EFFECTS OF TEST SPECIMEN REACTION LOADS ON SHAKING TABLES

by

Y. Takahashi[I], D. Rea[II], and S. Abedi-Hayati[III]

SYNOPSIS

The effect of load reaction on the performance of electro-hydraulically driven shaking tables is discussed. Although load reaction may cause a severe peak and notch effect in the frequency domain at the resonant frequency of the test specimen, the shaking table's ability to reproduce an acceleration-time history is not impaired significantly.

INTRODUCTION

Shaking tables designed specifically for use in problems related to earthquake engineering are generally driven by high-performance hydraulic actuators, or rams, equipped with a servo-valve. In these systems, the position of the actuator piston is controlled by means of an electronic closed-loop displacement feedback system. The basic displacement feedback is supplemented by velocity and force feedback signals to improve the performance characteristics. Such systems, when driving only a rigid mass, will exhibit a flat displacement frequency response up until the oil column resonant frequency. The oil column resonant frequency is determined by the magnitude of the rigid mass and the flexibility associated with the compressibility of the oil in the actuator's cylinder. However, if there is a resonant structure on the table the reaction loads from the test specimen cause the frequency response to develop sharp peak and notch effects at the resonant frequency of the structure. The effects of the peak and notch on the shaking table performance are described below.

COMPUTER SIMULATION OF A SHAKING TABLE

A shaking table with one horizontal direction of motion, driven by a single hydraulic actuator, and loaded by a single degree of freedom test structure, is shown in Fig. 1, and a block diagram of the system is shown in Fig. 2. The masses of the table and structure, M_1 and M_2 respectively, are both 2,000 lb; the servo-valve's natural frequency (ω_v) and damping factor (ζ_v) are 44 cps and 30% respectively; and the area of the actuator's piston (A) is 25 sq in, and its time constant (T_c), $.35 \times 10^{-2}$ sec. The values of the constants have been chosen so that the mathematical model would represent a shaking table and structure for which experimental data were available.

The system was simulated on a digital computer and the displacement loop gain k_a, and the gain of the force feedback were adjusted until the frequency response of the mathematical model was similar to the experimental frequency response. Frequency responses for two values of k_p and

---

[I] Professor of Mechanical Engineering; [II] Associate Research Engineer; and [III] Research Assistant; University of California, Berkeley, California, USA the experimental frequency response are shown in Fig. 3. The value of k_a was made large enough to keep the overall frequency response flat without causing instability. There is a considerable range of values over which k_a can achieve this objective, and within that range its value does not have much effect on the magnitudes of the peak and notch. In contrast, the magnitudes of the peak and notch are sensitive to the value of k_p because the force feedback counteracts the tendency of the structure to "drive" the actuator piston.

An optimum value of k_p may be found to reduce the magnitudes of the peak and notch to negligible amounts, see Fig. 3. However, because of difficulties in finding a suitable value of k_p in practice, most shaking tables are operated with a substantial peak and notch effect. Clearly, because of this effect, caution must be exercised in the determination of frequency response characteristics of structures by means of shaking tables. In order to determine the effect of the peak and notch phenomenon on the ability of a shaking table to simulate an earthquake, the acceleration history of the N-S component of the El Centro (1940) earthquake was doubly integrated to obtain a displacement command signal. The command signal was then fed to the mathematical model with a value of k_p that produced the larger magnitudes of peak and notch shown in Fig. 3. In addition, the spring characteristic of the structure on the table was made bi-linear hysteretic, and the yield force set so that the structure would behave nonlinearly in the El Centro earthquake. The original El Centro acceleration-time history is compared with the acceleration of the table in Fig. 4, and, as may be observed, although the acceleration peaks tend to be smaller, the fidelity of the simulation is excellent.

Although the peak and notch phenomenon did not appear to seriously impair the fidelity of the table's acceleration-time history, the structure's response to the shaking table motion and its response to the El Centro earthquake are compared in Figs. 5 and 6 for linear and nonlinear structural behavior respectively. In the case of linear behavior, the shaking table response is slightly smaller than the ideal response, but the differences in the case of nonlinear response are negligible.

CONCLUSION

Although the peak and notch phenomenon requires that caution be exercised in the interpretation of structural frequency responses obtained by means of shaking tables, the phenomenon does not appreciably affect the fidelity to which a shaking table will simulate an earthquake type motion.

ACKNOWLEDGMENT

The work described above was conducted under a National Science Foundation grant to the University of California, Berkeley.

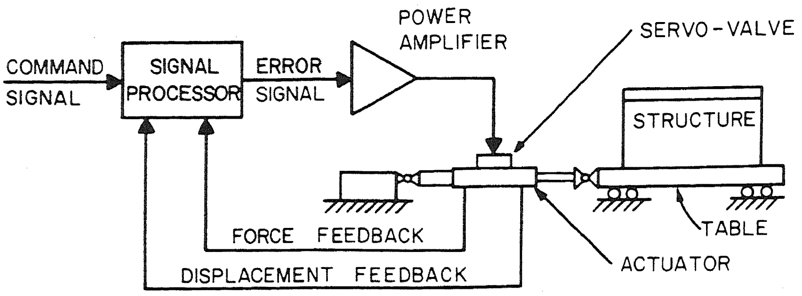

FIG. 1 SCHEMATIC DIAGRAM OF SHAKING-TABLE

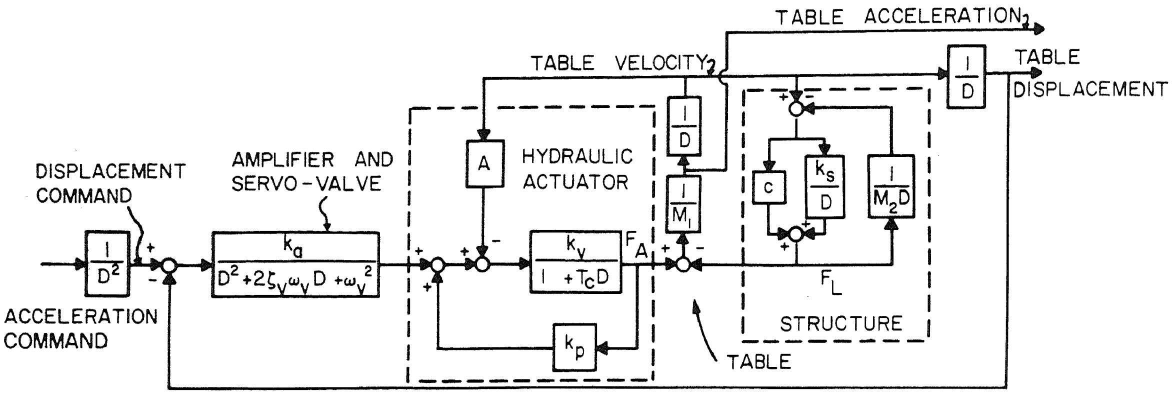

FIG. 2 STRUCTURE-ORIENTED BLOCK DIAGRAM

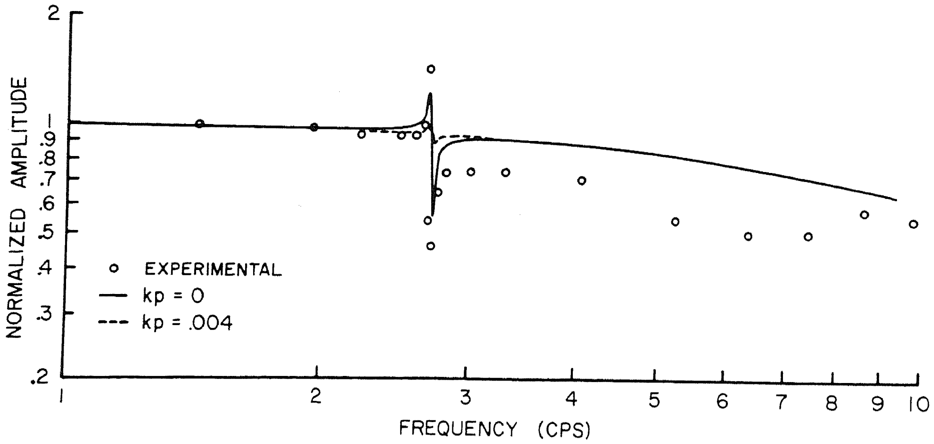

FIG. 3 ANALYTICAL AND EXPERIMENTAL FREQUENCY RESPONSES

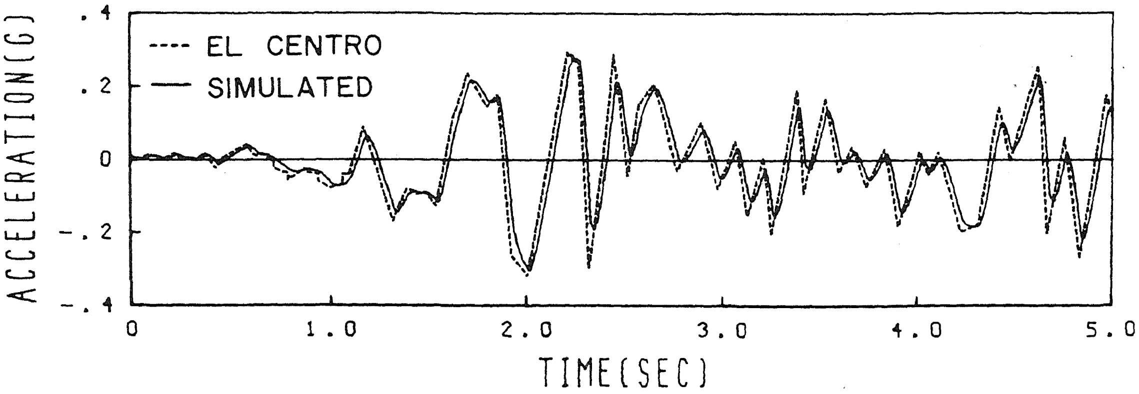

FIG. 4 REAL AND SIMULATED EARTHQUAKES

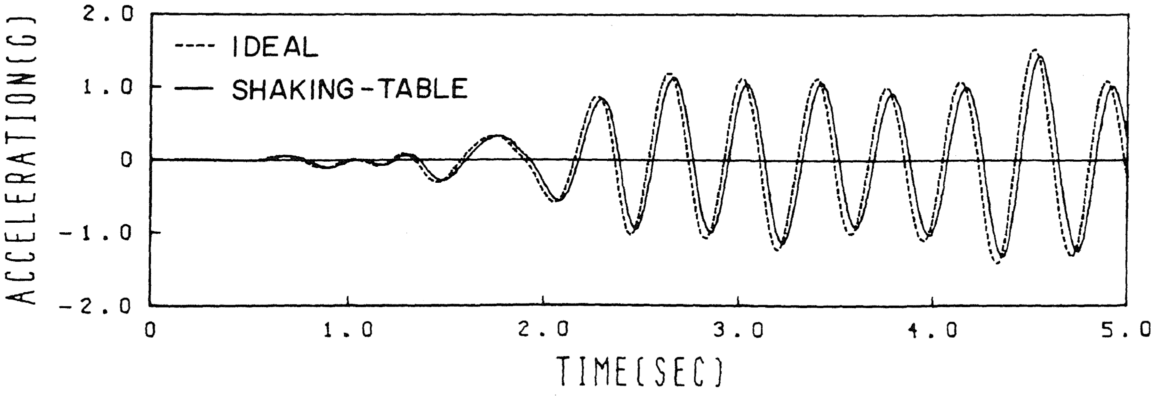

FIG.5 LINEAR STRUCTURAL RESPONSE

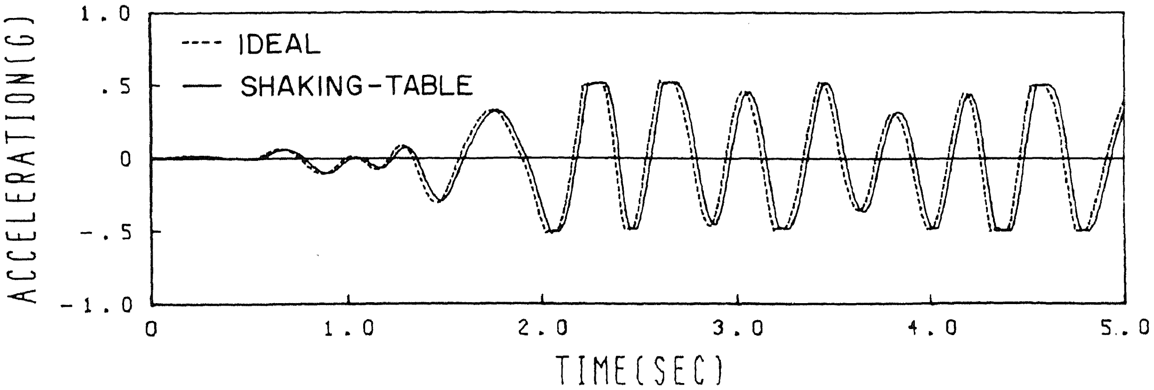

FIG.6 NONLINEAR STRUCTURAL RESPONSE