A STATISTICAL EVALUATION OF THE IMPORTANCE OF NON-STRUCTURAL DAMAGE TO BUILDINGS

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SUMMARY

The M 7.5 earthquake on February 4, 1976 in Guatemala was utilized to analyse statistically 2,280 cases of damage in the area of Guatemala City and 42 buildings in other regions. Among modern buildings, cases involving only non-structural damage account for more than 84% of the sample and 72% of the values involved. Considering non-structural elements contained in the sample which incorporates structural damage, more than 90% of damaged values are non-structural parts. In view of the importance of non-structural damage, some suggestions concerning risk optimization are made.

INTRODUCTION

It has been known for some time that non-structural damage to buildings (damage to fill-in and partition walls, plaster, paintwork, suspended ceilings, windows, doors, electric and sanitary fittings, etc.) contributes considerably to earthquake damage. In view of this, damage to a large number of buildings caused by the M 7.5 earthquake which hit Guatemala on February 4, 1976 was analysed to provide statistical information regarding the importance of non-structural damage. This data could be welcome as quantitative basis for decisions to be made by engineers, architects and those confronted with the potential social or economic impact of earthquakes.

Of the total sample, the vast majority represents buildings in Guatemala City and its immediate surroundings. This is a particular advantage as epicentral distance is practically uniform for all buildings, viz. abt. 160 to 175 km. As also building standards do not show much scatter in this area, the data is far more consistent than it would have been if collected over a large range of epicentral distances.

A further factor which should be mentioned is the rather homogeneous subsoil of Guatemala City. Nearly all formations are quarternary. One finds tephra with intercalated layers of pumice diamictons and fluvio-lacustrine sediments over most of the town area. These diamictons are massive unsorted valley filling deposits with locally stratified tops. In general, their maximum thickness is about 50 m. Over about 5% of the town area, one finds airfall pumice and cinders over volcanic rocks and mudflow, and only about 1 to 2% is light gray biotite tuff, i.e. tertiary material which is rather soft as well.

All this tends to reduce the generally multi-dimensional damage aspect permitting more direct deductions for this large sample which was exposed to MM VI if we follow Espinosa (1). The author would consider a MM-intensity of half but definitely not more than one degree more as equally defendable.

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OBSERVATIONS

The statistical material has been grouped in 3 tables, the first one showing buildings involving collapse or total constructive loss. If we disregard adobe buildings cases of collapse represent a minority. This is of interest in connection with potential danger to life.

Table 2 shows all buildings where structural damage was involved even if it was very small. This means that most of the losses (all of which are shown in US $) stem from non-structural parts which generally contribute about 70% of the building cost.

Table 3 contains all buildings where no structural damage was noted during inspections. As these inspections were done for insurance purposes, i.e. also for assessing pre-earthquake values and actual repair/replacement losses to permit calculating indemnities, inspections were rather thorough.

The first section in each table shows the findings for buildings in Guatemala City and its immediate neighbourhood. The second section is for other regions in Guatemala. This second section does not only represent a comparatively small sample but epicentral distance ranges from about 15 to 260 km.

In each table the findings are entered separately for single storey buildings, 2 - 4 storey buildings, 5 - 8 storey buildings, for 9 and more storeys, for factory sheds, as well as for adobe buildings which are predominantly one-storey structures.

If we disregard adobe buildings, the rest may be considered representative for modern building populations as found in many earthquake countries. Building quality generally increases with height as the taller structures are usually more modern and better engineered. Very tentatively, one may assume that on the average earthquake resistance is about as if designed for 4% g for 5 storey buildings reaching 6% g for many of the higher buildings in the sample. The data for factory buildings stems from a rather mixed population (diverse construction materials, design, span, height of columns) and should be viewed with reservation. Factory buildings listed under other regions contain some items which were at least partially of adobe.

The first column in each table gives the number of cases and the percentage this number represents of all buildings of this type in the region, e.g. Guatemala City. This tells us most about disruptiveness of the damage. Disruptiveness, e.g. indirect losses, loss of life and personal injury potential, social and commercial consequences may be severe if damage is only non-structural (Table 3).

In the following columns the total pre-earthquake value of the buildings is shown and the percentage of the total per building category this represents per section, followed by similar figures for the total loss. In connection with values, a discriminating reader not familiar with building cost in this or comparable countries may be surprised by the low average values which he may calculate from the data given. As we are dealing with

80% although the intensity was not above the one noted in Guatemala City.)

If we collect the data for modern buildings for residential, commercial, or administrative use, i.e. for buildings of one storey and more but excluding adobe and factory buildings, we note that only about 3.5% of the cases, 2.3% of their value and about 10.5% of the loss belong to this gravest class of damage.

TABLE 2

BUILDINGS INVOLVING SOME STRUCTURAL DAMAGE

	n	%	VALUE	%	LOSS	%	MDR
GUATEMALA CITY & SURROUNDINGS							
1 STOREY	237	11.78	2,661,900	12.83	1,186,350	23.54	44.57
2-4 STOR.	14	11.29	3,680,900	32.93	468,200	33.45	12.72
5-8 STOR.	12	50	3,988,900	45.94	1,259,000	66.86	31.56
9 & ABOVE	1	25	2,355,000	26.66	601,400	66.21	25.54
FACT.BLDGS.	22	25.29	5,071,200	23.17	614,300	21.57	12.11
ADOBE	8	27.59	195,100	30.06	82,800	24.21	42.44
OTHER REGIONS							
1 STOREY	5	18.52	136,100	21.10	34,300	20.71	25.20
2-4 STOR.	1	50	111,200	77.65	49.300	93.90	44.33
FACT. BLDGS.	5	38.46	564,000	38.95	83,000	23.04	14.72

Table 2 comprises those cases where structural damage was involved, however slight, but not collapse.

It is not surprising that the percentage of structural damage is similar for single and 2 - 4 storey buildings as both have similar resistance and building characteristics. It is, however, surprising that the 5 - 8 storey buildings, which are in general better engineered and have otherwise received more attention during construction than the lower class of buildings, are nearly five times more afflicted by structural damage than the preceding groups. In buildings of 9 storeys and more, the percentage drops to 25% but it is seen that not only the uncertainties from a meagre sample are to be considered but that grouping according to storey numbers is rather coarse. From a different set of statistical data compiled by the author, which will be published shortly, it may be seen that damage tends to accumulate in what one may call resonance bands. This supports the statement that the pronounced structural damage seen in the 5 - 8 storey group is probably due to unfavourable site effects.

As the figures in the table are self-explanatory (the interested reader may calculate confidence limits or other combinations of data), the combination of Tables 1 and 2 shall be discussed briefly.

If Tables 1 and 2 are combined, we find that 15.67% of the 1 to 9^+ storey buildings (excluding adobe and factories) in Guatemala City and surroundings involve structural damage. For values this percentage is 27.94% and for losses 48.56%. The MDR for this class of damage is 32.45%.

those where the loss amounted to few dollars only.

What does this mean? For the most interesting types of buildings discussed already earlier (1 to 9 storeys and more), we find that 84.33% of all cases relate to non-structural damage which represents disruptiveness better than percentage of values or losses. Considering values, we get 72.06%, and if we transfer about 70% from the earlier tables this percentage rises to beyond 90%! In terms of loss, we calculate 51.44% non-structural damage of the total damage to 1 - 9+ storey buildings in the area of Guatemala City as per Table 3. Adding the approximate non-structural element from the earlier tables, we reach more than 85%.

In passing it may be added that if (insured) earthquake losses to contents of buildings and factories, to machinery and indirect losses like loss of profit and on standing expenses are added, the amount of structural loss shrinks to less than 8% of the total loss. If we consider further that total indirect losses are much graver than those represented by the insured ones (where frequently only high-value risks are covered selectively), the importance of non-structural losses rises even more. Ambraseys (personal communication) found that non-structural losses caused by the Thessaloniki earthquake of June 20, 1978 amounted to about 99.5% of all damage.

RISK OPTIMIZATION

Efforts of earthquake engineers have so far concentrated predominantly on structural elements. This holds for earthquake building codes as well. The figures show that damage and misery caused by earthquakes could be reduced substantially if an equal amount of attention would be paid to non-structural parts of buildings. If we further consider that earthquakes have occured which caused losses amounting to about 50% of the GNP of the country although their magnitude was not impressive, we may take this as an additional incentive to improve those parts which cause most losses.

In conclusion, some suggestions are made which concern optimization of performance of non-structural parts. Much may appear obvious to the expert but more than two decades of experience with a large number of insured and un-insured loss cases demonstrates that it is generally the neglect of the obvious which causes most of the damage.

1. Compatibility of Structural and Non-Structural Parts: Most of the damage to non-structural parts concerns walls. If such walls are built of bricks or similar brittle material, it is evident that a flexible load supporting structure like a steel or soft RC-frame will produce deflections in such walls which lead to substantial damage. Flexible columns and plate glass are, for instance, far more compatible and such glass plates are far cheaper to replace, but prohibitive heating and air-conditioning cost may require stecial care in design. It is therefore suggested to look into the question of wall elements which are less vulnerable than brick walls.

2. Reduction of Amplitudes: One should try to avoid designs which would bring the building into the probable range of natural periods of the subsoil. Not much research has been done in this field, although it is obvious that