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TRENDS IN THE CASUALTY RATIO OF INJURED TO FATALITIES IN EARTHQUAKES

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ABSTRACT

The worldwide ratio of injured to fatalities in earthquakes, R = Inj/Fat, has increased over time. This shows that it is more likely by approximately a factor of 2 that a person survives an earthquake today than 50 years ago. However, any meaningful analysis of R requires (as a minimum) separation by type of country and by location of epicenter (land or offshore). R in earthquakes beneath land is typically half of that for events offshore. R in the industrialized world is about 2 to 3 times larger than in the developing world. The countries that have made the greatest progress in protecting their population are Japan and China. Countries where R has not increased with time include Iran, Turkey, and Greece. The basic trends are clear, but the data sets for some individual countries are too small for the averages to be considered firm. We propose to use R to adjust the casualty matrices for estimation of human losses due to earthquakes worldwide.

1. INTRODUCTION

Estimating human losses due to earthquakes in real-time and scenario mode is becoming more necessary as the world population increases dramatically. Methods and data sets for estimating losses have been improving. However they are still rudimentary for many parts of the world and for many aspects of the problem. We think that progress can be made in estimating human losses in earthquakes by modifying collapse rates of buildings and casualty matrices such that the historically observed casualty ratio, R = Injured/Fatalities, is correctly calculated. There are approximately 300 earthquakes since 1950 for which the numbers of fatalities and injured is known, after excluding events for which the data are not useful for one of the reasons given below. We are in the process of preparing and analyzing this data set in such a way that we can use it for calibrating casualty matrices for earthquakes in developing countries.

2. PROPERTIES OF THE CASUALTY RATIO

We propose R as a measure of change in resistance of buildings to shaking because it does not depend directly on the magnitude of earthquakes but on the intensity, regardless of the magnitude that generated it. Parameters such as fraction of the world population killed or injured depend on the distribution of magnitude of earthquakes in populated areas as a function of time. In the latter datasets, large earthquakes that kill tens- or hundreds of thousands dominate some periods, whereas in the data set on R unusually large numbers of fatalities are balanced by large numbers of injured.

R can be smaller than 1 in settlements built with adobe or mudstone walls and heavy roofs because the number of people killed at high intensities can be larger than those injured. The opposite extreme, namely R reaching infinity (zero fatalities, but numerous injured) is encountered at the same intensity, if buildings are built such that they do not collapse. In this case, there are no fatalities, but injuries may still occur, due to nonstructural damage, such as broken glass, falling furniture, and partial structural damage.

In a society that has advanced from a state of vulnerability to better earthquake resistance over the years, R should increase, from values between 1 and 3, observed around 1900 (Table 1), to larger values. However, to analyze R in detail, we have to consider the properties of this parameter to group the earthquakes studied in a way to reduce heterogeneity of underlying conditions. In the following, we list conditions that modify R and that should be considered in its analysis.

(1) Construction material, practice, and building codes in industrialized and developing countries are different. Thus, the effect of earthquakes on people, as measured by R, is so different that the data should not be mixed. R in industrialized countries is 2 to 3 times larger than in developing countries (Table 1, Fig. 1).

(2) R also depends on Intensity (I). In a settlement that experiences low shaking, there will be no fatalities, but injuries do occur. Earthquakes that produce only low intensities are small magnitude (M) events and those located far offshore. These types of earthquakes produce anomalously high R-values and cannot be used to estimate building quality.

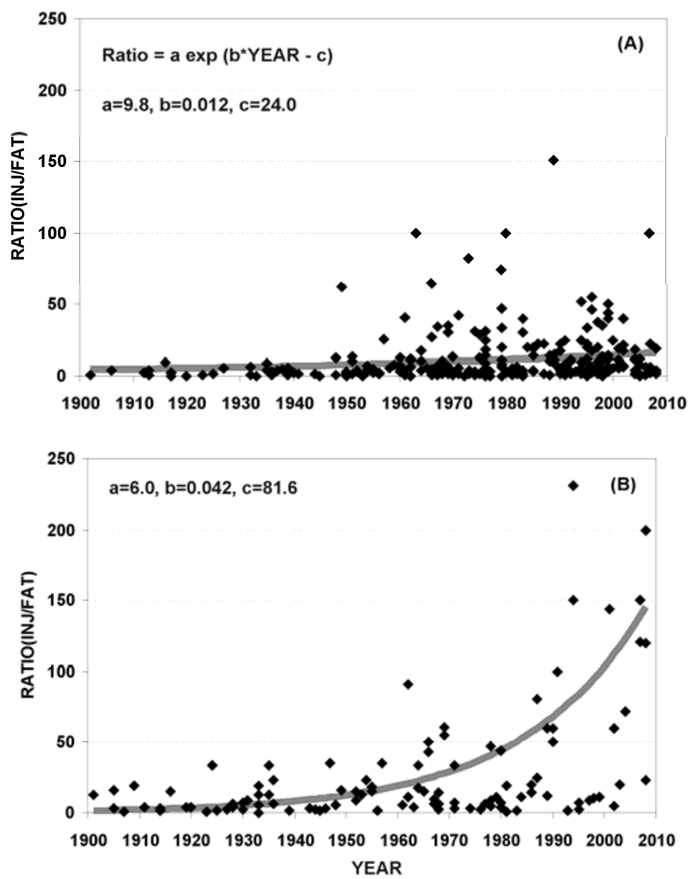

Figure 1. Casualty ratio in earthquakes as a function of time, (A) in developing and (B) in industrialized countries. The ratio has been increasing during the last several decades, indicating that the percentage of people dying in earthquakes is decreasing in the developing as well as in the industrialized world. The data are from Utsu (2002) completed for recent years from the list of significant earthquakes posted by the US Geological Survey on http://neic.usgs.gov/neis/epic/. To reduce spurious data, events with M<6, and those with both Fat and Inj<40, and earthquakes located offshore and deeper than 50 km were excluded. Coefficients of the exponential fit through the data are shown in the upper left.

(3) The building stock in large cities differs from that in rural settlements. Large cities contain engineered

structures and many five to ten story apartment buildings; types of buildings that do not exist in rural settlements. Thus, R depends on the type of settlements affected by a given earthquake. Some quakes are located far from any large city, others happen beneath one. Such earthquakes generate different R-values, even in the same country with uniform construction practices.

(4) The numbers of fatalities and injured in a single earthquake is composed of contributions by numerous to thousands of settlements. Some are located close to the epicenter and experience high intensities, those far away register only low intensities, and some environments are urban, others rural. R-values differ, depending on the composition of settlements affected.

3. DATA

To calculate the values of R, we used Utsu's catalog of deadly earthquakes worldwide (2002), supplemented with 29 events for 2005 through 2008 from the list of significant earthquakes maintained by the US Geological Service. To reduce the heterogeneity of the data and to enhance their quality, we took the following measures. (A) We separated industrialized and developing countries, and, where possible, analyzed data from single and neighboring countries. (B) We deleted events for which neither of the parameters Fat and Inj is larger or equal to 40, to avoid spurious R-values. (C) To eliminate anomalously high R-values due to earthquakes that produced only low intensities, we deleted small earthquakes ($4.2<M<6.0$), offshore earthquakes, and events with depth > 50 km. An additional necessity for eliminating small magnitude events is that their percentage in the world dataset increases with time, due to improving communication capabilities.

Casualties due to ancillary effects should be excluded in our study because we are aiming at understanding and modeling the behavior of residential and office buildings in strong shaking. In recent earthquakes where the numbers of fatalities attributed to tsunami and landslides are given, we subtract these and retain the event with its casualty numbers related to building damage. In the few cases where fatalities in old churches are known, we also subtract them from the total numbers. Earthquakes for which it is known that a large fraction of the fatalities were due to a tsunami, but the percentage is not known are excluded from the study.

The uncertainties that can affect the number of reported fatalities and injured include the following: Casualties from remote areas may not be included. Casualties due to landslides, tsunami, and other ancillary effects may be included. Local officials may purposely modify the reports. Reports of injured suffer in addition from the fact that the minimum level of injuries to be counted is not defined. For this reason it may be more appropriated to speak of 'patients', meaning those people that seek help in a health-care facility, and are therefore included in statistical counts. Given these uncertainties, we will rely on averaging many events to define relative levels of R in different data sets.

4. THE CASUALTY RATIO AS A FUNCTION OF TIME AND SPACE

In a crude first approximation of considering the data for the entire world, we have sufficient events to estimate R in five periods (Table 1, top row), finding that this parameter has increased. To decide the periods of data aggregation we considered the building construction practice worldwide, in particular those of having seismic design codes with various levels. R increases as a function of time in both, the developing and the industrialized world 'Fig. 1'. However, R is about twice as large in the industrialized world than in developing countries (Table 1).

China and Japan are the countries with the largest incidences of fatal earthquakes. In both of them, strong progress has been made in decreasing the percentage of fatalities, as demonstrated by five- and 11-fold increases of R in China and Japan, respectively (Table 1). In Latin America the increase is about 2-fold. In

Iran and Turkey, neighboring countries for which we combined the data, there is no change with time (Table 1).

Bilham (2006, 2009) has shown that the fraction of the world population killed by earthquakes has decreased with time. Figure 2 shows that the fraction of people injured by earthquakes is increasing. Together with our result that R increases 'Fig. 1' (Table 1), we conclude that improved building practice has moved victims of earthquakes from the fatality to the injured category, more than moving people from the injured to the unscathed category.

Table 1. Medians of the casualty ratio in earthquakes with minimum magnitudes of 6 and minimum numbers of injured or fatalities of 40. The periods over which the medians are taken are shaded. The numbers of observations are given in parentheses. Except for the top row, only shallow earthquakes on land are used.

Dataset	500-1899	1900-1949	1950-1969	1970-1985	1986-2008
World	**1.2** (72)	**2.8** (121)	**5.4** (139)	**4.3** (104)	**6.9** (190)
Beneath land and shallow only					
Developing no China			**3.0** (45)	**3.2** (23)	**4.8** (53)
Industrialized			**8.8** (44)		**11.2** (20)
China			**2.5** (35)		**12.8** (35)
Japan			**6.6** (21)		**47.5** (6)
Latin America				**2.6** (12)	**8.0** (11)
Turkey, Iran			**2.6** (19)		**3.6** (26)
Greece			**18.6** (9)		**11.2** (5)
Italy			**3.9** (8)		**7.0** (5)

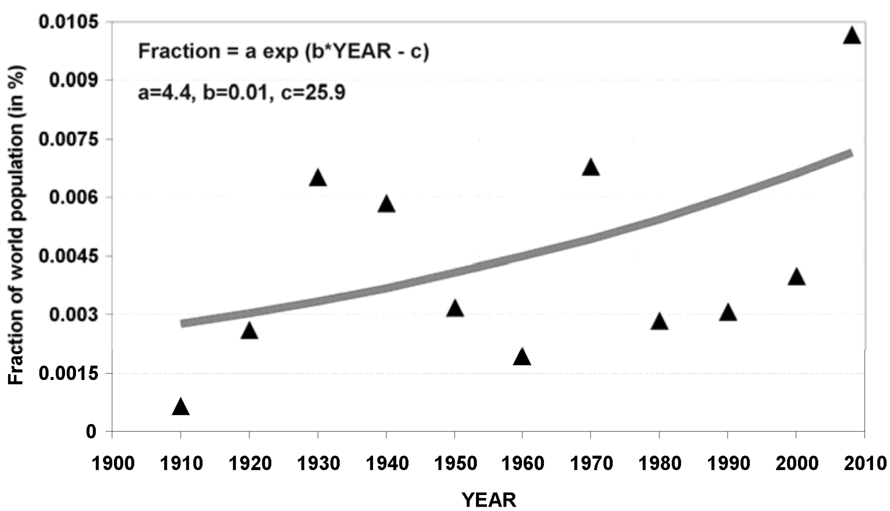

Figure 2: Fraction of the world population injured by earthquakes as a function of decades and exponential regression model fitting the observations.

The results we present here can only be considered as approximate because many uncertainties exist in the data. First, the reported numbers of fatalities and injured are often only estimated. In addition, it is generally not known what percentages of lightly injured persons are included in each count. Also, there are several factors other than the building quality that can influence R.

Using the standard deviate Z-test to estimate the statistical significance of the differences between averages with more than 30 samples, we find significances exceeding 99% for industrialized versus developing nations, and for industrial before versus after 1970. The differences of offshore versus land samples of both, the industrial and developing nations, score above the 95%, but below the 99% levels. Differences between some of the smaller samples in Table 1 score below the 90% significance level, but we present their medians nevertheless because the beginning and ending of the selected periods are times when new building codes came into effect in several countries.

5. ESTIMATION OF HUMAN LOSSES WORLDWIDE, USING THE CASUALTY RATIO

Currently, we are constructing our second-generation loss estimation tool QLARM (earth**Q**uake **L**oss **A**ssessment for **R**esponse and **M**itigation) and upgrading the input database to be used in real-time and scenario mode (Trendafiloski et al., 2009). To improve our loss estimates, in particular those of injured, we propose to fit the ratio injured to fatalities by adjusting the existing casualty matrices.

We evaluated the usefulness of the HAZUS and ATC-13 casualty matrices because they are frequently applied worldwide, although they were intended for use in the USA only. We believe that casualty matrices must be constructed separately for regions with similar building properties. Such regions may include several neighboring countries, or sub-regions of large and complex countries, like India and China. We used observations from Iran as an example in Figure 3 because there are 37 relatively recent earthquakes with data available (Utsu, 2002; Berberian 2005). The city model we assumed to calculate losses, is that of building conditions in medium-size settlements in Iran (population 3,000 – 30,000).

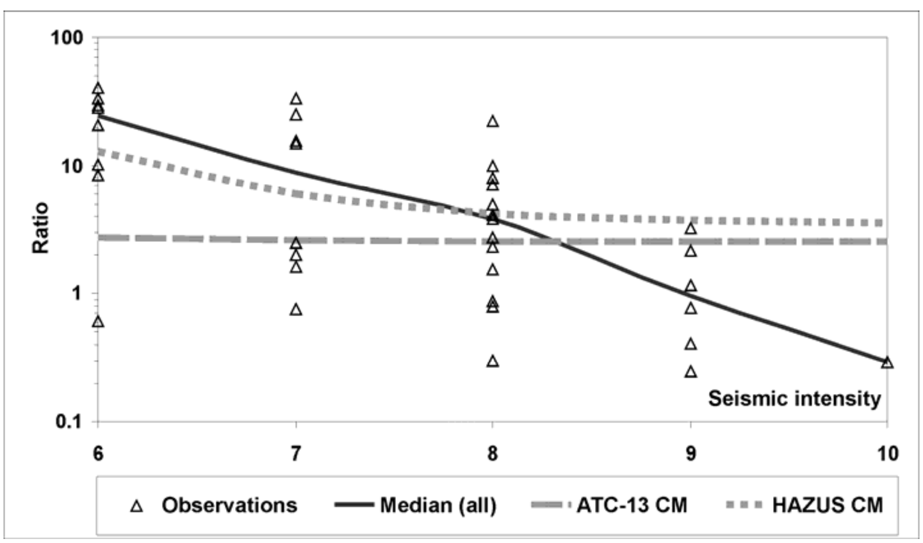

Figure 3. Comparison of the observed and calculated ratios for Iran for different seismic intensities with HAZUS and ATC-13 casualty matrices.

When calculated by the ATC-13 casualty matrices, the ratio R for Iran has a constant value of 2-3 for all intensities, which does not fit the observations 'Fig. 3'. The ratio calculated by use of HAZUS matrices fits the observations in the intensity range of 7.5-8.5, but not outside of it. Thus, we propose to adjust the casualty matrices in QLARM to account for the observed ratio as a function of the seismic intensity (Trendafiloski et al., 2009). This is important for developing countries in Southern Asia where very low values of R are observed (R < 1) for seismic intensities larger then 9.

6. DISCUSSION AND CONCLUSIONS

The uncertainties in reported fatalities and even more so in injured are considerable for many earthquakes. This is especially true for early times and for countries applying media control. Some case histories of outstanding reporting errors have been documented by Bilham (2009). Nevertheless, we have to work with the available official information. We must delete data from small earthquakes, offshore events, and deep ones. We must use averages, and we should group data from countries with similar building types. Provided we take these precautions, and provided we keep in mind that only our most basic results are firm, we can reach some conclusions.

The most basic, robust observation is that a decrease of fatalities compared to injured in earthquakes has been achieved globally (Table 1, Fig. 1). This supports the observation by Bilham (2004, 2009) that fatalities in earthquakes have not kept pace with the increase of the population of the planet with time. Spence (2007) shows in his figure 3 the dramatic loss of life in the years after 2000 due to earthquakes in a wide sense, including the approximately 280,000 fatalities caused by the tsunami in the Indian ocean in December 2004. Being concerned with the resistance of buildings to strong shaking, we have excluded deaths caused by tsunami. Therefore, we interpret the combination of Bilham's results (the percentage of the population killed by earthquakes decreases with time) and our results (increasing R, and increasing percentage of injured) as an indication of improved building practices.

We propose to use R as an indicator of building quality because the worldwide statistics have shown that about 75% of the fatalities attributed to earthquakes were caused by the collapse of buildings that were not adequately designed for earthquake resistance, were built with inadequate materials or were poorly constructed (Noji, 1997). However, the progress in reducing fatalities is uneven. Among the countries and regions where there were enough data so we could estimate the change in R, Japan is leading in improving the safety of its citizens (Table 1). China has also made great progress and seems to approach standards of the industrialized world, although the data in some cases may not be among the most reliable. Progress in Latin America appears to have been substantial, but earthquake safety still lags behind that in the industrialized world. Finally, it appears that not much progress has been made in Greece, Turkey and Iran, although the number of observations in a single country is too small to draw firm conclusions.

Improving the quality of the built environment is not an easy task and it requires resources. Building codes are not a panacea for all problems and mainly result in earthquake-resistant buildings rather than earthquake-proof buildings. Structures built according to code should resist minor earthquakes without damage, resist moderate earthquakes without significant structural damage, and resist severe earthquakes without collapse. The goal is to protect building occupants by preventing collapse, thus allowing evacuation of injured. Codes only recently began to address mitigation of nonstructural hazards in buildings, which might cause injuries.

When governments increase the requirements in building codes only new buildings are affected, but most people continue to live in old structures that are equivalent to death traps in some countries. Also, resources and the political will to enforce building codes by inspections on construction sites may be lacking in some countries. The established levels of earthquake-resistant design and construction of buildings are strongly related to a country's GDP level and they change over time. The level of acceptable seismic risk should be a realistic balance between building design requirements and a country's economic power.

There are countries where the record does not contain enough fatal events to estimate R, but where the potential for earthquake disasters exists. In countries like the USA and Canada, this poses no problem because awareness of the earthquake risk is high and efforts are made to protect the population. In other earthquake prone countries, where building materials and construction styles are poor, it would be desirable to quantify the danger the population faces by calculating parameters quantifying the earthquake risk, including the ratio R. Countries where this condition exists, but not enough recent deadly earthquakes have been registered for detailed analyses, include India, Pakistan, Nepal, and Afghanistan. We believe that India with its large risk potential is especially vulnerable (Wyss, 2005).

To improve the casualty estimates, in particular the number of injured in developing countries, we propose to consider the casualty ratio R to adjust casualty matrices pertinent to vulnerability classes of buildings with low resistance, such as A, B and C according to the European macroseismic scale.

We conclude that overall the engineering efforts to protect the population from dying in earthquakes has brought fruit.

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