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PRELIMINARY NOTES ON STRUCTURAL DAMAGE CAUSED BY GUATEMALA EARTHQUAKES OF 4 AND 6 FEBRUARY 1976

by

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Notes based on inspection of urban construction during 8-14 Feb. 1976 for the Panel on Earthquakes, Committee on Natural Disasters of the Commission on Sociotechnical Systems, National Research Council.

Guatemala - 42,000 sq. miles (size of Tennessee). Sea level to 13,000 ft. Population was 4,300,000 in 1964 census. Projected to 1976, 5,600,000. G.N.P. \$1.5 x 10^9 (1967). Mean G.N.P. increase 5% 1950 to 1967. Per capita income: \$85 - farmers, \$2,200 - upper 7% of urban population (1967). Economy primarily agricultural. Exports coffee (50% of all), cotton (20%), sugar, bananas, and beef. Unfavorable trade balance during 1960's.

Guatemala City - See map. Population 814,000 in 1964 census with a density of approximately 1,000 persons per sq. mile. Projected (1976) over one million. City grew by 85% between 1950 and 1964. Elevation 5,000 ft. Surrounded by mountains, including a few active volcanoes, and serrated by ravines.

Soils - To 10 or 15 meters: clay changing to silty sand. To 100 meters: volcanic ash. Allowable soil pressure from 15 tons/m^2 to 30 tons/m^2. Ninety degree cuts.

Structural History - As would be expected, nonengineered construction dominates the one- to three-stories category. (50% of housing substandard according to Guatemalan 1964 census.) City also has two dozen buildings in the 10- to 25-story range. Almost all were well designed and well built in the 1960's and 1970's. Many buildings four to nine stories. Most well conceived, some very poor. No building code. When used, ACI 318 with chronologically pertinent

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zone-3 requirements. ACI 318-71 not yet popular because of obfuscation factor. Deformed bars with few exceptions. Grade 40 (current construction tends to 60). Concrete 3,000 - 5,000 psi. Frame, in various disguises, is the norm. The waffle quite common in heavy construction. Relationship between architect and engineer difficult to comprehend. Possible cases of architect changing structural scheme or elements during construction.

Seismic History - City demolished previously in a series of quakes which started in December 1917 and continued into 1918.

"Great" Earthquakes

Year	Location
1530	Central Region (from Antigua to Quezaltenango)
1560	" "
1585	" "
1607	" "
1651	" "
1684	" "
1689	Antigua
1717	Central Region and Antigua
1751	Antigua
1757	Central Region
1765	Central Region and Quezaltenango
1773	Antigua (Capital moved to Guatemala City)
1798	Guatemala City
1846	" "
1854	Central Region
1863	Guatemala City
1902	Quezaltenango (demolished the town)
1907	Guatemala City
1917	" "
1918	" "
1942	Central Region

Earthquakes of 4 and 6 February 1976 - Major damage caused on 4th but that on 6th had considerable influence. In fact, structural damage increased daily at a perceptible rate to 14 February. Epicenter of 4 February event (3AM) was still uncertain (Latitude 15.7^{o} - Longitude 89.2^{o}, ?) but location of surface fault, inaccurately sketched on map, makes epicenter unimportant. Observed relative motion along the fault 60 to 120 cm. Magnitude 7.5 (from surface waves?). May have lasted about 30 sec. The event on 6 February was not as strong but did cause additional damage. Ground motion not measured for either quake. Reportedly, instrument out of order for first (no paper). Second occurred when it was being reloaded. One seismoscope record south of city, salvaged by Chuck Knudson, may provide an indication of maximum acceleration.

Mercalli - VIII to IX (our estimate)

Cost of the damage - Not yet established in the city (February 14). Figures of $600,000,000 to $800,000,000 have been mentioned (to be compared with G.N.P. of $1,500,000,000 in 1967). We think that there is more damage to buildings than meets the eye. Cost of repair will depend critically on the selected design earthquake and how rigidly a code will be enforced. Local engineers and authorities calm, not ready to rush to a punitive code.

Soil Effects - If the ground motion varied throughout the town as a result of soil depth or properties, it was not observed by the authors. There was a marked change in the extent of damage from the north to the south end of town, at least in the districts visited, but this could be attributed to the quality of construction and distance from the fault, in that order.

Soil Failures - There were slides at the top edges of ravines (very steep) and severe cracking indicating imminent slides. Many houses destroyed as a result. Aftershocks caused additional slides. Major slides along highways (reportedly) covered several cars at a time (especially the major event of 6 February).

One- to Three-Story Buildings - Adobe, brick, bahareque (adobe or brick reinforced by wood frame usually having X-bracing). Reinforced brick in a few instances. Primitive timber roof truss. Tiles or corrugated steel sheet roof covering. Performance of adobe worst. Destruction not uniform. Typically, house at block corners demolished if adobe. Some blocks lost 30%, some less than 10%. Did not see a completely destroyed block in the city but others did. Reported loss of approximately 60,000 dwelling units in this category. Intact survival of an impressive number of units in this class (adobe, etc.) makes one wonder if the sustained acceleration in Guatemala City could be over 0.25g.

Four- to Nine-Story Buildings - Except some disastrous examples of probably non-engineered construction, all in the frame class with the horizontal element typically hidden in the thick slab (the weight problem compensated by voids or waffle). Problems in the lower end of this class primarily with "captive columns" (columns partially or totally stiffened by nonstructural walls, in one case by a steel cabinet) failing in shear. At least three total collapses and many on the brink. Problems in the upper end (of this class) with flexibility (architecture in shambles) and apparent "exhaustion" (large steel strains and therefore cracks) of slab at column connections. Permanent displacements.

Moderate-Rise Buildings - Heavy construction. Well built. Typically long spans (8m or more). Waffle slabs predominant. Frames. Structural walls. One steel frame (the highest at 22 stories, in final stages of construction). Problems in a few instances with transverse reinforcement in R/C girders and short connecting beams. In one case, excessive movement of intact frame destroyed the brick skin although the structure was fine. Serious inclined cracking observed in one major column (2.3 by 2.3 meter column, 0.5 mm cracks). Guard said cracks existed previously, but were smaller in width. Series of failures in the first-story elements of an external R/C truss stiffening a building.

Bridges - One bridge on a curve, down (about 30km from town). A prestressed concrete bridge on tall columns (post-tensioned main span, approx. 120 meters) in place but must have moved "sideways" at least six inches during quake. A steel bridge also on tall columns (main span approx. 100 meters) off its supports, resting partially on abutment.

Miscellaneous Observations - Ground motion in town must have been less than in Managua or San Fernando. (70, maybe 90%, of "El Centro" with possibly a relatively depressed response in the nearly-constant-acceleration range).

(1) One of the major buildings has connecting girders, carrying primarily earthquake effects, which vary continuously in depth (by a ratio of over two) from one column face to the other! (2) One of the collapses was initiated by "nonstructural" facade walls terminated at the failure level. Situation exacerbated by a variation in stiffness in the horizontal plane again introduced by nonstructural elements (the coup de grace being delivered by lack of adequate transverse reinforcement in the columns). (3) The other two collapses (and many other imminent ones) are due to unsympathetic symbiosis of structural and nonstructural elements.

Sozen and Roesset

The Guatemala experience should make us look to our R/C buildings with transverse reinforcement proportioned before the current "exorbitant" requirements. There is, of course, the hope of discovering that the ground motion in the city was so high as to be nonrepeatable or that the web reinforcement provided was below the threshold, but neither speculation holds much promise on the basis of available evidence.

The observed responses of the steel structure and at least two (which we inspected in detail) of the major R/C structures (all three of recent vintage) were impeccable. We were told that one of these two R/C structures (19 stories) was designed with all the earthquake force assigned to the structural wall, despite the presence of a hefty frame.

Because of the close similarity of the structural types and design procedures in Guatemala to those in the U.S., detailed analysis of their experience is essential, despite the lack of a strong-motion record.