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GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

GUIDELINES

FOR

INTEGRITY TESTING OF PILES

BS-41 R1

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RESEARCH DESIGNS AND STANDARDS ORGANISATION
MANAK NAGAR, LUCKNOW-226011

PREFACE

1. There are a large number of bridges in India which are on piles. These piles are of various compositions. Normally, they are limited only to foundation part of the bridge. But in many cases of old bridges these piles also serve as the piers/abutments of bridge. Some such bridges are likely to have Cast Iron piles consisting of cast iron or steel pipes filled with lime concrete/lime mortar. The bridges built recently have concrete piles.

2. Attention was drawn towards these pile bridges with the failure of Kadalundi Bridge in Southern Railway. This brought out the need for inspection of these types of substructures particularly when they remain permanently under water.

3. Railway Board vide its letter No.2001/CE-I/BR-III/9 dated 13th July 2001 has asked RDSO to prepare guidelines on Ultrasonic Pulse Velocity Testing of piles.

4. Railway Board vide its letter No.2023/CE-IV/Misc./03 dated 22nd August 2023 has asked RDSO to Revise Guidelines on Integrity Testing of Pile Foundation.

5. Accordingly, the literature survey was carried out and data collected from various sources. The results of the study have been brought out as "Revised Guidelines for integrity testing of Piles."

6. It will be worthwhile to mention that Ultrasonic Pulse Velocity & Cross Hole Ultrasonic Method (CHUM) is used for integrity testing of Piles. However, there are other methods available for integrity testing of piles which have been covered in this report.

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EDBS-II/RDSO

INDEX

GUIDELINES FOR INTEGRITY TESTING OF PILES

1.0 INTRODUCTION

1.1 The existing old bridges which are required to be tested for pile integrity have generally cast iron piles i.e cast iron pipes filled with lime mortar/concrete as foundation and pier/abutment also. These are normally some of the oldest bridges. There are some bridges with steel piles i.e. of steel pipes filled with concrete. The new bridges generally have RCC pile foundation with or without mild steel casing.

1.2 For the new bridges having cast in situ RCC piles, only load test is being carried out as per codal provisions. There is no system to check the soil intrusions or loss of section etc. of these piles.

1.3 Thus, there is a need to have systems to check the integrity of piles which are existing as well as those which have been newly constructed. For this work, the following methods are available which may be required to be used alone or in combination with others:

1.3.1 Low Strain Integrity Testing – In this method, the integrity of piles is assessed by use of a low stress wave imparted to the pile shaft and is also known as the Sonic Integrity or Sonic Echo Test. This is carried out on new piles before casting of the pile cap. This method is covered under IS 14893: 2001.

1.3.2 High Strain Integrity Testing – In cases where the piles are too long or skin friction is high, low strain method does not provide sufficient information particularly the toe reflection. In such cases High Strain method can be used by giving higher impact energies and additional measurements of the pile top acceleration and strain observed. However, this method is basically used to monitor the performance of piles during driving and to estimate the bearing capacity.

1.3.3 Other methods which have been used to varying degrees of success for pile integrity testing are –

a) Frequency Response Method – Here the pile head is vibrated at high frequencies and responses analysed by computer aided technologies.

b) Sonic Coring – This method is based on measuring of signal between the sonic emitter and receiver placed in adjacent tubes in the pile in advance.

c) Seismic resistivity – This method requires an adjacent bore hole.

1.4 Though, there is no established/available method to check the integrity of the Cast Iron/Steel piles filled with lime concrete/concrete (as existing), Ultrasonic thickness meters can be used to check the thickness of the steel and have an idea of the corrosion and the section left. Presently, this is the only equipment which can be used for inspection of such piles.

1.5 Low Strain Integrity Testing, Ultrasonic Pulse Velocity Testing for concrete and the Thickness Meters are most commonly used and these have been elaborated upon further in this document.

2.0 SONIC ECHO TEST - LOW STRAIN INTEGRITY TESTING (IS 14893:2001)

2.1 Sonic echo testing has been used successfully for quite sometime now for checking the integrity of piles after installation.

2.2 It has been established that cast in situ piles in majority of the cases fail because of defective pile shaft necking, discontinuity of concrete, intrusion of foreign matter and improper toe formation due to contamination of concrete at base with soil particles, washing of concrete due to high water current, adoption of improper construction method, poor quality control on concreting etc. Cracks developed while handling of precast piles can also be a cause of failure. If pile integrity can be assessed before completion of pile caps, then this will go a long way towards certification of pile integrity.

2.3 Integrity testing is relatively quick and simple and enables number of piles to be examined in a single working day. The method does not identify all imperfections in a pile, but provides information about continuity, defects such as cracks, necking, soil incursions, changes in cross section and approximate pile lengths (unless the pile is very long or the skin friction is too high).

2.4 Integrity testing result for a particular area may not be necessarily valid for another area. Detailed results in a particular area for a number of sites have to be collected and evaluated before interpretation of tests result of a new site in that area. Integrity tests provide an indication of soundness of concrete but they should be undertaken by persons experienced in the method and capable of interpreting the results with specific regard to piling.

2.5 In this test, a small metal/hard rubber hammer is used to produce a light tap on the top of the pile. The shock traveling down the length of the pile is reflected back from the toe of the pile and recorded through a suitable transducer/accelerometer (also held on the top of the pile close to the point of impact) in a computer disk for subsequent analysis.

2.6 The primary shock wave which travels down the length of the shaft is reflected from the toe by change in density between the concrete and the sub strata. However, if the pile has any imperfections or discontinuities within its length these will set up secondary reflections which will be added to the return signal.

2.7 By a careful analysis of the captured signal and a knowledge of the conditions of the ground, age of the concrete etc. a picture of the location of such problems can be built up.

2.8 Normally more than one recording of signals is done until repeatability of signals is achieved.

2.9 In case of large diameter piles, the tests are conducted at 5-6 places to cover the entire section of the pile.

2.10 **General Requirements of the tests –**

a) Pile shall be trimmed to cut off level or sound concrete level before the test with all laitance removed.

b) The area surrounding the pile should be free from standing water and should be kept dewatered during the tests.

c) The cast in situ piles should not normally be tested before 14 days of casting.

d) The test piles, if available at site can be used for determination of pulse velocity and characteristic or reference signal generated. This can also be done from those piles whose depth is accurately recorded.

2.11 The following are the complimentary tests to the low strain integrity test method. These can be used to check the soundness of concrete at test level and to assess the stress wave velocity of pile concrete depending on concrete density and it’s in situ condition.

a) Ultrasonic Pulse Velocity Test – This test is carried out at the head of the pile in order to arrive at the speed of sound propagation through the cast concrete of the pipe.

b) Penetration Test – The test is used to assess the strength of the concrete at the pile head to ensure that the pile is sufficiently cured and ready for NDT.

c) Density Testing of Cast Cubes – In order to determine the density of concrete used each cube should be measured for density by weighing in air and water.

2.12 Limitations

a) The present experience of NDT of piles is upto diameter of 1500 mm.

b) This is applicable to cast in situ concrete bored and driven piles. The test cannot be conducted after provision/casting of pile cap.

c) This method is not suitable for piles surrounded by water as it may not give correct results.

d) It does not provide information regarding verticality or displacement (in position) of the piles.

e) Local loss of cover, small intrusions or type of conditions at the base of piles are undetectable.

3.0 ULTRASONIC PULSE VELOCITY TEST FOR CONCRETE

3.1 When the ultrasonic pulse generated by an electro acoustical transducer is induced into the concrete, it undergoes multiple reflections at the boundaries of different material phases within the concrete. A complex system of stress waves is developed which includes longitudinal (compressional), transverse (shear) and surface (Rayleigh) waves. The recording transducer deflects the onset of longitudinal waves which are the fastest.

3.2 For concrete testing, to prevent attenuation of the pulses when they pass through the heterogeneous materials the sound frequency used is lower, ranging from 20 kHz to 150 kHz. The suitable frequency for concrete is considered as 50 kHz

3.3 As per IS 13311 (Part1) 1992, which covers the Ultrasonic Pulse Velocity method of test for Non Destructive Testing of Concrete - the transducers may be piezoelectric or magneto-strictive type and the natural frequency for different path lengths is as shown below

Path Length (mm)	**Natural Frequency of Transducer (kHz)**	**Minimum Transverse Dimension of Members (mm)**
Upto 500	**150**	**25**
500 – 700	**≥ 60**	**70**
700 – 1500	**≥ 40**	**150**
Above 1500	**≥ 20**	**300**

3.4 There are three basic ways in which the transducers may be arranged as shown in Figure 1, Annexure –I. They are:

a) Opposite face (direct transmission or cross probing)

b) Adjacent faces (semi direct transmission)

c) Same face (indirect transmission or surface probing)

3.5 The first among the above is regarded as most accurate, the second being reliable to a lesser degree as there is uncertainty regarding the path length. Here length should be measured from the centre to centre of the transducers faces. The last method has much less reliability than the other two.

3.6 However, surface probe is useful:

a) When only one face of the concrete is available.

b) When inclination of the crack is to be determined.

c) When the depth of surface crack is to be determined.

d) When the quality of surface concrete relative to the overall quality is of interest.

3.7 It is desirable to measure the transit time and path length to an accuracy of 1%. It is also desirable to take sufficient number of readings by making a grid of 30 cm x 30 cm or even smaller so that the inherent variability of the test results are taken care of.

3.8 The quality in terms of uniformity, incidence or absence of internal flaws, cracks and segregation etc. indicative of the level of workmanship involved can be assessed using the guidelines given in IS 13311 (part 1): 1992 as given in the table below:

S.No.	Pulse Velocity By Cross Probing (km/s)	Concrete Quality Grading
1.	Above 4.5	Excellent
2.	3.5 to 4.5	Good
3.	3.0 to 3.5	Medium
4.	Below 3.0	Doubtful

3.9 Some factors that influence pulse velocity measurement are as follows:

a) **Surface Conditions –** The finish should be smooth so that good acoustical contact can be ensured by use of a coupling medium such as grease, petroleum jelly etc. and by pressing the transducers against the concrete surface.

b) **Moisture content –** Moisture content has a small effect and the pulse velocity in a concrete in saturated condition may be upto 2% higher. The moisture content has less influence in high strength concrete than it does on low strength concrete.

c) **Temperature of Concrete –** Variation of the concrete temp between 5^0C to 30^0C has been found to cause no significant change in the pulse velocity. Beyond this range, the pulse velocity may change, for example, from 30^0C to 60^0C there may be reduction of about 5% in the velocity and if the water within the concrete freezes, the pulse velocity may increase by upto 7.5%.

d) **Path Length –** The path length should be long enough not to be significantly influenced by the heterogeneous nature of concrete. Minimum path of 100 mm is required for concrete having aggregate size less than 20 mm and that of 150 mm is required for concrete having aggregate size of 20 – 40 mm.

e) **Minimum size of Specimen –** The velocity of short pulses of vibration is independent of the size and shape of the specimen in which they travel unless its least lateral dimension is less than a certain minimum value.

f) **Homogeneity of concrete –** For evaluating the homogeneity of concrete in structures, a system of measuring points in the form of a grid is chosen to cover the various parts of the structure. It is possible to express homogeneity in the form of a statistical parameter such a standard deviation of the pulse velocity measurements.

g) **Stress Level –** When the stress level is about 60% greater than the ultimate strength of the concrete, the pulse velocity will be reduced due to development of microcracks.

3.10 The **UPV techniques** are applied in concrete for

3.10.1 Determination of Modulus of Elasticity –

The velocity of a pulse of longitudinal ultrasonic vibrations travelling in an elastic solid is given by

$$V = \sqrt{(E_d K / \rho)}$$

where V is the compression wave velocity in km/s and given by :

V = Pulse Velocity = (Path Length / Transit Time)

And E_d is the dynamic elastic modulus

ρ is the density in kg/m3

υ is the dynamic Poisson's Ratio and

$K = (1-\upsilon)/\{(1+\upsilon)(1-2\upsilon)\}$

Here K is relatively insensitive to the variation in Dynamic Poisson's ratio υ. Hence if a reasonable estimate of this value and the density can be made, it is possible to compute Ed using a measured value of wave velocity V. The value of υ varies from 0.20 to 0.35 with 0.24 as average.

3.10.2 Estimation of strength by using correlation graphs obtained from laboratory testing – Estimation of strength is possible only with the help of standard correlation graphs obtained from laboratory tests. This has to be established for the particular concrete under consideration. The assessment of compressive strength of concrete from UPV method only is not adequate as a number of factors affect the assessment. However, if concrete materials and mix proportions are available, the estimation using suitable correlation graphs can give strength in the range of ±20% from the actual value.

3.10.3 Detection of defects – When an ultrasonic pulse traveling through concrete meets a concrete-air interface, there is negligible transmission of energy across this interface. This will increase the transit time and result in reduction of velocity. Thus voids shaving greater area than the transducers can be easily detected.

3.10.4 Type and depth of surface cracks can be detected by surface probing method.

4.0 ULTRASONIC BASED THICKNESS METERS FOR METALS

4.1 When a pulsed ultrasonic signal, from a piezo electric transducer, is applied, it will propagate through the material and can be received by a second transducer on the other side or the same surface. The accurate measurement of the transit time of the signal can be effectively used to evaluate parameters of the material and to detect flaws in the test pieces.

4.2 In metals a frequency range of 1 MHz to 30 MHz is used. The velocity of pulse in steel is about 5.9m/s. This velocity, in Cast Iron, however varies from 3.8 m/s to 5.5 m/s depending upon the graphite specs present in Cast Iron.

4.3 The efficient transfer of mechanical energy form the transducer face to the test piece is important. For this reason couplants are used between the transducer face and the test sample, to eliminate any air gap and reduce the acoustic impedance mismatch. Vaseline and Grease make excellent transducer couplants. There are specially designed solid rubber couplants available for use in situations where these cannot be used.

4.4 Based on this principle, Ultrasonic thickness meters are available in the market. Some of these meters can measure the thickness of steel through coatings of upto 6 mm (i.e. without removing these coatings). Models which can also be used underwater are available. There are models with topside repeater also for inspection in turbid waters. However, in these meters, the marine growth has to be removed before use.

4.5 For checking of Cast Iron/Steel piles filled with concrete, there is no established method. However, Ultrasonic thickness meters can be used to check the thickness of steel and estimate the corrosion as also the section left. Presently this is the only way of inspection of these piles.

4.6 Use of thickness meters for Cast Iron.

The applicability of use of the Ultrasonic thickness meters on Cast Iron has not yet been confirmed. This is because of two reasons:

a) Presence of random graphite specks in Cast Iron which reflect these waves and lead to erroneous data.

b) The velocity of the pulse changes with the change in the concentration of these graphite specs.

The information analysis at present indicates that these may not be useful for Cast Iron thickness detection.

5.0 CROSS HOLE ULTRASONIC METHOD

5.1 This test method is useful for checking the homogeneity and integrity of concrete in pile foundations. This method involves ultrasonic sound pulse.

5.2 This test measures the transit time and relative energy of the ultrasonic pulse propagated through a transmitter probe and received through a receiver probe in two parallel vertical water-filled access tubes, installed into the piles during construction or through drilled boreholes. This method is most applicable when access tubes are installed during construction.

5.3 In good quality concrete the ultrasonic pulse speed (P-waves) would typically range between 3600 to 4400 m/s. Poor quality concrete containing defects (for example, inclusion of soil, gravel, water, drilling mud, bentonite slurry, voids, contaminated concrete, or excessive segregation of the constituent particles) has a comparatively lower ultrasonic wave speed. By measuring the transit time of an ultrasonic pulse between a transmitter probe and receiver probe in two parallel vertical tubes at a known distance apart anomalies in concrete may be detected (see Fig. 4).

5.4 If defects are detected, then further investigations should be done by excavation or taking the sample of the concrete through core cutter or any other means as deems appropriate.

5.5 General Requirements

5.5.1 The access tubes shall preferably be of steel (PVC pipes may also be used) for cross hole testing so that it does not deform during concrete placement and also to prevent debonding of the access tube from the concrete resulting in an anomaly.

5.5.2 The internal diameter of the access tubes shall be sufficient to allow the easy passage of the ultrasonic probes over the entire access tube length. Preferable range of internal diameter should be from 38 to 50mm.

5.5.3 The total number of installed vertical access tubes in the pile foundation should be chosen consistent with good coverage of the cross-section. In general for cylindrical pile foundations, the number of access tubes is often selected as one access tube for every 0.25 to 0.30 m of pile foundation diameter, with a minimum of three and a maximum of eight access tube, spaced equally around the circumference.

5.5.4 The access tube shall be straight and free from internal obstructions. The exterior tube surface shall be free from contamination. The access tube shall be close-ended at the bottom and fitted with removable end caps at the top to prevent entry of concrete or foreign objects, which could block the tubes prior to testing operations.

5.5.5 The access tube shall be installed such that their bottom is as close as possible to the bottom of the concrete deep foundation element so that the bottom condition can be tested.

5.5.6 The access tubes shall have a minimum concrete cover of one tube diameter. Access tubes shall be secured to the inside of the main axial reinforcement of the steel cage at frequent and regular intervals along their length to maintain the tube alignment during cage lifting, lowering and subsequent concreting of the pile foundation. During tube installation, care should be taken to ensure that all access tubes are as parallel to each other as possible. After installation of the reinforcement cage into the deep foundation element, the top end caps shall be temporarily removed and the tubes shall be inspected to verify they are clear of obstructions. Access ducts shall preferably be filled with water prior to, or within one hour of, concrete placement to assure good bonding of the concrete to the tube after the concrete cools.

5.5.7 The tests shall be performed no sooner than 3 to 7 days after casting depending on concrete strength and pile diameter (larger diameter pile may take closer to 7 days).

5.5.8 Cross Hole Ultrasonic Method (CHUM), tests shall be performed on 25% of overall no. of piles. 25% of piles shall be selected from each pile group. Access tubes shall be installed in 100% of the piles and concerned engineer in charge (Deputy Chief Engineer and equivalent) of the project will randomly select and conduct tests on 25% of overall piles.

5.5.9 After completion of tests, all the access tubes shall be grouted up with suitable material.

5.6 Procedure

5.6.1 Carefully lower the probes down to the bottom of the access tubes, always keeping them at approximately the same level, until one probe reaches the bottom of the access tube or encounters an obstruction (for example, because one access tube is shorter, bent or blocked). Set the depth location to the bottom of the access tubes. Raise the probes from the bottom of the access tubes to a portion of the pile foundation with good quality concrete. If required by the test system manufacturer, to ensure that the distance between probes is minimized, the relative level of the probes should be adjusted until the first arrival of the signal is minimized. Temporarily secure the cables at that level with the cables remaining in equal tension.

5.6.2 Begin recording the ultrasonic pulses as the probes are raised. Lift both probes by steadily pulling the probe cables simultaneously at a speed of ascent slow enough to capture one ultrasonic pulse for each depth interval specified. If an ultrasonic pulse is not obtained for any depth interval, then the probes shall be lowered past that depth and the test repeated until all depth intervals have an associated ultrasonic pulse.

5.6.3 The probe depth and receiver probe's output (timed relative to the transmitter probe's ultrasonic pulse generation) are recorded for each pulse. The rate of pulse generation shall be at least one ultrasonic pulse for every required depth interval, typically 50 mm or less. The receiver's output signals are sampled and saved as voltage versus time (see Fig. 2) for each sampled depth. These signals can be then nested to produce a “waterfall” diagram (see right side of Fig. 3).

5.6.4 The data are further processed and presented to show the First Arrival Time (FAT) of the ultrasonic pulse and its Relative Energy (RE) to aid interpretation. The processed data are plotted versus depth as a graphical representation of the ultrasonic profile of the tested structure (see Fig.3 left). Special test methods to further investigate anomalies are employed where the probes are not raised together.

5.7 Limitations

5.7.1 Proper installation of the access tubes is essential for effective testing and interpretation. The method does not give the exact type of flaw but rather only that some flaw exists in the concrete.

5.7.2 This test can access to the integrity of the concrete mainly in the area bounded by the access tubes, which means typically inside the reinforcement cage.

6.0 AVAILABILITY OF ULTRASONIC TESTING EQUIPMENT IN THE MARKET

There are a number of suppliers of Ultrasonic pulse Velocity Testing equipment in the market. Some of the manufacturers are being listed here. This list should not be taken as an exhaustive list but only an indicative one and should not be used for the purpose of invitation of bids or other commercial activity.

6.1 Two firms who manufacture Ultrasonic thickness meters are:

a) M/s Electronics & Engg. Co.

EEC House, Plot –7, Off Link Road

Near Laxmi Industrial Estate

Andheri West ; Mumbai – 400053

Fax – 022 – 6369009

b) M/s Modsonic Instruments Mfg. Co. Pvt. Ltd.

Plot No. 33, Ph III

GIDC Indl Estate

Naroda, Ahmedabad – 382330

Fax – 079 – 2820012

6.2 A wider range of thickness of Ultrasonic Thickness and Coating meters including those which can be used under water with an option for surface repeater are manufactured by

Cygnus House

30, Prince Of Wales Road, Dorchester

Dorset, DT1 1PW, England

Tel - +44(0) 1305 265533

Fax - +44(0) 1305 269960

6.3 The equipment for low strain integrity testing is supplied in India by AIMIL Ltd, Naimex House, A-8, Mohan Cooperative Industrial Estate, Mathura Road, New Delhi.

6.4 This list is not exhaustive and there may be many more national / international suppliers of these equipment.

7.0 CONCLUSION

7.1 For integrity testing of new concrete piles, Low Strain Integrity Testing as per IS 14893: 2001 is a good method. It can also be used in combination with other tests if required as per site conditions. However, this test is only applicable to new construction and cannot be used underwater.

7.2 For existing piles, the steel pipe on the exterior can be checked by ultrasonic based thickness meters. Thickness meters which can be used under water are also available in the market. Coating meters which can be used to check the thickness of anti-corrosive coating on the steel pipes are also available.

7.3 For Cast Iron Piles, expert opinion is that because of the random structure of graphite specs, the Ultrasonic based thickness meters will not provide reliable data.

7.4 Ultrasonic Pulse velocity testing can be carried out for checking of concrete quality but the use of this test for checking the concrete of pile foundation of existing bridges may not be possible.

7.5 Cross Hole Ultrasonic Method is relatively quick and easy method, which can be performed above and below the waterline structures. Location and severity of defect may be identified easily through this method.

7.6 Integrity test of the pile should be done on 100% of the piles.

7.7 25% of overall number of piles should be tested by CHUM method with provision of access tubes in 100% of piles.

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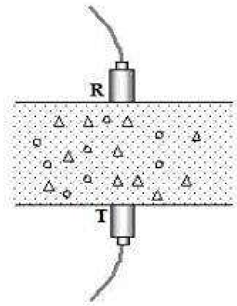
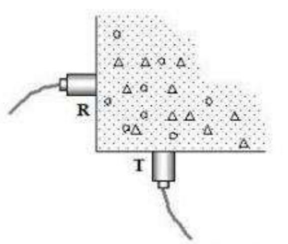
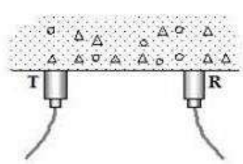
ANNEXURE-I



DIRECT METHOD



SEMI DIRECT METHOD



INDIRECT METHOD

Fig 1

DIFFERENT METHODS OF UPV MEASUREMENTS

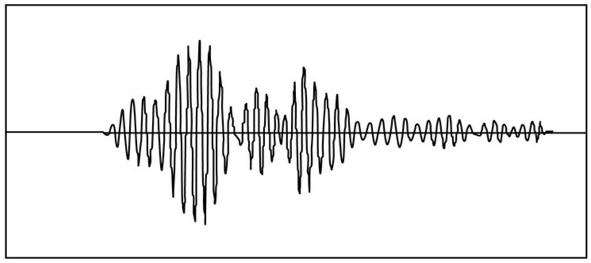


Fig. 2 Ultrasonic Pulse from Receiver

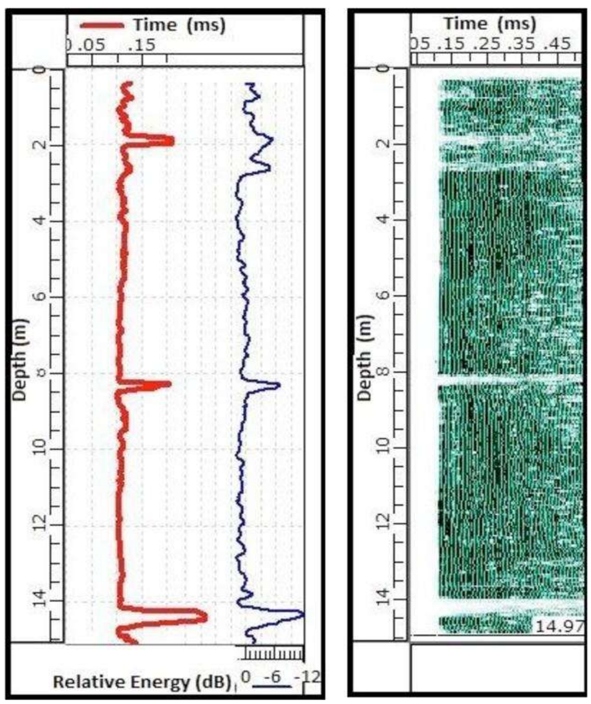


Fig. 3 Typical Ultrasonic Profile

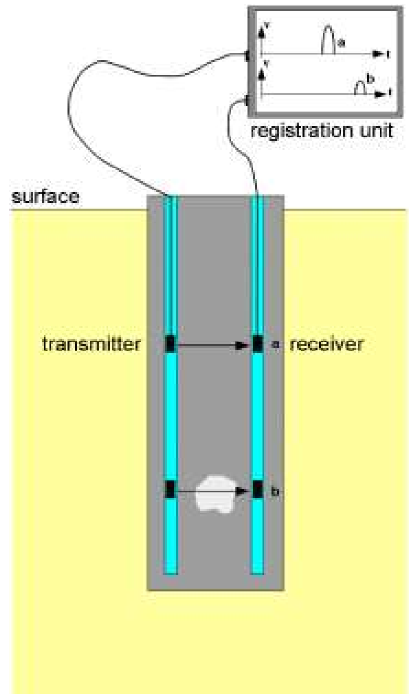


Fig. 4 Cross Hole Ultrasonic Test Arrangement

These guidelines are based on the studies conducted by Bridges & Structures Directorate of RDSO. The views expressed in these guidelines are subjected to modification from time to time in the light of more information. Further, they do not necessarily represent the views of the Ministry of Railways (Railway Board), Government of India.