Proceedings of Ninth World Conference on Earthquake Engineering
August 2-9, 1988, Tokyo-Kyoto, JAPAN (Vol.VIII)

SJ-7

LESSONS FROM THE MEXICAN EARTHQUAKE OF 1985: QUANTITATIVE EVALUATION OF DAMAGE AND DAMAGE PARAMETERS

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SUMMARY

In Mexico City all engineered buildings of more than 5 storeys were inspected in order to assess the relative importance of different damage parameters. The general mean damage rate (MDR) was 32.1%, ranging between 94.13% for 2% g buildings and 1.89% for 10% g buildings. Stiff buildings had much lower MDR's than soft ones. Irregularity and asymmetry increased MDR's significantly. MDR´s of oblong buildings were strongly depending on their orientation. Most of the overall damage resulted from failure of non-structural items. The paper presents a detailed account of these findings and the salient lessons herefrom.

INTRODUCTION

The purpose of the quantitative analysis was to improve the information compiled after earlier earthquakes (1). The most important damage parameters are shear strength, degree of softness or stiffness of buildings, regularity and symmetry, orientational sensitivity, hammering, quality of the foundation material, resonance between the subsoil and the building, and performance of non-structural parts.

Earthquake building codes address only some of the above parameters and, depending on the type and location of the building not necessarily the most important ones. Moreover, essential aspects are often left out.

This paper endeavours to present the most salient lessons concerning damage and damage parameters learned from the inspection of practically all modern buildings of more than 5 storeys in the Fondo del Lago region of Mexico City (the extinct part of the Lago de Texcoco).

METHOD AND SAMPLE

Following the method employed when investigating damage from earlier earthquakes we tried to achieve a complete sample, i.e. we investigated each building meeting the qualifications mentioned above. In addition to avoiding bias only complete samples will in general be large enough to provide subsamples of sufficient size per essential parameter. The total sample presented here comprises 491 buildings of 6 to 29 storeys. About 88% of the buildings had 6 to 15 storeys. The total volume of the investigated buildings exclusive of basements amounted to 15,278,989 cubicmetres.

A detailed questionnaire was used to record the location, orientation, and type of each building, architectural and structural layout, design, structural and non-structural parts, etc., cause(s) of damage, as well as the damage to all components.

RESULTS

Starting our discussion with general aspects damaged buildings were nearly exclusively located in the region of the extinct Lake of Texcoco and because of the predominant nearly harmonic low-frequency shaking of the ground generally only buildings of 5 or more storeys were affected. If one enters the damaged buildings in a map of Mexico City they appear to be concentrated in "pockets of damage". It has been tried to interprete this phenomenon as resonance effect of standing waves (2). These pockets are, however, more convincingly explained by the concentration of vulnerable buildings in such areas and their absence from others (3).

The general exposure depended most prominently on interaction of subsoil and buildings ("resonance"). Buildings of few storeys, even if old and frail suffered as a rule little or no damage. The mean damage ratio (MDR) of tall buildings was primarily controlled by the base shear and their relative stiffness. This must, however, be taken with a pinch of salt because buildings the natural frequency of which was a harmonic of the predominant ground frequency (abt. 0.5 Hz) show a higher MDR if the sample is normalized for base shear and if the effects of irregularity and asymmetry and of orientational sensitivity are removed. The correlation between base shear and MDR and the influence of other parameters is shown in Fig. 1.

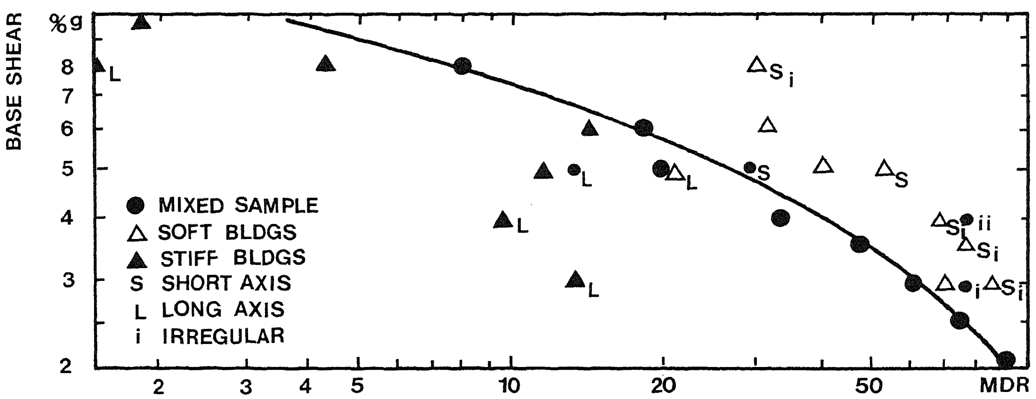

Fig.1. Correlation between base shear (% g) and mean damage ratio (MDR). To avoid crowding not all subsamples are shown. Adequate base shear, stiffness (also from fill-in walls in the long axis of buildings), and regularity are beneficial parameters. Stiff buildings of 3% and 4% g, for instance, shaken predominantly in their long axis suffer not more than average buildings designed for twice the base shear, and if these "stronger" buildings are soft and irregular their MDR is two to three times higher.

Stiff buildings suffered less than soft ones (Table 1, cf. also 1, 4, 5). The scatter in the MDR of stiff and soft buildings is caused by the other damage parameters mentioned above.

TABLE 1
MDR (%) of Stiff and Soft Buildings of Different Base Shear

BASE SHEAR (% g)	3	3.5	4	4.5	5	6	8
STIFF BUILDINGS	13.3	5	9.7	2	11.7	14.8	4.4
SOFT BUILDINGS	67.3	50	34	22	40	32	30

The stiffness of oblong buildings tends to be much greater in the direction of their long axis than in the direction of the short axis. In Mexico City accelerographs measured much stronger ground movements in the EW-direction than perpendicular to it. It must be noted, however, that unless ground movements are analysed vectorically it is difficult to state in which direction shaking was most promninent, in particular if one has to make proper allowance for interesting frequency bands. Buildings having their long, i.e. stronger axis about in the EW-direction suffered much less than identical buildings orientated perpendicular to them (6). We shall return to this aspect when discussing orientational sensitivity but it must be noted that also this observation underlines the importance of stiffness in reducing damage, in particular if tall buildings are founded on deep soft ground.

MDR's of irregular and asymmetrical buildings were persistently higher than those of regular ones even when considering the complete, i.e. heterogeneous samples. In brief, irregular buildings are those which have a floor plan or elevations which are not a simple rectangle, e.g. floor plans of the shape of an L, U, T, or H, or elevations like an L or inverted T, or buildings with a completely or partially soft ground floor or of different resistance and stiffness along the main axes, e.g. because of plate glass on one side and brick or concrete walls in others. Due to the effect of fill-in walls oblong rectangular buildings must, however, be considered irregular.

For the entire sample of buildings with base shears of about 3% g and 4% g all regular buildings had MDR's of about 62% and 26% whereas the one of irregular buildings was 77% and 42% respectively. Comparing soft regular with soft irregular buildings the difference in MDR was about 1:1.6.

As regards the beneficial influence of symmetry, for instance, all quadratic buildings of 3% g had an MDR of 15%, slightly higher than the one of all stiff buildings, but much lower than the MDR's of all buildings (64.7%), or of all irregular ones (76.8%). Such differences should not be taken as hard and fast rules because of the other contributing factors, but irregular and asymmetrical buildings are in general much more exposed than regular and symmetrical ones.

We discuss now the sub-samples of buildings arranged according to base shear and the influence of different damage parameters.

Buildings of about 2% g had a MDR of 94.13%. They were soft and exposed their short axis to the direction of maximum shaking. Also all 2.5% building were soft. Those shaken predominantly in the direction of their short axis had a MDR of 94%, those having their long axis about in the direction of maximum shaking had an MDR of only 23%. The average MDR for the complete sample was

75.8%. This illustrates how misleading statements may be which mention only average damage.

The sample representing 3% g buildings was contaminated by many parameters affecting damage. For all soft buildings which were shaken more strongly approximately in the direction of their width the MDR was 65% for regular and 85% for irregular buildings. In spite of the many other contributing parameters all buildings shaken more strongly in the direction of their length had a lower MDR than the others, viz. 59% compared with 68%. The MDR of all buildings which were more or less regular was 62% the one of irregular ones 77%. The differences in MDR's generally decrease in the high loss categories because of damage saturation (7).

Also the experience with 3.5% g buildings points at lacunae in structural design. The overall MDR was 48.1%. Soft buildings shaken mostly in the direction of their short axis had an MDR of 47% if they were regular, irregular ones, however, an MDR of 77.3%. Even for buildings of heterogeneous stiffness the MDR's differed very much depending on their orientation, viz. 20% (long axis) and 65% (short axis).

For 4% g buildings the overall MDR was 34.03%. The MDR of all rectangular buildings was 26%, but 42.4% for irregular ones. If elevations were irregular as well the MDR reached 78.6%. The MDR's of buildings having their long or short axis about in the direction of maximum shaking were not too different, 29% and 34% respectively, but this is explained by the other damage parameters concealing this effect. Irregular soft buildings shaken more along their length had 39.7% MDR, for those shaken more in the direction of the short axis it was, however, 69.2%. The MDR of buildings of this strength which were symmetrical (quadratic floor plan) and stiff, was only 1%. Oblong and stiff buildings with their long axis about in the direction of maximum shaking had an MDR of 2.83%.

The 5% g buildings had a global MDR of 19.67%. The MDR of those exposing their short axis was about 30% those shaken more along their long axis had one of only 14%. The MDR of irregular buildings was 30.3% against 15.9% for regular ones. For 6%g buildings MDR-differences, except the one for stiffness/softness (cf. Table 1), were smaller because of other contributing factors. Still MDR's for regular buildings and those having their long axis about in the direction of shaking were persistently lower.

For 8% g buildings the MDR-ratio for long to short-axis buildings was 1.73% to 7.63%. The MDR of stiff buildings experiencing shaking mostly in the direction of their long axis was only 0.81%! The 10% g buildings were all stiff except for one which belonged to the mixed type. The global MDR was 1.89%

As regards orientational sensitivity some cautioning remarks are appropriate. In fact the influence of the fill-in walls in oblong buildings is very much larger than indicated by the above figures. We have already published a special paper dealing with orientational sensitivity (6). MDR's quoted here are for heterogeneous samples. Firstly, the length to width-ratios differ considerably. For instance, a rectangular building measuring, e.g. 20 x 30 m is far less affected by this damage parameter than one measuring 12 x 60 m. Secondly, there is also scatter as regards orientation because the roads of Mexico City, i.e. the orientation of buildings, do not form a homogeneous rectangular grid. Thirdly, the direction of known average maximum and minimum shaking, did not exactly coincide with the orientation of the oblong buildings, in addition attention is invited to our earlier comment on ground movement.

CONCLUSIONS AND LESSONS

The conclusions and lessons from the investigation of earthquake damage to buildings in Mexico City confirm the results obtained from earlier earthquakes. The most important general lesson is that the shear strength of the structural parts of a building is just one parameter among many. More specifically the following lessons emerge as regards important damage parameters:

1. The philosophy on which today most earthquake "resistant" building codes are based is the protection of people against partial or total collapse. The incidence of casualties is correlated nearly exclusively with the base shear of the structure. As soon as buildings are, however, of reasonable strength the chance of severe structural failure drops very much and the risk of casualties and the contribution to damage shifts from structural to non-structural items. The Mexican sample shows, for instance, that of the 168 buildings of about 4% g 14 sustained damage rates (DR) of 75% and above (8.33% of the sample). Of the 6% g buildings (n = 62), however, only 2 had a DR of 75% and above, i.e. 3.22% of the sample.

2. When designing buildings, one should pay particular attention to columns. Of the 112 buildings equivalent to 6% g or better 17 had damage to columns and the MDR of these buildings was 43%. Only two had damage to beams but not to columns and the MDR was 6.3%.

3. The problem of "resonance" between building and predominant frequency bands of the subsoil must be considered, and not only in Mexico City where a chance to learn this lesson arose already in 1957 (8, 9). The author showed a significant dependence of predominant frequencies of soft layers on their depth (10) permitting pragmatic corrective steps.

4. The importance of stiffness of buildings, particularly if founded on soft foundation material cannot be overestimated. Already Ch. F. Richter drew attention to this (11), and our Mexican data which is in line with our global sample (1) support this view.

5. The lack of knowledge about the contribution of "fill-in walls" to the shear strength and/or stiffness of a building is appalling. The differentiation between load bearing and non-load bearing members of a building is too parochial. This attitude is responsible for very severe damage and even for loss of life. It is not logical. In a building constructed entirely of brick the respective walls are considered load-bearing. As soon as bricks fill the spaces between the columns, these walls are, however, thought of as non-structural elements and their contribution to strength (and damping) is neglected. A pragmatic approach is, however, possible (7).

6. Asymmetrical and irregular buildings are more exposed than symmetrical and regular ones. This factor must be considered in an attempt to reduce casualties and economic damage. An approach has been published (7).

7. Orientational sensitivity is an important aspect, in particular for oblong buildings (6). The present study underscores this, for instance, all buildings of 6% g or better which collapsed experienced maximum shaking in the direction of their short axis.

8. Damage is in general mostly found in the ground floor of buildings. In Mexico City damage was, however, scattered over all storeys and severe damage was often noted in the upper ones. A general conclusion is inescapable, viz. that it still appears to be impossible to design buildings in such a manner that all storeys are of about similar strength.

9. Hammering between neighbouring buildings was far more important in Mexico than in all other earthquakes we inspected. This is mainly due to the long duration of nearly harmonic shaking which amplified the deflection of tall buildings. Important damage from hammering occurred in 8.18% of all buildings with a base shear below 6%g but only in 3.57% of the stronger ones.

10. By far and large most of the direct and indirect damage resulted from non-structural items. Also this is no new lesson (12, 13). Much more attention must be paid to these items.

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