EARTHQUAKE SIMULATOR TEST OF A THREE STORY STEEL FRAME STRUCTURE

by

R. W. Clough[I], D. Rea[II], D. Tang[III], and M. Watabe[IV]

SYNOPSIS

A test conducted on a three-story steel frame structure using the 20ft square shaking table at the University of California, Berkeley, is described. The structure was subjected to table motions simulating the El Centro (1940) earthquake record and an artificial earthquake. The intensity of the table motions were increased progressively to cause material yielding in all 12 of the structures panel zones. With the El Centro earthquake normalized to a peak acceleration of 0.5g, ductility factors ranged from 5.4 for the first floor panel zones to 1.6 for the top floor (roof) panel zones.

INTRODUCTION

Techniques have been developed to predict by means of digital computers the behavior of steel frame building structures subjected to earthquake motions. However, the accuracy of such predictions, when the ground motions are strong enough to cause substantial inelastic behavior, has never been verified. A series of tests is being conducted on small steel framed structures using the 20ft square shaking table (1) at the University of California, Berkeley, California. The objective of this test series is to provide data to check, and where necessary to improve, existing non-linear computer programs for predicting the behavior of steel frames undergoing vibrations large enough to cause inelastic behavior. The results from a single test on a 3-story steel frame, a structure in the test series on steel frames, is described below. In this structure the panel zones (the joints between beams and columns) were deliberately left understrength so that yielding would occur first in the panel zones. During the test the intensity of the shaking table motion was progressively increased to cause yielding in the panel zones, but it was kept below the level at which significant inelastic behavior would occur in the beams and columns. In this way the panel zones could be strengthened with doubler plates after the first test so that essentially the same structure could be used for the second test in which yielding would be induced in regions outside the panel zones.

[I] Professor of Civil Engineering,

[II] Associate Research Engineer,

[III] Graduate Student, and

[IV] Former Associate Research Engineer;
University of California, Berkeley, California, U.S.A.

TEST STRUCTURE

The test structure consists of two identical three-story, single bay moment resistant steel (A36) frames connected together with essentially rigid floor diaphragms. The total height of the structure is 17ft 5in, the story heights being 6ft 9in, 5ft 4in, and 5ft 4in. The bay width is 12ft and the distance between frames is 6ft. The columns and beams consist of regular rolled sections W5x16 and W6x16 respectively; they are welded together with a typical moment resistant connection. Concrete blocks weighing 8000 lbs were added to each floor level to simulate the dead loads acting on a real structure. The bases of the columns were bolted to heavy footings which in turn were prestressed to the shaking table by means of high strength rods. The structure is shown on the shaking table in Fig. 1 and details of the steel frames are shown in Fig. 2.

An elastic analysis of the structure, assuming rigid panel zones, indicated frequencies of 2.4, 8.6 and 17.7 cps for the three translational modes of vibration in the direction the frame was to be shaken. Small amplitude forced vibration tests employing an eccentric mass exciter, and free vibration tests were conducted on the structure before it was placed on the shaking table. These preliminary tests revealed the three significant natural frequencies to be 2.2, 7.8, 15.3 cps and the associated damping factors to be 0.1%, 0.1%, and 0.6% of critical damping.

TEST PROCEDURES

The behavior of the structure during the tests was monitored by a total of seventy instrumentation channels. Accelerometers were placed on each floor level, and the absolute displacements of the floor levels were also measured by means of potentiometers attached to a rigid frame located off the shaking table. Relative deformations between opposite corners of the first floor panel zones were measured by means of displacement transducers, as shown in Fig. 3, and electric resistance strain gages were used to measure the strains at 48 locations over the structure. The strain gages were installed to measure elastic strains in beams and columns as well as to record inelastic strains in the panel zones. The signals from the transducers monitoring the structure's behavior, in addition to the signals from transducers monitoring the motions of the shaking table, were fed to a mini-computer based data acquisition system, (2) which placed the information on magnetic tape for subsequent processing and permanent storage.

The structure was subjected to the recorded El Centro (1940) ground motions and to the motions of an artificial earthquake. Initially the peak accelerations in the motions were limited to values less than 0.2g and the data from these tests were used to check that the instrumentation was operating satisfactorily. After these checks were made, the intensity of the motions were increased progressively in successive tests up to a maximum in which the peak accelerations in the motions were about 0.5g.

TEST RESULTS

The results from only one test, that in which the peak acceleration of the shaking table while simulating the El Centro earthquake was 0.5g, will be described briefly. During this test the maximum recorded acceleration and absolute displacement of the third floor (roof) of the structure were 1.4g and 4.9in respectively. The time histories of the shaking table's horizontal acceleration, the third floor acceleration, strain in a first floor panel zone, and strain at the base of a column, are shown in Fig. 4. The maximum dynamic strains (excluding dead load strains, 0.3 mil/in, and residual strains from welding and prior tests) were 6.2, 4.5, and 1.8 mil/in in the first, second, and third floor panel zones respectively, see Table 1. These strains are equivalent to strain ductilities of 5.4, 3.8 and 1.6 respectively based on the mill test report's value of 46 ksi for yield stress and Von Mise's yield criterion. The maximum strain to occur in a column, occurred at the base of one of the columns and is estimated from the strain recorded 12in away from the point of maximum strain to be 1.6 mil/in. Similarly, the maximum strain to occur in a beam is estimated to be 1.6 mil/in also. Thus a small amount of material yielding may have occurred at the outer fibers of the first floor beams and columns at the points of maximum moment.

The results described above, and the results from the other tests conducted on this structure, will be used in analytical studies to determine the accuracy to which current computer programs can predict the strains in the panel zones of such structures subjected to earthquake type loadings. The panel zones of the structure will be strengthened by welding in doubler plates so that when the structure is tested again, material yielding will occur in regions outside the panel zones.

ACKNOWLEDGEMENTS

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REFERENCES

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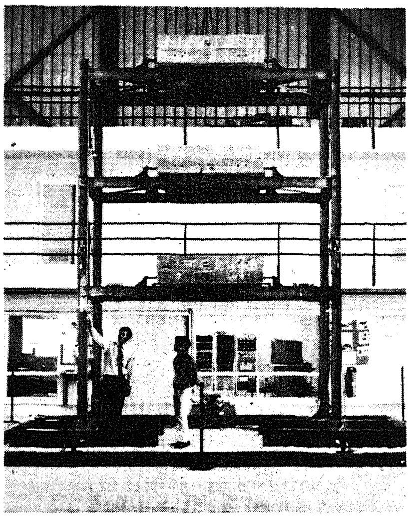
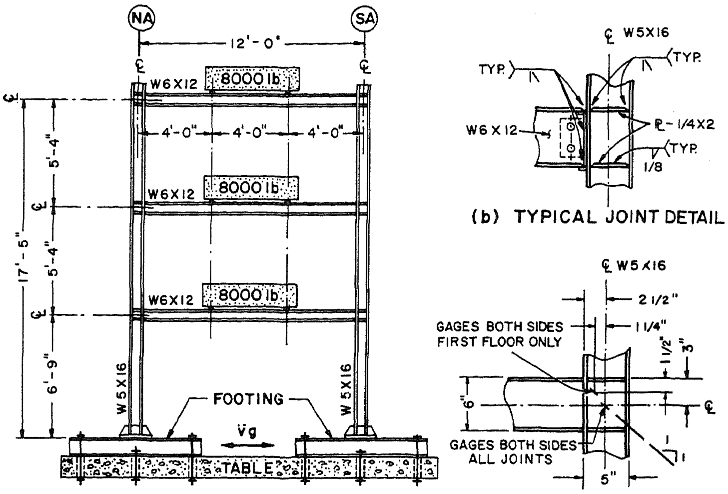


FIG. 1 TEST STRUCTURE ON THE SHAKING TABLE

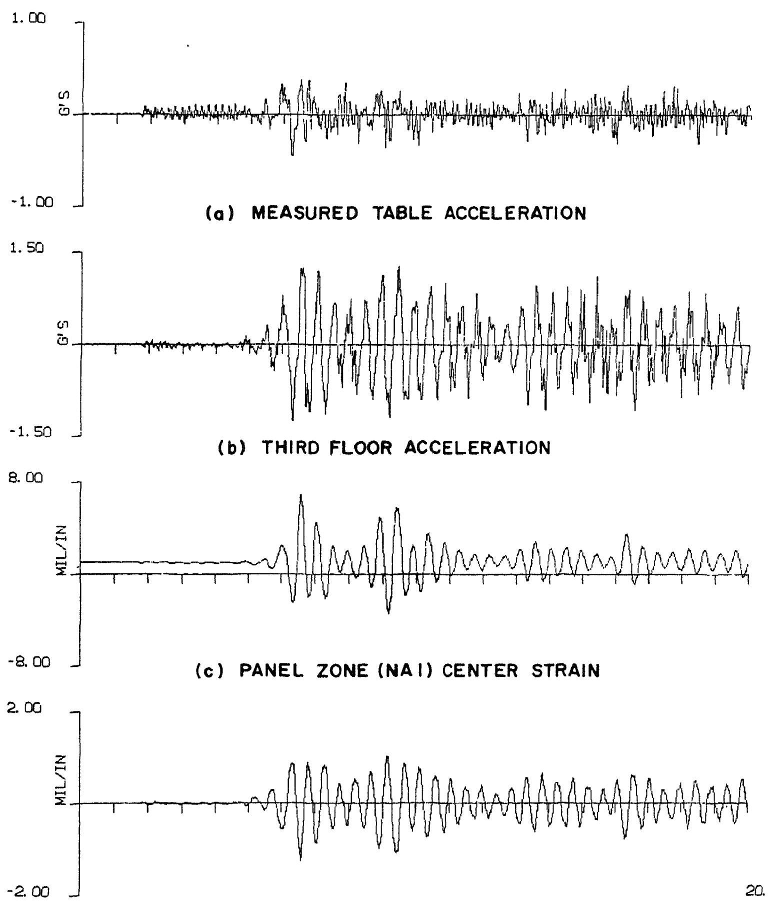


(a) FRONT VIEW

(b) TYPICAL JOINT DETAIL

(c) STRAIN GAGES AT PANEL ZONES

FIG. 2 TEST STRUCTURE AND DETAILS



(a) MEASURED TABLE ACCELERATION

(b) THIRD FLOOR ACCELERATION

(c) PANEL ZONE (NA1) CENTER STRAIN

(d) COLUMN (NA1B) FLEXURAL STRAIN - 12" FROM BASE

FIG. 4 TIME HISTORIES FOR 20 SECONDS

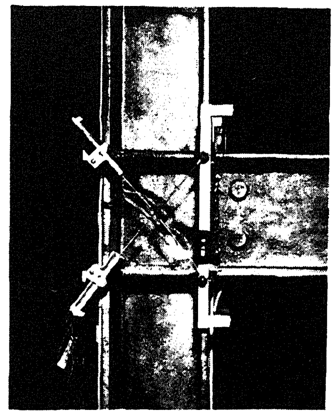


FIG. 3 FIRST FLOOR PANEL ZONE

TABLE I

MAXIMUM DYNAMIC STRAIN DUCTILITIES IN PANEL ZONES

($\epsilon_y = \gamma_y/2 = 1.17$ mil/in)

FLOOR \ COLUMN	NA	SA	NB	SB
3-CENTER	1.5	1.1	1.6	1.2
2-CENTER	3.8	2.7	3.8	3.0
1-CENTER	5.2	3.8	5.4	4.2
1-CORNER	5.3	3.6	5.3	3.9