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IS 13372-2 (1992): Code of practice for seismic testing of rock mass, Part 2: Between the borehole [CED 48: Rock Mechanics]



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भारतीय मानक

शैल संहति के भूकम्पी परीक्षण – रीति संहिता

भाग 2 वेध छेद के बीच

*Indian Standard*

**SEISMIC TESTING OF ROCK MASS —  
CODE OF PRACTICE**

**PART 2 BETWEEN THE BOREHOLES**

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NEW DELHI 110002

## FOREWORD

This Indian Standard 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 of 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 propagating 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 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 2 deals with the method in which generation is in a borehole and detection is in one or more nearby holes. This method is also called 'cross hole' seismic method. Theoretically, in this method the depth is unlimited, but in practice the accuracy is limited by borehole alignment deviations in the case of deep holes. Very precise borehole surveying is required in such cases.

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 2 BETWEEN THE BOREHOLES

#### 1 SCOPE

This standard describes method for seismic testing between borehole for the purpose of either to locate and map straightgraphic 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 the 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 TEST METHOD

In this method, also called as "crosshole" seismic method, dynamic elastic properties are calculated from the velocities of the P and S waves and the density of rock mass. The velocity distribution of the rockmass is measured between boreholes from the travel times of P and S waves and the distances from the source to several receivers.

Variations in the velocity of P and S waves can indicate the physical and mechanical properties and the degree of weathering, fracturing and jointing of the rock mass between boreholes.

#### 4 APPARATUS

**4.1** The following apparatus shall be required for carrying out the seismic testing.

- a) A seismic source, either an explosive, a mechanical device or an electrical device should be selected to generate the type of wave required. Table 1 shows alternative seismic sources for crosshole measurements.

**Table 1 Seismic Source for Seismic Testing  
Between Boreholes**

Sl No.	Types of Waves	Sources
1.	P wave source	air gun, explosives, sparker, downhole hammering device, piezoelectric vibrator, magnetostrictive source, etc
2.	SH wave source	downhole hammering device, piezoelectric vibrator, etc
3.	SV wave source	explosives, air gun, sparker, downhole hammering device, piezoelectric vibrator, etc

- b) A Seismic Receiver may be any one of the following types:

- i) 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.

- ii) A piezoelectric accelerometer generating a voltage directly proportional to the particle acceleration of the seismic waves. The most suitable frequency range is 10 Hz-60kHz. The natural frequency of the piezoelectric accelerometer shall 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 water surrounding it, acceptable only for measurements in water-filled boreholes. The most suitable frequency range is 10 Hz-60kHz.

d) To facilitate wave identification when geophones or piezoelectric accelerometers are 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.

Both seismic source and receiver should have a sensitivity and frequency response suitable for the purpose of the investigation. A typical frequency band for general purpose crosshole measurement is between 10Hz-2kHz. For a more detailed study, higher frequencies are required.

e) Equipment for mounting the seismic source and receivers in the boreholes, and for surveying spacing depth, direction and deviation of the borehole and also the locations of seismic sources and receivers.

f) A data acquisition system, shown in Fig. 1 for example, should include the following:

- i) 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 4 Hz-2kHz.
- ii) Signal enhancement equipment when measuring in a 'noisy' area and/or in the case of a wide hole spacing 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.
- iii) A timing device to give an accurate time mark. The interval of the time mark is normally either, 0.1, 1 or 10 msec, depending on the size of the area to be surveyed.
- iv) 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 used, firing current, contact breaking (wire coil around detonator) or contact making (through the explosion generated plasma) shall used to obtain the time break signal, but for other seismic sources, the signal shall obtained from a pick-up sensor or an electric signal from an electronically controlled source.

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

### 5 PROCEDURE

5.1 Test holes shall be drilled at the most suitable locations considering the topography and geology at the site. Measurements shall preferably be made in an uncased hole. In case of cased hole preferably a low velocity material such as a high impact PVC should be used for casing and it is essential that it should be well grouted behind in order to make an intimate contact with wall material. Other requirements of the hole shall be as follows:

a) The number and spacing of holes shall be determined by the nature of the project so as to obtain good results.

With an increase in the borehole spacing, the probability of measurement of refracted waves rather than direct waves in each layer increases.

b) The positions, directions, depths and deviations of each hole shall be surveyed to determine the coordinates for all shot and receiver positions. Accuracy of the survey should be specified in accordance with the purpose of the seismic measurements.

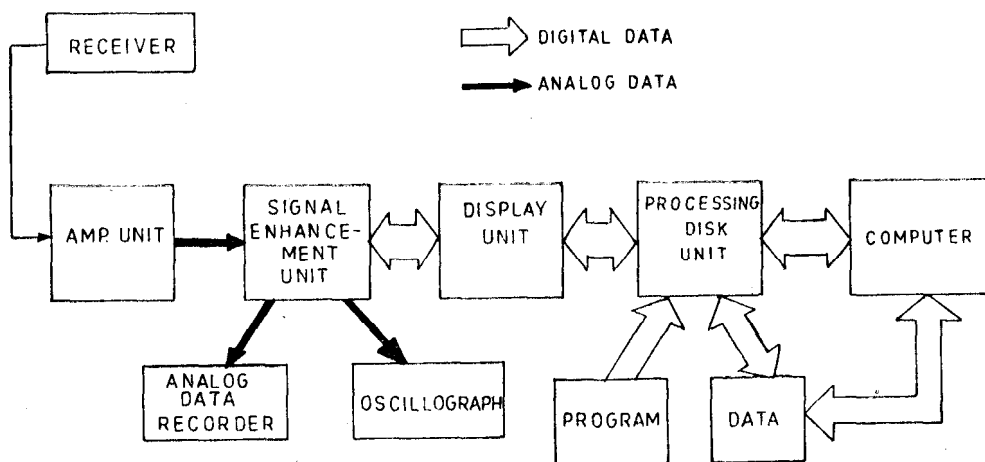


FIG. 1 A TYPICAL EXAMPLE OF OBSERVATION SYSTEM

5.2 The seismic source shall be installed in one of the boreholes and one or any array of multiple receiver units shall be installed in the others at the required depth.

Receivers shall be held in firm contact with the sidewall of the hole, except for measurements in water filled holes, in which case a suspension type of receiver may be used.

5.3 Seismic waves shall be generated and measured after each relocation of the seismic source, the receiver or the array of multiple receiver units.

5.4 The interval distance of measurement corresponds to the relocation interval of the source and/or the receivers, or the geophone spacing of a multiple receiver system in the hole ( Fig. 2 ). It shall generally be determined according to the required accuracy and efficiency of velocity measurements, and shall be usually in the range of 0.5-5.0 m.

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

Recording on magnetic tape or disk is strongly recommended.

## 6 CALCULATION AND INTERPRETATION

6.1 The travel times of P and S waves from the source to each receiver shall be determined by measuring the time from the time break to their first break in the record. When two or more receivers are located in the same ray path, the travel times of P and S waves between receivers shall be determined by measuring the time between their first breaks in the respective record. For the S wave the travel time of the predominant phase of S wave shall also be measured.

6.2 For both P and S waves, the distance from the source to each receiver or the distance between receivers when these are located in the same ray path is divided by the travel time, to obtain the 'average velocity' from the shot point to the receiving point and also between receivers.

6.3 The average velocity distribution between holes shall be plotted.

6.4 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.

$$\text{Dynamic Poisson's ratio, } \nu_d = \frac{1}{2} \frac{(V_p/V_s)^2 - 2}{(V_p/V_s)^2 - 1} \quad (1)$$

$$\text{Dynamic modulus of rigidity, } G_d = \rho V_s^2 = E_d / (2 + 2\nu_d) \quad (2)$$

$$\text{Dynamic bulk modulus, } K_d = \rho (V_p^2 - 4V_s^2/3) = E_d / (3 - 6\nu_d) \quad (3)$$

$$\text{Dynamic Young's modulus, } E_d = \rho V_s^2 \frac{3(V_p/V_s)^2 - 4}{(V_p/V_s)^2 - 1} \quad (4)$$

where

$\rho$  = the density of rock ( kg/m<sup>3</sup> ),

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

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

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

6.5 When the amplitudes of P and S waves are measured by the use of suitable apparatus and also the waves which travel through the formation are identified, the Q-value (quality factor), a measure of attenuation in the rock mass may be calculated by spectral ratio method and rise time method in their amplitude spectra.

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

## 7 REPORTING OF THE RESULTS

The reports shall contain the following:

- a) The borehole location and length, diameter, direction and inclination, also the location and details of any casing and cement.
- b) Drawings showing the positions of all seismic sources and receivers, and the co-ordinates for all points.
- c) A description and specifications of the methods of measurement and equipment including the frequency characteristics of each apparatus used.
- d) Waveforms for each source and receiver positions.
- e) The average computed propagation velocities between shot points and receiving points ( see Fig. 3 ), and also between boreholes, when multiple receiver holes in a same plane are used.
- f) A tabulation of computed dynamic elastic modulus values.
- g) A description of any equations used in addition to those given in this 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.



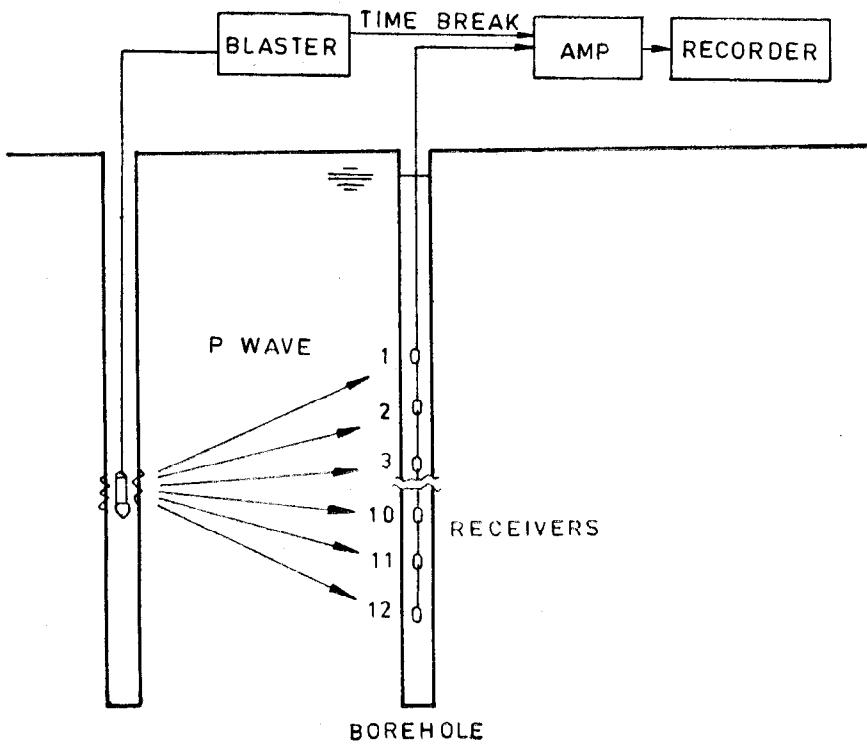
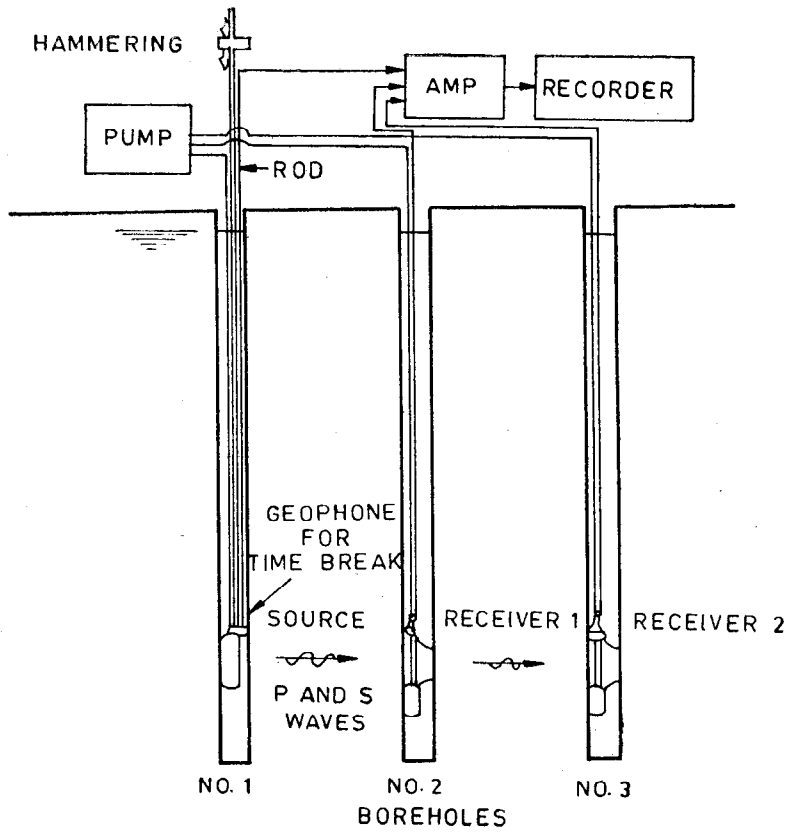


FIG. 2 SEISMIC TESTING BETWEEN BOREHOLES

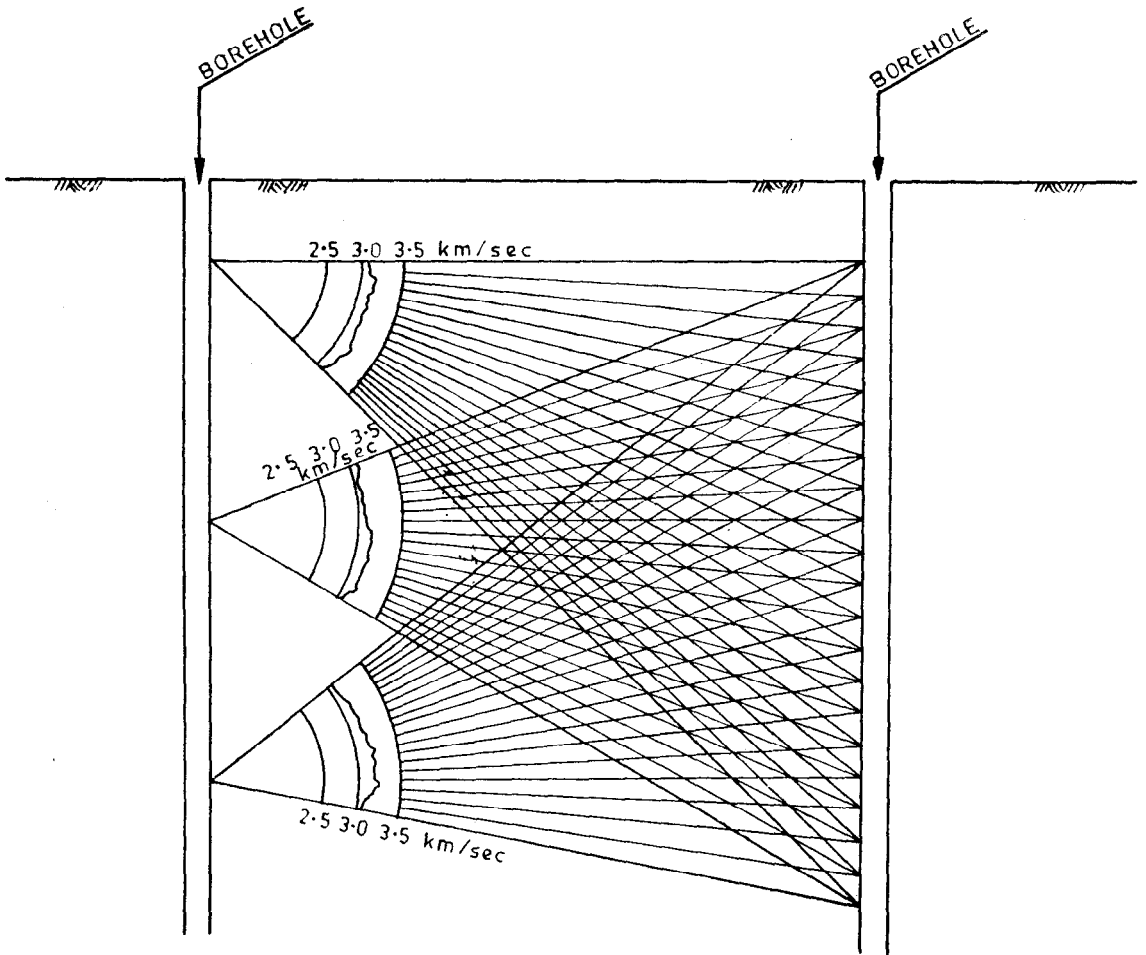


FIG. 3 SCHEMATIC DIAGRAM OF SEISMIC TESTING BETWEEN BOREHOLES SHOWING ONE WAY OF GRAPHICALLY DISPLAYING AVERAGE VELOCITIES FOR EACH LINE OF MEASUREMENT

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