NSF/ENG-88028

ARCHITECTURAL ENGINEERING DEPARTMENT
SCHOOL OF ARCHITECTURE AND ENVIRONMENTAL DESIGN

CALIFORNIA POLYTECHNIC STATE UNIVERSITY
SAN LUIS OBISPO, CALIFORNIA 93407

REPORT ARCE R88-1

SEISMIC BEHAVIOR AND DESIGN OF PRECAST FACADES/CLADDINGS & CONNECTIONS IN LOW/MEDIUM-RISE BUILDINGS

FINAL TECHNICAL REPORT

BY
DR. SATWANT S. RIHAL
PROFESSOR, ARCHITECTURAL ENGINEERING DEPARTMENT

NOVEMBER 1988

SPONSORED BY
THE NATIONAL SCIENCE FOUNDATION
DIVISION OF CIVIL AND ENVIRONMENTAL ENGINEERING
EARTHQUAKE HAZARD MITIGATION PROGRAM

GRANT NO. CEE-8410543

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. NSF/ENG-88028	2.	3. Recipient's Accession No. PB89 160709/AS

4. Title and Subtitle
Seismic Behavior and Design of Precast Facades/Claddings and Connections in Low/Medium-Rise Buildings, Final Technical Report

5. Report Date
November 1988

6.

7. Author(s)
S.S. Rihal

8. Performing Organization Rept. No.
ARCE R88-1

9. Performing Organization Name and Address
California Polytechnic State University
Architectural Engineering Department
San Luis Obispo, CA 93407

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G) CEE8410543

12. Sponsoring Organization Name and Address
Directorate for Engineering (ENG)
National Science Foundation
1800 G Street, N.W.
Washington, DC 20550

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

Seismic behavior and design of heavy facades/claddings and connections in buildings has been investigated, and unique cyclic racking tests of representative precast concrete facade/cladding panels and connections have been carried out. Test results consist of cyclic load-displacement curves; time-history plots of loads, displacements, accelerations, etc., during each test; analysis of peak response quantities, e.g., displacements and load-levels reached; estimated rigidities of the cladding panel-connection assembly at increasing levels of peak displacements of block cycles; as well as the relationship between drift levels and behavior of cladding panel-connection assemblies. Dynamic testing of a representative reduced scale three dimensional model two story steel-framed building structure with and without precast concrete cladding panels, was carried out. Results provide quantitative experimental data on the earthquake resistance and stiffness of cladding connections and the overall seismic behavior of cladding connection assemblies.

17. Document Analysis a. Descriptors

Earthquakes
Joints (junctions)
Architectural concrete
Earthquake resistant structures
Buildings
Facings
Design
Concrete construction
Structural engineering
Structural design

b. Identifiers/Open-Ended Terms

Seismic behavior
Earthquake engineering

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
NTIS		172
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

SUMMARY

Seismic behavior and design of heavy facades/claddings and connections in buildings has been investigated, and unique cyclic racking tests of representative precast concrete facade/cladding panels and connections have been carried out. During the first major phase of the research project current practices for design and detailing of heavy facade/claddings and their connections to supporting structural systems, were evaluated. In consultation with practicing architects, engineers, researchers and facade/cladding manufacturers, state-of-the-art data for facade/cladding design, detailing and erection practices was compiled. Available data on the performance of building facade/cladding during previous destructive earthquakes including the recent Mexico City Earthquake of September 1985 was evaluated. Analytical and experimental techniques of modeling the seismic behavior of heavy precast concrete facade/cladding panels and connections have been investigated. The role of modern testing methodology in assessing the seismic behavior of building facades/claddings and connections has been evaluated. Pilot static tests of typical ductile (push-pull) cladding connections were carried out to investigate the strength and behavior of these connections. Cyclic in-plane racking test of a full-size precast concrete cladding panel with bearing connections at the bottom and ductile (push-pull) connections at the top, representative of California current practices, has been carried out. Test results consist of cyclic load-displacement curves; time-history plots of loads, displacements, accelerations, etc., during each test; analysis of peak response quantities, e.g., displacements and load-levels reached; estimated rigidities of the cladding panel-connection assembly at increasing levels of peak displacements of block cycles; as well as the relationship between drift levels and behavior of cladding panel-connection assemblies. Dynamic testing of a representative reduced scale three dimensional model two story steel-framed building structure with and without precast concrete cladding panels, was carried out. Results provide quantitative experimental data on the earthquake resistance and stiffness of cladding connections and the overall seismic behavior of cladding connection assemblies. The test results obtained will help develop improved and more realistic analytical modeling of building structural systems interacting with heavy facades/cladding and connection systems in low/medium-rise buildings during earthquakes.

ACKNOWLEDGEMENTS

This research work was supported by the National Science Foundation under Grant No. CEE-8410543, Dr. A.J. Eggenberger, Program Manager. This support is gratefully acknowledged. Any opinions, findings and conclusions or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Dr. Satwant Rihal, Professor, Architectural Engineering Department, served as the principal investigator and project director for this research project.

Author acknowledges the assistance and contribution of Dr. Gary Granneman of the ET/EL Department, Cal Poly State University, San Luis Obispo, California, for testing and instrumentation; student research assistants Kurt Clandening, Dwayne Slavin and John Cotton during the course of this research investigation. The contribution of Mr. John Cotton, in the analytical evaluation of test results is acknowledged.

The assistance of Mr. Ed Knowles, Vice-president, Lafayette Manufacturing Inc., Hayward, California, for providing precast concrete cladding panel specimens for this research project is acknowledged and sincerely appreciated.

TABLE OF CONTENTS

LIST OF FIGURES AND PHOTOGRAPHS

APPENDIX A - TEST I
LIST OF FIGURES AND PHOTOGRAPHS

APPENDIX B - TEST II
LIST OF FIGURES AND PHOTOGRAPHS

APPENDIX C - TEST III
LIST OF FIGURES AND PHOTOGRAPHS

DRAWINGS OF TEST FRAME STRUCTURE

LIST OF TABLES

LIST OF TABLES - APPENDIX B

CHAPTER 1: INTRODUCTION

This report documents results of a research program carried out to investigate the behavior of heavy facades/claddings and connections in buildings during earthquakes.

The widespread use of heavy facades and claddings in a broad class of buildings in seismic zones, and the potential life-hazards and significant economic losses posed by damage and/or collapse of such heavy exterior finish systems warrants a systematic and thorough examination of the behavior of heavy facades and claddings during earthquakes.

The overall nature and scope of the problem is further evidenced by available observed damage data on the behavior of exterior facade/cladding enclosure systems in buildings 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.

A study of the limited available observed damage data clearly shows that mitigation of earthquake damage of building facades/claddings is a very important issue because of the potential hazard to public and significant economic losses posed by such non-structural damage in buildings during earthquakes.

The importance of mitigation of earthquake damage of exterior architectural components, e.g., facades/claddings in buildings was also highlighted at the EERI/NSF workshop (40) on non-structural issues, to attempt to define practical research needs and further research work.

Furthermore, heavy facades and cladding can have significant influence on the overall lateral stiffness of buildings and thus alter the fundamental dynamic properties, e.g., natural frequencies, and also damping, and hence the response and behavior of the overall building system during earthquakes.

It is only recently that efforts have been directed to developing a better understanding of behavior of claddings and connections during earthquakes.

The general lack of an adequate base of test data on the static and cyclic behavior of building facades/claddings and connections, necessitates that testing be carried out to provide quantitative results on the strength and cyclic behavior of typical building facades/claddings and connections, including threshholds of damage, as well as their fundamental characteristics, e.g., natural frequencies, damping, etc.

It is also necessary to document and evaluate the effectiveness of the applicable design provisions of the regulatory standards, e.g., Uniform Building Code (86), ATC 3-06 (7), SEAOC (133), State of California (101), Tri-Services Manual (139) and the recently developed NEHRP Guidelines (28), through correlation with test results and available field data.

---

[1] Numbers in parenthesis refer to Bibliography on page 71.

CHAPTER 2: BUILDING FACADES/CLADDINGS

2.1 BACKGROUND

In general, facades/claddings are regarded as a means of enclosing a building structure by attachment of enclosure material assemblies, capable of spanning between supporting points, on the exterior face of a building. The sizes of the cladding components are based in most part on their ability to resist lateral loads (e.g., wind and earthquakes) acting on the building, and then transfer those loads safely to the building.

The function of building facades/claddings may be described as follows, to provide:

a. Building envelope that protects the interior of the building from all climatic conditions and maintain a comfortable thermal environment.

b. Acoustic insulation that protects the occupants from noise pollution.

c. Fire resistance.

d. Solar protection and possibly reduce the energy demand of HVAC systems.

e. Enhancement to building's external appearance.

Photographs (Figures 1-9) show the many different facade/cladding types, their configurations, materials and exterior finishes in use in low- and medium-rise buildings on the West Coast.

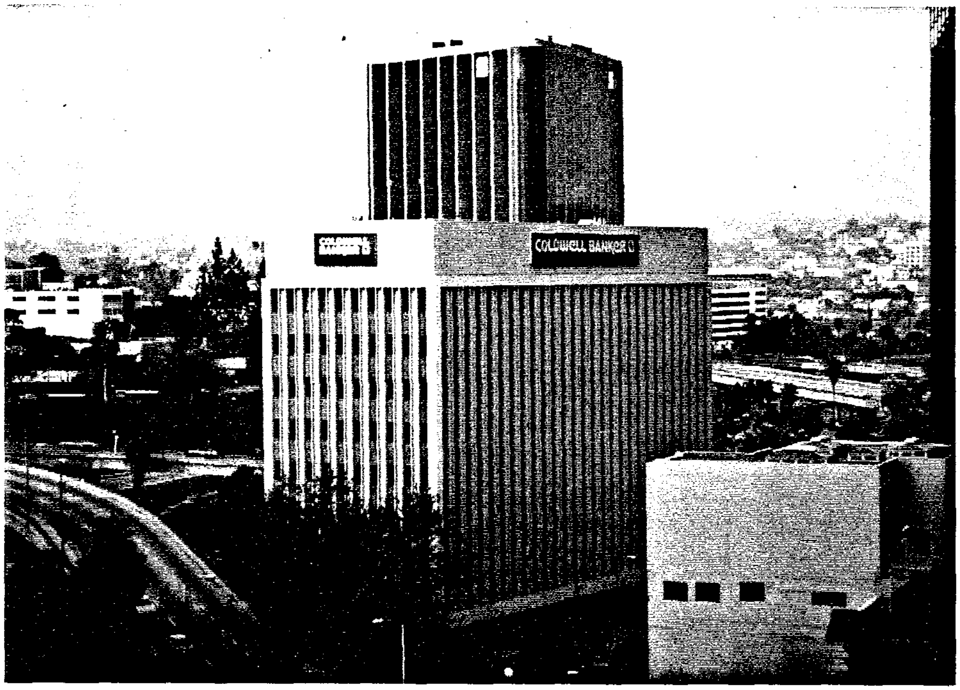


Figure 1 Precast Cladding - Medium-Rise Building
Los Angeles, California

Figure 2 Precast Cladding - Medium-Rise Building
Los Angeles, California

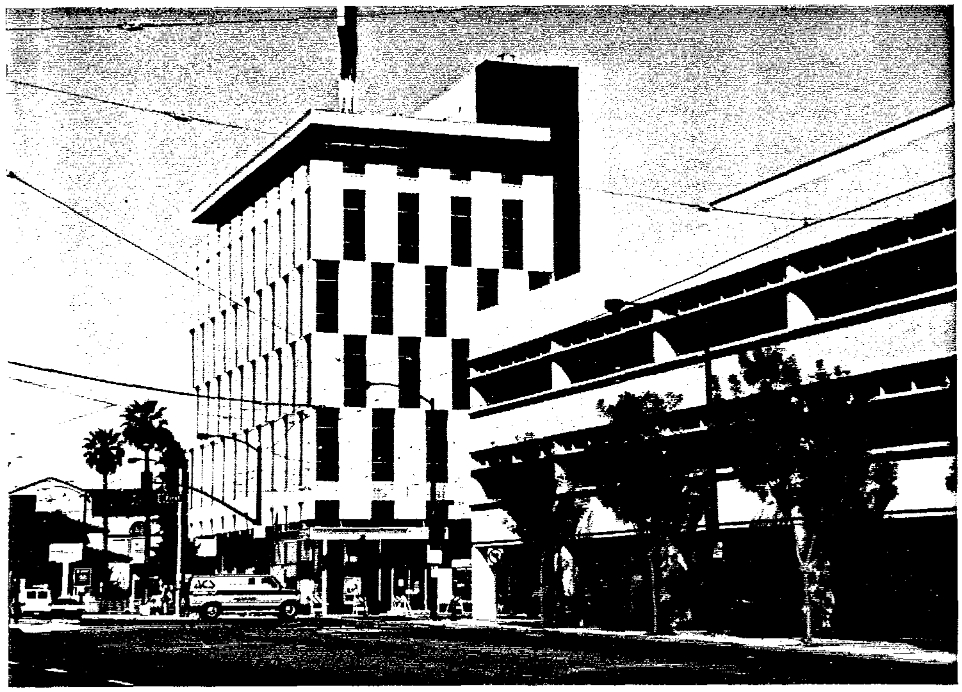


Figure 3 Precast Cladding - Checker-Board Pattern
Medium-Rise Building - San Jose, California

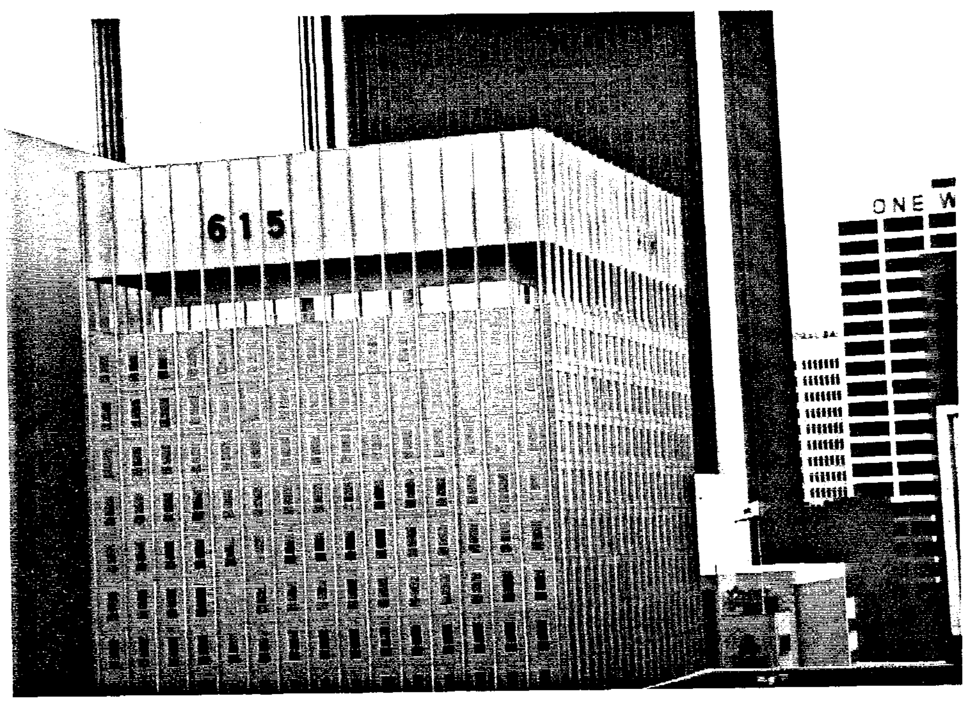


Figure 4 Curtain-Wall Facade - High-Rise Buildings
Downtown, Los Angeles, California

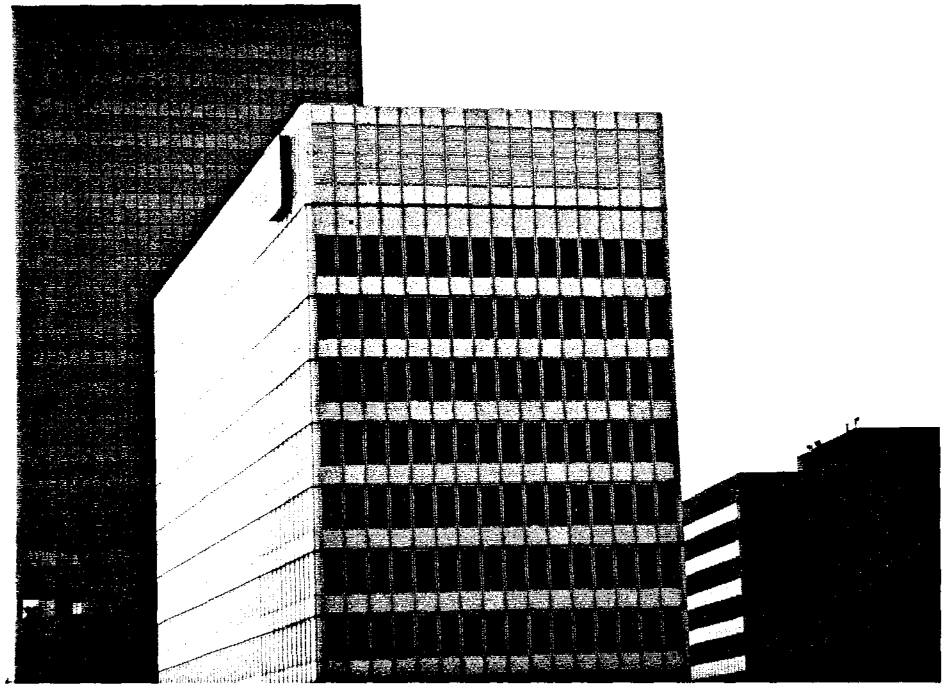


Figure 5 Facade/Cladding Elevation - Medium-Rise Building
Downtown, Los Angeles, California

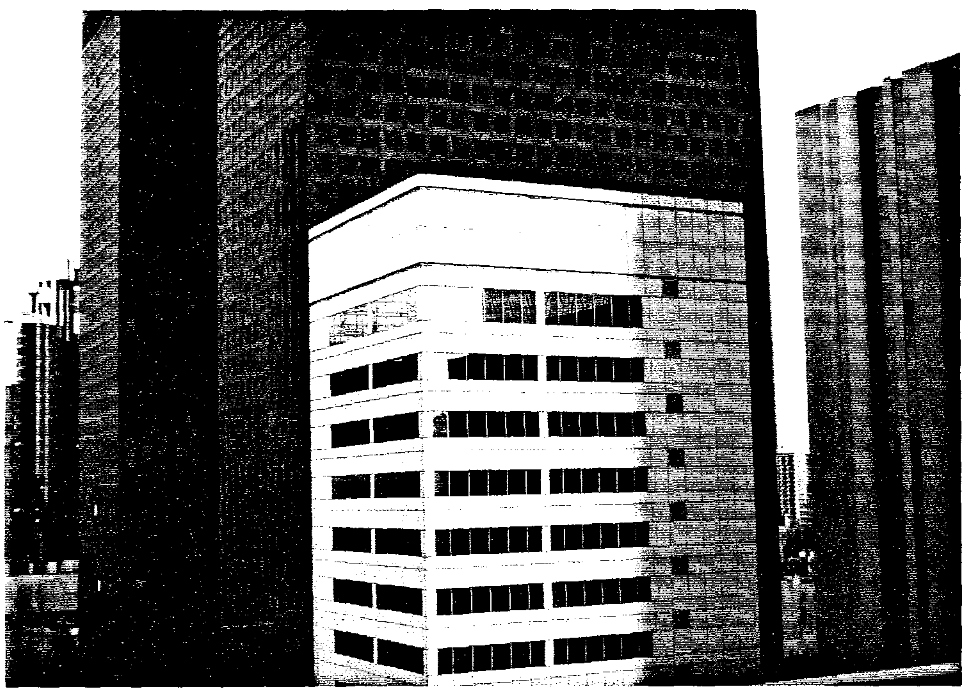


Figure 6 Spandrel Cladding/Facades - Medium-Rise Building
Downtown, Los Angeles, California

Figure 7 Precast Cladding (Window-Wall Units) - Medium-Rise Building Downtown, Los Angeles, California

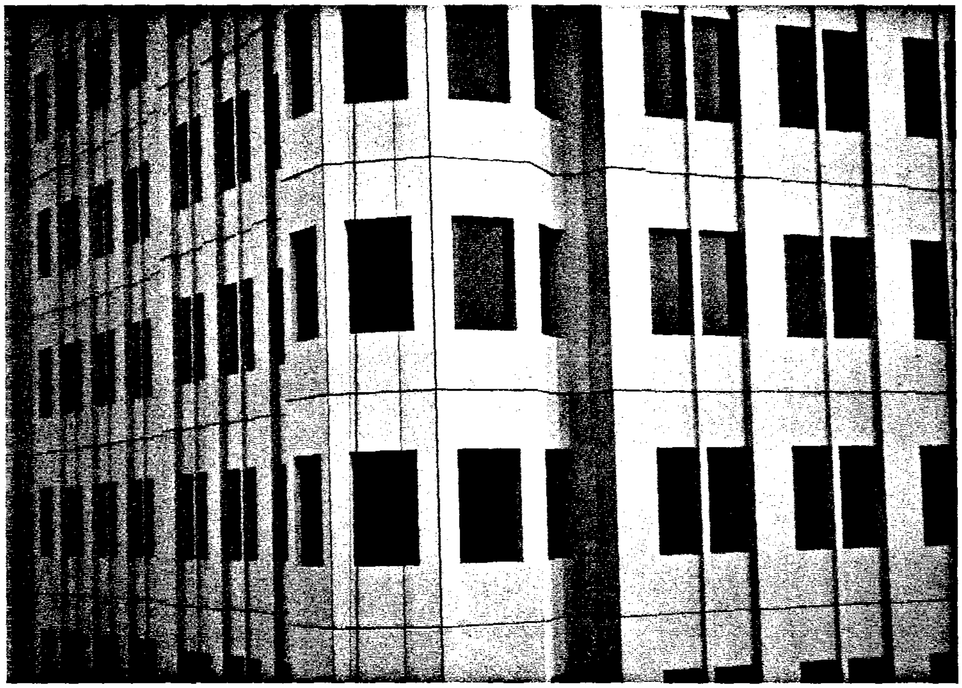


Figure 8 Close-up Detail - Precast Cladding (Window-Wall Units) - Medium-Rise Building, Downtown, Los Angeles, California

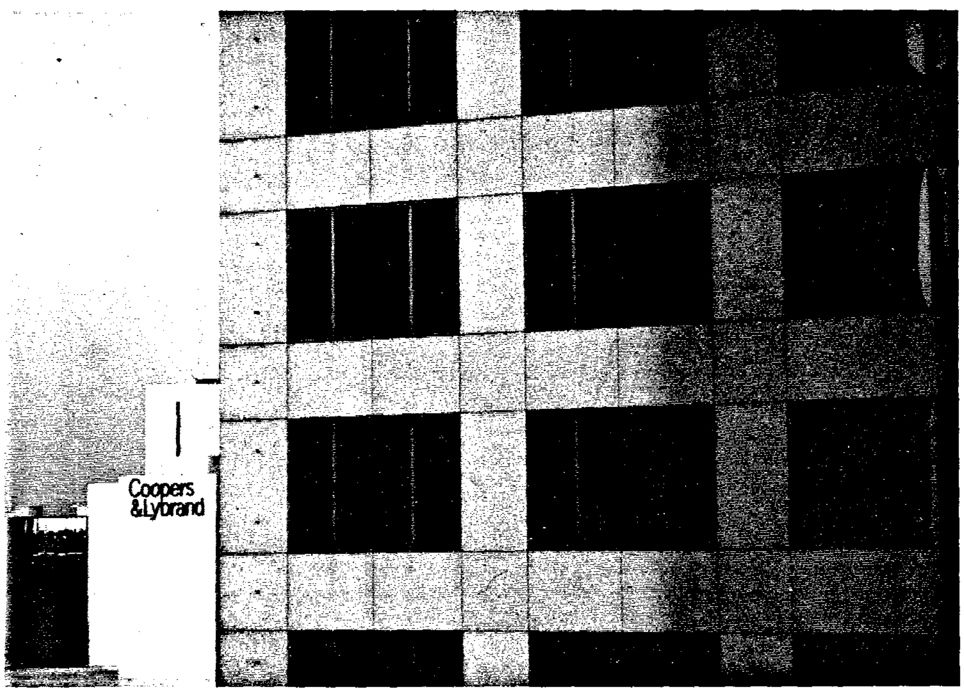


Figure 9 Precast Cadding - Spandrel - Panels & Column-Cover-Panels, Medium-Rise Building, Downtown, Los Angeles, California

2.2 CLASSIFICATION OF BUILDING FACADE/CLADDING SYSTEMS

For this research report, facades and claddings fastened to moment-resisting frame building systems may be classified as follows:

FACADE/CLADDING TYPE	CONFIGURATION	
	WINDOW-WALL PANELS	SPANDREL PANELS
I. Precast Concrete Cladding	■	■
II. Glass Fiber Reinforced Cement (GFRC) Cladding	■	■
III. Masonry Veneer Facades on Framed-Backing	■	■
IV. Stone/Granite/Marble Facades on Framed-Backing	■	■

The above list is not intended to be complete and only represents a partial summary of representative facade and cladding types that should be considered.

2.3 DESIGN ISSUES

Development of facade/cladding systems in buildings in seismic zones requires the consideration of the following design issues:

- **Facade/Cladding Component Issues**

  Under this category the following should be considered:

  (i) Materials

  From the point of view of earthquake resistance of facades/claddings, the following material issues should be considered in addition to the general considerations of appearance, durability and weather-staining:

  - Mass Properties

  - Strength and Deformation Properties

  (ii) Geometry and Configuration

  Important issues under this category are:

  - Shape and Proportions of precast facade/cladding components, e.g., solid shapes, open vs. closed shapes and their combination thereof to provide desired facade/cladding elevations.

  - Size of precast facade/cladding components, e.g., length, width, thickness, etc.

- **Connections - Design Issues**

  Important connection design issues are:

  - Types of connections with respect to number, types and methods of load transfer or accommodation of movement/deformation.

  - Location of connections.

  - Connections between precast facade/cladding components and supporting structural system.

  - Connections between precast facade/cladding components.

- **Supporting Structural System - Design Issues**

  The important issues under this category may be summarized as follows:

  Gravity Loads - Supporting structural system must safely carry the weights of the precast facade/cladding components in addition to usual dead and live loads, through the connections between the precast facade/cladding components and the supporting structure.

Lateral Loads (Wind, Earthquakes) - Supporting structural system must safely resist the effects of lateral loads, e.g., wind and earthquake loading, transmitted through the connections between the facade/cladding components and the supporting structure.

The interrelationship of the above design issues is graphically illustrated in Figure 10.

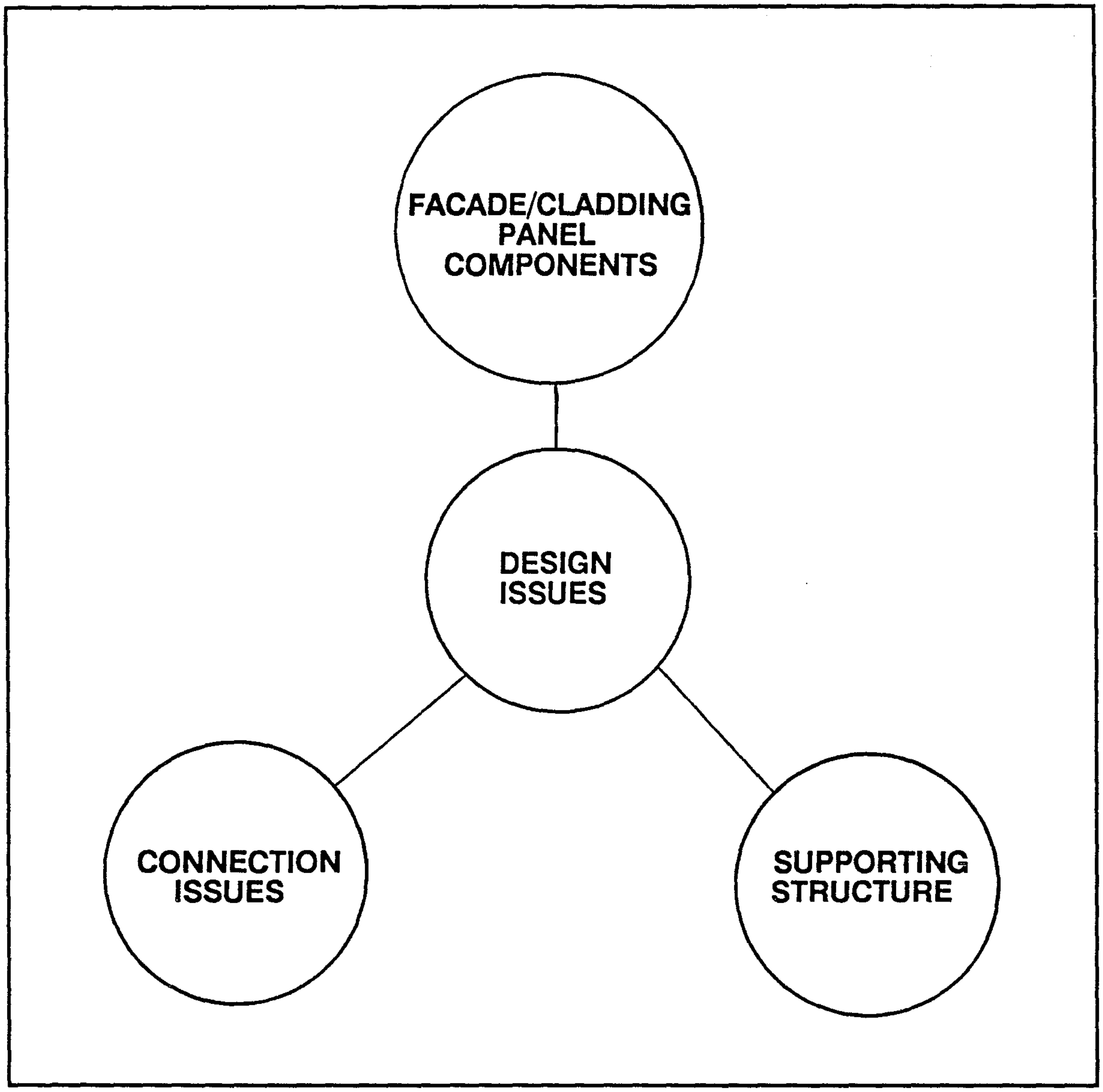


Figure 10: Facade/Cladding Design Issues and Inter-relationships

CHAPTER 3: SCOPE AND OBJECTIVES

The main focus of this research program is to analytically and experimentally investigate the seismic behavior and design of heavy facades/claddings and their connections in low/medium-rise buildings.

The general objective of this research program is to document and evaluate applicable current provisions of the Uniform Building Code (86) and other regulatory standards, e.g., State of California Title 21 and Title 24 (101), ATC 3-06 (7), SEAOC (131), Tri-Services Manual (139), NEHRP Guidelines (28), and current practices governing the design, detailing and installation of heavy facades/claddings and their connections in low and medium-rise buildings with different framing systems.

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., it was decided to focus on investigating the seismic behavior and design of the following exterior finish systems representative of practices in California and other western states.

I. Precast Concrete Cladding Panels Attached to Moment-Resisting Rigid Frame Building Systems

II. Brick Veneer/Granite/Marble Facades on Framed Backing Attached to Moment-Resisting Rigid Frame Building Systems

It should be noted that a significant percentage of exterior building facades/claddings in California, are of the types outlined above.

Upon further consideration it was further decided to focus attention only on the study of Precast Concrete Cladding Panels and their attachments to steel-framed building systems, at this time.

CHAPTER 4: LITERATURE REVIEW

A comprehensive survey of pertinent literature was conducted. The results of this survey are presented in the form of an extensive bibliography (p.71) which provides an exhaustive source of information on a broad range of issues governing behavior, analysis and design of heavy facades/claddings and connections in buildings in seismic zones.

McCue, et al. (93) reported the results of an 'Enclosure Wall - Case Study' as an application of the conceptualized behavior models developed to investigate interaction of building components during earthquakes.

Sack, et al. (118) reported the first detailed investigation of the seismic response of precast curtain-walls in high-rise buildings. This research involved both analytical modeling of precast curtain-wall panels and their connections; as well as testing of curtain-walls and their connections.

Goodno, et al. (66), (67), (68), (69), (102), reported results of investigations of seismic response of glass curtain-walls as well as precast concrete cladding; cladding-structure interaction, analytical modeling for investigating the stiffening effects of cladding on the seismic response of buildings, as well as testing of cladding connections to investigate their behavior.

Wang (147), (148) reported the results of large-scale testing of precast cladding attached to a Full-Scale Steel Test Frame carried out under a U.S.-Japan Cooperative Research Project.

CHAPTER 5: FACADE/CLADDING PERFORMANCE DURING PREVIOUS EARTHQUAKES

In the initial phases of this research project, sincere efforts were made to systematically document the available data on observed performance of non-structural facades/claddings in buildings during previous earthquakes.

The first attempt to systematically document non-structural damage during earthquakes was reported by Ayres, et al. (12) for documenting the non-structural building damage caused by the Anchorage, Alaska, earthquake of 1964. Even though this was an excellent start, no consistent coordinated efforts have since been made to document non-structural building damage in general and facade/cladding damage in particular, during earthquakes since then.

Selected highlights of building facade/cladding performance and damage during the previous earthquakes are presented below as follows:

Table I : Anchorage, Alaska, Earthquake of 1964
Table II : San Fernando, California, Earthquake of 1971
Table III: Miyagi-Ken-Oki, Japan, Earthquake of 1978
Table IV : Mexico City, Mexico, Earthquake of 1985

TABLE IB: FACADE/CLADDING PERFORMANCE DURING THE ANCHORAGE, ALASKA, EARTHQUAKE OF 1964

BUILDING NAME	NO. OF STORIES	MATERIAL LATERAL FORCE RESISTING SYSTEM	FACADE TYPE AND CONNECTION DETAILS	FACADE/CLADDING DAMAGE	SOURCE
J.C. Penney Building	5	Reinforced Concrete Building 129'x149' in plan, six bays wide in each direction. Floors were ten inch thick reinforced concrete flat plates. Full-height reinforced concrete shear walls @ west and south sides.	Heavy Facades Precast Concrete Panels North and east walls were covered with four inch thick precast non-structural concrete panels extending from second floor to roof. Precast concrete panels were fastened at each floor by two brackets on each panel.	This building suffered catastrophic structural damage as well as non-structural facade damage due to severe torsional displacements caused by the center of rigidity being far removed from the center of mass. The heavy precast concrete facades on the north and east walls contributed to the development of torsional forces and as the structural system failed and became more flexible, the stiffness of the precast facade panels themselves contributed to the failures of the supporting bracket connections. Most of the four inch thick precast panels in the north wall were shaken loose and fell to the street below. Many of the supporting brackets were torn out of floor slabs and were still found to be attached to the backs of facade panels that fell to the street below. Two people were killed when the heavy facade panels fell onto parked cars. Figures 11, 12	Ref.[12]

TABLE IA: FACADE/CLADDING PERFORMANCE DURING THE ANCHORAGE, ALASKA, EARTHQUAKE OF 1964

BUILDING NAME	NO. OF STORIES	MATERIAL LATERAL FORCE RESISTING SYSTEM	FACADE TYPE AND CONNECTION DETAILS	FACADE/CLADDING PERFORMANCE AND DAMAGE	SOURCE
First Federal Savings Building	3	Steel-Framed Office Building 50'x130' in plan. Floors are 3-1/2 inch concrete slabs supported by steel beams. Lateral force resistance in the N-S direction (long direction) supposed to be provided by a reinforced block wall in the west face and two brick panels in the east face. Lateral force resistance in the east-west direction (narrow direction) provided by a reinforced block wall at the north end and a brick panel and an x-braced steel bent in the south face.	Variety of exterior wall materials. Glass-Spandrel curtain walls - East, South & portion of West facades. Brick filler panels with steel x-braced frame backing Ref.[12] presents exact details of the curtain wall and its connection to the steel frame.	The curtain walls suffered only minor damage during this earthquake because of compatibility between the flexible curtain wall and the flexible steel frame of the building. One brick panel on the east facade collapsed and the other brick panels on the east and south sides were severely damaged. Rigid non-structural facade were not compatible with the flexible structural frame and therefore the rigid facade suffered extensive damage. The panel on the south facade could not cope with the movements of the steel frame, and was severely damaged. Figures 13, 14	Ref.[12]

SUMMARY OF BUILDING FACADE DAMAGE - ANCHORAGE, ALASKA EARTHQUAKE OF 1964 [Source Ref. 12]

"1. Heavy precast-concrete panels that were attached to the building frame by clip angles and inserts collapsed.

2. Concrete-masonry-units filler walls were badly cracked and in some instances they damaged the surrounding structural frame.

3. Brick veneers, attached to flexible steel frames without backing or with insufficient backing, cracked and in some instances collapsed. Some stone and brick veneers collapsed where they were imporperly tied to concrete walls

4. Curtain Walls sustained very little damage, except in the vicinity of structural failures. Some mounting brackets broke or pulled loose their concrete inserts at the floor slabs.

5. Glass-block panels were practically undamaged.

6. Window-glass was damaged where adjacent structural elements failed or sustained excessive deflections. Where mounts were rigid and mullions were weak, large panels of glass in storefronts were broken. Some glass panels in curtain walls were damaged when flexible mountings worked loose."

TABLE II FACADE/CLADDING PERFORMANCE DURING THE SAN FERNANDO, CALIFORNIA EARTHQUAKE OF 1971 [REF. 139]

BUILDING NAME	NO. OF STORIES	MATERIAL LATERAL FORCE RESISTING SYSTEM	FACADE TYPE AND CONNECTION DETAILS	FACADE/CLADDING PERFORMANCE AND DAMAGE	SOURCE
Olive View Hospital Medical Treatment and Care Unit	5	Reinforced Concrete Basic Framing scheme is a two-way flat slab reinforced concrete system supported either on tied or spiral columns. The lateral force resisting system consists of a system of shear walls above the second floor and moment resisting frames in the lower two stories.	Precast Concrete Facia Elements Masonry veneered wall	Many precast concrete facia elements were dislodged. Masonry veneered walls fell away from the building due to earthquake movements. Connections anchoring the concrete failed. Figure 15	Ref. [140]

TABLE III FACADE/CLADDING PERFORMANCE DURING THE MIYAGI-KEN-OKI, JAPAN, EARTHQUAKE OF 1978 [REF. 39]

BUILDING NAME	NO. OF STORIES	MATERIAL LATERAL FORCE RESISTING SYSTEM	FACADE TYPE AND CONNECTION DETAILS	FACADE/CLADDING PERFORMANCE AND DAMAGE	SOURCE
Sasaki Building Izumi City, Japan	4	Steel Framed Building	Precast Concrete Curtain Walls	Catastrophic collapse of precast concrete curtain walls. The precast concrete cladding panels broke loose from the building exterior and fell crashing to the ground below onto parked cars. Figure 16	Ref. [39]

TABLE IV FACADE/CLADDING PERFORMANCE DURING THE MEXICO CITY, MEXICO EARTHQUAKE OF 1985 *

FACADE/CLADDING TYPE AND CONNECTIONS	BUILDING TYPE / NO. OF STORIES	MATERIAL AND STRUCTURAL SYSTEM	FACADE/CLADDING PERFORMANCE AND DAMAGE	SOURCE
Precast Concrete Cladding Panels in Pino Suarez Building	Medium-Rise Building 14-21 stories	Steel Framed Building with moment-resisting frames and braced frame system	Heavy Precast Concrete Cladding attached to this medium-rise steel framed building were subjected to large drift incursions during this earthquake. These large drift levels were responsible for damage of the precast panels which consisted of relative shifting of panels by 3-4 inches. Figures 17, 18.	
Light Metal-Glass Curtain Walls	Medium-Rise Buildings 6-16 stories	Moment-Resisting Concrete Framed Systems Moment-Resisting Steel Framed	Metal-Glass Curtain Walls in medium-rise buildings suffered moderate levels of damage due to very large distortions (drifts) induced by this earthquake.	Ref.[41] [42]
Masonry Infill Facades	Medium-Rise Buildings 6-16 stories	Reinforced Concrete Buildings with moment-resisting frames	Masonry Infill facades in medium-rise buildings with reinforced concrete moment-resisting frames, suffered extensive damage during this earthquake. Masonry Infill facades also provided initial lateral force resistance and may have contributed to the survival of many medium-rise buildings during this earthquake. Figures 19-20.	

* This brief summary of facade/cladding performance during the Mexico City Earthquake of 1985 is based on observed damage data available to-date.

Figure 11 Collapsed Precast Concrete Facade Panels
J. C. Penney Building
Anchorage, Alaska Earthquake of 1964 (Ref.12)

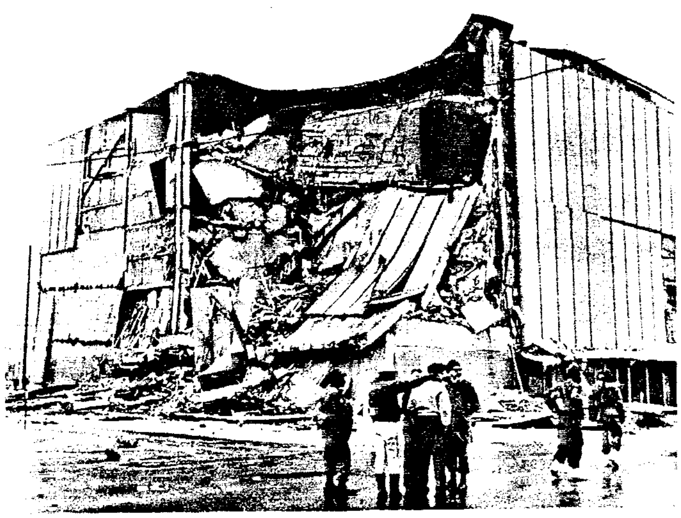


Figure 12 Collapsed Precast Concrete Facade Panels
J. C. Penney Building
Anchorage, Alaska Earthquake of 1964 (Ref.12)

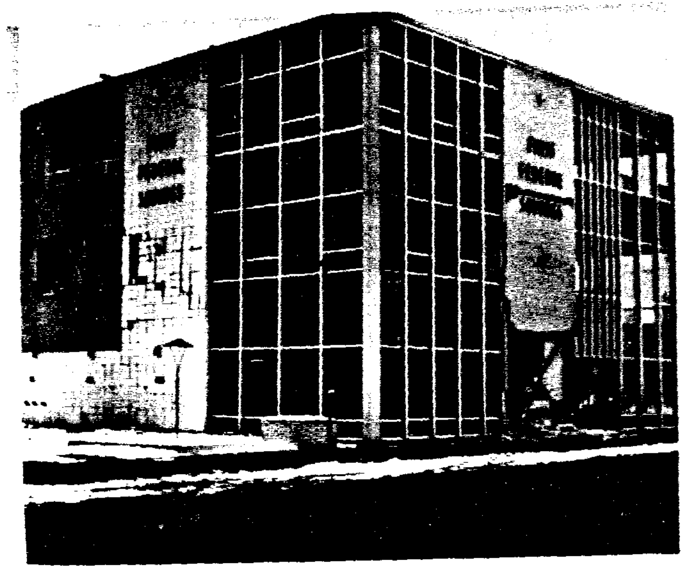


Figure 13 Facade Damage
First Federal Savings and Loan Building
Anchorage, Alaska Earthquake of 1964 (Ref.12)

Figure 14 Facade Damage
First Federal Savings and Loan Building
Anchorage, Alaska Earthquake of 1964 (Ref.12)

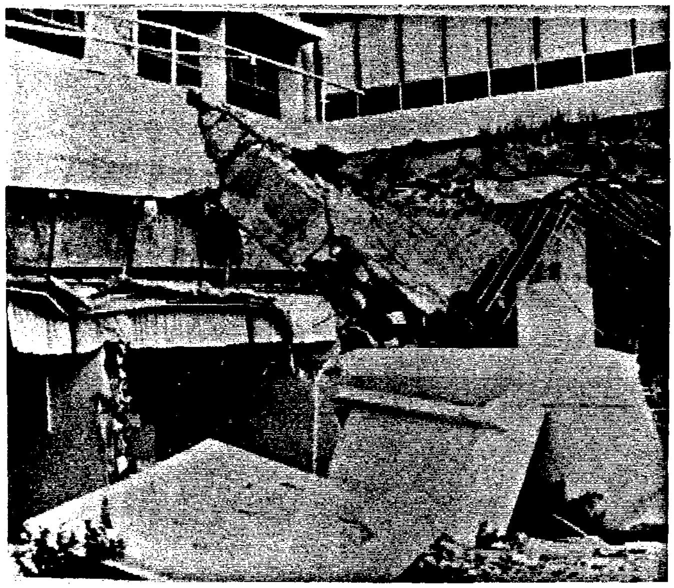


Figure 15 Failure of Precast Concrete Wall Panels
San Fernando, California Earthquake; 1971
(Ref.139)

Figure 16 Collapse of Precast Concrete Curtain Walls
Miyagi-Ken-Oki, Japan Earthquake, 1978 (Ref.39)

Figure 17 Pino-Suarez Building, Mexico City
Damaged Precast Concrete Cladding Already
Removed, Mexico City, Mexico Earthquake of 1985

Figure 18 Pino-Suarez Building, Mexico City
Damaged Precast Concrete Cladding Already
Removed, Mexico City, Mexico Earthquake of 1985

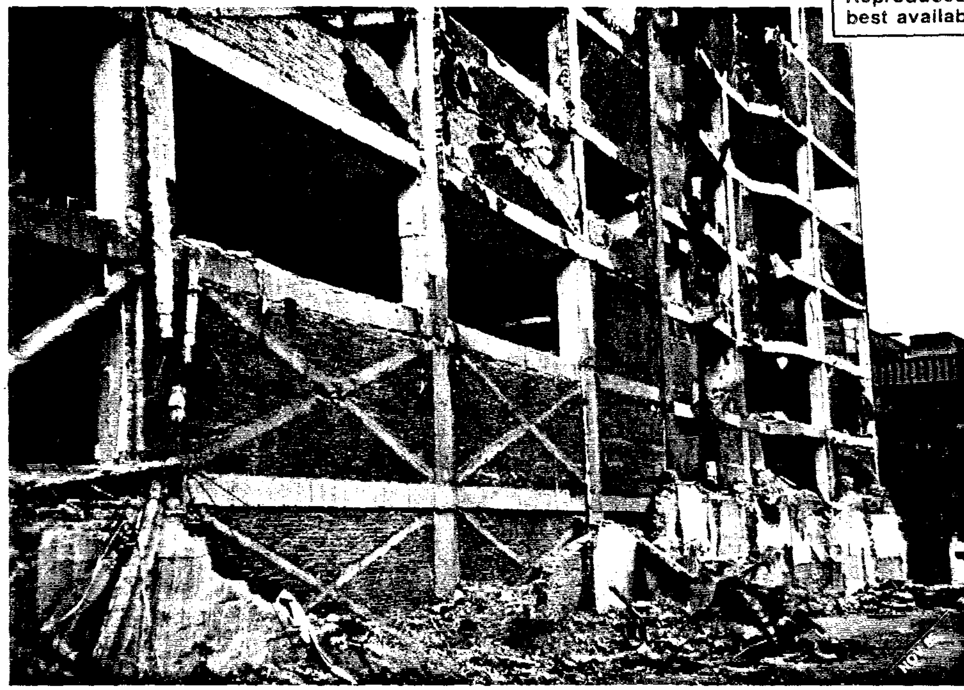


Figure 19 Masonry Infill Facade Damage
Medium-Rise Building With Reinforced
Concrete Moment-Resisting Frames,
Mexico City, Mexico Earthquake of 1985

Figure 20 Masonry Infill Facade Damage, Medium-Rise Building
With Reinforced Concrete Moment-Resisting Frames,
Mexico City, Mexico Earthquake of 1985

CHAPTER 6: SEISMIC DESIGN CODES AND REGULATIONS

The provisions of the following codes and regulatory standards governing the seismic design and detailing of facades/claddings and their connections were reviewed:

- ATC 03-6
- UBC
- Tri-Services Manual
- SEAOC
- OSA - State of California
- NEHRP

A summary of the applicable code provisions is presented in Tables V-A and V-B.

CODE PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL FACADE/CLADDING PANELS AND CONNECTIONS

FACADE/CLADDING PANELS AND CONNECTIONS	UNIFORM BUILDING CODE 1985 EDITION	PRESTRESSED CONCRETE INSTITUTE - 1977 EDITION	APPLIED TECHNOLOGY COUNCIL ATC 3-06 - 1978
	GOVERNING PROVISIONS	GOVERNING PROVISIONS	GOVERNING PROVISIONS
1. LATERAL DESIGN FORCE LEVELS FOR FACADE/CLADDING COMPONENTS	SEC. 2311 WIND LOADS SEC. 2312(g) SEISMIC FORCES $F_p = ZIC_pW_p$ (EQ 12-8) C_p....TABLE 23-J * I.....TABLE 23-K K.....TABLE 23-I Z.....FIGURES 23-1,23-2, 23-3 *FOR PANELS I=1.0 NOTE: EQ 12-8 IS VALID FOR IN-PLANE AND OUT-OF-PLANE FORCES.	SEC. 2.3.6 STRUCTURAL DESIGN CONSIDERATIONS SEC. 11.3 SEISMIC FORCES SEC. 11.4 DESIGN GUIDELINES FOR PANELS $F_p = ZIC_pSW_p$ (EQ 2-6) C_p = 0.2 FOR PANELS C_p = 2.0 FOR CONNECTIONS IF C_p = 2.0 THEN I.S = 1.0 ALL OTHER VALUES TAKEN FROM THE UBC NOTE: EQ 2-6 IS VALID FOR BOTH IN-PLANE AND OUT-OF-PLANE FORCES.	SEC. 3.7.7 ANCHORAGE OF NON-STRUCTURAL SYSTEMS SEC. 8.2 ARCHITECTURAL DESIGN REQUIREMENTS $F_p = A_vC_cPW_c$ (EQ 8-1) SEC. 1.4.1 A_v = SEISMIC COEFFICIENT FOR THE EFFECTIVE PEAK VELOCITY-RELATED ACCELERATIONS C_c = SEISMIC COEFFICIENT FOR NON-STRUCTURAL COMPONENTS...TABLE 8-B P = PERFORMANCE CRITERIA....TABLE 8-A NOTE: THE FORCE DETERMINED BY EQ 8-1 SHALL BE APPLIED AT THE COMPONENT'S CENTER OF GRAVITY AND MAY ACT IN ANY HORIZONTAL DIRECTION.
2. LOADS DUE TO VOLUMETRIC CHANGES		SEC. 2.3.4 FORCE SYSTEMS EQ: 2-2,2-3,2-4,2-5	
3. LOADS DUE TO SHIPPING AND HANDLING		SEC. 2.3.3 ERECTION CONSIDERATIONS	

TABLE V-A

CODE PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL FACADE/CLADDING PANELS AND CONNECTIONS

FACADE/CLADDING PANELS AND CONNECTIONS	UNIFORM BUILDING CODE 1985 EDITION	PRESTRESSED CONCRETE INSTITUTE - 1977 EDITION	APPLIED TECHNOLOGY COUNCIL ATC 3-06 - 1978
	GOVERNING PROVISIONS	GOVERNING PROVISIONS	GOVERNING PROVISIONS
4. DRIFT PROVISIONS	SEC. 2312(h) INTER-STORY DRIFT = [INTER-STORY LATERAL DEFLECTION UNDER DESIGN SEISMIC FORCES] · [1.0/K] WHERE K....GIVEN BY TABLE 23-I MAX. INTER-STORY DRIFT < 0.005h h = STORY HEIGHT	SEC. 2.3.6 FOLLOWS 1976 UBC DEFLECTION MUST BE LESS THAN: a) 2/K (WIND DRIFT) b) 3/K (SEISMIC DRIFT) c) 1/4 INCH WHICHEVER IS GREATER. K = HORIZONTAL FORCE FACTOR ....TABLE 11-1	SEC. 3.8 DEFLECTION & DRIFT LIMITS USE TABLES 3-B, 3-C SEC. 4.6 DRIFT DETERMINATION AND P-Δ EFFECTS $\Delta = \delta x_2 - \delta x_1$ δx_1 = DEFLECTION AT 1st FLOOR $\delta x = C_d \, \delta_{xe}$ (EQ 4-9) δC_d = DEFLECTION AMPLIFICATION FACTOR....TABLE 3B δ_{xe} = DEFLECTIONS DETERMINED BY ELASTIC ANALYSIS
5. PROVISIONS FOR DESIGN OF CONNECTIONS BETWEEN THE FACADE/ CLADDING PANELS AND THE STRUCTURAL FRAME	SEC. 2312(j)3C $F_{connection} = 1\frac{1}{3}F_p$ $F_{bolt\ or\ weld} = 4F_p$ RELATIVE MOVEMENT OF THE CONNECTIONS Δ_{allow} < 2·(WIND DRIFT) < 3/K·(SEISMIC DRIFT) < 1/2 INCH GREATER OF THE THREE CONTROLS NOTE: CONNECTIONS SHALL BE DESIGNED TO PERMIT MOVEMENT IN THE PLANE OF THE PANEL EQUAL TO THE DEFLECTION CALCULATED.	SEC. 11.3 SEISMIC FORCES $F_p = 2ZW_p$ (EQ 11-3) SEC. 2.5 ANALYSIS AND DESIGN OF CONNECTIONS CONNECTION DETAILS FOR NON-LOAD BEARING PANELS	SEISMIC FORCES SAME AS FOR DESIGN OF PANEL MOVEMENT OF PANEL SHALL ACCOMMODATE THE STORY DRIFT CALCULATED USING SECTION 4.6

TABLE V-A

CODE PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL FACADE/CLADDING PANELS AND CONNECTIONS

FACADE/CLADDING PANELS AND CONNECTIONS	TRI-SERVICES MANUAL 1982 SEAOC 1978	TITLE 24 STATE OF CALIFORNIA 1979	NEHRP SEISMIC DESIGN GUIDELINES 1985
	GOVERNING PROVISIONS	GOVERNING PROVISIONS	GOVERNING PROVISIONS
1. LATERAL DESIGN FORCE LEVELS FOR FACADE/ CLADDING COMPONENTS	SEC. 9-3 SEISMIC FORCES $F_p = ZIC_pW_p$ (EQ 3-8) $C_p = 0.3$ [table 3-4] SPECIAL PROVISIONS FOR EXTERIOR ELEMENTS I.....IMPORTANCE COEFFICIENT SAME AS VALUE USED FOR THE BUILDING SEC. 3-3(J)3d W_p.....WEIGHT OF FACADE/CLADDING COMPONENT SEC. 3-3(D)-1 Z.....NUMERICAL COEFFICIENT RELATED TO SEISMICITY OF A REGION. NOTE: EQ 3-8 IS VALID FOR IN-PLANE AND OUT-OF-PLANE FORCES.	SEISMIC FORCE F_p DETERMINED SIMILAR TO UBC	SEC. 8.2.2 SEISMIC FORCE APPLIED TO BUILDING COMPONENT AT ITS CENTER OF GRAVITY $F_p = A_vC_cPW_c$ (EQ 8-1) C_c = SEISMIC COEFFICIENT FOR ARCHITECTURAL COMPONENTS GIVEN IN TABLE 8-B. VARIES FROM 0.6-3.0 x PERFORMANCE FACTOR REALTED TO LIFE SAFETY (0.5-1.5) A_v = SEISMIC COEFFICIENT REPRESENTING THE EFFECTIVE-PEAK-VELOCITY-RELATED ACCELERATION PER SEC. 1.4 P = PERFORMANCE CRITERIA FACTOR GIVEN IN TABLE 8-A W_c = WEIGHT OF BUILDING COMPONENT NOTE: THE FORCE F_p SHALL BE APPLIED INDEPENDENTLY LONGITUDINALLY (IN-PLANE), LATERALLY (OUT-OF-PLANE), OR VERTICALLY IN COMBINATION WITH WEIGHT OF COMPONENT.
2. LOADS DUE TO VOLUMETRIC CHANGES	SEC. 3-3(J)3d SPECIAL PROVISIONS FOR EXTERIOR ELEMENTS...TEMPERATURE CHANGES		
3. LOADS DUE TO SHIPPING AND HANDLING			

TABLE V-B

CODE PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL FACADE/CLADDING PANELS AND CONNECTIONS

FACADE/CLADDING PANELS AND CONNECTIONS	TRI-SERVICES MANUAL 1982 SEAOC 1978	TITLE 24 STATE OF CALIFORNIA 1979	NEHRP SEISMIC DESIGN GUIDELINES 1985
	GOVERNING PROVISIONS	GOVERNING PROVISIONS	GOVERNING PROVISIONS
4. DRIFT PROVISIONS	SEC. 3-3(H) INTER-STORY DRIFT = [INTER-STORY LATERAL DEFLECTION UNDER DESIGN SEISMIC FORCES] $\cdot$ (1.0/K) WHERE 1.0/K > 1.0 K = NUMERICAL COEFFICIENT GIVEN BY TABLE 3-3 MAX. INTER-STORY DRIFT $\leqslant$ 0.005h h = STORY HEIGHT	MAX INTERSTORY DRIFT $\leqslant$ 0.005h h = STORY HEIGHT MAX. INTERSTORY DRIFT $\leqslant$ 0.0025h′ h′ = HEAD TO SILL OF GLAZED OPENINGS	SEC 3.8 DEFLECTION AND DRIFT LIMITS DESIGN STORY DRIFT $\Delta <$ ALLOW. STORY DRIFT Δ_a TABLE 3-C ALLOWABLE STORY DRIFT Δ_a = 0.010-0.015h_{sx} BASED ON SEISMIC HAZARD EXPOSURE GROUP h_{sx} = STORY HEIGHT SEC. 4-6.1 STORY DRIFT DETERMINATION DESIGN STORY DRIFT $\Delta = \delta_{xt} - \delta_{xb}$ WHERE δ_{xt} & δ_{xb} ARE LATERAL DEFLECTIONS @ TOP & BOTTOM OF THE STORY UNDER CONSIDERATION LATERAL DEFLECTION $\delta_x = C_d\delta_{xe}$ C_d = DEFLECTION AMPLIFICATION FACTOR GIVEN IN TABLE 3-B δ_{xe} = DEFLECTIONS DETERMINED BY AN ELASTIC ANALYSIS USING SEISMIC DESIGN FORCES GIVEN IN SEC. 4.3. DESIGN STORY DRIFT SHALL BE INCREASED BY THE INCREMENTAL FACTOR FOR P-Δ EFFECTS AS PER SEC. 4.6.2.

TABLE V-B

CODE PROVISIONS FOR SEISMIC DESIGN OF NON-STRUCTURAL FACADE/CLADDING PANELS AND CONNECTIONS

FACADE/CLADDING PANELS AND CONNECTIONS	TRI-SERVICES MANUAL/1982 SEAOC 1978	TITLE 24 STATE OF CALIFORNIA 1979	NEHRP SEISMIC DESIGN GUIDELINES 1985
	GOVERNING PROVISIONS	GOVERNING PROVISIONS	GOVERNING PROVISIONS
5. PROVISIONS FOR DESIGN OF CONNECTIONS BETWEEN FACADE/CLADDING PANELS AND THE STRUCTURAL FRAME	$F_{connection} = 1.33\ F_p$ $F_{bolts,\ welds,\ inserts} = 4F_p$ ALLOWABLE RELATIVE MOMENTS OF THE CONNECTIONS & PANEL JOINTS: $_{allow}$ < 2·(WIND DRIFT) < 3/K·(SEISMIC DRIFT) < 1/2 INCH NOTE: CONNECTIONS SHALL BE DESIGNED TO PERMIT MOVEMENT IN THE PLANE OF THE PANEL EQUAL TO THE DEFLECTION CALCULATED.	SAME AS FOR UBC	SEC. 8.2.3 EXTERIOR WALL PANEL ATTACHMENT CONNECTIONS SHALL HAVE SUFFICIENT DUCTILITY AND PROVIDE ROTATIONAL CAPACITY NEEDED TO ACCOMMODATE THE DESIGN STORY DRIFT DETERMINED BY SEC. 4.6.1. FACADE/CLADDING PANELS CONNECTED TO STRUCTURAL FRAMING SYSTEM MUST BE ABLE TO ACCOMMODATE THE DESIGN STORY DRIFT WITHOUT FAILURE.

TABLE V-B

CHAPTER 7: REVIEW OF CURRENT DESIGN AND CONSTRUCTION PRACTICES

7.1 FACADES/CLADDING PANELS

7.2 CONNECTIONS

A schematic block diagram of the overall design process governing the seismic design and detailing of non-structural facades/cladding components and connections in buildings is presented on p.

Basically, the current facade/cladding and connections design and detailing practices are based on the following:

- **Seismic Design Codes and Regulations**, e.g., UBC, ATC, Tri-Services Manual, SEAOC, OSA, NEHRP

  Comparative evaluation of applicable seismic design codes was presented in Chapter 6.

- **Industry Standards and Guidelines**

  Guidelines for design, detailing, production, and erection of precast concrete facade/cladding panels and connections are provided by Prestressed Concrete Institute (106), (107), (108), (109), (110), (124), Precast Product Manufacturers (89) and others (103).

Current Facade/Cladding Construction Practices

GFRC Cladding Panels

This type of cladding is becoming increasingly popular on the West Coast. Figure 21 shows a GFRC cladding panel fabricted at a precasting plant before being shipped to the construction site.

Figure 22 shows a typical GFRC cladding panel being lifted for shipment at a precasting plant on the West Coast.

Precast Concrete Spandrel Panels

This type of facade/cladding is widely used not only on the West Coast but other states as well, in the United States.

Figures 23 and 24 show typical precast concrete spandrel panels being delivered to a construction site in the San Francisco Bay Area. The precast panels already have steel-angle-attachment assemblies embedded in them during the panel fabrication process.

Figure 25 shows typical layout and configuration of precast concrete spandral panels during construction in a low-rise steel-framed building near San Francisco.

Figure 26 shows close-up detail of precast concrete spandrel panels and column-cover-panels during construction.

Figure 27 shows the installation of precast column-cover-panels in progress in a low-rise steel-framed building near San Francisco.

Precast Concrete Window-Wall Cladding Panels

Figure 28 shows the installation and connection details of a story-high precast concrete cladding panel in a steel-framed high-rise buildings in San Francisco.

Figure 29 shows the detailing and installation of precast concrete cladding corner units in a steel-framed high-rise building in San Francisco.

Precast Concrete Facades/Claddings and Connections

In light of the diverse range of facade/cladding components and connections used in low/medium-rise buildings in seismic zones across the U.S., it was decided to focus on investigating the seismic behavior and design of precast concrete cladding panels attached to rigid-frame building structural systems representative of current practices in the U.S. It was further decided to focus on the investigation of seismic behavior and design of story-high window-wall panel components and connections in buildings with moment-resisting frame structural systems.

Connections

A study of the state-of-the-art of seismic design and detailing of cladding connections shows that there are many different types of connections and details in use in different parts of the U.S.

According to current design practice in California and other seismic zones of the U.S., Ref. (89), (93), (106), (53), (124), (125), (103), (108), (109), (110), (147), (148) connections of precast concrete window-wall facade/cladding panels to the building structural frames may be divided into the following categories:

- **Flexible Connection at Top**

  Typically there are two attachment points at top of the cladding panel. These felxible or push-pull connections between the cladding panel and the structural frame are expected to accommodate all possible differential movements including inter-story drifts caused by lateral load, e.g., wind and earthquakes; as well as differential movements due to unbalanced gravity loads, temperature changes, creep and shrinkage.

- **Bearing Connection at Bottom**

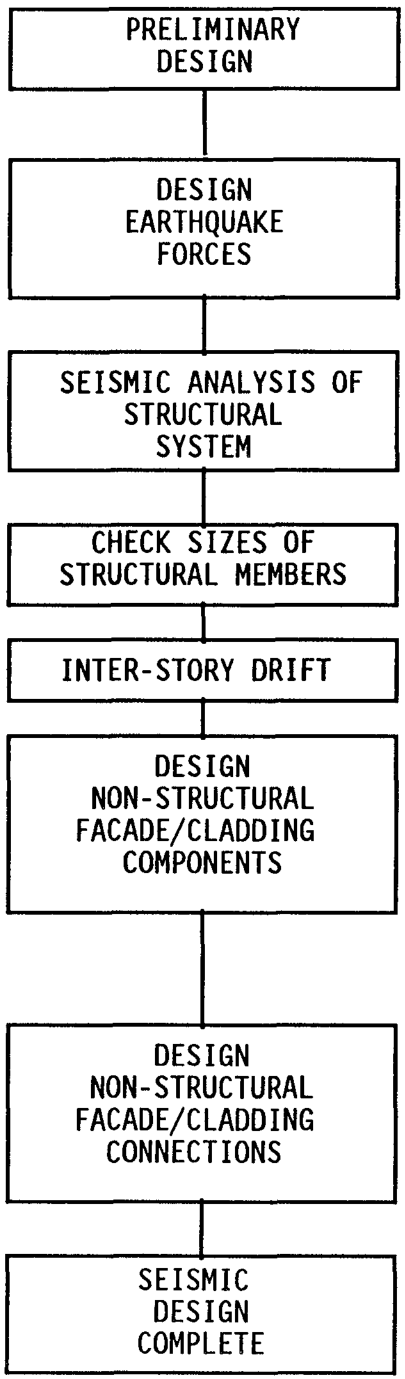
  Typically there are two attachment points at the bottom of the cladding panel. These rigid connections at the bottom of cladding panels are designed to provide resistance to gravity and lateral loads, e.g., wind and earthquakes.

In current design practice, it is assumed that cladding contributes only mass to building system. Thus the designer accounts for facade/cladding in the seismic design process by including only the dead weight of cladding panels tributary to building floor under consideration. The total mass distribution in the building, thus obtained is used along with the lateral stiffness of the building to determine fundamental dynamic properties, e.g., modal frequencies and mode shapes, as well as seismic response analysis and design of the building system.

It is also assumed that the flexible lateral connections at top of the cladding panels provide no in-plane earthquake resistance and function only to accommodate differential movements between the facade/cladding panels and building structural frames.

SEISMIC DESIGN PROCESS FOR NON-STRUCTURAL FACADE/CLADDING COMPONENTS AND CONNECTIONS

SCHEMATIC



PROCEDURES

I. Establish:
1. Floor Dead & Live Loads
2. Preliminary Cladding Configuration, Sizes, Loads
3. Story Heights and Elevations
4. Design Preliminary Sizes

II. Establish: Seismic Base Shear
Distribution of Seismic Forces

III. Perform Seismic Analysis of Structural System
Determine Member Forces and Deflections

IV. Compile Results of Seismic Analysis of Structural System
Check Strength Required vs. Strength Provided

V. Compile Deflection Results From Seismic Analysis of Structural System

VI. Design Precast Concrete Panels
1. Calculate Center of Gravity of Panel
2. Compute Design Loads
   a. Gravity...Dead & Live Loads
   b. Lateral...Wind & Seismic
   c. Volumetric Changes...Shrinkage, Creep, Temperature
   d. Handling...Stripping, Shipping, Erection
3. Design Panel Using PCI and ACI Specifications

VII. Choose Type of Connection
1. Bolted, Welded
2. Clip Angle

Figure 21 GFRC Cladding Panels During Fabrication at Fabrication Plant

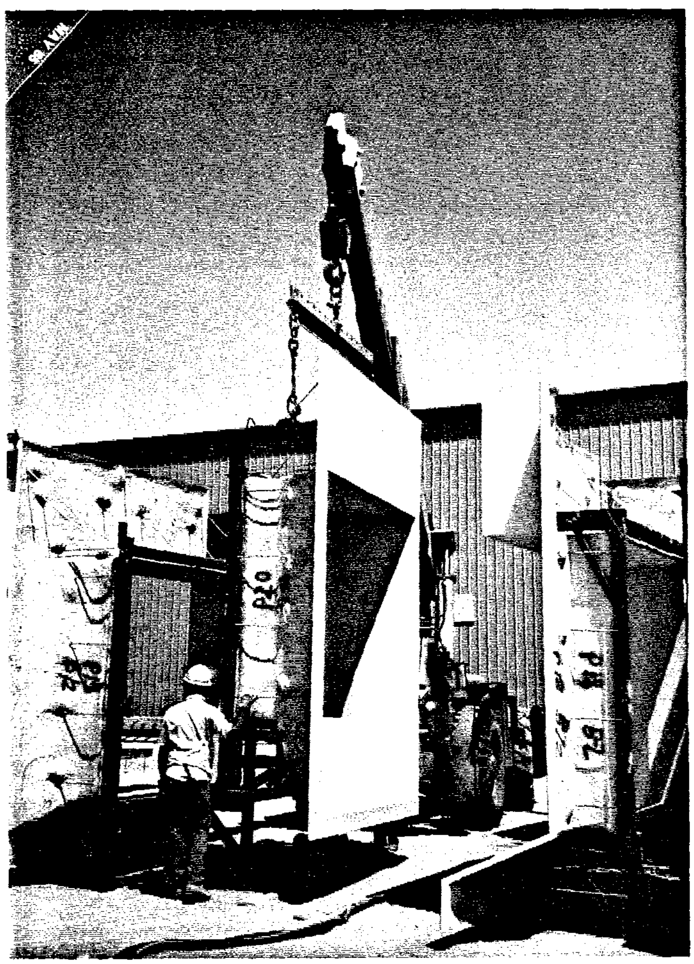


Figure 22 Typical GFRC Cladding Panel Being Lifted for Shipment at Precasting Plant

Figure 23 Typical Precast Concrete Spandrel Panels Being Delivered to Construction Site

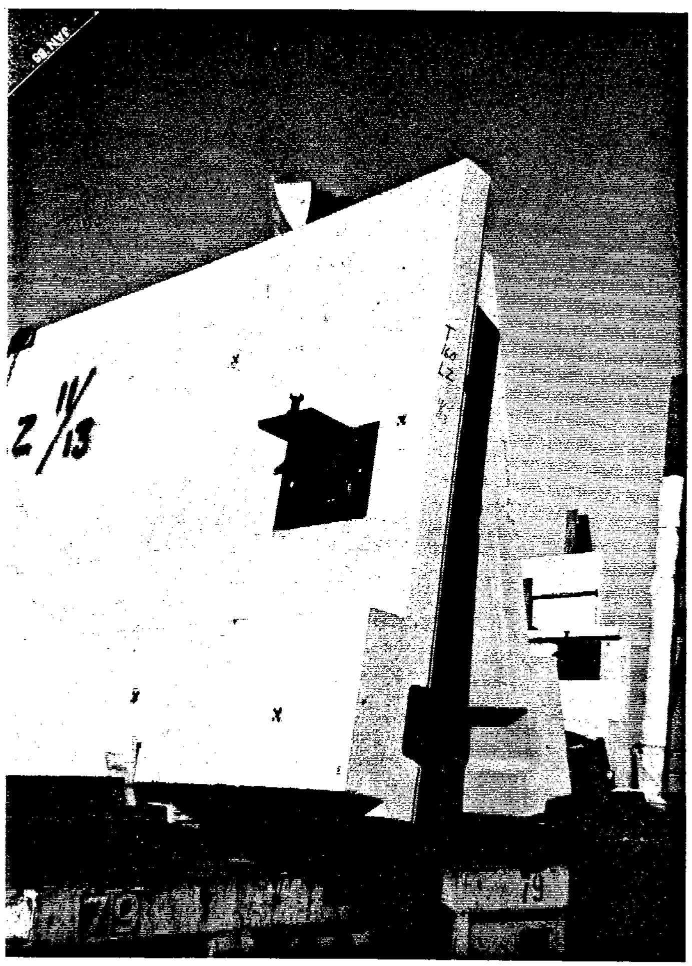


Figure 24 Typical Precast Concrete Spandrel Panels Being Delivered to Construction Site

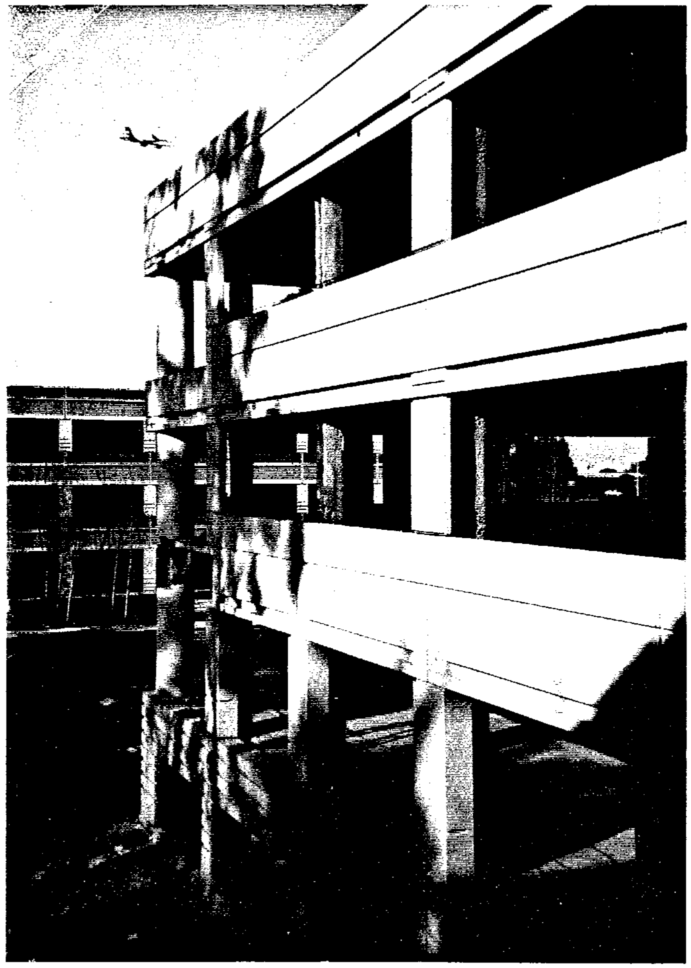


Figure 25 Typical Configuration of Precast Concrete Spandrel Panels in a Low-Rise Steel-Framed Building - During Construction

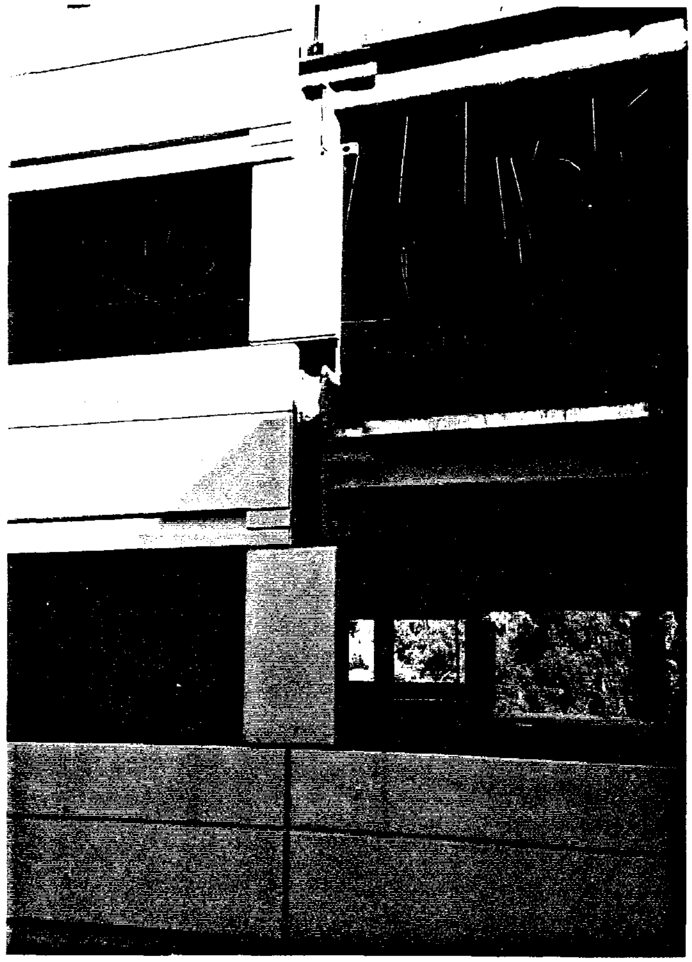


Figure 26 Close-up of Precast Concrete Spandrel Panels and Column-Cover-Panels - During Construction

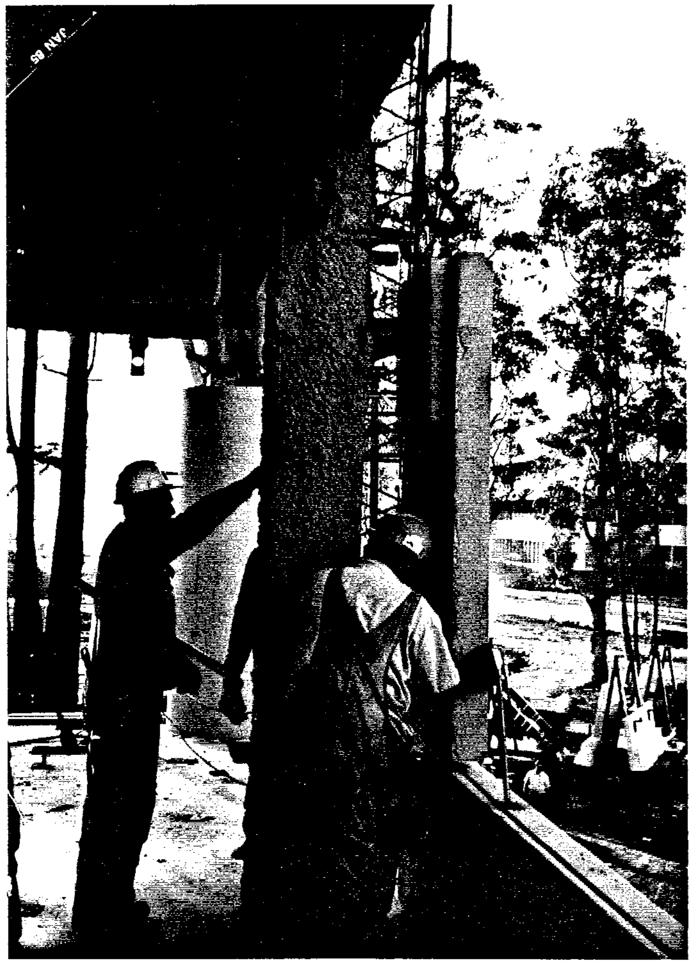


Figure 27 Installation of Precast Concrete Column-Cover-Panels in a Low-Rise Steel-Framed Buildings

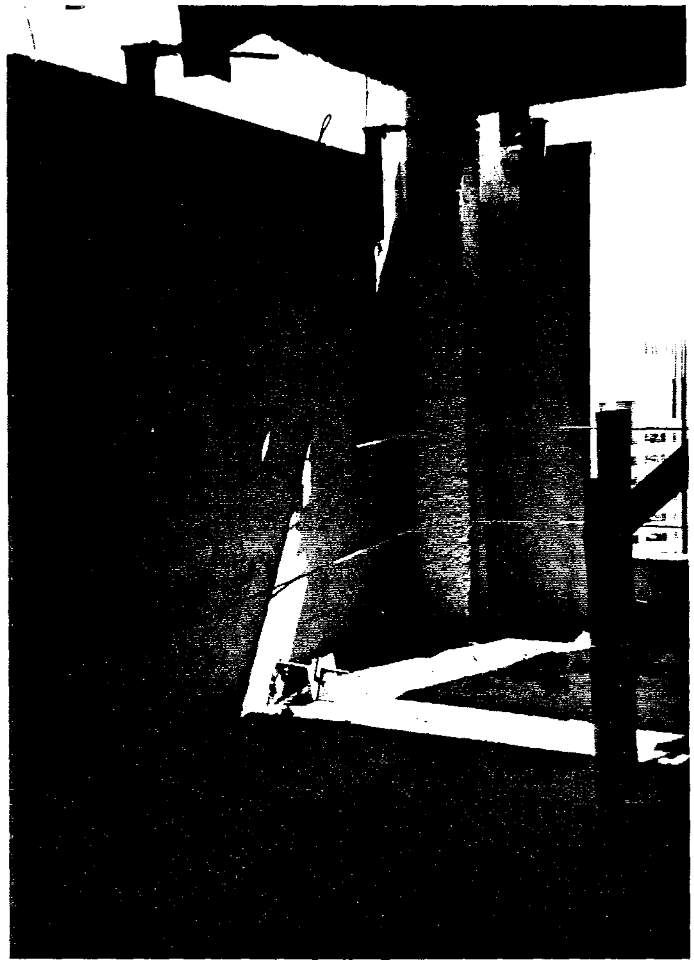


Figure 28 Installation and Connection Details of a Story-High Precast Connection Cladding Panel in a Steel-Framed High-Rise Building

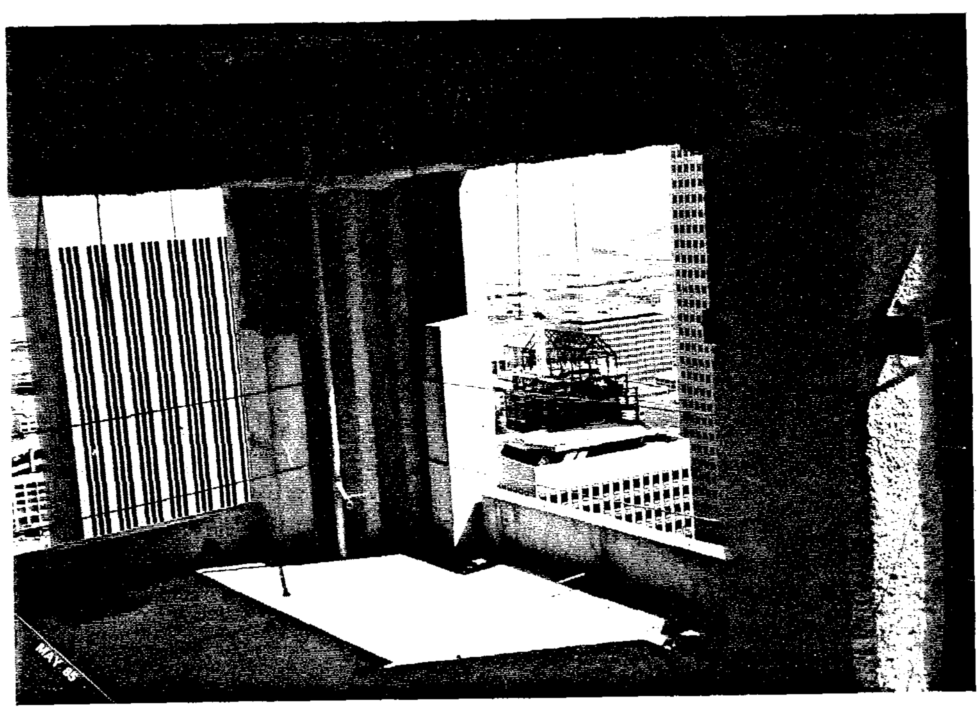


Figure 29 Installation and Details of Precast Concrete Cladding Corner Units in a Steel-Framed High-Rise Building

CHAPTER 8: TESTING PROGRAM

GENERAL

In light of a general lack of test data on claddings and connections, a testing program was developed and carried out to investigate the behavior of precast concrete cladding panels with threaded-rod flexible lateral connections at top and rigid bearing connections at bottom, representative of design practices on the west coast of the U.S.

8.1 TEST I TESTING OF LATERAL (THREADED-ROD) CONNECTIONS

8.1.1 TEST OBJECTIVE

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 representative of those used in precast concrete cladding panels.

8.1.2 DESCRIPTION OF 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, as shown in Figures 2, 3 (Appendix A).

8.1.3 TEST SET-UP AND PROCEDURE

The overall test set-up is shown in Figures 1, 4, 5 (AppendixA). 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.

8.1.4 TEST RESULTS

A summary of results of static tests of threaded-rod lateral connections is presented in Table VI. Typical load-deflection curves for all threaded-rods are presented in Figs. 7 to 11 (Appendix A).

Based on an experimentally obtained uniaxial tensile stress-strain curve for a 5/8 inch diameter threaded-rod (Fig.6

-Appendix A), an analytical model for prediction of the load-deflection relationship for the threaded-rods tested, was developed. A plot of estimated stiffness of threaded-rod specimens at different load levels is presented in Fig. 12 (Appendix A).

TEST I: STATIC TESTS OF THREADED ROD-TYPE LATERAL CONNECTIONS

SPECIMEN NO.	THREADED ROD		MAX. TEST LOAD LBS.	MAX. ROD DEFLECTION IN.	MAX. BENDING STRESS IN ROD @ MAX. LOAD: BASED ON ANALYTICAL MODEL KSI
	LENGTH IN.	DIA. IN.			
CST-L4	4	0.625	478	0.64	77
CST-L4A	4	0.625	415	0.78	
CST-L6	6	0.625	290	0.87	73
CST-L6A	6	0.625	290	0.79	
CST-L8	8	0.625	180	1.34	73
CST-L8A	8	0.625	178	1.00	
CST-L10	10	0.625	133	0.86	65
CST-L10A	10	0.625	145	0.95	
CST-L12	12	0.625	103	1.11	65
CST-L12A	12	0.625	104	1.06	

TABLE VI: SUMMARY OF TEST RESULTS

8.2 TEST II CYCLIC TESTS OF PRECAST CONCRETE CLADDING PANELS AND CONNECTION ASSEMBLY

8.2.1 TEST OBJECTIVE

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.

8.2.2 DESCRIPTION OF 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.

Figure 30 shows an overall schematic of Test II Precast Cladding Specimen including location of Threaded-Rod Flexible Connections and Rigid Bearing Connections.

Details of cladding cyclic test specimen and top and bottom connections are shown in Figures 1, 2, 3, 4, 5 (Appendix B).

8.2.3 TEST SET-UP AND PROCEDURE

The overall cyclic test set-up for Test II is shown in FIgures 1, 4 (Appendix B). The cyclic displacements were applied to the precast cladding specimen through a loading assembly attached to the threaded-rod laterall connections as shown in Figures 2, 4 (Appendix B).

The cladding test specimens were subjected to cyclic racking motions using an MTS electro-hydraulic shaking system located in the High-Bay laboratory of the School of Architecture. An overview of the dynamic testing instrumentation set-up is ppresented in the Block Diagram of Figure 31. The cyclic 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.

A summary o the Cyclic Test Control Parameters is presented in Table VII.

Representative Cyclic Test Data and Cyclic Load-Displacement Curves are presented in Appendix B (Figures 11-15).

8.2.4 TEST RESULTS

Time-History Data for all transducer channels was analyzed and peak-responses were recorded. Representative plots of time-history data for force, displacement and strain are presented in Figures 11-20 (Appendix B). The peak-response data for all cyclic test runs is presented in Tables I-IV (Appendix B).

The observed behavior and fracturing of threaded-rod lateral connection under cyclic displacements just prior to failure is shown in Fig. 32. Graphs of peak lateral-force resistance of threaded-rod lateral connections vs. horizontal displacement (drift) are shown in Figs. 16, 17 (Appendix B). A summary of cyclic test results for the precast cladding specimens with 6-inch and 8-inch long threaded-rod lateral connections is presented in Tables VIII and IX. These tables document not only the peak load and horizontal displacement (drift) levels reached but also present estimates of service load-surcharge to the bearing angle for each of the test runs up to failure. The service-load surcharge is expressed as a percentage of the standard design load both for the bearing connection angles and the headed-studs in the bearing connection. Details of the computation of the service-load surcharge to the bearing connection due to the resistance of the threaded-rod connections are given in Appendix B.

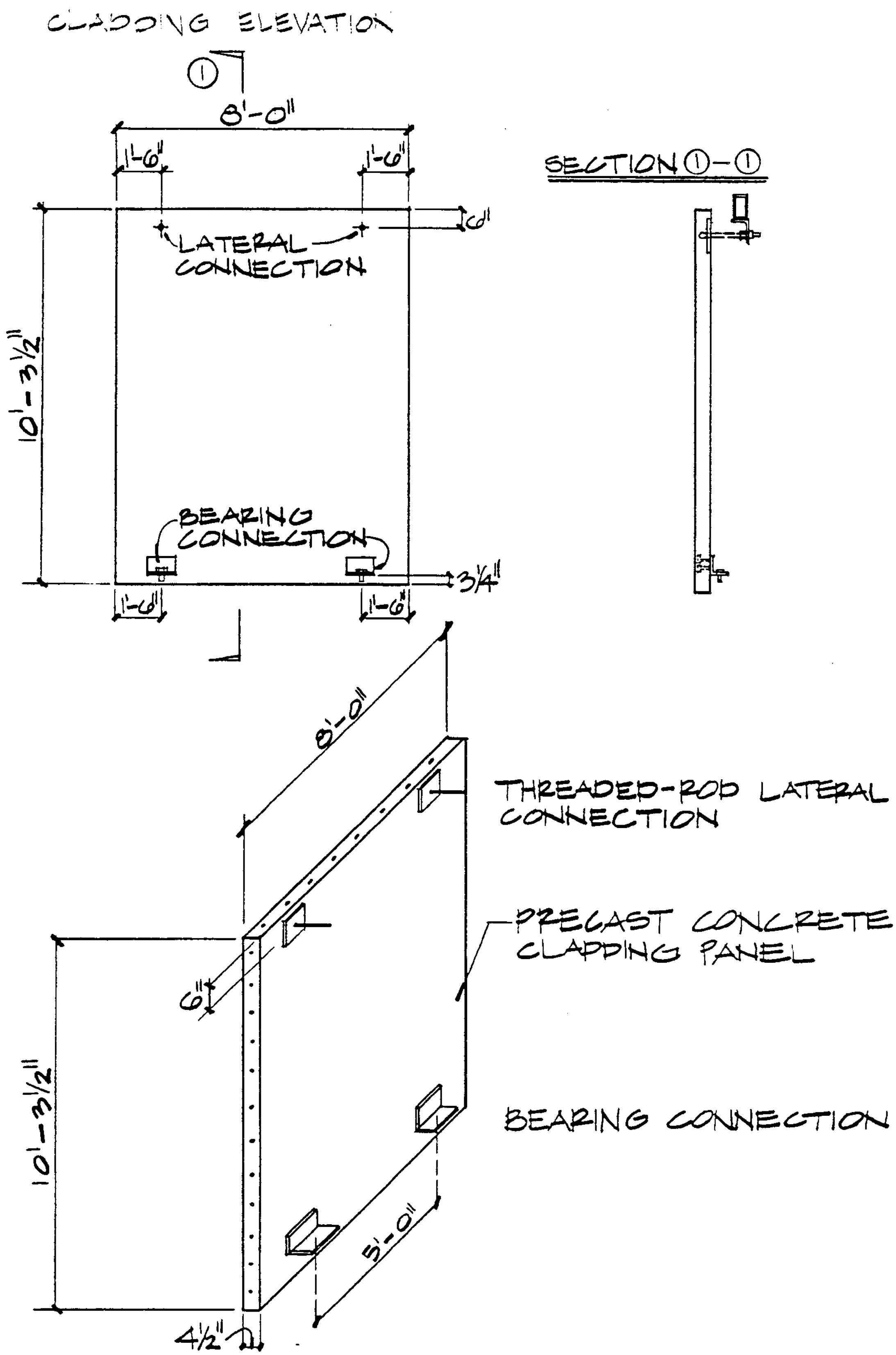
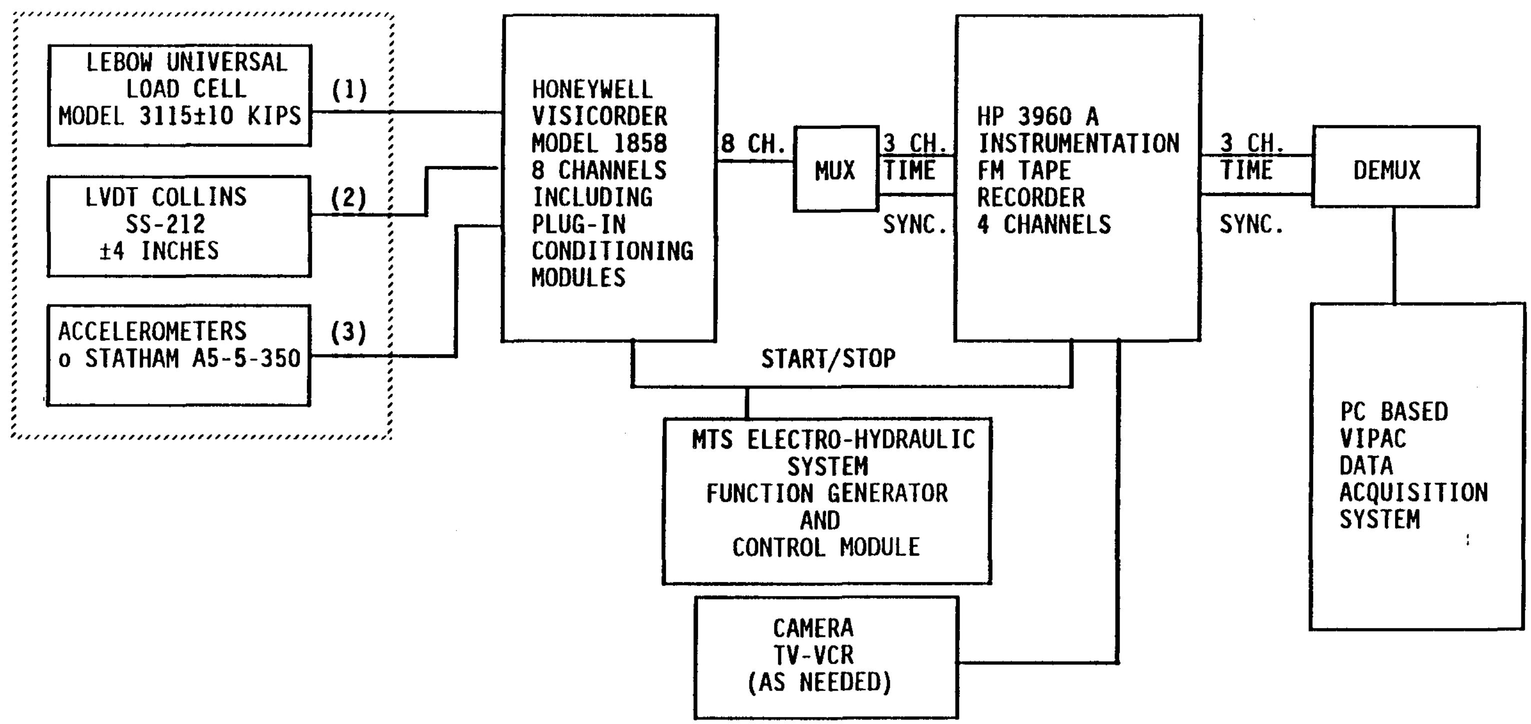


FIG. 30 TEST II
SCHEMATIC OVERVIEW OF PRECAST CLADDING TEST SPECIMEN AND CONNECTIONS



BLOCK DIAGRAM
DYNAMIC TESTING INSTRUMENTATION & DATA PROCESSING

FIGURE 31	NSF SPONSORED RESEARCH PROJECT SEISMIC TESTING OF HEAVY PRECAST FACADES/CLADDING PANEL AND CONNECTIONS PRINCIPAL INVESTIGATOR: DR. SAT RIHAL, ARCH. ENGR. DEPT.	PREPARED BY: DR. GARY GRANNEMAN, ET/EL DEPT. DATE: 8/86 CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CALIFORNIA 93407

NSF SPONSORED RESEARCH PROJECT
SEISMIC TESTING OF HEAVY PRECAST FACADES/CLADDING & CONNECTIONS

TABLE VII: SUMMARY OF DYNAMIC TEST CONTROL PARAMETERS

SPECIMEN	PRECAST CONCRETE CLADDING PANEL WITH THREADED-ROD LATERAL CONNECTIONS @ TOP & BEARING CONNECTIONS @ BOTTOM			FREQUENCY Hz	NO. OF CYCLES	BLOCK CYCLIC TEST COMMAND PEAK DISPLACEMENT OF CYCLES - INCHES								
	SIZE	PANEL THICKNESS INCHES	THREAD-ROD LENGTH INCHES			1	2	3	4	5	6	7	8	9
						±1/4	±3/8	±1/2	±3/4	±1	±1 1/2	±1 3/4	±2	±2 1/2
FPCRT-L6	8'-0" WIDE x 10'-0" HIGH	4 1/2	6	0.1	5	X		X	X	X	X	X		
				0.5	5	X		X	X	X	X		Run #7 X	Run #8 X
FPCRT-L8	8'-0" WIDE x 10'-0" HIGH	4 1/2	8	0.1	5	X		X	X	X	X	X		
				0.5	5	X		X	X	X	X	X	X	±2 1/4 X

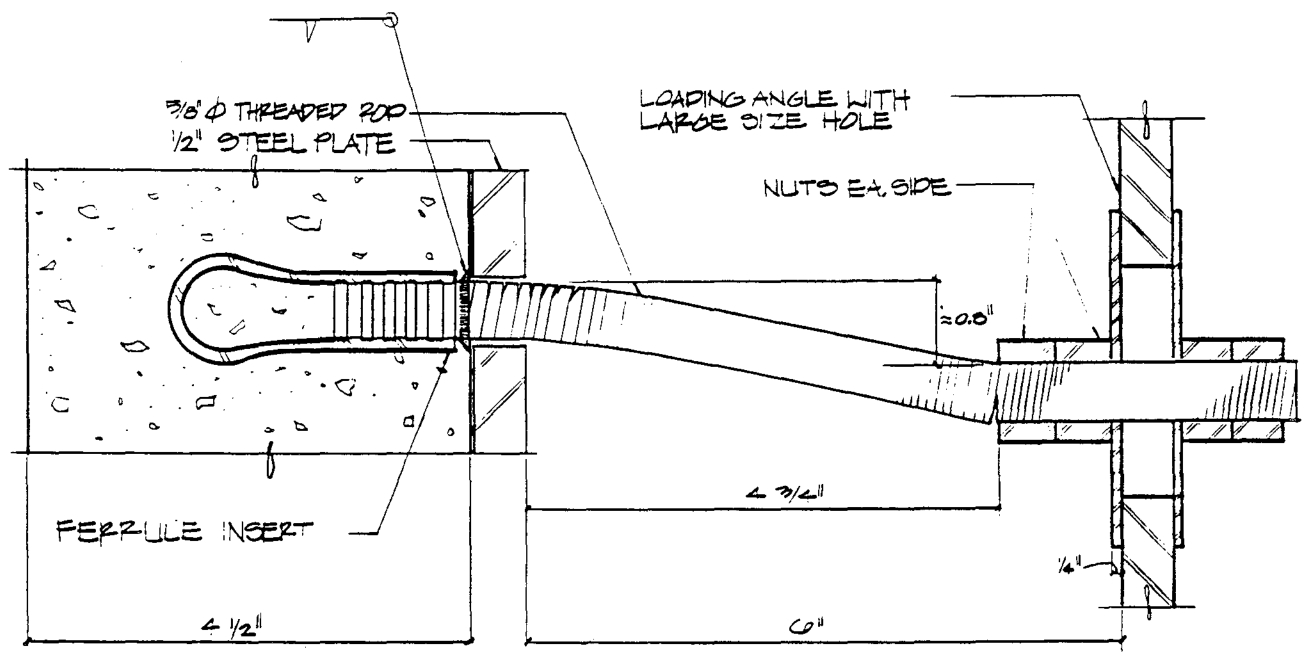


FIG. 32 TEST II
TYPICAL CYCLIC BEHAVIOR AND FRACTURING OF THREADED-ROD CONNECTIONS JUST PRIOR TO FAILURE

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

SUMMARY OF TEST RESULTS - ESTIMATE OF LOAD SURCHARGE TO BEARING CONNECTION

THREADED ROD - LENGTH = 6 INCHES. TEST FREQUENCY = 0.1 Hz					
RUN	HORIZONTAL RELATIVE DISPLACEMENT (DRIFT) Δ INCHES	MAX. PEAK LOAD-CELL READING kips	Δ/H	ESTIMATED LOAD SURCHARGE AS % OF STANDARD DESIGN LOAD	
				TO BEARING CONNECTION ANGLE	TO STUDS IN BEARING CONNECTION
AF 1	0.171	1.075	0.0014	52	28
AF 3	0.374	1.466	0.0031	70	38
AF 4	0.591	1.661	0.0049	80	43
AF 6	0.811	1.759	0.0068	84	45

THREADED ROD - LENGTH = 6 INCHES. TEST FREQUENCY = 0.5 Hz					
RUN	HORIZONTAL RELATIVE DISPLACEMENT (DRIFT) Δ INCHES	MAX. PEAK LOAD-CELL READING kips	Δ/H	ESTIMATED LOAD SURCHARGE AS % OF STANDARD DESIGN LOAD	
				TO BEARING CONNECTION ANGLE	TO STUDS IN BEARING CONNECTION
BF 1	0.122	0.885	0.0010	41	22
BF 3	0.266	1.319	0.0022	63	34
BF 4	0.437	1.637	0.0036	78	42
BF 5	0.623	1.734	0.0052	83	45
BF 6	0.967	1.881	0.0081	90	48
BF 7	1.151	1.808	0.0096	87	46

TABLE VIII

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

SUMMARY OF TEST RESULTS - ESTIMATE OF LOAD SURCHARGE TO BEARING CONNECTION

THREADED ROD - LENGTH = 8 INCHES. TEST FREQUENCY = 0.1 Hz					
RUN	HORIZONTAL RELATIVE DISPLACEMENT (DRIFT) Δ INCHES	MAX. PEAK LOAD-CELL READING kips	Δ/H	ESTIMATED LOAD SURCHARGE AS % OF STANDARD DESIGN LOAD	
				TO BEARING CONNECTION ANGLE	TO STUDS IN BEARING CONNECTION
A 1	0.186	0.782	0.0015	38	20
A 3	0.393	1.075	0.0033	52	28
A 4	0.608	1.172	0.0051	56	30
A 5	0.838	1.246	0.0070	60	32
A 6	1.290	1.343	0.0108	64	35

THREADED ROD - LENGTH = 8 INCHES. TEST FREQUENCY = 0.5 Hz					
RUN	HORIZONTAL RELATIVE DISPLACEMENT (DRIFT) Δ INCHES	MAX. PEAK LOAD-CELL READING kips	Δ/H	ESTIMATED LOAD SURCHARGE AS % OF STANDARD DESIGN LOAD	
				TO BEARING CONNECTION ANGLE	TO STUDS IN BEARING CONNECTION
B 1	0.152	0.554	0.0013	26	14
B 3	0.340	0.953	0.0028	46	24
B 4	0.506	1.050	0.0042	50	27
B 5	0.696	1.172	0.0058	56	30
B 6	1.058	1.163	0.0088	56	30
B 7	1.231	1.196	0.0103	57	31
B 8	1.400	1.197	0.0117	57	31

TABLE IX

8.3 TEST III DYNAMIC TESTING OF PRECAST CONCRETE FACADE/CLADDING AND CONNECTIONS IN A MODEL TWO-STORY STEEL MOMENT-RESISTING-FRAME STRUCTURE

8.3.1 TEST OBJECTIVE

The objective of Test III was to experimentally determine the fundamental periods and modal responses of a model two-story steel moment-resisting-frame structure as follows:

- Steel Test-Frame without Cladding Panels

- Steel Test-Frame with Cladding Panels

8.3.2 DESCRIPTION OF TEST SPECIMEN

STEEL TEST STRUCTURE

This test structure is a model two-story one-bay x one-bay steel moment-resisting frame structure with roof/floor system and connections representative of current practice including the base-plate connections at the base. This test structure is a scaled down version of a larger (full-size) steel test structure that was designed sometime back to be tested at an appropriate time at a large earthquake simulator such as the one at U.C. Berkeley. Geometry of the test frame was established by the scaling considerations as well as considerations of laboratory space. The steel test frame was designed to carry a maximum lateral force of 11 kips at roof level in the N-S direction and so as to undergo inter-story drift levels that are significant to investigate the behavior of precast cladding and connections. All beams and columns are W6x9, A-36 steel sections. The test structure was fabricated by a local fabricator and erected in the high-bay laboratory of the School of Architecture. The steel test structure was connected at the bottom to a precast concrete base (bolted to the strong floor slab of the laboratory) using standard base-plate connections that were assumed pinned for analysis and design of the test structure.

Details of the test structure are presented in Figure 1 (Appendix C) and drawing sheets C-4 to C-10 (Appendix C)

Precast Concrete Cladding Panels and Connections

Precast concrete cladding panels were 4-1/2 inches thick, as in Test II and the width and height dimensions of the panels were established so that the mass of the cladding panels expressed as a percentage of the mass of the steel test structure is the same as that in the prototype structure. The cladding panel thickness was kept the same as in Test II so that the cladding connection details will be the same in Test II and III. Details of the precast concrete cladding 2 panel and connections are presented in Figure 5 (Appendix C) and sheets C-6, C-7, C-8 (Appendix C).

The cladding configuration and connection details were developed in consultation with a Precast Manufacturer (89) on the west coast who also fabricated the cladding panels in accordance with current practices of manufacture of architectural precast cladding panels including their connections.

8.3.3 DYNAMIC TEST SET-UP AND PROCEDURE

The test structure was dynamically excited by an APS Electro-Seis shaker positioned on the floor of the test structure. This shaker could be oriented in the Transverse direction (N-S) or the Longitudinal direction (E-W). For study of torsional response characteristics this shaker was positioned 12 inches off-center on the floor of test structure in the Transverse direction (N-S).

Figures 2 and 4 (Appendix C) show photographs of the APS shaker and Test III in progress.

Basically Test III was divided into three separate parts:

Test III-A Steel Test Frame Structure without Precast Cladding Panels.

Test III-B Steel Test Frame Structure with One Precast Cladding Panel attached to east face of the structure.

Test III-C Steel Test Frame Structure with Two Precast Cladding Penels, attached one each to the east and west faces of the structure.

Two types of excitations were used in Test III, as follows:

- **Random Excitation**
  This was provided by the HP Spectrun Analyzer used in this test.

- **Sinusoidal Excitation**
  This was provided by a function generator used in this test.

A schematic block diagram of Dynamic Test Set-up is shown in Fig. 33.

The sequence of the Dynamic Test Runs and Test Control Parameters are presented in Table X.

For each test run the selected excitation was continuously applied and dynamic responses of test structure at roof & floor levels measured by appropriately positioned statham accelerometers.

Modal response of the test structure was obtained by feeding the accelerometer output into the HP Spectrum Analyzer Fig. 3 (Appendix C) which provided a screen display of modal response and then dumping the screen-display down to an x-y plotter.

Figure 1 (Appendx C) shows the overall dynamic test set-up. Figures 2 & 3 (Appendix C) show the test instrumentation and in Test III.

8.3.4 Test Results

A summary of test results obtained for Test III-A (No Cladding Panels) is presented in Table XI.

A summary of test results obtained for Test III-C (Test Structure with Two Cladding Panels in Transverse Direction N-S) is presented in Table XII.

TEST III DYNAMIC TESTING OF MODEL TEST STRUCTURE WITHOUT & WITH CLADDING PANELS

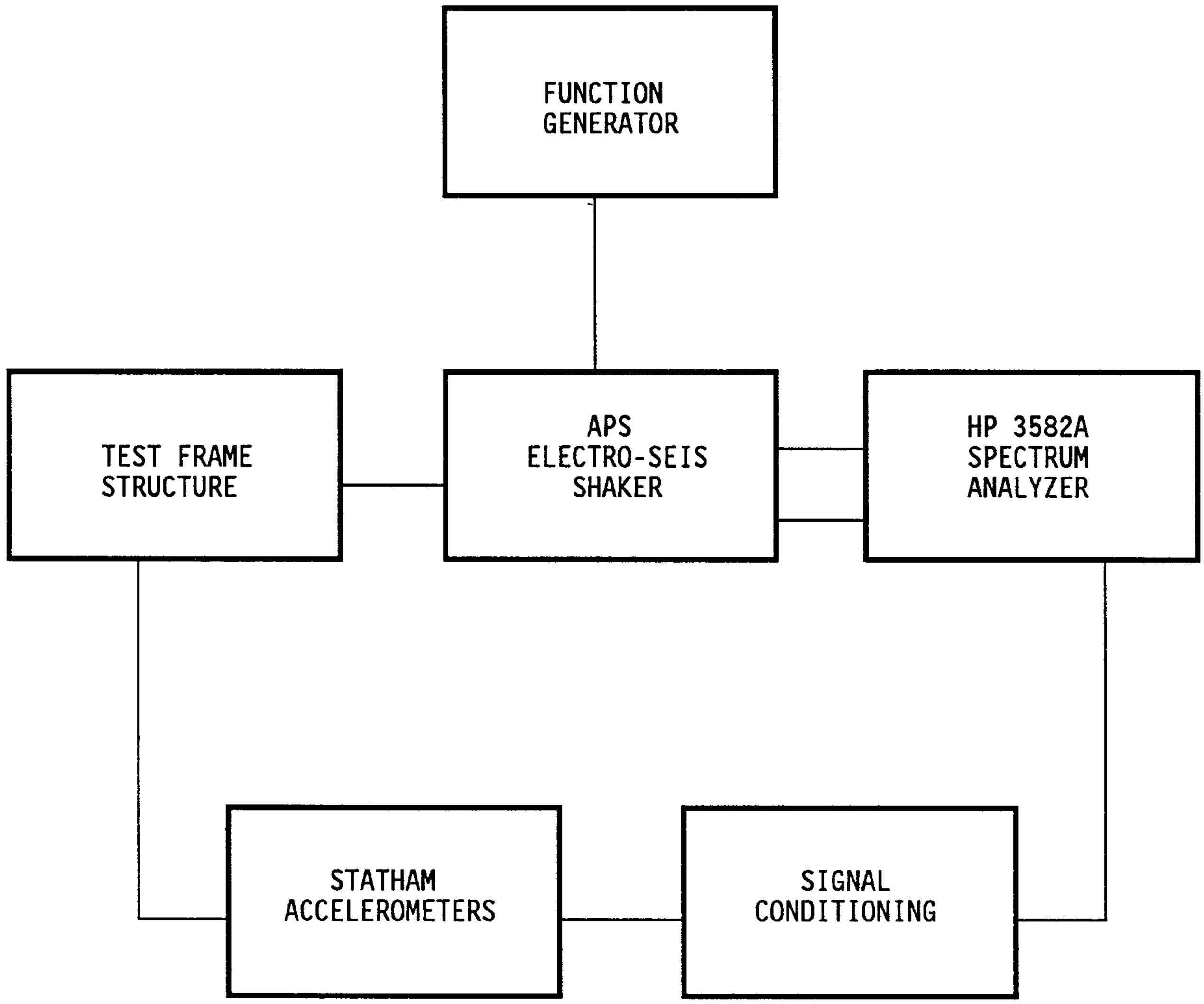


Figure 33 BLOCK DIAGRAM OF DYNAMIC TEST SET-UP

TEST III DYNAMIC TESTING OF MODEL STEEL TEST STRUCTURE

TYPE OF EXCITATION	TEST RUN III-A			TEST RUN III-B			TEST RUN III-C		
	STEEL TEST FRAME WITHOUT CLADDING PANELS			STEEL TEST FRAME WITH ONE CLADDING PANEL ATTACHED TO EAST FACE OF TEST STRUCTURE			STEEL TEST FRAME WITH TWO PRECAST CLADDING PANELS ATTACHED ONE EACH TO THE EAST AND WEST FACES OF THE TEST STRUCTURE		
	ORIENTATION OF SHAKER			ORIENTATION OF SHAKER			ORIENTATION OF SHAKER		
	TRANSVERSE DIRECTION N-S	LONGITU-DINAL DIRECTION E-W	OFF-CENTER TRANSVERSE DIRECTION N-S	TRANSVERSE DIRECTION N-S	LONGITU-DINAL DIRECTION E-W	OFF-CENTER TRANSVERSE DIRECTION N-S	TRANSVERSE DIRECTION N-S	LONGITU-DINAL DIRECTION E-W	OFF-CENTER TRANSVERSE DIRECTION N-S
RANDOM	X	X	X	X	X	X	X	X	X
SINUSOIDAL	X	X	X	X	X	X	X	X	X

TABLE X DYNAMIC TEST RUNS AND TEST PARAMETERS

TEST III-A DYNAMIC TEST OF MOMENT-RESISTING STEEL FRAME STRUCTURE WITHOUT PRECAST CONCRETE FACADE/CLADDING PANELS

MODE	NATURAL FREQUENCY Hz		
	SHORT DIRECTION N-S	LONGITUDINAL DIRECTION E-W	TORSION
First Translational Mode	7.0 Hz	10.6 Hz	
Second Translational Mode	19.75 Hz	39.6 Hz	
First Torsional Mode			13.0 Hz
Second Torsional Mode			43.0 Hz

Table XI SUMMARY OF TEST RESULTS TEST III-A

TEST III-C DYNAMIC TEST OF MOMENT-RESISTING STEEL FRAME STRUCTURE WITH TWO PRECAST CLADDING PANELS ATTACHED ONE EACH TO THE EAST AND WEST FACES (SHORT DIRECTION) OF TEST STRUCTURE

MODE	NATURAL FREQUENCY Hz		
	SHORT DIRECTION N-S	LONGITUDINAL DIRECTION E-W	TORSION
First Translational Mode	5.9 Hz	7.4 Hz	
Second Translational Mode	17.0 Hz	34.5 Hz	
First Torsional Mode			9.2 Hz
Second Torsional Mode			34.8 Hz

Table XII SUMMARY OF TEST RESULTS TEST III-C

CHAPTER 9: ANALYTICAL MODELING OF BEHAVIOR OF CLADDING AND CONNECTIONS

- **Behavior of Thread-Rod Flexible Connections [TEST I]**

Based on an experimentally obtained stress-strain curve for a 5/8-inch diameter threaded-rod, an analytical model for load-deflection prediction of contilever threaded-rod specimens with support conditions similar to those used in practice, was developed.

Details of the analytical model development process are presented below (p.62-66). Figure 34 shows the assumed stress and strain distribution for the cantilever threaded-rod specimens. A block diagram outlining the steps involved in the analytical prediction model is shown in Figure 35. Details of the derivations required to obtain theoretical moment-curvature relations and load-deflection relations are presented on p.65-66.

A polynominal fit to experimental stress-strain curve for a 5/8-inch diameter threaded steel-rod specimen is presented in Figure 13 (Appendix A).

The moment-curvature curve that was obtained with this analytical model is shown in Figure 14 (Appendix A).

Results in the form of Load-Deflection curves obtained with this analytical prediction model for threaded-rod specimens of 4, 6, 8, 10 and 12 inch lengths are presented in Figures 7-11 (Appendix A).

- **In-Plane Behavior of Precast Facades/Claddings and Connection Assemblies [TEST II]**

The behavior of full-scale precast facades/claddings and connection assemblies is very complex, especially under cyclic motions. In light of these complexities only practical and simplified analytical evaluation of results of Test II was carried out.

The basic objective of this analytical evaluation was to obtain an overall behavior model, based on cyclic test results of Test II, and compare this model to the conceptual behavior model used in seismic analysis and design of precast cladding and connections.

Based on peak cyclic lateral force and peak cyclic displacements levels reached in each run of Test II, the proposed analytical behavior model was based on the assumption that the peak lateral-force resistance is controlled by the resistance of the top flexible threaded-rod connections. This concept is presented graphically in Figure 36. A seismic design evaluation of the cladding panel and connections was made to determine if any design changes were necessary to account for the lateral-force resistance provided by the threaded-rod flexible connections.

In any case, the fact remains that a great deal of work needs to be done to improve our understanding of the behavior of cladding panels and connections especially under cyclic motions.

The standard design
calculation for vertical load R transferred to bearing connection is given by Eqn.(1).

$$R = 0.5W + (0.5h)F/b \qquad (1)$$

The effect of binding-force P developed in the threaded-rod lateral connection, on the vertical load R′ transferred to bearing connection is given by Eqn.(2).

$$R' = 0.5W + (0.5h)F/b + (P)(h)/b \qquad (2)$$

The service load-surcharge to bearing angles expressed as a percentage of standard design load is given by Eqn.(3).

$$= 200 \frac{h/b}{1 + 0.4h/b} \cdot \frac{P}{W} \qquad (3)$$

The service load-surcharge to studs in bearing connection expressed as a percentage of standard design load is given by Fig.(4).

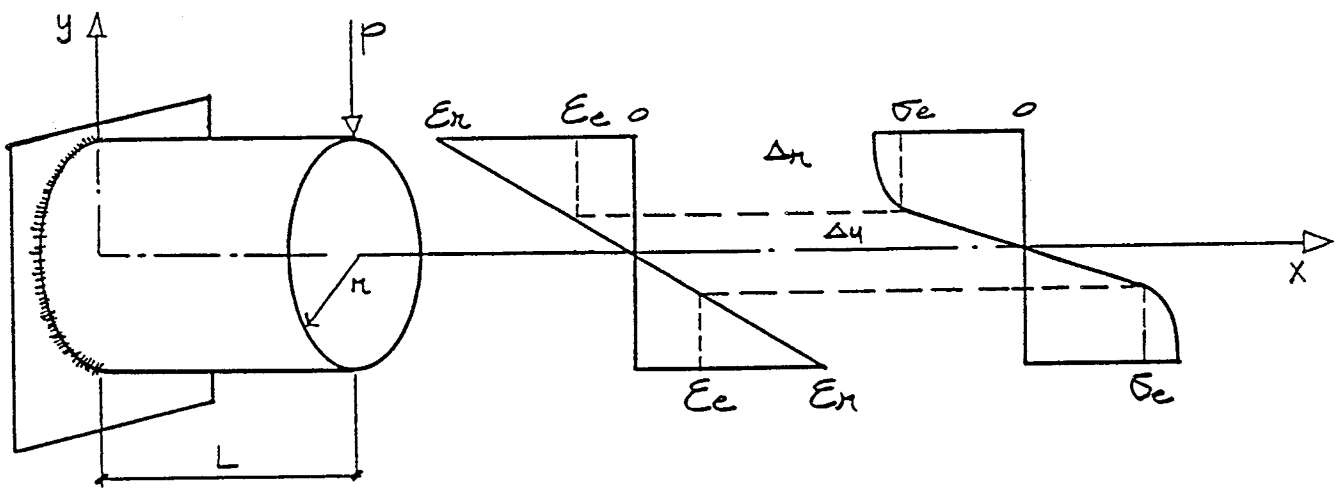
$$= 200 \frac{h/b}{1 + 1.2h/b} \cdot \frac{P}{W} \qquad (4)$$

where W = weight of cladding panel
h = height of threaded-rod lateral connection from the bearing connection
b = horizontal distance between the centerline of the bearing connection
F = Standard Seismic Design Load

- **Modal Response of Two-Story Steel Moment-Resisting Frame Structure With and Without Precast Concrete Cladding Panels (TEST III)**

  The analytical evaluation of modal response results obtained during Test III is still in progress.

  A mode-shape and frequency analysis of the test structure without any cladding panels was carried out using the computer program ETABS, using appropriate modeling to simulate the pinned-base condition assumed. The modal frequencies obtained are presented in Table XIII.



CANTILEVER THREADED-ROD SPECIMEN

STRAIN DIAGRAM

STRESS DIAGRAM

$$\sigma(y) = \sigma_e \left[\frac{\varepsilon(y)}{\varepsilon_e} \right] \quad \varepsilon \leq \varepsilon_e \quad \text{or} \quad y \leq y$$

$$\sigma(y) = \sigma_e \left[\frac{\varepsilon(y)}{\varepsilon_e} \right]^n \quad \varepsilon > \varepsilon_e \quad \text{or} \quad y > y$$

FIG. 34

ANALYTICAL MODEL FOR LOAD-DEFLECTION PREDICTION
TEST I: TESTS OF THREADED-ROD FLEXIBLE CONNECTIONS

VARIABLES AND PARAMETERS

P: LOAD, LBS.

L: ROD LENGTH - INCHES

E: ROD ELASTICITY

r: ROD RADIUS, INCHES

ϕ: CURVATURE = $\varepsilon_r/R = \varepsilon_e/Y$

δ: END DEFLECTION OF ROD ALONE

δ_c: END DEFLECTION DUE TO ROTATION OF RIGID CONNECTION

$\sigma(y)$: STRESS AT y

$\varepsilon(y)$: STRAIN AT y

n: STRAIN HARDENING EXPONENT

ε_r: STRAIN AT $y = r$

ε_e: STRAIN AT YIELD, $y = Y$

σ_e: STRESS AT YIELD, $y = Y$

Y: DISTANCE ELASTIC ZONE EXTENDS ABOVE AND BELOW ROD CENTERLINE

δ_T: $\delta + \delta_c$: TOTAL END DEFLECTION

$m(\phi)$: MOMENT CORRESPONDING TO CURVATURE ϕ

$X(P,L; m(\phi))$: LOCATION ALONG ROD CORRESPONDING TO CURVATURE ϕ

$\sigma_{max}(P,L)$: MAXIMUM STRESS IN ROD FOR GIVEN P,L

CS: CANTILEVER CONNECTION STIFFNESS, LB-IN/RADIAN

ANALYTICAL MODEL FOR LOAD-DEFLECTION PREDICTION
TEST I: TESTS OF THREADED-ROD LATERAL CONNECTIONS

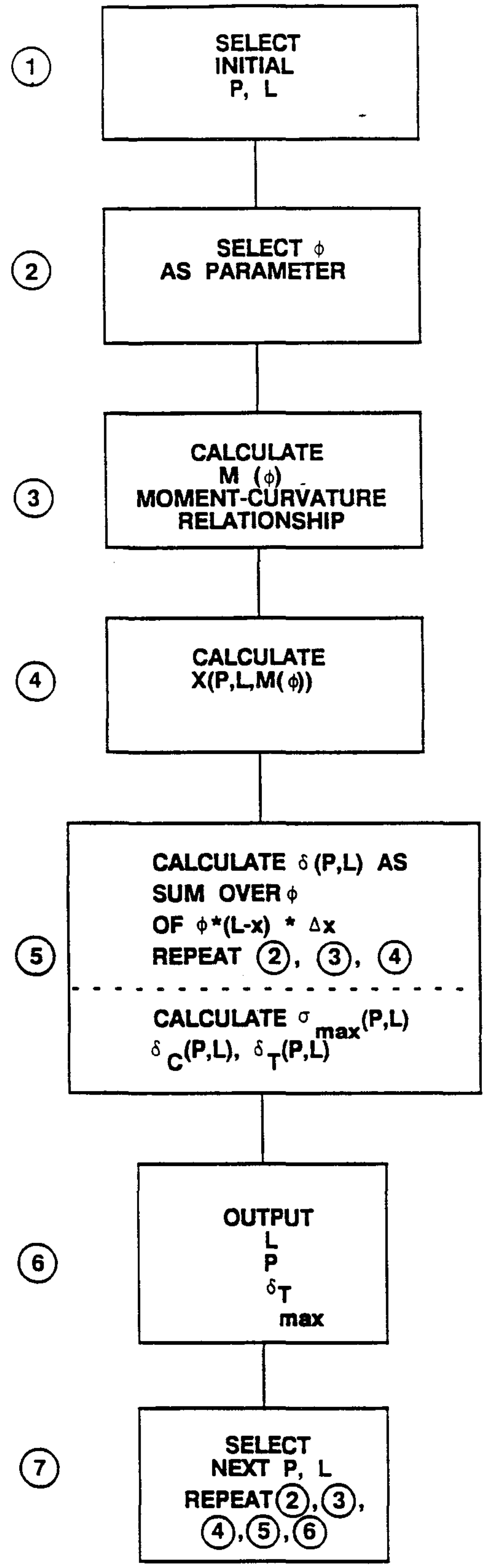


FIG. 35 BLOCK DIAGRAM
ANALYTICAL MODEL FOR LOAD-DEFLECTION PREDICTION

TEST I: TESTS OF THREADED-ROD LATERAL CONNECTIONS

COMPUTATION OF $m(\phi)$ [BLOCK 3]: MOMENT-CURVATURE

(i) For a specific value of Y, the moment m(Y) producing corresponding state of stress/strain is:

$$m(Y) = \int \delta(y) y dA = 2 \int_{-r}^{r} \sigma(y) * y\sqrt{r^2-y^2} \; dy$$

$$= 4\sigma_e [\int_{o}^{y} (\varepsilon/\varepsilon_e) y\sqrt{r^2-y^2} \; dy \; + \int_{y}^{r} (\varepsilon/\varepsilon_e)^n y\sqrt{r^2-y^2} \; dy]$$

$$= 4\sigma_e [\int_{o}^{y} (y/Y) y\sqrt{r^2-y^2} \; dy \; + \int_{y}^{r} (y/Y)^n y\sqrt{r^2-y^2} \; dy]$$

(ii) Substitute ϕ for Y where $Y = \varepsilon_e/\phi = \delta_e/E\,\phi$

$$\boxed{m(\phi) = 4\sigma_e [\int_{o}^{\sigma_e/E\phi} (yE\phi/\sigma_e) * y\sqrt{r^2-y^2} \; dy + \int_{\sigma_e/E\phi}^{r} (yE\phi/\sigma_e)^n * y\sqrt{r^2-y^2} \; dy]}$$

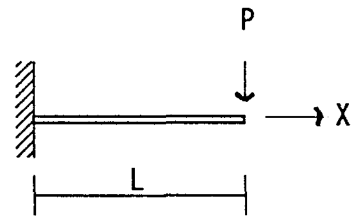
(iii) Numerically this is calculated as a sum over I

$$m(\phi) = \sum_{I} f(\phi, y_I) * \Delta y_I \qquad \text{where } \Delta y_I \text{ is incremented from 0 to r}$$

COMPUTATION OF X(P,L,m(ϕ)) [BLOCK 4]

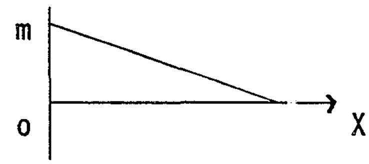
(i) For cantilever

m = P * (L-X)



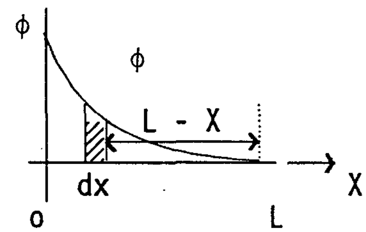
(II) Then

$$\boxed{X(P,L;m(\phi)) = L - m(\phi)/P}$$



COMPUTATION OF δ(P,L) [BLOCK 5]

(i)
$$\boxed{(P,L) = \int_L^0 \phi*[L-X(\phi)] * dx(\phi)}$$



(ii) Numerically this is calculated using ϕ_J as a parameter and summing over J:

$$(P,L) = \sum_J \tfrac{1}{2}\{\phi_J*[L-X(\phi_J)] + \phi_{J-1}*[L-X(\phi_{J-1})]\} * [X(\phi_{J-1})-X(\phi_J)]$$

The moment enters implicitly through X(P,L;m(ϕ))

X is computed for sequential ϕ_J pairs. The iteration sensitivity is interactively varied to assure adequate precision.

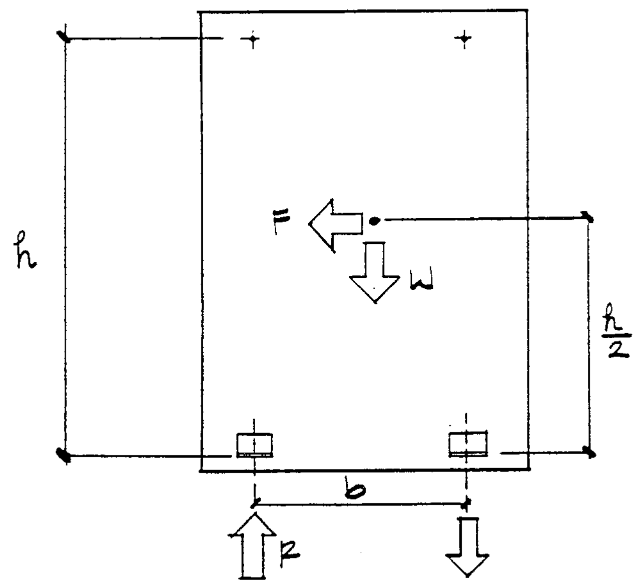
COMPUTATION OF σ_{max} & σ_T [BLOCK 5]

(i)
$$\boxed{\sigma_{max}(P,L) = \sigma_e(r/Y_{min})^n}$$

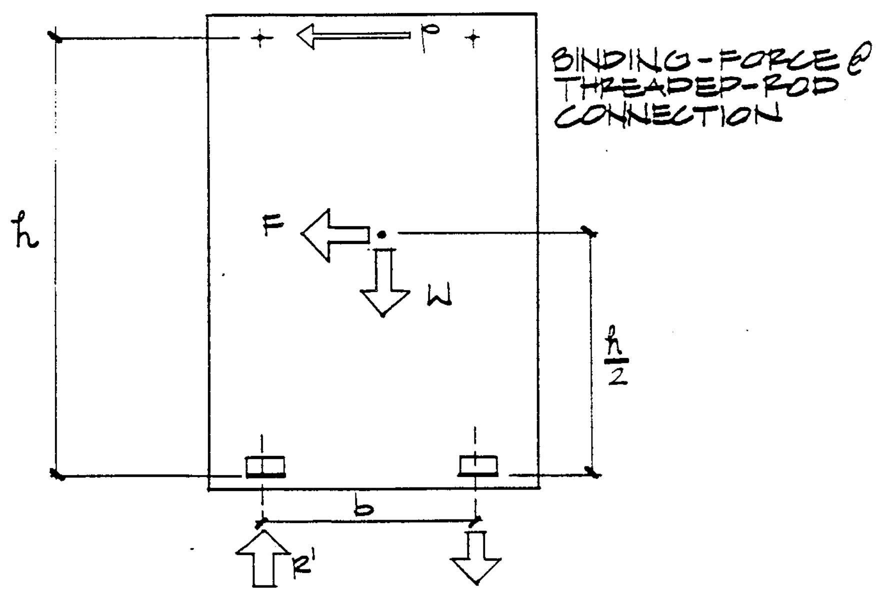
where $2Y_{min}$ is the depth of elastic zone when $m=m_{max} = P\cdot L$

(ii)
$$\boxed{\sigma_T(P,L) = \sigma(P,L) + PL^2/CS}$$

where CS is the stiffness, Lb.-In./Rad. of the support connection of cantilever threaded rod



CONCEPTUAL MODEL OF STANDARD DESIGN PROCEDURE FOR VERTICAL LOAD TRANSFER TO BEARING CONNECTIONS



CONCEPTUAL MODEL OF MODIFIED DESIGN PRODECURE FOR VERTICAL LOAD TRANSFER TO BEARING CONNECTION

Figure 36 Test II
Conceptual Simple Behavior Model for Seismic Analysis and Design of Cladding Panels Connections

ANALYTICAL EVALUATION OF RESULTS OF TEST III-A

MODAL FREQUENCIES OF MOMENT-RESISTING STEEL FRAME STRUCTURE WITHOUT PRECAST CONCRETE FACADE/CLADDING PANELS

MODE	NATURAL FREQUENCY Hz		
	SHORT DIRECTION N-S	LONGITUDINAL DIRECTION E-W	TORSION
FIRST TRANSLATIONAL MODE	4.4 Hz	8.5 Hz	
SECOND TRANSLATIONAL MODE	19.5 Hz	39.6 Hz	
FIRST TORSIONAL MODE			10.9 Hz
SECOND TORSIONAL MODE			49.9 Hz

TABLE XIII

CHAPTER 10: DISCUSSION OF RESULTS AND CONCLUSIONS

BEHAVIOR OF LATERAL/THREADED-ROD CONNECTIONS [TEST I]

- A study of the results of Test I specimens shows that load-capacity of threaded-rod cladding connections decreases with increasing length.
- Behavior of threaded-rod specimen in uniaxial tension shows evidence of strain-hardening that must be considered in design and analysis.
- Load-Deflection behavior of cantilever threaded-rod specimens can be predicted using experimentally obtained stress-strain data with reasonably good correlation between experimental and analytical results. Simple elastic beam theory does not appear to be adequate to explain the load-deflection behavior obtained in these static tests.

CYCLIC BEHAVIOR OF PRECAST CONCRETE CLADDING PANELS AND CONNECTION ASSEMBLY [TEST II]

- In-plane resistance of precast concrete cladding panels is controlled by the resistance provided by the threaded-rod lateral connections at top of panels.
- In all cyclic test runs failure occurred in the threaded-rods at the loading-end of top lateral connections.
- The levels of inter-story drift that can be accommodated by the threaded-rod lateral connections can be established from the drifts at failure which varied from 0.0068 H at 0.1 Hz [6-inch threaded-rod length] to 0.0117H at 0.5 Hz [8-inch threaded-rod length].
- Behavior of threaded-rod connections under cyclic displacements shows that further studies are needed to explain the fracturing mechanism of failures observed possibly caused by low-cycle fatigue.
- The lateral-force resistance offered by the threaded-rod lateral connections at top of panels results in a service-load surcharge on the bearing connections at bottom of the panels, which should be taken into account in the seismic design of precast concrete cladding and connection assemblies.

INFLUENCE OF PRECAST CONCRETE CLADDING PANELS ON MODAL RESPONSE OF STEEL FRAME TEST STRUCTURE [TEST III]

- A preliminary study of the results of shaking tests carried out in Test III shows that the addition of precast cladding panels to the test structure reduced the first translation mode frequency from 7 Hz to 5.9 Hz. (approx. 15.71%) and second translational mode frequency from 19.75 Hz to 17 Hz (approx. 13.92%) in the transverse direction, i.e., parallel to the plane of the cladding panels. These preliminary results show that the stiffening effects of precast concrete cladding are significant and must be considered in the seismic design and analysis of buildings.

BIBLIOGRAPHY

1. AUTHOR: Adham, S.A.

   TITLE: Out-of-Plane Response of Masonry Walls

   SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

   KEYWORDS: Masonry, Out-of-Plane Seismic Loading, Testing, Walls

2. AUTHOR: AIA Research Corporation

   TITLE: Seismic Design for Police and Fire Stations

   SOURCE: AIA Research Corporation, Washington D.C., 1978

   KEYWORDS: Earthquakes, Design, Criteria, Building Components

3. AUTHOR: Algan, Bekir

   TITLE: Drift and Damage Considerations in Earthquake Resistant Design of Reinforced Concrete Buildings

   SOURCE: University of Illinois at Urbana-Champaign, 1976

   KEYWORDS: Earthquakes, Drift, Damage, Reinforced Concrete

4. AUTHOR: Allen, Edward

   TITLE: The Professional Handbook of Building Construction

   SOURCE: John Wiley & Sons, New York, 1985

   KEYWORDS: Cladding, Basic Concepts, Design Requirements, Precast Concrete, Curtain Walls, Masonry, Stone, Veneer, Construction, Details, Building Codes, Building Case Studies

5. AUTHOR: Armhein, James; Kesler, James; Thompson, Leonard; Van Houten, John

   TITLE: Masonry Design Manual

   SOURCE: Masonry Industry Advancement Committee, 1979

   KEYWORDS: Masonry, Veneer, Construction, Details, Practice

6. AUTHOR: Andersen, Arthur B.

TITLE: Steel Frame, Precast Forms Meet Impossible Time Constraints

SOURCE: Civil Engineering, ASCE, February 1976, pp. 54-56

KEYWORDS: Curtain Walls, Steel Frame, Design, Construction, Practice

7. AUTHOR: Applied Technology Council

TITLE: Tentative Provisions for the Development of Seismic Regulations for Buildings, ATC 3-06, 1978

SOURCE: Applied Technology Council, Redwood City, California

KEYWORDS: Earthquakes, Regulations, Design Provisions

8. AUTHOR: Armula, Joseph; Brown, Russell

TITLE: Performance Evaluation of Brick Veneer with Steel Stud-Backup

SOURCE: Clemson University, College of Engineering, Department of Civil Engineering, 1982

KEYWORDS: Masonry, Veneer, Steel Studs, Research, Testing

9. AUTHOR: Arnold, Chris; Hopkins, David; Elsesser, Eric

TITLE: Seismic Design of Architectural Elements. Report submitted to the National Science Foundation, March 1987.

SOURCE: Building System Development, Inc., San Mateo, California

KEYWORDS: Earthquakes, Non-Structural Components, Cladding, Precast Concrete, Glazing, United States, New Zealand, Codes, Standards, Design, Construction Detailing, Practice

10. AUTHOR: Asher, Jefferson W.; Selna, Lawrence G.

TITLE: Anchors for Prefabricated Brick Panels

SOURCE: Proceedings, Third North American Masonry Conference, June

1985, University of Texas, Arlington, Texas

KEYWORDS: Prefabrication, Brick, Anchors, Testing, Failure

11. AUTHOR: Association of the Wall and Ceiling Industries International and Metal Lath/Steel Framing Association

TITLE: Steel Framing Systems Manual

SOURCE: Association of the Wall and Ceiling Industries International and Metal Lath/Steel Framing Association, 1979

KEYWORDS: Facades, Metal Studs, Lath, Details, Erection, Practice

12. AUTHOR: Ayres, J. Marx; Sun, T-Y.; Brown, F.R.

TITLE: Non-Structural Damage to Buildings, The Great Alaska Earthquake of 1964: Engineering

SOURCE: National Academy of Sciences, Washington D.C., 1973

KEYWORDS: Earthquakes, Damage, Facades, Glazing, Brick Veneer, Curtain Walls, Case-Studies, Recommendation

13. AUTHOR: Beall, Christine

TITLE: Masonry Design and Detailing

SOURCE: Prentice-Hall, New Jersey, 1984

KEYWORDS: Masonry, Veneer, Construction, Details, Practice

14. AUTHOR: Bell, Glenn R.; Gumpertz, Werner H.

TITLE: Engineering Evaluation of Brick Veneer/Steel Stud Walls

SOURCE: Proceeding, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Brick, Veneer, Steel Stud Walls, Current Practice, Design, Construction

15. AUTHOR: Bertero, V.; Brokken, Steven

TITLE: Infills in Seismic Resistant Building

SOURCE: Journal of the Structural Division, ASCE, Vol. 109, No. 6, June 1983, pp. 1337-1361

KEYWORDS: Earthquakes, Infills, Masonry, Lightweight Concrete, Reinforced Concrete Frames, Research, Testing, Analysis, Retrofitting, Existing Buildings

16. AUTHOR: Blume, John A. & Associates

TITLE: Report on Structural Damage in Anchorage, Alaska Caused by the Earthquake of March 27, 1964

SOURCE: John A. Blume & Associates, San Francisco, California, January, 1966

KEYWORDS: Earthquakes, Damage, Cladding, Facades, Building Case Studies

17. AUTHOR: Borchelt, J. Gregg

TITLE: Construction Tolerances and Design Considerations for Masonry Veneer and Structural Frames

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Construction, Design, Masonry, Veneer, Structural Frames

18. AUTHOR: Botsai, E.; Goldberg, A.; Fisher, J.; Lagorio, H.; Wosser, T.

TITLE: Architects and Earthquakes

SOURCE: AIA Research Corporation, 1975

KEYWORDS: Earthquakes, Precast Concrete, Cladding, Facades, Damage, Details

19. AUTHOR: Bouwkamp, J.G.; Meehan, J.F.

TITLE: Drift Limitations Imposed by Glass

SOURCE: 2nd World Conference on Earthquake Engineering Vol. 3, 1960

KEYWORDS: Drift Behavior, Glass, Design, Criteria

20. AUTHOR: Brick Institute of America

TITLE: Brick Veneer Existing Construction

SOURCE: Technical Notes on Brick Construction, Brick Institute of America, July/August, 1978

KEYWORDS: Masonry, Veneer, Construction, Details, Practice

21. AUTHOR: Brick Institute of America

TITLE: Brick Veneer Existing Construction

SOURCE: Technical Notes on Brick Construction, Sept/Oct 1978

KEYWORDS: Masonry, Veneer, Construction, Details, Practice

22. AUTHOR: Brick Institute of America

TITLE: Brick Veneer Panel and Curtain Walls

SOURCE: Technical Notes on Brick Construction, Brick Institute of America, February, 1980

KEYWORDS: Masonry, Veneer, Brick, Curtain Walls, Construction, Details, Practice

23. AUTHOR: Brokken, S.T.; Bertero, V.V.

TITLE: Studies on Effects of Infills in Seismic Resistant R/C Construction

SOURCE: Earthquake Engineering Research Center Report, University of California, Berkeley, CA, 1981

KEYWORDS: Masonry, Infills, Earthquakes, Research, Analysis

24. AUTHOR: Brookes, A.J.

TITLE: Cladding Methods in New Zealand--A State of the Art Report

SOURCE: Building Research Association of New Zealand, Technical Paper P40

KEYWORDS: Claddings, Curtain Walls, Design, GRC, Installing, New Zealand, Panels, Precast, Production, Specifying

25. AUTHOR: Brooks, Alan

TITLE: Cladding of Buildings

SOURCE: Construction Press, London, 1983

KEYWORDS: Precast Concrete Cladding, GRP, GRC, Sheet Metal Cladding, Curtain Walls, Construction, Details, United Kingdom

26. AUTHOR: Brown, R.H.; Brown, M.L.; Dalrympale, G.A.

TITLE: Strength and Behavior of Retrofit Embedments in Masonry

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Masonry, Anchorages, Testing

27. AUTHOR: Brown, Russell H.; Armula, Joseph

TITLE: Brick Veneer with Steel Study Backup - An Analytical Study

SOURCE: Proceedings of the 2nd North American Masonry Conference, August, 1982

KEYWORDS: Masonry, Veneer, Steel Study, Research, Testing

28. AUTHOR: Building Seismic Safety Council

TITLE: NEHRP Recommended Provisions for the Development of Seismic Regulations for New Buildings (Prepared for FEMA): Part 1: Provisions, Part 2: Commentary, Part 3: Appendix

SOURCE: Building Seismic Safety Council, Washington D.C.

KEYWORDS: Earthquakes, Seismic Regulation, FEMA, Research

29. AUTHOR: Canada Mortgage and Housing Corporation

TITLE: Exterior Wall Construction in High-Rise Buildings

SOURCE: Canada Mortgage and Housing Corporation, 1980

KEYWORDS: Masonry, Facades, Differential Movements, Details, Practice

30. AUTHOR: Canadian Prestressed Concrete Institute

TITLE: Metric Design Manual

SOURCE: Canadian Prestressed Concrete Institute, 1982

KEYWORDS: Precast Concrete, Design, Details

31. AUTHOR: Cheung, Tong Chun

TITLE: The Seismic Performance of Precast Concrete Facades

SOURCE: M. Arch Thesis, (Dr. S. Rihal, Advisor), School of Architecture and Environmental Design, California Polytechnic State University, San Luis Obispo, June 1985

KEYWORDS: Precast Concrete, Earthquakes, Research

32. AUTHOR: Chin, Ian R.; Stecich, John P.; Erlin, Bernard

TITLE: Design of Thin Stone Veneers on Buildings

SOURCE: Proceeding, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Stone, Veneer, Design

33. AUTHOR: Clough, D.P.

TITLE: Design of Connections for Precast Prestressed Concrete Buildings for the Effects of Earthquakes, Phase Two of the Three-Phase Program

SOURCE: ABAM Engineers Inc., Federal Way, Washington, 98003, (NSF Sponsored Research), March 1985

KEYWORDS: Earthquakes, Precast Concrete, Connections, Research, Analysis, Seismic Design

34. AUTHOR: Dayton Superior Corporation

TITLE: Precast-Prestress Concrete Handbook

SOURCE: Dayton Superior Corporation, 1983

KEYWORDS: Precast Concrete, Construction, Details

35. AUTHOR: de Vekey, R.C.

TITLE: Performance Specifications for Wall Ties

SOURCE: Building Research Information Paper, March 1984

KEYWORDS: Cladding, Masonry, Ties, Performance Standards, Tests

36. AUTHOR: Dickey, Walter L.

TITLE: Adhered Veneer in Earthquake, Storm and Prefabrication

SOURCE: Proceedings of the 2nd North American Masonry Conference, August, 1982

KEYWORDS: Masonry, Veneer, Earthquakes, Prefabrication

37. AUTHOR: Dowrick, David J.

TITLE: Earthquake Resistant Design

SOURCE: John Wiley & Sons, London, 1987

KEYWORDS: Architectural Detailing for Cladding, Earthquake Resistance, Details

38. AUTHOR: Eagling, Donald G.

TITLE: Seismic Safety Guide

SOURCE: Lawrence Berkeley Laboratory, Berkeley, California, no date listed

KEYWORDS: Earthquakes, Safety, Guidelines

39. AUTHOR: Earthquake Engineering Research Institute (EERI)

TITLE: Miyagi-Ken-Oki, Japan Earthquake of June 12, 1978

SOURCE: Reconnaissance Report, Earthquake Engineering Research Insititue, El Cerrito, California, December 1978

KEYWORDS: Precast Cladding, Performance During Earthquakes

40. AUTHOR: Earthquake Engineering Research Institute (EERI)

TITLE: Non-Structural Issues of Seismic Design and Construction

SOURCE: Earthquake Engineering Research Institute, El Cerrito, California, Publication no. 84-04, June 1984

KEYWORDS: Research Needs, Non-Structural Components

41. AUTHOR: Earthquake Engineering Research Insitute (EERI)

TITLE: Technical Briefing on the September 19, 1985 Earthquake in Mexico

SOURCE: Earthquake Engineering Research Institute

KEYWORDS: 1985 Mexico City, Mexico Earthquake

42. AUTHOR: Earthquake Engineering Research Institute (EERI)

TITLE: 2nd U.S.-Mexico Workshop on 1985 Mexico Earthquake Research, Mexico City, Mexico, November, 1987.

SOURCE: Earthquake Engineering Research Institute, Research Program Reports.

KEYWORDS: 1985 Mexico City, Mexico Earthquake, U.S.-Mexico Research-in-Progress.

43. AUTHOR: Eaton, Keith J.

TITLE: "Cladding and the Wind"

SOURCE: Journal of the Structural Division, ASCE, Vol. 102, No. ST5, May 1976, pp. 1043-1058

KEYWORDS: Cladding, Research

44. AUTHOR: Edgell, G.J.; West, H.W.H.

TITLE: The Effect of Wall-Tie Spacing on the Strength of Cavity Wall: a Review

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Testing, Masonry, Connections

45. AUTHOR: El-Dakhakhni, Wagih M.

TITLE: Shear of Light Partitions in Tall Buildings

SOURCE: Journal of the Structural Division, ASCE, Vol. 102, No. ST7, July, 1976, pp. 1431-1445

KEYWORDS: Fabrication, Fasteners, Flexibility, Frames, Shear, Walls

46. AUTHOR: Engineering News Record

TITLE: Facades: Errors Can Be Expensive

SOURCE: Engineering News Record, January 24, 1980

KEYWORDS: Facade, Failure, Damage

47. AUTHOR: Engineering News Record

TITLE: Symposium Tags Ignorance as Root of Facade Problems

SOURCE: Engineering News Record, December 11, 1980

KEYWORDS: Facade, Failure, Damage

48. AUTHOR: Engineering News Record

TITLE: Lack of Design Data, New Building Techniques Cause Facade Failures

SOURCE: Engineering News Record, February 2, 1978

KEYWORDS: Facade, Failure, Damage

49. AUTHOR: Engineering News Record

TITLE: Designing Brick Masonry Walls to Avoid Structural Problems

SOURCE: Engineering News Record, October, 1977

KEYWORDS: Masonry, Differential Movements, Design

50. AUTHOR: Engineering News Record

TITLE: Marble Falls from Skyscraper Facade

SOURCE: Engineering News Record, December 23, 1976

KEYWORDS: Facades, Marble, Damage

51. AUTHOR: Engineering News Record

TITLE: Brick Clad Concrete Proves Troublesome

SOURCE: Engineering News Record, August 25, 1977

KEYWORDS: Masonry, Brick, Facades, Problems

52. AUTHOR: Foster, Jack; Harington, Raymond

TITLE: Structure & Fabric Part 2

SOURCE: B.T. Batsford Ltd, London, 1976

KEYWORDS: Claddings, Facades, Construction, Details, United Kingdom

53. AUTHOR: Fratessa, Paul F. & Associates

TITLE: Example of GFRC and precast concrete panel calculations

SOURCE: Fratessa, Paul F. & Associates, Oakland, California, 1980-1984

KEYWORDS: Precast Concrete Cladding, GFRC Cladding, Design, Details, Current Practice

54. AUTHOR: Freeland, Gary E.

TITLE: Lawrence Livermore National Earthquake Safety Program

SOURCE: Lawrence Livermore National Laboratory, Livermore, California, 1984

55. AUTHOR: Freeman, Sigmund

TITLE: Seismic Design Criteria for Multistory Precast Prestressed Buildings

SOURCE: PCI Journal, May/June, 1979

KEYWORDS: Precast Concrete, Earthquakes, Design Criteria

56. AUTHOR: Freeman, S.A.

TITLE: Drift Limits: Are They Realistic?

SOURCE: Structural Moments, Structural Engineers Association of Northern California, No. 4, May 1980

KEYWORDS: Drift, Earthquakes, Non-Structural Damage, Guidelines, Examples

57. AUTHOR: Freeman, S.A.; Honda, K.K.

TITLE: Response of Two Identical Seven-Story Structures to the San Fernando Earthquake of February 9, 1971

SOURCE: John A. Blume & Associates, San Francisco, California, 1973

KEYWORDS: Earthquakes, Non-Structural Damage

58. AUTHOR: Friedman, Jack P.; Harris, Jack C.

TITLE: A Critical Comparison of Office Building Facade Materials: Brick Versus Glass

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Brick, Glass, Facade

59. AUTHOR: Gail Architectural Ceramics

TITLE: Prefabricated Brickplate Panels for High-Rise Exteriors

SOURCE: Gail Architectural Ceramics, Tustin, California, 1980

KEYWORDS: Facades, Brick Veneer, Stud Frame, Prefabricated Panels, Connection

60. AUTHOR: Gates, William

TITLE: Parts and Portions of Structures

SOURCE: Dames and Moore Consulting Engineers, Los Angeles, California, March 14, 1983

KEYWORDS: Cladding, Design, Current Practice

61. AUTHOR: Girija Vallabhan, C.V.; Chou, Gee David

TITLE: Interactive Nonlinear Analysis of Insulating Glass Units

SOURCE: Journal of Structural Engineering, Col. 112, No. 6, June, 1986

KEYWORDS: Glass, Cladding, Analysis, Interaction

62. AUTHOR: Girija Vallabhan, C.V.; Wang, Bob Yao-Ting; Chou, Gee David; Minor, Joseph E.

TITLE: Thin Glass Plates on Elastic Supports

SOURCE: Journal of Structural Engineering, Vol. 111, No. 11, November, 1985, ASCE

KEYWORDS: Facade, Glass, Wind, Analysis, Elastic Supports

63. AUTHOR: Gjelsvik, Atle

TITLE: Frames and Precast Panel Walls

SOURCE: Journal of the Structural Division, ASCE, Vol. 100, No. ST2, February, 1974, pp. 405-426

KEYWORDS: Precast Concrete, Cladding, Frames, Design, Plastic Analysis, Stiffness, Walls, Interaction, Lateral Bracing

64. AUTHOR: Glogau, O.A.

TITLE: Separation of Non-Structural Components in Buildings

SOURCE: Bulletin of the New Zealand National Society of Earthquake Engineering

KEYWORDS: Precast Concrete, Cladding, Earthquakes, Detailing, Separation, Current Practice, New Zealand

65. AUTHOR: Glogau, O.A.

TITLE: Damage Control in New Zealand Public Buildings Through Separation on Nonstructural Components

SOURCE: 6th World Conference on Earthquake Engineering, 1977

KEYWORDS: Precast Concrete, Cladding, Earthquakes, Detailing, Separation, Current Practice, New Zealand

66. AUTHOR: Goodno, B.J.; Craig, J.I.

TITLE: Response Studies of Glass Cladding Panels

SOURCE: Proceedings, Symposium on Behavior of Building Systems and Building Components, Department of Civil Engineering, Vanderbilt University, Nashville, Tennessee, 1979

KEYWORDS: Cladding, Glass, Analytical Modelling, Dynamic Testing, Research

67. AUTHOR: Goodno, B.J.; Craig, J.I.; Meyyappa, M.; Palsson, H.

TITLE: Cladding-Structure Interaction in Highrise Building

SOURCE: Georgia Institute of Technology, School of Civil Engineering and Aerospace Engineering, January 1983

KEYWORDS: Precast Concrete, Cladding, Cladding-Structure Interaction, Research, Analysis, Behavior

68. AUTHOR: Goodno, Barry J.; Palsson, Hafsteinn

TITLE: Analytical Studies of Building Cladding

SOURCE: Journal of Structural Engineering, Vol. 112, No. 4, April, 1986, ASCE

KEYWORDS: Cladding, Precast Concrete, Measurements, Testing, Research, Analysis, Lateral Stiffening Effect, Vibration Measurements

69. AUTHOR: Goodno, B.J. and Pineli, Jean-Paul

TITLE: The Role of Cladding in Seismic Response of Low-Rise Buildings in the Southeastern U.S.

SOURCE: Proceedings, Third U.S. National Conference on Earthquake Engineering, Charleston, S.C., Vol. II, 1986

KEYWORDS: Precast Cladding, Seismic Analysis, Connections

70. AUTHOR: Gordon, Douglas E.

TITLE: Curtain-Wall Connections: The Search for Strength, Flexibility and Watertightness

SOURCE: Architectural Technology, May/June, 1986, AIA

KEYWORDS: Curtain Wall, Connections, Architectural, Construction

71. AUTHOR: Grimm, Clayford

TITLE: Metal Ties and Anchors for Brick Walls

SOURCE: ASCE, April 1976

KEYWORDS: Masonry, Brick, Metal Ties, Anchors

72. AUTHOR: Grimm, Clayford

TITLE: Design for Differential Movement in Brick Walls

SOURCE: ASCE, November, 1975

KEYWORDS: Masonry, Brick, Differential Movements, Design

73. AUTHOR: Ha, H.K.

TITLE: Lateral Load Behavior of Multistory Frames Stiffened with Corrugated Panels

SOURCE: Proceedings, Symposium on Behavior of Building Systems and Building Components, Department of Civil Engineering, Vanderbilt University, Nashville, Tennessee, 1979

KEYWORDS: Drift, Cladding, Corrugated Steel Panels, Analytical Models

74. AUTHOR: Hatzinikolas, M.; Longworth, J.; Warwaruk, J.

TITLE: Corrugated Strip Ties in Curtain Wall Construction

SOURCE: Proceedings 2nd North American Masonry Conference, August, 1982

KEYWORDS: Masonry, Curtain Walls, Metal Ties

75. AUTHOR: Hatzinikolas, M.; Pacholok, R.

TITLE: Prefabricated Masonry

SOURCE: Proceeding, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Prefabrication, Masonry, Design

76. AUTHOR: Hawkins, N.M.

TITLE: Seismic Resistance of Prestressed and Precast Concrete Structures: State-of-the-Art Report

SOURCE: Journal of the PCI, Nov./Dec. 1978

KEYWORDS: Precast Concrete, Seismic Design, Research, Connections, Details, Test Results, Analysis

77. AUTHOR: Heller, Barbara

TITLE: The Pros and Cons of Prefabricated Panels

SOURCE: Architectural Technology, Journal, AIA, Washington D.C., Fall 1983

KEYWORDS: Cladding, Panels, Prefabrication, Construction, Details, GFRC, Brick Veneer, Curtain Wall

78. AUTHOR: Henry, Robert M.

TITLE: Cladding Frame Interaction of a Reinforced Concrete Building

SOURCE: Ph.D. Dissertation for University of Pennsylvania, Department of Civil and Urban Engineering, 1980

KEYWORDS: Precast Concrete, Cladding, Cladding-Structure Interaction, Research, Analysis, Behavior

79. AUTHOR: Higgins Brick Company

TITLE: Prefabricated Masonry Panel Anchorage Inserts, I.C.B.O. Evaluation Report No. 4268

SOURCE: Higgins Brick Company, I.C.B.O. Evaluation Report No. 4268, Redondo Beach, California, August 1985

KEYWORDS: Facades, Masonry, Prefabricated Panels, Connections, Anchorage Inserts, Allowable Loads, Details

80. AUTHOR: Hotz, Roger W.

TITLE: Special Considerations in Designing Cladding Attachments

SOURCE: Modern Steel Construction, Third Quarter 1982

KEYWORDS: Cladding, Attachments, Design, Installation

81. AUTHOR: Huntington, Bert; Huntington, Craig

TITLE: Design Guidelines for GFRC Panels

SOURCE: Architectural Technology, Winter, 1985

KEYWORDS: Cladding, GFRC, Guidelines, Design, Details, Practice

82. AUTHOR: Indiana Limestone Institute

TITLE: Preassembled Indiana Limestone Facade

SOURCE: Civil Engineering, ASCE, January 1973

KEYWORDS: Facades, Limestone, Preassembled Units, Connections, Details, Erection, Practice

83. AUTHOR: International Association for Earthquake Engineering

TITLE: Earthquake Resistant Regulations: A World List

SOURCE: International Association for Earthquake Engineering

KEYWORDS: Earthquakes, Worldwide Regulations, Design

84. AUTHOR: International Association for Earthquake Engineering

TITLE: Basic Concepts of Seismic Codes Vol. 2

SOURCE: International Association for Earthquake Engineering, Tokyo, 1982

KEYWORDS: Earthquakes, Design, Worldwide Regulations

85. AUTHOR: International Association for Earthquake Engineering

TITLE: Basic Concepts of Seismic Codes Vol. 1

SOURCE: International Association for Earthquake Engineering, Tokyo, 1980

KEYWORDS: Earthquakes, Design, Worldwide Regulations

86. AUTHOR: International Conference of Building Officials

TITLE: Uniform Building Code, 1985, 1988 Edition

SOURCE: International Conference of Building Officials, Whittier, California

KEYWORDS: Non-Structural Components, Seismic Design, Drift, Exterior Elements and Connections

87. AUTHOR: Joint Committee on Review and Refinement of ATC 3-06 Tentative Seismic Provisions

TITLE: Report of Technical Committee 8: Architectural, Mechanical and Electrical

SOURCE: National Bureau of Standards NBSIR 80-2111-8, 1980

KEYWORDS: Earthquakes, Design Provisions, Regulations

88. AUTHOR: Keller, H.; Suter, G.T.

TITLE: Concrete Masonry Veneer Distress

SOURCE: Proceeding, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Masonry, Veneer, Problems, Investigation, Details

89. AUTHOR: Lafayette Manufacturing Incorporated

TITLE: Product Manual for GFRC

SOURCE: Lafayette Manufacturing Incorporated, Hayward, California

KEYWORDS: Cladding, GFRC, Product Manual, Fabrication, Practice

90. AUTHOR: Limperis, Thomas

TITLE: Design of Cladding Attachments for High-Rise Steel Buildings

SOURCE: Modern Steel Construction, Second Quarter 1982

KEYWORDS: Cladding, Attachments, Facade, Design, Curtain Walls

91. AUTHOR: Martin, L.D.; Korkosz, W.J.

TITLE: Connections for Precast Prestressed Concrete Buildings

SOURCE: Prestressed Concrete Institute, 1982

KEYWORDS: Precast Concrete, Connections, Details, Current Practice

92. AUTHOR: Masonry Institute of America

TITLE: Marble Veneer

SOURCE: Masonry Institute of America, Los Angeles

KEYWORDS: Facades, Veneer, Brick, Steel Studs, Details, Construction

93. AUTHOR: McCue, Gerald; Skaff, Ann; Boyce, John

TITLE: Architectural Design of Building Components for Earthquakes

SOURCE: MBT Associates, San Francisco, California, 1978

KEYWORDS: Earthquakes, Building Components, Conceptual Design, Detailing

94. AUTHOR: Meehan, J.F.

TITLE: Masonry Veneer Anchorage Details-Personal Communication

SOURCE: Meehan, J.F., Head, Structural Safety Section, Office of the State Architects, 1983

KEYWORDS: Masonry, Veneer, Connections, Anchorages, Details

95. AUTHOR: Metal Lath/Steel Framing Association

TITLE: Here Are the Facts About Steel Framing-Brick Veneer Systems Design

SOURCE: Metal Lath/Steel Framing Association

KEYWORDS: Facades, Veneer, Brick, Steel Studs, Details, Construction

96. AUTHOR: Moore, J.F.A.

TITLE: The Use of Glass-Reinforced Cement in Cladding Panels

SOURCE: Building Research Establishment Information Paper, IP 5/84, United Kingdom

KEYWORDS: Cladding, GRC, Cracking Performance, Materials Data, Analysis, Design Parameters

97. AUTHOR: Morris, A.E.J.

TITLE: Precast Concrete Cladding

SOURCE: The Fountain Press, London, 1966

KEYWORDS: Precast Concrete, Cladding, General, Practice, United Kingdom

98. AUTHOR: Morris, A.E.J.

TITLE: Precast Concrete in Architecture

SOURCE: George Godwin Ltd, London, 1978

KEYWORDS: Precast Concrete, Cladding, General, Practice, United Kingdom

99. AUTHOR: National Concrete Masonry Association

TITLE: Connecting Concrete Masonry to Adjoining Construction

SOURCE: National Concrete Masonry Association, No. 21, 1970

KEYWORDS: Masonry, Veneer, Metal Ties, Anchorage, Connections, Construction

100. AUTHOR: Neuss, C.F.; Maison, B.F.; Bouwkamp, J.G.

TITLE: A Study of Computer Modelling Formulation and Special Analytical Procedures for Earthquake Response of Multistory Buildings

SOURCE: J.G. Bouwkamp, Inc., Berkeley, California, January, 1983

KEYWORDS: Earthquakes, Analytical Modelling, Experimental Studies, Case Studies, Approximate Seismic Analysis

101. AUTHOR: Office of the State Architect, California

TITLE: Title 24, California Administrative Code, Chapter 2-30 - Veneer Requirements

SOURCE: Mr. Jack Mechan, Head, Structural Safety Section, Office of the State Architect, Sacramento, California, 1983

KEYWORDS: Masonry, Earthquakes, Veneer, Connections, Anchorages, State Regulations, Codes and Standards

102. AUTHOR: Palsson, Hafsteinn; Goodno, Barry; Craig, James; Will, Kenneth

TITLE: Cladding Influence on Dynamic Response of Tall Buildings

SOURCE: Earthquake Engineering and Structural Dynamics, Vol. 12, 1983

KEYWORDS: Precast Concrete, Cladding, Cladding-Structure Interaction, Research, Analysis, Behavior

103. AUTHOR: Phillips, William; Sheppard, David

TITLE: Plant Cast Precast and Prestressed Concrete

SOURCE: Prestressed Concrete Manufacturers Association of California Inc., 1977

KEYWORDS: Precast Concrete, Cladding, Design, Practice

104. AUTHOR: Pinney, William E.

TITLE: Comparative Analysis of Life Cycle Costs of Brick and Wood Exterior Single Family Dwellings

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Brick, Wood, Cost Comparison, Veneer

105. AUTHOR: Portland Cement Association

TITLE: Building Movements and Joints

SOURCE: Portland Cement Association, Skokie, Illinois, 1982

KEYWORDS: Differential Movements, Joints

106. AUTHOR: Prestressed Concrete Institute

TITLE: PCI Design Handbook 3rd Edition

SOURCE: Prestressed Concrete Institute, 1985

KEYWORDS: Precast Concrete, Design, Details, Practice

107. AUTHOR: Prestressed Concrete Institute

TITLE: Glass Fiber Reinforced Concrete Cladding

SOURCE: Prestressed Concrete Institute, Chicago, Illinois

KEYWORDS: Cladding, GFRC, Design, Guidelines

108. AUTHOR: Prestressed Concrete Institute

TITLE: PCI Manual for Structural Design of Architectural Precast Concrete

SOURCE: Prestressed Concrete Institute, 1866

KEYWORDS: Precast Concrete, Cladding, Design, Details, Practice

109. AUTHOR: Prestressed Concrete Institute

TITLE: Architectural Precast Concrete

SOURCE: Prestressed Concrete Institute, 1973

KEYWORDS: Precast Concrete, Construction, Details, Practice

110. AUTHOR: Prestressed Concrete Institute Committee on Connection Details

TITLE: PCI Manual on Design of Connections for Precast Prestressed Concrete

SOURCE: Prestressed Concrete Institute, 1973

KEYWORDS: Precast Concrete, Connections, Design, Details

111. AUTHOR: Priestley, M.J.N.; Thorby, P.N.; McLarin, M.W.; Bridgeman, D.O.

TITLE: Dynamic Performance of Brick Masonry Veneer Panels

SOURCE: South Pacific Regional Conference on Earthquake Engineering, Vol. 2, Wellington, New Zealand, 1979

KEYWORDS: Facades, Masonry, Veneer, Research, Testing

112. AUTHOR: Proceedings from

TITLE: Proceedings, Workshop on Design of Prefabricated Concrete Buildings for Earthquake Loads, 1981

SOURCE: Applied Technology Council, Berkeley, California

KEYWORDS: Precast Concrete, State-of-the-Art, Seismic Design, Wall Systems, Connections, Details, Testing, Practice, Research Needs

113. AUTHOR: Rainger, Philip

TITLE: Movement Control in the Fabric of Buildings

SOURCE: Batsford Academic and Educational Ltd, London, Nichols Publishing Company, London, 1983

KEYWORDS: Movement, Design, Wall Claddings

114. AUTHOR: Reitherman, Robert

TITLE: Reducing the Risks of Non-Structural Earthquake Damage: A Practical Guide

SOURCE: California Seismic Safety Commission, Sacramento, California, 1983

KEYWORDS: Earthquakes, Non-Structural Damage, Guidelines

115. AUTHOR: Rivero, C.E.; Walker, W.H.

TITLE: A Model to Study the Interaction of Frames and Infill Masonry Walls

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Masonry, Infill Walls, Frames, Interaction, Analysis

116. AUTHOR: Ross, Steven S.

TITLE: Construction Disasters

SOURCE: McGraw-Hill, New York, 1984

KEYWORDS: Facades, Cladding, Earthquakes, Wind, Damage

117. AUTHOR: Sabol, Tom A.; Hart, G.C.

TITLE: Non-Structural Element Seismic Damage Evaluation Methodology

SOURCE: Englekirk and Hart Consulting Engineers, Inc., Los Angeles, California, July 1984

KEYWORDS: Earthquakes, Non-Structural Damage, Methodology, Architectural Components, Research

118. AUTHOR: Sack, Ronald L., et al

TITLE: Seismic Behavior of Precast Curtain Walls in High-Rise Buildings, Final Project Report to the National Science Foundation (NSF Grant No. PFR-7720884)

SOURCE: Department of Civil Engineering, University of Idaho, Moscow, Idaho 83843, January 1981

KEYWORDS: Precast Cladding, Curtain Walls, Earthquakes, Research, Testing, Connections

119. AUTHOR: Sakamoto, Isao

TITLE: Seismic Performance of Non-structural and Secondary Structural Elements

SOURCE: Earthquake Engineering Research Center, College of Engineering, U.C. of Berkeley, Berkeley, California, June 1978

KEYWORDS: Earthquake, Non-structural, Secondary Elements

120. AUTHOR: Sands, Herman

TITLE: Wall Systems

SOURCE: McGraw-Hill Book Company, New York, 1986

KEYWORDS: Cladding, Facades, Curtain Walls, Details, Construction, Building Case Studies

121. AUTHOR: Schaupp, Wilhelm

TITLE: External Walls

SOURCE: Crosby Lockwood & Sons, Ltd., London, 1967

KEYWORDS: Cladding, Facades, Sheetmetal Wall Cladding, Wall Cladding with Glass, Materials, Construction, Testing

122. AUTHOR: Selna, Lawrence G.

TITLE: Test Report on Anchorage for Prefabricated Masonry Systems

SOURCE: Proceedings Structural Engineers Association of California Annual Convention, Coronado, California, 1983

KEYWORDS: Facades, Masonry, Prefabrication, Connections, Anchorages, Research, Testing

123. AUTHOR: Selna, Lawrence G.; Asher, Jefferson W.

TITLE: Use of Prefabricated Brick Panels on a Four Story Building

SOURCE: Proceedings, Third North American Masonry Conference, June, 1985, University of Texas, Arlington, Texas

KEYWORDS: Prefabrication, Brick Panels, Design

124. AUTHOR: Sheppard, David A.

TITLE: Seismic Design of Plant Cast Precast Concrete Cladding Panels for Buildings

SOURCE: Prestressed Concrete Institute, 1979

KEYWORDS: Precast Concrete, Cladding, Design, Details, Practice

125. AUTHOR: Skidmore, Owings and Merrill, San Francisco, California

TITLE: Facade/Cladding Systems-Design Data, 1986

SOURCE: Skidmore, Owings and Merrill, San Francisco, California

KEYWORDS: Precast Concrete Cladding, Medium-Rise Buildings, Seismic Design, Erection, Connections, Details, Building Case Studies

126. AUTHOR: Sozen, Mete A.

TITLE: Lateral Drift of Reinforced Concrete Structures Subjected to Strong Ground Motion

SOURCE: Proceedings of the Third South Pacific Regional Conference on Earthquake Engineering, Wellington, New Zealand

KEYWORDS: Earthquakes, Drift, Damage, Design Criteria

127. AUTHOR: Standards Association of New Zealand

TITLE: New Zealand Code of Practice for General Structural Design and Design Loading for Buildings

SOURCE: Standards Association of New Zealand, Wellington, New Zealand, 1976

KEYWORDS: Cladding, Codes, Regulations, Current Practice, New Zealand

128. AUTHOR: Steinbrugge, Karl; Cloud, William; Scott, Nina

TITLE: The Santa Rosa California Earthquakes of October 1, 1969

SOURCE: U.S. Department of Commerce, 1970

KEYWORDS: Earthquake, Damage

129. AUTHOR: Steinhardt, Otto; Scalzi, John; Vanmark, Erik

TITLE: Structural Design of Tall Steel Buildings

SOURCE: American Society of Civil Engineers, New York, 1979

130. AUTHOR: Stockbridge, Jerry

TITLE: The Interaction Between Exterior Walls and Building Frames in Historic Tall Buildings

SOURCE: Development in Tall Buildings, 1983, Hutchinson Ross, Stroudsberg PA, 1983

KEYWORDS: Facades, Masonry, Building Frame, Interaction, Research

131. AUTHOR: Stockbridge, Jerry G.

TITLE: Woolworth Building Renovation - Precast Concrete Used for Terra Cotta Facade

SOURCE: PCI Journal, July/August, 1983

KEYWORDS: Precast Concrete, Terra Cotta, Facade, Renovation

132. AUTHOR: Stockbridge, Jerry G.

TITLE: Experimental Methods for Evaluation of the Condition of Facades to Resist Seismic Forces

SOURCE: Eighth World Conference on Earthquake Engineering, San Francisco, California, 1984

KEYWORDS: Earthquakes, Facades, Conditions Assessment, Testing, Current Practice

133. AUTHOR: Structural Engineers Association of California

TITLE: Recommended Lateral Force Requirements and Commentary

SOURCE: Structural Engineers Association of California, San Francisco, California, 1988

KEYWORDS: Non-Structural Elements, Seismic Design, Connections, Drift

134. AUTHOR: Suter, G.T. and J.S. Hall

TITLE: How Safe Are Our Cladding Connections?

SOURCE: Proceedings, First Canadian Masonry Symposium, The University of Calgary, Alberta, Canada, June 7-10, 1976

KEYWORDS: Cladding, Connections, Masonry, Detailing, Study

135. AUTHOR: Tawresey, John G.

TITLE: Factors of Safety for Masonry Connections

SOURCE: Proceedings, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Masonry, Connections

136. AUTHOR: Teal, E.J.

TITLE: Seismic Drift Control and Building Periods

SOURCE: Engineering Journal, Second Quarter, 1978, Vol. 15, No. 2, AISC, Chicago, Illinois

KEYWORDS: Earthquakes, Drift, Building Period

137. AUTHOR: Teal, E.J.

TITLE: Seismic Drift Control Criteria

SOURCE: Engineering Journal, Second Quarter, 1975, AISC, Chicago, Illinois, pp. 56-67

KEYWORDS: Earthquakes, Drift, Design, Criteria

138. AUTHOR: Toomath, S. William

TITLE: Architectural Detailing for Earthquake Movement

SOURCE: not listed

KEYWORDS: not listed

139. AUTHOR: Tri-Services, Department of the Army, The Navy and the Air Force

TITLE: Seismic Design for Buildings

SOURCE: Tri-Services, Department of the Army, The Navy and the Air Force

KEYWORDS: Non-Structural Components, Seismic Design, Drift, Exterior Elements and Connections

140. AUTHOR: U.S. Department of Commerce

TITLE: San Fernando, California Earthquake of February 9, 1971, Volumes I, II and III, 1973

SOURCE: National Oceanic and Atmospheric Administration, U.S. Department of Commerce, Washington D.C., 1973

KEYWORDS: Earthquakes, Damage, Building Case Studies, Non-Structural Damage

141. AUTHOR: Uchida, N.; Aoyagi, T.; Kawamura, M.; Nakagawa, K.

TITLE: Vibration Test of Steel Frame Having Precast Concrete Panels

SOURCE: Proceedings 5th World Conference on Earthquake Engineering Vol. 1, Rome, 1973

KEYWORDS: Precast Concrete, Cladding, Steel Frame, Earthquake, Research Testing

142. AUTHOR: United States Gypsum

TITLE: USG Curtain Wall Systems

SOURCE: United States Gypsum Co., 1979

KEYWORDS: Curtain Walls, Erection, Details

143. AUTHOR: URS/John A. Blume & Associates

TITLE: Seismic Design Guidelines for Essential Buildings

SOURCE: URS/John A. Blume & Associates,

KEYWORDS: Earthquakes, Design Guidelines, Non-Structural Elements, Essential Buildings

144. AUTHOR: Vogel & Meyer Partnership

TITLE: Examples of Calculations and Details

SOURCE: Vogel & Meyer Partnership, Walnut Creek, California, February, 1985

KEYWORDS: Precast Concrete, Cladding, Design, Details, Current Practice

145. AUTHOR: Waddell, Joseph

TITLE: Precast Concrete: Handling and Erection

SOURCE: Iowa State University Press, Ames, Iowa and American Concrete Institute, Detroit, 1974

KEYWORDS: Precast Concrete, Cladding, Erection, Details, Practice

146. AUTHOR: Wallis, Rick W.

TITLE: Designing Glass Panels Against Wind

SOURCE: Civil Engineering, May, 1961

KEYWORDS: Glass, Facades, Wind, Design

147. AUTHOR: Wang, Marcy Li

TITLE: Non-Structural Element Test Phase, U.S. Side Final Report to the National Science Foundation, U.S.-Japan Cooperation Research Project

SOURCE: Center for Environmental Design Research, University of California, Berkeley, California, October, 1986.

KEYWORDS: Earthquakes, Precast Concrete, Cladding, Steel Frames, Connections, Research Testing, Practice

148. AUTHOR: Wang, Marcy Li

TITLE: Cladding Performance on a Large Scale Test Frame

SOURCE: Earthquake Spectra, Earthquake Engineering Research Institute, El Cerrito, California, Vol. III, No. 1, February 1987

KEYWORDS: Earthquakes, Precast Concrete, Cladding, Steel Frames, Connections, Research Testing, Practice

149. AUTHOR: Weidlinger, Paul

TITLE: Shear Field Panel Bracing

SOURCE: Journal of the Structural Division, ASCE, Vol. 99, No. ST7, July 1973, pp. 1615-1631

KEYWORDS: Concrete (precast), Frames, Panels, Shear, Steel Structures

150. AUTHOR: Whitlock, A. Rhett; Brown, Russell H.

TITLE: Cyclic and Monotonic Strength of Anchor Bolts in Masonry

SOURCE: Proceeding, Third North American Masonry Conference, June 1985, University of Texas, Arlington, Texas

KEYWORDS: Anchorage, Masonry, Testing

151. AUTHOR: Wilden, H. & Associates

TITLE: Examples of Precast Panel Details

SOURCE: H. Wilden & Associates, 1984

KEYWORDS: Precast Concrete, Cladding, Design, Details, Current Practice

152. AUTHOR: Yura, Joseph A.

TITLE: Differential Movement Effects in Steel Shelf Angles

SOURCE: Journal of the Structural Division, ASCE, Vol. 112, No. 3, March 1986, pp. 636-652

KEYWORDS: Connections, Masonry, Cladding, Structural Analysis

APPENDIX A TEST I

DRAWINGS OF TEST SET-UP AND TEST SPECIMEN

PHOTOGRAPHS

GRAPHS OF TEST RESULTS

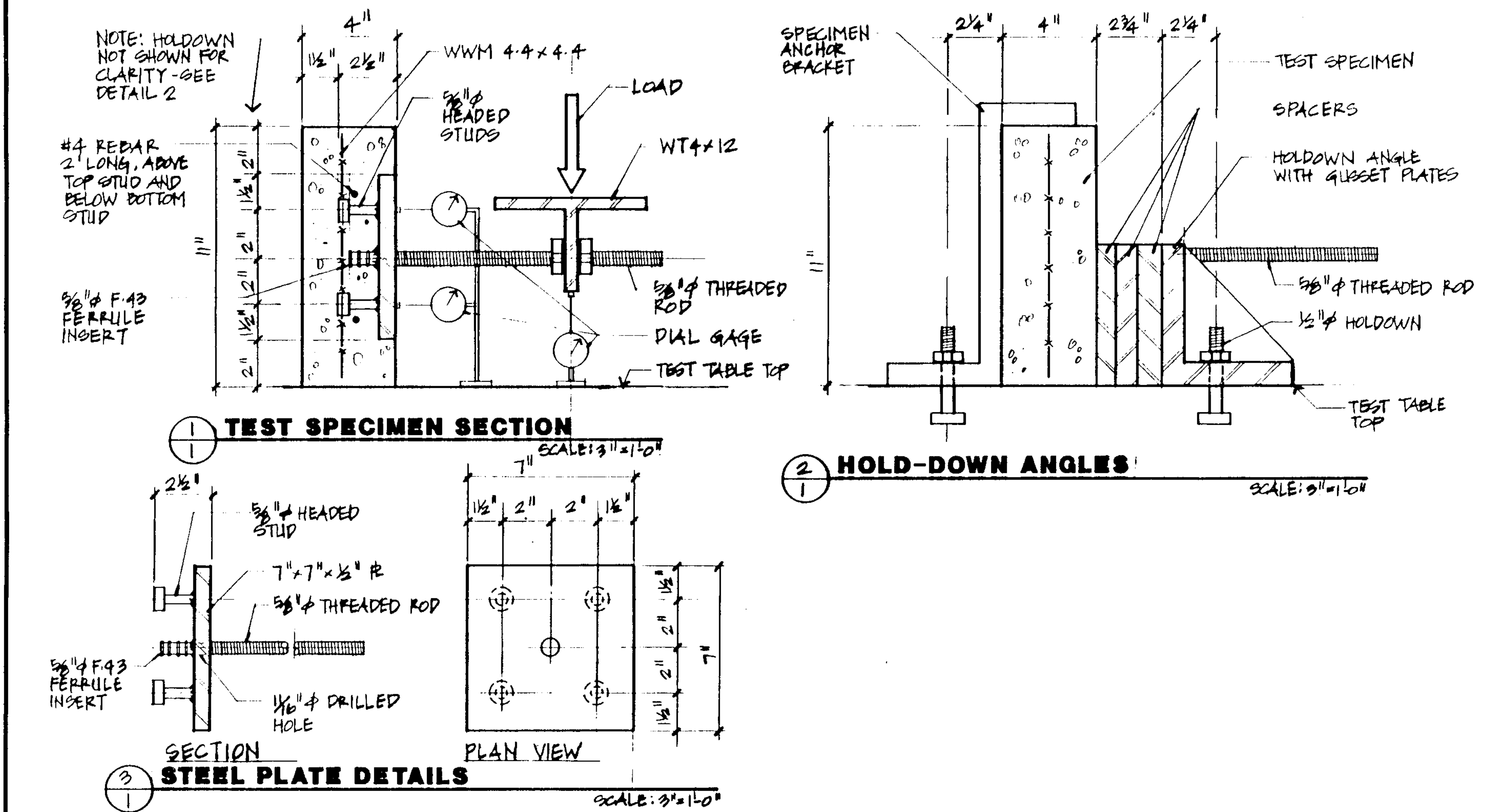


Fig. 1	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	TEST I DUCTILE CONNECTION TEST SET-UP	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA. 93401	DRWN: CIL DATE: 11/87 CHCK: DATE:

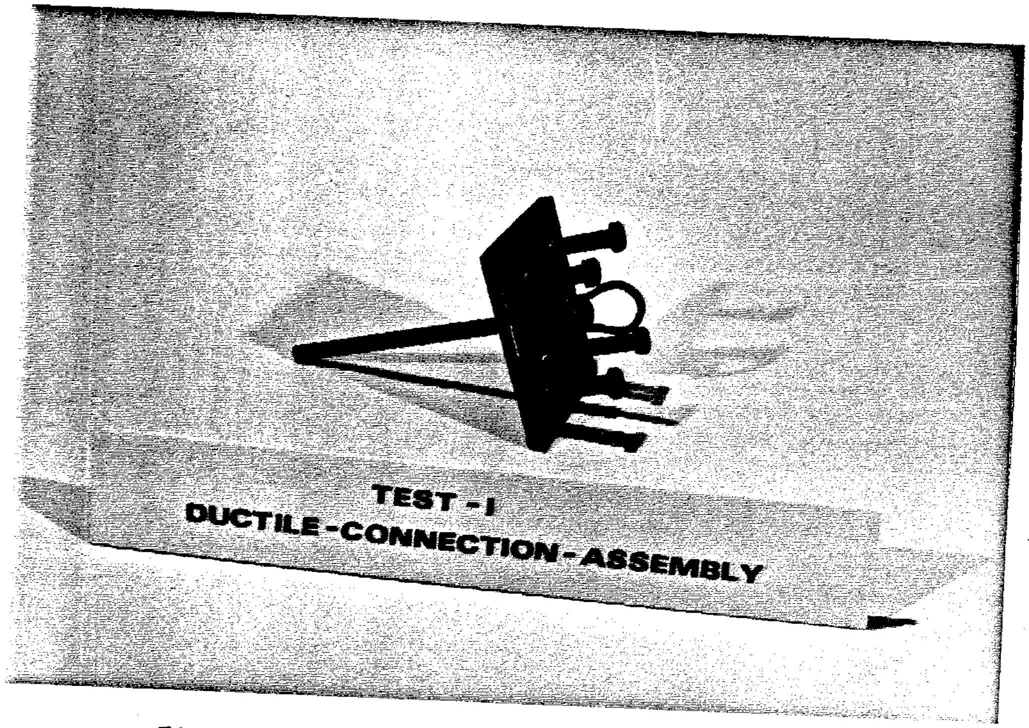


Figure 2 Test I - Connection Assembly

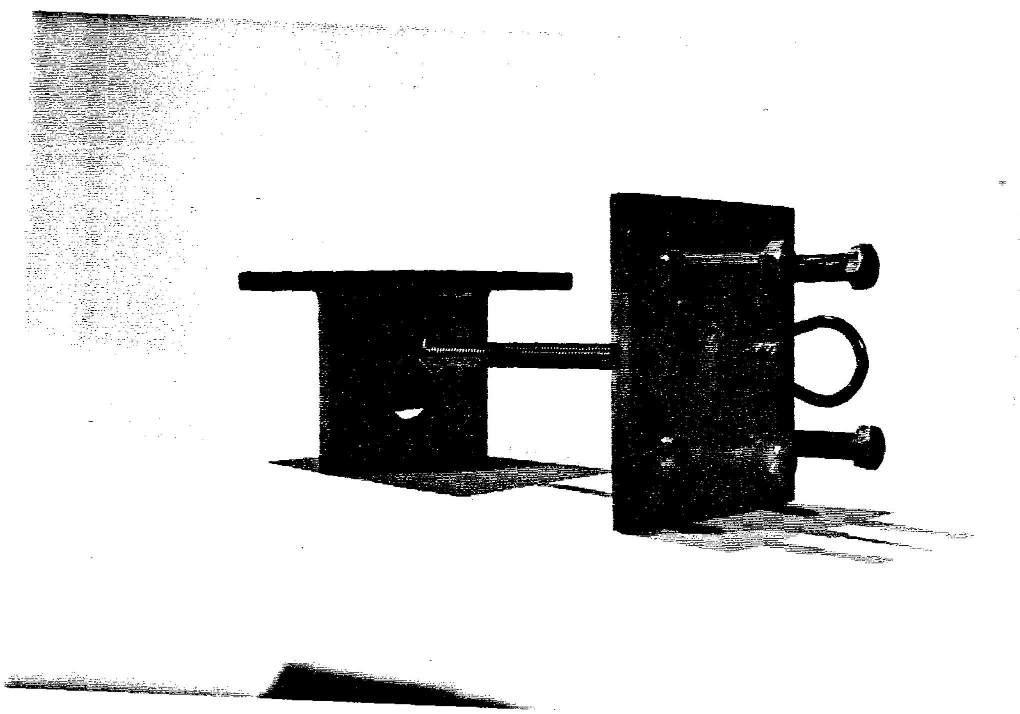


Figure 3 Test I - Connection Assembly Showing Placement of Threaded-Rod Specimen and The Loading-Tee

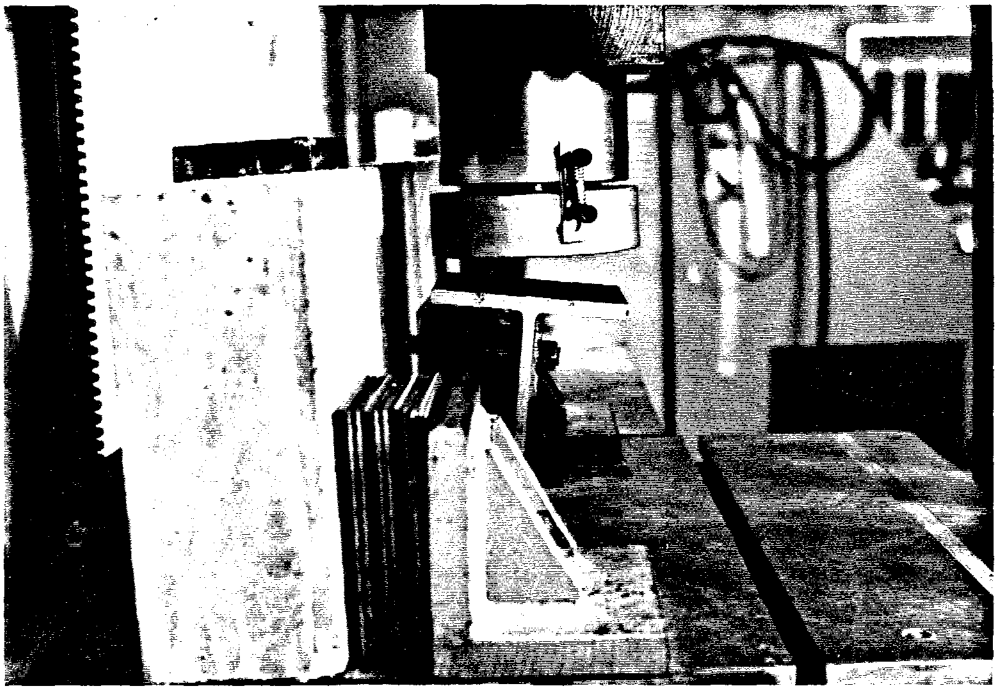


Figure 4 Test I: Test Set-up, Threaded-Rod Specimen Length=4 Inches After Load-Test

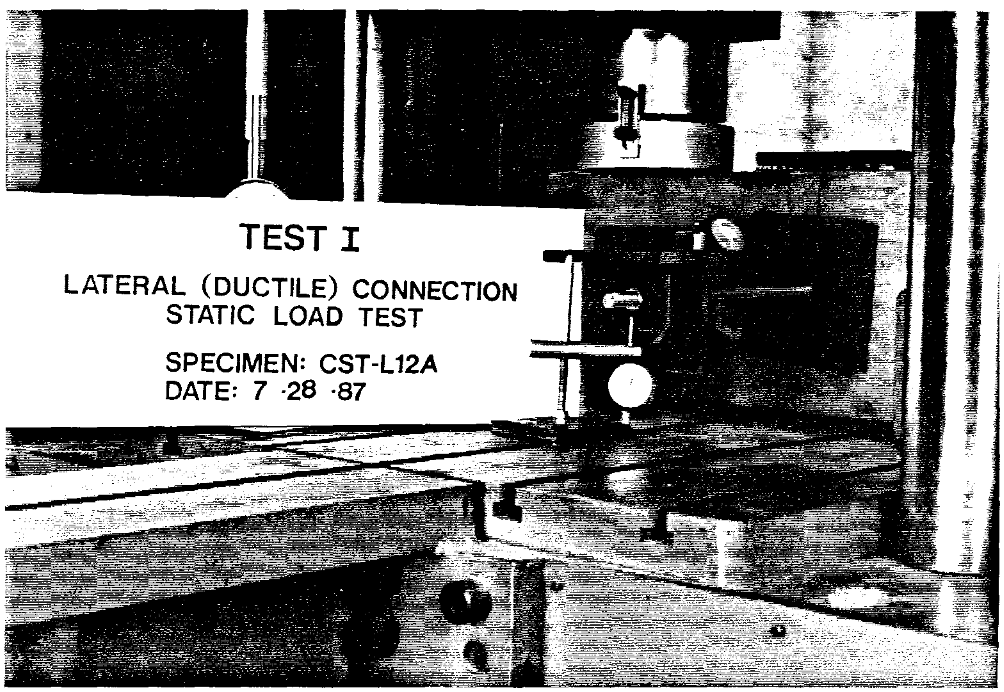


Figure 5 Test I: Test Set-up, Threaded-Rod Specimen Length=12 Inches Before Load-Test

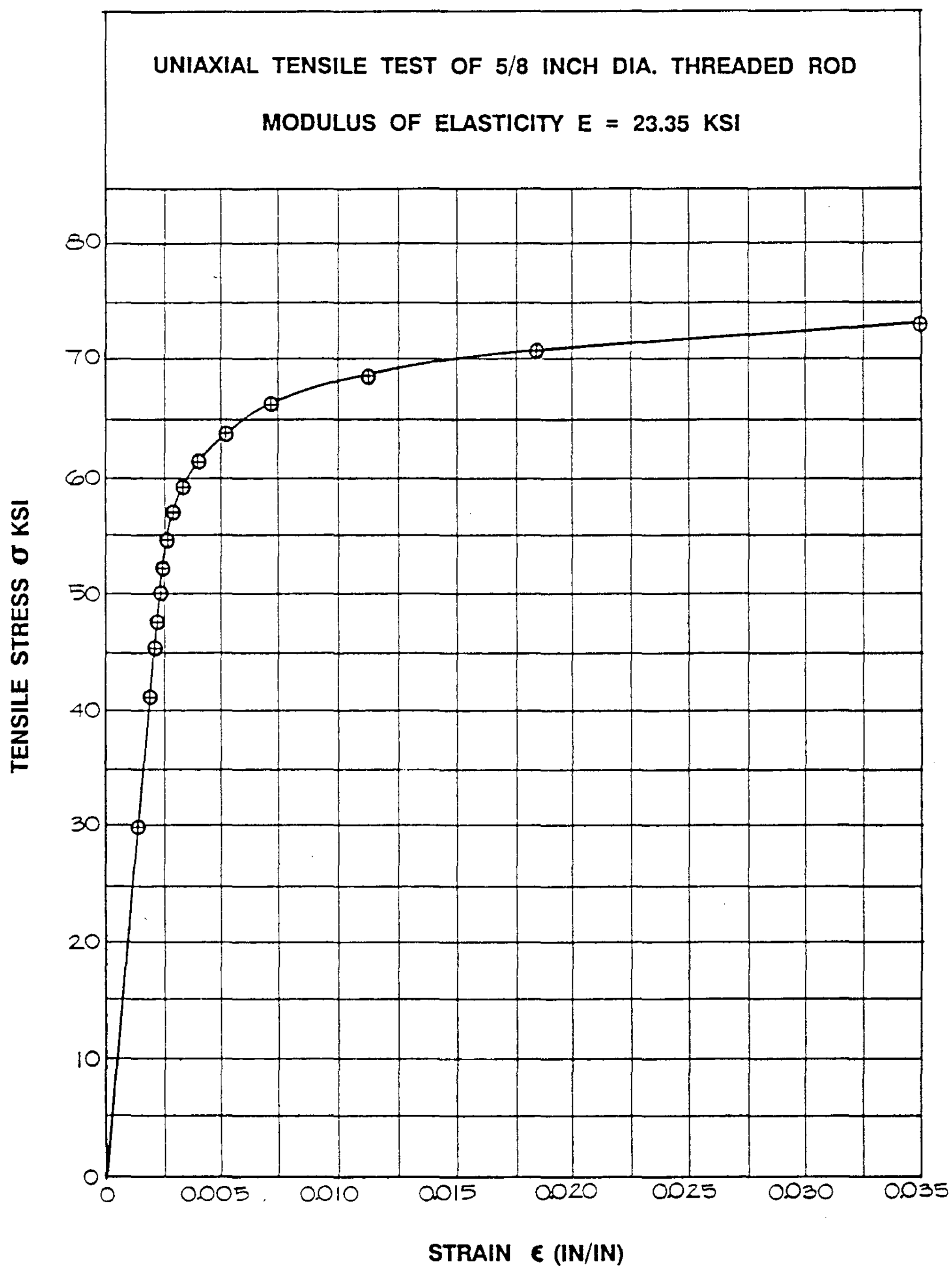


FIG. 6 GRAPH OF UNIAXIAL TENSILE STRESS VS. STRAIN
5/8 INCH DIAMETER THREADED-ROD SPECIMEN

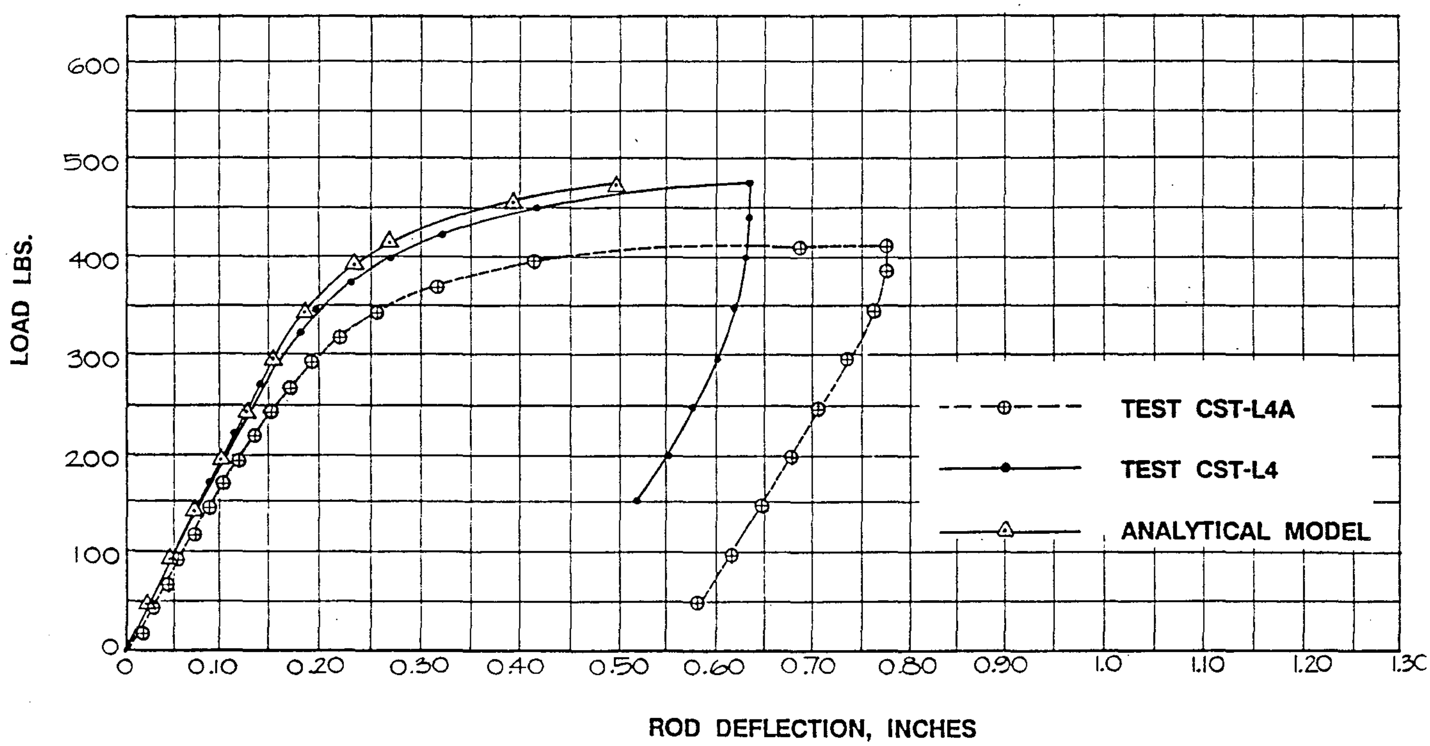


FIG. 7 LOAD VS. DISPLACEMENT CURVES
THREADED-ROD LENGTH = 4 INCHES

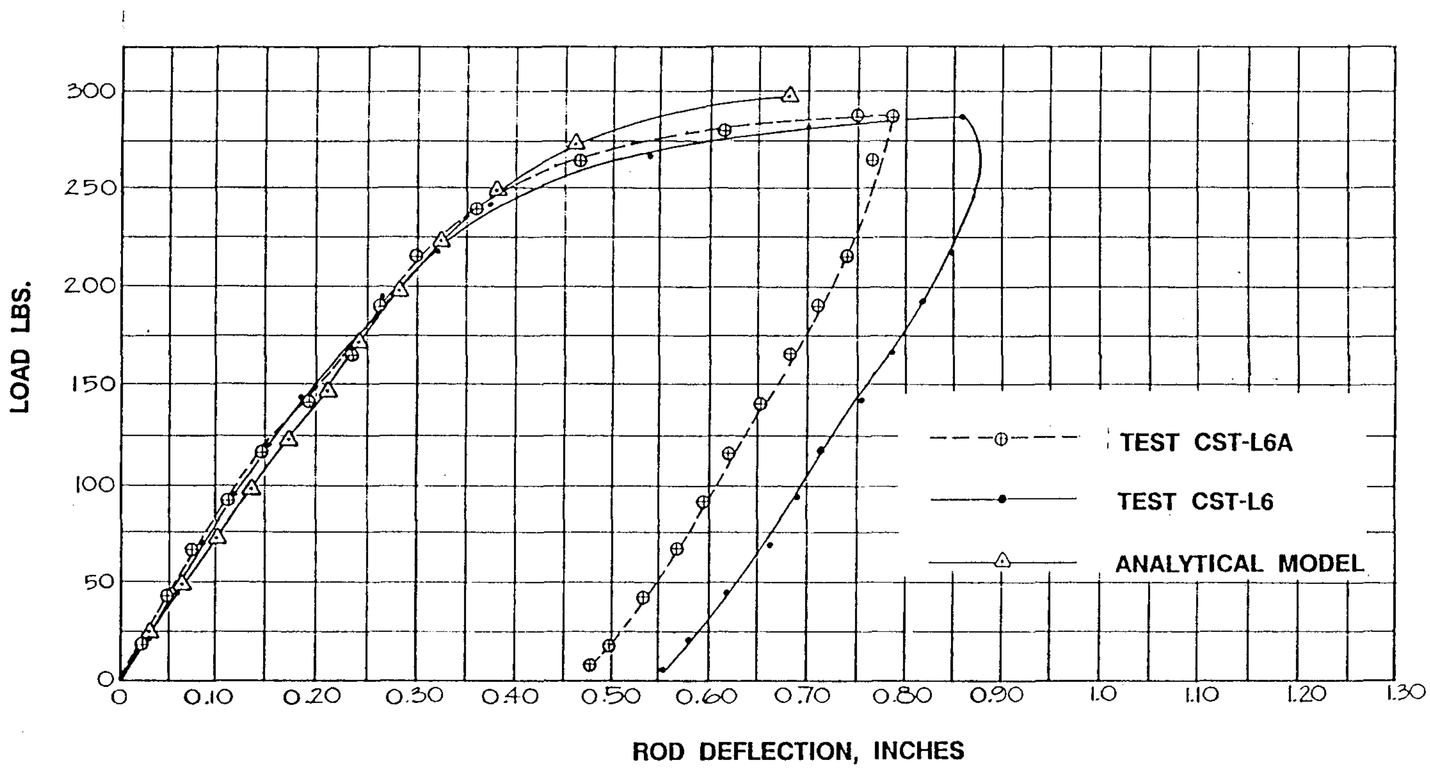


FIG. 8 LOAD VS. DISPLACEMENT CURVES
THREADED-ROD LENGTH = 6 INCHES

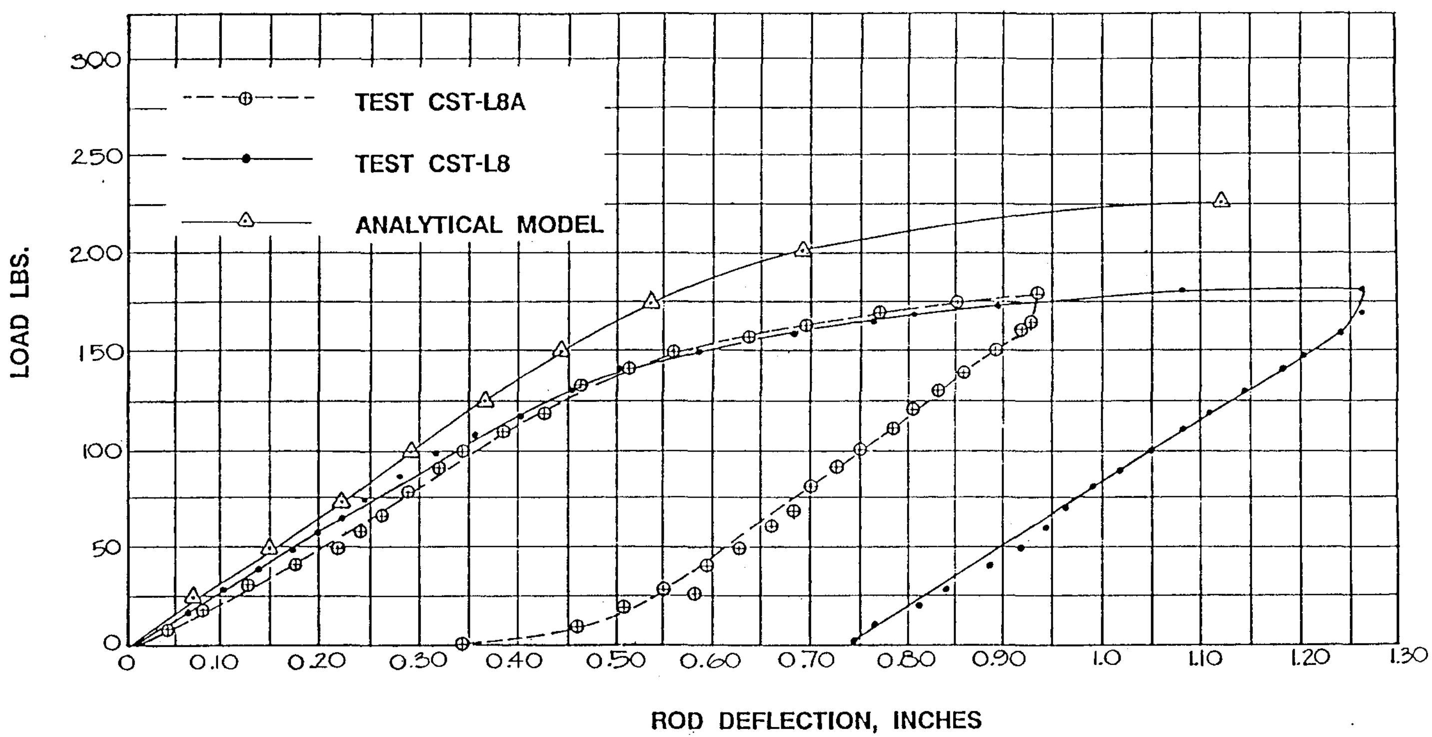


FIG. 9 LOAD VS. DISPLACEMENT CURVES
THREADED-ROD LENGTH = 8 INCHES

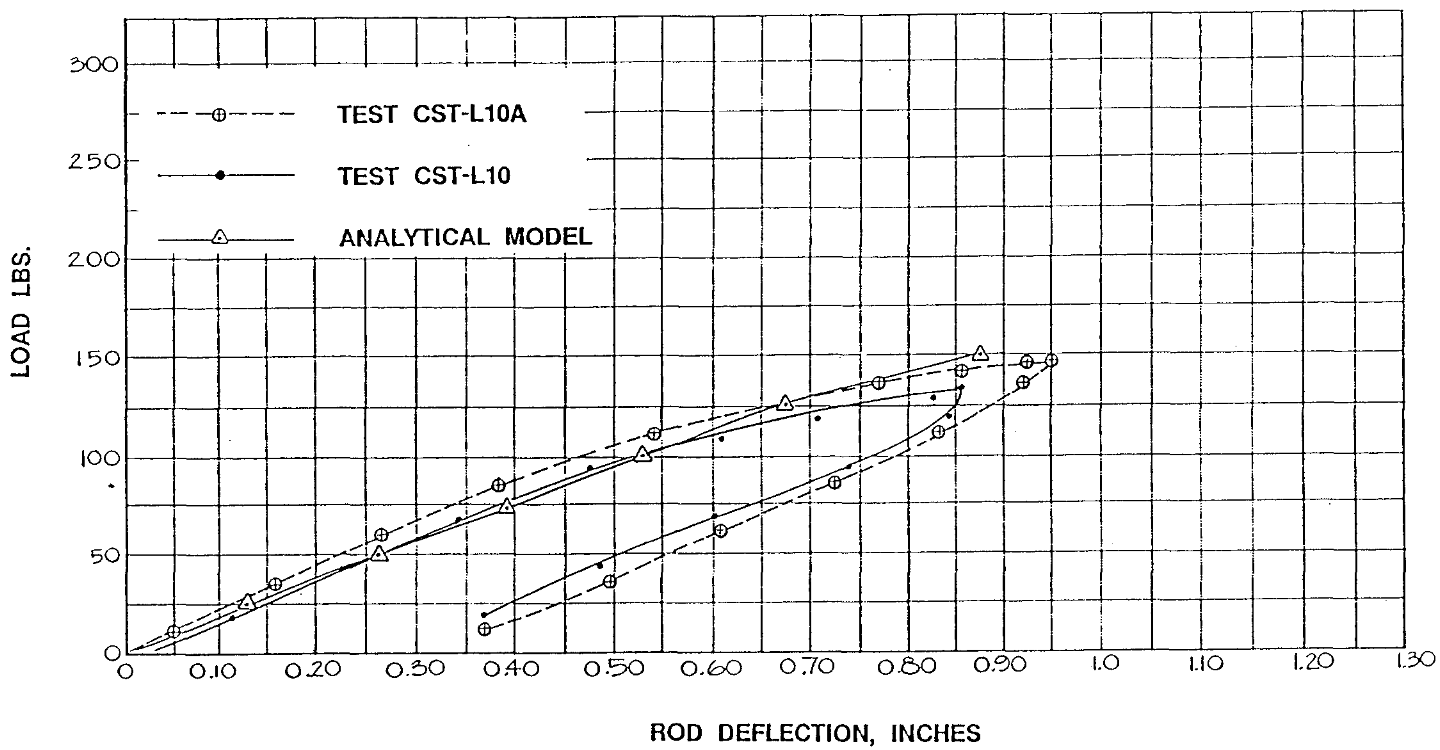


FIG. 10 LOAD VS. DISPLACEMENT CURVES
THREADED-ROD LENGTH = 10 INCHES

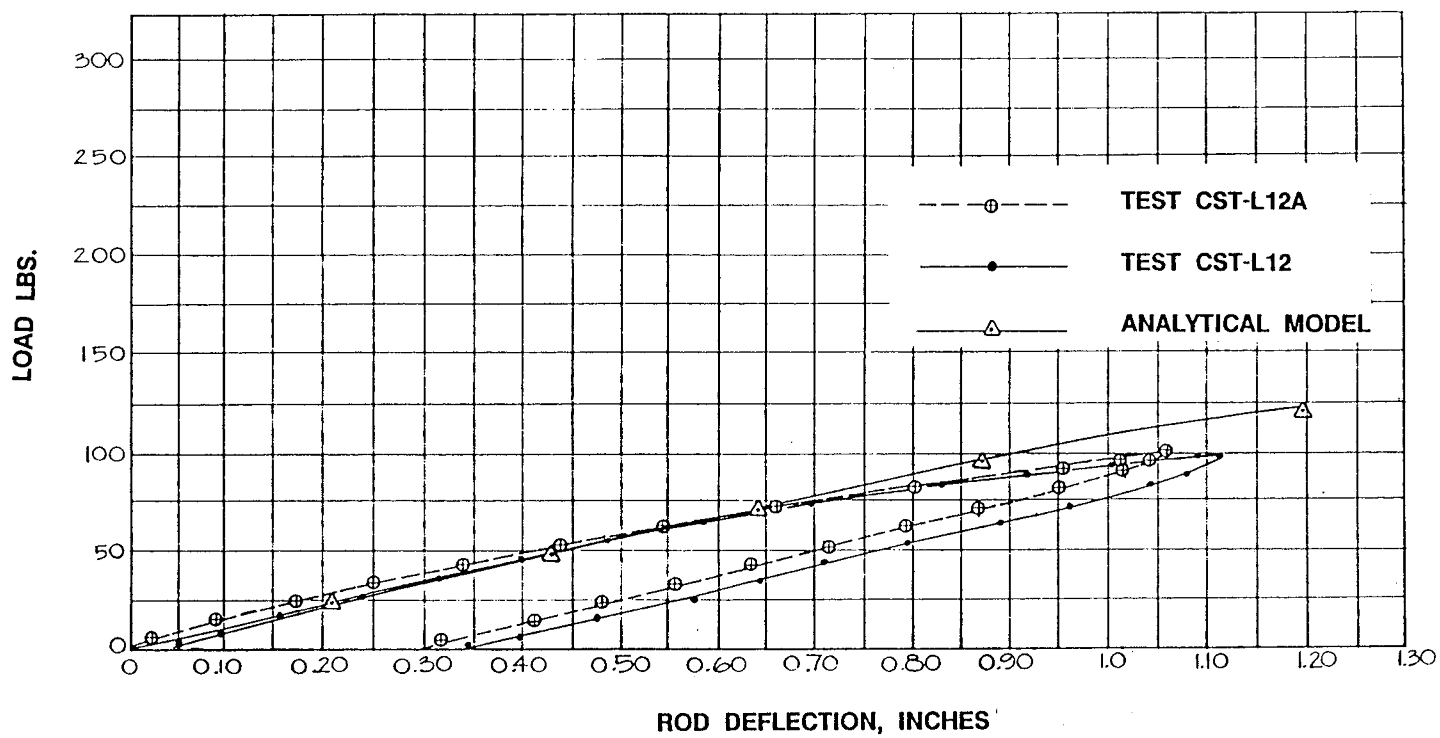


FIG. 11 LOAD VS. DISPLACEMENT CURVES
THREADED-ROD LENGTH = 12 INCHES

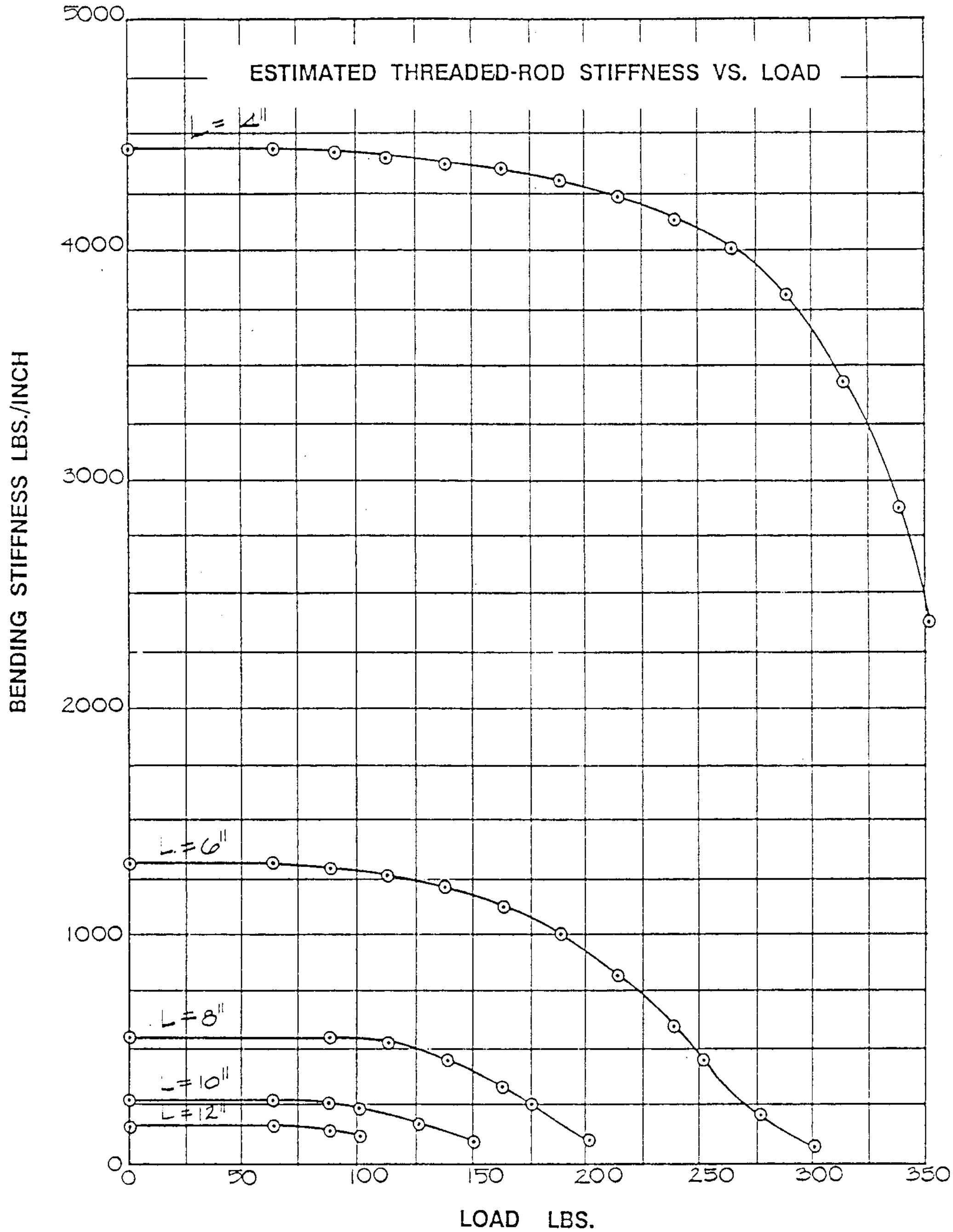


FIG. 12 ESTIMATED BENDING STIFFNESS OF THREADED-ROD SPECIMENS AT VARIOUS LOAD LEVELS

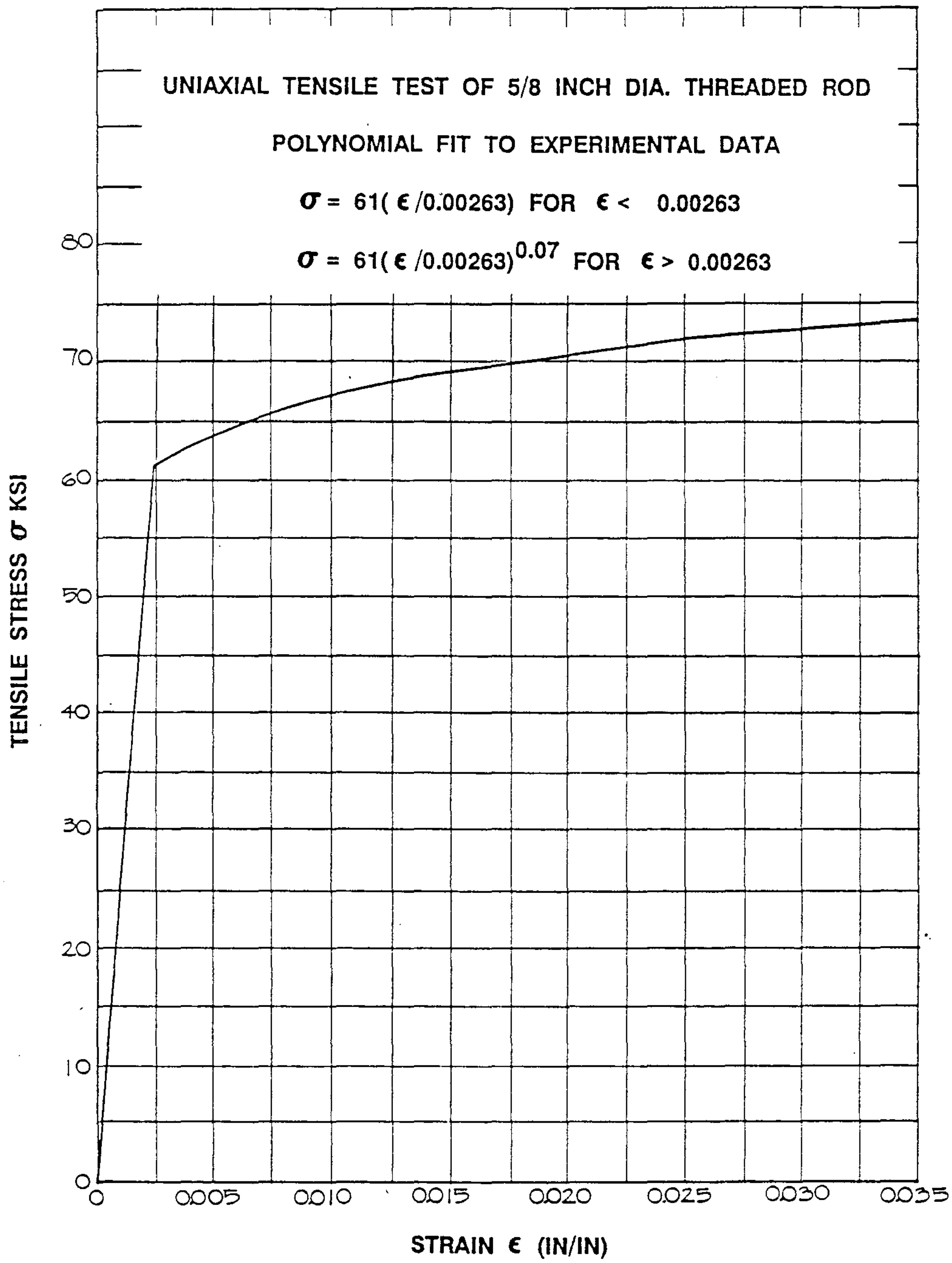


FIG. 13 STRESS-STRAIN CURVE FOR 5/8 INCH THREADED-ROD USED FOR ANALYTICAL MODELING

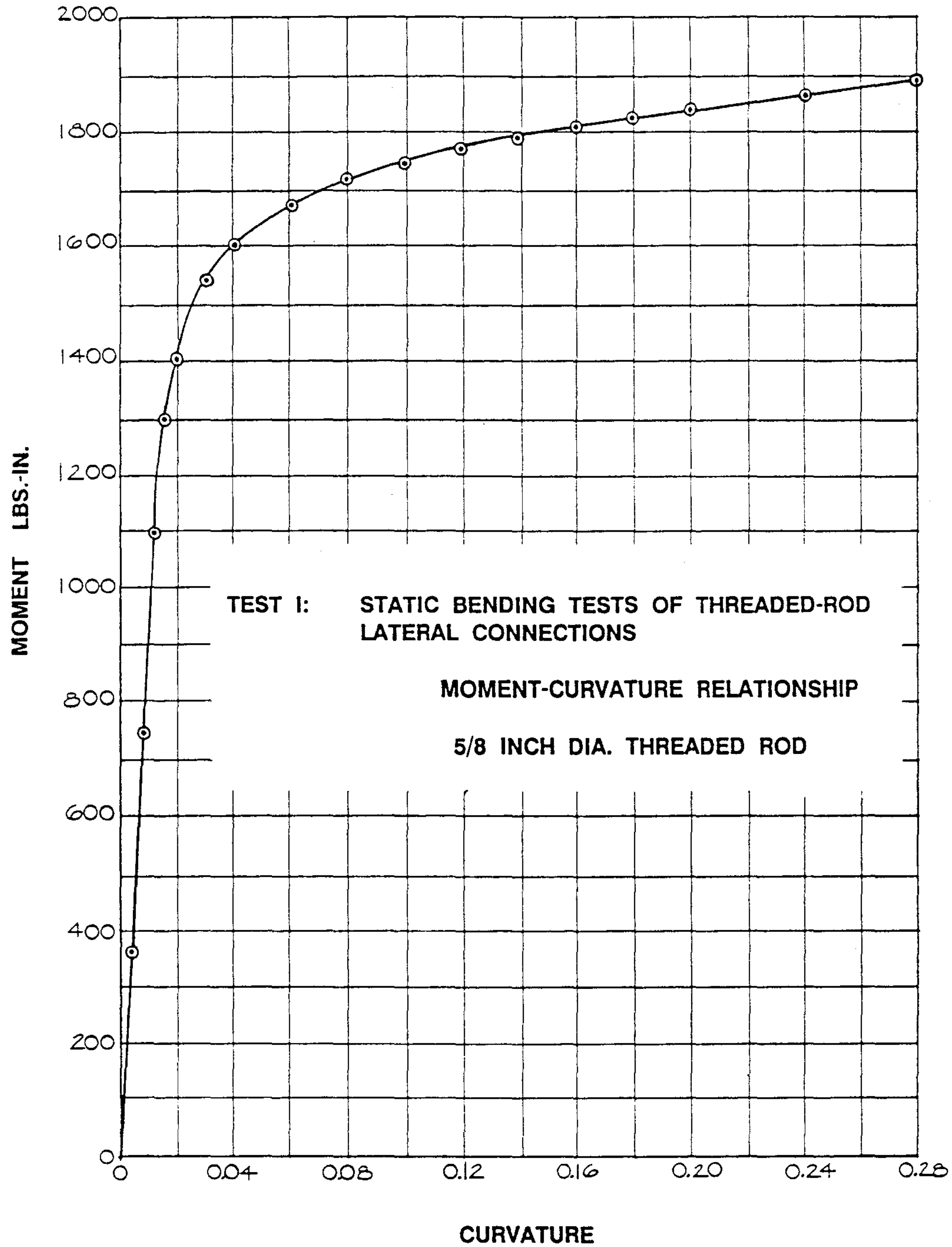


FIG. 14 PREDICTED MOMENT-CURVATURE CURVE - 5/8 INCH DIAMETER THREADED-ROD

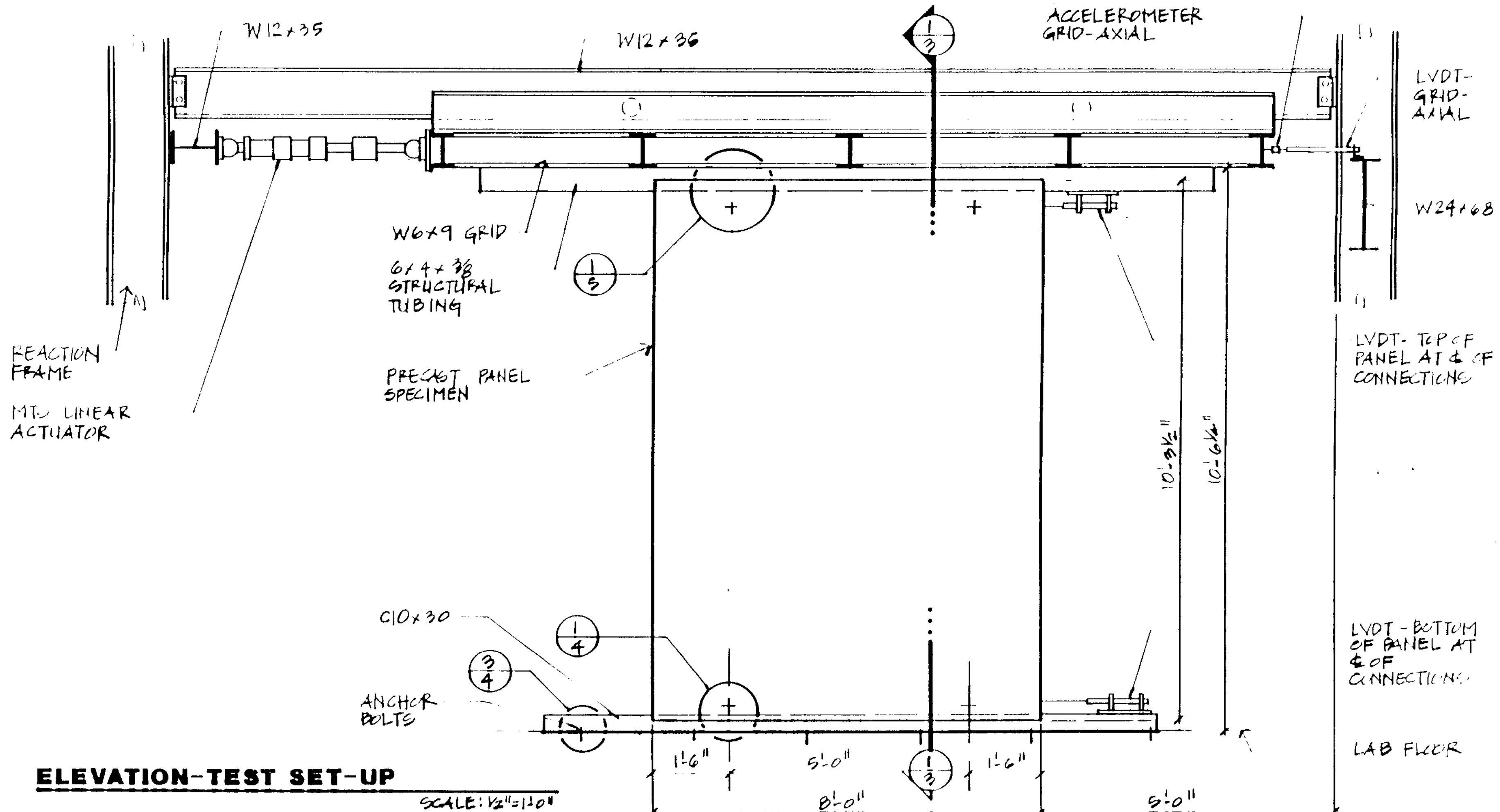
APPENDIX B TEST II

DRAWINGS OF TEST SET-UP AND TEST SPECIMEN

PHOTOGRAPHS

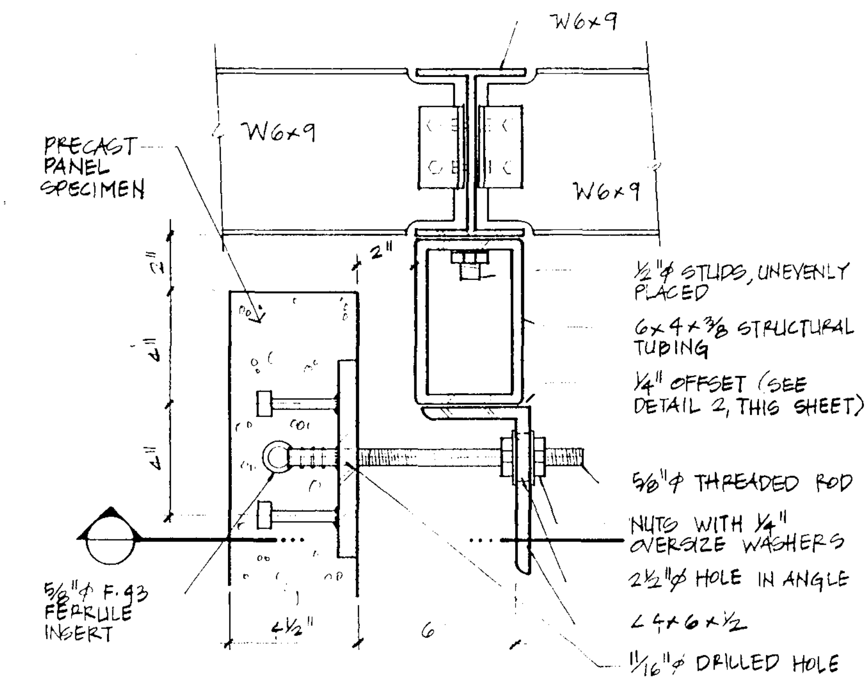
TIME HISTORY PLOTS

GRAPHS OF TEST RESULTS

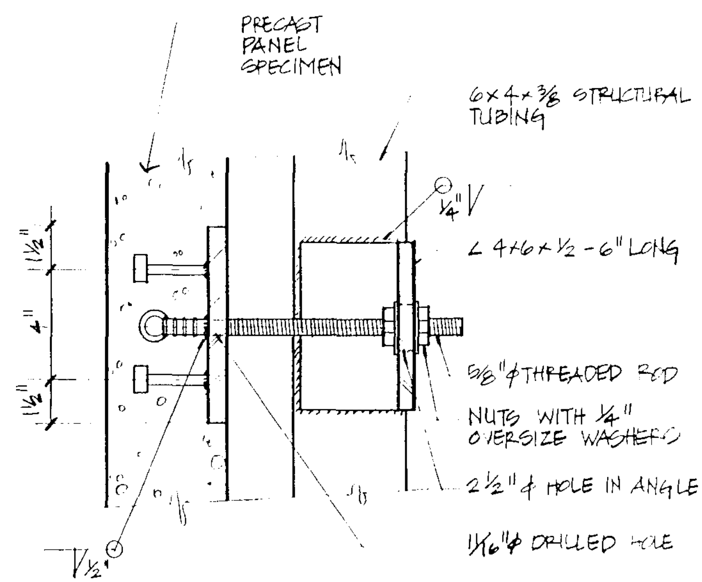


ELEVATION-TEST SET-UP

Fig. 1	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	**TEST II** IN-PLANE CYCLIC TESTING OF PRECAST FACADE/CLADDING PANEL & CONNECTIONS	**SEISMIC TEST FACILITY** ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA. 93401	DRWN: CIL DATE: 1/87 CHCK: DATE:

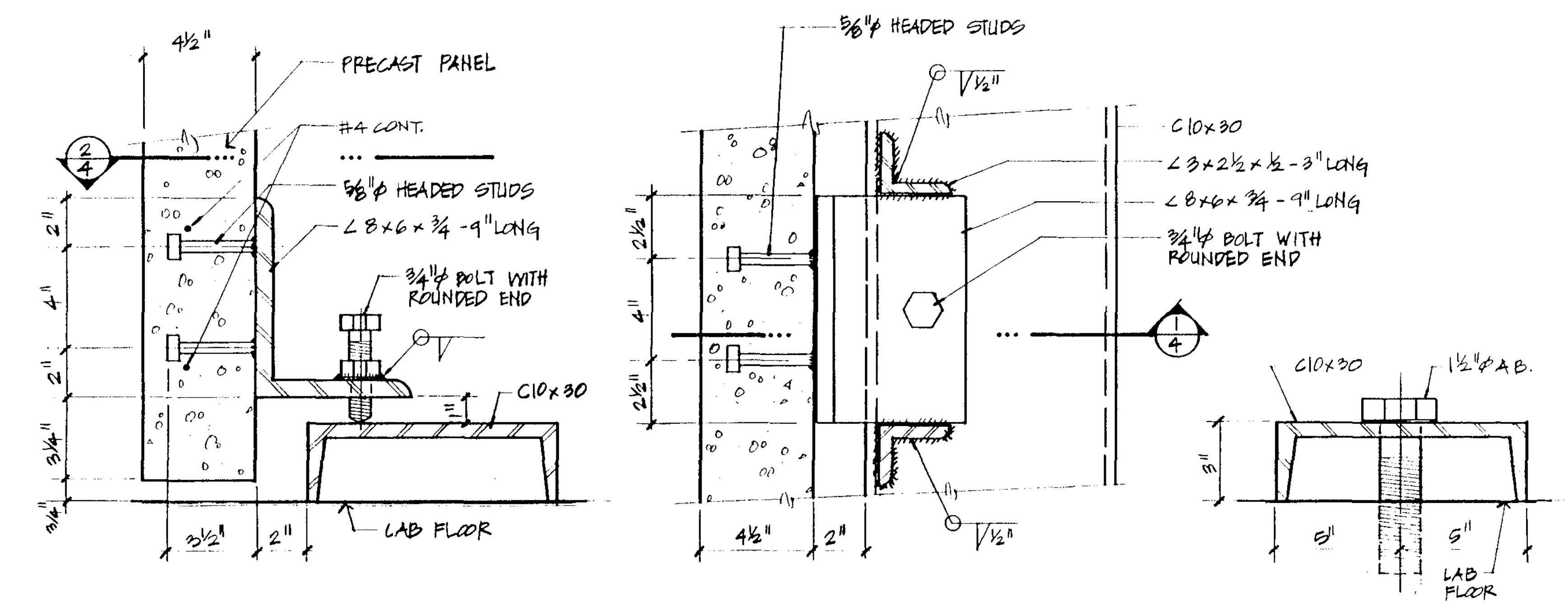


DUCTILE CONNECTION–SECTION (1/6)
SCALE: 3"=1'-0"



DUCTILE CONNECTION–BOTTOM VIEW (2/6)
SCALE: 3"=1'-0"

Fig. 2	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	TEST II IN-PLANE CYCLIC TESTING OF PRECAST FACADE/CLADDING PANEL + CONNECTIONS	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA. 93401	DRWN: CIL DATE: 11/87 CHCK: DATE:



1/4 **BEARING CONNECTION-SECTION**
SCALE: 3"=1'-0"

2/4 **BEARING CONNECTION-PLAN**
SCALE: 3"=1'-0"

3/4 **CHANNEL TO LAB-FLOOR CONNECTION**
SCALE: 3"=1'-0"

Fig. 3	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	TEST II IN-PLANE CYCLIC TESTING OF PRECAST FACADE/CLADDING PANEL + CONNECTIONS	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA. 93401	DRWN: CIL DATE: 1/87 CHCK: DATE:

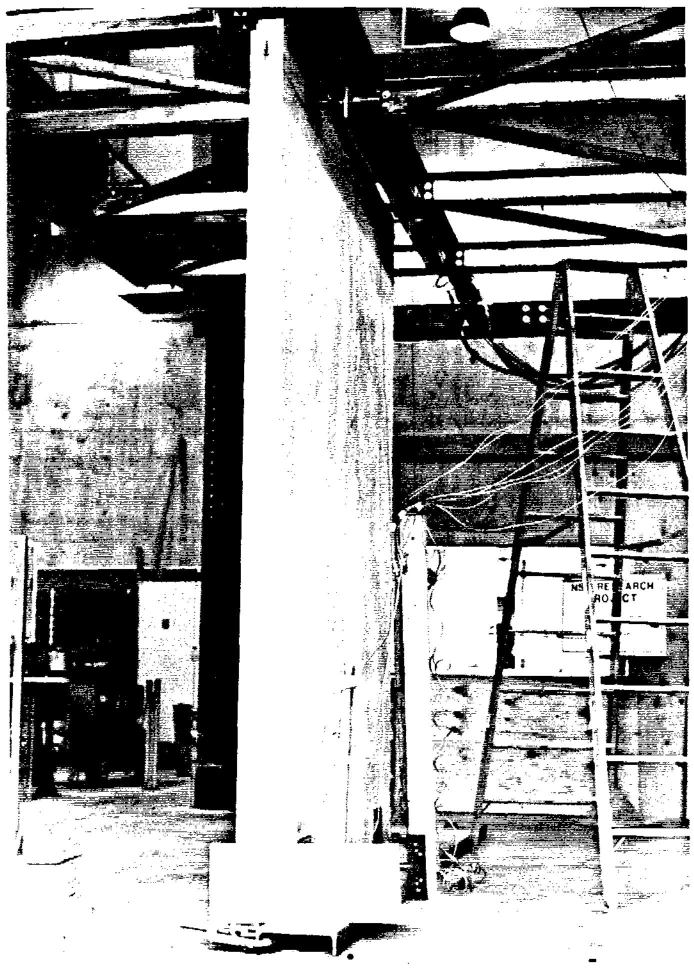


Figure 4 Overall View of Full-Size Precast Concrete Cladding Panel Test Specimen and Cyclic Test Set-up

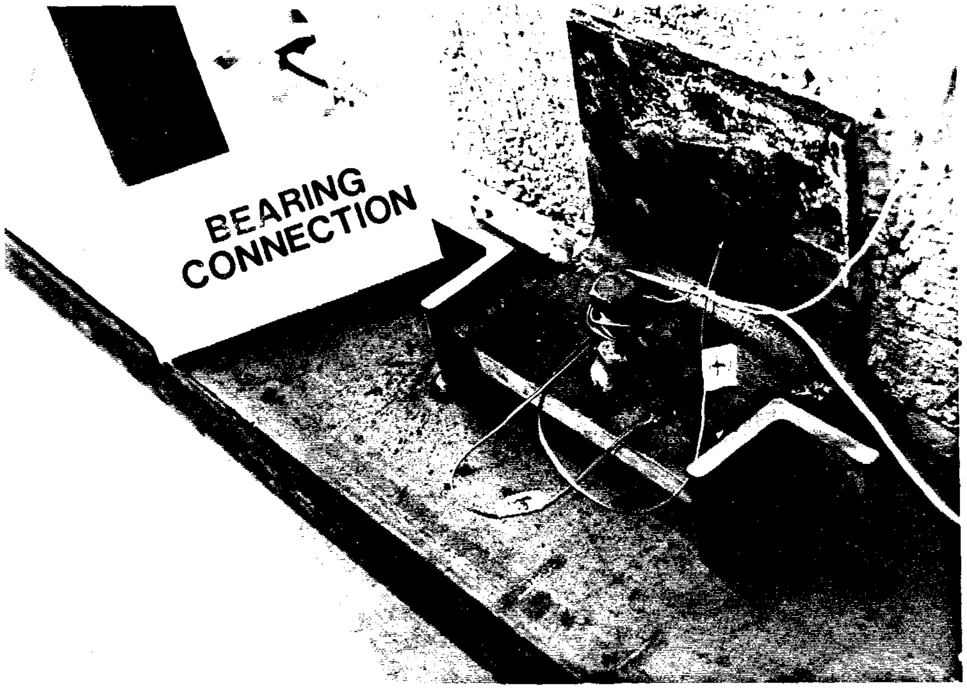


Figure 5 Rigid Bearing Connection
Close-up View

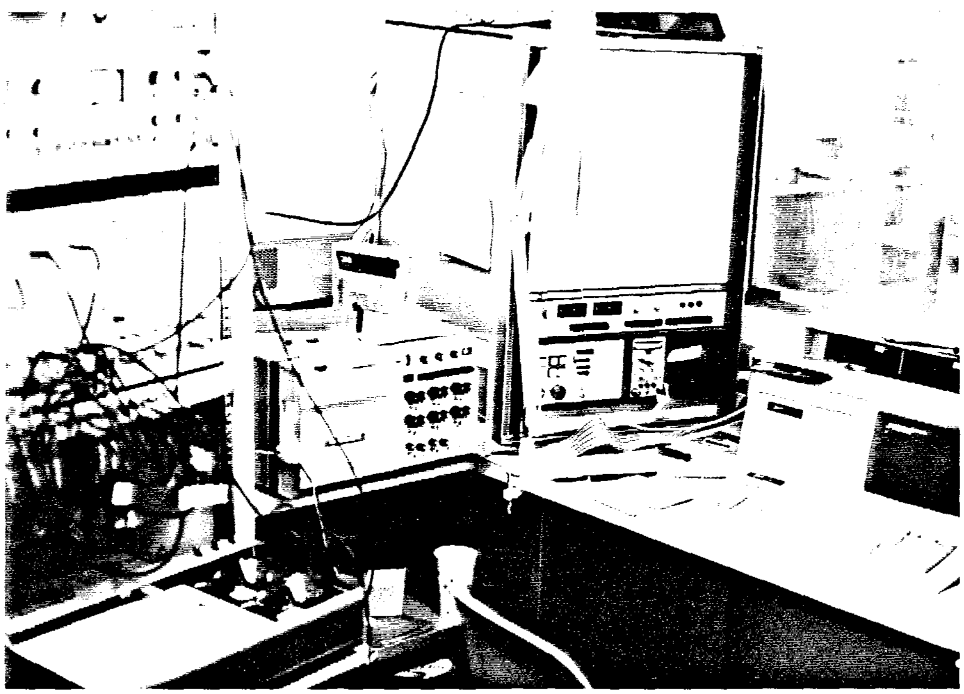


Figure 6 Test Instrumentation

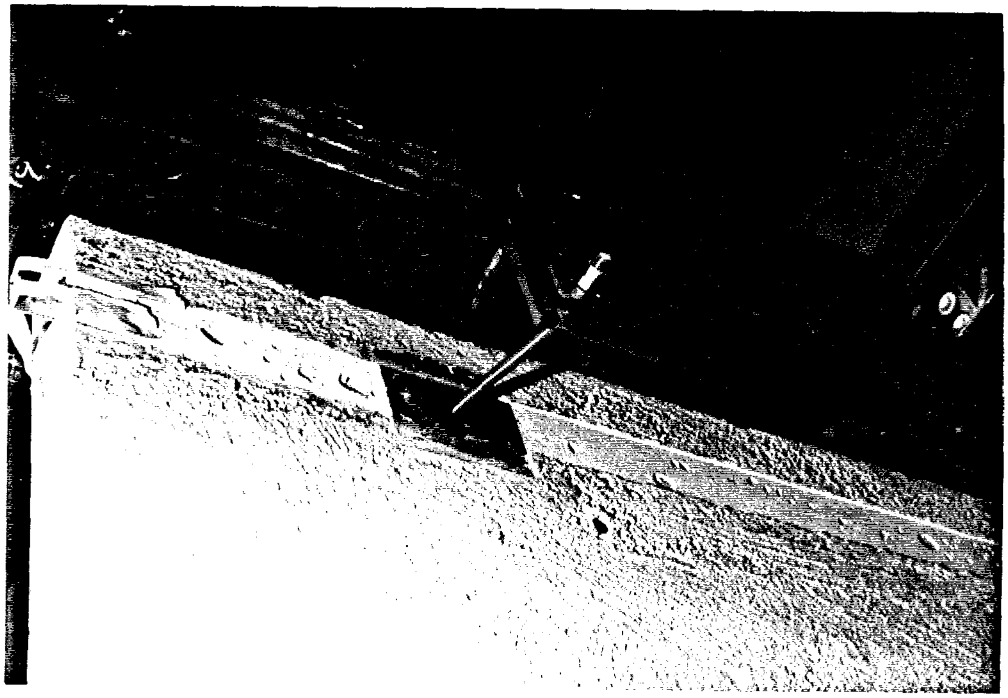


Figure 7 Typical Cyclic Behaviour of Threaded-Rod Lateral Connection at Top
Specimen FRCRT-L8; Run No. AF-6
Amplitude=±1.5 Inches; Frequency=0.1 Hz

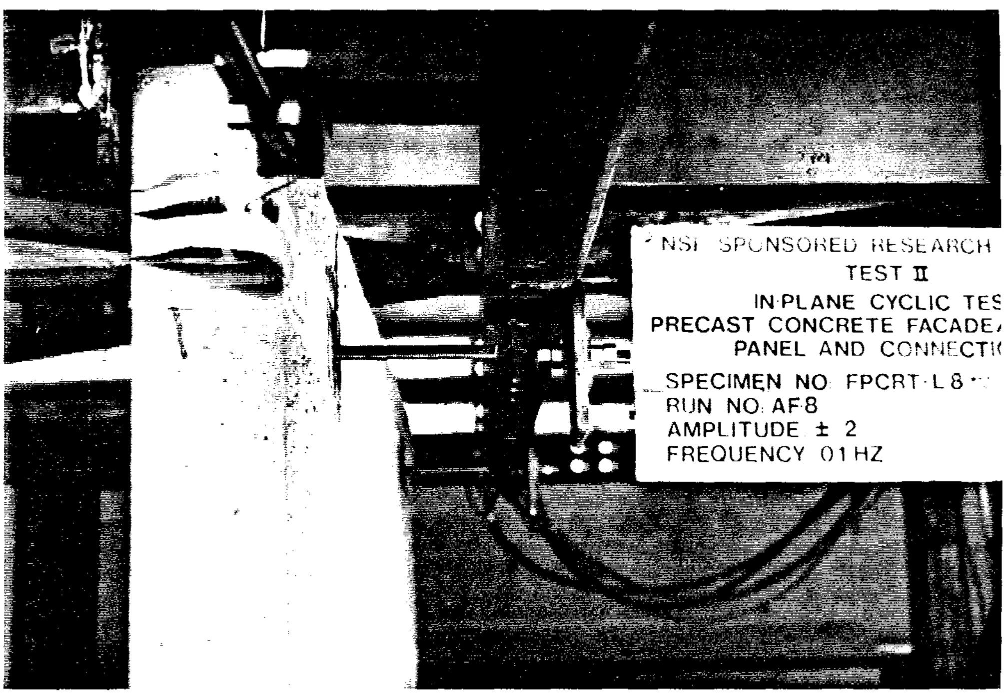


Figure 8 Overall View of Upper Portion of Cladding Panel
Typical Failure of Threaded-Rod Connections at Top
Cyclic Test Specimen FPCRT-L8; Run No. AF-8
Amplitude=±2 Inches; Frequency=0.1 Hz

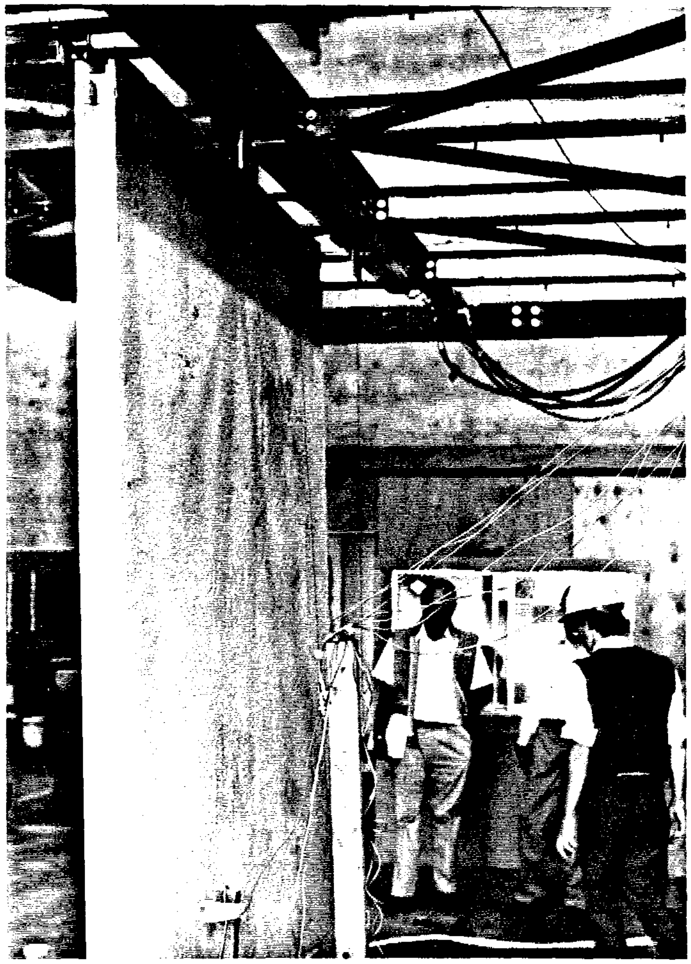


Figure 9   Overall View of Typical Failure of Threaded-Rod Lateral Connections at Top
Cyclic Test Specimen FPCRT-L6; Run No. A6

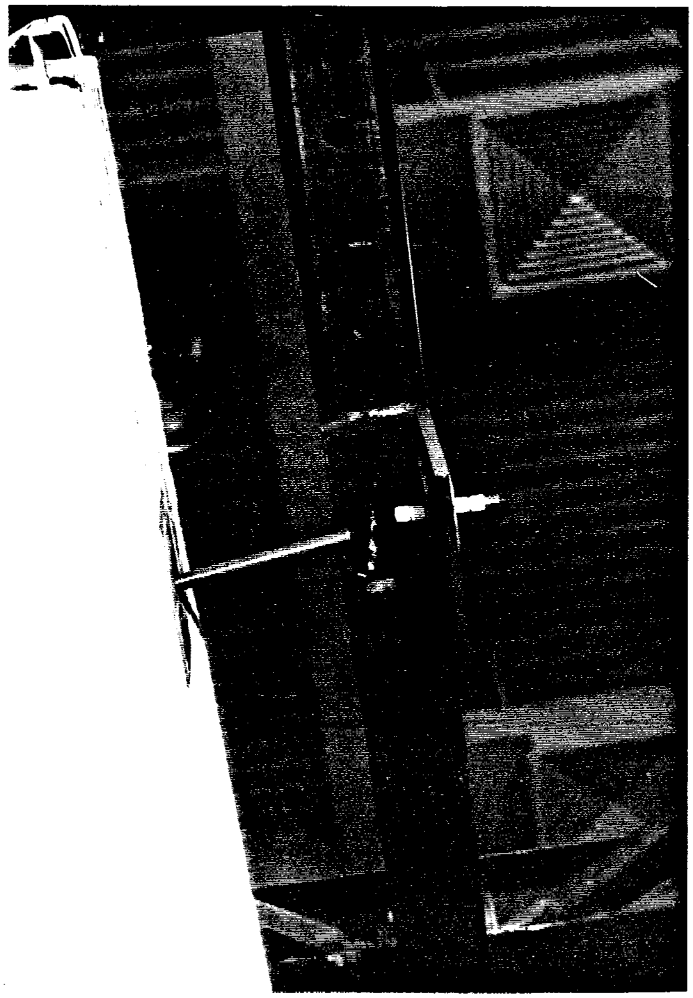


Figure 10 Typical Failure of Threaded-Rod Connection at Top Cyclic Cladding Test Specimen FPCRT-L8; Run No. AF-8 Amplitude=±2 Inches; Frequency=0.1 Hz

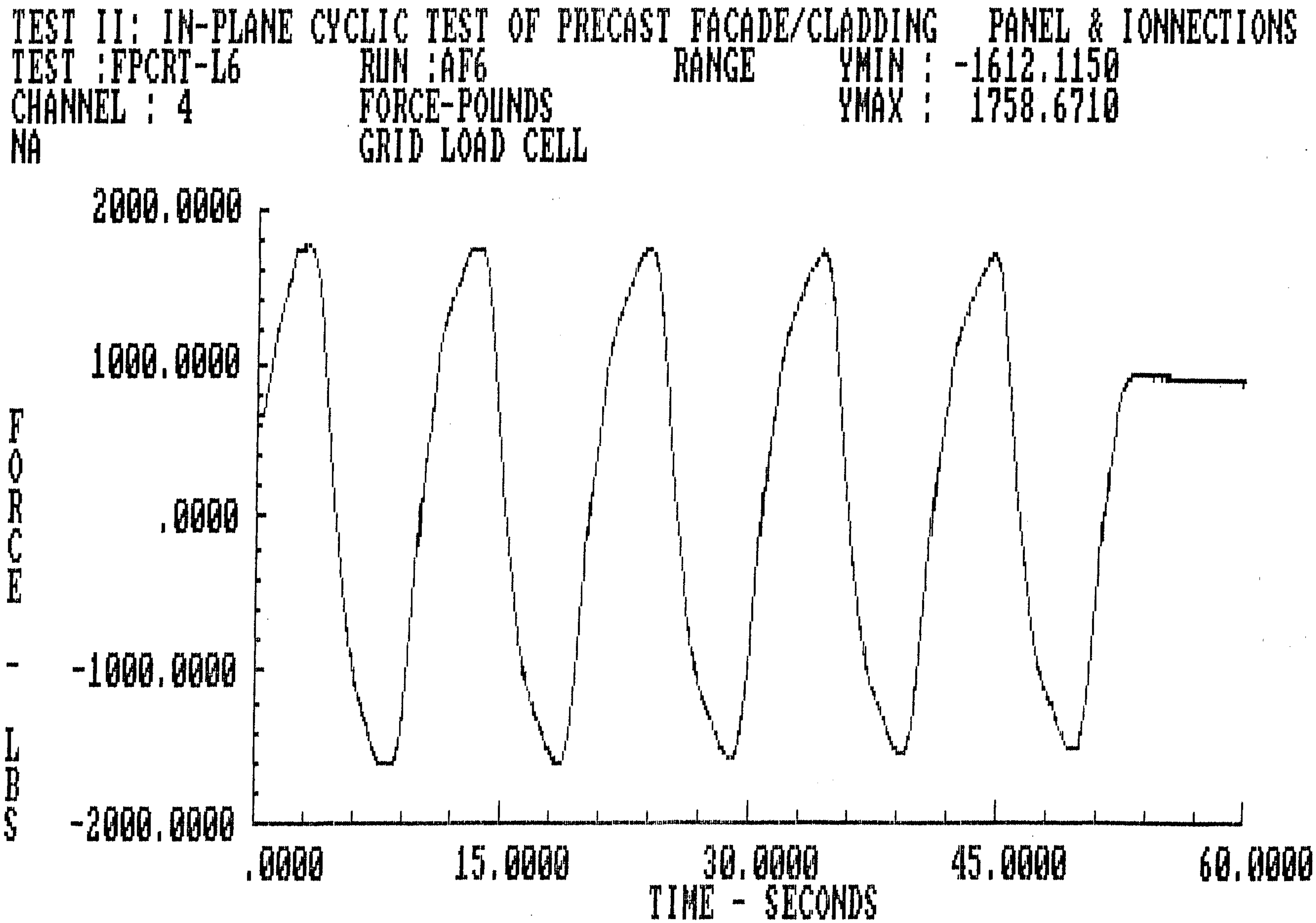


Figure 11 Time-History Plot of Load
Cladding Specimen FPCRT-L6; Run AF-6

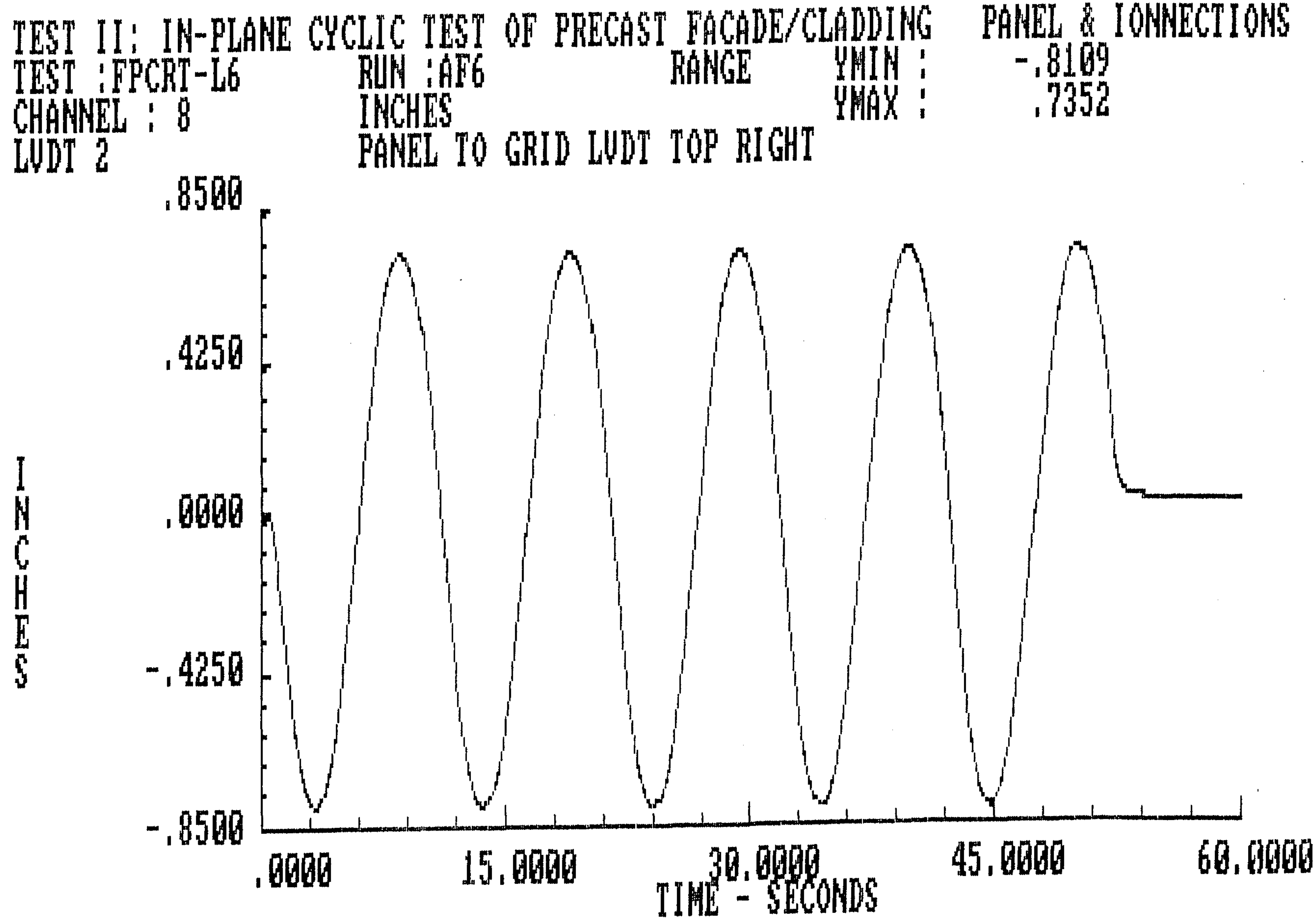


Figure 12 Time-History Plot of Top Horizontal Displacement
Cladding Specimen FPCRT-L6; Run AF-6

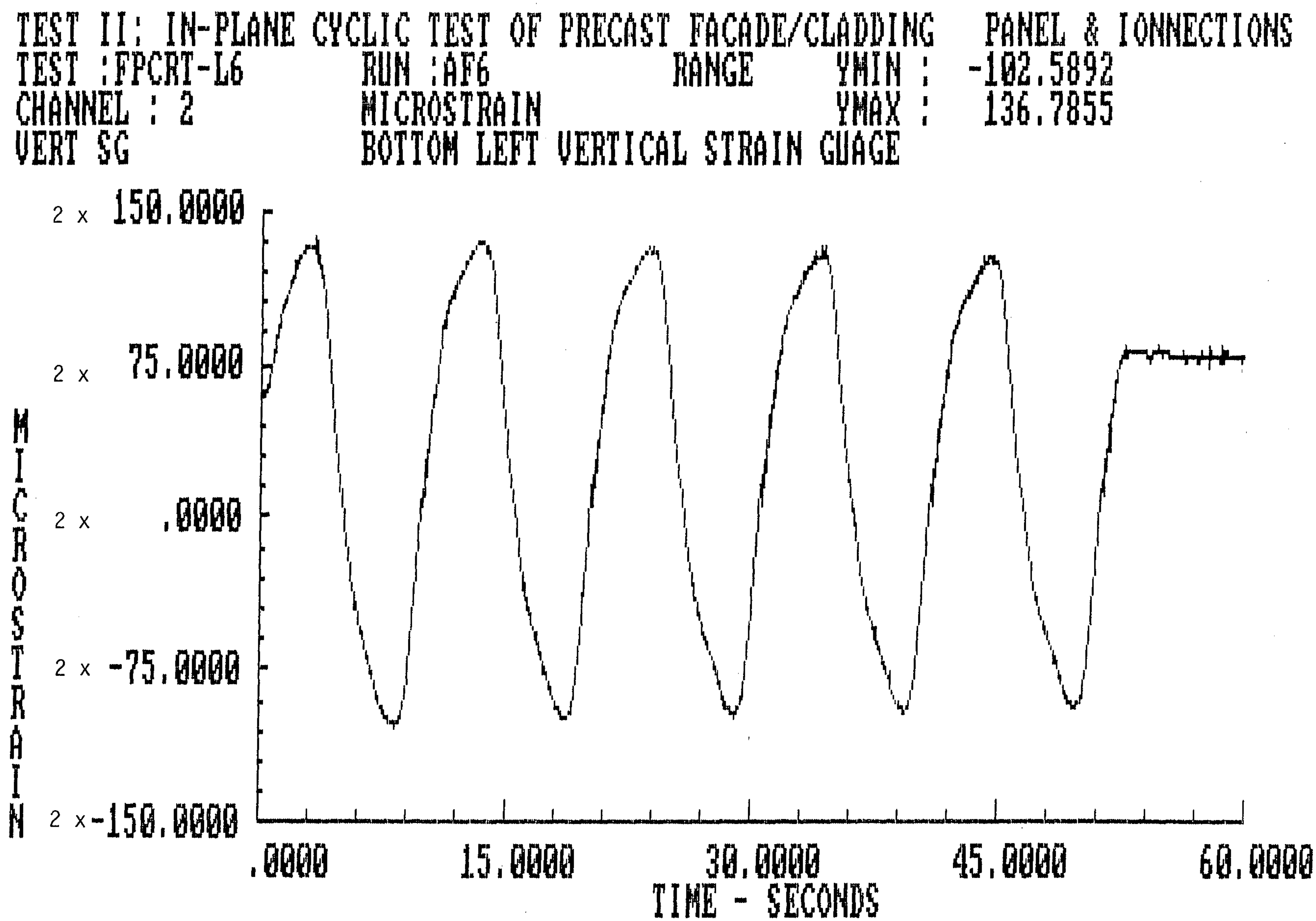


Figure 13 Time-History Plot of Strain
Bottom Left Vertical Strain Gage
Cladding Specimen FPCRT-L6; Run AF-6

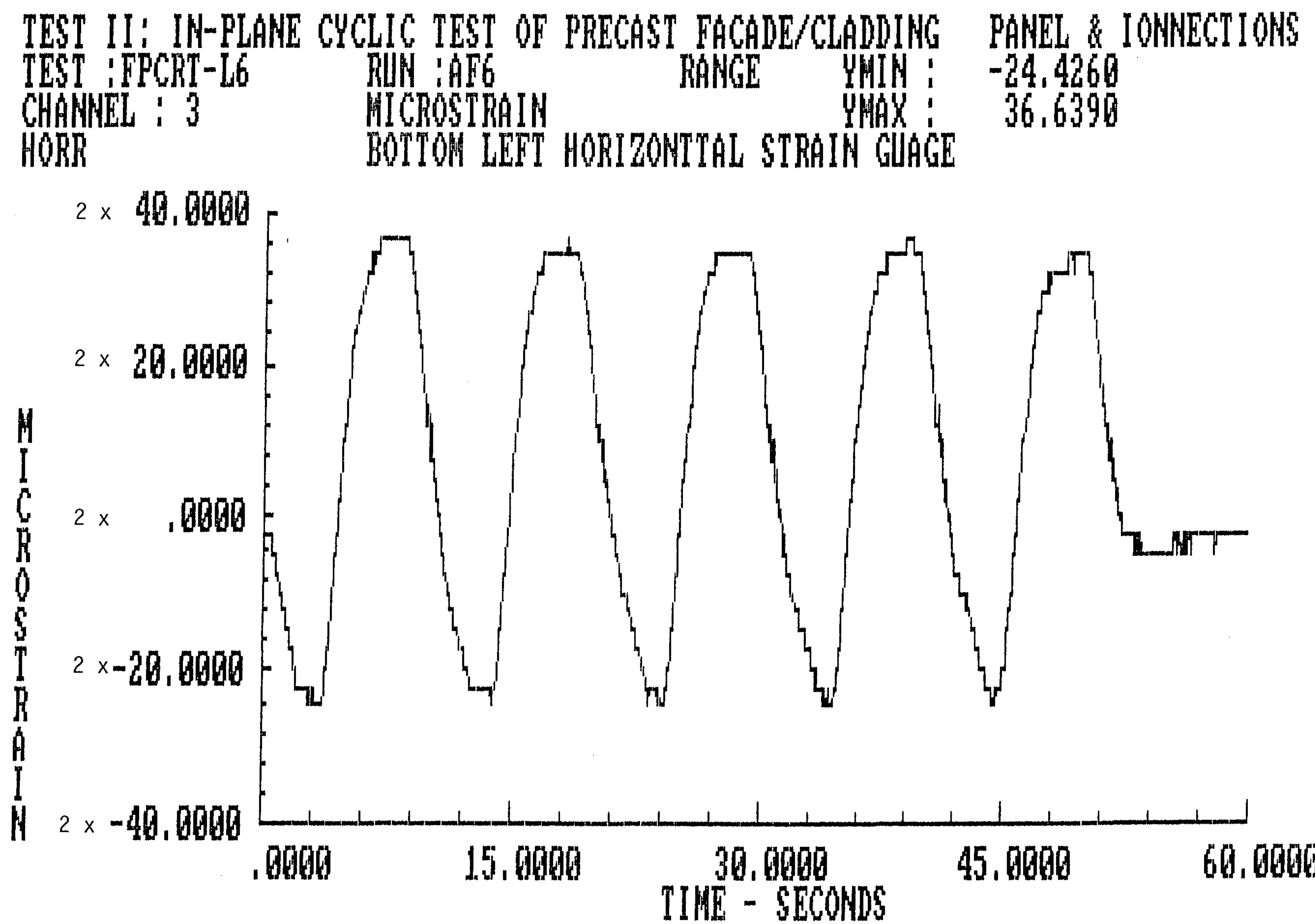


Figure 14 Time-History Plot of Strain
Bottom Left Horizontal Strain Gage
Cladding Specimen FPCRT-L6; Run AF-6

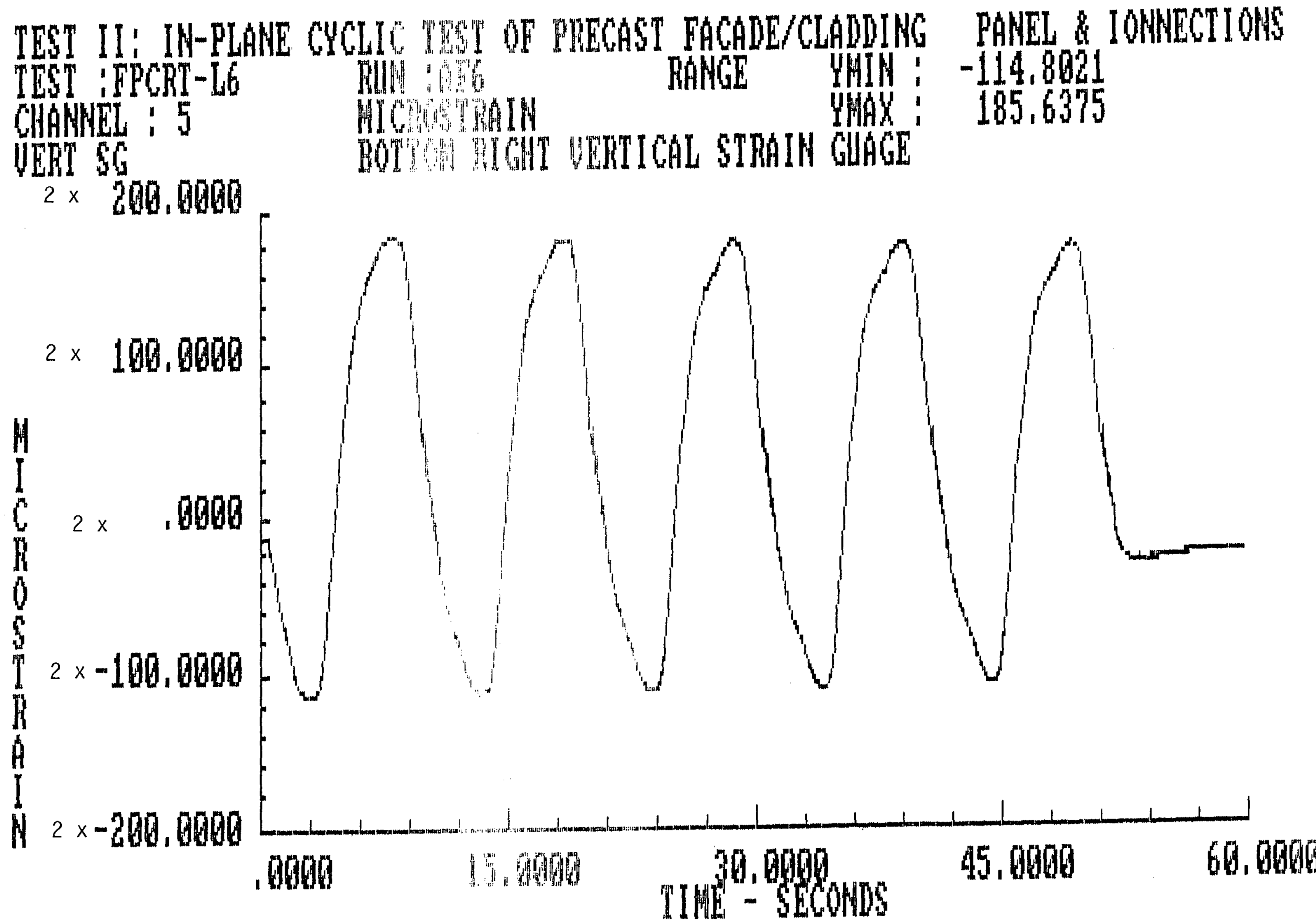


Figure 15 Time-History Plot of Strain
Bottom Right Vertical Strain Gage
Cladding Specimen FPCRT-L6; Run AF-6

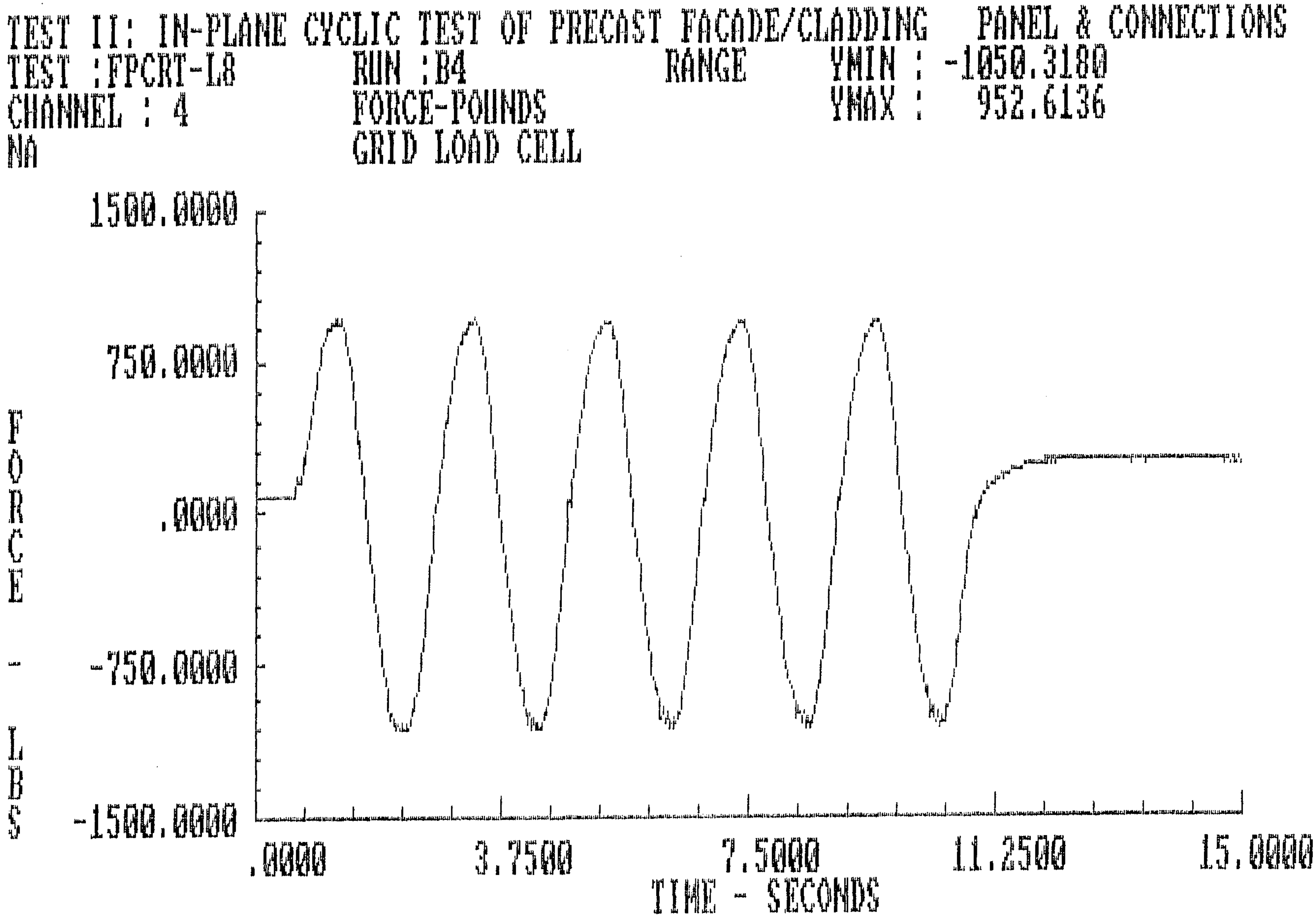


Figure 16 Time-History Plot of Load
Cladding Specimen FPCRT-L8; Run B4

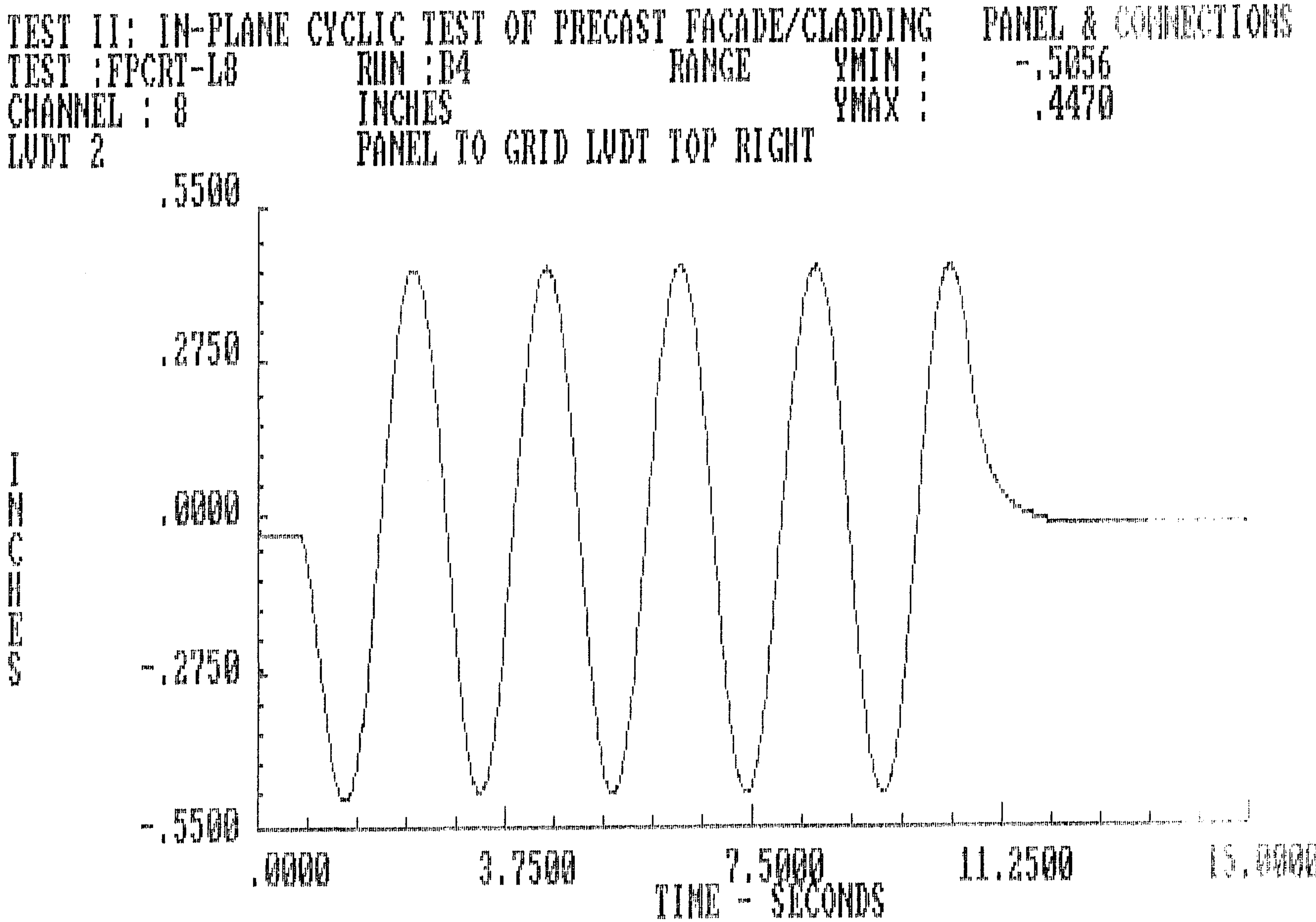


Figure 17 Time-History Plot of Top Horizontal Displacement
Cladding Specimen FPCRT-L8; Run B4

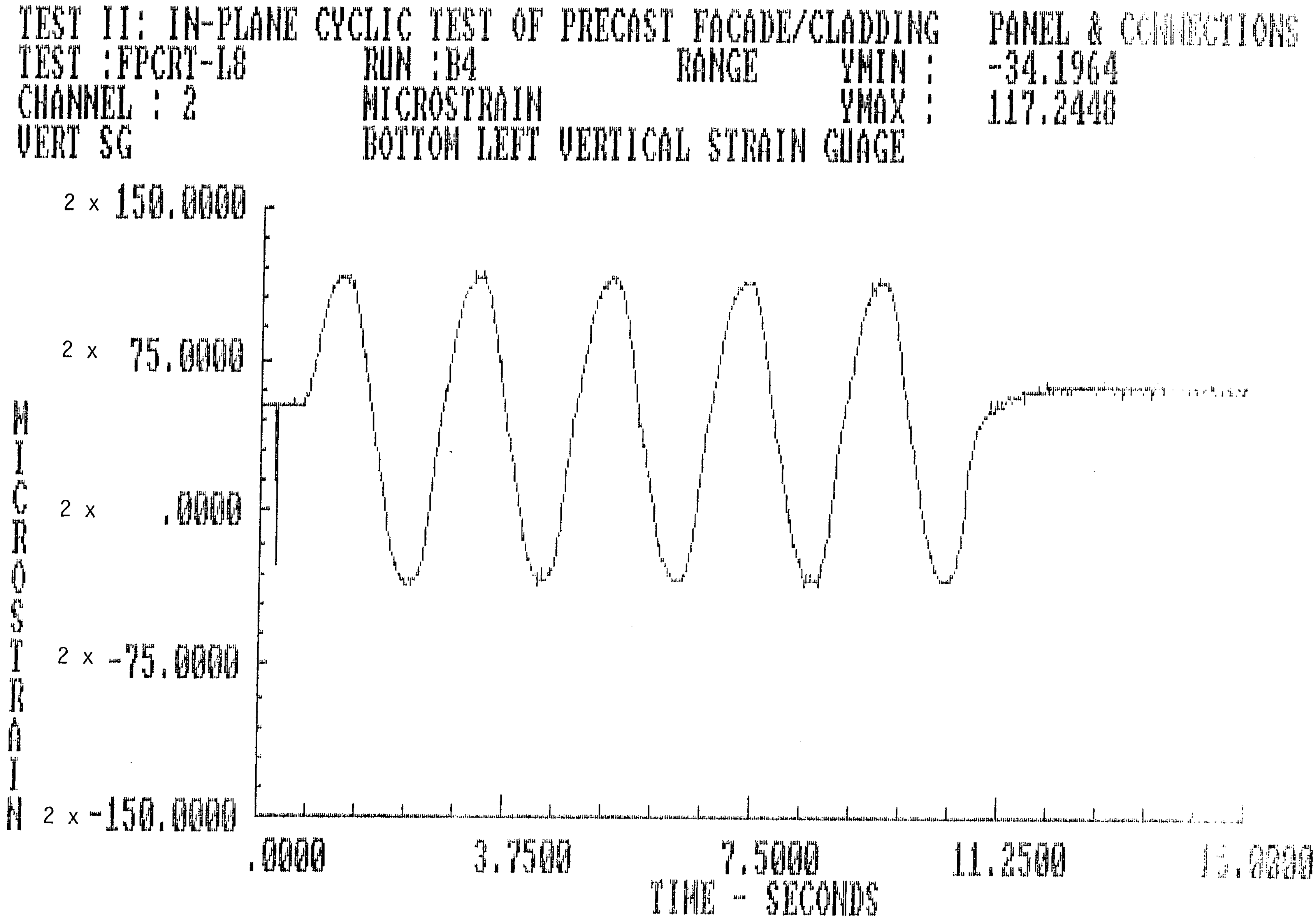


Figure 18 Time-History Plot of Strain
Bottom Left Vertical Strain Gage
Cladding Specimen FPCRT-L8; Run B4

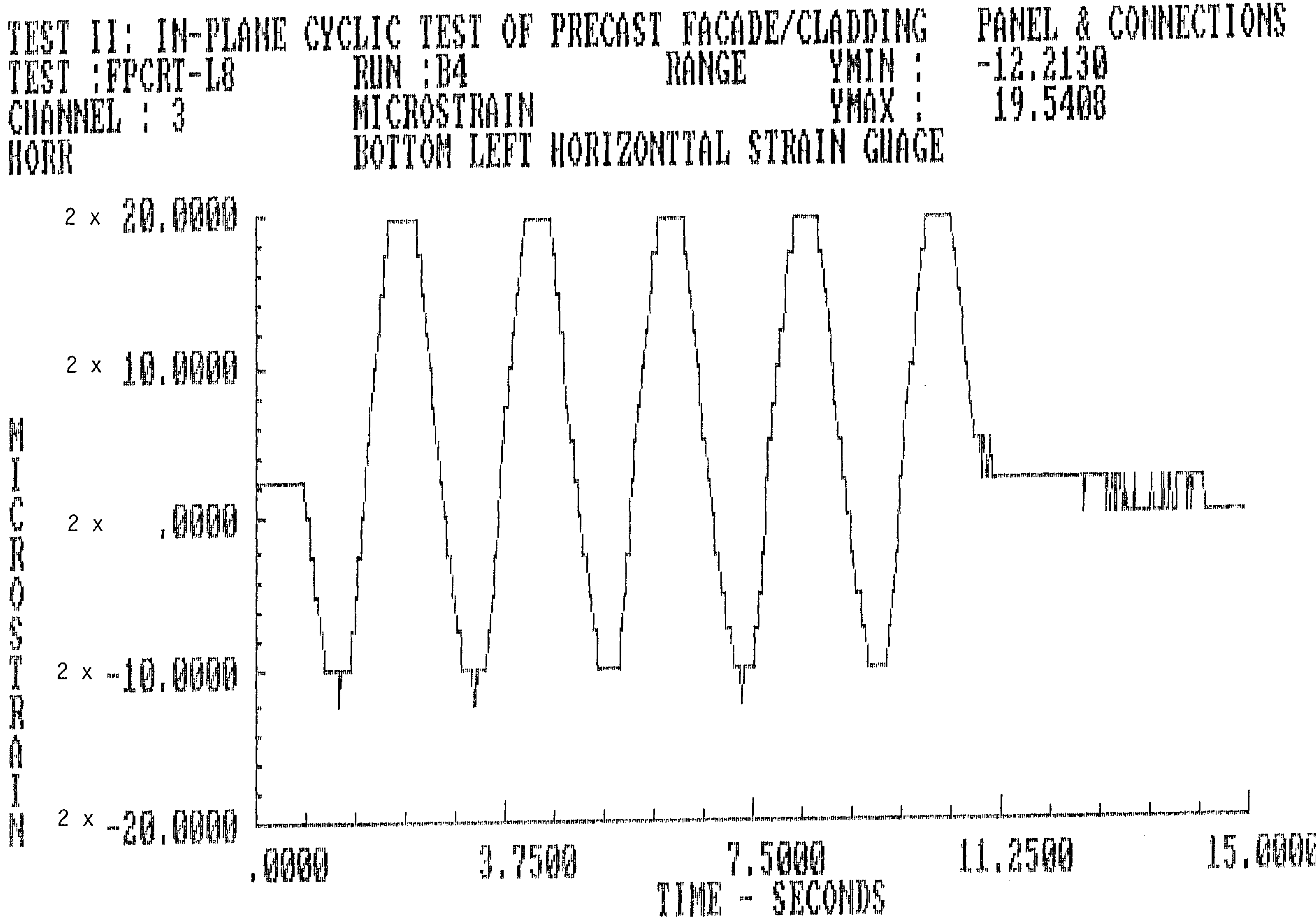


Figure 19 Time-History Plot of Strain
Bottom Left Horizontal Strain Gage
Cladding Sp-cimen FPCRT-L8; Run B4

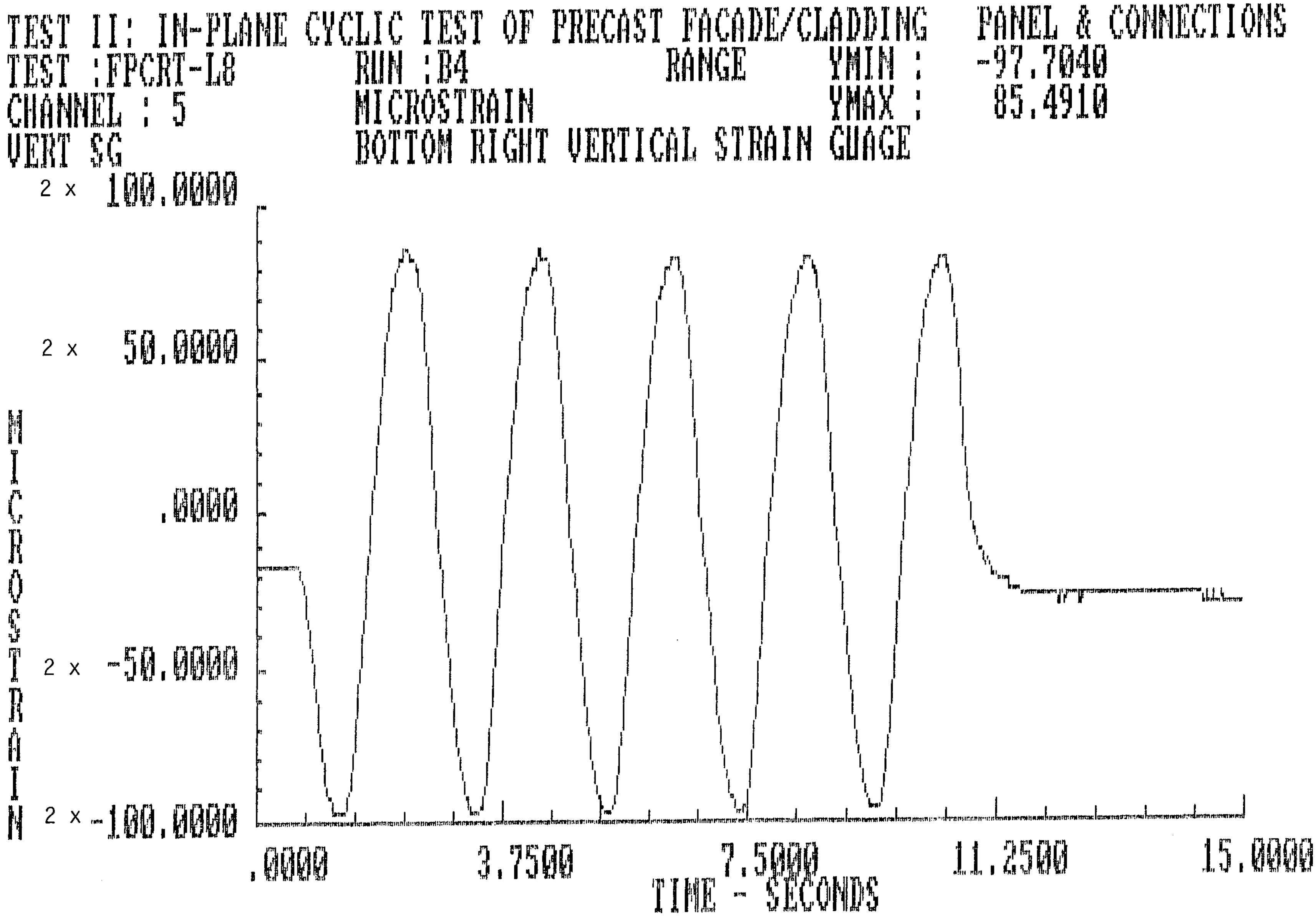


Figure 20 Time-History Plot of Strain
Bottom Right Vertical Strain Gage
Cladding Specimen FPCRT-L8; Run B4

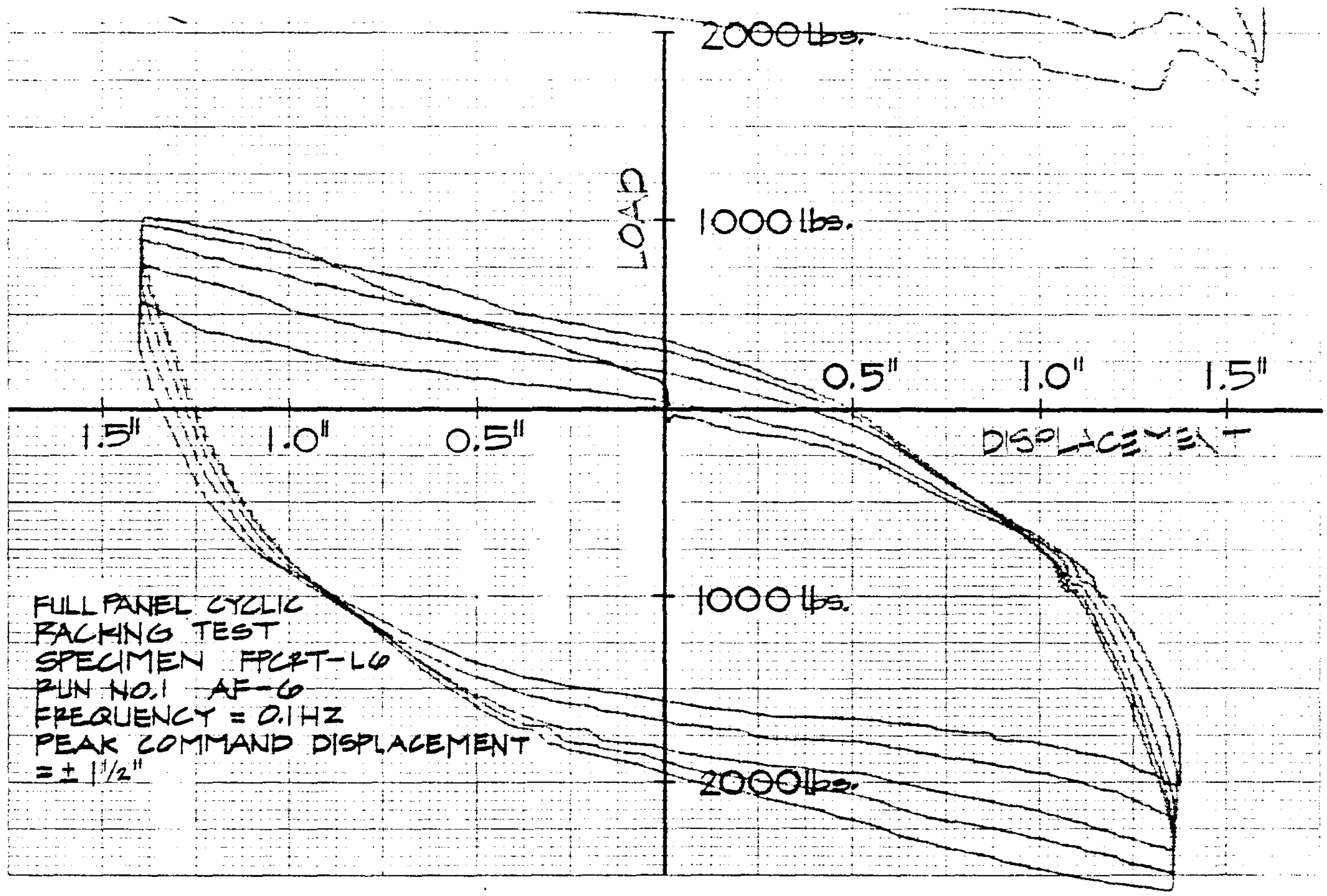


Figure 21

FULL PANEL CYCLIC
RACKING TEST
SPECIMEN FPCRT-L6
RUN NO. AF-6
PEAK COMMAND DISPLACEENT
$=\pm 1\frac{1}{2}$"

TEST II: IN-PLANE CYCLIC TESTING OF PRECAST FACADE/CLADDING PANEL & CONNECTIONS

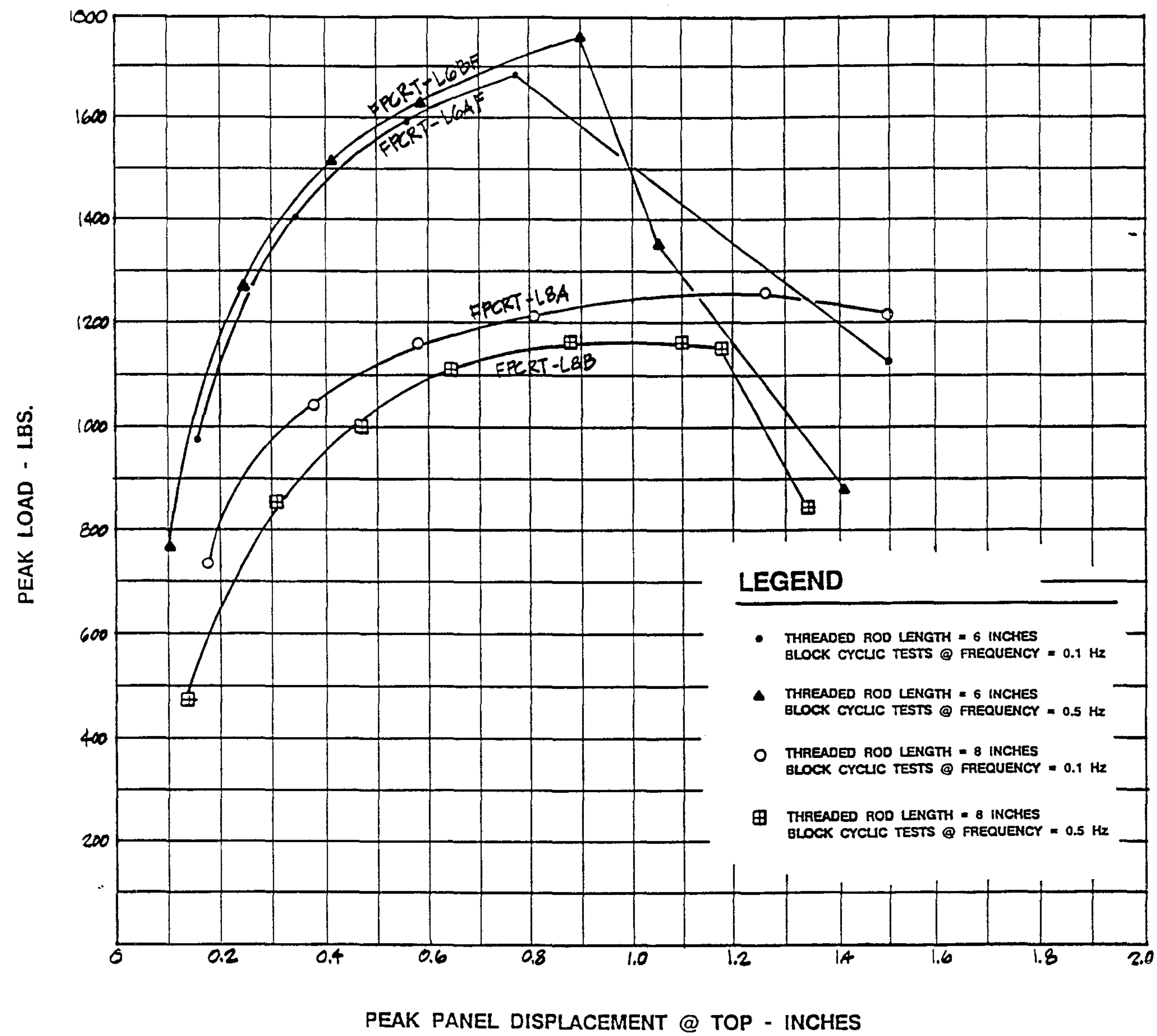
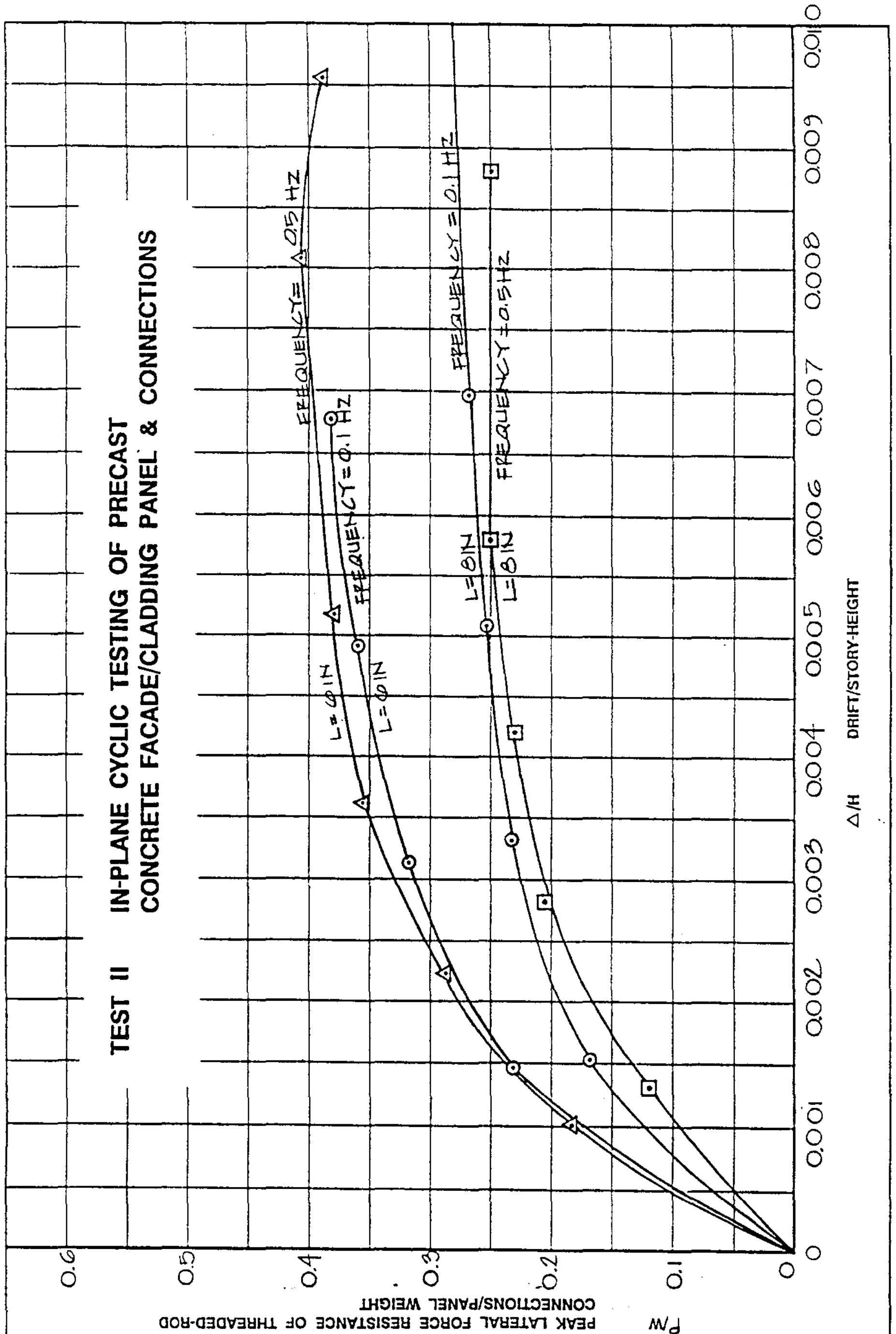
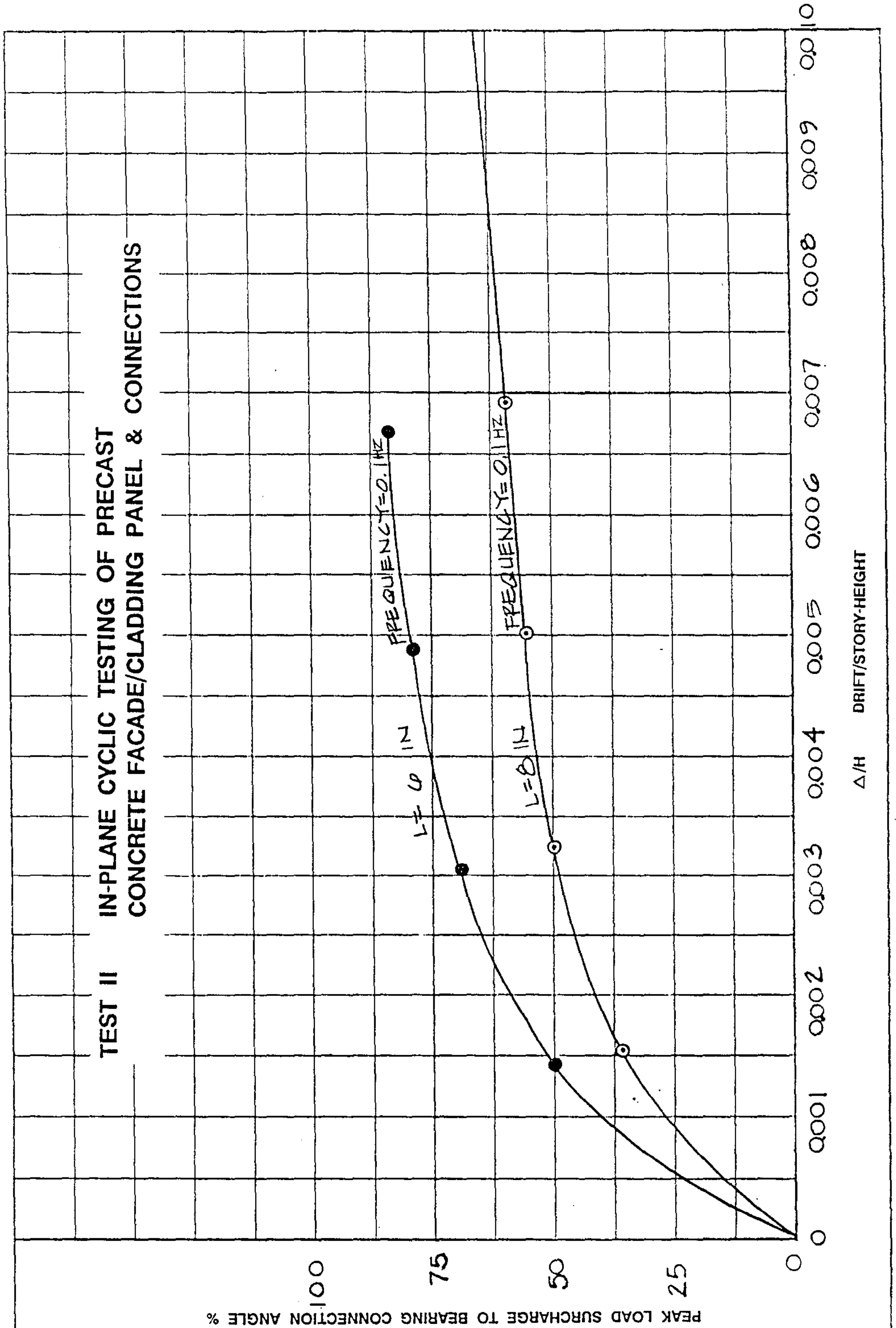


Fig. 22 PEAK LOAD VS. PEAK DISPLACEMENT CURVES

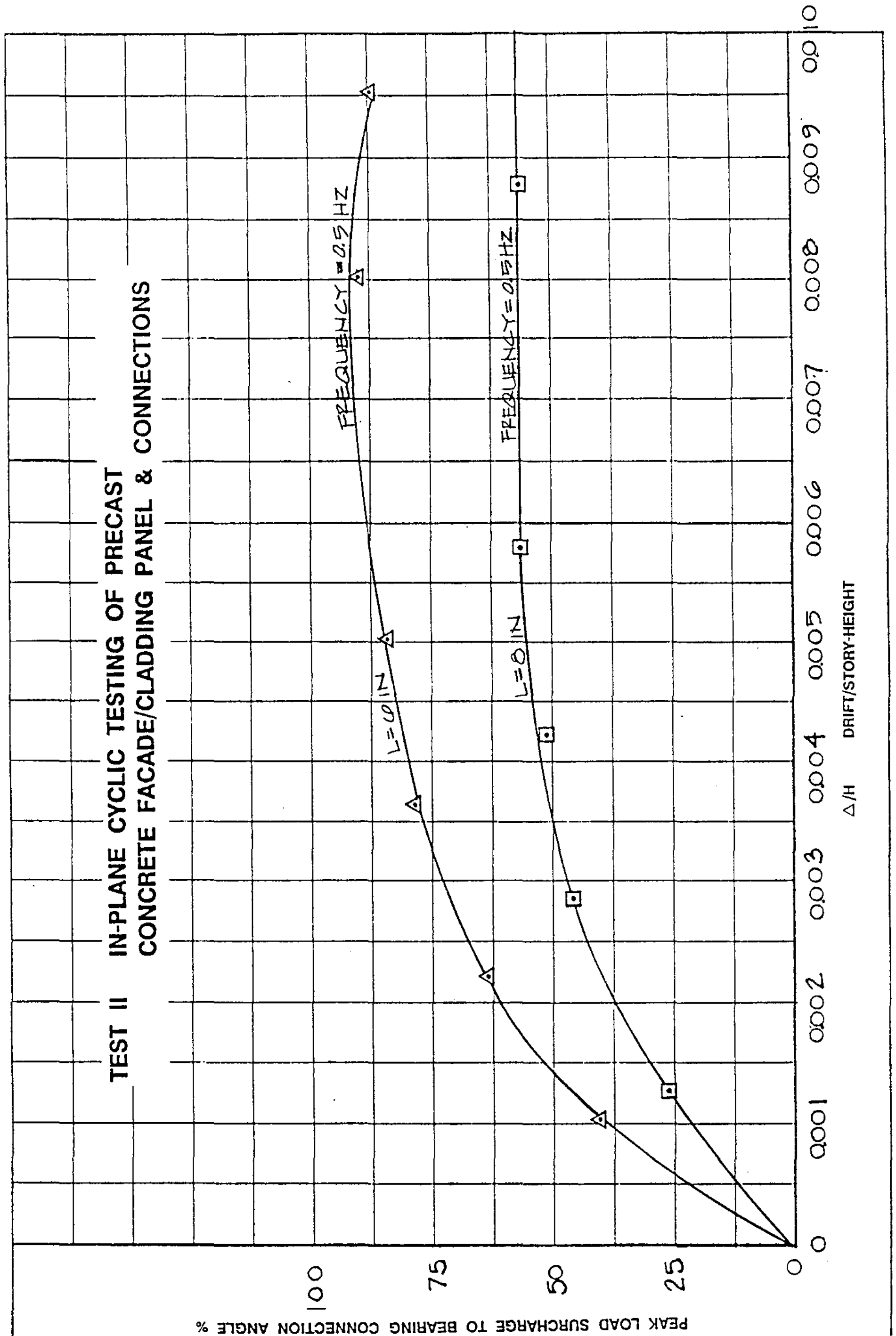


	NSF SPONSORED RESEARCH PROJECT SEISMIC TESTING OF PRECAST CONCRETE FACADES/CLADDING & CONNECTIONS
FIG. 23 PEAK LATERAL FORCE RESISTANCE OF THREADED-ROD LATERAL CONNECTIONS VS. DRIFT	SEISMIC TEST FACILITY ARCHITECTURAL ENGINEERING DEPARTMENT CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407 DRAWN____ DATE____ CHECKED____ DATE____



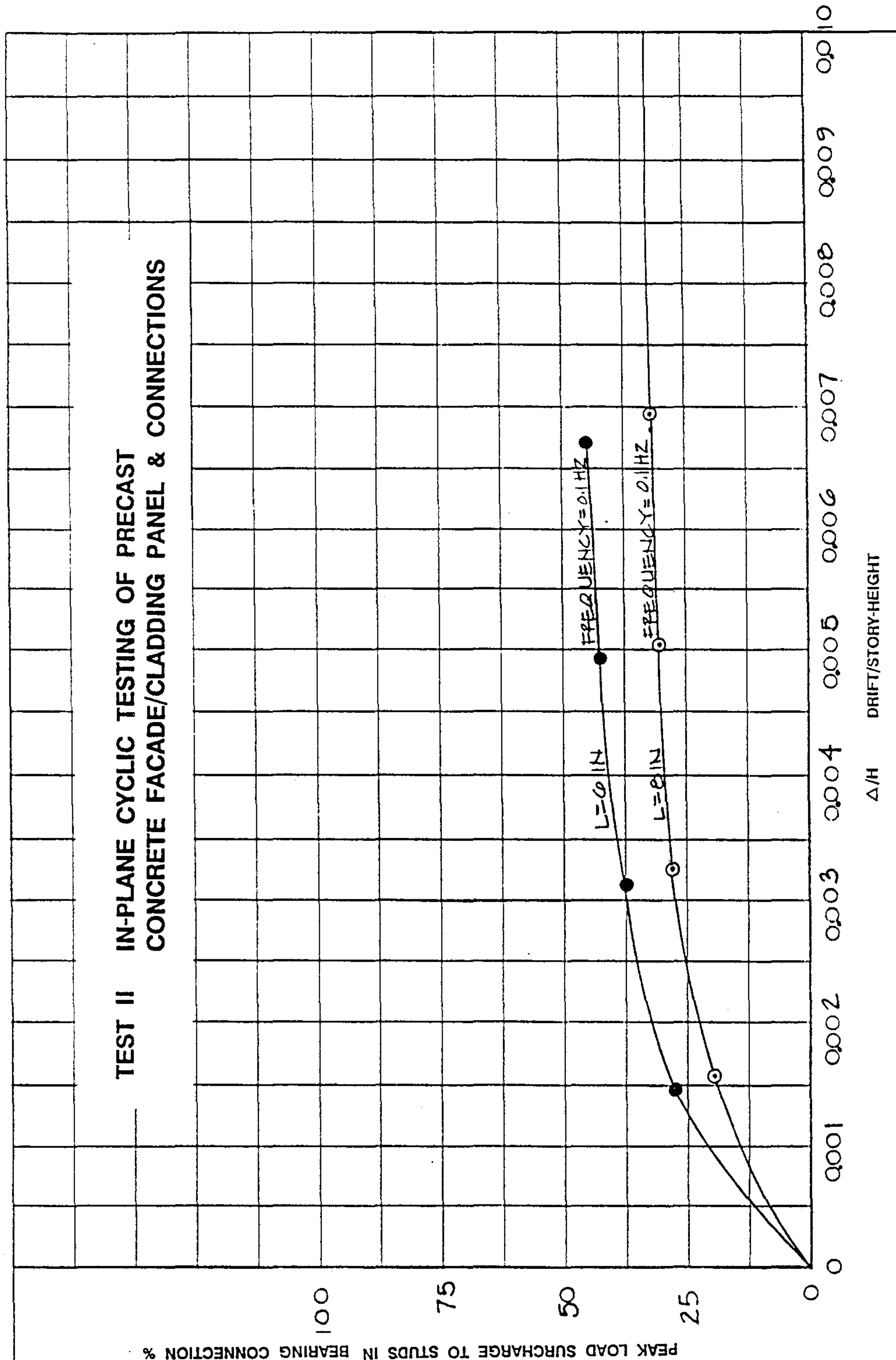
NSF SPONSORED RESEARCH PROJECT
SEISMIC TESTING OF PRECAST CONCRETE
FACADES/CLADDING & CONNECTIONS

FIG. 24	PEAK LOAD SURCHARGE TO BEARING CONNECTION ANGLE VS. DRIFT TEST FREQUENCY = 0.1 Hz	SEISMIC TEST FACILITY ARCHITECTURAL ENGINEERING DEPARTMENT CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407 DRAWN____ DATE____ CHECKED____ DATE____

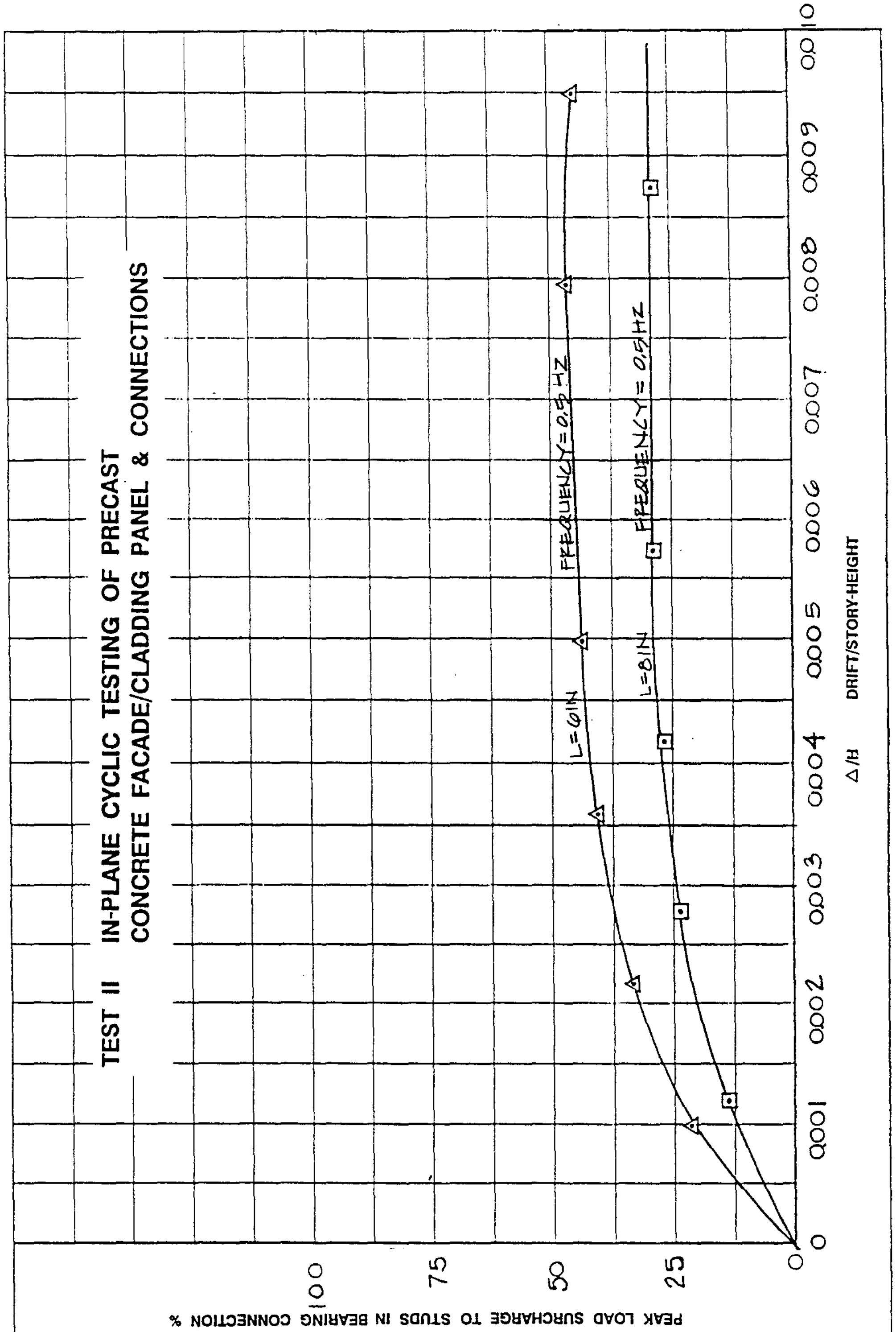


NSF SPONSORED RESEARCH PROJECT
SEISMIC TESTING OF PRECAST CONCRETE
FACADES/CLADDING & CONNECTIONS

FIG. 25	PEAK LOAD SURCHARGE TO BEARING CONNECTION ANGLE VS. DRIFT TEST FREQUENCY = 0.5 Hz	SEISMIC TEST FACILITY ARCHITECTURAL ENGINEERING DEPARTMENT CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407 DRAWN____ DATE____ CHECKED____ DATE____



	NSF SPONSORED RESEARCH PROJECT SEISMIC TESTING OF PRECAST CONCRETE FACADES/CLADDING & CONNECTIONS
FIG. 26 — PEAK LOAD SURCHARGE TO STUDS IN BEARING CONNECTION VS. DRIFT TEST FREQUENCY = 0.1 Hz	SEISMIC TEST FACILITY ARCHITECTURAL ENGINEERING DEPARTMENT CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407 DRAWN____ DATE____ CHECKED____ DATE____



NSF SPONSORED RESEARCH PROJECT
SEISMIC TESTING OF PRECAST CONCRETE
FACADES/CLADDING & CONNECTIONS

FIG. 27 PEAK LOAD SURCHARGE TO STUDS IN BEARING CONNECTION VS. DRIFT
TEST FREQUENCY = 0.5 Hz

SEISMIC TEST FACILITY
ARCHITECTURAL ENGINEERING DEPARTMENT
CAL POLY STATE UNIVERSITY
SAN LUIS OBISPO, CA 93407
DRAWN____ DATE____ CHECKED____ DATE____

CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CA 93407
ARCHITECTURAL ENGINEERING DEPARTMENT - HIGH BAY LAB

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

PRINCIPAL INVESTIGATOR: SAT RIHAL, ARCHITECTURAL ENGINEERING DEPARTMENT
FACULTY ASSOCIATE: GARY GRANNEMAN, ET/EL DEPARTMENT (TESTING AND INSTRUMENTATION)
STUDENT RESEARCH ASSISTANTS: KURT J. CLANDENING AND DWAYNE P. SLAVIN, ARCE SENIORS
TECHNICIAN: BOB MYERS

TEST SCHEDULE: SPECIMEN NO: FPCRT-L6 DATE: 8/27/87 TIME: 1:30 PM LENGTH OF THREADED ROD: 6" PANEL THICKNESS: 4-1/2" PANEL SIZE: 8'w x 10'h
GENERAL DESCRIPTION: In-plane Cyclic Test of Full Size Precast Concrete Cladding Panel with Threaded-Rod Lateral Connections @ Top & Bearing Connections @ Bottom

RUN NO.	FIXED FREQUENCY	NO. OF CYCLES				COMMAND PEAK DISPLACEMENT OF CYCLES (INCHES)							
						1	2	3	4	5	6	7	8
						±1/4"	±3/8"	±1/2"	±3/4"	±1"	±1-1/2"	±1-3/4"	±2-1/2"
AF	0.1 Hz	5	REMARK							NO P.C. DATA		FAILURE	
			X-Y RECORDER	X									
				Y									
			MAG-TAPE READING	INITIAL									
				FINAL									
			TRANSDUCER: VISI = VISICORDER, PC = PERSONAL COMPUTER	VISI CH #	PC CH #								
			ACCELEROMETER GRID - AXIAL (g's)	1	1	±0.003		±0.002	±0.005	?	±0.004	±0.02	
			PANEL BOTTOM LEFT CONNECTION VERTICAL STRAIN GAGE (με)	2	2	±142		±202	±218	±240	±240	±160	
			PANEL BOTTOM LEFT CONNECTION HORIZONTAL STRAIN GAGE (με)	3	3	±35		±49	±56	±60	±61	±46	
			LOAD CELL (LBS.)	4	4	±977		±1404	±1588	±1630	±1685	±1124	
			PANEL BOTTOM RIGHT CONNECTION VERTICAL STRAIN GAGE (με)	5	5	±169		±246	±278	±288	±300	±180	
			PANEL BOTTOM RIGHT CONNECTION HORIZONTAL STRAIN GAGE (με)	6	6	drift		drift	drift	drift	drift		
			LVDT - GRID AXIAL (inches)	7	7	±0.222		±0.442	±0.619	±0.90	±0.911	±1.65	
			LVDT - PANEL TOP (inches)	8	8	±0.161		±0.343	±0.557	±0.75	±0.773	±1.70	
			PANEL TOP LEFT CONNECTION VERTICAL POTENTIOMETER (P) (inches)	11	11	±0.006		±0.017	±0.023	-	±0.033	±0.06	
			PANEL TOP RIGHT CONNECTION VERTICAL POTENTIOMETER (G) (inches)	10	10	±0.006		±0.017	±0.023	-	±0.033	±0.06	
			LVDT - PANEL BOTTOM (inches)	9	9	very small		very small	very small	-	very small	very small	

Table I

CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CA 93407
ARCHITECTURAL ENGINEERING DEPARTMENT - HIGH BAY LAB

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

PRINCIPAL INVESTIGATOR: SAT RIHAL, ARCHITECTURAL ENGINEERING DEPARTMENT
FACULTY ASSOCIATE: GARY GRANNEMAN, ET/EL DEPARTMENT (TESTING AND INSTRUMENTATION)
STUDENT RESEARCH ASSISTANTS: KURT J. CLANDENING AND DWAYNE P. SLAVIN, ARCE SENIORS
TECHNICIAN: BOB MYERS

TEST SCHEDULE: SPECIMEN NO: FPCRT-L6 DATE: 8/27/87 TIME: 2:45 PM LENGTH OF THREADED ROD: 6" PANEL THICKNESS: 4-1/2" PANEL SIZE: 8'w X 10'h
GENERAL DESCRIPTION: In-Plane Cyclic Test of Full Size Precast Concrete Cladding Panel with Threaded Rod Lateral Connections @ Top & Bearing Connections @ Bottom

RUN NO.	FIXED FREQUENCY	NO. OF CYCLES					COMMAND PEAK DISPLACEMENT OF CYCLES (INCHES)							
							1	2	3	4	5	6	7	8
							±1/4"	±3/8"	±1/2"	±3/4"	±1"	±1-1/2"	±2"	±2-1/2"
BF	0.5 Hz	5	REMARK											FAILURE
			X-Y RECORDER LOAD CELL	X mV/in			100		100	100	100			
			LVDT 1	Y mV/in			100		100	250	250	250/1000	1000	1000
			MAG-TAPE READING	INITIAL			1835		1848	1862	1875	1888	1977	1988
				FINAL			1848		1862	1875	1888	1977	1988	2000
			TRANSDUCER: VISI = VISICORDER, PC = PERSONAL COMPUTER		VISI CH #	PC CH #								
			ACCELEROMETER GRID - AXIAL	g's	1	1								
			PANEL BOTTOM LEFT CONNECTION VERTICAL STRAIN GAGE	με	2	2	±102		±176	±214	±232	±254	±200	±120
			PANEL BOTTOM LEFT CONNECTION HORIZONTAL STRAIN GAGE	με	3	3	±27		±47	±59	±60	±66	±52	±60
			LOAD CELL	LBS.	4	4	±769		±1270	±1514	±1624	±1759	±1348	±880
			PANEL BOTTOM RIGHT CONNECTION VERTICAL STRAIN GAGE	με	5	5	±133		±234	±278	±300	±311	±240	
			PANEL BOTTOM RIGHT CONNECTION HORIZONTAL STRAIN GAGE	με	6	6	drift		drift	drift	drift	drift	drift	
			LVDT - GRID AXIAL	inches	7	7	±0.156		±0.331	±0.532	±0.716	±1.06	±1.19	±1.36
			LVDT - PANEL TOP	inches	8	8	±0.109		±0.248	±0.416	±0.591	±0.912	±1.058	±1.41/1.22
			PANEL TOP LEFT CONNECTION VERTICAL POTENTIOMETER (P)	inches	11	11	±0.004		±0.011	±0.017	±0.027	±0.034	±0.044	±0.048/0.054
			PANEL TOP RIGHT CONNECTION VERTICAL POTENTIOMETER (G)	inches	10	10	±0.004		±0.011	±0.017	-	±0.034	±0.044	±0.048/0.054
			LVDT - PANEL BOTTOM	inches	9	9	very small		very small	very small	very small	very small	very small	very small

Table II

CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CA 93407
ARCHITECTURAL ENGINEERING DEPARTMENT - HIGH BAY LAB

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

PRINCIPAL INVESTIGATOR: SAT RIHAL, ARCHITECTURAL ENGINEERING DEPARTMENT
FACULTY ASSOCIATE: GARY GRANNEMAN, ET/EL DEPARTMENT (TESTING AND INSTRUMENTATION)
STUDENT RESEARCH ASSISTANTS: KURT J. CLANDENING AND DWAYNE P. SLAVIN, ARCE SENIORS
TECHNICIAN: BOB MYERS

TEST SCHEDULE: SPECIMEN NO: FPCRT-L8 DATE: 8/25/87 TIME: _______ LENGTH OF THREADED ROD: 8" PANEL THICKNESS: 4-1/2" PANEL SIZE: 8'w x 10'h
GENERAL DESCRIPTION: In-Plane Cyclic Test of Full Size Precast Concrete Cladding Panel with Threaded-Rod Lateral Connections @ Top & Bearing Connections @ Bottom

RUN NO.	FIXED FREQUENCY	NO. OF CYCLES				COMMAND PEAK DISPLACEMENT OF CYCLES (INCHES) 1	2	3	4	5	6	7	8
						±1/4"	±3/8"	±1/2"	±3/4"	±1"	±1-1/2"	±1-3/4"	±2-1/2"
A	0.1 Hz	5	REMARK			B:FPTL8 A1	SKIP	B:FPTL8 A3	B:FPTL8 A4	B:FPTL8 A5	B:FPTL8 A6	B:FPTL8 A7 FAILURE	
			X-Y RECORDER LOAD CELL	X mV/in		100		100	100	100			
			LVDT1	y mV/in		100		200	200	500			
			MAG-TAPE READING	INITIAL		928		1014	1097	1169	1241	1315	
				FINAL		1014		1097	1169	1241	1315	1386	
			TRANSDUCER: VISI = VISICORDER, PC = PERSONAL COMPUTER	VISI CH #	PC CH #								
			ACCELEROMETER GRID - AXIAL g's	1	1	±0.001		±0.004	±0.004	±0.004	±0.005	±0.008	
			PANEL BOTTOM LEFT CONNECTION VERTICAL STRAIN GAGE με	2	2	±110		±156	±171	±177	±181	±200	
			PANEL BOTTOM LEFT CONNECTION HORIZONTAL STRAIN GAGE με	3	3	±22		±34	±34	±37	±44	±50	
			LOAD CELL LBS.	4	4	±733		±1038	±1160	±1209	±1253	±1209	
			PANEL BOTTOM RIGHT CONNECTION VERTICAL STRAIN GAGE με	5	5	±125		±188	±205	±213	±230	±240	
			PANEL BOTTOM RIGHT CONNECTION HORIZONTAL STRAIN GAGE με	6	6	drift		drift	drift	drift	drift	drift	
			LVDT - GRID AXIAL inches	7	7	±0.233		±0.463	±0.684	±0.929	±1.397	±1.7	
			LVDT - PANEL TOP inches	8	8	±0.181		±0.380	±0.584	±0.813	±1.260	±1.5	
			PANEL TOP LEFT CONNECTION VERTICAL POTENTIOMETER (P) inches		11	±0.009		±0.016	±0.024	±0.033	±0.053	±0.06	
			PANEL TOP RIGHT CONNECTION VERTICAL POTENTIOMETER (G) inches		10	±0.009		±0.016	±0.024	±0.034	±0.053	±0.06	
			LVDT - PANEL BOTTOM inches		9	very small		-	very small	-	-	-	
			LOAD CELL LBS.		12					±1203	±1257	±1207	

Table III

CALIFORNIA POLYTECHNIC STATE UNIVERSITY, SAN LUIS OBISPO, CA 93407
ARCHITECTURAL ENGINEERING DEPARTMENT - HIGH BAY LAB

TEST II: IN-PLANE CYCLIC TEST OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS

PRINCIPAL INVESTIGATOR: SAT RIHAL, ARCHITECTURAL ENGINEERING DEPARTMENT
FACULTY ASSOCIATE: GARY GRANNEMAN, ET/EL DEPARTMENT (TESTING AND INSTRUMENTATION)
STUDENT RESEARCH ASSISTANTS: KURT J. CLANDENING AND DWAYNE P. SLAVIN, ARCE SENIORS
TECHNICIAN: BOB MYERS

TEST SCHEDULE: SPECIMEN NO: FPCRT-L8 DATE: 8/26/87 TIME: 5:25 PM LENGTH OF THREADED ROD: 8" PANEL THICKNESS: 4-1/2" PANEL SIZE: 8'w x 10'h
GENERAL DESCRIPTION: In-plane Cyclic Test of Full Size Precast Concrete Cladding Panel with Threaded-Rod Lateral Connections @ Top & Bearing Connections @ Bottom

RUN NO.	FIXED FREQUENCY	NO. OF CYCLES			VISI CH #	PC CH #	COMMAND PEAK DISPLACEMENT OF CYCLES (INCHES)							
							1	3	4	5	6	7	8	9
							±1/4"	±1/2"	±3/4"	±1"	±1-1/2"	±1-3/4"	±2"	±2-1/4"
B	0.5 Hz	5	REMARK DATA FILE NAMES				FPTL8 B1.CDS	FPTL8 B3.CDS	FPTL8 B4.CDS	FPTL8 B5.CDS	FPTL8 B6.CDS	FPTL8 B7.CDS	FPTTL8 B8.CDS	FPTTL8 B9.CDS
			X-Y RECORDER LOAD CELL		X mV/in		100	100	100	100	100	100	100	100
			LVDT1		y mV/in		100	100	200	500	500	500	500	500
			MAG-TAPE READING		INITIAL		1386	1404	1420	1436	1451	1466	1483	1500
					FINAL		1404	1436	1436	1451	1466	1483	1500	
			TRANSDUCER	VISI = VISICORDER, PC = PERSONAL COMPUTER	VISI CH #	PC CH #								
				ACCELEROMETER GRID - AXIAL g's	1	1	±0.009	±0.018	±0.017	±0.038	±0.045	±0.045	±0.053	±0.06
				PANEL BOTTOM LEFT CONNECTION VERTICAL STRAIN GAGE με	2	2	±68	±129	±151	±166	±176	±169	±161	±88
				PANEL BOTTOM LEFT CONNECTION HORIZONTAL STRAIN GAGE με	3	3	±15	±27	±29	±34	±39	±36	±39	±30
				LOAD CELL LBS.	4	4	±474	±855	±1001	±1111	±1160	±1160	±1148	±843
				PANEL BOTTOM RIGHT CONNECTION VERTICAL STRAIN GAGE με	5	5	±83	±154	±183	±200	±215	±210	±192	±100
				PANEL BOTTOM RIGHT CONNECTION HORIZONTAL STRAIN GAGE με	6	6	±10	±14	±14	±15				±26
				LVDT - GRID AXIAL inches	7	7	±0.172	±0.380	±0.564	±0.754	±1.114	±1.196	±1.229	±1.462
				LVDT - PANEL TOP inches	8	8	±0.137	±0.311	±0.476	±0.650	±0.988	±1.101	±1.183	±1.347
				PANEL TOP LEFT CONNECTION VERTICAL POTENTIOMETER (P) inches		11	±0.006	-	±0.019	±0.026	±0.038	±0.042	±0.042	±0.055
				PANEL TOP RIGHT CONNECTION VERTICAL POTENTIOMETER (G) inches		10	±0.005	±0.013	±0.018	±0.026	±0.039	±0.043	±0.043	±0.055
				LVDT - PANEL BOTTOM inches		9				±0.002	±0.002			
				LOAD CELL (CHECK FOR CH#4) LBS.		12	±470	±871	±1010	±1133	±1157	±1181	±1143	±842

Table IV

APPENDIX C TEST III

PHOTOGRAPHS

DRAWINGS OF TEST STRUCTURE AND CLADDING PANELS
AND CONNECTION DETAILS

TYPICAL OUTPUT FROM ANALYZER

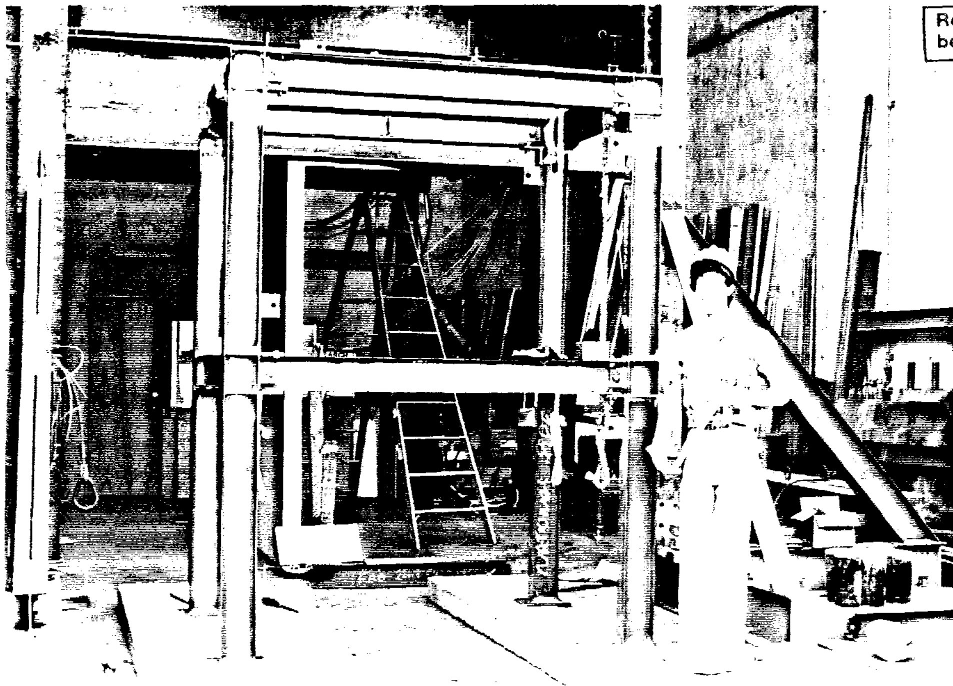


Figure 1 Photograph - Two-Story Moment-Resisting Rigid-Frame Test Structure for Dynamic Testing of Cladding and Connections

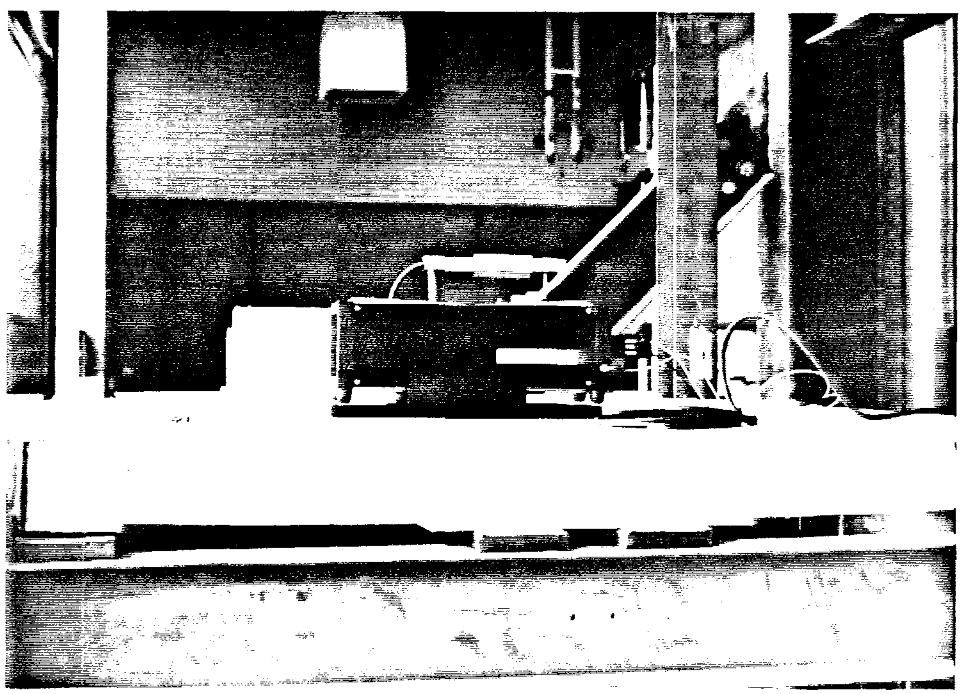


Figure 2 Photograph - APS Electro-Seis Shaker Positioned in the Floor of Test Structure in the N-S Direction

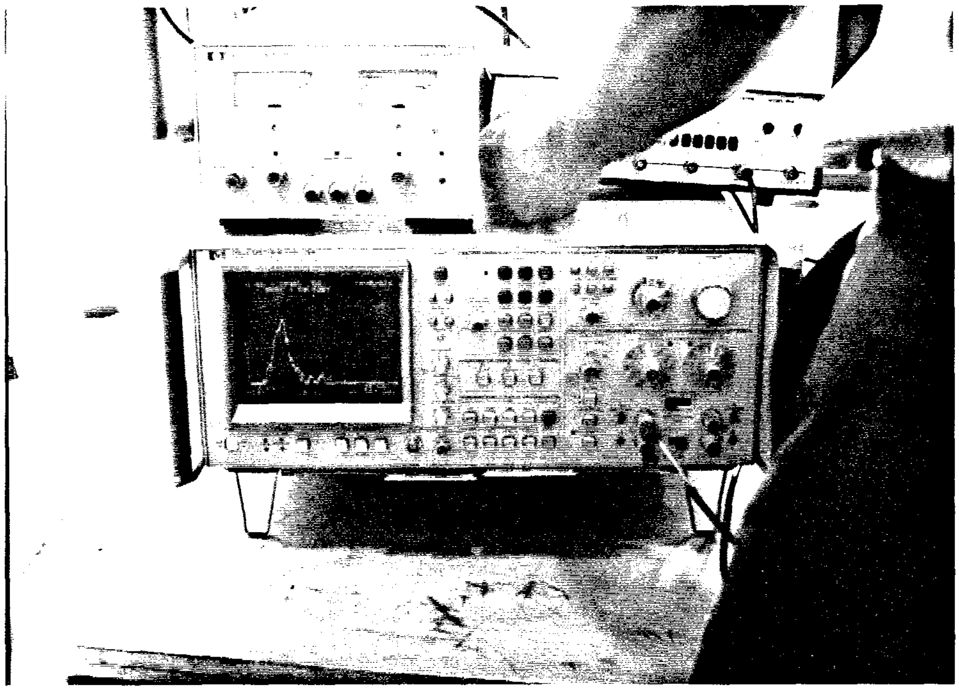


Figure 3 Photograph - Test Instrumentation
HP3582A Spectrum Analyzer

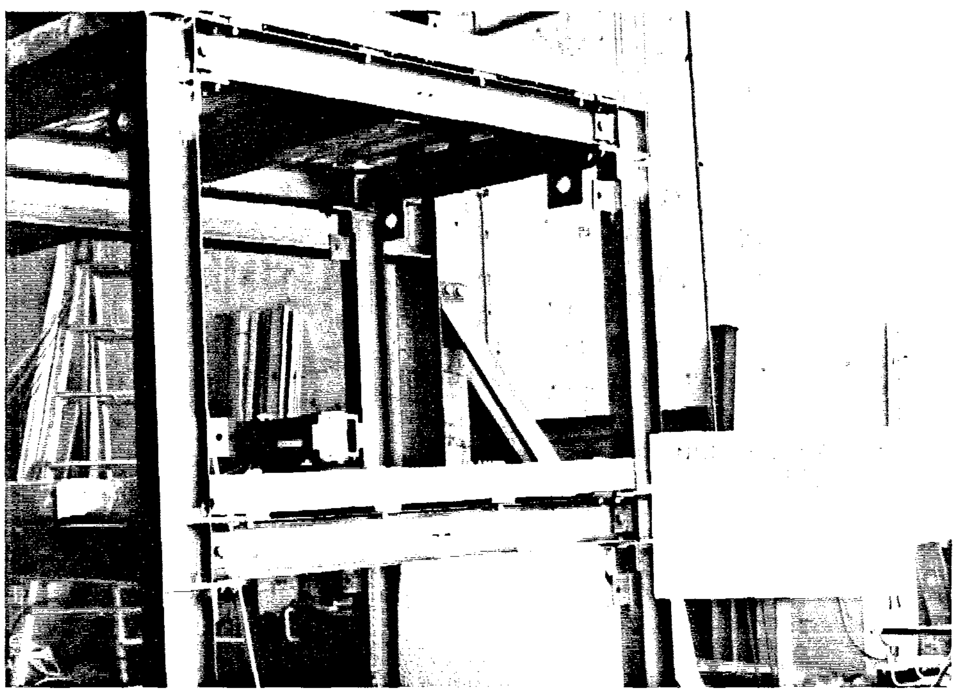


Figure 4 Photograph - Dynamic Test of Test-Structure Without Cladding Panels
APS Electro-Seis Shaker Positioned on Floor in the N-S Direction

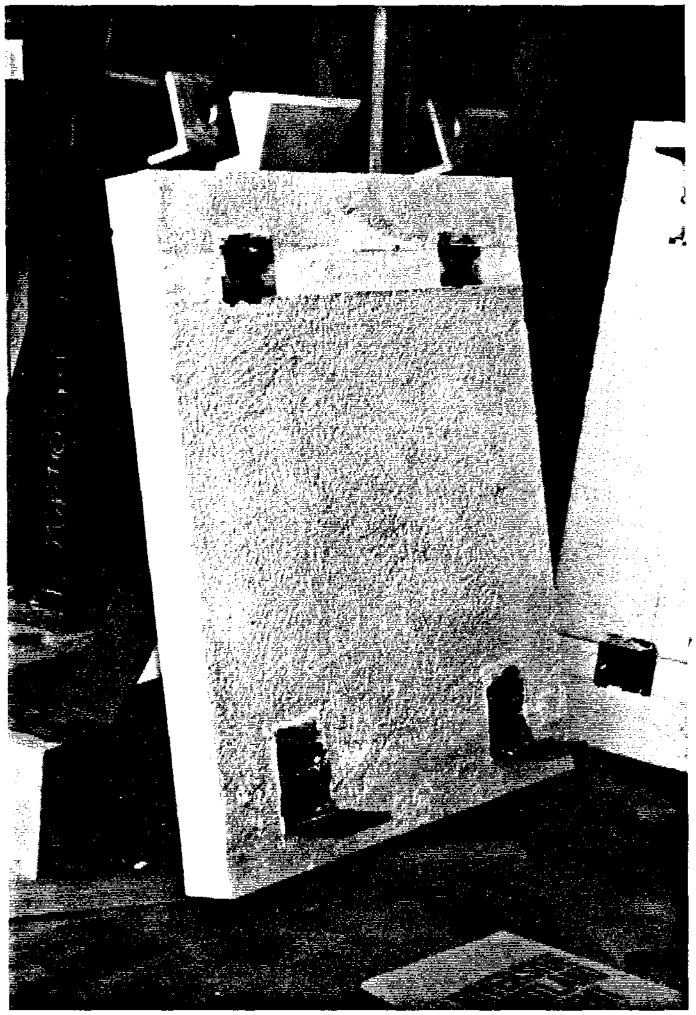
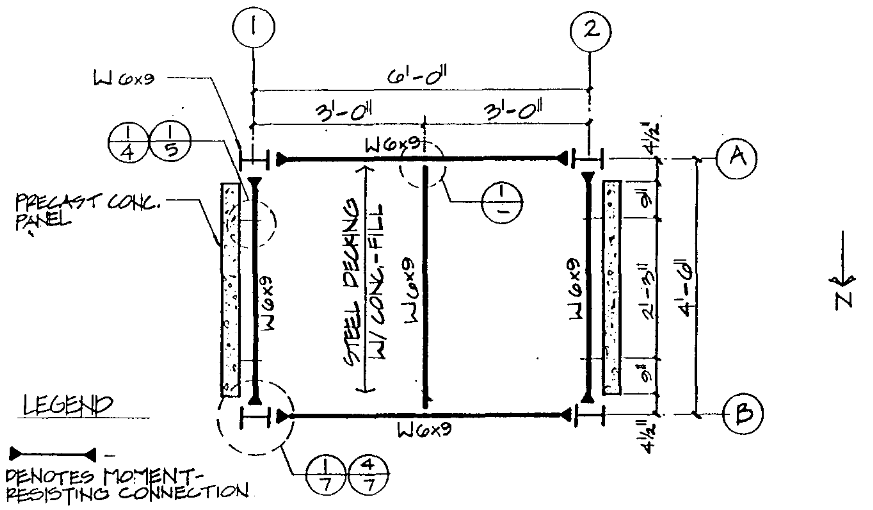
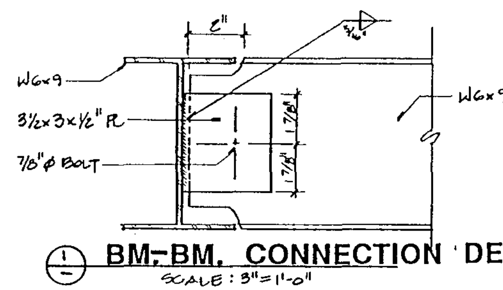


Figure 5 Photograph - $4\frac{1}{2}$-inch Thick Precast Cladding Panel Before Attachment to the Test III Steel Test Frame Structure



FIRST AND SECOND FLOOR FRAMING PLAN

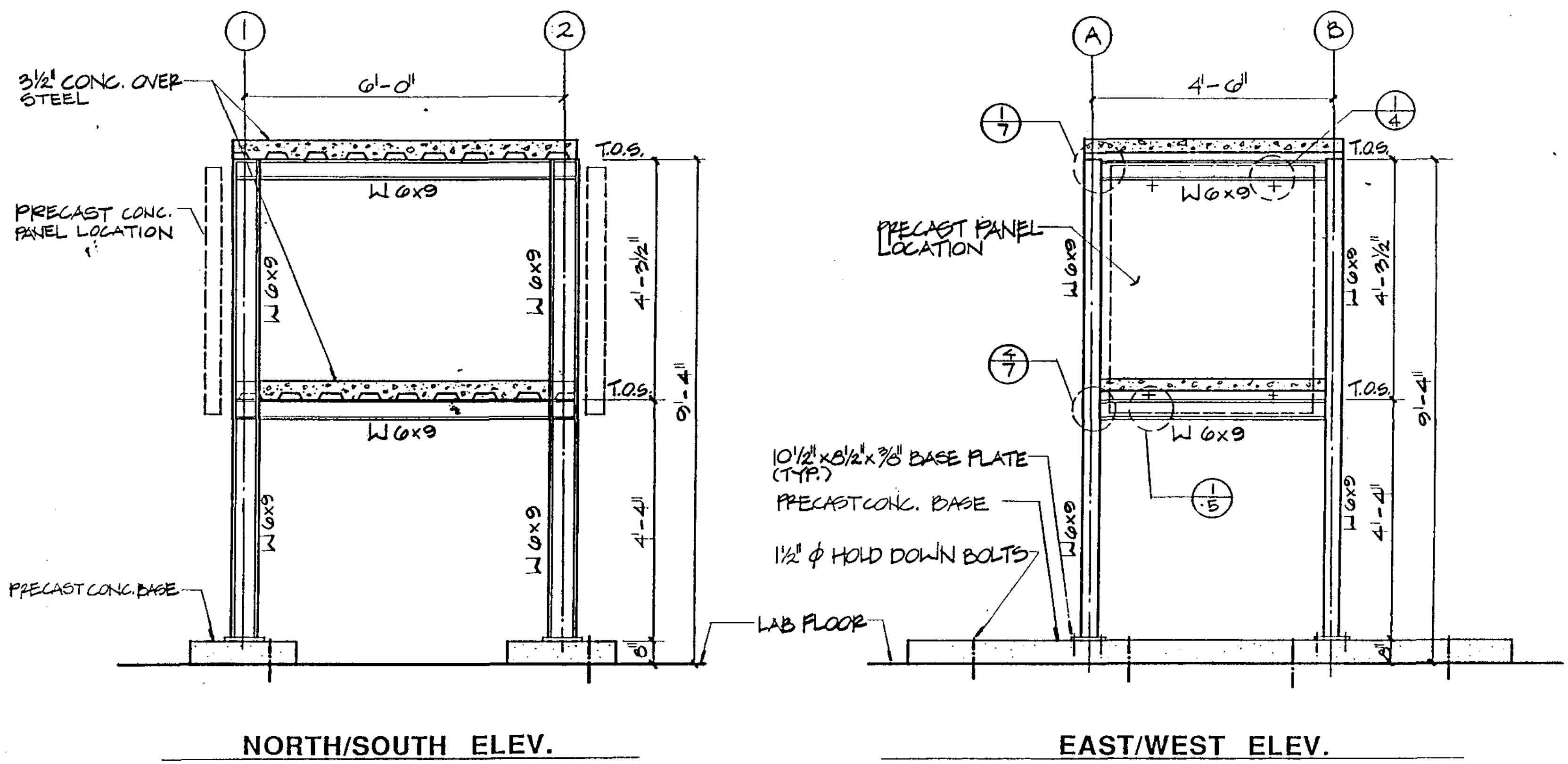
SCALE ½"=1'-0"



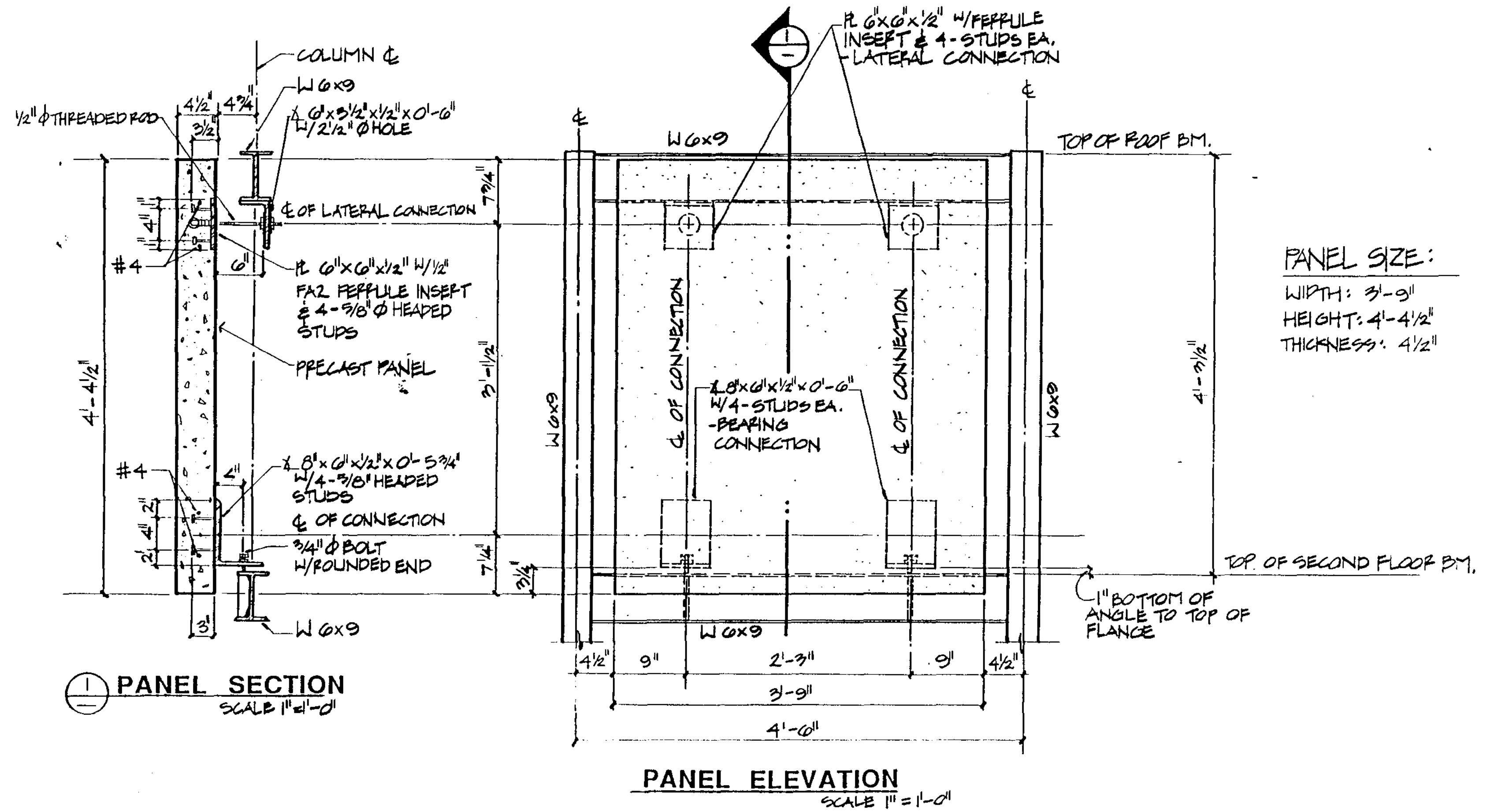
BM-BM. CONNECTION DETAIL

SCALE: 3"=1'-0"

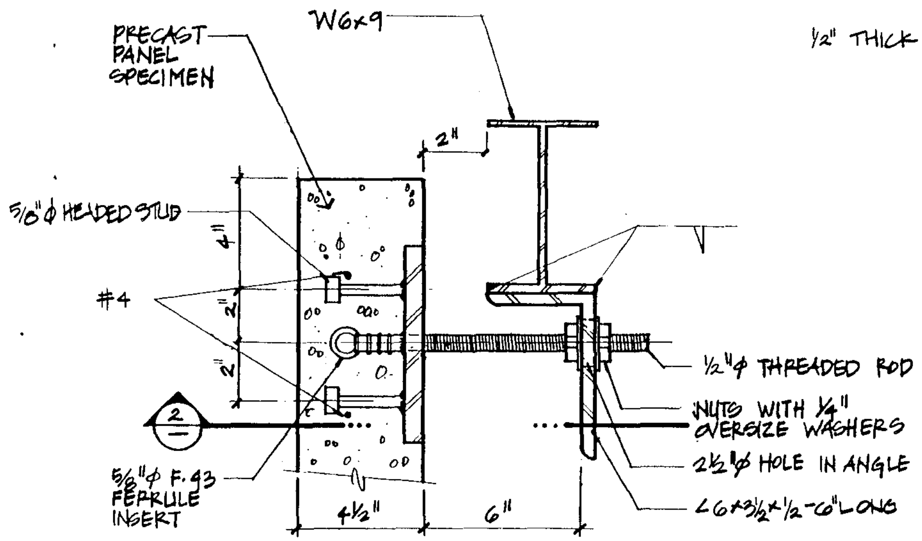
SHEET	NSF SPONSORED RESEARCH PROJECT:	TEST III	SEISMIC TEST FACILITY	DRWN:
1	SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDINGS AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	ARCHITECTURAL ENGR. DEPT.	DATE:
			CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	



SHEET	NSF SPONSORED RESEARCH PROJECT:	TEST III	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT.	DRWN:
2	SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDINGS AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	DATE:

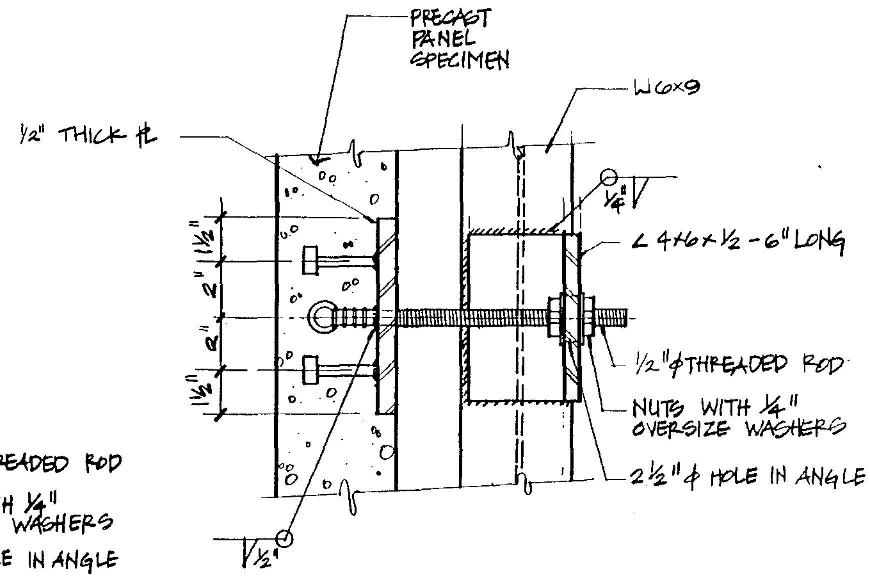


SHEET	NSF SPONSORED RESEARCH PROJECT:	TEST III	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT.	DRWN:
3	SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDINGS AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	DATE:



① 1/4 **DUCTILE CONNECTION–SECTION**

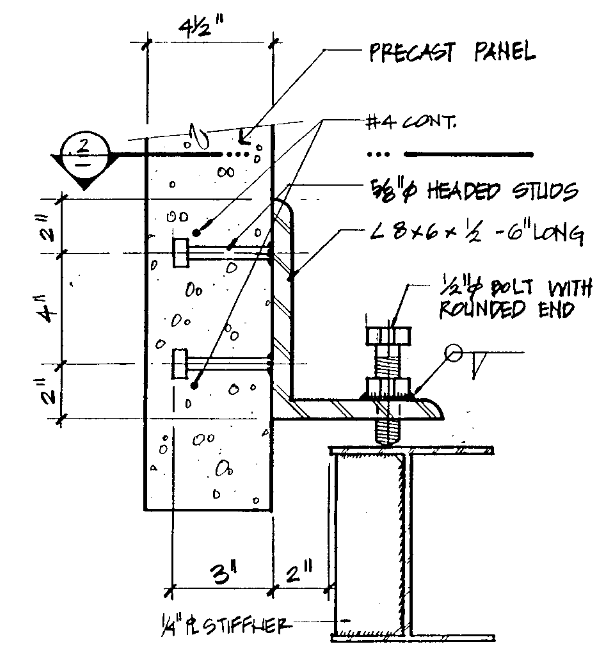
SCALE: 3"=1'-0"



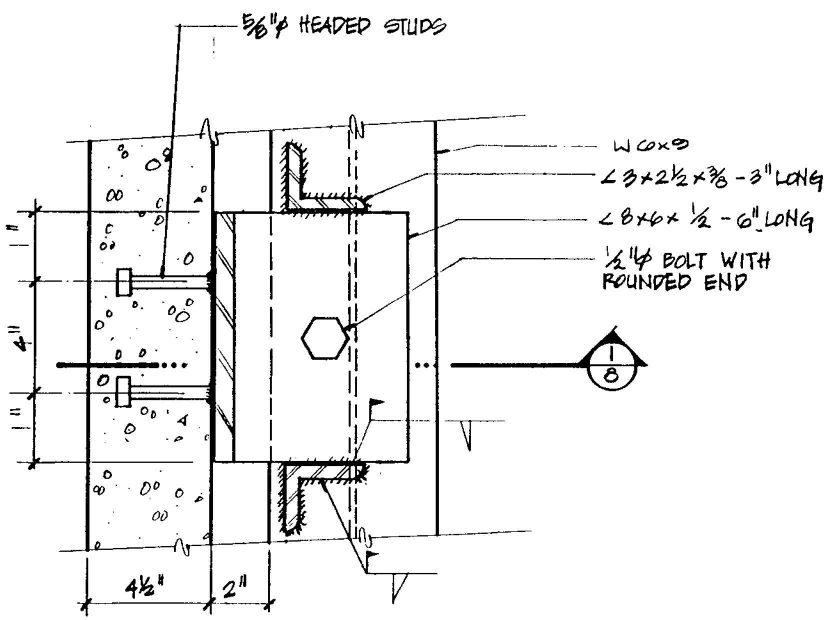
② 2/4 **DUCTILE CONNECTION–BOTTOM VIEW**

SCALE: 3"=1'-0"

SHEET 4	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	TEST III DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	DRWN: CJL DATE: 1/87 CHCK: DATE:

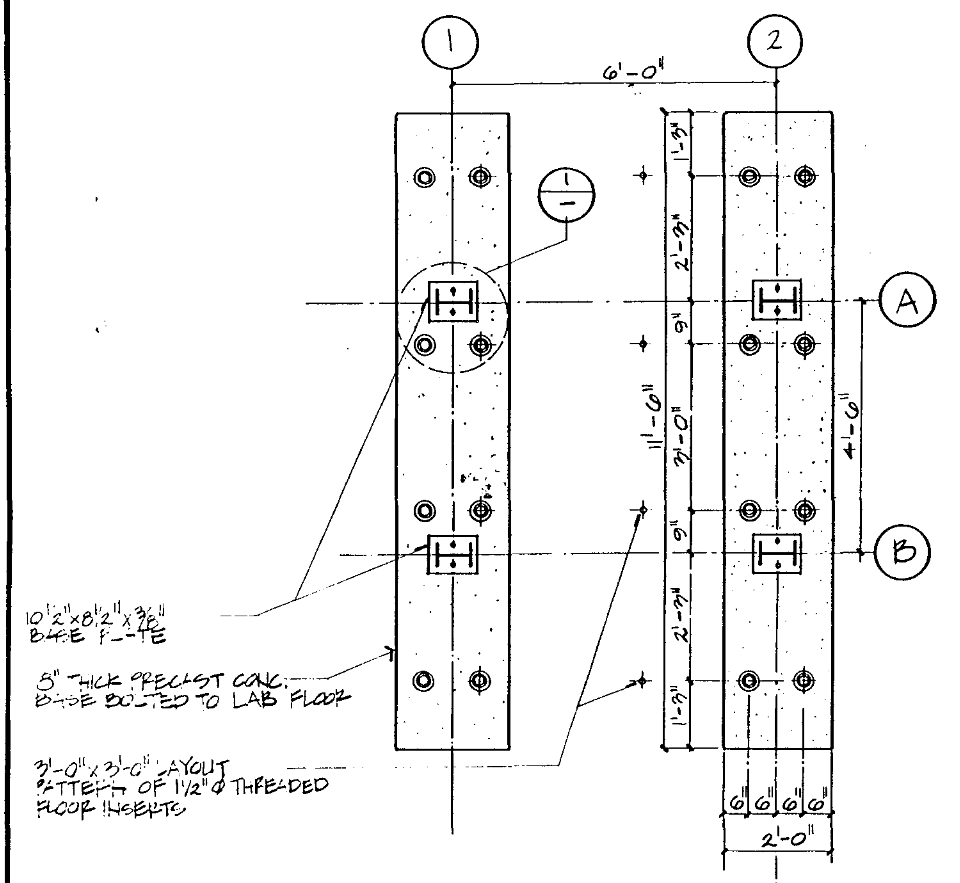


BEARING CONNECTION–SECTION (1/5)
SCALE: 3"=1'-0"



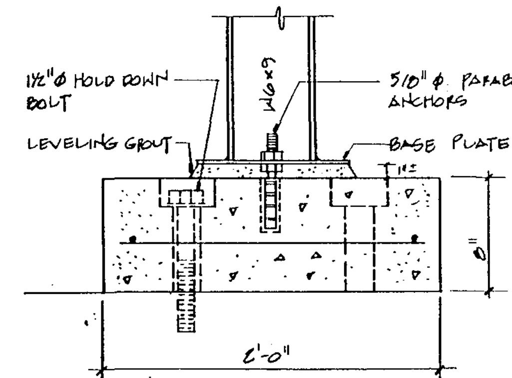
BEARING CONNECTION–PLAN (2/–)
SCALE: 3"=1'-0"

SHEET 5	**NSF SPONSORED RESEARCH PROJECT:** SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDING AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	TEST III DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT. CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	DRWN: CIL DATE: 1/87 CHCK: DATE:



FOUNDATION PLAN

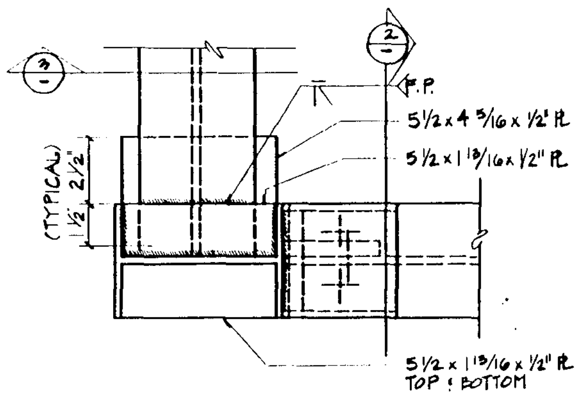
SCALE 1/2"=1'-0"



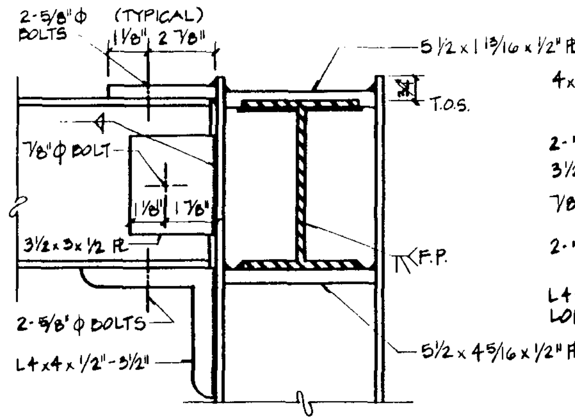
FTG./BASE PLATE DETAIL

SCALE: 1 1/2"=1'-0"

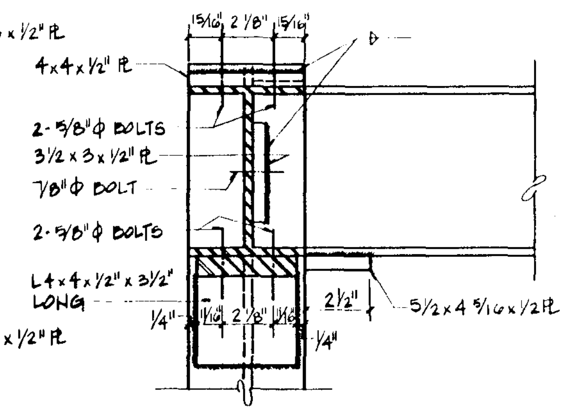
SHEET	NSF SPONSORED RESEARCH PROJECT:	TEST III	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT.	DRWN: DATE:
6	SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDINGS AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407	



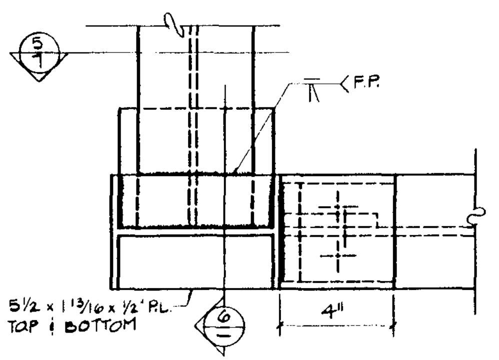
1/7 RIGID FRAME CONNECTION DETAIL



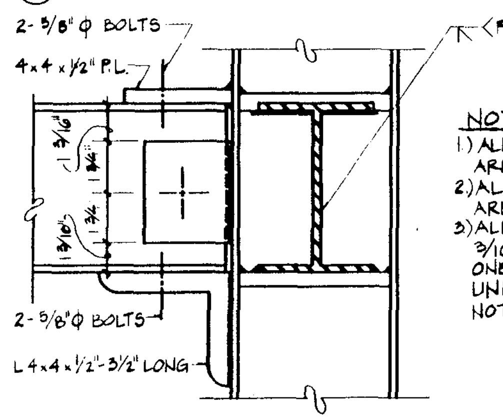
2 RIGID FRAME CONNECTION DETAIL



3 RIGID FRAME CONNECTION DETAIL



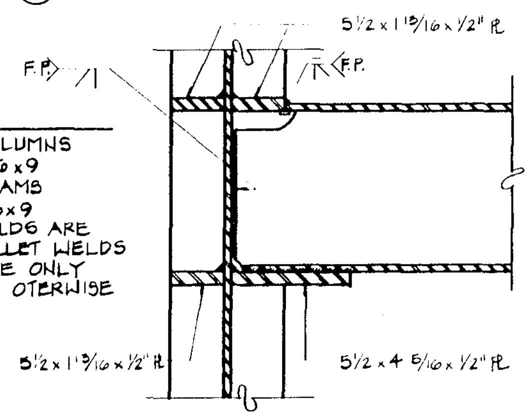
4/7 RIGID FRAME CONNECTION DETAIL



5 RIGID FRAME CONNECTION DETAIL

NOTES

1.) ALL COLUMNS ARE W6x9
2.) ALL BEAMS ARE W6x9
3.) ALL WELDS ARE 3/16" FILLET WELDS ONE SIDE ONLY UNLESS OTERWISE NOTED.



6 RIGID FRAME CONNECTION DETAIL

SHEET	NSF SPONSORED RESEARCH PROJECT:	TEST III	SEISMIC TEST FACILITY ARCHITECTURAL ENGR. DEPT.
7	SEISMIC TESTING OF HEAVY PRECAST FACADES/ CLADDINGS AND CONNECTIONS IN STEEL BUILDINGS WITH MOMENT RESISTING FRAMES	DYNAMIC TESTING OF PRECAST FACADE/CLADDING PANEL AND CONNECTIONS ON A MODEL TWO-STORY STEEL MOMENT-RESISTING FRAME STRUCTURE	CAL POLY STATE UNIVERSITY SAN LUIS OBISPO, CA 93407

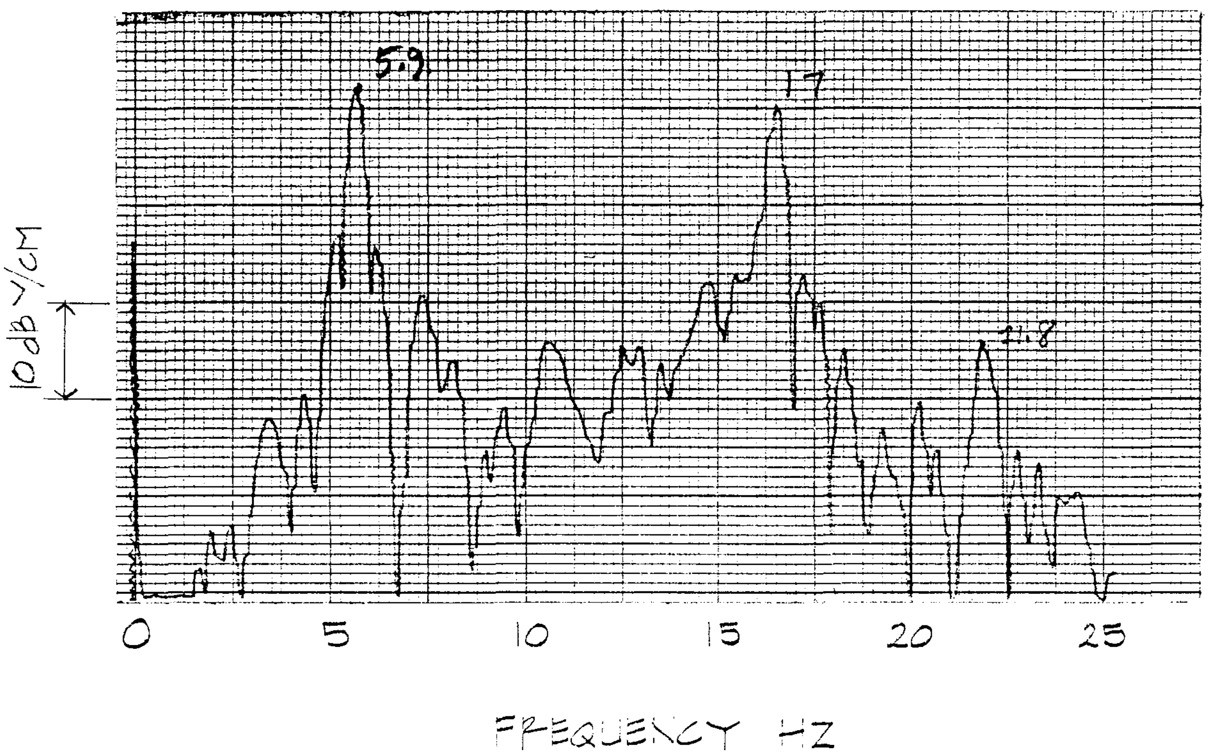


Figure 6 TEST III
Typical Printout of Spectrum Analyzer
Display
Test Run III-C
Short Direction
Random Excitation