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WORLD LARGE DESTRUCTIVE EARTHQUAKES SINCE 1900

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INTRODUCTION One of the best measures of future earthquake damage is the performance of similar structures and regions under similar seismic conditions in the past. However, most individual regions have not had enough experience in recent times for their own history to be a sufficient descriptor of building performance, casualty rates and other damage statistics. Thus, various regions' experiences must be collated and analyzed to determine damage patterns. Towards this end, a list of all large destructive earthquakes of the 20th Century was compiled.

DATA The list was compiled from all available references (totaling 85), notably Rikanenpyō[5], Båth[1], UNESCO[7], Rothé[6], BSSA[2], and Usami[8]. It should be noted that, although the Rikanenpyō was the best available source, it contains serious omissions (eg- Managua, 1972). To the best of the authors' knowledge, the present compilation is the most exhaustive in existence, for the period since 1900. This period was chosen because it was felt that previous experience (ie- before 1900) had little relevance to modern construction or existing buildings, and because a satisfactory list is already in existence (Milne[4]). Criterion for inclusion on the list were similar though less restrictive than Båth's, and consisted of (1) any earthquake causing more than about 20 fatalities (this lower limit was approximate, depending upon other factors), or (2) all earthquakes with $M_S \geq 7.5$ and causing any fatalities. In contrast to almost all other lists, many other categories than just fatalities were catalogued. A typical entry is seen in Fig. 1:

Figure 1

NUM	YR	MO	DY	GMT	LAT	LONG	DEP	MAG	IO	RVI	••REGION••		AC	LTIM	REFS(1)
KILLED		INJURED			HMLS (TH)		STC (TH)	BDST (TH)	BDMG (TH)	DOLLS (MIL)	POPUL (MIL)		REFS(2) & REMARKS		
•••• 1923 ••••															
56	23	9	1	259	N35	E140	0.	8.3	10	220	TOKYO	JAPAN	2	1159	(2,2X12)
143000.		104000.			0.		128.0	570.0	126.0	3000.0	11.76		(5X12,4,73) FIRE		

DEP refers to the depth of focus, not definitively determined for the particular earthquake in Fig. 1, the 1923 Tokyo earthquake. IO is the epicentral intensity (Modified Mercalli). AC is an area code (2 for Japan). HMLS refers to thousands of persons homeless. STC is structural collapses. BDST is buildings destroyed. BDMG is buildings damaged. DOLLS is total damage (published estimate) in US dollars at the time of the disaster. REFS(1) and REFS(2) are references for the damage data. The other headings are self-explanatory. Other information that might have been included are duration of shaking, and foreshock and aftershock events. Well-known problems in defining these phenomena, together with scarcity of data, precluded inclusion. Table 1 summarises the data in the list. Necessarily, all data are to be regarded as estimates and not exact numbers.

TABLE 1

Item	Earthquakes	Killed	Injured	BDST	DOLLS[a]
No. Data	246	226	115	49	55
Sum	-	1,840,700	1,587,900	13,693,000	$17.1x10^9

a-NB- Dollars are in various years and no price deflator is used in summing them.

Comparing Båth's list with the present author's, for the same period (1900-1964) and

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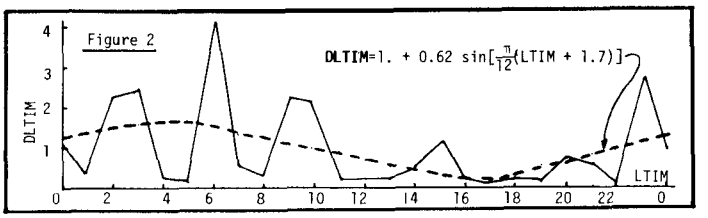
using Båth's criteria, we find that Båth had 53 earthquakes for total fatalities of *ca* 746,000 while the present list has 99 earthquakes for a total of *ca* 1,020,800.

ANALYSIS AND RESULTS A plot of the list's earthquakes on a world map (not shown), is quite different from the usual map of epicenters and strikingly reflects the interaction seismicity, population and building performance. Fig. 2 is a plot of LTIM (local time, eg, for Japan, GMT+8 hours, where GMT is Greenwich Mean Time) vs the sum of all fatalities (less than 10^5) caused by earthquakes occurring at local times nearest to the LTIM hours. It has been well known (*cf* Lomnitz[3]) that a correlation exists between earthquake casualties and local time, but this has never been quantified. From Fig. 2, the following relation was determined from all earthquakes with deaths less than 10^5:



$$\text{Dead} = \text{DLTIM}[\text{LN}(0.8,0.75)] \quad \text{where} \quad \text{DLTIM} = \bar{D}\{1. + 0.62\sin[\tfrac{\pi}{12}(\text{LTIM} + 1.7)]\}$$

and Dead is the total dead with [Dead/DLTIM] lognormally distributed about DLTIM (the mean number of dead, dependent on the LTIM of the earthquake) and LTIM is defined as above. Thus, if damage studies indicate (from building collapses, etc) that a mean of 1000 fatalities ($\bar{D}$) are to be expected from a given earthquake, then:

CASE	ACTUAL TIME OF OCCURRENCE	DLTIM	$D_{.05}$	$D_{.95}$
1	0418	1620	377	4451
2	1018	1000	233	2747
3	1618	380	89	1044

This appears reasonable due to human activity being synchronized with the sun, thus making for higher fatalities at night when people are asleep.

If the annual maximum individual earthquake fatalities are ranked in increasing order, their probability distributions may be expressed as a Weibull distribution:

$$\text{CDF}(D) = 1. - \exp[-(\frac{D}{4993.})^{0.364}] \quad \text{where} \quad D = \text{deaths and } \chi^2 = 5.94 < \chi^2_{.95,4} = 9.49$$

which enable estimates to be made of the frequency of world earthquake disasters (eg- 10,000 death return period = T_{10^4}= 3.62 years). Studies are continuing to determine correlations between number killed and building damage.

CONCLUSION AND SUMMARY A new compilation of large destructive earthquakes and their damage since 1900 has been reported. This list is more extensive than any previous list. Geographical distribution of damage is quite different than seismicity, representing interaction of seismicity, building performance and population. The influence of Local Time of an earthquake on fatalities has been quantified. The global distribution of large earthquake fatalities with respect to time has been represented with a good fit as a Weibull distribution, providing estimates of world earthquake disaster return periods.

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