SOME LESSONS FROM THE MARCH 14, 1979 EARTHQUAKE IN MEXICO CITY

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Summary. Some of the problems caused by a severe earthquake, $M_s = 7.6$, that occurred on march 14,1979 near the coast of Guerrero, but wich affected --- mainly Mexico City, are described.

There were three cases of complete collapse of three story structures; flexural, torsional or compression damage in beams and columns, pounding - with adjacent buildings due to excessive flexibility or inadequate separa-- tion; non-structural damage in a very large number of buildings was observv- ed. Watermains were disrupted in several places.

Reparation criteria for two buildings are presented

Introduction. A strong seismic movement was felt on march 14, 1979 in Mexico City. The origin was located on the Pacific coast, near the limits of the states of Guerrero and Michoacán.

According to U.S. Geological Service, magnitude of this event was 7.6; coordinates of the epicenter assigned by a group of seismologists who had instrumented the zone prior to the earthquake are 17.31 N, 101.35 W; focal depth was estimated around 59 Km. The movement occurred at 11 h 07 m 02 s (Greenwich), 05h 07m 02s local time. Several repetitions were felt, some of them with magnitudes larger than 5 (ref. 1).

Fortunately the number of persons killed or injured was very low, but damage to structures was extensive, especially in Mexico City where soft -- soil conditions amplified and filtered the motion, affecting mainly relatively long period structures.

The larger towns near the epicenter were Zihuatanejo, Iztapa and Petatlán where many adobe and bahareque houses were destroyed or severely damaged. Masonry structures reinforced with beams and small columns embedded in the walls were practically undamaged. Zihuatanejo and Iztapa are touristic spots with several tall hotel buildings wich suffered some structural as well as non-structural damage (ref. 2).

Damage observed in Mexico City. From the geological point of view the city can be subdivided in three different soil zones. The oldest part of the city corresponds to the lake zone, with high compressibility clay deposits with depths to the first load bearing stratum ranging from 20 to 38 m. Soil in the hills surrounding the city is stiff with high load bearing capacity; - some parts of this zone are covered by volcanic lava. In the middle of the above zones is a transition zone having less compressible clay deposits -- with depths ranging from 3 to 20 m approximately, fig. 1.

Most structural damage was concentrated in the soft-soil zone where there are many tall buildings with relatively long periods, which have a - large structural seismic response due to similarity with dominant periods of the soil stratum.

More than one hundred buildings located in this area were inspected; they suffered variable damage, from minor cracking in partition walls and broken window glasses to severe damage in bearing walls, columns and beams.

From the point of view of number of buildings damaged compared with total number of buildings in the city, one of the largest in the world, it is possible to say that damaged buildings were but a small percentage of the

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total number, reflecting that seismic codes and constructive practices used are adequate; however, it is necessary to determine the causes of damage in order to correct any sistematic deficiency observed.

A very common case of failure was that of theoretically "non-structural" elements, especially infill walls and facades, joined to the structure in such a way that its movement was impeded; this caused that the stiff - but not always resistant enough partition walls, resulted seriously cracked, with some instances where the structure was also damaged.

Reinforced concrete structures with shallow flat slabs as horizontal resisting elements have become very popular in Mexico City in recent years; this type of structure has very low lateral stiffness that leads to large story deformations, difficult to absorb with gaps between structure and non-structural elements when these gaps are provided.

The largest losses in this earthquake came from the combined effects - of the above considerations.

Mexico City Code allows lateral deformations up to 0.016 times the story height when special provisions are taken to avoid damage to non-structural elements and deformations are computed multiplying those obtained - with forces reduced by ductility of the structure by the applied reduction factor, that is, with unreduced forces. Several studies are under way at this moment to evaluate if this regulation should be modified.

Fig. 2 shows a severely damaged building that was located at a corner; large torsional effects developed due to the stiffness of lateral infilled walls which were assumed "non-structural"; most columns in the first story were badly damaged, figs. 3, 4, 5, as well as short facade walls in the upper stories, fig. 6. Flat slab floors were also damaged as can be seen in fig. 7.

Fig. 8 shows another case where lateral walls were diagonally rein-- forced to resist seismic effects but were placed on a plane not coincident with the frame. Here the strenght of the walls was not enough and the diagonal reinforcement was damaged.

Pounding between adjacent buildings in some cases was due to the combined effects of excessive flexibility of structures and differential settlement of buildings. Figs. 9 and 10 show how the separation between two buildings was reduced considerably due to settlement of the short building, causing that one fourth floor column of the tall one resulted with damage. Fig. 11 illustrates a similar case where adjacent walls were seriously damaged due to pounding with the neighbouring buildings. Here partition walls in the short direction were badly cracked due to excessive flexibility combined with null separation between them and the structure; reparation of this building is described later.

Deep facade beams, when spandrels are incorporated to the resistant structure, increase frame stiffness due to reduction of column lengths. This produces two effects: a larger force than that assumed in the analysis neglecting the increase in stiffness is absorbed by facade frames and shear failure of the columns becomes possible. Vibration periods are also reduced and this may lead to a higher earthquake response. Figs. 12 and 13 show damage to the columns of a twelve story building where this happened. As there is an architectural current in Mexico that tends to use this type of elements, it has been necessary to include joint effects in the frame analysis to take into account zones of very large moment of inertia at the ends of the columns.

The worst case of damage was the total collapse of three school buildings of a private university (figs. 14 to 17) located far away from the zone where most damage occurred,fig. 1. The buildings were three stories high, constructed in 1961 approximately, therefore they had survived several strong motions that affected the city since that time. Seismic forces - were resisted by rigid frames; however, due to architectural reasons, the beams of the longitudinal direction were connected to the beams of the -- transverse direction rather than to the columns,transmitting seismic effects to them through torsional action on transverse beams. fig. 19.

Is is well known, at present, that torsional failures are brittle and should be avoided; however, it is difficult to explain the failure from - this single point of view. Cumulative damage due to previous movements - might have contributed largely to the collapse, as the structure had several cracks that were studied in several occasions before the 1979 earthquake, and recommendations were made in order to strengthen the structure; however, this was never made. Estimated periods of vibration in the longitudinal direction are larger than 1.5 sec (very long for a 3 story building) and a large response due to soft soil conditions might have also contributed to the failure. Three identical buildings remained standing, fig. 18, 19 but severely damaged; they were demolished without opportunity to make - some field studies on them. The time at which the earthquake occurred was certainly fortunate in this case, as two hours later the buildings would have been completely occupied.

Among other problems caused by the march 14 earthquake was the damage to water mains in several places, especially at the border of transition and firm zones of soil, where differential movements took place. Restoration of the service delayed for more than one week in some parts of the city.

Additional comments about damage observed. In some appartment buildings with damage in non-structural elements only, where the ownership system is condominium, it was found a tendency of each proprietor to repair its damage independently from the other tennants, thereby increasing the possibility of larger damage in future earthquakes, as the dynamic characteristics of the buildings might be altered strongly when some of this elements became "structural" in several stories due to differences in reparation criteria. As there is a very large number of condominium appartment buildings in Mexico City with flexible flat slab structures, damage to non-structural elements is very common during strong earthquakes,therefore, in addition to the economic aspects, the unified repair of the structure certainly poses a social and regulatory problem.

Damage caused by pounding due to reduction of the gap left to absorb movements during earthquake because of differential settlement of an adjoining building may also be a regulatory problem, in cities as Mexico City with zones of very compressible soil.

Reparation criteria. Two case examples

It is well known among structural engineers that present codes imply some type of failure during strong earthquakes, (perhaps the public should be informed of this in a more specific way); however, according to ref. 3: "Few problems in structural engineering offer a challenge comparable to the one that faces the engineer who must decide whether to patch up a structure damaged by earthquake, to strengthen it, what extent and in which manner, to demolish it in part or to condemn it"

The author was consulted on the reparation of two buildings that were damaged to a certain extent by the earthquake and after analyzing them it was concluded that reparation could be relatively easy and possible.

The first one was illustrated in fig. 11. It was mentioned with regards to pounding with adjacent buildings due to insufficient seismic gap. It had mainly non structural damage in the partition walls of the short direction; however, a column of the fourth floor had failed as shown in fig. 20. It is one of the condominium appartment buildings that was being repaired by each tennant without studying the structure as a whole. Plan of the typical floor is shown in fig. 21. The structure consisted of flat slab floors and concrete columns; it is supported on friction piles. Due to the insufficient depth of beams the frames were very flexible causing pounding with the neighbours, therefore, it was decided to increase lateral stiffness by means of diagonal steel members infilled in three of the frames of the transverse direction combined with column reinforcement using steel angles and lattice, as shown by fig. 22. Longitudinal walls were also reinforced using wire mesh and plaster. Fig. 23 shows period measurements of the building taken before and after strenghtening, evidencing the increase in lateral stiffness that will eliminate most of the pounding problem with neighbours.

The second building is also a condominium medical building, mentioned with regards to deep facade beams. Structural damage in this case was more pronounced, as columns in several frames were badly cracked in the first three stories and beams were also cracked by shear and flexural effects; the building is 12 stories high, typical floor plan is shown in fig. 24. Two different types of reinforcement were studied, both trying to reduce seismic effects on the affected members. One consisted of slender concrete shear walls in the interior frames close to the elevator shafts; however this solution was not stiff enough to reduce effects on the cracked elements and led to high moments in the connecting beams, so, another option consisting of vertical and diagonal reinforcement parallel to extreme frames of the short direction combined with slab reinforcement in order to transmit most of the seismic shear forces to this new very rigid facades, was used, fig. 25. Broken columns were repaired with expansive mortar and lined with steel plates on the first levels, cracks in the beams were repaired using epoxy resins. Reparation is in progress at the time of writing this paper.

Modal dynamic analysis were carried out in both cases to compute the forces that should take the new elements and the remaining stresses in the original structure. A step by step analysis for the first case using the soft-soil accelerogram of the march 14, 1979 earthquake, is being made by a student as part of his thesis.

Final comments. Several investigations were made concerning the adecuacy of the present Mexico City code; one of them, still unfinished, seems to lead to the conclusion that story drift should be reduced in order to diminish non-structural damage in flexible buildings. Another investigation concerning flat slab floors mentions that equivalent width of slab contributing to frame stiffness is overestimated by the code and should be reduced, it also indicates that the reduction ductility factor for this type of construction should not be taken larger than 2, due to a tendency to shear failure at the slab-column connection (ref. 4)

One of the most difficult problems to solve is to avoid interference of the non-structural elements with structure deformations during strong earthquakes. Different means to solve it have been presented, refs. 5,6; however, it is costly and difficult at the job to leave an effective gap between structure and partition walls, especially in the case of lateral walls which have to protect the building from the outside moisture and cold temperatures. Out of plane effects have to be considered also. Adequate filling materials to be used at the gap are in general expensive: They have to be compressible enough, and if possible, elastic, in order to recover -- its shape after deformation has occurred; otherwise, they have to be re-- placed after strong movements.

Considering that in every earthquake affecting tall buildings a large-part of the damage occurs in non-structural partition walls, extensive -- studies should be made to develop an adequate solution to this problem.

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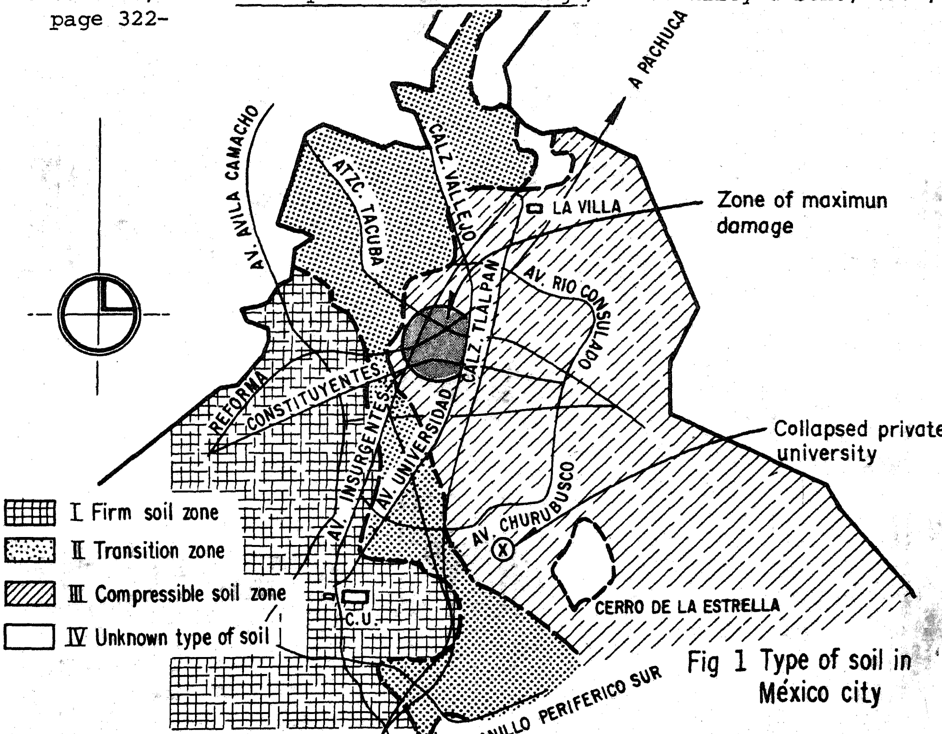


Fig 1 Type of soil in México city

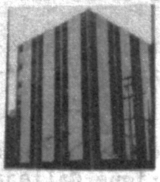
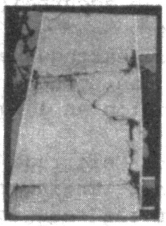


Fig. 2


Fig. 3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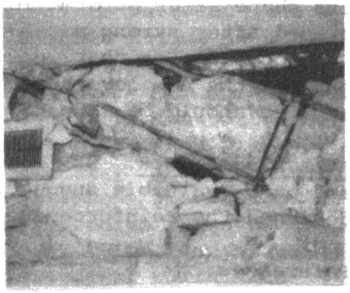
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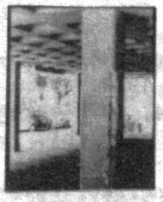
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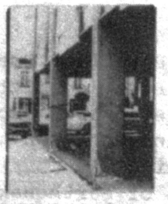
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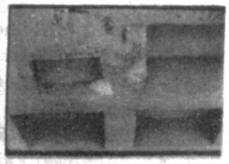
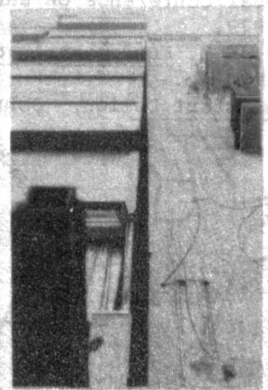


Fig. 7


Fig. 9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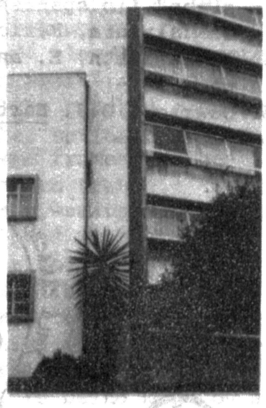
Fig. 11


Fig. 12

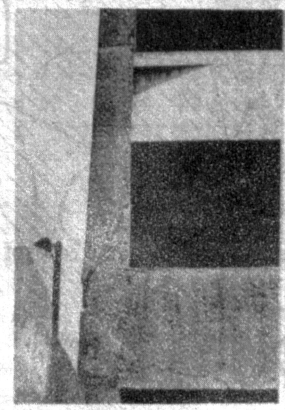
Fig. 13


Fig. 14

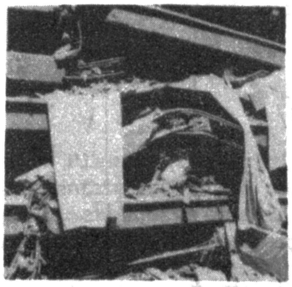

Fig. 15

Fig. 16

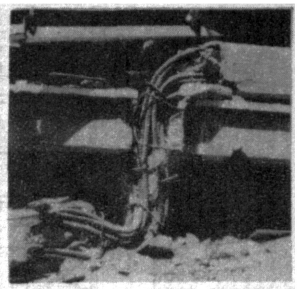

Fig. 17

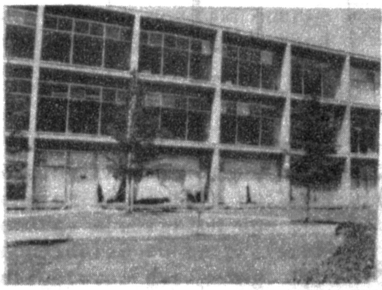

Fig. 18

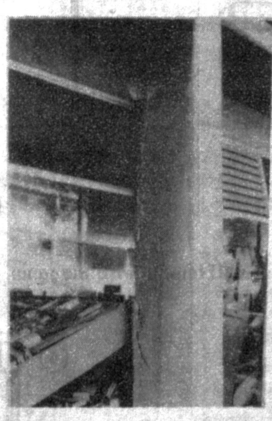

Fig. 19

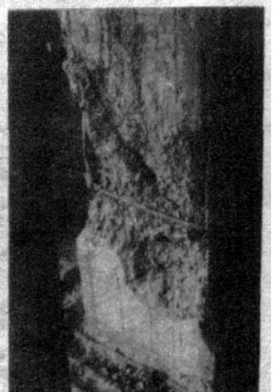

Fig. 20

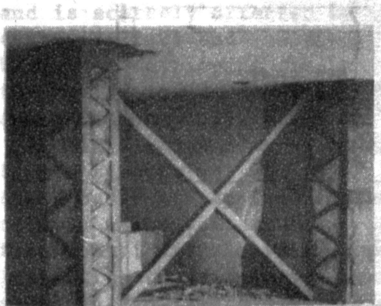

Fig. 22

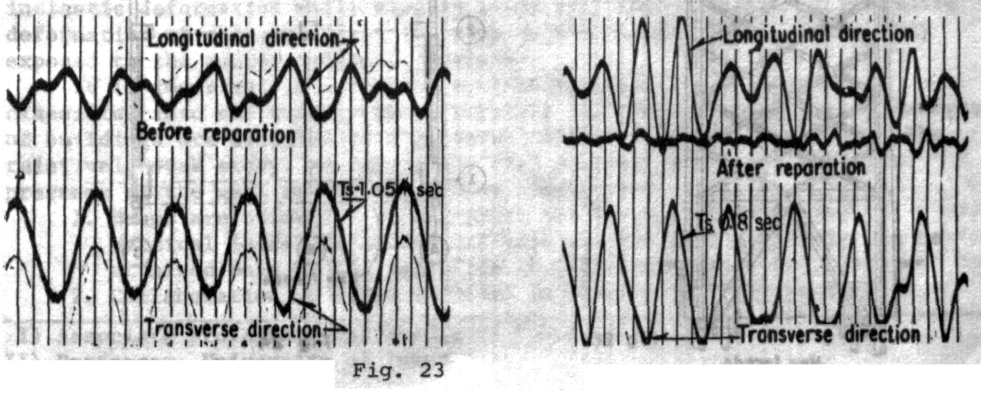

Fig. 23

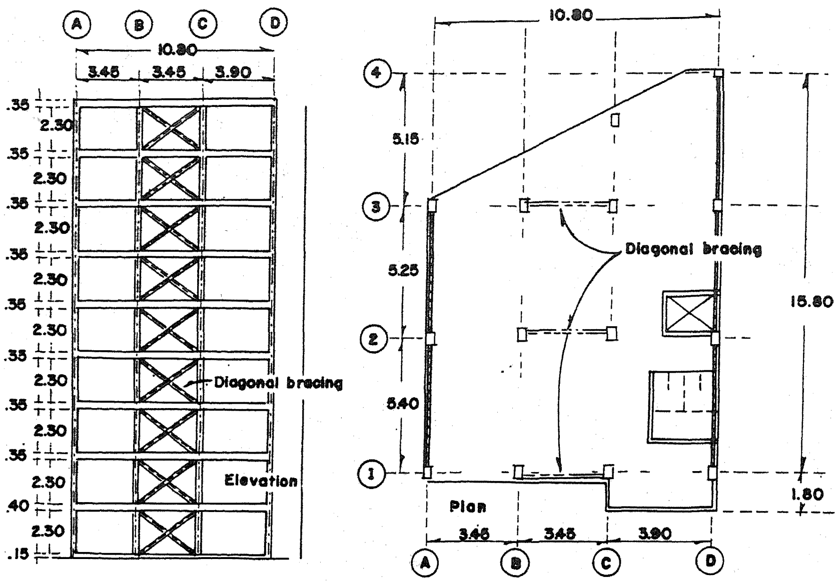

Fig 21 Structure stiffening with diagonal bracing

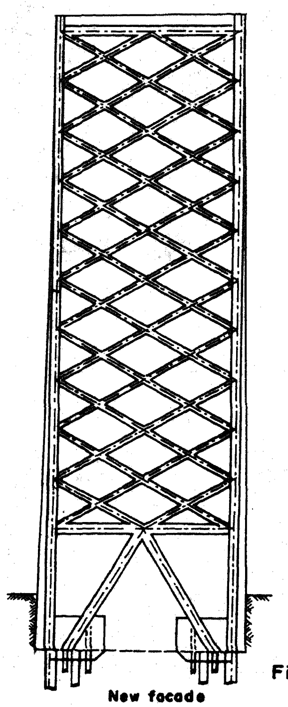

Fig 25

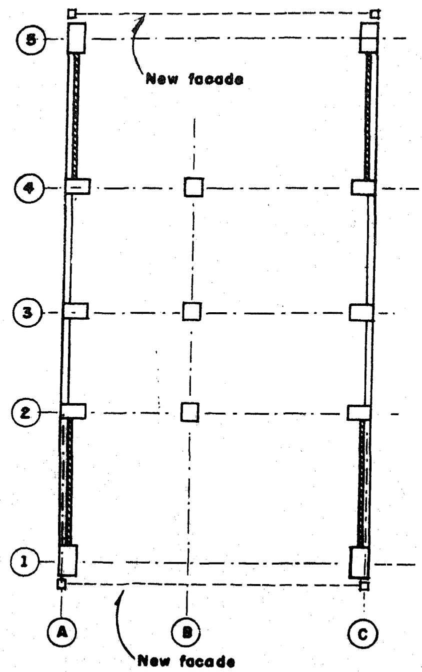

Fig 24