IS 13372-1 (1992): Code of practice for seismic testing of rock mass, Part 1: within a borehole [CED 48: Rock Mechanics]

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Indian Standard

SEISMIC TESTING OF ROCK MASS — CODE OF PRACTICE

PART 1 WITHIN A BOREHOLE

UDC 622·245 : 624·042·7 : 620·1

BUREAU OF INDIAN STANDARDS
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NEW DELHI 110002

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Rock Mechanics Sectional Committee, CED 48

FOREWORD

This Indian Standard (Part 1) was adopted by the Bureau of Indian Standards. after the draft finalized by the Rock Mechanics Sectional Committee had been approved by the Civil Engineering Division Council.

The seismic method is one of the most practical and convenient for obtaining a stratigraphic map and information on the geological character and mechanical properties of the ground. It does this by inference from the propagation velocities and attenuations of elastic waves. The velocities, frequency, attenuations and wave shapes of a propagating wave can be used as indices to important characteristic of the *in-situ* rock and soil, not only average mechanical properties but also structure, degree of weathering, etc.

If ground is assumed to behave elastically, at least at the small strains imposed by propogating seismic wave, elastic constants such as Young's Modulus and Poisson's ratio could be computed from the observed seismic velocities and measured density values. It has been observed over the decades by conventional seismic technique using exclusively measured velocity values that the above modulus known as dynamic elastic modulus is always greater than the static modulus of deformability determined by plate loading or other static test.

Differences in strain rate, strain level and the different response of joints to dynamic as opposite to static loading account for the disagreement between dynamic and static 'constant'. Differences in rock quality have a significant effect on ratio between dynamic and static modulus which in principle is close to 1·0 when the rock is free from defects, but increases as the quality of the rock mass decreases.

In many urban regions, the dynamic properties of soil and rock shall be determined as input data for the solution of a variety of earthquake engineering problems and seismic testing in and between the boreholes is used extensively in these application.

Seismic method has been covered in the following two parts:

Part 1 Within a borehole

Part 2 Between the boreholes

Part 1 deals with following methods:

a) generation at the surface and detection in a borehole, or vice-versa; and

b) generation and detection in the same borehole.

The first method in this part which is also called the 'well shooting' or 'downhole' or 'uphole' seismic method is commonly used for determining rock structure and characteristics in the immediate vicinity of the hole. The depth of investigation obtained with this method is limited by the energy of seismic source. With powerful P and S waves the technique has been found to be capable of penetrating to depth of up to 1 000 m.

Second method may be used at any depth and involves measurements with both seismic source and receiver in the same hole.

The method described in this standard is based on suggested methods for seismic testing by International Society of Rock Mechanics.

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

SEISMIC TESTING OF ROCK MASS — CODE OF PRACTICE

PART 1 WITHIN A BOREHOLE

1 SCOPE

This standard describes methods for seismic testing of rock mass within a borehole by downhole method and uphold method for the purpose of either to locate and map stratigraphic boundaries, or to determine seismic and, by inference mechanical characteristics of the individual rock or soil units between these boundaries.

2 TERMINOLOGY

2.0 For the purpose of this standard following definitions shall apply.

2.1 *P* Wave

P wave is a longitudinal wave and is also called a compressional wave. The direction of particle motion coincides with that of wave propagation. The propagation velocity of a *P* wave is faster than that of an *S* wave.

2.2 *S* Wave

S wave is a transverse wave and is also called a shear wave. The particle motion of an *S* wave is in the plane perpendicular to the direction of wave propagation. An *S* wave can be classified into two types (*SH* wave and *SV* wave) according to the direction of particle motion.

2.3 *SH* Wave

The particle motion of an *SH* wave is in the plane perpendicular to the direction of wave propagation and in the direction parallel to a boundary. The boundary is normally the ground surface.

2.4 *SV* Wave

The particle motion of an *SV* wave is in the plane perpendicular to the direction of wave propagation and in the direction perpendicular to that of particle motion of the *SH* wave.

2.5 Quality Factor

Quality factor (*Q*) is a dimensionless factor indicating the degree of attenuation of waves or vibrations.

3 PRINCIPLE OF TESTING

Seismic testing within a borehole consists of measuring the travel time of *P* and *S* waves and the distance from a source to receivers, along the walls of a single borehole, so as to determine the elastic wave velocity distribution in the borehole direction. Also attenuation characteristics of *P* and *S* waves may be estimated by measuring the amplitudes of seismic waves.

This method is classified into following two alternatives according to the arrangement of the seismic source and receiver as shown in Fig. 1:

a) In the 'downhole method', the seismic source is placed at the ground surface or at the rock surface of an underground opening, and one or more receivers are successively positioned at different depths in a borehole.

b) In the 'uphole method', one or more receivers are planted at the ground surface or the rock surface of an underground opening, and the source is successively positioned at different depths in a borehole. Occasionally, one or more receivers are placed in the same hole above the source, and the source and receiver(s) are both moved.

4 APPARATUS

4.1 Seismic Source

A seismic source may either be an explosive or a mechanical device depending upon the type of wave required. See Table 1 for alternatives for both surface and downhole sources.

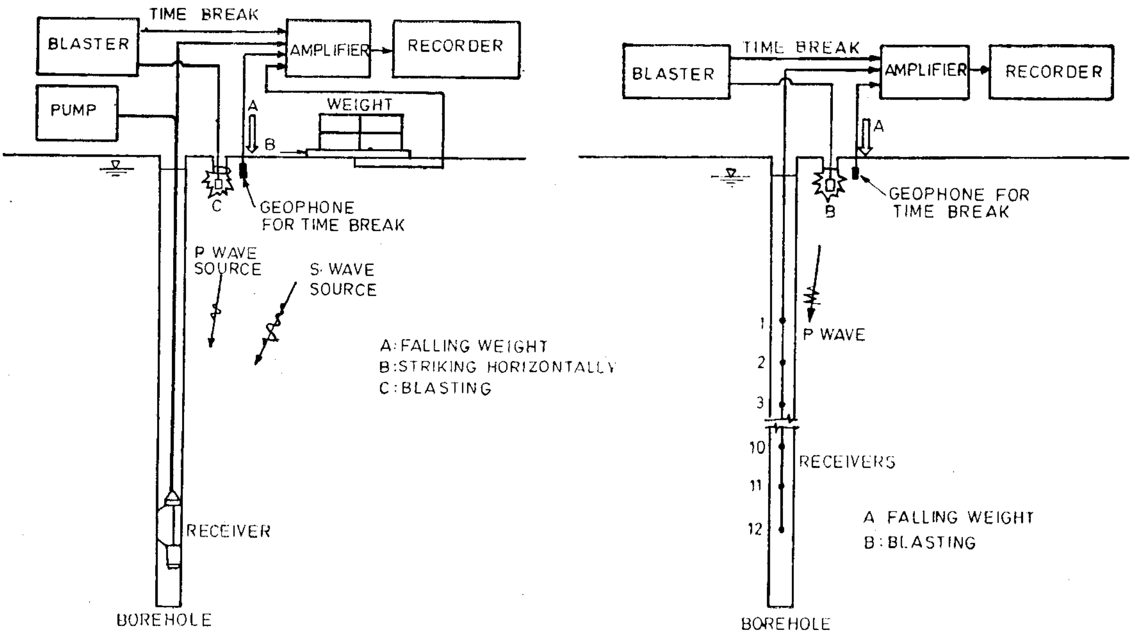
Table 1 Seismic Source for Seismic Testing Within a Borehole

Sl No.	Types of Waves	Surface Sources	Borehole Sources
1)	*P* wave	explosives sledgehammer falling weight, etc	explosive, sparker, air gun hammering device, etc
2)	*SH* wave	plank hammering *SH* gun horizontal vibrator, etc	horizontal hammering device vibrator, etc
3)	*SV* wave	sledgehammer falling weight, etc	explosives air, gun, sparker hammering device vibrator, etc

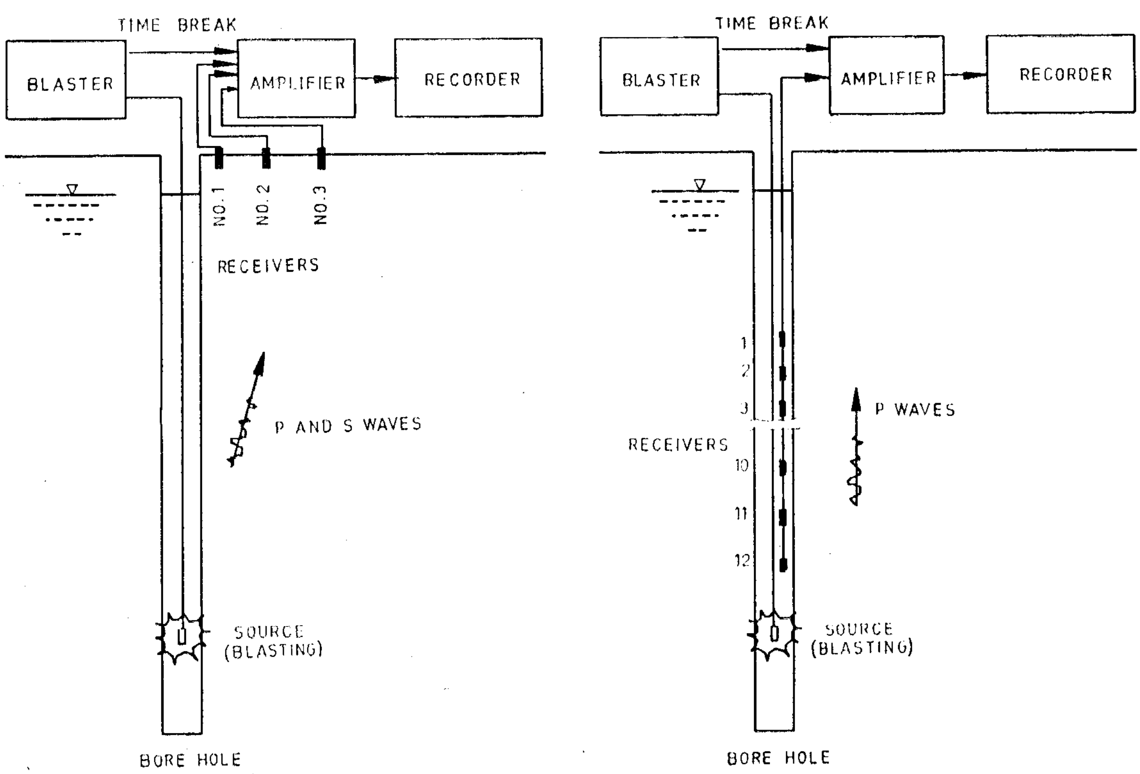
4.2 Seismic Receiver

The seismic receiver may be of the following types:

a) A geophone generating a voltage directly proportional to the particle velocity of the seismic waves. The most suitable frequency range is 10 Hz-2kHz. The natural frequency of the geophone shall be less than one half of the predominant frequency of the seismic waves.



1A Downhole Method



1B Uphole Method

FIG. 1 SEISMIC TESTING WITHIN A BOREHOLE

b) A piezoelectric accelerometer generating a voltage directly proportional to the particle acceleration of the seismic waves. The most suitable frequency range is 10 Hz-60 kHz. The natural frequency of the piezoelectric accelerometer must be at least twice as high as the predominant frequency of the seismic waves.

c) A hydrophone generating a voltage directly proportional to the pressure in the wager surrounding it, acceptable only to measurements in water-filled boreholes. The most suitable frequency range is 10Hz-60 kHz.

4.3 To facilitate wave identification when geophones or piezoelectric accelerometers shall be used, each receiving unit should consist of at least three receivers combined orthogonally to form a triaxial array, that is, one vertical and two horizontal receivers mounted at right angles.

4.4 Both seismic source and receiver should have a sensitivity and frequency response suitable for the purpose of the investigation. A typical frequency band for well shooting is 10-500 Hz. For a more detailed study, higher frequencies are required.

4.5 Equipment for mounting the seismic source and receivers in the boreholes, and for surveying depth, direction and deviation of the boreholes and also location of the seismic source and receivers.

4.6 A data acquisition system as shown in Fig. 1, this should include the following:

a) An amplifier, selected to match the type of receiver used. The maximum gain of an amplifier is normally 70-130 dB with a flat frequency response of 4Hz-2kHz.

b) Signal enhancement equipment, when measuring in a 'noisy' area and/or in a deep hole in order to improve the signal-to-noise ratio of the record. Use of a high-resolution digital data acquisition system with a signal enhancement function is strongly recommended.

c) A timing device to give an accurate time mark. The interval of the time mark shall be normally either 0·1, 1 or 10 msec, depending on the size of the area to be surveyed.

d) A time break unit, to give a time break signal on the record at the instant of wave generation. The time break mark shall be recorded on a separate channel and not superposed on the signal. When an explosive is exployed, firing current, contact break (wire coil around detonator) or contact making (through the explosion generated plasma) is employed to obtain the time break signal, but for other seismic sources, the signal is obtained from a pick-up sensor or an electric signal from an electronically controlled source.

e) A recorder, to give a visual, analog or digital record of the seismic wave from each receiver. An electromagnetic oscillograph which is the most popular means of obtaining a hard copy of the visual record, shall be preferred.

5 PROCEDURE

5.1 For carrying out the test, holes shall be drilled at the most suitable location considering the topography and geology at the site.

The depth, direction and deviation of the borehole shall be surveyed to determine the coordinates of receiver or source position. Accuracy of the survey shall be specified in accordance with the purpose of the measurement.

5.2 Procedure for Downhole Method

5.2.1 One or any array of multiple receiver units shall be installed in the borehole at the required depth, and the seismic source shall be placed on the surface or in a supplementary hole near the main one so as to improve the coupling between the source and the ground and to avoid extremely weathered, soft or broken surface layers. The receivers shall be held in firm contact with the sidewall of the borehole, except for measurements in a water-filled hole, in which case a suspension type of receiver can be used.

5.2.2 Seismic waves shall be generated and measurements shall be made after each relocation of the receiver in the hole. When measuring *S* waves by the downhole method, generation and detection of the *SH* wave are strongly recommended.

5.2.3 The interval distance of measurement corresponds to the relocation interval of the receiver, or the geophone spacing of a multiple receiver system in the hole (*see* Fig. 1). Generally, it is selected in view of the required accuracy and efficiency of velocity measurement, and is usually in the range 0·5-5·0 m.

5.3 Procedure for Uphole Method

5.3.1 In this method, the seismic source shall be placed in the hole, and the receivers shall be planted on the surface near the hole, or in the same borehole above the seismic source. The receiver may be installed in a shallow supplementary hole drilled near the main one so as to avoid extremely weathered, soft or broken surface layers.

5.3.2 With this arrangement, general and measurement of the seismic wave should be carried out after each relocation of the seismic source (or seismic source and receiver if both are in the same hole).

5.3.3 To obtain a good record of the *SV* wave, it is necessary to plant the receiver on the surface at the appropriate position considering the radiation pattern of the *SV* wave.

5.3.4 The interval distance of measurement corresponds to the relocation interval of the seismic source, or the geophone interval of a receiver system in the hole (*see* Fig. 2). Generally it shall be determined according to the required accuracy and efficiency of velocity measurement, and shall be usually in the range of 0·5-5·0 m.

5.3.5 The signals from receivers should be recorded on magnetic media or displayed on a visual recorder. The signal amplitude and travel time should be adquate for reading the records with the required accuracy.

Recording on magnetic tape or disk is strongly recommended.

6 CALCULATIONS AND INTERPRETATION OF RESULTS

6.1 The travel times of *P* and *S* waves from source to receiver shall be determined by measuring the time break to their first break in the record. For the *S* wave the travel time of predominant phase of *S* wave shall also be measured. The travel times should be corrected for actual distances and hence provide vertical travel times from which the average velocity between the surface and receiver depth position shall be calculated.

6.2 A time-distance curve shall be drawn by plotting travel time *versus* travel distance (*see* Fig. 3).

6.3 The propagation velocities of *P* and *S* wave shall be obtained from the time-distance curve as the inverse of the slope of the straight line best fitting the points within the range of interest.

6.4 By plotting the propagation velocity profile along the borehole, the seismic velocities may be correlated with the geological conditions of rock obtained by drilling.

6.5 The following dynamic elastic parameters may be calculated, using equations (1-4), from *P* and *S* wave velocities and the density of the corresponding rock mass:

Dynamic Poisson's ratio,

$$\nu_d = 1/2 \; \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \qquad \ldots\ldots(1)$$

Dynamic modulus of rigidity,

$$G_d = \rho V_s^2 = E_d/(2 + 2\nu_d) \qquad \ldots\ldots(2)$$

Dynamic bulk modulus,

$$K_d = \rho\,(V_p^2 - 4V_s^2/3) = E_d/(3 - 6\nu_d) \qquad \ldots\ldots(3)$$

Dynamic Young's modulus E_d,

$$E_d = \rho V_s^2 \; \frac{3\,(V_p/V_s)^2 - 4}{(V_p/V_s)^2 - 1} = \rho V_p^2\,(1 + \nu_d)\,(1 - 2\,\nu_d)\,(1 - \nu_d) \qquad \ldots\ldots(4)$$

where

ρ = density of rock (kg/m^3),

V_p = velocity of the *P* wave (m/sec), and

V_s = velocity of the *S* wave (m/sec).

NOTE — The dynamic elastic moduli are expressed in pascals, or more often in megapascals or gigapascals [1 megapascal (MPa) = 10^6 pascals and 1 gigapascal (GPa) = 10^9 pascals]. Poisson's ratio is dimensionless.

When the amplitudes of *P* and *S* waves are measured by the use of suitable apparatus, the *Q* value (quality factor), a measure of attenuation in rock mass by spectral ratio method and rise time method in their amplitude spectra, may be calculated from changes in their amplitude spectra.

By comparing the velocity so obtained with the velocity measured from specimens, the properties of the rock mass may be evaluated.

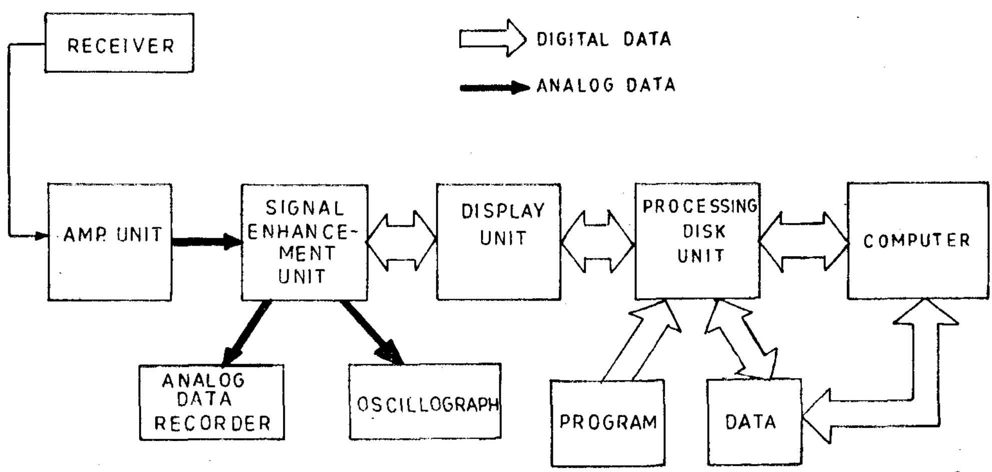


FIG. 2 AN EXAMPLE OF OBSERVATION SYSTEM

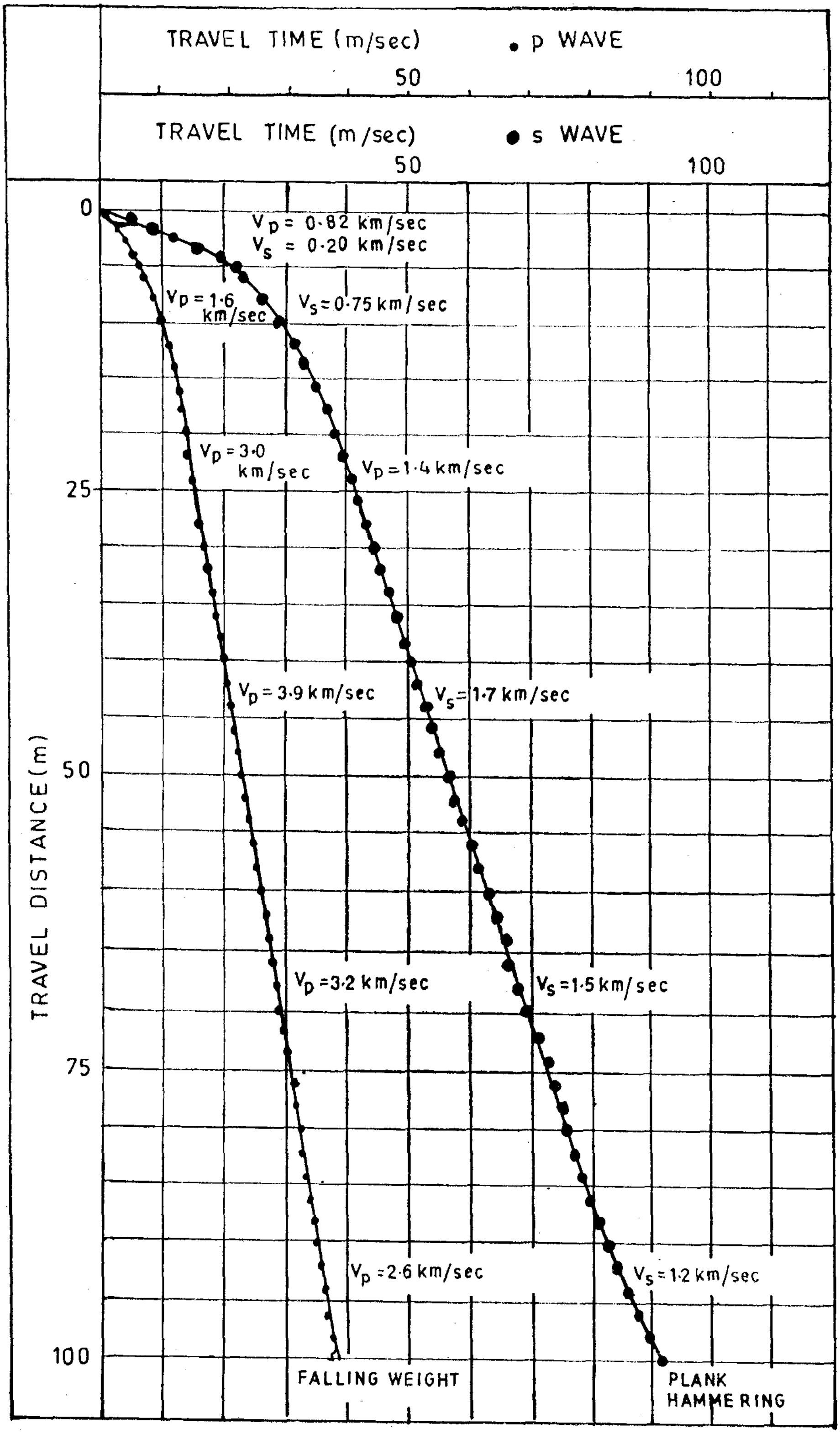


FIG. 3 AN EXAMPLE OF A TIME-DISTANCE CURVE

7 REPORTING OF RESULTS

7.1 The report shall contain the following:

a) The borehole location and length, diameter, direction and inclination, also the location and details of any casting and cement.

b) Drawings showing the position of all seismic source and receivers and co-ordinates for all points.

c) A description and specifications of the methods of measurement and equipment including for frequency characteristics of each apparatus used. Reference may be made to this method, stating only any departures from these procedures, and the reasons from these.

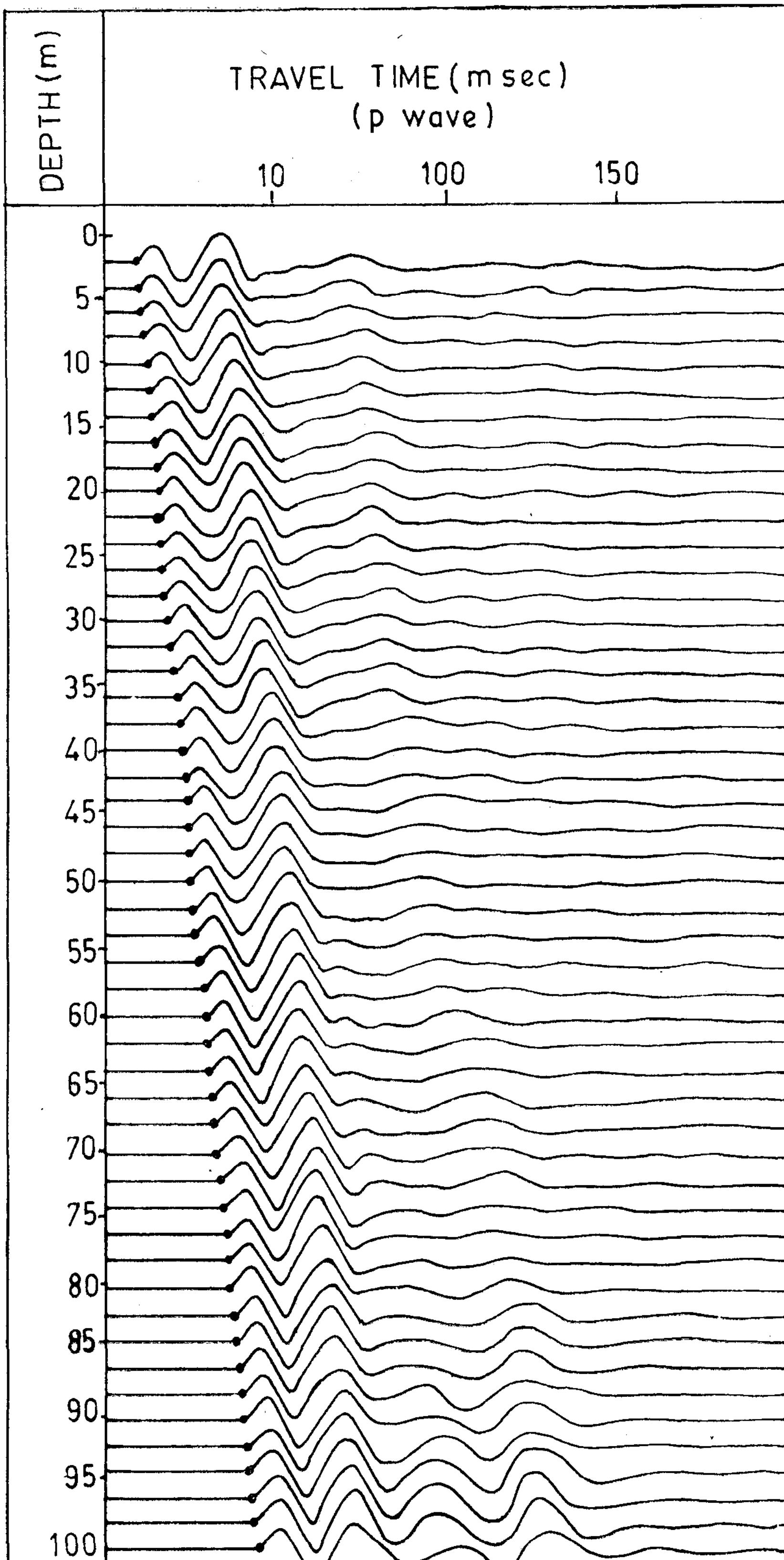
d) Waveforms at each depth, and time-distance curves such as shown in Fig. 3 and 4.

e) Drilling log and velocity distribution (*see* Fig. 5).

f) A tabulation of computed dynamic elastic modulus values.

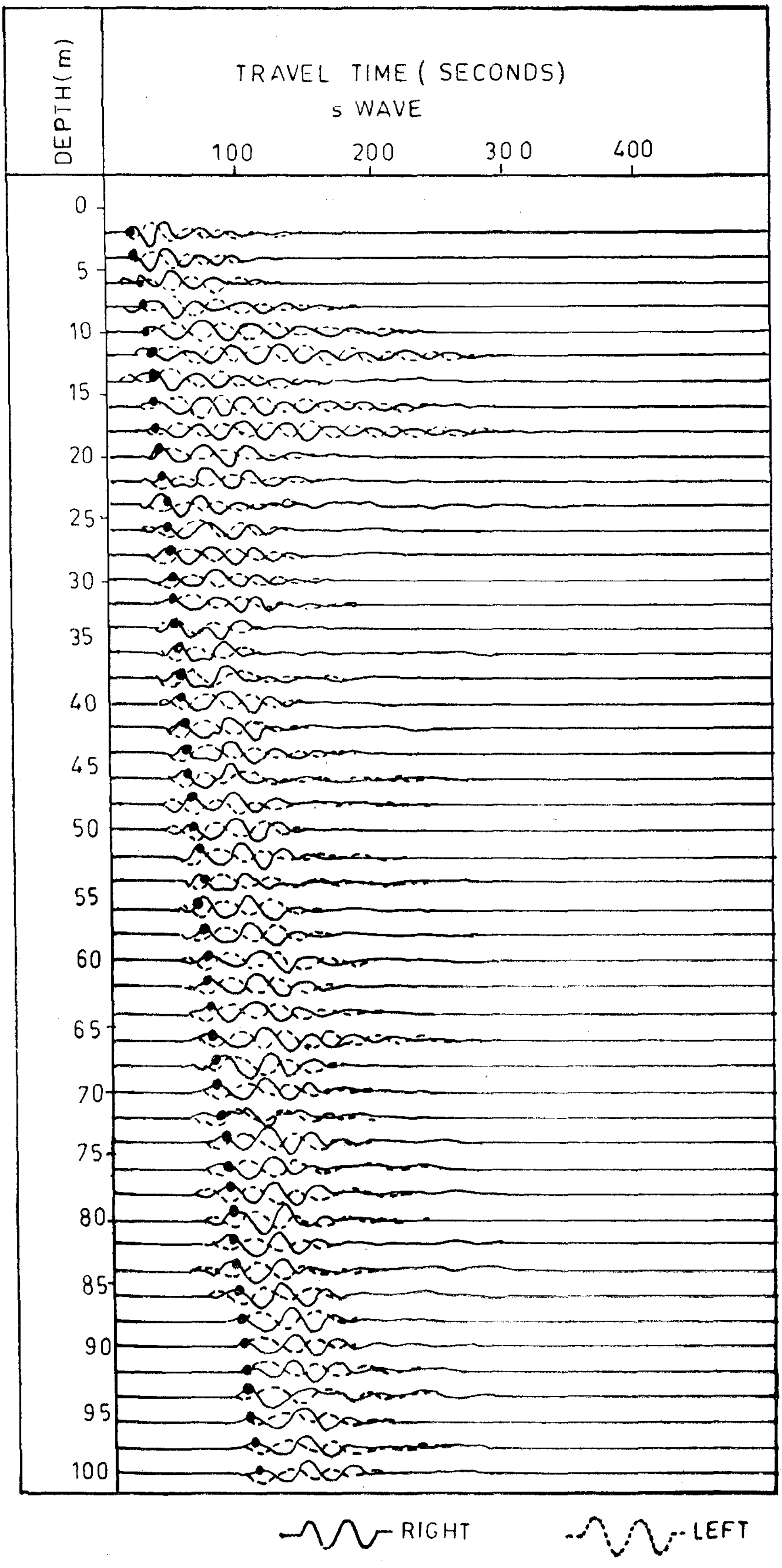
g) A description of any equations used in addition to those given in the suggested method, together with a statement of any assumptions used in the analysis.

h) When required, a geotechnical interpretation of the results of measurement, considering the geological conditions in the test area.



4A Falling Weight Source

FIG. 4 AN EXAMPLE OF SEISMIC RECORDER



4B Plank Hammering Source

FIG. 4 AN EXAMPLE OF SEISMIC RECORDER

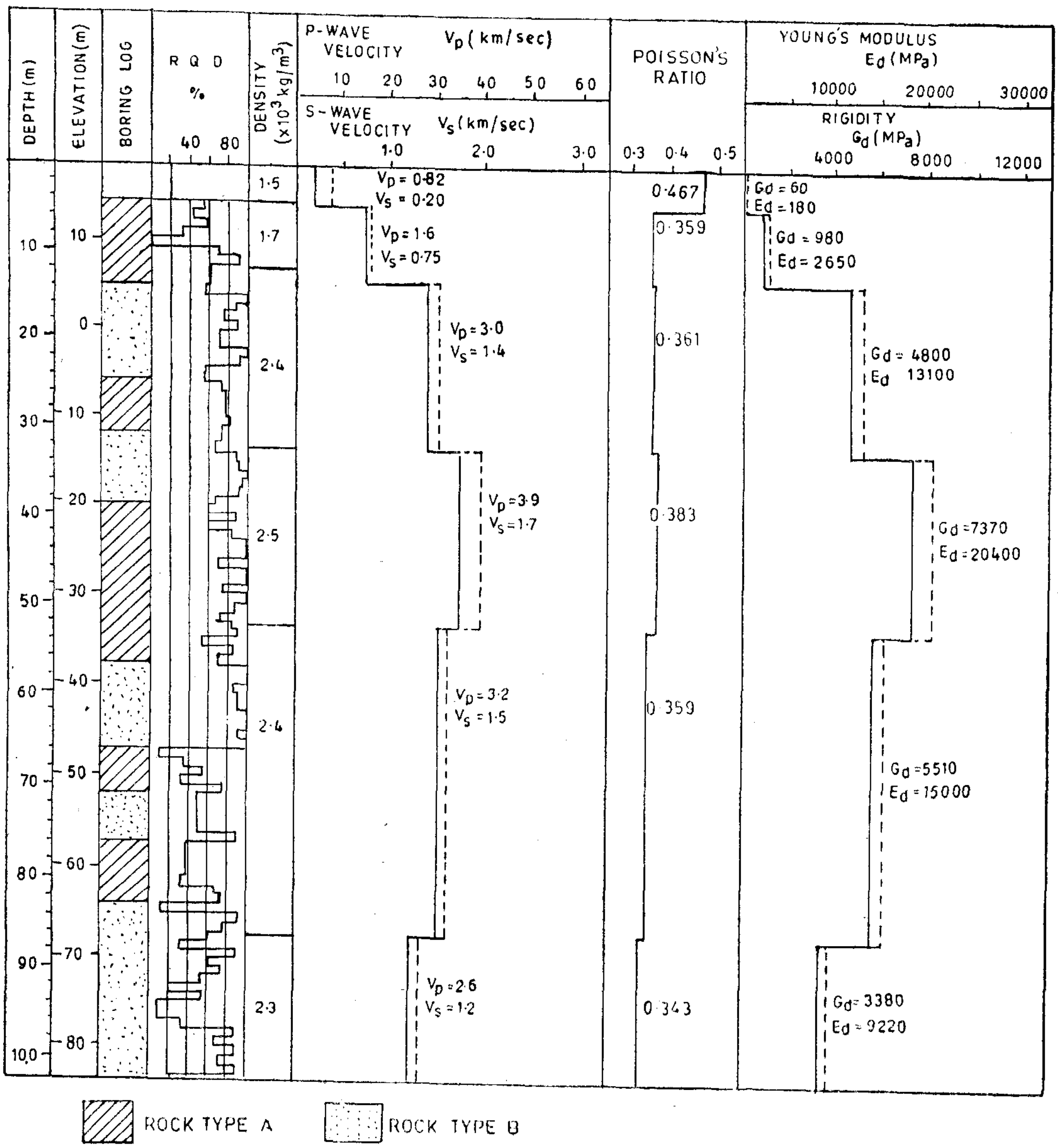


FIG. 5 AN EXAMPLE OF DRILLING LOG AND VELOCITY DISTRIBUTION OBTAINED BY SEISMIC TESTING WITHIN A BOREHOLE

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