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# TEST OF A MICRO-CONCRETE MODEL OF A BUILDING DAMAGED DURING THE 1985 CHILE EARTHQUAKE

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## ABSTRACT

A 1:10 scale model of the El Faro building, which collapsed during the 1985 Chile earthquake, was constructed and tested under cyclic reversed quasi-static lateral loads. The objective of this work was to study the three-dimensional behavior of the structure, and the effect of the rest of the elements on the critical wall suspected to initiate the collapse. In a previous study, six 1:10 scale micro-concrete models of this critical wall were constructed and tested in order to study their behavior.

None of the tests reproduced the failure of the actual building, showing the models a behavior characterized by stable hysteresis cycles, with acceptable levels of strength and stiffness degradation. The building model was able to sustain a top displacement of nearly 25 mm (1.5% of the height), with extensive cracking and fracture of longitudinal reinforcing steel and with no catastrophic failure. In consequence, the real cause of the El Faro building collapse could not be inferred from the data obtained during this work. These results lead to confirm that the failure originated in a local weakness of the wall, such as a defective construction joint, assumption based on the construction history of the building.

## KEYWORDS

Reinforced concrete buildings, reinforced concrete walls; reinforced concrete models

## INTRODUCTION

"El Faro de Reñaca", a 9-story reinforced concrete building located in Viña del Mar, Chile, suffered severe damage during the earthquake of March 3, 1985. The building was left with a permanent inclination of aproximately 15 degrees from the vertical, and had to be demolished soon after the earthquake due to a failure initiated at the M-axis wall. A crack opened at mid-height at the first story of this wall, and ran up to the top of the window, as shown in Fig. 1. The portion of the wall above the crack slid forward out of the plane and fell to the ground. No damage was observed in the upper stories.

According to some authors (Stark, 1988; Wood, 1989), one of the main causes of the collapse was the fracture of the flexural reinforcement near the base of the walls, resulting from the low steel ratio, which caused a brittle failure. Other studies (De la Llera, 1989) have concluded that a strong dynamic coupling effect between the lateral and rotational displacements, led the insufficiency of flexural reinforcement to a critical point, especially taking into account the simultaneous effect of the two orthogonal components of the seismic action. Results form linear dynamic analyses show that the lateral displacement at the extremes of the story slab may have been as large as twice the displacement at the center of mass. Those displacements were large enough to cause flexural failure in some wall sections in one of the lowest stories.

Riveros (1987) has shown that the failure may have started in a flexural mode in a construction joint near the base of the walls (Fig. 1), thus pointing to deficiencies during the construction. As he observed from photographs and inspections of the site, he concluded the building would have moved mainly along one of its diagonals.

In order to study the behavior of the walls of the El Faro building, six 1:10 scale micro-concrete models representing the most damaged M-axis wall of the building were constructed and tested at the laboratory. It was verified that a flexural failure, associated with the fracture of the longitudinal reinforcing bars, could occur due to the low reinforcement ratio of the walls. However, this failure was not as brittle as expected. It was also verified that this kind of failure may be prevented by using an appropriate flexural reinforcement ratio.

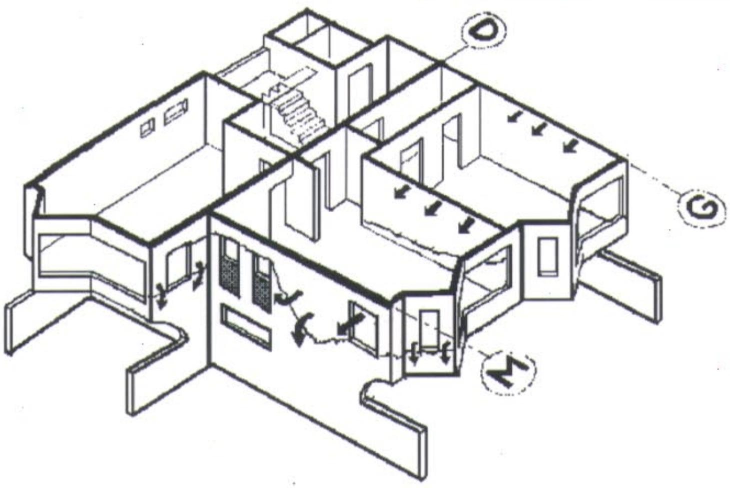
Results of the final stage of this study, consisting in the test of a six-story 1:10 scale micro-concrete model of the whole building, are presented in this paper.

## TEST OF THE BUILDING MODEL

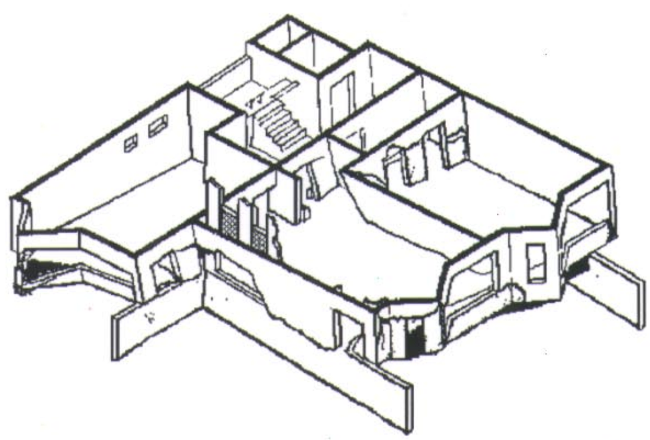
The 1:10 scale micro-concrete model (Fig. 2) was intended to reproduce, in a simplified way, the complete structure, taking a special care to reproduce the M-axis wall and surrounding areas. The objective of this work was to study the three-dimensional behavior of the structure, especially the effect of the rest of the elements on the critical M-axis wall.

Code-type linear dynamic analyses of the El Faro building, showed the importance of the torsion in plan on building behavior, increasing the demand on the elements along the perimeter of the building plan. The shear force carried by the M-axis wall was about 40% larger, when the building was subjected to a seismic action transverse to the plane of the wall (X-direction), than when it was parallel to the wall (Y-direction). On the other hand, the axial forces on the M-axis wall induced by the building overturning moment, reached their maximum level when the building was being loaded in the direction transverse to the wall. Since the objective was to study the most critical conditions for this wall, the building model was loaded in the X-direction during the test (Fig. 3).

a)




b)



c)

**Fig. 1** El Faro Building: (a) After the earthquake; (b) First-story schematic view. The arrows show the displacement directions of the walls before the collapse; (c) First-story schematic view after the earthquake.

**Fig. 2** 1:10 scale building model

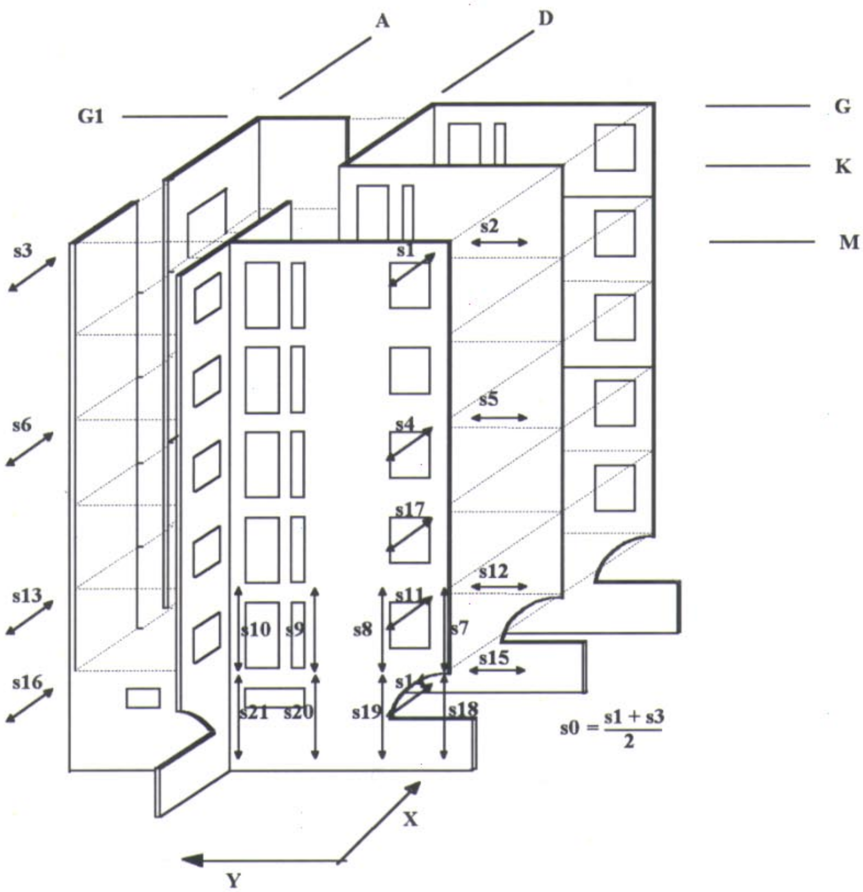



**Fig. 3** General view of the 3-D building model showing the location of the displacement transducers

The test was carried out in a displacement controlled scheme. Cyclic reversed quasi-static lateral loads were applied in the direction of the X axis at the center of gravity of the roof slab using hydraulic actuators. Forces were measured by using load cells placed on the actuators. In order to measure deformations, the model was completely instrumented. The position of the displacement transducers, as indicated in Fig. 3, permitted the measurement of the displacement and rotations of each story slab, and deformations at the bottom stories of the M-axis wall. The displacement at the roof slab, used to control the test, was taken as the mean value $s_o$ of the displacements recorded by transducers $s_1$ and $s_3$.

## RESULTS

The first cracks were observed in several walls at an overall drift ratio of 0.25% (4 mm top displacements) . Cracking was concentrated mainly in the walls along the axes M and G on the perimeter of the building plan and on the central axis D, parallel to the direction of the load. At an overall drift ratio of 0.62% (10 mm) cracks had developed across the complete sections of walls D and G. Flexural reinforcement fractured first in axis-D wall at an overall drift ratio of 1.23% (20 mm). The test was ended at an overall drift ratio of 1.84% (30 mm).

Fig. 4 shows the cracking pattern of the M-axis wall and the distribution of the wall lateral displacements on the building height after the completion the 1.53% overall drift ratio (25 mm) cycles, which represent a stage of high level of deformation. The plan views of the position of each story slab at the same stages, for both directions of the tests, are also shown in these figures. For the sake of clarity, rotations of the plans are not scaled. Finally, the figures show the applied load- lateral top displacement curves obtained during the tests. Fig. 5 shows the lateral displacements and cracking patterns for each wall of the model at the final loading cycle.

Large levels of inter-story drifts were measured during the test. For instance, at the 1.53% overall drift ratio cycles, a relative displacement of 3.6% of the story height was measured at one of the plan corners at the second level of the model.

The test of the model did not reproduce the building's behavior during the earthquake, i.e., the failure of the M-axis wall with the complete opening of the crack at the height of the first-story window and its later out-of-plane displacement. Deformations observed during the test were distributed among several cracks of limited width. Even at an overall drift ratio as high as 1.84%, the cracked M-axis wall remained stable.

Despite of some minor differences, the M-Axis wall showed a similar behavior than that observed in isolated wall tests, exhibiting the same tendency to fail in the bottom level, whereas in the actual building it failed in the second level.

## CONCLUSIONS

The test of the building model did not reproduce the behavior of the actual building during the earthquake. Even at an overall drift ratio as high as 1.84%, the critical M-axis wall remained stable. The behavior of the model was characterized by stable hysteresis cycles, with acceptable levels of strength and stiffness degradation.

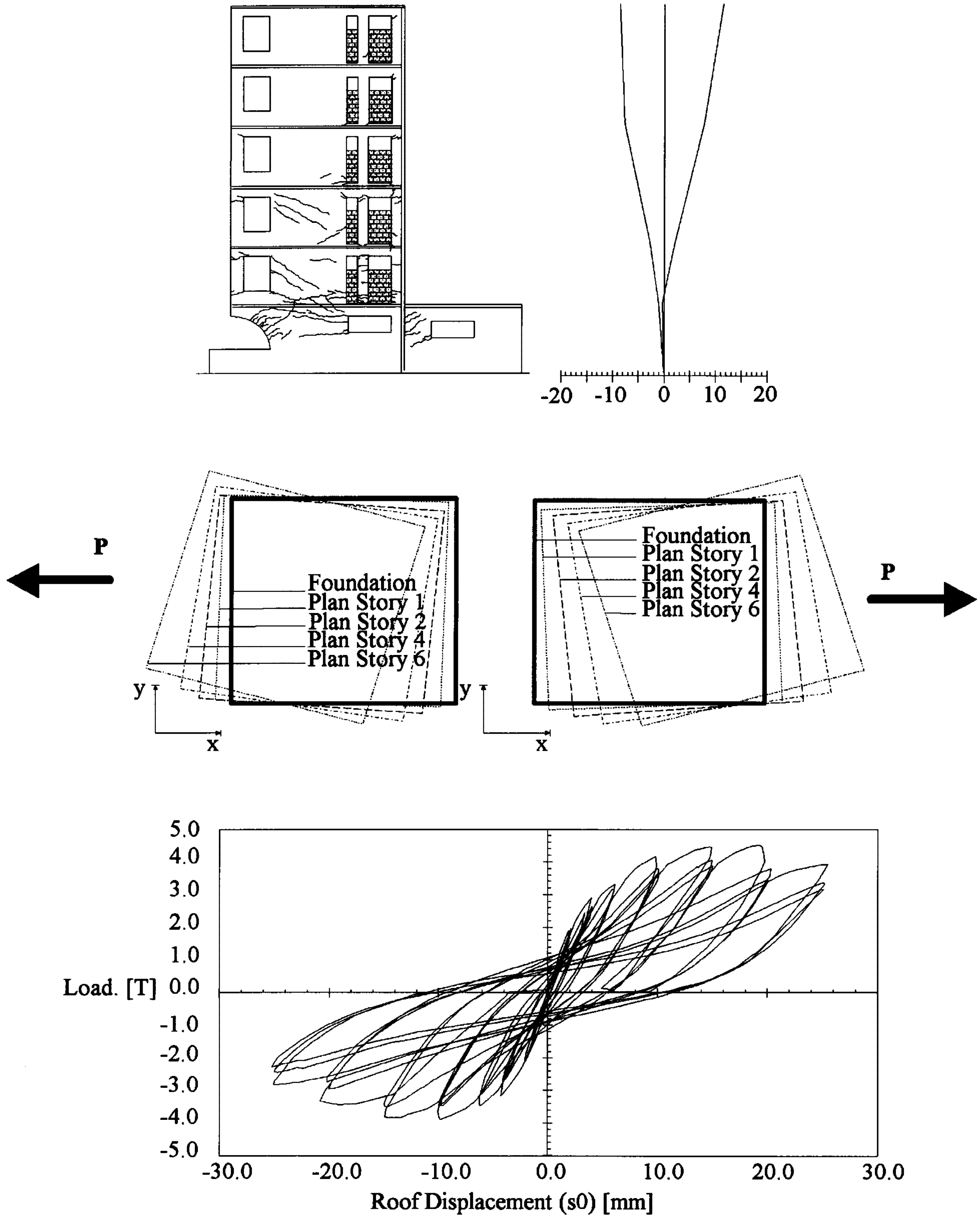



**Fig. 4** 1.53% overall drift ratio (6 mm) cycles: Cracking pattern and distribution of wall displacements on the height for M-axis wall; Schematic plan view of the position of each story slab; Applied load - top displacement curve

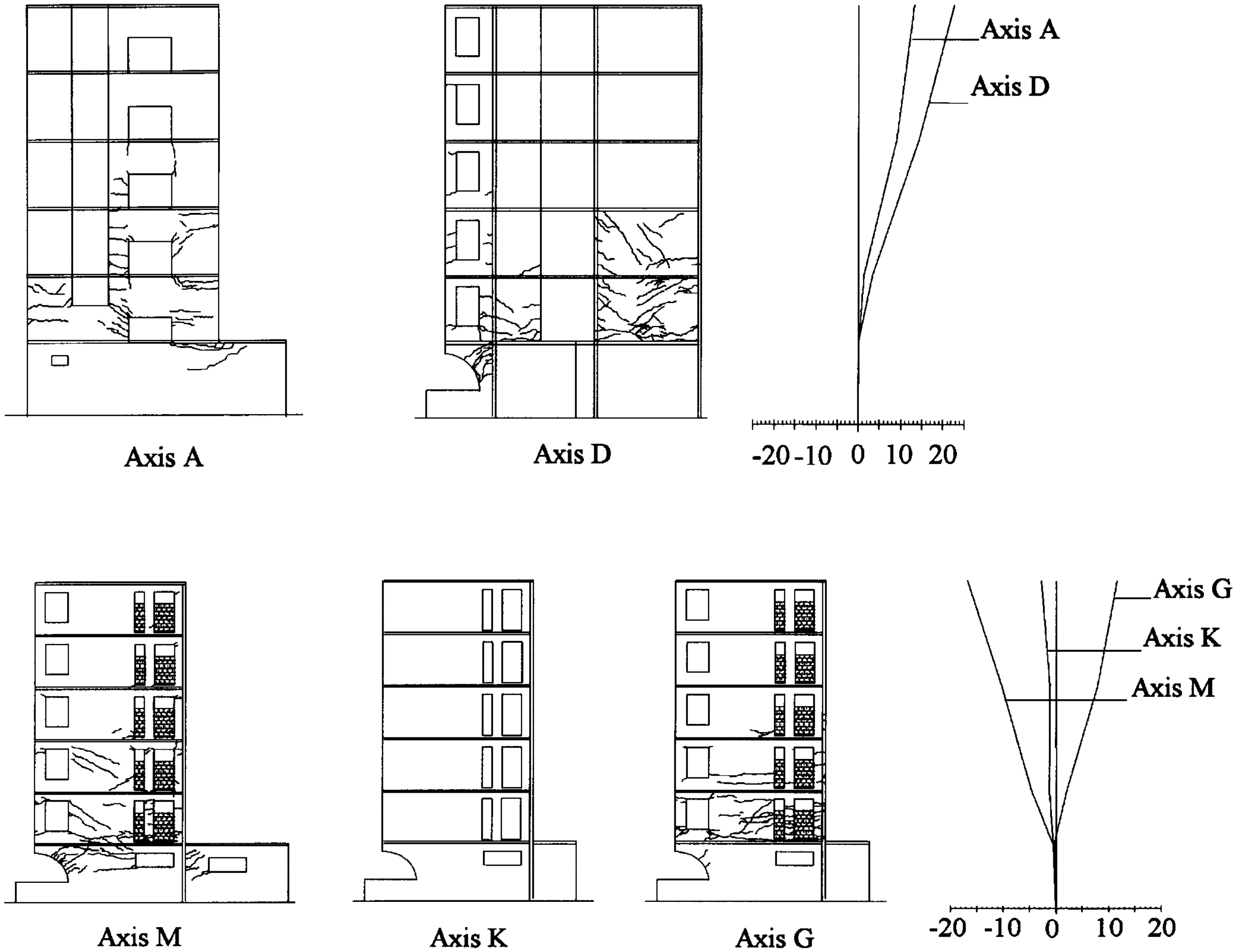



**Fig. 5** Lateral displacement distributions and cracking patterns for each wall of the model at the final loading cycle

In consequence, the real cause of the El Faro building collapse could not be inferred from the data obtained during this work. These results lead to confirm that the failure originated in a local weakness of the wall, such as a defective construction joint, assumption based on the construction history of the building.

Finally, it must be mentioned that some dynamic effects not considered in this study may severly have affected the behavior of the building during the earthquake. A local amplification of the ground motion and the presence of a long pulse in the earthquake motion may have led to very large deformations that made critical the weakness of the building.

## ACKNOWLEDGMENTS

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