Evaluation of the seismic hazard parameters for selected regions of the world: the maximum regional magnitude

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Abstract
Parameters of seismic hazard are estimated by the application of the maximum likelihood method. The technique is based on a procedure which utilizes data of different quality, *e.g.*, the ones where the uncertainty in the assessment of the magnitudes is great and those where the magnitudes are computed with great precision. In other words, the data were extracted from both historical (incomplete) and recorded (complete) files. The historical part of the catalogue contains only the strongest events, whereas the complete part can be divided into several subcatalogues each one assumed to be complete above a specified threshold magnitude. Uncertainty in the determination of magnitudes has also been taken into account. The method allow us to estimate the seismic hazard parameters which are the maximum regional magnitude, M_{max}, the activity rate, $\hat{\lambda}$, of the seismic events and the well known b-value, the slope of the magnitude-frequency relationship. The parameter β, which is interrelated to b ($b = \beta \log e$), is also obtained. All these parameters are of physical significance. The mean Return Periods, RP, of earthquakes with a certain lower magnitude $M \geq m$ are also determined. The method is applied in some regions of the circum-Pacific belt, which includes various tectonic features, and where catastrophic earthquakes are known from the historical era. The seismic hazard level is also calculated as a function of the form $\theta(M_{max}, RP_{7.5})$ and a relative hazard scale (defined as an index K) is defined for each seismic region. According to this, the investigated regions are classified into five groups of very low, low, intermediate, high and very high seismic hazard levels. This classification is useful for both theoretical and practical reasons and provides a picture of quantitative seismicity.

Key words *maximum regional magnitude – activity rate – seismic hazard parameters – seismic hazard level – K-index – circum-Pacific belt*

1. Introduction

A large number of earthquake occurrence models are currently available for seismic hazard assessment. The objective in seismic hazard modeling is to obtain long term probabilities of the occurrences of seismic events (Anagnos and Kiremidjian, 1988) of specified size in given time interval.

The first and the third asymptotic distributions of extreme values of Gumbel (1958) have proved a useful tool in estimating seismic hazard. Studies concerning the evaluation of seismic hazard parameters in different parts of the world based on the extreme statistics were published by many authors (Yegulalp and Kuo, 1974; Makropoulos, 1978; Makropoulos and Burton, 1983; Tsapanos and Burton, 1991; Tsapanos, 1997) among others, who used data sets of the instrumental era (*i.e.* beginning of the present

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century). On the other hand, problems concerning the seismic hazard parameters obtained through this technique discussed by Knopoff and Kagan (1977). The Gumbel's asymptotic distributions have the advantage that they do not require analysis of the whole data set. These procedures require fixed time intervals (*e.g.*, 1 year), from which largest magnitudes are selected. As we know, the requirement of short time intervals (like 1 year) is satisfied only for recent catalogues of seismicity. In order to use historical catalogues, the magnitudes must be selected from longer time intervals, and the classical Gumbel procedure does not provide tools for resolving this deficiency.

In order to overcome this inconsistency, Kijko and Sellevoll (1989, 1992) have developed an approach which permits calculation of the maximum likelihood estimates of the parameters of extreme magnitude distributions in the case when the maximum magnitudes are taken from both incomplete (historical) and complete (recorded) earthquake files. The complete part of a file allows the possibility to divide the catalogue into different time intervals of different time lengths, each assumed complete above a specific threshold magnitude.

In the present study, the method for estimation of M_{max} and the related parameters β (or b-value) and λ introduced by Kijko and Sellevoll (1989, 1992) is applied. For this purpose the technique of the maximum likelihood estimation is applied in the circum-Pacific belt on a basis of a procedure which utilizes data from both incomplete and complete files. The computations of the method are based on assumptions of the Poisson occurrence of main earthquakes in time with the mean activity rate $\hat{\lambda}$ and the doubly truncated Gutenberg-Richter distribution of earthquake magnitude. The mean return periods of earthquakes with a certain lower magnitude $M \geq m$ are also determined.

2. Data used

A global and homogeneous (in sense of magnitudes) catalogue of earthquakes is used in the present study. This catalogue was constructed by Tsapanos *et al.* (1990) spanning the time period 1897-1985. This initial catalogue is not complete for the whole time span. Thus the catalogue is statistically tested by Papazachos *et al.* (1990) and was divided into four sets of complete data. Their subperiods and the corresponding magnitude threshold are given here: (1897-1929 with $M_s \geq 7.0$; 1930-1952 with $M_s \geq 6.5$; 1953-1985 with $M_s \geq 6.0$, and 1966-1985 with $M_s \geq 5.5$). This catalogue was then improved by considering the magnitudes given by Pacheco and Sykes (1992). The method used to assess the completeness of the data of this catalogue has been described elsewhere (see for details in Tsapanos, 1990; Tsapanos and Papazachos, 1998). In brief the completeness was assessed on the basis of the cumulative frequency distribution of the magnitudes, and of the cumulative frequency distribution of the number of earthquakes with magnitudes larger than a certain value. In order to extend this catalogue up to 1996 the magnitudes listed in the bulletins of the NEIC have been used. We based the construction of this catalogue on the fact that «the older the earthquake is the less accurate the information we have». Thus the final catalogue used encompasses the time span between 1900-1996. This is the complete or instrumental part of the catalogue. Events which occurred in a «time period ≤ 1899» are considered as historical earthquakes. We want to note here that this study is restricted to shallow ($h \leq 60$ km) earthquakes. The time subperiods for which this catalogue is complete and the corresponding lower threshold magnitude are: 1900-1929 with $M_s \geq 7.0$; 1930-1952 with $M_s \geq 6.5$; 1953-1965 with $M_s \geq 6.0$, and 1966-1996 with $M_s \geq 5.5$. It is assumed that the standard deviation, which describes uncertainty of magnitude determination, is the same for the earthquakes which belong to the each one of the above subcatalogues but differs between these files (subcatalogues), followed the criterion we put «the older-the less accurate-the highest standard deviation». Hereafter we shall call them subcatalogue 1, subcatalogue 2, subcatalogue 3 and subcatalogue 4, respectively. In addition to these subcatalogues, historical files (earthquakes occurred in years earlier than 1900) are used where they are available, in order to compute the M_{max} from both periods, historical and instrumental one. Table I lists the examined

Table I. The available historical data for some of the examined regions.

Regions	Period	Number of events	Source
Chile	570-1899	30	1
Mexico	1806-1899	25	2
Alaska-Aleutians Islands	1788-1899	7	3
Kamchatka-Kuril Islands	1737-1899	8	4
Japan	1605-1899	30	4
Philippines	1897-1899	8	5 and 6
Caribbean	1690-1899	8	7
Peru	only one event in 1746 is taken into account		4

1 = Lomnitz (1970); 2 = Singh *et al.* (1981); 3 = Sykes *et al.* (1980); 4 = Nishenko (1991); 5 = Abe (1994); 6 = Abe and Noguchi (1983); 7 = McCann *et al.* (1979).

regions, the available historical period, the number of data in each one and the source from which we obtained the data. Whenever historical files are not found the results are obtained from the instrumental period only.

3. Method for assessing the maximum regional magnitude M_{max} and other seismic hazard parameters

According to Reiter (1990), there are three definitions of the maximum magnitude in common use in contemporary seismic hazard analysis: a) the maximum regional earthquake, which is the maximum possible earthquake that could occur in a given time interval and tectonic regime and defines an upper boundary to earthquake size determined by earthquake processes. This is primarily used in probabilistic analyses; b) the maximum credible magnitudes which are more commonly estimated in deterministic analyses and define that earthquake which is based on a reasonable assessment of maximum earthquake potential in light of current tectonics, and c) the maximum historic earthquake, which is the maximum earthquake associated with a seismotectonic source of which there is historical or instrumental evidence. The first estimation is the subject of the present work.

The evaluation of the maximum regional magnitude $\hat{M}_{max}$ is based on the condition that the largest *observed* magnitude M_{max}^{obs} is equal to the maximum *expected* magnitude $E(M_{max}/T)$ in the span of the catalogue, and this condition provides a quite satisfactory estimate of $\hat{M}_{max}$ (Kijko, 1988). If this equation is applied to the Gutenberg-Richter magnitude distribution, the following estimator of maximum regional magnitude M_{max} is obtained (Kijko and Graham, 1998)

$$\hat{M}_{max} = M_{max}^{obs} + \frac{E_1(TZ_2) - E_1(TZ_1)}{\beta\exp(-TZ_2)} + M_{min}\exp(-\lambda T). \tag{3.1}$$

The quantities in eq. (3.1) are computed as: $Z_1 = \lambda A_1/(A_1 - A_2)$; $Z_2 = \lambda A_2/(A_1 - A_2)$; $A_1 = \exp(-\beta M_{min})$; $A_2 = \exp(-\beta M_{max}^{obs})$ and $E_1(.)$ denotes an exponential integral function (Abramowitz and Stegum, 1970)

$$E_1(Z) = \int_Z^\infty \exp(-\zeta)/\zeta d\zeta. \tag{3.2}$$

It is not difficult to show that the approximate variance of the maximum regional magnitude $\hat{M}_{max}$ estimated according to eq. (3.1) is equal to that derived by Kijko and Graham (1998)

$$Var(\hat{M}_{max}) = \sigma_M^2 + \left[\frac{E_1(TZ_2) - E_1(TZ_1)}{\beta\exp(-TZ_2)} + M_{min}\exp(-\lambda T)\right]^2 \tag{3.3}$$

where we assumed that the observed (apparent) magnitude is distorted by an observational error, which is distributed normally with a know standard deviation σ_M, following in the applied procedure Tinti and Mulargia (1985).

The approximate standard deviation of $\hat{M}_{max}$ is derived through Kijko and Dessokey (1987) procedure

$$\sigma_{M_{max}} = T_c(\hat{\Theta})\sigma_x \tag{3.4}$$

where

$$T_c(\Theta) = ABS[\xi \exp(\xi) E_1(\xi)]^{-1} \tag{3.5}$$

with $\xi = TZ_2$ and σ_x is the standard deviation of M^{obs}_{max}. $T_c(\Theta)$ can be considered as a «transmission coefficient» that transmits the uncertainties in M^{obs}_{max} into uncertainties of $\hat{M}_{max}$.

The parameters $\hat{\beta}$ and $\hat{\lambda}$ for a given area are estimated by the maximum likelihood procedure described by Kijko and Sellevoll (1989, 1992). The method allows for the utilization of all available seismicity information, as it makes use of an earthquake catalogue containing both incomplete historical observations and more congruous and complete instrumental data (fig. 1). In addition, the procedure accepts division of the complete part into some subcomplete catalogues, each being complete starting from its own level of completeness.

The relative quantity of information provided by each part of the data used (historical and/or instrumental) can be calculated. Using the

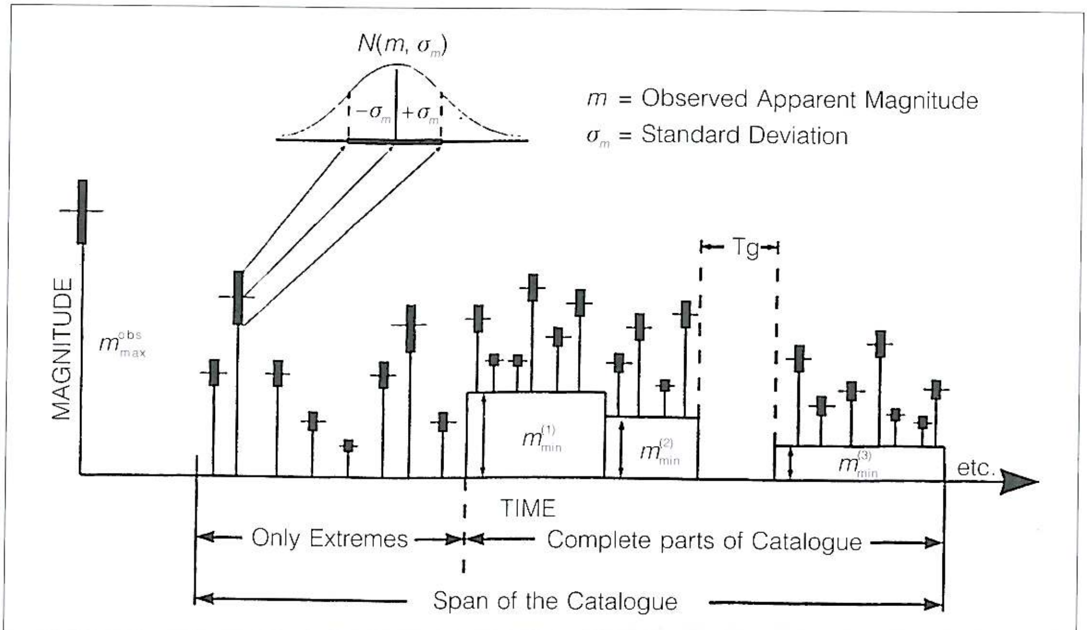

Fig. 1. An illustration of the data which can be used to obtain the seismic parameters by the procedure described (Kijko and Sellevoll, 1989, 1992). This approach permits combination of the largest earthquakes with complete data having variable threshold magnitudes ($M^{(1)}_{min}$, $M^{(2)}_{min}$, etc.). It accepts «gaps» (as Tg) when records are missing for various reasons. It also makes it possible to use the largest observed magnitude M^{obs}_{max}, either from complete or historical earthquakes which could occurred before our catalogue begins. Following Tinti and Mulargia (1985), it is assumed that the observed magnitude it is the true magnitude distorted by a random error, *i.e.* is from systematic errors and follows a Gaussian distribution with zero mean and standard deviation σ_M (after Kijko and Sellevoll, 1992).

Edwards (1972) definition, the expected information matrix provided by the experiment is of the form

$$I_{ij} = \frac{\partial^2 \ell nL(\Theta|X)}{\partial\Theta_i \, \partial\Theta_j}|_{\Theta=\hat{\Theta}}. \tag{3.6}$$

For our study, the rate of information of (Θ_i) parameter provided by the kth subcatalogue takes the form

$$\frac{\partial^2 \ell nL_k(\Theta|X)}{\partial\Theta_i^2}|_{\Theta=\hat{\Theta}} \Big/ \frac{\partial^2 \ell nL(\Theta|X)}{\partial\Theta_i^2}|_{\Theta=\hat{\Theta}}. \tag{3.7}$$

where in our case $i = h, 1, 2, 3, 4$ (h = historical) and $k = 1, ..., s$.

If M_{max} is the largest earthquake within a time interval of one year the RP (in years) is given (Kijko and Sellevol, 1989) by

$$\mathrm{RP}(M) = \frac{1}{[1 - \Pr(M_{max})]} \tag{3.8}$$

where $[1-\Pr(M_{max})]$, is the probability that an earthquake maximum magnitude will be exceeded.

4. Results

Most of the examined areas belong to the circum-Pacific belt. Caribbean loop and South Antilles are also taken into account because these are Pacific-type structures (Gutenberg and Richter, 1954), although they front on a non-Pacific area.

The regions under investigation according to Tsapanos' (1985) separation are: Chile (1); northwest coasts of South America (3); Middle America (4); Mexico (5); Alaska and Aleutian Islands (9); Caribbean loop (10); Kamchatka and Kuril Islands (11); Japan (12); Marianne Islands (13); Philippines Islands (15); Sunda arc (16); Papua-Solomon Islands-New Hebrides Islands (17); Fiji-Kermadec-Tonga-New Zealand (18), and South Antilles (26). The numbers in brackets refer to the seismic region numbers as they are presented in fig. 2a.

The values of the maximum regional magnitude $\hat{M}_{max}$ the parameter $\hat{b}$ of the Gutenberg-Richter relationship (as well as the $\hat{\beta}$ parameter) and the mean seismic activity rate $\hat{\lambda}$ estimated for the areas referred above are shown in table II. All mean activity rates $\hat{\lambda}$ are calculated for earthquakes with magnitude $M \geq 5.5$. For comparison purposes, the b-values obtained by least squares procedure (Tsapanos, 1990) and calculated from complete files only, are also illustrated in table II.

Tsapanos (1990) found that AREA 1 which consists of regions 1, 3, 4 and 5 have relatively lower $\hat{b}$-values (with a mean $\hat{b}(LS) = 0.90 \pm 0.09$) than AREA 2 which includes regions 9, 11, 12, 13, 15, 16, 17, 18, and has a mean $\hat{b}(LS)$ – value = = 1.01 ± 0.06. Caribbean loop (10) and South Antilles (26) were not included in that study. It is interesting to note that both the $\hat{b}$-values and the mean activity rates, $\hat{\lambda}$, estimated by maximum likelihood technique, show the same pattern: low values in AREA 1 (means $\hat{\lambda} = 6.43 \pm 2.54$ and $\hat{b} = 0.70 \pm 0.04$), and high ones in AREA 2 (with means $\hat{\lambda} = 17.30 \pm 8.09$ and $\hat{b} = 0.88 \pm 0.09$).

If the Gutenberg-Richter parameter b is considered to be closely related to the tectonic characteristics of a region (Allen *et al.*, 1965; Wang, 1988; Tsapanos, 1990) then the Caribbean loop and South Antilles (table II) should be included in AREA 1 and AREA 2, respectively.

On regional scale, the estimated $\hat{M}_{max}$ values do not differ strongly, with exceptions in regions 4, 13 and 26 (with $\hat{M}_{max} = 7.73$, 7.83 and 7.59, respectively) which are surrounded by regions of $\hat{M}_{max} > 8.0$. The largest M_{max} appears in Chile (region 1 with $\hat{M}_{max} = 8.75$), where according to Kanamori (1977) the highest earthquake of the present century occurred in 1960, with $M_S = 8.5$ (or $M_w = 9.5$). The maximum observed magnitude in this region, $\hat{M}_{max} = 8.7$ and is extracted from a historical file as this event occurred in 1730. On the west side of the Pacific $\hat{M}_{max} = 8.69$, is computed for Japan, where a shock with $M_{max}^{obs} = 8.6$ occurred in 1707. There are 14 regions analyzed and for eight (8) of them incomplete data are contributing to the assessment of the seismic hazard parameters. The maximum observed magnitude M_{max}^{obs} is considered from historical files not only for Chile

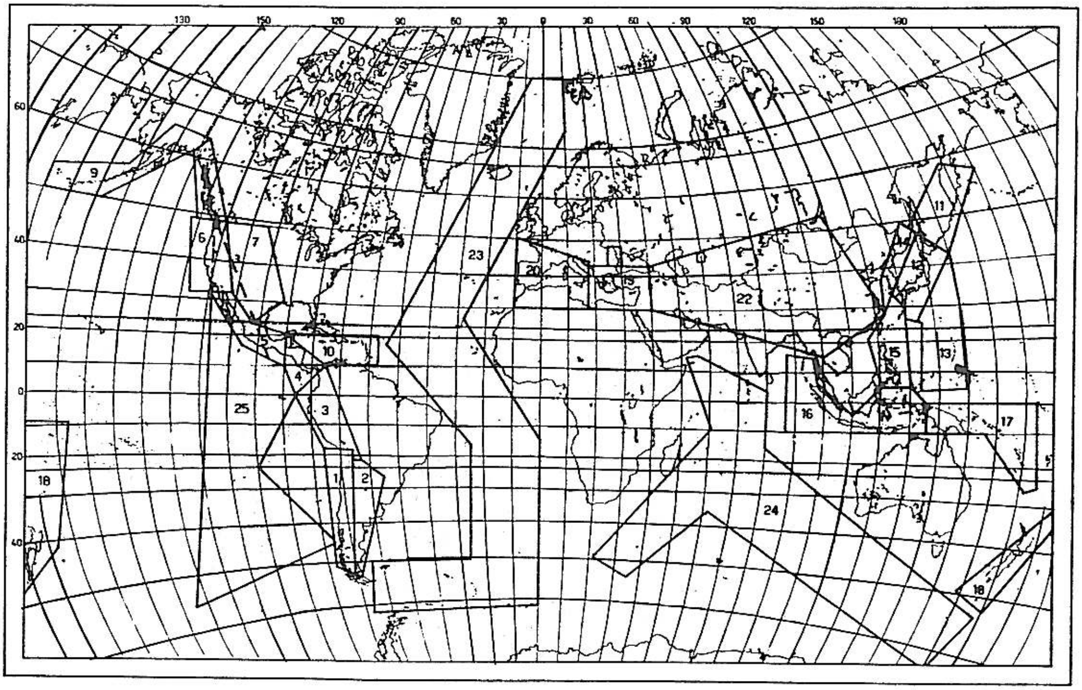

Fig. 2a. The examined seismic regions of the world: Chile (1); northwest coasts of South America (3); Middle America (4); Mexico (5); Alaska and Aleutian Islands (9); Caribbean loop (10); Kamchatka and Kuril Islands (11); Japan (12); Marianne Islands (13); Philippines Islands (15); Sunda arc (16); Papua-Solomon Islands-New Hebrides Islands (17); Fiji-Kermadec-Tonga- New Zealand Islands (18) and South Antilles (26). The numbers in brackets refer to the number of the examined seismic regions as they presented in the present figure (after Tsapanos, 1985, 1990).

and Japan, but as well as for Kamchatka and Kuril Islands (11) where an earthquake of M^{obs}_{max} = 8.4 occurred in 1792, and also for the Caribbean loop where in 1690 and 1751 shocks of M^{obs}_{max} = 8.0 were generated. The corresponding maximum regional magnitudes are $\hat{M}_{max}$ = 8.50 and $\hat{M}_{max}$ = 8.06. Although there are historical files, the M^{obs}_{max} values for the regions Mexico (5), Alaska (9) and Philippines (15) are taken from the complete files; 1985 for Mexico with M^{obs}_{max} = 8.1, 1964 for Alaska and Aleutian Islands with M^{obs}_{max} = 8.4 and for Philippines in 1924 with M^{obs}_{max} = 8.1. The estimated maximum regional magnitudes are $\hat{M}_{max}$ = 8.13 for Mexico, $\hat{M}_{max}$ = 8.46 for Alaska and Aleutian Islands and $\hat{M}_{max}$ = 8.16 for the Philippines Islands. As we can see in table I only one historical event is taken into account for region 3 which occurred in 28 October 1746 with M_S = 8.4. In table II the estimated maximum regional $\hat{M}_{max}$ and the maximum observed M^{obs}_{max} magnitudes are tabulated. The mean seismic activity rate, λ, and the Return Periods, RP (which is a useful parameter in seismic hazard determination), of earthquakes with a magnitude equal or larger than a certain value M are also listed in table II.

A first inspection of table II shows that $\hat{M}_{max}$ and M^{obs}_{max} do not differ significantly. This is because in several analyzed cases the estimation of M_{max} is based on relatively long seismic catalogues, which is comparable with seismic cycle of the strongest earthquake.

Another interesting observation is that the mean activity rate, λ is lower in AREA 1 than in AREA 2. This means that in a given time interval

Table II. The results of the determination of: a) the maximum regional magnitude $\hat{M}_{max}$ with its standard deviation; b) the mean seismic activity rate $\hat{\lambda}$ with its standard deviation, the $\hat{b}$-value with its standard deviation; c) the least squares b-value based on complete catalogues only, and d) the mean Return Periods, RP, of earthquakes with magnitudes equal or greater to a certain value M. The maximum observed magnitude M_{max}^{obs}, and the parameter $\hat{\beta}$ are also given for each region.

Region	$\hat{M}_{max}$ ± SD	$\hat{\lambda}$ ± SD	$\hat{b}$ ± SD	b(LS)	Return Periods RP (years)					M_{max}^{obs}	$\hat{\beta}$ ± SD
					M = 6.0	M = 6.5	M = 7.0	M = 7.5	M = 8.0		
1	8.75 0.55	10.10 0.51	0.78 0.02	0.90	0.3	0.8	1.9	5.1	15.5	8.7	1.83 0.05
3	8.47 0.43	7.50 0.44	0.69 0.03	0.96	0.4	0.8	2.0	5.2	18.0	8.4	1.63 0.07
4	7.73 0.27	3.89 0.24	0.67 0.05	0.99	0.4	0.9	2.4	11.7	–	7.7	1.57 0.11
5	8.13 0.25	4.23 0.25	0.69 0.04	0.77	0.3	0.8	1.9	5.7	43.3	8.1	1.62 0.09
9	8.46 0.34	17.66 0.70	0.88 0.02	1.04	0.2	0.6	1.6	5.0	19.9	8.4	2.07 0.05
11	8.50 0.61	13.28 0.61	0.93 0.03	1.02	0.3	0.8	2.6	8.3	33.1	8.4	2.18 0.06
12	8.69 0.60	13.81 0.62	0.92 0.02	0.88	0.3	0.8	2.4	7.6	26.9	8.6	2.19 0.06
13	7.83 0.33	5.20 0.40	1.07 0.05	0.97	0.9	3.2	12.3	67.2	–	7.6	2.52 0.13
15	8.16 0.43	13.64 0.58	0.78 0.03	1.11	0.2	0.6	1.6	5.0	34.6	8.1	1.85 0.06
16	8.05 0.32	18.11 0.71	0.84 0.02	1.04	0.2	0.5	1.5	5.4	102.6	8.0	1.99 0.05
17	8.12 0.26	35.09 0.97	0.77 0.02	1.04	0.1	0.2	0.6	7.5	16.4	8.1	1.82 0.04
18	8.29 0.30	21.63 0.79	0.91 0.02	1.02	0.2	0.5	1.5	5.2	26.8	8.2	2.15 0.05
10	8.06 0.55	1.71 0.20	0.68 0.06	–	1.3	3.1	7.8	23.8	324.4	8.0	1.60 0.15
26	7.59 0.35	4.10 0.34	0.83 0.05	–	0.8	2.3	8.0	90.2	–	7.5	1.95 0.13

the number of earthquakes expected to occur in the AREA 1 is lower than the expected number of earthquakes in the same time interval in AREA 2. Such an observation is in good agreement with the strong coupling between the lithospheric plates suggested by Ruff and Kanamori (1980) for the East Pacific (AREA 1) which can be explained by the existence of few heterogeneities (Tajima and Kanamori, 1985).

Regions around the circum-Pacific zone are characterized of high seismicity. As we can see in table II the return periods of earthquakes with M = 7.5 make sense, because this magnitude is considered to be a catastrophic one and the values of the return periods are reliable for further processing. In order to classify the examined regions in groups, based on their difference in the hazard level, we follow the technique used by Papadopoulos and Kijko (1991). In accordance with this technique we equally took into account their $\hat{M}_{max}$ and $RP_{7.5}$. We considered that the seismic hazard is a function of the form $\theta(M_{max}, RP_{7.5})$, increasing with M_{max} and decreasing with $RP_{7.5}$. In this way we constructed the following groups, $M_{max} \leq 8.0$, $8.1 \leq M_{max} < 8.5$, $M_{max} \geq 8.5$ and we defined $\theta(M_{max})$ equal to 2, 4 and 6, respectively. Similarly, we defined $\theta(RP_{7.5})$ equal to 2, 4 and 6 for the corresponding $RP_{7.5} \geq$ ≥ 20.0, $6.1 \leq RP_{7.5} < 20.0$ and $RP_{7.5} \leq 6.0$. The arithmetic mean $K = \frac{1}{2}[\theta(M_{max}) + (RP_{7.5})]$ signifies the adopted relative seismic hazard level of a specific region. The values that index K took are 2, 3, 4, 5 and 6 defining in this way five groups of relative seismic hazard which are very low, low, intermediate, high and very high, respectively.

It is well known that the data of the incomplete and the four complete subcatalogues contributed much or less in the determination of the hazard parameters. An application of relationship (3.7) to our data shows the percentage contribution of each subcatalogue in the total information of $\hat{\beta}$ and $\hat{\lambda}$. In table III we illustrate the percentage of information which contributed to the parameters $\hat{\beta}$ and $\hat{\lambda}$.

Some interesting conclusions are derived from table III. First, we can see that historical data do

Table III. Relative amounts of information (in percent) provided by different catalogues.

Region	Historical		Subcat1		Subcat2		Subcat3		Subcat4	
	$\hat{b}$	$\hat{\lambda}$	$\hat{b}$	$\hat{\lambda}$	$\hat{b}$	$\hat{\lambda}$	$\hat{b}$	$\hat{\lambda}$	$\hat{b}$	$\hat{\lambda}$
1	29.8	4.7	22.1	11.9	21.0	22.3	16.6	32.6	9.7	28.4
3	–	–	33.4	12.2	30.3	22.6	21.8	32.0	14.5	33.1
4	–	–	34.2	16.1	30.2	27.2	23.1	37.6	12.5	19.1
5	14.1	6.3	32.9	19.1	26.2	27.5	17.6	31.7	9.2	15.4
9	14.1	0.8	23.8	6.5	25.6	18.1	26.0	49.0	10.5	25.7
11	19.0	1.3	22.1	8.0	24.6	16.2	23.4	44.1	10.9	30.4
12	23.1	3.9	21.2	7.8	22.8	15.9	22.1	42.8	10.8	29.6
13	–	–	22.2	7.1	31.0	16.6	25.2	24.6	21.6	51.7
15	1.1	1.0	33.7	11.5	20.2	16.7	25.5	31.5	19.5	39.3
16	–	–	28.4	8.4	31.3	19.6	22.8	29.8	17.5	42.2
17	–	–	30.5	9.2	30.7	19.6	22.7	32.2	16.1	39.0
18	–	–	25.8	5.0	30.2	14.5	25.9	36.9	18.1	43.6
10	13.9	7.0	26.2	13.3	28.6	23.9	17.2	25.7	14.1	30.1
26	–	–	22.6	7.0	31.0	17.1	27.0	34.7	19.4	41.2

not contribute significantly in the estimation of parameter $\hat{\lambda}$, although two exceptions existed, 29.8% in Chile and 23.1% in Japan. The contribution is less for the parameter $\hat{b}$ estimation. The contribution of the four subcatalogues in the estimation of the $\hat{b}$ parameter show a descending order. Thus, the contribution of the intervals of percentages in subcatalogue 1 is 21-34 (%), 20-32 (%) in subcatalogue 2, 16-27 (%) in subcatalogue 3 and 9-22 (%) in subcatalogue 4. Both minimum and maximum values of these intervals decreased from subcatalogue 4.

On the other hand, the contribution of the four subcatalogues in the estimation of the $\hat{\lambda}$ parameter indicated an ascending order. So subcatalogue 1 contributes with 6-18 (%), while subcatalogue 2 is involved with 15-28 (%), subcatalogue 3 with 24-49 (%) and finally the percentage interval of subcatalogue 4 is 15-52 (%). Obviously both minimum and maximum values indicate an increase from subcatalogue 1 to subcatalogue 4, with an exception to the minimum value of subcatalogue 4.

5. Discussion and conclusions

The seismic hazard parameters for the regions of the circum-Pacific belt are estimated here by the application of the maximum likelihood method. The three computed hazard parameters are the mean seismic activity rate, $\hat{\lambda}$, and the parameter $\hat{b}$, while emphasis is given to

Table IV. Comparison between the values of $\hat{M}_{max}$ and the M_w. The maximum moment magnitude and the sources from where these data are extracted, are given in parentheses.

Regions	$\hat{M}_{max}$	M_w
1	8.75	9.5 (1)
3	8.47	8.8 (1)
4	7.73	8.1 (2)
5	8.13	8.1 (1)
9	8.46	9.2 (1)
11	8.50	9.0 (1)
12	8.69	8.4 (1)
13	7.83	8.0 (3)
15	8.16	8.1 (1)
16	8.05	8.3 (4)
17	8.12	8.1 (4)
18	8.29	8.3 (2)
10	8.06	8.0 (3)
26	7.59	7.6 (3)

References: (1) Kanamori (1977); (2) Kanamori (1982); (3) Heaton *et al.* (1986); (4) Abe and Kanamori (1980).

the third parameter which is the maximum regional magnitude $\hat{M}_{max}$. In order to calculate these parameters we adopted the procedures proposed by Kijko (1988), Kijko and Sellevoll (1989, 1992), and Kijko and Graham (1998).

The maximum regional magnitude is characteristic for each region. According to our knowledge this quantity has never been computed before on a global scale, so there is a difficulty in comparisons. A comparable quantity can be considered the maximum moment magnitude. In table IV the maximum regional magnitude for the examined regions, and the maximum moment magnitude deduced from various sources (Kanamori, 1977, 1982; Abe and Kanamori, 1980; Heaton *et. al.*, 1986) are listed, for comparison reasons. There is no any clear evidence for a pattern between $\hat{M}_{max}$ and M_w. In general we can inspect that M_w is greater than $\hat{M}_{max}$, although admittedly a number of exceptions to this generalization are also observed.

A map (fig. 2b) based on the different seismic hazard level of the examined regions is given and it is an essential part of this work. We computed this seismic hazard level taken into consideration that the seismic hazard increases with $\hat{M}_{max}$ and decreases with RP as a function of the form $\theta(M_{max}, RP_{7.5})$. A relative hazard scale is defined and the index K is calculated for each region. The values that the index K took are 2, 3, 4, 5 and 6. According to this, we classified the regions into five groups of very low, low, intermediate, high and very high seismic hazard levels. In fig. 2b we can see that Chile is a region

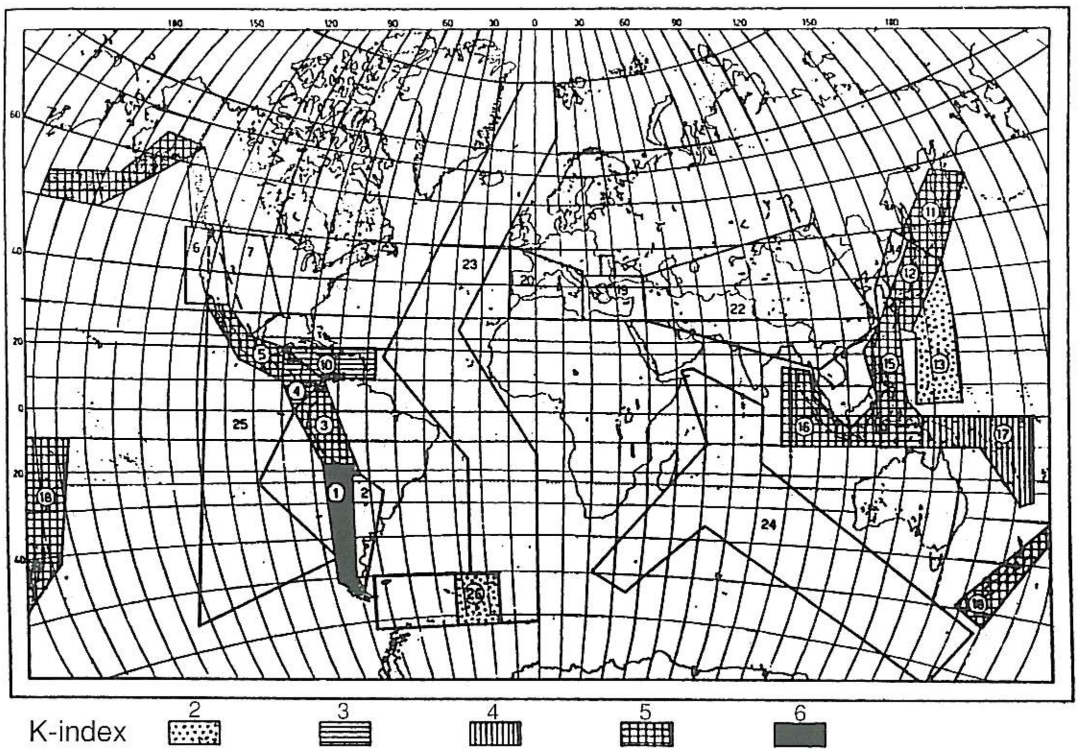

Fig. 2b. The examined regions of the circum-Pacific belt, with their relative hazard level as it is illustrated through index K. Regions of: 1) very low seismic hazard ($K = 2$) are presented by dots; 2) low seismic hazard ($K = 3$) are shown with horizontal lines; 3) intermediate seismic hazard ($K = 4$) are illustrated with vertical lines; 4) cross hatching present high seismic hazard ($K = 5$), and 5) very high seismic hazard ($K = 6$) are demonstrated by black color.

of very high seismic hazard. Very low seismic hazard appeared in South Antilles and in Marianne Islands, while low seismic hazard dominates in Middle America as well as in Caribbean loop. Intermediate values of seismic hazard appeared in the region of Papua-Solomon Islands and New Hebrides Islands. All the other regions were dominated by high seismic hazard levels. The distribution of hazard level from region to region is informative and useful not only from a theoretical but also from a practical point of view. The relative hazard classification is useful for engineers or other scientific purposes, allowing the designation of priority regions for earthquake resistant design.

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