BUILDING DAMAGE AND CASUALTIES IN RECENT EARTHQUAKES AND TSUNAMIS IN ASIA: A CROSS-EVENT SURVEY OF SURVIVORS

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ABSTRACT :

To plan disaster management strategies, and to develop appropriate building regulations, as well as improving the modeling of earthquake impacts, an understanding of the relationship between human casualties and building damage is crucial. However, until recently, no systematic attempt to collect such data following major earthquakes has been made. Following the development of a questionnaire after the 2004 South Asian tsunami by the team at the University of Cambridge, surveys of survivors from four Asian earthquakes and tsunamis have now been carried out to assess the experience of human casualties and their relationship to building damage and location. In the South Asian tsunami 87 interviews were carried out, in the Pakistan earthquake a further 500 questionnaires were completed, and 120 questionnaires were completed after the Central Java tsunami in July 2006, all in collaboration with local teams.

Another 500 interviews were collected in the Yogyakarta province following the May 2006 earthquake. Important findings from each of these events as depicted by the survivors are drawn out and a database of the survey responses has been built. Cross-event analyses are of importance as these highlight differences in levels of building damage and provide an insight into the relationships between building damage and extent of injuries. In addition, relationships can also be deduced between rescue times and treatment and how these are related to building damage and causes of collapse, which are crucial for emergency planning and search and rescue efforts. The project which this paper describes (funded by the UK Engineering and Physical Sciences Research Council) was designed to compare and contrast these recent events, drawing out critical differences and examining their implications for the global casualty database.

KEYWORDS: building damage, casualties, survey, Asia

1. INTRODUCTION

Loss estimation is an essential part of modelling for civil protection, insurance as well as emergency planning within a community after a disaster. The ability to predict casualty losses after an earthquake requires knowledge of the type and level of ground motion, the soil conditions and topography of the affected area and the infrastructure, the types of buildings housing commerce and different levels of occupants sited in the area. Apart from a segregation of efforts amongst disciplines, progress in this research area has been hampered by disparities of casualty reporting and data collection. One of the main problems is that data available is patchy and uncoordinated. The main source of better data is likely to be from field studies from future earthquakes. Unfortunately, at present, the lack of standardisation of injury data and an established methodology for studying casualties in the field means that the data gathered is often not relevant for use in quantitative studies which are essential for formulating more credible and realistic models. There is a large amount of new data available from recent events which need to be assessed and included into loss estimation models.

The South Asia Tsunami of 26th December 2004 was an event from which engineers can learn vital lessons on what happened to existing structures in order to guide future coastal developments. The sheer scale of the disaster (more than 20,000km of coastline affected in 12 or more separate countries) created considerable difficulties in assembling impact and damage assessments in the field. Many of the survivors were UK tourists, and therefore their eyewitness reports and photographs contain a direct, vivid and in many respects unique record of the impact of a tsunami in a human settlement distinct from, and complementary to, that obtained from a reconnaissance mission (EEFIT, 2006). Therefore a questionnaire was devised and interviews were undertaken by the team at Cambridge to investigate written descriptions from 87 people who witnessed the tsunami first hand, all of whom volunteered to take part in the project.

On 8th October, 2005, a magnitude 7.6 earthquake occurred affecting Pakistan and India, officially killing just under 80,000 people and injuring over 200,000. The immense death and injuries toll was unexpected but the number of people suffering serious injuries and surviving surprised many in the field of disaster management. This earthquake provided a unique opportunity for the team at Cambridge to plan and collect data by questionnaire survey, designed in consultation with medical and public health practitioners. 530 questionnaires were carried out in the main study in June 2006 by the University of Peshawar in the earthquake affected area.

By July 2006, two major events had occurred in the region of Yogyakarta in Indonesia. A 6.3 magnitude earthquake in May 2006 and a tsunami from a 7.7Mw event in July 2006, though much smaller in sizes compared to the previous two, in spite of a lower death toll, at just under 6000 and 600 (CRED, 2007) both left hundreds of thousands homeless indicating serious building damage in the area. For these events, understanding why so many people survived under such widespread and heavy damage were of interest and with the help of the WHO stationed at Yogyakarta, surveys were carried out in collaboration with Gadjah Mada University.

In this paper, the aim is to describe the work carried out to collect this valuable data from recent events and the cross-event analysis done to draw out key lessons and the appraisal on how these may impact future loss estimation models

2. DATA COLLECTION

The assembly and mapping of damage and casualty data following major events plays a vital part in developing our understanding of the phenomena themselves and of the demand placed on buildings and infrastructure by natural forces. This damage data is essential information for developing appropriate regulations for future buildings and infrastructure, the design of protection systems, and the development of loss models to estimate future impacts. Unlike engineering damage surveys, where damage states classifications have been developed and are used, there has been no standard methodology used in the collection of injury data from earthquakes in the past. This lack of standardisation and incoherent nature of data assembly has meant that there has been very little published work assessing global trends and modelling of casualty data.

In her PhD study, Dr Petal carried out a survey on a random sample of the community of Gölcük after the Kocaeli earthquake in 1999 (Petal, 2004). This was the first survey of its kind which looked at collecting information on causes of injuries from survivors of earthquake although her focus was learning about public awareness and prevention. Different sampling techniques were used in each of these surveys due to varying topography, accessibility and availability of resources. Ideally, conventional sampling techniques should be employed with a control set of the non-injured or studies of a group before and after the disaster, however as the windows of opportunity for carrying out these surveys were closing, it was felt that obtaining the data was more important and the surveying methods reflect this.

2.1 The Questionnaires and Interviews

The thinking behind the design of the questionnaire was simple; it needed to capture what happened to a survivor of an earthquake or tsunami from the moment it happened to where they are now and the factors contributing to their survival. The key relationships explored are human behaviour and the causal pathways of injuries and deaths, seeking out links between types and severity of injuries and their causes.

Table 1: The categories covered in the questionnaires

<table>
<tr><th>Questions</th><th>Tsunamis</th><th>Earthquakes</th></tr>
<tr><td>1)</td><td colspan="2">The physical location of the survivor (whether inside a building or outside)</td></tr>
<tr><td>2)</td><td>Observations of warnings of tsunami</td><td></td></tr>
<tr><td>3)</td><td colspan="2">Aspects of human behaviour in response to the earthquake and tsunamis</td></tr>
<tr><td>4)</td><td>Run-up heights and speed of water</td><td></td></tr>
<tr><td>5)</td><td colspan="2">Physical damage to structures and likely cause</td></tr>
<tr><td>6)</td><td colspan="2">Causes of death and nature and extent of injury to survivors (themselves and others with them)</td></tr>
<tr><td>7)</td><td></td><td>Search and rescue efforts</td></tr>
<tr><td>8)</td><td></td><td>Treatment of injuries</td></tr>
<tr><td>9)</td><td colspan="2">Infrastructure and communication disruption</td></tr>
<tr><td>10)</td><td colspan="2">Where they are now and hopes and concerns for the future</td></tr>
</table>

The survey questionnaire introduced the research aims and sought informed consent, all in the local language. The lead questions were open-ended and carefully ordered to give survivors the opportunity to tell their stories to an empathetic and active listener and these were recorded in field notes. This meant preparing interviewers to focus on the human story, before asking detailed questions about the buildings, their injuries and the aftermath of the disaster. From here the interview sought factual responses to more specific questions. All interviews were carried out in person and interviewers visited homes and temporary housing of survivors in the affected areas. The interviews of eyewitnesses of the South Asian Tsunami were carried out in the UK and were taped. Although it would have been advantageous to tape record testimonies in the field for the other events, it was thought to be inappropriate in these particular countries surveyed.

A comprehensive database framework was established using FileMakerPro structured around the interview questions. The database is fully searchable by region, effect on building, injury types and other aspects of the survivors' experience. There are some obvious limitations to this dataset as a representative sample of those affected. First, it is of course a small sample compared to the number of people affected by the events. Further, we could only interview families who survived and there were families which completely perished. Therefore, for example, we have more reports from the better building types, and from those on flatter lands. The interviews assembled two different kinds of information, descriptive and factual. In many ways the descriptive accounts provide the best evidence of what occurred and what was observed by the survivor, but this information is difficult to summarise or analyse. Each set of forms were translated into the regional language by local collaborators and improvements were made over time as preliminary analyses of collected data revealed limitations or confusion to the data captured in the forms.

3. THE STUDIED EVENTS

3.1 South Asian Tsunami

On 26th December 2004 at 07:58am local time, a magnitude 9Mw earthquake occurred off the west coast of northern Sumatra, Indonesia, the largest to have occurred since the 1964 Prince William Sound Event in Alaska, and only the fourth largest since 1900.

A great tsunami was generated and waves arrived at the coast of Aceh province within half an hour of the main shock. Heavy damage and fatalities were reported from Banda Aceh and other towns in this province. Satellite photos show the true extent of the damage to the city, with large sections in the north of the town completely washed away. The tsunami subsequently traveled east across the Andaman sea and west across the Indian Ocean. In Sri Lanka, a wave reported to be 12m high struck the eastern and southern coast.

According to official figures, over 290,500 people were killed at this event with the worst hit being Indonesia where over 237,071 were listed as dead or missing. In Thailand some of the worst affected areas were tourist resort where thousands of holidaymakers from all over the world lost their lives. In light of this the survey carried out by the team was amongst UK tourists affected by the event. Most interviewed survivors said their survival were aided by being on higher floors of intact buildings and also the ability to move. They witnessed those killed being overcome by water; with the height and volume of water often carrying sizeable debris, it was simply too forceful and many drowned.

3.2 Kashmir Earthquake

This 7.6magnitude earthquake occurred at 8:50am during Ramadan affecting the mountainous areas of Pakistan and India. Over 80,000 people died and over 200,000 people suffered serious injuries. The devastation was immense, many reports citing intensities of X+ at the city of Balakot and Muzaffarabad (EERI, 2005).

The typical failure mode from damage surveys in the area was collapse of walls due to the lack lateral support leading to a subsequent roof collapse. There was also evidence of column failures in 2-storey reinforced concrete buildings. Many of these residential houses in the Kaghan Valley and in Muzaffarabad were on steep instable slopes and houses toppled with the failure of these slopes. Landslides and vulnerable infrastructure also hampered rescue and medical efforts and the media reported at the time, many of the injured were carried for days by relatives down mountains to seek for help.

Surveys suggested most people were inside at the time of the earthquakes, especially men who had returned to bed after waking up early for food before fasting. Mothers were injured when returning indoors to rescue their young children. Over 3,000 schools collapsed, many in the Kaghan Valley were on steep unstable slopes and given that the earthquake occurred in school-hours, many children perished.

3.3 Yogyakarta Earthquake

Centred in the Yogyakarta region of Java, the 6.3Mw earthquake occurred at 5:53am local time killing nearly 6,000 people whilst the injury list exceeded 130,000 (CRED, 2007). An area of 200km^2 of intense shaking (over Intensity VIII) and over 156,000 houses and other structures were totally destroyed. The earthquake occurred on a Saturday and in Yogyakarta it is a working day for public companies but for private companies, schools and universities, it is a holiday and most people were relaxing at home, sitting in their terrace; many of those surveyed were injured by the collapses of these terraces.

The local emergency rescue teams included volunteers supported by government and the community and most of those trapped were rescued within an hour. The level of earthquake knowledge was much higher than in Pakistan coupled with the ease of escape, due to the flat topography, many more survivors moved outside when the earthquake hit (>70% of surveyed respondents moved). This also meant that many in Yogyakarta were not trapped and did not need to be rescued as shown in the chart below comparing rescue times.

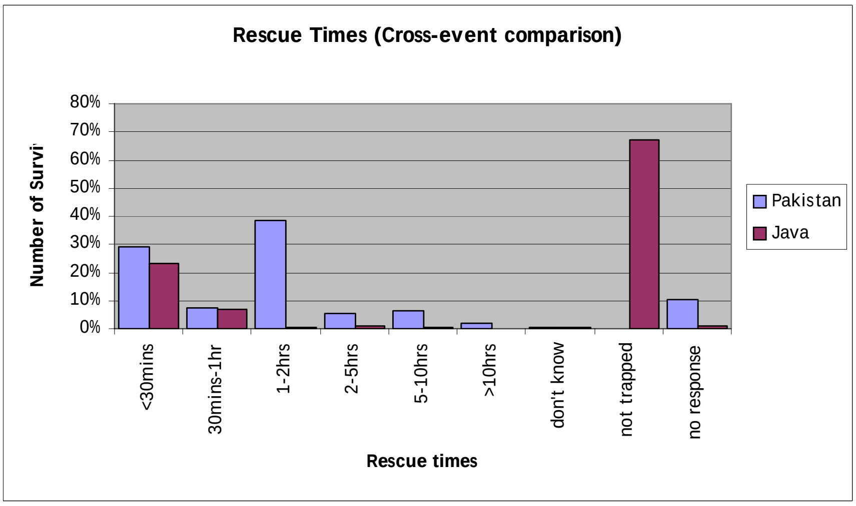

Figure 1: Chart comparing rescue times of trapped victims in the Kashmir and Yogyakarta earthquakes

3.4 Java Tsunami 17th July 2006

The magnitude 7.7 earthquake of 17th July 2006 generated a destructive local tsunami that impacted about 129 miles of the southern coast of the Island of Java. Tsunami waves of up to 5m in height were reported to sweep through fishing villages and resorts on Indonesia's Java Island destroying houses, restaurants, hotels, boats, and spreading devastation 0.5km inland. The death toll stood at 600, with more than 54,000 people displaced. According to local sources, tsunami warning was issued but not disseminated. Surveyed eyewitnesses report that the first wave reached the nearest shore of southern Java within half hour after the earthquake with waves of up to 4-5m along the Pangandaran coast, sweeping cars, motorbikes and boats into hotels and storefronts, homes and restaurants. Most of the reported deaths occurred in this area.

4. SURVEY ANALYSIS RESULTS

Some of the main aspects and conclusions drawn from reviewing these 4 datasets are shown in the table below.

Table 2: Main aspects and conclusions from surveys

					Survey conclusions (from interviewed areas)			
Event	**Mag**	**Time**	**Deaths**	**General Terrain**	**Main type of building stock**	**Main type of injuries**	**Contribution to survival**	**Wait before help arrived**
South Asian Tsunami	9.0	07:58	>290,000	Coastal area	Concrete frame buildings	Cuts and bruises	Luck, rapid action	Seeked help themselves
Kashmir	7.6	08:50	> 73,338	Mountai nous	Stone Masonry with thick concrete roofs (Kalhua)	Lower Extremities fractures	"Help of God"	92% waited for more than a day (average 3 days)
Yogyakarta	6.3	05:53	>5,700	Flat	Unreinforced masonry with tiled pitched roofs (Katcha)	Light head injuries	Moving outside	4% waited for more than a day
Java Tsunami	7.7	15:19	>730	Coastal area	Unreinforced masonry with concrete slab roofs	Minor cuts	Moving to higher grounds	Of the survivors, 58% waited for more than 5 hours

4.1 Comparing the Tsunamis

In both tsunamis, the sea was reported to have receded before the arrival of the sequences of waves. Most survivors had not felt the earthquake and in neither case were warnings issued. Witnesses from the South Asian Tsunami reported accurate inundation depths at the various locations as compared to other sources and when asked what contributed to their survival, where waves were over 5 m high, they cited luck and the fact that the buildings they were in or moved to provided the protection which saved them. Out of the 120 individuals accounted for in the households interviewed in Java after the 17th July 2006 tsunami, 22 (12%) were killed and over 75% were unwounded as they moved to higher grounds. It is evident that even without early warnings quick reaction times do save lives.

Over 70% of the eyewitnesses in the Boxing Day tsunami were in buildings and mostly in concrete frame building, nearly 50% of those were inside. These were however still shown to be vulnerable to the effects of tsunami and 10% of these collapsed and nearly 20% were heavily damaged. In the 17th July Java tsunami, 19% of the interviewed survivors were in a building and all reported collapses. Timber and bamboo framed buildings were all reported to have collapsed (all 10 surveyed). Eyewitness reports strongly suggest that damage was less and survival rates were better in hotels which had open ground floors. When the passage of water was not restricted by walls perpendicular to the flow, water pressure was less intense and the waves or surges were less destructive. Moreover, where ground floors were enclosed, occupants became trapped and were also victims of collapsing masonry infills.

For the two tsunami events, it was clear that deaths were caused by drowning and with pre-warning and those who headed to higher grounds, injuries were only minor in the forms of cuts and bruises. What is interesting in comparing the two events is the difference in reaction times and also levels of fear of survivors. In the South Asian tsunami 2 years before the Yogyakarta event, only a small percentage knew what tsunamis were and 90% reported to being extremely frightened. In contrast, during the July 2007 event, over 40% of the interviewed survivors were reported to be only slightly frightened and responders headed inland rather than towards the sea to watch the receding waterline.

4.2 Comparing the Earthquakes

The two charts below show the casualty severity breakdown for the interviewed households according to damage states of their dwellings (if they were inside at the time of the earthquakes), supporting the hypothesis that most severe injuries are caused by structural collapses (damage state D5) and some injuries are caused by failure of non-structure or contents: these are mostly in buildings which do not collapse (D1-4). However, what existing casualty models do not show are serious injuries related to lower damage states.

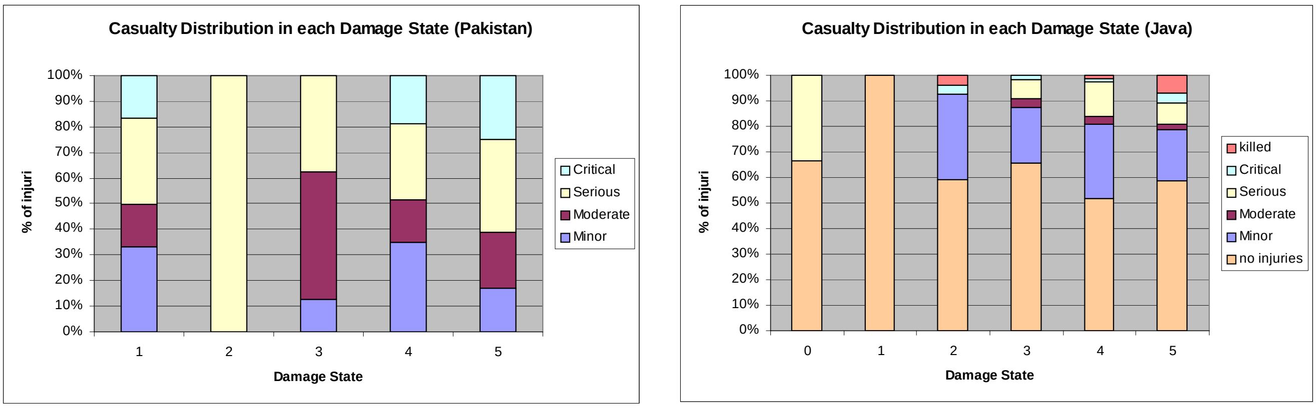

Figure 2: Charts comparing casualty distribution in each damage state

For both events, the surveyed results show that for those inside buildings at the time of the earthquake, nearly all deaths and injuries are directly caused by building collapse as assumed by models such as HAZUS (FEMA, 1999) and the Cambridge Casualty Model (Coburn and Spence, 2002). What the surveys show is that there are a significant number of people who do survive in completely collapsed buildings: out of 269 collapsed dwellings in Yogyakarta, only 3% of inhabitants were killed. There is also strong evidence to support the hypothesis that those in buildings which do not collapse have a much lower risk of death; in Yogyakarta, out of 40 reported deaths, only 5 were in buildings which did not collapse.

Unfortunately, the datasets have not produced convincing evidence of different death and entrapment rates between different types of construction when these collapse. Taking Yogyakarta as an example, most collapsed housing was of brick masonry but only 30% of those in these buildings were trapped. By contrast, in Pakistan almost all of those who were in collapsed buildings were trapped (over 92%) but there is little to distinguish between forms of construction, which were mainly of concrete block closely followed by stone masonry. This could imply 2 things: first that people were more likely to be trapped in concrete block and other unreinforced masonry buildings with concrete or heavy roofing typical of northern Pakistan or the data suggest that entrapment also depends on other factors like evasive action. 83% of the respondents who were not trapped in D5 buildings in Indonesia also moved as the earthquake struck. What the surveys have highlighted in terms of evasive action is that people who moved in Yogyakarta also knew what earthquakes were (>80% of respondents who moved, also had knowledge of earthquakes). This is an area still under assessment at the moment but raises interesting questions of climate, culture and knowledge as contributors to the proportion of occupant entrapment in collapsed buildings.

Although the 2 earthquakes happened at different times of the day, the majority of the survivors interviewed were indoors at the time of the earthquake. In the case of Kashmir, nearly 90% were in collapsed buildings and out of these; over 90% were trapped inside these collapsed heavy masonry houses. However, by contrast, although nearly 70% were in collapsed houses in Indonesia, only 35% were trapped and these do explain the differences in severity and types of injuries experienced in these earthquakes shown in Table 2. Amongst the survivors who were outside at the time of the earthquake, in Kashmir, all of these were injured in some way, mainly due to falling debris from closely spaced housing.

There is therefore one common key finding arising from the cross- event analyses carried out from these surveys and that is: taking evasive action saves lives. In spite of the lack of early warning from the local governments, people who took evasive action by running to higher grounds in both tsunamis survived. Similarly, the ability to move out of the collapsing buildings, helped by weaker ground motions, the collapse mechanisms and availability and proximity of safe open spaces outside the buildings saved lives in Yogyakarta. The devastation in terms of damaged dwellings in Yogyakarta was substantial but many more survived than in Pakistan.

6. RELEVANCE OF RESULTS TO FUTURE EVENTS

Although this work is not complete, the preliminary analysis of the datasets has not only provided us with details on building damage associated with these events and tested the robustness of accepted wisdom on casualty occurrence but also provided an insight into the complexity of estimating casualties due to the specific characteristics of each event and the possible scenarios associated with each respondent. For example, a survivor could have survived suffering only minor injuries in a collapsed unreinforced masonry house in Yogyakarta because he was by the door at the time and his knowledge of earthquake made him move outside where there is sufficient space. By contrast, where there is no warning given when a tsunami is generated, therefore there may be little time to react and take evasive action as the high waters move in. In such cases, the integrity of the house becomes irrelevant and evasive action is essential.

The samples of eyewitnesses interviewed in these studies were relatively small, it is clear that such surveys can reveal aspects of the event which post-event reconnaissance missions cannot. Collectively, these datasets are invaluable in raising questions on what should be considered in casualty estimation models and disaster mitigation and management, highlighting that loss estimation, especially in casualty rates in current published sources fall far short of accurately modeling of what happens in reality. The data collected is aimed at assisting in the development of casualty loss modelling to include tsunami risk areas, for insurance, for urban management and development; and calls for new parameters to be included in future approaches for both developed and developing countries with high seismic hazards.

7. CONCLUSIONS

It is evident that the integration of engineering studies with those of other disciplines such as architecture, social sciences and epidemiological studies is essential for improved understanding of injuries following earthquakes and tsunamis. Better epidemiological knowledge of risk factors for death and the type of injuries and illness caused by earthquakes is clearly an essential requirement for determining what relief supplies, equipment and personnel are needed to respond effectively to earthquakes.

Through our study of the collected datasets, as engineers we have improved our understanding of the nature of tsunami impacts on buildings and the built environment and through our multidisciplinary approach have extended this to capturing the history of survivors of recent earthquake events. It is intended that a worldwide database of survivor accounts and casualty will be compiled with other researchers in the field to preserve this valuable information (Spence et al, 2008).

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