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METHODOLOGIES FOR ESTIMATING THE SOCIOECONOMIC IMPACTS OF LARGE EARTHQUAKES: A MULTIDISCIPLINARY RESEARCH APPROACH

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ABSTRACT

The objective of this research is to develop new methods for estimating the likely emergency response resource needs, mitigation opportunities, and socioeconomic impacts of large earthquakes in ways that allow inclusion of such methods in loss estimation models.

Using a Geographic Information System (GIS) based loss estimation model being developed at Stanford University with support from researchers at the University of California at Los Angeles, the impact assessment team from the University of California at Berkeley is developing new socioeconomic loss estimation methods capable of being included in GIS systems. These methods will be capable of predicting the response problems, social impact consequences, and direct and indirect economic effects of damages to critical facilities due to large earthquakes.

KEYWORDS

Socioeconomic; loss estimation; modelling; impacts; critical facilities; GIS; case study; emergency response.

MODELLING SOCIOECONOMIC IMPACTS

The objective of this research is to develop new methods for estimating the likely emergency response resource needs and socioeconomic impacts of large earthquakes in ways that allow inclusion of such methods in loss estimation models.

A multidisciplinary team of engineers and social scientists is developing new methods of estimating the local and regional consequences of damage to critical facilities and lifelines. Financially supported by Kajima Corporation of Japan, this project is being done under the auspices of the California Universities for Research in Earthquake Engineering (CUREe).

Conceptual Approach

The purpose of identifying critical facilities is to provide the owner of those facilities guidance about what pre-earthquake mitigation or post-earthquake emergency preparedness activities should be taken to limit the most adverse consequences of the earthquake. Adverse consequences are lumped into three categories: high dollar losses from direct damage; high casualty losses; and high economic impact due to functional loss of a facility.

Different types of facility owners will be impacted by these three types of adverse losses in different ways. For many public facility owners, especially lifeline operators, long duration disruption of critical services can lead to very high functional economic impact losses, and hence may warrant some improvement in post-earthquake response. For other types of owners, especially private building owners, direct damage and casualty loss potentials may make a facility critical, and hence may warrant some pre-earthquake mitigation actions.

One aspect of the research is the explicit consideration that earthquake losses occur at two time intervals: during the earthquake and after the earthquake. If the sum of these two sets of losses is sufficiently high for a particular facility, then that facility is relatively more critical. This project develops the methodology to explicitly calculate the "during" and "after" earthquake losses. In particular, two possible strategies are studied to reduce earthquake losses for these critical facilities: first, the owner could perform some pre-earthquake mitigation, like seismic strengthening, to reduce the direct damage and casualty losses; second, the owner could prepare better emergency response plans, so that more resources can be mobilized after the earthquake, thereby reducing the duration of time when the facility is not available, thereby reducing the functional losses.

Identifying Critical Facilities

A Critical Facility is one that fails in an earthquake (or which did not exist prior to the earthquake) such that an unacceptably high level of adverse consequences occurs after the earthquake. Adverse consequences include (but are not limited to):

1. High Damage Loss Potential

2. High Life Loss Potential

3. High Functionality Loss Potential

Some definitions are presented to provide a quantitative analysis as to which specific facilities are "most" critical:

- Facilities are structures and components of structures. For example, a structure might be a mid-rise reinforced concrete building which functions as a hospital. For another example, a component might be a diesel generator located at the hospital, which must function when off site power is lost after an earthquake.

- Facilities are part of Systems. A System is a combination of facilities (structures and components) which work together. For example, a water distribution network is a System, composed of many structures and components, such as pumping plant buildings, underground pipes, pumps, motors, and tanks.

- A System may be essential or non-essential. An Essential System is one which provides an Essential Service after an earthquake. A non-essential system is one which provides non-essential services after an earthquake.

Therefore, a facility is critical if:

"The consequences of failure of the facility results in unacceptably high losses to society".

Failure of a facility could be manifested in several ways:

1. The facility collapses in the earthquake. This leads to a high dollar repair cost, and disrupts society.

2. The facility collapses or is damaged, leading to major loss of life or serious casualties.

3. A component of the facility does not work (like a backup power generator), which renders the facility out-of-service right after the earthquake. Because the facility is out of service, essential services cannot be delivered.

4. The lack of adequate number of facilities, even if they are all undamaged, could also be called a "failure". For example, if the earthquake causes 10 fires, and there are only three fire trucks in the community, fires may spread and cause unacceptably high losses.

<u>Ranking Critical Facilities</u>

Just about everything in a community can be considered "critical" to somebody, for some purpose. What is needed is a methodology, or Ranking System, by which one can sort out the more critical facilities from the less critical facilities out of the entire inventory of buildings and infrastructure in the community.

The methodology that drives this ranking system is the estimation of the total economic impact from the failure of a facility or the lack of emergency response on the community. The key emphasis of the methodology is to provide tools to rapidly assist the "owner" (or owners) of the inventory, assess which parts of the inventory are likely to be the most critical. Once this initial sort is done, then the owners can begin to perform detailed benefit-cost analyses to study different mitigation or emergency response strategies that may be effective in dealing with these critical structures.

The study then applies this methodology to the Palo Alto area. It should be pointed out that since the case study is geared to an entire city, the methodology has been generalized to process the large numbers of structures. For practical application, a government institution, for example, that owns just a subset of the total city's building inventory, the methodology is applied in much the same manner, but with a small inventory, with perhaps higher resolution of the items in the inventory.

<u>Direct Damage</u>. In the formulation of direct damage, the value for each structure is based on the actual replacement value of the structure (excluding land). To somewhat simplify the current effort, it does not differentiate between the value of the superstructure from the value of the interior non-structural items.

The probability that a building reaches a particular damage state is the *median* probability. For general loss estimation purposes, like tabulating the total losses expected within a city, it is reasonable to use the median. It is recognized that not all buildings of a particular type will suffer the median level of damage predicted for that type of building as a whole. For global loss estimation purposes, it is often assumed that the sum of all the medians will approximate the sum of the actual damage distributions. Since the loss rates are nonlinear, the sum of the medians is not necessarily the same as the sum of the actual distribution, but for practical planning purposes, such an approximation is usually sufficient.

However, if the purpose of the loss study is to identify critical buildings, perhaps for the purpose of developing an insurance premium, it is very important to study the actual distribution of damage within a building class. If, for example, the insurance company wishes to set premium with a deductible at 10% of the building's value, then the insurance company will wish to know what percentage of buildings will have losses under 10% of value (in which case they pay out nothing after the earthquake), as well as what percentage of buildings suffer higher damage rates (11% through 100%).

The direct damage to each individual building is calculated. This involves the estimation of ground motion at that building location; the choice of a fragility curve for that type of building; use of the fragility curves to estimate the probabilities of that building being in one of four damage states (the fifth damage state, undamaged, is neglected); and the application of an equation to calculate the direct damage loss.

The "critical" building in terms of high direct damage loss potential is then simply the ordinal ranking of the resulting losses. It should be recognized that the total ranking of whether the building is "critical" is the sum of all losses associated with the building (direct plus casualty plus functional).

<u>Casualty Losses</u>. The model for casualty losses takes into consideration the two time periods of the earthquake: during the period of ground shaking and after the ground stops shaking. We consider this distinction an improvement over past casualty loss estimation techniques, in that it directly provides us with a tool to study the effectiveness (or lack thereof) of post-earthquake urban search and rescue and hospital services.

To narrow the focus of the current effort, casualties occur in one of four categories, stemming from direct damage to the building inventory.

1. <u>Injury requiring basic medical attention, but not requiring hospitalization.</u> The basic medical attention can be provided by other citizens or by the victim. This type of injury does not impose need for post-earthquake emergency services. Examples are bruises, cuts, etc.

2. <u>Injury requiring hospitalization, but not needing immediate attention.</u> The medical attention can be provided at a convenient time (perhaps several days after the earthquake), without any particular threat to the victim of rapidly degrading medical condition. This type of injury might include broken fingers, moderate bruising, etc.

3. <u>Injury requiring rapid hospitalization.</u> This type of injury most often occurs in buildings that have partially collapsed, entrapping victims, and causing serious injury to the victims (crushing of limbs, etc.). Medical attention may be given by emergency workers at the scene of the injury, or at hospitals or other health care facilities. If there are insufficient medical services rapidly available, a significant portion of these types of injuries will lead to fatality of the victim.

4. <u>Instant fatality</u>. Instant fatalities generally occur due to collapse or partial collapse of

structures which result in rapid expiration, well before any possible relief effort can be mobilized.

In most major earthquakes, most casualties occur due to damage to buildings. However, casualties can also arise due to bridge collapse, (direct casualty, or accident casualty due to people driving off a damaged bridge), inundation (dam or aqueduct failure), electrocution (dropped live power lines), burns (entrapped victims within collapsed and burning structures), etc. The current effort does not consider these types of casualties.

To apply the casualty model, calculate the expected number of casualties in each individual structure using daytime occupancy rates for the building. The equation should be repeated for nighttime occupancy, owing to the great differences in day to night occupancies for many types of structures. For the purposes of a city-wide study, the occupancy rates can be developed based on generalized inventory data. For application to subsets of the total inventory, accurate occupancy rates for each structure can be established through discussions with the owners.

<u>Functional Losses</u>. The identification of critical structures in terms of their functional loss is more difficult than the identification of critical structures in terms of direct damage or casualty losses. The main issues that make such identifications difficult are as follows:

- For conventional-use building owners, losses include direct damage losses (building repair, building replacement, content replacement, inventory losses); casualty losses (severe injuries, fatalities); and functional losses (business interruption losses; relocation expenses; loss of income; and rental income losses).

- For lifeline operators, functional losses include all the above, plus the economic impacts that are caused by service disruptions. For example, factories cannot operate without electricity, even if the factory is undamaged and people and material are available.

- For water lifeline operators, functional losses are further compounded by the potential fire following earthquakes due to the lack of water for firefighting purposes.

A unifying theme is that the amount of functional loss is closely tied to the duration of time after the earthquake when the structure/system/component is functionally unavailable. For example, the losses to the economy will continue to climb for every day that lifeline operators cannot provide service (water, power, etc.). Therefore, the key to estimation of these functional losses is the evaluation of how fast the direct damages get "fixed" after the earthquake.

Conceptually, it is possible to estimate the functional losses after an earthquake in a three step approach:

1. <u>Estimate the demand for post-earthquake service as a function of time.</u> This will be a function of the amount of damage that occurred. For example, the earthquake will cause casualties, direct losses, and socio-economic impacts collectively, the consequences of the earthquake. These consequences create a demand for certain types of services. Immediately after the earthquake, the demand for certain services (fire fighting) will be very high, much higher than normal, and depending upon the effectiveness of the supply of these services, the demand may return to near normal levels shortly after the earthquake. Other types of demands may be very low immediately after the earthquake, but increase with time; one example is temporary housing.

2. Estimate the supply of post-earthquake service as a function of time. This should consider the amount of damage and mobilization or repair forces. To mitigate the adverse consequences, society will need to supply post-earthquake services. For example, these services include fire fighting, urban search and rescue, temporary housing, etc. Depending upon the damage distribution, some of these services will be supplied from within the earthquake-affected area, and some will be supplied from outside the earthquake-affected area. In all cases, it will take some amount of time to mobilize the needed services after the earthquake, longer if the earthquake-affected-area has extensive damage.

3. The shortage of services (demand less supply) can be multiplied by suitable constants to convert the functional losses into economic losses. Depending upon the type of service, the constants could convert the value of urban search and rescue teams versus the prevention of fatalities from casualty type 3; or convert the value of water service to business interruption economic impacts.

Case Study: City of Palo Alto, California.

To estimate functional losses due to failure of a particular facility, the methodology examines post-earthquake response resources from three areas: first, within Palo Alto itself; second, within other areas nearby Palo Alto, which are also affected by the earthquake: third, from distant locations which are not affected by the earthquake. These resources provide mutual aid workers; fire trucks; etc., which are all factored in determining how long it takes to restore functional service for a particular facility. The availability of resources for various emergency services will depend upon concurrent damage and resource demands in nearby strongly shaken areas, as well as the ease of moving these resources to the Palo Alto area.

Four scenario earthquakes are studied, namely San Andreas fault magnitude 8 and 7.5 events; and Hayward fault magnitude 7 and 7.5 events. The inventory used in this report includes over 18,000 privately-owned structures in Palo Alto (about 90% of all structures); 220 miles of distribution pipe and associated reservoirs and pump stations for the City of Palo Alto's water distribution system; and the resources of the Palo Alto fire department. Aspects of the methodology which are explored are: identification of high dollar loss critical structures; structures which cause a high number of instant fatalities; structures which cause a high number of critical injuries requiring rapid victim extraction and hospitalization (otherwise the victims may die); examination of water system damage and outage duration in different parts of Palo Alto; number of fire ignitions within Palo Alto; and potential fire spread within Palo Alto; and indirect losses due to water lifeline system outage within Palo Alto.

Example: Economic Impact of Water Service Outages. After a San Andreas M 8.0 event, there are expected to be about 343 pipe repairs that will need to be performed. Repair work can begin only after the main aqueducts are returned to service, beginning about three days after the earthquake. In the following paragraphs, it can be studied whether the breakage of the distribution pipe creates "critical" function losses.

The average number of manhours to perform emergency pipe repairs (dig holes in street, fix pipe, flush pipe) is 20 manhours per repair, average. It is assumed that the City of Palo Alto's water department, being a small agency, will be able to muster six repair staff on day three after the earthquake, increasing to 12 repair staff by day seven after the earthquake. If no mutual aid repair people are available, and assuming each person works 12 hour days, six days per week, then the time to fix all pipes (100% customer service restoration) will be:

Time after Earthquake	Pipe to be Repaired	Repair Crew Staff	Customers with Water
0 hours	343	0	22%
3 days	343	6	65%
4 days	340	9	70%
5 days	335	10	71%
6 days	329	12	71%
7 days	323	12	72%
	repair 6 per day	12	linear increase
60 days	0	12	100%

By applying the methodology being developed in this effort, it is hoped to provide a balanced approach for decision makers in identifying which facilities are critical, and to balance the corrective actions between candidate facilities for pre-earthquake mitigation upgrades, and candidate emergency response plans which can be improved to limit the adverse consequences of long functional outages.

RESULTS

To date, conceptual models for these elements have been developed and data requirements have been determined. Detailed data about the City of Palo Alto has been collected, and this will be supplemented by field work. Response and consequence information is being collected from studies of previous earthquakes and by analyzing common loss estimation methods currently in use or being developed.

Using damage state information and previous work on benefit/cost analysis for hazard mitigation and seismic rehabilitation, the economic modelling will provide methods for estimating local economic impacts on individual buildings, such as hospitals.

It is expected that at the conclusion of this three year research project, software and manuals will be produced that will enhance earthquake loss estimation approaches and methods for estimating emergency response resource needs and strategies. It also is expected that another result will be to show how priorities might be established for replacing or strengthening facilities and systems so that the most serious short and long term socioeconomic consequences could be ameliorated through mitigation.

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