GROUT QUALITY ASSESSMENT IN PRECAST WALL PANELS USING IMPACT-ECHO METHOD

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Abstract

Precast construction is gaining popularity in India as the demand for housing is exponentially increasing. The government is also very keen with its agenda of housing for all. It is also willing to provide financial support to the housing scheme through the PM Awas yojana. In this regard, research works have been funded to provide indigenous housing schemes for the economically weaker section and low income groups. Such a research work has been carried out at CSIR-SERC in the recent years.

A full-scale G+1 building has been tested at CSIR- Structural Engineering Research Centre using precast sandwich wall panels. In this project, it has been proposed to evaluate the quality of the grouting used in the joints. This becomes even more essential in precast construction as the joints between precast elements are more vulnerable to seismic events. In addition to this, the quality of the concrete in the precast elements is also evaluated. For this investigation, it has been proposed to apply the impact-echo method which is one of the advanced non-destructive testing methods. Grid points were marked and data has been collected at several points before and after the grouting. The results indicate that the grouting has been carried out without defects. Thus, it has been demonstrated that the impact-echo method is a reliable method for quality assessment of precast elements and their grouts in the construction and manufacturing industry.

Keywords: Concrete, Grout quality, Precast, Non-destructive evaluation, Impact-echo method
1 INTRODUCTION
Every nation has their distinctive infrastructural assets which showcases the legacy their population came across in the past centuries. The necessity to increase their service life has stressed the need for focussed research on Non-destructive Evaluation techniques for concrete structures. The Non-Destructive Testing (NDT) methods are being used for the evaluation of older and newly constructed structures. In India, there are several structures, especially bridges, which are serving for centuries. Those structures have also become the part of our livelihood. Utilising them further more makes it psychologically unfit. However, construction of newer structure in that region has more practical difficulties and in addition to that reconstructing the same bridge to accommodate present traffic condition requires huge financial support. This would affect the economy of the nation. Hence, it becomes essential to assess them periodically to ascertain their structural health. The NDE process not only reveals the degradation level of the structure but also helps to evaluate the residual strength to support increased structural / traffic loads. Hence, the need for effective and reliable NDT methods gains greater significance.

It is often necessary to test concrete structures after the concrete has hardened to determine whether the structure is suitable for its designed use. Ideally such testing should be done without damaging the concrete. The tests available for testing concrete range from the completely non-destructive, where there is no damage to the concrete, to those where the concrete surface is slightly damaged, partially destructive tests, such as core tests, pull out and pull off tests, where the surface has to be repaired after the test. The range of properties that can be assessed using non-destructive tests and partially destructive tests is quite large and includes such fundamental parameters as density, elastic modulus and strength as well as surface hardness and surface absorption, and reinforcement location, size and distance from the surface. In some cases, it is also possible to check the quality of workmanship and structural integrity by the ability to detect voids, cracking and delamination.

The Non-Destructive Testing is necessary not only in aged structure but also in evaluating the construction quality in new structures. Developing countries like India undergo a well spread infrastructural development with large numbers of industries, bridges, power plants and high rise structures. By conducting the NDE of newer structures before commissioning of the machineries, the industries ensure good quality of construction. This saves the large amount of money that would be spent on repairs later.

1.1 IMPACT-ECHO APPLICATIONS FOR CONCRETE INFRASTRUCTURE
Impact echo is a method that measures surface movement of a concrete specimen due to a mechanical wave produced by a short pulse impact. The impact creates an elastic wave that propagates through the specimen and interacts with changes in the subsurface. When the wave encounters a material with different mechanical properties, such as air or steel, the entire wave no longer travels forward. Part of the wave energy transmits into the material while the remaining energy reflects away from the material. The wave will then reach the surface and reflect back into the concrete again due to the air interface. The surface movement from the wave propagation is recorded by a piezoelectric displacement transducer, the received signal is analysed and the results help identify the subsurface defects.
1.2 TESTING PROCEDURE - ASTM C1383

The impact-echo method has developed into a popular non-destructive testing method for civil engineering applications. It took over a decade long committed and dedicated research before the method could receive worldwide acceptance. However, the wider acceptance and application to real structures in the field required the standardization of the test procedure by standards or codal provisions. But field-testing using the IE method involves many influencing variables. Also, the types of defects vary from honeycombs, voids and cracks to micro-cracks and material degradation. The shape of the structural members that is tested is also another variable which according to the literature would influence the evaluation process [1]. Hence, the development of a standard test procedure involving all of them would be difficult.

In 1998, ASTM adopted two test procedures for the use of impact-echo method for plate-like structural elements [2]. The first test procedure (Procedure A) focussed on the evaluation of P-wave speed in concrete. This procedure recommends the use of two transducers placed at some distance, as discussed in the research works of Sansalone et al. [3]. The schematic of Procedure A is shown in Figure 1a. The second procedure (Procedure B) provides the steps to be followed for the evaluation of the thickness of plate-like structural elements [4]. The schematic of the Procedure B is shown in Figure 1b. It is also mentioned that the wave speed in concrete is 0.96 times the P-wave speed evaluated using Procedure A.

1.2.1 PROCEDURE A- EVALUATION OF P-WAVE SPEED

The IE signal is dominated by the multiple reflections of the P-wave. The evaluation process uses equations,

\[ C_{pp} = 0.96 C_p \]  

\[ D = \frac{C_{pp}}{2f} \]

Where, \( C_{pp} \) is the velocity of p-wave related to the frequency \( f \) and the path length \( 2D \) and \( D \) is the depth of the reflected surface. These equations rely on the P-wave speed. Errors in the estimation of the P-wave speed will result in erroneous determination of the depth of the defect. Hence, the correct estimation of the P-wave speed becomes essential. It has been observed that the P-wave travels between 3600-4500 m/s in the concrete medium [5]. With the possibility of such large variation, it is not advisable to use an arbitrary value for the NDE process.

The P-wave speed is estimated with the use of two transducers placed at a constant distance (L) from each other. The transducers are held in vertical position and at a distance using the spacer bar. The impact is made at a distance from the first transducer, in-line with the two transducers. By maintaining the two transducers in the same line, the wave is supposed to reach transducer 2 after travelling a distance of \( L \) since reaching the first transducer. The signals are recorded by both the transducers. Figure 1 shows the schematic of the P-wave assessment and the equipment with the two transducers held by the spacer bar. Figure 1 explains the procedure used for the P-wave speed assessment using a typical wave. If the P-wave is captured by the first transducer at time \( t_1 \) and by the second...
transducer at time $t_2$ then the time taken for the wave to travel the distance $L$ is $(t_2 - t_1)$. Thus, the P-wave speed can be computed using the relation

$$P_{wave\,velocity} = (t_2 - t_1) / L$$

(3)

Figure 1. Two-step procedure for measuring plate thickness according to ACTM C 1383 [2]

1.2.2 PROCEDURE B- EVALUATION THICKNESS

Position the transducer on the concrete surface where thickness is to be measured as shown in Figure 2. Position the impactor to strike at a distance less than 0.4 of the nominal plate thickness away from the transducer. Ready the data-acquisition system with correct data acquisition parameters (sampling frequency, voltage range, triggering level, delay, and so forth). Data acquisition shall be triggered by the transducer signal or by an instrumented impact device. If necessary, establish data acquisition parameters by trial test. Perform the impact. Examine the acquired waveform and corresponding amplitude spectrum. In making a judgment about the validity of the waveform, examine whether the portion of the waveform corresponding to the surface wave is of the correct shape and that the surface wave is followed by periodic oscillations corresponding to multiple reflections between the plate boundaries. The amplitude spectrum of a valid waveform will have a single dominant peak at a frequency corresponding to the plate thickness. If a valid waveform and amplitude spectrum have been obtained, store the waveform and amplitude spectrum. Repeat the test to verify the results. If the results are repeatable and valid, move to the next test point. If the waveform and amplitude spectrum are not valid, check that the test surface is free of dust and debris and that the transducer is coupled properly to the test surface. Also check that the impact point is flat and free of debris, and that the correct size of impactor is being used. Repeat the test until a valid waveform and amplitude spectrum are obtained. Earlier to this, researchers have investigated the defects in grouted tendon ducts [6,7]. However, the present work focuses on analyzing the quality of grout in precast wall panels.
2 SPECIMEN DETAILS

Before conducting the study, a preliminary investigation on some essential parameters needs to be carried out. These include the evaluation of the velocity of the acoustic wave in the concrete. The Grout quality study is made on a full scale precast wall panel elements. The structure is precast system consisting of wall panel each side of 3000 x 3000 x 150 mm each and covered up by a roof panel of 3000 x 3000 x 150 mm. In the present work, wall panel 1 and 2 are taken for investigation wherein the wall panels contain 4 vertical and horizontal ribs, each.

Each panel consist of open grout slots at rib 1 and 2 as shown in Figure 3 and 4 which are joined and grouted with adjacent panel member. And every vertical rib contains grout pockets which is hallow inside with concrete cover of 25mm where rebars from foundation are inserted and grouted. These open grout slot and grout pocket are assessed for quality to ensure joint strength and integrity of structure.
2.1 MARKING OF GRID POINTS AND TEST PROCEDURE
Before commencing the investigation, grid points are marked along the length of the vertical ribs as per ASTM standard at every 50mm spacing. These grid points guide the investigator to place the transducer and to produce impact at specific points. Every rib comprises of 53 grid points where testing is done in all grid points to capture the response at all portions of the rib and data are stored for analysis and interpretation. Figure 5 shows the grid marking process and Figure 6 shows the data collection and analysis on the wall panel.
Figure 4. Schematic sketch of Wall panel 2

Figure 5. Grid marking on the wall panel.
2.3 RIB NOTATION
With 53 grid points in each ribs, a single wall panel contains 212 grid point. That is, 212 data need to be collected and processed for single wall panel. Hence the data sets are organised by using prescribed notations. The wall panel ribs are given specific notations as listed in Table 1.

<table>
<thead>
<tr>
<th>WALL PANEL</th>
<th>VERTICAL RIB</th>
<th>ASSESSMENT BEFORE GROUTING</th>
<th>ASSESSMENT AFTER GROUTING</th>
</tr>
</thead>
<tbody>
<tr>
<td>WALL PANEL 1</td>
<td>RIB 1</td>
<td>WP1_R1_BG</td>
<td>WP1_R1_AG</td>
</tr>
<tr>
<td></td>
<td>RIB 2</td>
<td>WP1_R2_BG</td>
<td>WP1_R2_AG</td>
</tr>
<tr>
<td></td>
<td>RIB 3</td>
<td>WP1_R3_BG</td>
<td>WP1_R3_AG</td>
</tr>
<tr>
<td></td>
<td>RIB 4</td>
<td>WP1_R4_BG</td>
<td>WP1_R4_AG</td>
</tr>
<tr>
<td>WALL PANEL 2</td>
<td>RIB 1</td>
<td>WP2_R1_BG</td>
<td>WP2_R1_AG</td>
</tr>
<tr>
<td></td>
<td>RIB 2</td>
<td>WP2_R2_BG</td>
<td>WP2_R2_AG</td>
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<tr>
<td></td>
<td>RIB 3</td>
<td>WP2_R3_BG</td>
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<tr>
<td></td>
<td>RIB 4</td>
<td>WP2_R4_BG</td>
<td>WP2_R4_AG</td>
</tr>
</tbody>
</table>

3 RESULTS and DISCUSSIONS - BEFORE AND AFTER GROUTING
The data is analysed at each grid point. The data is first converted into frequency domain. The dominant frequency in the frequency spectrum is used for the evaluation of the depth of the concrete specimen or the concrete quality. The time domain signal is converted into the frequency domain using the fast fourier transforms. This process is
carried out for all the grid point data. However, the visualisation and presentation of each of the data is cumbersome. Hence, the data is analyzed and the cumulative result of the whole wall panel is represented in two-dimensional format for better understanding. The variation in the frequency is represented as colour variation while the variation in the geometrical coordinated along the X and Y axes are represented along the X and Y axes, respectively. Table 2 lists the colour representation adopted in this work to represent the different concrete quality.

Table 2. Concrete quality and corresponding colour representation adopted

<table>
<thead>
<tr>
<th>Colour</th>
<th>Representation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>Good concrete</td>
</tr>
<tr>
<td>Red</td>
<td>Not good concrete</td>
</tr>
<tr>
<td>Blue</td>
<td>Very bad / No data</td>
</tr>
</tbody>
</table>

Figure 7 shows 2D chart of wall panel 1 before grouting and it has been made using MATLAB software. The X-axis represents the width of the wall panel and y-axis represents the height of the wall panel. In figure 7, the vertical bars represent the vertical ribs before grouting. The bottom Grout Pockets have the frequency range at 5000Hz and 20000 Hz which are caused by noise and edge reflections. The grout slots at mid height are open for grouting, hence they are represented as blue colour meaning ‘no data’.

![Figure 7. 2D chart of wall panel 1 before grouting](image-url)
After the erection of wall panel, the grouting work is completed, same NDE testing is carried out after grouting and the chart is created. Figure 8 is the 2D chart of wall panel 1 after grouting. Now, the grout pockets and the open grout slot are shown as green colour with frequency range of 10000Hz to 15000Hz representing good grouting work monolithically to the concrete portion. This method helps easily visualise the quality of grout work from the received resonant frequency.

Similarly, the data is collected on the wall panel 2. The collected data is analysed using fast fourier transforms. The same procedure is carried out for wall panel to evaluate the quality of grout work. The results obtained for the wall panel 2 before grouting is shown in Figure 9. In figure 10, the results of the wall panel obtained after grouting are shown in 2D format. The results of the wall panel 2 shown in Figure 10 and that of wall panel 1 shown in Figure 8 could be compared. From the figures it can be observed that the results look very similar representing similar quality of the grout in both the wall panels. It is also, interesting to note that the frequency obtained from the monolithically cast concrete region is similar to the grout region. This shows that the integrity of the grout is similar to that of the concrete.
Figure 9. 2D chart of wall panel 2 before grouting

Figure 10. 2D chart of wall panel 2 after grouting
4 CONCLUSIONS
This study focused on assessing the quality of the grout in precast concrete wall panels. For the study two full scale wall panels of size 3m x 3m has been cast and the nondestructive testing carried out using impact-echo method. The data is collected at each grid point. The analysis is also carried out at each grid point by converting the time domain signal into the frequency domain using the fast Fourier transform. The dominant frequency in the frequency spectrum is used for the interpretation of the concrete and grout quality. A colour representation as mentioned in Table 2 is adopted to represent good and bad grout regions. The results have been represented in 2D format for better visualisation and discussion.

From the study, it has been observed that the ungrouted regions in the concrete produced either much lower or higher frequencies to the solid concrete region. This helped in isolating the monolithic concrete region from the ungrouted region. After the erection of the wall panel, the grouting is carried out. After the maturing of the grout, data is again collected. The data is analysed and interpreted. The results in the 2D format represent the concrete and the grouted regions with the same frequency. Thus, it can be concluded that the quality of the grouting has been very good and consistent in all the ribs of the two wall panels. The integrity of the grout region is found to be on par to the monolithic concrete as their vibration characteristics have been found to be very similar.

Based on the experimental study carried out on Quality assessment and depth evaluation by Impact echo, it can be concluded that Impact echo method can be used to visualise the defects in the grout region and 2D chart representation makes Impact echo more understandable by the field engineers.

5 REFERENCE