Optimum Seismic Protection for New Building Construction in Eastern Metropolitan Areas

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Internal Study Report # 5

CONTRIBUTION TO STATE-OF-THE-ART REPORT OF THE
EARTHQUAKE COMMITTEE OF THE IABSE-ASCE TALL BUILDINGS COMMITTEE

"ECONOMIC AND SOCIAL ASPECTS"

R.V. Whitman

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Department of Civil Engineering
Massachusetts Institute of Technology
Cambridge, Massachusetts

The IABSE-ASCE Tall Buildings Project has an earthquake committee and the state-of-the art recorder for this committee is Kiyoshi Muto. One subtopic for this committee is "Economic and Social Aspects," and Dr. Muto asked Professor C. Martin Duke of UCLA to prepare this particular state-of-the-art report. Professor Duke in turn asked that several engineers, including the writer, collaborate in preparing the report on this sub-topic. The particular items which Professor Duke assigned to the writer were: risk damage and cost--including an abstract of the Whitman-Cornell-Vanmarcke-Reed paper to the recent U.S. National Conference on Earthquake Engineering.

This internal study report contains the draft which the writer submitted to Professor Duke.

A list of previous internal study reports appears on the following sheet.

List of Internal Study Reports

1. R.V. Whitman, "Preliminary Work Plans and Schedules," August, 1971.

2. E.H. Vanmarcke and R.V. Whitman, "Background for Preliminary Expected Future Loss Computations," October, 1971.

3. P.J. Trudeau, "Identification of Typical Soil Profiles in the Boston Basin Area," November, 1971.

4. J.M. Biggs, "Comparison of Wind and Seismic Forces on Tall Buildings," December, 1971.

SEISMIC RISK

It is generally agreed that a tall building must not collapse during the largest earthquake that is realistically imaginable. In addition, earthquakes which can be expected to occur during the lifetime of the building must not cause damage that is economically unacceptable either to an owner or to a community.

While both of these principles are widely accepted as the basis for seismic design, it is difficult to be precise in the implementation of these principles. The second principle clearly implies a balancing of risk of future loss against the initial cost of providing a stronger building. Even the first principal implies some balancing of risk, since the phrase "largest realistically imaginable earthquake" hardly provides a precise definition. The engineer by himself should not be expected to determine the balance point, for this choice involves many considerations affecting the owner and the community. Rather, the engineer's responsibility is to marshall all available facts into a form which makes the costs and risks clear to owners and public bodies.

For many years, engineers have juggled the available facts so as to recommend a reasonable balance between initial cost and future risk, although seldom has the actual balance been stated in an explicit way. Today, it is beginning to be possible to face this balance openly and realisitically. In fact, the city of Long Beach, California, has recently adopted a new code that is explicitly based upon balanced risk (Wiggins and Moran, 1971).

Methodology for optimizing seismic protection

Figure 1 outlines, by means of a flow chart, a possible methodology for analyzing the costs and risks associated with designing tall buildings against earthquakes. This methodology can never (and should never) be a substitute for judgment and experience, but rather provides for a systematic organization of such experience and judgement. As outlined in Fig. 1, the methodology is aimed at selecting seismic design requirements for a specific project or for use in a building code. However, the same general methodology can be used as a basis for insurance considerations or for federal disaster relief laws. A very similar methodology has already been applied to estimating possible future losses to residential dwellings in California (ESSA, 1969).

The heart of the methodology is examination, in probabilistic terms, of the damage which one earthquake will cause to a particular building system built with a particular design strategy. This evaluation is repeated for different levels of earthquake, different design strategies and, where appropriate, different building systems. For each different design strategy, the initial cost required by that strategy is added to the present value of possible future losses.

In simplest terms, a particular <u>building system</u> might be defined as: all buildings having 8 to 13 stories. In a more refined study, a building system might be: 8 to 13 story reinforced concrete buildings with ductile moment resisting frames. Other building systems are then defined by different ranges of stories, different construction materials, and different lateral force resisting systems. The soil conditions upon which the building is to be built also form part of the definition of the building system.

The simplest statement of <u>design strategy</u> is: design in accordance with the Uniform Building Code for Zone 2 (or 0, 1 or 3). More refined variations on the design requirements might also be considered. The initial cost is a function of the design strategy. This cost might be expressed as the extra cost to design for Zone 2 requirements as compared to making no provision for earthquake resistance.

One key step is determining the earthquake occurance probability. This is the probability that a ground motion of some given intensity will occur during, say, 1 year, at the site of interest. Intensity may be expressed by the modified Mercalli scale, or better yet by the spectral acceleration for the periods appropriate to the building system. Methods now exist for making reasonable estimates for the earthquake intensity probability for any location, by appropriate analysis of the historical record and of geological information (Cornell, 1971).

The effect of various levels of ground motion upon the building system is expressed by a family of damage probability matrices. Each matrix applies to a particular building system and design strategy, and gives the probability that various levels of damage will result from earthquakes of various intensities. Table 1 shows one possible categorization of levels of damage. These levels of damage are described both by words and by the ratio, to replacement cost, of physical damage to the building and its contents. Fig. 2 illustrates a damage probability matrix based on the categories of damage in Table 1. For example, the numbers in the column labeled intensity VIII (modified Mercalli) show the fraction of all buildings expected to experience each of the levels of damage, given that an earthquake of intensity VIII occurs.

With each damage state, there is an associated cost. These are different from the costs shown in Table 1, which are intended only to identify the level of damage. The total associated cost for each damage state includes, in addition to repair of structural and non-structural damage, loss of function or lost time during repairs and, in extreme cases, injury and loss of life and impact on community. Not all of the factors can be readily expressed in dollars, and many engineers and politicians find it very difficult to accept the notion of placing any sort of value on life. Yet today communities already make such judgment implicitly. For example, how do we know that it is better to make a building owner pay extra for added resistance to earthquakes instead of contributing the same sum toward a transit system which would reduce highway deaths.

If it were possible to express all losses in dollars, then the criterion for optimization would be minimum present total cost. Actually, future losses will be only partly expressible in dollars, and multi-variate objectives must be considered. Nonetheless, the approach here outlined will serve to make clear the considerations which must be balanced to achieve an optimum design.

Damage probability

The damage probability matrices are at the heart of the optimization study. A family of such matrices is required. At a minimum, different design strategies and soil conditions must be represented. It would be desirable to have data for several ranges of story heights and for different types of construction.

By assembling experience during actual earthquakes plus using results from theoretical studies, it now is possible to provide tentative estimates for damage probabilities for various building systems with different levels of earthquake resistance. Fig. 2, for example, represents a first guess at the probabilities applying to modern buildings having 8 or more stories, founded on firm ground and designed approximately in accordance with the requirements of the Uniform Building Code for Zone 3. Fig. 2 was assembled by analyzing preliminary data from the San Fernando, California, earthquake of 9 February 1971. Steinbrugge et al (1971) have prepared an excellent summary of damage to some multi-story buildings; their results are summarized in Fig. 3. The main conclusions concerning high-rise buildings were:

1. Steel frame and reinforced concrete (earthquake resistive) high rise buildings performed equally well, with some exceptions, when located 15 to 25 miles from the epicenter. Where exceptions occurred, they were usually adverse with regard to reinforced concrete construction.
2. From a percentage loss standpoint, completed steel frame buildings never exceeded about 1% of value. A total of 5 reinforced concrete structures had losses over 1%, and two of these had losses over 5%.
3. Older non-earthquake resistive high-rise buildings performed quite badly when compared to modern high-rise construction. A limited selection of older structures in the downtown Los Angeles area all had losses over 5%.

Collection and analysis of the performance of high rise buildings during the San Fernando earthquake is continuing (Whitman et al, 1972).

Status of risk studies

We are at a stage where first attempts can be made to undertake a systematic risk analyses and to learn how such analyses can be used in the making of actual decisions. More study and research of course will be required before such analyses can be applied widely. Particular needs are:

1. Additional data concerning damage probability. In future earthquakes, the type and magnitude of damage in all buildings (including buildings with little or no damage) must be documented accurately. Cities located in seismic areas should prepare and maintain a list of all buildings having 5 or more stories, listing location of building, overall dimensions, type of construction, type of foundations, and earthquake design criteria. Immediately following an earthquake, each such building should be visited to ascertain the general level of damage. Regulations should also be enacted now that will give building officials access to information concerning the total actual cost of repairs necessitated by future earthquakes.
2. Good methods must be developed for evaluating costs in addition to physical damage.
3. Clearer information must be obtained as to the additional initial cost of providing additional resistance to earthquakes.

Cornell, C.A., 1971, "Probabilistic Analysis of Damage to Structures Under Seismic Loads," in Dynamic Waves in Civil Engineering, Proceedings of a Conference, Swansea, Wales, July, 1970, J. Wiley and Sons, England.

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Steinbrugge, K.V., E.E. Schader, H.C. Bigglestone and C.A. Weers, 1971, San Fernando Earthquake, February 9, 1971, Pacific Fire Rating Bureau, San Francisco.

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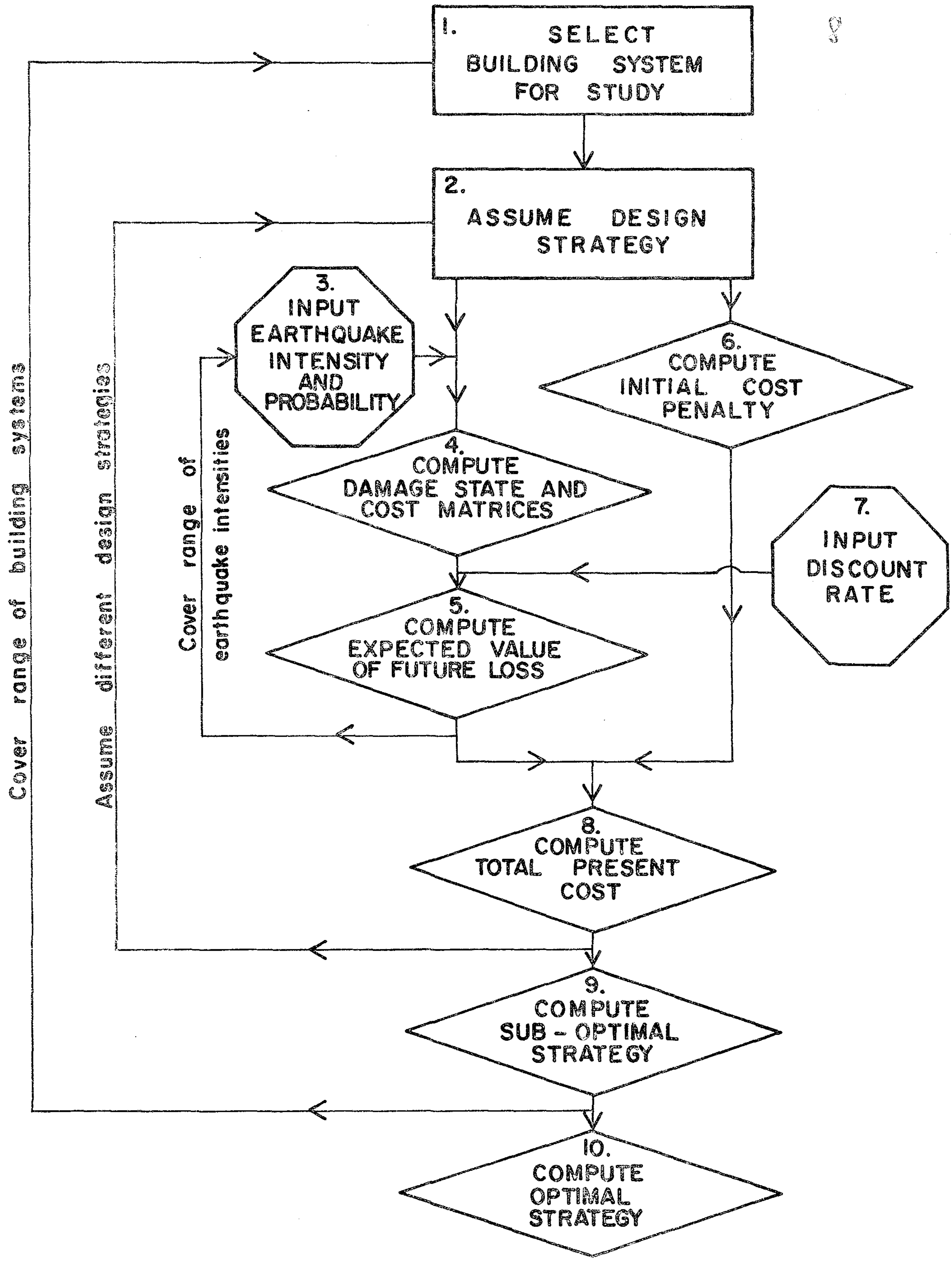

FIGURE 1: FLOW DIAGRAM FOR GENERAL METHODOLOGY

	EARTHQUAKE INTENSITY						
LEVEL (MMI)		4	5	6	6.5	7	8
DAMAGE STATE	0	1.00	0.99	0.90	0.85	0.80	0.25
	1	0	0.01	0.09	0.10	0.12	0.25
	2	0	0	0.01	0.04	0.05	0.20
	3	0	0	0	0.01	0.02	0.15
	4	0	0	0	0	0.01	0.10
	5	0	0	0	0	0	0.04
	6	0	0	0	0	0	0.01
	7	0	0	0	0	0	0
	8	0	0	0	0	0	0

FIGURE 2 Example of Damage Probability Matrix

Table 1

Damage States

	Description of Level of Damage	Ratio to Replacement Cost
0	No Damage	0
1	Minor non-structural damage--a few walls and partitions cracked, incidental mechanical and electrical damage	.001
2	Localized non-structural damage--more extensive cracking (but still not widespread); possibly damage to elevators and/or other mechanical/ electrical components	.005
3	Widespread non-structural damage--possibly a few beams and columns cracked, although not noticeable	.02
4	Minor structural damage--obvious cracking or yielding in a few structural members; substantial non-structural damage with widespread cracking	.05
5	Substantial structural damage requiring repair or replacement of some structural members; associated extensive non-structural damage	.10
6	Major structural damage requiring repair or replacement of many structural members; associated non-structural damage requiring repairs to major portion of interior; building vacated during repairs	.30
7	Building condemned	1.0
8	Collapse	1.0

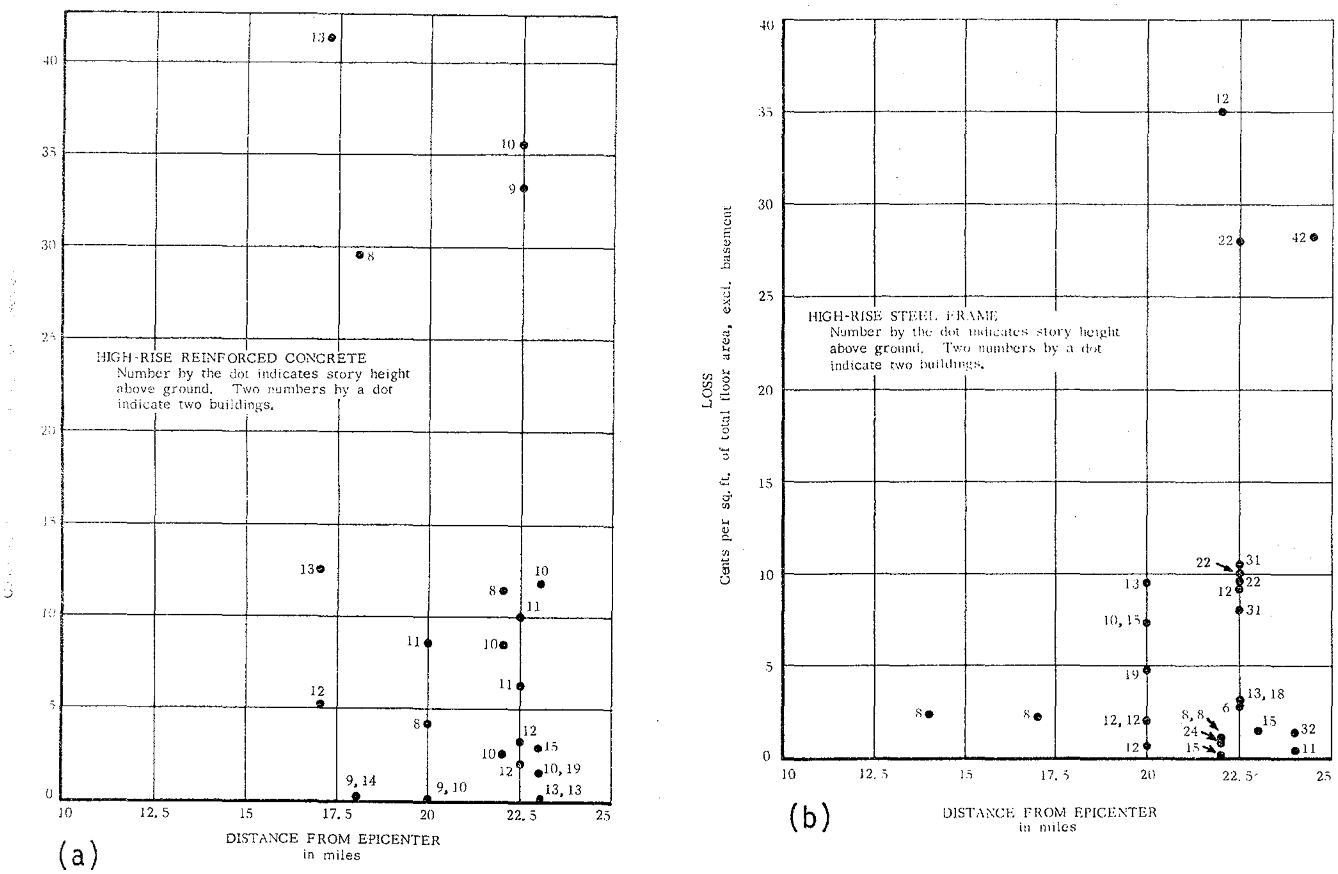

FIGURE 3 Losses to Earthquake Resistive High-Rise Buildings from San Fernando Earthquake of 9 February 1971