THE IMPLICATIONS OF THE MAY 27TH 2006 JAVA EARTHQUAKE FOR MASONRY DESIGN AND CONSTRUCTION.

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SUMMARY

An M 6.3 earthquake occurred near the city of Yogyakarta (20 km SSW) on the island of Java on May 27, 2006 resulting in 5782 deaths, and 36,299 injuries. This earthquake represents the most deadly earthquake for the magnitude ever recorded historically. This paper addresses the design and construction implications for masonry buildings from a site investigation study undertaken on the island of Java after the earthquake. The study also provides a further critical calibration point in the primary equation used to estimate deaths in earthquakes in all building types.

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 5782 deaths, and 36,299 injuries (CNN.COM, 2006). 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 (U.S. Geological Survey, 2006). The earthquake occurred near Mt. Merapi, which is an active volcano. The 2006 Yogyakarta earthquake falls into a special category of rare earthquakes. These rare events define the bounds of deaths in such events. This paper considers the implications of the large fatality and injury count for the design and construction of masonry structures.

LITERATURE REVIEW

Figure 1 shows Mt Merapi in the distance. The photograph was taken from the Quality Inn adjacent to the Yogyakarta airport. The typical style of housing for the city is visible in the foreground. The city has a number of areas of medium rise buildings principally near the main university centers and in the main business district. The predominate building materials are reinforced concrete frame, which are generally constructed in a 100 mm square form, fired clay infill masonry and clay roof tiles. The vast bulk of the dwellings are single storey, built on a stone lined edged fill pad in the farming areas.

Figure 1. Mt Merapi viewed from the Airport District in Yogyakarta

The Geological Engineering Department of the Gadjah Mada University issued the first major English language report on the 2006 earthquake (Karnawati, Pramumijoyo and Husein, 2007). This report presents initial reports on the earthquake including the geology, building issues and health issues. The critical issue for understanding the fatality count in this event is the form of housing used in the region. Figure 2 shows a typical house construction procedure observed by the author in the region south of Yogyakarta, near to the epicenter of the earthquake.

Figure 2. Typical Single Storey Dwelling under construction in Java (Nichols, 2007).

Typical house construction details are presented in standard construction manuals available in Java (Praktis and Mudah, 2006). This is an excellent manual for constructing your home from masonry. Figure 3 shows the typical style of house covered by the self-help manual.

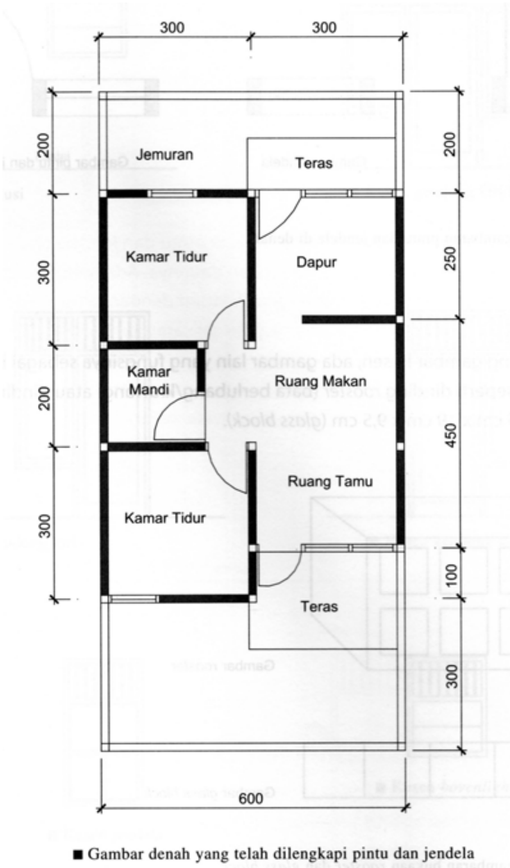

Figure 3. Typical Single Storey Dwelling Layout (Courtesy Griya Kreasi, 2007).
(All dimensions in cm.)

The rate of building collapse in Java during the earthquake was significant causing a high fatality rate and injury rate particularly fractures. A recent analysis of the mortality in the September 1999 Taiwan earthquake (M_w 7.6) showed a strong relationship between the percentage of collapsed buildings and the fatality rate (Chan, Lin, Chen, Chang, Cheng and Chen, 2003), which supports the conclusion reached by Shiono (1995) for the 242,000 deaths in Tangshan in China in 1976. Nichols, Lopes De Oliveira, and Totoev (2000) show in a study of the earthquake fatality count against earthquake magnitude that a bounding function could be established for the twentieth century earthquake fatality data. This analysis is based on the fatality database (NOAA, 2000). The interesting observation for the bounding function is the relatively limited number of fatal earthquake events, seven, which clearly define the function for the twentieth century. Standard regression techniques provide the constants for this original bounding function (Eqn. 1). The function has a regression coefficient of 0.95 for a fatality count of $\Xi_B(M)$ and an earthquake magnitude M .

$$\log(\Xi_B(M)) = 9.335M - 0.577M^2 - 32.405 \quad (1)$$

The feature of the first 7 years of the 21st century is that three such bounding events have occurred in this period. The first in Italy with deaths of 22 school children in a M 5.4 event (BBC, 2002), the Bam event and now the deaths of 5782 people in a M_w 6.3 earthquake in Java. The recent Iranian, Italian, and Javanese earthquakes have been added to the simple database used to develop the bounding function. This simple database was analyzed to determine the revised bounding function for peak fatality rates plotted against earthquake magnitude. Figure 4 shows the revised plot and revised bounding equation.

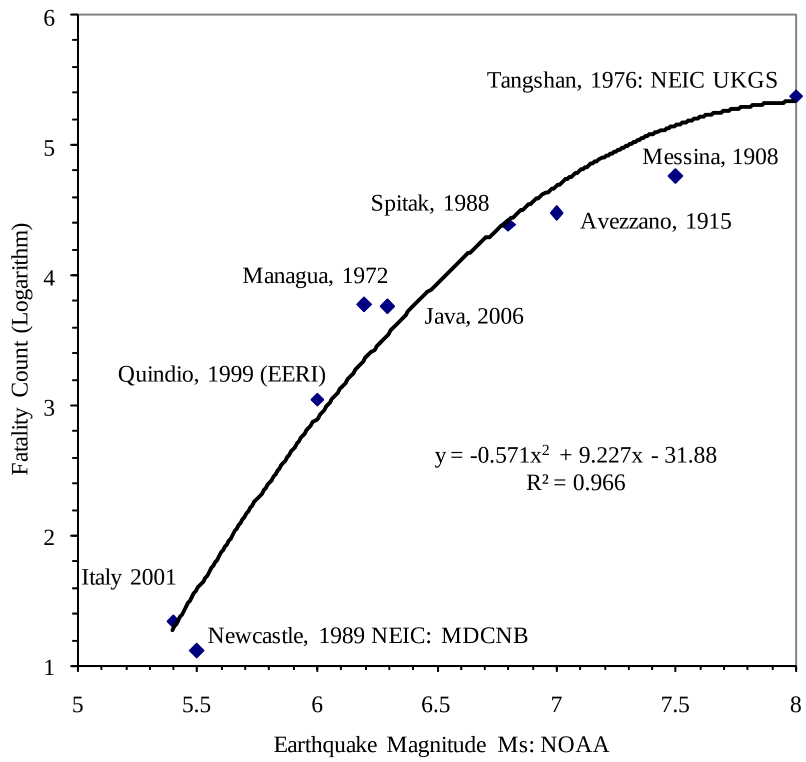

Figure 4. Revised Fatality Bounding Function 2007.

The revised bounding equation is shown in equation (2). The revised equation has an approximate twenty percent increase in the bounding function for the earthquake magnitude range of M5 to 6.

$$\log(\Xi_B(M)) = 9.2276M - 0.572M^2 - 31.884 \quad (2)$$

The clear question is whether the 1908 Messina event should be considered a point on the bounding function and this question will be the subject of further research. The conclusions from this analysis is that a number of factors influence the death toll in an earthquake, with the two primary factors being the size of the exposed population and the

magnitude of the event. The ultimate upper bound to the fatality count is the population present in the fatal meizoseismal area (Richter, 1958).

YOGYAKARTA

Yogyakarta is one of the principal capital cities on Java and is a major centre for tertiary education in Indonesia. The total population of the greater Yogyakarta area is about one million. A map showing the location of the city is shown in Figure 5.

Figure 5. Yogyakarta in Java (Courtesy (CIA, 2002))

VILLAGE SITE INSPECTION

The village of Bantel in the Kampung of Becari lies on the eastern bank of the Opek River, which is one of the main rivers draining the valley containing the Yogyakarta regional area. The village is about 30 kilometers south of Yogyakarta. The village suffered a coarse death toll of about 15% from a population of approximately 200 people. The dwelling shown in Figure 2 is one of the recent additions to the village after the earthquake.

Figure 6 shows one of the remaining remnants of a damaged wall. One of the recently constructed houses can be seen in the background to the picture. A sample of the mortar from the wall was obtained for further analysis.

Figure 6. Damaged Wall Remnant from the 2006 Yogyakarta Earthquake.

A microscopic view of the surface of the mortar sample is shown in Figure 7.

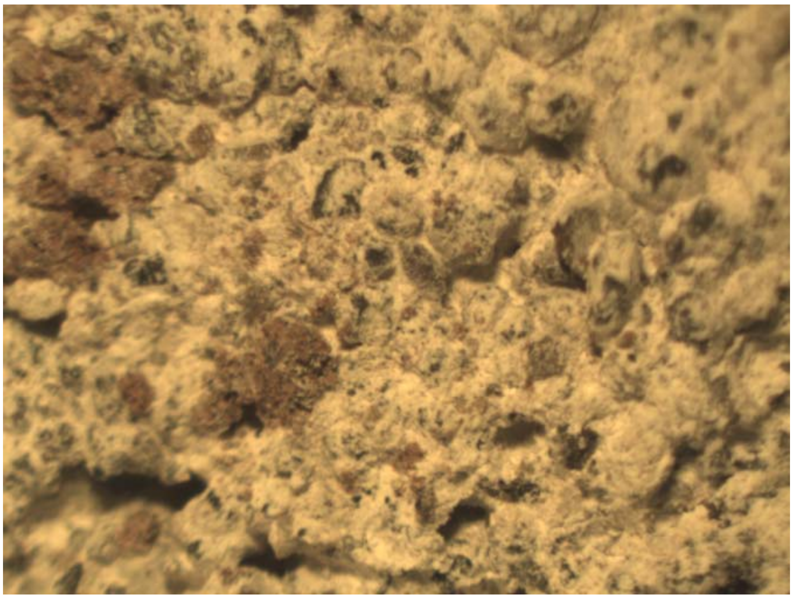

Figure 7. Close up of the surface of the mortar sample

A chemical and physical analysis has not yet been completed for the mortar. The interesting question for this chemical and physical analysis will be to investigate whether the friable nature of the mortar can be attributed to the use of local clays in the mortar, as has been claimed. The brown material visually evident on the surface of the mortar sample can be clearly seen in Figure 7. Figure 8 shows a surface texture mapping of a 80 by 105 mm sample from the mortar, with a resolution of 0.5 mm.

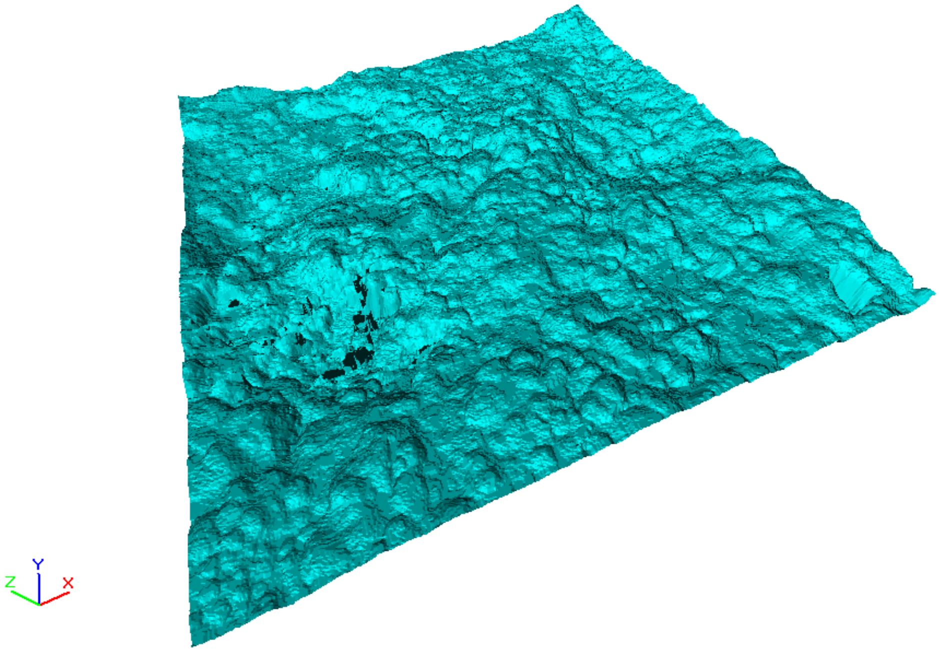

Figure 8 Surface Texture Mapping of Mortar Sample

Figure 9 shows a microscopic view of the same sample of material scratched from the surface of the sample during transportation. The left hand view focuses on the larger particles showing some remains of cementitious material and the right hand view focuses on the smaller particles. The brown material particles are evident in the right hand sample.

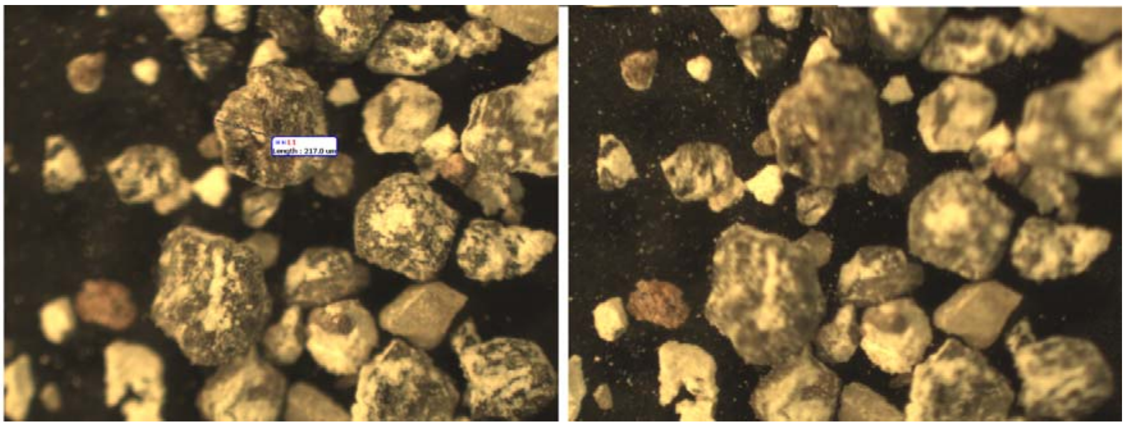

Figure 9 Microscopic View of Material eroded from the Mortar Sample

The brick type used in this regional area appears to be a flat pressed brick of low strength. Figure 10 shows a sample of the brick used in the construction shown in Figure 2. The bricks are handled at least three times from the kiln to the field. The method of delivery is not automated at all. This handling provides one quality control measure to reduce the incidence of soft bricks.

Figure 10. Brick Samples

About 10 kilometres north of the village is a small valley nestled in the foothills to Mt Merapi. A landslide occurred in the valley resulting in the loss of at least three houses. Figure 11 shows one of the two remaining houses in the valley. This house sits on a small hill and the landslip passed on either side of the hill.

Figure 11. Building damaged in Landslip

MASONRY BUILDING IMPLICATIONS

The masonry community has learned over the last 130 years that poorly constructed masonry is a poor performer in earthquakes (Melchers and Page, 1992; Nuttli, 1987; Page, 1973). The key indicators of poor performance are low quality bricks, poor mortar that clearly and usually lacks lime and often lacks cement, the use of clays in the mortar and a poor method for tying the structure together to resist the earthquake forces. The impact of poor quality of construction is observable in figures six and eleven. These buildings are near the epicentre area of the earthquake. It will take a few more months to fully analyse the composition for masonry mortar samples and confirm the exact causes of the weak mortar, however in comparing the current methods of construction using a reinforced concrete frame with columns typically 120 by 120 mm and using 6 mm steel bars for vertical and stirrup reinforcement with the previous construction techniques relying on unconfined masonry it must be observed that construction techniques have improved. This style of construction is used in Mexico and Greece for safeguarding masonry homes from collapse in earthquakes.

There is clearly a need for further studies on the use of narrow section columns and beams as tie elements in what is essentially a very light RC frame in a predominately masonry dwelling. The critical steps would appear to be further finite element analysis and if possible shaking table tests on this style of construction. This will build on the excellent work of the local engineering community.

The injury rate in this earthquake points to a very real concern with a similar earthquake in large unreinforced masonry communities. The planning in such communities should allow for the projected deaths and injuries requiring surgery.

CONCLUSIONS

Dutch colonization brought the European style of building to Java moving the population away from timber housing and into bricks, mortar walls and tile rooves. The local adaption of the masonry style of construction reflects the ability of the community to fund such practices and to adapt the style by introducing a low level of confinement with a reinforced concrete frame. This style of construction can be adapted for other areas of moderate seismicity. The magnitude of the death toll is of concern as is the occurrence of a third bounding function earthquake in less than seven years.

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