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Assessment of Masonry Structure using Impact-Echo Technique

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***Abstract**: Non-destructive testing of masonry structures is not common in practice. However methods of NDT testing of masonry structures are available which can be used for evaluation of existing masonry structures when visual inspection is not sufficient or is not reliable. Appearance of cracks in masonry structure is a clear indication of distress and deterioration of masonry structures which can be evaluated through visual inspection. But, deterioration of masonry materials inside the structural element, internal cavities, weak bond etc. can cause the safety concern for the structural masonry elements. Thus, the use of NDT technology (Non-Destructive Testing) can provide valuable information on the current internal condition and Hidden faults or flaws can be detected and can be repaired before serious damage. The impact-echo method can be used to locate cracks, voids and other defects where the bricks or blocks are joined together with mortar.*

The present study aims at applicability of impact echo in the measurement of thickness in masonry wall, locate and measure depth of defects such as flaws and voids inside structure. In addition, results of field testing on an old masonry building is presented, which illustrates the capabilities of an impact-echo system to help with evaluating the structural stability of critical components, particularly the bonding conditions and presence of voids and cavities

***Keywords**: Non-destructive Method, Impact Echo, NDE 360, Condition Evaluation, Masonry Structure.*

I- INTRODUCTION

NDT is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods include impact-echo (IE), vibration response (VR), impulse response (IR), ground penetrating radar (GPR), infrared thermography (IT) etc. Among various non-destructive testing (NDT) techniques, impact-echo is suitable for integrity evaluation of masonry structures since it can provide information about the thickness and the presence of flaws.

The Impact-Echo Method

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. Figure 1 shows the Components of Impact Echo test. The IE tests with the normal test head involve impacting the concrete / masonry member with an impactor solenoid and identifying the reflected wave energy with the displacement transducer as shown in Figure 1 below. Note that the solenoid impactor and displacement transducer are built into IE head. The test head is pressed against the top of the tested member and held while tests are performed at each test point. The resonant echoes of the displacement responses are usually not apparent in the time domain, but are more easily identified in the frequency domain. Therefore, amplitude spectra of the displacement responses are calculated by performing a Fast Fourier Transform (FFT) analysis to determine the resonant echo peaks. The relationship among the resonant echo depth frequency peak (f), the compression wave velocity (C_p) and the echo depth (D) is expressed in the following equation.

$$D = C_p/(2*f)$$

Fig. 1- Impact Echo Equipment

Measurement of the concrete velocity can be done with of any of the NDE-360 IE systems with the Surface Wave (SW) option, the velocity calibration with known thickness of concrete. For systems with the SW option, the velocity calibration can be done on any concrete member with a thickness of greater than 5 inches. Figure 2 shows the wave propagation due impact of solenoid.

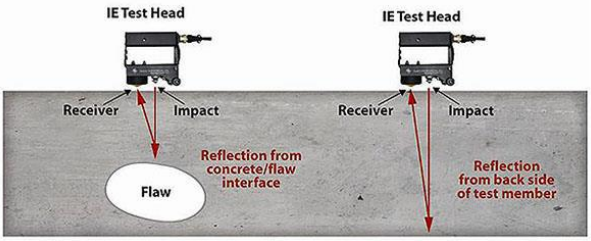

Fig. 2- Wave propagation of Impact Echo

Working principle

Impact-echo method 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 impact produces a force-time history that can be approximated as a half-cycle sine curve. The duration of the impact is called the contact time and has to be chosen carefully. The receiver measures displacement normal to the surface, and the displacement history is recorded and stored as a time-domain waveform. The first successful applications of impact methods occurred in geotechnical engineering to evaluate the integrity of concrete piles and caissons. The technique became known as the sonic-echo or seismic-echo method. This method is based on the assumption that the concrete plate has the same p-wave speed throughout its depth. Figure 3 shows the principle and working of Impact Echo technique.

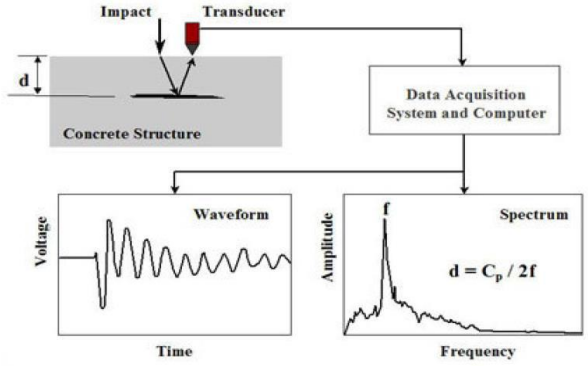

Fig. 3- Working of Impact Echo Technique and its outputs

Software

WinIE software is used for the analysis of results obtained from Impact Echo test. National Instruments Data Acquisition (NIDAQ) software is necessary to run the Olson Instruments WinIE program. By importing our results of Impact Echo test in WinIE software, we get amplitude-frequency graph. Similarly, by importing our results obtained from Impact echo test, we get time domain waveform, frequency graphs. From the nature of these graphs, we can determine the type of flaw present in Masonry structures comparing with the standard graphs which is obtained from casted wall. It is important to bear in mind that each IE test is only a test at a single point. Only the reflections below the impactor and transducer are recorded.

METHOLOGY

The masonry wall consists of 9 brick layer (with different class of brick) as shown in figure 4. The thickness of wall is 230mm. The vertical arrow shows the scan line direction (bottom to top). The impact echo test has been proposed to carry out in this wall specimen in order to find the thickness of wall and voids inside wall.

Experimental setup

1) Considering prototype of brick wall (1.0 x 1.0 x 0.23m) for carrying out IE Testing.

2) Test specimens are to be casted with inserting desired flaws (voids, cracks in brick, poor mortar proportion for bonding) at predefined locations.

From bottom of wall, first four layer is made up of 1st class brick having mortar proportion of 1:3, another three layer made up of 2nd class brick having mortar proportion of 1:8 and last three layer is made up of 3rd class brick with 1:12 mortar proportion as shown in figure 4. From top of wall 2nd, 5th and 8th layer containing voids as shown in figure 5.

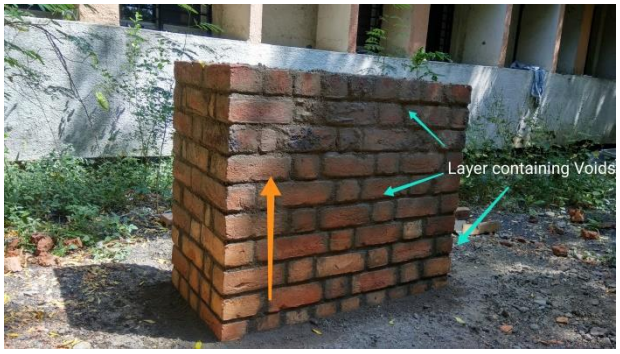

Fig. 4- Brick masonry wall casted in Laboratory


Fig. 5- Improper filling of mortar

Above figure 5 shows the voids and improper filling of mortar between bricks and cracks in bricks, this will help to find the bonding condition of bricks wall (means good condition, fair condition and serious condition) so that we will take necessary action.

Test procedure

The impact point and transducer were placed adjacent to each other on the same brick. Impact duration was about 30 micro second. After application of IE frequency spectrum obtained as shown in figure 6, but all frequency spectrum contained 1024 points recorded at intervals of 2 micro second. For clarity, only the initial portion of the frequency spectrum is shown. In each station, the final signal was the resulting average of ten waveforms (frequency), taken from the center of each brick.

RESULTS AND DISCUSSION

1) Thickness of wall

Figure 6 shows a typical impact-echo response obtained from casted brick wall. The thickness of masonry wall which is casted in lab is 234.2 mm. while actual thickness of wall is 230mm. As per (ASTM 1383-15) code thickness accuracy ± 2%. The average frequency which is obtained by IE is 7.8 KHz.

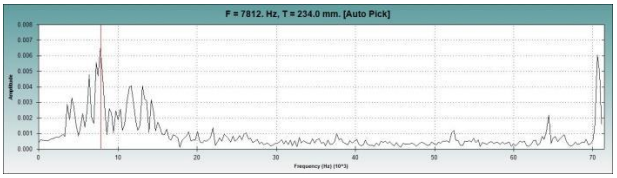

Fig. 6- Frequency spectrum for thickness of wall

2) Voids in masonry wall

Figure 7 shows a typical impact-echo response obtained from casted brick wall (where voids are already present). The thickness of masonry wall is 156 mm. which is indicate the depth of voids or cracks present in masonry wall. The average frequency for this layer is 11 KHz. It means that if frequency is greater than actual wall thickness frequency about (25% to 30%) then it means that voids or cracks are present in wall.

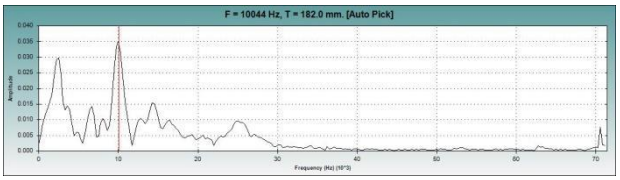

Fig. 7- Frequency spectrum for layer containing voids or cracks

3) Bonding condition between bricks

Figure 8 shows a typical impact-echo response for the good mortar joint for bottom 1st ,2nd and 4th layer. The average frequency obtained as 11.9 KHz.

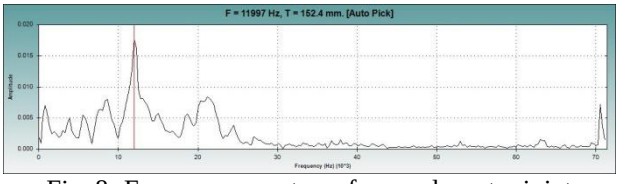

Fig. 8- Frequency spectrum for good mortar joint condition

Figure 9 shows a typical impact-echo response for the mortar joint (which is containing voids in mortar as shown in fig 5) for bottom 3th and 5th layer. The average frequency obtained as 13.6 KHz. The bonding condition

between the joint is classified as fair and serious condition joint because frequency is increases about 12.5% as compared to good bonding condition.

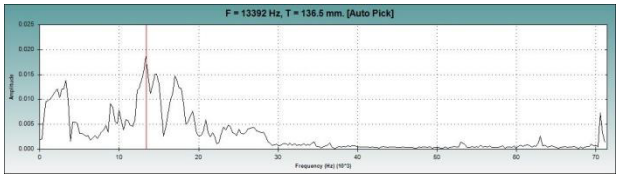

Fig. 9- Frequency spectrum for mortar joint (containing voids)

Case study

Impact echo testing is performed on old masonry building (G+1) as shown in figure 9. This is located near Jawahar Gate, Amravati (India).

Fig. 10- Old masonry building (Amravati, India)

The building has pointed brick masonry wall having thickness 230mm. the building was constructed in the 1985s. As part of survey of the exterior of the building, a feasibility study was performed to determine whether the hidden flaws could be located through impact-echo tests on the exterior surface. Tests were performed on three areas of the building. First of all we have select the wall at ground level and perform the impact echo test and calculate the results. After completing ground level, we go for the 1st story level and perform IE test on pointed brick wall surface and interpret the results and compared with casted brick masonry wall.

Impact echo testing performed on front view of brick masonry wall as shown in figure 10 and also figure 10 shows test locations points. The test has been carried out on three test points. Two recordings for each test point are obtained and analyzed in WinIE Software. results obtained is as shown in Table 1.

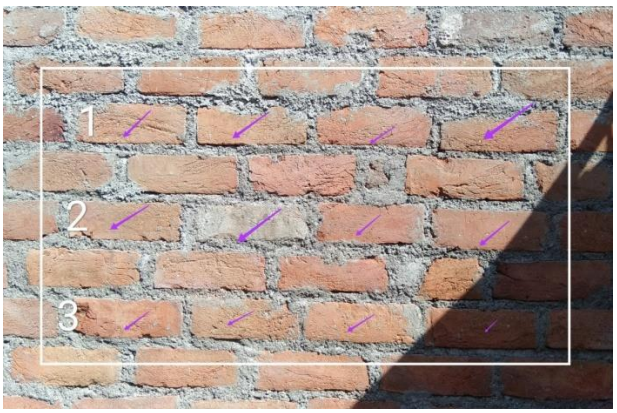

Fig. 11- Front view of wall

Impact echo testing performed on side of brick masonry wall as shown in Figure 11 and also figure shows test locations points.

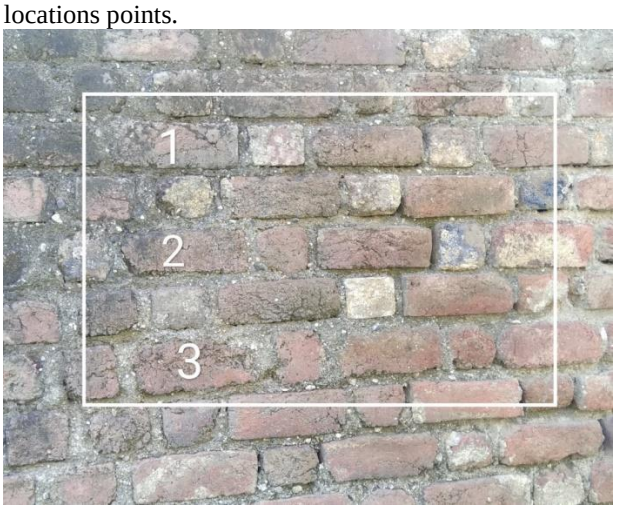

Fig. 11- side view of wall

Similarly we have performed impact echo test on all brick masonry wall of building in which some of results are shown in table 1.

Table 1- Test results

Wall name	File name	Velocity (m/s)	Frequency (KHz)	Thickness (mm)	Voids	Bonding condition
Front wall	ie47.nde	3630	7.5	242	Not present	Good
Side wall	ie73.nde	3630	12.1	150	Present	Fair
Back side wall	ie95.nde	3630	18.97	96	Present	serious

After performing impact echo test we conclude that, in the top story brick masonry wall the bonding condition is good. While in bottom story wall the bonding between brick is fair. In back side of wall some layer has shown serious damage condition, so it has to be repaired.

CONCLUSION

1) The thickness of masonry wall is correctly estimated by impact echo technique. As per ASTM 1383-15 code thickness accuracy ± 2%.
2) The presence of voids, discontinuities and bonding condition between brick in masonry structure is correctly estimated by impact echo method.
3) If frequency of wall (containing voids) is greater than actual wall (solid) thickness frequency about (25% to 30%) then it means that voids or cracks are present in wall.
4) If frequency of mortar joint between bricks is same as the thickness of actual brick masonry wall. Then it means that there are no voids present in mortar and the bond is classified as good bond.
5) If frequency of mortar joint between bricks is increases by 10% to 15% of actual frequency. Then it means that little amount of voids are present in mortar and the bond is classified as fair bond.
6) If frequency of mortar joint between bricks is increases by 30% to 40% of actual frequency. Then it means that huge amount of voids are present in mortar and the bond is classified as serious bond.

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