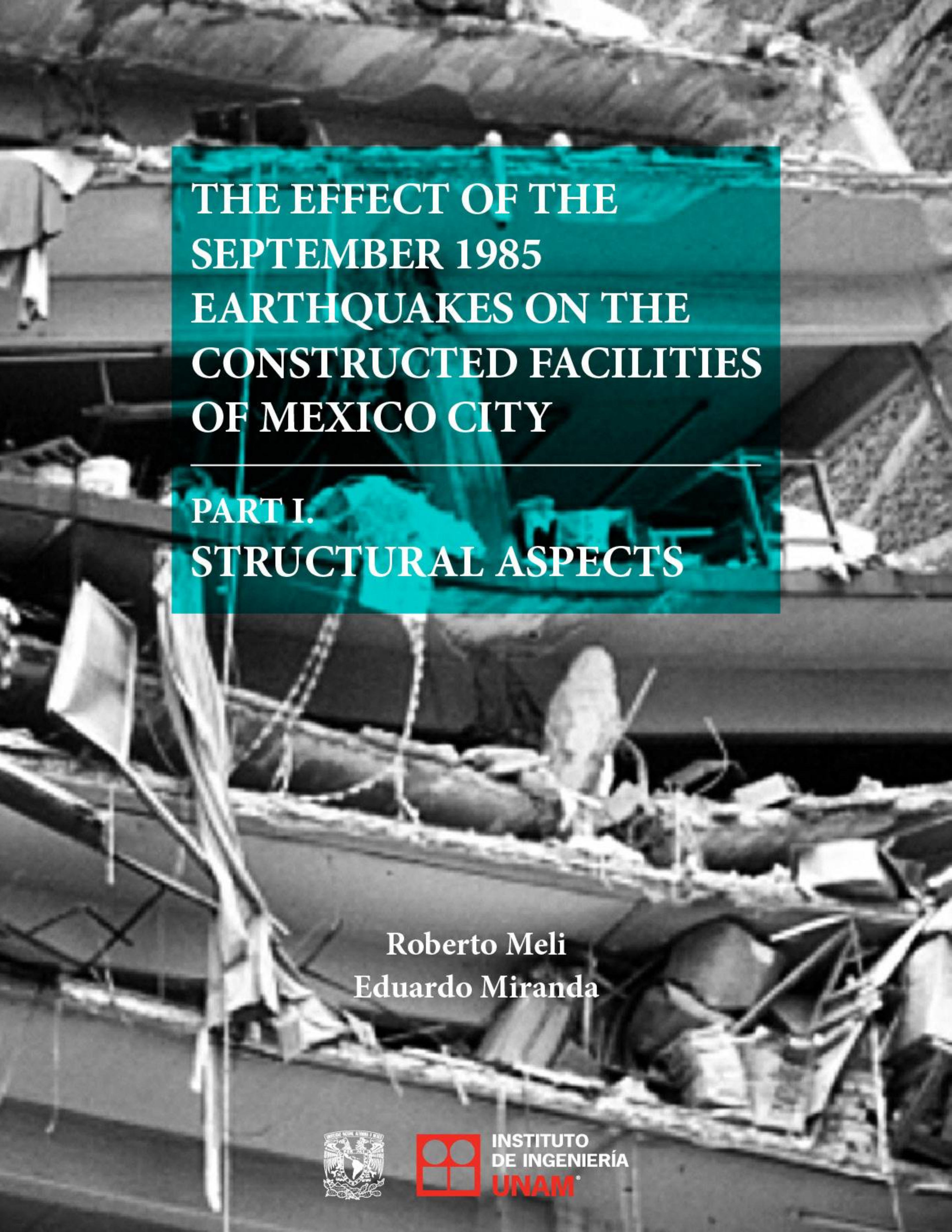

THE EFFECT OF THE SEPTEMBER 1985 EARTHQUAKES ON THE CONSTRUCTED FACILITIES OF MEXICO CITY

PART I. STRUCTURAL ASPECTS

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STRUCTURAL ASPECTS

SECOND REPORT OF THE ENGINEERING INSTITUTE OF THE NATIONAL UNIVERSITY OF MEXICO (UNAM)

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1. SCOPE

This report contains the results of the evaluation of damage of constructed facilities put together by personnel of the Division of Structures of the Engineering Institute in collaboration with specialists of other institutions. A preliminary report was prepared on September 30, 1985. This subsequent report will contain revisions and amplifications of the preliminary report as well as more detailed statistical analyses and more quantitative conclusions with respect to the types of damaged constructed facilities and the characteristics which influenced the failures. The evaluation will be limited to structural aspects. The deformation of soil and the foundation problems which had some relevant influence in the structural behavior and in the damage of the structures, will only be treated marginally in this report.

2. EVALUATION PROCEDURE

The assessment was carried out by dividing the city area where damage occurred into 17 zones identified in Fig. 1. These zones were gone over by teams who inspected the buildings with evidence of damage, filling out for each case an evaluation sheet such as that found in Appendix A. In the majority of cases, it was not possible to obtain all the information requested on the evaluation sheet and only essential data relative to the location and characteristics of the structures and the type of damage were noted. Photographs were obtained in each case, as well. The following levels of damage were noted:

1. Total or partial collapse: this includes a not insignificant number of damaged adjacent buildings induced by failure; the data compiled can be considered practically complete regarding buildings of many stories, but they were not evaluated individually, and no statistics were included regarding a large number of failures in small, very deteriorated structures generally containing poor materials.
2. Severe damage: This includes buildings with failure in columns, important distortions in the floors, and serious inclinations. Here also, the statistics relating to these buildings can be considered complete, since the damage can be seen from outside.
3. Intermediate structural damage: includes local failures in columns and beams which represent in general a significant loss in their capability. The statistics for this level of damage and for the next, includes only a small fraction of the real cases, since this type of damage is frequently not detectable from the outside and could pass unnoticed.
4. Minor damage; including cracks in small openings and local damage: In each case identification was attempted of some structural aspects which could have been the partial or principal cause of the damage, such as torsions or important irregularities, defects in construction or faulty reinforced concrete. It was possible to make a statisticsl evaluation of some of these characteristics

3. ZONING OF DAMAGE

In order to localize the areas most densely damaged, the level 1 and 2 cases (collapse or grave damage), which were those we were most sure of, were placed on a map. The distribution is shown in Fig. 2, where the zone of high damage density is defined with a surface area of 27 km^2. It is interesting to compare the zone of greatest damage on this occasion with the corresponding two former major earthquakes in which the damages to the city were surveyed: that of July 28, 1957, and that of March 14, 1979. In Fig. 6 the zone of major damage density in this earthquake is compared with those of the two former earthquakes including each of the four levels described in Section 2. In this present earthquake, the damages were much more severe and the damaged zone is wider, but a certain coincidence is appreciated between the most greatly affected zones in the three cases where they are located west of the zone of compressed ground.

4. CHARACTERISTICS OF DAMAGED STRUCTURES

For a complete evaluation of the damages, some characteristics were studied which, besides having a certain relevance, could still be found in totally destroyed buildings. These were: the number of floors, the structural system and the date of construction.

The respective data for each one of the 17 zones found in Fig. 1 are listed in Table 1. These data, as anticipated, correspond exclusively to the cases of severe damage or collapse and do not include a good number of residences of poor quality, mostly in the extreme northeast of the zone of major damage density.

The differences in the results between the distinct zones are owed essentially to the diversity of the types of construction prevalent in each one. To analyze the three aforementioned characteristics, it will be neceesary to refer to the summary for all the zones presented at the end of the same table and the results concentrated in Table 2.

In referring to the number of floors, it is noted that the greater quantity of failures correspond to structures of more than 5 floors. Structures of less height, which are much more numerous in the affected zone, have natural vibration periods lower than the dominant periods found in the ground in the zones of compressed soil, and for this reason were seen to be subject to much less effect than those that correspond to higher buildings. Also, the good behavior of the majority of the very tall structures whose natural periods exceed those of the dominant ground, were notable, and they changed after suffering initial damage and rigidity was diminished. In those buildings of medium height, the natural period corresponds to high spectral ordinates and grow toward zones of even greater spectra ordinates when sustaining damages which diminish the rigidity of the structure.

In one evaluation of an engineering firm, an approximate census of existing buildings in the most affected zones was made identifying the number of floors and the type of construction. The areas studied, the classification of buildings and the data criteria of damage differed from those considered in this study, but the results are very illustrative. Fig. 7 indicates the number of buildings with distinct existing characteristics in each zone and the percentage with resulting damages. It is important to note that in this study, cases of minor levels of damage than those considered earlier are included as well as small structures of marginal residences.

Summarizing the 10 zones indicated in Fig. 7, the percentages of constructed facilities with severe damage are the following:

Structures up to 2 floors	0.9%
Structures of 3 to 5 floors	1.3%
Structures of 6 to 8 floors	8.4%
Structures of 9 to 12 floors	13.6%
Structures of more than 12 floors	10.5%
Total structures existing	53,356
Percentage of damage of the total	1.4%

Based on these findings, 1.0% damages resulted in buildings of less than 5 floors and 10% in those of greater height.

In referring to the age, three intervals corresponding to the period of effective distinct Rules of Construction in the city were chosen. Prior to 1957 no rational regulations relative to seismic design existed; between 1958 and 1976 there were in operation emergency norms and subsequent rules which contained detailed requisites of seismic design. On this latter date, the actual rule was vigorously enforced, which contained substantial modifications.

To interpret the former distribution, it is necessary to take under consideration that the smaller density of damage in some zones could be attributed to the fact that the number of types of structures most affected by earthquakes were reduced and not necessarily that the movements were less.

There is a clear correlation between the distribution of damages and the type of subsoil. Fig. 3 shows the zoning with the most commonly found subsoils in the city defined as firm ground, compressed ground and one intermediate fringe, named transition, in which the thickness of the compressible strata is small. It is noted that the zone of major damage density is found totally in the zone of compressed ground, toward the extreme northwest.

The former zoning of subsoil is not very precise for the south of the city where the data were very scarce at the time in which said zoning was determined. With basis in more recent examinations it has been found that the southern part of the compressed ground zone corresponds to the bed of the ancient lake of Texcoco and unites with that of the lake of Xochimilco. In accordance with these data, the damages found near the crossing of Avenidas Tlalpan and Taxquena, and more to the south of this area, are totally located in zones of compressed ground.

Fig. 4 shows stratigraphy of the subsoil in two cuts north-south and east-west for the most affected zone by the earthquake. It is noted that below the superficial filling, a first layer of very compressible clay, followed by a first hard layer, a second stratum of very compressible clay and the lower firm deposits. In Fig. 5 curves of equal depth to the second hard layer have been outlined, and it is noted that in the zone of greatest damage density, the depth to the deep firm deposits were found to be between 25 and 50 m. In other zones with similar depths to these deposits, the damages were much less. For this reason, it is not possible to correlate the intensity of damage directly due to this variable, nor with the depth of the first hard layer, nor with the total thickness of the two layers of soft clay.

The extraordinary amplification of ground motion in said zone appears to be due to a coincidence between the dominant period of movement which originated in the deep deposits and the natural vibration period of the clay deposits. Measurements of this period of movements of small amplitude stimulated by microseisms also are shown in Fig. 5 and indicate values of 1.5 to 2.5 second for the damaged zone, lesser values in the transition zone and firm zone and periods clearly greater in the rest of the lake zone where the densities of clay were similar. The natural period does not depend only on density of strata, but also on its properties, and in particular on its grade of consolidation which is probably greater in the damaged zone.

The third characteristic analyzed is the structural system. For the main part structures with concrete foundations and with columns and beams forming frames in two directions, structures of columns and concrete waffle slabs, structures of steel columns with laminated and open-web steel beams, and structures whose walls were made up of masonry were identified. The subdivision is very broad and it should be made clear that the structures of the first three categories had in general a large number of masonry walls of different quality and these contributed significantly to their rigidity. It was not possible to identify a category of constructed facilities with structures of frames stiffened by concrete walls. The number of damaged buildings with these characteristics was small, but also it is noted that few of the existing buildings in the affected zones had concrete walls; furthermore the identification of the possible existence of these walls from outside was difficult.

The statistics relative to the structures system reveals mainly the low incidence of failures in construction with walls of masonry, which were surely the largest group, but which because of their low height and rigidity fall in an interval of vibration periods in which the effects of the ground movement in the compressed zone were minor.

With respect to the other three structural systems, the conclusions were not as definite. The number of failures in steel structures is small and for the most part consist of low and ancient structures with inadequate connections between beams and columns. Also, the number of structures with this type of structure is small and only four cases of collapse or severe damage corresponded to modern structures.

The large majority of failures occurred in concrete structures. Although the total number of structures with concrete frames is high, proportionately it is much higher in the buildings with waffle slabs. From the census of existing structures mentioned above, it is concluded that 2.9% of the buildings with concrete frames in the zone of greatest damage density suffered important damage, while a 5.9 percentage was found in those with waffle slabs. If consideration were given to the proportion of structures with severe damage and collapse, those buildings constructed with waffle slabs are almost double those of concrete frames. For the structures before 1976, the number of failures is clearly largest in those of plain slabs. This probably reflects the growing popularity of this system and perhaps a need for improvement in the practical planning and construction of other systems.

5. TYPES OF STRUCTURAL FAILURES

The reason for failure in a great number of buildings was mainly the exceptional intensity which the earthquake reached in a zone of the city where the ground movements were amplified in an extraordinary manner by the vibration characteristics of the strata of soft soil which comprised the subsoil of the city and which were particularly sensitive to dominant periods of movement transmitted by the adjacent firm ground. The soil movement in that zone was characterized by the repetition of a heightened number of cycles of intense amplification and with frequencies close to two seconds.

The structures which had vibration periods not much less than two seconds responded with higher vibrations and introduced strong inertial forces which in many cases caused damage, which, on reduction of the rigidity of the structure increased natural period and were seen to be subject to moving forces which became stronger each time and occasionally led to failure. The evidence of the available recording instruments indicates that the structures in one zone of the city were subject to higher loading effects than those specified in the construction rules effective as of that date.

On the pages citing evaluation of building damages, indication was made of some structural characteristics which helped to make the effects of the earthquake more severe and pointed out some prevalent modes of failure. Although the identification of these characteristics depends on the evaluator's criteria, some apsects were repeated in a sufficient number of cases to stand out. In Table 3 some statistics are summarized regarding the above and on the principal types of failures.

a) Weakness behavior due to column failures

In the greater majority of building failures with frame foundations, the collapse originated from the failure of the columns through bending compression or by shearing or by a combination of both. The condition of the beams or waffle slabs brings to mind that the majority of cases did not have sufficient reinforcement and so were not able to develop a ductile behavior which would have been needed to make valid the reduction factors permitted by the current regulations. The commonest failure method was identified as the loss of capacity in the vertical load of the building due to progressive deterioration of the concrete in the columns by the repetition of an increased number of lateral load cycles which exceeded their resistance by bending/compression or in shear. The former was brought about in some cases by the scarcity of transverse reinforcement and the excessive separation along the longitudinal reinforcement of the column, which gave way to sagging of the reinforcing rods or to a very poor confinement of the concrete contained in the core of the column. Another factor which contributed to the loss of the columns' capacity was the extreme concentration of longitudinal reinforcement in bundles in the corners. This provoked, not only a defective confinement of concrete, but also the concentration of high bond forces in the concrete around the bundles, which gave place to progressive failure by crumbling concrete.

b) Effect of the masonary partitions. As has been said, a large part of the buildings with many floors in the affected area had a large density of masonry walls which in the majority of cases were supposed to function mainly as partitions and not as part of the structure; while in other cases they were considered to have a structural function and were reinforced and hung in a manner to complete said purpose. It was thought that the presence of these walls was in large part beneficial and prevented the collapse of the large number of buildings in the affected zone. This occurred when the walls were arranged in a symmetric and regular form on all floors. These walls absorbed a large portion of the lateral loads due to the earthquake and protected the columns from their possible failure. Thus when this gave place in many cases to diagonal cracking of the same walls, they continued to contribute to the resistence and helped dissipate the energy induced by the earthquake. In other cases the presence of the masonry walls contributed significantly to failure, in situations such as:

b1) Asymmetric distribution of design. It was notable that 42% of the buildings which failed were on street corners. In the majority of the cases these buildings had masonry walls on both sides of the corner joinings, and wide open facades on the other two sides. The torsion which provoked the failure significantly increased forces which occurred in the axes of the columns in front. In many other cases of buildings not located on the corners, there was failure due to asymmetric distribution of walls.

b2) There is also the case in which there is much greater rigidity and resistance to lateral loads in the upper floors than in the first floor. This situation was seen in a large number of buildings in which there is an abundance of partition walls in the upper floors, while they do not occur in the lower floors such as in the case of apartment buildings or lobbies of hotels. This causes a great demand in dissipation of energy concentrated in the first floor and propagates the failure of columns. This type of failures was very frequent and in many cases associated with the above.

b3) Asymmetries caused by the destruction of walls. In diverse cases it was observed that walls made of weak material or badly anchored to the structure were totally destroyed by failures of normal bending or by shear; this resulted in loss of resistance to lateral loads of walls which were vital to maintain symmetry, thus increasing significantly the forces on the columns. The destruction of partition walls or of the adjacent ones was significant, in general, by the large lateral deformations to which the buildings were subjected.

d) Previous harm by earthquakes. It has been known that a certain number of the failed buidings had had damage caused by earlier earthquakes, and in many cases had not been repaired or, if they had, it was done in a deficient manner. A case-by-case evaluation of buildings that were damaged by earlier earthquakes is being made, to verify the efficiency of steps that were taken. The preliminary indications are that in the majority of the cases, the same problems repeated themselves since past earthquakes, but on one level, were more serious.

d) Short columns. In this category are identified cases where columns on some axes were restricted in lateral deformation by masonry walls or by stone or brick facades. This situation makes them more rigid than columns on other axes, and hence they absorb a major fraction of the lateral forces for which they were not generally designed, giving place to weakness failure generally through shear. This characteristic was found in 15 of the most damaged buildings.

e) Collisions with adjacent buildings. In more than 40 cases of damaged buidings, evidence of collisions with adjacent buidings was observed. On occasion this caused only local damage in the structure in the outer layers. There are cases where the impact provoked a weakness in a floor which was the principal cause of its collapse. One supposes that this fact is responsible for a good number of the failures observed in the upper floors. It is apparent that the requisite regulation of a minimum separation between adjacent buildings was violated in a systematic manner. The separation between contiguous buildings was on the order of 10 cm, which is clearly insufficient.

f) Failures in the upper stories. The number of failures in the upper stories was notable. Of the total number of partial and total collapses, close to 40% corresponded to collapse of a floor in the upper third of the structure. The number of cases of grave damage to the upper third parts of structures were very high. Only a fraction of these cases could be explained by weakness caused by the collision of buildings. In others these failures could be attributed to abrupt reductions in resistence and rigidity in the affected levels of the structures due to a diminution in a section of columns and walls or to a weakening by a reduction of the transverse reinforcement.

g) Excessive overload in the structure. In at least 39 cases of collapse or serious damage, vertical loads were present which substantially exceeded that which was projected. On certain occasions the outer cladding, the infill and the partitions had a weight greater than the dead weights usually considered, but above all there were numerous cases of extraordinaily high live loads. This was notable in office buildings, particularly public ones, in which many floors were used as archives. Also it happened frequently in the case of buildings whose uses were clearly different from what was originally projected. Buildings that were originally planned as offices or apartments were transformed with time into warehouses or factories and accumulated heavy loads, frequently in the upper floors.

The increase of the masses, particularly in the upper floors, provoked major lateral forces in the structures, which together with the gravitational effects of these overloads, must have contributed significantly to the damages.

h) P-Δ Effect. This corresponds to the additional moments which the vertical loads introduced in the structure when it suffered increased lateral displacements. There is no clear evidence of the moments, but the information that some buildings failed by lateral displacement is suspicious that bending moments in the columns of the lower floors were increased by this effect.

i) Bad behavior of waffle slabs. A high incidence of collapse and grave damage has been indicated in buildings made with concrete columns and waffle slabs, of close to double that which occurred in buildings with a concrete frame. These structures were highly flexible and had a reduced ductility. In the majority of the cases the failure was across the columns, but in close to half a dozen of the cases there occurred a failure through a puncturing of the slab by the shear forces due to the sum of the effects of the vertical loads and the earthquake. In different buildings of this type, diagonal cracks occurred in the slabs around the columns, symptomatic of incipient failure by puncturing. In the majority of cases of this type of failure it was evidently lack of a solid zone of concrete for appropriately reinforcing around the column.

j) Problems due to the movements of foundation. The influence that foundation problems had in the failure of the structures are not easy to determine. A certain number of failed structures had previous damage through differential settlement which had reduced their capacity to resist seismic effects. There is evidence, on the other hand, that many structures, especially those slender buildings on friction piles, suffered important movements in their bases, which increased on occasion the forces which were introduced into the structures.

k) Damage in secondary elements. What with the great intensity of the earthquake and the heightened number of failures in the principal structure, very little attention has been paid to the behavior of secondary elements. It is notable, however, that there was increased incidence of damage to stairways, which made it difficult to evacuate the buildings. To a lesser degree, also, should be noted the elevated number of failures of the roof structures, such as water tanks, and elevator housings.

6. PRELIMINARY CONCLUSIONS

The effects of the earthquake of September indicate the necessity for some important changes in the standard and the practice of seismic design of buildings in Mexico City. Some of these are as follows:

1) The extraordinary intensity of movement in one well defined area makes it necessary to revise the design specifications, most especially in the zone of compressed soil. Inside this, it is evident that there are areas where ground movement increases in a different way and the parts where amplification was greatest coincided approximately with the three last important earthquakes.

Therefore, it is recommended that a micro-zoning of the compressed soil zone of the valley be made.

2) The ductility demands that this earthquake generated in the structures on soft soil were greatly elevated by the large number of repetitions of high amplitude cycles and in a form that was almost harmonic. This leads to the necessity of revising the ductility reduction factors now acceptable by present regulations.

3) The concrete structures designed in common practice were not capable of developing high ductility and showed a marked deterioration in the capacity for repetitive load cycles. This should lead to revision, as in 2) above, of reduction factors for ductility, and imposition of stricter requirements for reinforcement, particularly in the columns. Examples of this would be better transverse confining reinforcement, more uniform distribution of longitudinal reinforcement, more generous and more confined overlapping and anchoring.

4) The use of structural systems which give highest rigidity and resistence to lateral loads to the buildings should be promoted. The stiffening with concrete walls or bracing concrete or steel allows substantial increase in the capacity before lateral loads and ductility demands are appreciably reduced.

5) The use of a system of columns and plane slabs should be limited to buildings which are low in height because of problems of excessive flexibility and weakness failures. In

buildings of a certain height, it is essential that the resistance to lateral loads be proportional to elements such as rigid walls or bracing and that the action of the frame which is found between the columns and the slab should be confined to a small part of the lateral loads. It is necessary also to appropriately detail the slab zones around the columns to avoid weakness failure by shortening.

6) There should be a tendency to avoid the use of masonry walls as dividing elements in very flexible structures. Their rigidity and fragility are incompatible with the high lateral deformations which are found in these structures. It is preferable to return to more resilient dividing elements. If masonry walls are used, they should be separated appropriately from the primary structure with procedures which guarantee both parts be independent. During the recent earthquakes, almost no case of precaution had been taken to separate the functioning walls and the damage was very high in these cases as much because of the effect of the forces on its plane as by overturnings. The use of masonry dividing walls offers much smaller problems in structures with high rigidity to lateral loads.

7) Attention should be paid to the problems of soil-structure interaction and take into account the movements of the foundations in the seismic design of buildings.

8) A stricter supervision in construction is needed to assure that the requirements of the norms and designs are rigorously followed. The lack of observance of the separations among adjacent buildings and the alterations in the structures to allocate ducts and other installations are marked examples of practices which contributed to the damages.

For the majority of the above points it is necessary to complete specific studies which are conducive to detailed and quantitative recommendations. Some of the recommendations above have already been considered in Emergency Modifications of the Construction Rules for the Federal District.

TABLE 1. BUILDING DAMAGES IN EACH ZONE

Zone	Type of Damage	No of Floors				Type of Construction					Age of Structure			TOTaL
						Concrete Base	Steel Base	Reticular Slabs	Masonry	Other				
I	Collapse	5	3	1	0	3	0	2	1	3	2	3	4	9
	Grave	3	3	1	0	0	0	3	1	3	2	5	0	7
	Total	8	6	2	0	3	0	5	2	6	4	8	4	16
II	Collapse	8	7	0	0	6	0	7	1	1	6	9	0	15
	Grave	3	3	0	0	5	0	0	1	0	2	4	0	6
	Total	11	10	0	0	11	0	7	2	1	8	13	0	21
III	Collapse	9	20	4	0	18	0	10	3	2	16	13	4	33
	Grave	4	9	3	1	9	1	5	1	1	4	8	5	17
	Total	13	29	7	1	27	1	15	4	3	20	21	9	50
IV	Collapse	14	21	4	3	14	10	16	0	2	18	22	2	42
	Grave	0	7	5	0	6	0	6	0	0	4	6	2	12
	Total	14	28	9	3	20	10	22	0	2	22	28	4	54
V	Collapse	27	17	2	0	25	0	16	4	1	5	37	4	46
	Grave	0	14	2	0	4	0	11	0	1	2	7	7	16
	Total	27	31	4	0	29	0	27	4	2	7	44	11	62
VI	Collapse	13	23	3	1	12	0	22	2	4	4	30	6	40
	Grave	13	14	8	1	13	1	11	11	0	10	19	7	36
	Total	26	37	11	2	25	1	33	13	4	14	49	13	76
II	Collapse	1	5	0	0	1	0	5	0	0	0	6	0	6
	Grave	0	1	0	0	0	0	1	0	0	0	1	0	1
	Total	1	6	0	0	1	0	6	0	0	0	7	0	7

Table 1 (CONTINUED)

ZONE	TYPE OF DAMAGE	NO. OF FLOORS				TYPE OF CONSTRUCTION					AGE OF STRUCTURES			TOTAL
		<5	6-10	11-15	>15	Concrete Base	Steel Base	Retic. Slab.	Masonry	Other				
VIII	Collapse	0	1	0	0	0	0	1	0	0	0	0	1	1
	Grave	3	0	0	0	0	0	0	3	0	3	0	0	3
	Total	3	1	0	0	0	0	1	3	0	3	0	1	4
IX	Collapse	0	3	0	0	0	0	3	0	0	0	0	3	3
	Grave	4	2	0	0	0	0	4	2	0	2	2	2	6
	Total	4	5	0	0	0	0	7	2	0	2	2	5	9
X	Collapse	1	0	0	0	0	0	0	1	0	0	0	1	1
	Grave	0	1	0	0	1	0	0	0	0	0	1	0	1
	Total	1	1	0	0	1	0	0	1	0	0	1	1	2
XI	Collapse	4	2	0	0	0	0	5	1	0	0	4	2	6
	GRAVE	1	2	1	0	2	0	2	0	0	0	1	3	4
	Total	5	4	1	0	2	0	7	1	0	0	5	5	10
XII	Collapse	2	1	0	0	0	0	2	0	1	1	1	1	3
	Grave	0	1	0	0	0	0	0	0	1	0	1	0	1
	Total	2	2	0	0	0	0	2	0	2	1	2	1	4
XIII	Collapse	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grave	2	0	0	0	1	0	0	1	0	0	2	0	2
	Total	2	0	0	0	1	0	0	1	0	0	2	0	2
XIV	Collapse	0	0	0	0	0	0	0	0	0	0	0	0	0
	Grave	1	0	0	0	0	0	0	1	0	1	0	0	1
	Total	1	0	0	0	0	0	0	1	0	1	0	0	1

TABLE 1 (CONTINUED)

Zone	Type of Damage	No. of Floors				Type of Construction					Age of Structure			TOTAL
		<5	6-10	11-15	>15	Concrete Base	Steel Base	Retic. Slab	Masonry	Other				
XV	Collapse	2	0	0	0	2	0	0	0	0	0	2	0	2
	Grave	0	1	0	0	0	0	1	0	0	0	1	0	1
	Total	2	1	0	0	2	0	1	0	0	0	3	0	3
XVI	Collapse	1	0	0	0	0	0	1	0	0	0	0	1	1
	Grave	4	0	0	0	3	0	0	1	0	0	3	1	4
	Total	5	0	0	0	3	0	1	1	0	0	3	2	5
XVII	Collapse	2	0	0	2	1	0	1	0	0	0	2	0	2
	Grave	2	0	0	2	1	0	0	1	0	0	2	0	2
	Total	4	0	0	4	2	0	1	1	0	0	4	0	4

SUMMARY N

All Zones	Collapse	89	103	14	4	82	10	91	13	14	52	129	29	210
	Grave	40	58	20	2	45	2	44	23	6	30	63	27	120
	Total	129	161	34	6	127	12	135	36	20	82	192	56	330

TABLA 2. RESUMEN ESTADISTICO DE DAÑOS EN EDIFICIOS

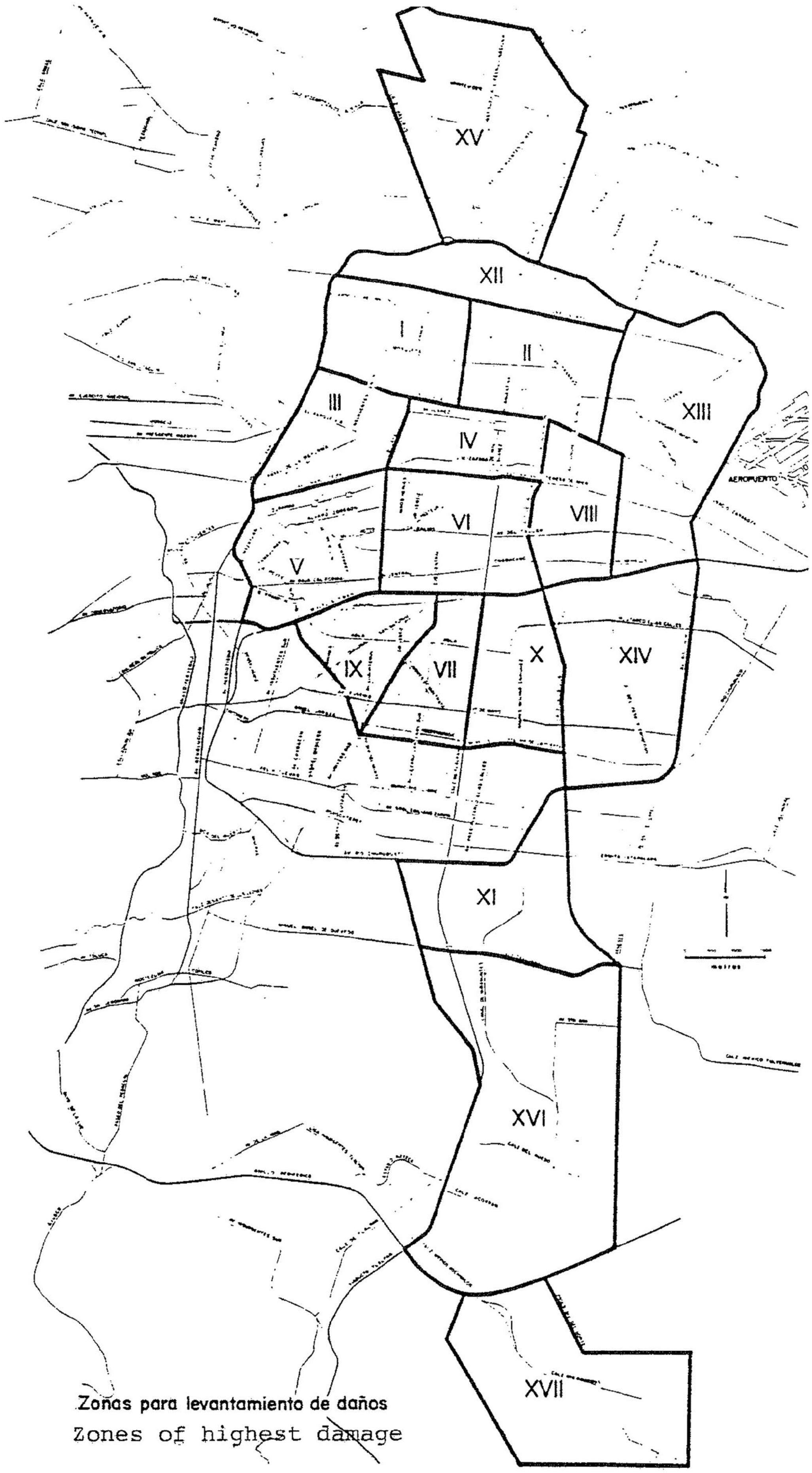
TABLE 2. STATISTICAL STUDY OF DAMAGES IN BUILDINGS

ESTRUCTURACION STRUCTURING	TIPO DE DAÑO TYPE OF DAMAGE	AÑO DE CONSTRUCCION Year of Construction			No. DE PISOS No. of Floors				TOTAL
		<1957	57-76	>1976	≤5	6-10	11-15	>15	
Marcos de Concreto Concrete frames	Derrumbe Collapse	27	51	4	27	46	8	1	82
	Grave Grave	16	23	6	10	28	6	1	45
Marcos de Acero Steel frames	Derrumbe Collapse	7	3	0	4	3	1	2	10
	Grave Grave	1	1	0	0	0	2	0	2
Losa plana Plain slabs	Derrumbe Collapse	8	62	21	36	49	5	1	91
	Grave Grave	4	22	18	5	26	12	1	44
Mampostería Masonry	Derrumbe Collapse	6	5	2	11	2	0	0	13
	Grave Grave	9	13	1	22	1	0	0	23
Otros Other	Derrumbe Collapse	4	8	2	12	2	0	0	14
	Grave Grave	0	4	2	2	4	0	0	6
Total	Derrumbes y graves Collapse & grave	82	192	56	129	161	34	6	330

TABLA 3. CARACTERISTICAS QUE INFLUYERON EN LA FALLA

TABLE 3. CHARACTERISTICS WHICH INFLUENCED FAILURE

	Porcentajes de casos en que se observó la característica Percentages of the cases in which the characteristic was observed
Asimetría notable de rigidez Asymmentry with noticeable rigidity	15%
Edificio de esquina Corner building	42%
Primer piso flexible Flexible first floor	8%
Columnas cortas Short columns	3%
Sobrecarga excesiva Excessive overloads	9%
Hundimientos diferenciales previos Previous differential sinking	2%
Problemas de cimentación Cementation promblems	13%
Choque con edificios cercanos Collision with nearby buildings	15%
Daños previos por sismo Previous earthquake damages	5%
Punzonamiento de losas reticulares Puncturing of retidular slabs	4%
Falla en pisos superiores Failure in the upper floors	38%
Falla en pisos intermedios Failure in the intermediate floors	40%

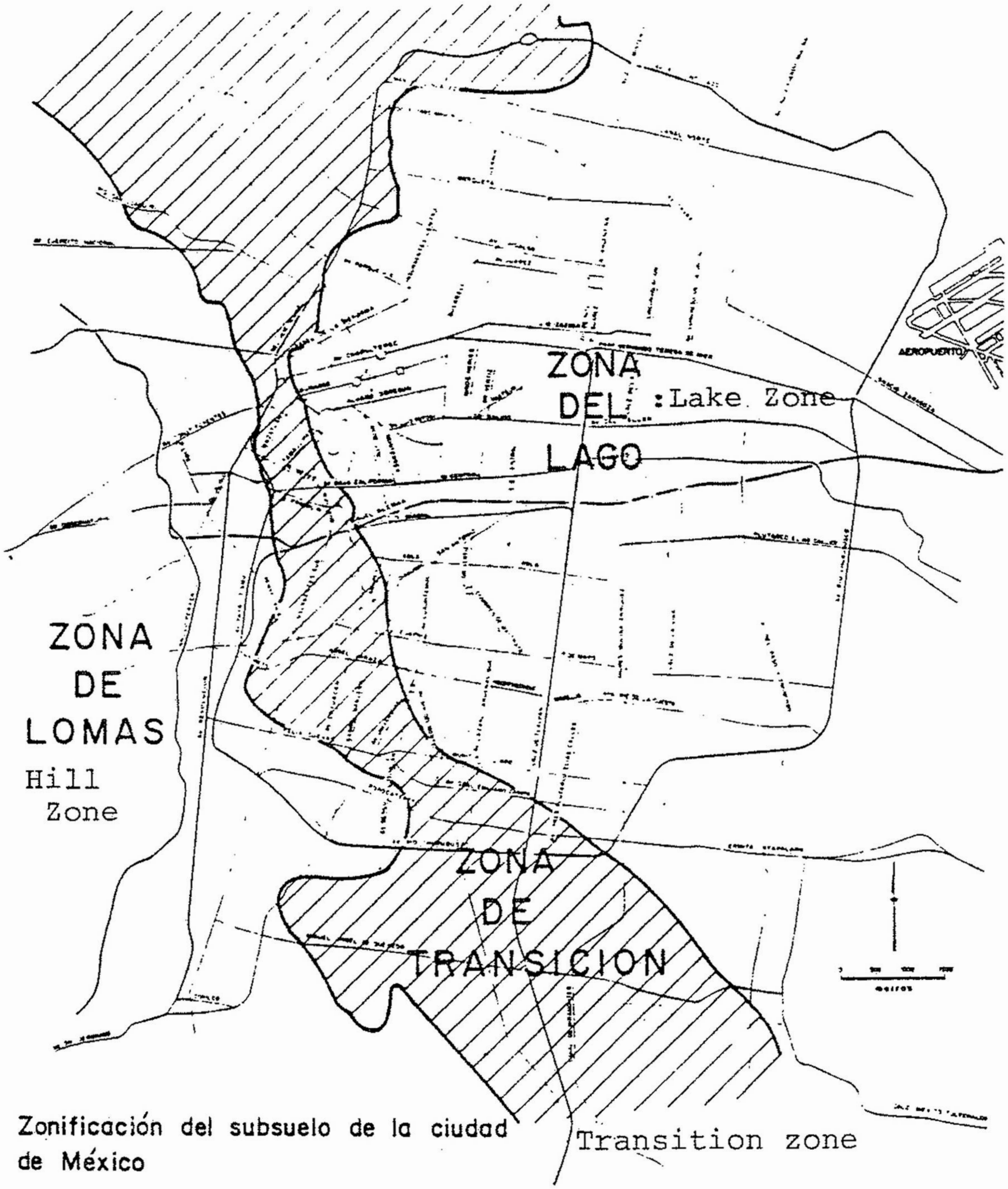


Zonas para levantamiento de daños

Zones of highest damage

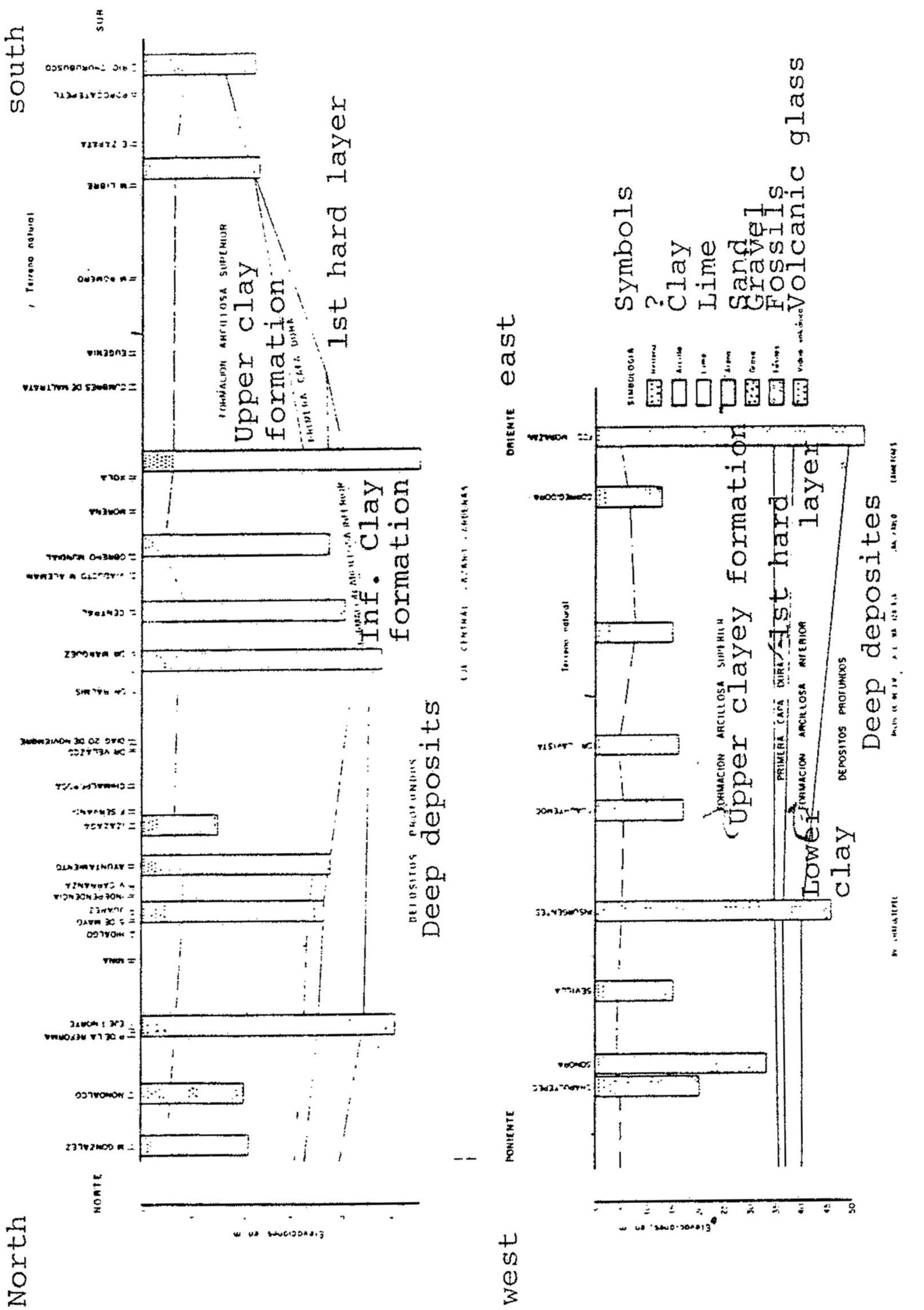
Ubicación de construcciones que sufrieron daño grave (x), o colapso (●)

Location of structures which suffered grave damage (x) or collapse (o)



Zonificación del subsuelo de la ciudad de México

Zoning of the subsoil of Mexico City



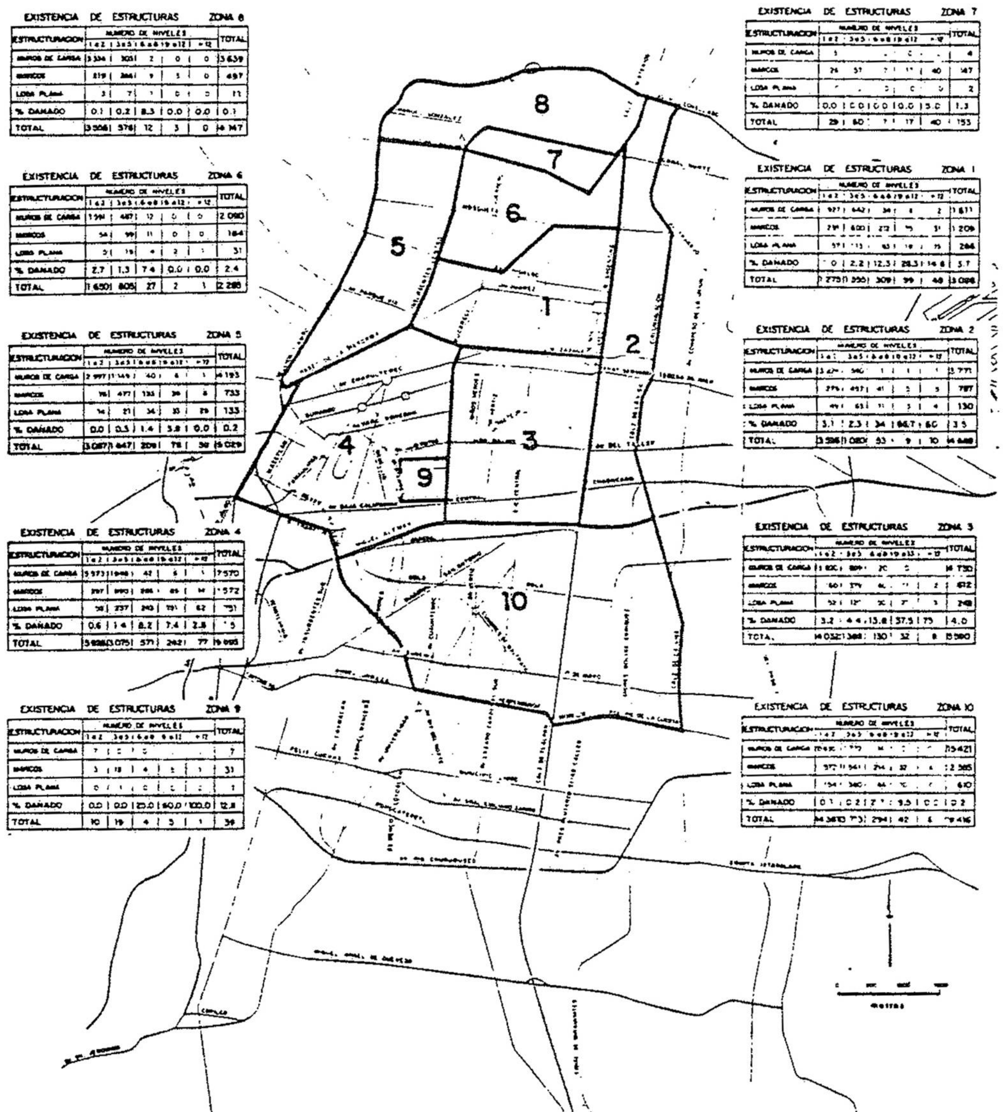
Cortes estratigráficos

Cross sections

Existence of strctures Zone No.

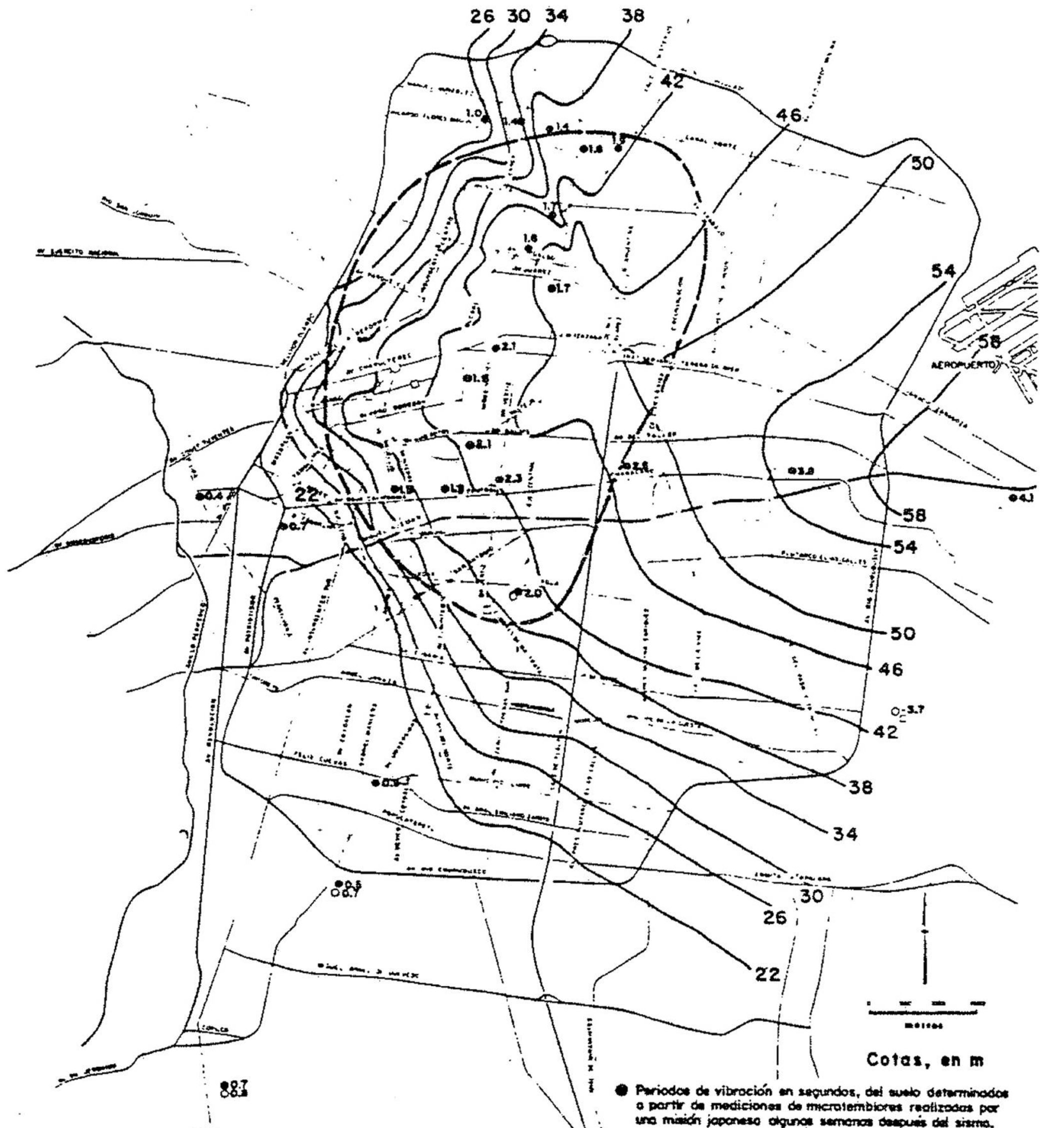
Structure	No. of levels 1-2	3-5	6-8	9-12	over 12	Total
Walls						
Frames						
Plane slabs						
% Damaged						
Total						

Boxes contain this information



Levantamiento de edificios existentes en la zona dañada

Heights of existing buildings in the damaged zones



● Periodos de vibración en segundos, del suelo determinados a partir de mediciones de microtemblores realizadas por una misión japonesa algunas semanas después del sismo.

○ Periodos dominantes del movimiento del suelo en los acelerogramas del sismo del 19 de septiembre de 1985.

Curvas de igual profundidad de depósitos profundos

Curves showing equal depths of deep deposits

● Periods of vibration in secs. of soil splitting determined by measurements of microquakes by a Japanese mission some week after the earthquake.

o Dominant periods of soil movement in the accelerograms of Sept. 19, 1985.

LOCATION OF DAMAGED ZONES

EVALUACION DE DAÑOS EN EDIFICIOS
Evaluation of Building Damages

I. Identificación del Edificio Identification of Building

1.1 Dirección (incluye colonia) Address ______

1.2 Nombre (de tenerlo) Name of Building (if it has one) ______

1.3 Función (oficina, deptos. etc.) Type (office, depts, etc) ______

1.4 Año de construcción (preguntar, o estimar) Year of construction (ask or estimate) ______

II. Descripción del Edificio Description of the building

2.1 Número de pisos No. of floors ______

2.2 Dimensiones en planta Dimensions of the ground plan ______

2.3 Croquis de planta(s) Rough sketch of ground plan ______
usar reverso use the back

2.4 Particularidades (cambios de forma en planta o elevación, volados, parapetos, apéndices) ______
Details (changes in form of the ground plan or height, additions, parapets, etc.)

III. Sistema Estructural Structural System

3.1 Cimentación (preguntar, zapatas, losa corrida, pilotes) ______
Cementation (Ask, running slabs, piles, etc.)

3.2 Sistema de soporte de cargas verticales (columnas de concreto o acero, muros de carga de mampostería o concreto) ______
System of support for vercial loads (concrete columns or Steel columns, walls of masonry or concrete)

3.3 Sistema de piso (losa de concreto, losa reticular, prefabricado)
System of floors (concrete slabs, reticular slabls, prefabricated
______

3.4 Sistema resistente a carga lateral (marcos, muros de concreto o mampostería, contraventeos, combinaciones, otros) ______
Systems resistant to lateral loads (frames, concrete walls or masonry walls, lateral supports, conbinations, others)

IV Clasificación del Daño Classification of Damage

Not structural No estructural. Nulo None Ligero Light, Sustancial Substantial ____, Elevado High,

Structural Estructural Nulo none, Ligero light, Intermedio Med., Grave grave, Colapso collapse.

V. Descripción Detallada del Daño Detailed description of damage

Usar hojas adicionales para describir Use additional pages to describe

a) Tipo de daño no estructural (p.e. grietas en muros divisorios, desprendimientos o dislocaciones de plafones, recubrimientos, vidrios, instalaciones, etc.)

a) Type of non-structural damage (crevices in dividing walls, etc.)

b) Tipo de daño estructural (grietas en vigas y columnas por flexión, cortante o carga axial; hacer croquis de elementos dañados, pandeo o rotura de refuerzo o de elementos de acero)

Type of structural damage (cracks in beams and columns through flexion short or axial load, - rough sketch of damages)

c) Identificar posibles defectos o causas de los daños (sistemas estructural inadecuado por rigidez o resistencia, excentricidades o irregularidades en planta, columnas cortas, huecos en elementos estructurales, etc.)

Identify possible defects or causes of damages (inadequate structure because of rigidity or resistnce, etc.)

VI. Otras Observaciones Other observations

Posibles daños anteriores al sismo y reparaciones efectuadas, mala calidad de materiales o de la ejecución, modificaciones de la estructura con el tiempo, usos inadecuados por cargas verticales excesivas, etc. Toda información que pueda justificar el daño

Possible former damages and effected repairs; bad quality of materials or their use, modification of the structure with time, unadequate uses of excessive vertical loads, etc.

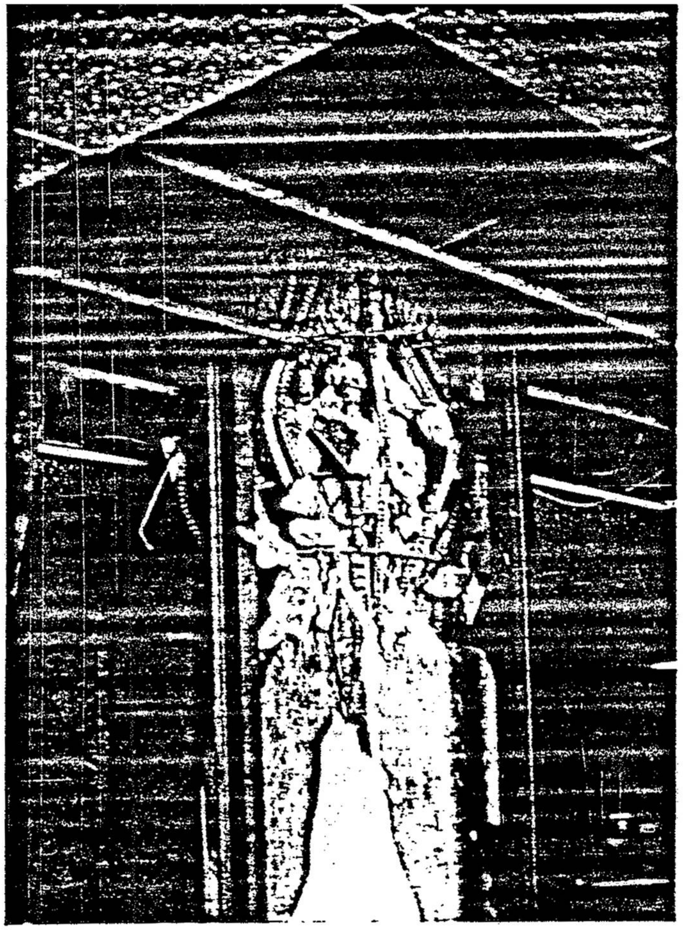
VII. Fotografías Tomadas (tema y ubicación)

Pictures taken (theme and location)

ANEXO B

FOTOGRAFIAS DE MODOS DE FALLA TIPICOS

Photographs of typical failures



Falla de columna por flexocompresión

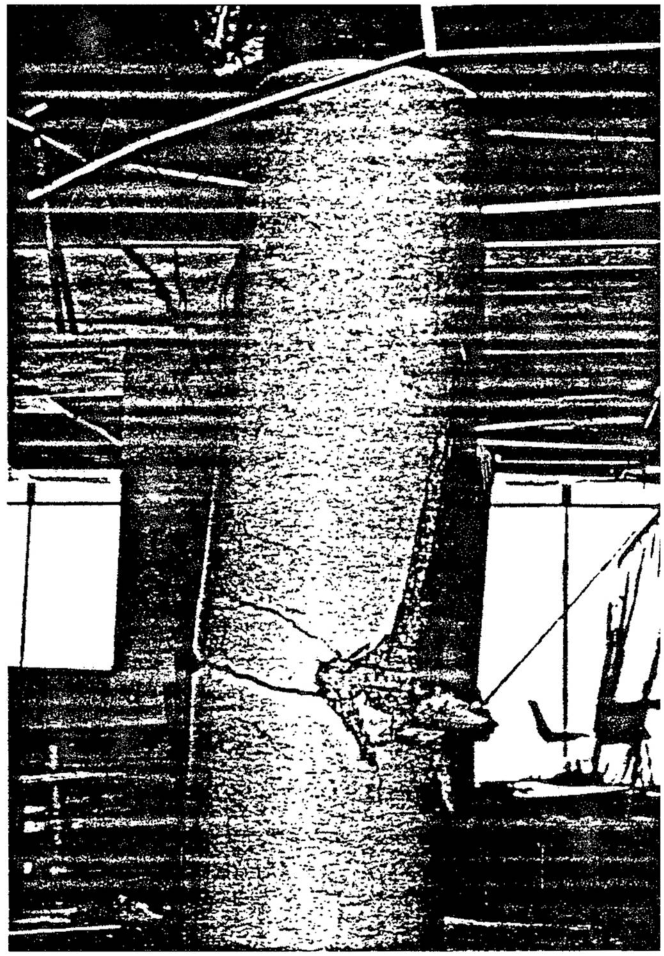
Failure of column by bending/compression

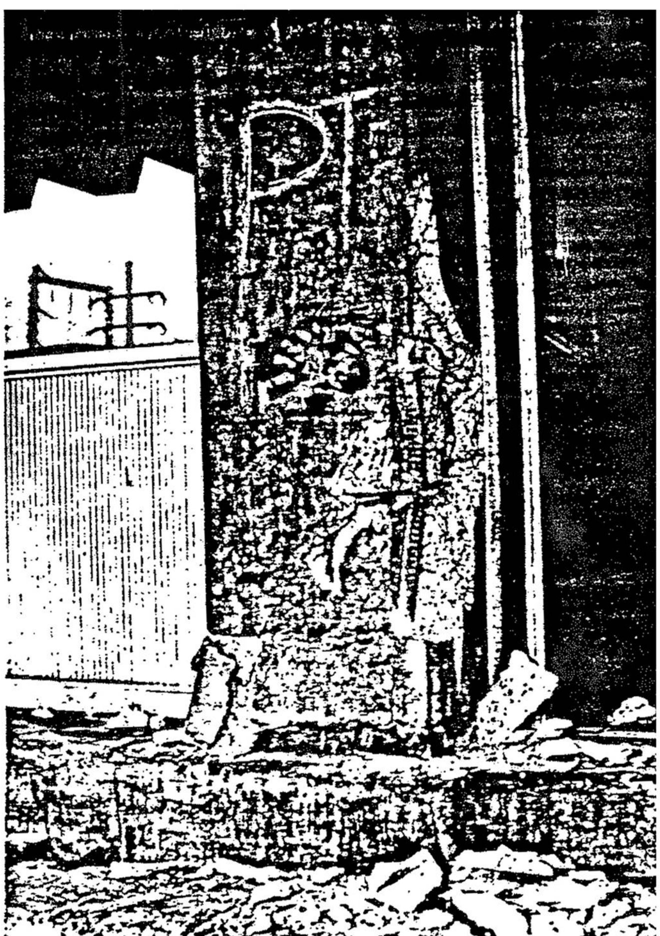
Falla de columna por cortante y carga axial

Failure of column by shortening and axial load

Falla de columna zunchada

Failure of a spirally
reinforced column



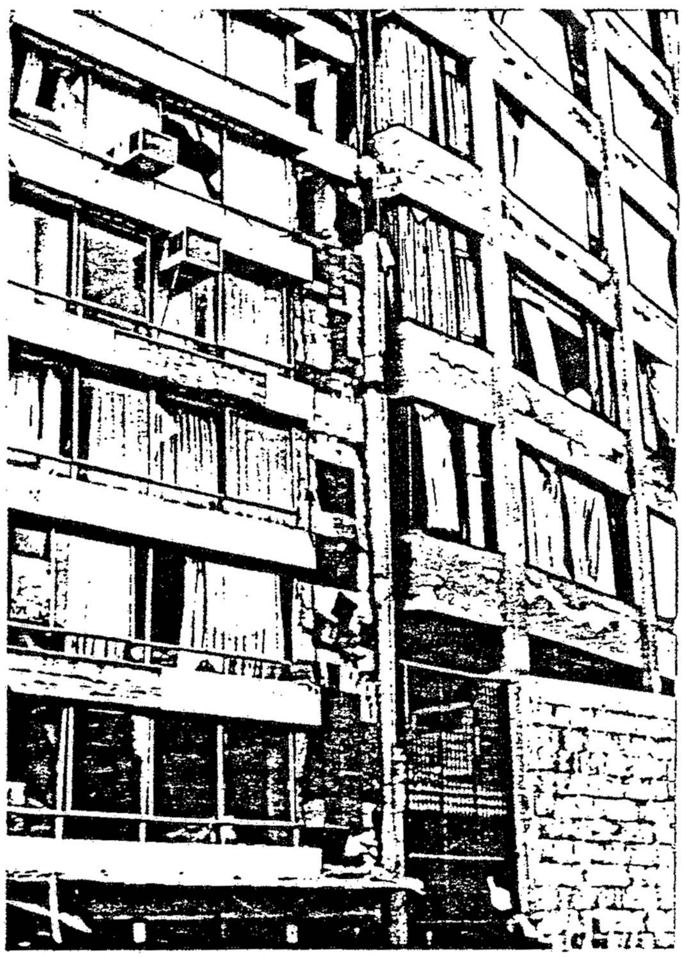


Falla de columna con desgarramiento del concreto por excesiva concentración de refuerzo longitudinal en paquetes en las esquinas

Failure of column with tearing of concrete due to excessive concentration of longitudinal reinforcements packed in the corners

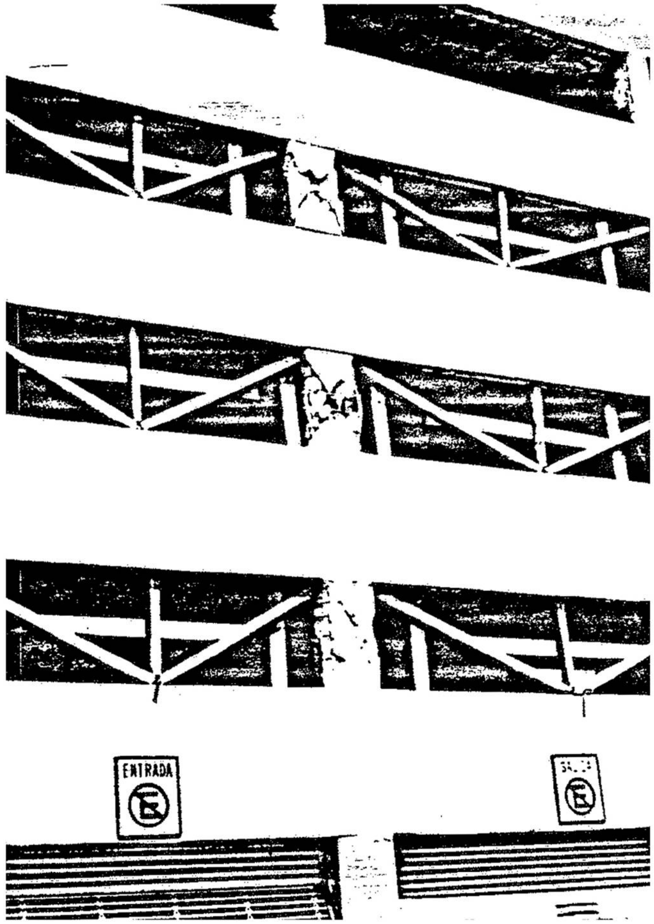
Falla de un entrepiso probablemente propiciada por choque con el adyacente

Failure of a between floor probably caused by collision with an adjacent

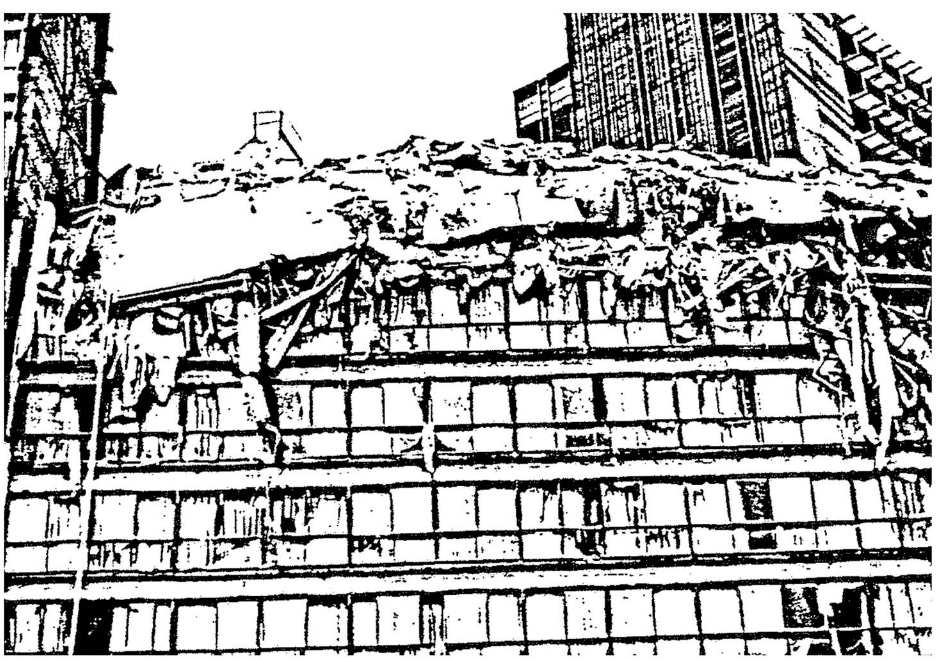


Daños por choques entre edificios adyacentes

Damages caused by collision with adjacent buildings



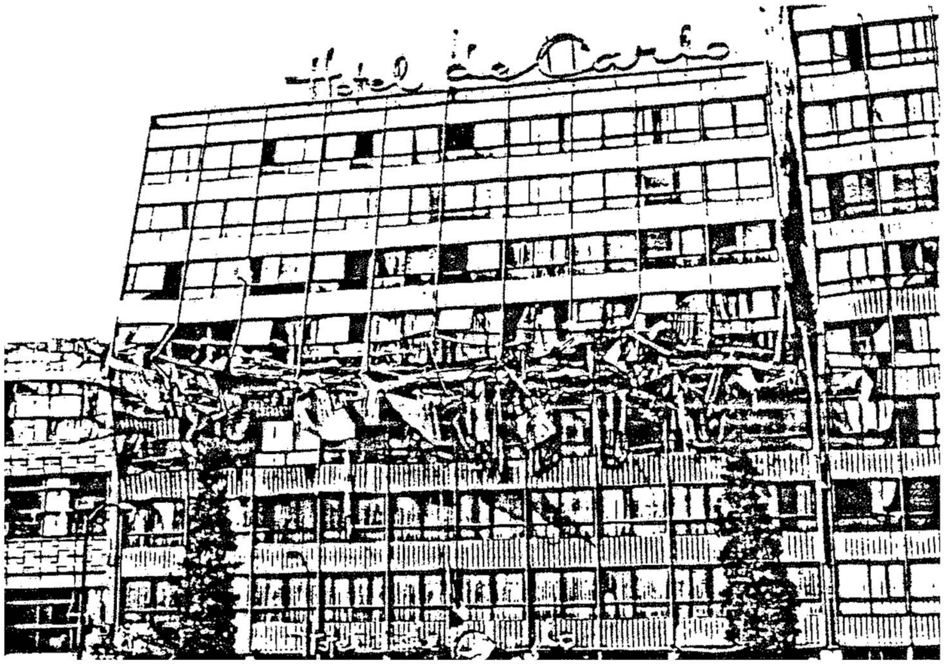
Falla de columnas cortas
Failures of short columns



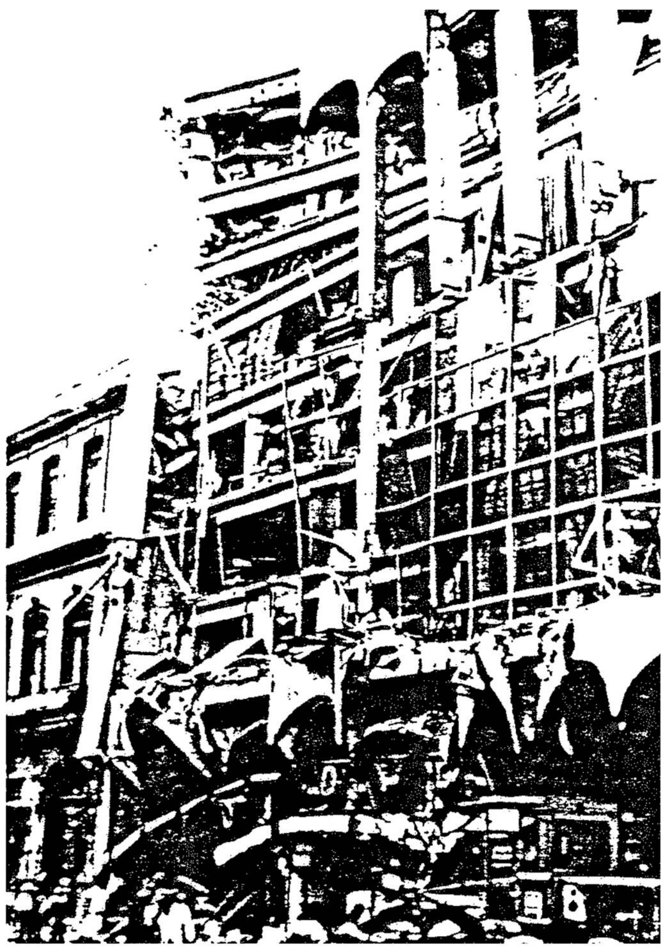
Falla de pisos superiores
Failure of upper floors

Colapso de edificio por inestabilidad lateral
Collapse of building through lateral instability

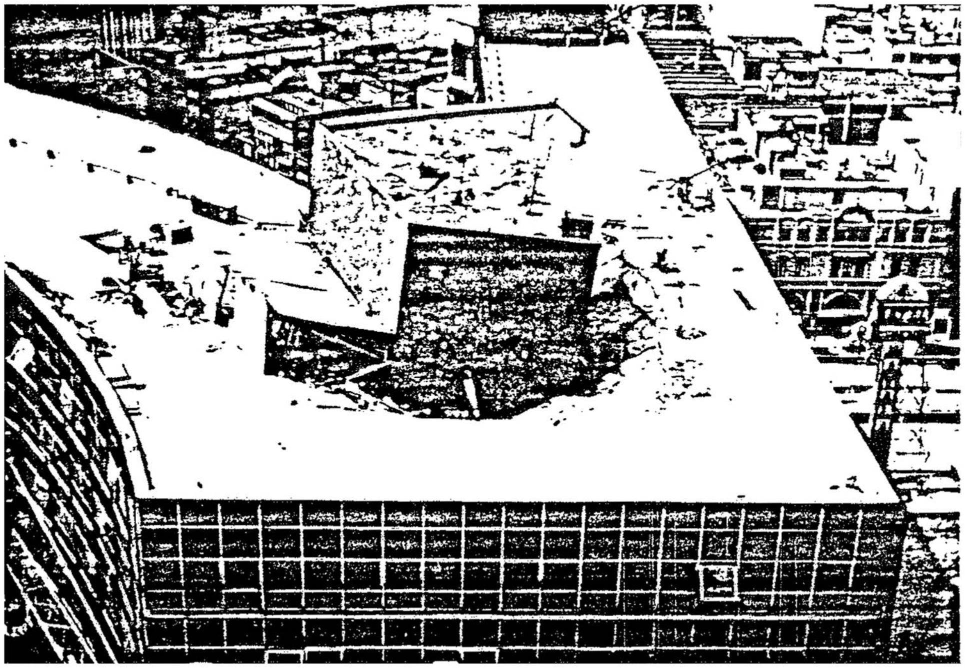
Inclinación de edificio por hundimiento
Leaning of building through settlement

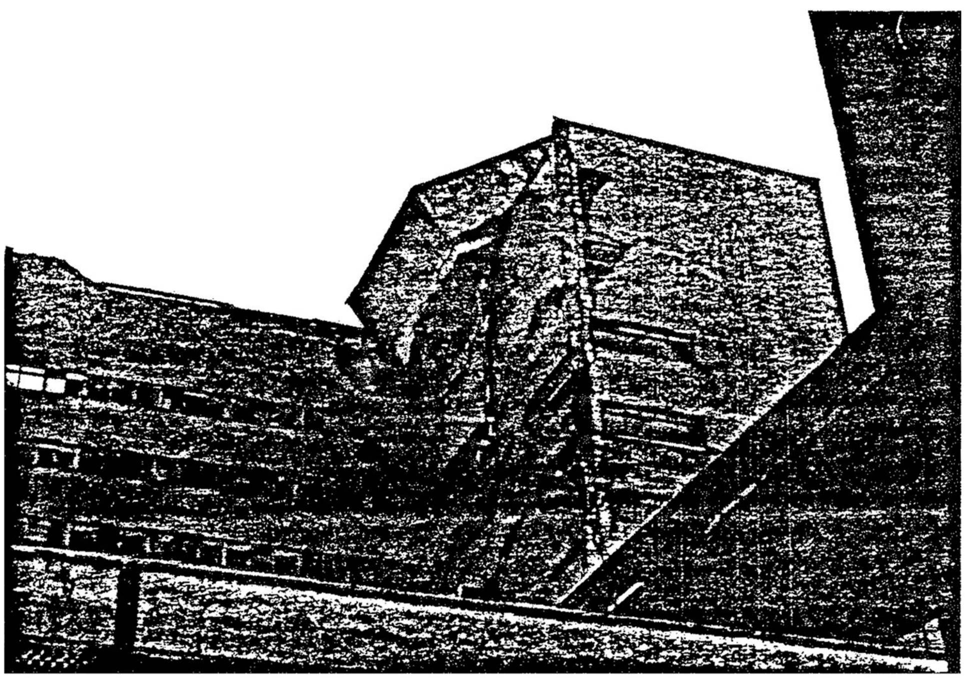


Falla de pisos intermedios
Failure of intermediate floors

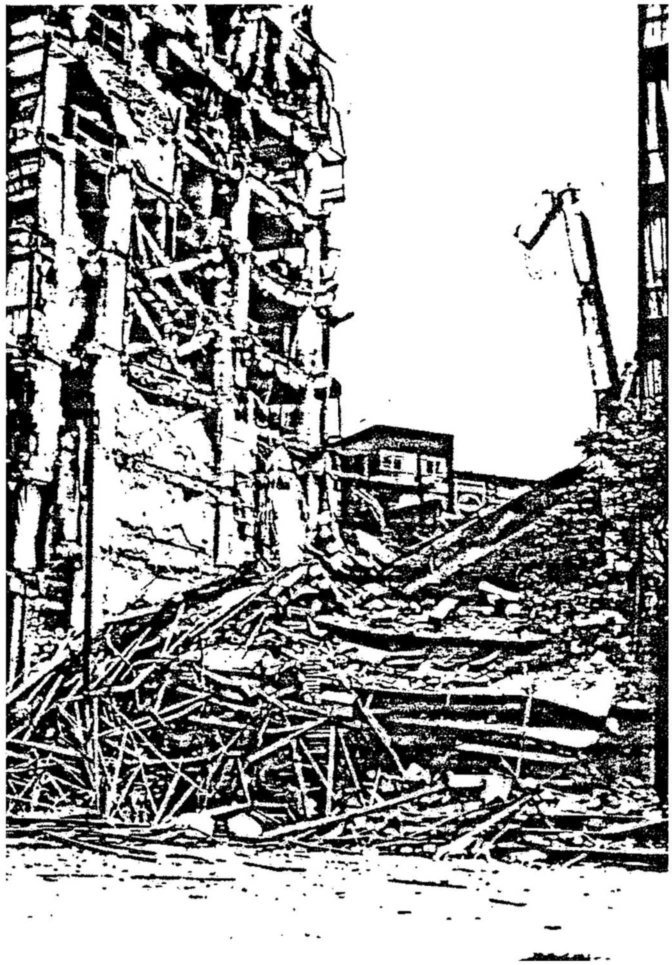


Sobrecarga excesiva en pisos superiores
Excessive overload in the upper floors

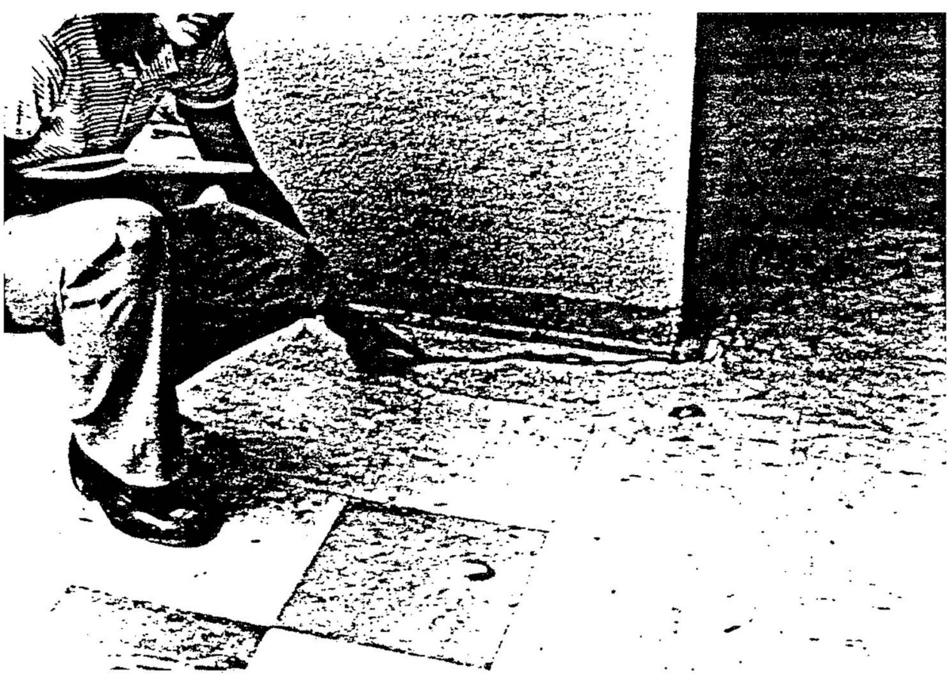




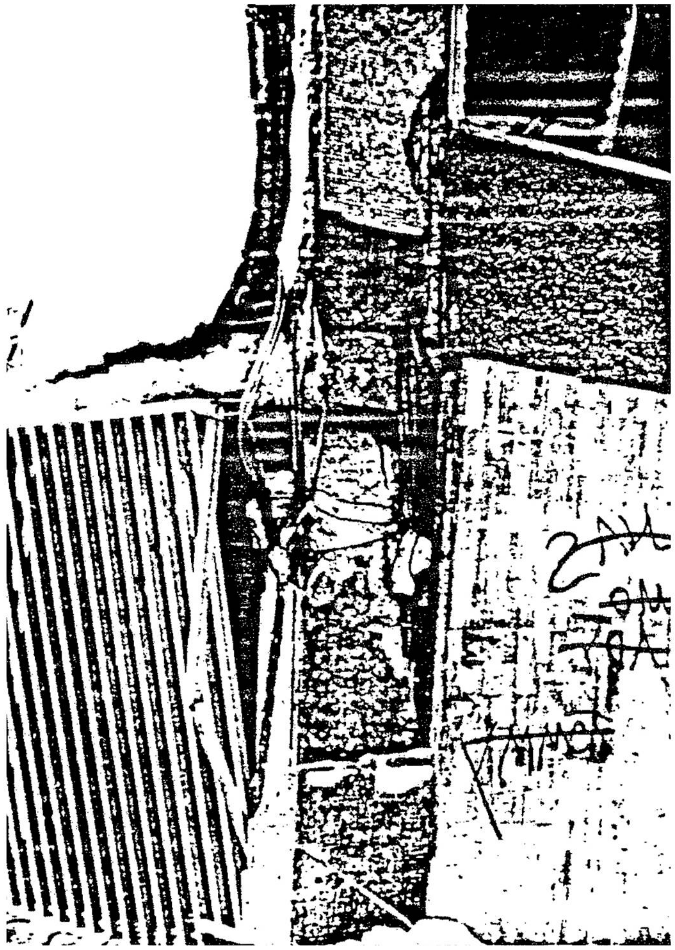
Falla de apéndices de edificios
Failure in additions to buildings



Colapso por punzonamiento de losas reticulares
Collapse through punching of waffle slabs

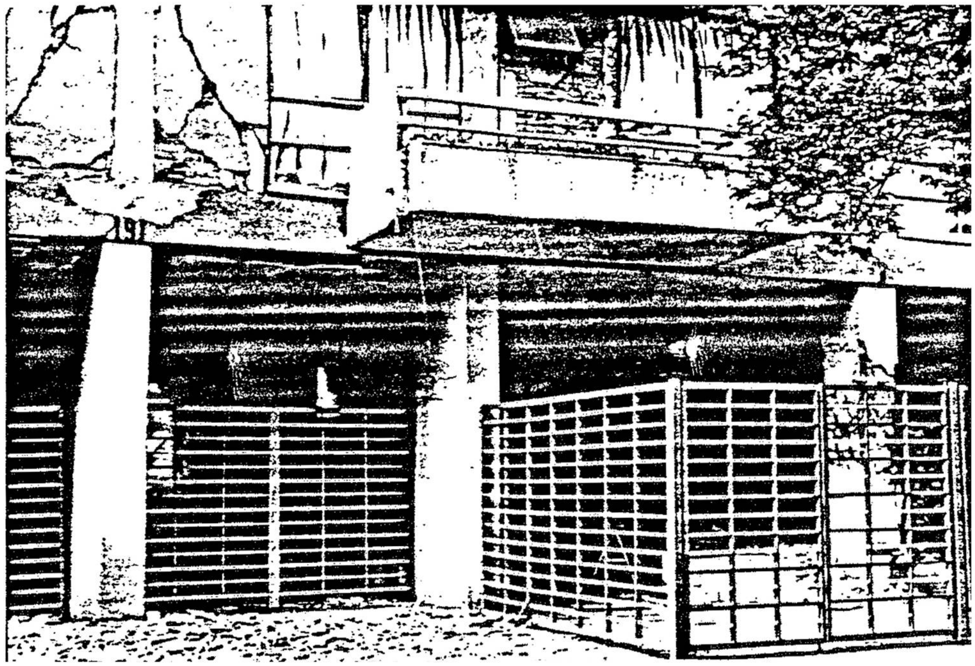


Falla incipiente por cortante en losa reticular
Incipient failures through shear in waffle slab



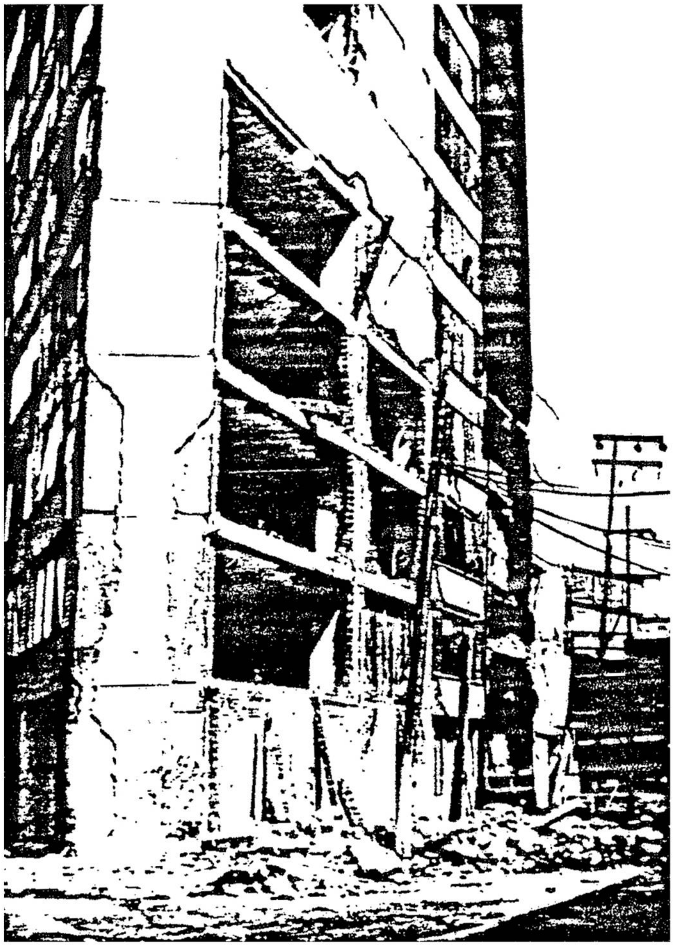
Falla de columna con escaso confinamiento lateral
Failure of column due to lateral confinement

Colapso de edificio por pérdida de capacidad de carga vertical
Failure of a building through loss of capability of vertical load



Falla en columnas de edificios con planta baja débil
Failure in columns of buildings with a weak ground floor

Distribución asimétrica de muros de mampostería en edificios en esquina
Asymmetric distribution of masonry walls in corner buildings



Destrucción de muros de relleno de mampostería

Destruction of walls filled with masonry.

Colapso de planta baja débil

Collapse of weak ground floor

La obra *Evaluación de los efectos de los sismos de septiembre de 1985 en los edificios de la Ciudad de México* fue editada por el Instituto de Ingeniería, de la Universidad Nacional Autónoma de México (IIUNAM), Ciudad Universitaria, CP 04510, México, DF. El cuidado de la edición estuvo a cargo de la Unidad de Promoción y Comunicación del IIUNAM.
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