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CALIBRATION OF LONG-PERIOD SEISMOGRAPHS AT THIRTEEN STATIONS THROUGHOUT THE WORLD

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ABSTRACT

During mid-1962 accurate calibrations were made of 42 special seismographs located at 13 stations throughout the world. The stations are Bermuda, Buenos Aires, Delhi, Hong Kong, Honolulu, Huancayo, Mt. Tsukuba, Perth, Rio de Janeiro, Santiago, Suva, Uppsala, and Waynesburg. Two methods of calibration were used, one based on a steady-state input signal, the other on a transient pulse-like input signal. The signals were applied through a Willmore-type bridge. Analysis of the steady-state output was conventional; analysis of the pulse was made by a comparison with a family of theoretical pulses obtained by means of an analog computer. Both methods provide displacement sensitivity and phase response curves.

The instruments were calibrated according to the existing conditions. They were then adjusted for standardization and recalibrated. The bridge and the pulse generating circuit were installed permanently for frequent calibration in the future. The results of the calibrations are given here in graphical form.

INTRODUCTION

This paper is a report of accurate calibrations of certain special seismographs installed during the interval 1954-1958. Prior to the calibrations described here, an approximate response, sufficient for many studies, was known for these instruments, but as other more exacting studies called for an improved knowledge of this response, this additional effort became necessary. Curves for amplitude and phase response for 42 seismographs at 13 stations are given here, together with a discussion of the methods used for calibration and certain of the problems encountered.

To study the propagation of long-period waves, Columbia University has installed some 17 seismograph systems, 13 of which are discussed here, at various stations throughout the world. Many of the instruments were installed during the International Geophysical Year as part of the LP-Lg Seismology Program. The seismometers are of the same general type, but they appear in several versions. The oldest version was originally designed and fabricated at Lamont Observatory. The remaining seismometers are of either the Press-Ewing design made by Lehner-Griffith, or the Columbia design made by Sprengnether. Both of the latter are patterned after the original Lamont design but they differ in certain details.

The seismometers are coupled to galvanometers through a resistor network as shown in Figure 1. There are two basic arrangements. One, commonly called the long-period (or LP) seismograph, consists of a 15-second seismometer coupled to a Lehner-Griffith galvanometer with an operating period of approximately 75 seconds. The other, designed for the study of Lg surface waves and hence sometimes called the Lg seismograph, has the same type and period of seismometer, but is coupled to a Leeds-Northrup galvanometer with an operating period of 7 seconds. All the stations listed in Table 1, with the exception of Huancayo, have a 15-75 arrangement. Two stations, Huancayo and Rio de Janeiro, have the 15-7 combination.

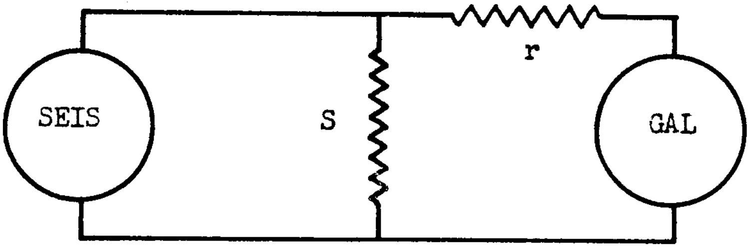

Figure 1

Network arrangement of seismometer coil, galvanometer coil, and coupling resistors, r and S.

In the original operating condition of the seismographs, the seismometer was overdamped by a factor of 1.5 while the galvanometer was overdamped by a factor of 6.0. Later, in order to improve the relative long-period response, the damping factors of the seismometer and galvanometer were changed to approximately 3.0 and 1.0, respectively. This arrangement provides a fairly flat response over a period range bounded approximately by the periods of the seismometer and galvanometer. Because of these changes which affect the response of the instrument, the first calibrations described here apply to the instruments only from the time of the last major change prior to calibration, i.e., when the damping factors were nominally 3.0 and 1.0. Since the time of final calibrations the seismographs have been operating with damping factors of approximately 2.5 to 2.8 for the seismometer and 1.0 for the galvanometer.

The purpose of these long-period seismographs is to encourage and facilitate the study of long-period seismic waves. Many valuable studies resulted from the data recorded from these seismographs, and a large number of papers have been published (see Publications List, Lamont Geological Observatory). The instruments continue to provide valuable data.

In the following there is given a discussion of the steady-state and transient calibration methods, response curves for the calibrated instruments and various associated problems.

STEADY-STATE CALIBRATION SYSTEM

Relative magnification. The steady-state calibration method consists of driving the seismometer with a known steady-state sinusoidal motion, and recording the output from the galvanometer system. When such calibrations are made for short-period instruments, the driving force is frequently a shaking table. The long-period seismometers, however, are heavy and highly tilt sensitive, and would require an elaborately engineered shaking table to provide controlled sinusoidal motions with periods up to 250 seconds. Furthermore, the shaking table method has the disadvantage that the seismograph must be moved from its operating position to the shaking table with consequent and inevitable instrumental changes. Such a system for calibrating instruments, especially long-period instruments at many stations would be impractical due to its importability.

Fortunately the electrical sine wave oscillator can be substituted for the shaking table. The portable oscillator provides an electrical sinusoidal wave which can drive the seismometer boom. The boom motion may then be detected by the galvanometer, magnified, and recorded as sinusoidal waves on photographic paper.

The sine wave current is applied to the seismometer through a Willmore calibration bridge. The purpose of this calibration bridge is to permit the application of a forcing signal to the seismometer coil without disturbing the recording element, but in such a way that this element is left free to respond to the motion of the seismometer boom resulting from the applied signal (Willmore, 1959). The steady-state sine wave current is directly proportional to simulated ground acceleration. The constant of proportionality relating the sine wave current to ground acceleration must be determined in order to compute the absolute magnification.

The bridge system of calibration has previously appeared in seismological writings by Duclaux, 1960; Sohon, 1932, and by Willmore, 1959. In his paper, Willmore describes in some detail the method of applying the Maxwell bridge to the seismometer-galvanometer network, and the steady-state calibration of the same by an electrical sine wave. The Maxwell bridge, as used in seismograph calibration, is also referred to here as the Willmore calibration bridge.

In Figure 2, a diagram of such a bridge, the components, R_1, R_2, R_3 have known values. The element, Z_s, is the component whose value is to be determined, and is assumed to have both resistance, R, and inductance, L. The resistance of the unknown component is balanced by a combination of the other three resistor components, as noted in Figure 2, while its inductance is balanced by a capacitor connected in parallel with the resistor element, R_3. Willmore placed the seismometer coil in the position of the unknown element of the Maxwell bridge. It was found by experimentation that the coils of the long-period seismometers had negligible reactive inductance in the operating frequency range of the seismometer. Consequently, the capacitor, used to balance out the inductance of the coil, is unnecessary. Since the inductance and capacitance of the long-period seismometer-bridge network are negligible, the Maxwell bridge reduces to a Wheatstone bridge. Thus though the calibration bridge is

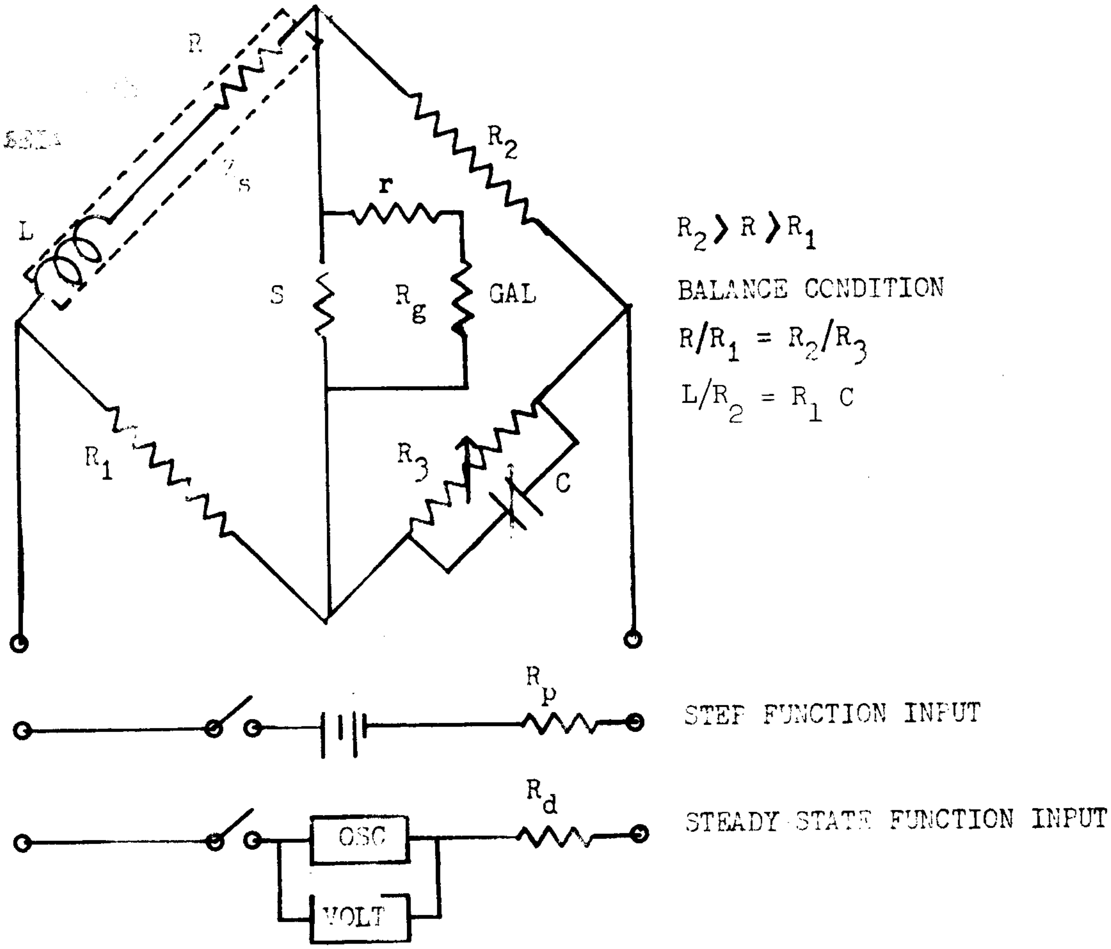

Figure 2. Circuit diagram of seismograph calibration bridge and calibration function generators. Resistors, R_p and R_d, are fixed resistors, preferably a precision type.

essentially a Maxwell bridge, when used for calibrating long-period seismographs it is a simple Wheatstone bridge.

The galvanometer and coupling resistors of the seismographs are placed in the conventional position for a bridge galvanometer. The seismograph galvanometer is therefore independent of the driving force of the sine wave current, but is sensitive to unbalance of the bridge caused by motion of the seismometer boom. The bridge is balanced by clamping the seismometer boom and adjusting the bridge's variable resistor, R_3, until no current flows through the galvanometer from the oscillator. When the bridge is balanced the galvanometer responds only to the motion of the seismometer coil and not to the driving force of the oscillator. Hence the fundamental features of the steady-state calibration system are attained, namely, that 1) the sine wave signal, which is proportional to a ground acceleration, is applied to the seismometer coil, and 2) the galvanometer responds only to the current generated in the coil, and records it as an amplified sine wave. The same result can be obtained using an auxiliary coil and magnet rather than the calibrating bridge. In this case the g of the calibrating coil must be used to determine the absolute magnification.

The sine wave current, applied to the seismometer-bridge system, is kept at constant amplitude, and if it is changed, a correction must be applied to the amplitude of the output. The sine wave used for calibration of the long-period systems has a range of periods from 2 seconds to approximately 250 seconds. The current at each period is applied to the seismometer system long enough to outlast the transient motion that results from switching from one frequency to another, and to record a sufficient number of oscillations to provide a good estimate of the average amplitude for each period.

When the output (or trace amplitude) for each frequency corresponding to the input driving force and the input voltage are recorded on the seismograph, sufficient data is available to graph the instrumental response of the seismograph. The amplitude of the input current at each frequency is tabulated, and any variation from a constant input current is normalized to an arbitrary constant value. Likewise the trace amplitude at each frequency on the output record is tabulated and normalized to correspond to the input current of constant value. The corrected trace amplitude of each frequency is plotted against the corresponding frequency (or period) giving a relative acceleration response curve. Each point of the acceleration response curve can be multiplied by ω and ω^2 to convert to velocity and displacement sensitivity curves, respectively.

Phase response. The phase response curve can be plotted from the records of the input current and trace amplitude. In Figure 3 the time difference between the same phase of the input and output of a given sine wave is represented by Δt, and this time interval corresponds to a phase angle, ϕ. The phase change is expressed in radians by the proportion, $\phi/\Delta t = 2\pi/\tau$ where τ is the value of each period in seconds, and Δt is the time difference between input and output peaks or zero crossings. The phase response, ϕ, in radians, is plotted against period, τ, in seconds.

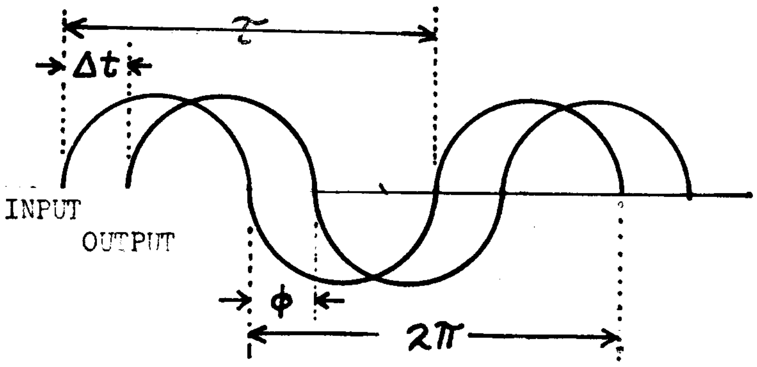

Figure 3. Input and output waves show the phase difference given by the expression, $\phi = 2\pi\,\Delta t/\tau$.