ABSTRACT

of the paper

THE UNIVERSITY OF ILLINOIS EARTHQUAKE SIMULATOR

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The University of Illinois Earthquake Simulator is an experimental facility designed to subject small-scale structures to vibratory base motions, of a regular or random character, in one horizontal direction.

The system comprises a 12 by 12-ft test platform and a 75-kip hydraulic ram. The platform has been designed to support test specimens up to 10,000 lb. and permit a double-amplitude displacement of four in. If not limited by the mass, the ram has operational maximum limits of four-in. double-amplitude displacement, 15-in. per sec velocity, 7.5g acceleration, and 100 cps.

Preliminary tests using the system have indicated that it is possible to generate "random" motions of the platform with resulting spectra comparable to those produced by measured earthquake motions. The particular promise of the electro-hydraulic system in such an application is that it is possible to produce and reproduce simulated earthquate motions with a sizeable force.

THE UNIVERSITY OF ILLINOIS EARTHQUAKE SIMULATOR

by

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SYNOPSIS

A description of the components and performance limits of the University of Illinois Earthquake Simulator, an experimental system designed to test model structures and structural components under conditions simulating strong ground motion in one direction.

INTRODUCTION

The University of Illinois Earthquake Simulator is an experimental facility designed to subject small-scale structures to vibratory base motions, of a regular or random character, in one horizontal direction. The facility has been in operation since February 1968. This paper describes the facility and its capabilities.

DESCRIPTION OF THE FACILITY

The University of Illinois Earthquake Simulator (to be referred to as the "Earthquake Simulator" in the rest of the paper) is currently housed in the Structural Research Laboratory of the Civil Engineering Building in Urbana, Illinois. The structural test floor, to which the Earthquake Simulator is tied, comprises a series of parallel 17-ft deep reinforced concrete box girders providing a mass of approximately four million lbs.

An overall view of the Earthquake Simulator is shown in Fig. 1. The system can be broken down into four parts: (1) A hydraulic ram equipped with a servo-valve, (2) a power supply, (3) a command center, and (4) a test platform.

(1) The hydraulic ram (B1 in Fig. 2) is rated at a peak capacity of 75,000 lb, a maximum velocity of 15 in./sec. and a maximum double-amplitude displacement of 4 in. The servo-valve controls the ram motion through displacement signals transmitted by an LVDT mounted in the actuator assembly. As indicated in Fig. 3, the longitudinal axis of the ram is in the horizontal plane. The ram reacts against a steel pedestal which is tied to the test floor (top flange of the reinforced concrete box girder) with prestressed two-in. bolts.

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(2) The hydraulic power supply (A1 in Fig. 2) is provided by a variable-volume 120-HP pump with a flow capacity of 70 gpm. The pump is located below the test floor.

(3) The command center is equipped to receive input through three different instruments:

(a) Commands for sinusoidal motion are generated by a low-frequency oscillator (C2 in Fig. 2) with a range from 5 x 10^{-5} to 6 x 10^{4} cycles/sec. The frequency registers on an attached counter.

(b) Commands for programmed motion with periods longer than 1/60 of the test duration can be given through a function generator (C3 in Fig. 2) which translates arbitrary hand-drawn waveforms into command signals.

(c) Commands for earthquake simulation can be input by magnetic tape (C4 in Fig. 2) either as displacement, velocity, or acceleration vs time.

(4) The test platform is 12 by 12 ft in plan and comprises a 3/8-in. plate welded to 5-in. I-beams. It is supported by four series of flexure plates as shown in Fig. 3. The flexure plates are 3/4-in. plates with flexure joints at each end as shown in the detail in Fig. 3. The 3/8-in. test bed plate is drilled and tapped for 1/2-in. bolts on 12-in. centers in both directions. The double-amplitude displacement for the flexures is 4 in. The platform is designed to carry a 10,000-lb mass which can be concentrated over an area of 2 by 2 ft, with its center of gravity 3 ft above the test bed and one ft away from the axis of the ram at a maximum acceleration of three times that of gravity. The total weight of the moving parts of the platform was kept below 6000 lb. Free vibration tests indicated a natural period of 2.5 seconds for the table. The resistance provided by the flexure plates was 90 lb per in., with the force applied at the level of the platform.

The platform is constructed in three parts and bolted together such that a central portion 3-ft wide (1 ft 6 in. on each side of the ram axis) can be separated from the rest of the platform in order to reduce the mass of the platform.

The connection between the platform and the ram is provided by a "double-flexure," a steel shaft with two reduced sections as shown ideally in Fig. 3.

PERFORMANCE LIMITS

A series of initial tests were carried out in order to establish the performance limits of the entire system. A large concrete prism measuring 1 ft 4 in. by 2 ft 4 1/4 in. in cross section and 9 ft 0 in. in length was placed on the test platform with its long axis parallel to the axis of the ram. The shorter dimension of the cross section was in contact with the test platform. The weight of the concrete prism was 4100 lb. The total mass to be moved was 9600 lb including the platform.

The concrete prism was tied to the table by eight yokes formed by 5 by 3.5-in. steel angles bearing against the top of the concrete and 0.5-in. bolts connecting the steel angles to the platform. The bolts were prestressed. In addition, each end of the prism on its longitudinal axis was wedged against steel channels bolted to the table.

The system was driven over a range of frequencies in sinusoidal and "square-wave" motions. Its operation was found to be satisfactory within the domain indicated in Fig. 4. The operation limits of the system were ± 2.0 in. for displacement, 15 in. per sec. for velocity and approximately 7.0 g for acceleration. The stable frequency limit for steady-state motion was 100 cps. Furthermore, a phase difference was noted between frequencies of 40 and 100 cps. The phase difference was negligible to 40 cps, reached 180 deg. at approximately 60 cps and decreased to a small value as the frequency was increased to 100 cps. Part of the phase difference was attributable to the vibrations excited in the pedestal and the compressibility of the link between the ram and the platform.

There were lower as well as upper limits to the operational domain of the system. For example, it was not possible to maintain constant acceleration as the frequency was varied to values above 15 cps at an acceleration level of 0.5g. At an intended acceleration level of 0.1g, the platform acceleration started increasing at frequencies above 10 cps.

While the check-out tests were continuing, occupants of the offices in the Civil Engineering Building lodged complaints about the vibrations excited in the building. The four-story plus basement office building surrounds the test floor on which the earthquake simulator is situated. Measurements were made in the floor and walls of various rooms. The results are summarized in Fig. 5. The occupants of the building were affected primarily by the sound of the vibrations coupled with the psychological implications of the term "earthquake." However, test systems rigidly attached to the walls and used for soil consolidation tests in the basement and various sensitive measuring equipment in the sanitary engineering laboratory in the fourth floor were affected physically. Consequently, no further tests were carried out using the earthquake simulator near its maximum capacity. In all subsequent tests, the dynamic force was limited to less than 20,000 lb.

TESTS OF A SIMPLE MODEL

Tests were carried out using a simple steel model in order to study the performance of the earthquake simulation system under conditions comparable to the planned tests of structural models with complex responses. The test specimen, which represents a mass and a spring, is shown in Fig. 6. It had a measured linear resistance to lateral load (applied at center of the top mass) of 900 lb per in. in a direction perpendicular to the plane of the 1/4-in. plates and a measured period in free vibration of 0.104 sec. The weight of the top mass was 93.2 lb. The damping for the model was found to be very small. The measured logarithmic-decrement indicated the damping to be less than 0.3% of the critical damping.

Tests With A Steady-State Motion

The model was bolted on the test platform, in line with the axis of the ram. Then the platform was set into sinusoidal motion at a constant acceleration of less than 0.01 g in order not to cause any permanent deformation in the spring-plates of the model.

The acceleration of the mass was measured as the frequency was increased from 9 to 10 cps in steps of approximately 0.02 cps. After each frequency step, the model was allowed to vibrate for about three minutes. At the end of three minutes the maximum acceleration became reasonably stable: it varied periodically from plus to minus three percent of its average magnitude.

The frequency at which maximum excitation was obtained corresponded to a period of 0.104 sec. The damping, based on the band-width method, was found to be approximately 0.33% of the critical damping.

The measured model accelerations at various frequencies are plotted as ratios of the base acceleration in Fig. 7.

Tests With Random Motion

The test platform was programmed to move in a "random" manner using the following procedure. A displacement vs time record comparable to what would be measured in an earthquake was recorded on tape. The original length of the record was 30 seconds. The magnitude of the excursion is unimportant because this can be varied at will. The tape was fed into the displacement input of the earthquake simulator at a speed eight times the original. This was done in order to scale the array of frequencies in the record by a factor of eight, assuming that the model with a period of 0.104 sec. should have a "full-scale period" of 0.83 sec. Two problems, both related to "noise," were observed in the resulting platform accelerations. One was a very small amplitude acceleration with a frequency of about 400 cps. Its maximum magnitude was less than one percent of the platform acceleration. The other was a similar motion resulting in larger accelerations with a frequency of approximately 50 cps. It was not possible to purge the system of these spurious motions although it appears that they may eventually be filtered out.

The resulting acceleration vs time record for the platform is shown in Fig. 8a. The 400-cps noise was ignored in converting the analog oscillograph record to numerical values. The curve shown in Fig. 8a is plotted using the "smoothed" numerical values. The magnitude of the maximum platform acceleration was selected arbitrarily before the test.

The measured response of the steel model is shown in Fig. 8b. Figure 8c shows the calculated response of a single-degree-of-freedom model with a period of 0.104 sec. and a damping of 0.5% of critical to the base accelerations shown in Fig. 8a. The response curve calculated for a damping coefficient of 0.5% of critical gave slightly better overall agreement with the measured curve than did the calculated response curve for a damping coefficient of 0.33% of critical. The comparison is quite favorable.

CONCLUDING REMARKS

Preliminary tests using the Earthquake Simulator indicate that the system promises to provide a satisfactory vehicle for testing structural components and models under conditions simulating earthquakes.

The system at the University of Illinois has fulfilled most of its design goals. On the basis of the preliminary tests, it appears that reproducing precisely an acceleration vs time plot registered in an earthquake may not be a straightforward operation and may require a trial-and-error approach unless the control system is improved. However, it is questionable whether faithful reproduction is essential to meaningful tests. The elastic response spectra calculated for the "earthquake" in Fig. 8a is shown in Fig. 9.

ACKNOWLEDGMENTS

The actuator and related components of the University of Illinois Earthquake Simulator were acquired under Equipment Grant GK 980 by the U. S. National Science Foundation. The continuing research work is carried out under Research Grant GK1118X from the same agency. The writers would like to acknowledge the invaluable contribution of Professor V. J. McDonald and his staff in all phases of the installation, instrumentation, and operation of the Earthquake Simulator.

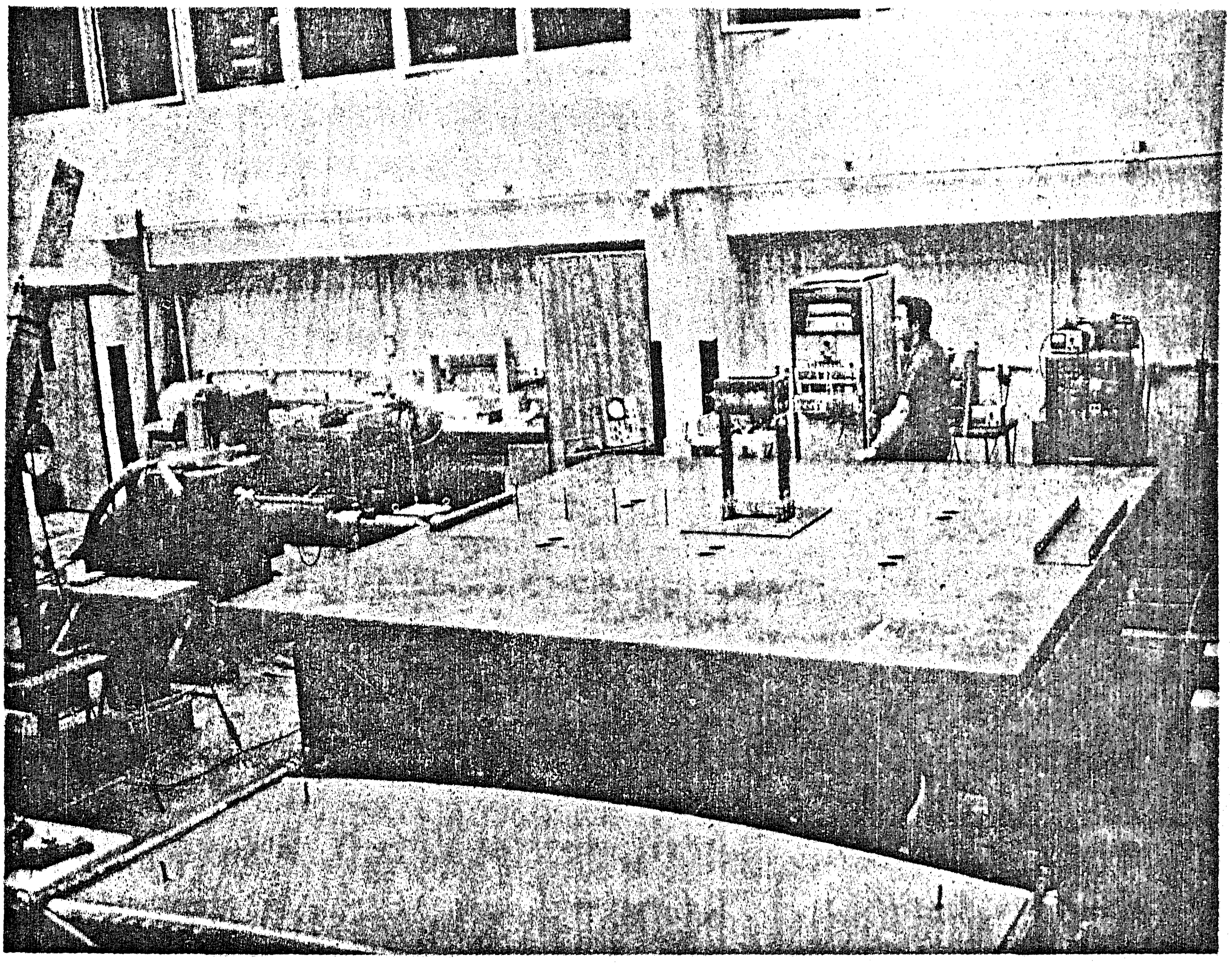


FIG. 1 OVERALL VIEW OF THE UNIVERSITY OF ILLINOIS EARTHQUAKE SIMULATOR

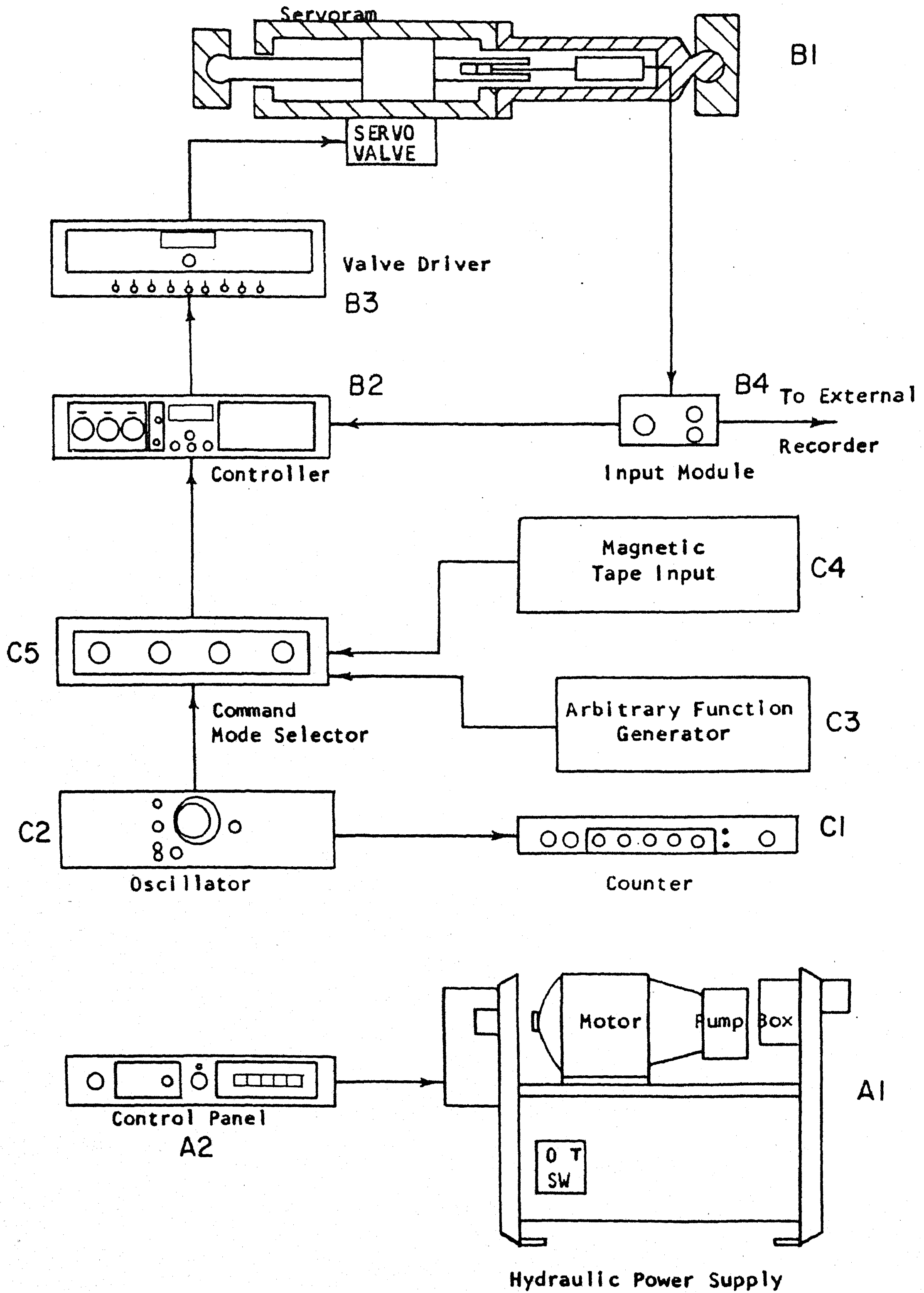
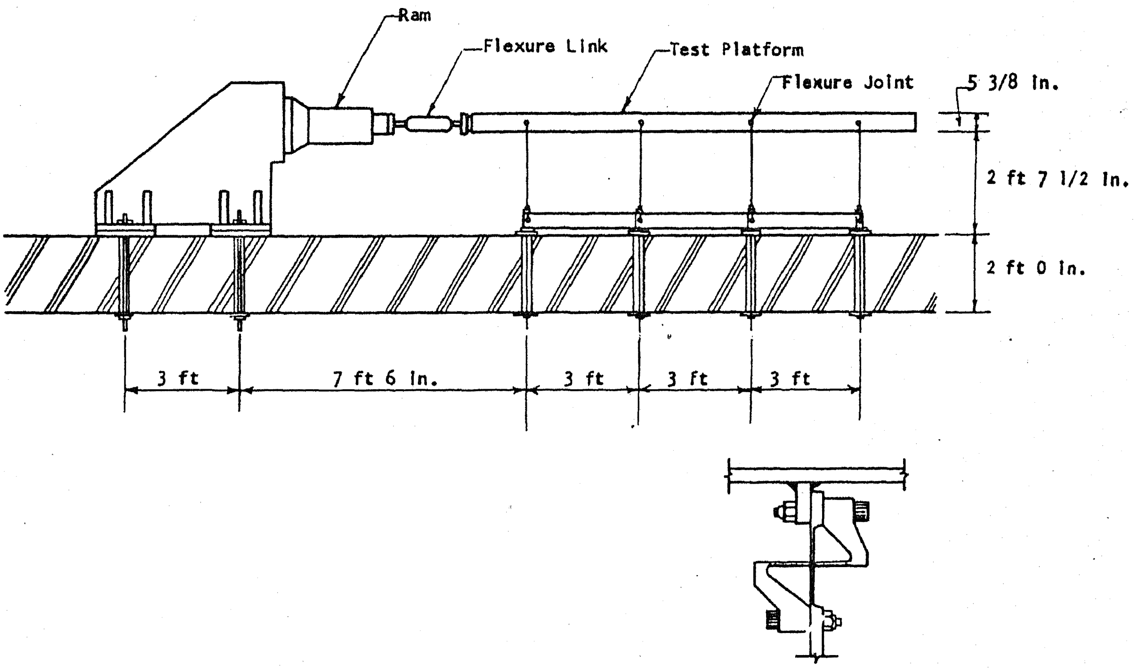


FIG. 2 COMPONENTS OF THE UNIVERSITY OF ILLINOIS EARTHQUAKE SIMULATOR



Detail of Flexure Joint

FIG. 3 ARRANGEMENT OF RAM AND TEST PLATFORM

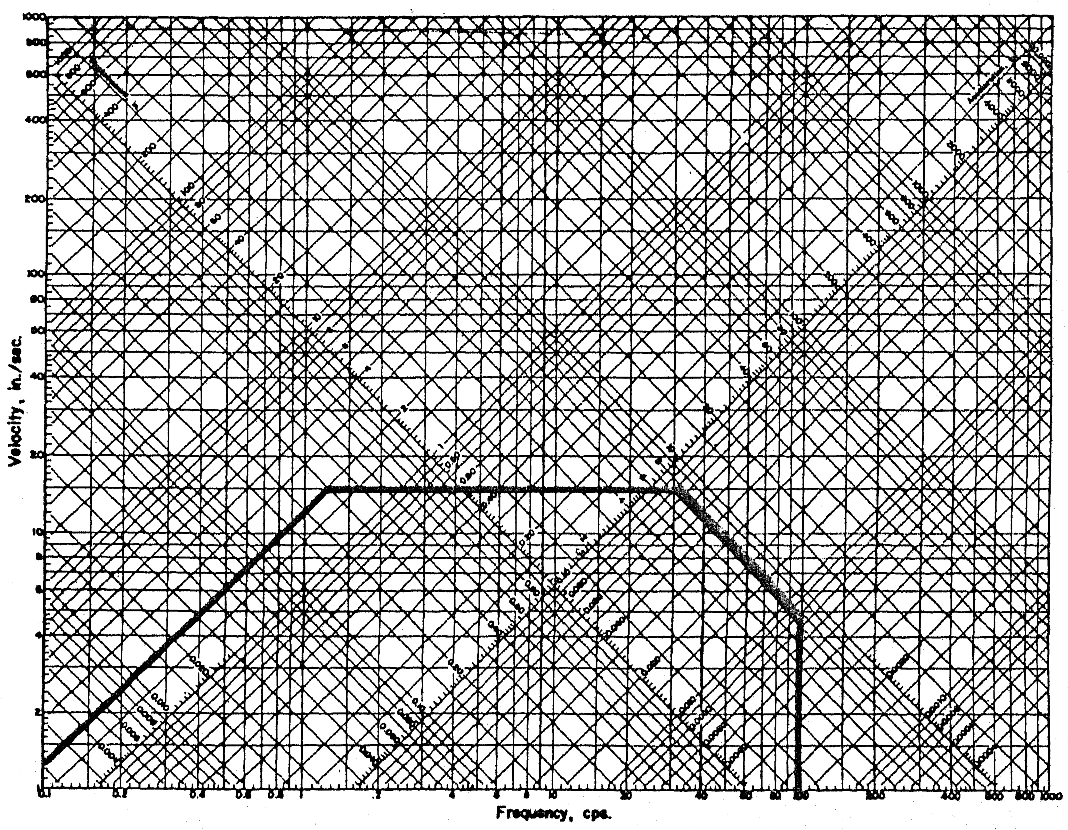


FIG. 4 PERFORMANCE LIMITS OF THE UNIVERSITY OF ILLINOIS EARTHQUAKE SIMULATOR

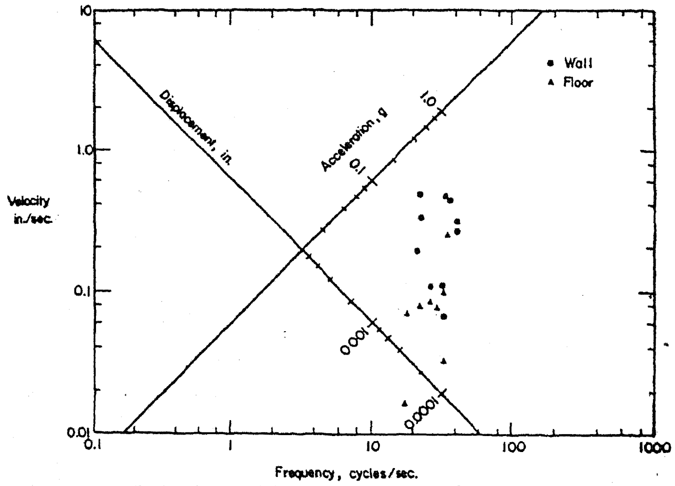


FIG. 5 ACCELERATION MEASUREMENTS IN VARIOUS PARTS OF THE CIVIL ENGINEERING BUILDING

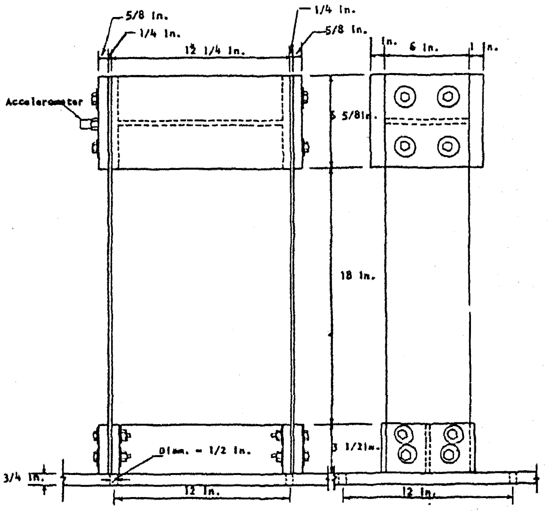


FIG. 6 THE STEEL MODEL

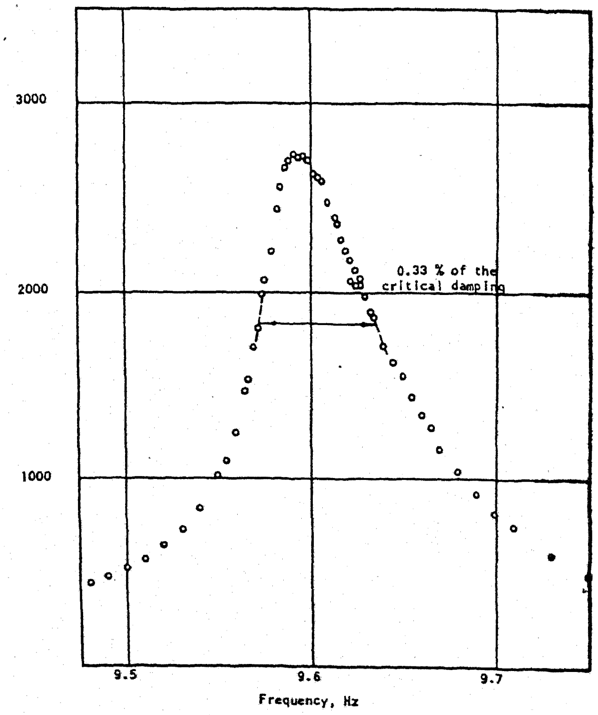


FIG. 7 RESULTS OF TESTS WITH SIMPLE HARMONIC MOTION

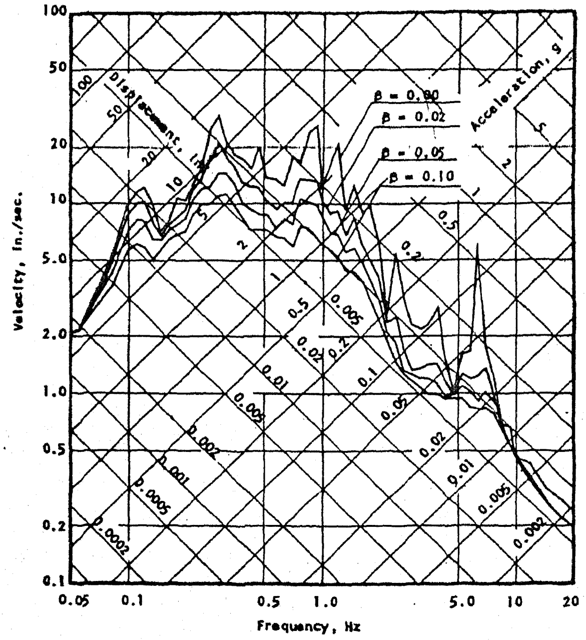


FIG. 9 RESPONSE SPECTRA FOR ELASTIC SYSTEMS

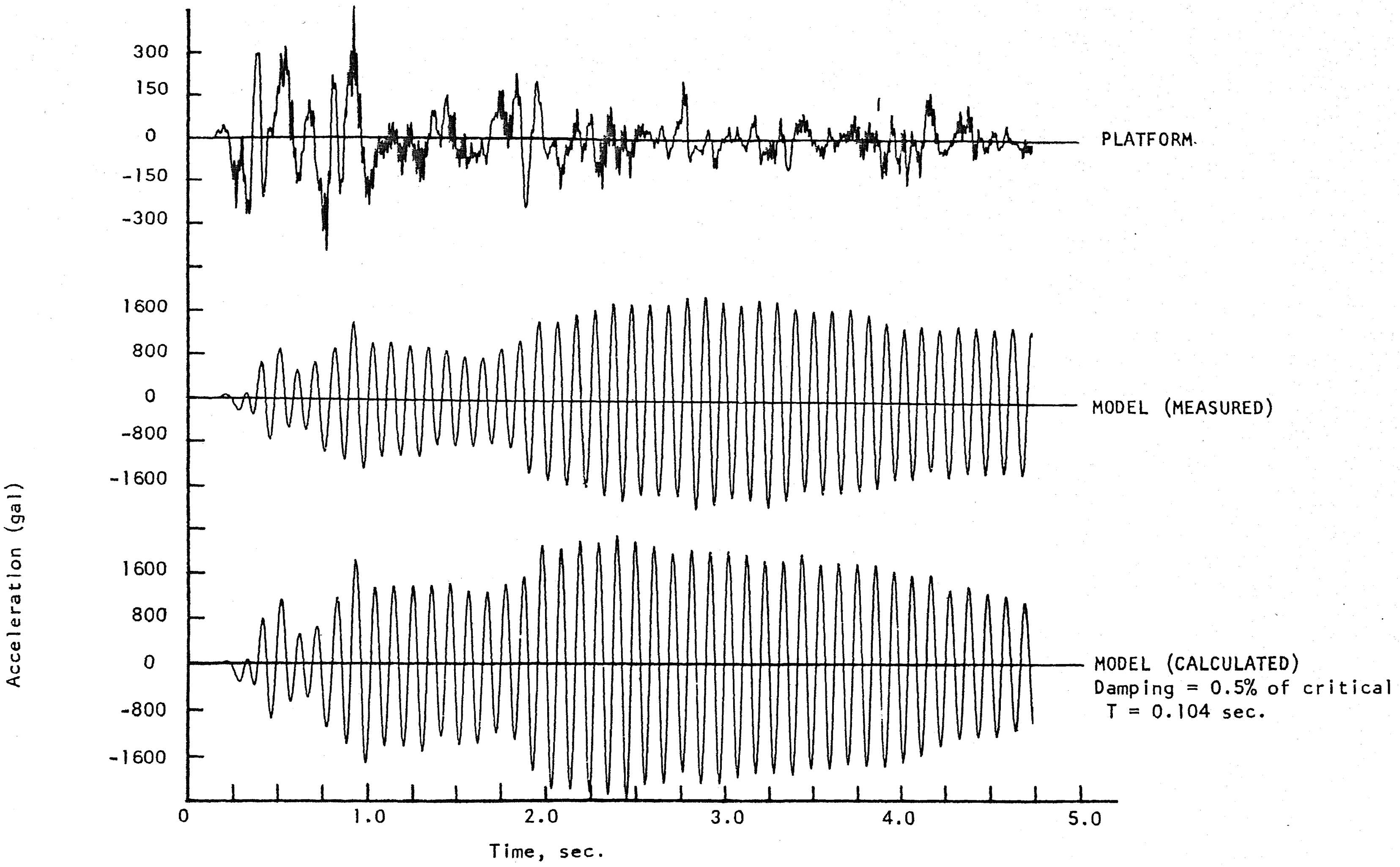


FIG. 8 RESULTS OF TEST WITH RANDOM MOTION