SONIC WAVE VELOCITY MEASUREMENT FOR EVALUATION OF IN-SITU QUALITY OF DAM

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ABSTRACT

Non-destructive testing using sonic wave transmission method to evaluate the in-situ quality of the materials of structures, is used very widely due to its simplicity, safety and great practical utility in quickly detecting the weak portions in a structure, if available any. It is based on the principle that the propagation velocity of elastic waves through a material is independent of the geometry of the material and depends only on its modulus of elasticity and density. Thus, evaluation of seismic wave velocity is a very convenient technique for investigating the quality of concrete/ masonry/earthen in structures.

In Non-destructive testing by sonic wave transmission technique of the dams, low frequency sonic waves are generated by mild impact of a 5 kg hammer on the upstream face of the dam. A twenty four channel signal enhancement seismograph and a twelve channel signal enhancement seismograph with vertical geophones, are used for picking-up the seismic (elastic) waves simultaneously at different locations on the downstream face of the dam. In all, different hammer points are used to generate elastic waves through the masonry and earthen dams. The present technical paper describes the methodology of the sonic wave transmission technique conducted and the results obtained in detail for Vihar, Tulsi and Powai dams of M.C.G.M., Maharashtra.

***Key Words** : Sonic wave velocity, elastic wave velocity, velocity criteria*

1. INTRODUCTION

Non destructive testing (NDT) methods such as Ultrasonic Pulse Velocity (UPV) transmission technique, Sonic wave transmission technique, Impact Echo test method, Resonance frequency testing method etc., have been used for detection of anomalies and assessing in-situ condition of the dams or any other civil structure. Due to ageing or after natural disasters such as earthquake of high magnitude near the area of the dams etc. may results distresses in the structures, thus it becomes necessary to assess the safety status of the structure. For assessing the in-situ quality of the structure, NDT methods are used prior to finalizing remedial measures for repair/rehabilitation of the structure. Due to ease in conducting Non destructive testing, these methods are widely used for investigating in-situ quality of civil structures such as dams, aqueducts, turbo generation foundations, bridges, barrages, Jetties, dock yards, historical monuments, etc. NDT technique is a powerful tool for health monitoring of civil structures as it does not harm and damage the structure. It gives the qualitative information of body material such as homogeneities, cracks, types of ingredients etc. Sonic wave transmission technique is also commonly used in geological survey for detecting layers, sub layers, types of rock strata etc.

2. METHODOLOGYOFNON-DESTRUCTIVETESTINGBYSONICPULSETRANSMISSION TECHNIQUE

The non-destructive technique for testing the quality of materials, is based on principle that the propagation velocity of elastic (mechanical) waves through a specimen of the material is related to the elastic constants and the density of the medium. At the same time it is independent of the shape and size of the material. Therefore, the propagation velocity of elastic waves gives an indication of the quality and homogeneity of the material in the direction of wave transmission. Higher wave velocities correspond to better quality of the material (IS 13311-1992, Agarwal, S.P et.al., 1972, Wedpathak, A.V., 1980) and the distribution of wave velocities along different paths of wave transmission through a structure provides a safe method to quickly get an idea about the quality of its material. In principle such findings will also be applicable for masonry structures.

Depending upon the size of in-homogeneities present in different materials, elastic waves over a very wide range of frequencies are used for non-destructive testing. Ultrasonic waves are defined as the waves with frequencies more than 20 KHz, above the audible range where as waves with frequencies between 20 Hz and 20 KHz are audible to human ear and are termed as “sonic” waves. In a highly heterogeneous material like masonry, the ultrasonic waves with high frequency (small wave length) cannot penetrate a thickness of more than about 2 m to 5 m. Therefore, for non-destructive testing of masonry structures with large depth commonly sonic waves are used.

The sonic waves in the frequency range of about 500-1000 Hz can be generated by mild impact of a hammer on the surface of the structure to be tested. When the elastic waves induced into structural masonry, it undergoes multiple reflections at the boundary of the different material within the structure (Lindonor Mota, 1954, Milton B. Dobrin 1952 and Bruce B. Redpath, 1973). As a result, a complex system of elastic waves developed which includes longitudinal (compressional, P-wave), transverse (shear wave) and surface waves. Among the various types of elastic waves, P-wave travels faster than the others. By detecting the arrival of P-waves and measuring the travel times along different paths through the material, the wave velocities along the travel paths are estimated.

3. INSTRUMENTATION FOR SONIC PULSE TRANSMISSION METHOD

The arrival time of seismic waves generated at the upstream face were detected at the downstream face of the dam at different locations by deploying a 1) 24-channel signal enhancement seismograph and 2) 12-channel signal enhancement seismograph. The equipment has very high resolution and can automatically store the recorded signals in the digital form and the equipment. It has the facility to take onsite print of the record and the same can be analyzed later. The time of arrival of compressional waves on each geophone with very high precision, can also be read directly on display screen of the equipment. Figs.1 and 2 show a photographs of 24-channel and 12-channel signal enhancement seismographs with accessories and typical records obtained during field study respectively.

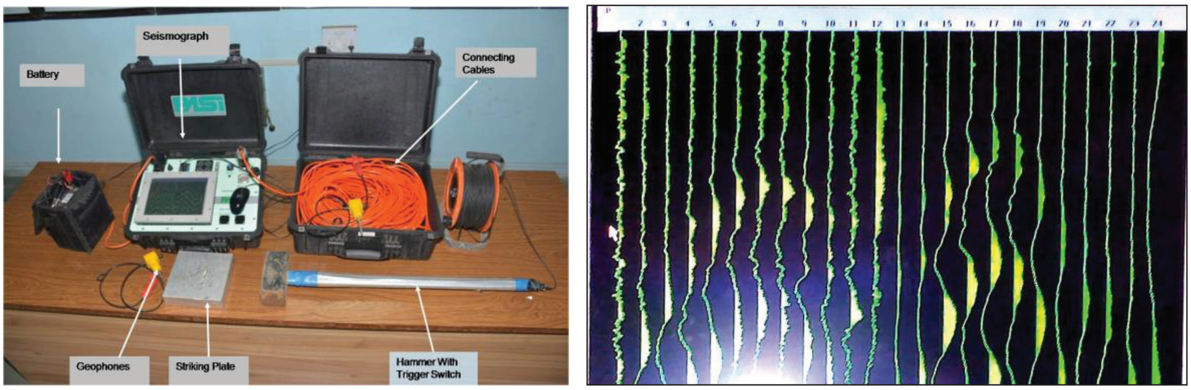

Figure 1 : 24-channel signal enhancement seismograph with accessories and a typical record showing the onset of P-waves at 24 locations

Figure 2 : 12-channel signal enhancement seismograph with accessories and a typical record showing the onset of P-waves at 12 locations

A 5 kg hammer is used for generation of seismic waves and vertical geophones with natural frequency of 8 Hz were used for detecting the arrival of the seismic waves. A starter switch attached to the hammer triggers the instrument and recording of waveforms from all the geophones starts as soon as the hammer strikes the dam surface.

4. GEOPHONE ARRANGEMENTS

Different geophone patterns viz. single line, two lines, square, etc. are fixed according to site conditions and measurement of interest.

Pattern - A (5 points x 5 lines) : To cover selected portion, 24 geophones are fixed in a square type pattern on downstream side as shown in Fig. 3. First line taken at 1m from top of the dam and five points are marked horizontally at an interval of 3 m. Similarly four lines are marked below first line at an interval of 3 m and five points are marked horizontally at an interval of 3 m on each line. In this manner, 5 points in 5 horizontal lines are marked and named as Pattern - A. The Locations of geophones are marked as 1 to 24 (Fig. 3). Pattern - A is used for testing of earthen dams.

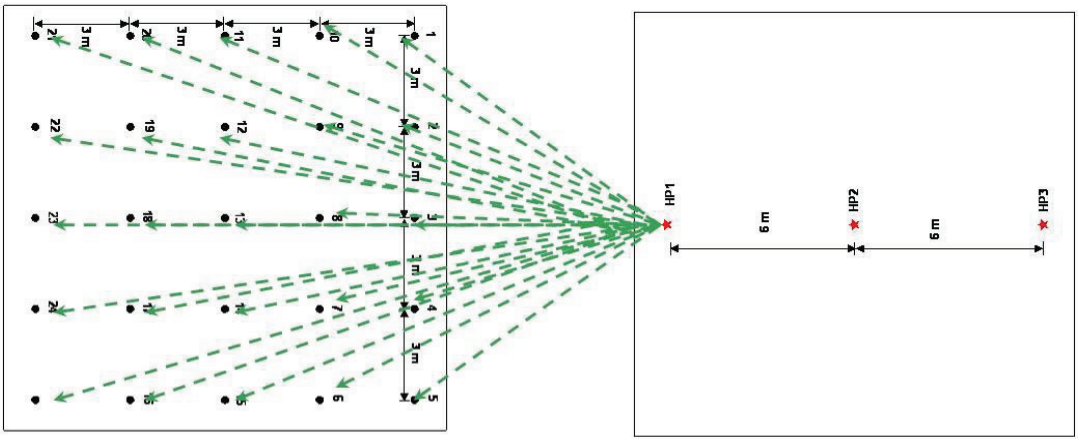

Figure 3 : Marking of geophones and location of Hammer points in Pattern - A for Earthen Dams

Three hammer points for generating seismic waves are marked in vertical line of 6 m spacing on the upstream face of the dam; Hammer Point 1 (HP1) opposite to geophone location 3, HP2 opposite to geophone location 13 and HP3 opposite to geophone location 23. Fig. 3 shows the location of three hammer points HP1, HP2 and HP3 located on the upstream face.

Pattern - B (12 points x 2 lines) : To cover selected portion 24 geophones are fixed in a linear type pattern on downstream side as shown in Fig. 4. First line twelve points are marked horizontally at an interval of 3 m. In second line (3 m below first line), twelve points are marked horizontally at an interval of 3 m. I this way, 12 points in 2 horizontal lines are marked and named as Pattern - B. The Locations of geophones have been marked as 1 to 24 (Fig. 4). Pattern - B is used for testing of masonry dams.

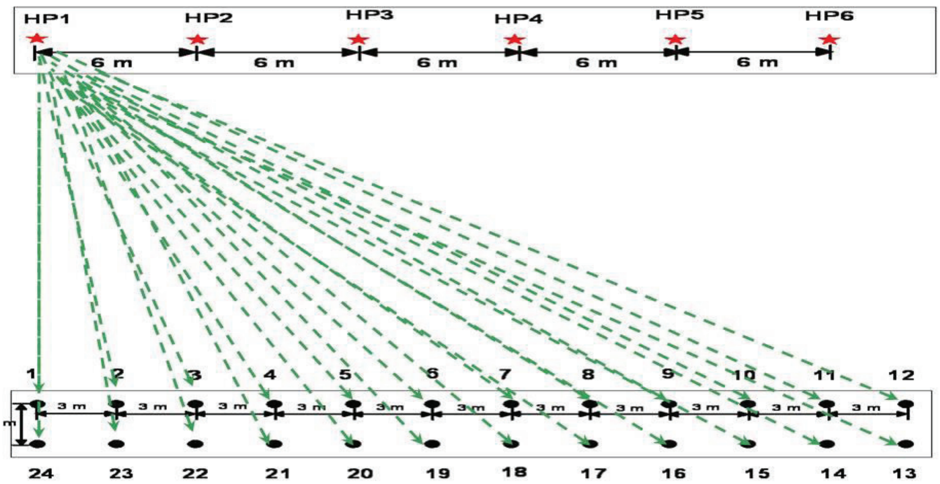

Figure 4 : Marking of geophones and location of Hammer points in Pattern – B for Masonry Dams

Six hammer points of 6 m spacing for generating seismic waves are marked in horizontal line on the upstream face of the dam; Hammer Point 1 (HP1) - opposite to geophone location 1, HP2 - opposite to geophone location 3, like that HP3 to HP6, opposite to geophone location 3, 5, 7 and 11. Fig. 4 shows the photograph of six hammer points HP1 to HP6 located on the upstream face.

5. SAFETY CRITERIA

5.1 Velocity criteria for safety of masonry dam

Though there is no single criterion which can be adopted to predict the compressive strength of in-situ masonry from the experimentally obtained velocities. Quality for a given design compressive strength could be arrived, based on experience gained over past few decades from similar non-destructive studies conducted elsewhere in the country for a large number of structures having a wide range of different design compressive strength. The results of compressional wave velocities in the various structural members under study are considered to arrive at reasonable conclusions regarding the quality of in-situ masonry/ earthen portions of dams.

The following velocity criteria is adopted to categorize the masonry structure of the dam. It may be noted that these velocity criteria are based on the fact that there is no unduly large absorption of wave energy along the travel-path of waves.

Table 1 : Velocity criteria adopted for masonry dams

Criteria	Velocity (km/s)	Quality of Masonry dams
1.	≥ 3	Very Good
2.	2 to 3	Good
3.	< 2	Poor

5.2 Velocity criteria for safety of earthen dam

Similarly, in this case also there is no single criterion available which can be adopted to predict the compressive strength of in-situ earthen portion from the experimentally obtained compression wave velocities passing through earthen portion. The values of compression wave velocity passing through earthen portion are found to be in the range of 0.2 to 2.0 km/s as per various available literature and Malhotra and Carnio (2004). The compression wave velocity passing through earthen portion in the range of 0.2 to 2.0 km/s is considered as good to very good quality and less than 0.2 km/s is considered as questionable to poor quality.

In the present paper, NDT by sonic pulse transmission technique has been used for detection of any anomalies such as cracks, voids, deterioration etc. if present in the dam body and present status of the masonry and earthen dams which are oldest dams constructed about 100 – 150 years back for the water supply of Mumbai city, Maharashtra. Moreover, methodology of the sonic wave transmission technique conducted and the results obtained in detail for Vihar, Tulsi and Powai dams of M.C.G.M., Maharashtra have been discussed in brief as example studies.

6. EXAMPLE 1 : NON-DESTRUCTIVE TESTING OF TULSI DAM (MASONRY AND EARTHEN)

Tulsi Dam is the one of the oldest Earthen & Masonry Dam in Maharashtra, India, commissioned in 1879 and is located at Latitude of 19o 10' N – 19o 15'N and Longitude of 72o 50'E – 73o E. It's catchment area is about 6.76 sq.km. with total length of 841 m, top width of a) 0.91m for earthen, b) 6.09 m for masonry and maximum height of a) 25.90 mfor earthen, b) 10.66 m for masonry. Tulsi dam is used for the water supply of Mumbai city. Due to ageing, distresses have been observed in the dam body in the form of seepage and leaching of material from masonry portion necessitating repair and rehabilitation measures. Before finalizing repair and rehabilitation measures non-destructive testing for the masonry portion of the dam has been carried out to ascertain the in-situ quality of the dam body masonry.

For conducting non destructive testing of masonry portion, two profiles have been made as per Pattern B shown in Fig.4. Selected locations of Tulsi dam have been marked at about 31.5 m and 51.5 m bottom and top of downstream side respectively. Fig. 5 shows its upstream and downstream side of the dam.

Figure 5 : Locations of Geophones at the downstream face and upstream face of the Tulsi dam No.1

The distribution of P-wave velocities of Tulsi dam is shown in Fig. 6. It has been observed that the velocities of elastic compressional waves in the masonry dam lie in the range of 3.32 km/s to 4.31 km/s and the average P-wave velocity was 3.95 km/s which indicates the in-situ quality of material in this masonry portion to be good to very good.

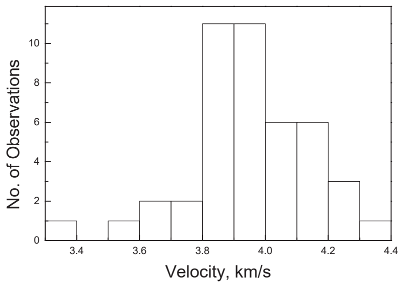

Figure 6 : P-wave velocities at Tulsi dam (Masonry)

For conducting non-destructive testing of earthen portion of the dam, two profiles have been made as per Pattern A and are shown in Fig.3. Selected locations of Tulsi dam have been marked at about 23 m from left side on downstream side from intake well bridge. Fig. 7 shows its upstream and downstream side.

Figure 7 : Locations of Geophones at the downstream face and upstream face of the Tulsi dam No.2

The distribution of P-wave velocities of Tulsi dam is shown in Fig. 8. It has been observed that the velocities of elastic compressional waves in the earthen dam lie in the range of 0.2 km/s to 0.36 km/s and the average P-wave velocity was 0.27 km/s which indicates in-situ quality of material in this earthen portion to be good to very good.

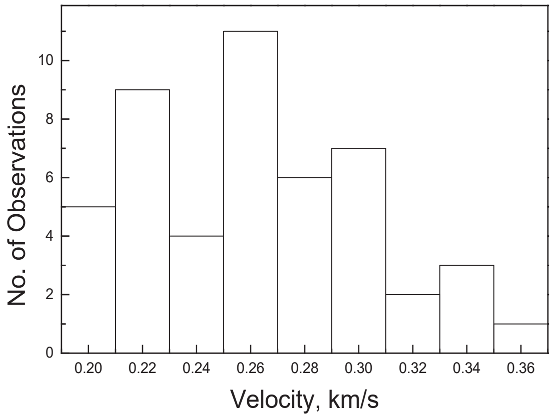

Figure 8 : P-wave velocities at earthen portion of Tulsi dam

7. EXAMPLE 2 : NON-DESTRUCTIVE TESTING OF MASONRY PORTION OF POWAI DAM

Powai Dam is the one of the oldest masonry Dam in Maharashtra, India, commissioned in 1890 located at Latitude of 19° 5' N – 19° 10' N and Longitude of 72° 50'E – 72° 55'E. It's catchment area is about 6.61 sq.km. with total length of 191.80 m, top width of 1.98 m and maximum height of 9.14 m. Powai dam is mainly used for irrigation and water supply of Mumbai city. Due to ageing, distresses have been observed in the dam body in the form of seepage and leaching of material from masonry portion necessitating repair and rehabilitation measures. Accordingly, Project Authority decided to carry out the NDT tests in order to assess the in-situ quality the dam masonry. Non-destructive testing for the masonry sections of the dam has been carried out by CWPRS, Pune to assess the in-situ quality of the dam masonry. For conducting studies, one profile has been made as per Pattern B shown in Fig.4. Selected locations of Powai dam Profile 1 (12 Geophones in 2 lines) have been marked at about 7 m from intake well at bottom of downstream side. Fig.9 shows its upstream & downstream side of the dam.

Figure 9 : Locations of Geophones at the downstream face and upstream face of the Powai dam

The distribution of P-wave velocities of Tulsi dam is shown in Fig. 10. It has been observed that the velocities of elastic compressional waves in the masonry dam lie in the range of 2 km/s to 3.4 km/s and the average P-wave velocity was 2.5 km/s which indicates the in-situ quality of material in this masonry portion to be good to very good.

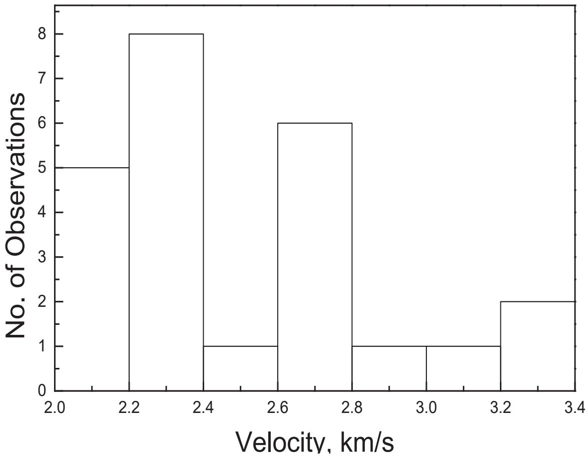

Figure 10 : Distribution of P-wave velocities at Powai dam

8. EXAMPLE 3 : NON-DESTRUCTIVE TESTING OF VIHAR DAM

Vihar Dam is the one of the oldest earthen Dam in Maharashtra, India commissioned in 1859 and located at Latitude of 19º 5'N – 19º 10'N and Longitude of 72º 50'E – 73º E. It's catchment area is about 18.96 sq.km. with total length of 711.20 m, top width of (a) 7.31 m, (b) 6.09 m, (c) 6.09 m and maximum height of (a) 25.60 m, (b)12.80 m, (c) 14.90 m. Fig.11 shows its upstream & downstream side of the dam.

Figure 11 : Locations of Geophones at the downstream face, upstream face of the Vihar dam (Central Portion)

Vihar dam is used for the water supply of Mumbai city. Since it is a very old dam therefore based on request from Project Authority non-destructive testing for the masonry portion of the dam has been carried out in order to ascertain the in-situ quality of the masonry. NDT have been carried out at three locations in Vihar dam viz. central portion, near Durgah and near Pumping station.

For conducting non destructive testing of main portion of the dam, four profiles have been made as per Pattern - A as shown in Fig. 3. Selected locations of Vihar dam have been marked on downstream side, at 85 m from left side of the dam, profile 2 marked to the right side of profile 1, profile 3 marked below profile 1 and profile 4 marked below profile 2. The distribution of P-wave velocities in Vihar dam (Main Dam) is shown in Fig. 12. It has been observed that the velocities of elastic compressional waves in the earthen portion of the dam is in the range of 0.64 km/s to 1.17 km/s and the average P-wave velocity has been observed to be 0.92 km/s which indicates the in-situ quality of material in the earthen portion to be good to very good.

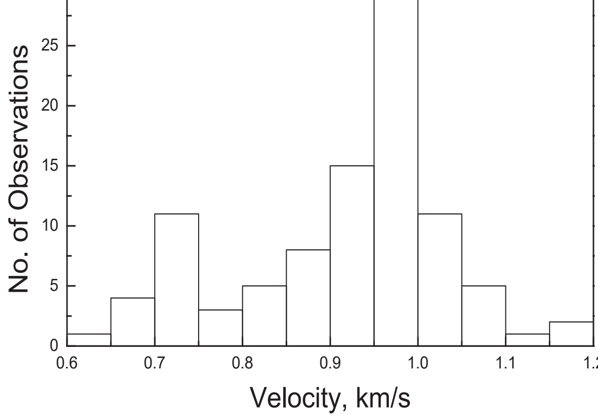

Figure 12 : P-wave velocities at Vihar dam Central Portion

For conducting non-destructive testing of earthen portion near to Durgah, two profiles have been made as per Pattern A shown in Fig.3 at selected locations of Vihar dam No. 2. Profile 1 and 2 (12 m x 12 m) have been marked about 78 m from left side on downstream side. Fig.13 shows its upstream & downstream side of the dam.

Figure 13 : Locations of Geophones at the downstream and upstream faces of the Vihar dam near Durgah

The distribution of P-wave velocities of Vihar dam is shown in Fig. 14. It has been observed that the velocities of elastic compressional waves in the earthen dam, lie in the range of 0.2 km/s to 0.29 km/s and the average P-wave velocity has been observed to be 0.24 km/s which indicates in-situ quality of material in earthen dam to be good to very good.

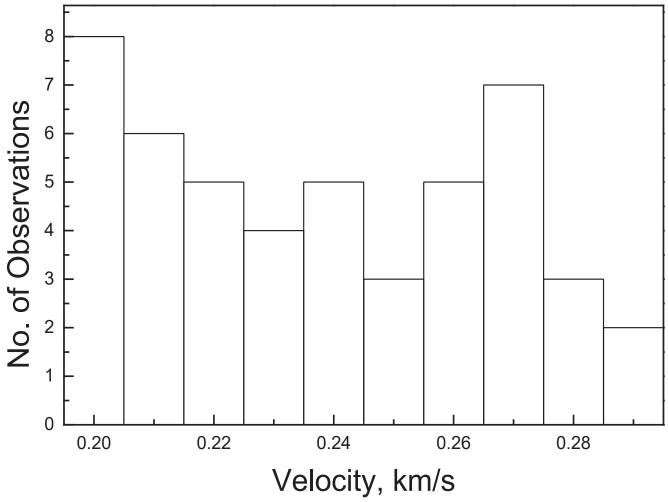

Figure 14 : P-wave velocities at Vihar dam near Durgah

For conducting non-destructive testing of earthen portion near to pumping station, two profiles have been made as per Pattern A as shown in Fig.3. Selected locations of Vihar dam profile 1 and 2 (12 m x 12 m) have been marked at about 66 m from board side located at left and right side of steps on downstream side respectively. Fig.15 shows its upstream & downstream side of the dam.

Figure 15 : Locations of Geophones at the downstream face, upstream face of the Vihar dam near Durgah

The distribution of P-wave velocities of Vihar dam is shown in fig. 16. It has been observed that the velocities of elastic compressional waves in the earthen dam near Durgah lie in the range of 0.23 km/s to 0.47 km/s and the average P-wave velocity has been observed to be 0.31 km/s which indicates in-situ quality of material in this earthen portion to be good to very good.

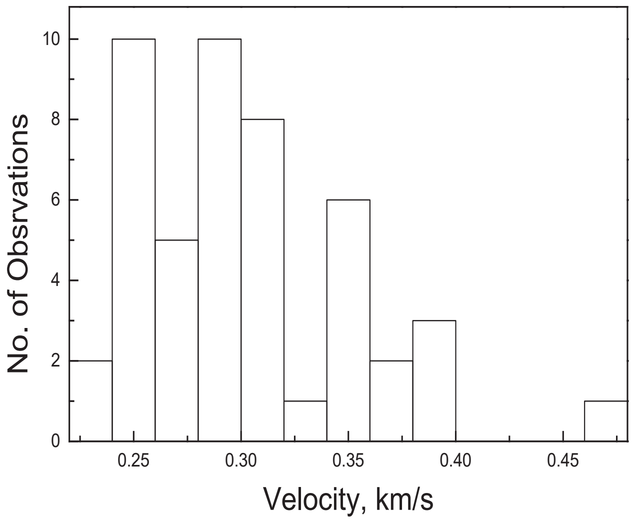

Figure 16 : P-wave velocities at Vihar dam near Durgah

9. CONCLUSIONS

From the Non destructive studies conducted on several projects, following conclusions are drawn:

- Non destructive testing by sonic wave transmission technique is very useful and cost effective method for assessing in-situ quality of the materials in several types of structures viz. dams, aqueducts, weir etc. towards assessment of structural safety.
- The technique has been successfully applied for assessing three dams viz.,Tulsi, Vihar and Powai dams, discussed in this paper which enabled Project Authority to take suitable remedial measures.

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REFERENCES

1. Agarwal, S.P., Krishna Nand, A.V. Wedpathak and S. K. Guha (1972), Non-destructive Testing of Concrete and Masonry Structures, Proceedings of 42nd Research Session of CBIP, Vol. 3, Madras, T.N., PP 1-12
2. IS 13311 (Part-I) 1992, Indian standard Non-destructive testing of concrete-Methods of test, Part-I Ultrasonic pulse velocity
3. Wedpathak, A.V., S. C. Marwadi, P. K. Bhandwalkar, P. D. Gosavi and S. K. Guha (1980), Application of Non-destructive Test Techniques for Assessment of In-situ Quality of Concrete in Large Concrete Structures, Proceedings of 48th Research Session of CBIP, Hyderabad, A.P., PP 111-124
4. V. M. Malhotra and N. J. Carino, Handbook on Non-destructive testing of concrete, CRC Press, London, Newyork, 2004.
5. Lindonor Mota (1954). "Determination of Dips and Depths of Geological Layers by the Seismic Refraction Method." Geophysics, 19(2), 242-254.
6. Milton B. Dobrin 1952, Introduction to Geophysical Prospecting.. New York-London: McGraw-Hill,.
7. Bruce B. Redpath May 1973, Seismic Refraction Exploration For Engineering Site Investigations, Explosive Excavation Research Laboratory Livermore, California