SHAKiNG TABLE TESTS OF WET JOINTED PRECAST PANEL WALLS

Michael G. Oliva [1]
Bahram M. Shahrooz [2]
Presenting Author: M. G. Oliva

SUMMARY

Experimental results from shaking table tests of large scale precast panel wall systems are presented. One-third size true scale models were tested under simulated earthquake motions. Qualitative and quantitative results are preceded by a brief description of the model configurations, testing, and instrumentation. Examination of model behavior and data indicated that rocking motion of the precast panels provided the major contribution to the overall displacement. Shear-slip motion was effectively constrained by shear keys. The rocking motion isolated the wall from ground motion and limited the amplitude of the base shear which could be transferred into the wall system.

INTRODUCTION

Precast large panel concrete structures are being used extensively throughout the world to meet a growing demand for residential housing. Economic limitations within many countries have required that the demand be met with large scale industrially produced units which can be erected with semi-skilled labor. Many such building systems exist with varied design, mateials, and assembly techniques. The research described in this paper concerns one such system using factory produced precast concrete elements with cast-in-place field joints.

Panelized buildings, as considered in this paper, are composed of vertical panels supporting horizontal floor panels to form a complete box like structure. The vertical panels act as load bearing shear walls and the horizontal panels act as roof and floor systems with diaphragm action. These structures present a unique challenge in terms of behavior and design because of the usage of the vertical panels to resist combined vertical and lateral loading (with a failure in either mode likely to result in collapse) and because of the necessary field joints between panels. The lack of secondary mechanisms to carry loads if wall panels fail is particularly important with

----

1. Assistant Professor, Civil Engineering, University of Wisconsin, Madison, Wisconsin, U.S.A.
2. Research Assistant, University of Wisconsin, Madison, Wisconsin, U.S.A.

their increasing use in regions of seismic risk.

The large panel system, composed of strong precast wall elements with relatively weak and often brittle interconnecting joints, tends to exhibit two prime deformation mechanisms when overloaded. The first mechanism is a result of overturning moments induced by the lateral loading. The joint between vertical panels is generally designed with a minimum of continuous reinforcing between upper and lower panels to simplify field assemblage.

The lack of vertical reinforcing across the joint, and hence tensile capacity, results in flexural cracking at the joint and a rocking of the panel above as exhibited in Figure 1. The second mechanism involves a shearing along the joint, a result of shear force induced by lateral load, and subsequent slip between joined panels as seen in Figure 1. The flexural mechanism is difficult to model using beam analogy because of the wall's deep narrow cross section.

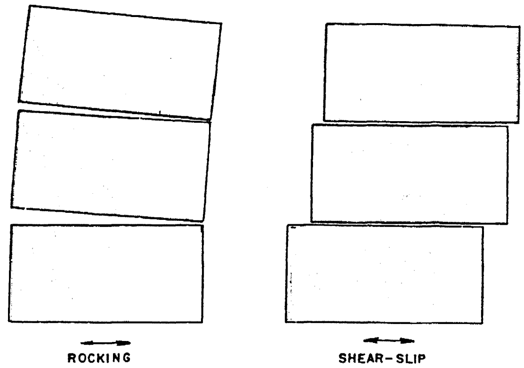

Fig. 1. Wall deformation mechanisms

Shear-slip involves numerous resistance sources including friction, aggregate interlock, dowel action and key strength. The capacity of the mechanisms is difficult to define analytically, requiring experimental verification.

The behavior of the structure with weak joints has been analytically investigated by various studies including Becker [Ref.1], Mueller [Ref.2] and Schricker [Ref.3]. Behavior of individual resisting mechanisms within the wall systems has been experimentally studied at the PCA [Ref.4] and other researchers [Refs. 5, 6, and 7] under statically applied loads either monotonic or cyclic. The present study considered the behavior of a complete wall system, at a reduced scale, under actual dynamic earthquake motion.

MODEL DESCRIPTION

Three large scale models of various precast wall panel configurations were tested under earthquake motions at the University of California Earthquake Simulator Laboratory to establish quantitative data describing the behavior of wall systems in seismic conditions. The one-third scale models were composed of precast components produced by RAD Construction of Belgrade, Yugoslavia with wet joint connections completed at the University of California Laboratory. Each model was a three story wall segment in variations including a plain solid wall, wall panels with door openings, and wall panels with adjoining end flange walls. The specimens were carefully instrumented and tested with earthquake motion of varying amplitude.

The test wall configuration was a derivative of the Balency system developed by RAD, the University of Beograd and IZIIS of Skopje. All connections were of the wet joint type with panels providing forming for the poured joints. Details of the panels and connections are illustrated in Figures 2 and 3. The three story walls were designed and loaded to simulate conditions near the middle of a 15 story structure. Added mass blocks above the specimens created necessary axial stresses and lateral load. Near the central height of medium rise buildings the gravity axial loads are relatively small, decreasing the friction portion of shear resistance, yet the shear and overturning moments may be high enough to crack the section. Vertical continuity is provided by small cast in place columns with continuous reinforcing in vertical joints between wall panels, and from a single bar extending from the top and bottom at each end of the wall panel welded to the similar bar in adjoining panels (Figure 4). The test specimens were true scale models, at one-third scale, made of prototype material. Stresses in the model would be equal to prototype stresses to correctly simulate the inelastic response.

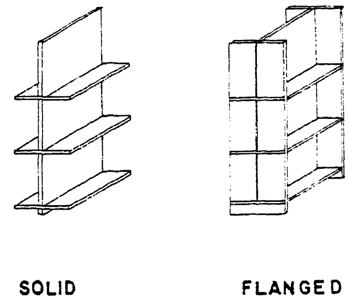

Fig. 2. Precast test walls

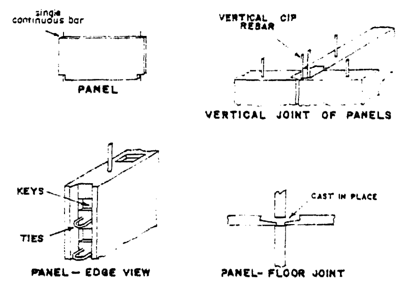

Fig. 3. Joint details

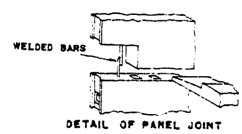

Fig. 4. Detail: cont. panel bar

TEST METHOD

All of the tests took place on the U.C. shaking table. In each model a small amplitude test, during which the model remained essentially elastic, was followed by a high amplitude test and a subsequent medium amplitude test simulating an aftershock.

INSTRUMENTATION

Three categories of test information were recorded using precision instrumentation and a high speed data acquisition system. The instrumentation was designed to monitor: (1) actual table motion, (2) overall global deformation of the models, and (3) local deformations-particularly in joint region. A total of 85 instruments recorded most of the critical quantities occurring during the test. Measured dynamic response included displacements, accelerations, base shear, slip and uplift of panels at horizontal joints, and strain. The instrumentation was particularly designed to provide response information which might be needed to verify proposed analytic response modelling techniques [Refs. 3, 8].

BEHAVIOR OF SOLID WALL

The solid wall model was subjected to three shaking tests. The first test occurred with a maximum ground acceleration of 0.18g, small enough to induce solely elastic response. The second test was intended to create major damage and used a peak ground acceleration of 0.67g. A final test, to simulate aftershock response of a damaged structure had a 0.50g base acceleration. All of the tests used the same shaped time scaled displacement record, each at a different amplitude. The described step from low amplitude to high amplitude motion was necessary to avoid progressive deterioration which might occur under a gradual program of increasing intensity.

Visual Observations:

There was no visible damage apparent after the initial shake. The structure did experience extensive deformation during the second test. Rocking of the wall system above the lower horizontal joint was predominant during the test. Shear-slip behavior couldn't be detected, however later viewing of slow motion films of the test proved that limited slip had been occurring.

Inspection of post test damage, particularly cracking, showed that rocking motion had opened the first floor joint above the cast in place joint concrete. The concentrated compression induced by the rocking had crushed concrete at the wall ends and in the key elements. Two of the vertical reinforcing bars at the south wall end had buckled and the continuous panel bar ruptured. Figure 5 illustrates the damage.

The "aftershock" test showed continued rocking motion.

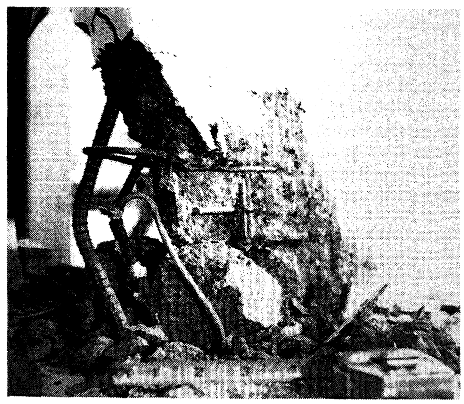

Fig. 5. Damage, south end of wall

There was little additional damage other than concrete spalling in regions that had previously been crushed.

Measured Behavior:

The initial stiffness of the wall system, as determined during the low amplitude test from base force and top displacement, was 96kN/cm.(54k/in.). Measured deformations and strains indicated that the behavior had remained essentially linear elastic.

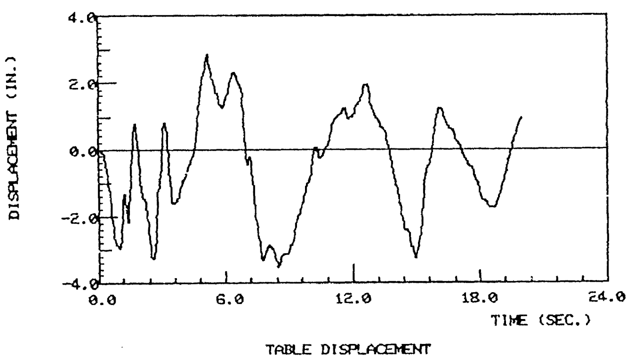

Fig. 6. Displacement history-shaking table

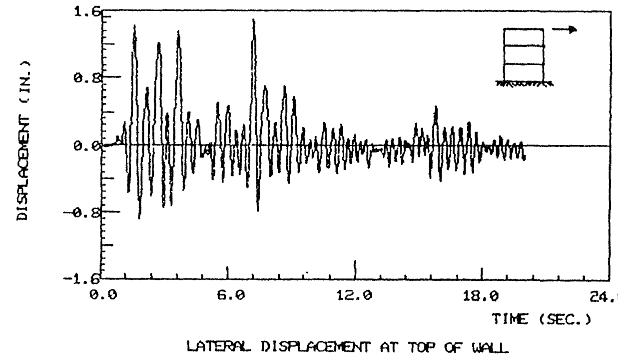

Fig. 7. Wall top displacement history

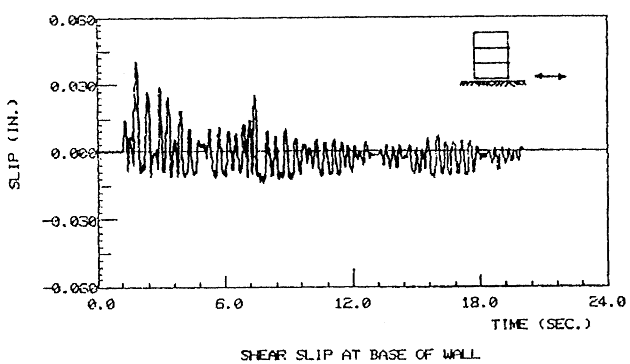

Fig. 8. Slip at bottom of wall

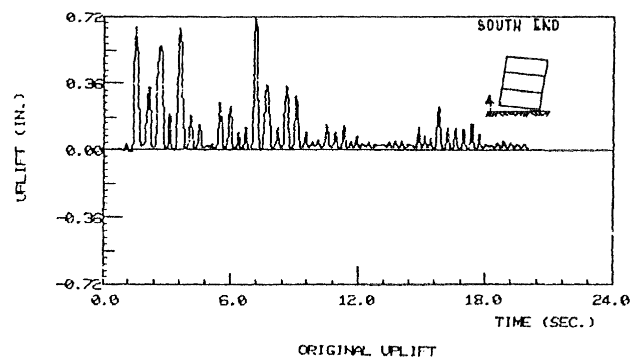

Fig. 9. Uplift at south end of wall

REFERENCES

1. Becker, J.M., Mueller, P., "The Role of Connections in the Aseismic Design of Large Panel Buildings", Research Conference, U.S.-Yugoslav Joint Board of Scientific and Technological Cooperation, Skopje, July 1980.

2. Mueller, P., Becker, J.M., "Seismic Characteristics of Composite Precast Walls', 3rd Canadian Conf. On Earthquake Engineering, Montreal, Canada, June 1979.

3. Schricker, V., Powell, G., "Inelastic Seismic Analysis of Large Panel Buildings", EERC Report 80/38, University of California, Berkeley, California, Sept. 1980.

4. Hanson, N., Portland Cement Association, "Design and Construction of Large-Panel Structures, Supp. C, Seismic Tests of Horizontal Joints", PCA, Skokie, Illinois, Jan. 1979.

5. Verbic, B., "Test of Panel Joints in Vranica Type Large Panel Building", Institute of Materials and Construction, Sarajevo, Yugoslavia, 1977.

6. Cholewicki, A., "Loadbearing Capacity and Deformability of Vertical Joints in Structural Walls of Large Panel Buildings", Building Science, V6, 1971.

7. Wiss, Janney, Elstner and Assoc., "Cyclic and Monotonic Shear Tests on Connections Between Precast Concrete Panels", report for Massachusetts Institute of Technology, Vol. I & II, July 1981.

8. Liorente, C.A., "Inelastic Behavior of Precast Concrete Shear Walls", MIT Report No. 5, Massachusetts Institute of Technology, Cambridge, Massachusetts, August 1981.