RRoS

UNIT VI
INVESTIGATION OF STRUCTURES

Distress in Structures of Building: In course of time, with ageing, distress would appear in structures as a natural phenomenon. This natural metamorphosis is due to natural wear and tear. Moreover, in the present days, the structures are in extreme aggressive environment. The old structures which were constructed in non-aggressive environment and without any special preventive measure are now very badly affected due to gradual deterioration of the environment around them. The structures are undergoing rapid metamorphosis and showing signs of distress. These structures need immediate attention for ascertaining the causes of their distress and for proper diagnosis and selection of methodology for proper solution and rehabilitation of the structures.

Causes of Distress: A structure, if designed properly and constructed to requisite standards of workmanship and proper specifications adopted and materials used are of quality, i.e., if all the parameters related to the construction of the structure are in ideal condition, its life can be predicted and the load bearing capacity of the structure can be guaranteed, however, of course, during its use, the parts of the structure would not be put under undue and unforeseen stresses. But in practice, this ideal condition very rarely exists. The construction of a structure involves a large quantity and large number of materials which have to be collected in stages and subjected to great difficulties in maintaining the quality. Further, the construction itself involves human factor at every stage. The structure would remain in service for a considerably long period and guarantying that during this long period there would be no addition and alteration and overloading of any part causing unforeseen stresses is difficult. Further, there would be the influence of environment which is getting aggressive with the passage of time due to various reasons, especially in developing countries, and would degrade the materials and affect the durability of the structure.

(i) Defect:

When a structure or a member is subjected permanently to some unforeseen stresses exceeding its load-bearing capacity, the structure may be termed as having a defect. This may be due to various reasons excess loading, change in pattern of loading and use, bad materials used in construction, effect of environment, etc.

(ii) Decay:

Decay is the development of defect in a structure or may be due to natural cause of ageing. A building or any part of it may be considered decayed if it is considered not capable of sustaining the designed stresses and its early failure is anticipated.

There are various causes behind decay; some of them are:

i. Inadequate or no maintenance,

ii. Bad use of the building,

iii. Bad workmanship during construction,

iv. Use of under-specified quality of materials during construction,

v. Natural wear and tear,

vi. Adoption of wrong specification during construction,

vii. Action of atmospheric agencies, and

viii. Physical influences.

Precaution against Early Damage:
Early decay of a structure or its members may be arrested or, at least, may be retarded by taking the following actions as may be necessary:
i. Proper and regular maintenance, specially by stopping of leakages in roof or walls, sanitary and plumbing and waste water pipelines and rain water pipes;

ii. Use of specified materials with adoption of good workmanship during construction;

iii. Adoption of correct specification of items of works during construction;

iv. Protecting the structure from weathering agencies;

v. Protecting the structure from physical influences;

vi. Protecting the structure from aggressive environmental influences; and

vii. Proper use of the structure, i.e., by avoiding bad and improper use and avoiding overloading.

(iii) Damage:
Damage is the consequence of defect or decay existing in structure. It may be visible on the surface or may be hidden within. The signs of damage are termed signs of distress.

Detection of Damages:
Damage due to whatever reason when existing in a structure should be identified correctly, in locations and the cause of damage ascertained. Then only a proper and effective measure could be taken for removal of the damage by repairing the structure and prevent aggravation of the damage or recurrences of it.

Removal of Damage:
The damage in a building need be removed early to save it from early dilapidation and shortening of the life cycle. The damages of a structure are removed by their proper repairs which may be minor or may be major or, sometimes, may be a case of complete rehabilitation.

Repairs of Structures:
Repairs of a structure are necessary either to stop deterioration or to arrest acceleration of degradation. The damages of a structure may be of various categories in terms of their seriousness and urgency. There may be some damages which may wait and there may be

some repairs which could be attended as routine work to resist further decay and damage. The repair works are done annually unless requiring early action.

Distress Identification:

Before attempting any repair procedure it is necessary to have a planned approach to investigate the condition of concrete and reinforcement. While the diagnosis of damage or deterioration in some cases is reasonably straightforward, it may not be so in many cases. Particularly difficult are cases in which the cause and effect phenomenon cannot be readily explained or when prognosis in terms of long-term performance of restored structure is to be made. This will require a thorough technical inspection and an understanding of the behaviour of the structural component, which is being repaired. Inspection calls for detailed mapping of affected areas, documentation of type and location of symptoms and their history and photographic evidences. It may also include the environmental factors, which are likely to accelerate the damage process. Existence of concealed ducts, water lines, wet areas require special attention. Some areas impose severe limitations on access to damaged areas. A comprehensive inspection data helps in making an effective strategy for repair and rehabilitation.

Non-destructive evaluation (NDE) of concrete and components are well known and extensively used. While they are very good tools for establishing quality levels in new constructions, applying these techniques to damaged structures requires certain level of experience and understanding of limitations of these methods. Solving the problem successfully is entirely dependent on the ability of a team of experts engaged to do this job. Both field and laboratory tests are available. It is important to select the appropriate Non Destructive Evaluation (NDE) techniques and location of investigation. This is a specialized job and requires sophisticated instruments and trained personnel. A single technique may not be adequate and a combination of techniques has to be adopted to get a truly representative data on the condition of the building.

Once the evaluation phase has been completed for a structure, the next step is to establish the cause or causes for the damage that has been detected. Since many of the symptoms may be caused by more than one mechanism acting upon the concrete, it is necessary to have an understanding of the basic underlying causes of damage and deterioration. This chapter presents information on the common causes of problems in concrete. With the development of newer construction material & methodology, the present day concrete is more durable as compared to the early 30s & 40s. It is also well established factor that if the concrete is properly designed, mixed & applied, it can have a longer durability under normal service conditions. With the increase in the construction activities in the last two decades mainly in the building / infrastructure sector, it has been observed that many of the structures are already showing signs of distress. In some cases repair measures become necessary even within a span of 5 to 10 years of completion of structure. Distress happens due to host of factors like poor workmanship, lack of maintenance, atmospheric effects, abuses, accidents, natural calamities. In all the cases, the methodology to be adopted depends on the type of distress and its magnitude. Thus repair and rehabilitation of a concrete structure becomes necessary to extend its life to ensure durability of structure. The rehabilitation envisages restoration of structural system as close as possible to the original position. The distressed structure needs to be brought in line, level and to required strength so that it can be put into service without endangering its safety and utility. Looking to the magnitude and complexity of the work involved, it appears that the concept of repair and rehabilitation is bound to become an important discipline of the construction industry in time to come.

Concrete Degradation may have various causes & reasons. It can be damaged by factors like fire, alkali - aggregate reaction expansion, sea water effects, bacterial corrosion, calcium leaching, physical and chemical damage from carbonation, corrosion of reinforcements & many others. Rapid industrialization in India after independence required infrastructure for transport of goods and raw materials and that has led to construction of wide network of roads with inbuilt bridges and flyovers. A number of existing bridges are showing sign of distress within their designed service life in many cases as early as 10-20 years of construction in India and in several other countries. Collapse of I-35W bridge at Mississippi river in United States of America in the month of August 2007 has drawn attention of international media. In India, collapse of Mandovi Bridge at Goa in 1986 (after 16 years of service life) and serious distress in Zuari bridge (rehabilitated in 2000 with the held of international consultant) at Goa and several other bridges like Khalghat and Borad Bridge on NH3 (Agra to Mumbai route) due to environmental loads is drawing the attention of transport authorities and scientific community to evolve an efficient bridge management system. Identification of the cause of distress, level of distress and reduction in load carrying capacity of the bridge may be ascertained in order to proceed with necessary repair to ensure safety of the bridge during their service life. The evaluation of state of stress and load carrying capacity of the existing bridges and enhancement of the load carrying capacity is required during upgradation of the highways. India has already implemented strengthening and four lanning of 7000 Km of highways under Golden Quadrilateral scheme where strengthening/retrofitting of many existing bridges was required. The various causes of distress of reinforced concrete bridges are poor quality of construction, corrosion of steel in reinforced concrete bridges and pre-stressing cables in prestressed concrete bridges, improper design and detailing for normal loads and seismic forces, improper functioning of bearings etc.

Case Studies and Type of Distress

i. Soil / foundation related factors
ii. Corrosion of reinforcement in abutment, pier, super structure
iii. Bearing Failure
iv. Structural distress exceeding design loads

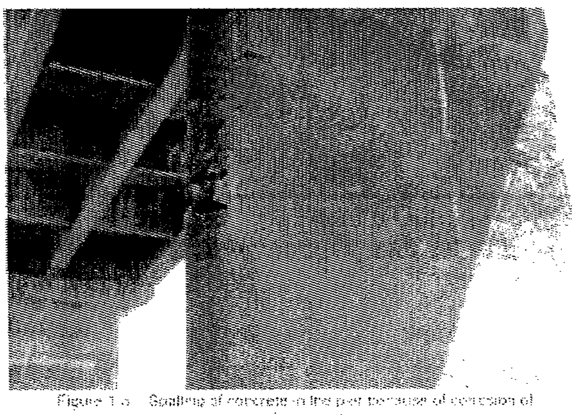


Figure 1.5 Spalling of concrete in the pier because of corrosion of [illegible]

Soil / foundation related factors

Bridges are built on spread footings or on deep foundations (pile and well). Bridges on spread footings are supported on firm soil layers or on rock close to the surface.

Normally, bridge failure because of settlement of foundation for normal loads has been rarely reported however damage to superstructure because of foundation failure has been reported during earthquakes.

Bridges built on sites with soft clay or silt, loose saturated sand or improperly compacted fills have been damaged by amplification of ground motion or by soil failure during earthquake. Bridges supported on soft or sensitive clay have been particularly vulnerable to earthquakes. When close to epicenter, weak clay will undergo large displacements that can drag the foundations and pier out from bridge super structure. Saturated loose sand and silty layers of soil are potentially liquefiable. Soil liquefaction can cause a loss of bearing capacity and that may result into lateral movement of the sub structure. Another common problem is settlement of bridge approaches during earthquakes. Even well compacted structural backfill may be vulnerable to this type of damage.

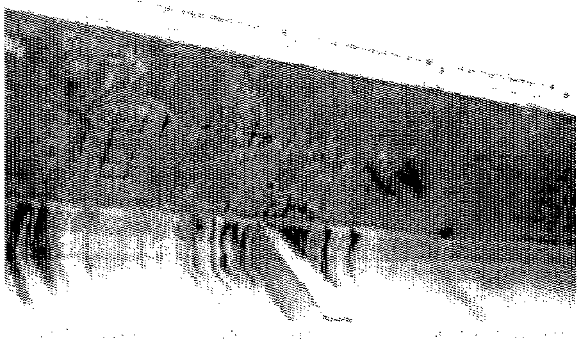
Corrosion of reinforcement in abutment, pier & superstructure

The corrosion of reinforcement in concrete in adverse environment is cause of concern in many reinforced concrete and composite bridges. Two of the most common causes of deterioration are due to chloride penetration and carbonation of concrete leading to pitting and general corrosion of steel respectively. Corrosion of steel results in cracking and spalling of the concrete and this in turn leads to secondary damage caused by enhanced ingress of aggressive agents. As shown in Figure 1 (a, b) corrosion of reinforcement in the pier and slab has resulted in spalling of concrete.

Bearing Failure

The function of bridge bearing is to transmit the dead load of the superstructure and live load to the substructure while accommodating the necessary movement (including the thermal movement) of the superstructure. A defective bearing may induce overstresses at the bridge seat and restrain movement of super structure which may induce stress in the super structure. Therefore, bearings that fail to perform as designed have to be replaced so as not to damage the bridge. During earthquakes, many examples of bearing failure have been reported in India. There was failure of bearings in Silchar in Cachar earthquake of 1984. There was failure of elastomeric bearings in Surjabari Bridge in Bhuj earthquake of 2001. Structural distress of abutment/ pier and super structure exceeding designed load

Distress in abutment/pier and super structure of reinforced and prestressed concrete during earthquake are widely reported. There are cases where distress in abutment/ pier and superstructure has occurred because of increased loading than the designed load. In July 2004, Bailey bridge on NH-37 at Deosila, Assam collapsed because 60 tonne heavy truck was allowed to pass which much more than the designed axle load. The first author has been associated in a project in which load carrying capacity of an arch bridge was



required for transporting heavier equipment for BHEL.

Distress Diagnosis

Sometimes the cause of distress is known i.e. distress during earthquake, impact and blasts is known probably the exerted loadings exceeding the designed load however many times it is difficult to ascertain the actual cause of distress where many variables are involved e.g. poor quality of construction (faulty detailing, improper materials and workmanship), shrinkage, creep, reinforcement corrosion etc., The quantification of the level of distress is required to succeed the repair/ strengthening strategy. Following test may be required to ascertain the cause and level of distress.

i. Determination of Compressive Strength from NDT and concrete cores
ii. Crack detection techniques
iii. Signature/Vibration Analysis
iv. Load tests to find out deflections/strains and load distribution
v. Corrosion Studies (pH, carbonation depth, chloride)
vi. Deflections/slopes strains from Instrumented Bridge

Determination of Compressive Strength from NDT and Cores

Non destructive tests like Rebound Hammer, Ultra Sound Pulse Velocity are used to assess the compressive strength and quality of concrete on bridges and other structures. Rebound hammer test is based on the principle of dynamic impact in which when a moving object hits a body, the rebounding energy is proportional to the surface stiffness, strength, and static inertia of the body. This test gives fair idea about the strength of concrete, especially near the surface. The accuracy of the test results depends upon the following factors.

i. The reading of the hammer on the standard steel anvil should be 79 ± 2, however the springs used in the rebound hammer show fatigue after certain number of blows and reading on the steel tester reduces. The author has observed after long use the hammer develops permanent deformation in springs and linearity of the spring gets affected.
ii. Rebound number is more if the impact is made on an aggregate (normally the impact is to be made in the mortar between the aggregates) and therefore sufficient number of readings are required to be taken and offshoots has to be taken out.
iii. For old concrete structures the surface concrete becomes harder because of carbonation however the inside concrete strength is relatively less therefore the strength reported from rebound hammer test is to be corrected for old concretes.

To know about the quality of concrete, a method based on ultrasonic technique is used. In this technique, sound-waves of ultrasonic frequencies are transmitted through the concrete members under test to measure the velocity of ultrasonic pulses. The velocity of ultrasonic pulses traveling through the concrete mainly depends on the elastic properties of concrete which indirectly indicate the strength of concrete. Since, there is no unique correlation between the velocity and strength of concrete for different mix proportions, this technique is used more as a qualitative test rather than a quantitative one. Determination of compressive strength by extracting cylindrical cores from the structure is the most reliable method however it is partially destructive test therefore a limited number of cores are only taken from the bridge sub and super structure.

Crack detection technique

Damage due to deterioration process, over load, bad design, poor quality of material including durability aspects may grow with passage of time until collapse of the structure. Acoustic emission technique and infrared thermography, impact echo and ground penetrating radar techniques have been used for damage detection and progression in laboratory and field in some cases.

Signature/Vibration Analysis

Distress in the superstructure/sub structure of the bridges changes the strength and stiffness and this may be reflected in the form of change in the frequency and mode shape of the structure.

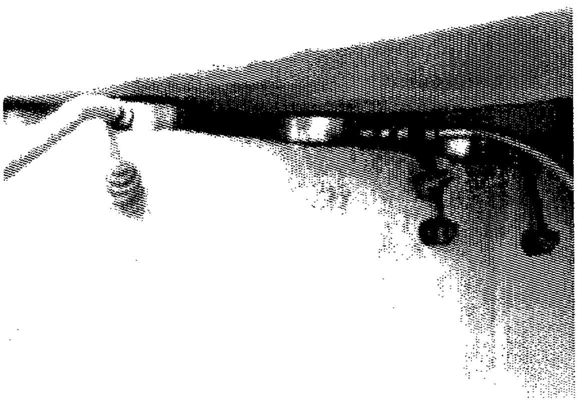


Figure 2 Placement of [illegible]

Various studies have indicated that increase in damage reflects decreased natural frequency of the structure. The author has been associated in two projects (repair and rehabilitation of Khalghat and Borad Bridge on NH-3 in Madhya Pradesh) in which for damage identification signature/vibration analysis was also used. Both the bridges were simply supported composite bridges (Reinforced Concrete Diaphragm and Deck Slab and Prestressed Concrete Main Girders). The analysis indicated change in the frequencies is not appreciable with the decrease in the stiffness (damage). Several laboratory studies also has confirmed this finding. However, through the vibration tests structural integrity (main girder, diaphragm and deck) of the bridge may be ascertained.

Load test to find out deflections/strains and load distribution

Load test is a reliable method for assessing the level of damage in the bridge. The static load equivalent to design load is placed on the deck in stages and measurement of deflection in the girders is recorded from dial gauges in stages. Total deflection as well as recovery of deflection is important when fully loaded and when load is removed. As per IS- 456-2000 under imposed load 75% recovery is must for satisfactory performance. The sharing of the load in girders can be back calculated based on deflections in each girder and may be compared with the designed load sharing in the girders which indicate relative stiffness of the girders of the bridge.

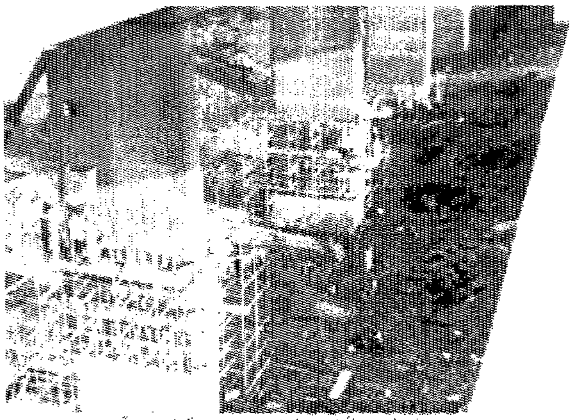
Corrosion Studies (pH, carbonation depth, chloride)

If a risk of reinforcement corrosion is detected early during routine inspection, damage can be avoided or reduced significantly by relatively simple protective measures. On the other hand, if corrosion of the reinforcement has proceeded to the point where it has caused cracking and spalling of the concrete, repair measures are normally more complicated and expensive. The condition assessment of the structure for the corrosion involves determination of pH of concrete samples taken from the structure, measurement of carbonation depth in the actual structure and chloride content and sometimes even the corrosion rate.

Concrete is alkaline in nature as the pH of concrete is more than 12.5 and due to the alkaline nature of concrete steel is protected from corrosion. Calcium present in concrete reacts with moisture and lowers the alkalinity of concrete. The outer zone is affected first but with the passage of time, carbonation penetrates deeper into the mass and once it reaches to the reinforcement the corrosion is initiated. The carbonation depth is determined at various location using Phenolpthlein indicator. Chloride ions react with $Ca(OH)_2$ present in cement matrix thereby reducing the alkalinity of the cement paste. The two parameters responsible which influence the ingress of chloride ion into concrete are diffusion resistance of the concrete (impermeability of concrete) and the other binding capacity of the concrete with respect to the chloride ions. The chloride ion concentration is also determined for the samples collected from the field. The pH of the concrete samples collected from site is tested from the laboratory will indicated the severity of the corrosion process.

Deflections/slopes strains from Instrumented Bridge

Scientific monitoring of health and performance of major concrete structures is no longer in dispute in view of the large number of distressed structures. The author has been associated with long term performance monitoring of bridges and nuclear power structures. The sensors are embedded in the concrete during the construction of the major long span bridges and these are monitored for change in values in an interval of six months. Creep and shrinkage specimens of specific dimensions (to simulate the condition in the actual structure) are cast during the construction and values obtained in these will be used to separate the stresses, strains and deflections.



Repair/Retrofitting Techniques

i. Superstructure
   a. External Pre-stressing
   b. Epoxy and Polymer Mortar for crack repair
   c. Composite Materials
ii. Bearings Replacement
iii. Substructure
   a. Steel jacketing for columns/ piers
   b. Concrete jacketing for columns/ piers

Super-structure

Normally, during earthquake loading, super structure is not critical because of its high rigidity and large flexural capacity, super structure deficiency is associated with their unseating in expansion joints or on bearing supports due to relative displacements. Distress in slabs and diaphragms has been observed in composite bridges (Prestressed concrete longitudinal girders and Reinforced concrete Diaphragms and Slabs) due to corrosion of reinforcement. The author has been associated with the rehabilitation of two composite bridges (Khalghat, Borad Bridge in on NH3 in MP), where major distress in the form of cracking and spalling of concrete because of corrosion of reinforcement reducing the strength and stiffness.

(a) External Pre-stressing

Pre-stressed concrete bridges are also subjected to environmental effects like corrosion of reinforcement in aggressive sea environments. The stress corrosion in pre-stressing cables of Juari bridge at Goa has lead to distress in super structure and the structure was rehabilitated by external prestressing.

(b) Epoxy and polymer mortar for crack repair

Distress due to corrosion of steel in concrete may result in cracks in concrete and if the distress is less than 30% of the concrete surface, patch repair using epoxy or polymer modified mortar may be done.

(c) Composite Materials

Fiber reinforced polymer laminates (both glass and carbon) have been used for repair and strengthening of reinforced concrete bridges. The fiber reinforced polymer laminates are used for increasing the shear as well as flexural capacity of reinforced concrete girder and flexural capacity of slabs. The cost of these laminates is much more than the conventional techniques and use of these fibers has been reported some structures in India

Bearing Replacement

In many cases, distress in the superstructure is caused because of defective bearings and replacement of defective bearing is required. Bridge bearings are required to be periodically inspected and damaged bearings as well as bearings for which service life is over has to be replaced. Replacement of bearings below pre-stressed girders has to be cautiously done. Normally, limitation of space requires proper selection of jacks and jacking operations. The end diaphragm for long span girders should have sufficient flexural and shear capacity for jacking operations.

Substructure

The distress in abutments and piers has been found because of reinforcement corrosion. Enhancement in load carrying capacity (axial/shear) of piers/ columns may be required during upgradation of highways. The columns/piers of bridges which have not been designed for earthquake loading may need retrofitting for increasing ductility, flexural and shear resistance of the piers/columns. Steel or concrete jacketing of piers/columns has been used for increasing the load carrying capacity.

(a) Concrete Jacketing forColumns/Piers

Concrete jacketing around the bride piers and columns for enhancing the load carrying capacity as well as ductility has been widely used. The footing has also to be ensured that it will be able to take the increased load and the vertical reinforcement should be dowelled with adequate anchorage with footing. The distressed surface because of corrosion of reinforcement has to be cleaned properly and bond improving chemicals has to be applied for bonding between old and new concrete. Normally, a thick layer of reinforced concrete (vertical bars and vertical and horizontal reinforcement) is provided. In Figure 3, concrete jacketing is being used to increase the load carrying capacity of the bridge.

(b) Steel Jacketing for columns/piers

The repair/strengthening of columns/piers of the bridge is done using steel sheets circular/elliptic in shape [4]. The steel sheets provide a continuous tube around the concrete with an annular gap. The gap is grouted with cement grout or epoxy resin. The jacket primarily increases shear strength and confinement.

A large number of highway bridges and flyovers are showing sign of distress all over the globe. Identification of the cause and level of distress/damage is a very important step for successful repair and to achieve the designed service life of the bridge. Several new techniques new radar mapping, infrared thermography and impact echo to detect flaws in concrete bridge decks has been tried which are intended to look into invisible defects in concrete in early stages. Various steps in distress diagnosis include determination of concrete compressive strength form non destructive tests, signature/vibration analysis, load tests, tests for state of corrosion etc. Distress diagnosis is important step for implementing proper repair scheme to achieve the designed life of the bridge. In view of large number of distressed bridges monitoring of state of health of important bridges through instrumentation during the construction stage will help in early detection of flaws and suggesting suitable strengthening scheme.