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SEISMIC CAPACITY AND RESPONSE OF A REINFORCED CONCRETE SCHOOL BUILDING IN MEXICO CITY WHICH SUFFERED THE EARTHQUAKE OF 1985

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SUMMARY

The inelastic behavior of a low-rise reinforced concrete building in Transition Zone in Mexico city, which suffered moderate damage to structures by the earthquake of September 1985, was investigated. Based on some analyses of the seismic capacity and response to the simulated earthquake motion, reasons for the structural damage and appropriateness of the proposed stregthening methods were discussed.

INTRODUCTION

The 4-story reinforced concrete building (Photo 1, Fig.1), suffered moderate damage to structures and moderate or severe damage to nonstructural elements during the earthquake of September 19, 1985. One month after the earthquake, this building was inspected by the authors' team with respect to the features of damage, properties of materials and vibrational characteristics of the building and the ground. The inspection was made as one of the activities of the technical mission which was sent to the Department of Federal District of Mexico (DDF) by Japanese Government through Japan International Cooperation Agency (JICA), in accordance with the cooperative program.

After field inspections, further studies were made on the seimic capacity and response to ground motions based on the obtained data from the inspection and design documents so that the behavior during the earthquake and the effectiveness of proposed seismic strengthening may be discussed in detail (Refs.1,2,3). In this paper, discussions on the failure mode and strength of members and a total building, and seismic response to ground motions are described as well as general features of damage. The seismic responses of buildings strengthened by proposed methods are also discussed.

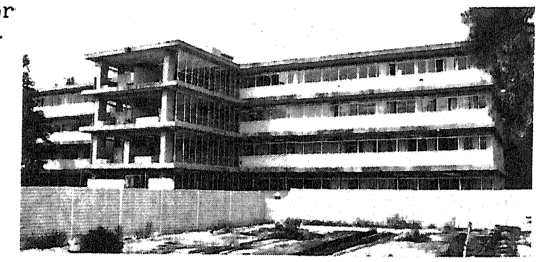


Photo 1 South View of Block E (1985.10)

GENERAL DESCRIPTION OF THE BUILDING AND ITS DAMAGE

The building, called "Escuela Superior Medicina (ESM)" in Instituto Politecnico National, was constructed in 1982 and has been used as a school for medical students. This building was composed of two blocks E and W. They were structurally identical except six months' difference of completion and the difference of measured concrete strength. The Block W had higher strength of concrete (36Mpa) than that of another block (25Mpa). They located on Transition Zone and the subsoil is consisted of soft clay of 16m thick (Fig.2). The building is consisted of moment-resisting frames of columns and flat slab systems called "Losa Plana". It should be noted that the grouped longitudinal reinforcements were arranged at each corner of a column (Fig.3).

Different types of damage to columns were observed between two blocks. Typical damage in Block E was caused by the bond-splitting as shown in Photo 2(a) and Fig.5, while that in block W was caused by the flexural compression (Photo 2(b)). The buckling of reinforcement, however, was not observed in any columns. No significant damage appeared on the Losa Plana except a few minor cracks on the floors. Nonstructural walls of hollow bricks suffered very severe shear cracks, fell down and/or turned over in the staircase and on the adjacent frames. Tilting and settlement were not observed. The observed damage levels of columns (Ref.4) are shown in Fig.6. The damage rank of a total building (Ref.4) was classified into "moderate damage", therefore, the strengthening by appropriate methods along with repair was recommended(Fig.7)(Ref.2).

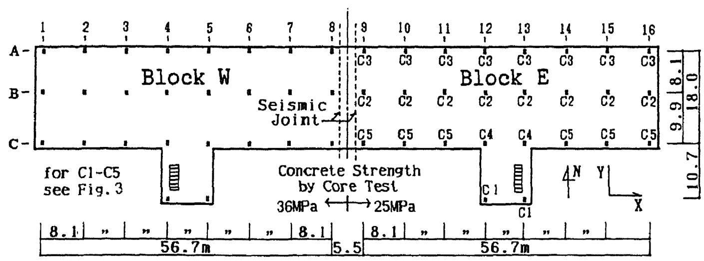


Fig.1 Plan of Building

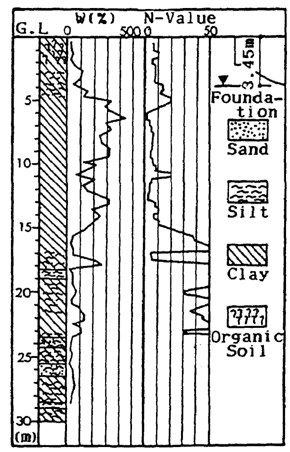


Fig.2 Soil Profile of the Site

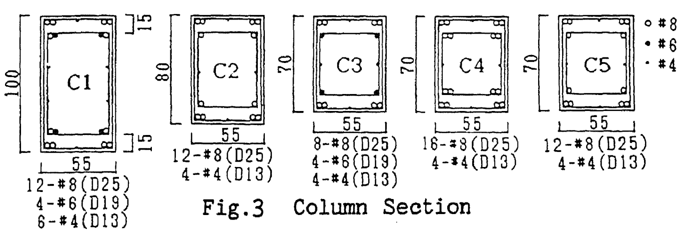
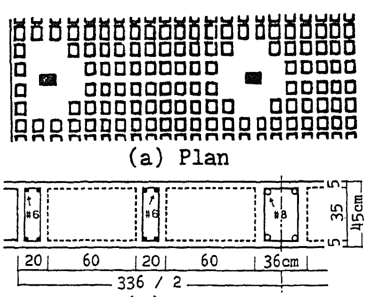


Fig.3 Column Section



(a) Plan

(b) Section

Fig.4 Floor System

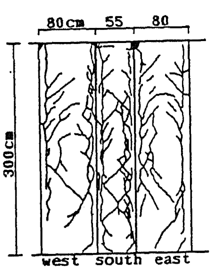


Fig.5 Crack Pattern in Block E

(a) Block E (b) Block W

Photo 2 Damage to Columns

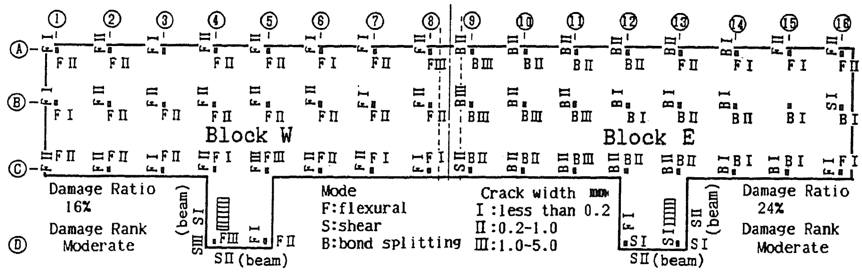


Fig.6 Damage Level of Columns(2F)

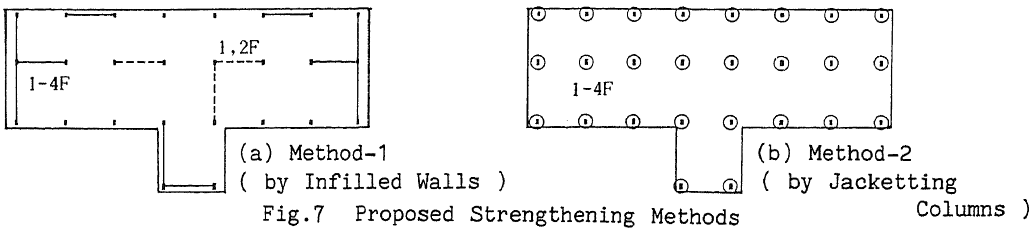


Fig.7 Proposed Strengthening Methods

EVALUATION OF SEISMIC CAPACITY

The seismic capacity of the building was evaluated as an "undamaged structure" (Ref.5) following the assumptions described below. 1) To use observed values of the concrete strength and the depth of concrete cover in a column section. 2) To calculate the capacity of bond-splitting based on the mechanism shown in Fig.8 (Ref.6). 3) To calculate the flexural capacity of "Losa Plana" for the case with the contribution of its whole width.

The obtained failure mode and corresponding capacity of colums are plotted in Fig.9. It is noted for longitudinal frames that the mode of bond-splitting is predominant throughout the stories of Block E, while that of flexure is predominant except the bottom story of Block W. The different failure mode is resulted mainly from the difference of concrete strength. The mode of shear failure is remarkable in transverse frames of both blocks. As shown in Fig.10, yield hinges are formed in each frame on each direction, except both the top and bottom stories, at the end of column capital of the floor system or at the portion where some reinforcements of joist beams are cut off. The obtained lateral force capacity was around 0.2 in terms of the base shear coefficient in each block and for each direction (Fig.11). Thus, it is suggested that columns of longitudinal frames may fail by the bond-splitting and the flexural compression in Blocks E and W, respectively. This corresponds to the features of the observed damage. It is also indicated that the building might consist of the "weak-beam" type structural system, though the observed damage was remarkable in columns.

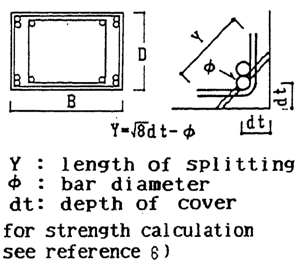


Fig.8 Mechanism of Bond Splitting Failure

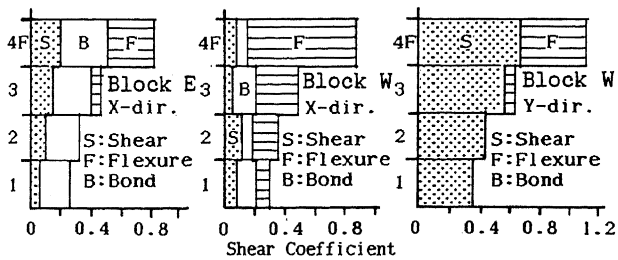


Fig.9 Failure Mode and Strength of Columns

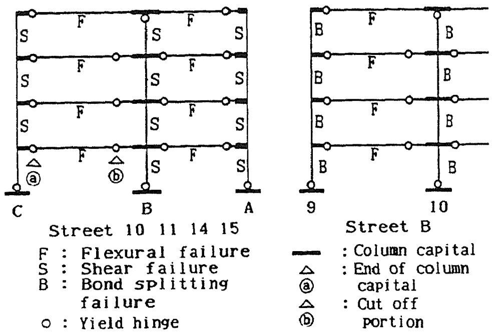


Fig.10 Failure Mechanism of Frames

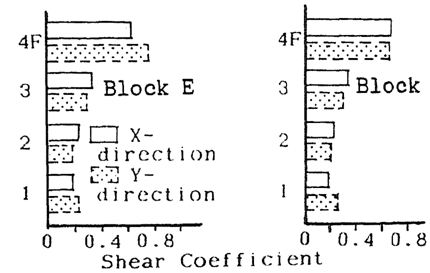
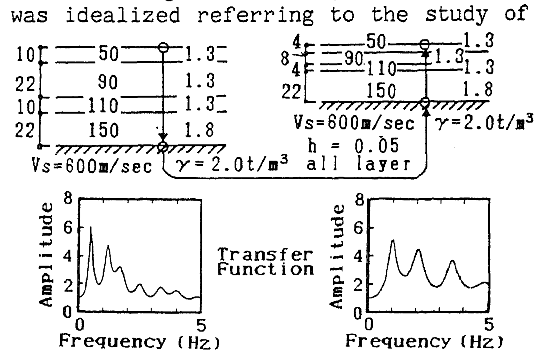


Fig.11 Lateral Force Capacity of Building

SEISMIC RESPONSE OF THE STRUCTURES

As there was no recorded ground motion at the site, the input motion for the building was simulated from a recorded motion at the site of the Secretaria de Comunicaciones y Transportes (SCT)(Ref.7) using the multiple reflection theory (Fig.12). The subsoil at the SCT was idealized referring to the study of Ref.8. The model of soil at the building site was determined from the observed soil profile in Fig.2. The physical property of each layer was determined so that the predominant period of the transfer function may correspond to that of the referring motion or microtremor of the site. Both the recorded and simulaterd motions and their response spectra are shown in Figs.13 and 14, respectively. The simulated motion possessed the property of shorter period and lower intensity compared with that of the SCT record.



(a) At the Site SCT (b) At the Site ESM

Fig.12 Assumed Soil Property

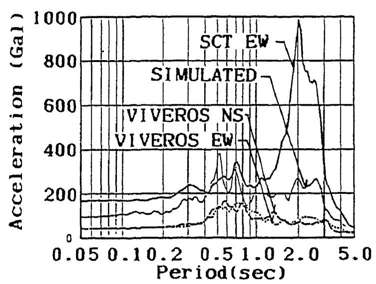


Fig.14 Response Spectra

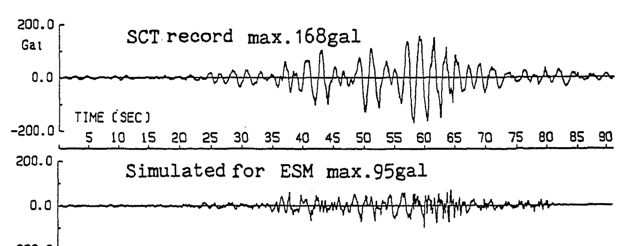


Fig.13 Simulated Ground Motion

Table 1 Fundamental Period (sec)

		1 st	2 nd	3 rd
Block E	x	0.791(0.92)	0.288	0.187
	y	0.731(0.70)	0.275	0.174
Block W	x	0.747(0.83)	0.272	0.173
	y	0.694(0.65)	0.259	0.161

( ) by Microtremor Measurement

The building was idealized into a lumped mass system and the force-displacement relationship of each story was idealized by tri-linear type hysteresis rules, where each breaking point indicates cracking or yielding derived from the flexure, shear or bondsplitting. The displacement at yielding was determined referring existing test data. The calculated fundamental periods shown in Table 1 is slightly shorter than that obtained from the microtremor measurement because of the damage. In the strengthening method 1, concrete walls were placed inside the existing frames to increase both the stiffness and strength, while all the columns were reinforced with additional concrete and reinforcement in the method 2 (Fig.7).

Maximum responses to the simulated ground motion are plotted in Figs.15 to 18. The obtained results are summarized as follows. 1) The maximum story drift (1F or 2F) is estimated to be approximately 1 cm or 0.33% to the story height, which could lead to moderate or partially severe damage to the structrue, though it is much less than the yield displacement. The displacements at upper stories (3F and 4F) are minor. These results agree well with the feature of the observed damage. 2) The strengthening by concrete walls leads to very minor displacement even to motions of twice the intensity of the simulated motion. 3)When most columns are reinforced, the structure is able to resist even an earthqake motion of twice the intensity of the simulated earthquake without brittle failures.

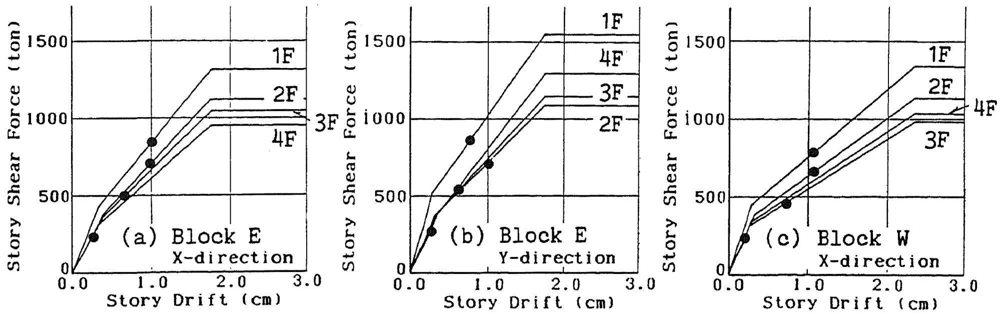


Fig.15 Maximum Response

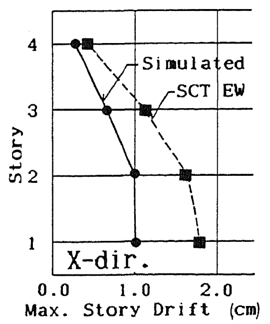


Fig.16 Max. Story Drift

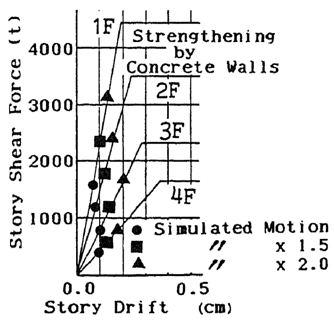


Fig.17 Max. Response
(Proposed Strengthening 1)

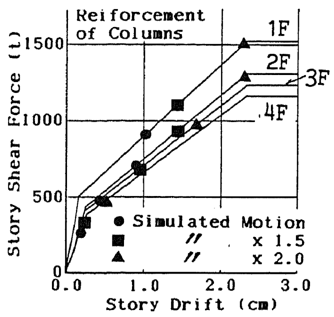


Fig.18 Max. Response
(Proposed Strengthening 2)

CONCLUDING REMARKS

The discussions described herein are summarized as follows. 1) It was indicated that the building would have been subjected to a ground motion of higher frequency and smaller amplitude than those at the Lake Zone. 2) The maximum drift during the motion would have been about 0.3 % which was enough to cause moderate or severe cracks, though it was less than that at yielding. 3) The grouped bars with thin concrete cover and the different concrete strength would have resulted in the bond-splitting failure and different crack pattern in two blocks, respectively. 4) The seismic capasity will be drastically improved when strengthened by concrete walls or jacketting columns.

EPILOGUE

The first author visited Mexico city again in November 1986, one year after the earthquake. The building was undergoing strengthening and repairing at the time (Photo 3). Cracked section had been repaired by epoxy injection, and severely damaged columns had been renewed by removing damaged concrete. The strengthening was made by adding concrete walls on each story. It was observed that the amount of the walls was almost the same as our proposal, except that they were arranged along the outer frames and that they had openings.

Photo 3 South View of Block E (1986.9)

ACKNOWLEDGEMENTS

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