DISCUSSION ON HUMAN LOSSES FROM EARTHQUAKE MODELS

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ABSTRACT

Several studies and methodologies had been developed during these years to model the number of victims and injuries caused by natural disasters like earthquakes. Unfortunately, models and simulators developed up to now show substantial variability in the numbers of victims when compared with real values, because they not include a multi-parameter analysis such as seismic intensity, building damage degree, percent of occupancy at the time of the event, individual behaviour (age, gender, etc.) or emergency response (effectiveness in response).

As we know, the most important risk factors for earthquake-induced mortality/injury are the degree of damage, type of the building and occupation index.

Another important risk factor is the location of the person inside the building, his mobility within the house during the shaking and the hour of the event.

People reactions prior and during the shaking together with the building behaviour causes great differences on the amount of deaths and injures for a given earthquake. The European Macroseismic Scale (EMS-98) provides 5 grades for damage classification from "Negligible to slight damage (D1) to Collapse (D5). While D5 class includes total or near total collapse of the buildings, we propose a class $D5^+$ to represent totally collapsed structures separately from almost collapsed which can establish a direct relation between damage grade and death percent.

Data from a few events in Portugal and Italy illustrate the difficulties in estimating human losses.

1. BACKGROUND

Outcomes of models and simulators developed to estimate casualties (fatalities and injuries) caused by natural events like earthquakes show systematically great variability between modelled and observed values.
This paper examines some factors that induce earthquake casualties as well as some conclusions obtained from recent earthquakes that can be incorporated into epidemiological studies in order to contribute to a rapid casualty assessment.
Accuracy of the model for earthquake casualties depends clearly on the rate of occupancy and on the damage state of a building. We cannot advance with any reliable estimate if these two ingredients are not present. A more adequate description of the building damage, especially in what concerns the total collapse as well as the rate of occupancy at the time of the event are crucial elements for a more realistic estimation. In what refers the first point, census information on building classes should be always updated specially on new construction and replacement of old construction. Totally collapsed reinforced concrete buildings are responsible for almost 100% of the occupant's death. For this reason we propose to Damage Level $D5^+$ which corresponds to this damage, solving the controversy in language between collapse in structural analysis which means "imminence of collapse", and real total collapse as we should have in estimating death toll.
In relation to the population inside the building we propose a "building occupancy" indicator, which measures the percentage of the population at the time of the earthquake. Census information is very crude and possibly misleading. For instance, in Algarve – south Portugal, the census 2001 values for December in a few large towns are 50% of the population present. This is due to large mobility of the population. In summer, due to touristic attraction, the population present is almost 5 times the Census values. But the problem to get the "occupancy indicator" at the time of the event is much more complex than a good estimator of mobility. It has to do with the impending of the event which can diverse the population from their houses to feel more safe in other places, as it has happen in recent events where fore-shocks were felt.
Figures 1 and 2 show the distribution of the fatalities in earthquakes in the last century. Figure 1 shows that fatalities grow with magnitude starting already with M5, in such a difficult pattern that many variables need to be considered in the process to reduce uncertainties to a reasonable value. Correlation with heavily damaged buildings is slightly better (Figure 2) but dispersion is still so large (in some cases with 5 orders of magnitude) that those values are of no use in simulation. In fact, the approximate mean value of victims being 30% of the number of "heavily damaged" buildings do not represent a reasonable rule for estimating victims.
Although the fatal consequences of large earthquakes depends on their proximity to urban populations, the vulnerability of dwellings including the construction type, and the time of day (Hough et al., 2006), it is also clear that some variables like "building occupancy" and "population dynamics" during the day can not be discarded in this studies and estimations.

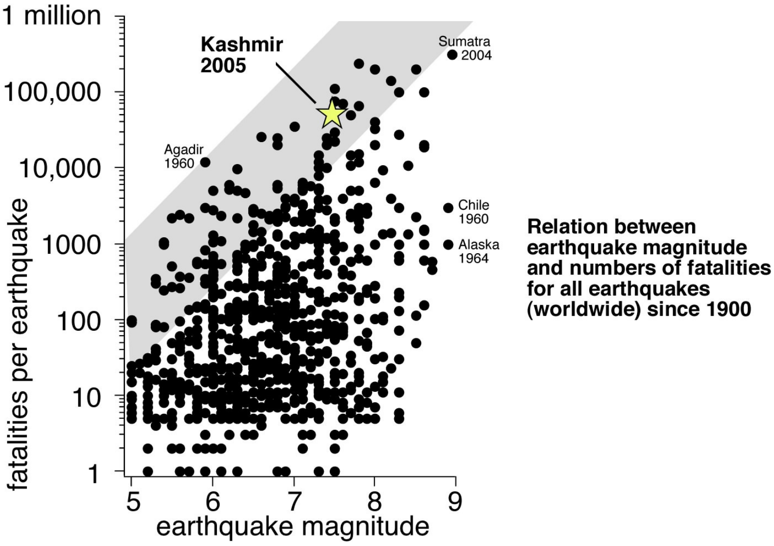

Fig. 1 Relation between earthquake magnitude and numbers of fatalities for all earthquakes since 1900 (Hough & Bilham, 2006)

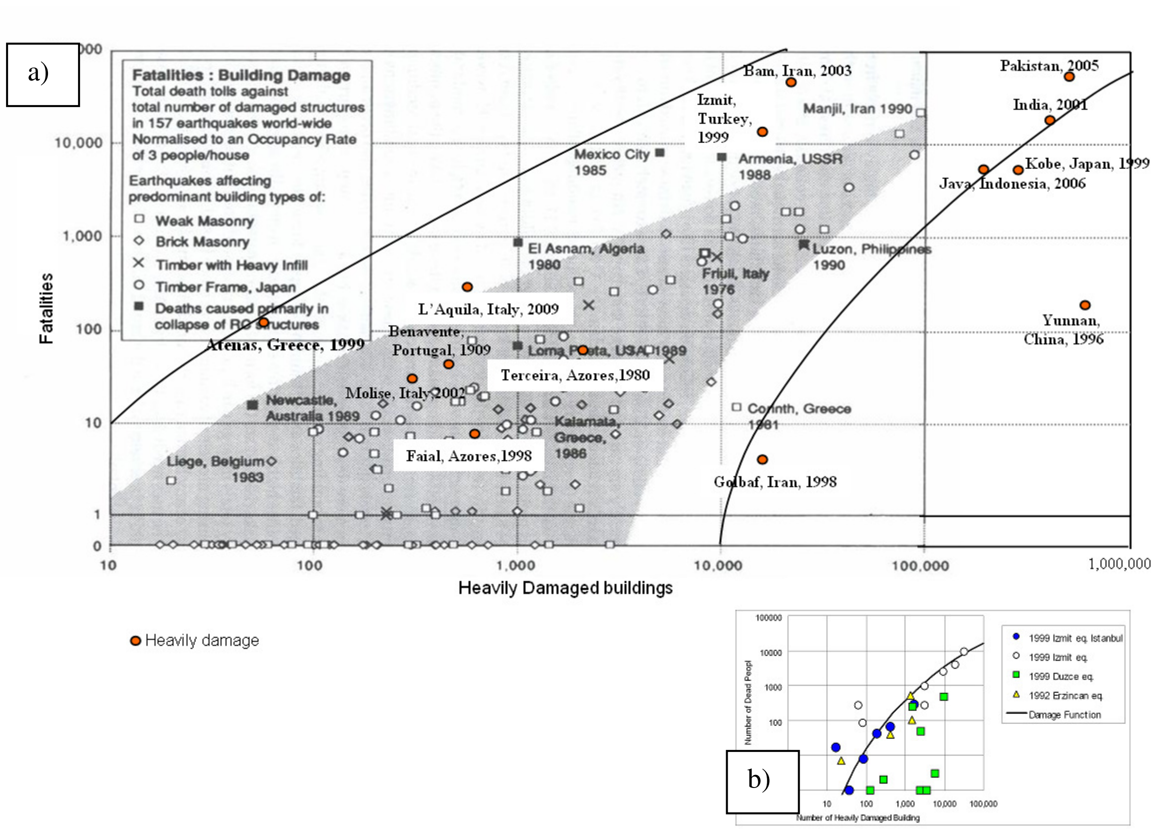

Fig. 2 Relation between heavily damaged buildings and the number of resulting deaths: a) adapted from Coburn & Spence, 1992; b) Erzincan and Izmit earthquakes

2. RESULTS FROM RECENTS EARTHQUAKES

1.1 L'Aquila Earthquake (Italy)

On April 6, 2009 an earthquake (M_L 5.8) rocked the mountainous Abruzzo region of central Italy, in the Holy Week, causing 306 deaths - 22 children (from 4 months-old to 14 years old) – and 1500 injuries (10% severely injured). According to Italian Civil Protection reports, around 62 200 persons are homeless: 24 300 are being housed in hotels near the Adriatic Coast and 9 400 have found accommodation with friends or relatives, 28 500 are living in tent villages (protezionecivile.it).

The population of L'Aquila province is 72 500 according to 2007 Census (comuni-italiani.it); if we divided the total number of deaths by the total population we obtained a mortality rate of 0.42%,

1.1.1 Post-Earthquake Numbers

The vast information assembled from the World Wide Web (Ferreira, 2009) has contributed to understand the relatively low death toll as well as other information free to use and updated.

Figure 3 summarizes the evolution of the number of fatalities during the first week from April 6 to 13, 2009.

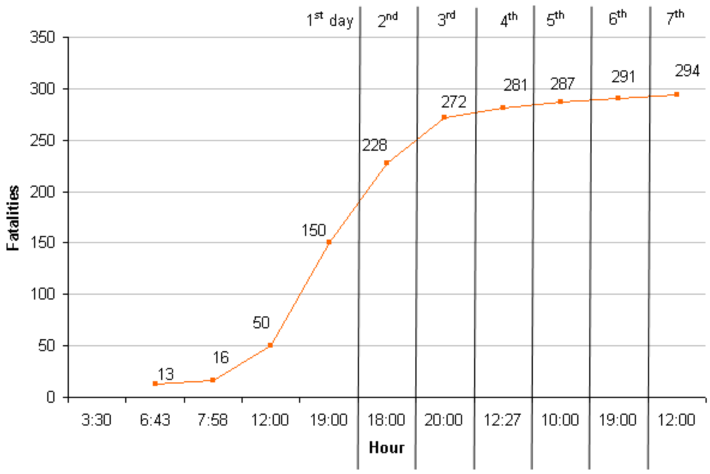

Fig. 3. Number of victims during the first week (Ferreira, 2009)

Using a list containing name, age, gender and addresses of all victims (176 female and 130 male), accessible on "Il Centro" online newspaper, a pyramid of ages was built (Figure 4), while Table 1 displays the spatial distribution of deaths by location. An analyse of Figure 4 shows that the distribution per age has two modes, one between 70 and 80 year range and the other between 20-29 with a large peak for the 20-24 year range. The lowest mortality group corresponds to those in the 35-44 year range.

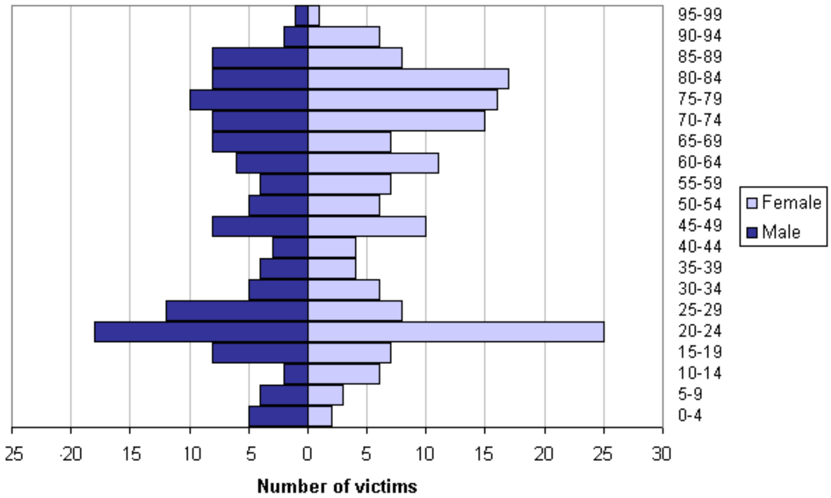

Fig. 4. Age and gender of total victims

L'Aquila is a university city with approximately 23 000 students; the peak value at those aged 20-24 was due to the half-collapse of the dormitory of the University of L'Aquila as well as other houses that collapsed/damaged located in the centre. The youngest victim is a boy with 4 months and the oldest a female with 96 years old.

Table 1 Spatial distribution of fatalities (Source:"Il Centro") – some examples
(Note: 11 people died few days after the event due to earthquake severe diseases or heart attacks)

Locality	*Comune*	Total fatalities	Fatalities after some days
Bazzano	L'Aquila	1	
Civita di Bagno	L'Aquila	2	
L'Aquila	L'Aquila	199	9 (2 heart attack)
Onna	L'Aquila	40	
Paganica	L'Aquila	5	
Locality	*Comune*	Total fatalities	Fatalities after some days
Pianola	L'Aquila	2	(1 heart attack)
Poggio di Roio	L'Aquila	1	
Roio Piano	L'Aquila	2	
San Gregorio	L'Aquila	8	
Sant'Angelo di Bagno	L'Aquila	1	
Tempera	L'Aquila	7	
Castelnuovo	San Pio delle Camere	5	
Fossa	Fossa	4	
Lucoli	Lucoli	1	
Poggio Picenze	Poggio Picenze	5	
San Demetrio	San Demetrio Ne' Vestini	2	
Tornimparte	Tornimparte	2	1
Villa Sant'Angelo	Villa Sant'Angelo	17	
Unknown		2	

Table 2 Addresses and number of fatalities – L'Aquila centre (Source: "Il Centro")

Address	Number of facilities
via Angioina, 23	1
via Antinori, 26	1
via Arischia	3
via Borgo di Rivera	1
via Campo di Fossa	21 (14 of them on N.º 6 and 6/B)
via del Capro, 29	2
via Cimino, 37	1
via Cola Dell'Amatrice, 17	8 (7 of them on N.º 17)
via Coppito	3
via degli Scardassieri	3
via Fortebraccio	3
via Francesco De Marchi, 7	1
via Gabriele D'Annunzio	13 (5 of them on N.º 24)
via Giuseppe Garibaldi	2
via Generale Francesco Rossi	5 (3 of them on N.º 22)
via Gennaro Finamore	2
via Gualtieri d'Ocre	2
via Madonna di Pettino	1
via Piave, 14	1
via Poggio Santa Maria, 8	7
via Porcinari, 20	1
via Roma	3
Address	Number of facilities
via Sant'Andrea	9
via XX Settembre	28 (11 on N.º 46 - Casa dello Studente – and 7 on N.º79)
No address	27

In L'Aquila historical centre where 199 people died the pattern was essentially 6-8 people per collapse ($D5^+$) building. Counting only these ones we arrive to about 30%-40% casualty rate for buildings having $D5^+$. The worst conditions were 10 to 14 people death per building (see Table 2).
The other hundred people were groups of 1-2 person spread throughout the region. The number of deaths in localities situated in the valley (near the fault trace) was about 1-3 per locality (rural areas) with exception of Onna and Villa Sant'Angelo where the death toll must have been 1-3 per building.

1.1.2 Understanding the Death Toll

Despite the considerable destruction that has occurred in L'Aquila province, relatively low casualty rates were verified and could be explained by :

i) The circumstances prior to the event with felt seismicity in the last two months before the earthquake scarred lots of people and some of them had decided to sleep outside. The warning announced by Giampaolo Giuliani from Laboratori Nazionali del Gran Sasso (although the earthquake occurred about a week later than he has predicted and at another locality - Sulmona about 70 km south of L'Aquila) and the foreshock four hours before the main event also contributed to save a great number of lifes. Social behaviour showed that few families changed housing in order to

feel more secure close to their relatives or were camping in their own garden or sleeping in the cars near their homes.
ii) Many houses in L'Aquila are second home used only to spend weekends. The earthquake occurred on Monday at 3.32 a.m. when people were on their main homes out of L'Aquila.

In contrast high mortality was verified among young people, students that returned back from weekend to L'Aquila and were caught by the earthquake in their apartments or Casa dello Studente (dormitory of University of L'Aquila). Also high mortality was observed in highly vulnerable rural or semirural areas with a poorly built environment like Onna where from 350 inhabitants living in 150 houses (1-3 storeys) there were 40 deaths corresponding to a death ratio of 11%. A preliminary Onna assessment (aerial view) indicates that about 50% of the building stock suffered total collapse ($D5^+$).

2.1 Azores and Benavente Earthquakes (Portugal)

In Portugal, for low rise buildings the rate of mortality according to historical data is very small, either in the Continent or in the Azores Islands, with exception of the 1755 Lisbon event. In rural and historical urban areas the construction typology is very similar throughout the different geographic regions with only differences in materials which are region dependent; the population habits are also very similar.
In this section we present a few earthquakes that shook mainland Portugal and Azores islands during the last century.

2.1.1 Azores

The 1980 Azores earthquake on January 1 devastated Terceira, São Jorge and Graciosa islands at 4:42 p.m. causing a death rate of 0.1%. At the time of the earthquake, many people were outside in the streets and consequently the building occupancy was very small. Only 63 people died.
During the 1998 Azores earthquake (Faial), where the housing stock is predominant one to two storey stone masonry houses, death and injury was substantially low (death rate: 0.05%) in face of the immense damage observed due to:

i) a high number of houses are secondary houses (seasonal), with no one inside;
ii) the outwards collapse of outer walls, remaining the inner partition walls protecting the inhabitants from the fall of roof (the earthquake occurred at 5 a.m. when most of the inhabitants were sleeping)
iii) a fore-shock took place 20 min before the main shock and probably initiated some individual alert.

2.1.2. Benavente

Benavente is a municipality of continental Portugal where the 1909 event, caused by rupture in the Lower Tagus Valley Fault Zone, destroyed few villages. Benavente was in 1909 composed by 3557 inhabitants and about 400 buildings (950 dwellings). The earthquake killed 30 people, 0.8% of total population, and 40% of housing stock were demolished.
The apparent low impact in lives was caused by:
i) the time – at 5 p.m. – in the afternoon a great part of the inhabitants, mostly agricultural workers, were out in the open, working on their farms/lands and;
ii) roofs and partition walls persisted, with no collapse, but the outer walls of buildings collapsed killing a few children that were playing near the houses (Rodrigues D'Azevedo, 1926).

With these descriptions we propose a graph (Fig. 5) which tries to explain the evolution of mortality rate take into account the type of structure and damage grade. In face of entirely reinforced concrete (RC) building collapse ($D5^+$) there is no chance of survive and mortality rate can reach 98-100%.

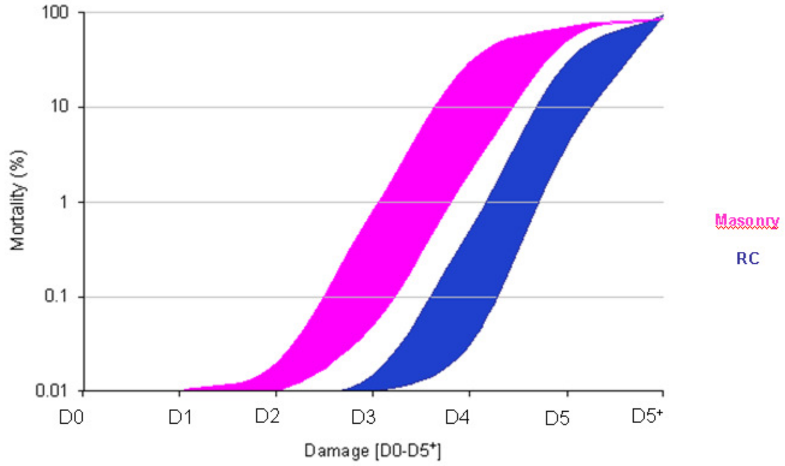

Fig. 5 Relation between building damage grade (masonry and reinforced concrete buildings) and percentage of deaths - proposal

3. HUMAN CASUALTY MODELS

Human casualty models should be looked in two different perspectives:

i) In the case of design a system for civil protection, insurance, urban planning, etc, where a population scenario has to be developed, including population dynamics more adequate to the study under consideration.

ii) To a rapid casualty assessment and emergency response in the case of a given earthquake, it is important to develop a human behaviour model in order to produce better results than the ones obtained with current scenarios/models. Besides the population dynamics along the day and year the model, to give more consistent information should include, among others, the following "building occupancy" indexes:

- signs of prediction;
- early-perception;
- panic reaction.

These indexes are very difficult to extract but the examples presented in Section 2 show how critical they are for a more accurate estimation of human casualties.

When analyzing complex themes, we have to take care to avoid oversimplification of the problem, loosing the relevant aspects of it and loosing the view of the target problem. Thus, mortality rate computations cannot be trivially explained in a straightforward manner using only the Census data due to the fact that mobility is not taken in to account in many cases.

Another example is related with tourist places where population growth could easily duplicate, like is verified in Faial island (Azores) during the Sea Week festival (between the first and second Sundays of August) where 12 000 people are present in this week, while Census indicates only 5 000 residents (Oliveira *et al.*, 2008), or in Algarve as already mentioned. To a rapid assessment after an event, the single use of Census data could generate wrong estimated population exposed to earthquake.

4. ACKNOWLEDGMENT

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