Health Assessment of Existing Nuclear Fuel Cycle Facility: A Case Study

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Abstract

Before taking up seismic re-qualification and retrofitting of an existing concrete structure, if required, assessment of the current strength of structure is an important aspect. Health assessment ascertains variation in properties of concrete, particularly strength, attained over the initial development phase when subjected to service exposure for a long time. It further tries to assess the deterioration of the reinforcing steel and degradation of the concrete through the various mechanisms over time. Health assessment of a reinforced concrete (RC) Nuclear Fuel Cycle Facility was taken up through Non-destructive (NDT) and Partially-destructive testing (PDT) in the recent past. The RCC framed-cum-shear wall structure was of dimensions 98 m by 84 m and had been constructed around 15 years back. From the results the various material properties of concrete like compressive strength and density were determined. The health of the concrete was found to be in satisfactory condition with chloride and sulphate content within permissible limits specified by International standards. The paper provides an overview of the different tests performed for health assessment and further provides a brief account of the results and inferences therefrom.

Keywords: Requalification, Health assessment, Non Destructive test, Core Sampling & Ultrasonic Pulse velocity Method

1. Introduction

Before taking up retrofitting or seismic re-qualification of an existing concrete structure, assessment of the current strength of structure is an important aspect. The significance of accurate and comprehensive evaluation cannot be overstated. Health assessment ascertains variation in properties of concrete, particularly strength, attained over the initial development phase when subjected to service exposure for a long time. It further tries to assess the deterioration of the reinforcing steel and degradation of the concrete through the various mechanisms over time.
The structure taken up for study is a Nuclear Fuel Cycle Facility. It is a reinforced concrete framed-cum-shear wall structure. Its plan dimensions are 98 m x 84 m and is divided into six zones by separation gaps. The elevations of the different zones vary with three levels in zones 1, 3 and 5, while Zones 2, 4 and 6 have two levels. For this structure, health assessment was performed to aid the seismic requalification deemed essential due to current safety requirements.

For this purpose, some non-destructive and some partially destructive tests were employed to assess health of concrete. The present paper provides an overview of the various tests performed on the structure and further attempts to assess the health of reinforced concrete from the results obtained.

2. Methodology

To ascertain the condition of concrete in different structural members of the structure, various properties like integrity, surface hardness, strength of concrete etc. need to be evaluated and the following tests were conducted for the same[1].

1. Ultrasonic pulse velocities tests at selected locations to assess the integrity of concrete as per BIS standard [2].
2. Rebound hammer test as per BIS standard [3].
3. Half-cell potential meter test at selected locations to assess the risk of corrosion including exposing the reinforcement for carrying out the test. The test shall be conducted as per ASTM standard [4]. Five potential observations taken at one location will form a unit for measurement purposes.
4. Extraction and testing of concrete drill dust samples from the structure. Three drill dust samples from depths 0-15mm, 15-30mm and 30-45mm shall be collected from each location. The samples shall be tested for chlorides, sulphates, pH and alkalinity.
5. Carbonation depth test study on the structure.
6. Extraction of concrete cores from locations specified and testing for crushing strength, water absorption & unit weight.
7. Profoscope scans at specified locations of the structure for reinforcement steel location, size and cover measurement.

This section presents an overview of the various tests conducted for the structures.

2.1 Ultrasonic Pulse Velocity Test

This method consists of measuring the transit time of ultrasonic pulse transmitted through the concrete medium and the pulse velocity is calculated by dividing the path length by time of transit. The pulse velocity measurements can be used to establish the following characteristics of the concrete structure:

1. Homogeneity
2. The presence of cracks, voids, and other imperfections
3. Changes in the structure of the concrete which occur with time
4. The quality of the concrete in relation to the standard requirements
5. The quality of one element of concrete in relation to another
6. The values of elastic modulus of concrete.

There are three possible ways of measuring pulse velocity, namely

1. Direct transmission: It is defined as the propagation of ultrasonic stress waves along a straight-line path between the opposite surfaces of a specimen.
2. Semi-direct transmission: It is defined as the propagation of ultrasonic stress waves between points that are located on the perpendicular surface of the material.
3. Indirect or surface transmission: It is defined as the propagation of ultrasonic stress waves between points that are located on the same surface of the material.

The direct transmission method is generally preferred, since the maximum energy of the pulse is being directed at the receiving transducer and this gives maximum sensitivity. In this investigation, direct transmission method was adopted in the case of most of the beam column joints, columns and beams. However, due to the
prevailing site conditions, indirect method of measurement was adopted in a few external beam column joints and all the walls.

Direct and indirect methods of measurement were adopted for the girders and corbels of the crane supporting structure in Zones 1, 3 and 6. In the case of the RC Stack, indirect method of measurement was adopted due to the prevailing site condition and the tests were conducted for a height of 2 m from the ground level. The indirect velocity is invariably lower than the direct velocity on the same concrete element. For good quality concrete, a difference of about 0.5 km/ sec may generally be expected as per BIS standard [2]. Hence, in this investigation, a correction factor of 0.5 km/sec has been applied to all the USPV values obtained through indirect method of measurement.

The general guidelines for assessing the quality of concrete based on pulse velocity values of concrete as per –BIS standard [2] are as follows:

| S. No | Indicative Quality | USPV readings in km/sec |
|-------|--------------------|-------------------------|
| 1     | Excellent          | Greater than 4.50 km/Sec.|  
| 2     | Good               | Between 4.50 & 3.50 km/Sec. |
| 3     | Medium             | Between 3.5 & 3.00 km/Sec. |
| 4     | Doubtful           | Lesser than 3.00 km/Sec.  |

2.1.1 Selection of Location for USPV test

Since the investigations were aimed at seismic requalification of the structure, prominence was given to the beam columns joints, which are most vulnerable during a seismic excitation. Durability is of prime concern in the long term performance of the structure towards serviceability and consequently play important role in the structural response during a seismic excitation. Therefore all the tests pertaining to the durability were performed in a majority of the locations on the external members.

In the case of USPV, the following structural elements were investigated

- External Beam Column Joints
- Internal Beam Column Joints
- Columns
- Beams
- Walls
- Crane supporting structure (Girders and Corbels)
- RC Stack

In the case of both internal as well as external beam column joints, the tests were conducted at a distance of 2D from the face of the joint in the column and beam locations at spacing of 300 mm c/c. The testing was conducted at all the levels of the various zones. In the case of the columns, the element was scanned along the height of the column while in the case of the beams; it was scanned along the span. The testing was conducted at all the levels of the various zones.

2.2 Rebound Hammer Test

The testing of concrete by rebound hammer method (also known as surface hardness test) is generally considered as a useful preliminary or complimentary method to other tests to assess the quality of near surface layer of the concrete. These tests will reveal whether any delamination has taken place due to corrosion initiation inside the structural member. In such cases, the energy will get dissipated in the area around the rebar due to corrosion and result in very low rebound hammer number. Hardness measurements provide information on the quality of only the near surface layer (about 30 mm to 90 mm thickness) of the concrete. Rebound hammer test requires smooth and
non-oily surface. The rebound hammer, which was used in this investigation, was of the type ‘N’ hammers, having impact energy of 2.2 Nm. Rebound hammer tests were conducted at the same locations as the UPV tests in order to obtain corroborated results at the various levels of Zones 1-6 of the building.

2.3 Core Sampling of Concrete

Concrete core samples were extracted from selected RC columns and beams of the Zones 1-6 of the structure. The diameter of the core samples that were extracted was 69 mm. A Profoscope was used to identify the locations of the reinforcement in the structural elements that were chosen for the core test. Subsequently, cores were drilled from those chosen locations of the members which did not contain reinforcement and following tests were performed on them.

2.3.1 Carbonation test

Immediately after the extraction of the concrete core samples, they were tested to check for carbonation. The cylindrical concrete core samples were sprayed with 1% solution of phenolphthalein in alcohol indicator. If the sprayed portion results in colorless surface, it indicated the extent of the carbonation.

2.3.2 Unit Weight and Water Absorption Tests

After the core samples were brought to the laboratory, they were dressed by cutting the edges suitably and the cylindrical test specimens of 69 mm diameter and of sufficient length were obtained. These core samples were then evaluated for their unit weight. Subsequently, they were placed in an oven at 105 D Celsius for 24 hours and their dry weight obtained (W1). They were then immersed in water for a period of 24 hours and their wet weight measured (W2). The water absorption of the core samples were then evaluated using the equation:

\[
\text{Water absorption (\%)} = 100 \times \frac{(W2 - W1)}{W1}
\]

2.3.3 Compression Test on Core Samples

The cylindrical test specimens were then capped with a sulphur compound and tested in a 3000 KN compression testing machine to obtain their compressive strength. The equivalent cube compressive strength was obtained after applying the necessary correction factors given in BIS standards [5&6].

The criteria laid down in the clause 17.4.3 of BIS standard [7] for the acceptance of the core test results states that ‘Concrete in the member represented by a core test shall be considered acceptable if the average equivalent cube strength of the cores is equal to at least 85 percent of the cube strength of the grade of concrete specified for the corresponding age and no individual core has a strength less than 75 percent’. Accordingly, the salient values for the different grades of concrete from M20 to M45 are tabulated in Table 2.

![Table 2: Salient Strengths of Core Samples for Different Grades of Concrete](image)

| Grade of Concrete | Average equivalent core’s cube strength ≥ 85 % of cube strength of grade of Concrete (MPa) | Individual core’s cube strength ≥ 75 % of cube strength of grade of Concrete (MPa) |
|-------------------|-----------------------------------------------|-----------------------------------------------|
| M25               | 21.25                                         | 18.75                                         |
| M30               | 25.5                                          | 22.5                                          |
| M35               | 29.75                                         | 26.25                                         |
| M40               | 34                                            | 30                                            |
| M45               | 38.25                                         | 33.75                                         |

2.4 Half Cell Potential Test

Half-cell potential test works on the principle of measuring voltage in the circuit of reinforcement and cover concrete using Copper Sulphate Half-Cell. This method essentially consists of measurement of the absolute potential of the concrete with reference to the reference electrode.
The half-cell potential measurements were conducted on the columns of the various zones of the buildings. It is a pre requisite that the structural elements that are to be subjected to half-cell measurements have to be fully saturated during the measurements and hence the structural elements were pre wetted before taking the readings.

2.5 Chemical Analysis of the Concrete Powder Samples

Concrete samples in powder form were drawn from the various locations of the beams, columns and walls of the 6 zones using a masonry drilling machine. These samples were collected for chemical analysis of concrete to check for the presence of aggressive chemical agents, such as, chlorides, sulphates and pH. In all 14 samples were extracted from the various columns, beams and walls of the six zones. Each sample in turn comprised of three samples drawn from 0-15 mm, 15-30 mm and 30-45 mm across the cross section to analyze the chloride, sulphate and pH profile of the concrete.

3. Results & Discussions

3.1 Ultrasonic Pulse Velocity Test

It is found that the average USPV values for the RC Beam column joints, columns and beams at the various levels of Zones 1, 3, 4 and 5 are above 4.0 km/sec and hence the integrity of concrete can be considered as ‘Good’ as per the guidelines of BIS standard [2] (Table 1). The average UPV values for the RC Beam column joints, columns, beams and walls in the various levels of Zones 2 and 6 are well above 3.5 km/sec and hence the integrity of concrete can be considered as ‘Good’ as per the guidelines of BIS standard [2]. The minimum values obtained from almost all of the locations itself are above 3.5 km/sec, indicating that the integrity of concrete is consistent throughout the structure.

The average USPV values for the girders and the corbels of the crane supporting structure as well as the RC Stack are determined to be above 4.0 km/sec and hence the integrity of concrete can be considered as ‘Good’ as per the guidelines of BIS standard [2] (Table 1).

3.2 Rebound Hammer Test

Rebound hammer values are consistently in the range of 40 and above, indicating that the quality of concrete in the near surface portions of the various structural elements is satisfactory in all the six zones.

3.3 Core Sampling of Concrete

Results of the tests conducted on core samples extracted from selected beams and columns of Zones 1-6 are discussed below.

3.3.1 Carbonation Test

The concrete core samples extracted from columns and beams from Zones 1 to 3 showed no carbonation. In the case of Zones 4 and 5, only one external column from each zone (External R1- 2- Level 1 and External column O4- Level 1) showed carbonation to a depth of 30 mm and 10 mm respectively. In the case of Zone 6, two columns (External column F-13- Level 1 and internal column D-2- Level 1) showed carbonation depths of 20 mm and 12 mm respectively. Reported Carbonation depths are much less than the provided clear cover to the reinforcement and hence it can be inferred that the concrete is in ‘Satisfactory’ condition regarding progress of carbonation and the propensity of corrosion in reinforcing steel would be minimal considering this aspect.

3.3.2 Unit Weight and Water Absorption Tests

The unit weights of the core samples range from 2378- 2581 kg/m3 for the various core samples. The water absorption values were in the range of 1.94-4.09% for the core samples in Zones 1-6. Since mineral admixtures have not been used in the design of the concrete mixes during construction, the water absorption values obtained appear to be reasonable and health of concrete appears to be satisfactory.
3.3.3 Compression Test

Average equivalent cube compressive strength was calculated for each zone and result are presented in Table 3 below.

As per the clause 17.4.3 of BIS standard [7]& Table 2, the concrete in Zones 1, 3, 4 and 6 may be deemed to be of M40 grade, while it may be deemed to be M35 grade in Zone 2 and M45 in Zone 5. In all the cases, the grade of concrete was decided based on the lowest equivalent cube compressive strength obtained in the respective zones. The variations in the equivalent cube compressive strengths could be attributed to the higher water cement ratios that must have been adopted at the time of construction of certain structural elements of the structure.

Table 3: Strengths of Core Samples obtained for Different Zones of the Building

| ZONE | Average equivalent cube compressive strength (N/mm²) | Minimum equivalent cube compressive strength (N/mm²) of any specimen |
|------|-----------------------------------------------------|-------------------------------------------------------------------|
| Zone I | 37.64                                               | 31.9                                                              |
| Zone II | 37.36                                              | 29.7                                                              |
| Zone III | 40.1                                                | 30.3                                                              |
| Zone IV | 39.1                                                | 30.5                                                              |
| Zone V | 45                                                  | 35.4                                                              |
| Zone VI | 45.1                                                 | 32.2                                                              |

3.4 Half Cell Potential Test

Reported half-cell potential readings were less than -200 mV in all of the locations in all zones indicating that there is no reinforcing steel corrosion is occurring in that area at the time of measurement as per the reference guidelines of ASTM standard [4]. In majority of locations there is no sign of corrosion, so the condition of concrete can be ascertained as ‘Good’.

3.5 Results of Chemical Analysis

It is seen that the pH values of the samples are above 11.8 indicating the availability of sufficient alkalinity, which is in tune with the results of the carbonation tests conducted on the core samples. The sulphate values of all the powder samples are well within the threshold limit of 4.0% specified in BIS standard [7]. The chloride values are much less than the threshold value of 0.6 kg/m³ specified in BIS standard [7]. Since values are found to be within threshold limits, quality of concrete can be considered as ‘good’ and satisfactory.

4. Summary and Conclusions

Based on the NDT investigations conducted on the various structural elements of the structure, the following conclusions may be drawn:

- The average USPV values for the RC Beam column joints, columns, beams and walls in the various levels of Zones 1-6 are well above 3.5 km/sec and hence the integrity of concrete can be considered as ‘Good’ as per the guidelines of BIS standard [2].
- The average USPV values for the girders and the corbels of the crane supporting structure as well as the RC Stack are above 4.0 km/sec and hence the integrity of concrete can be considered as ‘Good’ as per the guidelines of BIS standard [2].
- The rebound hammer values are consistently in the range of 40 and above, indicating that the quality of concrete in the near surface portions of the various structural elements is satisfactory in all the six zones.
- Reported carbonation depths for all beams and columns are much less than provided clear cover to the reinforcement.
The water absorption values of the core samples were in the range of 1.94-4.09% for the core samples in Zones 1-6. Since mineral admixtures have not been used in the design of the concrete mixes during construction, the water absorption values obtained appear to be in the reasonable range.

The unit weights of the core samples varied from 2378- 2581 kg/m³ for the various core samples.

As per the Clause 17.4.3 of BIS standard [7], the concrete in Zones 1, 3, 4 and 6 may be deemed to be of M40 grade, while it may be deemed to be M35 grade in the case of the Zone 5. The grade of concrete in Zone 2 may be deemed to be M30. In all the cases, the grade of concrete was decided based on the lowest equivalent cube compressive strength obtained in the respective zones.

The reported half-cell potential readings indicate that there is no sign of corrosion activity in all zones. The pH values of the samples are above 11.8 indicating the availability of sufficient alkalinity, which is in tune with the carbonation tests conducted on the core samples. The sulphate values of all the powder samples are well within the threshold limit of 4.0% specified in BIS standard [7]. The chloride values of the powder samples are much less than the threshold value of 0.6 kg/m³ specified in BIS standard [7].

Most important parameters in determination of health of concrete are strength and durability of concrete. For the results of compression test, compressive strength of concrete and corresponding grade was determined. The other tests like half-cell potential, carbonation, chemical analysis etc. impinge on the durability aspect of concrete. Results suggest concrete despite being exposed for a service period of 15 years has been able to withstand corrosion. Chemical analysis results determine that exposure to chemical like sulphates, chlorides which can destroy integrity of concrete and can have disastrous effects, is within bounds.

5. References

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