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EXPERIMENTAL STUDY OF A FLAT SLAB FRAME MODEL STRENGTHENED WITH WING WALLS

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ABSTRACT

A research project on evaluation and strengthening of structures in progress since 1986 is described. As part of this project, in this paper results of an experimental program related to a tridimensional model are presented, including the model in the original state and the model strengthned with wing walls. The model represents a portion of a frame structure with waffle slabs scaled to 1/2, consists of two levels, one and a half spans in the direction of loading and one and a quarter spans in the orthogonal direction. It was designed and constructed according with procedures in use before 1985. Loads were applied at two points of the top slab near the edge of the columns. Cycles of load reversals were applied at increasing lateral displacements until strength degradation was observed.

Measured response of both the original and the strengthened model are presented. In terms of these results comparisons are made related to strength, stiffness and energy dissipation. The addition of wing walls increased by three times the original strength and two times the original stiffness. Practical applications of results are also discussed.

KEYWORDS

Strengthening of structures; reticular slabs; wing walls; hysteretic behavior; seismic design.

INTRODUCTION

A research team focused on evaluation and strengthening of existing structures han been working at the Facultad de Ingeniería UAEM since more than ten years ago. Some of the work done up to date include:

a) The developing of two methods of evaluation, one for preliminary evaluation applicable to 16 structural types common in Mexican construction practice and the other for buildings up to six stories (Ramírez, 1992 a)

b) Experimental studies of models representing the beam-wall interface of three retrofitting schemes often used in local construcction practice when infill walls are added to structural frames (Ramírez, 1992 b).

c) With a grant of SEP-CONACYT it was possible to develop a facility for experimental work capaple for testing large tridimensional models. A model representing a building subassamblage of the type strog beam-weak column was constructed and tested. First the bare frame was tested with the application of increasing load reversals to produce damage comparable of that observed during strong ground motions. Then the model was strengthened with reinforced concrete walls constructed as infills and tested with load reversals (Ramírez, 1992 b).

As a result of the previously mentioned work design recommendations were developed for the upgrading of existing structures and they were applied to several cases including school and hospital buildings.
With this background, the current interest of this research team is oriented to reinforced concrete frame structures with flat-waffle -slabs. This paper describes the design, construction, instrumentation and testing of a tridimensional model representing a portion of a structure of this type. This study is justified because buildings with flat slabs exist in zones with seismic potential, thus methods for strengthening of existing buildings need to be investigated.

DESCRIPTION OF THE MODEL

The construction of buildings up to 15 stories with reticular slab systems became very popular in Mexico because of construction and economic advantages, however, under lateral loads this system exhibits low stiffness and the structural behavior is dictated by the shear stength of the slab to column connections which may cause progresive collapse under seismic loads (Del Valle, 1986). After the September 1985 Mexico Earthquake, it was estimated that 3% of the frame structures and 6% of the reticular slab structures collapsed or had severe damage, and that 15% of the frame structures and 22% of the reticular slab structures, suffered some degree os structural damage in such a way that strengthening was recommended (Aguilar,1989). During recent earthquakes occurred in Guerrero, Colima and Chiapas, several structures of this type suffered severe damage which is an indication that in order to decrease vulnerability retrofitting of structures is needed in seismic zones within México. With a grant of CONACYT, it was possible to conduct this experimental program based on a tridimensional model scaled to 1/2. The model consists of two stories, one and a half spans in the direction of loading and one and a quarter spans in the orthogonal direction. Free interstory height is 1200 mm, slab thickness is 160 mm, the voids to lighten the slab are 300, 300 and 130 mm. Principal ribs are 200 mm wide, ribs next to principal are 100 mm wide and the rest 50 mm wide. Original column section is square with 200 mm side. To simulate continuous internal spans in the direction of loading steel props with hinged ends were attached in both stories, see figure 1.

It was intended to simulate a subassamblage of a structure of several floors, the model corresponding to the first two floors of the corner of such a structure. The structure in which the model is based had typical dimensions and reinforcement quantities and details of building designed and constructed before 1985. However the model does not represent a particular prototype because it was not possible to apply vertical loads. The main purpose of this experimental programs was to obtain basic parameters related to the behavior of this type of structures and to study the possibility of increasing lateral strength and stiffness with the addition of wing walls.

Figure 2 shows a longitudinal view of the model and reinforcement details of the original columns. Figure 3 shows the reinforcement details of the wing walls added to the original model.

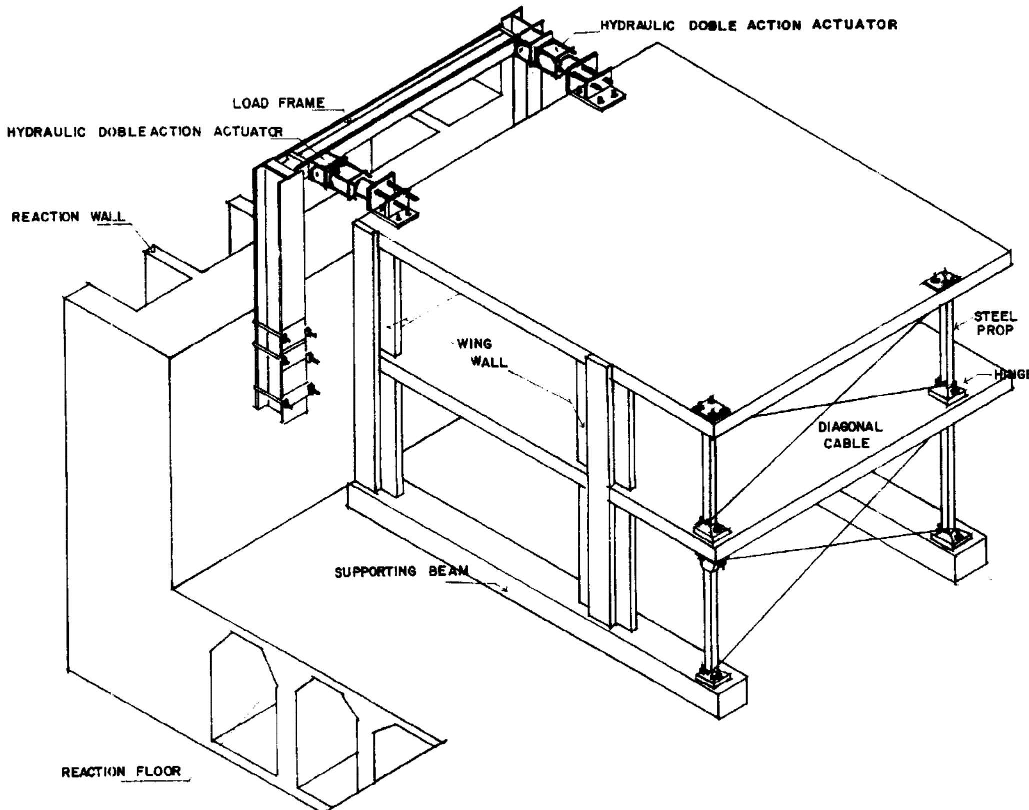


FIGURE 1. GENERAL VIEW OF THE MODEL WITH WING WALLS

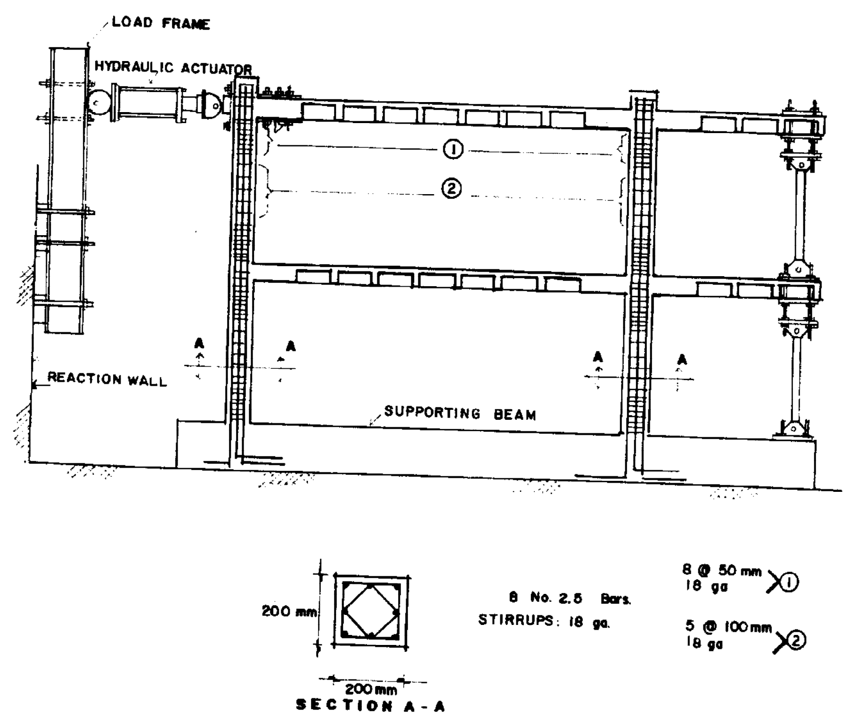


FIGURE 2. ORIGINAL MODEL

TEST OF THE ORIGINAL MODEL

Loads were applied at two points of the top slab near the edge of the columns. The test was deformation controlled in such a way to produce uniform displacements in the direction of loading. Cycles of load reversals were applied, the history of imposed deformations is represented at the top of figure 6a), one half is only shown.

The observed structural behavior is represented with the hysteresis curves shown in figure 5 a). For data reduction it was convenient to define an interior frame and an exterior frame corresponding to each of the column lines in the direction of loading. The envelopes of load vs. lateral deformation for the exterior frame, interior frame and the complete structure are shown in figure 6 a). On the basis of these results the next observations are made:

1. The contribution to strength of the interior frame was greater than the contribution of the exterior frame, the difference decreases as more deformation was imposed. At the beginning of the test the contiribution of the exterior frame was 37% of the corresponding to the interior frame, at the end of the test was 65%. This is attributed to inelastic behavior and stress redistribution.

2. Stiffnes degradation was more noticeable in the interior frame. The model exhibit a drastic stiffnes reduction, at the end of the test total stiffness was only 14% of the original. In real structures this loss of stiffness may be the cause of an increased responce as well as moment magnifying on columns, which may produce the collapse of the structure. Similar observations were reported by Rodríguez (1993).

3. Cracks in the slab formed near the column lines with paths perpendicular to load direction. The slab to column connection of the exterior frame exhibited considerable damage but the rest of the connections had moderate damage. Flexural cracking was observed in the columns, mainly in the lower 2/3 of the columns of first story.

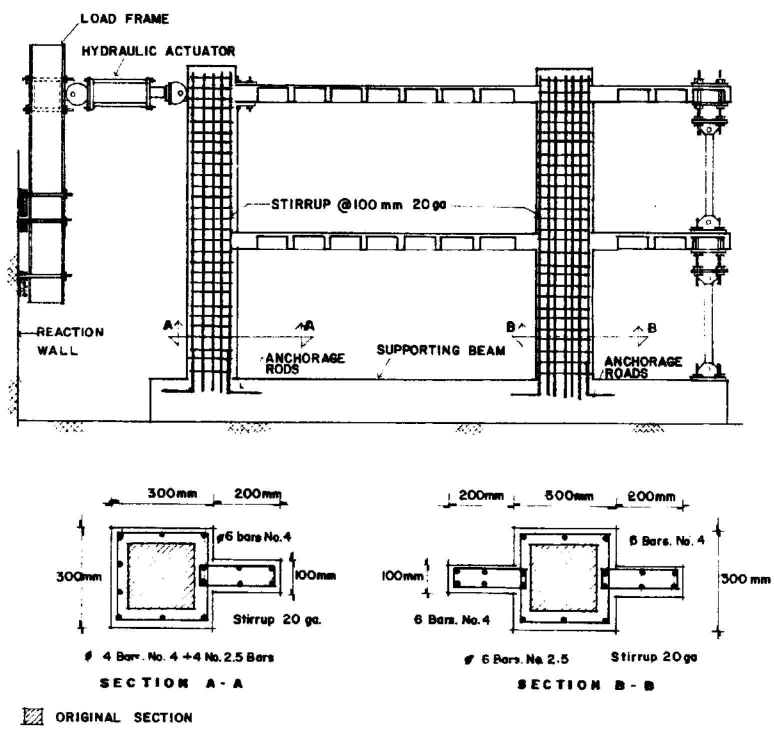


FIGURE 3. STRENGTHEN MODEL

TEST OF THE STRENGTHENED MODEL

One of the main purposes of this project was to obtain data to outline upgrading procedures for existing buildings with reticular slabs. The addition of wing walls was considered first because this procedure is compatible with the construction methods and materials often used for strenthening of structures in this country. It was decided to construct wing walls adjacent to the columns of the model including the jacketting of the original columns. The desing of the wing walls was based on the seismic analysis of the assumed prototype, and reinforcement details according with recommended practice (Aoyama, 1986) (Sugamo, 1981), Figure 3 shows the dimensions and reinforcement bars of the wing walls including the jacketting of the original columns.
Slab holes were perfomed in order to make continuous the vertical reinforcement of the wing walls which was anchored to the footing beam with anchor rods which were previosly prepared. Vertical reinforcement of the column jacketing was not continuous through the slab.

Concrete was fabricated according with local specifications using coarse agregate with maximum size of 9 mm, the average strength of the concrete was 285 kg/cm2 (28 MPa). Main longitudinal reinforcement consisted of 12.7 mm corrugated bars with nominal yield strength of 4200 kg/cm2 (412 MPa). Transverse reinforcement consisted of 4 mm plain wire with measured yield strength of 3370 Kg/cm2 (331 MPa).

Load was applied with the same equipment and procedure than in the previous test, the history of impossed lateral deformations is shown at the top of figure 6 b). Each of the pick displacements was reached in three steps, and monitoring load level, reinforcing steel strains, and rotations of the slab to column joints. Cracks were marked at the end of each cycle of loading. Cycles of load reversals at increasing lateral deformations were imposed until a decrease of lateral strength was observed respect to the previous cycle

The observed structural behavior is illustrated with the hysteresis curves shown in figure 5 b). The envelopes of load vs. lateral deformation for interior and exterior frames, as well as the complete structure, are shown in figure 6 b). As can be seen in figure 4, cracks in the wing walls was uniform and formed in most of the length of the element, this is an indication of the effectiveness of the wing walls and a good integration of old and new elements.

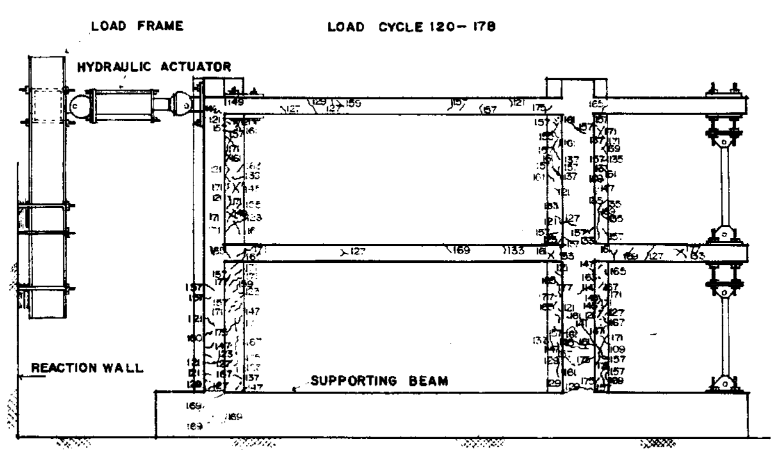
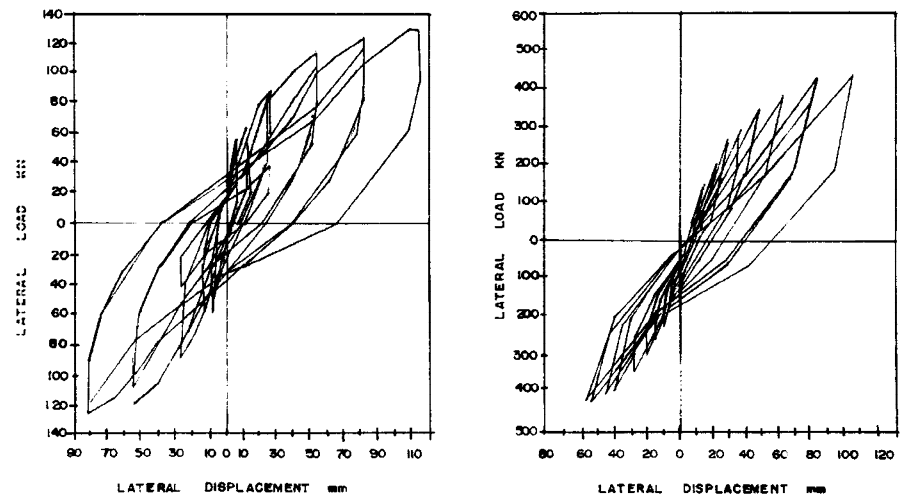


FIGURE 4. CRACK PATTERNS ON WING WALLS

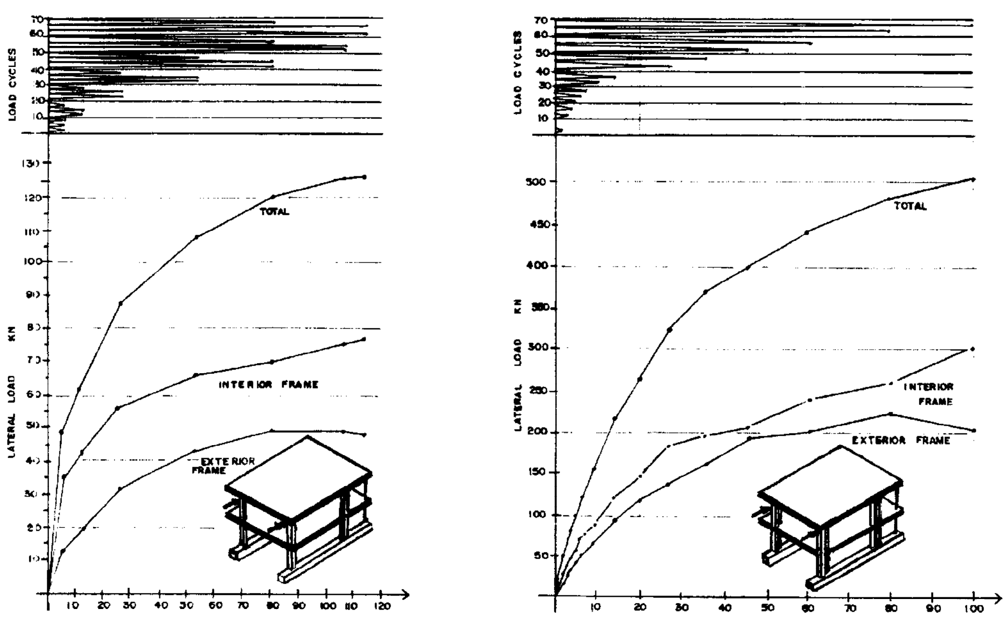
The global behavior observed is more stable than in the previous test, stiffness was not degradated as fast as in the original model and hysteresis loops were more uniform. Lateral capacity was increased by 3.7 times and lateral stiffness increased 2.9 times, see figure 7. The strengthened model exhibits about two times more energy dissipation relative to applied loads than the original model. Comparisons of observed and computed values of some key parameters are shown in table 1. The elastic load and stiffness were obtained with an analytical model based on the regulations of the México City Code (R.D.F. 1987) assuming first yielding of column reinforcement. The computed strength was obtained with plastic analysis of the interior and exterior frames. For the interpretation of these results it should be considered that only one structure was used and the cracks formed in the slabs were not repaired for the test of the strengthened model.



a). ORIGINAL MODEL

b). STRENGTHEN MODEL

FIGURE 5. HYSTERESIS CURVES



a) ORIGINAL MODEL

b) STRENGTHEN MODEL

FIGURE 6. ENVELOPES LATERAL LOAD TO DISPLACEMENT

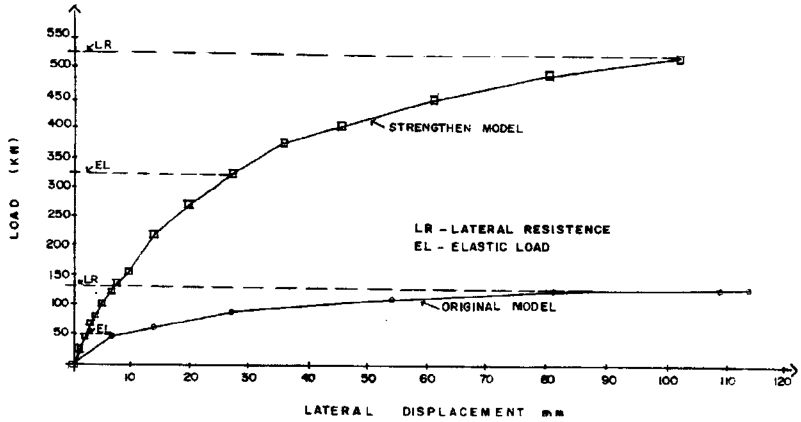


FIGURE 7. LOAD - DISPLACEMENT ENVELOPES, ORIGINAL AND STRENGTHEN MODEL

TABLE 1 . OBSERVED AND COMPUTED VALUES.

KEY PARAMETER	ORIGINAL MODEL			STRENGTHERNED MODEL		
	OBSERVED	COMPUTED	OBS/COMP	OBSERVED	COMPUTED	OBS/COMP
ELASTIC LOAD kN	49.2	65.1	0.89	321.1	311.0	1.03
LATERAL STIFFNESS kN/mm	7.2	6.1	1.18	22.7	27.6	0.83
LATERAL STREGTH kN	125.8	131.5	0.96	507.4	634.1	0.80

RESULTS

Conclusions

The test of the original model demonstrated the high flexibility of this structural system, the progressive loss of stiffnes explains some of the modes of failure observed during the occurrence of earthquakes. Under seismic movements reticular slab buildings may be in danger of progressive collapse as a consequence of lateral stiffness degradation.

For the model a different structural behavior between interior and exterior frames was observed, the influence of this effect may be more importante than the predictions based on usual desing procedures.

The theoretical strength of the strengthened model was not reached, however the results indicate that wing walls may be a practical method for upgrading of this type of structures because the cost is lower than for other techniques and the structural behavior is improved.

Application

This procedure was used to retrofit a six story hospital building in the city of Toluca. The building had some nonstructural damage during the 1985 México earthquake and persons who were in the building during the movements testify that very large displacementes were felt at the upper stories. Wing walls were added to the building in both directios in order to increase lateral stiffness. In additon the foundations was enlarged and strengthen so the overturing moments generated by the wing walls could be resisted.

The measurements from ambiental vibrations before and after the retrofitting process indicate that stiffness was increased by 2.1 times in the NW direction and 2.5 times in the SW direction. A torsional vibration mode which was detected in the original structure was practicaly eliminated in the strenghthened structure. The seismic response of the structure was improved.

This case shows that the problem studied has practial application, construction methods and details used in the experimental model were applied in this case, anchor bolts (Jirsa, 1986) were used in some wall joints where jacketing of the column was not possible.

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