

Real-Time Prediction of Earthquake Casualties

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Abstract

Quantitative estimates of the number of casualties are necessary immediately after an earthquake for organizing an appropriate response. Reliable earthquake parameters become available within about two hours of an earthquake occurrence, worldwide, and faster in countries with advanced seismograph networks. Losses are estimated, based on a dataset of population and condition of buildings in 1.6 million settlements worldwide. The intensity of shaking is calculated, assuming standard transmission of seismic energy in the area. Major earthquakes with insignificant consequences are identified as such in 93% of the cases, and 71% of the major disasters are recognized as such within two hours.

Keywords: Earthquake risk, earthquake loss estimates in real-time.

1 Introduction

Predicting how many people may be trapped beneath collapsed buildings must be attempted to help rescue agencies and disaster managers to implement a response appropriate to the extent of the disaster. If an earthquake has likely caused no serious disaster, in spite of its significant magnitude, local organizations can cope and international rescuers need not waste a mobilization effort. On the other hand, it is essential to know if a major disaster is likely to have happened, as soon as possible after an earthquake because the chance of rescue decreases rapidly with time.

For estimating the probable degree of destruction, accurate hypocenters and magnitudes are necessary. A difference in depth or coordinates of only 10 km can affect the numbers of casualties many fold. By ‘casualties’ we refer to the injured plus fatalities.

The quality of the built environment is crucial in earthquake losses, because collapsing buildings are the chief cause of fatalities and injuries. Dwellings’ resistance to shaking and their potential to injure varies enormously globally as a function of the degree of development of the affected society. The most primitive dwellings, bamboo huts or slum cabins, are so light that they cannot kill inhabitants and barely injure them, when they collapse. Well built wood-frame single story homes, as is customary in the US, together with buildings engineered, based on modern building codes, are also fairly safe, whereas shoddily built five to ten story apartment buildings are among the most dangerous.

Detailed surveys by engineers, of the type and quality of all buildings would be desirable, but are impossible in developing countries, because they would exceed resources, by far. Therefore, the approach taken here is to estimate the distribution of buildings into classes with specific fragility curves, and then to adjust these assumptions, based on calibration, using the losses sustained in past earthquakes. This means that losses can be estimated with more confidence in countries experiencing earthquakes frequently, than in those where no calibration events are available.

2 Method

The intensity of the ground motion is proportional to the magnitude of the earthquake and decreases as a function of distance from the source. The rate of decrease is not the same everywhere, but its variation influences the loss estimates by only about 10%. Therefore, it is reasonable to use an average attenuation curve, unless the specific values for the region in question are known.

Local amplification of the shaking, due to the top rock layers on which a building is resting, can be very significant. For important cities in developed countries, microzonation studies map the soil conditions. In that case, these effects can be taken into account in the loss estimates. However, for the vast majority of cities in zones of earthquake hazard, soil conditions are unknown. Thus, most of the loss estimates have to be carried out in ignorance of local amplification factors.

The most basic information about the population at risk is the number of inhabitants in each of about 1.6 million cities, worldwide. Without knowing the number of buildings in these settlements, one may calculate the percentage of injured and fatalities, based on the percentage of buildings collapsed and otherwise damaged. The loss to the built environment is also expressed in percent. In this case, it is the average percentage of the building value that will be required for restoration of the built environment to its pre-earthquake state. From this, and an estimate of the total value of the built environment, one can then derive the cost to rebuild.

For calculating the effect of the shaking on buildings, the latter are divided into five classes, each with an assumed fragility curve. The fragility curve specifies the probability that a building sustains a given damage state (e. g. collapse) as a function of the shaking intensity. Yet another set of equations connects the probability of a given damage level to the probability that an injury or fatality results. Summing the results over all the building classes gives then the most likely percentage of the population that will be injured and killed, with formal error limits.

Additional errors are introduced through inaccuracies in depth, coordinates and magnitude of earthquakes. In order to estimate the variability of the loss calculations due to earthquake parameter errors, we evaluate the losses for several hundred combinations of positions and magnitude within the error limits of the parameters. As a result, the loss estimates often range over an order of magnitude.

The hour of day is also taken into account. At night, most people are at home and at risk, whereas many of them are out of doors during daytime, especially during the early morning hours.

These calculations are performed by **QUAKELOSS**, a computer code and database that runs under the operating system of windows. This program is a development with roots in the earlier program and data base **EXTREMUM** (Larionov et al., 2000; Larionov, 1999a; Larionov, 1999b; Shakhramanjan et al., 2000; Shakhramanjan et al., 2001; Shojgu et al., 1992). The program is under continuous development. Refinements of calculations are being introduced and the database continues to be expanded.

3 Performance Test

The performance of the computer code **QUAKELOSS** was tested by comparing the number of fatalities reported, with that calculated (Wyss, 2004) for historic earthquakes. This test was based on a data set composed of events for which users expressed an interest. It included earthquakes that had caused losses and were part of the calibration data set, as well

as events that had not caused losses, but had attracted the interest of rescue agencies. The total number of events used was 544.

The number of fatalities had to be used as the key test-parameter because the observed values are published for many events. Only rarely are numbers of injured, or dollar losses, listed.

In this performance test, it became evident that the success rate was a function of the size of the disaster. Cases of insignificant losses were correctly identified with a 92% success rate. The success rate for intermediate sized disaster (200 to 1000 fatalities) was lowest, 58%. Disasters exceeding 1000 fatalities were correctly identified in 71% of the cases (Wyss, 2004).

4 Real-Time Predictions

Real-time predictions of losses were started in October 2002, in collaboration with the Swiss Seismological Service (SSS). At first, loss estimates were distributed to a few people only, but later the distribution was formalized. The chief recipient was the Humanitarian Aid and Swiss Humanitarian Aid Unit (SKH), which used the loss estimates, together with other information, for their decisions concerning offering aid in case of significant disasters. In addition, the members of WAPMERR's advisory board and other interested individuals were informed.

In the procedure worked out with the SSS, alerts are transmitted automatically from the SSS to WAPMERR, when an earthquake above a threshold magnitude occurs. This minimum magnitude varies as a function of position on the globe (Europe: lowest, Pacific Ocean: highest) and reflects the needs of the SKH. WAPMERR then scans all sources available on the internet for earthquake parameters. The first automatic solution becomes available typically within about 0.5 hours, but is not accurate enough to allow loss calculations. Thanks to its worldwide network of seismographs, the US Geological Survey (USGS) is able to announce reliable solutions within about two hours. These solutions have an epicenter error of typically 20 km, and furnish magnitudes derived from surface waves or moment magnitudes. These improvements over the inaccurate automatic solutions that are distributed earlier are essential, especially because early magnitudes are based on body waves, which are unreliable for large events. Once the USGS parameters are available, WAPMERR calculates losses and distributes these estimates by email within 10 minutes. When serious disasters are suspected, the possible errors and other sources of information are discussed by telephone between WAPMERR, SKH and SSS.

The 60 real-time loss estimates carried out to date are listed in Table 1, giving the minimum and maximum of the formal error calculations. In addition to the source parameters of the earthquakes in question, the last column gives the time the loss estimate was sent by email. A few of the messages were sent with many hours delay (emboldened in the table) because they were not initiated by WAPMERR, but were made in response to a delayed request for evaluation by an agency or an individual. The hours emboldened in Table 1 are not used to calculate the average response time between earthquake occurrence and email distribution, which is two hours.

The rules for judging success or failure of the estimates are based on the needs of the rescue agencies (Wyss, 2004). Successes in Figure 1 are those for which the reported number of deaths lies between the minimum and maximum estimate, or within 100 from these limits. Acceptable estimates are defined as within 200 fatalities, or within a factor of two from a minimum or maximum. In two cases, the number of fatalities is not known.

The correct plus acceptable results sum up to 93%. However, this result is dominated by cases with zero, or very few, fatalities. The five outstanding disasters during the study period were: (5) 21 May 2003, M6.7, Algeria; (19) 27 September 2003, M7.5, Southern Siberia; (33) 26 December 2003, M6.7, Iran; (43) 24 February 2004, M6.2, Morocco; (60) 28 May 2004, M6.2, Iran (numbers in parentheses refer to Table 1). For (19) the number of deaths is not accurately known, but the relief effort of the Russian federation was massive, thus the alarm issued in this case is scored, together with cases (5) and (43), as a success. These three successes are somewhat offset by the two Iranian cases, numbers (33) and (6), which are classified as failures.

Table 1: Loss Estimates by QUAKELOSS in Real Time

No	Date	H	Min	Lon. deg	Lat. deg	Z km	M	Deaths obsvd	Deaths est min	Deaths est max	Location	Delay hours
1	2002 10 31	10	2	14.9	41.8	10	5.7	29	13	42	Italy	
2	2002 11 02	1	26	96.2	3	20	7.5	30	16	55	Sumatra	
3	2002 11 20	21	32	74.52	35.4	20	6	19	7	12	Kashmir	
4	2003 01 22	2	6	104.1	18.5	20	7.3	29	42	130	Mexico	
5	2003 05 21	18	44	3.78	36.9	10	6.7	2217	1,690	3,660	Algeria	
6	2003 05 26	9	24	141.5	38.9	53	6.9	0	0	30	Japan	
7	2003 07 06	19	10	26.1	40.4	10	5.7	0	0	0	Turkey	
8	2003 07 10	17	6	54.2	28.3	10	5.7	1	6	19	Iran	
9	2003 07 21	15	16	101.2	26	14	6	16	95	260	China	
10	2003 07 25	22	13	141	38.4	15	6.1	0	29	100	Japan	
11	2003 07 26	23	18	92.31	22.9	10	5.6	2	10	28	Banglad.	
12	2003 08 14	5	14	20.74	39.2	10	6.1	0	70	230	Greece	
13	2003 08 21	12	12	167.2	45.1	20	7.4	0	0	0	N. Zeal.	
14	2003 09 01	23	16	75.21	38.6	10	5.8	0	0	1	China	
15	2003 09 21	18	16	95.72	19.9	10	6.7	?	80	200	Myanmar	
16	2003 09 22	4	45	-70.67	19.7	20	6.5	3	130	350	Dominic.	
17	2003 09 25	19	50	143.8	41.9	33	8	0	29	160	Hokkaido	
18	2003 09 25	21	8	143.5	41.8	33	7	0	0	6	Hokkaido	
19	2003 09 27	11	33	87.73	50.1	18	7.5	?	540	1,230	S. Siberia	3.0
20	2003 10 09	22	19	120	13.8	16	6.1	0	0	10	Mindoro	12.8
21	2003 11 05	0	58	-77.75	4.97	20	5.8	0	0	0	Colombia	6.3
22	2003 11 09	19	23	127.3	1.6	15	6.1	0	0	0	Halmahera	2.5
23	2003 11 12	8	26	137	33.6	391	6.4	0	0	0	Japan	0.8
24	2003 11 14	18	49	141	36.4	33	5.5	0	0	0	Honshu	0.6
25	2003 11 18	17	14	125.4	12	37	6.5	1	0	1	Philippines	0.7
26	2003 12 01	1	38	80.65	42.9	10	5.7	11	2	7	China	1.1
27	2003 12 03	14	11	144.6	42.5	23	5.7	0	0	0	Hokkaido	1.4
28	2003 12 10	4	38	121.4	23.1	23	6.6	0	130	330	Taiwan	1.0
29	2003 12 10	15	51	120.7	17.8	10	5.8	0	15	48	Luzon	2.0
30	2003 12 19	0	11	95.74	19.9	10	5.7	?	2	5	Myanmar	8.6
31	2003 12 22	19	15	-121.1	35.71	7	6.5	2	0	3	California	0.6
32	2003 12 25	7	11	-82.82	8.43	25	6.3	2	11	45	Panama	1.3

33	2003 12 26	1	57	58.27	29.1	20	6.3	26,271	410	1010	Iran	1.4
33a	2003 12 26	1	57	58.35	29.1	10	6.7	26,271	6090	11,810	Iran	9.1
34	2003 12 28	1	32	144.6	42.6	10	5.6	0	0	0	Hokkaido	0.9
35	2004 01 01	23	32	-101.17	17.57	14	6	0	0	10	Oaxaca	10.1
36	2004 01 09	22	35	149.36	-6	34	6.3	0	0	0	Papua	8.9
37	2004 01 14	16	58	52.3	27.7	10	5.4	0	0	100	Iran	1.0
38	2004 01 28	9	6	57.8	27.1	33	5.8	0	0	1000	Iran	1.2
39	2004 02 04	11	59	82.95	8.42	29	5.8	0	0	100	Panama	2.8
40	2004 02 05	21	5	135.52	-3.6	10	6.8	37	0	8	Indones.	9.4
41	2004 02 07	2	41	134.9	-3.8	10	7.3	0	0	10	Indones.	1.8
42	2004 02 22	6	46	100.4	-1.9	10	6.5	0	0	0	Sumatra	1.0
43	2004 02 24	2	27	4	35.2	10	6.2	628	0	2700	Morocco	0.7
44	2004 03 02	3	47	86.91	11.67	99	5.5	0	0	0	Nicarag.	2.2
45	2004 03 07	13	29	91.21	31.57	10	5.5	0	0	50	China	4.1
46	2004 03 17	3	21	-65.57	21.13	288	6.1	0	0	0	Bolivia	0.8
47	2004 03 17	5	21	23.54	34.65	40	5.7	0	0	0	Crete	1.5
48	2004 03 24	1	54	118.2	48.2	10	5.7	0	0	12	China	1.4
49	2004 03 25	19	31	40.9	39.9	10	5.5	10	0	12	Turkey	1.9
50	2004 03 26	15	20	144.09	41.91	39	5.5	0	0	0	Hokkaido	1.4
51	2004 03 27	18	47	89.25	34.03	10	5.8	0	0	0	Tibet	2.3
52	2004 04 05	21	24	71.04	36.47	196	6.6	3	0	0	Hindu Ku.	1.6
53	2004 04 11	18	8	144.82	42.91	40	6.1	0	0	0	Hokkaido	2.6
54	2004 04 23	1	50	122.82	-9.44	78	6.4	0	0	0	Savu Sea	1.6
55	2004 04 29	0	57	-85.95	10.7	21	6.1	0	0	1	Costa Ric.	3.1
56	2004 05 03	4	36	73.2	-37.6	25	6.6	0	170	450	Chile	1.5
57	2004 05 05	13	40	14.9	38.7	249	5.7	0	0	13	Sicily	0.6
59	2004 05 08	8	3	121.5	22	12	5.7	0	0	0	Taiwan	1.8
60	2004 05 28	12	38	51.57	36.27	22	6.2	35	250	680	Iran	1.8

Table 1: Minimum and maximum estimated numbers of deaths compared to reported numbers (from the USGS list of significant earthquakes). The parameters of the earthquakes are those available at the time of the real-time calculations, not the ultimately correct values. Last column gives the time difference between the earthquake occurrence and the posting of the loss estimate by email.

The number of casualties in the Bam earthquake (33) was at first underestimated because the available hypocenter was at a greater distance and greater depth from the city of Bam than the true energy release of this earthquake (Wyss et al., 2004). However, Bam was identified immediately as the crucial city. SKH was informed that it was important to find out what had happened in Bam, and that a major disaster could have happened there, although the calculation did not reflect this. Thus, this case was a success, in practice, but a failure according to our formal definitions.

The number of casualties in the second Iranian earthquake (60) was overestimated because the hypocentral depths broadcast and assumed (22 km) were shallower than the depth ultimately calculated (29 km). Also, in real-time, the possibility that the depth was as shallow as in the Bam event (4 km) had to be considered. Thus, the two Iranian cases are failures in the opposite sense. The first of these (Bam) was not a failure from the point of

view of rescue agencies, because WAPMERR recommended mobilization of the rescue team. However, in the second Iranian earthquake (number 60) WAPMERR also recommended mobilization, unnecessarily, as it turned out.

5 Discussion

Predicting the number of casualties in real-time after an earthquake is not easy. Nevertheless, one should attempt to make these estimates on a quantitative basis. Because some of the error sources cannot be excluded, sometimes the calculated real-time loss estimates are not much better than expert opinions of specialists familiar with the earthquake source region. However, the over all score, 93% acceptable estimates, is excellent. Because this applies mostly to small earthquakes, this chiefly benefits rescue agencies, which do not have to mobilize unnecessarily.

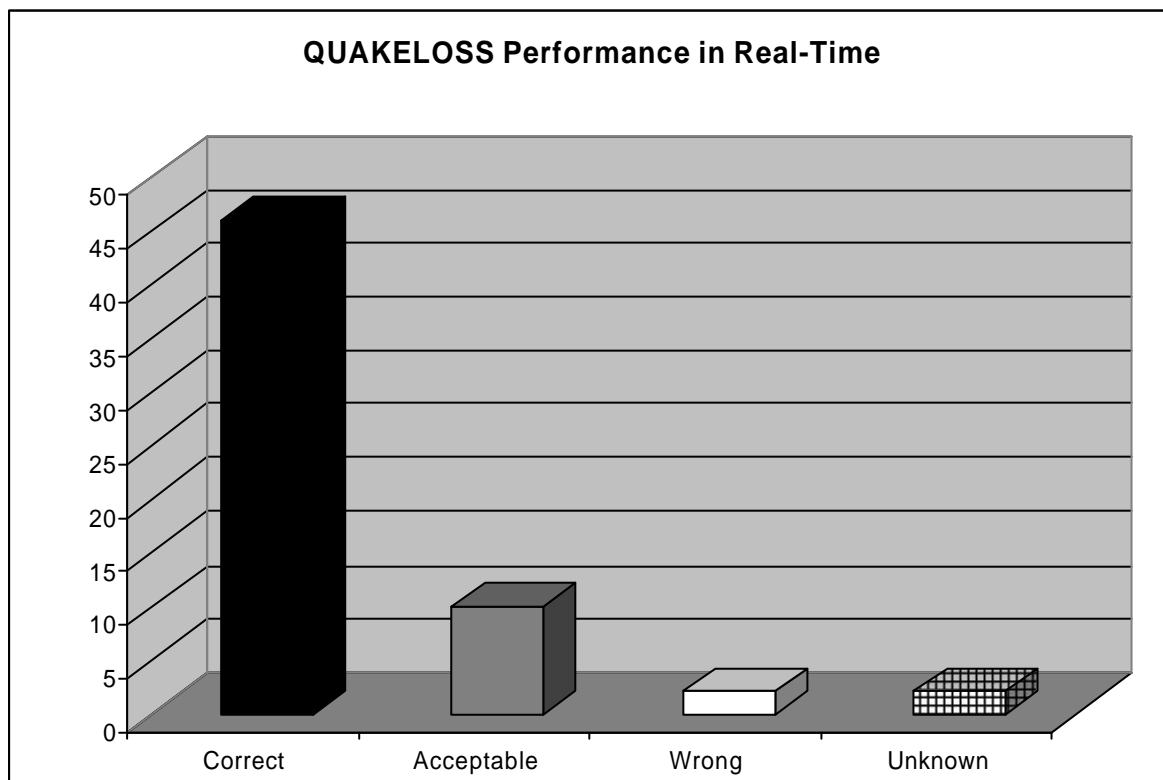


Figure1: Number of real-time loss estimates as a function of performance: correct, acceptable, wrong and unknown, as defined in the text.

For major disasters, the acceptable loss estimates still outnumber the incorrect ones, in real-time as well as in performance testing after the fact (Wyss, 2004), but errors do occur and cannot be avoided, unless more accurate information on all necessary input parameters (earthquake source, transmission path, built environment) become available.

The ways in which real-time loss estimates can be improved include the following. (1) Deepen the database on population and building stock. (2) Refine the earthquake source model used for strong motion calculations to allow extended sources of a length appropriate for the announced moment magnitude. (3) Reduce the uncertainty in hypocentral depth estimates by a catalog of regional most likely depths for the entire globe. (4) Educate local disaster managers on the benefits and limitations of international loss estimates in real time.

This latter point is important because local managers, along with news media, regularly insist for hours and days that no disaster, or only a minor one, had occurred, when in reality the real-time loss estimate was correct in predicting one or two orders of magnitude more casualties. This means that the best efforts to work toward efficient rescue efforts are of no use to the injured trapped beneath rubble, if their regional disaster managers do not accept help, because they do not recognize the value of international real-time loss estimates.

It is concluded that the real-time loss estimate technique used in QUAKELOSS has matured to the point that it can be used worldwide. Ways in which uncertainties can be reduced and usefulness of real-time loss estimates can be increased have been identified and should be implemented.

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