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Global earthquake and seismic index maps and catalogue

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ABSTRACT: Ordinary earthquake maps in general neither offer much guidance on event probability nor on historic seismicity. A growing number of different parties must, however, evaluate given exposures. We have therefore developed a set of maps and a catalogue which provides a basis for professional risk assessment. The catalogue is the most comprehensive global catalogue available so far and discusses approximately 5 000 important historical and instrumental earthquakes. The earthquake maps show these events and seismic zones, and a set of three seismic index maps give seismic indices for all important places permitting the calculation of return periods of intensities, magnitudes and ground accelerations, and the assessment of seismic gaps. These maps and the catalogue form part of "Earthquakes and Volcanic Eruptions: A Handbook on Risk Assessment.

1 EARTHQUAKE MAPS AND CATALOGUE

1.1 *Introduction*

The maps and the catalogue is a substantially enlarged version of the 1977 SwissRe Atlas on Seismicity and Volcanism. It can still only consist of generalizations based on the vast amount of data contained in a voluminous library on seismic and volcanic events. It is intended to aid not only those in insurance and reinsurance who are confronted with such problems, but also people in industry; construction; commerce; civil, mechanical, chemical or electrical engineering; financial institutions; and anyone else in need of information in this field. To derive maximum benefit from the maps, the entire catalogue it should be consulted, as some information referred to in connection with a particular event may be valuable when assessing exposure in other regions.

1.2 *Explanation related to exposure zones*

Obviously any subdivision of seismic zones invariably leads to a rather general approach. Although we have tried to grade such zones according to the combined effect of event probability and loss caused, differences necessarily exist from region to region, and are so considerable that a four-grade system cannot accommodate them all. We purposely do not give event probability zones as they would not reveal much to anyone unfamiliar with the interplay and effect of factors contributing to exposure. Besides such factors as event probability, transmission characteristics and subsoil quality, there are others such as building materials, design characteristics and code requirements. The quantifying probabilistic approach to the assessment of earthquake exposure is discussed in connection with the Seismic Index Maps.

In general the reader may interpret exposure zones as being representative for the region. He should, however, be extremely careful when relating zones of very different activity and background, e.g. Japan and Spain. In regions of generally low activity, areas have been shown in the zoning which are much less exposed than a similarly coloured region in a high activity area. Areas which have not been shaded are not necessarily free of earthquakes, and are therefore not free of earthquake exposure. The historical and instrumental events entered in such uncoloured zones (i. e. those where earthquakes are less probable than in the zone of low exposure) illustrate this. In fact, were earthquakes down to the smallest instrumentally observable magnitude to be entered, and not only those of a magnitude greater than about M 5, it would become apparent that there is hardly any region which is free of seismicity.

In view of present and particularly future activity in off-shore projects, we have included seismic regions in the oceans, also because of their tsunami-genic potential. In this connection, however, users should bear in mind the fact that tsunamis lose very little of their energy in crossing thousands of kilometers of ocean, if the water is deep. Seismic zones in other parts of the ocean must therefore also be considered.

1.3 *Explanation related to earthquakes*

The epicentres shown correspond to only a small fraction of historic and instrumentally recorded events which are discussed in the catalogue. These were selected according to various criteria, e.g. magnitude, damage caused, physical properties, general interest, or even to illustrate activity in border regions or areas frequently considered aseismic. In general, most instrumentally-recorded earthquakes of large magnitude are shown, unless limited space makes this impossible. In areas of considerable activity, medium-sized and small-magnitude events are only included to avoid the impression of gaps in activity, or to demonstrate foci in border regions.

For historical events, the symbols shown may be at quite some distance from the real epicentres, if for instance, sparse population, remoteness of such places from trade routes or important settlements, absence of recording, or loss of records, as well as incomplete evaluation of sources, do not provide a better basis for assessment. To avoid cluttering the map with too many epicentres we frequently used only one epicentre symbol to represent several historic events in the region. In such cases the explanatory text provides the required details.

The respective earthquakes are not only discussed under the symbol where damage was severest and/or where the epicentre may have been, but also under other symbols, that is places where such earthquakes were noted or caused damage. This makes it easier to estimate the exposure of a place on the basis of historical reports, as it does not require reading the entries under many symbols in a region. A correlative evaluation is indispensible, however, if more than a general picture is required.

For earlier historic reports from "unconventional" places, it is quite difficult to assess whether an intraplate event was involved or whether the shaking resulted from an earthquake which had its epicentre many hundred kilometers away. The latter alternative must in particular be allowed for if the place of observation is on deep alluvial layers.

To avoid errors in intensity transformation we have used the intensity scales of the original publications whenever possible. The reader should, therefore, note the respective indication, which is generally made only once per country or region.

A trickle of earthquakes in a particular century does not necessarily signify that recording started then. The reliability of such a deduction can only be judged after a painstaking study of the history of the region, in the widest sense of the word, and one would have to allow not only for changes in trade routes, seats of government and administration, changes in population, the effects of wars, civil wars, or conquests, or of fires gutting libraries and records, but also for seismic gaps and trends. In regions where seismicity is low, where the return period of medium-size earthquakes can be as long as several hundreds of years, seismic gaps can last for some thousands of years. The "physical" causes mentioned so far, which may have caused gaps in the records, can to some extent be traced. Far more difficult to ascertain are, however, human causes. Many documents kept in archives are difficult to find or have disappeared because archivists rearranged the collection or obliterated some sections. At any rate it should be noted that "historical seismology" is a new science, or more properly, a resurgent one. It can be assumed that many additional historical events will be found in the years ahead. For these reasons, the absence of reports on earthquakes does not signify that the area is aseismic. For some regions we present a sketch of some important historical events in order to render the general information more useful.

1.4 *Explanation related to the list of earthquakes and volcanoes*

For reasons of space, comments have had to be kept to a minimum, and some readers may feel that certain events did not receive enough attention. For similar reasons, and to make the list more readable for the non-expert, technical details found in the handbook (Tiedemann 1992) have not been included.

The absence of comments on certain features should not be taken to mean lack of such features, e.g. tsunami following earthquake. The intention was merely to list those features which, we feel, deserve special attention.

In connection with the indication of magnitude, attention is drawn to the fact that they vary and have been repeatedly revised in the past.

With historical earthquakes, particular care is required. The dates of earthquakes are often uncertain, in particular if the original reference as based on a calendar different from the Christian. Sometimes the indication is not better than a mention, for instance, that the event occurred in the reign of Theodosius II. The epicentral region can very rarely be accurately estimated. As mentioned earlier, reporting is often geared to the importance of the places involved at the time of the earthquake and to the reporters' knowlwdge of geography. Earthquake effects are far more likely to be reported if they relate to important settlements and trade routes. The absence of historical reports from less important regions, therefore does not signify that they were not affected by earthquakes. Even if information on damage is available from many towns affected by a particular earthquake, differences in vulnerability (general vulnerability of buildings, effects of earlier earthquakes, subsoil and site parameters) complicate assessments. Moreover, reports sometimes confuse different events.

Particular care is required in connection with intensities and it is stressed that critical assessments have been included only comparatively rarely. Earthquakes are and always have been exciting events, inviting exaggeration, and one must therefore evaluate statements on damage and later conversions into intensities with a healthy measure of scepticism. Neither historians nor seismologists are as a rule experts in the vulnerability of buildings, nor in a position to assess the parameters contributing to damage. Very often the information provided by old texts is imprecise. If a place was "affected" by an earthquake, the meaning can therefore range from a shock which was noticed or which caused alarm, to one causing substantial damage. We have in general refrained from qualifying intensity statements or even from adding a code indicating the level of reliability as found in some earthquake catalogues. The reader of the section on intensities in the handbook will appreciate the many uncertainties affecting nearly all intensity statements, and in particular the application of intensities drawn from historical accounts to the assessment of the exposure of modern buildings.

Some catalogues of historical earthquakes contain indications of magnitudes which were derived by "calculating" the magnitude from the epicentral intensity (I_0). As the correlation between magnitude and epicentral intensity is extremely poor we suggest using such data with extreme care.

We suggest evaluating the statements on historical events under the symbols of a region in a comparative manner. This assists in estimating the magnitude and severity of the earthquake. Moreover, to save space basic information has not been repeated under each symbol.

Monetary losses cited in connection with the events generally represent the value of the currency at the time of occurrence. The world maps are available in two scales: 1 : 32,000,000 identical to the SIMs and a library version of 1: 23,000,000.

2 SET OF SEISMIC INDEX MAPS (SIMs)

2.1 *General Remarks*

This text contains only a synopsis of the essential aspects and is therefore no substitute for the study of the corresponding chapters of the handbook. The scale of the SIMs is identical to the 1 : 32,000,000 World Map of Earthquakes and Volcanoes, permitting convenient superimposition. The set of three maps is basically intended to facilitate the assessment of general, i.e. not of specific, seismicity. The maps have been developed on the basis of instrumentally recorded events above about M 5. This means that the sample is small to very small in regions of low seismicity. Even in regions where seismicity is high, the seismicity as suggested by the indices may differ considerably from reality due to seismic gaps, seismic trends, which produce a negative deviation, and the chance of inclusion of large events which should be associated with return periods much longer than the observation period used.

2.2 *Observation Period*

We started with the great earthquakes listed by the USGS from 1897 onwards. Reliable observation started, however, much later. The SIMs take account of earthquakes up to December 31, 1986, resulting in the inclusion of part of the last globally rather seismic phase, i.e. from 1897 until about 1911, out of a phase of high activity which already started in about 1852 and which included some short periods of remission, e.g. in 1859 - 60 and 1877 - 84.

2.3 *Magnitude-Frequency Correlation*

The magnitude-frequency relation and the instrumental observation period for earthquakes of different magnitude groups was considered when determining the respective Seismic Indices (SI). The relative global frequency of events observed from 1953 until 1973 was used.

2.4 *Method and Counting Procedure*

All instrumentally recorded earthquakes above about M 5 or m_b 4.6 were entered on maps (scale 1 : 1,000,000). Three counting ellipses with a ratio of the axes of 2.5 : 1 and covering areas of 25,000 km^2, 50,000 km^2, and 125,000 km^2 were used to derive the number of earthquakes per magnitude group within the respective ellipses. One of these counting areas must be used when calculating return periods according to the formulae given hereunder or those for magnitudes and accelerations given in the handbook. The long axis of the ellipses was placed parallel to the general direction of minimum attenuation or, if unavailable to fault systems or valleys.

From the relative number of earthquakes within the ellipses SIs were calculated, considering the actual observation period per region per magnitude group and the global magnitude-frequency correlation. The SIs were entered on three separate transparent maps according to the size of the counting ellipse used. In general the counting ellipses were centred on towns or other important places. In regions where instrumental observations have recorded only isolated earthquakes the ellipses have been centred on those events.

We have in general refrained from shifting the counting ellipses in small steps as this results in an averaging process which may blur local differences in seismicity and, further, even show an enhancement of seismicity at places where it could be lower than indicated by the SI. Therefore any refined evaluation should be based on detailed local observations of historic and instrumental seismicity, faulting, tectonic movement, etc..

The SIs are used to calculate for instance the return period R of selected intensities (MM) or MDRs (mean damage ratios) with the aid of the following formula (Tiedemann 1984). This gives the "point probability" or more specifically the return period of the selected intensity for a town but not for a larger region.

$$R_{MM;\,MDR} = \frac{A_{count}\ n_G\ OP}{f_G\ f_T\ f\ SI\ A_{eff}} \qquad (1)$$

Herein A_{count} is the area of the counting ellipse used when developing the SIM, n_G is the global annual number of reference magnitude earthquakes (M 7 - 7.9), i.e. 17.74, OP is the observational period used (90 years), f_G is a correction factor for seismic gaps and f_T one for seismic trends, whereas f takes care of the statistical uncertainty related to the observational sample and the confidence range. SI is the seismic index of the place studied according to the respective SIM. A_{eff} is the effective area of intensities. A short description of the method and the data required to calculate return periods of given intensities and some examples has been published by Tiedemann (1990), which is available in English, French, German, and Spanish.

With different formulae it is possible to calculate the probability of earthquakes of selected magnitudes or of certain acceleration levels likely to be generated by such earthquakes.

The correlative use of the SIMs, of the world map and of the catalogue assists in estimating the seismicity of places for which only an inadequate sample of instrumentally recorded earthquakes is available.

2.5 *Estimation of Seismicity*

It will be seen that the SIs of the very active regions reflect the differences in area of the counting ellipses. At such places the SI of the 125,000 km^2 map will in general be about five times higher than that of the 25,000 km^2 map, and that of the 50,000 km^2 map about twice as high. It must, however, be noted that the occurrence of great earthquakes the return period of which within the area of the counting ellipses is as a rule longer than the available observation period of 90 years can result in scatter of the SIs. A careful correlative evaluation of return periods as estimated with the aid of the different SIMs is therefore recommended. It should take into account the epicentres shown in the earthquake map and if available detailed epicentral maps of the region, as well as the historical catalogue. It is recommended to compare the SIs of adjoining and similar regions for clues as to whether the SI stated for a place is not biased or blurred for one or more of the factors mentioned, whether it suggests a seismic gap, etc.

In particular in regions of comparatively low seismicity and where precise location of smaller events or precise epicentral location started late, a suitable safety factor should be allowed for, which should be determined after consultation with experts and considering the exposure.

The region approximately 500 km west of Ulan Bataar is used to illustrate some uncertainties when assessing regions for which the sample is small. The two great earthquakes of 1905 result in a SI of 40, irrespective of the size of the counting ellipse. Considering the general seismicity of this region and the paucity of smaller earthquakes it can be assumed that these two great earthquakes belong to an "observation period" which is considerably longer than the 90 years for which instrumental records are available, and that this SI is therefore too high. The two great earthquakes, however, like others which have occurred in regions of moderate seismicity show, that the possibility of great earthquakes must be considered, in particular because of the high damage level they may cause over a very large area. Similar problems exist in other regions where the ellipses were placed on isolated earthquakes of a smaller magnitude.

2.6 *Seismic Gaps and Trends*

Seismic gaps in particular can be estimated when comparing SIs of the 25,000 km^2 and 50,000 km^2 maps with that shown in the 125,000 km^2 version because the smaller ellipses do not produce the "averaging effect" of the large one. If a seismic index is low for a place within a seismic belt which should have roughly comparable seismicity this suggests the presence of a seismic gap. In this respect it must be considered that the larger the area of the counting ellipse the more the actual magnitude of the gap may be understated.

It is, however, also possible that a chance accumulation of large earthquakes during that part of the last seismic phase (seismic trend) which is included in the observation period leads to a more than proportionate effect on the SI. This question too can only be resolved by a special investigation. The catalogue and the earthquake map may be of assistance in this respect, if such a study cannot be entrusted to an experienced institute.

3 CONCLUSIONS

The SIMs along with the world map and the catalogue can be used to evaluate the return periods of intensities, magnitudes, and accelerations. If vulnerability functions (Tiedemann, 1990, 1992) are introduced the probability of certain damage levels and of risk in general can be calculated. Moreover, a correlative evaluation of the three SIMs and the data in the catalogue helps in estimating seismic gaps. The material is particularly useful to indicate the general risk and whether special expert studies are warranted.

REFERENCES

Tiedemann, H. 1984. A model for the assessment of seismic risk. *Proc. 8th WCEE, Vol. I: 199-206.*

Tiedemann, H. 1990. *Newcastle: the writing on the wall, Swiss Reinsurance Co., Zurich*

Tiedemann, H. 1992. *Earthquakes and volcanic eruptions: a handbook on risk assessment, Swiss Reinsurance Co., Zurich.*