ESTABLISHING PRIORITIES AND FINANCING FOR SEISMIC STRENGTHENING OF EXISTING BUILDINGS IN CALIFORNIA

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SUMMARY

Two methods of screening large groups of public buildings for potential seismic hazards and setting priorities for hazard mitigation in California are described in this paper. A general methodology using historical seismic performance data for various structural systems, occupancy and reconstruction costs is described. An evaluation methodology based on professional judgment is also described. Limitations of the methodologies are discussed as are funding possibilities for hazard mitigation.

INTRODUCTION

The problem of reviewing large numbers of existing buildings for potential seismic hazards and establishing priorities for detailed study and eventual hazard mitigation is an overwhelming problem for both engineers and administrators. With limited funds available to do engineering studies and strengthen buildings with poor anticipated seismic performance, an effective planning process becomes critical.

The paper describes recent experience in California, where a study established initial priorities for seismic strengthening of buildings owned by the State of California. Using a general methodology developed by the California Seismic Safety Commission, data was gathered on over 1350 buildings, and their relative potential Benefit Cost Ratios were established based on occupancy, building construction, seismic zonation and typical rehabilitation costs. A previous and separate study of University of California buildings, based on a judgmental methodology, provided further insight for planning to mitigate potential seismic hazards.

The presenting author had the privilege of performing both studies under contract with the Seismic Safety Commission and the University of California.

The paper not only describes these studies, but it also includes the presenting author's evaluation of the strengths and weaknesses of the methodologies. It also suggests procedures for further actions to achieve the strengthening of selected buildings which will most effectively

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reduce potential loss of life in a damaging earthquake. The paper also discusses attempts at financing mitigation measures by the State of California.

SEISMIC STRENGTHENING PRIORITY METHODOLOGIES

A General Methodology

A methodology was developed by the Seismic Safety Commission of the State of California (Ref. 1) to evaluate the seismic hazard of state-owned buildings. The methodology was based on historical evidence that certain classes of buildings have an inherent capability to resist earthquakes, even though they may not have been specifically designed to resist them. Likewise, it attempts to recognize the traditional poor performance of other types of construction.

The methodology results in an equation which yields a cost benefit ratio indicating where funds can most effectively be spent to reduce the potential hazard for the greatest number of occupants. The expression is:

$$\text{Benefit Cost Ratio (BCR)} = \frac{(LSR)^{*}\ (ECO)^{*}\ (SCF)^{*} - (LSRG)\ (ECO)^{**}}{10{,}000\ (RC)}$$

*denotes prior to reconstruction
**denotes after reconstruction

The terms are defined as follows:

BCR, Benefit-Cost Ratio, is the numbers of postulated lives saved per reconstruction dollar.

LSR, Life-Safety Ratio, is the postulated number of fatalities per 10,000 occupants for a particular type of structure for the level of shaking appropriate to the seismic zone in which the structure is located. Table 1 contains LSR data for various classes of buildings, which are described in more detail in Ref. (1).

ECO, Equivalent Continuous Occupancy, is the theoretical estimated number of persons continuously occupying the structure on a 24 hour basis, 365 days per year.

SCF, Seismicity Correction Factor, being a multiplier used to account for different seismicity (size and frequency of earthquakes) depending on the seismic zone in which the building is located, taken as 1.0 and 0.75 for different parts of California.

LSRG, Life Safety Ratio Goal, being the attainable life safety goal that could be achieved by changing the use of or strengthening the building. Based on experience, Table 1 contains estimates for attainable life safety goals for various classes of buildings.

TABLE 1

LIFE SAFETY RATIOS AND GOALS FOR BUILDINGS (FROM Ref. 1)

BUILDING CLASS		SUMMARY DESCRIPTIONS (Detailed definitions are attached)	LSR'S FOR BLDG. DESIGNED FOR EARTHQUAKES		LSR'S FOR BLDG. NOT DESIGNED FOR EARTHQUAKES	ATTAINABLE LIFE SAFETY GOALS (LSG)
						GOAL
I.	A	Small wood frame	2		4	2/10,000
	B'	Large wood frame	5		10	5/10,000
II.	A	Small all metal	2		4	2/10,000
	B	Large all metal	8		15	8/10,000
III.	A	Steel frame, poured concrete walls	5		10	5/10,000
	B	Steel frame, curtain walls	15		40	10/10,000
	C	Steel frame, better than III. B	10		25	5/10,000
	D	Steel frame, weak diaphram & walls	25		50	15/10,000
	E	III. A for auditoriums, long spans, etc.	25		50	15/10,000
	F	III.B for auditoriums, long spans, etc.	50		1500	15/10,000
			Non-ductile Concrete	Ductile Concrete		
IV.	A	Concrete frame & walls	50	25	100	15/10,000
	B	Concrete frame, floors, curtain walls	300 (600)	75	1000	25/10,000
	C	Better than IV. B	200 (400)	50	500	25/10,000
	D	Precast or lift slab	500 (1000)	75	1500	25/10,000
	E	Concrete frame, weak walls & diaphrams	800 (1600)	100	2000	25/10,000
	F	IV. A for auditoriums, long spans, etc.	75 (150)	50	200	35/10,000
	G	IV. B,D,E for auditoriums, long spans, etc.	1000 (2000)	200	2500	35/10,000
V.	A	Small mixed dwellings & similar	10		200	10/10,000
	B	Mixed superior tilt-up	15		800	15/10,000
	C	V.B. with ordinary control features	20 (100)		1000	15/10,000
	D	Mixed Concrete, precast reinforced masonry	40 (80)		2000	15/10,000
	E	Unreinforced masonry, wood, etc.			4000	15/10,000
	F	Adobe, hollow tile			5000	15/10,000

RC, Reconstruction Cost, being the cost to rehabilitate a given type of building so as to reduce the life hazard to the Life Safety Goal specified for the particular class of building in question.

An initial survey of about 1350 buildings owned by the State of California was performed in 1981 (Ref. 2). Forms were developed to gather data on dates of construction, type of structural system, size of building, type of occupancy, special earthquake resistant features and major structural remodeling. The equivalent continuous occupancy was estimated by the users. The data was gathered for the nine campuses of the University of California, the nineteen campuses of the California State University and Colleges and for state office buildings. The data was reviewed by H.J. Degenkolb Associates under contract with the Seismic Safety Commission. Life safety ratios and goals were assigned and the data was placed in a computer under a specially written program. Reconstruction costs were estimated at 65% of replacement cost based on published averages of current construction costs for various types of buildings. The report listed each building by its Benefit-Cost Ratio (BCR). This resulted in a de facto preliminary list of priorities to guide detailed structural reviews, reconstruction planning, and the preparation of cost estimates.

A Judgmental Methodology

A somewhat different approach to evaluate the potential hazards of buildings was developed by the University of California in 1975 (Ref. 3). The University Policy-Seismic Safety created four performance categories of buildings based on their expected behavior in damaging earthquakes which in turn establishes priorities for seismic strengthening of groups of structures. Utilizing his professional judgment, the policy requires the ratings to be established by a Consulting Structural Engineer experienced in field investigations and analyses of damage in earthquakes.

The four categories of anticipated seismic performance in this approach are defined as follows:

GOOD seismic performance rating would apply to buildings and other structures whose performance during a major seismic disturbance is anticipated to results in some structural and/or nonstructural damage and/or falling hazards that would not significantly jeopardize life. Buildings and other structures with a GOOD rating would have a level of seismic resistance such that funds need not be spent to improve their seismic resistance to gain greater life safety and would represent an acceptable level of earthquake safety.

FAIR seismic performance rating would apply to buildings and other structures whose performance during a major seismic disturbance is anticipated to result in structural and nonstructural damage and/or falling hazards that would represent low life hazards. Buildings and other structures with a FAIR seismic performance rating would be given a low priority for expenditures to improve their seismic resistance and/or to reduce falling hazards so the buildings would be reclassified GOOD.

POOR seismic performance rating would apply to buildings and other structures whose performance during a major seismic disturbance is anticipated to result in significant structural and nonstructural damage and/or falling hazards that would represent appreciable life hazards. Such buildings or structures either would be given a high priority for expenditures to improve their seismic resistance and/or to reduce falling hazards so that the building could be reclassified GOOD, or would be considered for other abatement programs, such as reduction of occupancy.

VERY POOR seismic performance rating would apply to the buildings and other structures whose performance during a major seismic disturbance is anticipated to result in extensive structural and nonstructural damage, potential structural collapse, and/or falling hazards that would represent high life hazards. Such buildings or structures either would be given the highest priority for expenditures to improve their seismic resistance and/or to reduce falling hazards so that the building could be reclassified GOOD, or would be considered for other abatement programs, such as reduction of occupancy.

Major seismic disturbance is defined for the purposes of these Seismic Performance ratings as an earthquake at the site which would be given a Modified Mercalli Intensity Scale (as modified by Charles F. Richter in 1958) rating of at least IX based on the description of the structural effects. It is assumed that the intensity of ground shaking is not appreciably greater in areas rated MM X, MM XI, and MM XII than in areas rated MM IX. The damage descriptions in MM X, MM XI and MM XII related more to the geologic features and non-building structures.

An initial evaluation of all major buildings of the nine campuses of the University of California was performed in 1978 (Ref. 4) to determine the order of magnitude of the potential seismic hazards of the University's buildings and determine an order of magnitude cost estimate to mitigate those potential hazards. Approximately 750 buildings consisting of 4,100,000 square meters (44,000,000 square feet) of floor area were evaluated in a very brief, cursory method based on judgment and experience. The result showed that about 80% of the total floor area was rated Good or Fair indicating relatively low potential hazards. The approximately 20% of floor area tentatively rated Poor or Very Poor was estimated in 1978 to represent a cost of $300,000,000 to mitigate while an additional $200,000,000 would be necessary to improve seismic resistance in the buildings rated Fair. The notes from this brief evaluation have assisted the University in identifying buildings for detailed study.

Evaluation of Methodologies

The general methodology of the Seismic Safety Commission can provide a reasonable method for establishing priorities for further detailed investigation when many buildings need to be screened. In processing the data for Ref. 2 and reflecting on the results for logic, several suggestions are offered for future usage of the methodology. The Life Safety Ratios for several building classes do not seem to fully reflect the potential hazards, especially for non-ductile concrete framed buildings and tilt-up concrete buildings, and recommended changes by the presenting author are those in brackets in Table 1. Also, buildings with auditoriums or long spans should be pro-rated between LSR's for the area of building containing auditoriums or long spans and the remainder of the building ignoring the long span area. These classes were to recognize traditional vulnerability of large theatres, etc., but the typical large academic building with one or two large auditorium-type lecture halls [defined at 232 square meters (2500 square feet)] receives an inflated hazard potential when the whole building receives the higher LSR. The methodology also does not consider non-human occupancies, and sensitive laboratories or facilities containing chemicals, nuclear products or fire-producing agents must be separately prioritized. It should be noted that the building classes deal only with typical California buildings, and extension to other parts of the world will require a Table 1 custom developed for structural systems present in the geographic area to be studied.

This generalized methodology can also be used to establish priorities for reconstruction. After a series of detailed building evaluations have been performed, and with schematic strengthening schemes prepared with budget cost estimates, the methodology can be used to prioritize buildings. With reasonable cost estimates, the methodology can indicate where funds can do the most good to protect the most lives. Obviously, the final decision must be based on judgment considering all factors, not the sole result of a BCR based on the methodology. At best, the methodology can group buildings for a judgmental decision.

The judgmental methodology of the University of California has worked well at identifying structures which may perform poorly in a strong seismic event. The approach is based on judgment so it is subject to the prejudices and intuition of the engineer assigning the ratings. It currently assumes that ground shaking is uniform throughout California, although the University is considering a modification to the policy to reflect varying seismicity at its nine campuses. Using this methodology, it only segregates buildings into four categories so additional prioritization is necessary. Pending availability of funding, each campus would prioritize its Very Poors and Poors and then the University's Systemwide Administration would assign University-wide priorities, considering anticipated earthquake potential at the various campuses, the nature of the building deficiency, the occupancy and the cost of repairs. Seismic strengthening would be combined with other major remodeling projects whenever possible.

Perhaps the best methodology is to combine the two described, utilizing both the historic data and professional judgment. The final decision of which building to fix when, must be based on many factors, some of which are beyond those which can be supplied by engineers.

POTENTIAL IMPLEMENTATION

The long term success of programs to abate the hazards from non-earthquake resistant buildings will be determined by finding acceptable methods to ameliorate the costs. Without such assistance, political pressure probably will cause the modification or revocation of some requirements, especially local ordinances.

At the state level, there appears to be increasing willingness to find solutions to this problem. In 1979, the California Seismic Safety Commission stated that one of its "most important goals is the methodical reduction of these hazards by strengthening, rehabilitating, or replacing such buildings or changing their uses to lower occupancies, thus reducing the risk to life." (Ref. 5) In a companion report (Ref. 6), the Commission outlined a model process to help guide local governments in establishing hazard abatement programs.

Several state legislative measures have been introduced in the last five years to deal with problems of hazardous buildings. Some have been successful and some have not. In 1979, provisions were added to the Health and Safety Code allowing local governments to adopt special "life safety standards" for the rehabilitation of unreinforced masonry buildings. The new law noted that, "In order to make building reconstruction economically feasible for, and to provide improvements of the safety of life in, seismically hazardous buildings, building standards enacted by local government for building reconstruction may differ from building standards which now govern new building construction." (Ref. 7) Statewide minimum performance standards were specified, such as requiring the development of a complete bracing system to resist earthquake forces.

In 1982, legislation was passed authorizing local governments in California to obligate the state for a total of $200 million to help owners finance the costs of reconstruction. A companion measure failed; it would have raised another $150 million. The money would have been used to replace or reconstruct hazardous public buildings, such as fire and police stations, communication centers, city halls, and others.

During the 1983-84 Regular Session of the Legislature, two items related to hazardous buildings were considered. One was a resolution (which does not have the force of law) requesting several state agencies and the University of California to require: (1) an engineering inspection before leasing space; (2) the independent review of future building plans by the Office of the State Architect; and (3) a detailed inspection program of state-owned buildings. Final action will be taken in 1984. The second was a proposed law which would exempt from property tax increases improvements made to unreinforced masonry bearing wall buildings for purposes of earthquake safety. This would be an important tax incentive for building owners. It passed, and was signed into law, effective January 1, 1984.

Some additional proposals are outlined in a new report by the Seismic Safety Commission (Ref. 8). With regard to hazardous buildings, it proposes that about $1 million be spent to help local governments identify and inspect potentially hazardous buildings. For state-owned buildings, the report proposes $83 million be spent for evaluations and actual reconstruction. Last, the report recommends that a $500 million bond issue be approved by the voters to finance a statewide low interest loan program to help finance the reconstruction of earthquake hazardous buildings. The Commission apparently intends to pursue implementation of these recommendations through legislative and executive means.

CONCLUSIONS

1. Two methodologies for setting priorities for public buildings in California for possible seismic strengthening measures have been described and initial implementation reported. Limitations and recommended improvements have been suggested.

2. Prioritizing facilities for seismic hazard mitigation must have foundations in technical and historical procedures similar to those described, but the ultimate decision of hazard mitigation must be based on judgment considering all pertinent factors.

3. Legislation to finance seismic hazard mitigation is essential if potential loss of life in public buildings in California is to be reduced. Possible funding methods are described, and the authors applaud all efforts towards their fulfillment.

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