The 2006 Yogyakarta earthquake – a preliminary study of deaths

J. M. Nichols
Department of Construction Science, TAMU, Texas, USA

Abstract

The M_W 6.3 Yogyakarta, Java, Indonesia, Earthquake occurred on May 27th 2006 and killed more than 5,000 people and injured more than 36,000 people. The earthquake had a duration of 52 seconds, which is a long duration for the magnitude of the event, and left 600,000 people without shelter. The earthquake occurred near Mt. Merapi, which is an active volcano. The paper's purpose is to outline the existing knowledge about the earthquake and place this knowledge within the context of recent studies of the statistics of earthquake fatalities. The study of the earthquake deaths and injuries form part of an ongoing investigation into the development of methods to estimate fatalities in given earthquakes, and in particular the upper bounds to the fatalities observed in a special group of rare fatal earthquakes.
Keywords: Java earthquake, earthquake fatalities, Maximum earthquake deaths.

1 Introduction

An M_w 6.3 earthquake occurred near the city of Yogyakarta (20 km SSW) on the island of Java on May 27, 2006 resulting in than 5782 deaths, and 36,299 injuries [1, 2]. This death toll places the 2006 Yogyakarta earthquake into the group of rare earthquakes in the last two millennia that define the bounds of deaths in such events. These rare events, only seven in the 20th century, are critical to understanding the site factors that affect losses in earthquakes. This paper updates the information available at the end of the 20th century to revise the original mathematical model [3] developed to estimate earthquake deaths for a given magnitude.

Shiono [4] completed the seminal study on earthquake fatality rates in 1995 using the 1976 Tangshan earthquake as the basis for the analysis. The 1976

WIT Transactions on The Built Environment, Vol 93, © 2007 WIT Press
www.witpress.com, ISSN 1743-3509 (on-line)
doi:10.2495/ERES070201

Tangshan earthquake estimated death toll was 242,000, with a peak fatality rate of 30 to 50% in the Felt X to XII area. This Chinese earthquake represents the largest fatal event of the 20th century. Shiono demonstrated a clear and unambiguous relationship between population fatality rates and the distance from the epicentre of the earthquake.

2 Literature review

Structural engineering standards developed in the latter part of the last century allow for the construction of modern houses, structures, and buildings that can withstand some, but not all, earthquakes [5]. Nichols et al [3] show in a study of the earthquake fatalities against earthquake magnitude that a bounding function could be established for the twentieth century earthquake fatality data. Figure 1 shows the original bounding function, plotted with the rare fatal events that provide the points to determine the bounding function for fatalities.

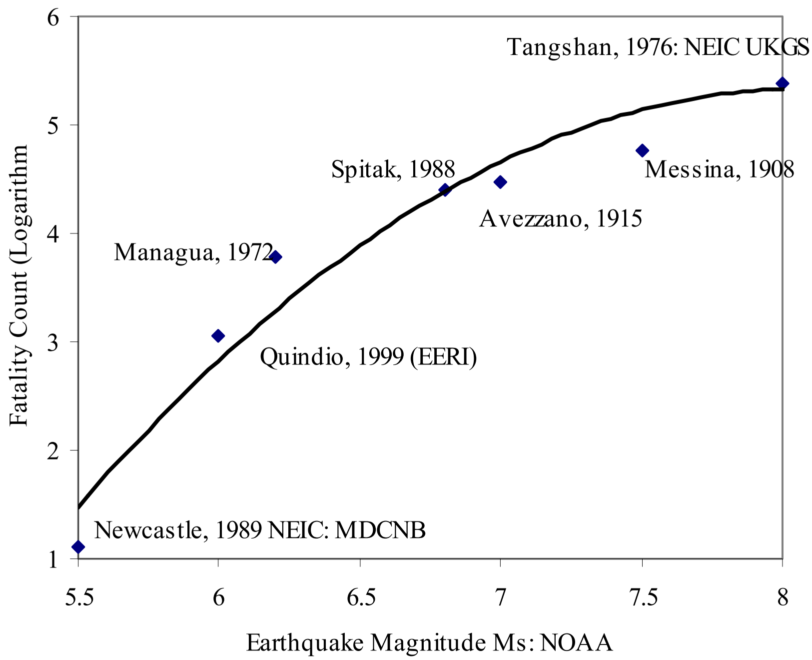

Figure 1: The original bounding function for the fatality count against earthquake magnitude.

The form of this original bounding function, based on data from the period before 2000 AD, was estimated using standard regression techniques (Eqn. (1)).

$$\log(\Xi_B(M)) = 9.335M - 0.577M^2 - 32.405 \tag{1}$$

The function has a regression coefficient of 0.95 for a fatality count of $\Xi_B(M)$ and an earthquake magnitude M. Earthquake magnitudes were determined from the USGS National Earthquake Information Center [6]. These magnitudes are Ms from the NOAA catalogue, except for 1976 Tangshan, and the 1989 Newcastle earthquakes that are coded UKGS and MDCNB respectively in the catalogue. The magnitude of the 1999 Quindío, Columbia, earthquake was based on the EERI report [7] and was coded M_l. The fatality counts, Ξ_R, for the remaining earthquakes of this last century are below the bounding function, $\Xi_B(M)$.

There are usually observable and simple reasons why these fatality counts are lower than the bounding function, e.g., earthquakes in remote regions, rates of attenuation, population densities, higher building construction standards, and timing of the event. However, given the post earthquake studies from the twentieth century it was evident that the closer the meizoseismal area of a large earthquake was to the center of a population, then the higher was the potential mortality rate [7–9].

The fatal meizoseismal area in the context of this paper is the area of damage that can cause death. In this case we are very specifically referring to areas enclosed by the line of building damage likely to cause death. Shiono's data [4] indicates that this limit of deaths is at about the iso-seismal delineating the felt intensities five and six. The damage outside this area is economically significant, but not generally fatal. The second recent observation is the increase in fatal earthquakes per annum during the 20th century from about 4 annually in 1900 to 16–20 annually in 2000.

3 2006 Yogyakarta earthquake details

Figure 2 shows the location of the major damage center in Java from the May 27th earthquake. Table 1 presents the earthquake details from the USGS report [2] for the event. The USGS report provides the following MMI intensity data, "*felt (IX) at Bantul and Klaten, (VIII) at Sleman and Yogyakarta, (V) at Surakarta, (IV) at Salatiga and Blitar and (II) at Surabaya. Felt in much of Java. Also felt at Denpasar, Bali*"

The critical data for the study is the distribution of losses in the event and the corresponding distribution of the population at the time of the event. The estimated population of Yogyakarta is 500,000, providing a raw estimate of the fatality rate across the city of about 1.2%. This fatality rate is comparable with the overall rate in the M 7.7 2001 Gujarat earthquake of 1.1%, even though the Java event is a significantly smaller earthquake. The other interesting feature is the relatively poor construction in India which is blamed for the large death toll, needs to be compared to the Indonesian building standards.

4 Earthquake consequences to the bounding function

The 27th May Java earthquake proved to be one of those earthquakes that cause fatalities as well as building damage, but at an overall fatality rate for the magnitude of the earthquake that only occurs about once a decade. The interesting feature of the first 7 years of the 21st century is that two such events have occurred in this period. The first in Italy with deaths of 22 schoolchildren in an M 5.4 event and now the deaths of 5782 people in an M_w of 6.3 in Java.

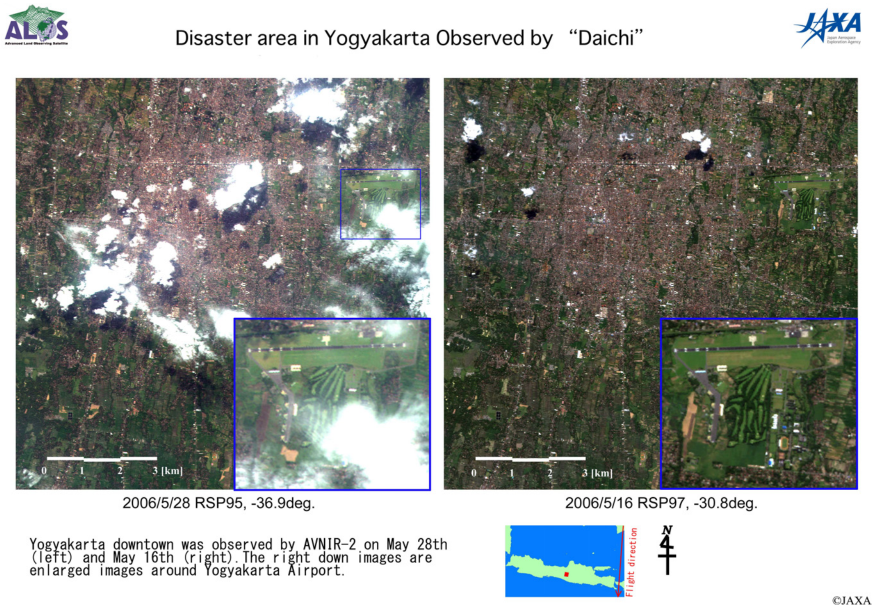

Figure 2: Disaster area in Java (Jaxa [10]).

Table 1: USGS Report on Event.

Description	USGS Official	Comments
Magnitude M_w	6.3	Strong
Date (UTC)	Friday May 26, 2006	
Time (UTC)	22:53:58	
Date (Local)	Saturday May 27, 2006	
Time (Local)	5:53:58 AM	
Location	7.962°S, 110.458°E	
Depth	10 (km)	Set by location program
Distances from Cities	(1.) 20 km SSE of Yogyakarta (2.) 455 km ESE of Jakarta	
Location uncertainty - horizontal	± 7.5 km	
Parameters	$N_{st} = 130$ $N_{ph} = 130$ $D_{min} = 220.2$ km $R_{mss} = 1.4$ seconds $G_p = 43°$	Teleseismic moment magnitude

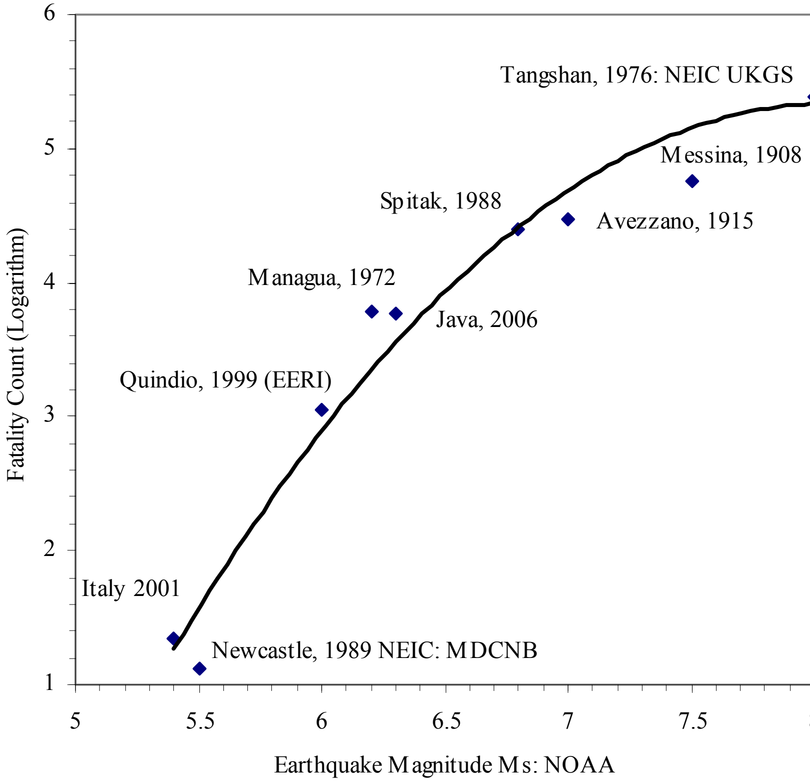

Figure 3: Revised fatality data and bounding function.

Figure 1 shows the plot of the pre-2000 data for high fatality rate earthquakes against earthquake magnitude. The recent Italian and Javanese earthquakes have been added to the simple database used to develop Figure 1. This simple database was analysed to determine the revised bounding function for peak fatality rates plotted against earthquake magnitude. Figure 3 shows the revised plot and revised bounding equation.

The form of this revised bounding function, based on data from the period before 2008 AD, was estimated using standard regression techniques and is given in Eqn. (2)

$$\log(\Xi_B(M)) = 9.2276M - 0.572M^2 - 31.884 \tag{2}$$

The function has a regression coefficient of 0.97 for a fatality count of $\Xi_B(M)$. The slight increase in the regression coefficient can be attributed to the increased number of points in the plot. The critical difference is the estimates of the fatalities for the two bounding functions. Table 2 lists a set of the fatality estimates for the two bounding functions for a range of earthquake magnitudes. The percentage differences between the two equations are presented in Table 2.

The differences show a slight fall at the upper end of the range, and a 15% increase in losses in the mid range event. The clear question is whether the 1908 Messina event should be considered a bounding function and this question will be the subject of further research.

Table 2: Changes in the bounding equation from 2000 to 2007 AD.

Earthquake Magnitude	Original Equation 2000 AD (Estimated fatalities)	Revised Equation 2007 AD (Estimated Fatalities)	Percentage Difference
5	1	1	129%
5.5	30	37	121%
6	681	782	115%
6.5	7,839	8,563	109%
7	46,452	48,540	104%
7.5	141,661	142,438	101%
8	222,331	216,371	97%

The May 27th 2006 Yogyakarta earthquake is clearly one of the largest fatal events for a given earthquake magnitude recorded in the last 100 years. This event will provide with further research a better picture of the impacts that the five factors have on the earthquake fatality rate for mid range fatal earthquakes. The five factors are a density function, a building and ground factor, an attenuation factor, a fatality rate factor and an aleatory uncertainty factor.

5 Conclusions

The Yogyakarta earthquake that occurred on the 27th May 2006 has an official death toll of 5782 people, with many more injured and left homeless. Recent research on fatal earthquakes has shown an increase in the number of fatal events from about four per annum in the year 1900 to about sixteen to twenty in the year 2000. A much smaller group of fatal earthquakes have particularly high fatality rates for the magnitude of the event. This group of high rate fatal earthquakes has had two new members added to the set since 2000 AD, which are the M 5.4 2001 Italian earthquake resulted in the death of 22 schoolchildren and the 2006 Yogyakarta earthquake. This paper presents the changes to the estimated fatality bounding function when plotted as a function of earthquake magnitude for these two additional rare fatal events. The mid range of the earthquake magnitudes has a fifteen percent increase in the estimated tolls. The upper end has a small drop of three percent, which is not considered statistically significant. The Yogyakarta earthquake requires further study to determine the factors that caused the high death toll.

Acknowledgements

The National Science Foundation funded this research under Grant Number CMMI-0703846 entitled “2006 Java Earthquake -- A Study of the Deaths and Injuries”

References

[1] CNN.COM, http://www.cnn.com/2006/WORLD/asiapcf/06/05 /indonesia.quake/ (accessed 26th Feb 2007), June 6th 2006, 2006.

[2] USGS Report on the 2006 Yogyakarta Earthquake http://earthquake.usgs.gov/eqcenter/recenteqsww/Quakes/usneb6.php (Accessed 9 Feb 2007), 2006.

[3] Nichols, J.M., Lopes De Oliveira, F., And Totoev, Y.Z., The development of a synthetic fatality function for use in the economic analysis of the rehabilitation and repair of structures, *StrucDam Conference*, Brazil, 2000.

[4] USGS, Current Earthquake Information http://neic.usgs.gov/ neis/bulletin/01_EVENTS/01_EVENTS.html (Accessed March 28, 2001), 2001.

[5] EERI, *The Quindío, Columbia Earthquake of January 25, 1999,* www.eeri.org., 1999.

[6] Holmes, W.T., (2000), The 1997 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, *Earthquake Spectra*, **16(1),** pp. 101-14, 2000.

[7] Shiono, K., (1995) Interpretation of published data of the 1976 Tangshan, China Earthquake for the determination of a fatality rate function, *Structural Engineering / Earthquake Engineering,* **11(4),** pp. 155s-163s, 1995.

[8] Ward, S.N., and Valensise, G. R., Fault parameters and slip distribution of the 1915 Avezzano, Italy, earthquake derived from geodetic observations, *BSSA,* **79(3),** pp. 690-710, 1982

[9] Algermissen, S.T., *A study of earthquake losses in the San Francisco Bay Area Data and Analysis,* US Dept of Commerce, NOAA: SF, 220, 1972.

[10] JAXA, Yogyakarta earthquake satellite imagery http://www.jaxa.jp/press /2006/05/20060528_daichi_e.html (accessed 26th Feb 2007), 2006.