# CONDITION ASSESSMENT OF BUILDINGS

# FOR

# REPAIR AND UPGRADING

*Prepared under:-*

**GoI-UNDP Disaster, Risk Management Programme**

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# Contents

# CONDITION ASSESSMENT OF BUILDINGS FOR REPAIR AND SEISMIC UPGRADING

## 1 Objective of this guide

The main purpose of guide is to briefly describe how to carry out the *condition assessment of buildings* before taking up repair and upgrading work. This will determine whether or not a distressed building should be demolished to *build back better* or whether it will be cost-effective to either repair or retrofit it, in the context of overall safety.

## 2 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, nor in maintenance.

(v) The current [Indian standard (I.S.)] building codes and guidelines in India have been tested and found effective in achieving safety of the residents during the last six earthquakes (Uttarkashi 1991 to J & K 2005). Hence not following these codes in design and construction is sure recipe for distress in future.

## 3 Rehabilitation and Seismic Retrofitting of buildings

Rehabilitation denotes repairing buildings damaged during service or by earthquakes without upgrading the seismic resistance, while seismic retrofitting denotes upgrading the safety of damaged or existing deficient buildings. The effects of these operations on the structural strength and deformation capacity may be seen in the figure 1:

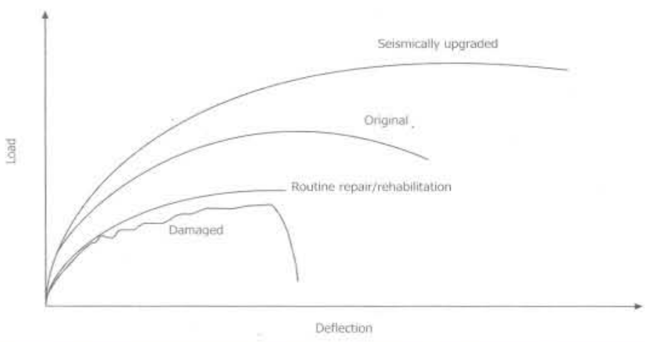


Fig.1:- Effects of seismic retrofitting and routine repair or rehabilitation

## 4 Condition Assessment of Buildings

4.1 *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.

*4.2 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.

*4.3 Typical visible distress detrimental to the safety of buildings*

Cracks in RC beams (Fig.2), Columns (Fig 3), slabs, masonry walls (particularly if the walls are load bearing walls) (Fig. 4, 5), spalling of concrete, sagging of beams or slabs (Fig.6), and tilting of columns or RC frames (out of plumb) (Figs. 7) and major failure of structural members (8-11) 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 if that is also decided for the building in question.

Fig.2:- Diagonal cracks of the beam and failure at the column top

Fig.3:- Cracks in column

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Fig.4:- Cracks in masonry wall

Fig.5:- Cracks in good quality brick wall

Fig.6:- Failure of a portion of building (at expansion joint)

Fig.7:- Failure in column-beam joint (lack of stirrups)

Fig.8:- Column failure (absence of tiers, buckling of longitudinal bars)

Fig.9:- Column top failure (bad joint detail)

Fig.10:- Corrosion in RC beam

Fig.11:- Corrosion in the RC Column

Fig.12:- Corrosion in the RC slab (lack of control on the cover)

*4.4 Main causes of such distress in buildings*

Either one or more of the factors listed below may cause distress in buildings (Figs.2-12):

- 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.

## 5 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.

### *5.1 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

### *5.2 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.

### *5.3 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.
- 1dentification of visible structural damage, such as concrete cracking or spa1ling, 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.

### *5.4 Observation of settlement or differential settlement of buildings*

Ground failures due to the following causes may be observed:

- Liquefaction of soil (under moderate to severe earthquakes)
- Landsliding, under monsoon rain or earthquakes
- Surface fault rupture under the building (remote possibility)

Fig.13:- Damage of building due to ground failure

Some types of damage to the buildings because of ground failures may be seen in Figs. 13 and 14.

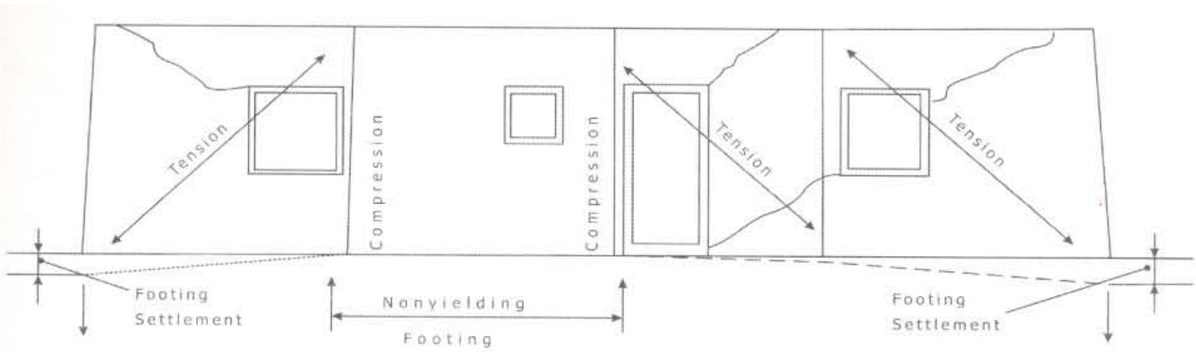


Fig.14:- Diagrammatic explanation of diagonal tension crack due to differential settlement

## 6 Detailed Investigations

### *6.1 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.

### *6.2 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:

| Sl. No. | Property under investigation | Test | Equipment type |
|---|---|---|---|
| 1 | Concrete Strength | Cores | Mechanical |
| 2 | | Pull-out | Mechanical |
| 3 | | Pull-off | Mechanical |
| 4 | | Break-off | Mechanical |
| 5 | | Internal fracture | Mechanical |
| 6 | | ESCOT | Mechanical |
| 7 | | Penetration resistance | Mechanical |
| 8 | | Maturity | Chemical/Electrical |
| 9 | | Temperature -matched curing | Electrical/electronic |
| 10 | Concrete quality, durability and deterioration | Surface hardness | Mechanical |
| 11 | | Ultrasonic pulse velocity | Electronic |
| 12 | | Radiography | Radioactive |
| 13 | | Radiometry | Radioactive |
| 14 | | Neutron absorption | Radioactive |
| 15 | | Relative humidity | Chemical/electronic |
| 16 | | Permeability | Hydraulic |
| 17 | | Absorption | Hydraulic |
| 18 | | Petrography | Microscopic |
| 19 | | Sulphate content | Chemical |
| 20 | | Expansion | Mechanical |
| 21 | | Air content | Microscopic |
| 22 | | Cement type and content | Chemical/Microscopic |
| 23 | | Abrasion resistance | Mechanical |
| 24 | Corrosion of embedded steel | Half-cell potential | Electrical |
| 25 | | Resistivity | Electrical |
| 26 | | Cover depth | Electromagnetic |
| 27 | | Carbonation depth | Chemical/Microscopic |
| 28 | | Chloride concentration | Chemical/Electrical |

*6.3 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. |

*6.4 Rebound Hammer Test*

A simple equipment known as Rebound Hammer or Schmidt Hammer is used for this purpose. The details of the equipment are shown in Fig. 15.

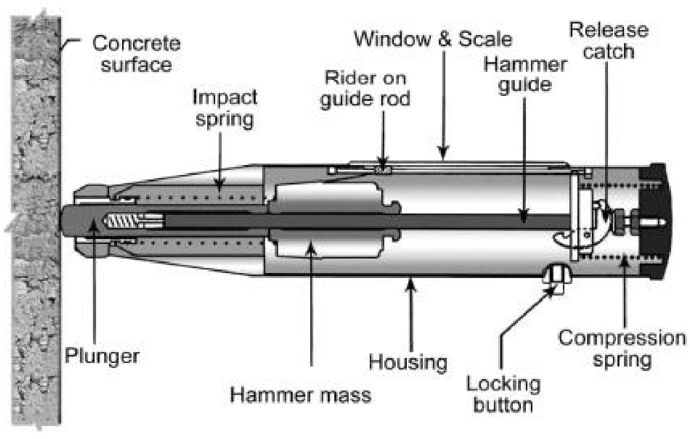


Fig.15:- Rebound Hammer

Surface hardness measured during

the test give 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.

*Table 2: Average Rebound number and quality of concrete*

| **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 |

*6.5 Ultrasonic Pulse Velocity (UPV) technique?*

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. 16. Good acoustic coupling between the transducers and concrete is to be established for correct measurement of the speed.

Fig. 16:- UPV Testing equipment

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.

*Table 3: UPV value and concrete quality*

| **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 |

*6.6 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.

## 7. 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.

*7.1 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

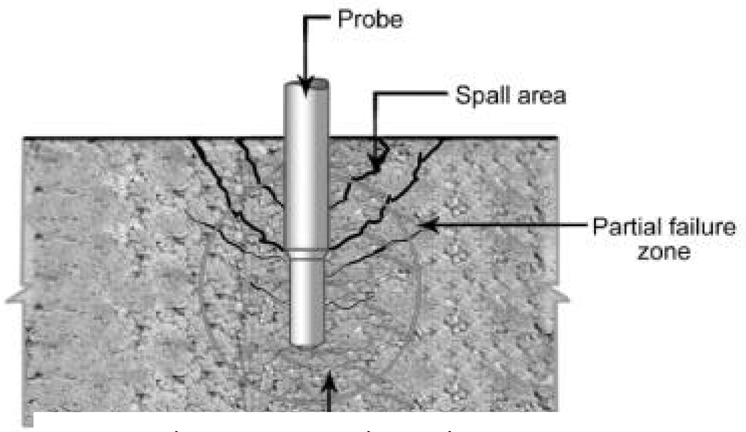

Fig. 17:- Penetration resistance test

concrete has been found. The details of failure process of concrete under penetration have been shown in Fig. 17.

7.2 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

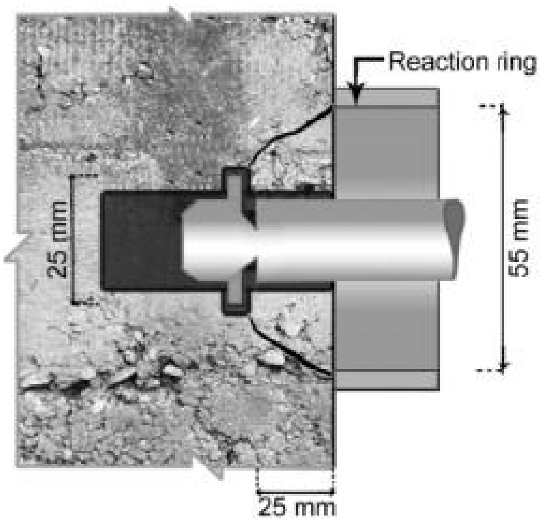


Fig.18:- (a) Pull – out test

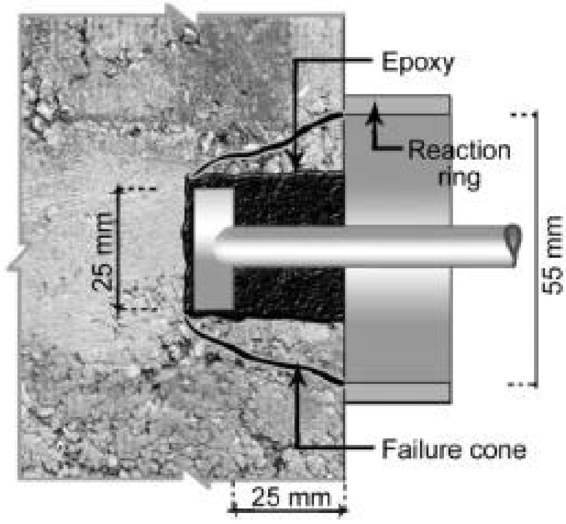


Fig. 18:- (b) CAPO test

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. The details of insert and failure zone are shown in Fig.18. Different versions of this test are in practice in different parts of the world, such as, Lok-test, North American Pull-out Method, Internal fracture test, ESCOT, CAPO test etc.

*7.3 Pull – off method*

The pull-off method is based on the measurement of in-situ tensile strength of concrete. The

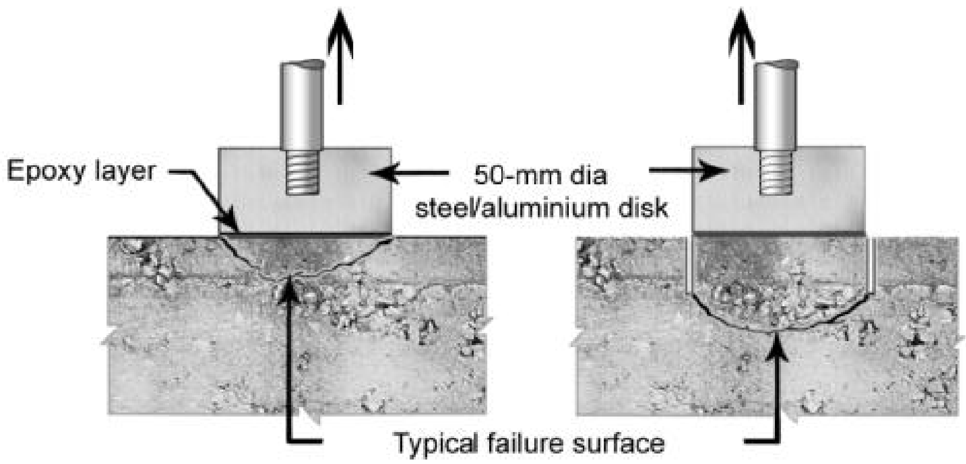


Fig. 19:- Pull - off test

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. The details of the test are shown in Fig.19. 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.

### *7.4 Interpretation about corrosion based on chemical analysis of concrete?*

The following Table gives some tips for interpretation about corrosion:

*Table 4: Interpretation of test results on corrosion*

| **Test Results from Chemical Analysis** | **Interpretation about Corrosion** |
|---|---|
| High pH value( > 11.5) and very low chloride content | No corrosion |
| High pH value and high chloride content greater than 0.4% - 0.6% by weight of cement | Corrosion prone |
| Low pH value and high chloride content greater than 0.4% - 0.6% by weight of cement | Highly corrosion prone |

### *7.5 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 e magnetic field of the probe. Alternately, X-ray testing can be used to determine the location and quantity of steel reinforcement.

### *7.6 Samples of steel reinforcement for determining the strength and other properties?*

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.

### *7.7 Corrosion of reinforcement in RC structures?*

Corrosion of reinforcement in concrete structures is a complex electrochemical process. Migration of moisture and aggressive chemicals through the porous cover concrete would cause corrosion of steel reinforcement. The parameters or factors that influence corrosion are:

- cover thickness
- quality of concrete in the cover region, especially its permeability and diffusivity
- environmental conditions

- pH value and chloride level in concrete, and
- presence of cracks

## 8 Soil profiles at the site

Soil profiles may be broadly categorized as:

- Rocky
- Very dense soil and soft rock
- Stiff soil
- Soft soil

This categorization may be based on average soil properties of shear wave velocity, standard penetration number, and undrained shear strength [for simple qualification Ref IS:1893 (Part 1) 2002 for preliminary liquefaction potential of site refer cl…..]

## 9 Concluding Remarks

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.

## 10 Acknowledgement

The information contained in this guide is largely extracted from the book 'Condition Assessment of Buildings in Disaster Prone Areas' authored by TVSR Appa Rao and R.K.Bhandari and published by Centre for Disaster Mitigation and Management, VIT University, Vellore, Tamil Nadu, India, 2007. Assistance has also been taken from Chapter 13 seismic vulnerability assessment of existing buildings by Y. Singh & D.K.Paul in lecture notes for National Programme for Capacity Building of Engineers in Earthquake Risk Management (NPCBEERM), Dec 2006.

## 11 References

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