

REPAIR AND RETROFITTING OF DAMAGED STRUCTURES

M.D. Pidurkar¹, Dr. A.M. Shende², A.V. Harde³

¹ (Department of Civil Engg, Priyadarshini J L College of Engineering, Nagpur, / RTMNU, India)

² (Principal, Priyadarshini J L College of Engineering, Nagpur, / RTMNU, India)

³(Department of Mech Engg, Priyadarshini J L College of Engineering, Nagpur, / RTMNU, India,)

Abstract : The importance and need for condition assessment and evaluation of safety of existing buildings and foundations in disaster prone areas have been highlighted in this guideline. An overview of the procedures and different investigations including tests involved in condition assessment and evaluation of safety is presented in a simple. It can be seen that detailed visual inspection and Non Destructive Testing (NDT) plays an important role in condition assessment of existing buildings. It may be emphasized here that a great deal of expertise is required for interpretation of field observations and test results to make a proper assessment of the condition as well as for analyzing and evaluating safety

Keywords: - Condition Assessment, Stability, Durability of RCC Buildings

I. INTRODUCTION

FACTORS CAUSING BUILDING DISTRESS

- (i) The reason for distress during service is the lack of maintenance of the building which results in deterioration/aging of materials and structural components leading to corrosion and cracking.
- (ii) Buildings or structures are damaged at different grades of damage when they experience extreme loading conditions like in severe earthquakes or cyclonic storms for which they are not designed.
- (iii) They may also fail if the building including the foundation is not properly designed and constructed following the standard Codes of practice. An impression exists that taller structures are seismically unsafe in comparison with low-rise buildings. On the contrary, when properly designed and built, taller structures are generally safer. It is to be noted that most lives were lost in Kachchh (Gujarat) earthquake of 2001 in one and two storeyed masonry buildings. Hence, *all* buildings have to be built safe.
- (iv) Inadequacy of design and poor quality of construction and maintenance are therefore the main reasons for the distress seen in buildings during service or under natural hazards. This is because building codes and byelaws are not conscientiously followed in design and quality of construction, or in maintenance.

II. CONDITION ASSESSMENT OF BUILDINGS

- 2.1 Main objective of condition assessment are to place the building into one of the following three categories:
- A. The building has not shown any signs of distress and it satisfies all the safety and serviceability requirements according to relevant Codes of practice, hence no action is needed towards retrofitting.
 - B. The building is seen to be deficient (or distressed) but it can be repaired and strengthened to satisfy the Codal safety requirements or performance criteria set by the user.
 - C. The building is badly damaged. It is to be demolished and a new building may be built, build back better.
- 2.2 Main steps of condition assessment will be
- a) To record the damage if any, and find out the causes for distress
 - b) To assess the extent of distress and to estimate the residual strengths of structural components and the system including the foundation.
 - c) To plan the rehabilitation and retrofitting/strengthening of the building.
- 2.3 Typical visible distress detrimental to the safety of buildings Cracks in RC beams (Fig.1), Columns (Fig 2), slabs, masonry walls (particularly if the walls are load bearing walls) (Fig. 3, 4), spalling of concrete, sagging of beams or slabs and tilting of columns or RC frames (out of plumb) (Fig.5), and major failure of

structural members (Fig.6), Corrosion in the RC slab (lack of control on the cover) (Fig. 7) are the typical types of crucial damages that will require structural repairs to bring back the lost strength. Such actions will need to be done along with retrofitting.



Figure 1: Cracks in RC beams



Figure 2: Cracks in Columns



Figure 3: Cracks in Masonary Wall

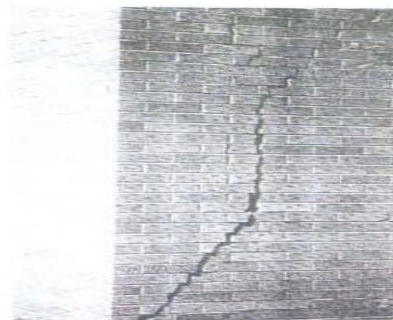


Figure 4: Cracks in Masonary Wall



Figure 5: Tilting of Columns



Figure 6: failure in column beam joint



Figure 7: Corrosion in the RC slab (lack of control on the cover)

III. MAIN CAUSES OF SUCH DISTRESS IN BUILDINGS

Either one or more of the factors listed below may cause distress in buildings:

- Deficiencies in design
- Poor detailing of reinforcement in RC structural members and joints
- Poor quality of construction
- Corrosion of reinforcement due to aggressive environment.
- Inadequacies in the structural system to resist lateral forces due to natural hazards like cyclones and earthquakes.
- Settlement or differential settlement of foundation
- Extreme and unforeseen loading.

IV. METHODOLOGY OF CONDITION ASSESSMENT

Condition assessment and evaluation is generally carried out in two levels:

- (i) Preliminary and
- (ii) Detailed.

If we get adequate information to assess the safety of the building at the preliminary investigation level, detailed investigation, which involves considerable cost and time, may not be recommended.

4.1 Rapid (Visual) Investigation

There are mainly three components and steps:

- Collection of information and details about the building design, construction, utilization, and maintenance in the past
- Visual inspection of condition at site and recording details of distress
- Evaluation of safety against the provisions in building codes or specified performance criteria

4.2 Information needed for Rapid investigation

One needs a complete record of building design details and drawings, architectural details, construction details and drawings including the specifications of materials used, geotechnical details of the area and foundation particulars, details of any repair or retrofitting done from the time of construction, details of usage of the building including the loads. Some nondestructive testing may be required to check the strength of concrete masonry etc.

If the above information is not available, detailed investigations have to be conducted.

4.3 Details in visual Investigation

The main purpose of visual investigation is to observe and note down all the items of distress or design deficiency and their locations, supported by sketches and drawings. The visual inspection includes:

- Verification of the accuracy of the original drawings or determination of basic building information, if no drawings are available.
- Identification of major alterations not shown on the original construction documents.
- Identification of visible structural damage, such as concrete cracking or spalling, and observations on quality of construction
- Identification of potential non-structural falling hazards, including ceilings, partitions, curtain Walls, parapets, fixtures, and other non-structural building elements.
- Observations on the condition of soil and the foundation
- Documentation of existing conditions with photographs at key locations.

Details about any deviations observed at the site from the original drawings have also to be recorded.

Based on the data collected about the details of the building, visual observation of damage/distress in different structural components and the system, structural engineers experts can categorize the type and severity of damage and make judgments about further course of action.

Rapid assessment of safety of buildings becomes necessary in the aftermath of natural disasters like earthquakes to take decisions about possible evacuation of unsafe buildings to save lives.

4.4 DETAILED INVESTIGATIONS

4.4.1 Need and actions

When the construction drawings about the building giving the layout and the structural details of the system (including the specifications of materials used) and its foundation are not available, detailed investigations have to be conducted about the total structural system besides of course the details on type, location, and severity of damage or distress in various members and the system.

Measurements may have to be made on the existing building to note the dimensions of the structural elements. Properties of structural materials, namely, concrete, steel reinforcement and masonry, in the representative structural members, will be necessary by conducting Non-Destructive Testing (NDT) in the field and by carrying out laboratory investigations on samples collected from the field. Details of soil profile and its characterization have to be obtained by collecting data or by conducting necessary geotechnical investigations. These details are necessary for analyzing/evaluating the safety of the building and to recommend retrofitting/strengthening measures.

Tests for assessment of in-situ quality of reinforced concrete

After identification of weak zones in a structure, detailed assessment of the in-situ quality of the material is to be done. A number of tests have been developed and standardized for different properties of concrete. Suitable tests are to be selected based on the aims of testing. A list of various available tests is given below:

4.5 TESTS FOR CONCRETE STRENGTH

Concrete strength is the most important parameter in assessing the safety of a structure against loading. Due to lack of construction supervision, sometimes, very low strength concrete may be encountered in existing structures. Such locations are to be identified and suitable remedial measures to be taken. The testing methods for concrete strength vary from very indirect surface hardness test to the direct testing of concrete strength by removing cores.

Non-destructive tests

These tests are based on indirect measurement of concrete strength through measurement of surface hardness and dynamic modulus of elasticity. Calibration curves relating these properties with the strength of concrete are available. For surface hardness rebound of an impact from the concrete surface is measured.

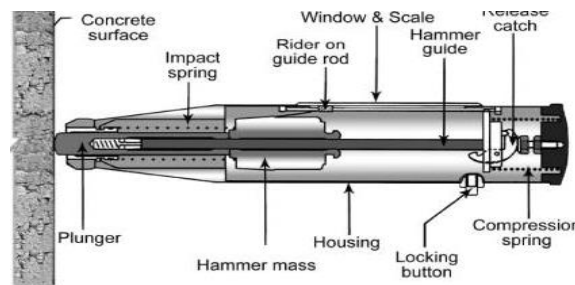
The most commonly adopted NDT methods for assessment of strength of concrete and their principles are given in the following:

Table 1: NDT methods and principles

Rebound Hammer	Spring-driven mass strikes surface of concrete and rebound distance is given in R-values. Surface hardness is measured and strength estimated from calibration curves, keeping in mind the limitations.
Ultrasonic Pulse Velocity	It operates on principle that stress wave propagation velocity is affected by quality of concrete. Pulse waves are induced in materials and the time of arrival measured at the receiving surface with a receiver. Ultrasonic pulse velocity is influenced by elastic modulus and strength of concrete.
Penetration resistance	Probes are gun-driven into concrete, depth of penetration converted to estimates of concrete strength by using calibration curves
Pull-off testing	Circular steel probe is bonded to concrete. Tensile force is applied using portable mechanical system until concrete fails. Compressive strength can be estimated using calibration charts
Core testing	Drilled cylindrical core is removed from structure, tests may be performed on core to determine compressive and tensile strength, torsional properties, static modulus of elasticity, etc.

4.5.1 Rebound Hammer Test

A simple equipment known as Rebound Hammer or Schmidt Hammer is used for this purpose. The test gives an idea about the soundness and quality of cover concrete. Locations having very low rebound numbers indicate weak surface concrete and may be affected by corrosion. The quality of concrete may be interpreted as shown in the Table 2.



Average Rebound Number	Quality of Concrete
>40	Very good hard layer
30 to 40	Good layer
20 to 30	Fair
< 20	Poor concrete
0	Delaminated

4.5.2. Ultrasonic Pulse Velocity (UPV)

The dynamic modulus of elasticity of concrete is measured by measuring the velocity of ultrasonic pulse through concrete. The test equipment has provisions for generating ultrasonic pulse, transmitting it to concrete, receiving and amplifying the pulse and measuring and displaying the pulse travel time. The details of the equipment are shown in Fig. Good acoustic coupling between the transducers and concrete is to be established for correct measurement of the speed. By this technique one can assess the quality of concrete such as honey combing & compaction indicated in the table, However, a great deal of caution has to be exercised in predicting the strength of concrete based on pulse velocity values.

UPV value in km/sec (V)	Concrete quality
V greater than 4.0	Very good
V between 3.5 and 4.0	Good, but may be porous
V between 3.0 and 3.5	Poor
V between 2.5 and 3.0	Very poor
V between 2.0 and 2.5	Very poor and low integrity
V Less than 2.0 and reading fluctuating	No integrity, large voids suspected



4.5.3. Core tests

The core test provides the visual inspection of the interior of the concrete and direct measurement of the compressive strength. Other physical properties, such as, density, water absorption, indirect tensile strength and expansion due to alkali-aggregate reaction can also be measured. After strength testing, these can be used as samples for chemical analysis. The procedure has been standardized by BS, ASTM and ACI codes.

In core testing, the determination of core size and location is a crucial factor. The test should be taken at points where minimum strength and maximum stress are likely to coincide. But, at the same time, the core cutting causes some damage to the member and may impair the future performance of the member. Therefore, in slender members, the core should be taken away from the critical section. For compression testing, the diameter of the core should be at least three times the nominal maximum aggregate size. The accuracy of the test increases with the ratio of core diameter to the aggregate size. The generally recommended length to diameter ratio of the cores is between 1 to 2.

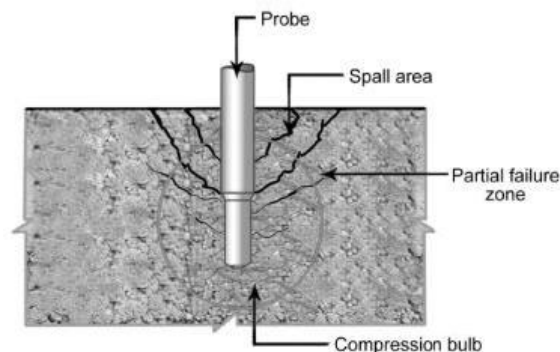
The core samples can be used for determination of unit weight, estimation of voids, and chemical analysis, a graphic analysis and analysis. Broken samples from the cores can be used to determine the pH value and the chloride content in the sample. These tests on cores and core samples will also provide information that can be used to assess the state of corrosion of reinforcing steel.

4.5.4. Partially destructive tests

These are surface zone tests, which require access to one exposed concrete face and cause some localized damage. This damage is sufficiently small to cause no loss in structural performance. The strength of concrete is estimated with the help of correlation charts, which are sensitive to lesser number of parameters compared to the surface hardness and ultrasonic pulse velocity tests. Hence reliability of these tests is higher. The advantage compared to core test is that these are faster and less disruptive and damaging. Different tests in this category are based on penetration resistance, pull-out pull-off and break-off.

Penetration Resistance

In penetration resistance testing, a specially designed bolt is fired into concrete with the help of a standardized explosive cartridge. The equipment and testing procedure have been standardized by ASTM C803. A consistent correlation of the depth of the penetration with the strength of concrete has been found. The details of failure process of concrete under penetration have been shown in Fig.



4.5.5. Pull-out Testing

In pull-out testing, the force needed to pull a bolt or some similar device embedded into concrete is measured and correlated with the strength of concrete. This correlation has been shown to be unaffected by the mix characteristics and the curing history. The bolt may be inserted at the time of casting of the concrete or it may be epoxy grouted into a hole drilled into hardened concrete. The testing has high reliability and it is accepted by a number of public agencies in some countries as equivalent to cylinders for acceptance testing.

4.5.6. Pull – off method

The pull-off method is based on the measurement of in-situ tensile strength of concrete. The compressive strength of concrete is well known to be related with the tensile strength. Another application of the test is in testing of the bond between original and new concrete in repairs and strengthening. Two versions of the test are possible. In first case a metallic disk is glued directly to the surface of concrete and pulled off to measure the force necessary to pull a piece of concrete away from the surface. In the second case partial coring is done with a standard diameter of 75mm and the above procedure is repeated by gluing the disk at the top of the partial core. For assessing the bonding strength of the repairs with the original concrete, the depth of the partial coring should be below the surface of the original concrete.

4.5.7. Location of steel reinforcement in RC structures by nondestructive tests

It is possible to locate steel reinforcement in concrete and to measure the size and concrete/masonry cover by using Cover meters/ Pachometers, which work on the principle that steel affects the magnetic field of the probe. Alternately, X-ray testing can be used to determine the location and quantity of steel reinforcement. Samples of steel reinforcement may be taken from the structural members to determine their strength, physical and chemical properties. The removed reinforcing steel has to be replaced as required by designer' Sample specimens have to be taken from locations of minimum stress in the reinforcement

V. METHODS OF REPAIR TO BE RECOMMENDED

1. Improvement and repair to services
 - a) Replace the broken/damaged drainage and water pipes
 - b) Replace the worn out GI pipelines.
 - c) Relocating of service lines from garbage chute to protect them from damage

2. Structural Repairs

- A) Slabs: Provide alternate structural system comprising of RSJ's to support RCC slabs.
- B) RCC Beams & Columns: Carry out structural Repairs to RCC beams / columns.
- D) RCC Parapet Wall

The wall to be reconstructed by using super plasticizer admixed concrete of mix 1:1.5:3 with proper w/c ratio.

3. Non Structural Repairs

- a) Remove the vegetation growth from roof and other places to avoid further deterioration of building.
- b) Routine maintenance defects to be attended to.
- c) Concealed service pipes to be shifted to external face of walls.

VI. CONCLUSION

The importance and need for condition assessment and evaluation of safety of existing buildings and foundations in disaster prone areas have been highlighted in this guideline. Safety evaluation forms the basis for designing and carrying out retrofitting/strengthening of buildings to satisfy the safety and performance standards as per the extant building codes. An overview of the procedures and different investigations including tests involved in condition assessment and evaluation of safety is presented in a simple. It can be seen that detailed visual inspection and Non Destructive Testing (NDT) plays an important role in condition assessment of existing buildings. It may be emphasized here that a great deal of expertise is required for interpretation of field observations and test results to make a proper assessment of the condition as well as for analyzing and evaluating safety.

REFERENCES:

- [1] Guide for Evaluation of Concrete Structures Prior to Rehabilitation (ACI 364. 1R-94(99)), By ACI Committee 364, Rehabilitation
- [2] CPWD Handbook on Repair and Rehabilitation of RCC Structures, Central Public Works Department (CPWD), Government of India, New Delhi, 2002.
- [3] Formulation of Guidelines for Assessment of Strength and Performance of Existing Buildings and Recommendations on Retrofitting Schemes to Ensure resistance to Earthquake, Report No.SSP05441, SERC, Chennai, September 2002.
- [4] IS 13311 (Part 1): 1992, Non-Destructive Testing of Concrete – Methods of Test, Part – 1, Ultra Sound Pulse Velocity, Bureau of India Standards.
- [5] IS 13311 (Part 2): 1992, Non-Destructive Testing of Concrete – Methods of Test, Part – 2, Rebound Hammer, Bureau of India Standards.