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EARTHQUAKE RESISTANCE AND BEHAVIOR OF HEAVY FACADES/CLADDINGS & CONNECTIONS IN MEDIUM-RISE STEEL-FRAMED BUILDINGS

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SUMMARY

This paper presents the results of a research program carried out to investigate the earthquake resistance and behavior of precast concrete facades/claddings & connections in medium-rise steel-framed buildings. Pilot static tests of typical threaded-rod lateral (push-pull) cladding connections have been carried out to investigate the strength and behavior of these connections. Cyclic in-plane racking tests of a precast concrete cladding panel with bearing connections at the bottom and threaded-rod lateral connections at the top, representative of current practice have been carried out. Results provide quantitative data on the in-plane earthquake resistance, and levels of movement and inter-story drift that can be accommodated; including a suggested modified seismic design procedure based on observed behavior and experimental results obtained.

INTRODUCTION

The importance of heavy facades and claddings in the seismic design of buildings is now widely recognized. Exterior facades are not only important architectural components serving as enclosure systems for the building structure, but can also have significant influence on the response and behavior of building structural system during earthquakes (Ref.1, 2). The mitigation of damage of heavy facades and claddings is an issue of high priority because of the life-hazard posed by failure of cladding panels or connections and the resulting significant economic loss, during earthquakes. Facade/cladding considerations are especially critical in buildings with lateral force resisting systems consisting of steel or concrete rigid frames with moment-resisting connections. There are a significant number of buildings that fall in this category located in seismic zones of the United States.

A review of the available data on building facade/cladding performance and damage during previous earthquakes, e.g. Anchorage, Alaska, 1964; San Fernando, California, 1971; Miyagi-ken-oki, Japan, 1978; Mexico City, Mexico, 1985 and Whittier Narrows, California, 1987 clearly shows the urgent need to improve our understanding of the behavior of facades/claddings and connections during earthquakes (Ref.3, 4). It is also necessary to evaluate the provisions of regulatory codes and standards, e.g. UBC, ATC, SEAOC, OSA, NEHRP governing the seismic design of building facades/claddings and connections, through correlation with results of tests carried out to verify conceptual behavior models which are the basis of current seismic design provisions (Ref.3, 4).

OBJECTIVES OF THE TESTING PROGRAM

The testing program was planned and carried out to investigate the in-plane earthquake resistance of precast concrete facades/claddings and connections in medium-rise steel-framed buildings with moment-resisting connections.

Objectives of the research program may be further outlined as follows:

- To investigate the behavior of threaded-rod type lateral connections
- To investigate the behavior of precast concrete facade/cladding and connection assemblies under cyclic displacements of different frequencies.
- To develop more realistic analytical models for seismic design of precast concrete facades/claddings and connections.

REVIEW OF CURRENT DESIGN AND CONSTRUCTION PRACTICES

In general, facades/claddings serve as a means of enclosing a building structure by attachment of panel components, capable of spanning between supporting points, on the exterior face of a building.

<u>Precast concrete facades/claddings and connections</u> In light of the diverse range of facade/cladding components and connections in use in low/medium-rise buildings in seismic zones across the U.S. (Ref.2, 3, 4), it was decided to focus on investigating the seismic behavior and design of precast concrete cladding panels attached to rigid-frame building systems, representative of practices not only in California but other states as well. Precast concrete claddings in buildings may be basically classified into two categories: (i) window-wall panel systems and (ii) spandrel-panel systems. The main focus of this study is to investigate the seismic behavior and design of window-wall panel components and connections in buildings with moment-resisting frame systems.

<u>Connections</u> According to current practice in California and other seismic zones of the U.S. (Ref.2, 3, 4, 5, 6), connections of precast concrete window-wall cladding panels to building structural frames are of the following two types:

<u>Flexible Connections at Top</u> There are two attachment points at top of the cladding panel. These flexible/push-pull connections between the cladding panel and the adjacent structural frame are expected to accommodate all possible movements including inter-story drifts caused by lateral load, e.g. wind and earthquakes; as well as effects of unbalanced gravity loads and differential movements caused by temperature changes, creep and shrinkage.

<u>Bearing Connections at Bottom</u> There are two attachment points at bottom of the cladding panel. These rigid bearing connections provide resistance to gravity and lateral loads, e.g. wind and earthquakes.

In current design practice (Ref.8, 9, 10), it is assumed that the flexible lateral connections at top of the cladding panels provide no in-plane earthquake resistance and serve only to accommodate differential movements between the facade/cladding panels and the building structural frames. Furthermore, it is now widely believed that the unintended stiffness contribution of facades/claddings and connections leads to increased lateral stiffness of the overall building system resulting in higher natural frequencies and corresponding lower fundamental periods (Ref.1, 2, 6).

TESTING PROGRAM

The testing program was planned and carried out to investigate the behavior of precast concrete cladding panels with threaded-rod flexible lateral connections at top and bearing connection at bottom.

Test I Static Tests of Threaded-Rod Lateral Connections The objective of these tests was to study the static load-deflection behavior of 5/8-inch diameter threaded rods of different lengths and support conditions similar to those used in full-size precast concrete cladding panels.

Test Specimen Test I specimens consisted of a mock-up assembly of flexible lateral connection at the top part of a precast concrete cladding panel. The mock-up assembly consisted of a block of concrete 4 inches thick, 11 inches high and 40 inches long. Threaded-rods of different lengths, e.g. 4, 6, 8, 10 and 12 inches were connected to the block of concrete by a typical assembly consisting of a steel plate with a hole at the center and a Ferrule insert welded to the back of the plate in addition to four headed studs.

Test Set-Up and Procedure The overall test set-up is shown in Figure 1. Loading was applied by means of a loading structural Tee with a 2-inch diameter hole, with 1/4-inch thick washers and one nut on each side of the stem of the loading Tee. Loading was applied using a Riehle Universal Testing machine, and threaded-rod deflections were measured using dial gages. Each threaded-rod specimen was subjected to statically applied loading and unloading. A uniaxial tensile test of a 5/8-inch diameter threaded rod was also carried out to investigate the behavior of such a rod in axial tension and establish its fundamental strength and deformation properties.

Test II In-Plane Cyclic Testing of Precast Concrete Facade/Cladding Panel and Connections The objective of Test II was to investigate the in-plane resistance and behavior of full-size precast concrete cladding panels and connections under cyclic displacements of increasing amplitudes and different frequencies.

Test Specimen Test II specimen consisted of a solid precast concrete cladding panel 8′ wide x 10′ high x 4-1/2" thick, with two threaded-rod lateral connections at top of panel and two bearing connections at the bottom. The bearing connection consists of a steel angle assembly with four 5/8-inch diameter studs welded to back of the angle, and embedded in the cladding panel. Two threaded-rod lengths of 6 and 8 inches were used for Test II.

Test Set-Up and Cyclic Testing Procedure The overall test set-up for Test II is shown in Fig. 2 and Photo 1. The cyclic displacements were applied to the precast cladding specimen through a loading assembly attached to the threaded-rods of the lateral connections as shown in Fig. 2 and Photo 1. The test sequence consisted of block cyclic tests. During each test run frequency was fixed at 0.1 Hz or 0.5 Hz and the test specimen was subjected to five cycles of loading for each peak command displacement starting with 1/4, 3/8, 1/2, 3/4, 1, 1-1/2, 1-3/4, 2, 2-1/2 inches. Complete data showing all details of cyclic testing, measurement transducers, calibration of measuring instruments, recording devices and data acquisition system are presented in a previous report (Ref.4).

TEST RESULTS

Test I A summary of results of static tests of threaded-rod lateral connections is presented in Table I. Typical load-deflection curves for all threaded-rods

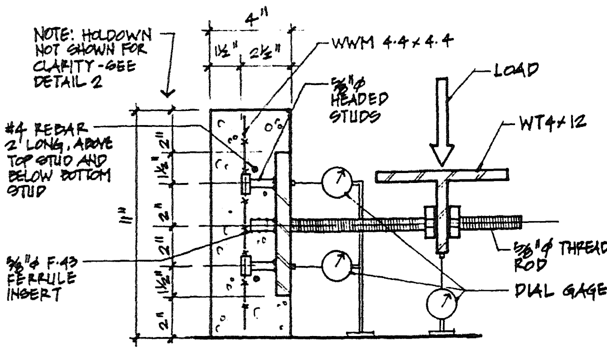

Fig.1 Test I Test Set-Up

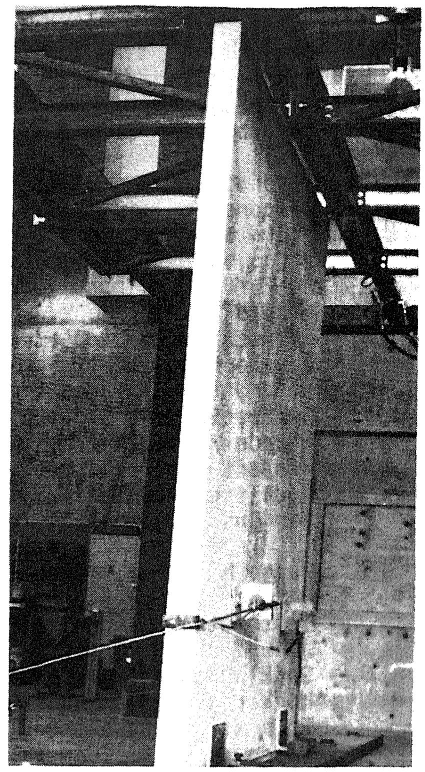

Photo 1 Test II Overall View of Precast Cladding Panel & Test Set-up

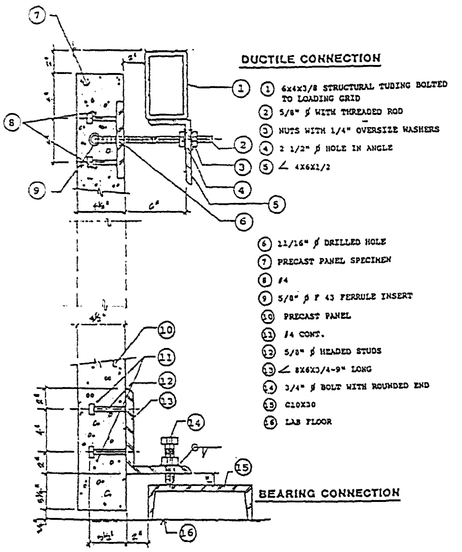

Fig.2 Test II Cladding Specimen Connection Details

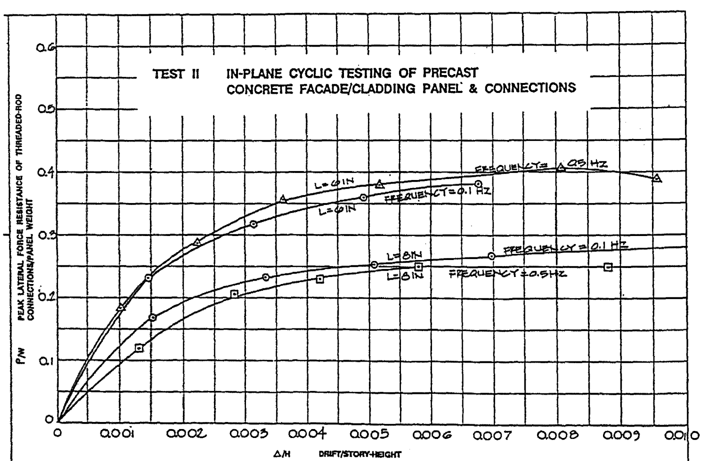

Fig.3 Peak Lateral Force Resistance of Threaded-Rod Lateral Connections vs. Drift