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LIFE-SAFETY AND BENEFIT-COST-RISK FACTOR ANALYSIS FOR SEISMIC UPGRADING DECISIONS OF DIFFERENT TYPES OF HAZARDOUS STRUCTURES

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SUMMARY

Presented in this paper is an analysis and a case study of a multi-disciplinary approach to seismic upgrading of existing hazardous structures. A parametric study of benefit-cost factors is made in terms of lives saved per rehabilitation dollars due to the direct effects of earthquakes for different levels of seismic upgrading technology. These factors are assessed in terms of cost-effectiveness for increments of life-safety improvement. The paper also presents a case study of a multi-disciplinary approach involving trade-offs among socio-economic, political, and technical factors affecting life-safety for existing hazardous structures in earthquake zones.

INTRODUCTION AND OBJECTIVE

This paper deals with the development of a seismic rehabilitation systems methodology applicable to different parts of the country and the world (Refs. 1,2). It deals with techno-economic-social interaction in decision making and implementation of retrofit of existing hazardous structures and contents in structures. Some private buildings bought over and planned with community redevelopment agency funding for future development in Los Angeles are discussed from the viewpoint of life-safety. This is a multi-disciplinary approach with the aim towards systemic integration towards urban seismic risk reduction. The emphasis is on analysis for designing suitable policy and implementation strategies. Although the paper gives case studies about life safety of buildings for determining effectiveness reconstruction money, the authors realize that the mobility and seismic safety in open spaces between buildings (due to failure of secondary and non-structural elements such as glass, etc.) is also a crucial factor. The approach in this paper is contrasted with the benefit-cost ratio or rate of return methods used for private sector rehabilitation when there is no low interest government loads. In some cases, using some of the damage probability models, Day and Rao (Ref. 3) show that even when the interest rate is as high as 15%, commercial buildings could be economically rehabilitated for higher levels of seismic upgrading to limit damages as against protection of cost-effective safety only.

CURRENT STATUS OF SEISMICALLY HAZARDOUS STRUCTURES

Currently, there are thousands of seismic hazardous buildings in U.S.A. and other parts of the world. For example, Los Angeles and Long Beach areas have approximately 9,000 unreinforced masonry buildings that were built before 1933 in which approximately 1 million people live or work in them according to Sarin (Ref. 4). The cost of strengthening these buildings against seismic force is estimated to be around $1 billion. Sarin also points out that while the cost for upgrading the buildings is large, the risk to property, human life, economic production is much more significant (Refs. 5 and 6).

In the Boston metropolitan, Whitman (Ref. 7) estimates that about 5,000 buildings are very susceptible to moderate or severe damage in Metropolitan Boston during an earthquake similar to that experienced in 1755. These range from unreinforced brick buildings to some poorly reinforced concrete buildings. Taken together, these particularly vulnerable/hazardous structures typically shelter from 60,000 to 120,000 people depending upon the time of day and week. They further estimate that another 700,000 to a million people are in buildings which have only modest resistance to ground shaking.

CONSEQUENCES OF EARTHQUAKES

The consequences of earthquake can be measured by life loss, injury and structural collapse or damage. Life loss and injury are the focus for our building codes and most other community regulations (Ref. 8). Property damage, both to the structure and its contents, bear on the economic wellbeing of the occupants and the community. Functional disruption is also important since the indirect consequences of earthquake damage are measured in multiples of the actual physical damage.

In addition, the 1980's study of the consequences of a major catastrophic earthquake in California was completed for the President's Office through the National Security Council (Ref. 9)indicates that the damage resulting from an earthquake creates abundant opportunities for litigation. These litigation opportunities are great for lawyers, especially when you note that about one in seven U.S. lawyers practices in California. It does not take much imagination to conclude that an earthquake provides an unparalleled opportunity for litigation.

COST AND LEVELS OF SEISMIC UPGRADING

The development of a rehabilitation system perspective for existing structures for multiple hazards is a complicated task and involves several technical, policy, socio-behavioral and economic considerations, is quite complex, and is discussed in Ref. 8.

The problem of cost vs. seismic risk is the heart of the existing structures problem and the likelihood of damage from unsatisfactory or poor earthquake performance and the cost of that damage in terms of repair and other incidental losses and expenses. Day and Rao (Ref. 10) showed cases of commercial structures where rehabilitation to limit damages was more economical than just designing for life-safety even when interest rates were 15%, with stringent Long Beach earthquake requirements (as compared to Los Angeles area).

Earthquake damage is a function of earthquake magnitude, the distance from the facility, location of the building relative to the fault, and the site's response spectrum. Fig. 1 illustrates the variation of mean damage with distance for the 1906 San Francisco and the 1971 San Fernando earthquakes (Ref. 11) which indicates that magnitude, in itself, is not a strong indicator of damageability unless it is coupled with the distance of the building from the fault.

EARTHQUAKE DAMAGE: PROPERTY LOSS, HOMELESS, INJURIES

Simply stated, earthquake hazard mitigation refers to the steps (engineering and nonengineering - policy, institutional, land-use, etc.) taken in order to mitigate the consequences of earthquake hazards. The consequences of earthquake hazards are the varying amounts of damage to different elements within a community due to the occurrence of a seismic event. Earthquake damage may be quantified in three general categories: (1) damages to building structures and properties (2) loss of life or injury and (3) loss of functional and economic production.

An effective seismic mitigation policy must therefore reduce and lessen the expected damage levels of these three categories. This reduction of direct damage levels to structures in the first category also impacts the second category. With the structures experiencing lesser amounts of damage, the people housed within those structures will in effect be safer; hence, the potential loss of life and injury to persons will also be reduced. Additionally, stronger new structures and rehabilitated, older structures will have a higher probability of retaining their post earthquake functioning. This will, in turn, positively effect the third category by lessening the loss of economic production following a seismic event that would have occurred if the structure had become non-functional due to excessive damage.

For the rest of the paper, the following are used:

Damage Factor (DF) = Dollar Loss (DL) / Replacement Value (RV)
Damage Ratio (DR) = Number of Buildings Damaged / Total Number of Buildings

Fig. 2 shows the variations of different estimates by different researchers for earthquake Zone 3.

LIFE SAFETY: LIFE LOSSES AND INJURIES

The methodologies for assessing potential life loss and injuries have been studied by many investigators, such as Algermissen et al (Ref. 12), Steinbrugge et al (Refs. 13 and 14). Steinbrugge shows that death and injuries are a function of construction type, number of occupants and failures of man-made facilities, such as dams, bridges, buildings.

In his studies, Steinbrugge (Ref. 14) gives the realistic current attainable life safety goals (LSRG) for various building classes which are listed in the last column of Table 1 and the benefit-cost ratio (BCR) can be expressed as follows:

$$BCR = \frac{(LSR).(ESOa).(SCF) - (LSRG).(ECOb).(SCF)}{(10{,}000).(RC)} \qquad \text{.......................} \quad (1)$$

in which:

BCR = Benefit-Cost Ratio, being the number of postulated lives saved for reconstruction dollars
LSR = Life-Safety Ratio, being the postulated number of fatalities per 10,000 building occupants prior to reconstruction for a particular type of structures for the level of shaking appropriate to the seismic zone
ECOa = Equivalent continuous occupancy prior to reconstruction, being the theoretical estimated number of persons continuously occupying the structure on a 24 hour basis, 365 days per year
ECOb = Same as ECOa, except after reconstruction
SCF = Seismicity Correction Factor, being a coefficient applied to subzones of the study area to account for differences in seismicity. This factor is 1 where the seismicity is uniform throughout the study area
LSRG = Life Safety Ratio Goal, being the attainable life safety goal that could be achieved by changing the use of or strengthening the building
RC = Reconstruction cost, being the cost to strengthen a given type of building so as to reduce the life hazard to the Life Safety Goal (LSRG) specified for the particular class of cuilding in reports.

CASE STUDIES OF SEISMIC REHABILITATION

This section presents examples of seismic risk analysis, rehabilitation process and life loss for existing buildings in downtown Los Angeles and Long Beach areas. These buildings were classified as seismic hazardous buildings; however, they were identified by Community Redevelopment Agency as historical buildings. The detailed discussion of these buildings is given in Refs. 1 and 3.

1. Arcade building on 541 S. Spring Street, Los Angeles
2. Security building on 500 S. Spring Street, Los Angeles, Fig. 3 & Table
3. Rowan building on 131 W. Street, Los Angeles
4. Bullock's Wilshire store on Wilshire Blvd., Los Angeles
5. Bank Huntley Building on 63243 S. Spring Street, Los Angeles
6. Benamil Building on 1620-1630 E. Anaheim Street, Long Beach

The methodology for estimating damages uses the work of Sauter and Shah (Ref. 15). Life-safety tables and realistic goals empirically estimated by Steinbrugge et al. (Ref. 14) and recurrence estimates of earthquake of different magnitude by Sieh et al. (Ref. 16). The procedure for estimating life loss reduction based on 10,000 population with parametric studies.

In these case studies, percentage of damages as a function of replacement is plotted as a function of intensity of ground shaking for the existing and upgraded condition so that benefit cost ratio can be calculated in terms of damage avoidance, and for Arcade building, the benefit cost factor in terms of life saved per reconstruction dollar. Refs. 1 and 3 describes complete studies of these buildings. Engineering calculations were done at Costa & Assoc., W.Covina.

CONCLUSIONS

This paper presented methods for estimating of seismicity, development of upgrading schemes, estimation of property loss in terms of replacement cost basis vs. loss probabilities in the next 50 years and percentage loss vs. effective maximum ground acceleration or intensity of ground shaking, and life-safety benefit-cost-risk factors using Steinbrugge's estimates. These methods deal with the techno-economic-social concerns of earthquake hazard mitigation. The results of the research are the development of an analytical framework with case studies applicable to different parts of the U.S. Preparedness and mitigation measures to improve life-safety of existing structures and facilities are incorporated into a techno-economic and social systems framework useful for implementation at local levels. The results for upgrading a multi-story concrete building, steel building, and an unreinforced masonry building are given in the paper. The table shows the risk improvements for steel bracing for a U-shaped 10-story building with existing terracotta cladding. The results show risk improvement for probable maximum loss is around 90 and around 2, for a 50-year maximum probable loss, while the cost-effectiveness is around 7.93 and 2.4, respectively; thereby indicating that it is worthwhile to seismically upgrade this building. Significant risk improvement in terms of Probably Maximum Loss is seen in this case, compared to the Arcade Building, while in terms of a 50-year period it is not significantly higher.

TABLE

Benefit Cost Factor for Security Building Using Ref. 16

Value at risk		$15,000,000
Estimated direct upgrade structural cost		700,000
		50 yr. E/Q loss
As-is condition	$8,850,000	$ 2,850,000
Upgrade condition	3,300,000	1,200,000
Loss reduction	5,550,000	1,650,000
Structural upgrade cost effectiveness	7.93	2.4
Risk improvement	90	2.0

REFERENCES

1. Rao, J.K., Gulkarov, B., and Petak W.J., "Political, Social, Economic Aspects of Life-Safety of Hazardous Structures in Earthquake Zones," Proceedings of the Third World Conference on Engineering, Charleston South Carolina, August 24-28, 1986.

2. Nguyen, R.P., "Rehabilitation of Existing Earthquake Hazardous Buildings" ASCE Structures Congress '86 Conference, New Orleans, Louisiana, September 15-18, 1986

3. Rao, J.K., Gulkarov, B., and Day, J., "Existing Hazardous Structures: Techno-Economic-Social Systems Analysis with Case Studies of Seismic Upgrading," Proceedings of the Third World Conference on Earthquake Engineering, Charleston, South Carolina, August 24-28, 1986.

4. Sarin, R.K., "A Social Decision Analysis of the Earthquake Safety Problem: The Case of Existing Los Angeles Buildings", Risk Analysis, Vol. 3, No. 1, pp. 35-50, 1983.

5. Long Beach Municipal Code, Subdivision of 80 of Part 1 of Chapter 1, Ordinance No. C-3600, 1959.

6. "Earthquake Hazard Reduction in Existing Buildings", Los Angeles Municipal Code, Ordinance No. 154, 807, approved January 1981.

7. Whitman, R.V., Remmer, N.S., and Schumacker, B., "Feasibility of Regulatory Guidelines for Earthquake Hazards Reduction in Existing Buildings in Northeast," Pub. No. R80-44, Department of Civil Engr., MIT, Cambridge, Mass.

8. Nguyen, R.P., Rao, J.K., "Countermeasures for Earthquake Rehabilitation of Existing Hazardous Masonry Building with Case Studies," Proceedings of the 1988 International Symposium on Earthquake Countermeasures, Beijing, China, May 1988.

9. An Assessment of the Consequences and Preparedness for a Catastrophic California Earthquake: Findings and Actions Taken, Federal Emergency Management Agency, Washington, D.C., 1980.

10. Day, J.E., and Rao, J.K., "Earthquake Hazard Mitigation: Public Policy, Technology, and Economic Factors Integrated in a Balanced Seismic Safety Program," Dept. of Civil Engr., California State University, Long Beach.

11. Thiel, C.C., "Earthquake Hazards, Risk and Managing Liability," Achieving Urban Conservation and Minimizing Earthquake Risk Seminar, Long Beach, Oct. 28, 1987.

12. Algermissen, S.T., Steinbrugge, K.V., and Lagorio, H.J., Estimation of Earthquake Losses to Buildings, Open File Report 78-441, n.p., Geological Survey, 1978.

13. Rojahn, C.R., et al., "Development of Earthquake Damage and Loss Estimates for Facilities in California", Proceedings of the Eighth World Conference on Earthquake Engineering, San Francisco, July 1984.

14. Steinbrugge, K.V., Algermissen, S.T., Lagorio, H.J., "Determining Monetary Losses and Casualties for Use in Earthquake Mitigation and Disaster Response Planning," Proceedings of the Eighth World Conference on Earthquake Engineering, San Francisco, July 1984.

15. Sauter, F., and Shah, H.C., Eestudio de Seguro Costa Terramoto, Instituto Nacional de Seguro, Costa Rica, 1987.

16. Sieh, K., and Jahns, R., "Study of Holocene Displacement History Along the South-Central Reach of the San Andreas Fault", Report under Contract No. 14-08-001-15525, Stanford University, San Francisco, 1977.

Table 1 - Life Safety Ratio

Simplified Description of Building Class	Life Safety Ratio Earthquake Resitive Buildings
1A Small Wood Frame	2
1B Large Wood Frame	5
2A Small All-Metal	2
2B Large All-Metal	6
3A Steel Frame, superior	5
3B Steel Frame, ordinary	15
3C Steel Frame, intermed.	10
3D Steel Frame, wood floor	25
4A Reinf. Conc., superior	25
4B Reinf. Conc., ordinary	75
4C Reinf. Conc., intermed.	50
4D Reinf. Conc., wood floor	75
5A Small Mixed Const., Dwellings	10
5B Mixed Const., superior	15
5C Mixed Const., ordinary	20
5D Mixed Const., interm.	40
5E Mixed Const., unreinf.	40

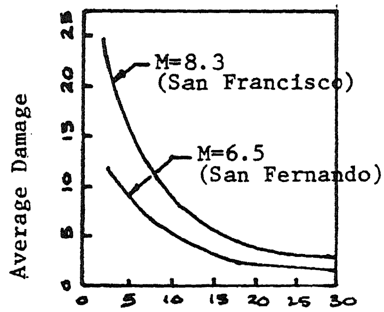


Fig. 1 - Average Damage, $M, Versus Distance

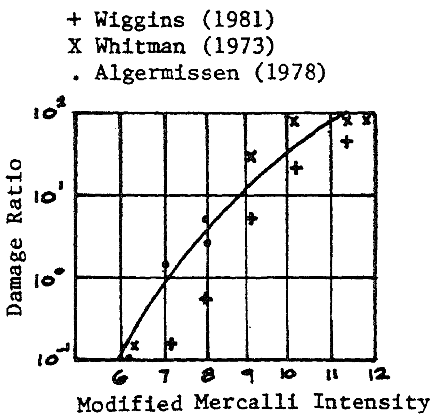
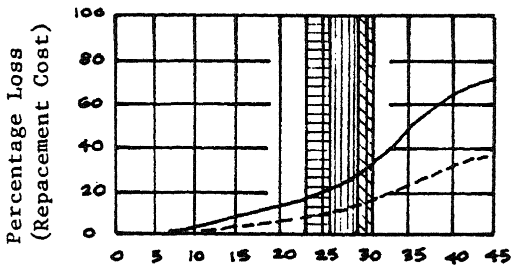


Fig. 2 - Mean Damage Ratio for Q4 Quality Equivalent to UBC Zone 4 Design



Effective Maximum Ground Acceleration

——— As existing condition

----- Upgraded condition

Fig. 3 - Property Damage Potential Curves for Security Building