A STRATEGY FOR SETTING PRIORITIES FOR THE EVALUATION OF SEISMIC RESISTANCE OF EXISTING BUILDINGS

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SUMMARY

A simple and inexpensive two "sieve" strategy is presented for setting priorities for the evaluation of the seismic resistance of existing buildings.

The first sieve relates probable earthquake damage to the type of building and the intensity of ground shaking given on regional acceleration contour maps. Buildings where major damage is anticipated are screened again.

The second sieve is based on Japanese studies of the Hochinohe Earthquake of 1968. By plotting a curve of each building of the group of buildings under consideration, the ordinate as the building weight divided by the resisting element areas and the abscissa as the resisting element areas divided by the total floor area, a priority of building resistance is established. Buildings falling in the left upper portion of the plot are judged to be the highest priority requiring detailed structural evaluations.

With this strategy, states, local governments and owners of large numbers of buildings in active seismic regions can quickly identify those structures requiring high priority evaluation.

INTRODUCTION

Detailed assessment of the seismic resistance of an existing structure is costly and time consuming. The United States government owns hundreds of thousands of buildings and other structures that may be vulnerable to earthquakes (1). Thus, a high priority of the Program is to develop a strategy to identify Federal structures that present high seismic risks. Such a strategy would also be useful to states, local governments, and other owners of large numbers of buildings in active seismic areas.

This paper presents a simple, rapid, and inexpensive "two-sieve" technical strategy for setting priorities in the evaluation of the seismic resistance of existing buildings. The strategy is based on earthquake damage studies and regional assessments of seismic risk. The strategy is outlined in Figure 1.

After buildings are ranked by priority, detailed analyses and field investigations are necessary to evaluate the actual level of earthquake resistance of those structures found to be most vulnerable.

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REGIONAL ASSESSMENT OF SEISMIC RISK

A comprehensive assessment of regional earthquake risk in the United States was developed as a part of the ATC 3-06 Report of the Applied Technology Council (2). A contour map of the United States that presents Effective Peak Acceleration is reproduced in Figure 3 of this paper. The accelerations shown have a probability of being exceeded of ten percent in fifty years.

The use of such maps is an integral part of the strategy presented here. It should be noted, however, that geologic and seismic information used for developing these maps was broad in nature, and local conditions may seriously affect local accelerations. Detailed site evaluations that consider local conditions are preferred where available.

CLASSES OF BUILDINGS

Classes of buildings assumed for this strategy are in Figure 2. They are based on either the seismic design code by which the building was designed or the type of construction. Single family and duplex houses are not included in this procedure.

The Uniform Building Code (3) includes the most widely used earthquake regulations in the United States. The regulations have been adopted in whole or in part by a number of state and local building departments over the years. Studies of earthquake damage (4, 5) as well as progressive increases in design requirements over the years justify differentiating among buildings by year of design code.

Recent seismic design requirements are those promulgated by the Veterans Administration (6), Applied Technology Council, and the 1979 Edition of the Uniform Building Code. Structures designed by these or comparable provisions may be expected to perform better in severe earthquakes than structures designed by earlier codes. The performance of buildings not designed specifically to resist earthquakes has varied by the type of construction as generally shown in Figure 2.

THE FIRST SIEVE

Figure 2 assigns priorities by class of building and intensity of ground shaking. Those buildings where Priority Number 1 is indicated should be further tested against the Second Sieve presented in the next section of this paper.

For several years, the writers have been assessing the seismic resistance of the hospital buildings of the Veterans Administration. Details of that program have been described elsewhere (7). The buildings studied ranged from single story warehouses to multi-story hospital buildings and were located in areas of moderate to high seismicity. The judgements in Figure 2 are based generally upon evaluations stemming from this Program as well as earthquake damage studies.

A summary by Housner and Jennings (8) of earthquake damage at San Fernando inspired the expanded tabulation presented in Figure 2.

THE SECOND SIEVE

Those buildings for which Priority 1 is indicated require further analysis to rank them against each other. The Second Sieve is based on studies of damage sustained in the Hochinohe Earthquake of 1968 (9). These studies indicated a high correlation between the level of earthquake damage of a low-rise reinforced concrete building and its weight, total floor area, and cross sectional area of the lateral force resisting elements. This correlation is shown on Figure 4.

The abscissa of Figure 4 is the lesser ratio of the area of lateral force resisting elements, in either the transverse or longitudinal direction, at any level to the total floor area above that level.

The ordinate of Figure 4, representing average shear stress, is:

$$V_{avg} = \left(\frac{W}{A_w + A_c}\right) \quad \text{(Eq. 1)}$$

Where:

V_{avg} = average shear stress
W = weight of building above level considered;
A_c = column area at the level; and
A_w = wall area at the level.

Buildings that collapsed or sustained major damage were found to fall into the upper left portion of the curve.

The Second Sieve extends this correlation to other types of construction and locations in the following manner.

In seismic analysis, base shear can be estimated as a function of the type of construction, period of the structure, maximum acceleration of the ground during earthquake motion, and weight of the structure.

If buildings of the same class are compared, the ordinate of Figure 4 can be directly proportioned to the total unit shear stress (corresponding to the base shear) if it is assumed that all of the energy of the structure is in the first mode and adjustments are made for period and ground acceleration.

Proportional adjustments for changes in intensity of ground motion can be introduced as direct ratio of reductions in the estimated acceleration values:

$$V_a = \left(\frac{W}{A_c + A_w}\right) \times \left(\frac{A_{max}}{0.4g}\right) \quad \text{(Eq. 2)}$$

Where: V_a = average shear stress on lateral force resisting elements, A_{max} = estimated acceleration at the site, and 0.4_g represents the upper bound for effective peak acceleration.

Equation 2 can be applied to all structures with a fundamental period less than 0.40 seconds.

Adjustments for structures where fundamental period is greater than 0.40 seconds can be introduced as follows:

$$V_{adj} = \left(\frac{W}{A_c + A_w}\right) x \left(\frac{A_{max}}{T_g}\right) \quad \text{(Eq. 3)}$$

Where:

V_{adj} = adjusted average shear stress
T = fundamental period of structure. [c]

[c] For this procedure, conservative estimates of the period T are: T = .05 N for masonry structures where N = Number of Stories; T = .08 N for reinforced concrete frame structures, and T = 0.12 N for structural steel frame structures.

Equation 3 reflects an adjustment of the dynamic amplification factor derived from Reference 6.

Basic assumptions for this method are: 1) column and wall areas used in the calculations are those that resist the horizontal component of the earthquake motion under consideration, 2) calculations include appropriate relative area adjustments in accordance with the shear moduli if columns and walls are of different materials, and 3) only those elements capable of resisting earthquake forces are included.

Estimates of floor area, building weight, period, and areas of lateral force resisting elements can be accomplished readily, particularly if construction drawings are available. Effective peak acceleration values can be obtained either from Figure 1 or specific site studies where available. If the information for each building of a class are plotted, the buildings will generally fall along a curve as shown in Figures 5 and 6. The buildings on the upper left side of the curve, representing those with the highest unit shear stress and the lowest ratio of area of lateral force resisting elements to total floor area, are judged to be the highest priority buildings for detailed evaluations. Because of the many variables, there is no definitive segment of high priority buildings. However, it can be observed that buildings on the lower right part of the curve have lower shear stresses and a higher proportional area of lateral force resisting elements, and, consequently, are more able to resist earthquake forces than the buildings on the upper left side of the curve.

Representative buildings were plotted in Figures 5 and 6 to illustrate this procedure and the results are comparable with those of more detailed analyses. From this, the writers proposed that if the characteristics of each building of a particular class are plotted on Figure 5, they will fall along a curve in such a manner that the buildings will be automatically ranked by priority in terms of their seismic resistance, with the most vulnerable buildings on the upper left side of the curve and the least vulnerable on the lower right.

Each class of building must be plotted separately.

The Olive View Hospital, which was destroyed in the San Fernando earthquake, is plotted on Figure 5. Although an inverted pendulum rather than of shear wall construction at the first story, the vulnerability of that building is clearly shown.

SUMMARY AND CONCLUSIONS

Hundreds of thousands of buildings are located in areas of high seismicity and there is a need to quickly identify those most vulnerable to earthquakes. A "Two-Sieve" strategy has been presented to meet this need.

This strategy serves only to establish priorities for detailed evaluations. The parameters for the strategy can be easily determined from the geographic locations and from a rudimentary description of the building. Factors such as local soil conditions and foundations, connections and ductility of the structural elements, building shape, and so on are to be considered in the detailed evaluation. Potential nonstructural damage assessment is also deferred.

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First Sieve

1. Classify Building by Type of Construction.
2. Determine Intensity of Ground Shaking at Site.
3. Determine Estimated Level of Damage Corresponding to Class of Building and Intensity of Ground Shaking (Figure 2).
4. Identify all buildings where Figure 2 estimates Priority No. 1.

Second Sieve

5. For each class of building, plot on Figure 3 all buildings identified in Step 4.
6. Buildings in the upper left (High Priority) section of Figure 4 should be reviewed by detailed analysis and field investigation.

STRATEGY FOR PRIORITY IDENTIFICATION OF HAZARDOUS BUILDINGS
FIGURE 1

Class of Building	Intensity of Ground Shaking[1, 2]				
	Red (.4g)	Blue (.3g)	Green (.2g)	Yellow (.15g)	Orange (.10g)
Seismic Design					
Recent Code	2	3	4	4	4
1961-73 UBC or Equiv.	1	2	2	3	4
1933-60 UBC or Equiv.	1	1	1	3	4
No Seismic Design					
Structural Steel Frame	1	1	2	2	3
Reinforced Conc. Frame	1	1	1	2	3
Prestressed Concrete	1	1	1	1	3
Masonry	1	1	1	1	2
Wood	1	1	1	1	2

[1] Priorities are in rank order. No. 1 indicates highest priority.

[2] Color coding corresponds to ATC-3 map (Reference 2).

FIRST SIEVE PRIORITY RANKING
FIGURE 2