value" for the calculation of response-spectra. Ground motion parameters, which are more representative in these respects, are the peak-particle velocity and the duration of shaking, or a combination of both.

Within the seismic engineering literature, no single measure of duration of shaking is in common usage and discussion. A crude but useful measure of duration is the time interval between the first and last peaks equal or greater than .05 g on the accelerogram (see Figure 2). This measure roughly corresponds to the intense or strong phase of shaking witnessed close to an epicenter during moderate sized earthquakes and defines one time-interval during which significant damage results from shaking. Duration usually increases with magnitude and decreases with distance. The dependence of duration on magnitude reflects the increase in fault-length with magnitude and the finite velocity of rupture-propagation. Relationships between earthquake intensity and duration seems to be a very useful one and should be investigated in detail, even, if we don't fully understand at the moment the meaning in terms of engineering application.

Another problem in seismic risk calculations is connected with the determination of the "maximum magnitude or intensity", which a region or province is capable to produce. This value has an important influence on the calculation of extreme values with very low probability of occurrence, for example 10^{-4} / year, as currently proposed for nuclear power plants in Switzerland. Different approaches seem to be possible, two of them are depicted in Figure 3. A bi-linear fit was adopted by the authors in a seismic risk study for Nicaragua, and a Gaussian fit was apparently more appropriate for the Central California-data displayed, also because of is lower trend at higher magnitudes.

The "maximum values" of magnitude are derived by more or less arbitrary truncation of the curves. A probably more reasonable approach to this problem must take into account (also) geophysical and seismotectonic considerations and depends not directly on the largest experienced event in the past. Correlation of the dimensions of crustalblocks, which behave tectonically uniform and a careful study of the active faults of the area and their possible extension should give an idea about the maximum possible length of a source and hence the maximum possible magnitude. Successful pattern-recognition studies, as shown by Press and Keilis-Borok, also should give an independent estimate on the maximum possible earthquake of an area.

Another problem, which should be addressed here, concerns strong motion data in the nearfield of an earthquake. Figure 4 shows the maximum peak accelerations for a distance of about 10 km from the causing fault as a function of magnitude. Vertical lines, connecting two or more symbols denote multiple observations of the same earthquake. Prominent earthquakes are indicated, also included are very recent data of the Oroville-earthquakes in Northern California. The figure shows, that peak ground accelerations at a distance of about 10 km are only weakly dependent on magnitude. Much, if not all of the observed dependence on magnitude can be attributed after Hanks (pers. comm.) to the effects of faulting duration, anelastic attenuation and instrumental response.

Most of the accelerograms used for the study in Figure 4 are recorded by accelerometers which have a frequency-range of up to about 25 Hz. It should be clear, that these nearfield data do not contradict the empirical relations between peak-acceleration and larger distances as found by many investigators. The new data merely show, that extrapolation of such curves, into the nearfield of earthquakes should be avoided without measured data. Following the implications of Figure 4 it is not advisable to calculate seismic risk in the nearfield of a possible earthquake source only on the basis of peak acceleration as a design value.

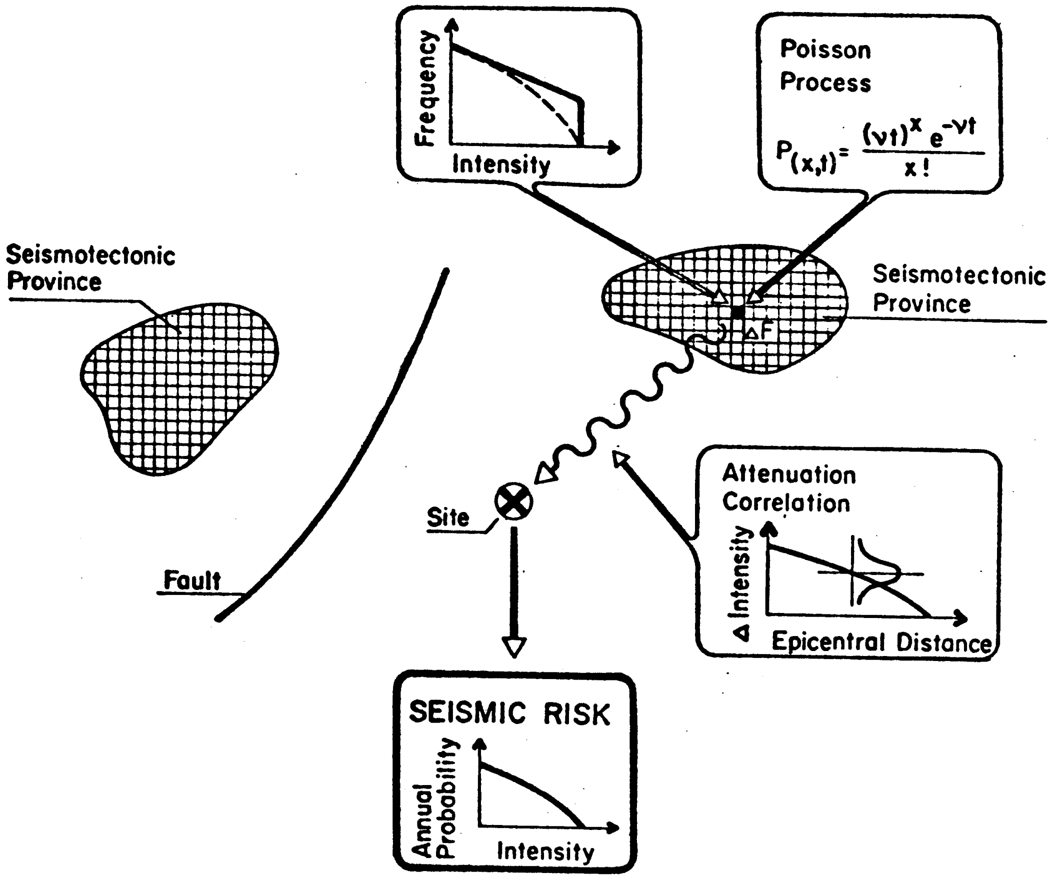


Figure 1 : Schematic Procedure for Determining the Seismic Risk at a Site

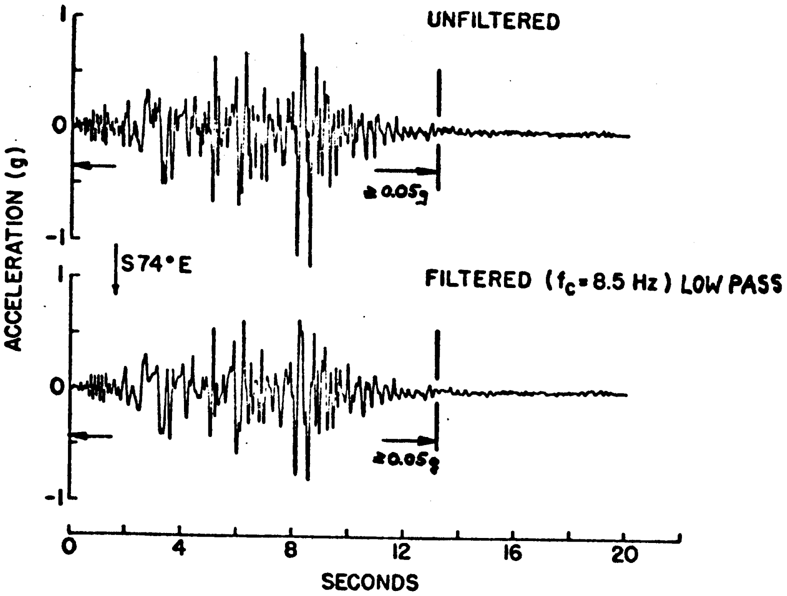
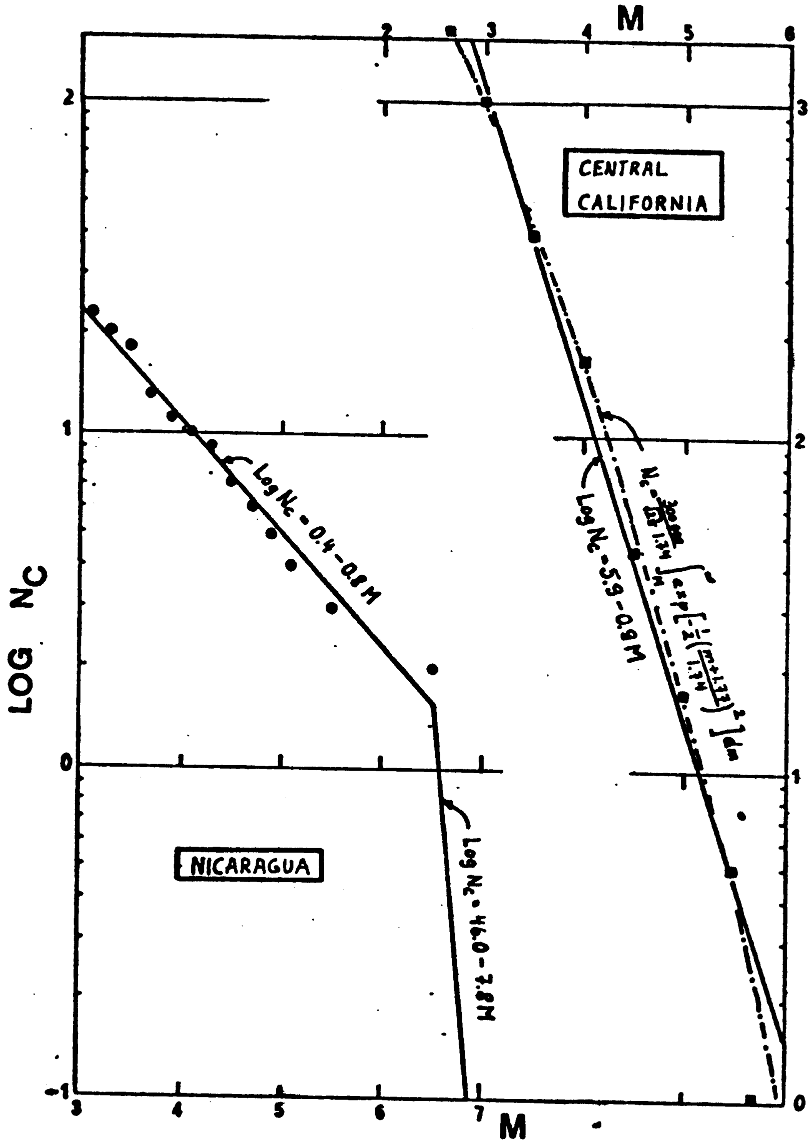


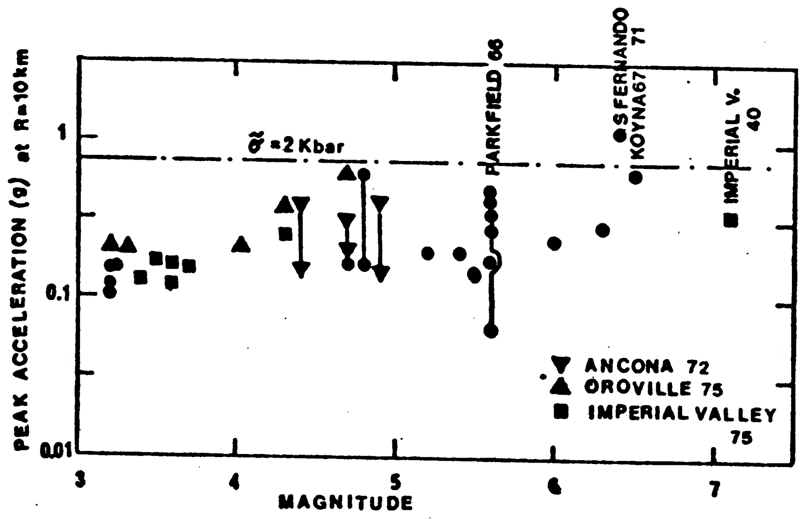
FIG.2 SAN FERNANDO, CALIFORNIA EARTHQUAKE 9 FEB. 1971 14:01 GMT $M_L = 6.6$ S 74°W COMPONENT PACOIMA STATION 5 KM FROM FAULT PLANE

"Duration" of strong motion, defined by acceleration ≤ 0.05 g. Other components give identical values for duration. Filtering has no effect on duration parameter.



Magnitude - (cumulative) frequency relationships for two different sets of data with different assumptions for the determination of greatest magnitudes and their frequency of occurrence.

FIG.3



Peak acceleration at 10 km distance versus magnitude. Vertical lines indicate observations for the same event. $\tilde{\sigma}$ = 2 kbar is an estimate of the maximum shear stress differences likely to be sustained by active fault zones at depthes = 10 km (see Hanks, in press)

DATA by T.C.HANKS USGS

FIG.4

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On the Principles of the Determination of the Safe Shut-Down Earthquake for Nuclear Power Plants in Austria

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Summary

At present no legal guiding lines exist in Austria for the determination of the Safe Shut-Down Earthquake. According to experience the present requirements on the site of a nuclear power plant are the following ones:

It must be free of marked tectonic faults and it must never have been situated within the epicentral region of a strong earthquake. - The maximum earthquake to be expected, and the Safe Shut-Down Earthquake respectively, are fixed by the aid of a map of frequency of strong earthquakes and a map of extreme earthquake intensities in Austria, based on macroseismic data since 1201 A.D. The corresponding values of acceleration will be prescribed according to the state of science, but must at least be 0.10 g for the horizontal and 0.05 g for the vertical component of acceleration at the basement.

At present in Austria no legal guiding lines exist for the determination of the Safe Shut-Down Earthquake for nuclear power plants, but there are principles of proceeding which are followed by the people concerned with this problem. According to my experience as an official expert concerning earthquakes I am able to tell about this subject the following:

The site of a nuclear power plant in Austria must be free of marked tectonic faults and it must never have been situated within the epicentral region of a strong earthquake, i.e., an earthquake with an epicentral intensity of at least 6° according to MEDVEDEV-SPONHEUER-KÁRNÍK. Systems and components important to safety must not be founded in Alluvium.

The maximum earthquake to be expected at the site, and the Safe Shut-Down Earthquake respectively, are fixed by the aid of a map of frequency of strong earthquakes in Austria and a map of extreme earthquake intensities, with regard of the seismotectonic structure. These maps framed by DRIMMEL and GANGL (presented on the occasion of the EGS-Meeting at Zürich, 1973) and revised by DRIMMEL are basing on sound macroseismic data since 1201 A.D., which were treated essentially and published by TOPERCZER and TRAPP (see TOPERCZER and TRAPP 1950, TRAPP 1961 and 1973). To consider the earthquake activ-

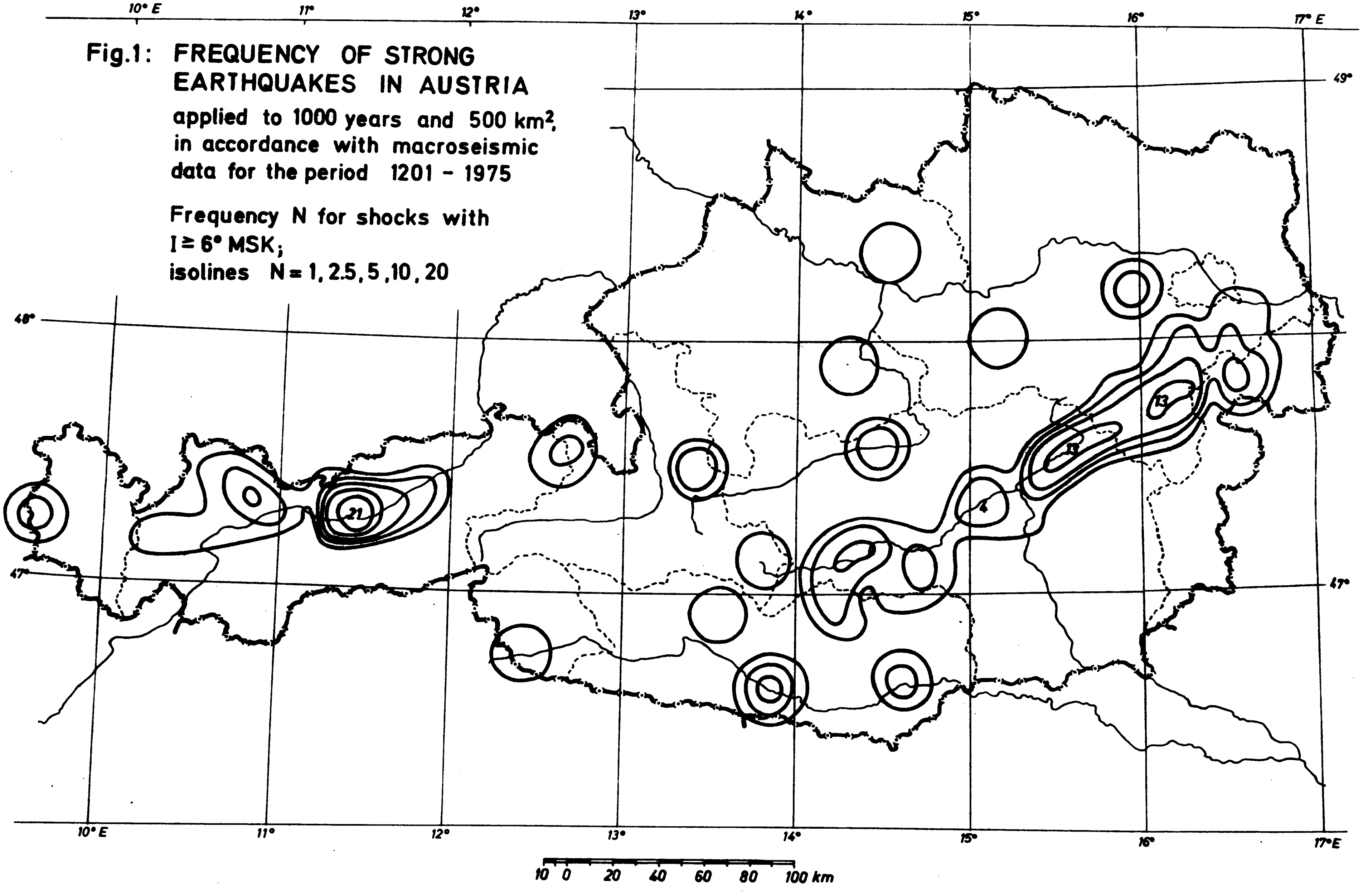

Fig.1: FREQUENCY OF STRONG EARTHQUAKES IN AUSTRIA
applied to 1000 years and 500 km²,
in accordance with macroseismic
data for the period 1201 - 1975

Frequency N for shocks with
I ≥ 6° MSK;
isolines N = 1, 2.5, 5, 10, 20

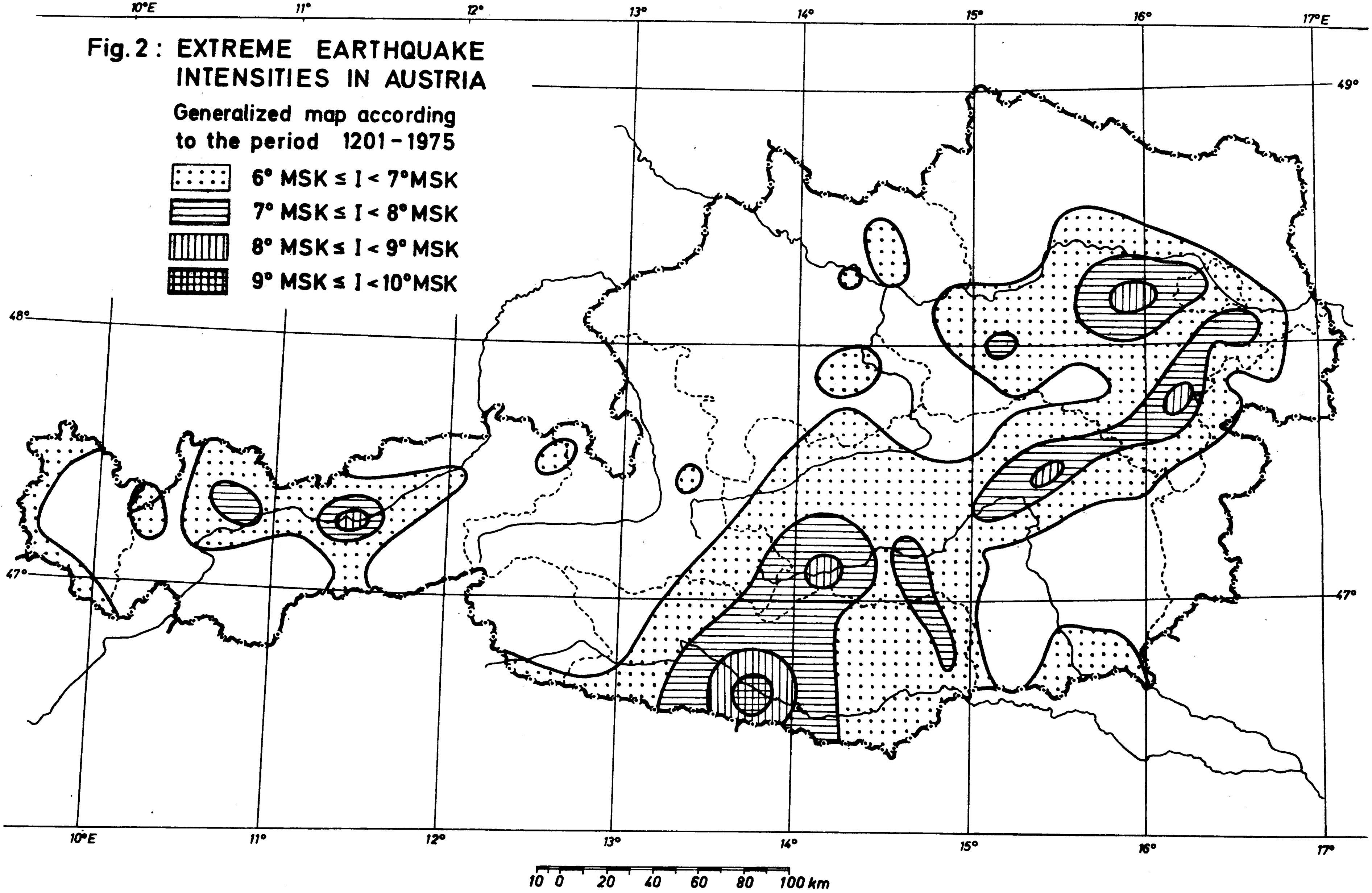

Fig. 2: EXTREME EARTHQUAKE INTENSITIES IN AUSTRIA

Generalized map according to the period 1201 - 1975 ity and its effects in the confines, too, macroseismic material of our neighbouring countries was also used.

As shown by the map of frequency of strong earthquakes in Austria (see fig. 1), the highest earthquake activity is concentrated as well to the region of Innsbruck as to the zone striking from the Vienna Basin to the Semmering Pass and along the valleys of the river Mürz and Mur. All the earthquakes occuring there have their foci within the upper crust. - In the Innsbruck area (47.3°N, 11.4°E) there are 21 autochthon strong earthquakes applied to 1000 years and 500 km^2 and in the southern Vienna Basin as well as in the Mürz valley there are thirteen each. It is true, the strongest Austrian earthquakes till now occured outside the regions with the maximum seismic activity, namely near Villach (46.6°N, 13.8°E), where in 1348 and 1690 destructive shocks with a magnitude M = 6 or more demanded major victims. - In Austria within 10 years on an average one earthquake with an epicentral intensity of at least 7° MSK and in the same period five earthquakes with an intensity of 6° MSK and more occur (see DRIMMEL et al. 1971).

The generalized map of extreme earthquake intensities in Austria shows clearly (see fig. 2) that the highest earthquake intensities, namely 9 to 10° MSK, occured in the region of Villach (46.6°N, 13.8°E) while intensities of 8° MSK and more were observed only at Neulengbach (48.2°N, 15.9°E) near Vienna, in the southern Vienna Basin, in the Mürz valley, near Murau (47.1°N, 14.2°E) and in the Innsbruck area (47.3°N, 11.4°E). - At the preparation of this map the shape and the extent of the shaken areas of historical earthquakes were estimated carefully by the aid of experiences collected by Austrian scientists within the last century in the East Alpine region.

Thus the Safe Shut-Down Earthquake for nuclear power plants and the maximum scale intensity are fixed conservatively by the aid of the two maps showed, and the corresponding values of the maximum ground acceleration will be prescribed according to the state of science, but must at least be 0.10 g for the horizontal and 0.05 g for the vertical component of acceleration at the basement. These lower threshold values result from the fact that in Upper Austria - aside of the known zones with strong earthquakes - in 1967 and 1972 unexpectedly the first strong earthquakes in the history of Upper Austria occured (see DRIMMEL and TRAPP 1975), which came up to an intensity of about 6.75° MSK. By means of the introduction of the mentioned minimum values of the ground acceleration harmful effects of unexpected shocks will be prevented.

The type of design response spectra and the envelopes of the temporal progress of the acceleration amplitudes will be determined in such a way that they are adequate both to the stratification of the subsoil and to the epicentral distance of the supposed Safe Shut-Down Earthquake.

The arrangements recommended to protect the environment against endangering by power plants as a consequence of earthquakes will be accepted as a rule without modification by the authority for radiological protection and prescribed obligatory to the power plant companies.

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Risk analysis against earthquake damage

on a seismotectonic basis

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Summary

Engineering calculations against future probable earthquake hazards have to be based on a sufficient large number of seismic spectra or time functions. The probable variations of the used functions in the frequency or in the time domaine should be estimated according to the seismicity and the seismotectonic situation of the area under study. First, the intervall between the smallest event with technical relevance and the largest thinkable earthquake of the studied unit has to be estimated. In a second step a certain number of variations have to be chosen regarding fracture velocity and stress drop as function in time and space distributed over the focal area. Limits are given by the time intervall between origin and stop time of the focal process.

Methods

For time history calculations the seismotectonic parameters can only be used to form a certain number of selective characteristics to choose from the existing ensamble of strong-motion records such seismograms which can be considered as typical for a certain site situation (SCHNEIDER, 1975). The advantages of working in the frequency domaine, if one studies seismic wave phenomena, has been demonstrated extensively by St. MUELLER (1962). Also important engineering methods are based on a frequency domaine input (response model analysis, power spectra analysis considering energy dissipation inside the structure).

Regular and irregular patterns in seismotectonics

All geo-processes including meteorological and oceanographic phenomena are showing a certain degree of conservative behavior in space and time. This tendency is increasing with the viscosity of the material. The tectonic stress-strain field which may-be regarded as causative for all kinds of tectonic deformations shows a long-time persistency also for geological time spans.

If we regard especially the dislocations along existing faults having sufficient extension to produce earthquake motions with effects felt on the Earth's surface then we have to take into account irregular influences on the single different processes taking place along a fracture zone. Two inhomogeneous blocks are dislocated in the same sense, relatively to each-other, over long time intervalls (millions of years). From this follows that this process is irreversible. No situation will occur a second time. For the seismic risk of a definite area these two contradictory characteristics have important consequen-

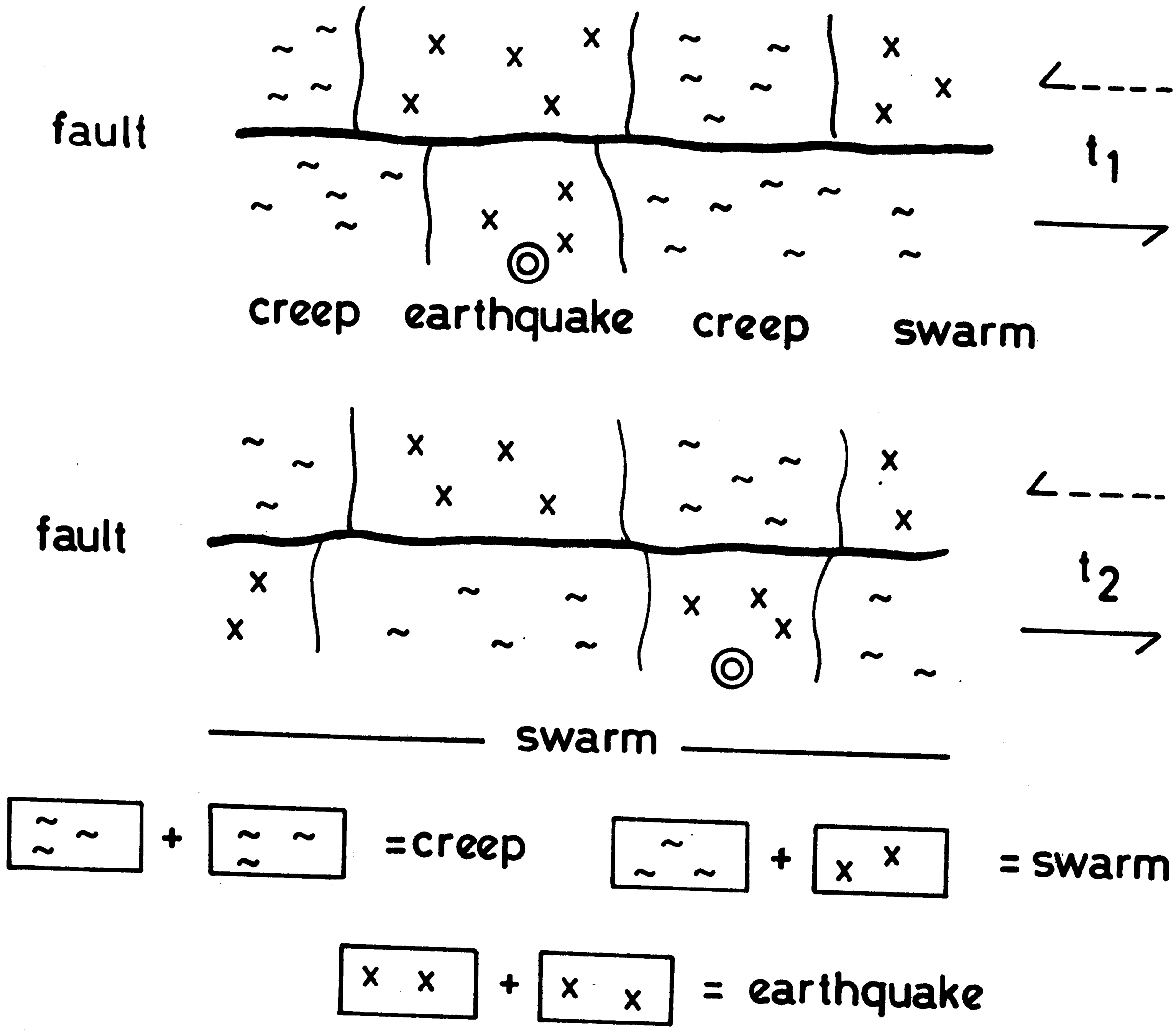

Fig. 1: Two different rheological situations along the same fault at two different times t_1 and t_2 .

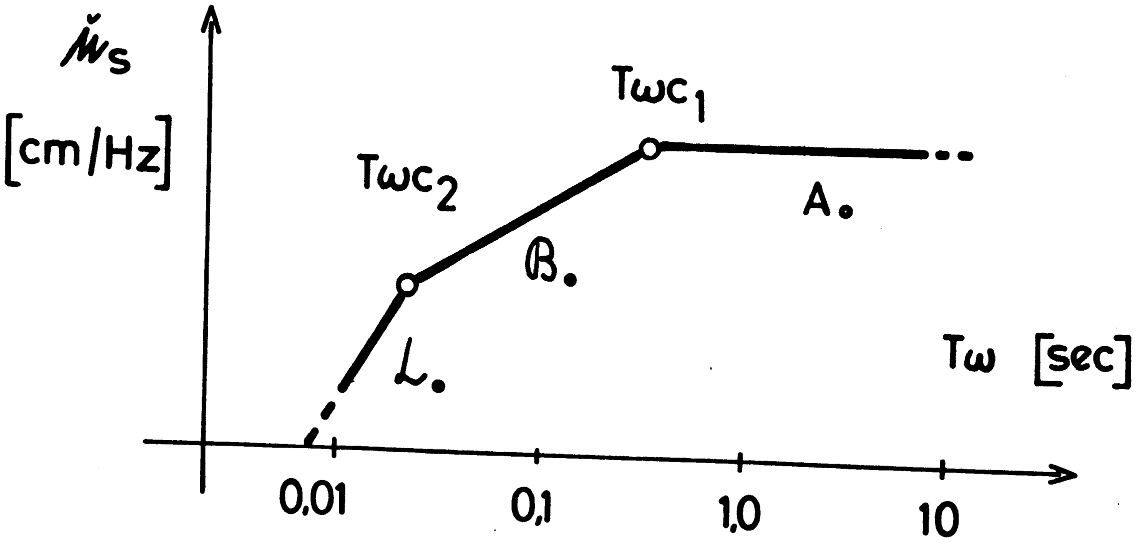

Fig. 2: Schematic seismic focal spectrum .

cies: Events and their records observed in the past can only be representative with regard to the "coarse" dimensions and parameters of the focal process: The small dimensioned properties will show a different character as soon as the neighboordhood conditions of the blocks are changing (Fig. 1). Since rheological conditions along the fault-surface are controlling stress accumulation, stress drop, critical value of stress before a dislocation event and the fracture velocity we can observe inside the same area creep phases or high velocity ruptures with radiation of seismic waves. At the same M_S-level we can find "blue" and "red" quakes if we compare the high frequency end of the spectrum (Fig. 4). The wandering of activity inside larger seismotectonic units and the changing M_b/M_s proportions are demonstrating the possible range of variations.
Tectonic and seismotectonic research as well as studies on the seismicity in the past will deliver us an estimation of the "coarse" and conservative parameters of a certain area: distribution function of magnitudes (M_s) or seismic moments (M_o), the average dislocation-velocity by the moment-methods of BRUNE (1968) or from repeated geodetic measurements (KUNTZ el al., 1970), radiation patterns and orientation of axes of principal stress acting in the focal volume as deduced from fault-plane solutions and in-situ-stress measurements (RITSEMA, 1960). For parameters as fracture velocity and stress drop we have to assume a variation intervall inside the limits set by theory and experiment.

Seismic focal spectra

The different physical models describing the focal process, as published during the last decades are showing in spite of important differences, some common features (AKI, 1967; BRUNE, 1970; RANDALL, 1973). If we take a look at a displacement focal spectrum (Fig. 2) we are remarking the following important characteristics:

a. The static as well as the long-period part of the spectrum is controlled by the seismic moment $M_o = \mu \cdot F_o \cdot d_o$ (μ = shear-modulus $\approx 3 \cdot 10^{11}$ dyn/cm^2; F_o = fracture area = $L_o \cdot W_o$ ≡ focal length·focal width; $\hat{d}_o$ = dislocation amount averaged over F_o). The amplitudes are modulated by the radiation pattern R_o (Fig. 3) and diminuished by geometric spreading $(4\pi \varrho v_s{}^3 s)^{-1}$ (ϱ = density; v_s = S-velocity; s = hypocentral distance).

b. The spectral intervall between $T\omega c_1$ and $T\omega c_2$ is mainly influenced by the fracture propagation in Lo or $\vec{v}F_o$ direction ($\vec{v}F_o$ = vector of fracture velocity).

c. The high-frequency part ($T\omega < T\omega c_2$) forms the most interesting intervall since natural frequencies of normal buildings are situated here. The spectral behavior depends on the build-up functions of the focal pulses when the fracture spreads in perpendicular direction related to the fracture velocity vector. The parameters mainly determining the build-up function are the focal width and the fracture velocity . Proposed forms for the FOURIER-transform of build-up function can be taken, for example from HASEGAWA (1974):

$$\ell_o = \omega^{-1} \left(1 + \omega^2 \tau_o{}^2\right)^{-1/2} \qquad (1)$$

τ_o is related to rise-time of the source function, to $W_o/\hat{v}_{F_o}$ (SAVAGE, 1972). To demonstrate the importance of fracture velocity, geometric spreading and absorption in the near-field three exemples are given in Fig. 4. The lower part shows the schematic behavior of the displacement focal spectra for two different hypocentral distances (s = 5 and 10 km, respectively). The upper part shows the according acceleration response spectra for zero damping. The spectrum is compared by the different factors as described before (see also Fig. 2):

$$|\breve{u}_s| = A_o \cdot \mathcal{B}_o \cdot \ell_o \cdot \omega \qquad (2)$$

$$A_o = M_o \cdot R_o \cdot \left(4\pi \varrho v_s{}^3 s\right)^{-1} \qquad (3)$$

$$\mathcal{B}_o = f\left(L_o, \hat{v}_{F_o}, \vartheta\right) \qquad (4)$$

$\hat{v}F_o$ = amount of fracture velocity averaged over the time intervall between origin time t_o and stop time for the source process. For a unilateral fracture it equals $L_o/\hat{v}_{F_o}$; ϑ = angle between Lo and the direction toward the observer. SAVAGE (1972) proposes for $\mathcal{B}_o$:

$$\mathcal{B}_o = \sin(\omega\tau_o/2)\,/\,\omega\tau_o/2 \qquad (5)$$

$$\tau_o = L_o\left[\left(v_s/\hat{v}_{F_o}\right) - \cos\vartheta\right]/v_s \qquad (5a)$$

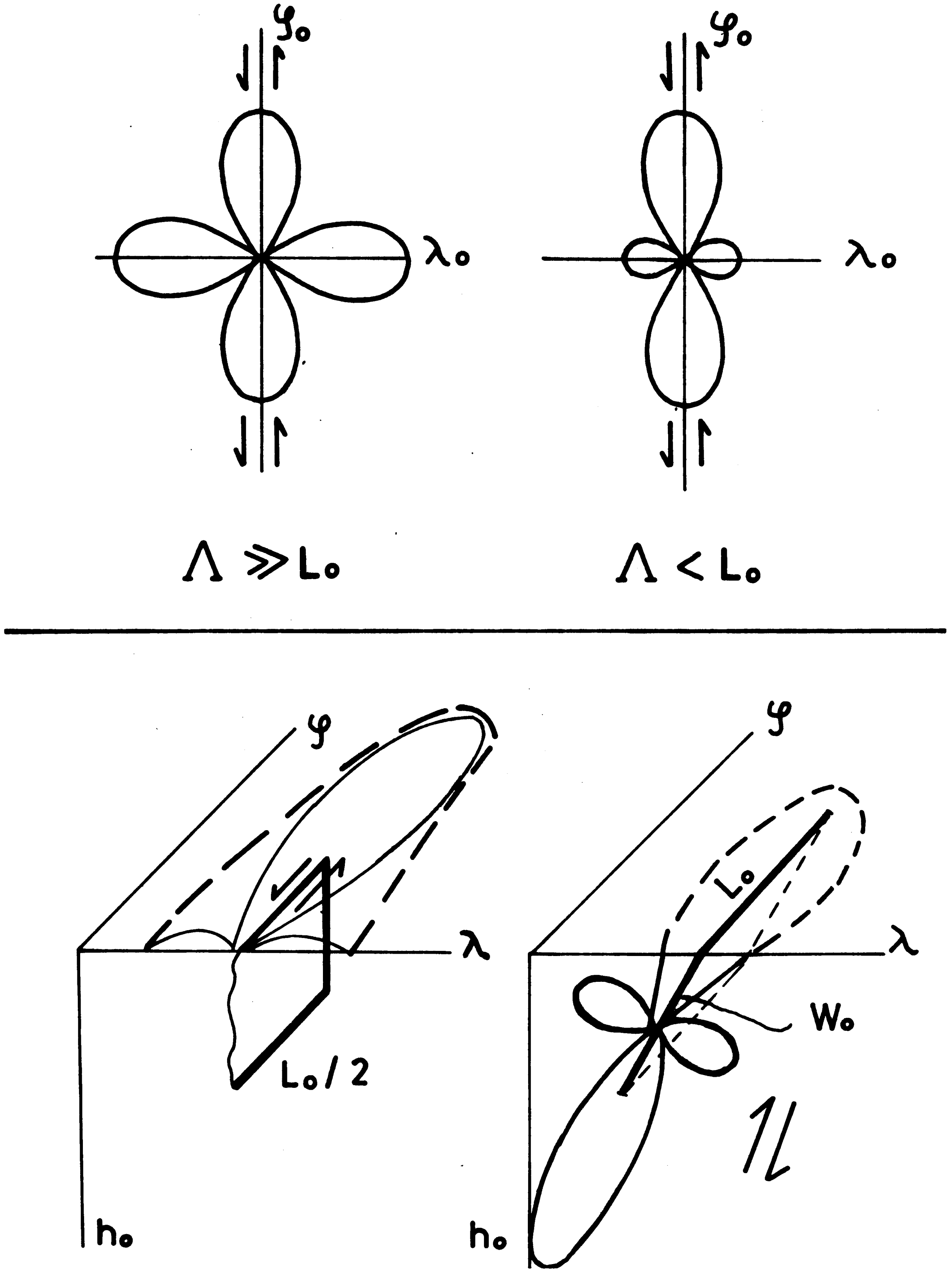

Fig. 3: Radiation pattern for S-waves for different relation Λ/Lo = wave length/ focal length (above); horizontal strike slip and thrust fault (below left and right, respectively). A thrust quake of the same magnitude M_s as a horizontal strike slip motion, both having near-surface focus will cause a high damage for a small area. The strike slip is showing a narrow pleistoseismic zone of large extension and lower damage concentration.

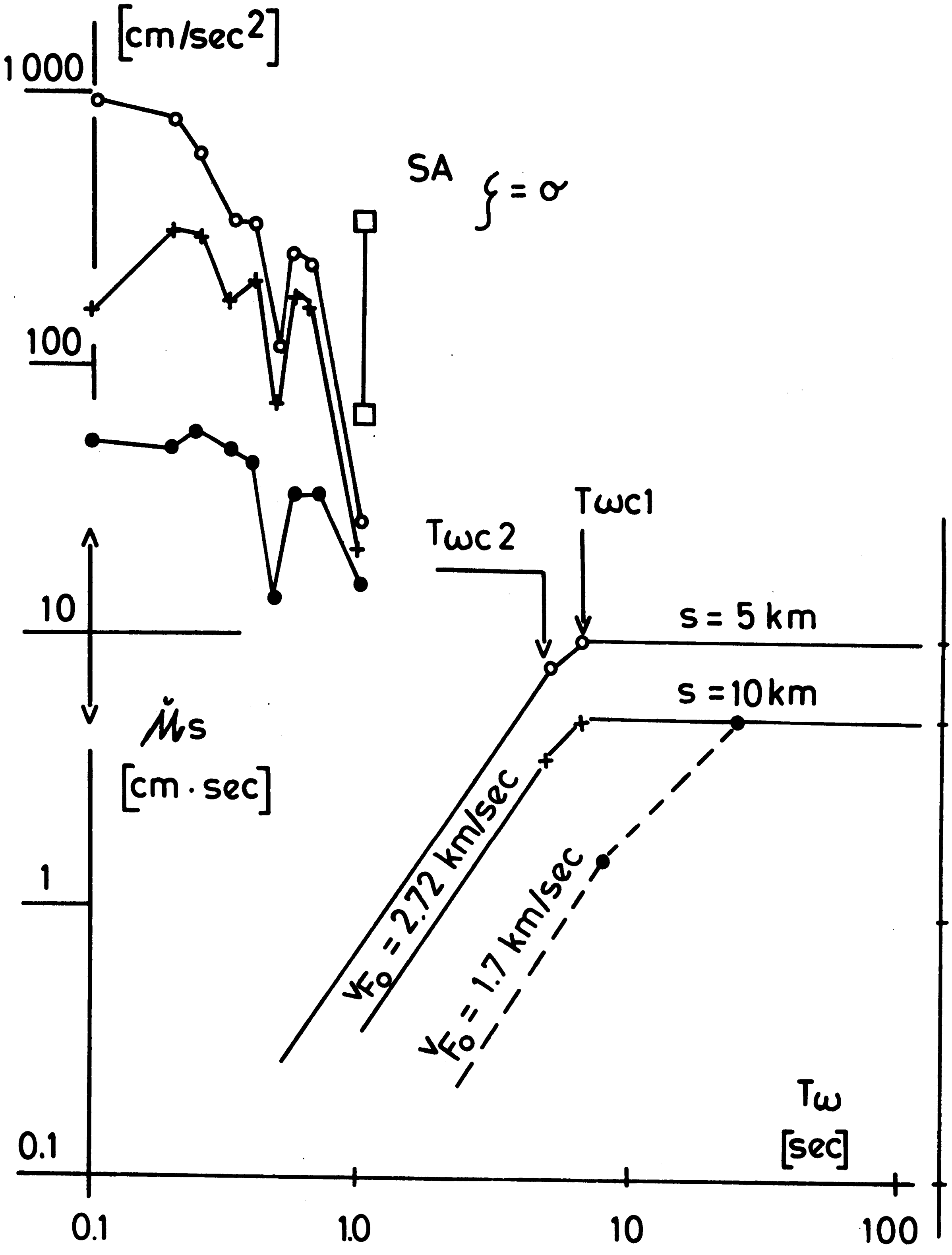

Fig. 4: 3 different response spectra for a seismotectonic situation as in Central Europe ($M_s = 5.5$, $M_0 = 6.3 \cdot 10^{24}$ dyn cm; $v_s = 3,4$ km/sec; $\vartheta = 0°$; $L_0 = 20$ km; $W_0 = 10$ km).

$$\tau_0 \rightarrow Lo/\hat{v}_{Fo}$$

For the factor an example is given in equation (1). To consider absorption a Q-value of 50 has been chosen for the near-field (HASEGAWA, 1974).

A comparison between the three examples of spectra in Fig. 4 should give a first impression how parameters, as fracture velocity in the source are influencing the high frequency part of the spectrum. Different assumptions about the size of average fracture velocity $\hat{v}_{Fo}$, the form of $\mathcal{B}o$ and $\mathcal{L}o$ will result in a variety of spectra for the same seismotectonic situation.

The assumptions made about the dynamic process are, of course, still very far from being a realistic picture of the source. Especially the time-space behavior of fracture velocity will allow a much larger number of probable variations in source spectra and time functions. We know that the fracture velocity has to be zero at the begin and the end of the focal process. Inside this intervall a more or less strong modulation according to the physical situation along the very fault-zone has to be assumed. Therefore one can observe displacement spectra with different ω^{-n}-decrease at the high end of the spectrum. Variations of n ranging between 1 and 3 (SCHICK, 1970; STÖCKL, 1975) have been observed or derived from focal process theory.

New developments of source modells have to consider these short-comings of the present forms of source spectra, especially the variability of v_{Fo} in time and space. For construction of artifical time spectra the study of phase spectra has to be considered. Time dependent spectra are requested for power spectra analysis of buildings. Synthetic spectra are a useful, but still poor beginning to produce a sufficient number of realistic field spectra.

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Contour mapping of seismic areas by numerical filtering and geological implications

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Summary

A method is described that makes possible the identification of the independent seismic units of a given area.

The seismic information is treated as a bidimensional signal disturbed by a certain background noise. The filtering of this noise makes it possible to delineate the seismic areas objectively and to draw their contours.

An indirect check on the method was made by the estimating with respect to the various regions identified the α and β parameters of the law

$$N_y = \alpha . e^{-\beta y}$$

which gives the number of earthquakes with magnitude (intensity) greater than or equal to y; the β coefficients are the same for all the rings of each seismic zone.

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Mechanical models of earthquakes and their statistics

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Summary

From observed data we find that, for each magnitude range M, M + ΔM and for a given time interval sufficiently long, the total area of the faults interested in the earthquakes is nearly independent of M. Then with elementary models we tentatively treat the problem to determine the density function of the number of earthquakes as function of the magnitude and the density function, of the number of faults which caused the earthquakes of a given area, as function of the area and direction of the faults. We find also that the log n(M) (n(M) number of earthquakes per unit area and time in the range M, M + ΔM) is a linear function for magnitudes $M < M_o$ (where M_o is a critical magnitude which can be determined both experimentally and theoretically) and is concave upwards for $M > M_o$, with a finite asymptotic value for $\frac{d \log n(M)}{dn}$.

The theory is checked in general for the seismic zones of Mediterranean area, Europe, the Middle East and in more detail for the Appennines; in this case the distribution function of the faults of this area as function of the area and the value of M_o are estimated tentatively.

Introduction

The brief discussion of the models presented in this note should be considered only as the beginning of long research that the laboratory research and the observation of natural phenomena suggest to begin since long. In other words, we should begin a systematic and scientific treatment of the numerous data on earthquakes as it was done for the perfect gas, for the atom and for other physical entities. The problem can be set as follows: let l be the linear dimension of faults of area S, also let

$$W = W\,(l,\ x_i) \tag{1}$$

$$\bar{E} \doteq \bar{E}\,(l,\ y_i,\ W) = E\,(l,\ x_i,\ y_i) \tag{2}$$

be the energy stored in the elastic medium before the earthquake and that radiated as elastic energy, where x_i and y_i are parameters which characterize the two energies. Let also n(l) be the number of faults of linear dimension in the range between l and l + dl which caused earthquakes. The total area A of the faults of the earthquakes occurred in a given time interval T_0 sufficiently large and in a given seismic region and the total elastic energy E_0 are

$$A = \int_{l_1}^{l_2} n(l)\, l^2\, dl \tag{3}$$

$$E_0 = \int_{l_1}^{l_2} n(l)\, E(l, x_i, y_i)\, dl \tag{4}$$

where l_1 and l_2 are the minimum and the maximum linear dimensions of the faults which caused the earthquakes. It is also assumed that the parameters x_i and y_i are constant in the considered time interval and seismic region.

The energy E_0 can be observed on the surface of the earth, whereas the functional A cannot be observed and should be discussed taking into account the laws of physics.

Models in one dimensional phase space

In statistical seismology a very simple empiric formula is used which gave good results approximating the number of earthquakes which occurred in a given region and in a given time interval. The formula expressed as function of the magnitude M is (Ishimoto M., Iida, K. 1939)

$$\log \Delta n = \bar{a}_i - b_i M + \log \Delta M \tag{5}$$

where ΔM is a magnitude range and Δn is the number of earthquakes of magnitude in the range between M and M + ΔM which occurred in a given area and in a given time interval: $\bar{a}_i$ and b_i are parameters which represent given seismic region in the given time interval.

It is known that there are various definitions of magnitude, but they are related linearly, therefore it is irrelevant which definition we use in formula (5). The data quoted in this note are referred to the definition based on surface waves. In this case, if the time interval is one year and the unit is 1000 km^2 we have for the regions of Europe, North Africa and the Middle East (Karnik 1971)

$$0 < \bar{a}_i < 3.5 \quad , \quad 0 < b_i < 1.2 \tag{6}$$

Formula (5) has been used by all seismologists, however, to my knowledge, there is no mechanical model to back it.

In this note, we shall briefly discuss a physical model of statistic distribution of tectonic earthquakes and we shall compare the results with (5) and obtaining some interesting results.

At this point, we should make clear that it has been understood that tectonic earthquakes, which are the most numerous, are believed to be caused by the relaxation of elastic energy, accumulated in the interior of the earth, by means of slipping along fractures which occur inside the earth itself. The fractures occur on planes which are called faults and have areas which could be tens of km^2.

The statistical model considered here is based on the mechanism of tectonic earthquakes and on their energy which is given by the formula (Keilis-Borok 1959)

$$W = \frac{\bar{K}\, p^2\, S^{3/2}}{\mu} \tag{7}$$

where $\bar{K}$ is a coefficient of form which is near to unity, μ is the rigidity of rocks, p the relaxation relaxed of elastic stress and S is the area of the fault which caused the earthquake. The associated radiated elastic energy E is

$$E = \bar{\eta}\, W \tag{8}$$

where $\bar{\eta}$ is a parameter which is estimated to lie between 1/3 and 1. Let W_o and E_o be the total energy and the elastic energy of the earthquakes of a given region in a given time interval, then it must be

$$\int_{l_1}^{l_2} n(l)\, \frac{\bar{\eta}\, \bar{K}\, p^2}{\mu}\, l^3 dl = E_o, \qquad \int_{l_1}^{l_2} n(l)\, l^2 dl = A \tag{9}$$

Let us set

$$l^3\, n(l) = \bar{\phi}\,(l) \tag{10}$$

then

$$\int_{l_1}^{l_2} \frac{\bar{\phi}\,(l)}{l}\, dl = A \tag{11}$$

$$\int_{l_1}^{l_2} \bar{\phi}\,(l)\, \frac{\bar{\eta}\, \bar{K}\, p^2}{\mu}\, dl = E_o \tag{12}$$

and the problem is to determine $\phi(l)$ which has on area $E_o/\bar{K}p^2$ between l_1 and l_2; or to determine the functional A under the condition E_o.

To solve the problem it is necessary to find the extremals of A. For this purpose, we find that the Euler's equation associated with (11) and (12) is degenerate. However, a direct analysis shows that the extremals are

$$\bar{\phi}(l) = \frac{E_o\, \mu}{\bar{\eta} p^2 \bar{K}}\, S(l - l_1) \tag{13}$$

for the maximum, and

$$\bar{\phi}(l) = \frac{E_o\, \mu}{\bar{\eta} p^2 \bar{K}}\, S(l - l_2) \tag{14}$$

for the minimum. From these one obtains

$$n(l) = \frac{E_o\, \mu}{\bar{\eta} \bar{K} p^2}\, \frac{S(l - l_1)}{l^3} \tag{15}$$

for the maximum and

$$n(l) = \frac{E_o \ \mu}{\bar{\eta}\bar{K}p^2} \ \frac{S(l - l_2)}{{l_2}^3} \tag{16}$$

for the minimum.

Both solutions are far from the experimental results and therefore are they unacceptable. They prove that the mechanism of energy release does extremize the functional A which represents the total area of the faults associated with the earthquakes.

Experimental checks

The empiric formula for E and n as functions of M are

$$E = 10^{12 + 1.44 \ M} = 10^{\beta + \gamma M} \tag{17}$$

$$n = 10^{a - b \ M} \tag{18}$$

from which follows

$$n = 10^a \ 10^{\frac{b\beta}{\gamma}} \ l^{-\frac{3b}{\gamma}} \ (\frac{\bar{\eta}\bar{K}p^2}{\mu})^{-b/\gamma} \tag{19}$$

$$E = 10^\beta \ (\frac{10^a}{n})^{\frac{\gamma}{b}} \tag{20}$$

and substituting (11) we obtain

$$A \simeq l^{2 - \frac{3b}{\gamma}} \tag{21}$$

We can see that for $b < 0.96$, A is increasing function of l; for $b = 0.96$, A is constant; and for $b > 0.96$, A is decreasing function of l. These results which are valid with the hypothesis of constant p, are also valid if p is independent of l and has a uniform distribution for all the values of l.

We may now discuss the observed values and the theoretical results. According to formula (15) and (16) one should expect that the elastic energy stored in rocks be released preferably by means of faults with largest area, in fact in these the ratio of the work done in the slipping fractures, which is proportional to the area of the fault S, to the energy released, which is proportional to $S^{3/2}$, is minimal.

The observations instead give (19) which represents a different distribution. Moreover, laboratory experiments on rock samples subjected to compression, have shown that the elastic energy stored is released by fractures whose area follows a law similar to that of earthquakes (Mogi 1962).

The figure 1 shows the distribution of the $\bar{a}_i$, b_i values and it may seem that they are linearly related, in the most active areas the values of b_i would tend to be larger. But a more detailed analysis shows that this is due to the variation of ΔM as we shall discuss later.

Concerning the laboratory experiments, one should keep in mind that rocks are formed by aggregates of crystals which are joined together along their faces. These are the weak points where fractures are and which condition the formation of slips.

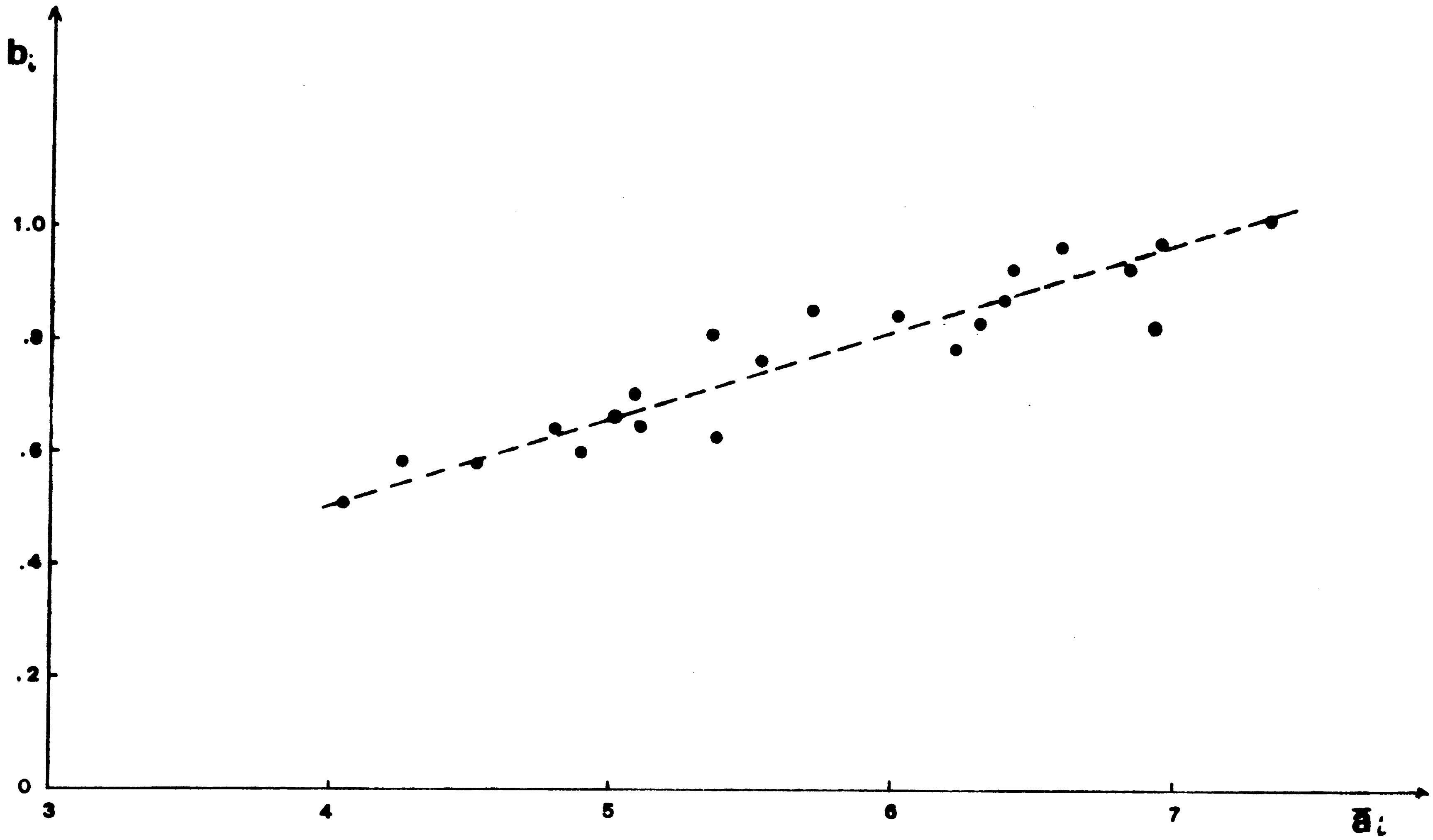

fig. 1 - Correlation of $\bar{a}_i$ and b_i data for seismic zones of Europe, the Mediterranean area and the Middle East according to formula (6) and table 1 (data with variance larger than 25% of the value are omitted).

The analysis of the value of b_i for Europe, North Africa and the Middle East shows that $0.50 < b_i < 1.17$; the average value is 0.94 very close to the value of the equipartition of energy, which is 0.96.

Models in the two dimensional phase space

The statistical distribution of earthquakes can be studied also from a geometric and mechanical point of view with an elementary model which gives results very close to reality. In this model earthquakes are represented with a system of faults of area S_i and direction of unit vectors l_{i1}, l_{i2}, l_{i3} in a solid (the earth crust) subject to uniform force f per unit area of direction d_1, d_2, d_3 and intensity linearly increasing with time

$$\bar{f} = \eta \bar{d} t = \eta t (d_1 l_1 + d_2 l_2 + d_3 l_3) \tag{22}$$

Given the friction coefficient f_a between the faces of the faults, each fault will release energy when the component of the force parallel to the one of the fault

$$S_i \eta t \{ 1 - (d_1 l_{i1} + d_2 l_{i2} + d_3 l_{i3}) \}^{\frac{1}{2}} \tag{23}$$

will be larger than the friction between the two faces

$$F S_i + S_i f_a \eta t (l_{i1} d_1 + l_{i2} d_2 + l_{i3} d_3) \tag{24}$$

where F is a frictional constant which depends on the contact between the faces of the faults. Assuming

$$f_a = f_a \{ (l_{i1} d_1 + l_{i2} d_2 + l_{i3} d_3) t, t \} = f_a \{ t \cos \alpha, t \} \tag{25}$$

this will occur when

$$\eta t \{ \sin \alpha \}^{\frac{1}{2}} = \eta t \cos \alpha \, f_a \{ t \cos \alpha, t \} + F \tag{26}$$

In this mechanism the elastic energy released by a fault of area S in a given time interval T_0, depends on T_0, on F and on the angle between the unit vectors l_{i1}, l_{i2}, l_{i3}, and d_1, d_2, d_3; the energy should be released periodically, and always in the same amount, with a period given by equation (26).

Given the vector d_1, d_2, d_3, the coefficient η of (22), F, and the friction mechanism, the value of T and the energy released by a fault of direction l_{i1}, l_{i2}, l_{i3}, will be inversely proportional to the value of $l_{i1} d_1 + l_{i2} d_2 + l_{i3} d_3$.

To explain this with other words, let us consider two faults with the same area and with directions given by the unit vectors l_{11}, l_{12}, l_{13} and l_{21}, l_{22}, l_{23} such that

$$l_{11} d_1 + l_{12} d_2 + l_{13} d_3 = \omega (l_{21} d_1 + l_{22} d_2 + l_{23} d_3) \tag{27}$$

then the number of earthquakes released by the two faults will be about in the ratio ω. If the elastic energy is supplied to the earth crust continuously the energy will be released periodically and in quanta, but the total elastic energy released by the two faults will be nearly the same. In a system of N faults of different area and directions one should find that the energy is released with N frequencies which are generally different.

In this model, the swarms of earthquakes are represented by systems of faults whose directions are very close. Also the energy released by a system of faults with the same area should depend only on $\eta(d_1\bar{l}_1 + d_2\bar{l}_2 + d_3\bar{l}_3)$. In the case of a system of faults with the same area, if $\bar{l}_{11}$, $\bar{l}_{12}$, $\bar{l}_{13}$ is the unit vector of the direction of the fault which releases the maximum energy E_{sm}, assuming $\bar{l}_{11}d_1 + \bar{l}_{12}d_2 + \bar{l}_{13}d_3 = 1$ for any other faults, it will be

$$E_s = E_{sm} (l_{11}d_1 + l_{12}d_2 + l_{13}d_3) \qquad (28)$$

The distribution of earthquakes in a given time interval as function of the energy should be given by the distribution of the cosinus of the angles between the directions of the faults and the direction of the acting tectonic force. If one introduces the return period T of the earthquakes of energy E_s, in a given time interval T_o, the number of earthquakes with energy E_s will be n (E_s)

$$n\,(E_s) = E_{sm} (l_{11}d_1 + l_{12}d_2 + l_{13}d_3) \frac{T_o}{T} \qquad (29)$$

where T is given by (26).
As an example let it be

$$\cos\alpha = l_{11}d_1 + l_{12}d_2 + l_{13}d_3 \qquad (30)$$

$$f_a = f\,(\alpha) \qquad (31)$$

then substituting into equation (26) one obtains

$$\eta t \sin\alpha = f\,(\alpha)\, \eta t \cos\alpha + F \qquad (32)$$

from which the return period and the released energy result

$$t = \frac{F}{\eta(\sin\alpha - f\,(\alpha)\cos\alpha)} \qquad (33)$$

$$E = \frac{\bar{n}K\, S^{3/2}\, \eta^2 t^2}{\mu} \qquad (34)$$

Since we assume that the faults of the system have the same area, the stress drop p, assumed to be equal to the energy accumulated, is proportional to the time of accumulation and given by (33); then the number of earthquakes of a given energy in a given time interval T_o is

$$n = \frac{T_o}{t} = \frac{T_o\eta}{F} (\sin\alpha - f\,(\alpha)\cos\alpha)$$

$$E = \frac{\bar{n}Kl^3\eta^2t^2}{\mu} = \frac{l^3}{R^3} (\sin\alpha - f(\alpha)\cos\alpha) \qquad (35)$$

If we consider that also l is variable in nature, than the number of earthquakes of a given magnitude M and therefore given energy E_1 in assigned area and time interval T_0, are obtained from (35). For this purpose one should consider the polar coordinate system α, l in a plane and the region Q defined by $\alpha_1 < \alpha < \frac{\pi}{2}$, $0 < l < l_2$ where α_1 is the largest zero of t given by (33), in the range $0, \frac{\pi}{2}$. To each point of this region, through (35), corresponds a given energy and a given return period; we should therefore consider the line Q_E of Q for which E is constant and integrate n (E) over that line.

This can easily be obtained by expressing α as a function of l by means of the second of (35), substituting in the first of (35) and then integrating on the path given by the second of (35):

$$n(R) = T_0 \eta \, D \, F \, R^{1-\nu} \int U(u)du =$$

$$= T_0 \, D\left(\frac{\eta}{F}\right)^{\frac{2\nu}{3}} R^{1-\nu} \int \left[\frac{[9(\sin\alpha - \cos\alpha)^2 + 4(\cos\alpha + \sin\alpha)]}{|\sin\alpha - \cos\alpha|^{\frac{4}{3}\nu-1}} \right]^{\frac{1}{2}} d\alpha$$

$$R^3 = \frac{E\mu}{\bar{\eta}\bar{K}F^2} \tag{36}$$

$$U(u) = u^{3/2-\nu} \left[1 + \frac{9}{4} \frac{u^3}{2-u^3} \right]^{\frac{1}{2}} ; \quad u = \frac{l}{R}$$

The factor $Dl^{-\nu}$ has been introduced to take into account the number of faults of linear dimension l which are present in the system. The interval of integration is $0, l_2$ if $E > E_0 = \frac{\bar{\eta}\bar{K} l_2{}^3 F^2}{\mu}$ or $0, \left[\frac{\bar{\eta}\bar{K}F^2}{\mu E}\right]^{1/3}$ if $E < E_0$ for the integral in dl.

For the integral in $d\alpha$, instead, the range of integration is (α_1, α_2); where $\alpha_2 = \pi/2$ when $E < E_0$ and α_2 is given by the second of (35), with $l = l_2$, when $E > E_0$.

If $f(a) = f =$ const. the behaviour of log n (M) can be found by differentiating (36), one finds that $\frac{d \log n(M)}{dM}$ is always negative. Also

$$\frac{d \log n(M)}{dM} = \frac{dR}{dE} \frac{dE}{dM} \frac{d \log n(R)}{dR} =$$

$$= \frac{dR}{dE} \frac{dE}{dM} \left\{ 1 - \nu - \frac{\frac{l_2}{R} \, U\left(\frac{l_2}{R}\right)}{\int_0^{l_2/R} U(u)du} \right\} \frac{\log e}{R} \tag{37}$$

When $\frac{l_2}{R} = 1$ and therefore $E_0 = \frac{l_2{}^3 \bar{\eta} \, \bar{K} \, F^2}{\mu}$ we have for the limit $E_0{}^+$

$$\left[\frac{d \log n(M)}{dM}\right]_{E=E_0{}^+} = \frac{\gamma}{3} \left\{ 1 - \nu - 1.8 \, \frac{(5-2\nu)(11-2\nu)}{30.03-7.212\,\nu} \right\} \tag{38}$$

while the limit $E_0{}^-$ is

$$\left[\frac{d \log n(M)}{dM}\right]_{E_0{}^-} = \frac{\gamma}{3} (1-\nu) \tag{39}$$

We see that there is a discontinuity in the derivative for $E = E_o$.
When $E >> E_o$, then $\frac{l_2}{R} < 1$; if $\frac{l_2}{R} < 0{,}6$ we have with satisfactory approximation

$$\frac{d \log n (M)}{d M} = - \frac{\gamma}{2} \qquad (40)$$

These results are valid also when $f \neq 1$.
For $E < E_o$ we obtain from the integral (36) in $d\alpha$ (and $f (\alpha)$ = const.)

$$\frac{d \log n (M)}{d M} = \frac{1 - \nu}{3} \gamma \qquad (41)$$

The second derivative of log n (M) shows that for $E > E_o$ the curve is concave upward.
When ν tends to the limiting value of 2.5 then

$$\frac{d \log n (M)}{d M} = - \frac{\gamma}{2}$$

for all values of M.

The observed data suggest that $\frac{d \log n (M)}{d M}$ is constant for $M < 5$, also they suggest that the function is decreasing with M for $M > 5$; since the data are effected by relevant errors, we shall assume $\nu = 2{,}3$ for our tentative model. We have:

$$\left[\frac{d \log n (M)}{d M}\right]_{E_o^+} = - 0.77$$
$$\left[\frac{d \log n (M)}{d M}\right]_{E_o^-} = - 0.62 \qquad (42)$$

By plotting fig. 2 the values of b_i and M_{i2} resulting from the table 1 we may see that b is related to M_{i2} therefore assuming that log n (M) is a quadratic function of M for $M > M_o$

$$\log n (M) = \omega_o M^2 + \omega_1 M + \omega_2 \qquad (43)$$

Then the values of table 1 allow to estimate ω_j $(j = 0,1)$ from the system

$$\frac{1}{M_{i2} - M_{i1}} \int \frac{d \log n}{d M} dM = -b_i, \; i=1,2,\ldots.. \qquad (44)$$

or

$$- b_i = \omega_o (M_{i2} + M_{i1}) + \omega_1 \qquad (45)$$

With the least square method we obtain $\omega_o = - 0.179$, $\omega_1 = 1.99$;
the equation (43) is then

$$\log n (M) = - 0.179 M^2 + 1.99 M + \omega_2 \qquad (46)$$

TABLE 1

Region	N	$\bar{a}_2$	b_2	M_1	M_2
1	83	5.52302	0.76	4.4	6.5
2	133	4.79839	0.64	4.3	7.4
14 , 15	118	5.07731	0.70	4.3	6.6
16	162	6.58448	0.96	4.3	6.3
17	55	5.35070	0.81	4.2	5.9
18	180	6.40600	0.92	4.3	6.1
19	398	6.82069	0.93	4.3	6.8
20	176	6.00649	0.84	4.3	7.3
21	81	5.70163	0.85	4.3	6.4
22	523	7.32653	1.01	4.3	6.3
23	74	4.23564	0.58	4.4	7.0
24	223	5.08512	0.65	4.3	7.8
25	244	6.30129	0.83	4.8	6.7
26	1105	6.90602	0.82	4.8	7.0
26a	634	5.36460	0.62	4.8	7.0
26b	157	6.39173	0.87	4.9	5.9
26c	314	6.20430	0.78	4.9	7.0
27	80	4.51564	0.58	4.9	7.3
29	86	4.03978	0.51	4.9	7.3
32	151	6.93898	0.97	4.9	6.2
33	144	4.89036	0.60	5.0	8.0
34	107	5.00175	0.66	5.0	7.3

- List of the $\bar{a}_i$ and b_i of formula (6) for Europe, the Mediterranean area and the Middle East according to Karnik (1971) (data with variance larger than 25% of the value are omitted).

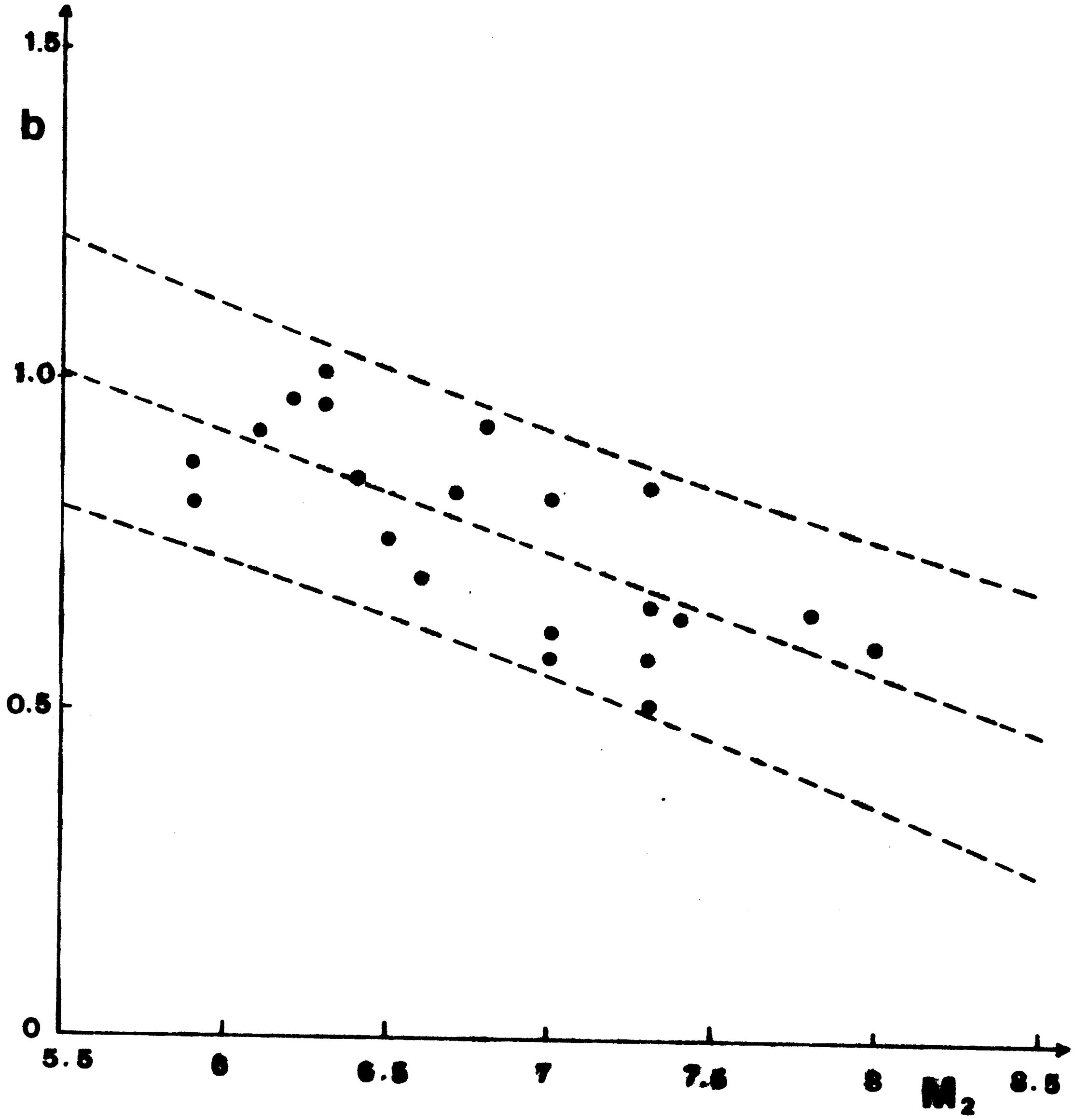

fig. 2 - Correlation of the b_i and M_{2i} values from the seismic data of Europe, the Mediterranean area and the Middle East according to table 1 (data with variance larger than 25% of the value are omitted).

Apart from the constant ω_2, equation (43) is in agreement with the theory presented in this paper.

The $\frac{d \log n(M)}{dM}$ may be obtained by using the correlation between b_i and $\frac{M_{i2} + M_{i1}}{2}$ which is less strong because of the small range of M_{i1}, but is physically more significant fig. 4

$$\frac{d \log n(M)}{dM} = -0.282\,M + 2.37 \tag{47}$$

Equation (47) should tentatively suggest the values of b_i in the various ranges of M, for Central Europe, the Mediterranean and the Middle East.

The estimate of n allows an estimate of D, or the number of faults of a given seismic area. In fact (36) can be written

$$n(M) = \frac{T_o \eta D}{FR^{\nu-1}} \int_0^{l_2/R} U(u)du; \cdot R^3 = \frac{E\mu}{\bar{\eta}\bar{K}F^2} = \frac{10^{\beta+\gamma M}\mu}{\bar{\eta}\bar{K}F^2} \tag{48}$$

The factor $\bar{\eta}\bar{K}$ can be assumed in the range $\frac{1}{3}, \frac{2}{3}$; T_o is known, the other parameters β, γ, μ can be estimated with satisfactory approximation, while η and F should be estimated from various sources.

By comparing then formula (48) with the experimental results one may have a rough estimate of D.

For the Appennines one may assume $\mu = 2.7.10^{-11}$ while $\beta = 12$, $\gamma = 1.44$ result from (27) (Bath 1973), η can be estimated from the stress accumulation relative to a strain accumulation 4.10^{-8}years^{-1}, which is comparable to the strain accumulation in the compression belts of the continental plates, with $\lambda + 2\,\mu = 1.3.10^{-11}$ we obtain $\eta = 5.2.10^3$ years^{-1}.
F represents the minimum stress drop, corresponding to $\alpha = \frac{\pi}{2}$, and can be assumed tentatively 0.5 bar.

The value of l_2 can be assumed around 16 km due to the geological nature of the crust and the depth of the hypocentres in the Appennines.

For M large we have from (48) and from Karnik (1971)

$$D = \frac{10^{\bar{a} + \beta/2}\,\mu^{\frac{1}{2}}}{2T_o\eta\sqrt{\bar{\eta}\,\bar{K}\,l_2}}\;10^{(\frac{\gamma}{2} - b)M_1} = 2.10^8$$

From this value of D we could infer that in the central part of the Appennines there should be the distribution of faults given tentatively in table 2.

The estimate of the value of E_o, where $\frac{d \log n(M)}{dM}$ is discontinuous, with the estimates of the parameters given above is $E_o = 1.9.10^{19}$, according to (17) this corresponds to M = 5.1 in agreement with the seismic data of the Appennines which is complete for magnitudes larger than 4 and also with the data of Karnik (1971).

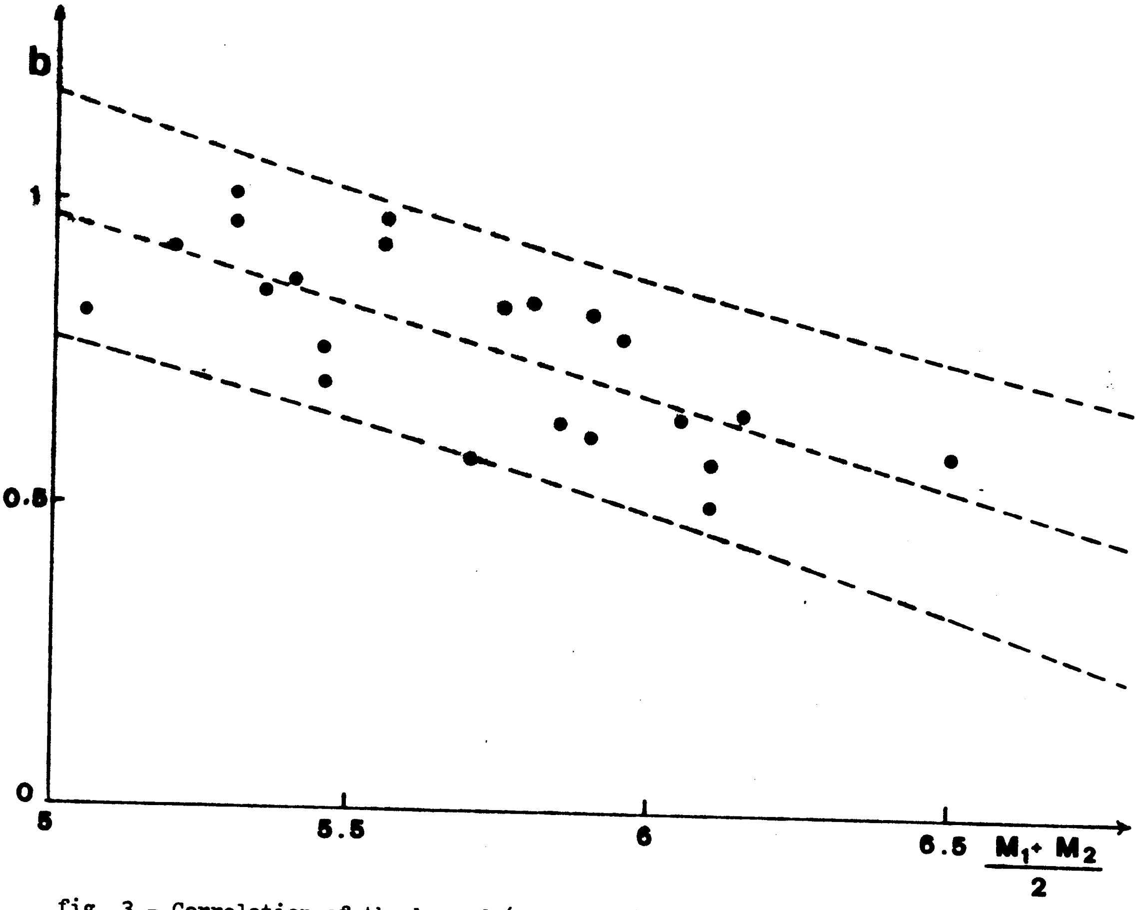

fig. 3 - Correlation of the b_i and $(M_{2i} + M_{1i})/2$ values from the seismic data of Europe, the Mediterranean area and the Middle East according to table 1 (data with variance larger than 25% of the value are omitted).

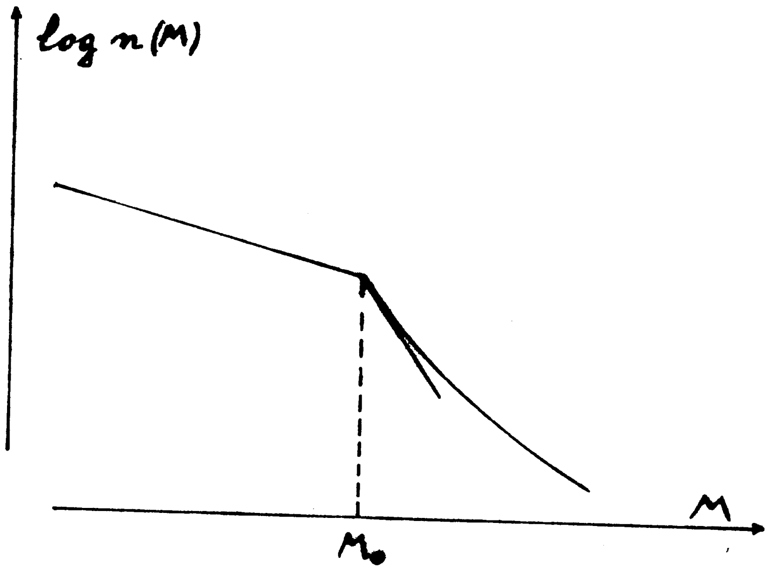

fig. 4 - Qualitative density distribution of the number of earthquakes according to formula (48).

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TABLE 2

NUMBER OF FAULTS

	2000	500	200	130	80	60	40	30	20	20	20	10	10	10	10
0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5	8,5	9,5	10,5	12,1	12,9	13,8	14,8	16,0

km

- Tentative estimate of density distribution of the faults of the Appennines. -

Deterministic and Probabilistic Approach to Determine Seismic Risk of Nuclear Power Plants. A practical example

by

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Summary

The two approaches, probabilistic and deterministic, to the determination of seismic risk of nuclear power plants, are applied to a particular case in Southern Spain. The results obtained by both methods when varying the input data are presented and some conclusions drawn in relation whit the applicability of the methods, their reliability and their sensitivity to such change.

Introduction

It has been common practice, in the study of seismic risk of proposed nuclear power plant sites, to follow what has been termed a deterministic approach.

Doubts always arise however in the application of such methods in relation with the validity of some of the hypothesis involved, namely:

- The data extends to a time interval long enough as to define the limiting value of the M.M. Intensity of the zone under study.
- The catalogued values of Epicentral Intensities are correct.
- Seismicity is time stationary.

A probabilistic approach has been suggested as an alternative solution as it can take into consideration some of the problems quoted above.

The purpose of the present paper is to compare both methods as applied to a practical example in order to derive some conclusions on their applicability.

Basic Data

The example refers to a site in the South of Spain near the coast of the Golfo de Cádiz. Seismic data has been taken from the Spanish catalogue. Such a catalogue is presently under revision but for the purpose of this analysis no corrections have been introduced. Only maximum values of the recorded epicentral intensity of some large historic earthquakes have been changed and this only with the purpose of comparing the sensitivity of both methods to such changes.

Isoseismal maps and attenuation laws have also been taken from the archive of the Seismological Service as compiled and prepared by D. Muñoz Sobrino (1974).

Tectonic data was obtained from maps published by the Spanish Geological Survey.

The Deterministic Method

A deterministic approach to a problem involving uncertainty on the basic parameters consists of taking the "best values" and finding the solution which corresponds to these previously fixed values. For the problem of seismic risk, basic factors of the problem are:

- Zone partitioning into homogeneous areas.
- Maximum value of epicentral intensities for each homogeneous area.
- Attenuation laws.

The maximum value of epicentral intensity for each area has to be determinedeither from the catalogued intensities or on the basis of the tectonic features of the region. Attenuation laws are also decided from catalogues.

Once these data are known, the solution to the problem in terms of maximum site intensity is calculated by assuming the maximum earthquake within each area to occur at the point nearest to the site under study and by decreasing the epicentral intensity through the use of the corresponding attenuation law.

For our particular problem two different zone partitioning have been considered as given in Figs 1 and 2. The first one is based only on tectonic information whereas the second one has been obtained modifying the first on the basis of seismic data.

Two different sets of epicentral intensities have been also considered; the first one accepting the catalogued values and the second one changing some of the largest intensities to more reasonable values on seismotectonic considerations. No change was introduced in the attenuation laws, as it was felt that a variation in them would affect in the same way to both methods.

The type of attenuation law used is

$$I = I_o - a \lg_{10} \frac{(R^2 + h^2)}{h} \qquad (1)$$

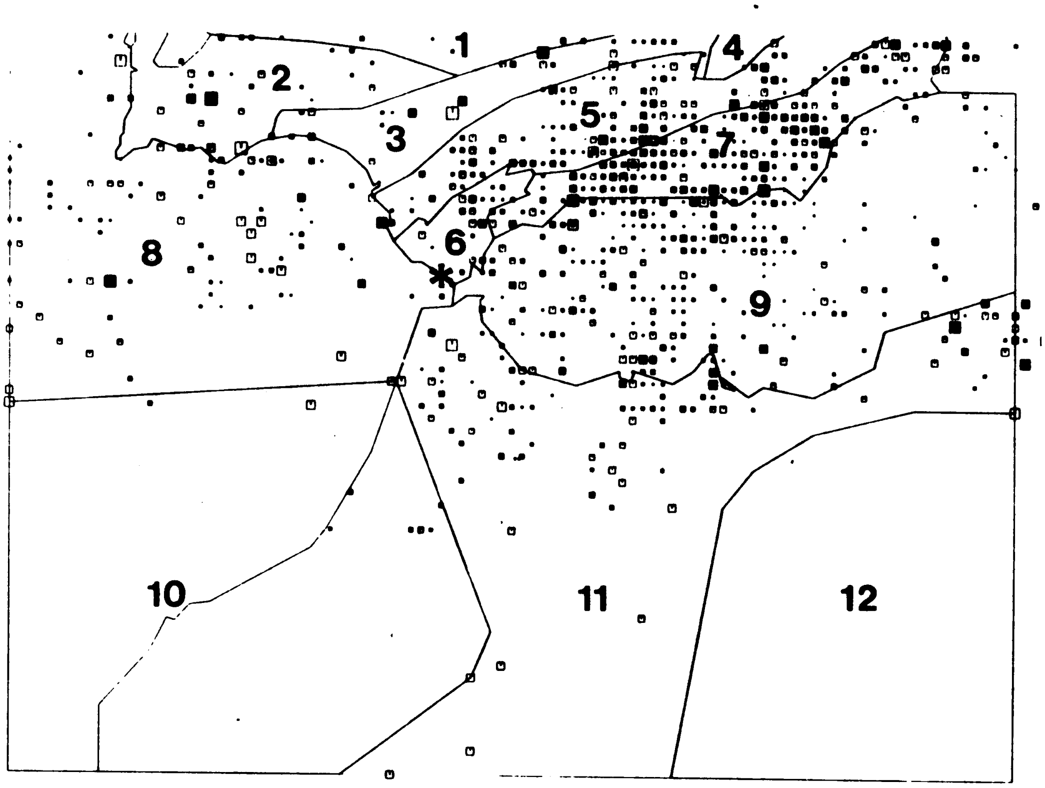

FIG. 1.- ZONE PARTITION (TECTONIC)

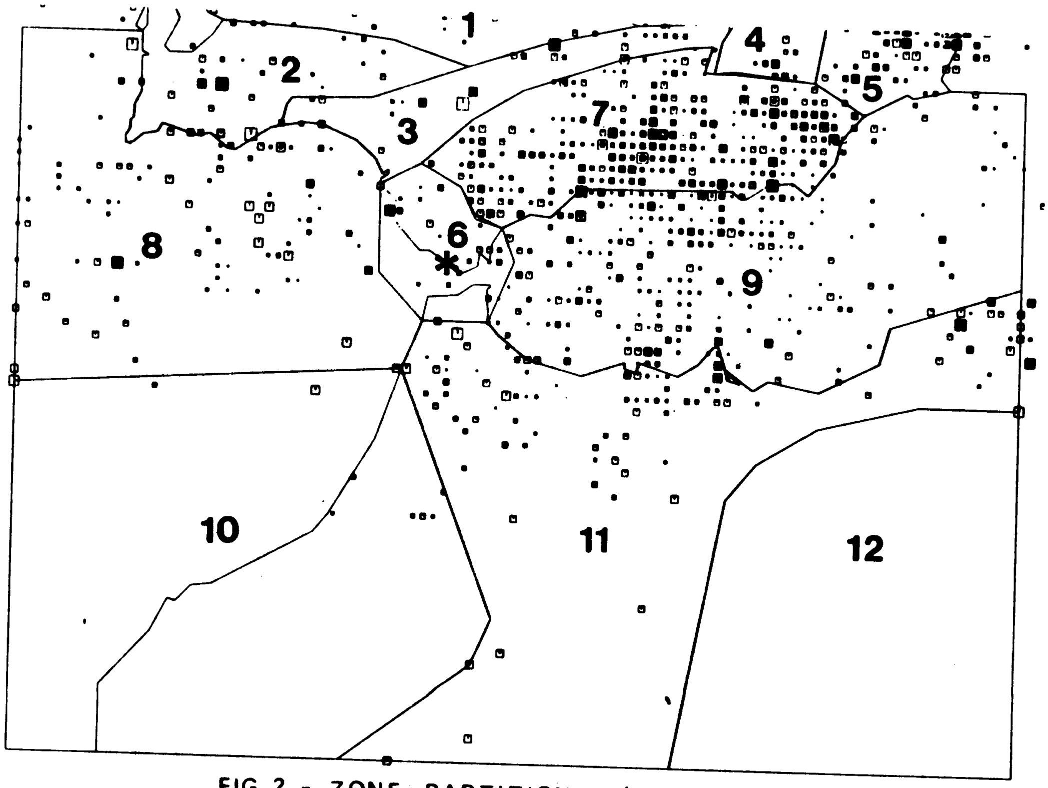

FIG. 2.- ZONE PARTITION (SEISMOTECTONIC)

The Probalistic Method

A probabilistic approach to problems involving uncertainty on the basic parameters consist of defining the input to the solution not as fixed values but as random variables with known statistical distributions.

For the problem of seismic risk the basic data consist of:

- Zone partitioning into homogeneous areas.
- Distribution law of the epicentral intensities for each area.
- Earthquakes time distribution.
- Attenuation laws.

The data needed are, therefore, similar to those for the deterministic approach; this time however zone partition has to be homogeneous not only with regard to maximum epicentral intensities and attenuation laws but for the distribution of epicentral intensities and the earthquake time distribution as well.

The probabilistic method, as it has been used here, estimates the probability that at a given site and within a given period of time the intensity of ground shaking will equal or exceed apreviously fixed level. Such probability is the same as that of having an earthquake, at any source area of such a size as to produce at the site considered an intensity larger than the one being analyzed.

By use of the attenuation law, this method estimates, for each potential source, what shall be the earthquake size in order to exceed the fixed intensity value at the site.

The product of the mean rate of occurrence of earthquakes of a given size and the probability of exceeding the fixed site intensity gives the mean rate of occurrence of events of interest, which is very closely the probability that, at the site and during the unit time interval, the previously fixed intensity value will be exceeded (Cornell, 1968).

These computations, made for different values of site intensity, have been carried out by means of a computer program which integrates the probabilities for each source area. Data to this program are the geometries of the different areas, which are later divided into small pieces by the program, rate of occurrence of events and its size distribution, and the attenuation correlation given as an analytical law plus a mean zero error term which is assumed normaly distributed and whose standard deviation is given.

The application of the method to this particular problem has been made for the same two zone partitions previously described.

To estimate the statistical distribution of epicentral intensities for each zone a computer program was prepared to divide and classify the data of the general catalogue into this zones.

Histograms of the distribution of epicentral intensities were prepared for each individual zone. The study of these histograms provided some insight on the problem. First, data of earthquake with epicentral intensity smaller than M.M. III, were highly incomplete, so they were excluded from the analysis.

Secondly it was observed that the shape of the histogram changed significantly when only modern data was considered; this meanly due, to incompleteness of old data on moderate size earthquake. Figure 3 shows histograms of the catalogued data for different periods for a particular zone, all of them normalized at a M.M. intensity of III. The relative frequency of large events is higher when old records are included.

Having these kind of insight in the catalogue the distribution of epicentral intensities was aproximated by a truncated quadratic exponential distribution as that described by Cornell (1974).

According to a quadrate exponential distribution the probability that the epicentral intensity Io exceeds a value x can be written,

$$P\ (I_o > x)\alpha \qquad \exp\ \{\beta_1\ (x - x_o) + \beta_2\ (x^2 - x_o^2)\} \tag{2}$$

where x_o is the theshold value of M.M. intensity III considered for this problem.

Truncation on the right of the distribution is obtained by assigning zero probability to the maximum possible epicentral intensity.

The truncated distribution becomes

$$P\ |I > x_o| = 1 - K\ \{1 - \exp\ (.)\}\ ;\ x_o < x < x_1 \tag{3}$$

where (.) stands for the exponent of equation (1) and K is given by

$$K = \{1 - \exp\}\ \beta_1\ (x_1 - x_o) + \beta_2\ (x_1^2 - x_o^2)\}^{-1} \tag{4}$$

Fig. 4 shows this type of distribution law. Values of β_1 and β_2 were obtained by specifying the initial slope of the distribution and the intensity with a probability 1/100 of that corresponding to x_o, to be the same as those of the histogram.

Values of x_1 have been given in the same maner as for the deterministic approach. These values are on the other hand in agreement with the maxima obtained by analysis of the catalogue by the third Gumbel's extreme value distribution (López Arroyo and Stepp, 1973).

Agreement of the distribution law and the histograms of the data is shown in Figure 5 and 6 for two different zones.

Mean rate of occurrence of earthquakes(M.M. III) for each zone was estimated by computing the relative frequency of those events for different periods af time. It was observed that the rate of events per year, in each zone was larger for the more recent part of the catalogue and these values were chosen.

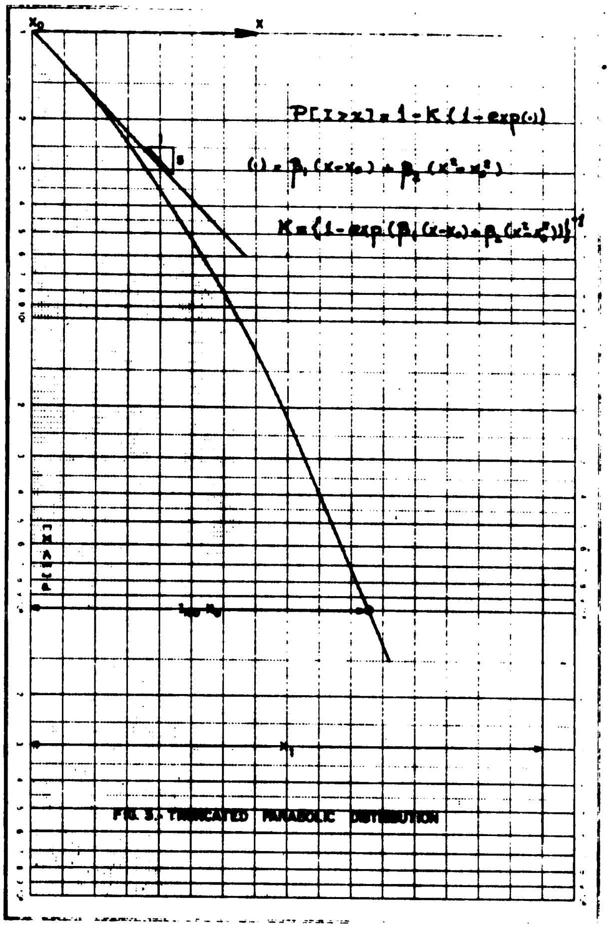

FIG. 3.- TRUNCATED PARABOLIC DISTRIBUTION

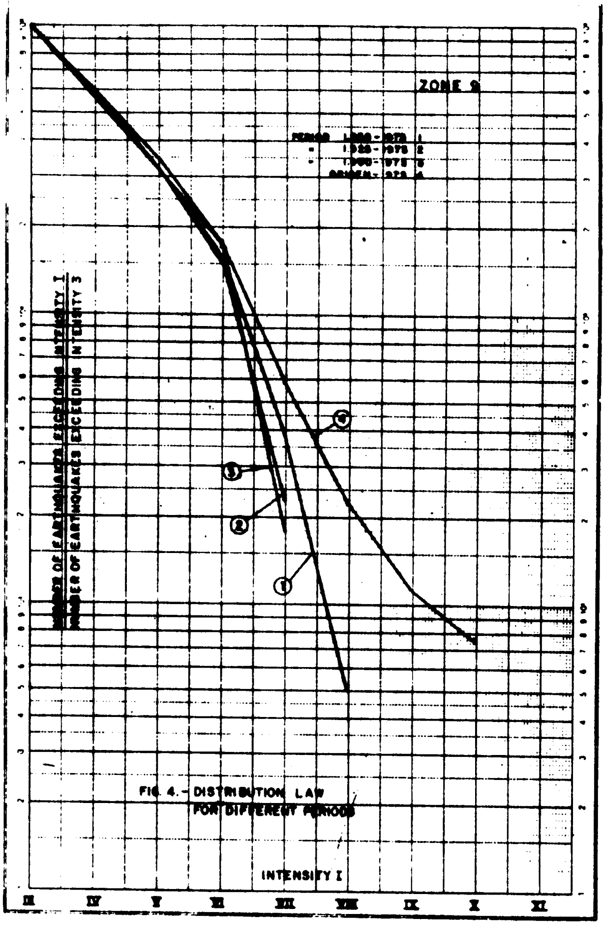

FIG. 4.- DISTRIBUTION LAW FOR DIFFERENT PERIODS

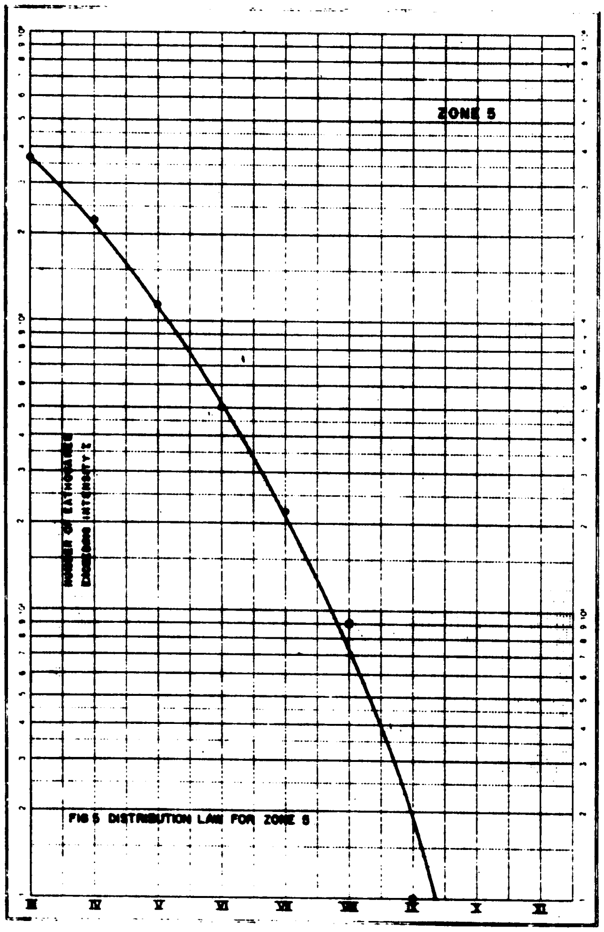

FIG 5 DISTRIBUTION LAW FOR ZONE 5

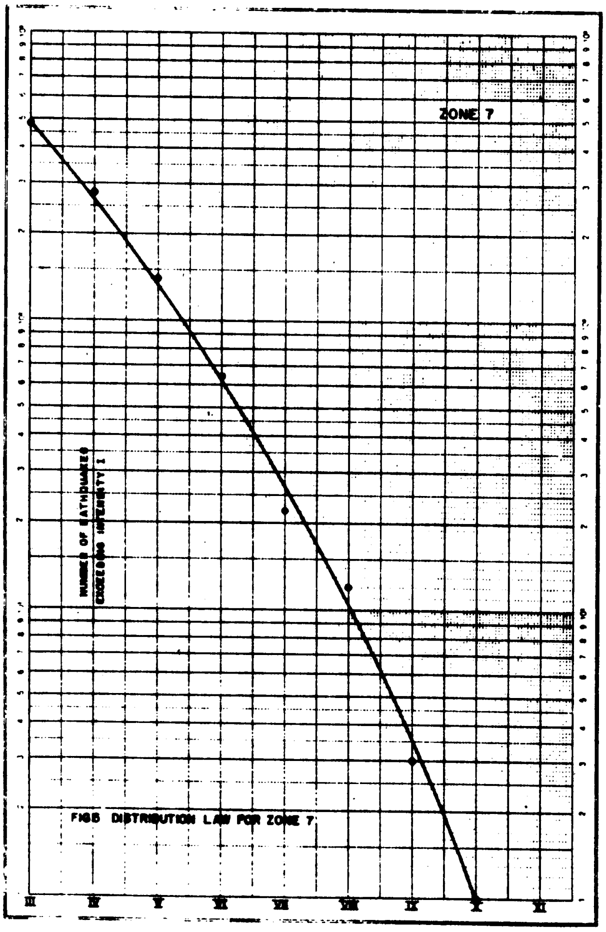

FIG 6 DISTRIBUTION LAW FOR ZONE 7

Attenuation laws were the same a those used for the deterministic analysis except for the added error term. This term was assumed to have a standard deviation of half a degree of the M.M. scale for R 20 km and a standard deviation of one fifth of a degree when R 20 km.

The main parameters used for the analysis are summarized in Table 1.

Results of Analysis

Three cases have been analized:

Case I, having the first (tectonic) zone partition and maximum epicentral intensities equal to those of the catalogue. Results of the probabilistic analysis for this case are summarized in Table 2. The return period for a M.M. site intensity of VIII is about 300 years (or the probability of exceeding this value in one year period equal to 1/300). For a M.M. intensity of IX the return period is about 3.000 years.

The deterministic analysis, for this case, gave a maximum site intensity of XI since the site was located at the border of a zone for which that intensity was considerd to be the maximum.

As a result of this part of the analysis it was observed that the influence of the Guadalquivir fault zone (zone 3) was very important as shown in the lower part of Table 2. Only one particular earthquake, the 1504 Carmona earthquake, had intensity XI. Since this particular datum is presently under debate, its intensity was changed to X and the analysis repeated. This is named Case II.

For Case II the return period corresponding to a M.M. site intensity VIII changed from 300 years to about 800 years. However the result of the deterministic approach for this analysis did not change since the maximum intensity was determined by seismicity of the Golfo de Cádiz (Zone 8).

Case III, was then considered, the differences being the zone partitioning (mainly, Guadalquivir fault was assumed as a line source and zone 6, which included the site, was enlarged) and maximum epicentral intensities were lowered by about half a degree. For this case the probabilistic analysis showed a return period for M.M. intensity VIII of about 2.000 years, and the deterministic analysis gave a maximum site intensity of VIII.

Results of the deterministic analysis for these three cases are given in Table 3 and those of the probabilistic analysis plotted in Fig.7.

Conclusions

A comparison of the probabilistic and deterministic approachs to determining the seismic risk of a particular site in the Southern coast of Spain has been carried out and the analysis yields the following conclusions:

- The probabilistic method behaves better under changes of the basic data than the deterministic method. The results of the first are moderately affected by those changes whereas the results of the second are either not affected at all or largely modified.

- The information obtained during the analysis of the seismic risk by means of the probabilistic method is very valuable to get insight on facts such as completness of the basic information, validity of some particular data records, seismic characteristics of different zones, etc. which could not be obtained by a purely deterministic approach.

- The result of the probabilistic approach gives a more complete picture of the seismic risk of a given site than the one obtained by the deterministic method.

- Although for this particular problem the deterministic analysis turned out to be in general pesimistic as compared to the probabilistic approach, we feel that this will not always be the case for other situations.

- As a final conclusion it seems to us that the probabilistic approach is a better way to handle the uncertainties involved with the determination of the seismic risk and it should not be omitted in the analysis of nuclear power plant sites.

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TABLE 1.- INPUT PARAMETERS

ZONE	EVENTS PER YEAR	DISTRIBUTION LAW			ATTENUATION LAW	
	MEAN RATE $I_0 > III$	β_1	β_2	I max. (X_1)	a	h (Km)
1	1.	0.200	-0.113	8	5	50.
2	0.5	-0.187	-0.0291	11	5.	50.
3	0.5	-0.032	-0.0404	11	5.	50.
4	3.	-0.012	-0.078	9	7.	10.
5	6.	-0.143	-0.057	10	7.	10.
6	1.	0.208	-0.124	8	7.	10.
7	6.5	-0.334	-0.0394	11	5.	5.
8	2.	-0.510	0.	11	7.	10.
9	5.5	-0.051	-0.0723	11	5.	5
10	–	–	–	–	–	–
11	2.2	-0.129	-0.0428	11	5.	5
12	–	–	–	–	–	–

FIG. 7.- FINAL RESULT

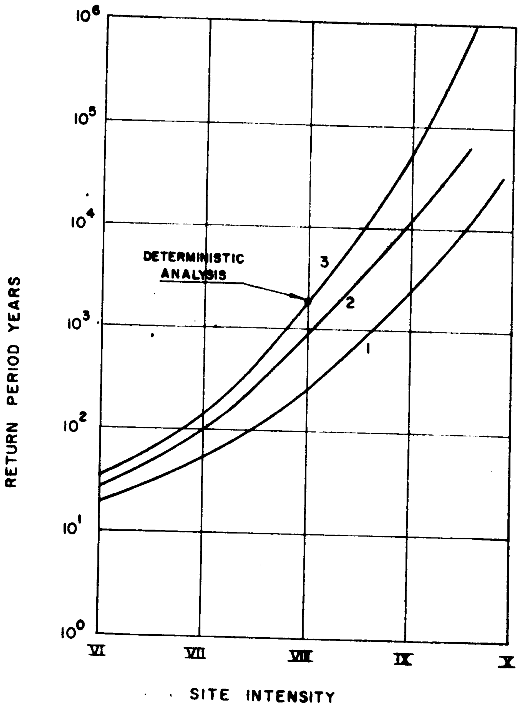

TABLE 2.- RESULTS OF PROBABILISTIC ANALYSIS (CASE I)

(M.M.) SITE INTENSITY	V	VI	VII	VIII	IX	X
(YEARS) RETURN PERIOD	10	28	60	295	2.860	50.000

CONTRIBUTIONS TO THE RISK. (%)

ZONE	V	VI	VII	VIII	IX	X
1	1	–	–	–	–	–
2	30	25	20	10	–	–
3	50	65	73	85	98	100
4	–	–	–	–	–	–
5	–	–	–	–	–	–
6	9	4	2	2	–	–
7	–	–	–	–	–	–
8	3	3	2	2	–	–
9	3	1	1	–	–	–
10	–	–	–	–	–	–
11	3	1	–	–	–	–
12	–	–	–	–	–	–

TABLE 3.- RESULTS OF THE DETERMINISTIC METHOD

ZONE	CASE I	CASE II	CASE III
1	V	V	IV
2	VIII	VIII	VIII
3	IX	VIII	VIII
4	–	–	–
5	V	V	V
6	VIII	VIII	VI
7	V	V	–
8	XI	XI	V
9	XI	XI	III
10	–	–	–
11	–	–	–
12	VIII	VIII	VI
RESULT	XI	XI	VIII

Seismic risk determination including local soil conditions for two possible nuclear power plant sites in Turkey

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Summary

This article contains a case study for two potential sites in northwestern Turkey under consideration for the construction of nuclear power plants. A global seismic risk evaluation as well as a geodynamical study were carried out for either site. It is determined that in terms of acceleration on "firm" soil, site A has greater seismic risk than site B. However when local geological formations are introduced into the study, it is found that site B amplifies oncoming ground motion to a greater degree than site A. In conclusion, the importance of incorporating local soil conditions in seismic risk calculations is pointed out.

Introduction

Two sites (which will be referred to as sites A and B, respectively) in highly seismic northwestern Turkey had been selected earlier by the Turkish Electricity Authority for consideration to build nuclear power plants. Inasmuch as the selection was based on criteria which did not include seismic considerations, members of the Earthquake Engineering Research Group of the Middle East Technical University were asked to prepare a report (1) on the seismic risk of the two potential sites in terms of possible and expected future ground motion. Only the highlights of this report will be included in this article; the following can therefore not be considered to constitute an exhaustive evaluation.

Past Seismic Activity

The purpose of all seismic risk studies is to use available data on past seismic activity in making "rational" estimates of expected future activity. An important step is the determination of areas or subareas which contribute to the potential earthquake risk at the site. In order to preserve the homogeneity of the available data derived from References (2), (3) and (4), it was decided to draw a circle with a radius of 120 km for site A, and 200 km for site B with the proposed sites at the center. Since it is the rate of seismic activity that influences risk studies rather than absolute numbers, the shorter radius region did not unfavourably alter the results.

All earthquakes with magnitude equal to or larger than 4.3 and which occurred after 1900 were included in the analysis. Quadratic cumulative frequency-magnitude relationships for the two sites are given in Fig.1. The quadratic form was chosen over the linear relationship inasmuch as this gives much too conservative values in risk analysis, and in this highly seismic area further conservatism would yield totally unrealistic results, especially at low risk levels (1).

Seismic Risk Analysis

Firstly a test of statistical independence was made for the magnitudes of earthquakes including after-shocks. From a chi-square control chart, it was determined with a probability of 0.999 that successive events are actually statistically independent for both regions. Thus the assumption of a Poisson process in the seismic risk analysis was justified.

Rather than identifying those subregions within both regions that would contribute to the total risk for sites A and B, it was decided to obtain an upper bound of the level of seismic risk that could be expected for them. For this reason all seismic activity which took place during the observation period was ascribed to one single fictitious fault within each circular region located at various distances to the potential sites. Using the quadratic frequency-magnitude relationship, Esteva's attenuation formula for acceleration (5) and the method developed by Mertz and Cornell (6) seismic risk curves were obtained for the two sites. These curves, referred to different hypocentral distances, are given in Figs. 2 and 3 for sites A and B, respectively. Obviously, hypocentral distances less than 10 km do not have much practical significance. For both regions, the maximum "credible" earthquake was assumed to have a magnitude of 8.3. The North Anatolian Fault which extends between these sites (about 25 km from each) has in fact generated an event with a magnitude of 8.0 in 1939 (2)

Although the risk values for site B are lower than those for site A, neither rates well when a standard risk level of, say, 10^{-4} is imposed on the evaluation.

Geodynamical Considerations

The idealized subsoil profiles for the two sites are given in Figure 4. Using a power spectrum simulation method developed earlier (7,8) the S-wave power spectra were computed and are plotted in Figure 5 for both sites. It is seen that site B gives a higher power spectrum than site A for all T. It was also calculated that the rms value for the expected acceleration at site B was about 2.5 times greater than that of site A within a frequency band of 0 - 30 rad/sec.

Conclusion

Incorporation the rms increase of site B into seismic risk curves, it can be concluded that both sites are expected to receive similar ground motion amplitudes in the future. It is generally advisable to incorporate this effect into risk analysis in order to obtain a consistant risk measure.

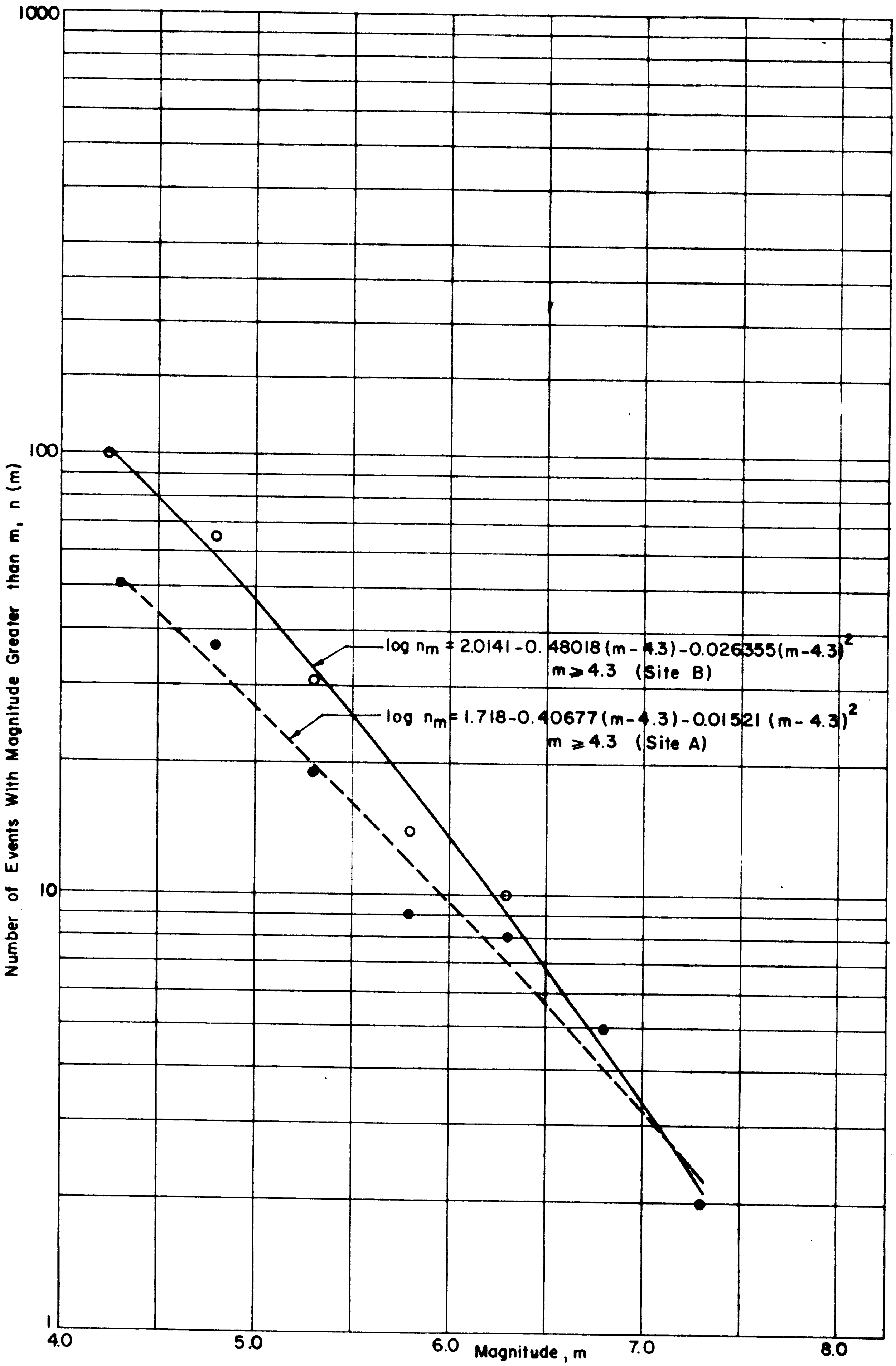

FIG. 1 - Magnitude - Frequency Relationships

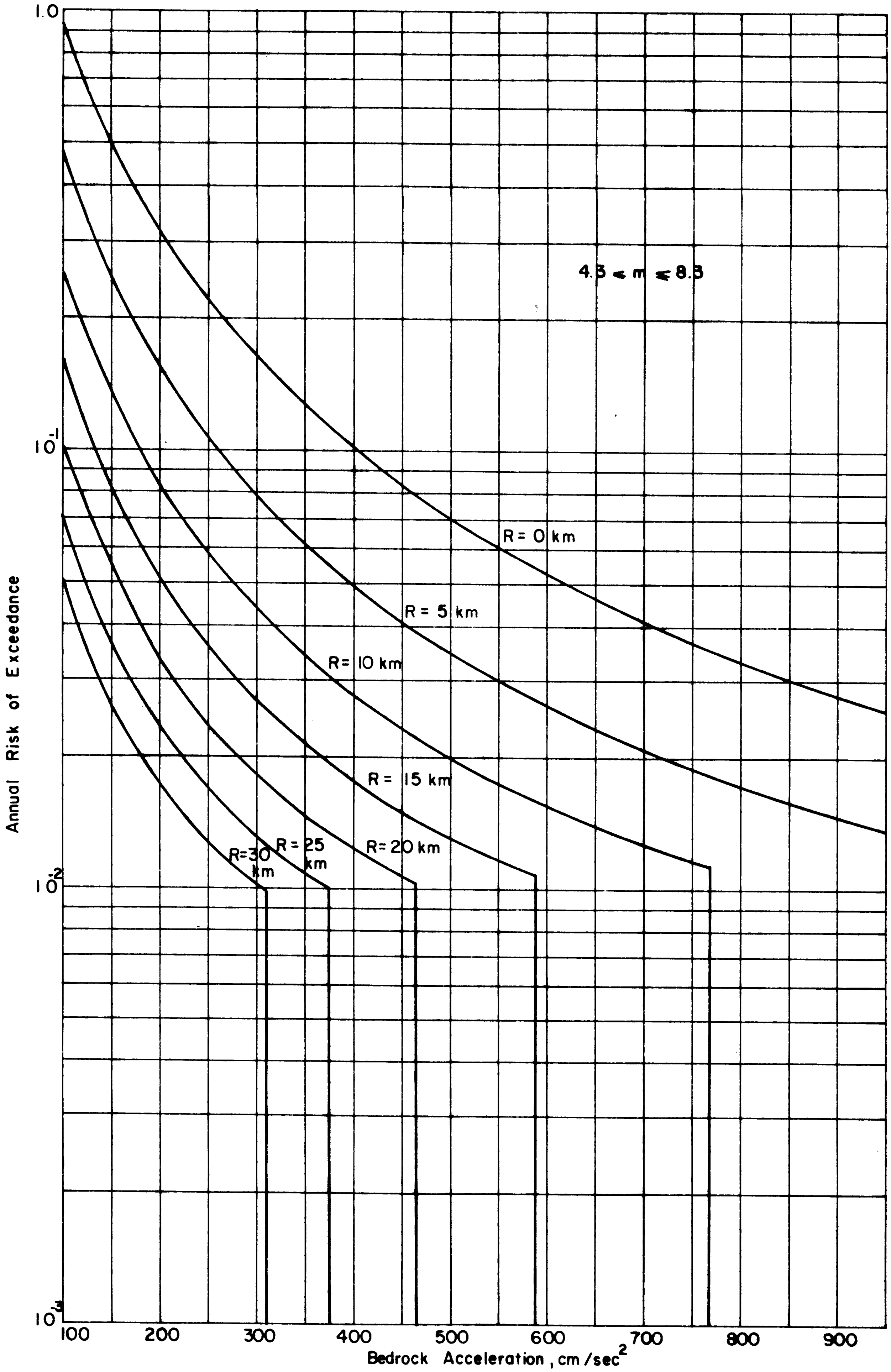

FIG. 2 - Acceleration Risk Curves, Site A

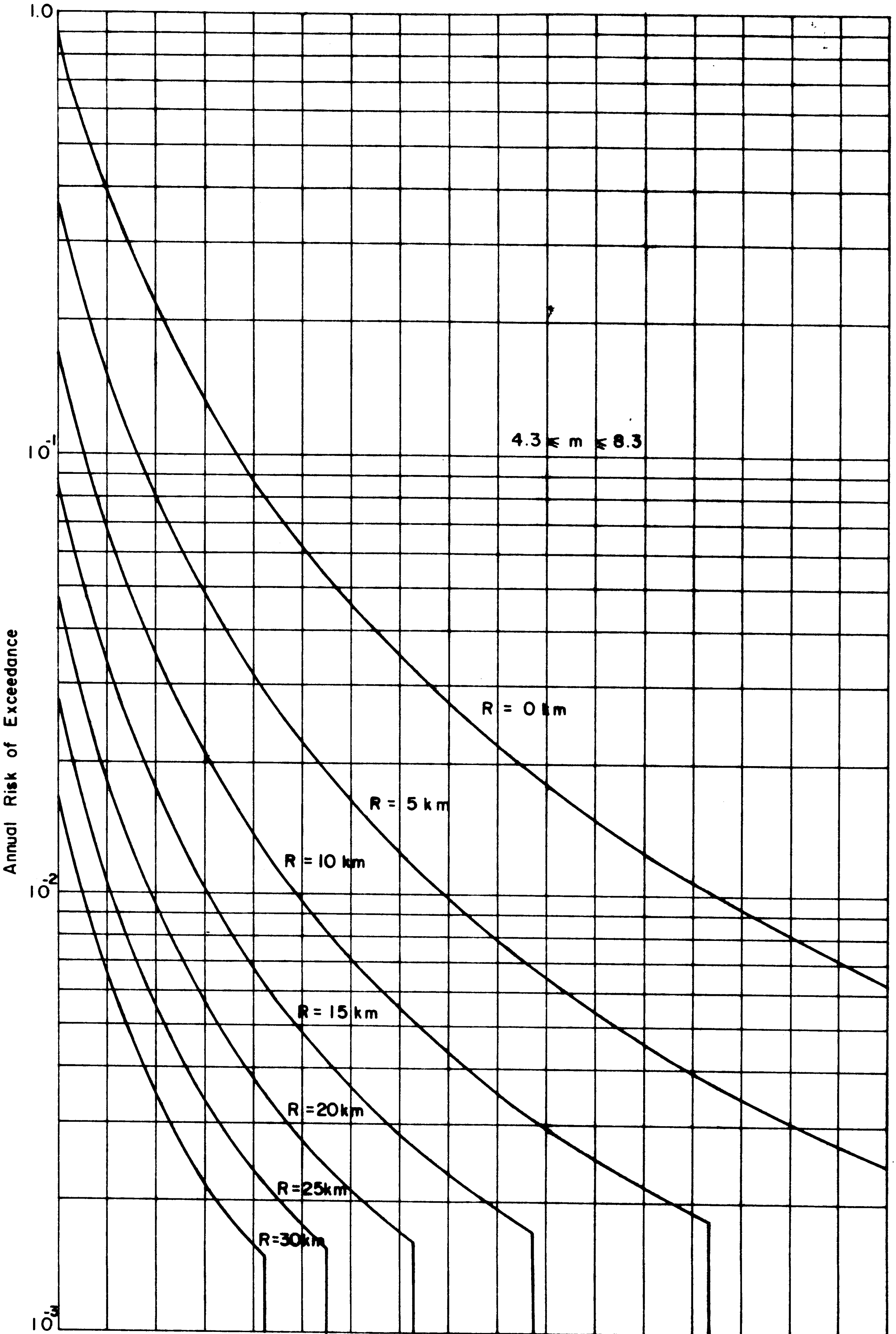

FIG. 3 - Acceleration Risk Curves, Site B

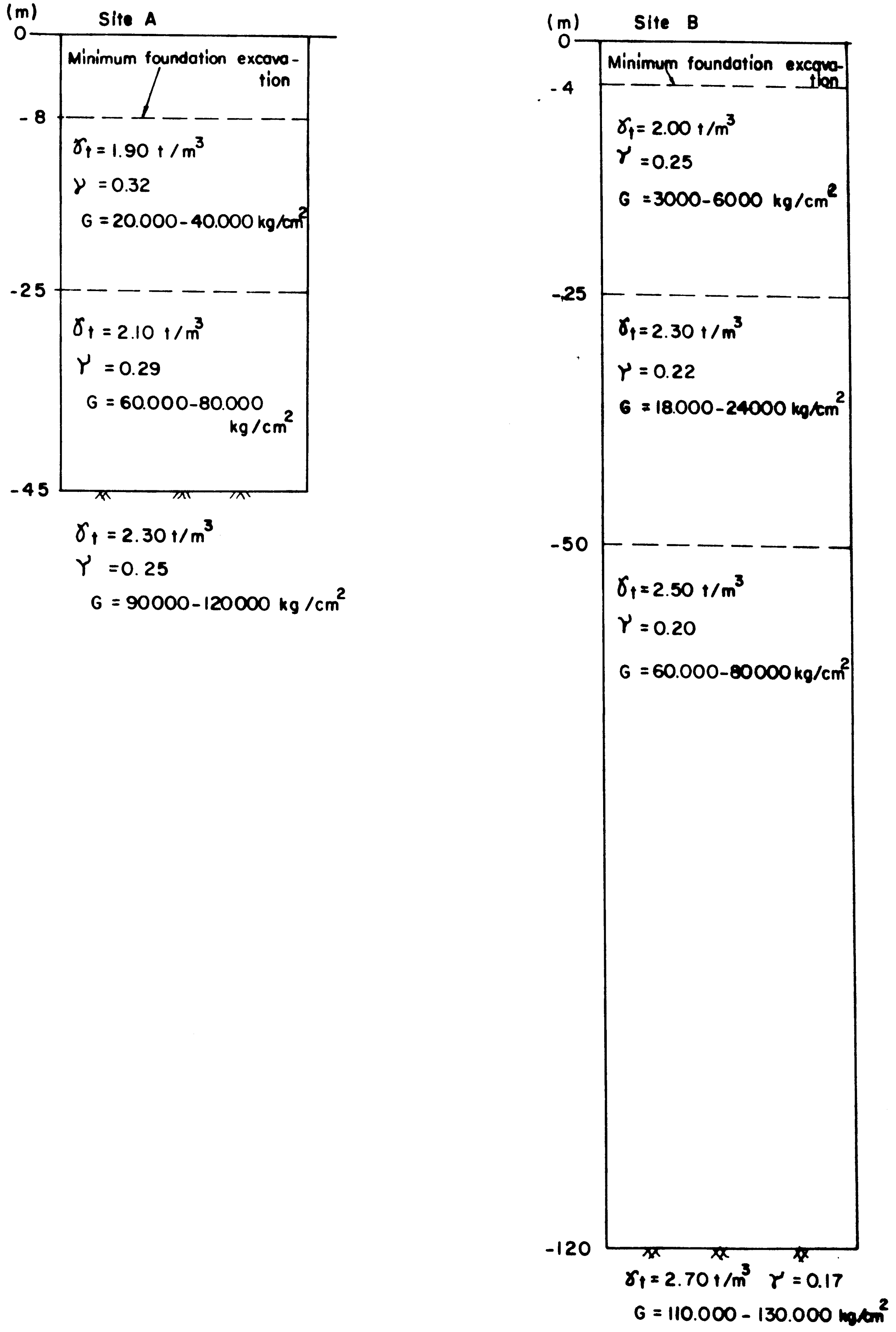

FIG. 4 - Subsoil Profiles for Sites

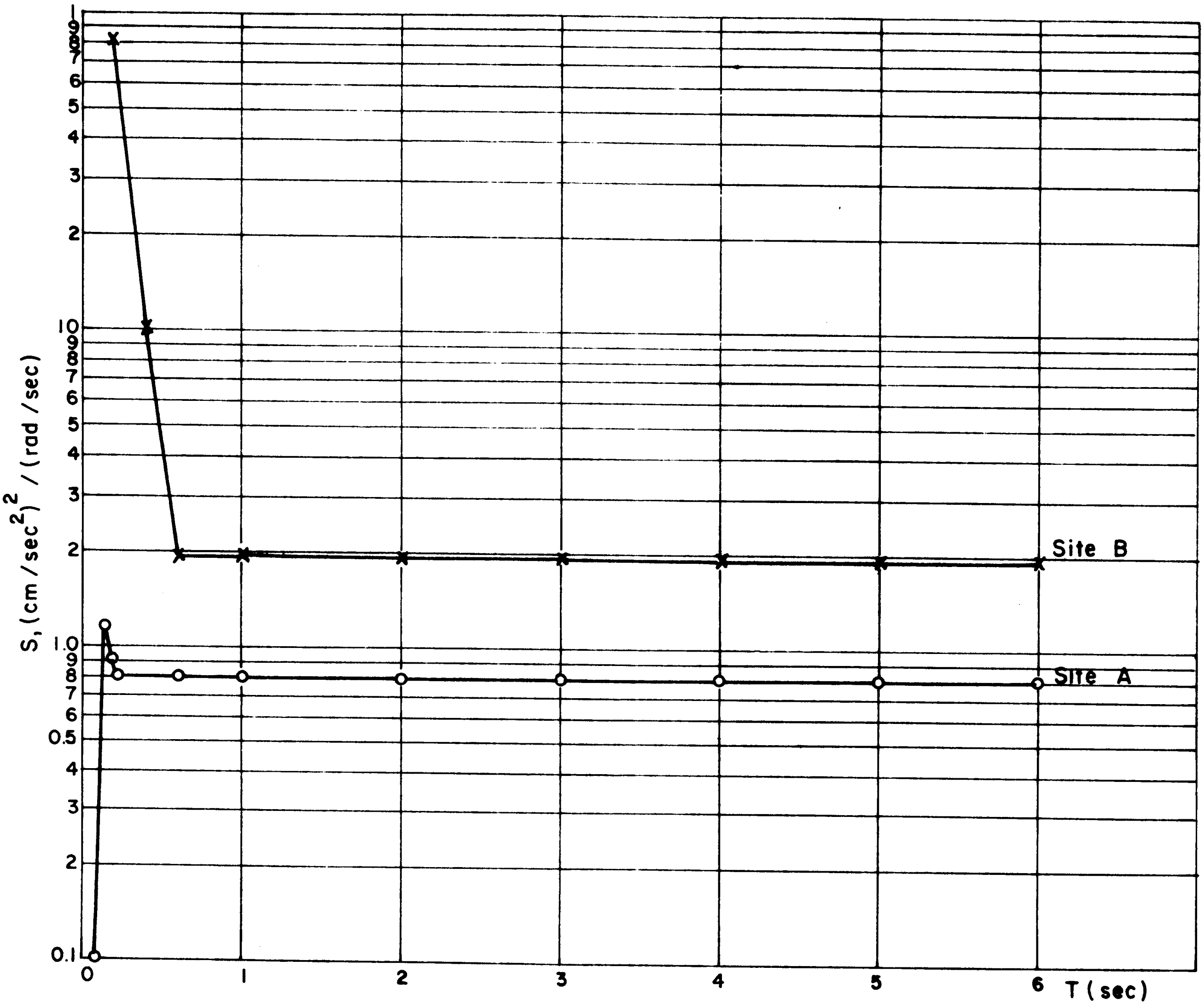

FIG. 5 - Simulated Acceleration Power Spectra for Sites A and B

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Complex study of seismic conditions of the Armenian nuclear power plant in a seismic dangerous region of the USSR

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The strong-motion seismometer network in Yugoslavia

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Current UNESCO Programmes in Seismology

This text, as a part of a review by Dr. E.M. FOURNIER D'ALBE on Current UNESCO programmes in seismology and volcanology, with approval has been extracted from "Nature and Resources" Vol. XI, 3, p. 13-15, July-September 1975.

Since the early 1960s, Unesco has been engaged in a long-term programme aimed at improving our knowledge of natural hazards and our means of protection against them. Within this programme, attention has been concentrated mainly on earthquakes and volcanic eruptions. In the following special attention is drawn to the seismic programmes.

As an intergovernmental organization, Unesco is concerned less with promoting scientific research for its own sake (this, at the international level, is the task of the international scientific unions and associations), than with the application of scientific and technical knowledge to the improvement of methods of risk assessment, warning systems and protection measures. Efforts have therefore been focused on (a) seismic zoning, and the estimation in statistical terms of the risks to life and property within these zones; (b) the development of improved monitoring systems and of methods of forecasting seismic activity; and (c) the refinement and wider application of earthquake-resistant design and construction.

In pursuing these objectives, Unesco's main functions are to provide opportunities and means for international consultation and co-operation by convening conferences, symposia, meetings of working groups on particular topics and to assist developing countries in carrying out research and training in the appropriate scientific and technical disciplines.

Seismology and earthquake engineering

During the 1975-76 biennium, the principal event will be the Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk that will be held at Unesco Headquarters in Paris from 10 to 19 February 1976. The main themes of this conference will be: the assessment of earthquake risk (zoning, microzoning, prediction, etc.); engineering measures for loss reduction (buildings, utilities, urban plans, etc.); implications of earthquake risk (human, social, economic, etc.).

For each item of this agenda, a basic working document will be prepared in advance of the conference, to serve as a point of departure for the discussions. Governments will be invited to present national reports, summarizing each country's activities. The conference will be expected to make recommendations for further action, both at the national and at the international level, to reduce human and economic losses due to earthquakes. It is hoped that it will be attended not only by seismologists and engineers but also by persons concerned with the human and social aspects of the earthquake problem, with civil defence, insurance, etc.

An aspect of Unesco's regular activities which should be mentioned is the sending of reconnaissance missions of experts to the sites of destructive earthquakes immediately after their occurrence. Several such missions have visited Latin American, Asian, African and South European countries. Their scientific value is widely recognized.

In addition to the above activities which are financed from Unesco's own budget, the Organization acts as the Executing Agency of the United Nations Development Programme (UNDP) in a number of projects aimed at developing seismology and earthquake engineering in various parts of the world. Among the most important projects in operation at the present time are:

1. Survey of the seismicity of the Balkan region.
   Five Balkan countries (Bulgaria, Greece, Romania, Turkey and Yugoslavia) are co-operating in this survey, which commenced in November 1970 with a total UNDP contribution of about $850,000. The results achieved so far include: (a) the compilation of a regional catalogue of earthquakes, covering a period of about 2,000 years and including the instrumental data acquired since 1900; (b) the improvement of the observatory network by the establishment of new stations and the modernization of existing ones; (c) the preparation of a seismotectonic map of the region, synthesizing all available seismological and geological data; (d) a statistical analysis of magnitude-frequency and magnitude-distance-focal depth-intensity relations for earthquakes in the region; (e) the preparation of maps of maximum expected magnitudes and intensities for various return periods; (f) the preparation of maps of seismic risk, showing ground accelerations and velocities and their probabilities of occurrence during various periods of time; and (g) a comparative study of various seismic microzoning methods in selected urban areas.

2. Soil dynamics research at the National Autonomous University of Mexico (UNAM).
   The principal objectives of this project, which began in May 1971, are (a) to improve understanding of the engineering implications of soil dynamic phenomena, and particularly the behaviour of soils and foundations during strong earthquakes; (b) to refine Mexican earthquake building codes; (c) to produce new design recommendations for engineering structures; (d) to provide consultant services in soil dynamics; and (e) to train engineers and architects in this subject.

   A network of strong-motion accelerographs, with radio-telemetry to the project headquarters, has been installed in the Valley of Mexico and in surrounding areas. A well-equiped soil dynamics laboratory has been installed, especially for the study of soil liquefaction problems. A vibrating table taking models up to 15 tons can simulate earthquake motions or harmonic vibrations of specified type, with accelerations of up to 1 x g.

   The results of the research now under way will have, of course, direct applications in seismic microzoning.

3. Regional seismological network in South-East Asia.
   This project, which commenced in November 1973 and will continue for five years, is aimed at building up an efficient network of seismological observatories in Indonesia, Malaysia, the Philippines and Thailand. The UNDP contribution of approximately $900,000. is being used mainly to supply standard sets of seismographs, specially designed for operation in difficult tropical conditions, and to finance a long-term training programme for station operators and professional seismologists. Arrangements are also being made for the processing, within the region, of the large volume of data which is expected to flow in as soon as the new equipment is installed. At a later stage in the project, a beginning will be made in the use of the data to define the patterns of seismicity in each of the participating countries.

At the present time, plans are being discussed for other projects in South America and the Hindu Kush-Himalayan region, similar to the Balkan and the South-East Asian projects described above.

Seismology and public safety

Seismologists have an inspiring task, and one of great social responsibility, in attempting to define seismic risk, both in time and space, as accurately as possible. Scientific progress in this direction has been rapid in recent years, and we may hope with some confidence that it will continue to be so in the future.

There are still, however, many obstacles to the full practical application even of the scientific knowledge which already exists. To overcome these, an effort will be required not only on the part of the public authorities to understand what scientists can tell them and to act accordingly, but also on the part of the scientists themselves. In his research, a scientist must necessarily detach himself from the world of practical realities; he is obliged to abstract from a welter of detail the essential parameters of the problem he is studying; he must, to some extent, forget about external social factors. But when it comes to drawing the practical conclusions from his research, he also must make an effort to understand the constraints under which those responsible for public safety have to work. In so far as he can give advice in situations involving human lives and livelihood, he must necessarily assume some of their heavy responsibilities. In the opinion of Unesco this is a challenge and a test to which many scientists are glad to respond.

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Ground motions in the near field of low magnitude earthquakes

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(not presented)

Problems in evaluating low probability ground motion

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Summary

Current approaches in evaluating low probability seismic risk follow either of two general methods, i.e. probabilistic or limiting seismic risk analysis. It is suggested that the two methods of analysis model different aspects of the problem with vastly different time factors, and complement each other. A seismic study is briefly described where both approaches were considered.

Introduction

In evaluating seismic risk at a site, one isolates a critical crustal volume relevant to the site and tries to understand a large scale fracture process within this volume. The underlying physical process evolves through a long term strain history, inside the critical crustal volume, interrupted by short term fracturing along crustal discontinuities (tectonic faults) and leads to a fracture critical to the site. (Critical fracture). The difference in scale between the long and short term processes is very large and difficult to bridge: the long term process of engineering interest is of the order of the life of the structure (tens of years) whereas the short term process is of the order of the duration of an individual earthquake (tens of seconds).

The engineering decision necessary to define a critical fracture is graded into two levels: the structure is designed to feel a moderate rather frequent earthquake without major damage (low level) and to survive a major rare earthquake (high level). The corresponding terms introduced in nuclear technology are quite descriptive of the philosophy underlying the two design criteria: the OBE (low level) is related to the normal operation of the network of the power generating units and constitutes an optimisation problem, whereas the SSE (high level) is defined for each individual nuclear power plant, on the basis of safety considerations. This paper is concerned with the low probability ground motion associated with Safety Shutdown Earthquake.

The critical crustal volume is defined by optimisation of the available information. In order to arrive at a critical crustal volume one starts from global tectonics considerations and focuses on the site by decreasing geographic areas. Methodology branches off after the definition of the critical crustal volume (Plate No.1):

One approach follows a probabilistic evaluation of the long term process inside the critical crustal volume. In this evaluation earthquakes are described by a single parameter (their magnitude) and are assumed to be Poisson's events deprived of memory. The model takes as input a probability distribution for magnitudes (Cornell, 1968). This distribution is obtained from events in the critical crustal volume. The size of the statistical sample defines the critical crustal volume, i.e., in order to obtain an acceptable statistical sample and since the length of the earthquakes record is limited in time, one has to collect information from a larger geographic area.

An alternative approach models stochastically the short term critical fracture and may be termed as limiting analysis. One arrives at the critical fracture subjectively starting from the critical crustal volume and approaching the site through seismotectonic correlations. In this case, one seeks information from the near field of large rare events and this requirement is again crucial in defining the critical crustal volume.

In this presentation the two approaches are discussed separately. It is suggested that they do not constitute alternative approaches. They rather complement each other in describing the long and short term characteristics of seismic activity. In the last section an example is given from a seismic study of the City of Tehran, Iran where both approaches were considered.

PROBABILISTIC SEISMIC RISK ANALYSIS

The basic quantitative input to this analysis is a probability distribution of magnitudes within the critical crustal volume. This distribution is bound by a limiting magnitude which should not be confused with the critical fracture; it is obtained by fitting a Gumbel III distribution to an enlarged set of data (Yegulalp & Kuo, 1974).

The probability distribution obtained from statistical processing of events within the critical crustal volume is channelled to seismic sources arranged in space on the basis of seismotectonic correlations. This procedure is bound to be subjective since by definition subsets of data inside the critical crustal volume do not form adequate statistical samples. Moreover, since events in this analysis are assumed independent, the probabilistic seismic risk analysis does not model the physics of the slow, long term, crustal strain time-history and may lead to a wide range of subjective conclusions, particularly in the low probability range (Cornell & Vanmarcke, 1969; Cornell & Mertz, 1974).

The short term fracture is taken care of by an attenuation relation (with incorporated uncertainties) which links point seismic sources of magnitude M to the particular site. It has been shown that most of the risk comes from near sources (small or large). (Cornell & Vanmarcke, 1969). Since ground motion in the near field depends more on seismic source parameters than magnitude, (Trifunac & Brady , 1975) representation of earthquakes as optical sources is inadequate.

The final results are presented in the form of recurrence curves for peak ground motion, i.e. description is shifted through the attenuation relation from the cause (seismic sources) to the effects (peak ground motion). Obviously, peak ground motion does not sufficiently describe expected ground motion, particularly since in the course of the analysis tracks of the seismic sources that produced this peak ground motion are widely dispersed.

LIMITING ANALYSIS

This analysis concentrates on the short term crustal rupture associated with an expected individual earthquake. Describing ground motion produced by the critical fracture involves many uncertainties. Even if we had a complete physical model of seismic source it would be impossible to determine the parameters of the model. Hence the need for a stochastic generating model describing ground motion around the critical fracture.

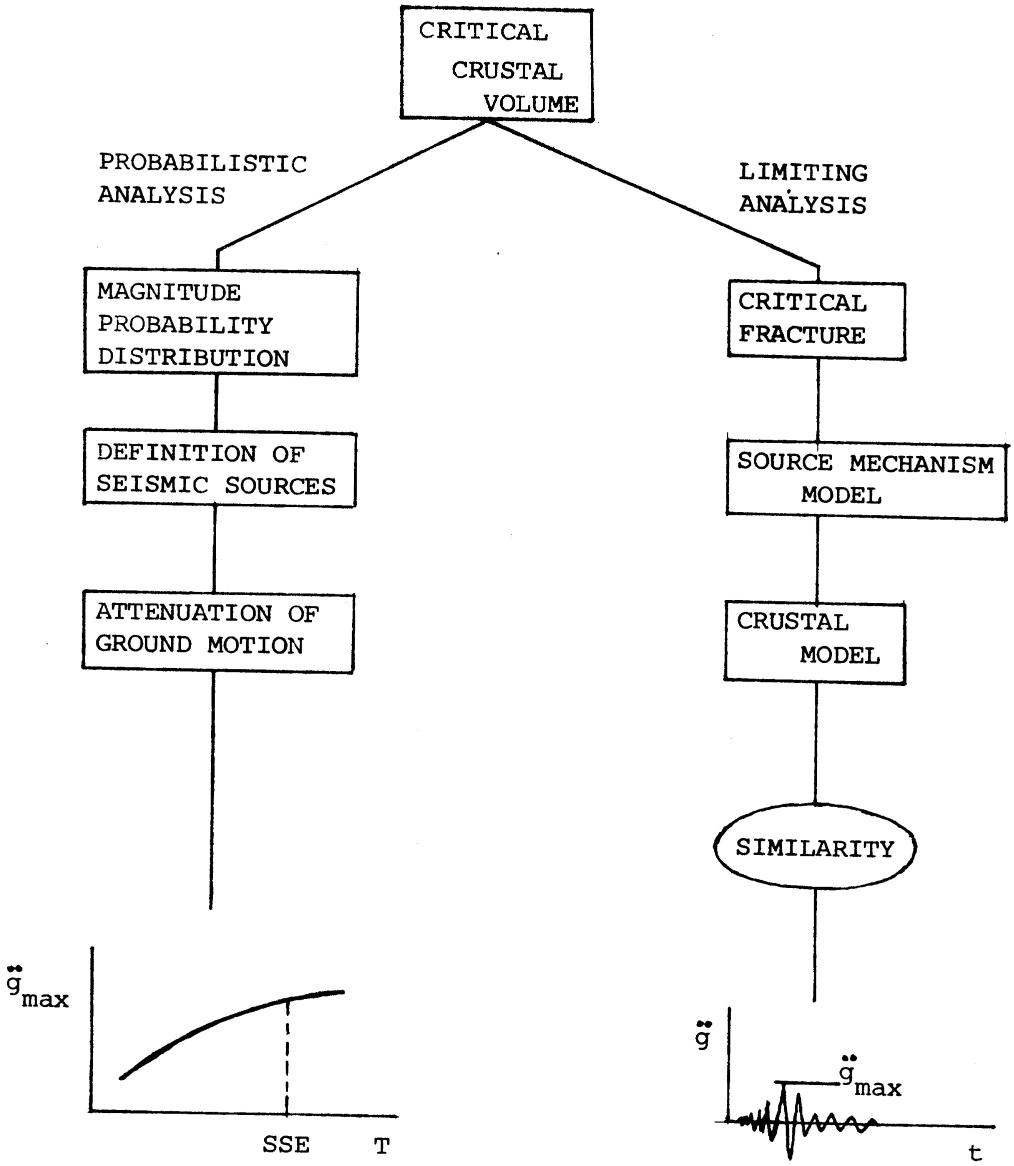


PLATE 1 CURRENT SEISMIC RISK APPROACHES

The stochastic generating model describes a physical model, i.e. the seismic source mechanism and the overall crustal properties encountered on the path of seismic waves. In most of the cases the amount of available information does not justify the use of more elaborate than simple dislocation and layered crustal models.

A simple dislocation model is shown on Plate 2 (Brune, 1970): a sudden stress drop $\Delta\sigma$(from a peak to a residual strength on the tectonic fault) produces an instantaneous average dislocation over a rupture area A. The source parameters may be computed either from field evidence or from processing of distant instrumental records. The near field average particle velocity may be computed from the radiation formula:

$$\dot{u} = 2\frac{\Delta\sigma}{\rho\beta}$$

where ρ = average crustal material density
β = average crustal shear wave velocity
and the factor of 2 accounts for
the doubling effect of a free surface.

Unfortunately, no major effort has so far been made to either document earthquakes in terms of source parameters and overall crustal properties or to analyse strong motion records on this line. Stochastic generating models have been checked against limited seismotectonic configurations (Jennings et al, 1969; Trifunac, 1971). Hence the best one can do is to work through similarity to the conditions for which a generating model has been validated. This procedure may indicate a good model which may be called to produce one or more time histories representative of expected ground motion at the site.

EXAMPLE

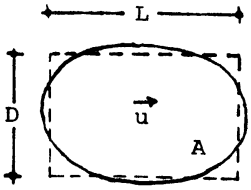
In conclusion, the two approaches model stochastically two different aspects of a complicated problem and complement each other. The probabilistic approach evaluates quantitatively the long term process (tens of years), whereas the limiting analysis models the short term process (tens of seconds).

Both probabilistic and limiting approaches were considered in evaluating the seismic risk associated with the city of Tehran, Iran.

The crustal volume was defined on the basis of the plate boundary between Iranian and South Caspian plates (McKenzie, 1972). This plate boundary is a broad one of compression between continental plates. The extent of the crustal volume was chosen large enough to provide sufficient data for both approaches (150 events larger than M=4 for the probabilistic risk analysis, 5 large earthquakes with magnitude exceeding 6½ for the limiting analysis).

The critical fracture was identified with the North Tehran fault running at 15 Km from the centre of the City (GSI, 1974). This major tectonic feature can accommodate an event of the size of the Buyin Zara, September 9, 1962 earthquake, (the most recent one of the two largest events that have occurred in the critical crustal volume within the period of instrumental seismology). The model Buyin Zara earthquake was compared to Californian events against which stochastic generating models have been validated. This comparison was carried out on the basis of the simple dislocation model (Table 1). Since all earthquakes considered in this comparison were accompanied by surface faulting, seismic source parameters were obtained from field data. The comparison indicated that the Buyin Zara earthquake, although a deep thrust similar to the San Fernando, was associated with source parameters similar to El Centro, 1940 earthquake. Now, the El Centro earthquake formed the basis for fixing the parameters of the stochastic generating model developed by Jennings, et al (Jennings et al, 1969) in their case B (which corresponds to the near field of a magnitude greater than 7 Earthquake). Therefore, it was concluded that the artificial records B1 and B2 may be considered representative of expected ground motion associated with a rare large event close to Tehran.

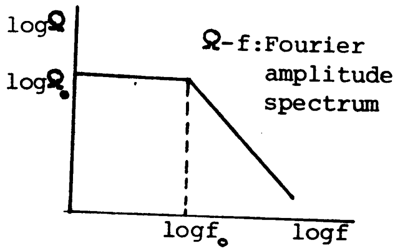
A parallel probabilistic study was conducted which led to the peak acceleration recurrence curves shown on Plate 3. These curves reflect the long term regional seismicity characteristics and provide a quantitative evaluation of the critical fracture considered in the limiting analysis. The mean acceleration of 35%g of the B1 and B2 records corresponds on Plate 3 to a return period of about 5,000 years. This period constitutes a lower bound since probabilities computed from the probabilistic analysis are cumulative.Moreover,



FIELD EVIDENCE

A=rupture area=LxD=πr^2
μ=average crustal rigidity
ρ=average crustal density
β=average crustal shear wave velocity

INSTRUMENTAL
RECORDS (FAR FIELD)



corner frequency : $f_0=2.34\frac{\beta}{r}$

seismic moment : $M_0=\mu u A$

$M_0 \propto \Omega_0$

stress drop : $\Delta\sigma=\frac{7\pi}{16}\frac{\mu u}{r}$

PLATE 2. Simple dislocation model.

TABLE 1. Comparison of the Buyin Zara, Iran to two earthquakes in California*

	M_L	M_S	M_0 (dyn-cm)	$\dot{u}$ (cm/sec)	$\Delta\sigma$ (bars)	u (m)	L (Km)	D (Km)
San Fernando Feb. 9, 1971	6.4		$1.35\ 10^{26}$	144	62	1.50	15	20
El Centro May 18, 1940	6.7	7.1	$4.9\ 10^{26}$	60	25	1.25	65	20
Buyin Zara Sept. 1, 1962		7.3	$4.9\ 10^{26}$	40	17	.90	90	20

* Values computed from field evidence

Assumed: β = 3.5 Km/sec
μ = 3.3 10* dyn/cm^2
D = 20 Km

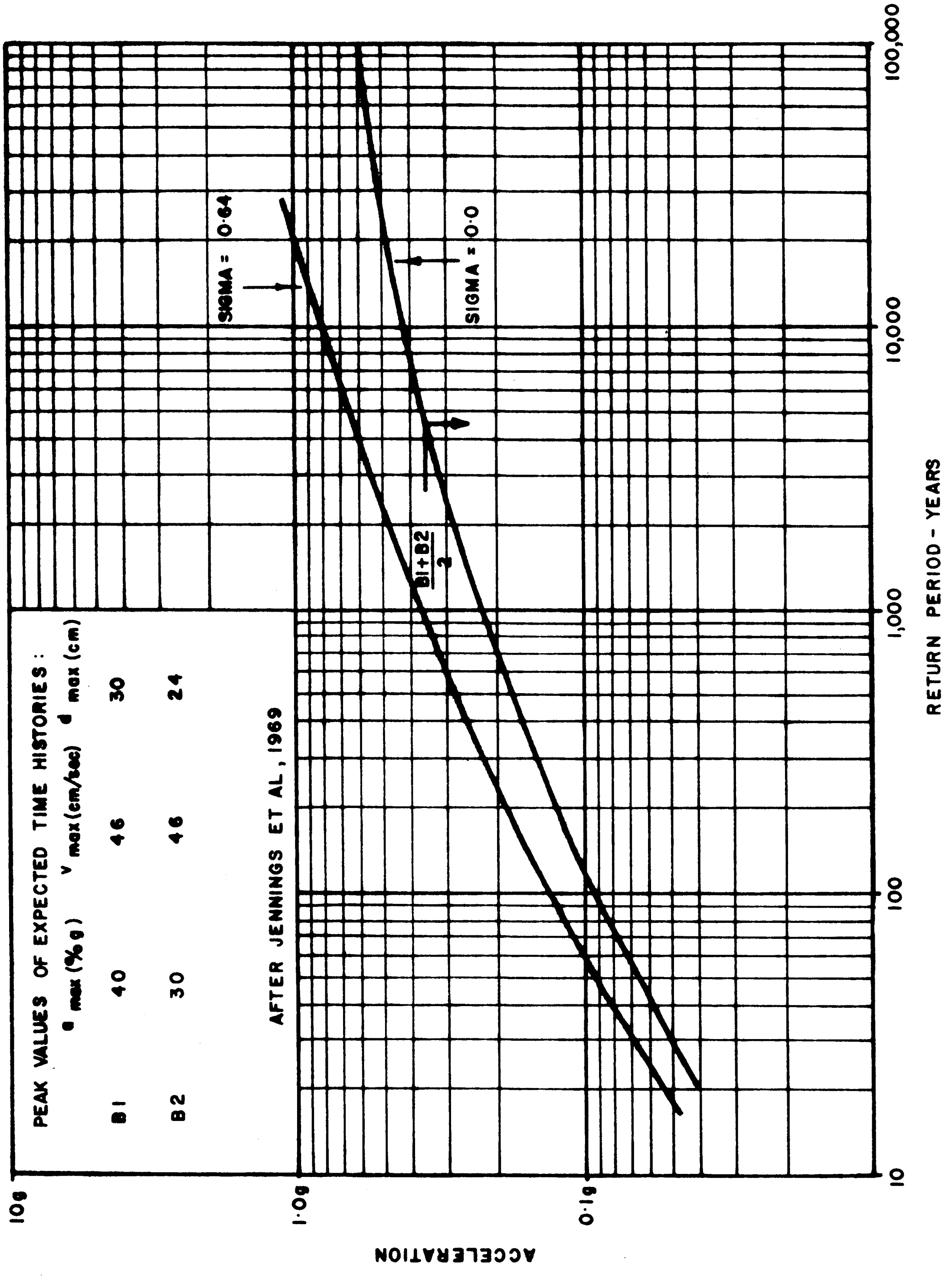


PLATE 3 SEISMIC RISK EVALUATION, TEHRAN, IRAN

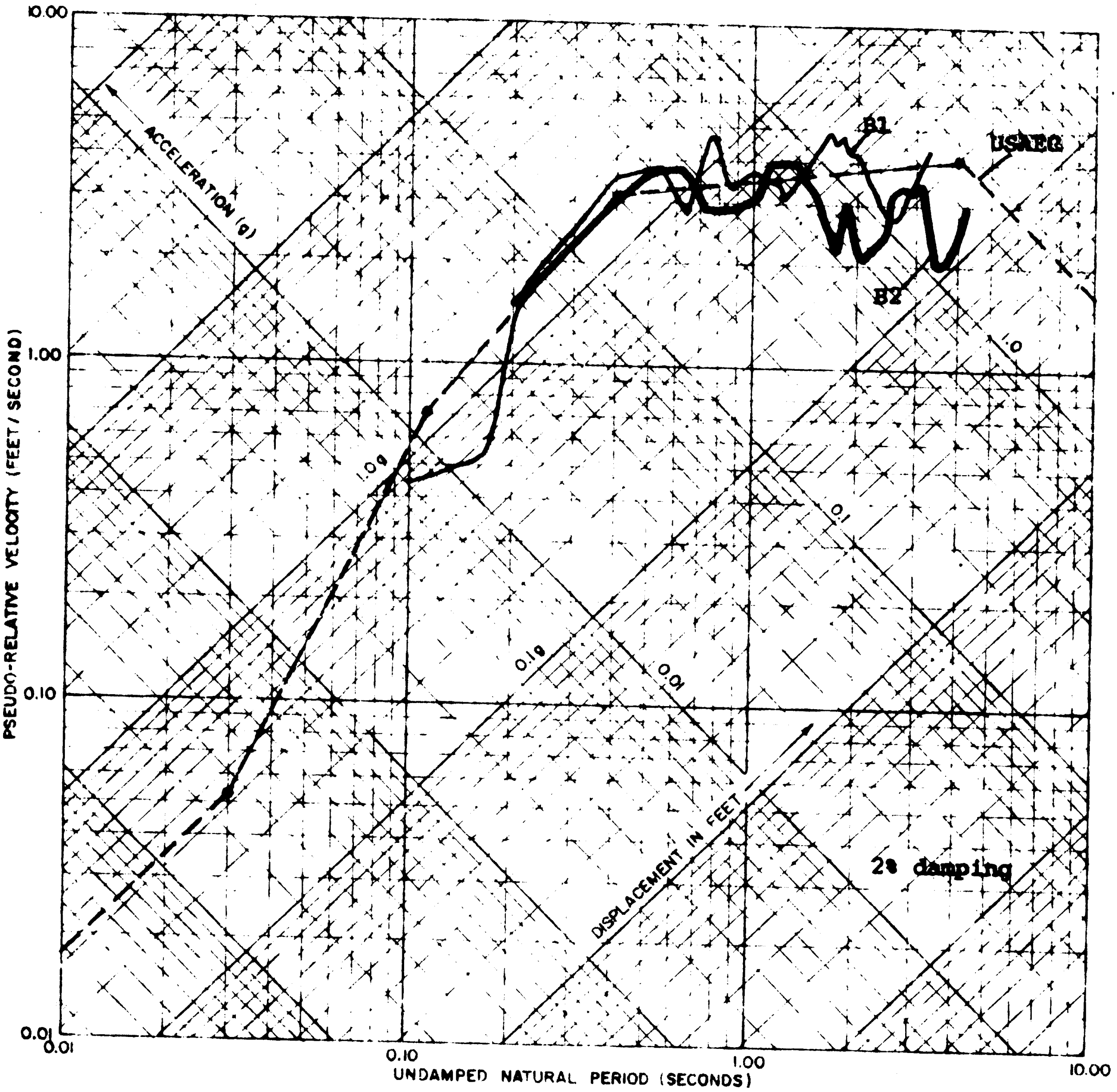


Plate 4 Comparison of B1, B2 response spectra with the USAEC spectrum (normalised to the 35%g of average peak acceleration).

the probability corresponding to 5,000 years is only indicative. For instance, Tchalenko has pointed out evidence on earthquake migration within the crustal volume (GSI, 1974). This migration alone may result in a decrease of return periods by a factor of 3. Finally, the response spectra of B1 and B2 records are compared on Plate 4 with the USAEC general purpose spectrum (Newmark, Blume & Kapur, 1973) one would have constructed on the basis of peak acceleration alone obtained from the probabilistic analysis.

ACKNOWLEDGEMENTS

I wish to thank Dr. John Tchalenko for continuous stimulating discussions and Dr. Roy Kunar for his joint effort in performing the seismic risk analysis for the City of Tehran, Iran.

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Soil-Structure Interaction for Nuclear Power Plants

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Summary

This paper reviews some of the basic principles of soil-structure interaction, and discusses the advantages and limitations of the lumped parameter and finite element approaches. An approach is presented for extending the lumped parameter model to include deeply embedded foundations. Finally, the State-of-the-Art of field and laboratory measurements of dynamic subsoil properties is briefly presented.

1.0 INTRODUCTION

One of the most complex aspects of seismic analysis is the topic of soil-structure interaction. The present State-of-the-Art provides the means for accurate solutions through two general approaches. One approach is to develop a lumped parameter model, as described by Richart, Hall and Woods (1970), utilizing information derived from elasticity solutions such as shown in Fig 1 and from finite element solutions for various boundary conditions such as shown in Fig 2. The other approach is to solve the problem using a dynamic finite element solution. The finite element approach affords greater capability to handle complex boundary values but requires considerable expenditures of manpower and computer time.

2.0 COMPARISON OF FINITE ELEMENT AND LUMPED PARAMETER ANALYSES

Several recent publications and reports have attempted to compare the results of a lumped parameter analysis based on elastic half-space theory with those of a finite element analysis. In most instances, large apparent differences in results have led to inferences that the finite element analysis is the "correct" solution, and that either the lumped parameter method is too conservative, or the results provide the peak response at the wrong frequency. Seldom has an attempt been made to explain the differences in the solutions or to justify the choice of parameters used for each analysis. Each method is of course, best suited for particular applications, and erroneous results have been obtained through either misuse or lack of understanding of fundamental concepts related to both techniques.

One of the most significant characteristics of the interaction phenomenon is the radiation damping associated with the propagation of wave energy away from the foundation. For translational modes of vibration, the damping ratios are very high compared with those normally encountered in mechanical vibration problems. While those unfamiliar with the half-space theory have tended to reject theoretical predictions for damping and have arbitrarily assumed a maximum value of 10 percent, they have often accepted stiffness parameters associated with the same theory. Usually, the material damping (associated with the hysteresis stress-strain characteristics of a soil) alone ranges from 5 to 15 percent, depending on the strain levels. Thus, choosing a damping ratio of 10 percent has the effect of completely neglecting radiation damping.

In the finite element technique, the material damping is often sufficient to prevent the reflection of significant wave energy to the foundation from the artificial boundaries of the finite element mesh. Radiation damping, therefore, is automatically included in such a finite element analysis. However, if no material damping were included in the soil elements, then a "boxed" system would exist, thereby introducing natural frequencies that are totally unrelated to the real system, unless special boundary elements are prescribed to prevent artificial reflection of wave energy. This particular problem has been considered by Lysmer and Kuhlemeyer (1969), Waas (1972), and others by the use of non-reflecting boundaries. Lysmer, Udaka, Seed and Hwang (1974) suggest, however, that such boundary conditions are not required as long as sufficient material damping is included.

3.0 DEEPLY EMBEDDED STRUCTURES

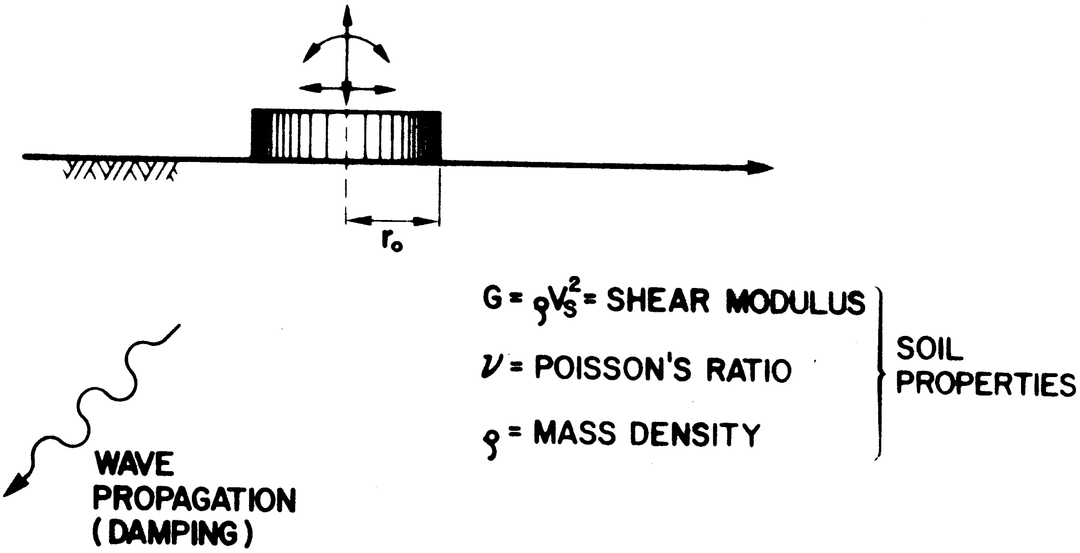
In this section a numerical illustration is presented of an approach to the analysis of soil-structure interaction for deeply embedded foundations. The results show that a deeply embedded foundation can be adequately modelled using a lumped parameter system by including as input the variation of free field ground motion as a function of depth below the ground surface.

Three cases, as shown in Fig 3, were analyzed using a two-dimensional plane strain finite element model. Case A represents a rigid structure, 10 meters in width, supported on the surface of a soil layer 20 meters in thickness. Case B represents the same structure with an embedment of 5 meters. Case C is with an embedment of 10 meters.

3.1 Lumped Parameter Model

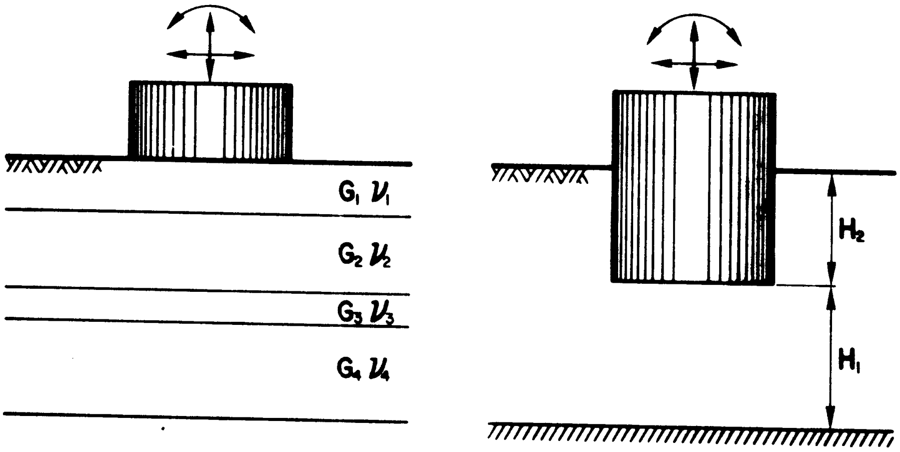
For the lumped parameter model the stiffness and damping parameters associated with the horizontal and rocking modes of vibration of the structure were considered. The stiffnesses were computed using the results presented by Johnson, Christiano and Epstein (1975). In their publication, a procedure is presented for computing the horizontal and rocking stiffness of a foundation embedded in a layer of finite thickness. In addition to the horizontal and rocking stiffness, a stiffness coupling parameter is also included. The coupling parameter as illustrated in Fig 4 defines the location of the resultant horizontal stiffness in terms of the distance from the base of the foundation. For simplicity the coupling term may be removed from the stiffness matrix by defining the location of the horizontal spring as shown in Fig 4. The rocking stiffness may then be adjusted to account for the convenient change in coordinates.

Finally, to account for the variations of free field soil motions with depth a one-dimensional soil column is introduced having the same dynamic characteristics as the free fld as shown in Fig 5. The horizontal soil interaction springs and dampers are distributed and connected between the nodes of the soil column and the sides of the foundation. These parameters are distributed by connecting the surface horizontal stiffness at the bottom of the foundation and linearly distributing the stiffness representing embedment to the other nodes of the free field soil model such that the resultant satisfies the coupling between horizontal and rocking motions.



ELASTIC CONTINUUM SOLUTIONS
(HALF-SPACE THEORY)

FIGURE 1



MULTIPLE LAYERED

EMBEDDED-LAYERED

TYPICAL SOLUTIONS AVAILABLE TO DEVELOP LUMPED PARAMETERS

FIGURE 2

3.2 Finite Element Model

The computer program LUSH (Lysmer et al. 1970) was used for the finite element study, to compare with the results obtained with the lumped parameter approach, described above. The vertical element size was chosen on the basis of one-fifth the wave length of the shortest wave.

3.3 Results of the Analysis

In each case the harmonic response at three points on the structure was computed relative to the free field surface motion.

Due to space limitations only the results of the finite element and lumped parameter analyses for Case B are illustrated in Fig 6. The results from Case A showed better agreement while Case C showed slightly poorer agreement above 10 Hz.

Several conclusions are drawn relative to the results indicated. First, the predominant soil interaction frequency is accurately predicted using the lumped parameter approach. It is noted that the influence of embedment increased the predominant soil interaction frequency from approximately 4.5 Hz to 8.75 Hz from Case A to Case C. At the same time, the peak response at the top of the structure decreased as a result of the increase in radiation damping. The good agreements at the peak responses indicate that the radiation damping, plus 15% material damping accurately represents the total damping. It also illustrates that the radiation damping is automatically included in finite element analyses.

In view of the accurate representation of the predominant soil interaction frequency, and since soil interaction effects are controlled primarily by the predominant soil interaction frequency, it is concluded that the lumped parameter model as described herein provides a simplified but accurate tool for including the influence of deep embedment on soil-structure interaction. Of particular importance is the fact that the parameters associated with soil interaction in a lumped parameter model may be adjusted to account for variations in the soil stiffness properties as well as the magnitude of radiation damping. By applying a reduction factor to the radiation damping, it is possible to introduce conservatism into the analysis. Since a finite element analysis automatically includes full radiation damping, it is not possible to introduce conservatism of the damping parameters into the finite element procedure.

4.0 DETERMINATION OF SOIL PROPERTIES

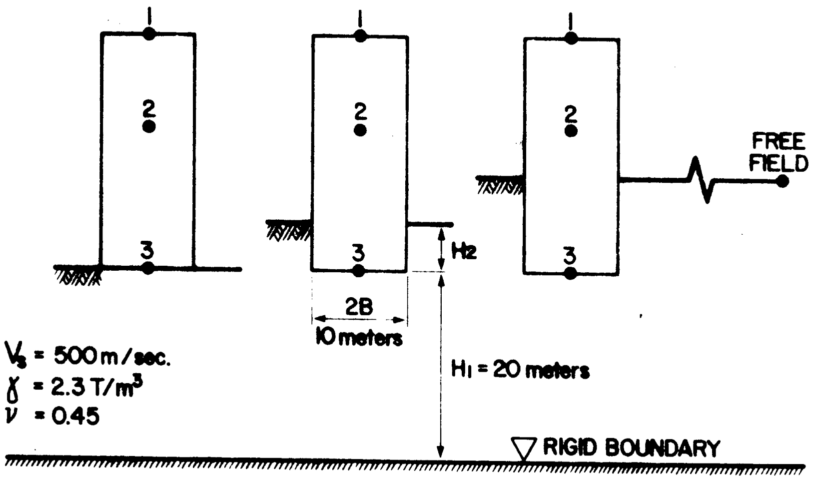
At the present time, field and laboratory measurements have been advanced to the point where relatively accurate shear moduli and damping characteristics for soil and rock may be measured. If the mass density and shear and compression wave velocities are known, the shear modulus and Poisson's ratio of a soil may be calculated from the following equations:

$$G = \rho V_s^2$$

$$\nu = (1-2R^2)/(2-2R^2)$$

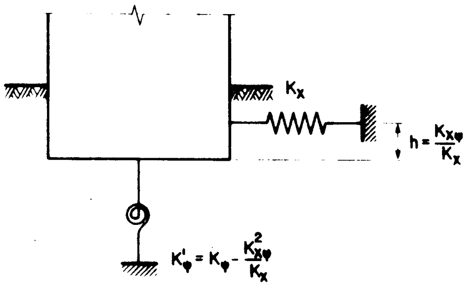
where V_s = shear wave velocity,
V_p = compression wave velocity, and
R = V_s/V_p

In the field, the cross-hole technique to measure shear wave velocities has been developed from the basic method described by Stokoe and Woods (1972). In addition, laboratory torsional resonant column tests on undisturbed samples are used to obtain modulus and damping properties for shear strains ranging from those that occur during the cross-hole field measurements to those that would occur during a strong earthquake.



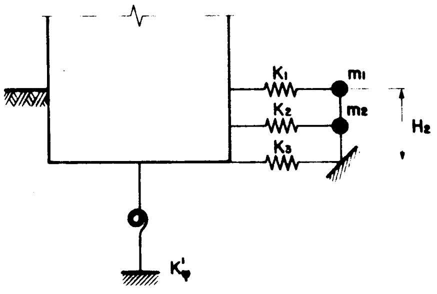
CASES CONSIDERED FOR ANALYSIS
OF DEEPLY EMBEDDED STRUCTURES

FIGURE 3



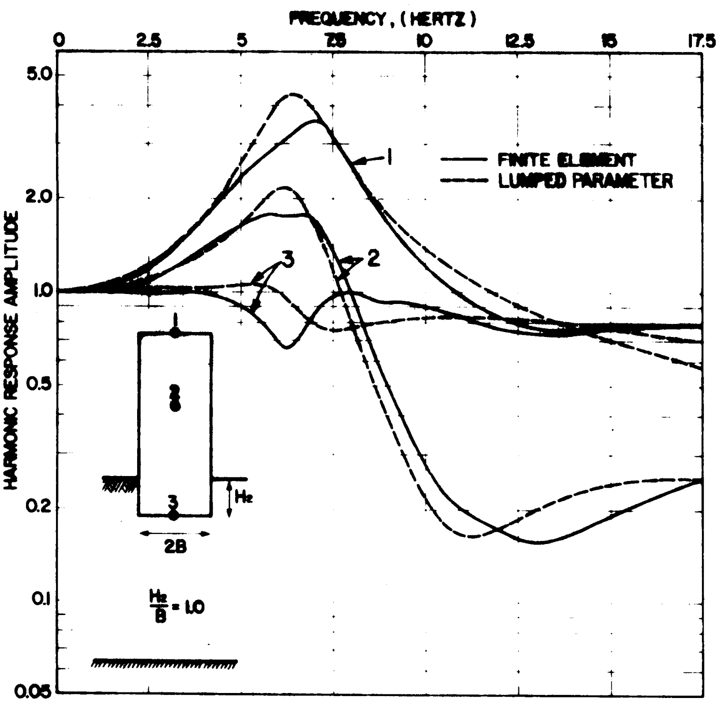
GROSS LUMPED STIFFNESS PARAMETERS
FOR EMBEDDED FOUNDATION

FIGURE 4



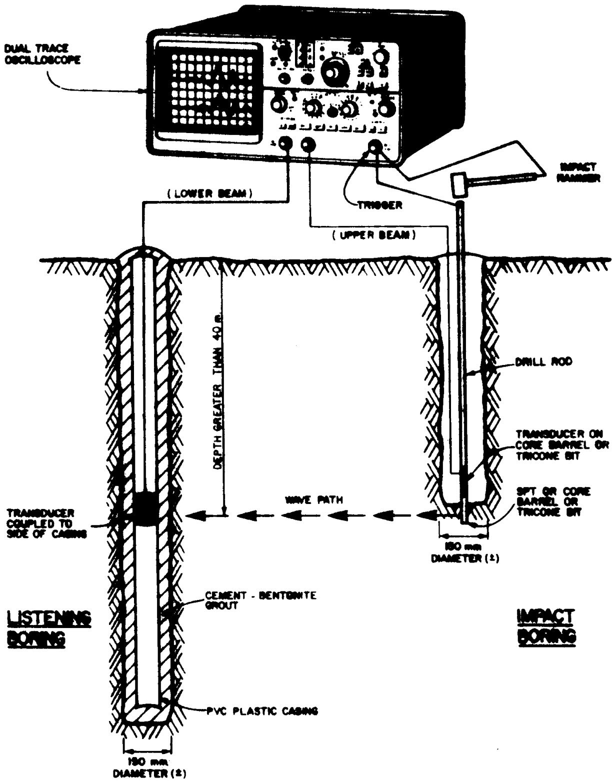
LUMPED PARAMETER MODEL
FOR EMBEDDED FOUNDATION

FIGURE 5



HARMONIC RESPONSE TO UNIT
FREE FIELD SURFACE MOTION

FIGURE 6



CROSS-HOLE TECHNIQUE

FIGURE 7

The cross-hole technique and the laboratory resonant column method are described briefly in the following paragraphs.

4.1 Cross-Hole Technique

As illustrated in Fig 7, the cross-hole technique consists of striking the top of a drilling rod thus triggering a storage oscilloscope and sending an impulse down through the drilling rod. This impact is then transmitted through the soil, and body waves arriving at the listening hole are displayed on an oscilloscope screen, from which the time for compression and shear waves to travel between the holes is measured. The primary advantage of the technique is the ability to obtain clear and accurate measurements of shear wave velocities.

4.2 Resonant Column Testing

The shear wave velocities derived from cross-hole measurements reflect the elastic behavior of soil at shear strains on the order of 10^{-4} percent. To obtain the strain dependent soil characteristics of shear modulus and material damping, the resonant column test is performed using a procedure developed by Hardin (1970). Briefly, a column of soil fixed at the base with a rigid mass attached to the top is excited torsionally with the Hardin oscillator until resonance occurs. The shear wave velocity is then determined from the frequency at resonance, the dimensions of the specimen, and the calibration constants for the apparatus.

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The influence of sub-soil conditions on earthquake induced stresses

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(not presented)

Exemples de surveillance sismique par des réseaux de stations à faible ouverture

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Résumé

On fait une rapide description de deux réseaux de stations sismologiques à faible ouverture (inférieure à 10 km entre deux stations) installés en France: légèreté du matériel, souplesse de fonctionnement, facilité d'exploitation .....

Les documents obtenus depuis deux ans environ, ont permis la mise en évidence des phénomènes intéressants, en particulier, une activité sismique remarquable dans les zones étudiées. On montera ensuite quelques recherches fondamentales qui peuvent découler de ces données.

Seismic noise investigations - a method for seismic microzoning in areas of nuclear power plants

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Abstract

In Europe and USA frequently standardised seismic data are used for designing nuclear power plants, which are secure from effects of earthquakes. Not considered in the standardised date are generally the seismic soil amplification; i.e. the amplification of the earthquake waves by the near surface layer. The soil amplification can be estimated by means of recordings of explosions, micro-earthquakes or microseismic noise.

The author considers the "noise method", which requires exact study of the noise at the site relative to the position of the noise sources. Procedures and an example are given.

1. Introduction

The earthquakeproof construction of nuclear power plants involves the interaction of many technical disciplines including seismology, engineering seismology, engineering geology, and civil and mechanical engineering. Each discipline is involved with a part of the path which the seismic waves take in reaching and entering the plant (Fig. 1). Mostly a simple model of the geologic setting of the site was used. For example assumed here is an infinitely thick layer of consolidated rock overlain by a cover layer of unconsolidated sediments. The major geophysical difference between the two layers is in the seismic shear velocity v_s and the density ρ. V_s and ρ should be lower in the sedimentary cover than in the underlying rocks.

Because of the requirement for large quantities of water, nuclear power plants are mostly built in river valleys. Since river valleys are usually filled with young sediments, our assumed geologic model is a good approximation for such locations.

2. Soil amplification

The discussion in this paper will be restricted to the seismic effects of the cover layer. Here, because of so-called "soil amplification", there are amplitude increases in the seismic signal. This work is based on the studies on soil amplification by KANAI et al. (1961), KUDO et al. (1970), ALLAM et al. (1967) and FACCIOLI (1971).

If no strong motion records are available at the site in practice the response spectrum at the earth's surface is to be determined from a response spectrum on consolidated rocks. In many cases the soil amplification has been considered as a frequency independent effect.

The bedrock response spectrum is then simply raised without changing its form. The amplification factor is taken from tables, such as those of Medvedev, in which the rock type is correlated with the earthquake intensities or with the soil acceleration.

In actual fact, the soil amplification is dependent on the frequency. Its strength differs for various frequency ranges depending upon the thickness of the cover layer. The effect on the response spectrum at the earth's surface is that particular frequency ranges are amplified. Consequently, it is desirable to estimate the frequency with the highest soil amplification and to check this by field measurements.

The appearance of resonance frequencies for a seismic wave in a cover layer, which was theoretically and empirically investigated by A.S. KATZ and others, can be explained by multiple reflections of waves. For the case of a single cover layer, there is resonance when the following simple relationship between wavelength λ and thickness d of the cover layer is fulfilled:

$$d = \frac{(2k - 1)}{4} \cdot \lambda$$

with $k = 1,2,3,\ldots..$

$k = 1: d = \lambda/4$

The resonance frequency f_r is calculated from the relationship:

$$f_r = \frac{v\,(2k - 1)}{4d}$$

where $d = v/f$ and v is the seismic velocity in the cover layer. The values of v and d necessary for the calculation of f_r are determined by refraction seismic measurements at the site involved.

3. Microzoning by using microseismic noise

The calculated resonance frequencies can be checked by recording seismic signals generated by microearthquakes, explosions, or microseismic noise. Recording is done at the relevant site and on outcropping rock or on bedrock in a borehole at one or more reference points.

Microseismic noise is particularly suited for seismic microzoning because the noise has a great frequency range and occurs naturally. We use radiotelemetric recording stations with distances up to 10 km. The resonance frequencies can be determined by comparing the spectra of the recordings at the site and at a reference point.

The application of the noise method requires careful study of the dominant frequencies and positions of the sources of the microseismic noise. As part of a research program, we have investigated the seismic noise at numerous localities in the Federal Republic of Germany.

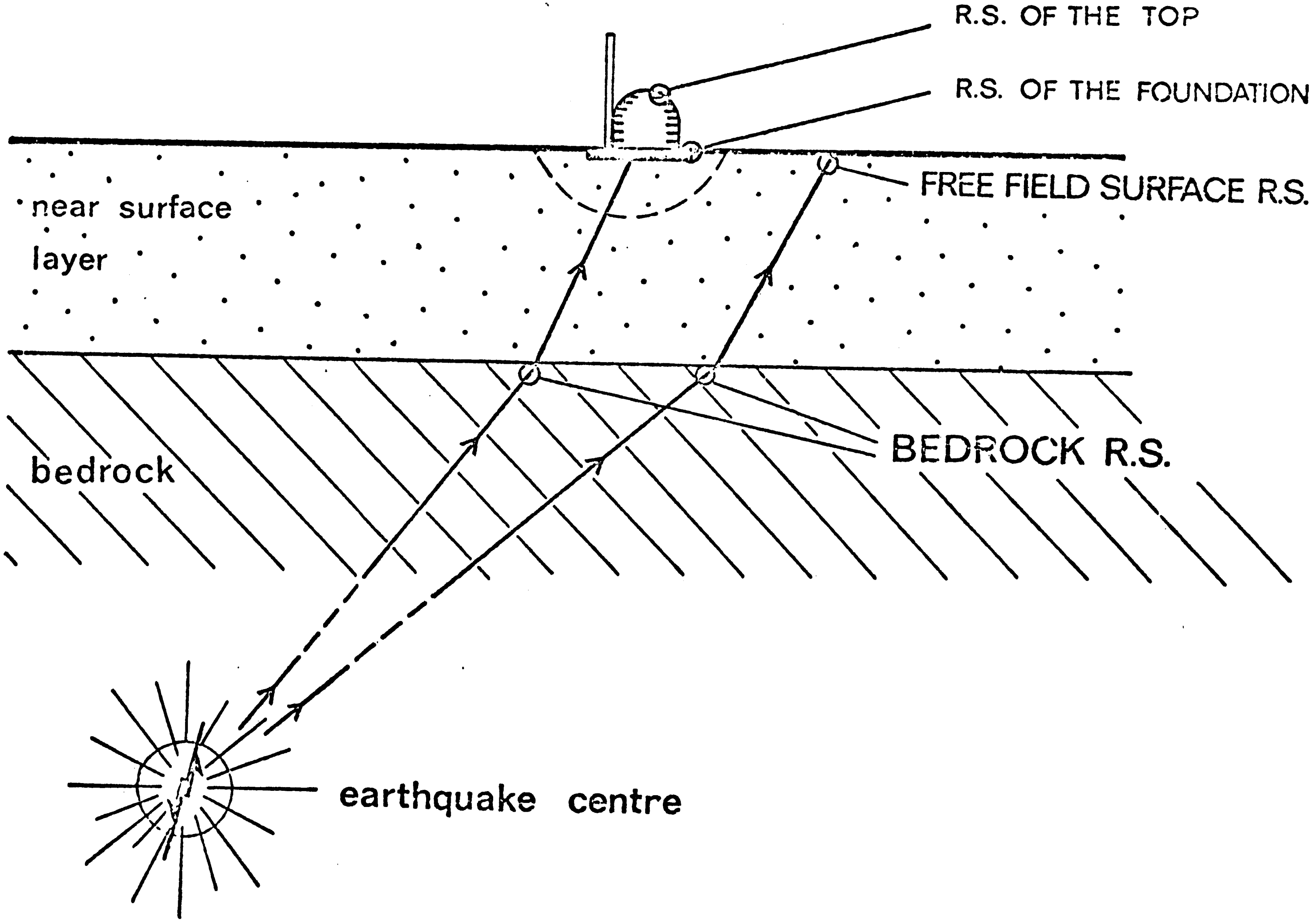


Fig. 1:Scheme of the path of earthquake waves (R.S.=response spectrum)

3.1. Some properties of microseismic noise

In interpreting records of noise for microzoning, only those components may be used that were produced by sources with large areas. Examples are the effects of wind pressure variations or oscillations in atmospheric pressure on the earth's surface. Unsuitable for microzoning are those noise components produced by nearby local sources such as vibrations caused by traffic and machines of all types. They distort the influence of the subsurface on the spectrum of seismic noise.

Since nuclear power plants are generally located outside of municipal areas, the component of the noise caused by traffic and machines is small. In addition, it becomes even less at night which results in a reduction in the amplitude of the noise. For some hours, it is reduced to the "residual noise", which, in most cases, is well-suited for microzoning.

Simultaneous recordings with two closely spaced seismic stations show if the noise contains seismic waves coming from a particular direction. If this is not the case, the noise is "isotropic" and local noise sources are not present in the vicinity of the station points.

According to STRICKLAND the isotropic characteristics of the noise can be found using the correlation functions. Fig. 2 shows examples from two survey areas in Germany. With ideal isotropy, the autocorrelation functions and the cross-correlation function (KKF) are identical (upper part of Fig. 2). The lower part of Fig. 2 shows an area with anisotropic noise.

3.2. An example of a study

The dominant frequencies in soil amplification were investigated in the vicinity of the site of a planned nuclear power plant in South Germany.

We initially carried out at the site and at several reference stations refraction seismic measurements using dropping weight equipment.

The result at one stationpoint in the site area (but not at the site of the planned power plant) is shown in Fig. 3. Using the previously mentioned formula, the P-wave is found to have a resonance frequency (f_p) of 7 Hz and the S-wave a resonance frequency (f_s) of 3.6 Hz.

The results of the microzoning at the same point are shown in Fig. 4 and 5. Shown in Fig. 4 is the trend of the noise throughout a single day. Plotted here are the maxima of the spectral density functions versus the time at intervals of two hours. The minimum, the residual noise, was reached at about 4 o'clock in the morning. Fig. 5 shows the spectral density function of the residual noise on the cover layer compared with the smoothed spectrum measured at reference points on consolidated rock (shown as a dashed line in Fig. 5). The comparison shows a significant difference between the two spectra in the frequency range from about 2 to 8 Hz. As the seismic noise contains S-waves, surface waves and P-waves, there is, understandable, no sharp maximum in the spectrum. f_s and f_p are the resonance frequencies of the S- and P-waves, which are computed from the simple two layer model.

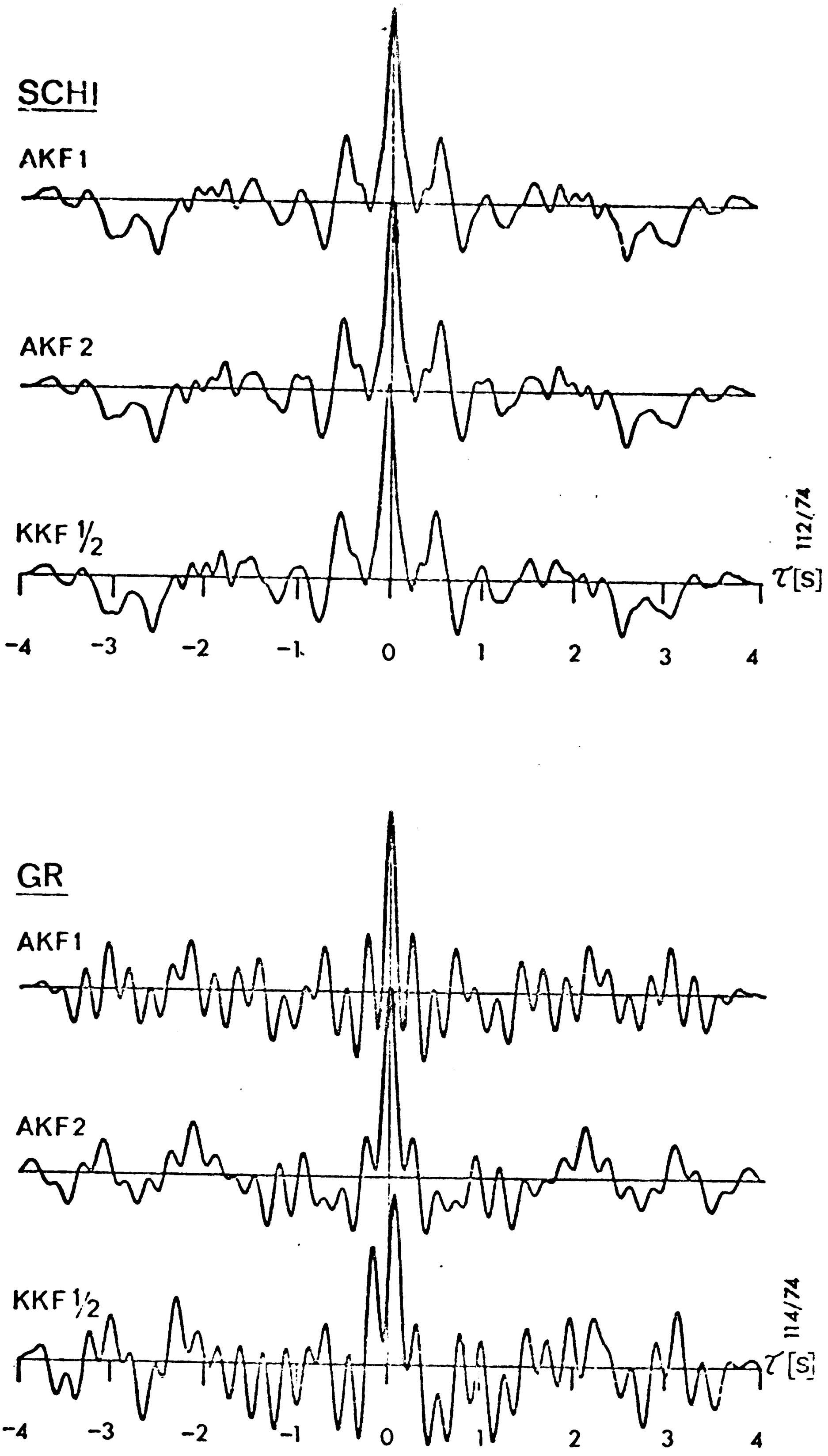
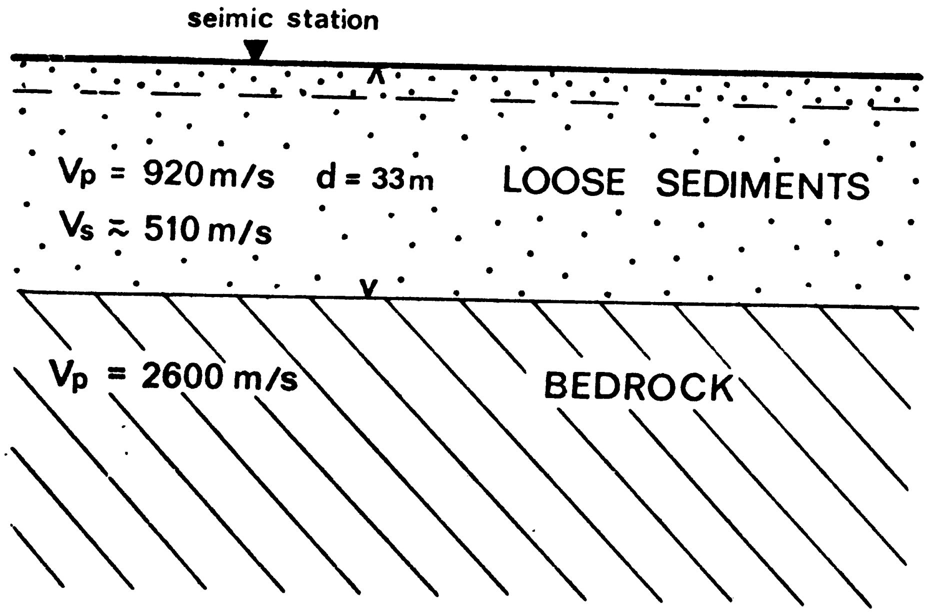


Fig.2: Autocorrelation - (AKF) and crosscorrelation functions (KKF) as criteria for the isotropic properties of the seismic noise.

EXAMPLE OF ESTIMATION OF RESONANCE FREQUENCY



$$f = \frac{v \quad (2k - 1)}{4d}$$

$$k = 1 : f_p = 6.97\,\text{Hz} \approx 7\,\text{Hz}$$

$$f_s = 3{,}55\,\text{Hz} \approx 3.6\,\text{Hz}$$

Fig.3

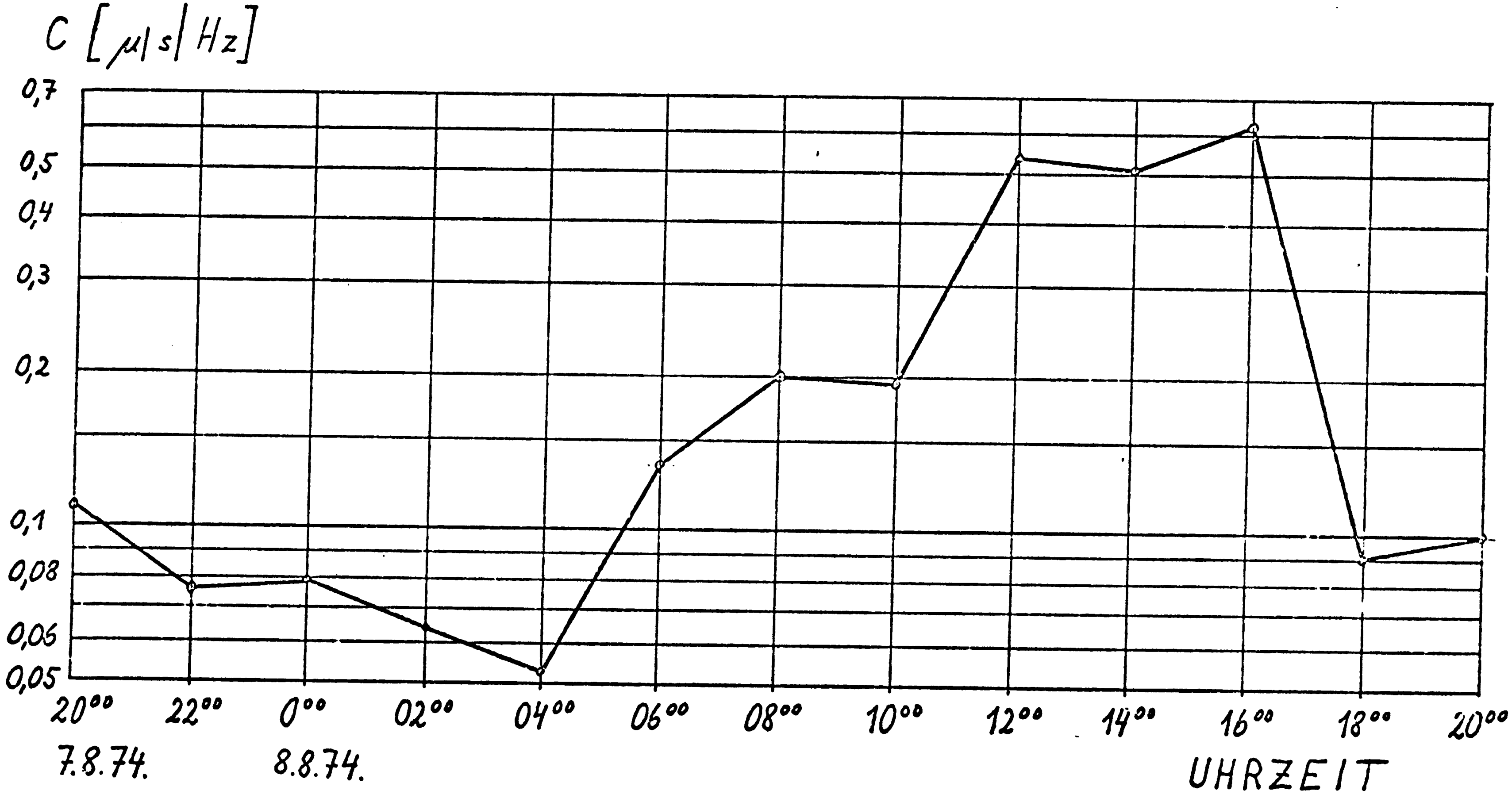


Fig.4: The trend of the noise throughout 24 hours
("C" means "maxima of the spectral density functions")

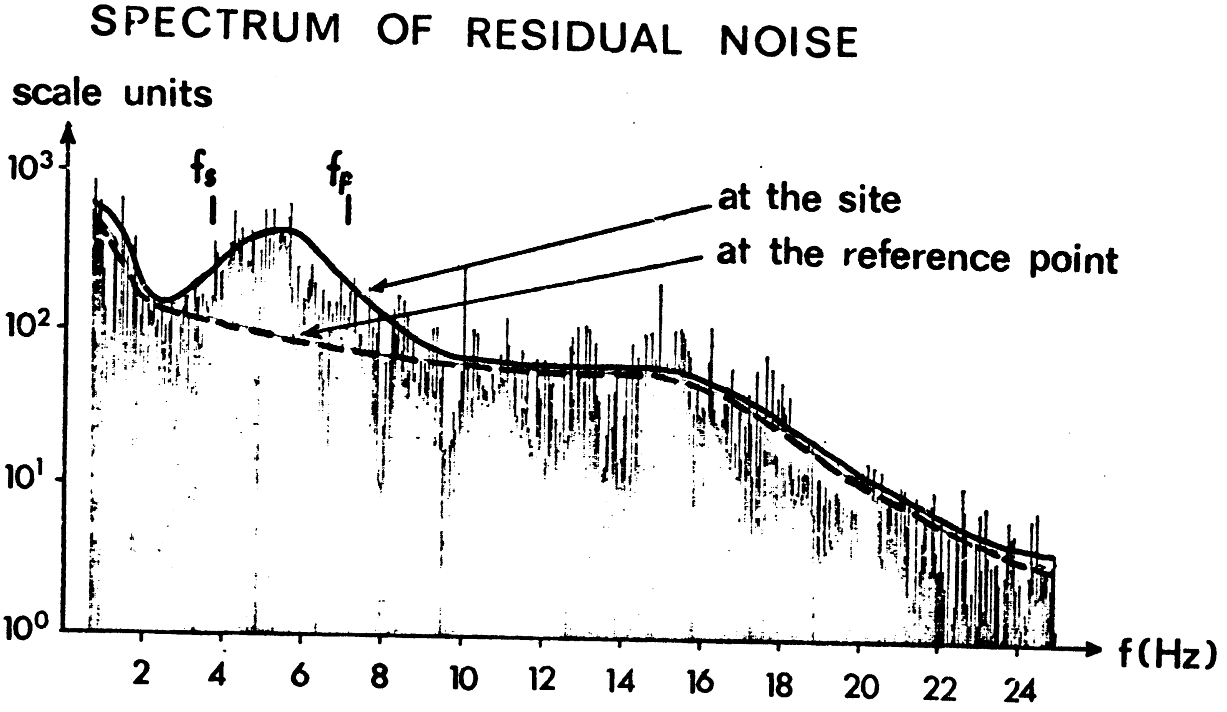


Fig.5: Comparison of the spectral density function of the residual noise at the site (cover layer) with the smoothed spectrum at the reference point (consolidated rock).

Seismic risk studies for nuclear power plants

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Abstract

This paper summarizes the macro and microzoning seismic risk studies carried out by LNEC in two places of the Portugese coast as part of a vast site studies program, still in course, aiming at a rational choice of the place where the first nuclear power plant is going to be located.

The macrozoning studies consisted basically of a statistical estimate of maximum ground accelerations liable to occur during a given return period. Such estimate was based on all the available data on epicenter location, magnitude and MM intensity of earthquakes that have been felt in Portugal since 1902. Seismic risk charts were thus established for the two sites under consideration.

Microzoning studies mainly consisted in the analysis of soil vibration records obtained by the National Meteorological Service (SMN) in a campaign of field tests using strong TNT charges blasted off-shore. Although these tests were performed for earth crust studies, the results have proved very adequate for the knowledge of wave propagation and dynamic characteristics of the soil vibration.

The information provided by the macro and microzoning studies was very useful for prescribing the seismic actions (accelerograms, power spectra and response spectra of acceleration) to be considered in the structural design of the plant.

TSUNAMIS INDUCED BY SUBMARINE SLUMPINGS OFF THE COAST OF ISRAEL *

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Israel Atomic Energy Commission

Summary

In the course of history several extreme changes in the sea level along the coast of the Levant have occurred. As these events have always been associated with earthquakes they were often described as tsunami or seismic sea waves.

Reviewing the historical descriptions of such events at Israel's coast one finds more often a recession of the sea than a flooding of the shore. Such events may have been caused by slumpings on the continental slope. Based on data of actual submarine scars, a quantitative evaluation of this hypothesis was made.

It was found that the slumping of a mass 6 km long, 2 km wide and about 50 m deep would cause the formation of a shock-induced solitary wave of about 10 m in height at the edge of the continental slope. The accompanying draw-down of the sea level at the coast would last about ½ - 1½ hours, and lay the sea floor bare for a distance of about ½ - 1½ km, in agreement with some historical descriptions. Though possibly occurring only once or twice in a millenium, earthquake-induced slumpings may constitute a danger to nuclear power plants, and not only to maritime vessels and installations.

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* Resumé of Research Report IA-LD-1-102, see Bibliography.

Israel intends to build a commercial nuclear power plant at its Mediterranean coast, and has therefore to consider not only the general seismological problems, which are weighty, but also the problem of tsunamis affecting the coast.

Mostly, tsunamis are considered as seismic sea waves, whose danger comes from their suddenly flooding the coast. However, when studying the historical record of earthquakes at our coast, we found more often described a recession of the sea than a flooding of the shore.

Our prophet Amos, who prophesied "in the days of Uzziah, King of Judah, and the days of Jerobeam, King of Israel, two years before the earthquake" (about 760 B.C.) mentioned "the desert springs withered, and the Head of the Carmel became dry".

The Greek geographer Strabo, who lived at the time of Christ, and who described earthquakes, wrote: "while we were at Alexandria in Egypt, the sea rose near Pelusium and Mount Cassius, invaded the land and the mount became an island" (Mount Cassius is a 60 m high hillock on a lagoonar bar, off North Sinai).

The great earthquake, which affected the entire Middle East, in July 551 caused much damage at the Levant coast, between Tyre and Tripoli, especially at Betrys (Beirut). Theophanes, the Greek chronicler, relates that "the sea receded a thousand paces (1 mile), consequently many ships submerged in the deep", and Michael the Syrian scribe wrote that "at the time of the earthquake in Beirut and other Phoenician towns, the sea withdrew 2 miles, and the sea bottom was exposed, laying bare sunken ships with much treasure. People ran down to the ships, but the sea waves returned, drowning all".

On the great earthquake of 1034, the Arab chronicler, Abu Faraj, reported, "half of Acre was destroyed, the sea receded 3 miles from the coast, so that many who walked out to collect things were drowned when the waters powerfully returned". Yahia Ben Said of Antiochia added "the water within the port of Acre receded and disappeared for one hour".

The renowned Arab Chronicler, As-Soyuti, who specialized in earthquakes, reported: "A severe earthquake affected Palestine on 18 March 1068. Ramle (then the local capital) was destroyed ... the sea receded from the coast, but soon returned to its place". Ibn El Athir gave a very similar description and added "the sea fled a day's walk".

On 14 January 1546 another great earthquake, reported by Bernhertz (1616) to have destroyed Ramle, also Nablus, caused "the sea at Jaffa to recede a day's journey, one could walk dryly on the bottom, about 10 thousand people came to pick up things from the sea (bottom), however, the sea returned soon and all drowned".

The last mention of tsunamis effects was in connection with the severe earthquake in Palestine and southern Lebanon on 30 October 1759, when Acre was reported to have its street flooded to a height of 10 feet.

The coast of Israel is almost straight, curving gently. The sea bottom slope of the southern coast is shallow, at Ashqelon the 100 m depth is reached at 18 km distance. The continental slope begins at about the 200 m depth (24 km from the shore) and decends to the 600 m depth at a gradient of about 1:20 or less.

On this slope were discovered several scars of submarine slumpings, at about 30 km from the coast. We used one of the larger niches to evaluate the possible effects of its slumping. The scar is about 2 km wide, at least 6 km long, and about 50 m deep, its mass therefore, about one billion tons. Assuming the slumping mass to have its center of gravity at 650 m depth and to come to rest at the bottom of the continental slope, at about 1050 m, it would release about 2 x 10^{22} erg, (on Iida's scale: a tsunamis of magnitude 1.5). Of course, not all the energy released would convert into gravity water waves. In general, only 1-2% of the energy of the generating event is converted into wave energy, however this would yet be about 2 x 10^{20} ergs.

The laboratory experiments of Wiegel, of Prins and of others have shown that a sudden change in the bottom elevation can cause one large and a few small solitary waves. It was found that when dropping an object in water, the resulting wave amplitude depended primarily on the energy of the falling object, the wave period depended mainly on the dimensions of the object. Furthermore, when the object was sliding down rather than falling in the water, the wave amplitude decreased and the period increased.

Using the data of the scar mentioned, and applying the results of the laboratory experiments, and some hydraulical reasoning (details in our IA-LD-1-102 report), we found that for a 1% transfer ratio of the potential energy, the height (H) and period (T) of a resulting solitary wave would be as follows:

	one wave		two equal waves	
at depth (m)	650	1050	650	1050
H	13 m	8 m	8 m	5 m
T	700 sec	1400 sec	900 sec	1850 sec

These values were derived assuming a vertical travel of the slumping mass, however, in fact, the mass did slide down a moderate slope, hence Wiegel's results should be applied, i.e., the period would be four times larger, the wave height compensatingly reduced by a factor of two (considering the shallow water wave energy to be proportional to H^2T).

Considering that the decrease in wave height will be offset by the shoaling effect, which would increase the amplitude by a factor of two, we thus evaluate a wave period of about 1-1½ hours, and a draw-down equal to the wave height of about 10 m or more. We regard these values as realistic, bearing in mind we used an energy transfer ratio of 1% only.

Thus, at our southern coast, such a slumping event would lay bare about 1 km of sea bottom, and even a larger distance in the bay of Acre's port, well in accord with the historical descriptions of one or two miles. The only duration specifically mentioned was one hour, in good agreement with our estimate.

From the historical evidence so far available, we do not think that such events did occur at Israel's southern coast more often than once or twice in a millenium, if that. The recurrence depends on various factors, possibly mainly on the frequency of the triggering earthquakes, and at present we cannot evaluate the risk of such events.

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Appropriate parameters of seismic risk for nuclear power plants and their estimation

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SAFE SHUTDOWN EARTHQUAKE AND OPERATING BASIS EARTHQUAKE DETERMINISTIC AND PROBABILISTIC EVALUATIONS

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Summary

The paper reviews the current probabilistic and deterministic procedures to determine the Safe Shutdown and Operating Basis Earthquakes (SSE and OBE). Nuclear practice establishes the SSE using a deterministic procedure referring to past seismicity and the OBE as a fraction of the SSE. The probabilistic procedures recently proposed extrapolate recurrence rate data on past earthquakes. This approach is not judged appropriate to establish rare events such as the SSE because the limited data sample precludes far extrapolation. Conversely, the probabilistic approach has merit in determining the more frequent OBE event.

1.0 Introduction

Seismic loads for nuclear power plants (NPP) often govern design and therefore the determination of basic design seismic inputs represents a fundamentally significant aspect of NPP design. The design input motion is widely termed as the Safe Shutdown Earthquake (SSE). The United States Nuclear Regulatory Commission (USNRC) provides the following definition (1)

> "The Safe Shutdown Earthquake is that earthquake which is based upon an evaluation of the maximum potential considering the regional and local geology and seismology and specific characteristics of local subsurface material...."

It is distinguished from the lower level Operating Basis Earthquake (OBE) by the USNRC as follows:

> "The Operating Basis Earthquake is that earthquake, which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant;..."

The current practice requires that a plant experiencing an OBE should be shutdown for complete inspection. The plant structure is designed to remain elastic during an OBE, whereas yield stress are used for an SSE design.

Current procedures for SSE evaluation are generally based upon "deterministic" concepts which account for the worst estimated seismic effects at the site in the recorded history (1). This approach is considered present State-of-the-Art and is briefly reviewed in Section 2.0. Another approach proposed in recent literature (2,3,4) evaluates the problem using "probabilistic" theory and determines the SSE as a very rare event, as discussed in Sections 3.0 and 4.0. Finally, Section 5.0 evaluates merits and drawbacks of both approaches in determination of the SSE and OBE at nuclear power sites. The paper concludes that a deterministic approach is required for definition of the SSE; while probabilistic considerations have merit for establishment of the OBE.

2.0 Step-by-Step Procedure for Establishing the SSE and OBE - Deterministic Approach

Utilizing the above definitions and following the steps of the USNRC Appendix A to 10 CFR 100, the following step-by-step procedure has evolved (5,6,7).

1. Review and summarize the basic geology and tectonics of the region of the site (200 miles or 320 kilo-meters radius) with particular attention paid to mapped faults and the boundaries of the seismotectonic provinces. A tectonic province is defined by the USNRC and International Atomic Energy Agency as a region characterized by a relative consistency of the geologic structural features contained therein (1,5).
2. Conduct a review of the seismic history of the region including offshore areas; locate the epicenters of all major earthquakes.
3. Relate these epicenters to mapped faults and/or seismotectonic provinces defined in Step 1.
4. Based on the results of Step 3, postulate a group of conceivable SSE's by selecting the most severe earthquake along each fault; or in each seismotectonic province, and move these earthquakes to the point along the fault, or within the seismotectonic province, that is closest to the site.
5. Develop a set of attenuation curves applicable to the region of the site.
6. Using the attenuation curves from Step 5 and the group of conceivable SSE's from Step 4, along with the minimum distances to the site, determine the site Intensity and classify this as the site SSE.
7. Through accepted correlations between Intensity and peak ground acceleration, establish the peak ground acceleration that corresponds to the SSE for the site (8).
8. Select the OBE as an earthquake with peak ground acceleration equal to at least one-half the SSE.

With minor exceptions, this process is generally used at most reactor sites in the Western World. For sites where Magnitudes are available, a similar approach may be adopted by making use of acceleration versus epicentral distance attenuation curves (9).

3.0 Step-by-Step Procedure for Establishing the SSE and OBE - Probabilistic Approach

An alternate to the deterministic approach, is based on probabilistic concepts. While the regulatory aspects of the probabilistic approach are not clear (1,5), the probabilistic approach, nevertheless, may provide the engineer, the seismologist and the regulatory group with additional quantitative insight into the safety aspects of the plant design. Essentially this approach estimates the rate of recurrence at the site of seismic events, and then the SSE or OBE is selected with a predetermined design recurrence rate.

The analysis rests mainly on two assumptions. First, the seismic activity within any seismotectonic province or along known major faults with characteristic seismicity is uniformly distributed. Secondly, the recurrence rates for earthquakes of a given Intensity in any seismotectonic province is assumed to remain the same as observed in the past. Regarding the first assumption, it is noted that any one seismotectonic province has a unit of geologic structure and equipotential seismicity. With regard to the second assumption, a review of the number of damaging events in the site region over the past few hundred years needs to be made. Generally speaking, since the projected life of a NPP is very small with respect to geologic, or even historic time, one may reasonably expect this assumption to be valid.

The following steps briefly describe the general approach used in the probabilistic determination of SSE or OBE.

1. The boundaries of the seismotectonic provinces are determined within a 320 kilometer radius of the site and known major faults with characteristic seismic history are defined.
2. Each contributory area is divided into a grid of small elements for purposes of numerical integration. Similarly, the significant faults in the contributory area are divided into linear source elements. The area or length of an element, j, is denoted as Aj, and its distance from the site is denoted as Rj. The seismic activity in each small element is assumed to originate at its geometrical center.
3. The recurrence rates for earthquakes are established by the well known empirical recurrence relationship (10) given as:

$$\log(N) = a_k + b_k I \qquad (1)$$

where N is the number of earthquakes per unit area (or length per year of Intensity I, or greater; I is the Intensity on the Modified Mercalli Scale; k denotes the seismotectonic province or fault; and a(k) and b(k) are constants characteristic of the earthquake recurrence rate for the provinces or faults.

4. For each element, j, in each seismotectonic province the seismic activity per year is computed in small Intensity increments of the order of 0.2, using the recurrence relationship given by Eqn 1. Thus, the number of earthquakes per year in element j, between Intensity I-0.1 and I+0.1 denoted here as nj is obtained as:

$$nj(I-0.1 < I < I+0.1) = Aj(10^{(a_k+b_k(I-0.1))} - 10^{(a_k+b_k(I+0.1)}) \qquad (2)$$

5. Due to attenuation of the earthquake ground motion, the ground motion, at the site experiences a lower Intensity than the epicentral area. Thus, an earthquake of Intensity I with its epicenter in the element j, causes an earthquake of Intensity Is at the site, where Is may be estimated by using regional attenuation curves.
6. The seismic activity between Intensities I-0.1 and I+0.1 in the element j causes nj (I-0.1< I< I+0.1) earthquakes of Intensity Is at the site. The contributions from all the elements are computed and summed, which in turn yields the seismic activity distribution for the site. From this, one derives the expected number of earthquakes per year at the site with Intensity Is or greater, N(Is). The expected return period, denoted as Rp(I) of an earthquake with Intensity I or greater is obtained as:

$$Rp(I) = 1/N(I) \qquad (3)$$

7. The earthquake with design return period, i.e. approximately the inverse of the probability of occurrence per year, is chosen as the SSE. Similarly an earthquake with return period one to two times the life of the plant could be chosen as OBE.
8. The acceleration corresponding to the SSE or OBE Intensity is determined, using accepted acceleration Intensity relationships (8).

If sufficient earthquake Magnitude data are available, the recurrence relationships in Step 3 are represented in terms of Magnitude, and the attenuation curves (9) then directly predict the postulated acceleration at the site, and Step 8 is not needed.

4.0 Discussion of Input Parameters

Several critical inputs to the probabilistic approach have not yet been established thoroughly. Specifically, the following points deserve careful consideration:

(1) Earthquake recurrence rate versus Intensity relationships.
(2) Maximum Intensity earthquake to be considered in the analysis.
(3) Choice of recurrence period for the SSE/OBE.
(4) Interpretation of seismic activity distribution in the near vicinity of the site.

4.1 Recurrence Rate Versus Intensity Relationships

As discussed above and illustrated on Figure 1, relationships between the logarithm of recurrence rate and Intensity are usually represented as a straight line. The recurrence data for medium Intensity earthquakes (say Intensity V, VI, VII, VIII and sometimes IX) are plotted and a straight line is fitted through them.

The procedure seems justifiable, but in general it has been observed (11) that it over-predicts the recurrence rate for high Intensity earthquakes. For example, in a given region, no earthquake of Intensity higher than VII may have been observed in the past 100 years and none higher than VIII may have been observed in the past 2000 years; whereas, the recurrence curves extrapolated from 50 year data may predict the recurrence rate of four or five Intensity X earthquake per 1000 years.

Based upon the observed data, some researchers (11) have proposed that a quadratic relation (curve 2 on Figure 1) be adopted, such that the recurrence rate decreases more rapidly with increasing Intensity. In the authors opinion, an exponential or extreme value type relationship (curve 3 of Figure 1) should be adopted, thereby predicting a limiting recurrence rate of zero (or logarithm of recurrence rate to minus infinity) for earthquakes with highest postulated Intensities. Another justification for adopting quadratic or exponential type recurrence rate curves is also provided by the observation that historicad records for low Intensity earthquakes tend to be incomplete as documented by Stepp (12). Ultimately, the authors feel that Bayesian theory should be used to evaluate the significance of all the proposed curves and their associated SSE-OBE's.

4.2 Maximum Intensity Earthquake on each Province

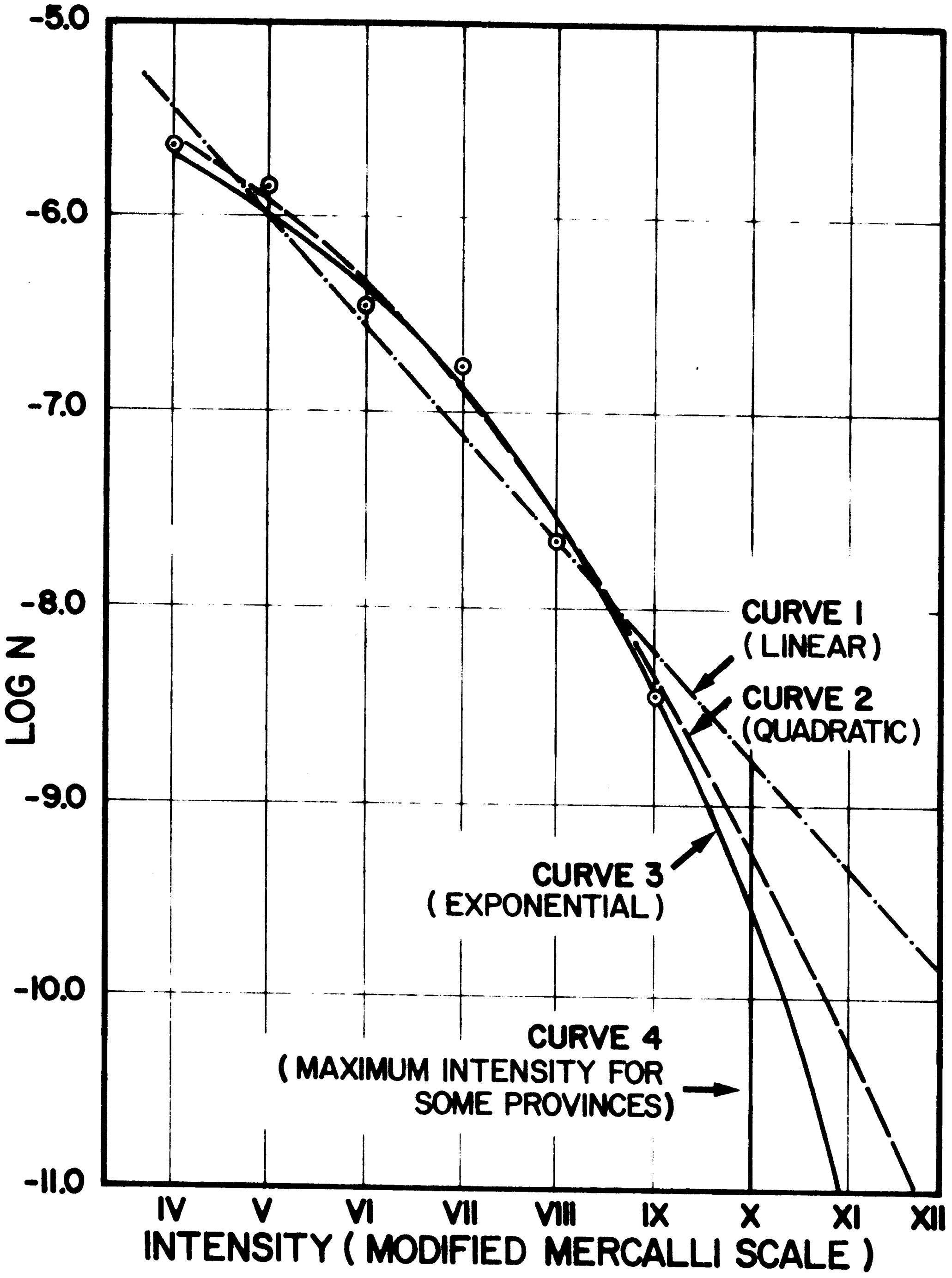
By definition, the maximum Intensity of the Modified Mercalli Intensity Scale is XII. However, as discussed with a few examples in the last section, a maximum Intensity of only VIII may have been observed in a region within the past 2000 years, whereas the recurrence rate curves may predict a high recurrence rate of significantly larger earthquakes. To avoid this obvious inconsistency between the observed historical data and the predicted recurrence rates, the authors recommend that within a given tectonic province or fault, a maximum Intensity of two degrees higher than the maximum observed Intensity in that province or fault be adopted for probabilistic computation (curve 4 on Figure 1). Using Magnitude data, the world-wide upper bound near M=9 appears appropriate and, within any province, the authors recommend a maximum Magnitude of one unit larger than the maximum Magnitude observed.

4.3 Choice of Recurrence Period for the Basis of the SSE and OBE

Discussions with professionals and regulatory groups indicate that a recurrence period varying between 1,000 and 10,000 years appears adequate for SSE determination in NPP design. A check on the SSE for a few sites, derived using the widely accepted deterministic procedures described above, seems to verify this opinion. The recent USNRC Rasmussen Report (13) or WASH-1400, also indicates that an earthquake with a 10,000 year recurrence will be sufficiently conservative for SSE determination in NPP design. The OBE is selected as a more frequent, lower level earthquake. The USNRC definition (1) of OBE suggests that this event could be expected in the lifetime of the plant and therefore a return period of 50 to 100 years is appropriate.

4.4 Seismic Activity Distribution Near Site

For high Intensity SSE values, the greatest contribution to the site SSE is generally provided by the seismic activity in the area within approximately 25 to 50



N = RECURRENCE RATE = NUMBER OF EARTHQUAKES PER YEAR PER UNIT AREA OF INTENSITY I OR LARGER

⊙ = TYPICAL DATA POINTS SYNTHESIZED FOR ILLUSTRATION ONLY

FIGURE I
RECURRENCE RATE-INTENSITY RELATIONS

kilometers from the site. Since these nearby earthquakes are of great interest as potential SSE values, it is important that the contributory area near the site be carefully subdivided into an elemental grid (see Step 2 in Section 3.1). The site itself should be assigned to the center of an area whose radius equals the distance for zero attenuation. If the analyses uses a site element larger than the zero attenuation distance, an overly conservative event will be derived, since the local seismic activity will be artificially concentrated at the site without any attenuation. Similarly, a too small site element will result in an unconservative value. Generally speaking, a ten kilometer seismic contributory element should be assigned to the site. The element size could be increased as the distance from the site increases.

5.0 Discussion of the Two Procedures

Whereas, the deterministic approach is based upon the most intense earthquakes observed, the probabilistic approach is based upon the numerical count of various Intensity earthquakes. The available historical data for Intensities lower than say MMI VI is usually incomplete and the number of high intensity earthquakes observed is usually not statistically sufficient, and thus the final results for a rare event such as SSE are chosen using a substantial amount of engineering judgement and interpretation; thereby losing the apparent exact "quantification" of seismic data. However, the probabilistic approach seems more meaningful for OBE, since this event is more frequent. Further, since the current USNRC regulations specify lower damping and allowable stress for OBE analysis than for SSE analysis, and the loads combined with OBE are more stringent, it is the OBE which sometimes governs the final design of some components of nuclear power plants (15). For this additional reason, the OBE should be determined with more care using probabilistic procedures, independently of the deterministic SSE. Incidently, the authors experience indicates that these more detailed studies will lead to OBE values smaller than the classical 0.5 SSE value.

6.0 Summary and Conclusions

This paper has summarized the present State-of-the-Art procedures for establishing the basic seismic design criteria for nuclear power plants; the procedures use a deterministic approach for the SSE and a probabilistic approach for the OBE. In the authors opinion, a deterministic procedure for the SSE has the following advantages:

(1) Heavy reliance is placed on regional and local geology, tectonics and seismicity
(2) The end product depends more on the quality of the data, rather than the quantity of the sample of data.
(3) The procedure in itself is logical, reflects the worst events observed, and can be verified and understood with ease by the Applicant and the Regulatory Groups.

The probabilistic - statistical approach has also been illustrated. This procedure may, at first, appear more attractive since it could provide a quantitative insight into the safety aspects of nuclear power plant design. However, the following pitfalls need to be considered:

(1) The procedure may lack an adequate sample of data and an adequate model of physical mechanisms. The basic philosophy of extrapolating 50 to 200 years of statistically significant earthquake data to predict rare 1000 to 10,000 year SSE events is considered inadequate.
(2) The mathematical procedure is quite complex and one may easily lose touch with the actual subject and artificially extract more information than exists in the source material.

In summary, the authors believe that the extrapolation of earthquake data should be limited to recurrence periods within one order of magnitude of the period for which statistically significant earthquake data are available. Accordingly, probabilistic determinations of SSE should be used with extreme caution and primary emphasis should still be placed on geology and historical seismicity. On the other hand, the OBE could be primarily determined from the probabilistic analyses, since the OBE recurrence period compares with the period for which a reasonably complete sample of data is available.

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Seismic Design Spectra for Nuclear Power Plants

State-of-the-Art

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Summary

The State-of-the-Art of nuclear power plant design involves the use of design response spectra together with a modal analysis of a mathematical idealization of the actual structure. The design response spectra give the maximum response of a family of single degree of freedom viscously damped oscillators to ground shaking usually described as an accelerogram giving ground acceleration as a function of time. The definition of a "standard" design response spectra is reviewed and illustrated by data relevant to "hard" or rock sites. Finally, the paper recommends a set of design response spectra applicable to rock sites.

Introduction

Seismic analysis of nuclear plants is typically based upon the use of some form of "standardized" design response spectra applied to a mathematical model of the structure. Structural response may be based directly upon modal analysis techniques or upon time history methods using an artificial time history derived to match the design response spectrum. The scope of this paper is not to discuss these mathematical models, but rather the philosophy which has evolved in arriving at "standard" design response spectra. This philosophy is illustrated by data from additional research concerning the shape of design response spectra applicable to "hard" or rock sites.

The concept of using response spectra to characterize the effects of ground motion was first introduced by Biot in 1934.(1) With the beginning of nuclear construction and computer-oriented analysis in the late 1950's, the number of papers on the subject grew exponentially. In nuclear design, this vast body of research has been reduced to the use of a relatively few "standard" design response curves.

The first attempt at establishing general seismic design criteria for nuclear power plants appeared with the publication of TID 7024(5) by the United States Atomic

Energy Commission in 1963. The basis of the design response spectra presented in TID 7024 was the work by Housner(3) in studying the response spectra of four strong motion earthquake records (El Centro 1940; El Centro 1934; Olympia 1949, and Taft 1952) in 1959. Housner's work was summarized as seismic design criteria for nuclear power plants in a paper presented at the Second World Conference on Earthquake Engineering in Tokyo, Japan in 1960.(4)

The Housner spectra remained the "standard" design response spectra for nuclear power plants until the results of a study by Newmark and Hall were presented at the Fourth World Conference on Earthquake Engineering in Santiago, Chile in 1969.(6)

Statistical studies of an expanded number of earthquake records were performed by Newmark(8) and Blume(2) which led to the 1973 Newmark-Blume-Kapur spectra(7) for the seismic design of nuclear power plants. The Newmark-Blume-Kapur spectra then became the basis of the present USNRC Regulatory Guide 1.60.(11) In these studies, the response spectra are normalized to peak ground motion parameters which are treated as being deterministic.

Figure 1 shows a plot of (1) the Housner 1959 Response Spectra (TID 7024), (2) the 1969 Newmark-Hall Spectra, (3) the 1972 Modified Newmark-Hall Spectra, and (4) the 1973 Newmark-Blume-Kapur Spectra for two percent critical damping. As shown on Figure 1, the trend in each iteration of design response spectra for nuclear power plants has been to add more and more conservatism to the design criteria with present day values a factor of two larger than the original Housner spectra.

The effects of foundation compliance received only limited treatment in the Newmark and Blume studies. Regulatory Guide 1.60 is therefore considered to be applicable to both soil and rock sites, with the exception of very soft sites. In this paper, results of additional research with respect to vertical and horizontal response spectra on "hard" or rock sites is presented. Blume and Newmark recognized that response spectra for records made on rock may be less severe than for soil deposits.

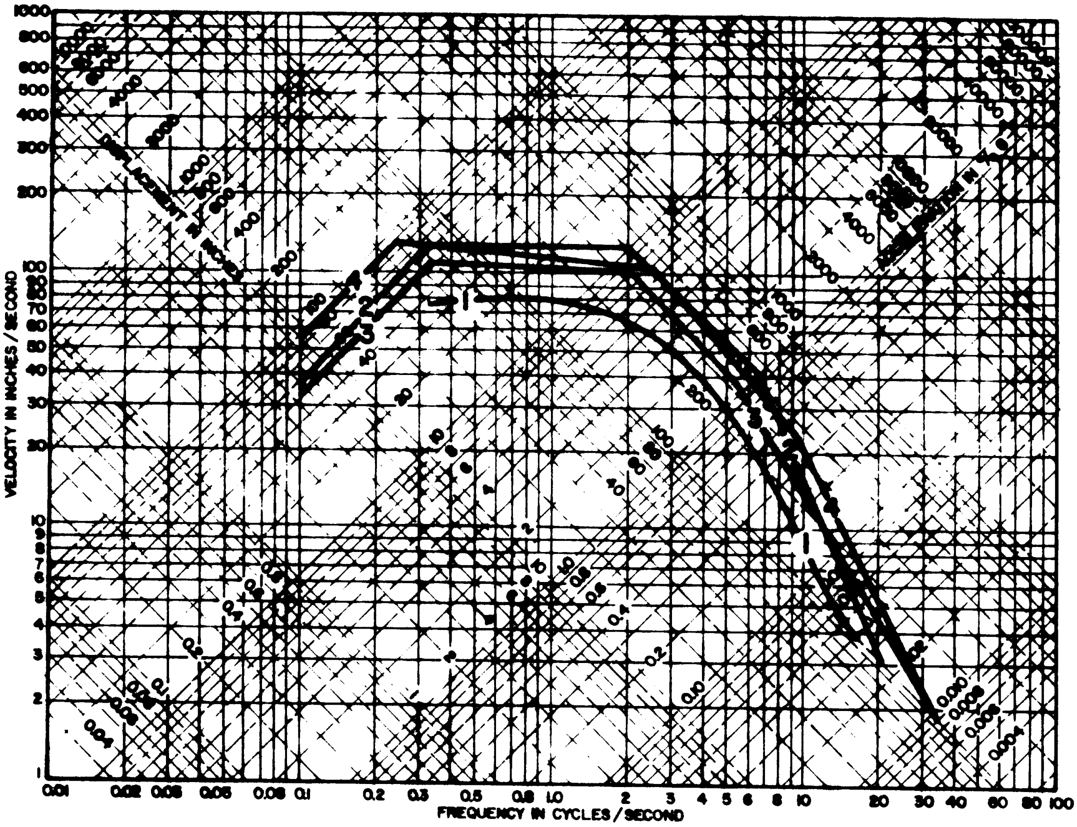
The research reported herein is based on an analysis of 30 vertical and 58 horizontal recordings made on "hard" sites. Briefly, the results indicate design response spectra for "hard" sites should be less severe than the recommendations of Regulatory Guide 1.60 in the frequency range below 5-6 Hz for the horizontal spectra and at all frequencies for the vertical spectra. In arriving at recommended design response spectra, the approaches of Blume and Newmark are followed with minor differences. The data base, however, is considered as representative of "rock" or hard sites.

Selection of Accerlerograms

One of the issues encountered in the study of strong motion records for "hard" or rock sites is the classification of sites with respect to rock or soil. Several records can be easily distinguished as being recorded on rock. These are the Helena, Montana (October 31, 1935); Bear Valley, California (June 22, 1973); Blue Mountain Lake, New York (July 29, and August 3, 1973); Koyna Dam, India (December 11, 1967); Hsinfengkiang Dam, China (March 19, 1962); San Francisco, California, Golden Gate (March 22, 1957); and San Fernando, California (February 9, 1971) Pacoima Dam and California Institute of Technology Seismological Laboratory Records. For the remainder of the records used in the study, the distinction between a "hard" or soil site is not as obvious. As suggested by Blume in Reference 2, for considering the site characteristics a ground impedance parameter of 4000 ft/sec, defined as the product of specific gravity and shear wave velocity, was used in this study to define "hard" conditions. Finally, for the 30 earthquakes chosen, the average horizontal acceleration is approximately 0.141 g while the range is from 0.015 g to 1.17 g.

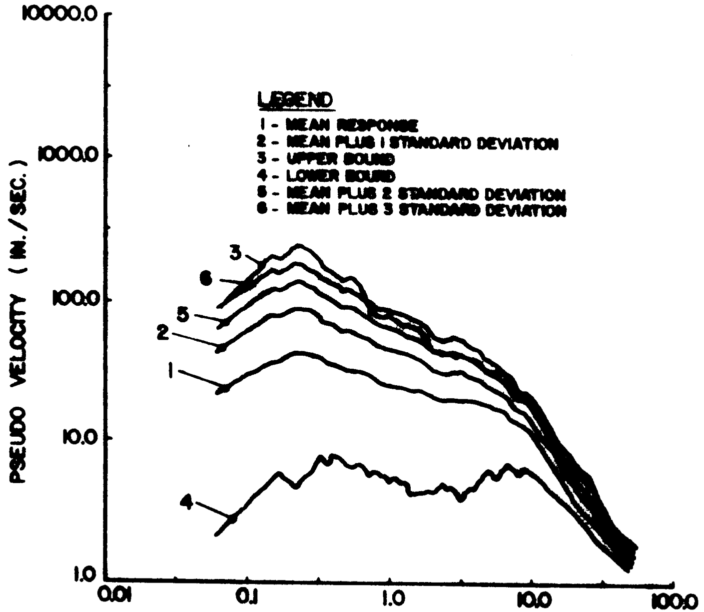
Data Processing Techniques

Strong motion time history records were corrected using standard processing techniques for both long period baseline errors and high frequency instrument response



COMPARISON OF NORMALIZED RESPONSE SPECTRUM FOR EARTHQUAKE GROUND MOTION OF THE INTENSITY 1.0g (CRITICAL DAMPING TWO PERCENT)

FIGURE 1



10 % SPECTRA NORMALIZED TO 1.0 g PEAK GROUND ACCELERATION (VERTICAL RECORDS)

FIGURE 2

errors. Baseline correction was performed by high pass filtering of data using a digital filter with a cut-off frequency of 0.07 Hz. Instrument correction was performed by low pass filtering of data with a cut-off frequency of 25 Hz and using a single degree of freedom representation of the instrument to obtain ground motion. The cut-off of 25 Hz was chosen on the basis of the observation that above this frequency, errors resulting from low signal-to-noise ratios, and spurious instrument response can lead to significant errors.(9) The algorithms and theoretical basis for these corrections are discussed more fully in References 9 and 10, respectively. The resulting corrected time histories accurately represent absolute ground acceleration over a frequency band between 0.07 Hz and 25 Hz. This frequency band represents the practical limits over which reliable information may be extracted using present recording and digitalization methods.

In addition to using the baseline and instrument corrected time history to determine response spectra associated with each strong motion record, the time histories were integrated to determine the velocity and displacement time histories as well as peak velocity and peak displacement. These peak velocities and displacements were then used to calculate ground motion parameters associated with each record.

Development of Design Response Spectrum based on Velocity, Displacement and Acceleration Normalized Spectra (after Newmark (8))

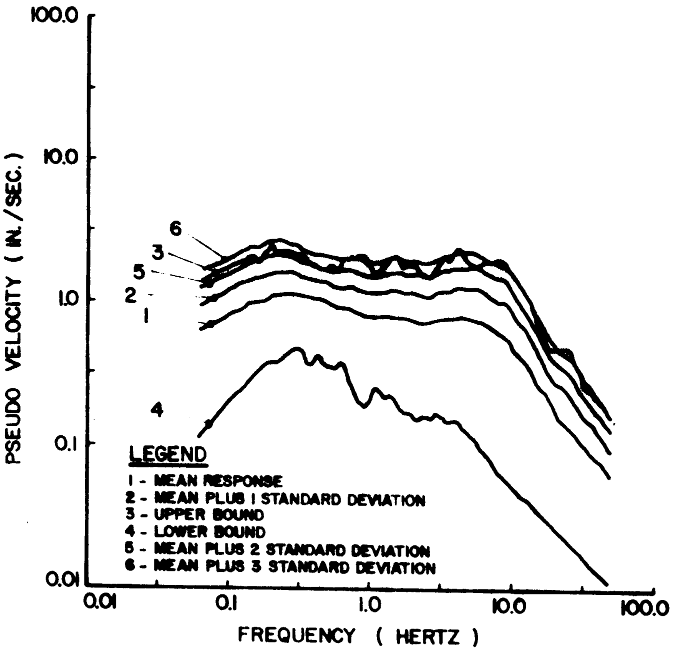
From the response spectra determined from each strong motion accelerogram, three normalized response spectra were determined by normalizing to peak ground displacement, velocity and acceleration as suggested by Newmark:(8) Displacement, velocity and acceleration normalized spectra were determined by scaling each record to the following peak ground motions;

Acceleration - 1.0 g
Velocity - 1.0 in/sec
Displacement - 1.0 in

The normalized spectra were then used to define spectral displacement, velocity and acceleration amplification factors at each of the 125 frequencies at which response spectra were computed. The displacement amplification factor is defined as the factor by which peak ground displacement is multiplied to obtain spectral displacement; velocity and acceleration amplification factors are defined similarly. Since the purpose of the normalization is to determine amplification factors, the values of 1.0 g, 1.0 in/sec and 1.0 in mentioned above, to which responses were scaled, are arbitrary in that they are only used for the numerical calculations of amplification factors.

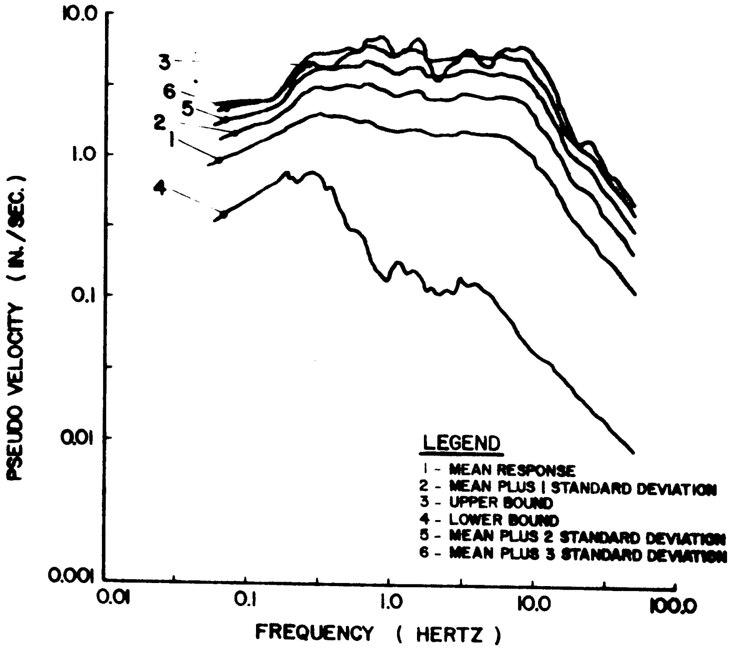
Each of the normalized spectra were used to determine mean amplification factors at each of the 125 frequencies at which the response spectra were computed by averaging over all 30 strong motion records. In the same manner the standard deviation of amplification factors was determined at each frequency point. Typical unsmoothed normalized response spectra for the mean, mean plus one standard deviation, mean plus two standard deviations and mean plus three standard deviations are shown on Figures 2 through 4. In addition, the upper and lower bound response spectra are also shown on these figures.

Having determined the mean and standard deviation of the amplification factors at each of the 125 frequencies, the means and standard deviations were averaged over selected frequency ranges following Newmark. Acceleration amplification factors were averaged over the range of 3 to 10 Hz; the velocity amplification factors were averaged over the range of 0.3 to 3 Hz, and the displacement amplification factors were averaged over the range of 0.05 to 0.3 Hz. Acceleration amplification factors were averaged over the interval 3 to 10 Hz since acceleration amplification is relatively constant over this frequency interval and among the three normalized spectra the acceleration normalized data have the smallest variation and, hence, dependence on the normalization procedures. Similar comments apply to the selection of frequency intervals over which displacement and velocity spectra were averaged. These frequency intervals were chosen by Newmark in Reference 8 for vertical motion at the sites represented therein and since they qualitatively agreed with results obtained herein for rock, they were adopted without modification.



10 % SPECTRA NORMALIZED TO 1.0 IN. / SEC.
PEAK GROUND VELOCITY
(VERTICAL RECORDS)

FIGURE 3



10 % SPECTRA NORMALIZED TO 1.0 IN.
PEAK GROUND DISPLACEMENT
(VERTICAL RECORDS)

FIGURE 4

After assessing the amplification factors, spectrum bounds were then determined by multiplying the amplification factor times the appropriate ground motion parameters confirmed by this study.

As in the recommendations of Blume and Newmark,(7) design response spectra are constructed using amplifications corresponding to the mean plus one standard deviation value. These design response spectra for 5 percent damping are shown on Figures 5 and 6.

Design Response Spectra based upon Acceleration Normalized Spectra (after Blume (2))

Design response spectra were also derived based on the approach of Blume; i.e. spectra were normalized only to peak ground acceleration. Of paramount importance in establishing the vertical design response spectra is its level relative to the horizontal spectra, i.e., the zero period or peak vertical ground acceleration. For the 30 events studied herein, the mean and median ratio of peak vertical to peak horizontal acceleration was 0.51 and 0.39, respectively. In computing this ratio, the maximum horizontal acceleration in the two horizontal orthogonal instrument directions is used. In the design response spectra reported herein, a round figure of 0.5 was adopted for the ratio of peak vertical to horizontal ground acceleration.

The Housner spectra originally adopted by the United States Atomic Energy Commission in TID 7024 did not consider vertical earthquake motion in the seismic design criteria. Newmark and Hall(6) suggested that vertical spectra be defined as two-thirds of the horizontal where fault motions are primarily horizontal and equal to the horizontal where fault motions are expected to involve large vertical components. The Newmark-Hall reference was the first appearance of the vertical excitation as part of the seismic design of nuclear power plants and set the traditional 2/3 value used for vertical which was maintained for the ratio of peak vertical ground acceleration to peak horizontal ground acceleration until the USNRC Regulatory Guide 1.60 design spectra.

The ratio of 0.5 presented in this study represents a departure from the traditional 2/3 value and was a direct result of the statistical processing of peak ground motion parameters for the 30 records considered in this study.

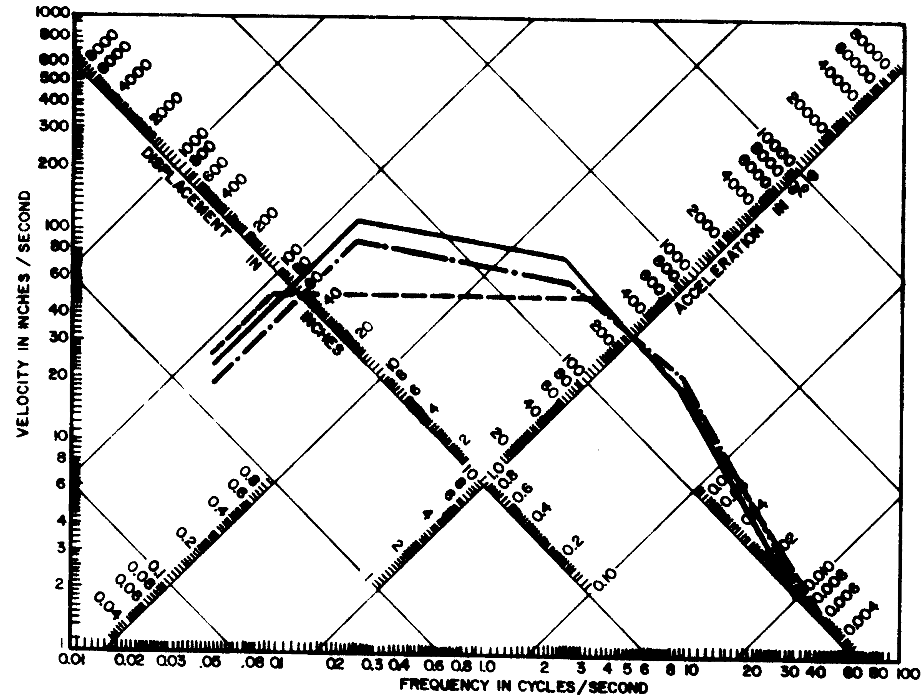
Also, for the records considered in this study for "hard" or rock sites, the average ratio of the smaller to larger peak horizontal ground acceleration in the two horizontal instrument directions was 0.80. In practice, the seismic structural design is based upon triaxial excitation with equal response spectra in the two horizontal directions.

As in Reference 7, recommended design response spectra are based upon the mean plus one standard deviation response. In order to construct design response spectra, the normalized mean plus one standard deviation spectra were fitted in a least square sense with straight line segments between the "control frequencies" as used in Regulatory Guide 1.60.(11) The straight line least squares fit was applied on log-log scales of amplification versus frequency as is normally plotted on tri-partite paper. The least squares line was forced to a value of 1.0 g and 0.5 g at 50 Hz. for the horizontal and vertical response spectra, respectively. Control frequencies were 0.25, 2.5, 9.0, 33.0 and 0.25, 3.5, 9.0 and 33.0 Hz for the horizontal and vertical spectra respectively. Below 0.25 Hz, the least squares line was specified by a constant displacement amplification. The resulting response spectra are compared to the recommendations of Regulatory Guide 1.60 on Figures 5 and 6.

Comparison with Regulatory Guide 1.60

The recommended design response spectra for rock sites, for 5 percent damping, are shown in Figures 5 and 6 compared to the recommendations of Regulatory Guide 1.60.

As shown on the figures, the recommended vertical response spectrum is lower than that of Regulatory Guide 1.60 at all frequencies.



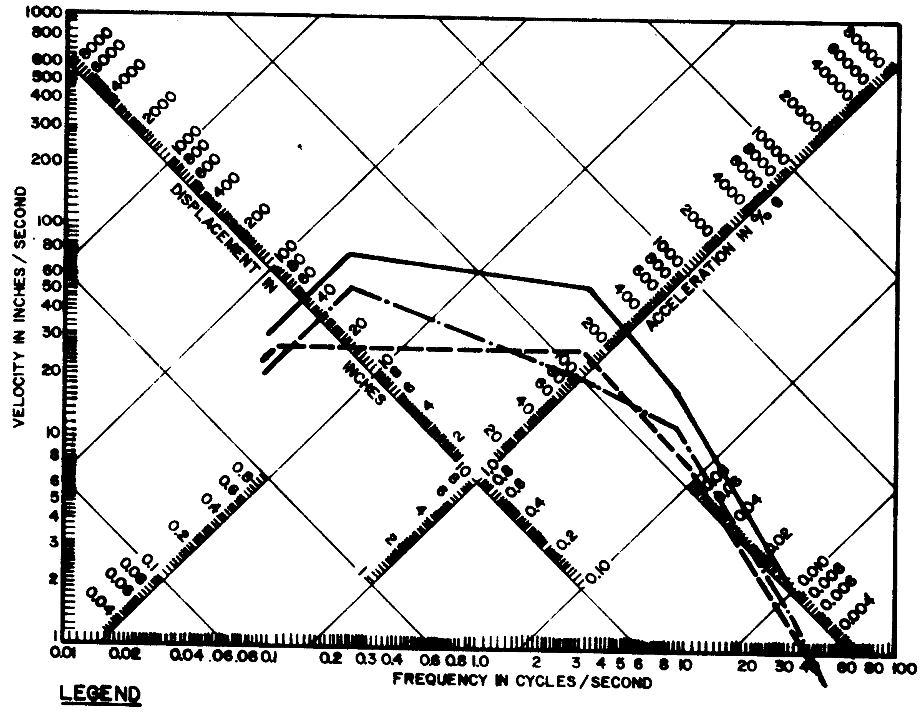
LEGEND

- – – – ROCK - FROM ACCELERATION AND DISPLACEMENT NORMALIZED DATA.
- —·—·— ROCK - LEAST SQUARES FIT OF ACCELERATION NORMALIZED DATA.
- ——— REGULATORY GUIDE 1.60

NOTE : PEAK VERTICAL ACCN. = 1/2 PEAK HORIZONTAL ACCN.

HORIZONTAL DESIGN RESPONSE SPECTRA (5.0 % DAMPING)

FIGURE 5



LEGEND

- – – – ROCK - FROM ACCELERATION AND DISPLACEMENT NORMALIZED DATA.
- —·—·— ROCK - LEAST SQUARES FIT OF ACCELERATION NORMALIZED DATA.
- ——— REGULATORY GUIDE 1.60

NOTE : PEAK VERTICAL ACCN. = 1/2 PEAK HORIZONTAL ACCN.

VERTICAL DESIGN RESPONSE SPECTRA (5.0 % DAMPING)

FIGURE 6

For the horizontal design response spectra, the recommended design response spectra are somewhat higher than Regulatory Guide 1.60 for frequencies greater than 5-6 Hz and lower for frequencies less than 5-6 Hz. This reflects greater high frequency content in rock ground motions.

Conclusions

The State-of-the-Art of definition "standard" design response spectra has been reviewed and illustrated by data relevant to "hard" or rock sites.

Finally, this paper recommends a set of design response spectra applicable to rock sites shown on Figures 7 and 8. The vertical spectra are consistently lower than those of Regulatory Guide 1.60, while the horizontal spectra are somewhat higher at higher frequencies.

Acknowledgement

The analytical work described in this paper was performed by Dr. D.E. Shaw and Dr. M.D. Snyder, Project Engineers, under the direction of Dr. P.C. Rizzo, Vice President of Operations, at E. D'Appolonia Consulting Engineers, Inc.

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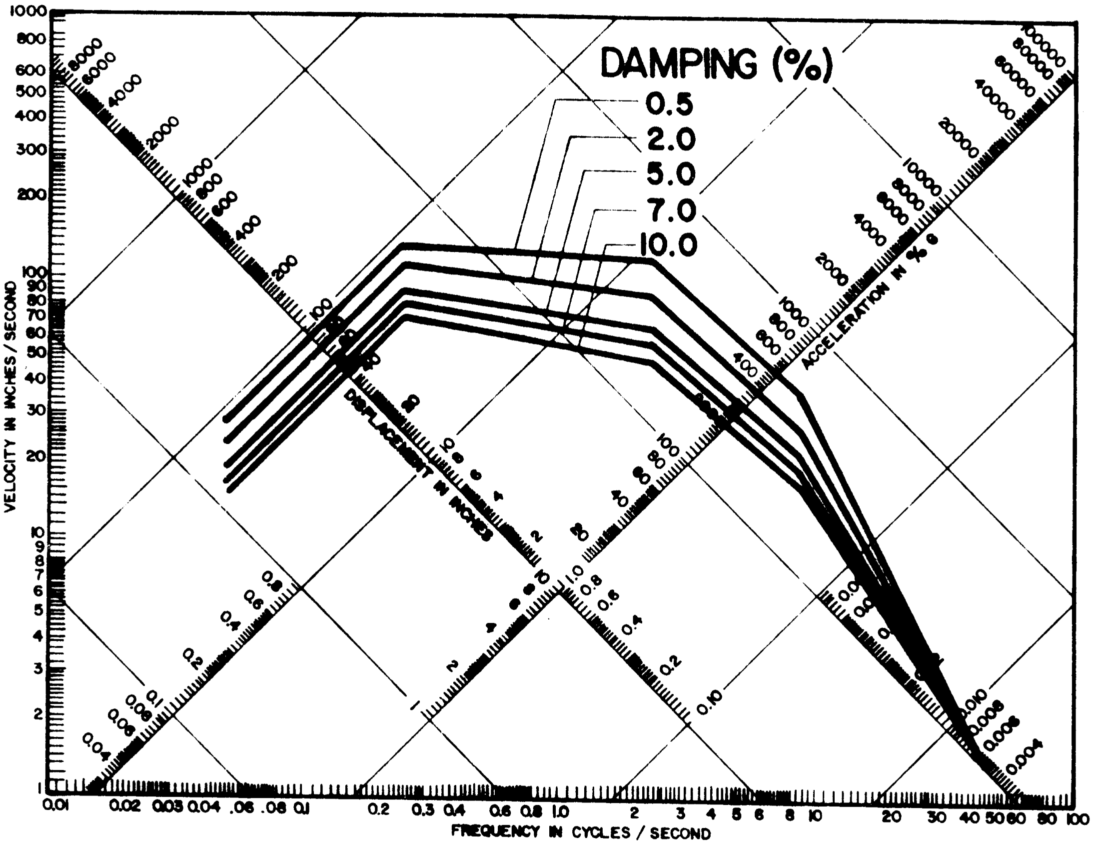
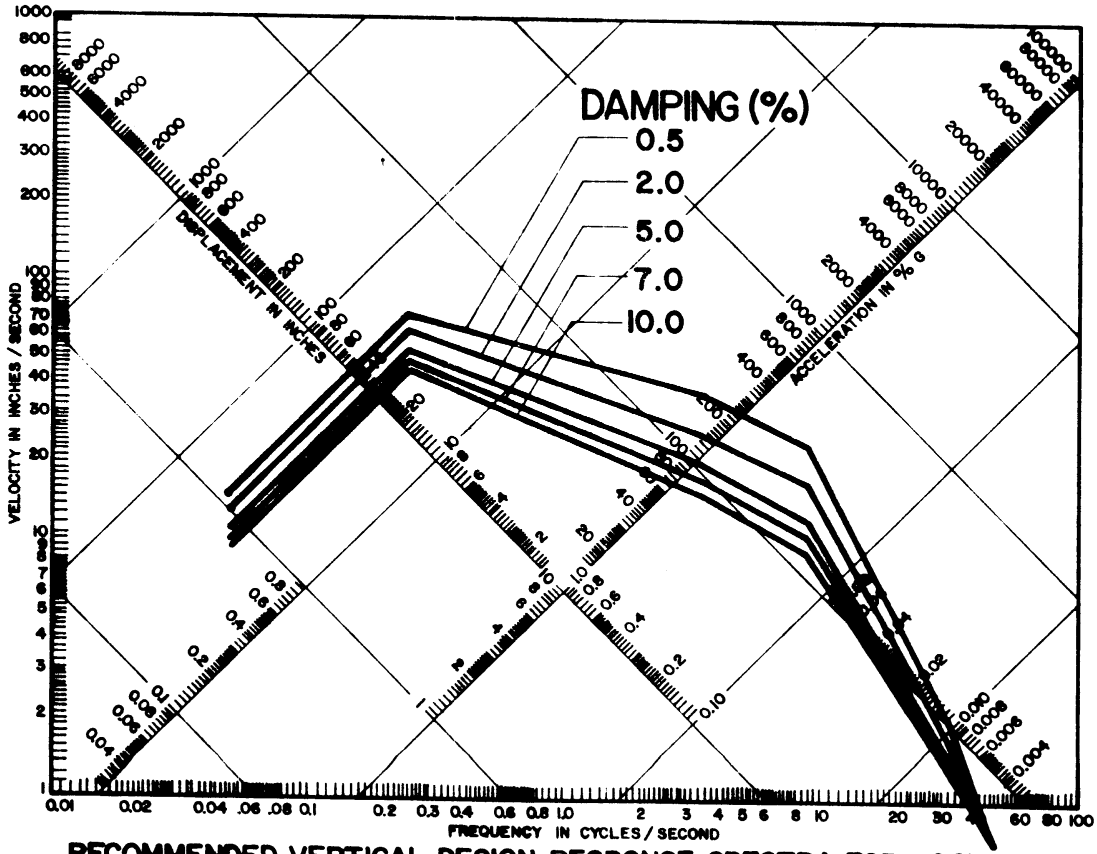


RECOMMENDED HORIZONTAL DESIGN RESPONSE SPECTRA FOR ROCK SITES
FIGURE 7 (1.0 g PEAK HORIZONTAL GROUND ACCELERATION)



RECOMMENDED VERTICAL DESIGN RESPONSE SPECTRA FOR ROCK SITES
FIGURE 8 (1.0 g PEAK HORIZONTAL GROUND ACCELERATION)

Earthquake Design of Nuclear Power Plants

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Today's Nuclear Power-Plants are provided with a great amount of inherent safety which exceeds by far that of non-nuclear plants.
Safety systems provided to cover a failure or a group of failures are installed redundantly, in suchway that an additional failure which might occur in one of these redundant systems does not lead to a dangerous state of the plant (single-failure-criterion). Generally, this criterion is fullfilled even if one of the redundant systems is being repaired.

Regarding to the low, probability , with which independent failures occur simultaneously at two systems, it is seen, that a release of radioactivity originating from failure of a component or system is not to be expected.

The further installation of redundant and diversified systems exceeding today's standard will yield a small gain only for the probability of the non-occurence of accidents.

You see that the security of modern nuclear power plants with a sufficient number of independent systems can be guaranteed as long as no events occur which damage many of the security systems at the same time. But such events are possible, they are called common mode failures.

To them belong events which come from outside the plant. According to their origin they can be subdivided into natural events like storm, flood, earthquake and into civilization-impacts like fire, airplane crash, chemical explosion. The goal of the protection of a nuclear power plant against such events is reached when

- the reactor can be shut down and can be kept in safe condition
- the emergency cooling and the after cooling systems remain intact
- the inclosure of dangerous quantities of radioactive material is guaranteed.

We are restricted here to the discussion of earthquake risk to nuclear power plants and to the problems which might it make difficult to reach the just defined goal of protecting nuclear power plants against earthquakes.

But at this point I would like to emphasize that even if we are only among seismologists here, earthquakes are not to be seen isolated in their threat to nuclear power plants. We have also to look for a general concept of protection against external events. I mention the vibration of components originating from an airplane crash or chemical explosions which is a problem very similar to earthquakes.

By earthquakes buildings and structures are shaken in their parts as well as on the whole. In a building the earthquake-movements cause different reactions from point to point and from floor to floor. That puts special demands upon the buildings as supporting structures and upon the components and systems which are fixed on them. Therefore it is necessary to get

- evidence of stability of structures
- knowledge about the movement and the resulting stress and strain of components
- and the judgement of the influence of the vibrations on the availability of components.

Out of that it is to be seen that earthquake design of a nuclear power plant is the common purpose for mechanical engineers and civil engineers. In general they intend to proove by calculations that any hazard to the availability of components or systems by earthquakes can be excluded.

As in many cases of technical calculations in a first step it is necessary to create a model. That means an idealized mathematically handable simplification of the given structure, which allows the calculation of the mechanical and physical properties as well as possible. The type of that model depends on the task of the investigation. For detailproblems for instance for a loadbearing member it may be sufficient to calculate loads or displacements, on the other hand for the evidence of stability of a structure you have to make a model of the whole building including its embedment in the soil. A general prescription how to transform a given structure into a model handable for all tasks does not exist.

The most simple models are rigid bodies or rigid body systems with spring and damping elements. For stiff buildings for which the forces within the single structure are not to be calculated such simple models produce very good results. The problem of stability or relative displacements of neighbouring buildings can be handled with a great ammount of accuracy too because in particular the buildings of a nuclear power plant are very stiff.

For the treatment of more detailed problems you have to use methods with great accuracy. Such a method is the universal applicable method of finite elements. To calculate loadings of earthquakes in a loadbearing system you may consider great elements if you have very detailed knowledge of the material properties or you have to use a very high number of elements if you have less exact material-data. For the design calculations you have to choose an applicable method.

Hereby the goal of the calculations is, independent of the applied calculation-method, to find out the maximum loadings for buildings, structures and components in case of earthquakes. Then it is task of the design to make the structures and components withstand these loadings without any damage.

As prescribed by rules and guidelines today three methods for these calculations are usual:

- Response Spectrum Modal Analysis
- Time History Modal Analysis
- Time History Analysis

First the Response Spectrum Modal Analysis:

The loading condition for earthquake is represented by a response spectrum. The method is able to determine the maximum values of displacement, Velocity and acceleration of an idealized structure which the geometrical data and the material data of the structure are to be known of. In a first step the eigenfrequencies and eigen-vectors of the modal-structure are to be calculated. In a second step the response of each mode of the modal structure to the response spectrum (the loading condition) are to be determined. Out of the given response spectra you can calculate - depending on eigenformen and damping - the maximum building responses for each mode. As a third step the single responses of each mode are superposed to a whole response of the system. For this superposition there exist different methods. The most usual is the root-mean-square method, which may be used only if the eigenfrequencies of the structure are not close to each other. The Response Spectrum Modal Analysis does not say anything about the vibrations as a function of time. The results are floor response spectra. For the Response Spectrum Modal Analysis the volume of the calculations in respect to other dynamic methods is small. The most work is to be done by calculating the eigenformen. The method is very attractive because a great number of earthquakes represented by one response spectrum can be considered within one calculation.

Second the Time History Modal Analysis

Here the calculated structure is to be known with its material-data and its geometric properties. As for the Response Spectrum Modal Analysis the eigen-frequencies and eigenvectors have to be determined. The loading function is given - as you can see by the name of the method - by a time history record of an earthquake. Then the participation of each mode in the motion are calculated under consideration of certain damping values of the system and are added up for each given time interval of the time-history. Then this calculation is to be done for all time intervals. That means that the time intervals are to be choosen in a way to include all relevant frequencies of the time history. The result are the time histories of structure movement, for instance floor time histories. From these results you derive the relevant design values like forces and strain as a function of time. The volume of calculation work is much greater here than in the first case. It is very important advantage of the Time History Modal Analysis that after determining the eigenformen you can calculate different time histories which is a necessity for reliable results.

Third Time History Analysis:

The input function for the model structure is also a time history record of an earthquake. With the Time History Analysis the equation of movement of a system is solved by direct integration. The calculations are also performed in certain time intervals. But, different from the Time History Modal Analysis the movement is not examined for the modes of the structure in each time step but the real response is calculated for each time step (by direct solving the equation of movement).

With this method the options for many calculations are given. Even problems where stiffnes or damping are given as function of time can be solved. The results are similar to those of the Time History Modal Analysis. The volume of calculation work is dependent on the degree, to which the great possibilities of the method are used but in most cases it is much greater than for the other dynamic methods, expecially because naturally each time history is to be calculated from the beginning.

These shortly discussed calculation methods are the first step in the design of a nuclear power plant. As I have emphasized the data from those analyses are the basis for the design of structures and components as there are size, kind and arrangement of reinforcement for concrete structures or the dimensioning of machinery equipment. From the discussion of these few general problems of earthquake design of nuclear power plants you see that the civil engineer needs applicable data from the seismologist as a loading condition.

The difficulties and the great responsibility which thus are imposed upon the seismologist have been discussed in this conference very intensively.

In the most european countries seismic networks do not exist which produce data for the design of nuclear power plants and furthermore some parts in Europe have relative low seismicity. The seismologist has to use historical data or has to make comparisons with other countries (like USA California) when he has to give loading conditions for earthquakes.

It may be relatively simple to assess intensities for any site. But as we all know we need data like

- soil acceleration
- response spectra
- time histories.

The maximum soil acceleration may be calculated by empirical formulas (for instance by Wiggins Blume Esteva). But for the applicability of those formulas there are necessary much detailed data of the soil properties which are often not yet available on time. In some cases especially if only historical data are available there are many uncertainties about it.

If response spectra are used for the design calculations there are also some demands to be fullfiled. The spectra should base on time histories which correspond with site properties. It means the earthquakes from which the spectra are computed should be similar in respect to magnitude, focal depth, focal mechanism, focal distance and so on to the expected earthquakes of the site. If we compute such spectra we have to consider soil parameters, expecially soil amplification effects as we heard from Mr. Steinwachs.

If we use time history methods the records also have to be choosen under consideration of the site properties so that we have similar conditions.

As known all these investigations are not necessary if we have original earthquake records for a site. But as in the Federal Rep. of Germany in most of the cases we have to use data from outside.

In the licensing practise of our country we often use data from California earthquakes. The spectra which are given for the design, or advised time histories come from California.

Seismologists are always to answer the question, whether computed data and data from outside are a conservative basis for earthquake design of nuclear power plants, for instance: are spectra based on Californian earthquakes applicable input functions for design calculations for nuclear power plants in the Rhine Graben.

I hope that I could show up some aspects regarding the role of the seismologist for the assessment of the earthquake threats to nuclear power plants.

OPEN
DISCUSSION

Towards more safety against earthquake hazards for nuclear power plants

An introduction to the general discussion

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Summary

Attention is drawn to a number of unsettled questions on the subject, most of which have been brought up during the present Symposium. These items are briefly reviewed and discussed.

A summing-up of the Symposium learns that the problem of earthquake risk for nuclear power plants is complex and has many sides. A unique solution for the complete problem does not exist. Moreover, there are divergent approaches for the solution of some of the separate part-problems. It has become clear that all these individual aspects need careful study, and that ultimately they may possibly be solved only by an international and multidisciplinary approach.

The present-time seismologist is confronted with the question: "What is the kind of information the engineer wants from me, and what can I offer him?" (quotation VAN GILS). Seismologists primarily are concerned with the seismic records and observations as the basic data, the effects of the earthquake on the earth's crust and building structures, and the theoretical background to explain the causes of earthquakes and the link between the events and the effects. Important tools for the seismologist to reach conclusions of value to the engineer are the models, the methods and the computer software to calculate seismic risk. The question of the impact of an earthquake-disaster on society, communications and economy cannot be answered by seismologists. This applies with greater force to questions concerning nuclear power plants, such as if there exists at all an acceptable risk-threshold for the life-time of such an installation. Such aspects, therefore, will not be developed here. In the following a non-exhaustive list of salient points, for the greater part also raised during the Symposium, and to be solved by seismologists in answer to the second part of the question mentioned above, is given.

1. Input

What are the types of data to be gathered for the analysis of seismicity and the calculation of earthquake risk? Of importance are lists of earthquakes, magnitudes, seismic moments, intensities, spectral analysis of records, peak-displacement, -velocity and -acceleration, frequency, duration of the signals, but also data from geology, tectonics, seismo-tectonics, neo-tectonics and crustal movements, and of geophysical anomaly fields such as gravity and magnetics. A good co-operation with geologists and geophysicists of other disciplines is essential.

2. Extension of raw data

Raw, non-manipulated, data are considered to be of primary importance. Means to extent the network of measuring instruments in Europe should be studied. As a base for an improvement of the data interpretation the free exchange of records and the compilation of summaries of station locations and instrument characteristics are stressed. A possible extension of early data could be made by a careful study of the strong-motion instrument records of the turn of the century at locations in different earthquake regions of the world.

3. Homogeneity of data, transfer relations

The difference between modern and historical data is that for the latter only descriptions of the earthquake effects are available that in favourable cases can be transcribed into intensity values and in exceptional cases into seismic moments. For an analysis of seismicity data homogeneity of the material is required. Therefore, it is not justified as yet to omit the factor intensity as the only unified parameter for both history and the present. For the solving of the transfer relations between intensity and other parameters, such as acceleration and magnitude a special study is recommended to be executed by seismologists active in this special field.

4. Earthquake effects on ground and structure

The study of the effect of seismic motion on ground and structures can only be effectuated with the help of colleagues from groundmechanics and civil-engineering. The purpose is the estimation of the probability of destruction due to shaking of different intensity. The determination of the transfer functions between intensity or acceleration and epicentral distance, between the duration of shaking and the extent of damage is of great importance. The general point of the choice of parameter (displacement, velocity, acceleration, peak- or mean values, duration of shaking etc.) optimally suited for a determination of possible damage needs considerably more attention.

5. Deterministic versus probabilistic approach

How to proceed with the input-data? Is one of the two, the deterministic or the probabilistic approach superior to the other? In recent years the last approach is clearly more in favour, but this does not take away certain advantages in using the deterministic method when possible. The respective results should be weighted by using both methods simultaneous for one and the same region.

6. Statistical tools

Are the statistical tools used the most appropriate for the problems in question? Recently Gumbel statistics have become very popular. How do the methods used here do compare with others such as that being widely used in the USSR and not being represented at the present Symposium?

7. Computer software

The development of the mathematical tools and computer software, i.e. the programming of an automatical risk determination with a certain set of input data, is essential. This software has been developed in various directions by different groups of investigators. Approved techniques do already exist and the initial problems of data handling have been solved (see also this Symposium). Apart from the formal exchange of computer software between groups of interested specialists, also other scientists should be enabled to get acquainted with the work-methods of different groups. To this end a one- of two-week work-shop could be arranged in which the mathematical tools are exposed and explained, and in which individual workers are trained in using these programs. This seems to be a clear-cut task for the Sub-commission on Seismicity of the European Seismological Commission.

8. Output

What are the types of information to be used as basis for the construction and presentation of the results in the form of seismic zoning or seismic risk maps? Homogeneity again is one of the first requirements - no discontinuities at national borders! For Europe one can think of a set of maps, scale 1:1.000.000, displaying (a) epicenters, (b) maximal observed intensities, (c) young tectonics (faults), depth base Quaternary and outline of Paleozoic and older massifs, (d) zoning map with maximal expected intensities, and (e) recurrence periods of intensity VII, VIII or IX. Is this what the engineer needs from the seismologist?

Apart from the above mentioned questions and problems there are three more general points which should be raised:

9. A-seismic regions

How should the problem of the a-seismic regions, where no historical or other data of local earthquakes are known, be solved? What are the probabilities for a sudden earthquake in such a region? It is known from other similar areas that such totally unexpected events may occur. How should the risk be evaluated in these cases? A rather large portion of the European territory falls under this type of region, so suggestions or directives for future use will be welcome!

10. Definitions, confidence limits

In any report clear definitions should be included of the used parameters. This is often neglected, which may result in a wrong interpretation of the conclusions. The parameter magnitude, of which a multitude of definitions exist to determine the proper value, is a good example in this case. This point is stressed since it is of basic importance. A related and equally important point is the necessity to add to each presented conclusion a value indicating the confidence limits in which the results are valid.

11. Organizational matters

The work of seismologists in the field of seismicity and risk evaluation, if properly executed, may be operative in the yearly saving of thousands of human lives and the prevention of loss or destruction of building structures to the equivalent value of tens of millions of dollars. The construction of nuclear power plants only gives this statement an extra dimension. The feeling grows that some of this potential in financial gain somehow should be made available to the seismic community for the proper execution of their responsible tasks. If indeed, this could be effectuated, some sort of a Consulting Board seems to be necessary which could guide relevant work and could give advice to the individual workers in the field. Also, it should be made responsible for the formulation of seismic risk in general, and for the homogeneity in presentation of workresults. International bodies that are candidates for the institutioning of such a Board seem to be ESC, IUGG and others.

The discussion of the points raised here, and the appropriate following action, are to be considered as a mere minimal program for the near future if any real progress is to be reached at all. The importance of international co-operation in this context has not been brought up expressly as a separate point, it is a conditio sine qua non, to which everyone will agree. In this respect also the invaluable impetus on seismology from UNESCO/UNDP sponsored Projects, such as that of the Balkan region during the past five years, should be stressed. And it seems a logical and straightforward task for us to investigate the possibilities for the starting off of a new UNESCO Project, similar to that of the Balkans, but now for the whole of Europe. The experiences gained during the life time of the former Project could extremely well be used as a base for this new and wider effort.

Acknowledgements

Professor V.I. Keilis-Borok, when reading this note, will undoubtedly recognize several parts of it. Partly, it is indeed a reflection of the talk we had on these and related matters in September 1975 during the IUGG General Assembly in Grenoble.

OPEN DISCUSSION

as recorded by G. Houtgast and A.R. Ritsema

(completeness has been pursued, but is not claimed)

The discussion falls apart in a statement of Dr. Fournier d'Albe on the preliminary stages of UNESCO Projects (A), the open discussion proper (B), the formulation of some recommendations (C), and some announcements (D).

A. Procedures UNESCO Projects

In answer to a question in the foregoing "Introduction to the Discussion" Dr. E.M. Fournier d'Albe summarizes the planning and organization preceding the active period of the UNESCO/UNDP Balkan Project, which in all took a time of four years! In future cases this planning-time could probably be reduced to three or minimal two years.

If the European countries could decide that a Project similar to the Balkan Project is useful and should be pursued, the first thing to do is to call a Planning Meeting of representatives of interested nations. Such a meeting could possibly be convened by UNESCO in Paris. An early consultation with, and support of ESC, EAEE, UECD and IAEA is advisable.

In this first meeting it should be stated what the type is of the information needed, and which type of maps should be produced. Moreover, a general planning-schedule of the work should be adopted.

Next, a Governmental Co-ordinating Meeting should be called. It seems questionable if UNDP will be willing to take part in the finances for such a European project. The bulk of the expenses definitly will have to come from the interested nations themselves.

If this meeting should make the way free for further action, the next step will be the formation of technical working-groups to formulate the problems in detail, and to contribute to the solving of particular questions. Naturally, ESC, EAEE, and possibly IAC of Mathematical Geophysics should actively take part in the work.

Preliminary discussions on the subject of a UNESCO/UNDP Project for the Seismicity of Europe could take place at the Intergovernmental Meeting in Paris of February 1976.

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B. Open Symposium Discussion

The following Agenda is adopted:

1. Definitions
2. Input Data
3. Type of approach
4. Theoretical background (software)
5. Transfer relations
6. Influence of distance, focal depth, magnitude, frequency, source characteristics, region
7. Probability criteria

1. Definitions

For many parameters definitions are needed: OBE - operating base earthquake, SSE - safe shutdown earthquake, acceleration (is the peak value of interest, or is it a fraction, f.e. 2/3, that is critical?), velocity, displacement, free field acceleration (as contrary to site acceleration), amplitude, period, magnitude (many different scales are in use, such as m_B - M_L - M_S), seismic moment, intensity, duration, power spectra, return period $T = 1/\lambda$ (where λ = number of events per year). This return period is not equivalent to the probability, but is often used as such. The probability also depends on the lifetime t of the plant. Therefore a risk factor should be introduced $= 1 - e^{-t/T}$. With small t, $\gamma \rightarrow 0$, and for great t, $\gamma \rightarrow 1$. It is also possible to define probability as probability per year.

For a review of different magnitude scales and some transfer relations see a.o. papers by Karnik, 1969 and 1971. A list of definitions should be drawn up for general use.

2. Input data

For historical events only intensity data are available, for recent events magnitude, intensity, strong motion records, depth, site-accelerations, seismicity maps, etc. An increase of strong-motion records is very much needed, the records should be continuous and not only restricted to the instances that a certain threshold has been surpassed. What the old records concerns, it should be made clear beforehand what is wanted and expected from these records so that no useless work will be done. A compilation of lists of seismic instrumentation and response characteristics could be of use. Raw data are preferred to prepared or converted data.

Some conversion, however, is needed when both historical and recent data are used together. In the case of bigger earthquakes it is better to determine not only M_S but also M_L. This gives a more homogeneous comparison with smaller shocks for which only M_L can be determined. Routine conversion from m_b to M_S should not be executed, errors than are unavoidable.

For a comparison of response spectra with intensity values more data are needed; the range of accelerations measured for one intensity value is very large indeed. Not all intensity values, however, are directly comparable. An Intensity VI in the epicentral region has high frequency content, a VI at larger distances has a completely different spectrum with lower frequencies dominant. A relation between the power spectrum and magnitude is more likely to be found than one between the spectrum and intensity or acceleration.

3. Type of approach

Are SSE deterministic or OBE probabilitic methods to be chosen? In other words, do we work in the time domain or in the frequency domain? Both are recognized approaches, with a present slight preference for the probabilistic approach or OBE. If possible, therefore, the probabilistic approach should be used, better still simultaneous with the deterministic approach.

The extrapolation of, say, 200 years of data to a period of 1.000 or 10.000 years remains problematic; the future cannot be known better than the past, whatever manipulation has been used on the known data of the past.

The goal ultimately is the production of a synthetic seismogram for the site that is completely comparable to that which will be observed during an earthquake. In principle this problem has been solved. The local and regional structure of the foundation of the site should be known in detail.

4. Theoretical background (soft-ware)

The extreme value theory as used in the Gumbel statistics has been proved to be very useful for the problem. Except this now widely used method also attention should be directed to other methods, such as that developed by Keilis-Borok and his group in Moscow.

5. Transfer relations

Most important are the conversions of intensity I in magnitude M and in acceleration a. Locally, other relations have been found empirically, such as that between the radius of perceptibility r and magnitude M. Such relations depend strongly on depth of focus and geological structure of the region, and they thus cannot be transposed directly to another region.

Apart from these empirical relations, the mechanical models of the earthquake process are of importance, since from them such relations also may be derived theoretically. The influence or response of the soil model may be compared with that derived empirically from artificial shocks (explosion) or noise studies.

In the high-frequency range the deterministic approach becomes difficult by scattering on local structural inhomogeneities. A close co-operation with geologists is needed for the interpretation of the data.

Good records are not easily obtained. In the USA with 3.000 instruments on the average 10 year is needed for a good record of one instrument!

Magnitude M does not correlate well with peak acceleration a or other derived values of the same, better with velocity v. For intensity I a combination of velocity v and duration t seems to be optimal.

6. Dependence of distance

Several empirical relations do exist for the attenuation of acceleration a with epicentral distance Δ. The influence of depth of focus is important, but not very well known. The measurements through explosion experiments is very helpful. The (a,Δ)-relation found for one region cannot without comment be used for another region. However, with the existing lack of data this is often the only possibility to get some impression of the effect of distance. The source characteristics are also of great importance.

7. Probability criteria

This is not the field of the seismologist. In the case of nuclear power plants the local governments should decide if a yearly probability for an OBE of 10^{-2} is used, such as in Sweden, or 10^{-3} or otherwise. The probability precision, however, is something else. This should be given by the seismologist. No general rules can presently be set. It is known, for example, that the seismicity may shift considerably in the course of historical time, the classical example being the seismicity of the past 2000 years of the Middle East.

The difference between the purely economically determined measure of OBE with SSE is also that SSE, unlike OBE, depends on the type of the reactor.

One of the difficulties with the higher acceleration thresholds is that the buildings will be constructed stronger but also less flexible. For very near shocks of high frequency (20-30 cps) the wavelength may be as low as 30 meters if the site is located on a foundation of loose alluvium. This is considerably smaller than the overall size of the nuclear power plant structure itself, which is of the order of 100-125 meter. It is clear than that the danger comes up for the developing of distortion cracks in the structure.

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C. General recommendations

a. The installation of more strong-motion instruments is strongly recommended in order to produce a better input data set. The recording should be continuous, or the threshold of recording should be lowered considerably. Instrument locations outside the plant on geologically the same structure also should be occupied.

b. The transfer function between intensity I and magnitude M and/or acceleration a and velocity v and duration t should be studied in more detail.

c. The production of synthetic seismograms should get more attention.

d. A critical review of historical events should be undertaken.

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D. Miscellaneous

The next ESC meeting on these problems will be the special symposium on earthquake risk on September 25, 1976, convened by Dr. V. Karnik, during the Krakow General Assembly of ESC, 22-28 September 1976.

The Intergovernmental Conference on the Assessment and Mitigation of Earthquake Risk in Paris, 10-20 February 1976, will be a possibility to present and test the results of the meeting in a wider circle.

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