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DETECTION OF FLAWS IN CONCRETE STRUCTURES USING IMPACT ECHO METHOD

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ABSTRACT

Determining the flaws in concrete elements can be a difficult job. One way to determine the flaws by Non destructive Testing is impact echo method. Three types of flaws are discussed and detected in this paper, viz, debonding of steel and concrete; corrosion of steel; honeycombing of concrete The output of this technique is in the form of graph of amplitude vs frequency. Comparison of these graphs for different types of flaws is carried out in this paper

Keywords : Impact-Echo (IE) Test, NDT-Non-Destructive Technique

I INTRODUCTION

1.1 Necessity

There have been numerous examples in the recent past of structural failures, such as the failure of the Kolkata flyover collapse or the most recent Mahad Bridge failure in Maharashtra. There has been a growing concern about the maintenance and inspection of the deterioration of concrete structures. The traditional test methods used on concrete structures are destructive methods, where coring is most widely used. Obtaining cores and determining the properties from that sample is a very reliable method for investigating the concrete at a particular location, but it is expensive and time consuming. As an outcome of this, very few cores are taken from the structure and so they represent only a small and unrepresentative portion of the whole structure. Also, destructive methods, as the name implies, damage the structure investigated and the defects they leave behind are usually focal points for further deterioration.

Condition assessment of building materials is critical when reassessing existing structures, since material ageing can result in performance loss, degradation of safety and maintenance costs. In contrast to NDT, other tests are destructive in nature for example, concrete core test, pull-out test and pull-off test. The use of these tests ends up damaging the structure and the surface has to repaired after the testing. For these reasons, the use of non-destructive testing has become more common to assess the condition of existing reinforced concrete structures. Over the past several decades, several types of non-destructive methods have been developed for concrete to overcome the problems of destructive testing.

1.2 Non Destructive Testing

Non destructive testing (NDT) is the process of inspecting, testing, and evaluating materials, components or assemblies for discontinuities, or differences in characteristics without destroying the serviceability of system. In other words, when the inspection or test is completed the part can still be used. Some of the non destructive tests used widely all over the world are Rebound Hammer Test, Ultrasonic Pulse Velocity Test. In some cases to detect chemical attack, carbonation test, chloride test and sulphate test are performed.

For concrete structures, ultrasound, radar, thermography, electro-potential-field methods and others are currently being used to detect voids, cracks, corrosion, etc. – with varying success. Impact echo test is one of the non destructive methods which is designed to determine the condition and thickness of concrete, wood, stone and masonry structural members when voids, honeycomb, and/or cracks are suspected.

1.3 Impact Echo Test

Impact-echo is an acoustic method for non destructive evaluation of concrete and masonry, invented at the U.S. National Bureau of Standards (NBS) in the mid-1980's, and developed at Cornell University, in Ithaca, New York, from 1987-1997.

Impact-Echo is a method for non destructive evaluation of concrete and masonry, based on the use of impact-generated stress (sound) waves that propagate through the structure and are reflected by internal flaws and external surfaces.

II PRINCIPLES OF IMPACT ECHO METHOD

Fig 1. is a schematic of the impact-echo method, which is based on using a short duration mechanical impact to generate stress waves and a transducer to monitor the surface displacement due to the arrival of direct and reflected stress waves. The use of mechanical impact provides a versatile method for introducing a much higher amount of energy than is possible with an electrical transducer. The impact produces a force-time history that can be approximated as a half-cycle sine curve. The receiver measures displacement normal to the surface, and the displacement history is recorded and stored as a time-domain waveform.

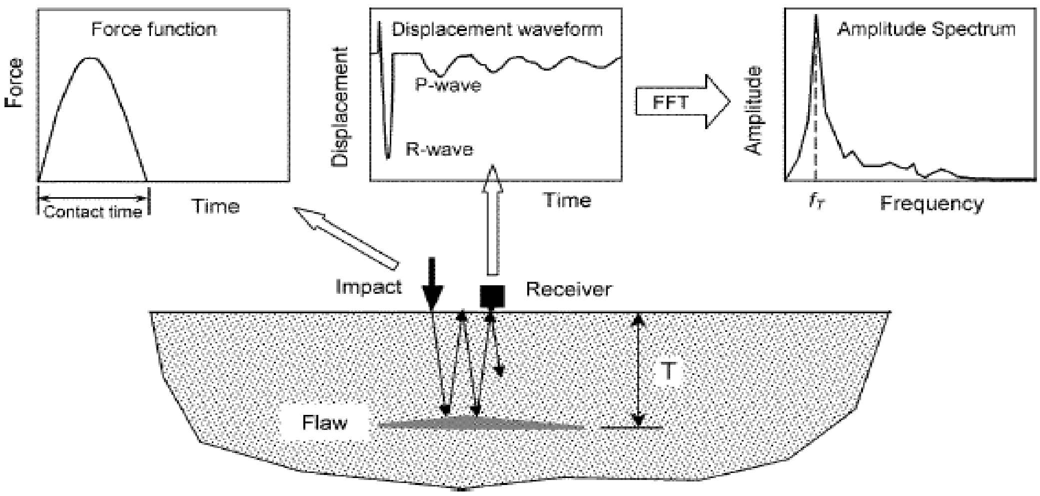

Fig1: Working of Impact Echo Technique[1]

If a solid is struck at a point, the disturbance propagates away from the impact point as three types of stress waves. The P-wave and the S-wave propagate into the solid along expanding spherical wavefronts, and the R-wave travels away from the impact along the "near-surface" region (this is similar to the ripples created when a pebble is thrown into a pond). The P-wave travels at the fastest speed and is associated with a normal stress. When the P-wave passes by a given point, a particle vibrates parallel to the direction of propagation, that is, along the radius drawn from the impact point to the location of the particle (this line is called a ray path by analogy to a light ray). The S-wave travels at a slower speed and is associated with a shearing stress.[1]

2.1 Reflection at Interface[2]

If a stress wave travelling through material *1* is incident on the interface between a dissimilar material *2*, a portion of the incident wave is reflected. The amplitude of the reflection is a function of the angle of incidence and is maximum if this angle is 90^0 (normal incidence). For normal incidence the reflection coefficient, *R*, is given by the following

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad (1)$$

where

Z2 = specific acoustic impedance of material 2, and

Z1 = specific acoustic imprudence of material 1

The specific acoustic impedance is a material property and is equal to the product of the wave speed and density of the material.

In summary, impact-echo testing is based on exciting the thickness mode of vibration of a plate. The thickness frequency (f_T) is related to the plate wave speed (C_{plate}) and plate thickness by the following equation:

$$T = \frac{C_{plate}}{2 f_T} \qquad (2)$$

2.2 Fast Fourier Transform[2]

The *fast Fourier transform* (FFT) is an efficient algorithm for performing the DFT calculations. The program is designed to work with time-domain records having the number of points equal to 2 raised to an integer. Thus typical numbers of points in the waveform are: $2^9 = 512$, $2^{10} = 1024$, $2^{11} = 2048$, or $2^{12} = 4096$. The amplitude spectrum will contain N/2 points. In the impact-echo test, the time-domain waveform represents the surface motion associated with different resonant frequencies that may be present. Transformation of the waveform into the frequency domain by using the FFT reveals the predominant frequency components in the response. These frequency components will appear as peaks in the amplitude spectrum. Figure 2 shows an example of a time-domain waveform obtained from an impact-echo test of a solid concrete plate.[3]

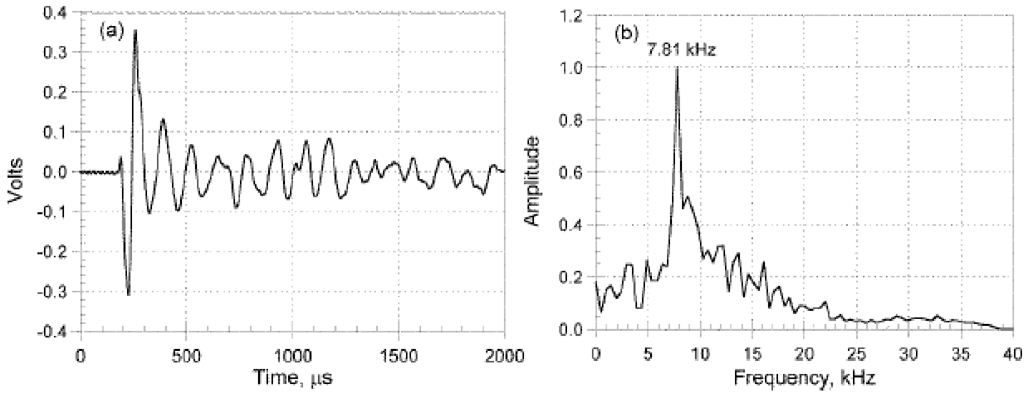

Fig 2: Outputs in Volts vs Time and transformation by FFT to Amplitude vs Frequency

III SLAB MODEL

A slab model of size 2000 mm x 1500 mm x 250mm of grade M25 was casted introduced with debonding, Corroded reinforcement and Honeycombing. Debonding of steel with concrete was achieved by covering the steel reinforcement with duct tape. Half of the lengths of the steel bars were covered with duct tape. Total 5 bars were kept in the slab model for debonding purposes. Two bars of 25mm diameter and three bars of 20mm diameter. The bars were kept at different depths as shown in figure. Corroded reinforcement cages were prepared of bars of diameter 8 mm of size 480mm x 480mm. One corroded cage was inserted in a saline solution to achieve corrosion and the second one was treated with HCl (both for 5 days). To achieve the effect of honeycombing, the portion was not properly tamped and a sand layer was inserted in the portion to exaggerate the effect of honeycombing.

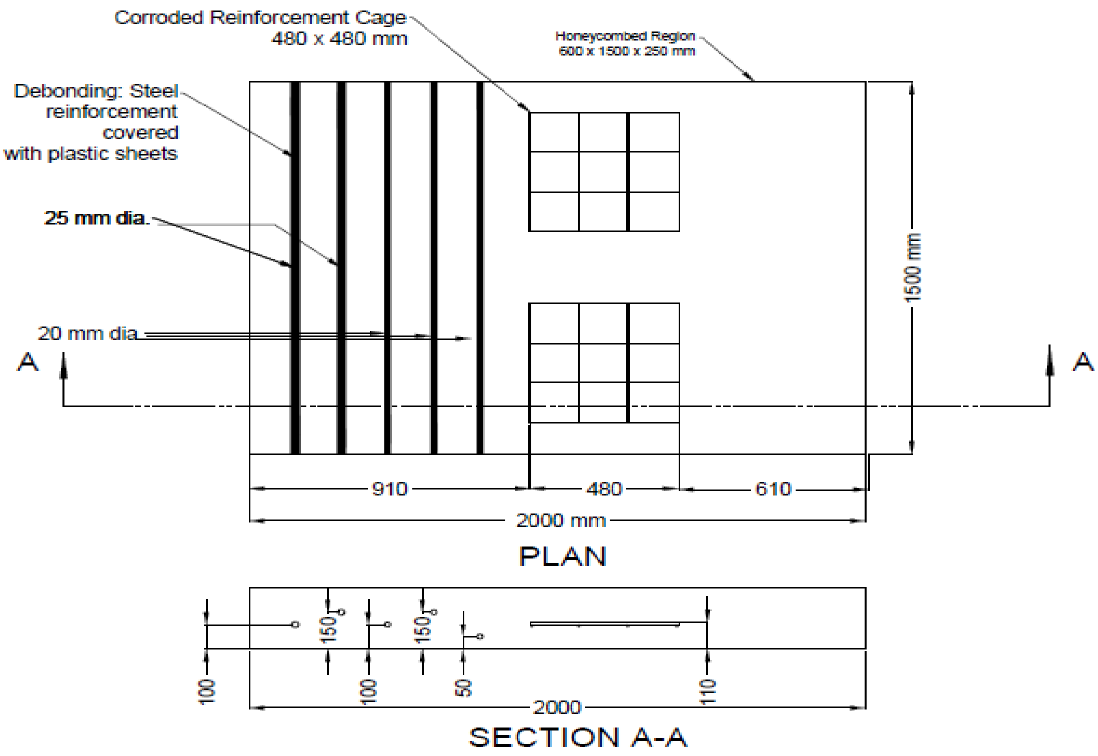

Fig 3: Plan and Section of Slab Model

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ASTM C 1383-15: Standard Test Method for measuring the P-wave speed and the thickness of concrete plates using Impact Echo Method[4] was referred to interpret the results obtained from Impact Echo apparatus

Table 1: Defects introduced in Slab

Type of Defect	Details	Photo
Debonding	Debonding of Steel bars is achieved by covering the bar by duct tape. Two steel bars of 25 mm diameter kept at 100 mm and 150 mm from the bottom of the slab. Three steel bars of diameter 20mm are kept at 100mm 150mm and 50mm from the bottom of the test slab.	
Corroded Steel	Two steel cages of size 480mm x 480mm sizes corroded to different levels are kept at depth of 110 mm from the bottom of the slab. One of the steel cages is corroded by HCl solution and and the other one by saline solution.	
Honeycombing	To exaggerate the effect of honeycombing, a layer of sand is introduced in the slab at a depth of 127mm from the top of the slab	

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IV RESULTS

The results show that depth of concrete slab is correctly estimated by the impact echo technique.

Table 2: Details of defects and depth calculated by IE technique

Bar Details	Depth	Steel Bars	File Name	Depth
25mm	150mm	Bonded Steel	Slab0.nde	250
		Debonded Steel	Slab7.nde	250.8961
25mm	100mm	Bonded Steel	Slab14.nde	250.0156
		Debonded Steel	Slab18.nde	250.0156
20mm	150mm	Bonded Steel	Slab27.nde	250.0156
		Debonded Steel	Slab33.nde	249.95
20mm	100mm	Bonded Steel	Slab39.nde	249.39
		Debonded Steel	Slab44.nde	249.4026
20mm	200mm	Bonded Steel	Slab51.nde	251.7494
		Debonded Steel	Slab57.nde	249.1893
Corroded Cage 1	140mm	Saline Solution	Slab73.nde	249.3922
Corroded Cage 2	140mm	Acid Solution	Slab77.nde	249.3922
Honeycombing	127mm	Sand layer	Slab95.nde	126.4

The results show that the depth of the test slab found out from impact echo technique is equal to that of actual depth of the test slab. Below are displayed some sample graphs of Amplitude vs Frequency.

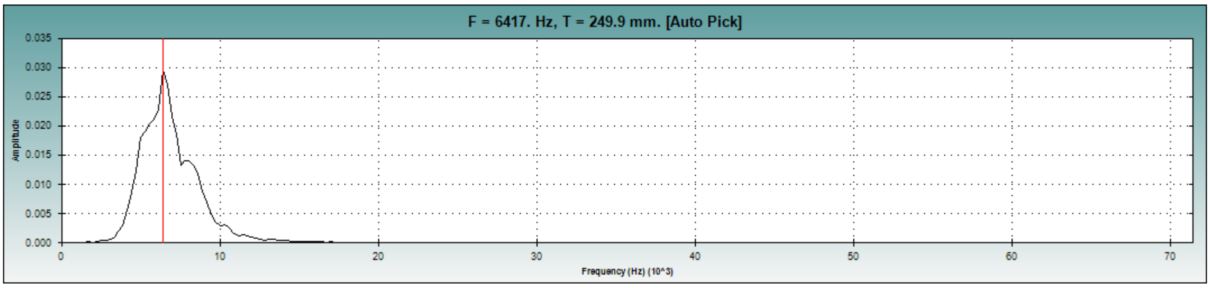

Fig 4: Amplitude vs Frequency for bonded steel bars

Amplitude vs Frequency of bonded steel bars depicts only one dominant frequency from which the depth is calculated as 249.9mm.

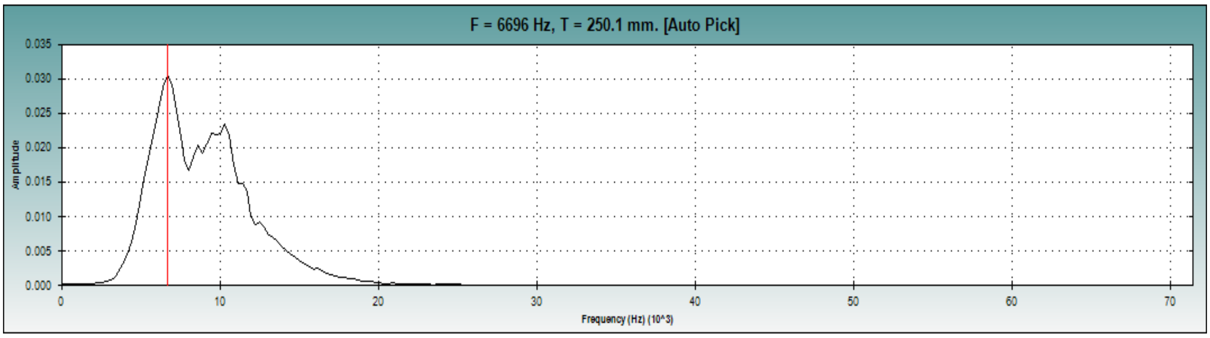

Fig 5: Amplitude vs Frequency for unbonded steel bars

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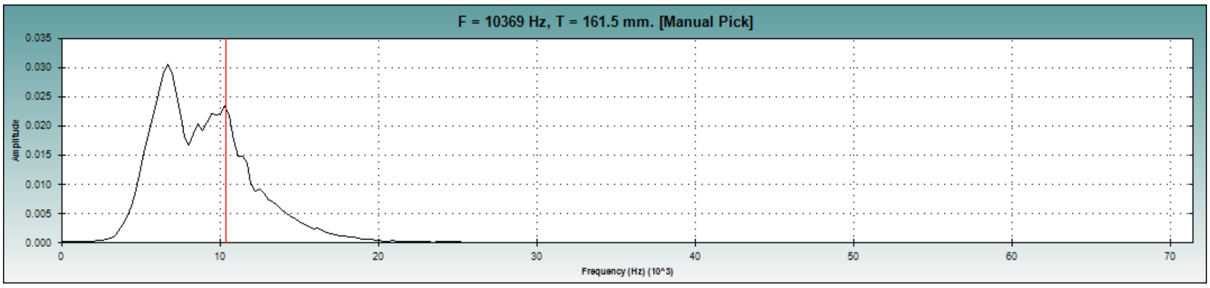

Fig 6: Amplitude vs Frequency; second peak at 161.5 mm

Above graphs are at the locations of debonding of steel. The second dominant frequency being 10369Hz denotes a flaw at a depth of 161.5mm from the top of the beam which is actually 150mm from the top of the beam.

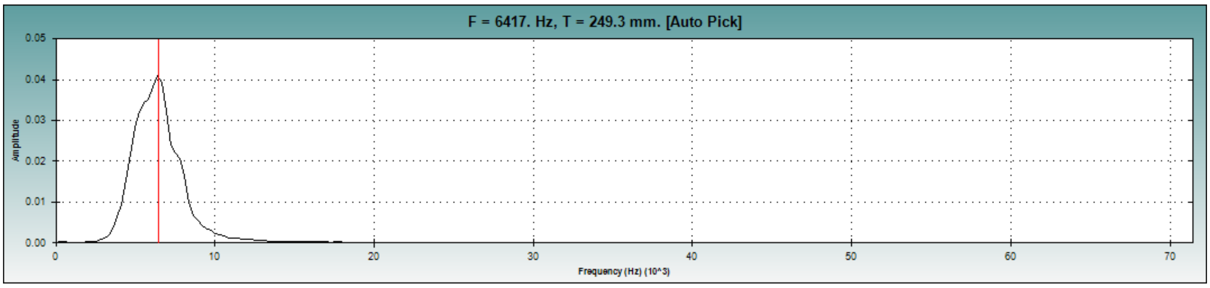

Fig 7: Amplitude vs Frequency for Corroded Steel Reinforcement (Acid)

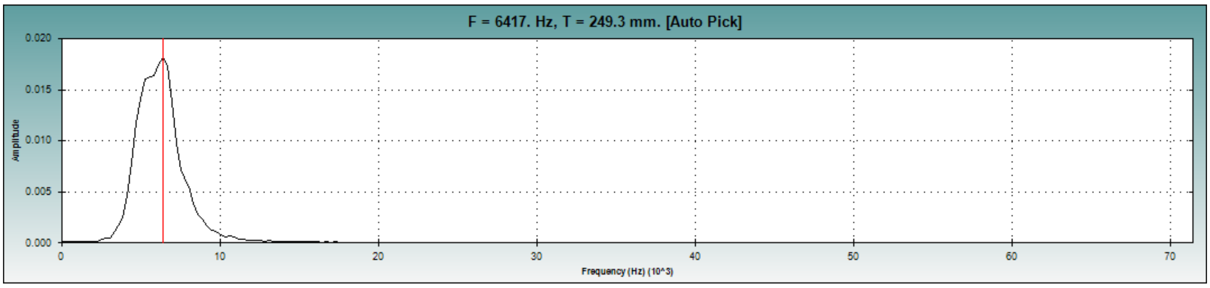

Fig 8: Amplitude vs Frequency for Corroded Steel Reinforcement (Saline)

Fig 7 & 8 shows that corrosion could not be detected by the impact echo Technique as there is only one dominant frequency. This could be because the cover formed by the oxidation of steel was removed by wet concrete and there was no gap between the two surfaces of concrete and steel.

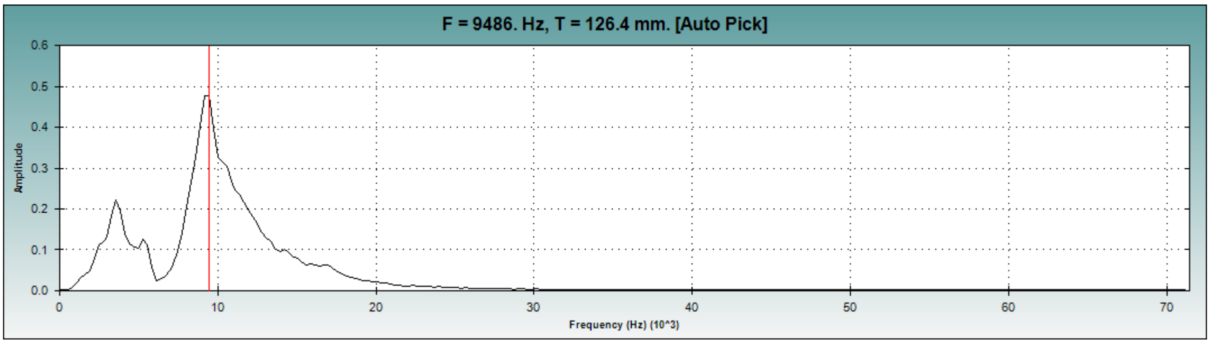

Fig: 9: Amplitude vs Frequency for Honeycombed concrete

Fig 9 clearly depicts the depth of concrete for honeycombed concrete which matches with the actual flaw introduced in the concrete.

V CONCLUSION

1. The depth of the slab is correctly estimated by the Impact Echo Technique.
2. There is no second dominant frequency in bonded bars, just the primary dominant frequency exists.
3. There exists a second dominant frequency at the depth of the bonded bar in the unbounded steel bars.
4. The corrosion could not be determined in the concrete as the corrosion was introduced in steel at the time of casting, which was washed out at the time of concreting.
5. Honeycombing was calculated correctly by Impact Echo Technique.

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