Predicting the Human Losses Implied by Predictions of Earthquakes: Southern Sumatra and Central Chile

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Abstract: Predictions of earthquakes worldwide by the M8-MSc algorithm, which defines locations of Times of Increased Probability (TIPs), have been tested for nearly two decades, and the authors claim a high rate of success. Thus, it might be appropriate to ask what the consequences in terms of human losses may be if the expected earthquakes should occur. The loss estimating tool QUAKELOSS also has been tested in real-time mode during the last five years with success. Therefore, it is reasonable to estimate the order of magnitude of human losses if great earthquakes should occur in TIPs. Here I compare the consequences if M8.5 earthquakes should happen in the current TIPs of southern Sumatra and central Chile (Kossobokov and Soloviev, 2008, centers at 4.75S/102.625E and 31.25S/71.77W, respectively). The selection of the attenuation function is calibrated in by matching theoretically calculated intensities and fatalities to the observed values in historic earthquakes. In both areas, the standard attenuation function I use is applicable. The results show that in southern Sumatra fatalities are expected to number fewer than 1,000 (possibly as much as a factor of 5 fewer), whereas they are likely to be larger than 1,000 (possibly as much as a factor six) in central Chile. These figures, however, do not account for possible tsunami effects. The difference is due to two factors. The earthquake sources are farther offshore, and there are only small settlements along the coast in southern Sumatra, whereas along the Chilean coast, large harbor cities are located in the northern part of the TIP area. Regardless of TIP predictions, large earthquakes are to be expected along the Chilean coast. Therefore, it seems advisable to implement mitigating measures in La Serena and Coquimbo, where most of the victims are expected.

Introduction

Every earthquake prediction carries with it implied consequences. I propose here that one should evaluate these consequences quantitatively. It is unpleasant to calculate expected fatalities in case a prediction comes true. However, failing to estimate the consequences does not make them go away. One might argue that predictions of earthquakes, as well as loss estimates, are so uncertain that it is not worthwhile to attempt either of them. Here, I advocate the position that in both fields large uncertainties exist, but that in both fields some tools have been tested long enough to warrant attempts at order of magnitude estimates of expected human losses.

The M8-MSc algorithm has now been tested for about twenty years (e.g. Keilis-Borok et al., 1988; Kossobokov et al., 1997), and the authors claim a high rate of success (Kossobokov and Soloviev, 2008). Their predictions are regularly posted and updated on their website (http://www.mitp.ru/restricted_global/predlist1.html) and transmitted by email interested seismologists. Thus, it seems reasonable to accept the notion that M8+

earthquakes are more likely in the areas defined in the current TIPs of this algorithm than elsewhere. The areas covered by the M8 TIPs are too large for the exercise proposed here because the locations of the expected earthquake are not restricted well enough. However, the areas defined as TIPs by the M8-MSc algorithm can be used to define an earthquake source specific enough for loss estimates. Out of more than a dozen current M8-MSc TIPs worldwide, I select two that are located along populated coasts: Southern Sumatra and Central Chile.

The loss estimating tool QUAKELOSS has been tested for five years in real-time now (Wyss, 2004; Wyss and Zibzibadze, 2008). After any 'significant' earthquake worldwide, we send an email alert containing an estimate of the expected losses to the Swiss rescue team, OCHA (UN Office for the Coordination of Humanitarian Affairs) and the interested community. The predefined minimum magnitude of a 'significant' earthquake is M6 in most areas (lower in Europe and higher in sparsely populated areas). These alerts constitute forward predictions because they are issued about 40 minutes after the respective earthquakes, at a time when the losses are unknown. These loss calculations can only be order of magnitude estimates because of the many uncertainties that enter the calculations. However, this inaccuracy is acceptable to users like disaster managers and rescue teams because, as a first step, they need to know only the answer to the question: Has this earthquake caused a disaster or not? In 380 real-time loss estimates in five years, we have made three mistakes, when judged by the criterion of having correctly answered the aforementioned question.

I have also attempted loss estimates for hypothetical scenario earthquakes that were not predicted but where a large potential is recognized in general. In March 2005, I published loss estimates in seven scenarios for M8.1 earthquakes in the Himalayas (Wyss, 2005). For one of these scenarios, the assumed epicenter was located in the Indian part of Kashmir. It predicted within a factor of 2 the losses sustained in the M7.5 earthquake of October 2005 that occurred in the Pakistani part of Kashmir (Wyss, 2006). Based on this success and the success of the real-time alerts I feel it is reasonable to attempt order of magnitude estimates of losses due to earthquakes expected in TIPs.

A further motivation for a study like this is testing the validity of our loss estimates in forward mode. Estimating losses before they have occurred will afford an opportunity to compare them to what will happen eventually along these plate boundaries.

Method

The method used to calculate human losses consists of the following steps. Given the location and magnitude of the earthquake, the QUAKELOSS program calculates the intensity of shaking at the appropriate distance for every settlement in the database. Then the probability of all damage grades is calculated for each of the building classes according to the respective fragility curves. In a third step, the number of fatalities and injured in three severity classes is calculated using a casualty matrix. This method follows closely the approach of Shackramanian et al. (2000) with a few modifications. Currently, we are constructing a second generation tool for estimating losses, QUAKELOSS2, which is open source and may be tested upon request by interested seismologists and engineers. Details of the method can be found in Trendafiloski et al. (2008).

Calibration

To validate our estimates, I compared reports of shaking and losses for historic earthquakes in the two regions studied with the values calculated using our loss estimating tool. The information on the intensities of shaking and the losses for historic earthquakes are seldom complete. Sometimes a macroseismic map is available. In other cases, intensities are known for only a few locations. The number of injured are seldom given, but the total number of fatalities is usually available, although it may only be a minimum estimate. I wish to match with our calculations any of these parameters that are available, considering the possibility to adjust the attenuation function to reach agreement.

In southern Sumatra, magnitude 8.5 and 7.9 earthquakes occurred on 12 September 2007. For both, our real-time loss estimates were correct within the rather wide margins I allowed due to the uncertainty of the epicentral distance from shore. A recalculation of the losses with the final parameters of these quakes showed that our standard attenuation function is appropriate for southern Sumatra (Wyss, 2008).

In Central Chile, the large earthquakes available for calibration are (1) 1946, M8.2 with 25 fatalities reported, (2) 1971, M7.5 with 90 fatalities reported, and (3) 1985, M7.8 with 177 fatalities, 2,575 injured and maximum intensity reported. I did not use the M7.6 earthquake of 1997 because it was located within the down-dipping slab (Pardo et al., 2002), not along the thrust interface, which means that a different attenuation function is appropriate for that event. I found that when using the standard attenuation function, the intensities and number of injured observed were well matched. In cases (1) and (2) the number of fatalities were also matched (within fewer than 70), but in case (3) the theoretically calculated fatalities were over estimated by a factor of 3, approximately. Changing the attenuation function would not bring a better match overall. Thus, I accepted the standard attenuation function as valid.

The QUAKELOSS program uses the Shebalin (1968) relationship as the standard attenuation function to predict shaking intensity as a function of magnitude and hypocentral distance. This relationship (with the constants b=1.5, c=4.5, e=3.5) is quite similar to the ECOS intensity relationship derived by Fäh et al (2003) from a central European macroseismic intensity database.

Results

Southern Sumatra: Figure 1 shows the location of the TIP by a dashed line. The rectangles show schematically the rupture areas of the two earthquakes in September 2007 (e.g. Lorito et al., 2008). The logic by which I selected the hypothetical epicenter was the following. (1) Given the fact that the M8.4 earthquake ruptured part of the TIP-area, a position in the part of the TIP-area that has not yet ruptured seems most probable for the next earthquake. (2) For the distance from shore, I selected the possibility closest to shore with the intent to calculate a worst case scenario. The distance selected is the average distance from shore of the two events in September 2007. For the magnitude, I selected 8.5 as the worst plausible one. For depth, 20 km was assumed.

The mean damage state in all settlements experiencing shaking of intensity V and larger is shown by a color code (Figure 1). The estimated numbers of fatalities and injured are given in Table 1.

Central Chile: In central Chile, no parts of the TIP have ruptured as recently as in southern Sumatra. Approximate outlines of historic ruptures since 1906 are shown in Figure 2 (McCann et al., 1979; Nishenko, 1991; Barrientos, 1995). Given the distribution of these ruptures, the southern and northern parts of the TIP area are least and most likely to produce a large earthquake, respectively, if one assumes that plate motions steadily load elastic energy along the plate boundary. Thus, I propose the scenario shown in Figure 3 as the most probable and the one with an epicenter at the center of the TIP (Figure 2) as a second choice.

The hypothetical epicenters are placed offshore at a distance in keeping with recent large earthquakes along the South American subduction zone. The magnitude of 8.5 is selected as the largest plausible, given that the 1922 event was of this magnitude, leading to worst case estimates. The expected numbers of fatalities and injured for the selected two hypothetical earthquakes within the TIP off Central Chile are listed in Table 1. The hypocentral depth for scenarios two and three were 25 and 30 km, respectively.

Scenario	Name	Lat (deg)	Lon (deg)	M	Fmin	Fmax	Imin	Imax
1	Sumatra	-5.93	103.74	8.5	200	700	600	2,000
2	Northern Chile	-29.70	-71.50	8.5	3,000	6,500	6,500	13,000
3	Central Chile	-31.25	-71.77	8.5	900	1,900	2,000	4,000

Table 1: Estimated human losses that may be expected in the worst cases if the TIPs defined by Kossobokov et al. (http://www.mitp.ru/restricted_global/predlist1.html) in Southern Sumatra and Central Chile should produce M8.5 earthquakes.

Discussion

The result is firm that a further rupture of the TIP in southern Sumatra may result in moderate human losses only. Firstly, it is backed by the recent experience in the M8.5 and M7.9 earthquakes of September 2007, where only 25 and zero fatalities were reported, respectively. Secondly, changes of position up or down along the coast do not influence the losses much because the coast is populated relative uniformly by small settlements (Figure 1). The epicenter might well be further offshore than selected in Figure 1, in which case zero fatalities may result.

The conclusion that more than 1,000 fatalities are likely in an M8.5 earthquake in the subduction zone of central Chile cannot be avoided. Here the rupture areas are closer to land, and there is a larger population at risk. In central Chile, the assumed epicentral position up and down along the coast strongly influences the loss estimates. Selecting an epicenter at the center of the TIP (scenario 3, Table 1, Figure 2) leads to the most benign case in Central Chile because the settlements in this section of the coast are small. The most likely epicenter (scenario 2, Table1, Figure 3) leads to the worst case because two large cities, La Serena and Coquimbo, are located in the northern part of the TIP.

One of the factors that may reduce losses below the numbers estimated is the hour of day in which the earthquake will occur. Here I assume the worst case: 1 AM at night, when most people are indoors. The numbers of casualties could be substantially reduced, if the earthquake happened during morning hours, when many people are out of doors on their way to work in the cities or at work in the fields in the country side.

The hypocentral depth assumed does not influence the results much in Sumatra because the epicenter is at a considerable distance from shore. This means that moderate differences in depth do not change the distance the waves travel to the settlement by much. However, in Chile the assumed depth influences the loss estimates because changes in depth map with little reduction into the distance traveled by the waves. If the main energy release were at 25 km (instead of 30 km) in scenario 2, then approximately 20% more casualties would have to be expected.

Victims due to possible tsunami are not included in the estimates presented here. The only parameters causing casualties considered are the intensity of the strong ground motions and the resistance of buildings to shaking.

Conclusions

I advocate that it is useful, even necessary, to attempt to predict human losses in cases where an increased probability of large and great earthquakes has been defined. However, one must recognize that these are order of magnitude estimates, subject to many uncertainties. I propose that the comparison of the loss potential in the two TIPs of southern Sumatra and central Chile demonstrates the usefulness of loss estimates. In the case of Sumatra, the probability of a major disaster is low, whereas in the other case, Chile, it is substantial.

Considering the fact that it is only a matter of time until the subduction zone off La Serena and Coquimbo will rupture in a large to great earthquake, it would seem worthwhile to take mitigating measures in these two cities.

Acknowledgments: This work was carried out with the support of the Swiss Agency for Development and Cooperation but does not necessarily reflect the opinion of this agency**.**

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