AN EXTENSION OF THE CONCEPT OF SPECIFIC DESTRUCTION OF EARTHQUAKES ON THE BASIS OF GROSS NATIONAL PRODUCT OF AFFECTED COUNTRIES

Vladimir Ribarič

Natural destructive earthquake hazard is defined as the probability of occurrence of a strong seismic event--mostly above the value of 5.0 on the Richter scale--in a given area and within a given period of time. This probability is expressed chiefly on the basis of seismicity, meaning that a number of seismic events within certain ranges of intensity or magnitude have occurred in a given volume of the earth within an interval of time. Seismicity parameters, seismic activity, and shakeability of a territory have been defined in many ways, and numerous results have been obtained for various regions of the world. The purpose of these definitions has been to develop measures to represent recent neotectonic activity of the region, to define potential hazard and risk at regional, local, or sub-local levels, and to provide a measure to permit making comparisons between the earthquake hazards of various regions or subregions of the world.

However, none of these definitions is able to deal with the complex picture of human loss attributed to earthquakes of a certain magnitude, intensity, or energy with material damage of various kinds, or with temporarily or permanently disabled persons. No attempt has ever been made to estimate the total damage to the landscape in the case of great catastrophic earthquakes simply because of the fact that we have not developed measures for evaluating such types of damage.

An additional concept called "specific destruction" was introduced some years ago by M. Båth [1967] and is defined as a measure of the number of human victims due to an earthquake per unit of seismic energy. In this paper an extension of this definition is developed by representing sums of human losses over a time interval of three decades in various countries versus sums of released seismic energies of events which caused these losses, compared with the gross national product of the affected countries and normalized in relation to the per capita gross national product of the United States in 1978.

The results of calculations from this new definition are suprising: the effects of earthquakes are not necessarily associated with basic seismicity or gross national product of a country alone. The vulnerability of a town or a region is mainly interconnected to a specific category of earthquakes which will be briefly described. A large destructive earthquake resulting in a considerable toll of human lives is not necessarily an event with a very important specific destruction, especially when introducing the economic productive capacity of the country.

There seem to exist some neurologic points in the world which contribute mainly to our new definition: densely settled regions or towns with high probability of the existence of seismic foci of considerable energy content at very shallow focal depths in a country with poor housing construction and low gross national product. Certainly, inadequate safety of buildings is correlated with low gross national product--at least to an important extent. On the other side, the natural hazard is a function of seismicity or seismic risk, if we try to extrapolate the "seismic climate" into the future.

Some Important Cases

According to data obtained from the Smithsonian Institution in the United States, natural catastrophes in the period from 1947 to 1970 have caused a death toll of 1,192,000 human lives, a number, which is comparable to casualties in a large-scale war. From this number about 190,000 human lives have been lost due to earthquakes, or on an average about 7,900 per year. Some important seismic accidents in the past decade have substantially changed these statistical figures. From May 1976 to June 1978 about 665,000 people lost their lives or about 332, 000 per year: this was due to the catastrophic earthquake in northeastern China on July 27, 1976 (655,237 victims).

A catastrophic earthquake in Peru on May 31, 1970, killed 66,794 people. Other great earthquakes in the seismic history of the earth (China, three events in years 1290, 1556, 1920, caused a loss of 1,130,000 human lives) had as a consequence a death toll which in some cases exceeds the number of victims in some past wars.

Most of these losses could be attributed to strong seismic events, but there is no direct correspondence between them. Some relatively weak events with magnitudes about 5.5 have in the past claimed hundreds of human victims, whereas some large seismic events with magnitudes over 8.0 were not associated with any death toll, for instance, if they originated in vast oceanic areas and caused no seismic sea-waves. The problem consists of how to define the susceptibility of a country to earthquakes, if we do not consider material damage and some other nonmaterial factors involved.

Basic Considerations

The concept of specific destruction does not include any economic factor, and it seems to be reasonable to provide for it in some practical way. But first, we have to define some basic facts and to explain the definition of specific destruction.

Examining the relations between I_0, the macroseismic intensity expressed in an appropriate scale, and M, the Richter magnitude (M_S, m_b or M_L), we can easily find that for most regions of the world the following expression is valid:

$$(1) \qquad M - 0.66 \cdot I_0 = 0$$

for h = 5-10 km.

This means that in regions with very poor quality of construction we could expect structural damage to begin at $I_0 = 7^o$ MSK, which further means M = 4.6 or slightly more, naturally under the condition that the hypocentral depth h is in the range from 5-10 km. The log(N) = f(M) relation which is known for many regions of the world, shows the number of earthquakes of certain magnitude intervals in terms of the distribution of their values. For Greece, for example, the relation according to Karnik [1968-1971] shows that for 50 events with magnitude 6.0 we have to expect as many as 400 seismic events of magnitude 5. This means that there is a rather high probability that earthquakes may happen which originate at shallow depths in the range of 5-10 km and have an intensity approaching 8^o MSK, and which according to the local circumstances could have a potential to destroy buildings and to kill people.

Therefore, on the basis of the frequent recurrence rate of smaller seismic events the conclusion can be drawn that the potential hazard in this region is to be expected to be equally or even more dangerous with respect to events with M = 5.0 than M = 6.0 or more. This apparent conclusion has in fact also some physical and not only purely statistical foundation.

Defining the earthquake volume V as the size of volume which is in a state of stress and in which a simultaneous release occurs, by magnitude dependent relation:

$$(2) \qquad \log V = 9.58 + 1.47 \cdot M$$

where V has to be expressed in cubic centimeters, we find that for

magnitude = 5.0 the radius of the

equivalent sphere has to be 2.7 km,

for M = 5.5, r = 4.8 km and

for M = 6.0, r = 8.4 km.

It means that for spherical shapes of foci and M = 6.0 the focal depths should exceed 8.4 km.

Of course, we could be confronted with cases where we might observe a dipole source with an ellipsoidal form of the source zone. There the minor axis of the ellipsoid could be very small, which would mean a very shallow focus and extremely pronounced seismic effects along the major axis of the ellipsoidal body, if this axis were parallel to the earth's surface.

The relation:

$$\frac{M_{max}}{h_{min}} \quad (3)$$

is in this respect very important but physically limited and yields the

Table 1

Some Results of Calculations of f
(Typical values)

Earthquake	Value of f
Agadir, Morocco (1960)	8.6
Italy (1857)	7.5
Avezzano, Italy (1915)	7.2
Skopje, Yugoslavia (1963)	7.2
Lar, Iran (1960)	7.0
Messina, Italy (1908)	6.9
Quazvin, Iran (1970)	6.8
Ambato, Ecuador (1949)	6.8
Ariano, Italy (1930)	6.6
Quetta, Pakistan (1935)	6.5

after (1)

highest specific destructions, if the earthquake originates in a densely settled area with non-resistant buildings.

The specific destruction f is by definition represented by the following equation:

$$f = \log\frac{c \cdot (N_k + 1)}{E} \quad (4)$$

The notation means: f = specific destruction,
N_k = number of human victims,
E = seismic wave energy,
M = Richter scale magnitude,
c = a constant.

Combining this with the E(M) relationship

(5) $$\log E = 12.24 + 1.44\ M$$

Table 2
Average Specific Destruction f_{av} in Seismically Active Regions of the World

Region	Number of Events Used	Average Specific Destruction f_{av}*
Mediterranean	11	6.3
Iran-Pakistan-Afghanistan	6	6.0
Central Asia	6	4.8
South America	7	4.7
Japan-Taiwan	11	4.6
India	3	4.3
New Zealand	2	3.3
North America	6	2.8

(after M. Båth)

* The standard deviation on the average is 1.0

and the condition that $f = 0$ for $N_k = 0$ and $M = 8.9$, which ensures that $f \geq 0$, we obtain the equation:

(6) $$f = \log (N_k + 1) - 1.44\ M + 12.82$$

Specific destruction f depends on many factors. Type and quality of building construction, subsoil conditions, slant distances to the focal zones, density of population, time of the day when the earthquake occurs, radiation properties of seismic waves, secondary seismic effects (sea waves - tsunamis, landslides or rockslides, inundations from dams, fires, etc.) are implicitly included in this factor. The factor of specific destruction is apt to give a good idea of which earthquakes rank as the most destructive in relation to their energy release. However, it does not account for the various categories of damage in the economic sense.

It is interesting to note that f for the above mentioned reasons is not highest on some very spectacular occasions. The Quetta, Pakistan, earthquake on May 30, 1935, with a death toll of about 30,000 human lives and M = 7.5 yields a specific destruction of only 6.49. The Peru earthquake in 1970 with N_k = 66,794 and M = 7.7 gives an f = 6.56 and the disastrous Tangshan events in China on July 27, 1976, characterized by N_k = 655,237 and M = 8.2 result "only" in an f = 6.83. On the other hand the Agadir earthquake in Morocco on February 29, 1960, yields for values of N_k = 15,000 and M = 5.8 the specific destruction f of 8.64.

An attempt to define an average specific destruction f_{av} has been made by M. Båth [1967]. Calculations of the average specific destruction f_{av} for the seismically most active regions of the world have been presented by the author. They are shown in Table 2.

Some comments are necessary on the contents of Table 2. On the basis of small sample numbers it is hardly possible to draw any conclusions about the "seismic weather" or "seismic climate" of regions. Complete data for certain regions and defined time intervals are required. However, in spite of the sometimes problematic numbers on human losses and differences in magnitudes obtained by various methods and techniques, a cumulative presentation of data for some countries and time periods seems to be justified.

Mean Cumulative Specific Destruction f_c for Selected Countries

The mean cumulative specific destruction--as it is proposed here--is defined as the sum of individual specific destructions in a given country during a time interval, expressed in decades of years. It includes all seismic events of certain magnitude classes which caused human losses in a certain country. It is defined by:

$$f_c = \frac{\sum_1^n f_i}{n} \qquad (7)$$

Where:

$\sum_1^n f_i$ = sum of specific destructions for a country during a time interval,

n = number of seismic events with human losses.

A presentation of values of specific destructions for a selected number of countries in the Mediterranean seismic belt and partly in the Transasiatic seismic belt for three decades from 1950 to 1979, as compared with figures for the United States (see Appendix 1) yields the mean values of f_c shown in Table 3.

Morrocco has had in this time period only one seismic event of considerable f, Iran with a destructive earthquake on March 21, 1977, is in the second place (f = 8.1427).

Table 3

Mean Cumulative Specific Destruction f_c, Sums of f_i and Number of Events n for Selected Countries for the Period 1950 - 1979

Country	f_c	$\sum_{i=1}^{n} f_i$	n
Greece	4.7216	42.4944	9
India	5.2168	15.6504	3
Iran	6.1026	146.4624	24
Italy	5.9934	59.9340	10
Morocco	8.6441	8.6441	1
Pakistan	5.6601	16.9803	3
Turkey	5.6568	135.7632	24
United States of America	3.9783	35.8047	9
Yugoslavia	5.4163	21.6652	4

Obviously the sums of f_i indicate a seismicity level connected with seismic vulnerability of a country. Iran and Turkey are in the first and second place. Rare events, as for instance in Morocco, contribute to mean cumulative specific destruction f_c, but they are not significant for a general long-term picture of specific destruction in the region because the sum of f_i (i = 1...n) is small.

Involvement of Economic Factors

The susceptibility of a country to earthquake hazard--partly included in the vulnerability definition--has been presented in a way by the mean cumulative specific destruction value f_c for the past three decades. It is obvious that f_c would not have a constant, or even an approximately constant, value over a longer period of time. It depends, as already has been said, on too many partly interdependent or independent factors, as for instance the state-of-the-art level of paraseismic construction. No attempt has been made in this paper to include damage of various kinds caused by earthquakes in our considerations.

However, the vulnerability of a country to seismic hazard on the basis of specific destruction should somehow be defined also from the economist's point of view. A long-term economic index of cumulative specific destruction f_{ce} is proposed and is referred to in this context to 3 decades of years from 1950 - 1979. It is defined as

$$(8) \qquad (f_{ce})_j = f_c \cdot \frac{GNP_o}{GNP_s} \cdot \frac{1}{d_j} = \frac{\Sigma f_i}{n} \cdot \frac{GNP_o}{GNP_s} \cdot \frac{1}{d_j}$$

The notations mean:

f_{ce} = long-term economic index of cumulative specific destruction for a country and a certain time period d_j, expressed in decades of years.

d_j = number of decades of years under consideration. For instance for $j = 3$, $d_j = 30$ years,

GNP = gross national product per capita in USA (year 1978), i.e., 9,700 US $,

GNP_s = gross national product per capita in country "s" under consideration.

The results shown in Table 4 have been obtained.

In terms of economic capability and specific destruction, f, or cumulative specific destruction, f_c, it can be clearly seen that in the past three decades India, Pakistan, and Morocco have been relatively more endangered by earthquakes--if they occur. The United States with relatively small number of seisms of this type, large territory, small f_c and high gross national product per capita is in the best position.

Normalized values in relation to $(f_{ce})_3$ = 1.00 (for USA) are presented in Table 5.

Conclusion

Sums of specific destructions, Σf_i, provide a measure of earthquake effects over the past three decades in countries compared. Mean cumulative specific destructions, f_c, provide an index for comparison in accordance with the vulnerability of a country. This index is related to

Table 4

Values of $(f_{ce})_3$ (1950 - 1979)

Country	$(f_{ce})_3$
Greece	14.00
India	289.16
Iran	27.15
Italy	14.13
Morocco	125.14
Pakistan	241.86
Turkey	45.35
USA	3.98
Yugoslavia	21.98

the economic capacity of the country by introduction of the index f_{ce}, simply because rebuilding of the damaged area could in principle mainly depend on this factor.

Table 5

Values of $(f_{ce})_3$ in Relation to
USA (in ascending order).
Time Interval 1950-1979

No.	Country	$(f_{ce})_3$
1.	USA	1.00
2.	Greece	3.52
3.	Italy	3.55
4.	Yugoslavia	5.52
5.	Iran	6.82
6.	Turkey	11.39
7.	Morocco	31.44
8.	Pakistan	60.77
9.	India	72.65

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Appendix A

List of Catastrophic Earthquakes, 1950 - 1979, in Greece, India, Iran, Italy, Morocco, Pakistan, Turkey, USA and Yugoslavia

Year	Date	Locality	Number of victims N_k	M	f
1950	AUG 15	Assam, India	1,530	8.7	3.4769
1951	AUG 13	Changra, Turkey	54	6.8	4.7684
1952	JAN 3	Eastern Turkey	62	6.0	5.9793
1952	JUL 21	Tehachapi, Kern County, USA	15	7.7	2.9361
1952	AUG 22	Bakersfield, Calif., USA	2	5.8	4.9451
1952	OCT 22	Southern Turkey	18	5.0	6.8987
1953	FEB 12	Mazandaran, Prov. Trud, Eastern Turkey	970	6.5	6.4472
1953	MAR 18	Canakkale, Balikesir, Bandirma, NW Turkey	240	7.4	4.5460
1953	AUG 12	Ionian Sea Islands, Greece	460	7.4	4.8277
1954	APR 30	Central Greece	31	6.8	4.5331
1954	DEC 21	Eureka, Calif., USA	1	6.6	3.6170
1955	FEB 18	Quetta, Pakistan	10	6.5	4.5014
1956	JUL 9	Thera, Santorin, Greece	57	7.4	3.9274
1956	JUL 21	Anjar, Cutch, Pakistan	117	6.5	5.5319
1956	OCT 31	Bastak, Prov. Laristan, SE Iran	410	6.8	5.6418
1957	APR 26	Fethiye, Turkey	23	6.3	5.1282
1957	MAY 28	Seben-Bolu, Turkey	53	7.2	4.1844
1957	JUL 2	Abegarm, Iran-Caspian coast	2,500	7.2	5.8501
1957	DEC 13	Farsinaj, Hamadan, Kermanshah, Western Iran	1,130	7.1	5.6794
1958	JUL 10	South. Alaska, Brit. Columbia Yukon Territory	5	7.8	2.3661
1958	AUG 16	Western Kermanshah, Iran	191	6.7	5.4553

Year	Date	Locality	Number of victims N_k	M	f
1959	AUG 17	West Yellowstone, Hebgen Lake, Montana, USA	28	7.1	4.0584
1959	OCT 25	Hinis, Varto, Eastern Turkey	18	6.2	5.1708
1960	FEB 29	Agadir, Morocco	15,000	5.8	8.6441
1960	APR 24	Girash, Lar-Iran	450	5.9	6.9781
1961	JUN 11	Dehkuyeh, Iran	62	6.5	5.2593
1962	AUG 21	Avellino, Ariano Irpino, Italy	16	6.1	5.2664
1962	AUG 28	Southeast of Peloponnesos, Greece	5	7.0	3.5181
1962	SEP 1	Qazvin, Danesfahan, Northwestern Iran	12,230	7.1	6.6835
1963	JUL 26	Skopje, Yugoslavia	1,100	6.0	7.2218
1963	SEP 2	Kashmere Valley, Pakistan border region	79	5.4	6.9471
1964	MAR 27	Prince William Sound, Anchorage, Seward, Valdez, Alaska, USA	131	8.5	2.7005
1964	OCT 6	Bursa, Balikesir, Turkey	30	6.8	4.5194
1965	APR 5	Megalopolis, Greece	18	6.2	5.1708
1965	APR 29	Puget Sound, Wash, USA	6	6.5	4.3050
1966	AUG 19	Varto, Eastern Turkey	2,520	6.9	6.2856
1967	JUL 22	Adapazari, Northwestern Anatolia, Turkey	97	7.2	4.4432
1967	JUL 26	Tunceli, Erzincan Prov., Turkey	112	5.8	6.5210
1967	NOV 30	Debar region, Yugoslavia - Albania	20	6.0	5.5022
1967	DEC 10	Koyna Nagar, India	172	6.5	5.6980
1968	JAN 15	Gibellina, Partanna, Salaparuta, Montevago, Sicily, Italy	740	6.1	6.9058
1968	FEB 19	Ayios, Efstratios, Lemnos Isl., Aegean Sea, Greece	20	6.5	4.7822

Year	Date	Locality	Number of victims N_k	M	f
1968	APR 29	Maku, Rizaiyeh, Western Iran	38	5.3	6.7791
1968	AUG 31	Khorasa, Kakhk, Dasthe Bayar, Northeastern Iran	20,000	7.4	6.4651
1968	SEP 1	Ferdows, Iran	2,000	5.7	6.4732
1969	JAN 3	Khorasan Prov., Iran	50	5.6	6.4636
1969	MAR 28	Alasehir, Western Turkey	53	6.4	5.3364
1969	OCT 26	Banja Luka, Yugoslavia	22	6.4	4.9657
1970	MAR 23	Broach, India	26	5.4	6.4754
1970	MAR 28	Gediz, Prov. Kutahya, Turkey	1,086	7.3	5.3442
1970	JUL 30	Gediz, Khorasan Prov., Northeastern Iran	176	6.5	5.5639
1971	FEB 6	Tuscania, Prov. Latium, Italy	24	4.6	7.5939
1971	FEB 9	San Fernando, Calif., USA	65	6.8	4.8476
1971	MAY 12	Burdur, Turkey	72	6.3	5.6113
1971	MAY 22	Bingöl, Genc, Turkey	863	6.7	6.1085
1972	FEB 4	Ancona, Italy	1	4.9	6.0650
1972	APR 10	Fars, Zagros Mts., Prov. Ghir, Iran	5,374	7.1	6.3263
1972	JUN 14	Ancona, Italy	2	4.7	6.5291
1973	NOV 14	Iran	1	5.5	5.2010
1974	FEB 1	Izmir, Turkey	2	5.2	5.8091
1975	APR 7	Bandar Abbas, Iran	7	5.8	5.3711
1975	SEP 6	Lice, Turkey	2,700	6.8	6.4595
1975	DEC 30	Hana, Hazr, Turkey	3	4.6	6.6240
1975	DEC 31	Aitolia, Greece	1	5.5	5.2310
1976	APR 2	Agri, Turkey	4	4.6	6.8949
1976	APR 29	Ardahan, Turkey - USSR border region	4	5.5	5.5990
1976	MAY 6	Friuli, Italy	978	6.9	5.8748

Year	Date	Locality	Number of victims N_k	M	f
1976	JUL 9	Turkey	1	4.2	7.0730
1976	AUG 19	Denizli, Turkey	4	4.9	6.4629
1976	SEP 11	Friuli, Italy	5	5.5	5.6782
1976	SEP 15	Friuli, Italy	11	6.0	5.2592
1976	NOV 7	Vandik, Prov. Khorasan, Iran	17	6.2	5.1473
1976	NOV 24	Prov. Van, Turkey	3,626	7.3	5.8675
1977	MAR 21	Bandar Abbas (Khvorgu, Qaleh Qazi) Southern Iran	900	5.3	8.1427
1977	MAR 25	Palu, Eastern Turkey	30	5.1	6.9674
1977	APR 6	Ardal, Borujen, Central Iran	500	6.5	6.1598
1977	DEC 19	Babtangal, Gisk, Sarasiab, Prov. Kermanshah, Iran	584	5.4	7.8112
1978	APR 15	Sicily, Italy	5	5.9	5.1022
1978	JUN 20	Thessaloniki, Greece	49	6.4	5.3030
1978	SEP 16	Tabas, Iran	16,000	7.7	5.9361
1978	DEC 14	Izeh, Masjed-e-Soleymon, Iran	76	5.5	6.7865
1979	JAN 16	Boznabad, Eastern Iran	200	6.1	6.3392
1979	APR 15	Montenegro, Yugoslavia, Albania	156	7.0	4.9359
1979	SEP 19	Umbria, Italy	5	5.9	5.1022
1979	NOV 6	Northwestern Greece	1	5.5	5.2010
1979	NOV 14	Northwestern Iran	280	6.0	6.6287
1979	NOV 27	Northwestern Iran	17	6.1	5.2913

(compiled by the author)