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16. Abstract (Limit: 200 words)

An investigation to develop improved criteria for reinforced concrete walls used as lateral bracing in earthquake resistant buildings is reported. This paper discusses the first of a three part program which includes tests of isolated walls, wall systems, coupling beams, and confined concrete. One of the goals for the isolated wall test program is to determine the load and formation capacity of walls. Emphasis is concentrated on determining ductility. During each test, measured load versus deflection relationships are recorded. Graphs show the loads plotted on the vertical scale and deflection on the horizontal scale. For walls with strength controlled by flexure, confinement hoops improved ductility but not strength. For walls governed by web crushing, confinement hoops improved strength, but not ductility. Photographs of the test walls are provided.

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IMPROVED SEISMIC DESIGN - INFLUENCE OF CURRENT STRUCTURAL CONCRETE RESEARCH

by

W. G. Corley*

INTRODUCTION

In the early part of this century, structural design of buildings was accomplished with rather simple mathematics and easy to understand structural configurations. In many cases, acceptance of a building system or even a single building itself was based on load tests. Though lateral loads due to wind were considered, earthquake was either ignored or considered in a simple way.

Within the last 20 to 30 years, engineering sophistication has greatly advanced. Computers have become available to carry out extremely complex analysis. In the experimental field, the use of electronic sensors and recorders has made it possible to greatly improve our understanding of structural performance.

In recent years, model building codes, and particularly those dealing with seismic design, have reflected the progress and technology with evermore complex requirements. In many

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cases, engineers have found the requirements time consuming to apply and sometimes confusing.

PREVIOUS RESEARCH

About 10 years ago, the Portland Cement Association began a major experimental investigation of structural walls for lateral load resistance in buildings. When these tests started, the best experimental data available was that produced by Professor Benjamin at Stanford University[1-5]. His work, plus some tests done at MIT[6] and in Japan[7], formed the basis for the limited design information then available.

The first experimental investigation started at the Portland Cement Association was a rather basic study to determine the shear strength of thin deep members having proportions similar to those of structural walls. Only monotonic loads were applied[8]. As seen in Fig. 1, the walls were tested on their side to permit the use of very large specimens. Some of the information obtained from these tests was described at the 1969 Structural Engineers Association of California Annual Meeting[9].

In the next phase of the PCA experimental work, very short walls were tested[11]. These walls, shown in Fig. 2, had a horizontal length equal to or less than their height. Results of these tests have just been published in a Portland Cement Association Research and Development Bulletin RD043[12].

Tests carried out in the first three phases of the Portland Cement Association work have contributed to a basic understanding of resistance of structural walls to lateral loads.

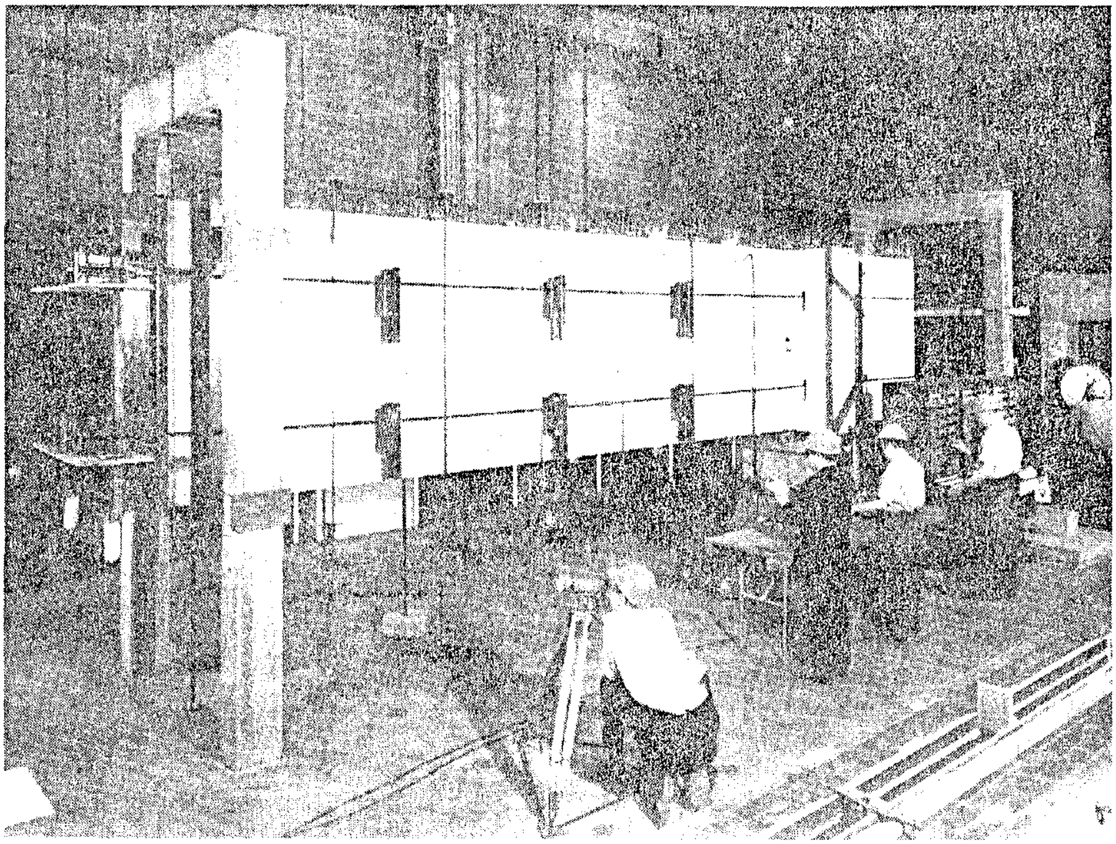


Fig. 1 Structural Wall Subjected to Monotonic Load

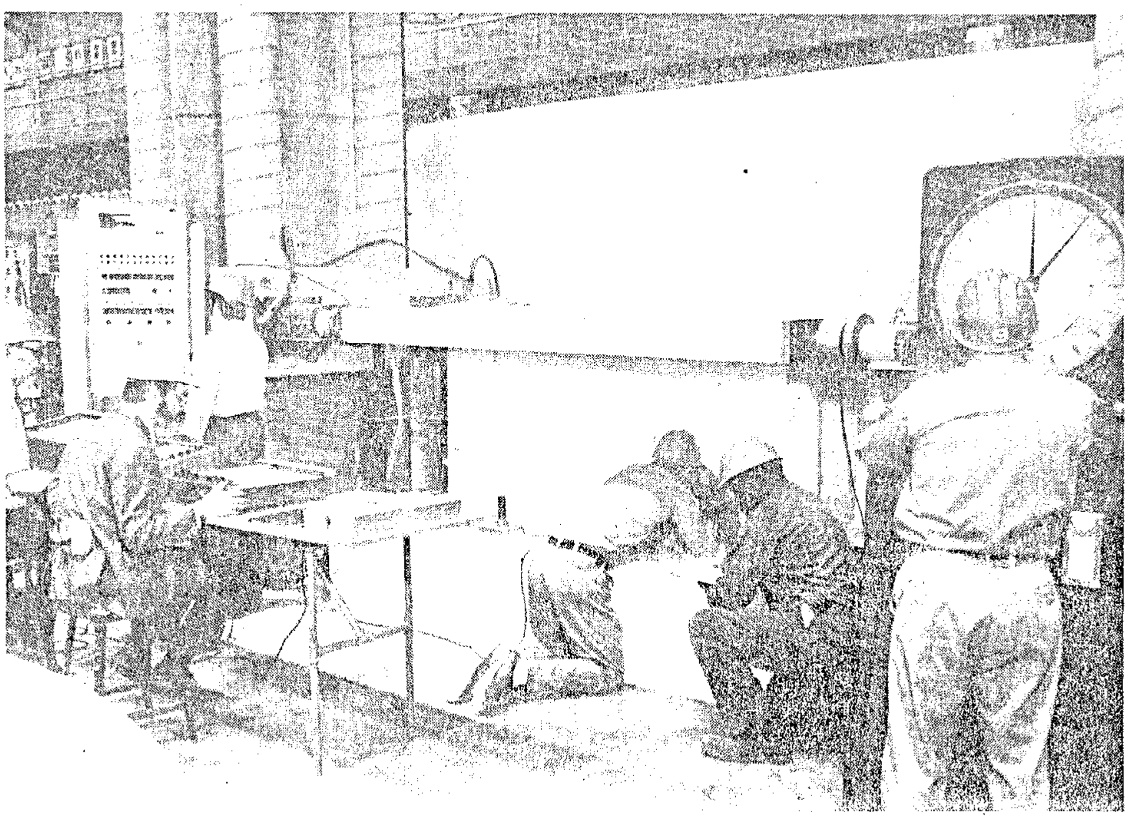


Fig. 2 Low Rise Structural Wall

Some of these results have been used to develop building code requirements. Both the UBC and ACI 318 have incorporated some of the results of these tests[9,10].

CURRENT TEST PROGRAM

Currently, the Portland Cement Association is carrying out a major analytical and experimental investigation to develop improved design criteria for reinforced concrete walls used as lateral bracing in earthquake resistant buildings. This project is sponsored jointly by the National Science Foundation and the Portland Cement Association.

The experimental program is divided into three parts. Part 1 includes tests of isolated walls, Part 2 includes tests of wall systems, Part 3 includes tests of coupling beams and of confined concrete. This paper discusses only Part 1, Tests on Isolated Walls. The test program and some of the results obtained to date are described.

One of the goals for the isolated wall test program is to determine the load and deformation capacity of walls. This portion of the investigation is intended to find a suitable way of determining the load deformation history under repeated loads.

Emphasis in the investigation is concentrated on determination of ductility. From this part of the program, the energy dissipation capability of the structures and their total deflection or rotational capacity are being determined. In addition to deformation, strength of the walls both in flexure and shear are being measured.

The primary goal in this program is to develop design criteria that will provide walls with adequate strength and ductility to resist the design earthquake. Part 1 of the experimental program uses relatively large isolated structural walls subjected to reversing loads. As shown in Fig. 3, the wall is 15-ft high and has a horizontal length of 6-ft 3-in. Walls are 4-in. thick to accommodate two layers of reinforcement. Reversing loads are applied to the specimen through a top slab. Post-tensioning forces clamp the base block to the laboratory floor.

Variables considered in the first phase of the program include shape of the wall cross section, percentage of longitudinal reinforcement, and amount of confinement reinforcement in the boundary elements.

Cross sections of the walls that are being evaluated include rectangular, barbell, and flanged shapes. The barbell section represents a wall with integral columns at each end. In this test program, the columns are 12-in. square. The flanged section represents a system of inner connecting walls. Flanges are 36-in. wide and 4-in. thick.

Main vertical flexural reinforcement in the specimens is either 1% or 4% of the area of the boundary element. These percentages were chosen to give section moment capacities corresponding to both low and high nominal shear stresses on the web of the test specimen. Vertical web reinforcement equal to 0.25% of the gross concrete area is provided. This is minimum reinforcement permitted by building codes[9,10].

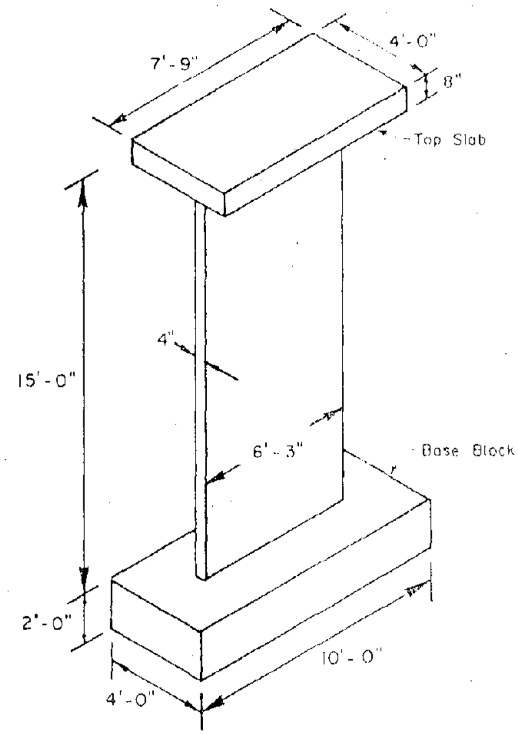


Fig. 3 Nominal Dimensions of Test Specimen With Rectangular Cross Section (1 in. = 25.4mm)

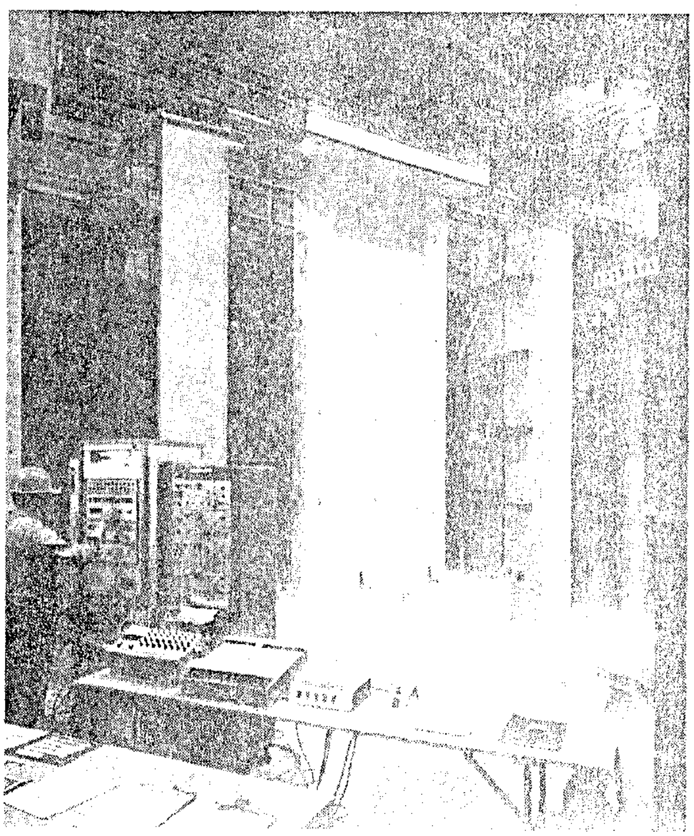


Fig. 4 Isolated Structural Wall

Where confinement hoops are provided, they are designed according to Appendix A of the 1971 ACI Building Code[10]. Hoops are provided only in the hinging region of the test specimen, normally the lower 6 ft. Walls are fabricated in a vertical position with six 3-ft lifts.

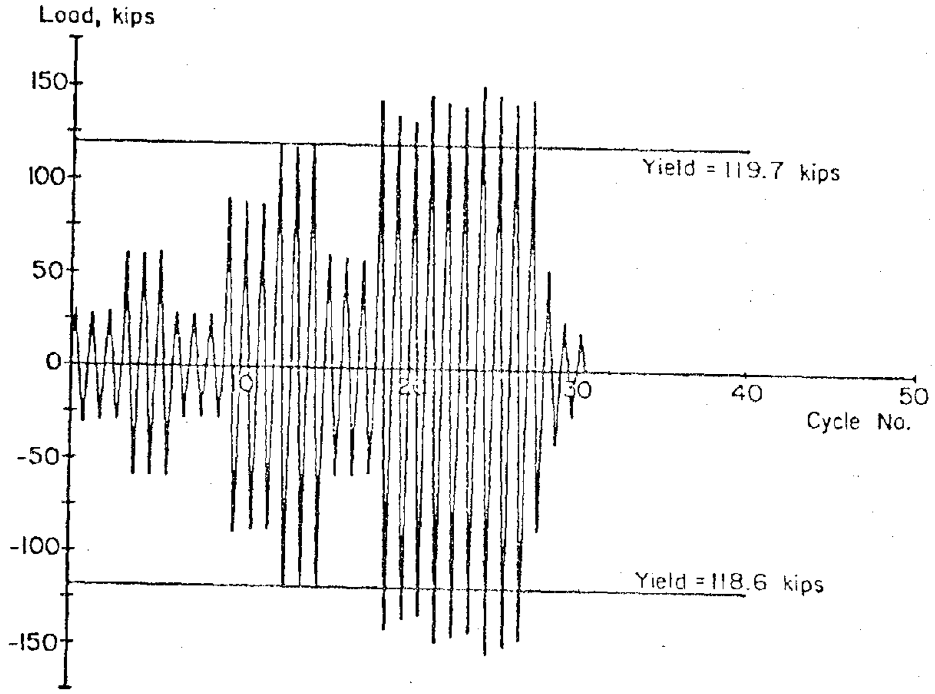
After a specimen has been completed, it is painted white and a 1-ft grid is marked on the surface as shown in Fig. 4. Hydraulic rams are used to apply the static reversing loads to the top of the slab.

Independent reference planes on each side of the wall are used to support instrumentation. During the test, measurements are made to determine applied loads, deflections, rotations, shear distortions, steel strains, and slip at construction joints. In addition, a complete photographic record including time lapse motion pictures is obtained.

Fully reversed loading cycles following the predetermined pattern shown in Fig. 5 are applied to each specimen. Prior to first yield, loading is controlled by increments of force. Beyond yield, increased increments of deflection are applied till the wall has been destroyed. Note that three complete cycles are applied at each new load or deflection increment.

TEST RESULTS

During each test, measured load versus deflection relationships are recorded. An envelope or boundary for these curves can be obtained by passing a curve through the peaks of the load deflection cycles. As shown in Fig. 6, load is plotted



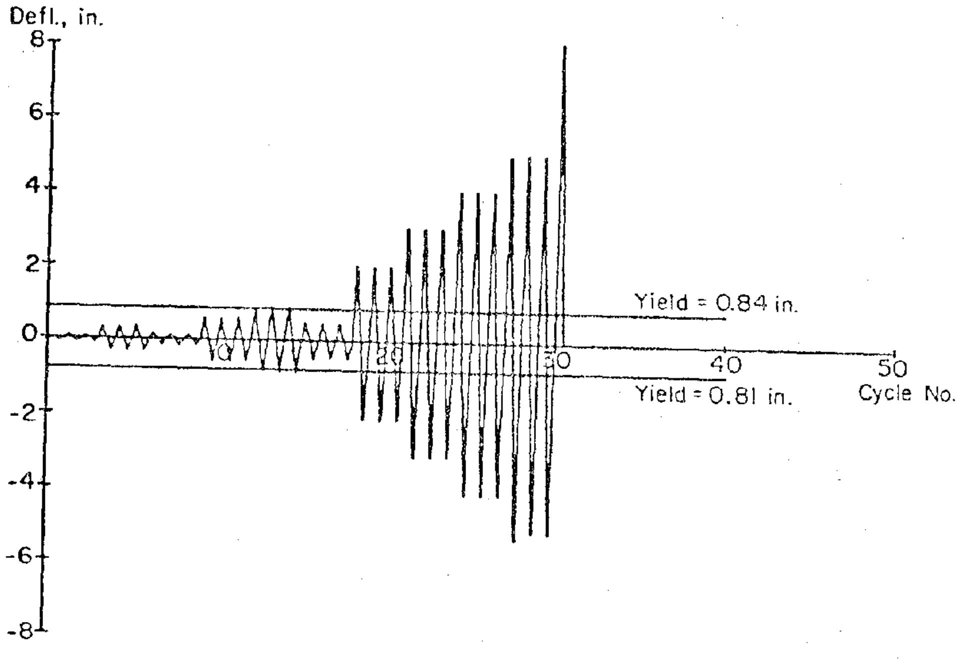


Fig. 5 Loading History for Specimen B2

on the vertical scale and deflection on the horizontal scale. Load deflection envelopes for the first five test specimens are shown in Fig. 7. The load scale is in terms of nominal shear stress divided by $\sqrt{f'_c}$. Deflection is that measured at the top of the wall.

Specimens indicated as F1 and B2 were reinforced so that loading produced relatively high nominal shear stress. These tests ended by crushing of the web.

Specimens R1, B1, and B3 were reinforced so that loading produced relatively low nominal shear stress. These tests ended with fracture of reinforcing bars caused by alternate tensile yielding and compressive buckling of the main flexural reinforcement.

SUMMARY

For walls with strength controlled by flexure, confinement hoops improved ductility but not strength. For walls governed by web crushing, confinement hoops improved strength, but not ductility. It should be noted that significant ductility was obtained even without confinement.

The goal of the experimental and analytical work in this investigation is to use the results along with those from the University of California, the University of Illinois and other institutions currently working on structural walls, and develop a design procedure that will take full advantage of the favorable performance provided by structural walls. These design

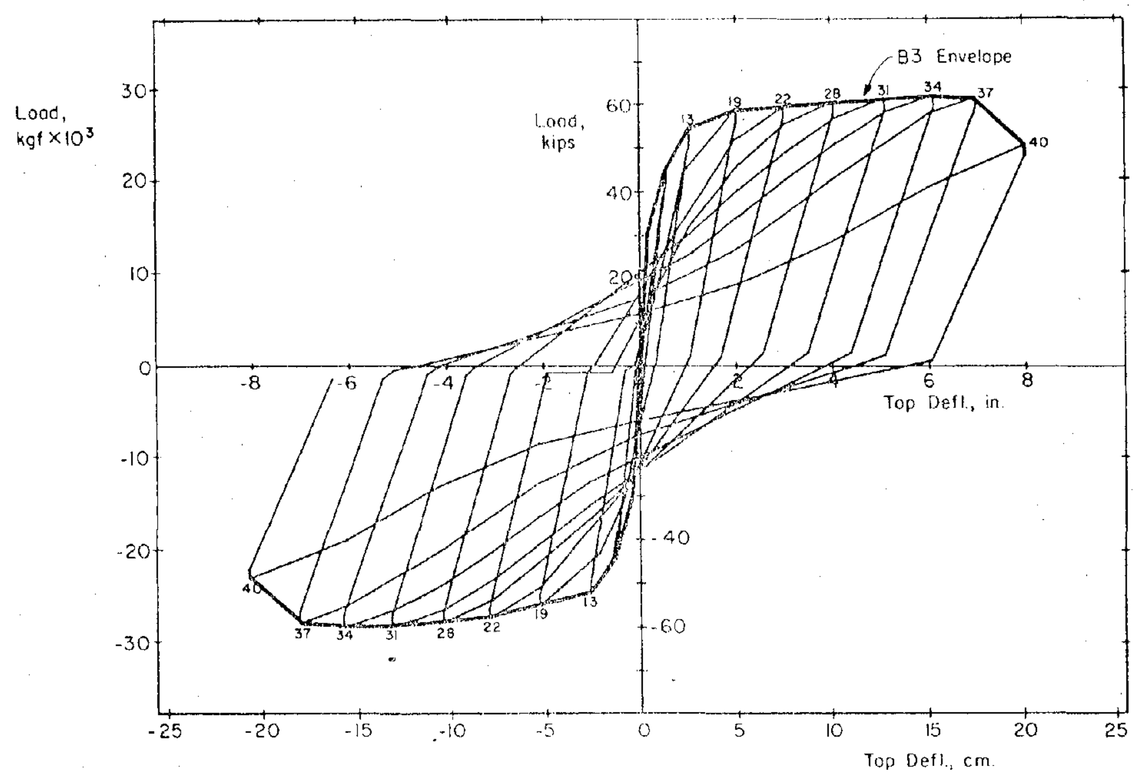


Fig. 6 Load Versus Top Deflection for Specimen B3

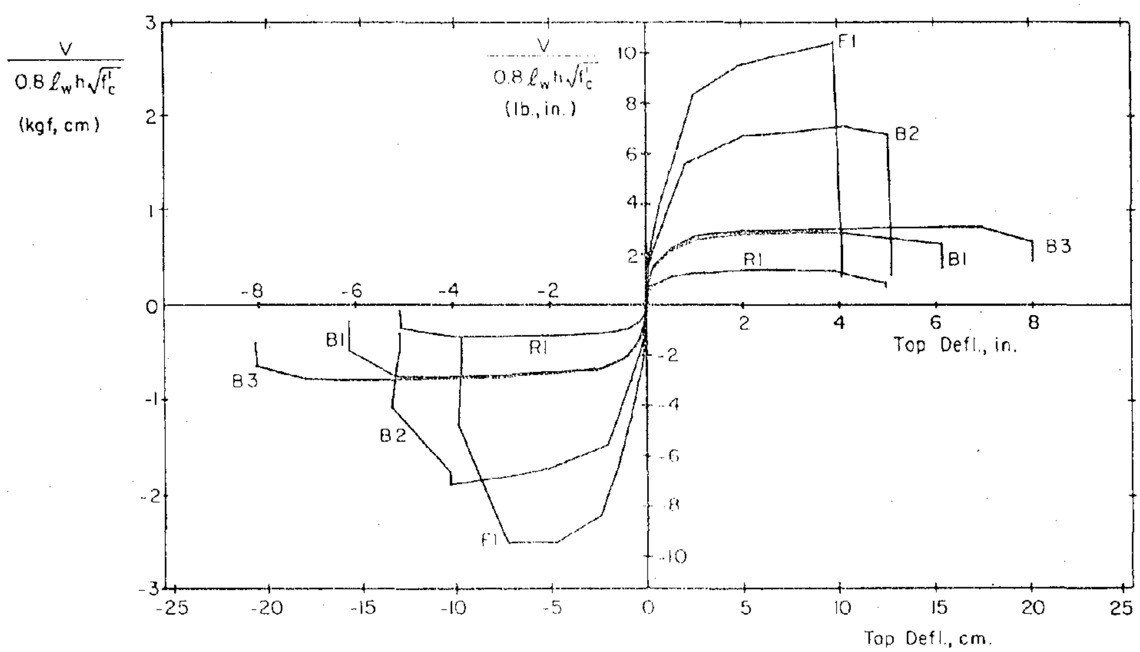


Fig. 7 Load Versus Deflection Envelopes

procedures should provide structures that are economical, have excellent resistance to lateral forces caused by earthquakes, and, an important consideration, provide excellent damage control during an earthquake.

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