Evaluation of Long-term Performance of a structure using Non-Destructive Testing Techniques

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Abstract--**Non-Destructive Testing is the technique which permit testing of materials and structures without impairing the usefulness and performance of the structures. Non-Destructive Testing (NDT) Techniques have been used since last 20 to 25 years. These techniques have been adopted for various applications and for variety of structures. The various applications of NDT Techniques include assessment of overall quality/strength of concrete, diagnosis and categorization of distressed structures and ascertaining existing condition of concrete. NDT techniques are also widely used to check performance of repairs. IS 456-2000 has also stipulated the use of some of NDT techniques under clause of inspection and testing of structures. Preliminary investigation of a distressed structure has to be carried out before application of NDT. The preliminary investigation consist a detailed visual inspection. Considering the findings of the preliminary investigations, it is to be decided to carry out appropriate NDT techniques at selected locations so that more representative idea about the present state of the structure as well as the extent of the damage could be obtained. Non-Destructive testing results can give better idea about quality of concrete. To correlate NDT results with in-situ concrete strength, one need to establish correlation between NDT results and in-situ concrete strength. Many of the NDT equipment manufacturers provide charts or tables to correlate results and concrete strength, but as many factors affect NDT results, the given correlation can not be applied in any condition. Ultrasonic Pulse Velocity test and Pull out test have been proved very effective Non-Destructive testing techniques to assess quality and in-situ strength of concrete. Though Pull-out test is semi destructive test, it can be considered as NDT technique because it does not impair strength and stability of structure.**

Index Terms--**Non-Destructive Testing (NDT), Quality of concrete, Deterioration, Strength of concrete**

I. INTRODUCTION

This work presents details of the testing work carried out for evaluation of a structure by NDT Techniques. The investigated structure was a tourist complex and constructed before 23 years. The structure had a combination of reinforced concrete beam-column system and load bearing wall system. It was ground plus one storey on three wings and only ground structure on fourth wing. Walls are of rubble masonry. The owner wanted to make the structure as ground plus two storeys. It was essential to consider existing available strength and safety aspects for further constructions. So, NDT was proposed to assess extent and cause of deterioration from the durability point of view. The NDT techniques which had been carried out were Ultrasonic Pulse Velocity test, Rebound Hammer test, Pull-out test, Half-cell Potentiometer test and Carbonation test.

II. VISUAL INSPECTION

Information regarding structural system, design parameters, mix grade, cover thickness and reinforcement details were not available. Structural system was identified by visual inspection. Positions of columns were found out and reinforcement details of columns, beams and footings were also detected. The proposed building was a composite structure having partly load bearing and partly beam-column-slab system. There is no R.C.C.framing in any of the wings.

It was revealed that Indian waterproofing system was provided on roof slab at a very later stage, as earlier leakage from roof slab had caused considerable deterioration.

Ingress of moisture and oxygen has made considerable damage to balcony slab, R.C.C. pardis, drop walls, copings, edges of floor and roof slabs, canopy slabs and lintels by way of corrosion of reinforcement, delaminating of covers to the concrete and cracking of cover along reinforcement which caused exposure of reinforcement in many areas. Carbonation, seepage, honeycombing and poor concreting were observed in several columns. Some of the column dowels had also exposed. Second lift was very poor in one of the outer face column of east side wing. About 30% columns showed horizontal cracks in concrete. These observations reflect on poor quality of concrete. All weather sheds, canopies, balconies, drop R.C.C. wall and railing, some external columns, edges of roof slab and some sunken slabs showed stains of seepage, elimination of concrete covers, cracking of covers along reinforcement and exposure of reinforcing bars in some areas.

III. NDT TECHNIQUES and PRACTICAL WORK

Ultrasonic Pulse Velocity Test (UPV)

Principle

In a concrete member pulse wave propagation is an effective indicator of the interior quality of that concrete.

Reference code

IS 13311 (part-I) 1992 Non- Destructive Testing of Concrete Methods of Test – Ultrasonic Pulse Velocity

Apparatus and Operation

The apparatus for UPV measurement consist of

(a) electrical pulse generator

(b) transducer – one pair

(c) amplifier

(d) electronic timing device

Transducers can be placed in three ways which are direct transmission, indirect transmission and surface transmission. Among three, direct method is the best to get accurate results. There should be an adequate acoustical coupling between the concrete and the face of each transducer by means of couplants like petroleum jelly, grease, liquid soap and kaolin glycerol paste.

An electro acoustical transducer generates the ultrasonic pulse. When the pulse is induced into the concrete from a transducer, it undergoes multiple reflections at the boundaries of the different material phases within the concrete.

A complex system of stress wave is developed which includes longitudinal, shear and surface waves. The receiving transducer detects the onset of the longitudinal waves, which are the fastest.

The pulse velocity is given by $V = \frac{L}{T}$ where,

L = path length of pulse and T = Travel time of measured pulse in microseconds.

Method Of Interpretation of Results

Higher pulse velocities are obtained when the quality of concrete in terms of density, homogeneity and uniformity is good. In case of poor quality of concrete, lower velocities are obtained.

If there is crack, void or flaw inside the concrete which comes in the way of transmission of the pulses, the pulse strength decreased and it passes around the discontinuity thereby making the path length longer. The actual pulse velocity obtained depends primary upon the materials of mix proportions of concrete, density and modulus of elasticity of aggregate. According to Indian Standard Code, following is the criteria to correlate pulse velocity reading and quality of concrete.

TABLE I
Velocity Criterion

Pulse Velocity (km/sec)	Concrete Quality Grading
Above 4.5	Excellent
3.5 to 4.5	Good
3 to 3.5	Medium
Below 3.0	Poor

EXPERIMENTAL WORK and EVALUATION OF RESULTS

In this test, two numbers of transducers with two inches diameter and 200 kHz frequency were used. A standard reference bar was provided for calibration having an accurately known indirect transmission time of about 64.5 microseconds. Correlation of quality of concrete with UPV results is as per IS:13311(part-1).

UPV test has been carried out on three footings, thirteen columns at ground floor, five columns at first floor, five beams and three roof slabs. Pulse velocity readings have been taken at four to five spots on each structural element which was to be inspected.

UPV test on footings showed poor to medium quality of concrete as readings varies from 2159 m/sec to 3919 m/sec. UPV values of internal column footings were 2324 m/sec to 3234 m/sec, also indicates medium quality of concrete. Both direct and indirect methods were used to measure ultrasonic pulse velocity on ground floor columns. Readings on most of the columns show pulse velocity below 3000 m/sec indicates poor quality of concrete.

It was revealed that nine among thirteen columns showed no readings on most of the spots, which indicates extremely poor quality of concrete.

Results of UPV on first floor columns also varied from 649 m/sec to 2173 m/sec indicated poor quality of concrete, while two of the columns showed no readings. Quality of concrete of three of the beams was extremely poor since yielded no readings at many spots.

Concrete quality of slab was also very poor as reading showed velocity below 3000 m/sec and no readings at most of the locations.

Rebound Hammer Test

Principle

When the plunger of the rebound hammer is pressed against the surface of the concrete, the spring controlled mass rebounds. The rebound distance depends on the kinetic energy in the hammer before impact and how much of that energy is absorbed during the impact. The energy absorbed is related to the strength, low strength concrete will absorb more energy than a high strength concrete. Thus the low strength concrete will result in a lower rebound.

Apparatus and Operation

The device consists of the following main components : (1) Plunger (2) Hammer (3) Spring

The plunger is pressed strongly and steadily against the spring loaded to its surface, until the spring loaded mass is triggered from its locked portion. After the impacts, the scale index is read on hammer. The locking button may be pressed to enable the reading to be retained. The scale reading is known as the rebound number.

Method of Interpretation of results

The influence of the variables are so great that it is very unlikely that a general calibration curve relating rebound number to strength, as provided by the equipment manufactures, will be of any practical value. The large derivation in strength can be narrowed down considerably by proper calibration of hammer. It is also pointed out that rebound numbers are indicative of compressive strength of concrete to a limited depth from the surface.

So, Rebound Hammer test must not be regarded as a substitute for standard compression test but should be considered as a method for determining the uniformity of concrete in the structures and comparing one concrete against another.

EXPERIMENTAL WORK and EVALUATION OF RESULTS

In this work, N-type rebound hammer was used. A standard steel anvil with known rebound number (32) was provided by manufacturer for calibration of rebound hammer. After each 3 readings hammer was calibrated. Interpretation charts for correlation between rebound number and compressive strength was given on rebound hammer.

Surface preparation was made by chipping out plaster and smoothen the surface. Rebound hammer test has been carried out on five ground floor columns. Readings of rebound number have been taken at four to five spots on each column which was to be inspected.

Rebound hammer results of columns at ground floor revealed concrete of varying surface hardness corresponding to varying compressive strength of 10 N/mm^2 to 40 N/mm^2. The low values of rebound number as below 20 indicates damaged areas.

CAPO TEST - Cut and Pull out test

Principle

Pull-out test measures the force required to pull out from the concrete a specially shaped steel rod that’s enlarged and has been cast into that concrete. The pull-out force is translated to compressive strength by the use of an empirical calibration.

Apparatus and Operation

In this test, concrete already cast can be handled by drilling a hole and under cutting the core for plate position. It is for use in situations where use cannot be pre planned. Pull-out insert consists of an expanding ring inserted into an undercut groove.

Procedure consists of drilling a 45 mm deep, 18 mm diameter hole, after which a 25 mm groove is cut at a depth of 25 mm using a portable drilling machine. The expanding ring insert is then placed, which is expanded in the groove and pulled by hand operated hydraulic pump.

Method of Interpretation of Results

The equipment can determine the force required to cause failure by pulling operation. Calibration charts and tables provided by the manufactures of equipment are them used to estimate the compressive strength of concrete. This test is proved very helpful when estimate of in-situ strength of concrete of unknown age or composition is required to be found out.

EXPERIMENTAL WORK and EVALUATION OF RESULTS

Manufacturer of pull out testing equipment was GERMANN INSTRUMENTS A/s, Denmark. Calibration table was provided by manufacturer to correlate pull-out force and compressive strength of concrete. This test had been carried out on two footings, two columns and two beams.

Concrete strength was normally expected as 15 N/mm^2 at the time of construction. Results of four out of six tested structural elements showed much less present concrete strength as varied from 9.6 N/mm^2 to 11 N/mm^2. Although two of them showed present compressive strength as 18.5 $N/mm^2$and 15.5 N/mm^2, it could not be concluded as good strength considering age of the structure. The results should also be seen in the light of UPV test.

Half-Cell Potentiometer test

Principle

This method describes the detection of areas of reinforcement corrosion by measuring the potential of the reinforcement against an externally located reference electrode. Because of the corrosion of steel in concrete is an electrochemical process, it represents a galvanic element which is similar to a battery producing an electric current, measurable as an electric field on the surface of the concrete. This potential field can be measured with an electrode known as a half-cell.

Apparatus and Operation

Half cell consists of a copper/silver electrode immersed in an electrolyte of copper sulphate/silver chloride solution. The usual procedure is to connect negative terminal of the mill voltmeter to the half-cell reference electrode and the positive terminal is connected to the reinforcement.

Method of Interpretation of results

Successive readings can be taken by means of potential. The areas showing potential more negative than -350 mV relative to reference half-cell electrode, there 95% chance of corrosion. In such areas reinforcement bars may be actively corroding. In areas showing potentials less negative than -200 mV, corrosion is likely to be negligible.

EXPERIMENTAL WORK and EVALUATION OF RESULTS

Half Cell used was made of a copper electrode immersed in an electrolyte of copper sulphate solution.

This test had been carried out on two footings and six columns, readings were taken above plinth level as well as below plinth level on one of the columns. Half Cell potentiometer readings were observed at five to six spots on each of the elements.

Half Cell potential measurements on almost all the locations of one of the footings and one of the columns were numerically more negative than -350 mV as results varied from -380 mV to -429 mV, indicating active corrosion.

Other members showed readings less negative than -200 mV as results varied from -24 mV to + 187 mV, hence there was no chance of active corrosion.

Carbonation Test

The extent of carbonation can be easily assessed by following procedure. The exposed surface of a piece of concrete which is to be extracted from respective member should be treat with phenolphthalein indicator. When the concrete has been unaffected by carbonation, a purple-red coloration will be obtained. No coloration will appear in carbonated zone.

EXPERIMENTAL WORK and EVALUATION OF RESULTS

Carbonation test had been carried out on two footings, two columns and two beams. Considerable carbonation was observed in one of the columns and one of the beams as carbonation depth was observed as 35 mm and 25 mm, where concrete cove thickness was 40 mm and 30 mm respectively. So, corrosion was suspected on those elements.

IV. CONCLUSION

Finally, considering Non-Destructive Testing and analysis of results, conclusion can be drawn that existing R.C.C. members were not found to have adequate quality and strength of concrete. Most of structural members were suffered from deterioration. Overall status of concrete was below required standard. Hence, all the R.C.C. members needed repair, restoration and improvement as per requirement before additional floor construction.

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