U.S.-JAPAN COOPERATIVE RESEARCH PROGRAM TESTS OF 1/3-SCALE PLANAR WALL ASSEMBLIES

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SUMMARY

The U.S.-Japan Cooperative Research Program on Reinforced Concrete Structures consists of full-scale tests, reduced-scale tests, component tests, and analytical investigations. This paper presents a review of tests of two approximately 1/3-scale planar specimens. Details of construction, load history and test results are presented. Comparison of test results with associated analytical predictions and full-scale test results are given.

HIGHLIGHTS

A planar wall-frame assembly and an isolated wall were constructed and tested under reversing static loads. The wall-frame assembly was a medium-scale representation of the wall-frame section of a full-scale structure tested in Japan. The isolated wall was constructed and tested to simulate the wall section of the wall-frame assembly. Analytically predicted strengths were ten and four percent less than the measured strengths of the wall-frame assembly and the isolated wall, respectively. Behavior of the wall of the wall-frame assembly was adequately predicted from behavior of the isolated wall.

Overall behavior of the medium-scale specimens and the full-scale structure were similar. The full-scale structure was stiffer and stronger than was predicted from scaling up the medium-scale results assuming planar behavior in the direction of load. Increased strength was due to three-dimensional effects and participation of floor slabs (Ref. 1). An analysis made assuming strength contributions of three-dimensional effects gave a predicted full-scale strength that agreed well with measured strength of the full-scale structure.

OBJECTIVE

The work described in this paper is based on "Recommendation for U.S.-Japan Cooperative Research Program Utilizing Large-Scale Testing

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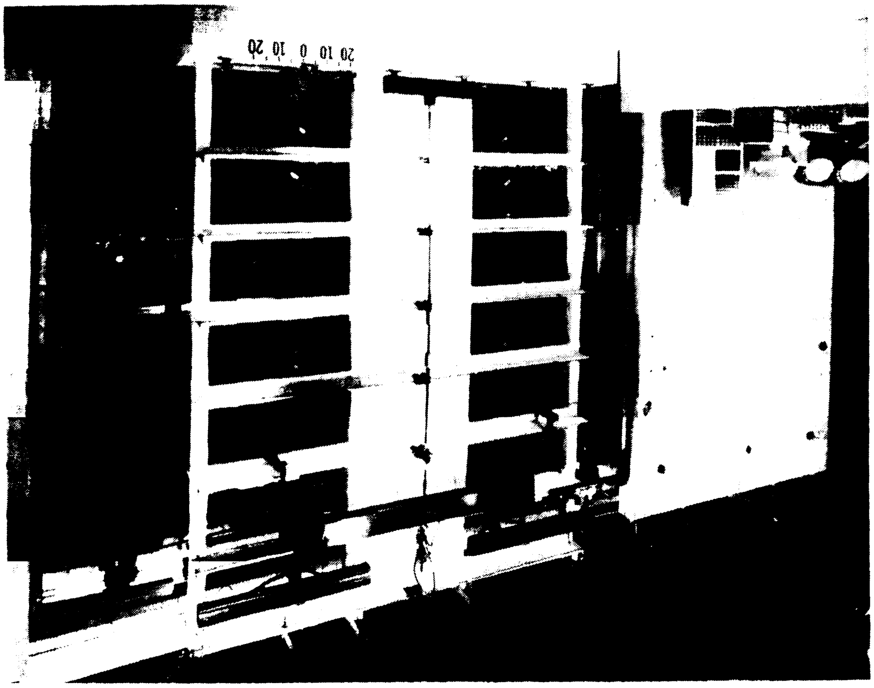

Figure 1. Wall Frame Assembly

The specific objectives of the tests of the planar structures were (a) to correlate test results of the two specimens, (b) to correlate test results with analytically predicted behavior to verify analytical and structural modeling techniques, and (c) to provide data for the overall study to determine the relationships from the various testing and analytical approaches.

TEST SPECIMENS

Full-Scale Structure

The full-scale structure was seven stories, 71-1/2 ft (21.8 m), high, three bays long in the direction of load application, and two bays wide. It contained a single structural wall in the center. The specified strength of the concrete used was 3840 psi (26.5 MPa). The specified yield strength of the reinforcement was 49,800 psi (343 MPa).

Wall-Frame

The medium-scale wall-frame specimen consisted of a single planar frame with a structural wall as shown in Fig. 1 (Ref. 1). The ratio of the concrete dimensions of the wall-frame test specimen to the full-scale structure was one to 3.5. This scaling provided a structure approximately 20-1/2 ft (6.2m) high and 16 ft (4.9m) wide from column to column.

Concrete design strength was 4000 psi (27.50 MPa) at 28 days, closely matching the concrete design strength of the full-scale structure. Primary reinforcement in the beams and columns was No. 3 bars conforming to ASTM Designation: A615 Grade 60 (Ref. 3). The percentage reinforcement in the wall frame specimen was chosen to give a stiffness for the planar specimen equivalent to the calculated two-dimensional stiffness of the entire full-scale structure.

Isolated Wall

The isolated wall test specimen duplicated the wall portion of the wall-frame structure except that it did not have slab stubs. The isolated wall also was shorter than the wall-frame specimen. It was loaded to represent the entire seven level wall-frame specimen. The same concrete mix design used for the wall-frame specimen was used for the isolated wall.

TEST PROCEDURE

Full-Scale Structure

Initially, the full-scale structure tested in Japan underwent a series of low level vibration and static tests. These were followed by four tests utilizing a modified pseudo-dynamic test procedure. During this series of tests, the structure was subjected to increasing lateral load cycles until extensive cracking and yielding occurred. After this series, the structure was repaired and tested again. It was then modified with non-structural elements, tested again, and finally tested to maximum strength levels. The medium-scale tests conducted at Construction Technology Laboratories corresponded to the full-scale tests utilizing the modified pseudo-dynamic test procedure.

The modified pseudo-dynamic test approach used the load apparatus at all seven levels. Also, real earthquake time-history data provided basic lateral load input. However, modifications were made to the input function to insure that the structure responded essentially in only its first mode. These modifications retained the earthquake-like load time-history at the roof level, while subjecting the lower levels to an inverted triangular load distribution.

Wall-Frame

The wall-frame specimen was loaded laterally with an inverted triangular distribution. This distribution closely simulated the earthquake-like lateral load used in the test of the full-scale structure. The specimen was loaded alternately in each lateral direction. Vertical load, in addition to the specimens self weight, was required to simulate the axial stresses present in the lower stories of the full-scale structure. Details of loading are described in Ref. 1.

Isolated Wall

The isolated wall was loaded laterally with a single force applied at the top, or fifth story level, of the specimen. This was the same level as the centroid of the inverted triangular load system used for the wall-frame specimen. Consequently, externally applied bending moment and shear at the first story were similar for both specimens (Ref. 1).

TEST RESULTS

Medium-Scale Specimens

Wall-Frame

The mechanism that developed within the wall-frame specimen consisted of hinging in the columns and wall at the base of the structure with all other hinging taking place in the beams. The mechanism was fully developed at a drift ratio of 1.5% measured at the top of the specimen. Maximum lateral load was maintained at this drift. Measured load versus drift is shown in Fig. 2.

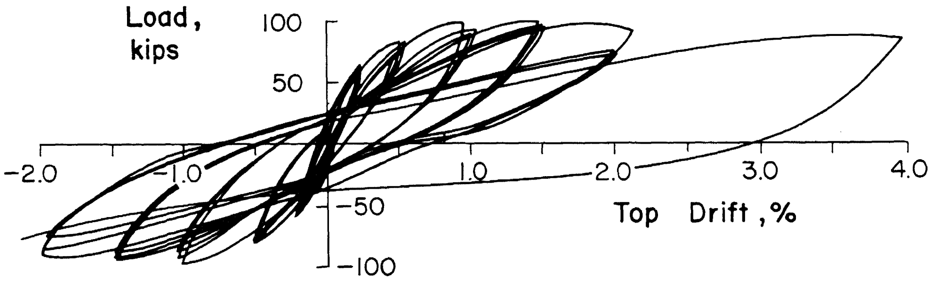

Figure 2. Load versus Drift - Wall-Frame

Isolated Wall

The isolated wall reached its maximum lateral load capacity at a drift of approximately 1%. However, significant additional drift was obtained while maintaining lateral load resistance. Measured load versus drift for the isolated wall is shown in Fig. 3.

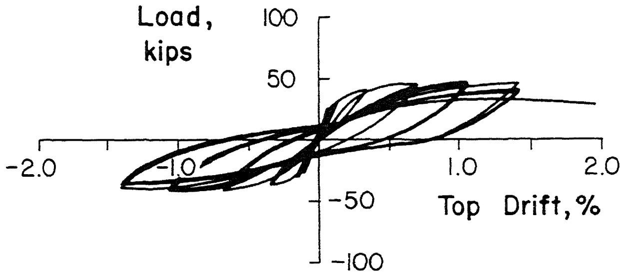

Figure 3. Load versus Drift - Isolated Wall

Basic Behavior

During both tests, the wall boundary element that was in tension elongated considerably when compared to the shortening of the boundary element in compression. Moreover, most of this vertical elongation was concentrated in the first story. After yield was well developed, the wall rotated essentially as a rigid body about a pivot point located at the base of the boundary element in compression. The boundary element in tension elongated more or less uniformly from the base to the top of the first story. The developed wall mechanisms were clearly flexural.

Analysis

A structural analysis was made of both specimens utilizing the measured mechanical properties of the materials. Maximum moment capacities of the wall, beams, and columns were determined from a moment versus curvature analysis assuming plane sections remain plane during bending. Strain hardening of the reinforcement was considered. Imposed axial load effects were included in the analysis (Ref. 1). Maximum load capacity of the wall-frame as determined by the test was 1.1 times the analytically predicted maximum load. Maximum test load for the isolated-wall was 1.04 times the analysis value.

Full-Scale Structure

Strength Comparison

The full-scale structure sustained a lateral load of approximately 961 kips at a drift of 1.5%. A predicted lateral load of 619 kips is obtained by scaling up the results of medium-scale tests to full-scale considering only planar structural behavior. This predicted load is considerably less than the load sustained by the full-scale structure. There is strong evidence from a preliminary review of the full-scale test results, however, to suggest that the increased strength obtained during the full-scale test is due in large measure to three-dimensional effects. The factors that appear to be the major contributors are the transverse beams, the floor slabs, and axial load induced in the wall.

As discussed previously, the boundary element of the structural wall in tension elongated considerably when compared to the shortening of the compressive boundary element. Most of this elongation was concentrated in the first story. As a consequence, beams running transverse to the tension boundary element in the full-scale structure experienced relative upward movement of their ends. This came about because they were connected on one end to the boundary element which was displacing vertically, and on the other end to a conventional frame which experienced little vertical deformation. Transverse beams framed into both sides of the boundary elements of the full-scale structure and therefore contributed to its overall strength.

In the planar wall-frame structure, the slab stubs were comparatively narrow and deformed in one plane only as they contributed to bending strength of the beams. In the full-scale structure, the slab in the vicinity of the tension boundary element deformed in two planes. The slab worked with beams both in the plane of, and transverse to, the structural wall. Therefore, the full-scale structure with slabs deforming in two planes had increased strength over that predicted from the test of a wall-frame specimen with slab stubs deforming in only one plane.

Scaling up the results of the medium-scale tests including the effects of transverse beams, and slabs assumed to be fully effective in negative moment with all hinging beams, yields a predicted lateral load of 1032 kips. A comparison of the scaled up load versus drift curve of the wall frame specimen and the envelope for the full-scale tests is shown in Fig. 4.

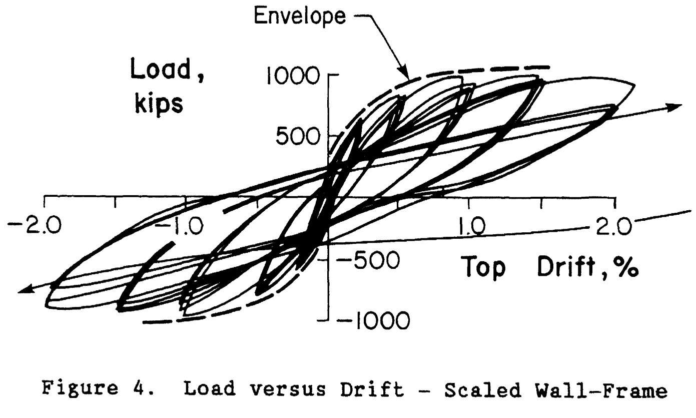

Figure 4. Load versus Drift - Scaled Wall-Frame

This analysis places the predicted and test lateral load values within acceptable agreement. The comparison further substanti- ates the assumption that three-dimensional effects were significant during the full-scale tests.

Strength and Ductility

The comparison between medium-scale wall-frame specimen and full-scale three-dimensional specimen test results indicates that a lower bound on the strength of a structure is arrived at by the individual analyses of planar frames. These are assumed to function together in the direction of load by the shearing transfer action of horizontal floor diaphragms. The current practice in design of neglecting out-of-plane, three dimensional effects is therefore conservative from a strength standpoint.

Structural walls of all specimens tested exhibited ductile flexural behavior during hinge formation and beyond. Shear stress in the walls was moderate. For these structures, the increased strength of the system due to three-dimensional effects also means that the structural wall will be required to absorb higher shear stresses. However, increased vertical load on the walls increases ductility above that determined from a planar analysis and ignoring vertical loads.

CONCLUSIONS

When correlated with results of tests on a full-scale structure tested in Japan, results of tests of planar specimens suggested a lower bound to strength can be calculated by analyses of individual planar frames. The current practice in design of neglecting out-of-plane, three-dimensional effects is therefore conservative from a strength strength standpoint. Increased strength of the system due to three-dimensional effects means that the structural wall will be required to absorb higher shear stresses. However, vertical forces on the wall increase strength and rotational capacity above values determined from a planar analysis. The structural walls of all specimens showed ductile flexural behavior during hinge formation and beyond.

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