MULTI-STORY WALLS SUBJECTED
TO SIMULATED EARTHQUAKES

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SYNOPSIS

An experimental investigation of the response to earthquake motions of reinforced concrete structural systems is in progress at the University of Illinois. This report describes some results from experimental studies of slender walls.

INTRODUCTION

This is a brief report on two series of tests involving small-scale multi-story reinforced concrete walls subjected to base motions simulating one horizontal component of various earthquake records. The immediate objective of the experimental work is to study the earthquake response of reinforced concrete structural systems resisting earthquake effects in the flexure-beam mode.

The first series of five test structures, shown in Fig. 1a, comprised pairs of perforated walls carrying three equal weights of 2,000 lb each distributed uniformly over the height of the structure. The main variable in the investigation was the stiffness and strength of the six connecting beams. The arrangement of the reinforcement was uniform. The piers had 1% reinforcement distributed uniformly while the reinforcement in the beams varied from 2 to 0.5%. The span to depth ratio for the beams was either 1.8 or 2.7.

The dimensions of the second series of four test structures are shown in Fig. 1b. The walls carried ten equal masses of 1,000 lbs spaced at 9-in. intervals. Three of the test structures in this series were designed to serve as physical tests of the substitute-structure method (1). The reinforcement in the walls was lumped at the extreme fibers of the individual piers and was approximately 1%. The beam reinforcement varied from 3.2 to 1.6%.

All walls were cast using small-aggregate concrete and in horizontal forms to be "tilted up" for final assembly. The yield stress of the small-scale reinforcement ranged from 43 to 72 ksi. Nominal concrete compressive strength was 4500 psi.

The base motion was applied using the University of Illinois Earthquake Simulater in a direction parallel to the planes of the walls. The motions were patterned after one horizontal component of the El Centro (1940) or Taft (1952) records. Each test structure was subjected to a series of test runs of increasing intensity. Measurements included accelerations and displacements at all levels.

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Effective Stiffness

The natural frequencies of the test structures measured in the initial free-vibration tests were consistently less than those calculated using stiffness properties based on uncracked section. Typically, the measured frequencies were approximately 80 percent of the calculated values, implying a substantial difference between the actual stiffness and that based on gross uncracked section. Static tests and studies of frequency sensitivity to various parameters such as base fixity indicated that the difference was due primarily to shrinkage cracking in the test structures. In some but not all cases, the shrinkage cracks were visible under 10X magnification.

Figure 2a shows the changes in fundamental frequency in successive test runs of a structure of series 1. The frequency is plotted against the maximum displacement attained. A similar plot is shown in Fig. 2 for a specimen of series two. As would be inferred from the force-displacement diagram, the effective stiffnesses is reduced almost proportionally as the displacement increases, causing the natural frequency to decrease at a decreasing rate. Stiffness does not change uniformly over the height of the structure, leading to variations in the relative values of the observed frequencies.

For all structures of both test series and for both types of base motion used, the reductions in natural frequencies occurred rapidly and at the beginning of the test duration (which coincided with one of the periods of maximum energy input). Thus, the dynamic response of the test structures in a given test run was better identified by their reduced rather than initial stiffnesses.

In this context it is relevant to emphasize a characteristic of the test structures which influenced the frequency measurably. Figure 3 compares, for the connecting beams of the series-2 structures, the cracked-section stiffness with measured moment-rotation curves from static tests. The discrepancy is caused by the slip of reinforcement at the beam-column interface. This is a general characteristic of all connecting beams with low span-to-depth ratios and must be taken into account in making estimates of the natural frequency of the system. The stiffness, in the linear range of response, of such beams is likely to be a fraction of the stiffness based on cracked section.

Dynamic Response

A particular example of measured acceleration response is provided in Fig. 5 which shows the acceleration response in levels 6, 8, and 10 of structure D1, which had ten stories. Base moments and displacements at all levels were dominated by the first-mode component while the higher-mode components were visible in the acceleration records. It is of interest to note the virtual disappearance of second-mode effects at level eight, corresponding to the calculated node point for mode two, an observation emphasized by comparison of the fourier-amplitude spectra for the three levels also shown in Fig. 5.

Three test structures (D1, D2, and D3) of series 2 were reinforced in accordance with the substitute-structure method (1). A design earthquake intensity and smoothed response spectra were assumed. Tolerable limits to damage (or softening with respect to the cracked-section stiffness) of the vertical and horizontal elements were selected to be one and two, respectively, with the cracked-section stiffness of the beams including the effect of reinforcement slip. Modal analysis of this model with damping values prescribed by reference 1 resulted in the member forces (RSS combination) for which reinforcement was provided. The design analysis also indicated the lateral displacements corresponding to an earthquake with the design intensity. Figure 4 compares the maximum displacements observed in "design earthquake" tests of D1, D2, and D3 with the calculated or anticipated values. The observed behavior of the structures was also consistent with the design objectives: yielding was limited to the beams.

Acknowledgments

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Reference

1. Shibata, A. and M. A. Sozen, "Substitute Structure Method for Seismic Design in R/C," Journal of the Structural Division, ASCE, Vol. 102, No. ST1, January 1976, pp. 1-18.

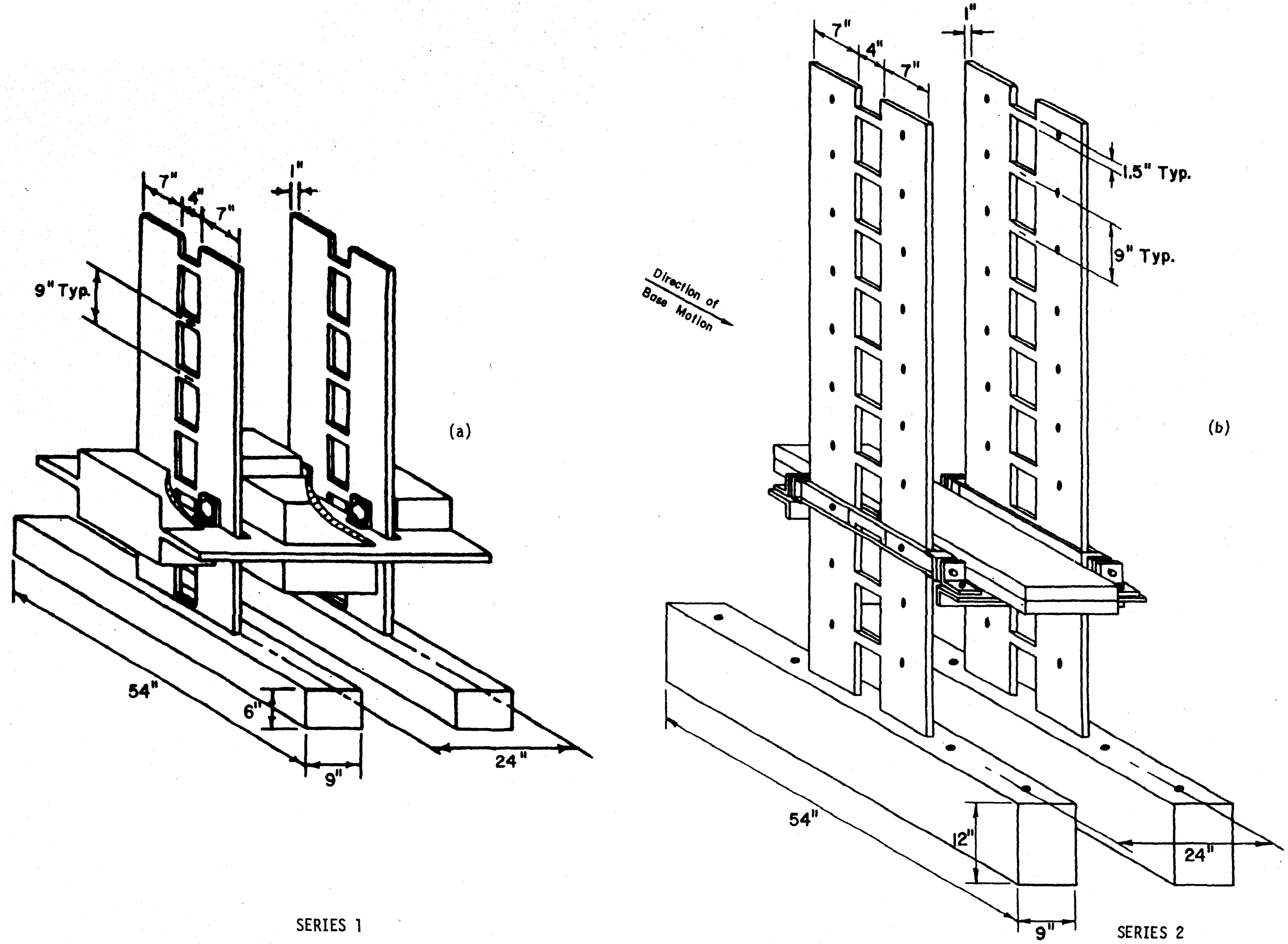

FIG. 1 TEST STRUCTURES

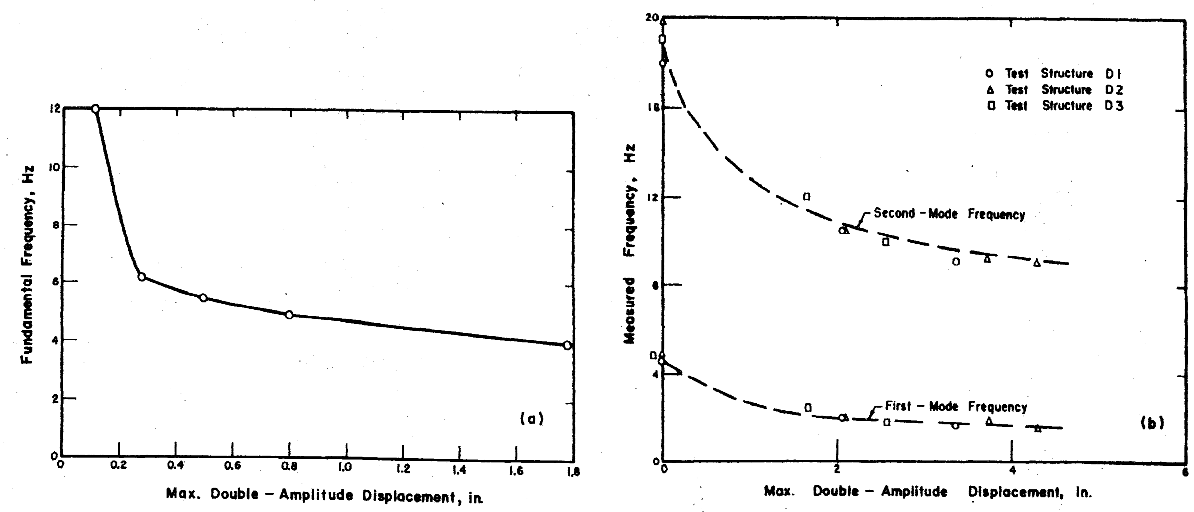

FIG. 2 VARIATION OF FREQUENCY WITH ATTAINED DISPLACEMENT

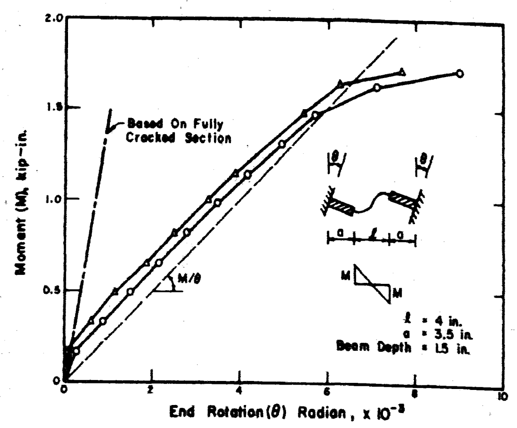

FIG. 3 STIFFNESS OF CONNECTING BEAMS

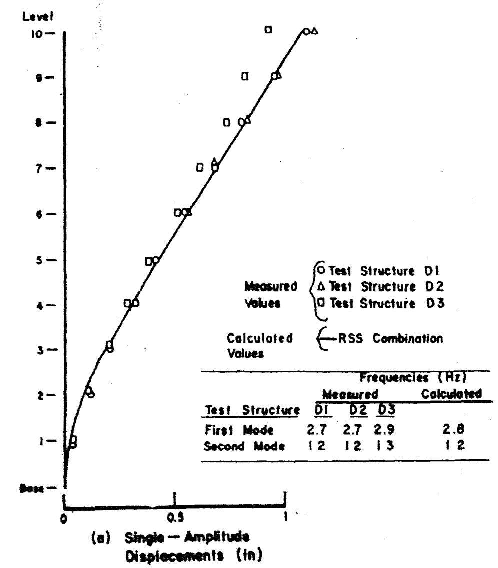

FIG. 4 COMPARISON OF MEASURED AND CALCULATED MAXIMUM DISPLACEMENTS FOR THREE TEST STRUCTURES OF SERIES 2

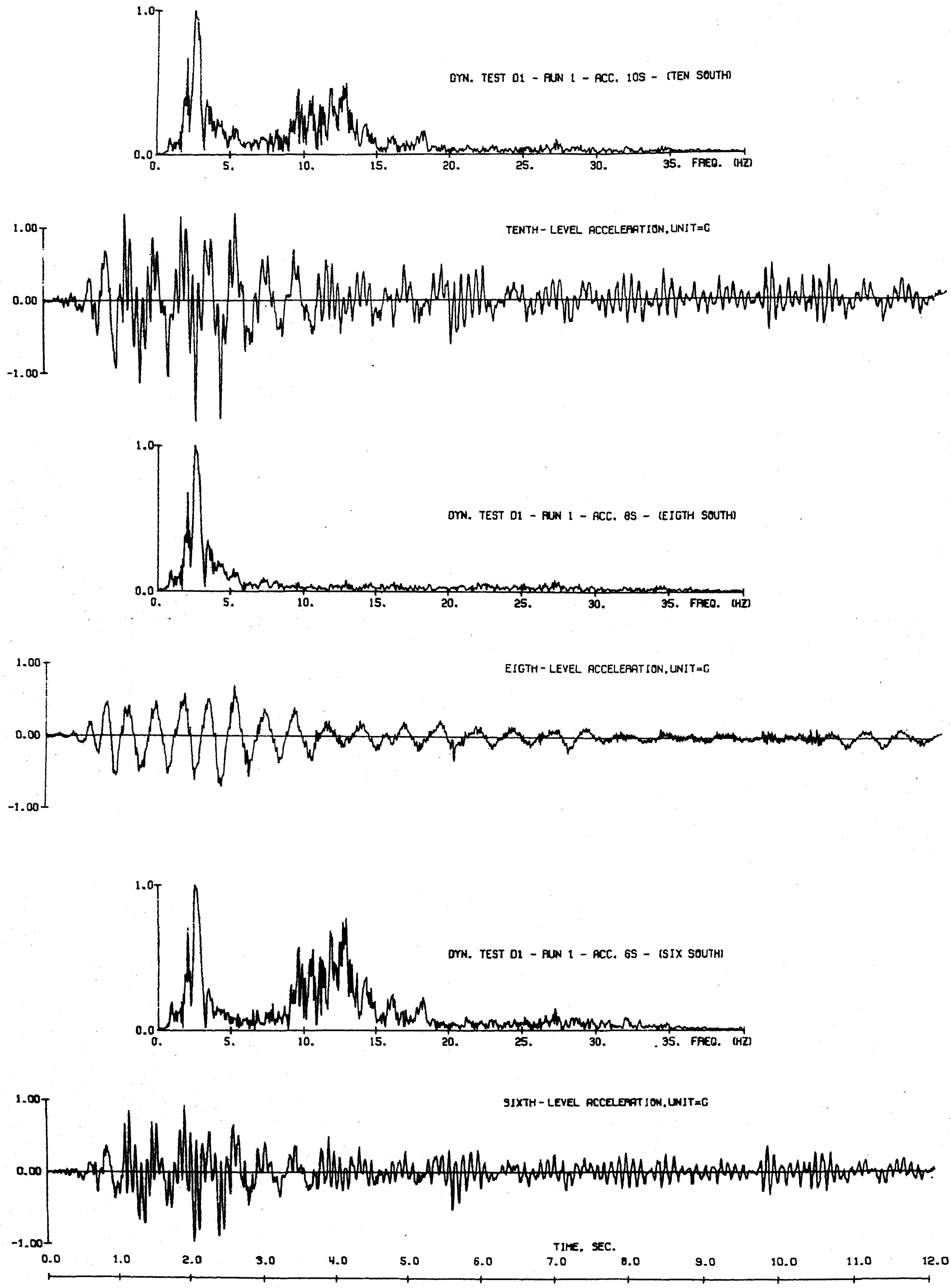

FIG. 5 ACCELERATION RESPONSE AND FOURIER AMPLITUDE PLOTS AT THREE LEVELS, STRUCTURE D1 SERIES 2