

THE FEBRUARY 4, 1976 EARTHQUAKE IN GUATEMALA CITY AND
VICINITY: ENGINEERING FIELD REPORT

RAUL HUSID^I

SUMMARY

The February 4, 1976 earthquake caused severe damage to several types of structures in Guatemala City.

From a detailed damage survey of Guatemala City, damage ratios were estimated for individual constructions. A map of the city showing damage ratios for more than 260 individual structures is presented using a five-point damage scale. Average damage ratios per block were also assessed for Guatemala City and a detailed average-damage-ratio map for Zones 1 through 6 is presented. Both maps are compared with the corresponding intensity distribution, and significant differences are found. Some results of a study of dynamic characteristics of local buildings are given.

INTRODUCTION

The destructive earthquake (surface wave magnitude $M_s = 7.5$) of February 4, 1976 took about 23,000 lives, caused more than 77,000 injuries and left the country with one sixth of the population homeless (1, 2, 3, 4). Secondary faulting occurred as much as 30 km from the main fault (5).

In this paper, the earthquake resistant design practice in Guatemala is reviewed. The results of a detailed damage survey are also presented in two-damage ratio (D.R., i.e., cost of repair/replacement cost) maps, one for more than 260 individual structures and the other prepared for Zones 1 through 6, using average D.R.'s per block. This paper shows some of the results the author obtained using the data collected during the three field trips he took to Guatemala after the earthquake. Some of the results obtained of dynamic characteristics of local buildings are also shown.

EARTHQUAKE-RESISTANT DESIGN PRACTICE AND TYPES OF STRUCTURES IN GUATEMALA

Until February 4, 1976, no earthquake-resistant design code had been enacted into law in Guatemala, and therefore it was not mandatory to design structures to withstand seismic forces. Each engineer selected a foreign code and designed accordingly. Many Guatemalan professionals used a version (not necessarily the latest) of the SEAOC code. Thus, structures in Guatemala City were not designed using common standards.

Guatemala City has many modern buildings; most of them are reinforced-concrete and a few are high-rise steel structures. The predominant type of modern construction is the framed structure with flat beams in one or two directions and masonry filler walls, most of which have no reinforcement.

However, one of the most common types of construction is adobe, which is used for the majority of houses, churches, and small structures through-

I. Senior Research Engineer, Shell Development Company, Houston, Texas, U.S.A.; Honorary Professor, National University of Engineering, Lima, Peru.

out the country. Their roofs are generally tile on wood-pole rafters. Bajareque construction is also used extensively in Guatemala. It consists of a wood frame covered with lath, the wall space being filled with mud and plastered. It is similar to quincha, used for building houses in the coastal region of Peru (6, 7).

Although wooden dwellings subjected to earthquakes generally behave very well (8), their cost becomes prohibitive for low income people and they are not very common in Guatemala City.

GENERAL OBSERVATIONS

Although there were structures that suffered complete or partial collapse, their general performance was clearly good (1). Many of the structural problems encountered in different zones of Guatemala City are summarized below:

- 1) Adobe houses did not have any edge members and sustained heavy damage.
- 2) Heavy roofs of adobe and unreinforced masonry houses frequently collapsed.
- 3) The effect of the use of nonstructural masonry walls in reinforced-concrete structures was usually not considered in the design. Severe damage occurred to walls and sometimes also to the structure.
- 4) Unreinforced parapets on top of structures created a potential lifeloss hazard.
- 5) Reinforced-concrete column ties and beam stirrups were often small in diameter, widely spaced, and sometimes not adequately hooked.
- 6) Strengths of reinforced-concrete lateral-load-resisting elements were often unrelated to their stiffnesses.
- 7) The lack of sufficient separation of structures was usually responsible for heavy damage to the structure having the shorter fundamental period of vibration.
- 8) Brick walls often lacked reinforced-concrete corner columns, and long walls also lacked intermediate reinforced-concrete columns.
- 9) The seismic coefficients used for water-tank design were small, and the dynamic effect of the water was usually disregarded. In the design, the anchor bolts were generally not well connected to the foundation; and, as a result, in several cases, the water tanks overturned.
- 10) Defective overlapping of vertical reinforcing steel in reinforced-concrete columns contributed to the poor behavior of a structure, and, in some cases, to their collapse.

DETAILED STUDY OF LOSSES

A detailed damage survey performed by the author and reports of others (2, 9, 10) suggest that the damage distribution for Guatemala City is complicated, due to special soil, topographical and geological conditions. A complete description of representative cases of damage in Guatemala City has

already been published (1). There was heavy damage to adobe, as observed in many previous earthquakes in other countries (6, 7, 8) and unreinforced masonry and some reinforced-concrete and steel structures completely collapsed.

The author collected detailed information about losses for the entire capital city. Because about 70 percent of the most severe damage occurred in Zones 1 through 6, only these contiguous zones are considered here. The Modified Mercalli Intensity (MMI) for these zones ranges between VI and IX (1). It was found that there were 25,169 houses severely damaged in those zones. Of those, 21,139 were made of adobe.

Methodologies for estimating property damage due to earthquakes have been developed (11, 12). They also make use of the concept of D. R. The way to test them is to have sufficient information about losses in a given area after a strong earthquake to be able to compare the estimates provided using different models with the observed losses and thus find the most adequate models and methodologies.

Extensive discussions with professionals, familiar with local building costs, provided invaluable data to estimate D.R.'s for various classes of buildings in Guatemala. As an example, a portion of the criteria for adobe buildings is as follows:

- 1) Collapse of part or all of the roof when some principal walls are severely cracked; $0.70 \leq D.R. \leq 0.95$.
- 2) Roof slightly damaged; some of the principal walls collapsed and other walls severely cracked; $0.60 \leq D. R. \leq 0.85$.
- 3) Roof and principal walls with slight damage and secondary walls and plaster severely cracked; $0.15 \leq D. R. \leq 0.30$.
- 4) Roof and principal walls without damage and secondary walls and plaster slightly damaged; $0.05 \leq D. R. \leq 0.20$.

For blocks of the city that were made up of predominately adobe brick or other masonry-type constructions, average damage ratios were estimated for each block. For more complex structures, damage ratios were estimated individually.

Husid and Arias (1) found that the percentage of adobe houses with $D. R. > 0.80$, according to zone, does not strongly change with the zone. In Zone 1, where there were 17,586 housing units (13) of which 9,351 were adobe, 58.3 percent of the adobe houses had a $D. R. > 0.80$. The MMI was VII. In Zone 2, with 4,577 housing units and 2,127 adobe houses, 44.7 percent of the adobe dwellings had a $D. R. > 0.80$ and an MMI of VIII.

When the survey was completed and damage ratios were estimated, it was apparent that the MMI map did not serve as a good basis for estimating losses in that area, because too many cases were found for which observed losses were not consistent with the mapped intensities.

Figure 1 shows a map of Guatemala City and D. R.'s for more than 260 individual structures, using a uniform five-point damage scale. The damage estimated from individual D.R.'s and from the MMI's do not show a good agreement.

Fig. 2 shows a detailed block-by-block distribution of average D.R.'s

for six zones in Guatemala City. Fig. 3 gives the same information superimposed on the MMI map.

Differences between the damage estimated from D.R.'s and the MMI's are obvious from Fig. 3. The Intensity map appears to be rather generalized in its representation of damage and is, in some cases, in conflict with the D.R. map. As an example, Zone 1 was assigned predominantly intensity VII; and Zone 2, predominantly intensity VIII. The D.R. data yield a larger number of adobe buildings with D.R.'s > 0.80 in Zone 1 than in Zone 2.

One reason for the observed differences in the estimated damage using the MMI map and the D.R. map may be the manner in which the two maps were prepared. The intensity map is based on data from questionnaires and thus represents some weighted average of the results of these questionnaires. Most of the questionnaires were the result of interviews with people who would not ordinarily be considered to be skilled observers of earthquake damage. The detailed damage survey and the resulting D.R.'s are based on the author's study of the damage and, therefore, if biased, probably are biased in a systematic way.

The results of this investigation clearly show that in urban areas particularly, where significant building damage occurs, intensities should be carefully assigned on the basis of the best damage-survey information available. Estimation of damage ratios for individual buildings is recommended when time and personnel for the task are available, because information of this type greatly improves the data base for the determination of damage versus intensity-of-ground-shaking relations used in earthquake-loss studies.

DYNAMIC CHARACTERISTICS OF GUATEMALAN BUILDINGS

Measurements of the dynamic characteristics of most of the important buildings located in Guatemala City were performed by the author using a VM-1 Kinematics vibration monitor. Man-excited motions were generated by the author (sometimes with the help of one, two, or three local engineers) by periodic motions of his body. Observing the vibration monitor and watching how the vibrations are building up, it is usually possible to produce rather large amplitudes at the fundamental period of oscillation (14). By stopping the excitation after an appreciable motion had been built up, the decay of the vibrations allows easy damping evaluations.

The fundamental periods of vibration and the corresponding damping ratios were obtained for 77 buildings, in two principal directions. The buildings range between 4 and 23 stories high and the measured periods vary between 0.29 sec and 1.98 sec. Although the results of this investigation will appear elsewhere, some are shown below:

- 1) A linear relationship between period and number of stories (N) yields $T \approx 0.08N$.
- 2) A linear relationship between period and height (H) yields $T \approx 0.024H$.
- 3) The parameter H/\sqrt{D} is not adequate to be used for estimating the period of vibration of Guatemalan buildings.
- 4) Guatemalan buildings appear to be more flexible than Chilean and Japanese structures, but stiffer than their Californian counterparts (15).

REFERENCES

1. Husid, R. and Arias, J., "Damage in Guatemala City and Vicinity due to the February 4, 1976, Earthquake, Proceedings International Symposium on the February 4, 1976 Earthquake, Vol. 1, pp. 1-60, May 1978, Guatemala.
2. Consejo Nacional de Planificación Económica, "Evaluación de los Daños Causados por el Terremoto", Guatemala City, March 1976, p. 1-78.
3. Dirección General de Estadística, "Preliminary Information about Human and Material Losses due to the February 4, 1976, Earthquake", Guatemala, April 1976, pp. 1-36.
4. Husid, R., Quesada, A., and Espina, A., "The Guatemalan Earthquake of February 4, 1976. Damage and Engineering Implications", U.S.G.S., Prof. Paper 1002, July 1976, pp. 67-79.
5. Spence, W. and Person, W., "The Guatemala Earthquake of February 4, 1976, Tectonic Setting and Seismicity", U.S.G.S., Prof. Paper 1002, July 1976, pp. 4-11.
6. Husid, R. and Gajardo, E., "Aspectos Sísmológicos y Estructurales en el Terremoto del Perú del 31 de Mayo de 1970", Simposio Pan Americano de Estructuras, Buenos Aires, Argentina, October 1970, Vol. IV, pp. 237-259.
7. Berg, G. and Husid, R., "Structural Behavior in the 1970 Peru Earthquake", 5th WCEE, June 1973, Rome, Italy, pp. 1-10.
8. Husid, R., de las Casas, J., and Espina, A., "The Lima Earthquake of October 3, 1974. Damage Distribution", BSSA, Vol. 67, No. 5, October 1977, pp. 1441-1472.
9. Lottmann, J., "Investigación de los Daños Ocasionados por el Terremoto del 4 de Febrero de 1976 en Ciudad de Guatemala", Universidad de San Carlos de Guatemala, July 1976, pp. 1-32.
10. Cámara Guatemalteca de la Construcción, "Unpub. Emergency Inspection Questionnaires", Guatemala, February 1976.
11. Algermissen, S. T., Stepp, J. C., Rinehart, W. A. and Arnold, E. P., Appendix B, in Studies in Seismicity and Earthquake Damage Statistics, U.S.C.G.S., 1969, pp. 168.
12. Steinbrugge, K. V., McClure, F. E., and Snow, A. J., Appendix A, in Studies in Seismicity and Earthquake Damage Statistics, U.S.C.G.S., 1969, pp. 1142.
13. Dirección General de Estadística, "Daños Ocasionados en las Viviendas por el Sismo del 4 de Febrero de 1976", Guatemala, 1976, pp. 1-17.
14. Hudson, D. E., Keightley, W. O., and Nielsen, N. N., "A New Method for the Measurement of the Natural Periods of Buildings", BSSA, Vol. 54, No. 1, pp. 233-241, 1964.
15. Husid, R., "Análisis de las Medidas de Períodos de Vibración de Edificios Nuevos", Bulletin of IDIEM, Santiago, Chile, Vol. 4, No. 3, December 1965, pp. 175-188.
16. Arias, A., and Husid, R., "Formula Empírica para el Cálculo del Período Propio de Vibración de Edificios de Hormigón Armado con Muros de Rigidez", Bulletin of IDIEM, Santiago, Chile, Vol. 1, No. 1, March 1962, pp. 1-11.

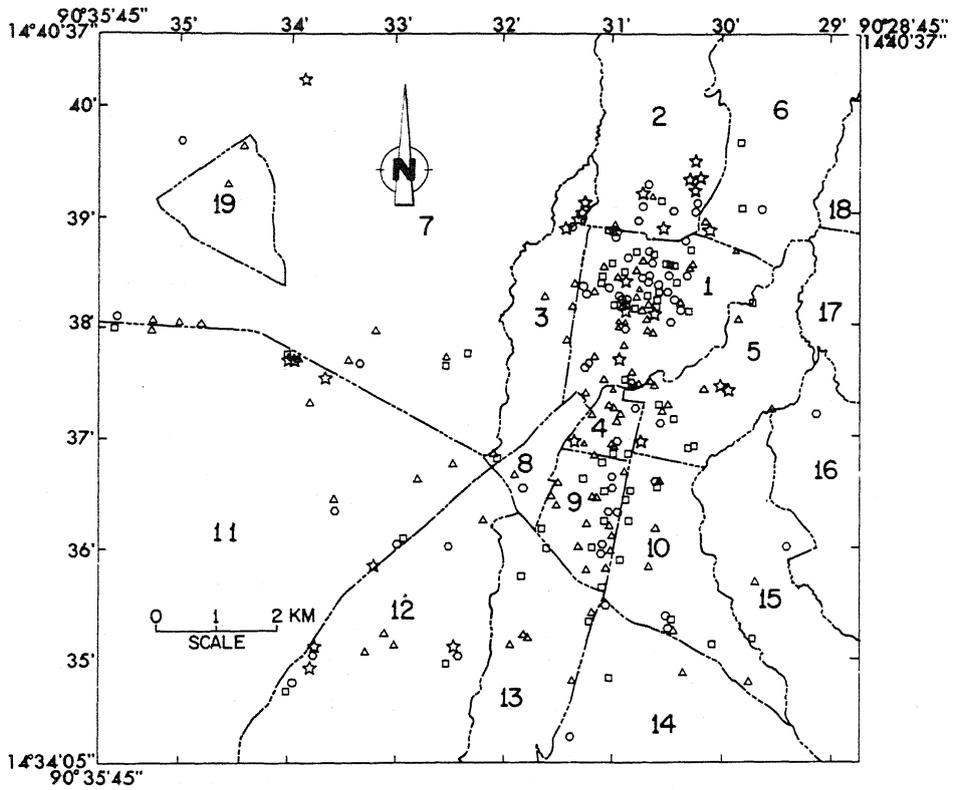


FIGURE 1
INDIVIDUAL DAMAGE RATIO MAP FOR GUATEMALA CITY

- | | | | |
|---|----------------------------|---|----------------------------|
| △ | 0 < DAMAGE RATIO ≤ 0.20 | ○ | 0.60 < DAMAGE RATIO ≤ 0.80 |
| □ | 0.20 < DAMAGE RATIO ≤ 0.40 | ☆ | 0.80 < DAMAGE RATIO ≤ 1.00 |
| ○ | 0.40 < DAMAGE RATIO ≤ 0.60 | | |

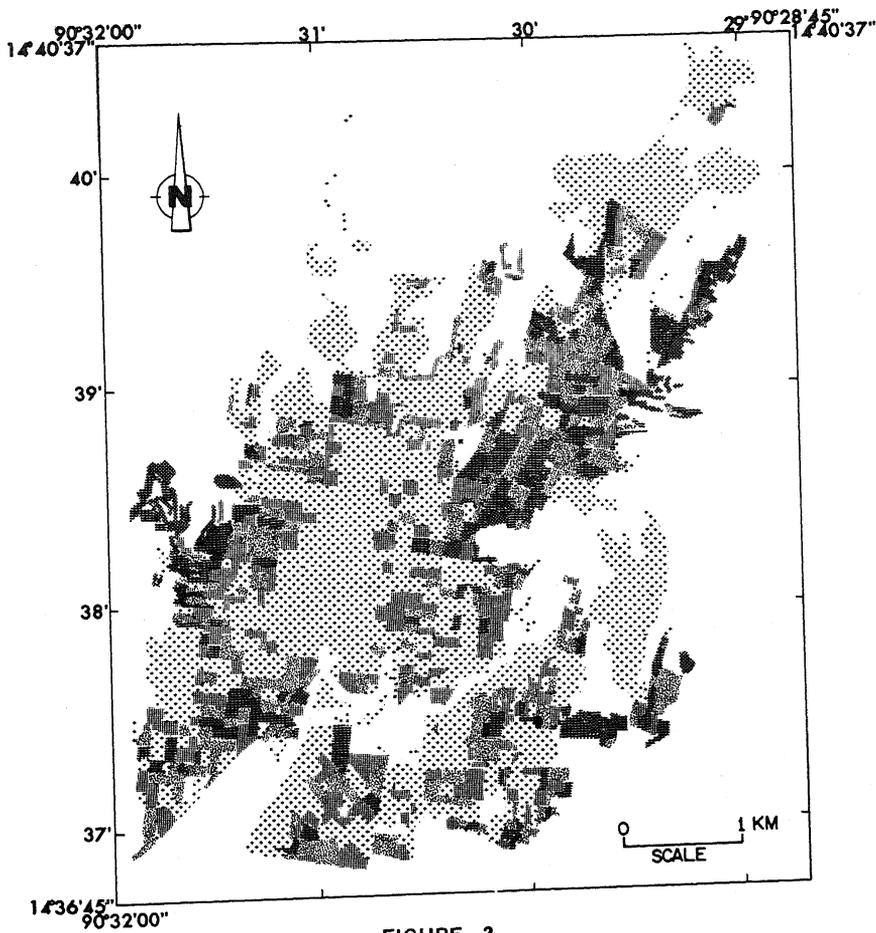


FIGURE 2

DETAILED AVERAGE DAMAGE RATIO MAP FOR ZONES 1 THROUGH 6 FOR GUATEMALA CITY



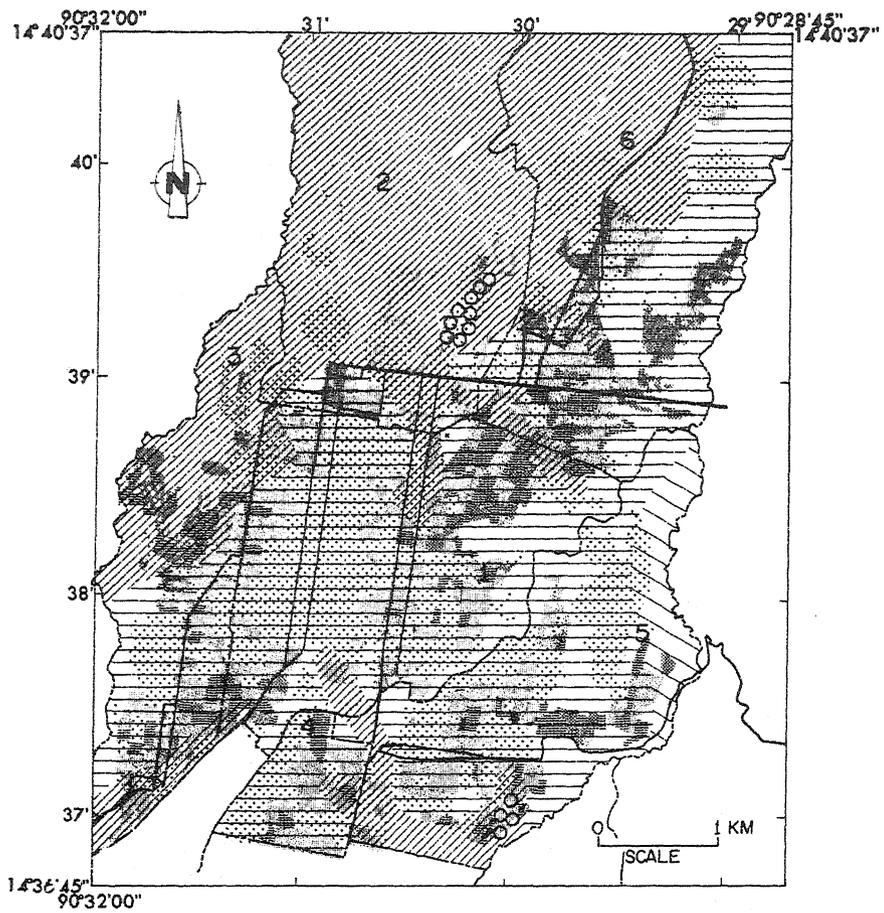


FIGURE 3
 DETAILED AVERAGE DAMAGE RATIO MAP & INTENSITY DISTRIBUTION
 FOR ZONES 1 THROUGH 6 FOR GUATEMALA CITY

