

# A NEW SEISMIC FREQUENCY RANGE SHAKER FOR MODAL TESTING OF LARGE STRUCTURES

by

Frank M. Tillou<sup>I</sup> and Kenneth J. Metzgar<sup>II</sup>

## SYNOPSIS

A new, long-stroke, electrodynamic shaker is described which has been designed and optimized specifically for exciting the natural modes of large structures in the seismic frequency range. The shaker's physical and performance characteristics are presented, and its applications and modes of operation are discussed. Also briefly described are a reaction mass assembly and auxiliary tables which further extend the usefulness of the shaker.

## INTRODUCTION

Shakers are commonly used to excite natural modes of structures for study. They deliver a definable, controllable forcing function to the structure, adjustable in both amplitude and frequency. Of the various types of shakers available commercially, the electrodynamic shaker is particularly well suited to modal testing requirements because of its inherent versatility. It has been widely employed in modal tests on aerospace structures, but has not previously found extensive usage in studies of earth-mounted structures subject to seismic excitation. Perhaps the major reason it has not been widely employed in the earthquake field is that electrodynamic shakers and systems have not heretofore been optimized for the long-stroke, low frequency operation necessary in this application. This paper describes the characteristics of a new seismic frequency range, long stroke, electrodynamic modal shaker, developed specifically for driving antinodes of large structures down to low seismic frequencies. Designated as the Model 113 ELECTRO-SEIS, the unit is portable, and can be used alone or in arrays for field or laboratory excitation of such complex structures as piping systems, electrical power system apparatus and structures, towers, bridges, buildings, etc.

## CHARACTERISTICS AND MODES OF OPERATION

An electrodynamic shaker is fundamentally a force generator, as opposed to rotating eccentric mass or electrohydraulic shakers which are fundamentally motion generators. Its basic operating principle is that of the generation of a force on a current carrying coil, located in a dc magnetic field. The magnitude of the generated force is directly proportional to the instantaneous value of drive current. Corresponding to the force generated on the coil and its associated armature structure, there is an equal and oppositely directed reaction force developed on the magnetic field structure constituting the body of the shaker. Therefore, the electrodynamic shaker can generate any time waveform of force between its armature and body, in accordance with an identical waveform of current supplied to it (e.g., sinusoidal, random, transient, etc.). The force

---

<sup>I</sup> Vice President, Acoustic Power Systems, Inc., Anaheim, California 92806

<sup>II</sup> President, Acoustic Power Systems, Inc., Anaheim, California 92806

magnitude is directly adjustable, independent of the frequency or time waveform of operation, and for vibration decay studies, it may be instantaneously terminated by interrupting the current. For a given force, the resulting relative motion between its armature and body is a function of the mechanical impedance of the structures to which the two portions of the shaker are attached. That is, for a given current, the same force will be produced whether either or both the armature and body are blocked or free, or loaded to any degree between these extremes. In contrast, the force output of a shaker that is fundamentally a motion generator depends directly upon the mechanical impedance of the structure(s) to which it is attached.

The Model 113 ELECTRO-SEIS is an electrodynamic shaker with sinusoidal performance ratings of 30 pounds (133 N) vector force, 30 inches/second (76.2 cm/s) vector velocity, and 6.25 inches (15.9 cm) peak-to-peak stroke. It is designed to be driven by a 125-watt, dc power amplifier. The shaker has a 4.9-pound (2.22 kg) armature for minimum mass loading of the drive point and a total weight of 80 pounds (36.3 kg), for one- or two-man portability. The unit employs permanent magnets and is configured such that the armature coil remains in a uniform magnetic field over the entire stroke range, thereby achieving force linearity. The armature and body are constrained to move coaxially by a high cross-axis stiffness, linear ball bushing and shaft guidance system, which also allows support of the entire shaker weight via the armature. The dynamic neutral positions of the armature and body are centered in the stroke range by means of an internal, low-stiffness, spring suspension system. An adjustable feature of this system allows centering of the neutral positions and retention of full stroke capability for any inclination of the thrust axis.

To excite a diversity of drive points and types of structures, the shaker has been designed to operate in various modes, characterized by the manner in which the reaction force and static weight are accommodated. In the first mode, termed the fixed body mode, a rigid external support structure is employed between the body and ground to support the static weight and fix the body against the dynamic reaction force. The armature is attached to the structure drive point via a simple 1/4-inch (.64 cm) diameter thrust rod. In this mode, the full stroke capability is available for resonant motion of the drive point, up to the maximum velocity. Rated force may be delivered from 0.1 Hz to 30 Hz (0.7 times rated force from dc to 0.1 Hz).

Since the desired drive points on many large structures lie at a considerable distance above ground level, it is frequently impractical to employ fixed body mode support structures. In such cases, the body mass can be allowed to accelerate freely in response to the reaction force, and the static weight of the shaker can be supported in various ways which do not restrict axial body motion. For example, the resiliently suspended body mode may be employed, as illustrated in Figure 1. In this case, the static weight is supported by lines attached at one end to the body and at the other end to existing overhead building or structural members, to simply erected pipe or channel frames, or in some cases to the test structure itself. Force is delivered through a thrust rod, and body reaction motion is accommodated by the pendulous suspension. Neutral position centering is accomplished by the adjustable internal suspension system.

The internal guidance and suspension systems also allow static weight support via the armature, leaving the body free to vibrate axially, but centered in the stroke range. In one mode, termed the fixed armature mode, the shaker weight is supported by short lines, attached to four upper armature support points, passed through slots in the top of the shaker body, and affixed to the test structure at a location above the drive point. In another mode, termed the cradle mode, the shaker is placed onto a small support stand, having vertical members which penetrate slots on the bottom of the shaker body and support the armature from beneath. In this case, force is delivered from the shaker to the structure via the cradle, in a direction parallel to the mounting surface. The cradle mode can be employed on structures having appropriately located horizontal or nearly horizontal surfaces such as floors, roofs, platforms, or stair landings on buildings, bridges, tanks, elevated structures, etc.

#### PERFORMANCE ENVELOPES

Fixed body performance has been described above. Resonant load performance envelopes for all of the free body modes are given in Figure 2. In the upper portion of the frequency range where relative stroke and velocity are not limiting factors, full rated force may be delivered to a resonant structure drive point, and drive point absolute velocities up to the rated value can be accommodated. In that portion of the frequency range below approximately 2 Hz, shaker body stroke and velocity reduce the force and the absolute stroke and velocity available to the drive point. The performance envelopes in this region represent the limiting cases of the maximum force that can be delivered to a zero velocity load and the maximum resonant load velocity that can be developed when the delivered force is zero. The dashed lines represent maximum performance with a matched resonant load.

Figure 3 shows the shaker mounted on a reaction mass assembly. The assembly contains four solid steel bars mounted on a low friction linear guidance system similar to, and having the same stroke as, that of the shaker. The shaker is supported in its cradle mode on the common assembly base, and the body is connected to the bars, providing a total reaction mass of approximately 400 pounds (181 kg). Portability of the assembly to and from a test site is achieved by a bolted construction which allows disassembly of the unit into individual elements, each weighing approximately 80 pounds (36 kg). This unit extends the low frequency limit of full force, cradle mode performance down to 0.5 Hz and optionally down to 0.35 Hz with five additional 80-pound bars. It is especially useful for excitation of large structures such as bridges and buildings having natural modes in this low frequency range.

#### AUXILIARY TABLES

By virtue of the shaker's long stroke capability and internal guidance and suspension systems, horizontal or vertical mode auxiliary tables may be attached to the armature to extend the shaker's usefulness to vibration of such items as components, model buildings and structures, accelerometers, accelerographs, and other seismic frequency instruments, mounted on the tables. A horizontal mode table is shown in Figure 4. The full shaker force, velocity, and stroke ratings are retained with the tables installed.

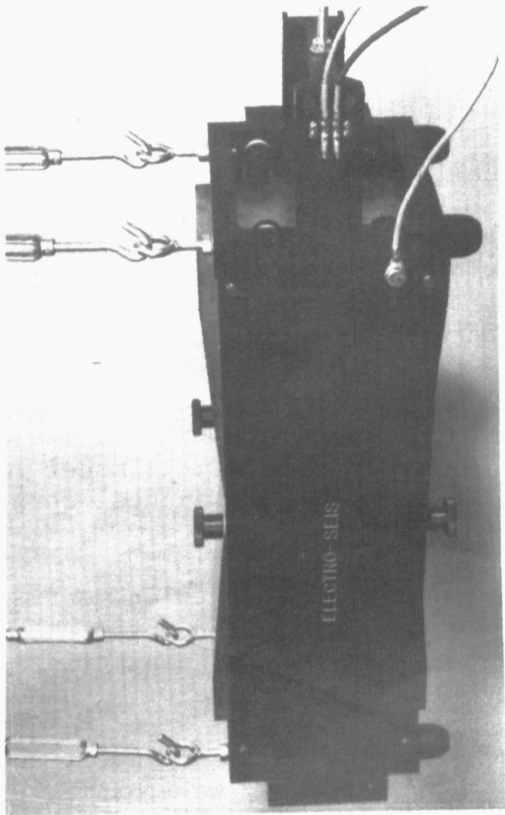


FIGURE 1. RESILIENTLY SUSPENDED BODY MODE

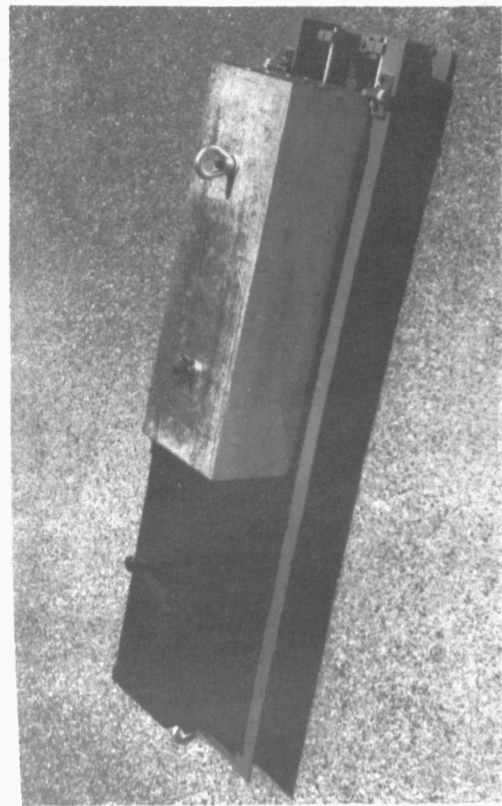


FIGURE 3. SHAKER ON REACTION MASS ASSEMBLY

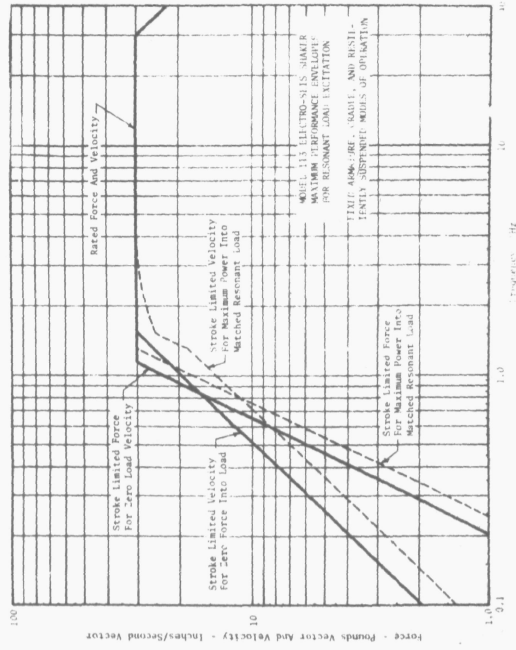


FIGURE 2. RESONANT LOAD PERFORMANCE ENVELOPES

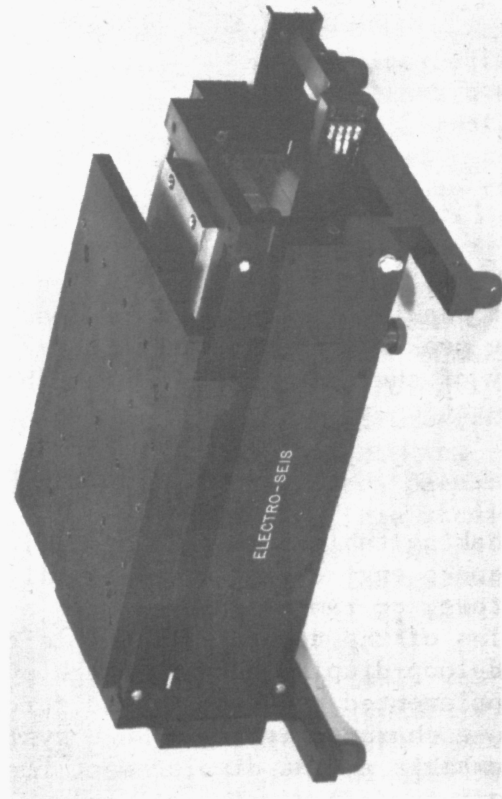


FIGURE 4. SHAKER WITH AUXILIARY TABLE ASSEMBLY