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CONSIDERATIONS IN NON-DESTRUCTIVE ASSESSMENT OF CONCRETE STRUCTURES

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Abstract- *Assessment of concrete structures is required every now & then. Applications of nondestructive testing techniques in Structures become more specific since these have to serve for longer time. Various Non-Destructive Testing techniques are available to accomplish the task. Being indirect in nature in depth study of these techniques is prerequisite for both qualitative and quantitative analysis. Visit to site at the time of Non Destructive Testing of Concrete Structures is vital for appropriate inferences.*

Keywords- *NDT, visual inspection, Deterioration, UPV, RH, ESR*

I. INTRODUCTION

Structures are subjected to Natural disasters, Deterioration to be in distressed condition. Decision regard to their retrofitting, demolition has to be taken based on their condition assessment which is carried out using Non Destructive Testing techniques. Even in some structures Addition/ alterations may be required which again requires their NDT assessment. A good number of techniques are available in wide range of NDT. It is well known that NDT being indirect techniques requires inferences by expertise based on various aspects of material technology, Structural design, detailing and construction aspects. Additionally usefulness and limitations of these NDT techniques plays key role.

Problems in structures: There could be a number of problems in concrete structures well known to an engineer some of them are: Related to Foundation, Poor design/ detailing, Construction techniques, inferior material, Deterioration due to various reasons, excessive loading, natural catastrophes etc. Distress in structures can be seen visually at a later stage resulting in physical / chemical changes. Problems may be limited to few structural elements or the structure as a whole.

Preliminary assessment can be executed using Rapid Visual Screening i.e. by visual observation notes on standard format sheets with dimensions, physical changes visually seen, photo and basic input to decide for in depth survey using appropriate NDT scheme. Basic environmental features which can affect health of structure should be recorded in addition to other inputs e.g. repair history, reasons for distressed condition if known by interaction with local people.

Visual inspection is essentially required to plan NDT assessment of the concrete structure. Needless to mention that structure has to be checked and identified for good and bad quality of concrete, distressed locations in the structure, basic problems in the structure, nomenclature of structural elements. Measurement of elements/ structure's dimensions, presence of cracks & their nature/ properties, excessive deflections are to be paid attention to. Physical/ Chemical changes in the structure should be recorded. Ambient environment has to be taken care of e.g. presence of chloride in soil foundation media, water used in storage or construction or present in ground water, location of water body/ industry nearby.

User Requirement: Agency approaching Non Destructive assessment will have certain queries namely- Quality of constructed structure, Problems in structures with their reasons, Residual strength/ life or the structure, Retrofitting/ remedial measures etc.

Before visiting the site some important data is required: Age of the structure, reasons for its assessment, Geo technical investigation report, Ambient Environment, Design and detailing of the structure, Use of the structure and its repair history etc. This provides certain status to consider appropriate NDT techniques for investigation.

NDT techniques commonly available are Schmidt Rebound Hammer and Ultrasonic Pulse Velocity tester and Core extractor. Numerous other techniques available include: Pull off test, Sonic Integrity Tester, Pile Integrity Tester, Equipment to trace rebar's i.e. their alignment/ diameter/ cover to concrete, Half Cell Potentiometer, Resistivity Meter etc. Equipment's for chemical analysis comprise of Moisture meter, pH tester, Carbonation detector, Chloride tester, Alkali Aggregate Reactivity tester, Sulphate analyzer etc. Additionally Digital camera, portable microscope, equipments to trace rebars/ measure distances etc are useful tools. In case continuous monitoring is required on may be required to

use suitable sensors with real time data acquisition system. In certain cases advanced imaging equipments may be required.

II. TECHNIQUES FOR ASSESSMENT

Non Destructive Testing techniques available are:

1. Visual observations to find common defects e.g. cracking, excessive deflection, corrosion/ deterioration of concrete, Dimensional changes, Construction defects, problems of natural or manmade disasters etc.
2. Hardness based technique: Schmidt Rebound hammer can be used to find hardness of the concrete structure surface.
3. Ultra sound wave transmission: Ultra sonic Pulse Velocity Equipment can be used to observe wave transmission through Concrete structure.
4. Impact Echo technique: This Technique is used for two types of equipments namely Sonic Integrity Tester and Pile Integrity Tester. The technique is used to observe feature of a pile or structural element.
5. Electro Magnetic Techniques: Commonly these are known as Rebar locator, Profo meter, Cover meter etc. and used to locate details of Reinforcement bars e.g. Cover depth, bar diameter & their alignment. This has to be used very carefully.
6. Equipments to monitor Corrosion: Commonly used equipments are known as Half Cell Potentiometer, Resistivity Meter. In case of half-cell potentiometer structure forms part of cell circuit thus the name half-cell potentiometer. It measures voltage across the cell circuit to indicate state of the corrosion. Resistivity meter uses four point Wenner proceq probe to monitor resistivity of cover concrete. With this rate of corrosion is indicated. Thus a combination of these two equipments state and rate of corrosion can be estimated.
7. Permeability based tests: Laboratory and field test can be carried out using appropriate equipments e.g. Test on specimen in lab for permeability, ISAT test, Auto Clam equipment can be used find Water & Air permeability indices, Water absorption/ sorptivity, Initial Surface absorption whereas Permit can be used to observe Chloride migration through concrete cover. These two tests equipments are very important to know quality of cover concrete to estimate state of the structure related to deterioration & corrosion.
8. Pull Off test: Adhesion of overlay or new layer to old one can be tested with this equipment. Other variants of this test are Pull out test, Break off test etc.
9. Core testing: This is a typical test where core from concrete structure are extracted in different dia and length. Core can be used for evaluation of strength and deterioration process studying cover quality concrete.
10. Microscopic examination: Simple microscope or advanced one can be used at site or in lab depending on situation. Study using this is very useful to know visual observation at micro structure level.
11. Chemical Analysis Kit: Chemical tests at site can provide good information to assess impact of environment on structure. Various agencies affecting health of structure can be identified and accordingly remedial measures can be suggested. The kit can be used to monitor pH value, moisture content, Chloride effect, Carbonation, Alkali Aggregate Reaction, Sulphate affect etc
12. Advance techniques: Advance techniques can be employed if required these may include: Ground penetrating radar, Infra-Red Camera, X ray Diffraction meter, Scanning Electron Microscope etc
13. On site Loading test: This requires large paraphernalia including precise equipments and trained man power. The system includes Real time data acquisition system, appropriate sensors and loading system.
14. Recording devices which includes good camera and other accessories as needed for the work.

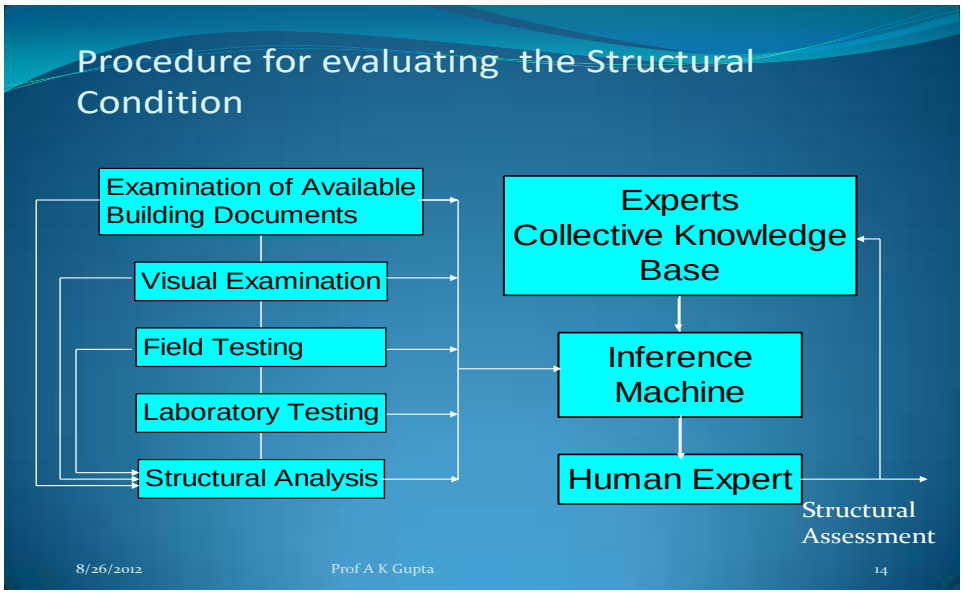

Figure 1 Procedure for Evaluating Structural Condition

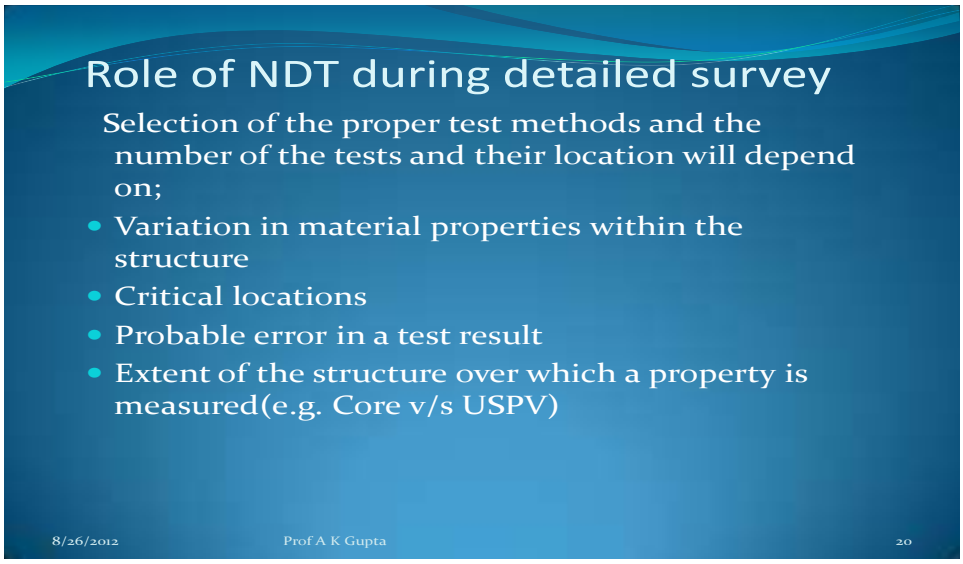

Figure 2 Role of NDT during detailed survey

15. NDT RESULTS

Results of a case study on a structure recently tested with certain NDT techniques is given here.

2.1 Data obtained from Schmidt Rebound Hammer Test:

Table:-1 Results of RH

S.N.	***Member No***	***Average Rebound no (6 readings)***	***Maximum Reading***	***Minimum Reading***	***Standard Deviation***	***Related Compressive Strength N /sq mm***	***Hammer Direction Horizontal, If not specified***
1.	J-6/4	32.7	27	38	4.5	29.5	
2.	J-6/9	28.8	25	33	3.2	23.2	
3.	J-6-13	25.8	23	29	2.0	18.5	
4.	J-6/16	33.7	25	42	6.4	31.2	
5.	J-1-14	27.5	22	33	4.9	21.1	
6.	J-1-19	22.8	16	29	4.4	19.0	
7.	J-1-21	21.7	20	24	1.5	12.3	
8.	H-10/16	20.3	18	23	1.6	10.4	
9.	H-11-16	17.8	15	22	2.6	Not given	
10.	H-11-13	21.0	17	27	3.8	11.4	

2.2 Data obtained with Ultra Sonic Pulse Velocity Tester

Table:-2 Results of UPV

S N	Member No.	Path length mm	Travel time µ sec	Velocity m/sec	(Direct Method if not mentioned) Strength with combined method N/ sq mm
1.	J-1-14	300	78.4	3830	
2.	J-2-25	300	224	1340	
3.	J-2/11	300	106.6	2810	
4.	G-2-22	300	74.7	4020	18.9
5.	G-4-2	300	74.6	4020	19.6
6.	G-7-16	300	76.6	3920	
7.	G-9/10	300	72.8	4120	22.3
8.	G-13-4	300	72	4170	24.8
9.	G-15/2	300	79.1	3790	12.3
10.	H-5/11	300	396	760	

2.3 Data obtained with Sonic Integrity Tester

Table:-3 Results of SIT

S.N.	Member No.	Wave Speed m/s	Depth with SIT mm	Height above Ground mm	Remarks
1.	H 66	2655	680	660	
2.	H 9-8	3947	1010	620	
3.	H 11-19	3046	780	600	Excavated up to 1.2m
4.	H 13-15	3659	937	570	
5.	H 15-4	3947	1010	580	
6.	H 15-2	-	1200	1220	

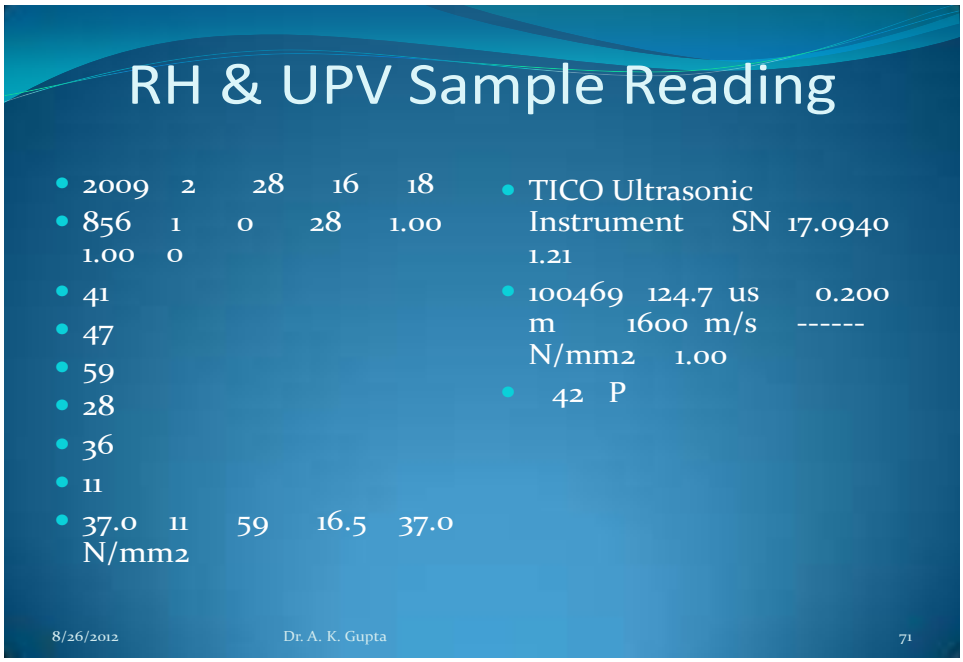

Figure 3 Sample readings obtained from Rebound hammer and Ultra sonic Tester

III. RESULTS OF SOME CASE STUDIES

Case -1 Raft Foundation of ESR:
Average Cube Compressive Strength at 7 days is 24.8 N/ sq mm
Average Rebound No at 4 days is 28.7 & Compressive strength by Rebound test is 22.9 N/ sq mm. Ultra sonic Pulse Velocity by Indirect method is 2940 m/s

Case -2 Slab of ESR:
Average Cube Compressive Strength at 7 days is 24.44 N/ sq mm and
at 28 days is 39.26 N/sq mm
Average Rebound No at 1 year is 48.2 & Compressive strength by Rebound test is 58.3 N/ sq mm. Ultra sonic Pulse Velocity by Direct method is 4150 m/s

Schmidt Rebound hammer readings observed on Schmidt Rebound hammer readings are related to surface hardness of the Concrete and its strength is related using inbuilt calibration curve in the instrument. The Schmidt Rebound hammer can have energy in the range of 0.75, 2.25 and 30.0 N-m. Two nearby points should be at least 20 mm away. The results may be affected by various factors e.g. Type of cement, type of Coarse Aggregates, Type of Form work, Moisture, Carbonation, Surface texture, Orientation of Instrument, Curing and Age etc. Advantages of the method are that it is speedy and simple. Whereas limitation is its wide range of results may up to +/- 25%. In certain cases strength with rebound hammer number may not necessarily be truly indicative of its compressive strength to the extent shown, these have to be corrected for different factors but it does give comparison of surface hardness for quality of concrete. Refer IS 13311 pt II.

Ultrasonic pulse velocity test indicate travel time through concrete continuous media. In Indirect method probes are kept on same side of the surface while in semi direct these are kept at right angles to each other. Selection of equipment is important one can refer to Path length, Frequency and Minimum dimension of the structural element as shown in the table.

Table:-4 UPV Standards

Path Length mm	< 500	500- 700	700- 1500	➢ 1500
Frequency KHz	150	➢ 60	➢ 40	➢ 20
Minimum Dimension mm	25	70	150	300

Higher pulse velocity indicates better quality of concrete e.g. velocity > 4.5 km/sec indicates excellent category, In between 4.5 to 3.5 it indicates Good category, In between 3.0 to 3.5 it indicates Medium and less than 3.0 indicates poor quality of concrete. Velocity may be affected by different factors e.g. Surface texture, Moisture, Temperature, Micro Cracks, Water/ Cement Ratio, Age of concrete, Presence of Rebars, Type of Cement and Coarse Aggregates, Size of C.A., Stress level of the component, Transmission method etc. Difference in velocities obtained by different methods should be compared with corrections as given in IS 13311 pt I.
Corrections, in percentage, for UPV are applied for temperature and moisture as given in the following table.

Table:-5 UPV Correction Factors

Temp C	+60	+50	+40	+20	0	-4 & below
Air Dried	+5.0	3.5	2.0	0.0	-0.5	-1.5
Water Saturated	+4.0	+2.8	+1.7	0.0	-1.0	-7.5

In Sonic Integrity Test instrument works on the basis of Impact Echo Method. In this technique low strain energy waves are transmitted through the medium. Response of wave transmission through the sample is recorded and studied. Two major instruments based on technique are popular namely Sonic Integrity Tester and Pile Integrity Tester. The method and the instrument developed by a team led by Mrs Dr Mary J Sansalone are considered to be successful for study of integrity and unknown geometric properties of the specimen.

Core can be extracted from the structure and tested as per Codal guidelines. The results have to be corrected for H/D ratio, Age of concrete, Presence of Rebars, Ratio of core to Cylinder and Cylinder to cube strength etc.

Corrosion is assessed with two tests namely Resistivity test and Half Cell Potentiometer test. Resistivity readings in the range (Ohm-Cm) > 12000, >5000->12000, < 5000 indicate Unlikely, Probable and Certain state of the corrosion respectively. Similarly for Half Cell Potentiometer readings in the range of >- 200 mV, -200 mV to -350 mV, < -350 mV indicate Initial phase, Transient Phase and Advanced Phase respectively.

NDT test indicate in surface hardness. Ultrasonic pulse velocity test show quality in undisturbed part. Rebound readings with standard deviation more than 5.0 show wide range of data and quality as well. Quality of concrete with Compressive strength obtained with Rebound hammer test more than 20.0 N / sq mm can be considered meeting desired level. Point where this is not shown may be checked with other methods to confirm their quality. Ultrasonic Pulse Velocity obtained less than 2000 m/s shows very poor quality, in the range of 2000 to 3000 m/sit shows doubtful quality of concrete. It can be considered medium if the velocity obtained is more than 3000 m/s, Good if the velocity is between 3500 to 4500 m/s and excellent if it is more than 4500 m/s. At some points compressive strength with combined Rebound and Ultra sonic Pulse Velocity are obtained showing more reliable results hence can be considered better. Sonic Integrity Test is a comparatively new technique in India. Its results are more sensitive to many factors hence should be used very carefully.

IV. RELIABILITY OF TECHNIQUES

Reliability of techniques

- Estimation of Loads: Gravity, Wind, Earthquake
- Methods of Analysis & Design
- Construction Techniques: Processes, Manpower, Tools, Quality Control- Testing Techniques
- Advancement in Technology: Modification in Standards, Techniques
- Use of Local/ Traditional Resources
- Environmental Friendly, Sustainable Techniques
- Assessment of Questionable Structures

Factors which can affect NDT results should be given due weightage to be closer to quantitative results. Use of multiple techniques is preferred to eliminate undesired data or affect may be due to moisture/ temperature or chemical exposure etc. In absence of proper calibration curve correlation of NDT results with core and lab testing should be established to

improve interpretations. With due consideration to various factors discussed above it is just possible to carry out quantitative assessment of concrete structures.

V. INTERPRETATION of N D T TECHNIQUES

Interpretation of N D T

- One should be aware of limitations of the NDT techniques
- Site conditions are critical to influence results
- NDT being Indirect requires Correlation between NDT and Destructive Tests
- Effects of Parameters on NDT and Destructive Tests is Essential
- Proper Correction Factors should be applied
- An Expert should be present at the site
- Basics of Concrete, Rebars etc are important for inferences
- Any doubt should be clarified by the load tests
- Being indirect in nature Calibration and correction factors become vital
- Any doubt should be clarified by the load tests

NDT techniques should be employed with care and practical considerations. It is generally preferred that combinations of techniques are employed to get better results.

P1- Schmidt Rebound Hammer observations

Photo-2 Ultrasonic Pulse Velocity test

Photo 3 Sonic IntegrityTesting at site

Photo-4 Core Testing in lab

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