EARTHQUAKE SIMULATOR STUDY OF A STEEL FRAME SMALL-SCALE MODEL

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SUMMARY

This paper presents the results of a comprehensive experimental study intended to illustrate the applicability of small-scale model analysis to problems in earthquake engineering. The method of artificial mass simulation was used to permit replication of gravity loads and of inelastic dynamic response to base motion for a steel frame structure. A testing procedure, encompassing material, subassembly and earthquake simulator tests, provided the basis for correlation of model and prototype behavior.

INTRODUCTION

One solution to the complex problem of evaluating the earthquake response characteristics of structures is testing of small-scale models on earthquake simulators (shake tables). In model studies, the principles of dimensional analysis are evoked to provide the scaling functions necessary to predict the prototype dynamic behavior from that observed for the model. One method applicable to a great number of building structures where gravity effects must be reproduced and inelastic similitude must be satisfied is artificial mass simulation (AMS). Such modeling involves the addition of structurally uncoupled mass to augment the density of the model. Thus, prototype structural materials may be used as the model materials or other materials with the required mechanical properties but with lower strength and stiffness may be substituted to reduce model weight.

TEST STRUCTURES

To enable an accurate evaluation of the suitability and reliability of a small-scale model for replicating structural response to earthquakes, it was necessary to choose a prototype structure with well-defined properties. Thus, a three story, single-bay, steel frame structure previously tested on the shake table at the University of California, Berkeley (1) was chosen as a prototype for an AMS model study performed at the John A. Blume Earthquake Engineering Center, Stanford University (2). The prototype utilized small, commercially available wide-flange sections of A36 steel for framing elements and fully welded moment resisting connections typical of modern construction practices. The structure was designed such that the girder-column joint panels would yield under shearing action prior to yielding in framing members. Thus, inelastic actions and energy dissipation are confined to these zones. Building masses were lumped at

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floor levels in the form of concrete blocks, making this a suitable prototype for a lumped-mass AMS model study.

A length scale of 1:6 was chosen for the model study. Model members were machined from A36 bar stock and primary structural connections were fully welded by the TIG heliarc process. Subsequent heat treatment of the finished model frames was performed to relieve high initial stresses and to satisfy construction tolerances derived from geometric scaling of standard specifications. Steel plates were used for the lumped floor masses. The finished model is shown in Fig. 1. With this system of fabrication, models to length scales of 1:20 are possible. However, duplication of the prototype initial stress state is extremely difficult, if not impossible, with these methods.

RESULTS

A comprehensive experimental study encompassing material, subassembly and earthquake simulator tests was used to define the adequacy of prototype simulation by the replica model. The material and subassembly tests served to define mechanical properties, to verify the adequacy of fabrication techniques and to refine the instrumentation system. Initial static and low amplitude dynamic tests of the completed model assembly were performed to determine the initial state of stress and to define fundamental dynamic properties, as shown in Fig. 2.

Earthquake simulator tests utilized the El Centro 1940 North-South component and an artificial earthquake composed of discrete spectral components to excite the structure both elastically and inelastically. During the inelastic test series an attempt was made to duplicate the prototype test history to provide similar degrees of inelastic behavior.

Both global and local response quantities were used as bases for prototype simulation by the model. Typical results for an inelastic test are shown in Figs. 3 and 4. All units have been converted to the prototype reference and prototype and model measurements are depicted by solid and dashed lines, respectively.

Figure 3a shows a comparison of energy terms for the two structures. The top curves for the prototype and model represent the effective energy transferred to the respective structure through base motion while the lower curves show the energy dissipated through inelastic action and damping. The difference between these two curves is the energy currently stored in the system as a sum of strain and kinetic energy.

Ductility demand and energy dissipation is illustrated on a local level by moment-deformation plots. The girder moments measured at equivalent distances from the column flange for the prototype and model are shown in Fig. 4 versus the strain measured in the center of the joint panel zone at a 45 degree angle. This strain is approximately equal to the maximum panel strain. Similar curves were developed for girder moment versus panel shear distortion, which was determined from the relative displacement between diagonally opposite corners of the joint panel.

CONCLUSIONS

Accurate simulation of the prototype structure was demonstrated by the similar dynamic properties and energy dissipation characteristics of the model. The bases for comparison were the amplitude and frequency content of response and the ductility demand and number of inelastic excursions. In general, the nature of inelastic response was duplicated by the model by yielding of the joint panel zones in shear.

Three primary sources of error prevented exact duplication of prototype response. First, the welding of the model base plate to the shake table produced high initial forces, contributing to early initial yielding. However, after first yielding had occurred, a redistribution of internal forces eliminated this effect in subsequent tests.

Second, the model joint stiffener welds were somewhat oversized, producing panel zones smaller than desired. The consequence was a stiffer system with an approximately ten percent higher yield strength than was characteristic of the prototype.

Of greater importance, the dynamic tests illustrated that the reproduction capability of an earthquake simulator has a great influence on the observed results. In particular, a lightly damped elastic structure is extremely sensitive to fluctuations in a narrow frequency interval of the input spectrum. This problem is of less importance for high intensity inelastic tests. However, sufficient energy must be transferred to the structure at the elastic level before inelastic action is reached. Since all shake tables will have some reproduction inadequacies, several types of input motion will be required to enable a thorough evaluation of structural response.

Finally, the results of this study indicate that tests of models with artificial mass simulation are suitable for many types of building systems. This is particularly true for building systems with large floor masses. However, rate and size effects will become more prominent at smaller model scales, making compensation for these effects essential for a successful model study.

ACKNOWLEDGMENT

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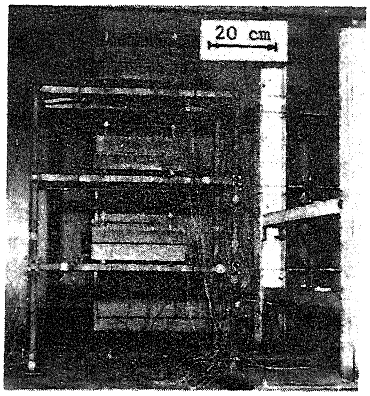
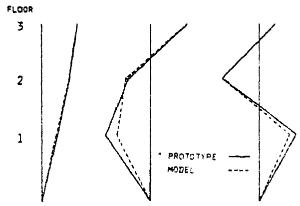


Figure 1 AMS Model Structure

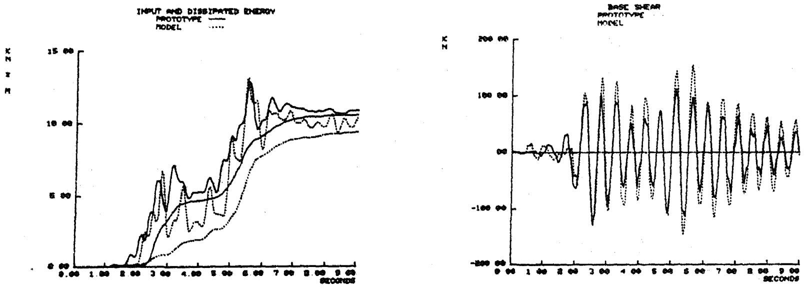


MODE	1ST	2ND	3RD	MODE
FREQUENCY, HZ*	2.3	7.8	15.2	PROTOTYPE
	2.4	8.3	15.5	MODEL
DAMPING, %	0.11	0.08	0.57	PROTOTYPE
	0.28	0.16	0.29	MODEL

* PROTOTYPE TIME REFERENCE

† PROTOTYPE STRUCTURE WITH 3.0 KN SHAKER AT THE FIRST FLOOR

Figure 2 Elastic Dynamic Properties



a.) Energy Distribution

b.) Base Shear

Figure 3 Global Inelastic Response to El Centro 1940

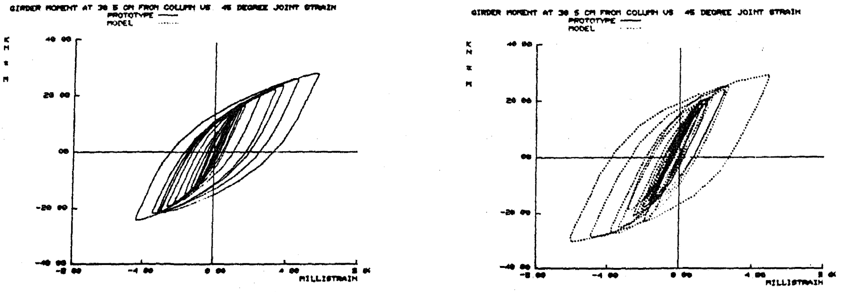


Figure 4 Local Inelastic Response to El Centro 1940
(Girder Moment vs. 45° Strain at Center of Joint Panel)