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OF
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CERTIFICATE

This is to certify that the dissertation entitled " **Rehabilitation of different structures"** that is being submitted by Shri Ajay kumar Jain (IDSE) for the award of the degree of Master Of Technology in Structural Engineering to the College Of Military Engineering, Pune is a bonafide research work carried out by him under my supervision and guidance, hence recommended for acceptance and approval.

The results embodied in this dissertation have not been submitted to any other university or institute for the award of any degree or diploma.

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EXAMINER'S CERTIFICATE OF APPROVAL

The dissertation entitled ***"Rehabilitation Of Different Structures"*** submitted by ***Shri Ajay Kumar Jain***, in partial fulfilment of the requirements of the degree of Master Of Technology in Civil Engineering (with specialisation in Structural Engineering), to the Jawaharlal Nehru University, New Delhi, is hereby approved for the award of the degree.

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estimation. A standard mix concrete has been defined and equation for estimation of concrete strength of that mix has been proposed. Further laboratory experiments have been carried out to determine various correction factors related to age of concrete, mix proportions of concrete, maximum size of aggregate, volume fraction of coarse aggregate and unit content of cement .

Once diagnosis is over and the cause of deterioration is found a remedial measure based on these findings has to be prescribed. However the diagnosis of cause as well as also prescribing remedial measures should be based on the knowledge gained from past experiences. A knowledge based expert system has thus been developed in this dissertation for diagnosis of cause of cracking in a given RCC structure and suggesting rehabilitation measures.

Many techniques are used for strengthening of RCC members and Jacketing is one of the most commonly used technique for strengthening of columns. However literature available does not indicate any unified method to assess the amount of concrete, its mix, reinforcement required and bonding material to be used for a particular case of strengthening. Experimental work have thus been carried out to ascertain the efficacy of this technique with respect to parameters of increase in size/ reinforcement, bonding material used between old and new concrete and use of shear links and results reported.

CONTENTS

Contents contd...

CHAPTER		TITLE	PAGE NO.

Contents contd...

Contents contd...

LIST OF TABLES

LIST OF FIGURES

Contd..

INTRODUCTION

Deterioration and maintenance of an engineering structure is a common and serious problem involving considerable cost and inconvenience to user. For an engineer, problem involves two basic aspects, prevention and repair.

Of the two considerations; prevention and repair, prevention of distress is more important, however need for adequate attention to potential maintenance problems during design and construction phases can't be overemphasised. So design engineer must select materials for his design which are suitable for the conditions of exposure at site, must detail structure in a manner which will prevent the occurrence of serious deterioration (at least for the assured service life of the structure), and must insist on proper construction through inspection/supervision. Clearly these three, proper material, proper details, proper construction require knowledge of what is improper, and imply a knowledge of various forms of deterioration which occur and understanding of their causes.

If the prevention of deterioration has been unsuccessful, then the structure must be abandoned, replaced or repaired. The execution of such a repair is an exacting, technical matter involving five basic steps:

a) Finding deterioration
b) Determining cause/causes of deterioration
c) Evaluating strength of existing structure
d) Evaluating need for repair
e) Selecting and implementing a repair procedure

For an engineer interested in finding deterioration, he must be trained technically in "Where to look", "How to look", before he can even be expected to realise that there is trouble. Knowing what, where, and how to look requires knowledge of various types of deterioration which can occur and the basic causes of deterioration which have been presented briefly in the report.

Next step is to determine the cause of deterioration for the given problem. This does not mean that specific cause must be identified, indeed particularly with concrete it can't be done easily because there are several agents simultaneously at work. What can however be done is to eliminate possibilities until few remain and than select a repair procedure which will correct the existing condition and prevent further deterioration by any and all of the suspect aggressive agents. Failure to understand the cause of the defect can lead to selection of repair procedure which may prove to be harmful rather than helpful.

Evaluating the strength of a deteriorated structure can be an engineering problem in itself. As the direct determination of strength implies that the concrete specimen must be loaded to failure so insitu nondestructive methods of testing concrete cannot be expected to yield absolute value of strength. The currently available nondestructive methods can be broadly classified in two categories. First type include those methods which do not measure strength directly but measure some other property of concrete from which an estimate of strength can be made. These include surface hardness, penetration resistance, ultrasonic pulse velocity, and maturity methods. The second type of test methods are those which measure some strength properties from which an estimate is then made of compressive strength and flexural strength of the concrete. These include various types of pullout methods and breakoff techniques. Both these methods have been described briefly in the report.

When the cause of deterioration has been determined and the strength of the existing structure is checked, decision must be made regarding:

a) To permit deterioration to continue.

b) To take measures to preserve the structure in its present condition without any attempts to strengthen the structure.

c) To strengthen the structure.

d) To reconstruct or possibly abandon it.

This decision has to be taken depending upon a host of considerations, such as availability of funds, requirement of appearance, consideration of safety, available expertise etc. and if decision is to repair the structure we go to next step i.e. selection and implementation of repairs.

The choice of repair method depends on a variety of factors. These include structural considerations, like extent of repairs, anticipated practical problems with the particular site, likely affect on the unrepaired areas, durability of repairs and protection against future deterioration etc.. Special emphasis needs to be given to economics of alternative repair methods not considering first cost only but we will have to consider first cost, maintenance cost and investment value of deferred cost also.

After selecting suitable method of repair considering all the ramification of its application, the last step is to prepare plans and specifications and to proceed with the work. It may be dreary and even annoying to have to be concerned with little picayune details, like wire brushing the concrete surface, wetting it, rubbing it with cement wash, placing concrete in specified thickness etc., but it must be ensured or there is no sense of doing repair job at all. Most repair work involves extensive manual operations, the workman must be trained. Repair may not be a glamour job, but it is an essential one which requires careful attention.

Combined nondestructive methods have become quite common for assessing the strength of concrete in existing structures. Practical expression for estimating the compressive strength of concrete using combined nondestructive testing methods, combining rebound number with ultra sonic pulse velocity has been given by Yasno[51] , the same has been used as a starting point and experimental investigation have been carried out to find the practical expression in Indian conditions and to examine the effects of following factors, w/c ratio, maximum size and volume fraction of coarse aggregate and curing condition. There were three basic objectives of this study :

a) To propose a practical equation for estimation of compressive strength of standard concrete mix as defined by combined nondestructive method.

b) To examine the effect of various factors such as cement content, maximum size and volume fraction of coarse aggregate, type of CA and age of concrete.

c) To analyse the accuracy of strength estimation and applicability of equation for evaluation of strength.

Based on experiments the value of correction factors for each variable considered have been proposed and comparison between measured strength and calculated strength have been shown.

Jacketing is one of the most common rehabilitation techniques used for rehabilitation of distressed columns. Jacketing basically consists of restoring or increasing the section of an existing member (principally compression member) by encasement in new concrete. The method is applicable for protecting a section against further deterioration as well as strengthening. Many a times jacketing of concrete column is done for strengthening due to deterioration of old concrete and reinforcement so as to restore or increase the load carrying capacity of the column.

Experimental studies were carried out with an objective to find out efficacy of jacketing technique with respect to increase in size, reinforcement, bonding material used between old and new concrete and type of concrete used for jacketing, and to study the actual increase in load carrying capacity of column vis-à-vis the expected increase in load carrying capacity based on theoretical results for increased cross-sectional provisions.

Since there is a lot of information available on assessing strength of existing structure by using NDT's, causes of distress in concrete structure, diagnosis of causes of distress and consequent repairs to be undertaken, accordingly an expert system has been developed for diagnosis of causes of cracks in concrete structures and recommending repair steps.

The study carried out in the dissertation and the expert system developed based on information and data collected has a long-standing application in the field of repair and rehabilitation of buildings. The study has a wide-ranging application in work services, which are involved in repair and maintenance of structures. With the availability of personal computers in remote offices the user interactive program will in no time suggest/ recommend the repair procedure based on inputs by the user. It may not fulfill the function of an expert as the site conditions vary considerably but it will certainly play the role of an assistant to decision maker who is not having experience or not having access to expertise available in the field. If the decision maker is also technically qualified (which is normally the case), the program will certainly improve his decision making, accordingly the work carried out will be of great help to maintenance engineers located in remote corners of country.

SUMMARY DETAILS OF CHAPTERS

First chapter of the report covers briefly the various factors, which can cause deterioration of RCC structure. It is only by careful review of "Why and How" the deterioration occurs, satisfactory technique of repair can be suggested. Only two basic type of materials have been considered in the chapter, i.e. concrete itself and reinforcement which is generally used in conjunction with it.

Second chapter deals with diagnosis of causes of deterioration in RCC structure. This is done by understanding, how the various causes of deterioration are likely to reveal themselves, possible causes of observed conditions at site and eliminating possibilities until some conclusion appears. Suggested steps/procedures have been given in the chapter. Based on the diagnosis of causes of distress the repairs have to be recommended. Flow diagrams have also been presented for selection of applicable methods of repairs.

Next chapter deals with Non destructive test methods available for estimating compressive strength of concrete for evaluating the strength/stability of existing structure. The different methods available have been described briefly with their implication and Ultra sonic pulse velocity and Schmidtz hammer methods have been described in detail.

Fourth chapter covers suggested specifications for RCC jacketing technique and guide lines to be followed while undertaking jacketing. This chapter will be of great help for preparation of good contract document for undertaking any repair/restoration work of columns.

Next chapter covers briefly about Expert systems, their utility in structural engineering.

Sixth chapter gives architecture of CONREP i.e. details of user interactive program/Expert system developed, its potential and drawbacks and future scope for development of full-fledged expert system for repair and rehabilitation of buildings.

Next chapter gives brief details of experimental work carried out.

Chapter eight deals with experimental results and discussions thereon.

Last chapter deals with conclusions drawn from the work carried out and the future scope of the work.

SYNOPSIS

The major problems in design and construction of civil engineering structure (mainly concrete structure) are well known and generally considered in practice at the planning stage. In addition design live load provisions incorporates a margin of safety. Design specifications generally provides a substantial safety factor and design assumptions are mostly conservative. However, while structures may be adequate for applied loads, many structures after being put to use, develop serious problems for the reasons which may be widely different depending upon the quality of inputs in the structure in the form of architectural and structural designs, provisions and detailing, specification and the construction workmanship, type of use, weather resistance and its response, additions and alteration carried out by the occupants etc.

Too much sophistication, highly evolved specific expertise, fine tuning of design calculation through computers, reduced material provision, high permitted stresses altogether have a counter effect on serviceability and in turn on durability due to limited load dispersal paths and reduced strength reserves.

Often the structure being investigated for its performance, is in active use and it is necessary to determine as quickly as possible, whether it is safe to continue to use the structure or facility should be restricted to some less severe use. Investigations in such case consists of assessment of residual strength, diagnosis of the cause and hence prescribing remedial measures. Determination of residual strength requires non destructive testing of concrete, which is very fast. However a single NDT test may not be reliable, hence combined non destructive testing methods, incorporating use of two or more NDT's have been proposed in the past to estimate concrete strength with high accuracy. Among the many combinations of non destructive test methods, the combined use of Schmidtz hammer with Ultra sonic pulse velocity method is likely to be of most practical use for strength

CHAPTER - 1

CAUSES OF DETERIORATION IN CONCRETE STRUCTURES

1. Causes of cracking in concrete structures can be broadly classified as following[26] :

1.1 Occurrence incident to construction operation :

a) Localised settlement of subgrade

b) Movement of formwork

c) Vibration

d) Setting shrinkage

e) Premature removal of formwork

1.2 Drying shrinkage and creep

1.3 Temperature stresses

1.4 Absorption of moisture by concrete

1.5 Corrosion of reinforcement

a) Due to chemical agents

b) Due to electrolytic attack

1.6 Chemical reaction

1.7 Weathering

1.8 Shock Waves

1.9 Poor design details

a) Reentrant corners

b) Abrupt changes in section

c) Rigid joint between precast slabs

d) Large deflection

e) Insufficient travel of expansion joints

1.10 Errors in design

1.1 <u>OCCURRENCE INCIDENT TO CONSTRUCTION OPERATION</u>

Improper procedures or carelessness during any phase of construction operation may result in concrete of inferior quality and may result in cracking of concrete which will be more susceptible to further deterioration than that produced by strict adherence to quality. Some of the likely instances have been discussed below:

1.1.1 <u>LOCALISED SETTLEMENT OF SUBGRADE</u>

If there is a local soft pocket in the subgrade on which flooring concrete is directly placed, or if there are any air pockets or hollow under the building paper, there will be localised settlement of concrete due to the weight of the plastic mass, and if this settlement takes place after the finishing of surface ,cracks will come to surface .

Prevention: By giving proper attention to compaction and draining of subgrade, eliminating trapped air. These cracks will be closed when finishing the concrete surface, unless the final finishing pass is made directly after placing the concrete.

1.1.2 MOVEMENT OF FORMWORK

Any movement of formwork which occurs between the time that the concrete begins to loose its fluidity and the time that it has fully set, will cause cracks to appear in the structure. These cracks may be internal and invisible from surface but are dangerous as they form a water pocket in the concrete mass which upon freezing will spall the concrete surface and may also cause corrosion of reinforcement .

Prevention: Formwork should be properly designed particularly with respect to deflection and all details and workmanship should be checked periodically during the pour. Nails should preferably be in shear to prevent loosening.

1.1.3 VIBRATION

Cracking of concrete during vibration, which takes place during the set, is mostly due to delayed vibratory compaction or accidental vibration of the form caused by the equipment movement or careless workman.

Prevention : Do not use or let use the formwork as work bench while concrete is setting.

1.1.4 SETTING SHRINKAGE

Volume changes during the initial setting of the concrete tends to cause the formation of shallow surface cracks with appearance of alligator scale and they can be avoided by delayed finishing.

1.1.5 PREMATURE REMOVAL OF FORMWORK

With modern pressure of speed and economy in construction there is a tendency of removing the formwork before concrete has attained the full strength, when this occurs, cracks often occur in concrete.

Prevention: Leave the formwork in place till the concrete is strong enough.

1.2 DRYING SHRINKAGE

Drying shrinkage is the chemical reaction incident to the hardening of concrete, which occurs over the extended period of time and involves decrease in volume. If the structure is restrained against free occurrence of these volume changes, stresses are created which may cause cracking of concrete mass

Prevention: Do the following:

a) Eliminate restraint on the structure by frequent use of the joints.

b) Provide adequate amount of reinforcement to distribute and reduce size of those cracks which do occur.

c) Lower the placement temperature of concrete.

1.3 TEMPERATURE STRESSES

Variation in the temperature of a hardened concrete mass will result in changes in shape and volume of that mass. If free occurrence of such changes in shape and volume is prevented by restraint of structure , stresses are created, and if such stresses produce tension in the concrete section, cracking will result.

Prevention: Do the following:

a) Minimum temperature /Distribution steel should be provided .

b) Greater amount of temperature steel should be used in balconies, parapets, and places where framing is such that the floor slab spans in the short direction of building, as in schools and dormitories .

c) Provision of adequate insulation on roof.

1.4 ABSORPTION OF MOISTURE BY CONCRETE

In varying degrees all concrete are porous. Based on experiments, it has been reported that expansion of concrete on absorption of moisture ranges from 0.01% to 0.2% depending upon mix of concrete, workmanship, age of concrete, type of aggregates, initial moisture content etc. If this swelling is prevented then cracks may occur .

Prevention: It is impractical to prevent swelling due to increased moisture content. The solution is to allow concrete to expand in buildings subjected to alternate wetting and drying process.

1.5 CORROSION OF REINFORCEMENT [35]

The complex phenomenon of corrosion process and the associated damage to the concrete structure considerably reduces the strength of reinforced concrete member and consequently its life. The present day design practice does not include estimation of design life and the durability of structure is expected to be ensured by specifying certain minimum requirements, with regards to materials, construction practice, structural dimensions, quality control etc. In case of corrosion protection of reinforcement bars, the general specifications include minimum cement content, maximum water/cement ratio, minimum cover thickness, limitation of harmful chemicals, etc. and compliance to these specifications is expected to guarantee an "adequate" service life of a structure. Considerable R&D work has been carried out from the time the problem was identified and a large amount of data is available which has helped to understand the mechanism and process of corrosion, these have been explained in following paragraphs.

1.5.1 DUE TO CHEMICAL AGENT [26]

In RCC structure it is the tendency of the designer to place the reinforcement closest to the surface to get maximum benefit of steel and consequent economy. However if the reinforcement is exposed to circulating water or humid air through air voids in concrete or small cracks, the reinforcement corrodes due to chemical reaction. The volume of oxides produced by corrosion is about eight times that of parent material and the result is that the concrete cover is cracked.

Prevention: Do the following:

a) Use dense concrete mix with low porosity.

b) Provide adequate cover to reinforcement.

c) Avoid details in drawings, which would promote pounding of water.

d) Keep weep holes open and see that roofs, balconies and similar features drip clear of the lower structure.

1.5.2 **CORROSION DUE TO ELECTROLYTIC ATTACK** [35]

In the presence of moisture, particularly if the moisture contains salt (as in sea water) concrete is electrically conductive, and presence of electric current can create electrolytic action on the steel causing violent corrosion.

In structures which are exposed to atmosphere, corrosion of reinforcement will occur only when concrete surrounding the steel undergoes some changes. These changes can be physical such as cracking and disintegration, with the result the embedded steel comes in direct contact with air making the steel to loose its physical and chemical protection. Chemical changes also occur where the alkalinity gets reduced due to ingress of carbondioxide or the passivation gets destroyed due to ingress of aggressive ions especially chloride ions. After the passivity breaks down, the corrosion process sets in and peculiar nature of volume growth of corrosion products causes damage to the concrete through its physical expansive force.

Prevention[26]: In addition to measures described above presence of excessive sulphates, chlorides and carbonates should be avoided. Sea water is a common source of salt and its use as mixing water should be discouraged.

If the reinforcement used is not of uniform composition corrosion will attack the intersection of stirrups with main bars and more particularly points of contact between the tie wires and the bars. Accordingly reinforcement section should be preferably of same grade.

1.5.3 **Corrosion Protection methods** [4]: A detailed analysis of the factors that influence corrosion mechanism and process indicates that corrosion protection requires a multiple approach as given below:

a) Coating to reinforcement
b) Cathodic protection
c) Using stainless steel
d) Using nonferrous reinforcement
e) Coating to concrete

f) Using corrosion inhibitors

g) Improving concrete and use of blended cements

1.5.3.1 COATING TO REINFORCEMENT

The objective of coating of steel bars is to provide a sufficiently durable barrier to aggressive agents such as chlorides and yet be robust enough to tolerate handling, fixing, and the pouring of concrete.

Fusion-bonded epoxy coating is one of the most popular methods and has been recognised and covered under codes of practice in U.K, the U.S.A, and India. In this process electrostatically charged particles are deposited evenly on the surface of the bar. The thickness is closely controlled to ensure that the bar is adequately protected and yet the surface characteristics, which will influence its bond capacity once embedded in concrete, are not unduly affected. The coating thickness typically varies from 130 microns to 300 microns. The bars are checked to thickness and for any holidays.

Although epoxy coated bars offer excellent protection to corrosion, There are a few limitations as listed below:

a) Presence of holidays can induce severe localised corrosion.

b) Cutting and bending require treatment at site.

c) The effect on bond is to be ascertained.

d) Cost is high.

e) Coated bars can not be welded.

f) During storage at site, UV radiation may affect the coating.

g) Coating may get damaged during vibration of concrete.

Research data is still insufficient to precisely estimate the life of structure built with coated rebars. Suitable design guidelines are required for designing the structure with coated reinforcement bars with regard to development length, cover thickness etc.

1.5.3.2 CATHODIC PROTECTION

Cathodic protection is a technique by which the electrical potential of the steel is increased to a level at which corrosion can not take place. It is widely used for both steel and concrete offshore structures etc.

Two different methods are employed, an impressed current and use of sacrificial anodes. In the first the structure is connected to negative terminal of a DC power source, ideally using an anode, which does not corrode. In the second the reinforcement is connected to anodes with a more negative corrosion potential than steel, such as zinc or aluminum. The current is reversed and corrosion now takes place at the anode, which is gradually used up. In both cases electrical continuity of reinforcement is required.

Most concrete application to date has been for repair and rehabilitation of structures that have already suffered the corrosion damage. To ensure uniform protection of embedded steel the anode must be fitted to the concrete, covering most of the surface area. There are a number of different methods of forming anodes. The first is copper wire, in a polymer sheath, which is fixed to the surface of the concrete in a serpentine arrangement. Alternatively, a coated titanium mesh must be used, which gives a more uniform covering to the surface. Simple clips are used to hold the anodes in place. After installation the whole area is covered with an overlay. This may be a cement grout or concrete depending on particular application.

In general, the application of cathodic protection will be part of rehabilitation work and hence it is likely that chloride contaminated or carbonated concrete will be removed. Thus, the overlay serves the additional function of reinstating the cover to the reinforcement. Alternatively, if the surface concrete does not have to be removed, the anode wires be set in grooves cut into the concrete, which are than filled with a suitable grout.

1.5.3.3 USING STAINLESS STEEL

Stainless steel is the name given to a family of corrosion resistant steels containing minimum of 12% chromium. On contact with air, the chromium forms a thin oxide layer on the surface of steel. This is passive and resists corrosion. The addition of other elements like nickel or molybdenum enhances the passivity and thus improves the corrosion resistance. This coating is self-repairing type so does not get damaged during handling and fixing.

Plain and ribbed bars are available in the same range of standard sizes as normal reinforcement, with a similar bond and other characteristics, hence no design or detail changes are required to be made when replacing normal rebars with stainless steel rebars. However physical contact between stainless steel rebars and other embedded metals/normal rebars should be prevented. This is to avoid phenomenon of bimetallic corrosion in which the less noble metal (i.e. normal steel) will act as a sacrificial anode and will corrode more rapidly. Bimetallic corrosion will be of more significance in aggressive environments such as those where chlorides are present. Stainless steel reinforcement is significantly more expensive than standard rebars, possibly 7 to 8 times as much.

1.5.3.4 USING NON-FERROUS REINFORCEMENT

Currently a number of man made fibers are being used, the most common being glass and carbon. These fibers have ultimate strength well in excess of that of rebars and are available with a range of elastic moduli and their stress strain curve does not show any sign of plasticity at high stresses which could be a limiting factor in some situations.

The fibers are used either in the form of ropes or combined with suitable resins to form the rods. Because of their low elastic modulus, they have generally been used for prestressing.

1.5.3.5 COATING TO CONCRETE

In western countries it has been a common practice to seal the surface of concrete in important structures with sialine or sialine derivatives. While penetration in low strength concrete is as much as 12mm, it is only 2 to 4mm in high strength concrete. In addition careful preparation and drying of concrete surface is required before application. Finally, it is not clear what life can be expected from the coating and when it will have to be replaced. Its performance has been assessed at SERC Chennai, and it was found that coating effectively delays the corrosion process and its rate.

1.5.3.5 CORROSION INHIBITORS

Certain admixtures can be used to inhibit corrosion of reinforcement like calcium nitrite. When corrosion takes place in untreated concrete, the ferrous ions at anode pass into solution and, in secondary reaction are converted into the rust. With calcium nitrite, ferric ions are formed which are insoluble and hence stay on surface preventing further corrosion.

a) The addition of calcium nitrite extends time of corrosion initiation.

b) Total corrosion with calcium nitrite is substantially less.

c) The corrosion rate, once corrosion is initiated, is less with calcium nitrite.

1.5.3.6 IMPROVING CONCRETE

Codes and standards aim to achieve good durability of RCC in aggressive environments by specifying:

a) Higher minimum cement content

b) Low w/c ratio

c) Suitable minimum cover to reinforcement

d) Careful curing

In addition many codes limit crack width, with narrower widths for aggressive environment.

High strength concrete having low permeability performs much better, so is also called high performance concrete. Two ways of achieving high strength and reduced permeability are the use of super plastisizer with low water/cement ratio and addition of micro-silica to the mix, which is about 30 times finer than OPC and gives improved long term properties to concrete which would now be having very low permeability.

1.6 CHEMICAL REACTION [26]

The reactions occurring in and the behavior of concrete during and after hardening have been described briefly giving some of the more common aggressive agents, a few or more common reactions, and some devices for preventing or inhibiting the chemical attack.

The use of unsound or fouled material in concrete results in volume changes, pattern cracks, and in all manner of unpredictable defects.

Commercial cements are alkaline and are attacked by acids, by organic compounds, which can be hydrolyzed to acids, and by some alcohol. Ground water having an acid content due to the presence of decayed material may sometimes cause problems. Seawater attacks concrete through salts containing ammonium and magnesium ions. Sulphate solutions reacts with tricalcium aluminate hydrate, which is a normal constituent of concrete, forming calcium sulphoalluminate hydrate(Ettringite). This reaction is accompanied by a substantial expansion and causes cracking and disruption of the concrete mass. Although most commonly encountered in concrete exposed to sea water, sulphate attack can occur in the presence of combustion products (if moisture is present), in water draining from mines and industrial sites, or in fact wherever sulphate solution comes in contact with hardened portland cement matrix. Tricalcium aluminate in the cement also reacts with chloride ions, which is another reason for not using salt water for mixing water.

Soft water tends to leach out the lime in the cement paste, leaving a porous silica skeleton. However this reaction is slow and is seldom the cause of the trouble unless the water is forced through the concrete mass under pressure.

High temperature (over 300^0C) will drive off the water of hydration in the cement gel and cause loss of cementing action.

Carbon dioxide is another material, which reacts deleteriously with concrete if the concrete is fresh. Deterioration of concrete may also occur through chemical reaction between cement of high alkali content and mineral constituents of certain aggregates. This results in "pop-outs" of the concrete surface, map cracking, and an overall expansion of the concrete mass.

Most corrosive chemical agents, to produce significant attack on concrete, must be in solution form and above some minimum concentration. Dry chemicals seldom attack concrete. This is the reason that concrete in submerged environments is more susceptible to chemical attack.

General symptoms of chemical attack on concrete are disintegration and spalling of the concrete surface and opening of cracks and joints. There is also general disruption of the concrete mass and swelling of the structure. The aggregate particles protrude from the matrix, and there is a loss of cementation in the cement paste.

Where reaction produces an internal swelling of the concrete mass(alkali-aggregate reaction, sulphate attack etc.), the symptoms consist of formation of a pattern of cracks which develop by opening and deepening until sections of concrete are spalled away. Where expansion is not restrained the crack pattern is random.

Prevention: Do the following:

a) Use good sound dense concrete so as to prevent the intrusion of aggressive chemical solution. Use aggregates from a proven source.

b) Use sulphate resistance cement in active sulphate environment .

c) To prevent the alkali-aggregate reaction, specify the maximum alkali content of cement (calculated as the percentage of Na_2O plus 0.658 times the percentage of K_2O) shall not exceed 0.60 percent. It has been demonstrated that the concrete made with the usual stone aggregates with cement having a lesser alkali content normally are not affected by this reaction to an objectionable degree.

1.7 WEATHERING

To some extent all concrete are porous and will absorb moisture, if exposed to sub freezing temperatures, the moisture will freeze and expand, and the resulting hydraulic pressure will tend to cause the concrete surface to crack. Upon thawing, the cracked surface will spall.

Prevention : By minimizing the porosity of concrete by the use of sound and dense concrete.

1.8 SHOCK WAVES

Concrete is a heterogeneous material which is susceptible to spalling when subjected to shock waves. This is due to different transmission rates at which the wave passes through the several materials, such as the aggregates, matrix, and the reinforcement, etc.

Prevention: Experiences have suggested that the use of heavily reinforced sections will provide the concrete structure with excellent resistance to shock waves.

1.9 POOR DESIGN DETAIL

Study of different structures shows that deterioration occurs repeatedly in connection with certain details or that certain effects have taken place which were not anticipated in design, some of such details have been discussed here.

1.9.1 REENTRANT CORNER

If proper reinforcement details are not followed at reentrant corners it creates a condition of stress concentration under reinforcing bars at corners leading to cracking.

Prevention: Stress concentration can be reduced by distributing the lateral restraining force required to produce the change in direction of bar tension.

1.9.2 ABRUPT CHANGES IN SECTION

Any abrupt changes in the section causes stress concentration, which may result in cracking.

Prevention: Following should be done:

a) Expansion or contraction joints in the structural framing should be carried through the fill and the finish.

b) Openings should be provided with extra reinforcement at corners and special attention should be paid to pipe opening and ducts which sometimes are two closely grouped in the slab .

1.9.3 RIGID JOINTS BETWEEN PRECAST SLAB UNITS

Unless special provisions are made to extend and splice the top bars, precast slab units are commonly designed for condition of simple support. However rotation at the end of slab unit will cause cracking at the junction between the precast slabs and the cast in place fills, unless floors are covered with flexible material like asphalt tiles etc.

1.10 <u>ERRORS IN DESIGN</u>

Design errors do occur and the symptom of their occurrence is cracking. So it should also be considered as a potential source of cracking while diagnosing the probable causes of cracking and suggesting remedial measures .

Prevention: In present day environment most of the structural design are done on computer but a small error in input of the data may give completely wrong results. So computer output should not be adopted at the face value and it should be properly understood and checked based on experience before final adaptation of design.

CHAPTER - 2

DIAGNOSIS OF CAUSES OF DETERIORATION IN CONCRETE STRUCTURES

Diagnosis of causes of cracks in concrete[26]

2.1 INTRODUCTION

It is not possible to evaluate the real need for repairs or select a repair procedure with assurance of satisfactory results unless the cause \causes of cracking are clearly understood. It may not always be possible to pinpoint a particular cause but what can be done though is to eliminate possibilities until only a few remain, and then select a repair procedure which corrects the existing condition and prevent further cracking by any or all of the suspected causes.

It should be noted that failure to understand the cause of a crack can lead to selection of a repair procedure which may be harmful rather than helpful. There are no specific rules or set procedures for diagnosis of a problem, however with experience some patterns have been observed to appear, for example cracks in walls due to foundation settlement run diagonally, the cement paste subjected to sulphate attack has whitish appearance, cracks due to corrosion run in parallel straight lines along the reinforcement. In general following steps should be taken:

2.2 CHECK FOR ERROR IN DESIGN

First step is to check if the condition is caused by overstress resulting from some deficiency in basic design? It is a tribute to profession of civil engineering that, this is rarely the case, however it should be checked as follows :

a) Consider type of stress which could have caused cracking e.g. tension causes cracking usually without spalling and usually one or few cracks are enough to relieve the stress, on the other hand excessive compression is almost always accompanied by spalling.

So if symptom is cracking with spalling it is likely to be due to excessive compression and rule out excessive tension, and if cracking is without spalling rule out excessive compression.

Then try to relate the location of crack and probable type of overstress e.g. it is known that webs take shear and flange take bending so observance of shear cracks in flange would be inconsistent.

b) Knowing what type of stress is at fault relate it with areas of element where cracking has occurred i.e. if problem is tentatively diagnosed as tension cracking and crack occurs in compression flange then it is inconsistent and overstress is probably not the problem .

c) If no inconsistency has yet occurred consider orientation of crack i.e. tension cracks should roughly run perpendicular to the line of stress, shear usually causes cracking by diagonal tension and cracks run diagonally. See the inconsistency, with the pattern of crack.

If an inconsistency is encountered at some point in the above steps the probability of some basic design defect is remote and can be temporarily eliminated .

2.3 **<u>CHECK FOR CORROSION OF REINFORCEMENT</u>**

It can be readily identified .The cracks occur as a series of parallel cracks running along the reinforcement. Also remove some of the cracked or loosened concrete cover and see if bars are rusted, chase down the bars to see if the limits of corrosion corresponds to the limit of cracking and spalling of concrete. Also check to see if concrete beyond the plane of the reinforcement mat is sound.

If answer to all is yes it is clearly the case of corrosion of reinforcement. Now if corrosion is found to be spread out uniformly the trouble is probably due to electrochemical corrosion. If corrosion occurs over some segment of bar, occurs as pitting, or occurs principally at the intersection of other bars, the electrolytic attack is probable.

Next find why this could have occurred. If the trouble is electrolytic attack, where are the stray current coming from ! They must be arrested or trouble will reoccur. However if trouble is chemical, then repair is easy i.e. seal the bars in some material which will prevent further corrosion or cathodic protection of bars can be considered.

2.4 CHECK FOR TEMPERATURE AND SHRINKAGE STRESSES

Check the crack location, if it occurs at the point of stress concentration, such as near pipe sleeves or duct opening, or abrupt change in section, if so, temperature or shrinkage effects are the probable cause. Next try to link location of defect and points of restraint with respect to likely stress flow pattern due to temperature changes. If cracking conforms to these i.e. if perpendicular to line of stress the probable cause is temperature or shrinkage, an alternative in such situation is nothing but cut loose the restraint in the structure .

2.5 CHECK FOR FAULTS IN CONSTRUCTION OPERATION

Consider the location and pattern of crack and check the consistency with one or more probable defects during construction as mentioned in chapter number 1. For example: settlement of subgrade may cause radial or concentric crack pattern. Local bulging and cracking parallel to and near the face of concrete section may be associated with movement of form work.

2.6 CHECK FOR CRACKS DUE TO CHEMICAL ACTION

Chemical action may be diagnosed by sign of protruding aggregates. The aggregates, being more inert than cement sand matrix, are not attacked by reaction and stand proud from surrounding surface. However, concrete attacked by chemical action loses cementation and bond with aggregate, and sometimes you can even disrupt the concrete by hand.

2.7 CHECK FOR POOR DESIGN DETAILS

Check for poor design details can be diagnosed by careful study of design drawings and location of cracks.

2.8 GENERAL POINTS

Investigate the history of the structure. When was it built? By whom? In what season of the year? What type of cement was used? What kind of aggregate were used and what was their source? How was the concrete cured. Survey the horizontal and vertical alignment. Make survey of the deterioration. Where does it occur? Where it is worst? Plot the cracks and see if any pattern is emerging. Over load cracks in particular follows the line of principle stress and are relatively easy to differentiate and other things to consider are:

a) Whether the cracks penetrate the tension area of concrete or the compression area as well?

b) Whether the cracks penetrate full section?

c) Whether they occur internally, externally, or both? If the crack is internal, only movement of forms or any factor tending to cause a volume changes such as temperature, moisture change or chemical reaction, such as alkali-silica reaction, sulphate attack etc.. It should also be noted that shallow surface cracking is generally related to shrinkage.

d) Whether the location of crack corresponds to some changes in reinforcement or section etc.?

e) Whether the crack line relates to a section of structure added at a later date or to some changes of use or occupancy?

f) Whether the crack is active or dormant? Check may be made by periodic observation or by marking the ends of concrete or by using pin or tapes or by gauge points.

g) Whether the crack is new or persisting since long?

h) Where and why does the crack stop?

From above it can be seen that diagnosis is complicated process and becomes more a matter of possibilities than probabilities and it should be clearly understood that the above procedure of diagnosis will give nothing more than the first approximation of the truth (actual cause or causes of cracks) and it is not the substitute of careful collection of data, consideration and evaluation of all facts pertinent to the problem at hand. In fact careless use of data out of context or oversimplification can be misleading rather than helpful. So unless a very clear and positive conclusion appears, the diagnosis procedure should be carried through to the end without overlooking secondary or any other contributive agents. Whatever the type or cause of the observed cracks, strength of cracked structure should be evaluated by available nondestructive tests to certify the safety of the building.

A likely approach to be followed has been given in the form of a simple flow chart[1] in Fig. 2.1 .

2.9 SELECTION OF METHOD OF REPAIR

Selection of applicable methods of repairs involves consideration of following:

a) Are the cracks active or dormant?

b) What is the primary purpose of repair? Is it just to reduce excessive leakage? Is strengthening required?

c) How do the cracks occur? Are they pattern cracks, i.e., large number of relatively narrow crevices, or are they large, isolated defects?

The process of selection proceeds in accordance with the flow diagrams given in Fig. 2.2 and Fig. 2.3. Some of the typical strengthening procedures including steps have been shown in Fig. 2.4 and Fig. 2.15.

CHAPTER - 3

NON DESTRUCTIVE TEST METHODS FOR ASSESSING STRENGTH OF CONCRETE

Non Destructive Test Methods

3.1 INTRODUCTION [29]

During the past 40 years in-situ/non-destructive testing of concrete has achieved increasing acceptance for evaluation of existing concrete structures with regards to their strength, uniformity, durability and other properties. This chapter critically reviews the available in-situ non-destructive methods for estimating concrete strength. Regardless of the type of test used, it is emphasised that interpretation of the test data must be performed by a specialist, and unless comprehensive laboratory correlation has been established between the strength parameters and the result of non-destructive tests, the use of these tests should be done with caution.

3.2 TYPES OF TEST METHODS

Two type of test methods are available for estimating compressive or flexural strength of concrete, the first type includes those methods which do not measure strength directly but measure some other property of concrete from which an estimate of strength can be made; these include surface hardness, penetration resistance, ultrasonic pulse velocity and maturity methods. The second type of test methods are those which measure some strength property from which an estimate is then made of compressive strength of concrete; these include various types of pullout methods and breakoff techniques.

3.2.1 SURFACE HARDNESS METHODS

The surface hardness methods consist essentially of impacting the concrete surface in a standard manner, using a given mass activated by a given energy and measuring the size of indentation or rebound. The most commonly used method is rebound hammer. Although the rebound hammer provides a quick, inexpensive means of checking uniformity, it has many serious limitations for example the result of rebound hammer are affected by smoothness, content of coarse aggregate, carbonation, and moisture condition of concrete surface, size and age of concrete specimen and type of coarse aggregate used in concrete.

3.2.2 PENETRATION RESISTANCE TECHNIQUE

The technique to determine penetration resistance of concrete consists essentially of powder activated devices, the currently available system being known as Windsor probe. In this system a powder activated driver is used to fire a hardened alloy probe into the concrete; the exposed length of the probe is a measure of the penetration resistance of the concrete. This method is excellent for measuring strength development of concrete at early ages in order to determine the stripping time for formwork and for determining the relative strengths of concrete in different parts of the same structure. The test results are affected by the hardness of the aggregates used.

3.2.3 PULLOUT TESTS

Briefly they consist of pulling out from concrete a specially shaped insert whose enlarged end has been cast into concrete. The pullout force required is measured by using a dynamometer. Because of its shape, the steel insert is pulled out with a cone of concrete. The concrete is in shear/tension with generating lines of the cone running at approximately 45^0 to the direction of the pull. The pull out strength is of the order of 20% of the compressive strength. Pullout method is also an excellent means of determining strength development of concrete at early ages.

The major drawbacks of the pullout tests are that these have to be planned in advance. Unlike the most other in-situ tests, they cannot be performed at random after the concrete has hardened. To overcome this, new techniques are being developed in which holes are drilled in hardened concrete, into which either normal pullout insert or split sleeve assemblies/wedge anchors are installed which are then pulled out; in the former case a cone of concrete is pulled out and in the later case internal cracking of concrete is caused.

3.2.4 ULTRASONIC PULSE VELOCITY METHOD

The ultrasonic pulse velocity method (UPV) consists of measuring the time of travel of an ultrasonic wave passing through the concrete. The time of travel between the initial onset and the reception of the pulse is measured electronically. The path length between the transducers divided by the time of travel gives average velocity of wave propagation.

The UPV technique has often been used for estimating strength of concrete, however this technique is excellent for establishing uniformity of concrete. The relationship between pulse velocity and strength is affected by a number of variables such as age of concrete, aggregate size, volume fraction of aggregates, type of aggregates and location of steel reinforcement.

3.3 GENERAL COMMENTS ON TEST METHODS

In-situ non-destructive test methods provide an effective way of obtaining a considerable amount of preliminary test data in very less time and at relatively low cost. Both rebound hammer and pulse velocity methods can be used to monitor structural elements to delineate zones of weaker concrete that can then be subjected to core testing if necessary. However unless the comprehensive laboratory correlation has been established between the strength parameters to be predicted and results of nondestructive tests the use of these tests needs to be discouraged.

3.4 USE OF MULTIPLE METHODS

In western countries the use of more than one in-situ/non-destructive testing technique to improve the accuracy of prediction of strength parameters of concrete has gained credibility. Some of the researchers have suggested the combined use of pullout and UPV tests. While a number of other combinations have also been suggested, among many combinations the combined use of Schmidt hammer technique with ultra sonic pulse velocity method is likely to be most available/useful in the strength estimation of concrete for practical use. The proponents of use of multiple methods claim that the use of two methods, each measuring different property, can overcome the limitation associated with the use of each method used independently. In Indian conditions the combined use of Schmidt hammer and UPV methods is picking up, because of availability of these instruments with all consulting engineers in the field of repair and rehabilitation of RCC structures. These instruments are now being manufactured indigenously and are available at reasonable cost.

Experimental studies have been carried out in Japan by Yasuo Tangiawa and others[51] and they have studied the accuracies of prediction of strength of concrete by various formulas and proposed practical equation for estimating the concrete strength with combined testing methods.

Experimental investigations were carried out in present study/thesis with three basic objectives:

a) To propose a practical equation for the estimation of compressive strength of standard concrete mix as defined by combined nondestructive method.

b) To examine the effect of various factors such as the unit content of cement, curing condition, age of concrete, size and volume fraction of coarse aggregates and type of coarse aggregates, on compressive strength of concrete (In Indian conditions) as estimated by proposed equation.

c) To examine the applicability of the equation in evaluation of the concrete compressive strength.

CHAPTER - 4

SPECIFICATION FOR RCC JACKETING

SPECIFICATION FOR RCC JACKETING[39]

4.1 MATERIALS

All materials like cement, aggregate, admixtures, reinforcement, water etc. should be as per requirements of prevailing IS codes. Cement should be OPC conforming to IS:269. Aggregate should be conforming to IS:383, Water should be conforming to IS:3025, Admixtures should be as per IS:9103 and reinforcement should conform to IS:432, IS:1139 and IS:1786. Storage of materials shall be as described in IS:4082.

4.2 CONCRETE

All concrete should be as per requirement of IS:456 and mix should be designed to produce the required grade of concrete with slump between 75 to 125 mm and specified strength.

As long as the quality of material does not change, a mix design done earlier should be considered adequate for later works.

4.3 DURABILITY

Durability should be ensured by providing proper cover to reinforcement as per IS codes and detailed drawings of existing structure.

The concrete should have minimum cement content of 360 Kg/m^3 and a maximum water cement ratio of 0.55.

4.4 PREPARATION OF SURFACE

4.4.1 A good base or foundation should be prepared for successful application of jacketing.

4.4.2 All unsound / weak concrete material should be first removed up to required depth. Chipping should continue until there are no offsets in the cavity, which will cause an abrupt change in thickness of repaired surface. No square shoulders should be left at the perimeter of the cavity, all edges should be tapered. The final cut surface should be critically examined to make sure that it is sound and properly shaped.

4.4.3 After it has been ensured that the surface to which jacket concrete is to be bonded is sound, holes of required depth and diameter should be drilled as per spacing stated or as shown on drawings for providing shear keys if they are specified (which are preferable as shown in conclusion). The drilled holes should be thoroughly cleaned off of loose particles by oil free air blast.

Approved epoxy dipped steel bars of required length, shape and diameter should then be driven inside the holes to form the shear keys, which should be allowed to set for 24 hours.

4.4.4 The balance of the concrete surface should then be cleaned off of all loose and foreign materials by means of sand blasting or stiff wire brushing if approved by engineer. All dust and loose particles resulting from such pretreatment should be removed by oil free air blast.

4.4.5 Approved epoxy based formulation should be applied to the prepared concrete and reinforcement substrate, before jacketing after tying in new reinforcement, inserts etc. Shuttering should be erected and fresh concrete should be poured as soon as possible after application of epoxy bonding coat, but always during open time of adhesive. If necessary, considering 'open time' appropriate concrete depths should be decided in advance and subsequent pours continued in sequence by continuation of formwork after application of epoxy formulation to the further part.

4.5 <u>FORMWORK</u>

The formwork should be designed and constructed to the shapes, lines and dimensions shown on drawings. Deviation from specified dimension of cross-sections of column should be within tolerance of -6mm to +12mm. Timely erection of formwork for restoration is a special requirement, particularly due to time constraint on the work due to limited application time, i.e. potlife of the special construction chemicals used in such works.

4.6 <u>FIXING OF REINFORCEMENT</u>

Reinforcement should be fixed in accordance with procedure specified in IS:2502 or as per detailed drawings.

4.7 **SUPERVISION**

Transporting, placing, compaction, curing, sampling for strength of concrete and acceptance criteria should be in conformity with relevant clauses of IS:456

4.8 **INSPECTION AND TESTING OF STRUCTURE**

Immediately after stripping the formwork, all concrete should be carefully inspected and any defective work or small defect should be either removed or made good before concrete has thoroughly hardened. The immediate rectification is necessary including its certification having done so. In case the engineer is not satisfied about the proper bond between old and new concrete or grade of concrete used, either due to poor workmanship or based on results of cube strength tests, contractor on instruction of engineer shall have to carry out core test/or load test.

4.9 **SPECIFICATION FOR BONDING PLASTIC CONCRETE TO HARDENED CONCRETE WITH EPOXY ADHESIVE :**

4.9.1 **SUBMITTALS AND LABELING**

Contractor should submit manufacturer's certification verifying conformance to material specification as specified and clearly mark all containers with following information.

a) Name of manufacturer
b) Manufacturer's instruction for mixing
c) Warning for handling and mixing

4.9.2 **STORAGE**

Contractor should arrange to store all materials at temperatures between 5^0C to 38^0C unless otherwise recommended by manufacturer.

4.9.3 **PRODUCT**

Epoxy adhesive should have following properties.

a) Viscosity at 25^0C : 2-10 Pas
b) Minimum gel time : 30 minutes
c) 14 days bond strength : 7.5 - 10 Mpa
d) Maximum shrinkage coefficient on cure(linear) : 0.005
d) Minimum compressive yield strength at 7 days : 55 Mpa

e) Absorption, 24 hours, Maximum : 1%

f) Tensile strength, 7 days minimum : 40 Mpa

g) Elongation at break, minimum : 1%

These specific quality requirements are stipulated for a common work of bonding needs in restoration. All the test facilities are not generally available so reliability of the product quality is important.

4.9.4 **ADHESIVE MIXES**

Epoxy components should be mixed in a clean container free from harmful residues, and they should also be thoroughly blended to a uniform and homogeneous mixture.

4.9.5 **SAFETY**

All workers working with adhesives should be advised to avoid contact with eyes and skin, inhalation of vapours, and ingestion.

4.9.6 **FIELD QUALITY PERFORMANCE REQUIREMENT**

Evaluation of bonding of fresh concrete to existing concrete shall be made after 7 days curing by sounding, by tapping fresh concrete with a blunt metal instrument. Detection of hollow sound in any area shall be a reason to suspect inadequate bonding. Under such circumstances cores shall be cut after 28 days for further determination of bonding adequacy. Length of core shall be twice the diameter of core or twice the thickness of fresh concrete. These cores shall be tested under tension to evaluate the quality of bond between old and new concrete.

CHAPTER - 5

EXPERT SYSTEM AND THEIR UTILITY IN STRUCTURAL ENGINEERING

EXPERT SYSTEM AND THEIR UTILITY IN STRUCTURAL ENGG.

5.1 EXPERT SYSTEMS[56]

Expert systems are among the most exiting new developments in the computer science and technology. Emerging as a practical application of research in artificial intelligence, these programs embody knowledge of a particular application area combined with inference mechanisms which enables the programmer to use this knowledge in problem solving situations.

Prototype systems are now in use around the world in areas such as medical diagnosis, mineral prospecting, computer system configuration etc. Efforts are now underway in industry and science to exploit this technology and extend it to new applications where human expertise is either expensive or in short supply.

Expert systems are tools, which perform tasks that require a great deal of expertise in a particular field acquired from long experience with such tasks. The field of expertise is known as domain of the system. Expert systems can also be defined as interactive computer programs incorporating judgment, experience, rules of thumb, intuition, and other expertise to provide knowledgeable advice about a variety of tasks (domains). Another way to define expert systems is to compare them with ordinary programs. The most basic difference is that expert systems manipulate *knowledge* while conventional programs manipulate *data*. The accumulation and codification of knowledge is one of the most important aspect of an expert system. Knowledge based expert system technology has been applied most successfully to diagnosis problems. ES have also been developed for fault detection, prediction, interpretation, monitoring, planning and design problems.

Rapid industrialisation has taken place in all the branches of engineering except Civil engg., where most of the decisions are still being taken on adhoc basis especially in attending problems related to repairs to structures. Over the years, inspection of structures for their requirements of repairs and for their stability assessment has become routine, and in routine works one tends to loose initiative and involvement. In this state of mind, there are likely to be omissions of noting some critical and crucial observations. Further, several observations with their variable nature also have to be expertly correlated, and evaluated for assessment. So Diagnosis of reasons of distress and suggesting repairs appears to be one of the most challenging areas of development of ES. On one hand heuristic nature of probable reasons of causes of distress make it suitable and on the other hand, repair is an open ended problem that ultimately requires creativity.

The process of diagnosis of causes of distress in concrete structure and suggesting repairs involves intuition, judgment, and previous experience for finding correct cause of distress and selecting best method of repairs for a particular situation.

Several attempts have been reported in literature for development of expert systems in the field of structural engineering. Some of these have been reviewed briefly later on. It should be noted that the knowledge base of all these expert systems, basically for design problems contains heuristic rules and experimental knowledge obtained from printed documents or human experts.

The fundamental method of knowledge acquisition recommended in practically all the recent books on ES is to find one or several human experts in the problem domain and use their knowledge in the ES. In fact, this is how the most celebrated ES in the field of medical diagnosis (MYSIN) , mineral exploration (PROPECTOR) and computer configuration (XCON) have been developed. The present work is novel in its approach since it is an integration of symbolic and numerical processing techniques. Such an ES is known as Coupled ES. It also embraces advanced techniques as graphics and user interface.

5.2 MAIN COMPONENTS OF AN EXPERT SYSTEM

An expert system typically consists of the following components:

5.2.1 KNOWLEDGE BASE

The knowledge base consists of general facts and heuristic knowledge (rules of thumb). A number of formulations, such as production rules, frames and sematic nets are available for the representation of knowledge. The production rule representation has been extensively used in the making of expert systems. In this approach, the knowledge is represented as "IF-AND/OR-THEN" rules or "Premise-Action" pairs, the "action" is taken if the "premise" evaluates to be true. The knowledge base may also be partitioned into knowledge levels in order to help organise problem solving.

5.2.2 CONTEXT

The context is a collection of symbols or facts that reflects the current state of the problem at hand. It consists of the information generated during a particular program execution.

5.2.3 INFERENCE ENGINE

The inference engine is used to monitor the execution of the program by using the knowledge base to modify the contents of the context. The formulation used in the process, are the forward chaining, backward chaining, back tracking, blackboard architecture, control using agendas and hierarchical planning.

5.2.4 INFERENCE MECHANISMS

5.2.4.1 FORWARD CHAINING

Inference works from an initial state of known facts to a goal state. All the facts supplied by the user are considered by the system and the system deduces the most appropriate hypothesis that fits the facts. This mechanism is useful when the user input data are few and the hypotheses are large in numbers.

5.2.4.2 BACKWARD CHAINING

It works from a goal state by trying to support a goal state or hypothesis using the known facts in the context. If the facts in the context at any stage do not support the hypothesis, then the rules having the goal state as the consequence are identified and the corresponding preconditions are setup as subgoals. This mechanism is continued until no further rule is available and at that stage the user is quarried the data. This is also called goal driven. Backward chaining is useful for problems that have a few hypotheses associated with a large input data.

5.3 OTHER COMPONENTS OF EXPERT SYSTEM

The components discussed above form the kernel of most of the existing ES. In addition, the user interface, knowledge acquisition and explanation modules are included depending upon the requirement of the system.

5.4 FEATURES OF EXPERT SYSTEM

Each system is designed for a particular purpose, but generally, an ES should have following features:

a) **The ES should be usable**: An ES should be user friendly, i.e. it should be designed such that even a novice computer user should be at home with the system.

b) **The ES should be useful**: The system should be developed to meet the specific requirement for which it is designed.

c) **The ES should be educational when appropriate**: A non-expert should be able to use and learn from the ES.

d) **The ES should be able to explain its reasoning.**

e) **The ES should be able to respond to quarries.**

f) **The ES should be able to learn from the new consultations.**

g) **The ES knowledge should be apendable.**

5.5 ADVANTAGES OF EXPERT SYSTEM

a) The primary advantage is **availability and convenience.** Human experts are very few and are not available easily.

b) **Permanence** : Human expertise can quickly fade or be lost. Unlike humans whose knowledge ceases along with him, ES knowledge is never lost.

c) **Ease of transfer and reproduction**: Transferring human knowledge is the laborious, lengthy and expensive process called education (or in some cases called knowledge engineering) while transferring ES is the trivial process of copying a program which takes only few seconds.

d) **Easier documentation.**

e) **Consistency** : ES produces more consistent, reproducible results than does human expertise. A human expert may take different decisions in identical situations because of emotional factors. For example a human may forget to use important rule in a crisis situation because of time or overstress while an expert system is not susceptible to these distractions.

f) A final advantage is **low cost** of ES. Human experts, especially the top ones, are very scarce, and hence very expensive. Expert system, by contrast are relatively inexpensive. They are costly to develop but cheap to operate because of their low operating costs and the ease with which new copies of the system can be made.

5.6 REQUIREMENT OF MODERATELY SKILLED EXPERT[56]

The most highly skilled experts can perhaps be eliminated while using expert system, but in many situations, like in diagnosis problems, a moderately skilled expert is required. The expert system can then be used to augment and enhance this user's skill. The reasons for requirement of moderately skilled human expert are as follows.

a) **Creativity**: Humans are much more creative and innovative than even the smartest of programs.

b) **Learning:** Humans expertise excels in learning and they adapt to the changing conditions, they adjust their strategies to conform to new situations while ES is not as good in this field. Progress has been made in developing programs that learn, but these programs tend to work in extremely simple domain and don't do well when confronted with the complexity and real world problems.

c) **Human expert can make direct use of complex sensory inputs**, whether it be visual, auditory, tactile or olfactory. But for expert system sensory data must be transformed into symbols that can be understood by the system and quite a bit of information may be lost in the translation, especially when visual scenes are mapped into sets of objects and the relations between them. The old saying, " a picture is worth a thousand words" turns out to be an understatement in this case.

d) **Commonsense knowledge:** Humans have commonsense knowledge, which ES does not have. Commonsense knowledge includes knowing what you don't know as well as what you do know.

For these reasons, expert systems are often used in an advisory capacity - as a consultant or aid to either an expert or a novice user in some problem area.

5.7 TOOLS FOR DEVELOPING EXPERT SYSTEM

ES can be written in almost any programming language depending on the requirements. There are also specific languages which cater for the use in ES, such as PROLOG which has a built in backtracking facility and LISP is used for list processing. Other symbolic languages are INTERLISP, SAIL, PLANNER, KRL, etc. Standard programming languages C, PASCAL, and BASIC can be used, if the system is a coupled system, which requires both algorithmic and symbolic processing.

General-purpose representation language (GPRL) are also available which require the feeding of the knowledge in the knowledge database and using it. Such GPRL's are AEE, SRL, OPS5, ROSIE, LOOPS etc..

ES building frameworks are also available. These are ES where only the original knowledge database is required to be replaced to suite the required application. These frameworks can be used for similar problems as the original one's. Some of the common frameworks are EMYCIN, KAS, EXPERT etc.

5.8 AVAILABLE EXPERT SYSTEMS IN STRUCTURAL ENGINEERING

HI_RISE is a knowledge based expert system developed by M.L.Maher for her Ph.D. thesis in the Carneige Mellon University. It was implemented on a production system language and scheme representation language (PSRL). This system aids the preliminary design of high rise buildings.

FLODER is used to design alternative floor systems and framing for a given architectural design. It was developed by Mr. Karakatsanis as thesis for MS in the Carneige Mellon University.

LOCATOR is a system used for finding appropriate location of lateral load resisting system in a three dimensional building grid. It was developed by Smith.

LOW-RISE developed by Camado for MS thesis in the Careige Mellon University is an ES for the planning and design of Industrial buildings.

ALL-RISE is a system developed by Sriram in the carneige Mellon University. It aids in the preliminary design of various types of structures.

SACON is structural analysis consultant developed by J.Bennet of Stanford University. This system was implemented on EMYSIN system to aid nonexpert engineers in the use of general structural analysis programs such as MARC, SESAM etc..

SPECON Specification consultant is developed to aid the engineers in checking of structural steel elements for conformance with the AISC steel design specification, using LISP and OPS5 system.

BTEXPERT is an ES for the design of bridge trusses developed by H. Adelli and K.V.Balasubramanyam.

DESTINY an ES developed by Sriram is an integrated system for design of buildings as thesis for Ph.D. in the Carneige Mellon University.

BDES is an ES used for the design of the super structure for the short and medium span bridges.

SPEX is a system for processing of standards for structural component design developed by Garret.

HI-COST is used to develop preliminary cost estimates for hi-rise buildings using a data base of component costs.

KADBASE is a Knowledge aided database management system which is a network database interface between database management system and knowledge based system components of an integrated CAD system.

SPERIL is an expert system for damage assessment of existing structures developed by Ogawa, Yaoand K.S of Purdue University.

The Indian Scene :

Pioneering work in India on Expert System has been carried out at SERC Chennai, IIT Chennai and IISC Banglore.

ESISYS system is been developed in the IIT Chennai which makes decisions for the design of main framing, truss system and bracing system in an Industrial building.

EDSEL is a system for the design of steel structural elements, based on IS800-1984 which has been developed by Ghosh for the thesis of MS in IIT Chennai.

EXTASY is a transmission tower analysis and design system implemented using PROLOG, FORTRAN and BASIC languages. This system was developed in SERC Chennai by Shri Murlidharan.

EXPRUSS[32] is an expert system developed by Shri R. Narendran for design of roof truss for his M.Tech thesis at College of Engineering Pune.

FLOREP[8] is an expert system for repairs to floors developed by Shri H.S. Badrinath, Reader University of Roorkee.

CHAPTER - 6

ARCHITECTURE
OF
C O N R E P

ARCHITECTURE OF C O N R E P

6.1 INTRODUCTION

The Process of rehabilitation of concrete structures has been discussed in previous chapters. The process involves extensive use of intuition, judgment, previous experience, and the knowledge obtained through consultation with experts in the field of repair and rehabilitation of structures. Furthermore extensive numerical processing is involved in checking the load carrying capacity of existing members (subroutines for finding required reinforcement in slab and beams have been given in the expert system). Thus to develop expert system a coupled ES involving symbolic and numerical processing has been developed and named CONREP. The scope of CONREP is limited to diagnosis of cause of distress and recommending repair steps for RCC structures and main emphasis has been given to checking of design errors, recommending method of strengthening and assessment of residual strength of concrete by using non destructive tests.

The symbolic, numerical and graphical processing is developed in 'C' language. The diagnosis part of the system has been developed based on steps given in chapter 2. The basic flow chart of the CONREP has been given in Fig. 2.1 to Fig. 2.3.

6.2 KNOWLEDGE REPRESENTATION

The knowledge base of CONREP consists of domain specific knowledge and control knowledge. The domain knowledge consists of control rules for solving the problems. The rule consists of an IF part and a THEN part or a premise-action parts.

A fact or a parameter has a name, type(mostly number),single or multiple value and other properties, for example

```
if(option==1)
        diagnosis1();
else
        ......
```

This means option is a number type parameter and has an integer value.

6.3 RULES

The example given above shows a rule meaning that if option ==1 , then subroutine diagnosis1 has to be activated. Rules are classified as:

6.3.1 INFERENCE RULES

The default type of any rule is the inference rule. These rules are processed either by forward or backward chaining.

6.3.2 SINGLE FIRE MONITORS

It functions independently without any reference to inference rules. Once a parameter in an IF part of a rule gets a value, single fire monitor is processed.

6.3.3 MULTIPLE FIRE MONITORS

They are processed exactly like single fire monitors except that they may be executed many times.

6.4 CONTROL FUNCTIONS

Control functions are the main building blocks in the ES. The control knowledge needed for solving a problem is developed in the control function. A control function represents certain tasks to be completed during the problem solving. For example selecting option in subfunction (opt1()) can represent a control function. A control function may be executed once or many times depending upon its function. The decision regarding the assignment of parameters and rules to various control function is done by the knowledge base builder. The control knowledge needed for solving a problem can be represented by means of control rules.

6.5 INFERENCE MECHANISMS

The system has forward chaining mechanism, for solving the problem. In forward chaining mechanism, the applicable inference rules are collected in a rule list and the known facts in the control function are collected in the fact list. Depending upon whether the applicable rule list has to be processed once or many times, the forward chaining mechanism can be either a single or multiple cycle strategy. The ES processes the rule list in a top-down manner. Based on value of facts in the facts list, the THEN part is executed for the rules having their IF part satisfied. The fact list is subsequently updated. If a single-cycle strategy is used, then the process stops after a complete cycle through the applicable rule list as in our case. In multiple cycle strategy, the rules are processed in the applicable rule list again and again until the applicable rule list is empty or no remaining rules can be fired.

6.6 PROCEDURAL INTERFACE

The algorithm processing like the graphical support, analysis and design procedure are done and called for whenever required in the system sequentially in the form of control functions.

6.7 USER INTERFACE

User interface is provided in the form of the menu driven screens in which the user has to input the values required by the system.

6.8 GRAPHICAL INTERFACE

A very user-friendly graphical interface has been provided such that input is aided by graphical bitnotes and menus.

6.9 EXPLANATION FACILITY

The explanation facility helps the user to reason out the input data required and results/goals arrived at, accordingly brief details have been presented in each screen for explanation.

6.10 KNOWLEDGE ACQUISITION

Knowledge acquisition is not limited to accumulation of new facts, it also involves relating something new to what we already know in a proper way. It is the most time consuming activity in the development of an ES. The knowledge acquisition in development of ES has been through text books, literature, personal experience and through consultation with the experts in the field of repair and rehabilitation of concrete structures.

6.11 KNOWLEDGE BASE

As discussed earlier, the domain knowledge is represented in the form of parameters and rules in the control functions. Each control function may own some parameters and rules of the knowledge base.

Since the control functions are the driving mechanisms for problem solving, each parameter is associated with the multiple control function in a hierarchy, each association is treated as a separate instance. Similarly if a rule is associated with multiple control function in a hierarchy, each association is treated as separate instance. The control knowledge of CONREP and accordingly the system has been divided into 41 subfunctions, to simplify the complex process of determining the cause of distress in concrete structure and suggesting repairs. The various subfunctions and their interrelationships have been described as following.

6.12 **LIST OF MODULES OR SUBFUNCTIONS :** The whole system has been programmed as combination of subfunctions which interact with each other and aids in problem solving. The different modules/subfunctions are described as below:

Initialize : Initializes the graphical mode .

Start : Provides starting screen with graphical interface .

Title : Draws the main title .

Opt1 : Offers the choice for running the diagnosis, preventive measure, details of manufacturing firms of concrete repairing compounds and quitting the system .

Music : Plays music while title etc. is on .

Changetextstyle: Changes the text style, font size and direction.

Border : Draws the border for each screen.

Pause : Pauses the screen till user responds by pressing [Enter] key.

Basic : Gives basics and constraints of present expert system.

Basic1 : Gives basic causes of deterioration of concrete.

Diagnosis1 : Checks for foundation failure.

Diagnosis2 : Checks for design error.

Diagnosis3 : Recommends the initial tests to be performed on concrete.

Diagnosis4 : Checks for disintegration as basic symptom and suggest repairs.

Diagnosis5 : checks for shock wave as basic cause.

Diagnosis6 : Checks for corrosion of reinforcement.

Diagnosis7 : Suggests steps for detailed investigation having eliminated the possibilities of underdesign, corrosion, chemical attack, shock waves.

Slabdeg : For quick checking the adequacy of reinforcement in slab.

Opt2 : Offers types of panels of slab to be checked.

Beamdeg : For quick checking of reinforcement in the beam.

Repair1 : Recommends repairs for foundation settlement.

Repair21 : Recommends repairs for strengthening of columns.

Repair22 : Recommends repairs for strengthening of beams.

Repair23 : Recommends repairs for strengthening of slabs.

Firms : Gives the addresses of the firms dealing with RCC repairing compounds.

Preven : Suggests corrosion protection methods.

Opt3 : Offers option for selecting method of corrosion protection for getting more details.

Protect1 : Gives brief details about coating to reinforcement as corrosion protection method.

Proect2 : Gives brief details about cathodic protection.

Protect3 : Gives brief details about stainless steel reinforcement.

Protect4 : Gives brief details about use of non ferrous reinforcement as corrosion protection method.

Protect5 : Gives brief details about corrosion inhibitors.

protect6 : Gives brief details about coating to concrete.

protect7 : Gives brief details about improving the concrete for protection of reinforcement in RCC against corrosion.

Diskette containing the complete program has been attached at the end at appendix-A which can be loaded as per instructions given in the appendix-A (Read Me) and the program can be viewed in details which is self explanatory to any one having some knowledge of programming language "C".

CHAPTER - 7

EXPERIMENTAL WORK

Experimental Work

7.1 INTRODUCTION

Non destructive tests are very commonly used to obtain the information on the current condition of structural materials, connections and general response of the structure to either static or dynamic loading and to change in environment, which is an ongoing age related response of the structure or its elements. This information provides an important contribution to overall evaluation of existing structure and mainly to the extent and probable reasons of deterioration of structure. Such tests reveal important technical data for decision making to select particular method of restoration with or without special support of bonding materials etc. So non destructive tests and consequent damage assessment permits engineer to determine with reasonable clarity the, true cause/s of damage and to measure its extent so as to check the stability of the structure and also to decide appropriate corrective measure.

So nondestructive testing is one of the basic and primary requirement for any rehabilitation work. Accordingly study of available NDT's and assessment of concrete strength have been undertaken in the work. As emphasised earlier, the combined non-destructive testing with Schmidt hammer and UPV is likely to give more precise assessment of strength. Study of combined method of NDT was carried out in details by Mr. Yasuo(51) who in his study has established a practical expression for estimating the compressive strength of concrete using the non destructive testing methods combining rebound number of Schmidt hammer and Ultra sonic pulse velocity. While verifying the efficacy/accuracy of such relation in Indian condition a lot of scatter was observed. Hence a new attempt was endeavored to modify his relation in Indian condition and examine the effects of following factors:

a) Maximum size of CA

b) Volume fraction of CA

c) Age of concrete

d) Cement content

e) Type of aggregates

Jacketing of columns is the most common technique being used widely for repair/rehabilitation of columns under distress. However jacketing of columns are being undertaken on random basis without any parameteric study to find the efficacy of this technique so as to recommend various parameters for jacketing such as strength of jacketing concrete, bonding agent to be used, amount of extra reinforcement to be used in jacketing and requirement of shear links between old and new shear stirrups. Accordingly experimental study was carried out to examine the effect of different parameters with respect to increase in load carrying capacity of columns jacketed under varying conditions.

Field conditions were simulated as far as possible and all the materials used were locally procured from easily available local source within Pune itself. Since two experimental works were carried out i.e. use of combined non destructive testing and jacketing of columns so they shall be discussed separately as experiment no. 1 and experiment no. 2 respectively.

7.2 PARAMETERS CONSIDERED

7.2.1 PARAMETERS CONSIDERED IN EXPERIMENT NO. 1

Cubes of standard concrete mix, as defined later with different w/c ratios were cast along with cubes of standard mix with varying coarse aggregate size, volume fraction of aggregates, cement content and type of aggregates and following parameters studied :

a) Relation between compressive strength of concrete and combined non destructive test results of Schmidt hammer and UPV.

b) Correction factor for different coarse aggregate sizes.

c) Correction factor for different volume fraction of coarse aggregate

d) Correction factor for cement content of concrete

e) Correction factor for age of concrete

f) Correction factor for type of coarse aggregates.

7.2.2 PARAMETER CONSIDERED IN EXPERIMENT NO. 2

Field condition of columns whose reinforcement has corroded and concrete spalled off, was simulated by removing cover concrete and columns were jacketed under varying condition and tested as under to evaluate effect of corresponding parameter:

a) Columns tested with cover concrete spalled of completely.

b) Columns jacketed with cement slurry as bonding compound between old and new concrete with varying extra reinforcement in jacketing.

c) Columns jacketed with epoxy compound as bonding compound between old and new concrete with varying extra reinforcement in jacketing.

d) Columns jacketed with epoxy compound as bonding compound between old and new concrete with varying grade of jacketing concrete.

e) Columns jacketed with shear links between old and new shear stirrups and epoxy compound as bonding compound between old and new concrete with varying reinforcement.

f) Columns jacketed with shear links between old and new shear stirrups without any bonding compound between old and new concrete.

7.3 EXPERIMENTAL DETAILS

7.3.1 EXPERIMENTAL DETAILS OF EXPERIMENT NO. 1

Total 48 nos. of cubes of size 150*150*150 were cast in 16 sets of 3 cubes each as shown in table 7.1

Out of 16 sets of cubes, 13 sets were cured for 28 days in uncontrolled laboratory conditions, 1 set was cured for 8 weeks, 1 set was cured for 12 weeks and 1 set was cured for 16 weeks. Study for ages more than 16 weeks could not be carried out due to shortage of time. Non destructive tests were carried out at specified dates and values of UPV and rebound number were recorded by UPV apparatus and Schmidt hammer respectively. Then the cubes were tested under uniaxial compression in UTM till failure.

UPV values were taken in two directions and average time taken was found and consequent velocity was recorded.

Schmidt Hammer values or rebound number were taken at 6 locations on top of the cube and 6 locations on sides of cube and their average value was recorded to reduce the possibility of errors.

7.3.2 EXPERIMENTAL DETAILS OF EXPERIMENT NO. 2

Total 33 nos. of columns of size 100*100*600 were cast with M15 concrete and 4nos. 6mm MS bars in 11 sets of 3 columns each (before strengthening). These columns were jacketed with concrete under following conditions, as also shown in table 7.2:

a) Varying mix of jacketing concrete

b) Varying bonding compound between old and new concrete

c) Varying reinforcement used in jacketing

d) With or without shear links

Proper surface preparation was ensured before jacketing. Columns were cured for 28 days in uncontrolled laboratory conditions before jacketing and after jacketing and tested under uniaxial compression till failure in UTM.

7.4 PRELIMINARY TESTS ON MATERIALS

Preliminary tests were carried out on all materials used in experiments i.e. cement, sand, coarse aggregates, reinforcing steel bars and epoxy compound. A commercially marketed epoxy bonding compound was used. Only materials those met relevant IS code specifications were utilised except in case of cement which was not in a good condition but had to be utilised under prevailing constraints.

7.5 CONCRETE MIX DESIGN

The concrete mix was designed for different characteristic strength by user interactive computer program developed in 'C' language based on SP-23.

CHAPTER - 8

TEST RESULTS AND DISCUSSION

TEST RESULTS AND DISCUSSION

8.1 COMBINED NON DESTRUCTIVE TESTING

Yasuo[51] in his study found out accuracies of strength estimation by following five types of equations based on experimental data.

$$Fc = k1*R + k2*V_{pc} + k3(w/c) + k4(Age) + k5(CRC) + C \quad ---(8.1)$$

$$\log(Fc) = k1*R + k2*V_{pc} + k3(w/c) + k4(Age) + k5(CRC) + C \quad -------(8.2)$$

$$V_{pc}/Fc = k1*R + k2*R^2 + k3*R^3 + k4(w/c) + k5(Age) + k6(CRC) + +C--(8.3)$$

$$Fc/V_{pc} = k1*R + k2*R^2 + k3*R^3 + k4(w/c) + k5(Age) + k6(CRC) + +C--(8.4)$$

$$Fc/V_{pc}^2 = k1*R + k2*R^2 + k3*R^3 + k4(w/c) + k5(Age) + k6(CRC) +C--(8.5)$$

The notations and their units in equations (1) through (5) are as follows:

Fc = Estimated compressive strength (MPa)

R = Rebound number (no-dimension)

V_{pc} = Ultra Sonic Pulse Velocity(UPV) (Km/sec)

w/c = Water cement ratio

Age = Age of concrete

CRC = Curing condition

k1 to k6 = Empirical constants

He carried out multiple regression analysis and in analysis various factors such as w/c ratio, age of concrete, and curing condition were added as variables in the equations, and correlation coefficient (r) of each equation and coefficient of contribution (Δr^2) of each variable were calculated and it was observed that value of (r) for equation (8.1) expressed in both rebound number and UPV increased upto 0.936. Thus it was concluded by him that combined use of Schmidt hammer and pulse velocity methods is very effective for estimating the concrete strength and compressive strength of concrete can be most accurately predicted by equation (8.1).

8.1.1 **EQUATION FOR STANDARD-MIX CONCRETE**

Based on the above findings, in his paper Yasuo[51] had applied the following expression for estimating the compressive strength of standard mix concrete:

$Fc = k1*R + k2*V_{pc} + C$ ------ (8.6)

Where k1 and k2 and C are empirical constants.

Based on these findings of Yasuo[51], experimental study was carried out with a standard concrete mix as defined below:

Type of cement: OPC

Unit content of cement: 300 Kg/m^3

Type of aggregates: Crushed stone

Maximum size of aggregates: 20mm

Unit volume of CA: 400 l/m^3

From experimental data as given in Table 8.1 and results as shown in Fig. 8.1.1 to 8.1.2 and regression analysis it was found that value of k1=1, k2=18.6 and C = -79 are most suitable(The value of coefficient of regression =0.94) to predict strength of standard mix concrete so the equation for estimating strength of standard mix concrete in our Indian condition becomes:

$Fc = R + 18.6 V_{pc} - 79$ --------(8.7)

8.1.2 **EQUATION FOR OTHER CONCRETE THAN STANDARD CONCRETE**

Compressive strength of concrete with other mix proportions than that of standard mix concrete is estimated by following expression :

$Fc = C1(R + 18.6V_{pc} - 79)$ ---(8.8)

$C1 = Ct*Ca*Cv*Cc*Ck$ ----(8.9)

where, C1 = Total correction factor related to mix proportions of concrete

Ct = Partial correction factor related to age of aggregates

Ca = Partial correction factor related to the maximum size of coarse aggregates(CA)

Cv = Partial correction factor related to volume fraction of CA

Cc = Partial correction factor related to unit content of cement

Ck = Partial correction factor related to type of CA

8.1.3 **DETERMINATION OF VARIOUS CORRECTION FACTORS**

8.1.3.1 **CORRECTION FACTOR RELATED TO AGE OF CONCRETE**

Fig. 8.2.1 to Fig. 8.2.3 shows the comparison between the measured strengths (cFc) and the estimated strengths (eFc) calculated by equation (8.8) and (8.9) for different sets of experiments, keeping rest of the factors as 1.0. From the plots the value of the correction factors can be found for different ages of concrete which is slope of the line. The values of correction factors as found have been listed in table 8.3.5

8.3.1.2 **CORRECTION FACTORS FOR MIX PROPORTION OF CONCRETE**

Fig. 8.3.1, 8.3.2, 8.4.1, 8.4.2, 8.5.1, 8.5.2, and Fig. 8.6 show the effects of the maximum size of aggregates (Ca), volume fraction coarse aggregates(Cv), unit content of cement (Cc),and type of coarse aggregates (Ck) respectively. As can be observed that the value of C decreases with the increase of the maximum size of coarse aggregates and the volume fraction of coarse aggregates and the value of C tends to increase slightly with increasing unit content. The values of different correction factors as obtained by curve fitting(basically linear) have been given in Table 8.3.1 to table 8.3.4.

8.1.4 **APPLICATION OF PROPOSED EXPRESSION**

The strength distribution of concrete column specimens casted for experiments on jacketing technique was estimated by the proposed equation. The section size of column was 200*200 and height was 600mm. OPC and crushed aggregates (Maximum size 25 mm) were used for fabrication of specimen. The unit content of the cement was 306Kg/m^3 and volume of CA was 380 l/m^3. The concrete was cast parallel to longitudinal axis of column. The tests were carried out at the age of 28 days.

The values of correction factors shall be as following:

Ct = 1.0, Ca = 0.93, Cv = 1.05, Cc = 0.998, Ck = 1.0

so value of total correction factor:

C = 1.0*0.93*1.05*0.998*1.0 = 0.975

The values of NDT results were as following:

R = 21, UPV = 3.89 Km/sec.

so estimated compressive strength from the expression:

cFc = 0.975*(21 + 18.6*3.89 - 79)

or cFc = 13.99 Mpa

The compressive strength found from the cube test under UTM as reported in Table 8.1 was 12.8 Mpa which is comparable to estimated strength (Diff. 9.37%).

So the estimated compressive strength is in fairly good agreement with the measured strength of concrete.

8.2 <u>JACKETING OF COLUMNS</u>

Experimental results obtained have been shown in Table 8.2 wherein columns (3) to column (6) shows the conditions of jacketing, column (7) shows the failure load under uniaxial loading in UTM, and column(8) shows the expected/theoretical failure load as calculated based on the cube strength of the same concrete i.e. M15, M20, M25, tested which have been given in table 8.1.

Following points can be observed from the results:

a) Failure load for the 'J' and 'K' series of columns was found to be 82.1% and 83.8% respectively of the theoretical failure load. So the strength of columns even before jacketing was observed lesser(By about 17.9%) than the theoretical failure load. This may be because of bad quality of cement, however same cement was used for casting of cubes so its effect is likely to be less, or this difference may be because of imperfect shuttering leading to columns which are not exactly vertical causing eccentricity in loading and consequent moment and failure earlier than expected. Since same cement was used through out the experiments and shuttering for the columns were same throughout so this difference will not have any direct affect on pattern of increase in load carrying capacities of jacketed columns under different conditions of bonding agent, reinforcement in jacketing etc.

b) Result for 'L' and 'M' series of column which were casted with cement slurry as bonding compound shows that failure load is only 31.8% and 35.07% respectively of the theoretical failure load for the jacketed column, this was because of failure of bonding compound i.e. cement slurry and failure was observed at the interface causing independent action of original column and jacketed concrete and the jacketed concrete spalled off quickly, leading to failure of jacketed column at lower loads and further it was observed that cracking has not taken place in the original column. So it can be deduced that the cement slurry as bonding compound is not at all effective in jacketing of columns.

c) Results of 'N' and 'O' series of columns show that with the use of epoxy as a bonding compound between old and new concrete the load carrying capacity of the columns increased considerably and failure load was about 49.85% and 52.5% respectively of the theoretical failure load of the jacketed column. In other terms the failure load increased by appx. 20% over the 'L' and 'M' series of columns where cement slurry was used as bonding compound between old and new concrete. However in this case also the failure was observed at the interface of old and new concrete and new concrete got crushed and spalled off leading to failure of complete jacketed column. Hairline cracks were also observed in the original column at the time of failure. So it can be deduced that epoxy bonding material is better than the cement slurry but it also does not give the perfect bond and study needs to be carried out on different branded epoxy compounds for bonding old and new concrete for their efficacy and these need to be standardised for their proper and effective use.

c) Results of 'P' and 'Q' series of columns show that increase in failure load over 'N' series was about 63.2% and 75.75% respectively of the increase in theoretical failure load consequent to change in grade of jacketing concrete. Further failure load for the 'P' series of columns were observed as 52.1% and for 'Q' series of columns as 56.7% of the theoretical failure load of jacketed columns. So it can be concluded from this that if better quality concrete of higher grade is provided in jacketing than increase in load carrying capacity is likely to be much more.

d) For 'S' series of columns where only shear links were used and no bonding compound was used failure load was observed about 62.44% of the theoretical failure load. So shear links are very effective in jacketing of columns.

e) For 'R' and 'T' series of columns where shear links were used between old and new shear stirrups and epoxy bonding compound was also used, the failure load was 82.6% and 83.5% respectively of the theoretical failure load, which is quite close to observed percentages of unjacketed columns. The failure was also observed simultaneously for the jacketed concrete and original concrete. So it can be concluded that use of shear links with epoxy compound as bonding compound between old and new concrete is likely to give the maximum load carrying capacity and jacketed column shall behave as a single unit.

f) It can also be observed from (b), (c) and (e) above that for more confining reinforcement of jacketing and keeping other parameters same we get more failure load, as a percentage of theoretical failure load this may be because of more confining action of reinforcement and consequent delayed separation of old and new concrete.

The above results have also been presented in the form of bar chart in Fig. 8.8.

CHAPTER - 9

CONCLUSIONS

CONCLUSIONS

9.1 CONCLUSIONS FROM THE STUDY

The following conclusions can be satisfactorily drawn from the test results and discussion arising from these experimental investigations.

a) The compressive strength of the set concrete can be estimated fairly closely using Non destructive methods of testing by combined use of Schmidt hammer (rebound number) and Ultra Sonic Pulse velocity method.

b) Compressive strength of standard mix concrete can be estimated by combined method using Equation No. (7), where, the standard mix concrete is defined in the experiments as follows: Concrete fabricated with OPC, crushed stone coarse aggregates (maximum size = 20mm), and with unit content of cement = 300Kg/m^3 and volume fraction of coarse aggregates = 0.40.

c) The strength of concrete other than standard mix concrete can be estimated by equation No. (8) and (9) with fairly good accuracy and the values of correction factors for concrete other than standard mix concrete and for age of concrete have been listed in Table 8.3.

e) Compressive strength estimated by Eq. (8) was found to be comparable to the observed strength of concrete in a column specimen casted for experimental work of jacketing technique.

f) Jacketing of columns with concrete is a very effective technique for repairs/strengthening of columns.

g) Result from the data presented and discussions thereon conclusively prove the effectiveness of jacketing technique in substantially increasing the load carrying capacity of damaged columns.

h) Jacketing concrete and reinforcement to be fully effective in sharing the load, shear links should be used between stirrups of old and new reinforcement, and epoxy based bonding compound to be used for having proper bond between old and new concrete.

j) Rehabilitation is a challenging area of research for the Artificial Intelligence technique where integrated CAD processes can also be linked to provide the comprehensive solution to the rehabilitation problems. In this study, an experimental coupled Expert System which marries arithmetic process (like data generation, calculation of estimated strength of concrete, some basic checks for design etc.) with symbolic processing (like selection of suitable method of repairs) and Graphical representation (of input and output) is successfully carried out.

9.2 SCOPE FOR FUTURE WORK

Rehabilitation of buildings is an upcoming discipline and a lot of standardisation is required to be done in this field. Work carried out in the field of combined nondestructive testing using Scmidt hammer and UPV test can be extended to establish the better relation and finding more factors related to curing condition, presence of reinforcement etc., with the backing of more experimental results which could not be done presently due to shortage of time.

Work carried out in the field of jacketing technique can be extended to find out effectiveness of this technique in columns subjected to moments and for columns which are preloaded and strengthened under partially loaded condition with an aim to develop an equation for designing the complete jacketing system with satisfactory confidence level and also predicting the strength of columns jacketed under known conditions.

Expert system developed in the work can be made more quantitative based after development of relations such as suggested in paragraph above for jacketing, once quantitative relations are developed in all fields of repairs to concrete the same can be incorporated in the expert system so as to make it more effective.

Table 7.1

Details of Cubes of Size 150*150*150 tested under UTM

Sl. No.	Set No.	Cube No.	Description
1	I	J1 to J3	3 sets of cubes with w/c ratio of 0.5,0.55,0.6 of standard concrete tested at 4 weeks
2	II	K1 to K3	Cubes of standard concrete with CA size 15mm
3	III	L1 to L3	Cubes of standard concrete with CA size 25mm
4	IV	M1 to M3	Cubes of standard concrete with volume fraction of CA as 0.3
5	V	N1 to N3	Cubes of standard concrete with volume fraction of CA as 0.35
6	VI	O1 to O3	Cubes of standard concrete with cement content as 200 Kg/m^3
7	VII	P1 to P3	Cubes of standard concrete with cement content as 400 Kg/m^3
8	VIII	Q1 to Q3	Cubes of standard concrete with gravel
9	IX	R1 to R3	Cubes of standard concrete tested at 8 weeks
10	X	S1 to S3	Cubes of standard concrete tested at 12 weeks
11	XI	T1 to T3	Cubes of standard concrete tested at 16 weeks
12	XII	U1 to U3	Cubes of design mix M15
13	XIII	V1 to V3	Cubes of design mix M20
14	XIV	W1 to W3	Cubes of design mix M25

Table 7.2

Details of Columns Tested

***** 11 sets of three columns each of size 100*100*600 with 4 no. 6mm MS reinforcement and 3 no. shear stirrups were cast with M15 design mix.**

S. No.	Set No.	C/S Size	Description
1	J1 to J3	100*100	Original columns tested to failure
2	K1 to K3	100*100	Cover concrete removed and column tested
3	L1 to L3	200*200	Strengthened with cement slurry as bonding compound and 4 no. 6 mm MS bars
4	M1 to M3	200*200	-----do----and 8 no. 6 mm MS bars
5	N1 to N3	200*200	Strengthened with epoxy as bonding compound and 4 no. 6 mm MS bars
6	O1 to O3	200*200	-----do---- and 8 no. 6mm MS bars
7	P1 to P3	200*200	Strengthened with epoxy as bonding compound with 4no. 6mm MS bars and M20 concrete
8	Q1 to Q3	200*200	------do----and M25 concrete
9	R1 to R3	200*200	Strengthened with epoxy as bonding compound with 4 no. 6mm bars and shear links between old and new shear stirrups
10	T1 to T3	200*200	---do---- with 8no. 6mm MS bars
11	S1 to S3	200*200	Strengthened with 8, 6mm, bars and shear links but without any bonding compound

Table 8.1

Results of Schmidt Hammer test, UPV test and UTM test

S. No.	Set No.	Cube No.	UPV in Km./second	Schmidt Hammer (Rebound No.)	Cube strength (UTM) in N/mm^2
1	I/1	J1	4.22	24	23.48
		J2	4.20	23	22.0
		J3	4.25	24	24.3
2	I/2	J1	4.18	22	20.75
		J2	4.19	23	22.1
		J3	4.17	22	20.6
3	I/3	J1	4.12	21	18.6
		J2	4.05	21	17.3
		J3	4.15	20	18.2
4	II	K1	4.1	22	21.2
		K2	4.07	21	19.5
		K3	4.08	21	19.7
5	III	L1	4.18	20	17.41
		L2	4.15	21	17.8
		L3	4.10	20	17.15
6	IV	M1	4.05	21	19.75
		M2	4.08	22	21.53
		M3	4.07	21	20.18
7	V	N1	4.10	21	19.35
		N2	4.08	22	20.0
		N3	4.09	21	19.16

Table 8.1(Contd.)

Results of Schmidt Hammer test, UPV test and UTM test

S. No.	Set No.	Cube No.	UPV in Km./second	Schmidt Hammer (Rebound No.)	Cube strength (UTM) in N/mm^2
8	VI	O1	3.92	18	12.40
		O2	3.90	19	13.04
		O3	3.91	19	13.23
9	VII	P1	4.81	23	32.80
		P2	4.79	24	32.43
		P3	4.80	23	32.61
10	VIII	Q1	3.91	21	17.40
		Q2	3.90	22	17.15
		Q3	3.92	21	18.75
11	IX	R1	4.14	22	19.55
		R2	4.12	22	19.20
		R3	4.15	22	19.75
12	X	S1	4.15	23	20.3
		S2	4.13	22	18.95
		S3	4.15	23	20.28
13	XI	T1	4.17	24	20.9
		T2	4.15	23	19.6
		T3	4.16	24	20.7
14	XII	U1	-	-	12.36
		U2	-	-	13.01
		U3	-	-	12.67 Avg.=12.68

Table 8.1(Contd.)

Results of Schmidt Hammer test, UPV test and UTM test

S. No.	Set No.	Cube No.	UPV in Km./second	Schmidt Hammer (Rebound No.)	Cube strength (UTM) in N/mm^2
15	XIII	V1	-	-	17.4
		V2	-	-	17.2
		V3	-	-	17.7 Avg.=17.43
16	XIV	W1	-	-	20.2
		W2	-	-	20.7
		W3	-	-	20.5 Avg.=20.47

Table 8.2

Results of columns tested under direct compression

S. No.	Column No.	Grade of encasing concrete	Bonding agent used	Shear links used	Reinf. used in jacketing	Failure load (Ton)	Theoretical failure load (Ton)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	J1	-	-	-	-	12.78	15.51
	J2	-	-	-	-	13.10	--do--
	J3	-	-	-	-	12.50	--do--
2	K1	-	-	-	-	10.10	12.00
	K2	-	-	-	-	10.20	--do--
	K3	-	-	-	-	9.90	--do--
3	L1	M15	Cement slurry	-	4, 6mm MS bars	18.0	56.37
	L2	--do--	--do--	-	--do--	18.3	--do--
	L3	--do--	--do--	-	--do--	17.6	--do--
4	M1	M15	Cement slurry	-	8, 6mm MS bars	21.0	59.2
	M2	--do--	--do--	-	--do--	20.7	--do--
	M3	--do--	--do--	-	--do--	20.6	--do--
5	N1	M15	Epoxy	-	4, 6mm MA bars	27.4	56.37
	N2	--do--	--do--	-	--do--	28.2	--do--
	N3	--do--	--do--	-	--do--	28.7	--do--

Table 8.2(Contd.)

Results of columns tested under direct compression

S. No.	Column No.	Grade of encasing concrete	Bonding agent used	Shear links used	Reinf. used in jacketing	Failure load (Ton)	Theore-tical failure load (Ton)
6	O1	M15	Epoxy	-	8, 6mm MS bars	30.1	59.20
	O2	--do--	--do--	-	--do--	31.0	--do--
	O3	--do--	--do--	-	--do--	31.1	--do--
7	P1	M20	Epoxy	-	4, 6mm MS bars	35.1	67.8
	P2	--do--	--do--	-	--do--	36.2	--do--
	P3	--do--	--do--	-	--do--	35.3	--do--
8	Q1	M25	Epoxy	-	4, 6mm MS bars	43.1	76.92
	Q2	--do--	--do--	-	--do--	44.2	--do--
	Q3	--do--	--do--	-	--do--	43.7	--do--
9	R1	M15	Epoxy	12 links of 4mm MS bars	4, 6mm MS bars	46.2	56.37
	R2	--do--	--do--	--do--	--do--	47.4	--do--
	R3	--do--	--do--	--do--	--do--	46.1	--do--
10	T1	M15	Epoxy	12 links of 4mm MS bars	8, 6mm MS bars	49.0	59.2
	T2	--do--	--do--	--do--	--do--	49.7	--do--
	T3	--do--	--do--	--do--	--do--	49.6	--do--
11	S1	--do--	-	--do--	--do--	37.8	59.2
	S2	--do--	-	--do--	--do--	38.9	--do--
	S3	--do--	-	--do--	--do--	34.2	--do--

Table 8.3.1

Values of correction factors related to maximum size of CA

Maximum size of coarse aggregate	C_a
15	1.10
20	1.00
25	0.93

Table 8.3.2

Values of correction factors related to unit content of cement

Unit content of cement	C_c
200	1.04
300	1.00
400	0.98

Table 8.3.3

Values of correction factors related to volume fraction of CA

Volume fraction of CA	C_v
0.30	1.14
0.35	1.06
0.40	1.00

Table 8.3.4

Values of correction factors related to type of coarse aggregates

Type of Coarse Aggregates	C_k
Crushed stone	1.00
River Gravel	1.18

Table 8.3.5

Values of correction factors related to age of concrete

Age factor	
Age of concrete	Age factor
4 weeks	1.00
8 weeks	0.98
12 weeks	0.96
16 weeks	0.93

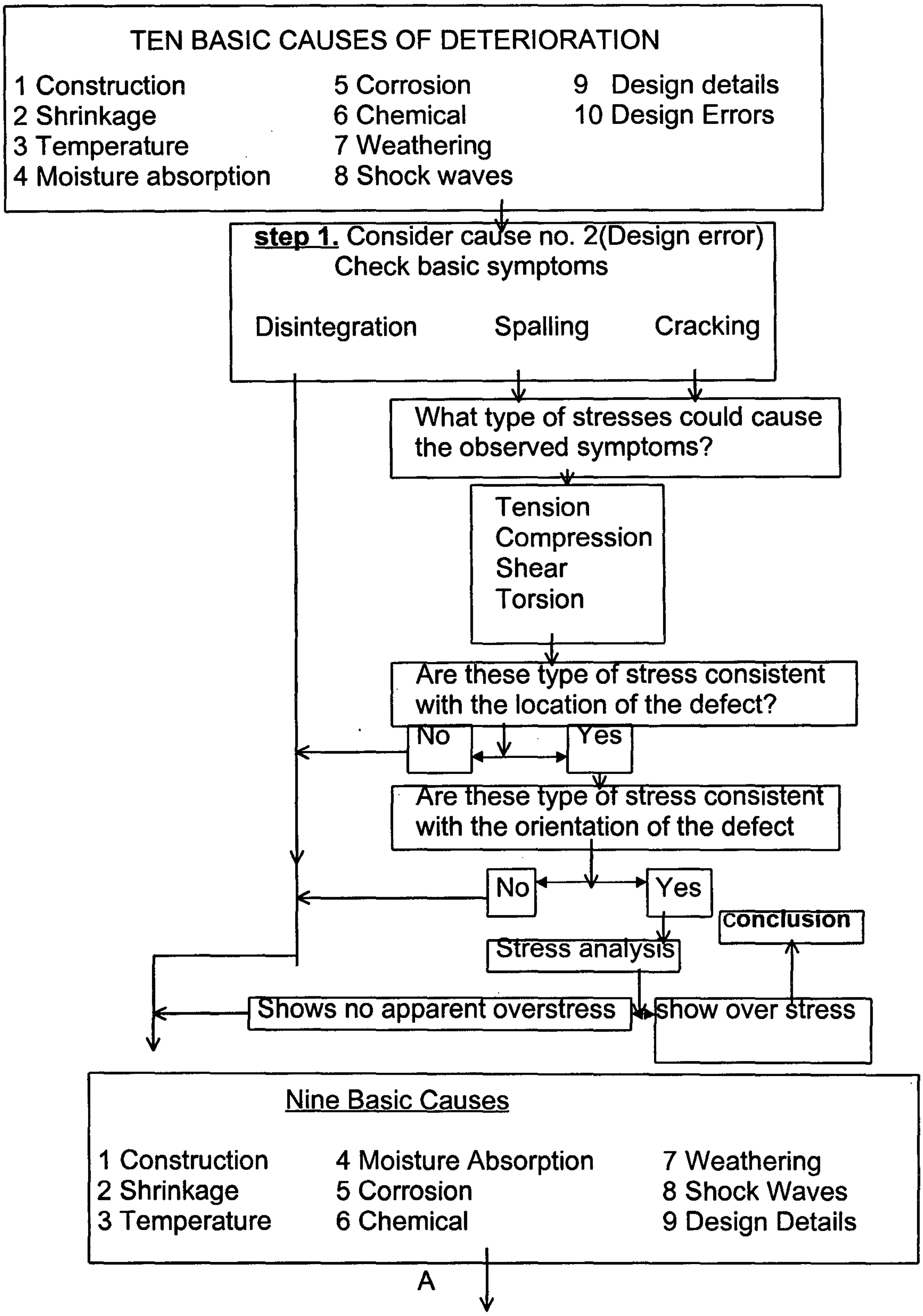


Fig. 2.1--Flow chart for diagnosis of causes of deterioration

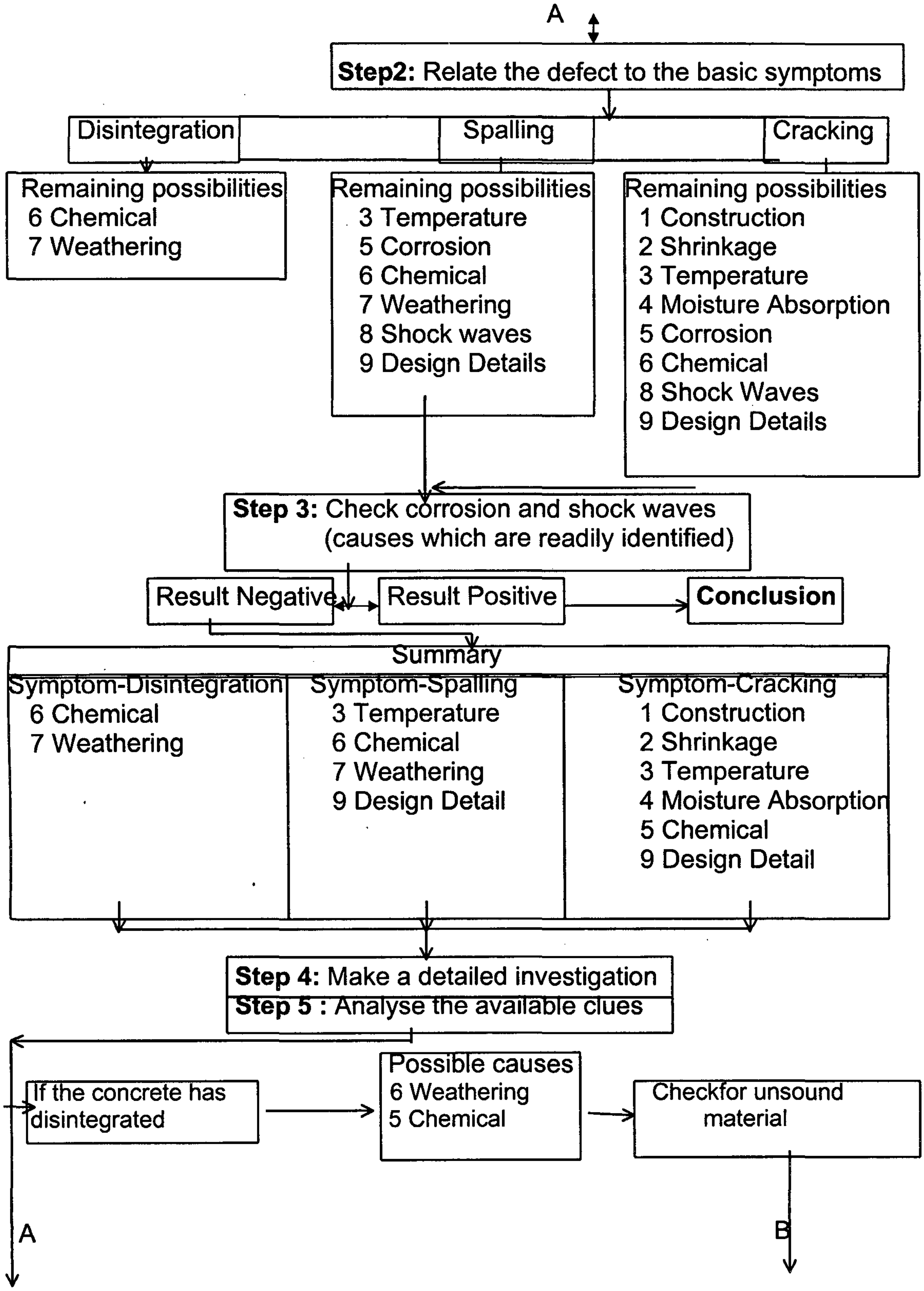


Fig. 2.1 (continued)

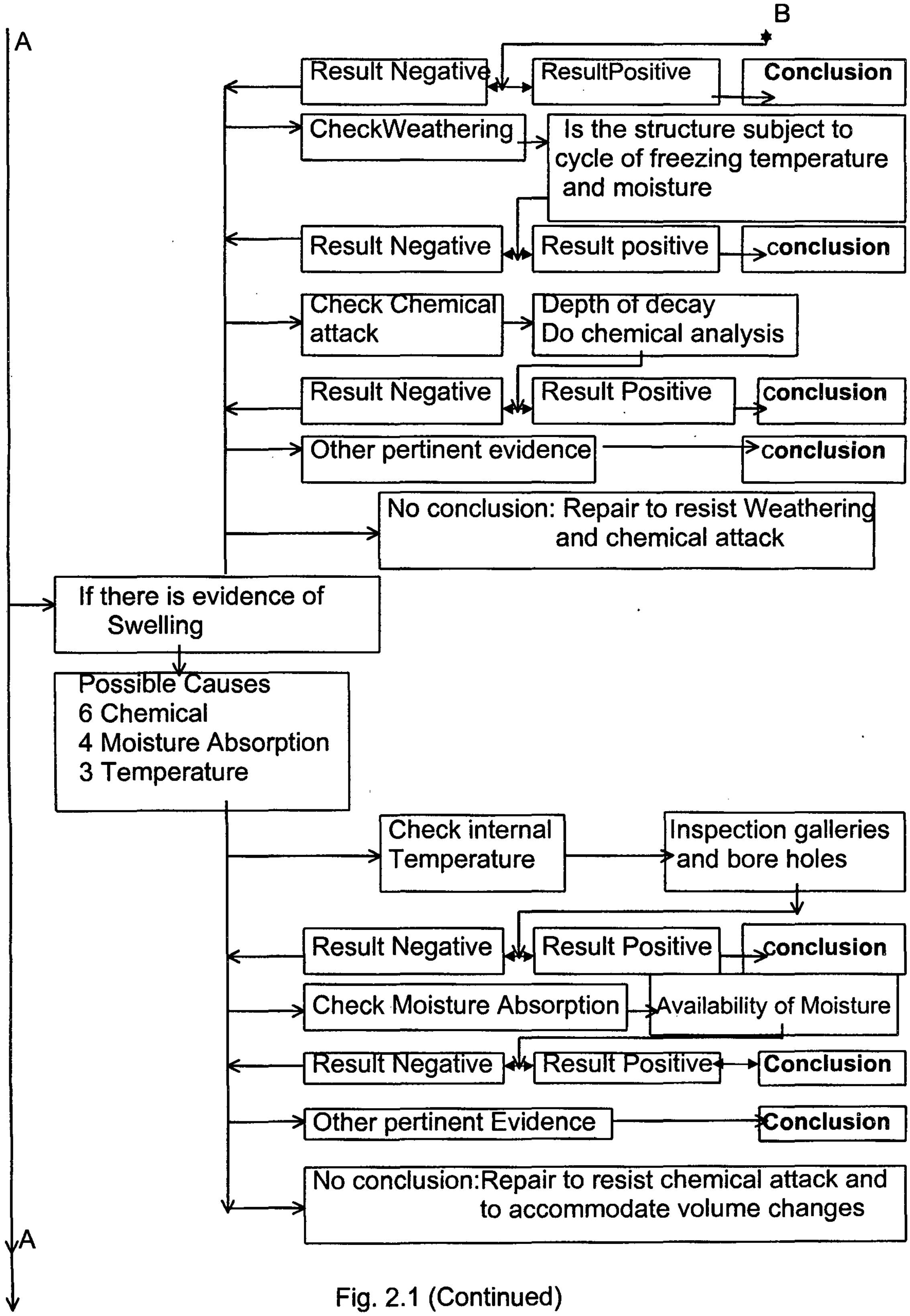


Fig. 2.1 (Continued)

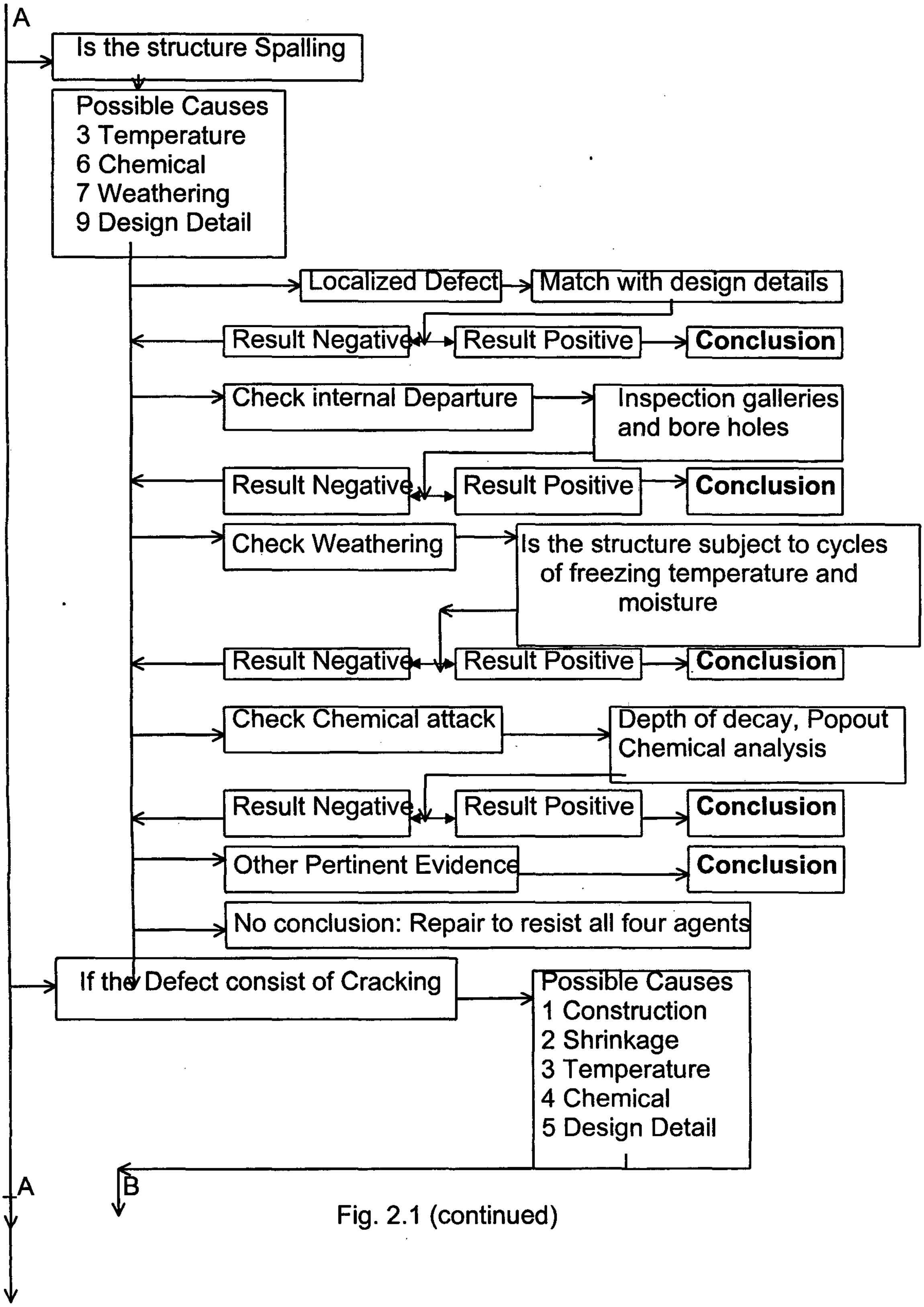


Fig. 2.1 (continued)

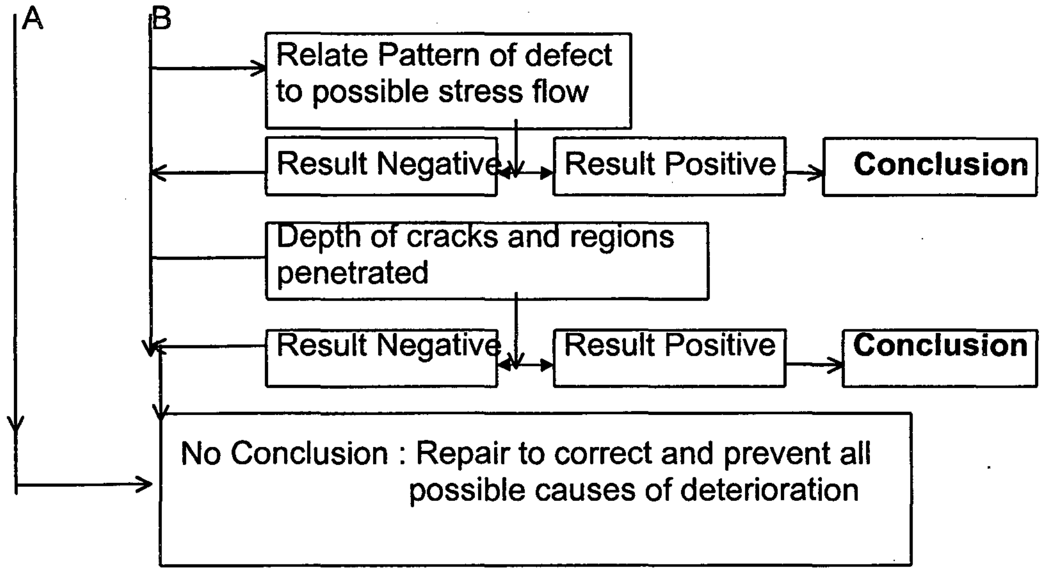
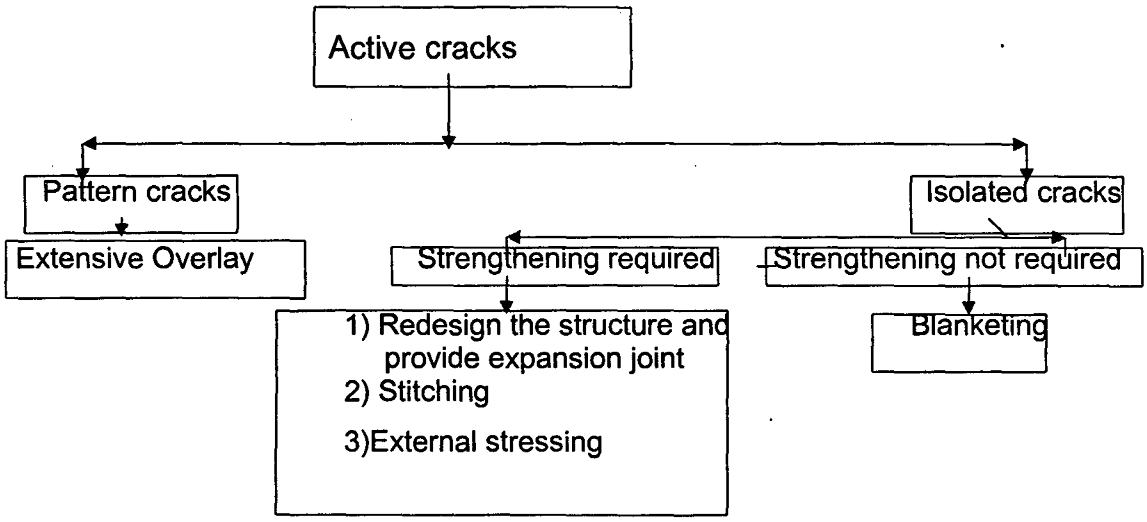
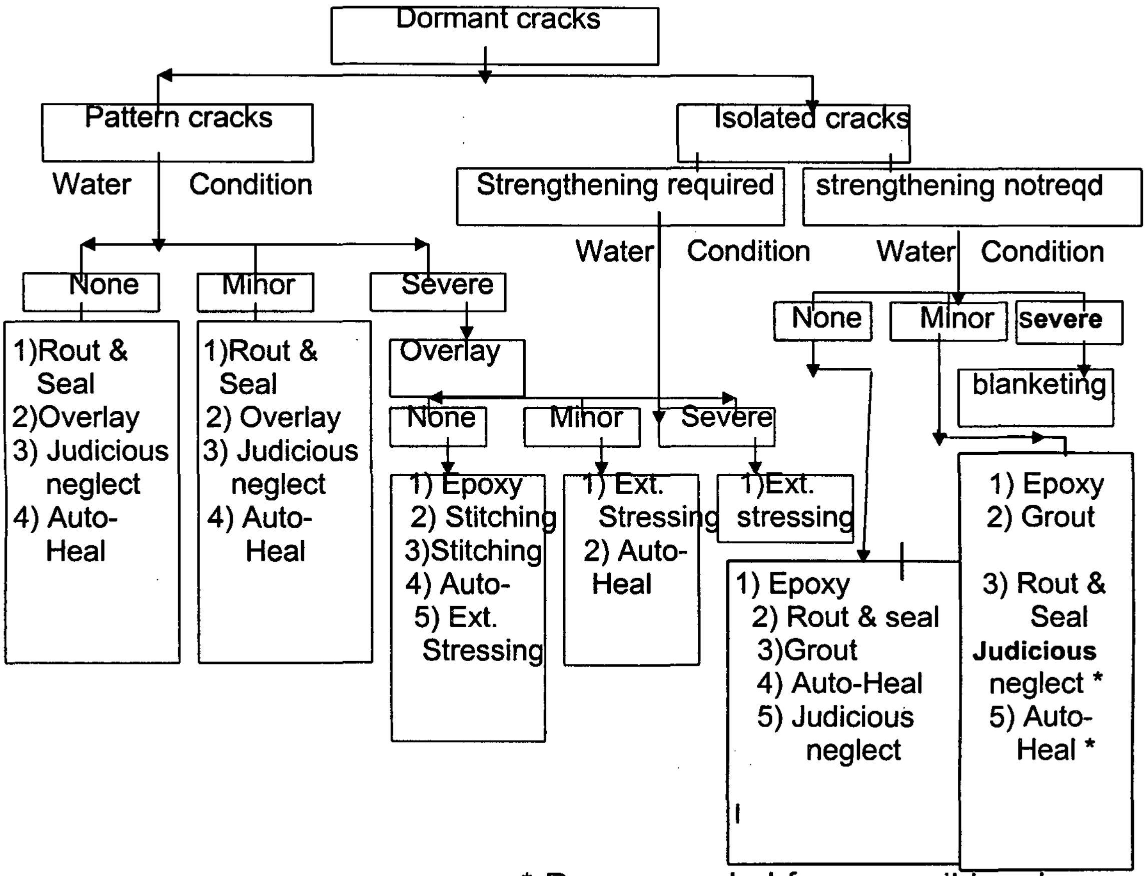


Fig. 2.1(Continued): Flow chart for diagnosis of cause of cracking in Concrete structures



* (2) and (3) are recommended for mild and temporary condition .

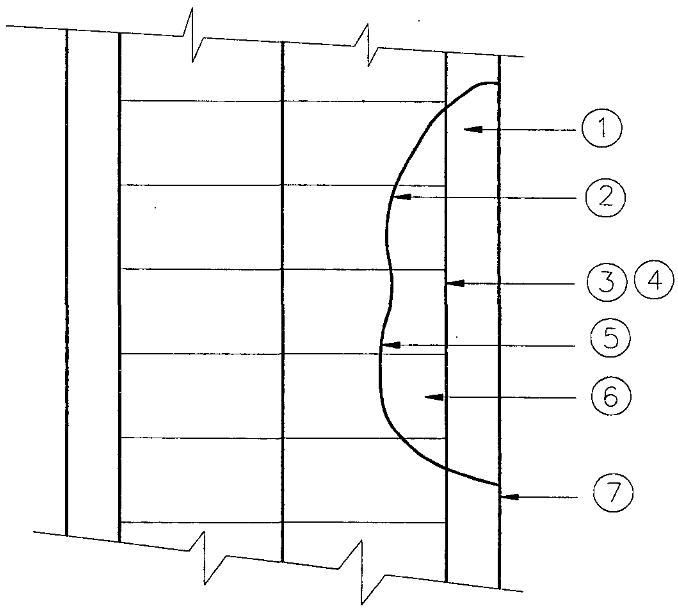
Fig. 2.2--Flow chart for selection of appropriate method of repairs of active cracks



* Recommended for very mild and temporary condition

Fig. 2.3--Flow chart for selection of appropriate method for repairs to dormant cracks

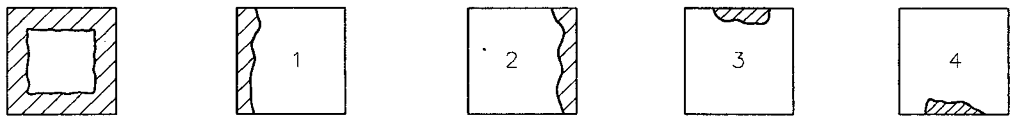
REPAIRS TO COLUMN AS WITH EPOXSY MORTAR - LOCALISED



1. Expose all loose delaminated concrete including guniting if any up to at least 6mm beyond main R/F.
2. Clean exposed surfaces by wire brushing; washing and drying etc.
3. Apply two coats of approved rust passivetor to exposed steel.
4. Replace worn out steel if required as per instruction.
5. Brush apply primer coat of epoxy to exposed surfaces.
6. Apply epoxy mortar of required formulation over primer coat when it is tacky; air cure for 24 hours.
7. Provide one coat of seal coat of epoxy over epoxy mortar.

Fig. 2.4_ At times localised corrosion damage is noted. It can be attended to the etent required only. This is a common mode of repairs if attended during early stage and it is effective enough if properly executed. This limits damage to other sound areas. This is generally adopted during initial damage observations, which are spread over at places in the structure.

HIGH SEVERITY DAMAGE - SEQUENCE OF REPAIRS



(A) DEFECTIVE (B) STAGE-1 (C) STAGE-2 (D) STAGE-3 (E) STAGE-4

- Hatched portion indicates sequence of replacement of damaged concrete.
- This is used where the element is deficient in provisions.

Fig. 2.5 Some times concrete cross-sectional provisions are marginal or even deficient. Corrosion damage appears to be heavy though locally or spread over to the major portion if remained unattended for few years. In such a case localised surface repairs in phases and stages as suggested are recommended. These are time consuming and yet for safety of the structure they are required in certain structures. They are effective enough if executed with due care and under the trained supervision. Possibility of strengthening with improved cross-sectional provisions need be explored.

MAJOR COLUMN RESTORATION

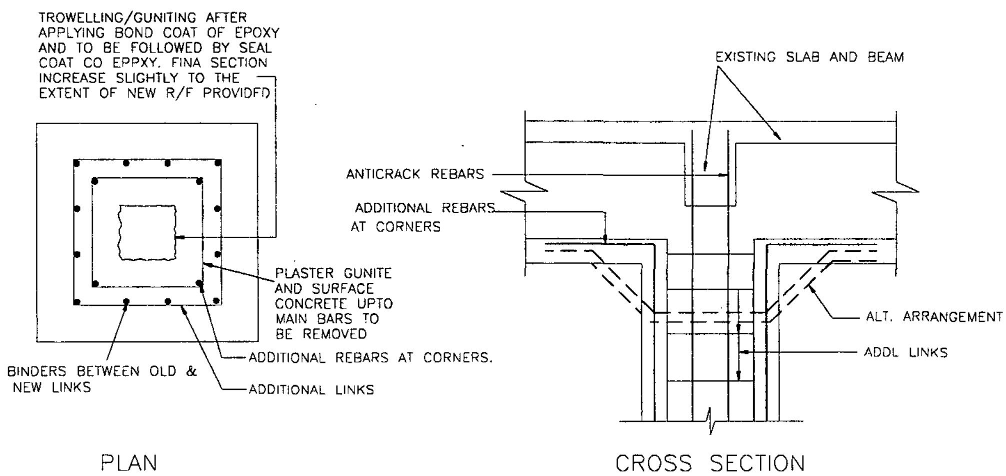


Fig. 2.6 Column concrete damage is major and spread throughout, which needs encased cross-sectional provisions. Usual popping is prerequisite before prerequisite for static stability. Repairs are carried out as shown including improvements to column beam junctions.

EXTENSION OF COLUMN THROUGH SLAB

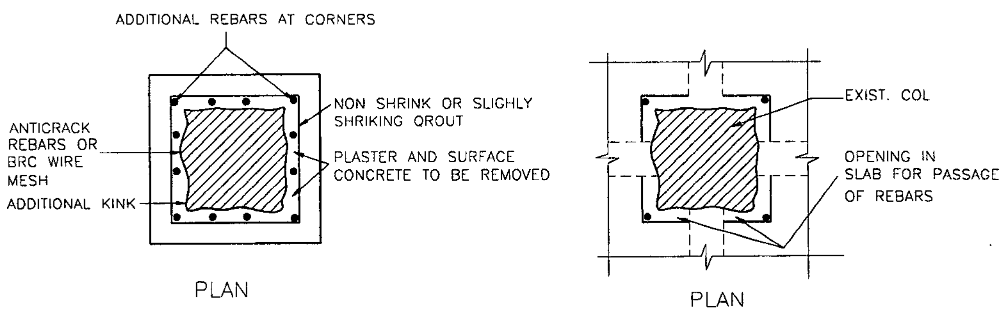
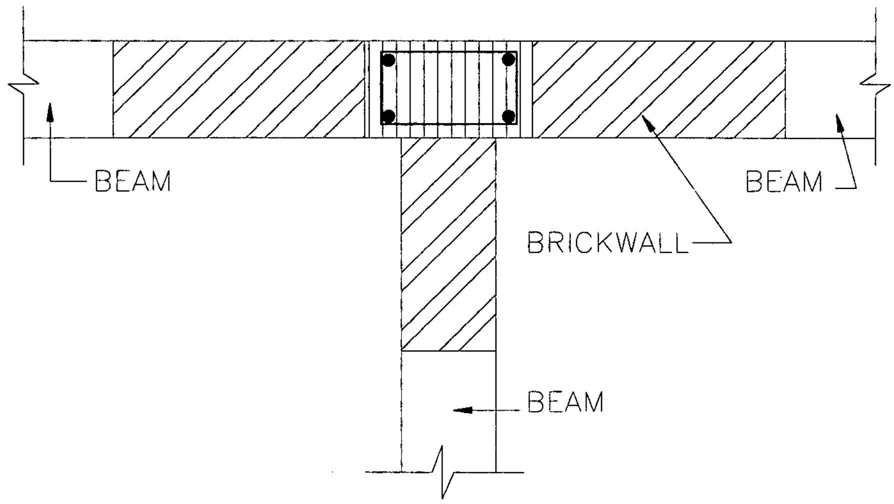


Fig. 2.7 Column extension through slab is important requirement which is achieved as shown. Local breaking of slab is necessary and is a routine job requirement, in fact. This ensures continuity of column R/F. Appropriate binding with beam portions within the columns concrete are achieved with usual surface preparation.

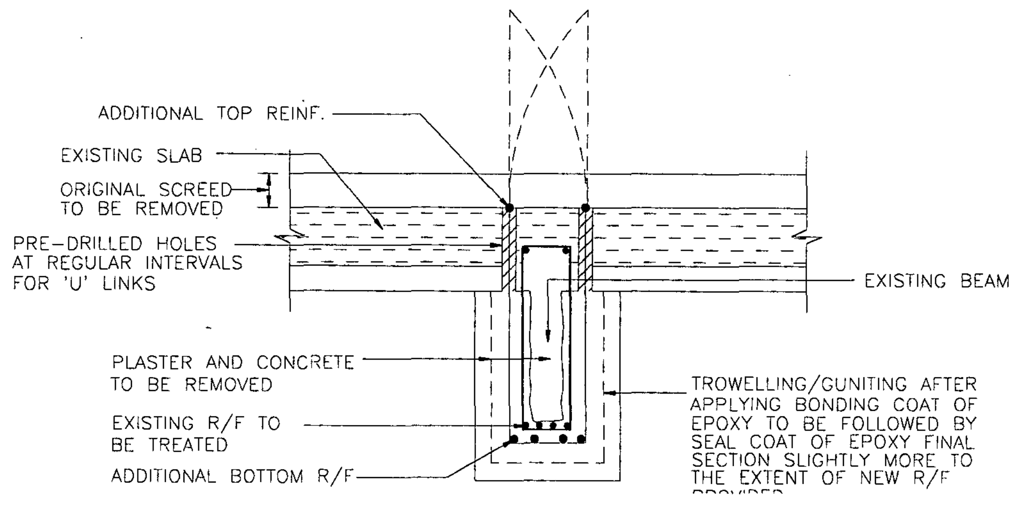
STILT - COLUMN REPAIRS + STRENGTHENING



- Reduces beams spans.
- Offers relief to columns
- retains stile functioning unaffected.
- Column of stilt floor to improve stability and reserve, construction of walls is recommended.

Fig. 2.8 At times still columns pose difficult restoration problems. Their damage is more and their cross-sectional provisions are marginal or deficient. During required restoration using propping. Construction of side walls is known to offer substantial reserve and improved composite action which is missing earlier.

DETAILS SHOWING STRENGTHENING OF SECONDARY BEAMS



DETAILS SHOWING STRENGTHENING OF SECONDARY BEAMS

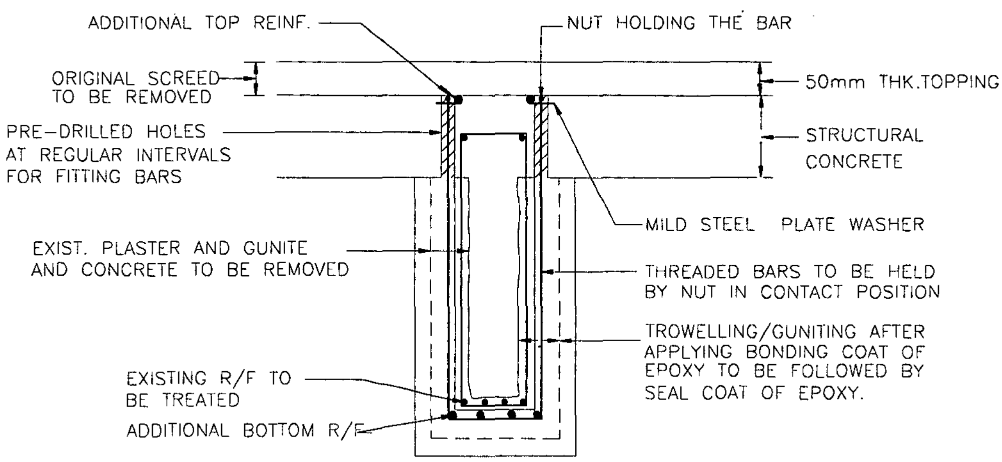
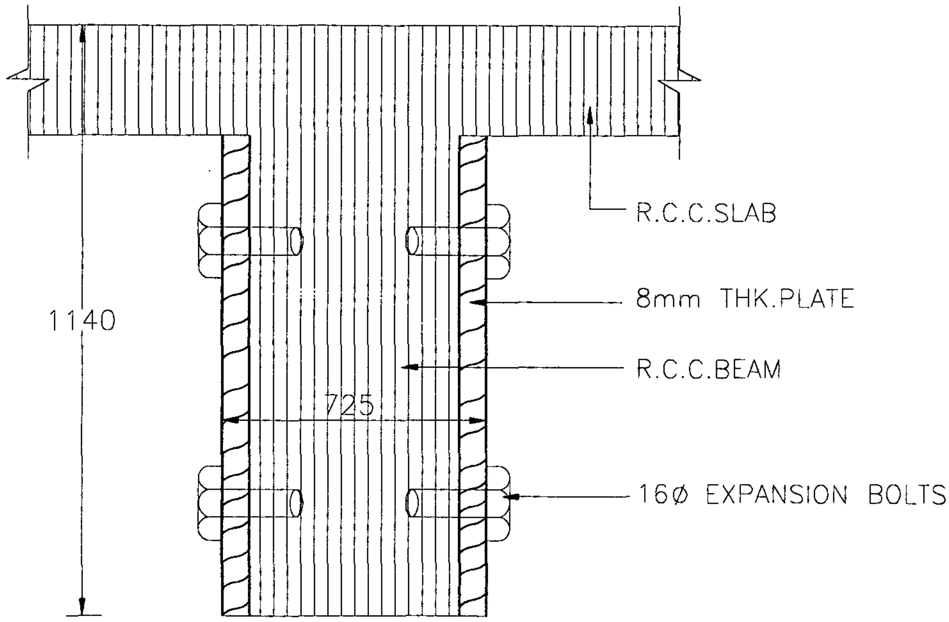


Fig. 2.9 & 2.10 Beam strengthening and repairs is a common requirement. Replacement of damage beam concrete is a basic requirement. Particular problem of stirrup corrosion is common. It is explained with couple of options in the figures.

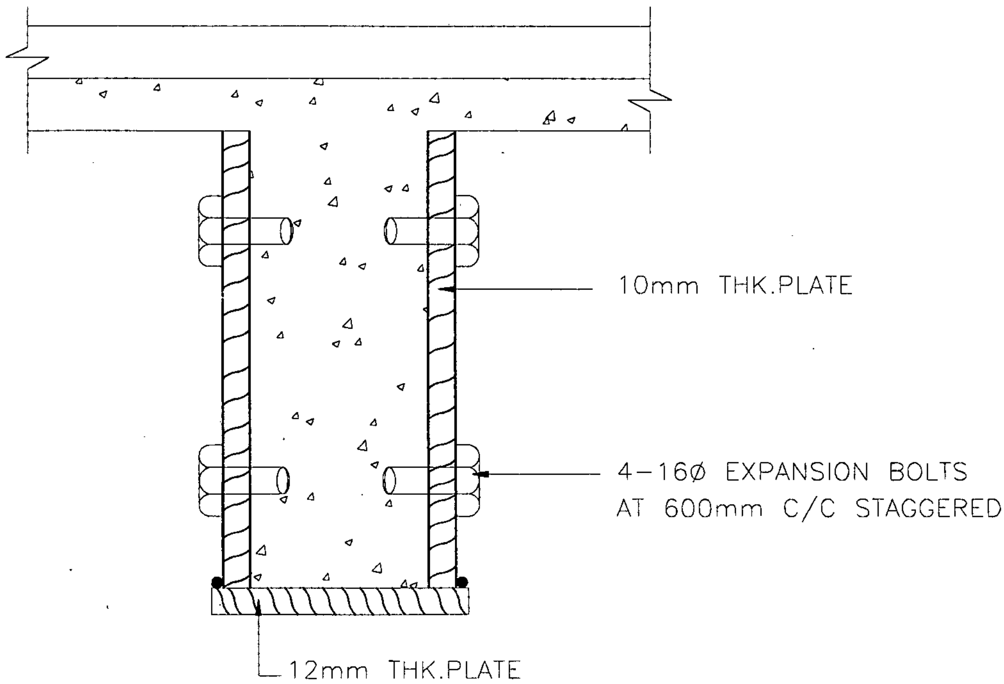
STRENGTHENING BEAM WITH STEEL FLITCHING



- Carry out repairs to the concrete and R/F as per general guidelines for slabs and beams.
- Additional strengthening by flitching as below.
- Connect 8mm thick plates on beam sides with expansion bolts and epoxy bonding.
- Bolts 16Ø 2 rows 1m c/c staggered mechanical clamping during epoxy set and bolting to be ensured.
- At ends top and bottom extra bolts desired to lock plate movement.
- Dimension are from typical restoration detail.

Fig. 2.11 At times, strengthening is required to beam cross-sections due to severe damage or need to improve beam cross-sectional capacity. Steel flitching is one of the important options for restoration. Epoxy bonding with mechanical bolting is recommended to achieve sound repairs. This is to take care of likely suspect concrete quality along cover, concealed weak spots within the beam sides and soffits. Usual repairs to concrete cross-sections prior to steel flitching is a normal procedure.

TYPICAL STRENGTHENING DETAIL OF BEAM



- Carry out the repairs to the concrete and R/F as stated.
- Additional strengthening by flitching as below.
- Connect 10mm thick plates on beam side with expansion bolts epoxy dipped.
- Bolts 16Ø 2 rows at 600mm c/c staggered mechanical clamping during epoxy set and bolting to be ensured.
- At ends top and bottom extra bolts desired to lock plate movement.
- Connect 10mm plate with two flange plate at the bottom of beam by 8mm fillet weld and epoxy bonds to concrete.
- Provide two coats of protective epoxy coating over one coat of epoxy primer on outer face of the steel plats.

Fig. 2.12 After a normal repairs to original concrete, wherever cover concrete is required to be improved in cross-section, there are few options available as shown in jacketing which permit improvised weather protection, improved bond between brick work around, addition to restoration requirements.

BEAM DETAIL IMPROVEMENT

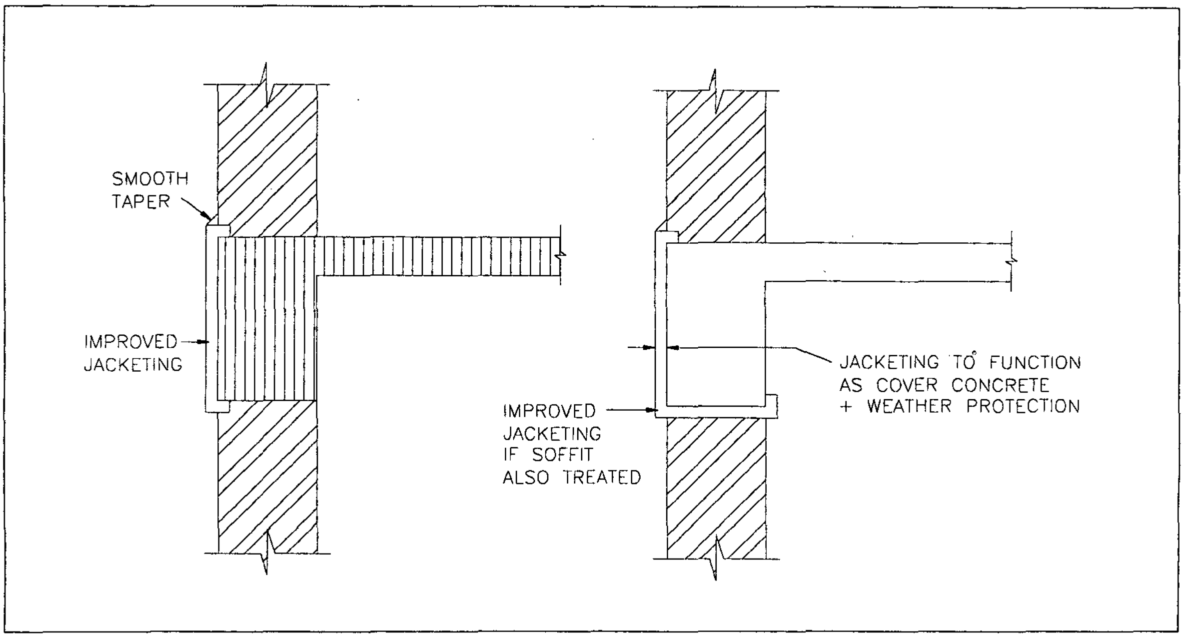
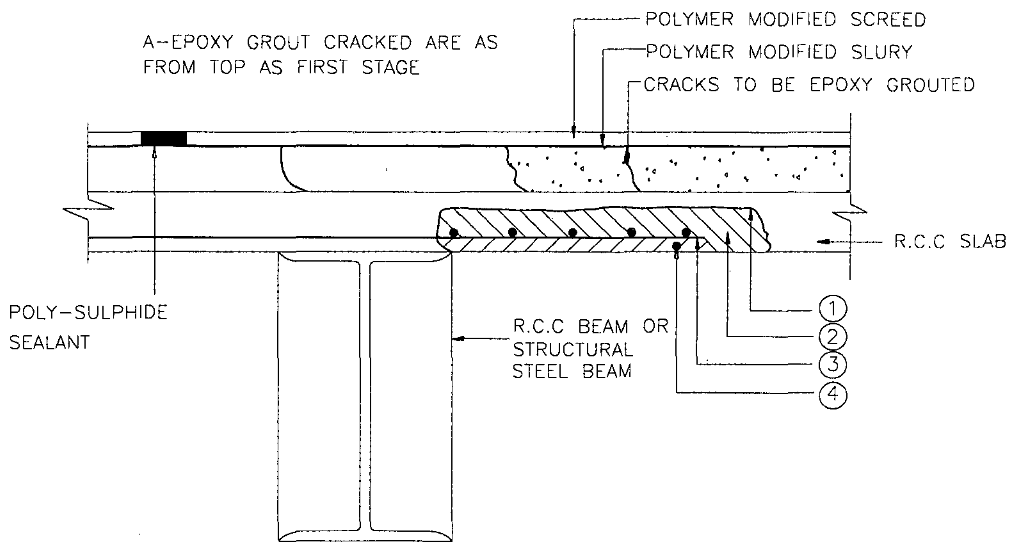


Fig. 2.13 External beams need improvements in detailing in addition to repairs. These are for weather protection, particularly rain water. Few options are available and some of them are detailed here.

REPAIRS TO R.C.C BEAMS AND SLABS TOP SURFACE SIDES AND SOFFIT - SALINE ENVIRONMENT RESTORATION AND PROTECTION



A - After removal of suspect concrete and dealing with corroded R/F and surface prepared.

B - 1. Lay polymer modified mortar screed 25mm thick over bonding coat of p.m. slurry.
2. Provided poly sulphide sealants along joints in the screed.

C - Procedure to make good the cover concrete;
1. Cement modified polymer slurry coating.
2. Cement modified polymer mortar upto the face of the bar.
3. Again cement modified polymer slurry coating.
4. Cover of cement mortar trowelled to required depth to make good the finished cross section.

Fig. 2.14 Repairs of strengthening of slabs. It covers severe slab damaged due to use of saline water, on-goingly used in the process for several yeras.

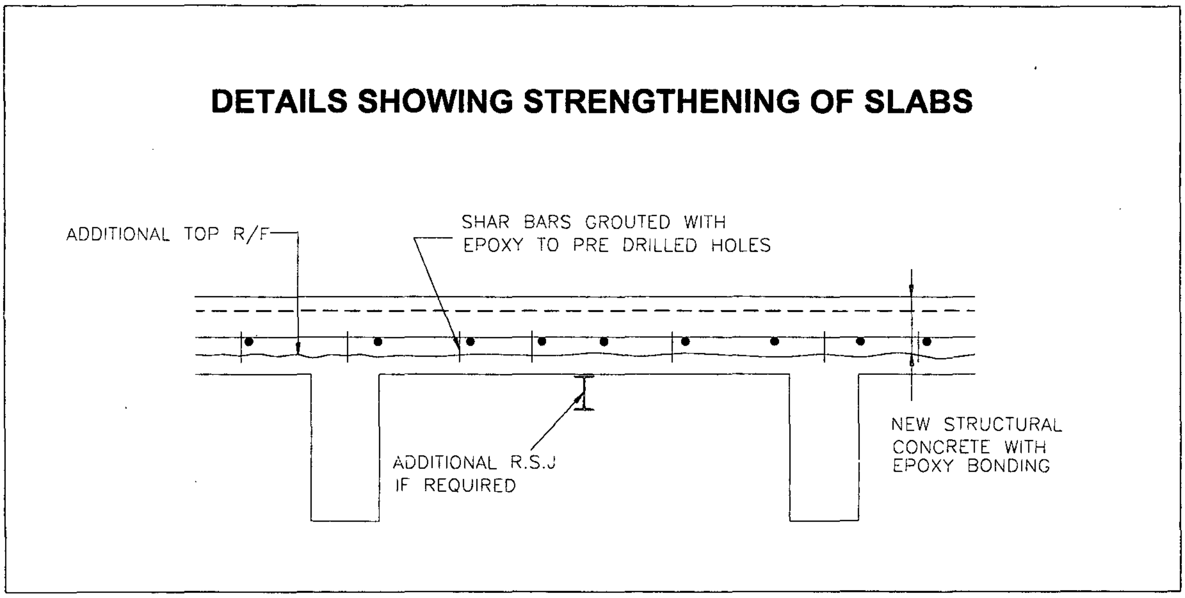


Fig. 2.15 Certain original slab design is marginal and even deficient. Provision of additional steel joist at a suitable location may be mid-span support, is a routine repair technique. Usual connection of flange of joist with slab soffit need be developed with appropriate mortar in fill. The apprehension generally raised for such repairs is about non-availability of R/F in the slab to deal with changed spans. However, some serious thinking invariably reveals that the proposal is good enough due to reduced span and sufficient strength of the concrete of the concrete cross-section alone. The changed behaviour offers immense relief at reduced repair cost. In slabs, the flexural variation is not substantial and extensive so as to be the cause of concern for such simple solutions. In extreme cases appropriate provisions of additional support reinforcement is also possible without undue difficulties.

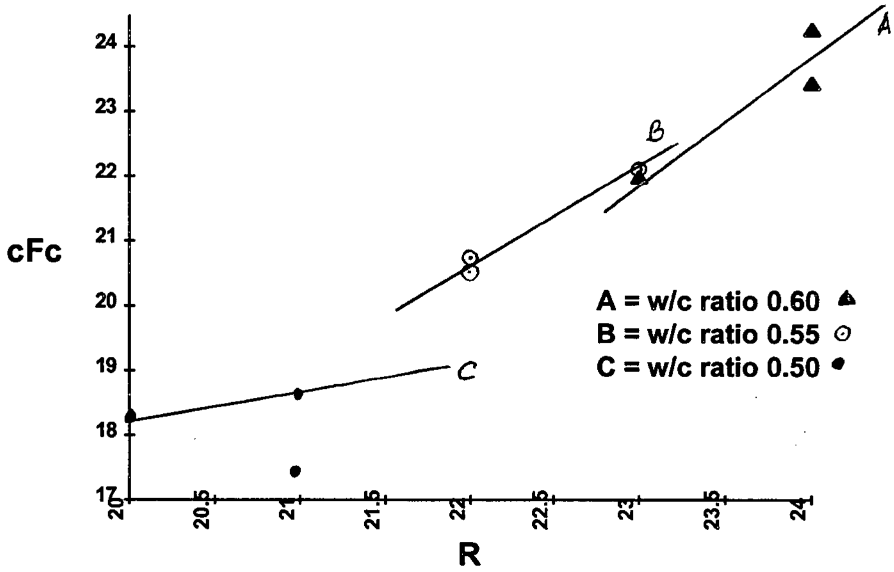


Fig 8.1.1 Relationship between measured compressive strength(cFc) and rebound number (R)

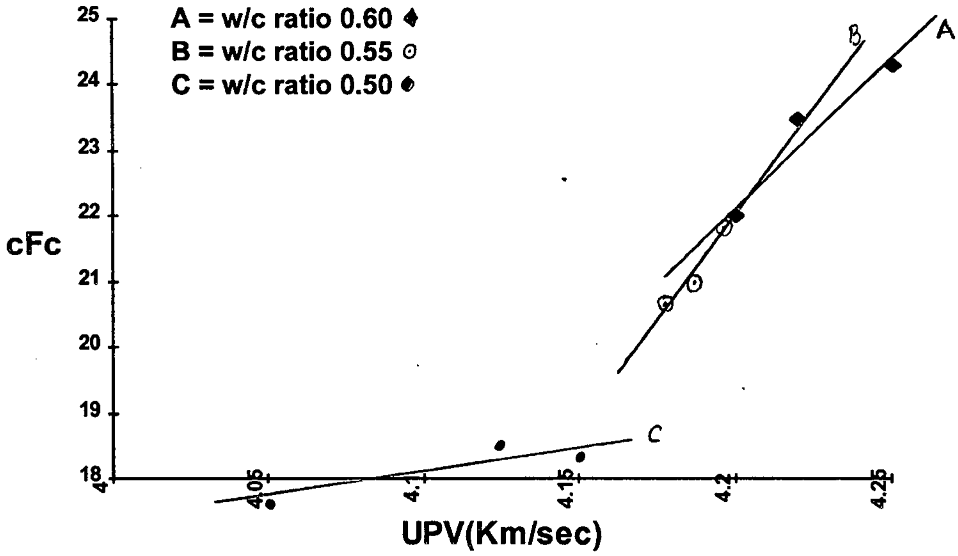


Fig. 8.1.2 Relationship between measured compressive strength(cFc) and ultra sonic pulse velocity(UPV)

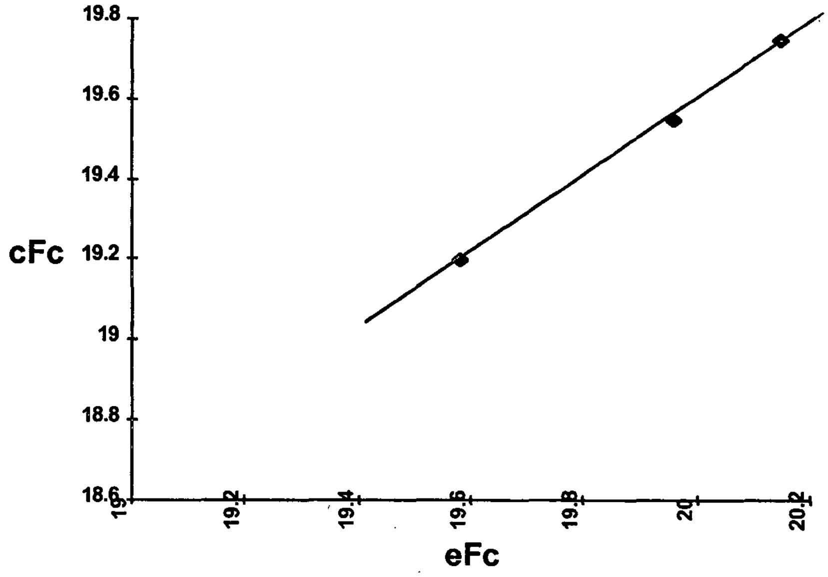


Fig. 8.2.1 Comparison between measured strength(cFc) and estimated strengths(eFc) at the age of 8 weeks

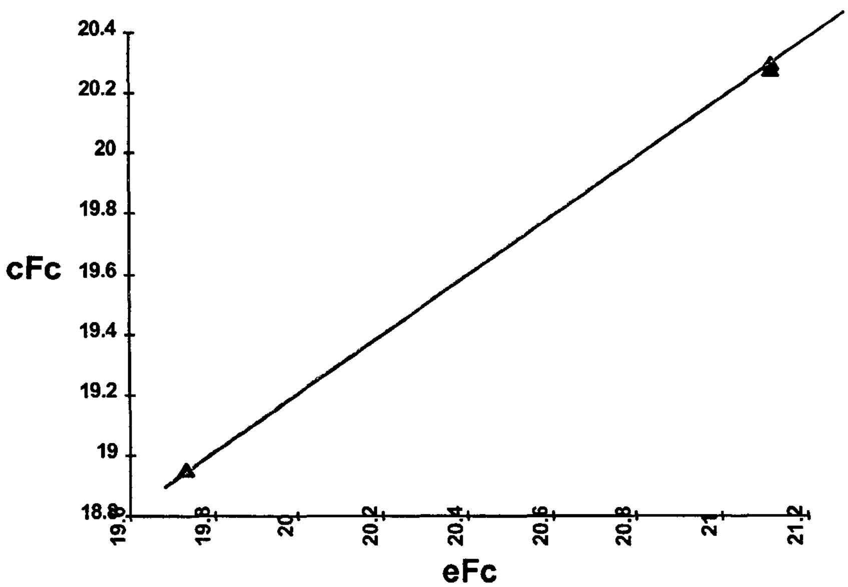


Fig. 8.2.2 Comparison between measured strength(cFc) and estimated strengths(eFc) at the age of 12 weeks

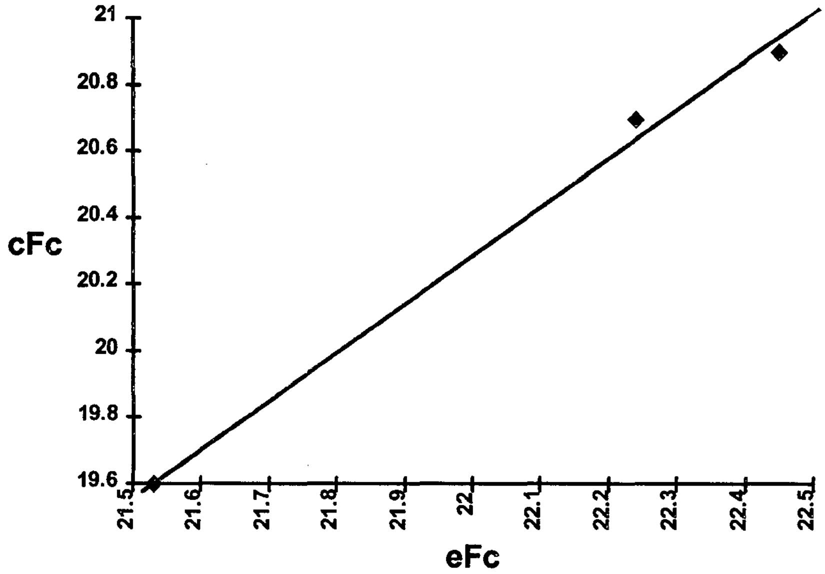


Fig. 8.2.3 Comparison between measured strength(cFc) and estimated strengths(eFc) at the age of 16 weeks

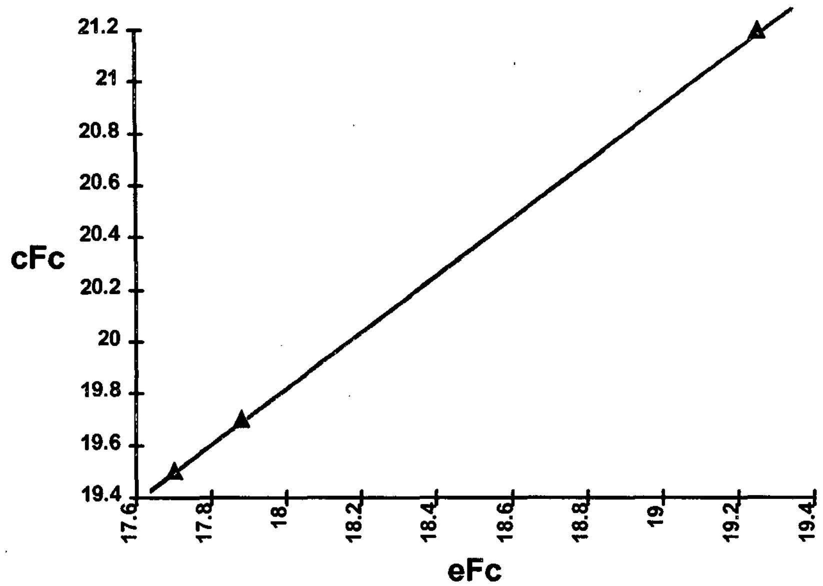


Fig.8.3.1Comparison between measured strength(cFc) and estimated strengths(cFc) for max^{m} size of CA as 15mm

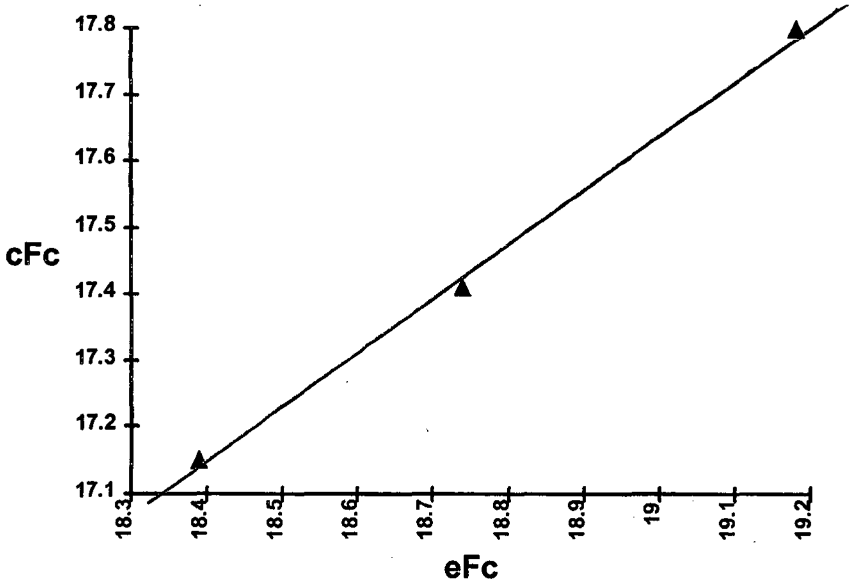


Fig.8.3.2Comparison between measured strength(cFc) and estimated strengths(eFc) for max^{m} size of CA as 25mm

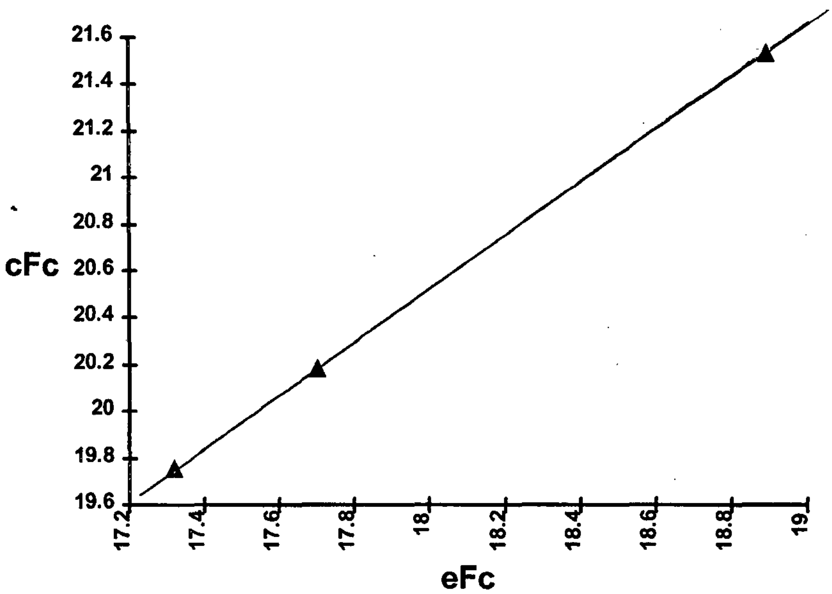


Fig.8.4.1Comparison between measured strength(cFc) and estimated strengths(eFc) for volume fraction of CA as 0.30

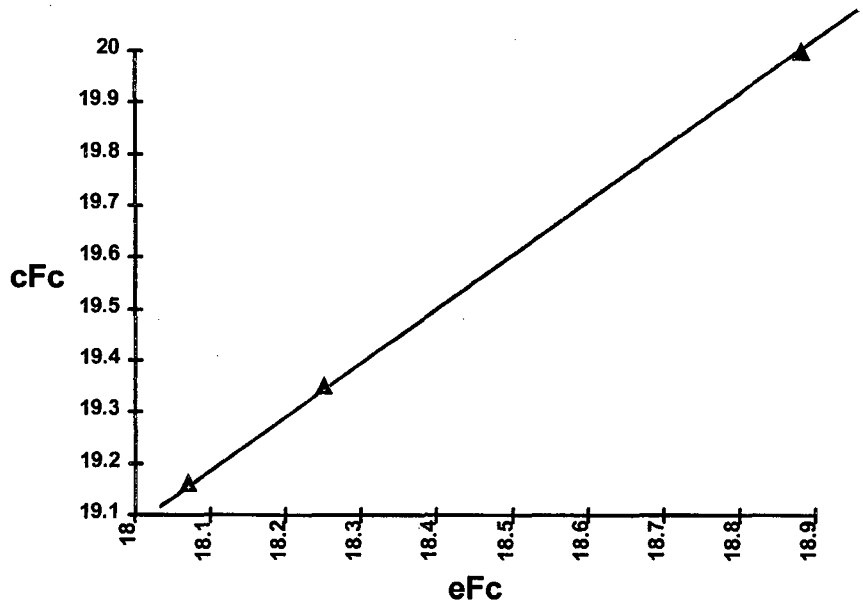


Fig.8.4.2Comparison between measured strength(cFc) and estimated strengths(eFc) for volume fraction of CA as 0.35

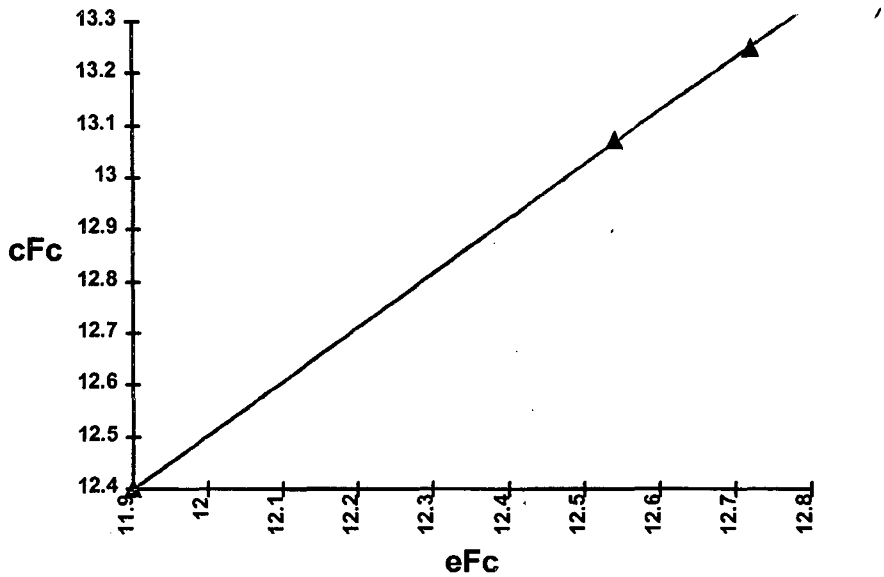


Fig.8.5.1Comparison between measured strength(cFc) and estimated strengths(eFc) for cement content as 200Kg/m^3

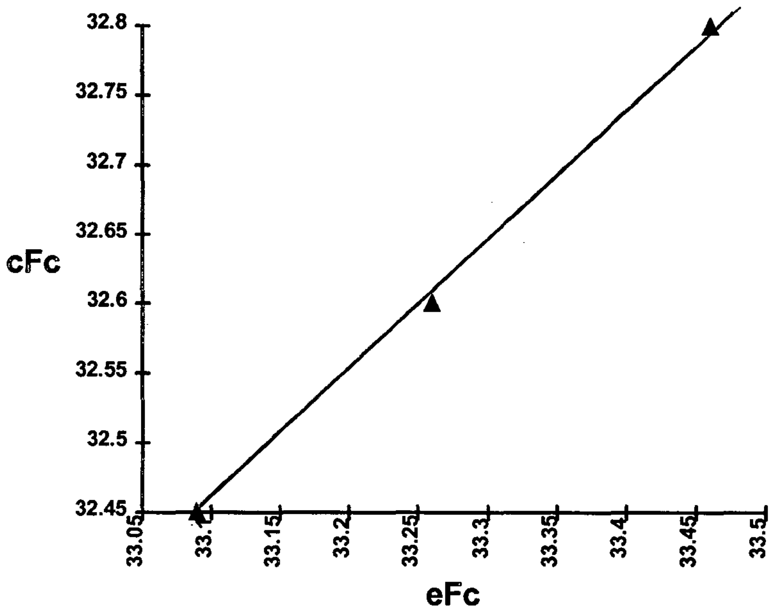


Fig.8.5.2 Comparison between measured strength(cFc) and estimated strengths(eFc) for cement content as 400Kg/m^3

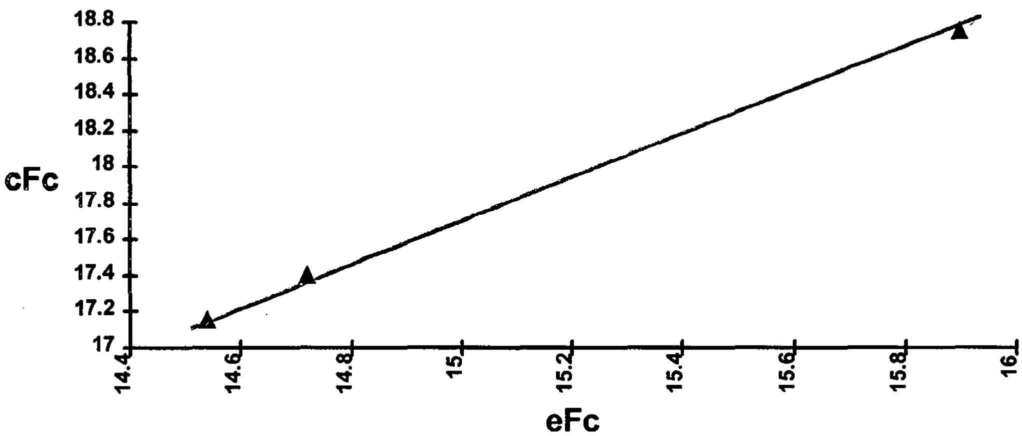


Fig.8.6 Comparison between measured strength(cFc) and estimated strengths(eFc) for Gravel as CA

[redacted]

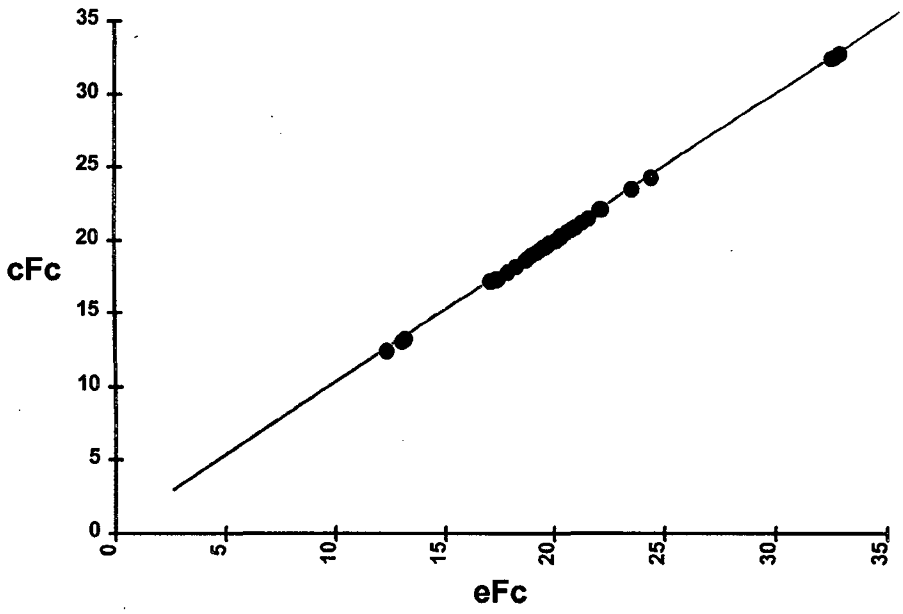


Fig.8.7 Comparison between measured strength(cFc) and estimated strengths(eFc) from Eqns.8.8 and 8.9

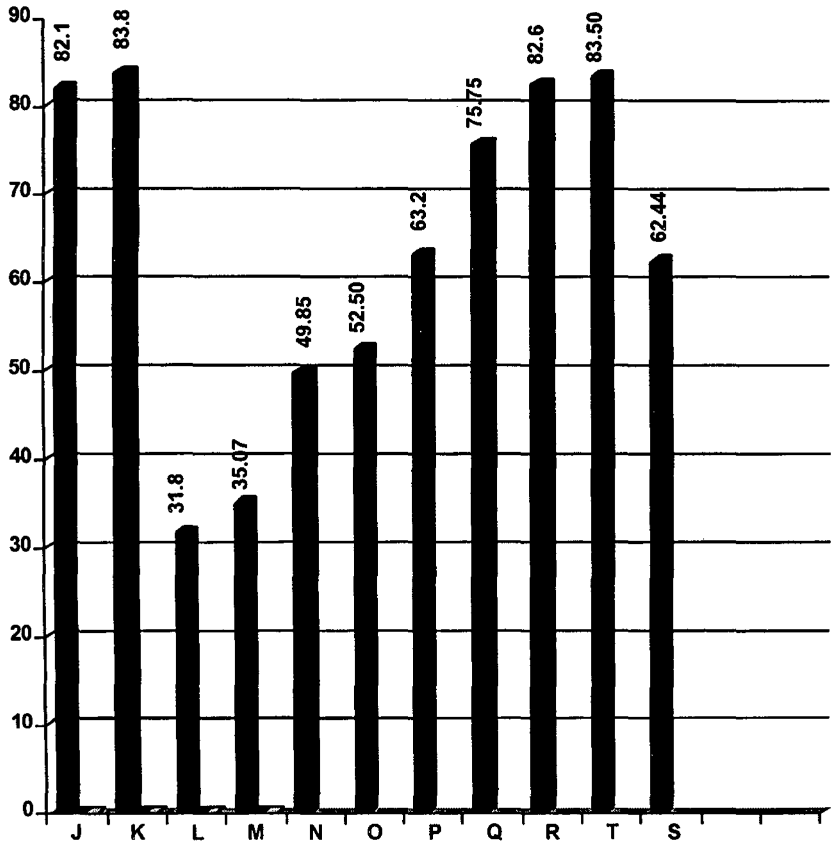


Fig. 8.8 Experimental results of failure load of jacketed columns as per table 7.2 and table 8.2 shown as bar chart, on Y-axis the value of actual failure load have been shown as % of theoretical failure load for different sets of columns.

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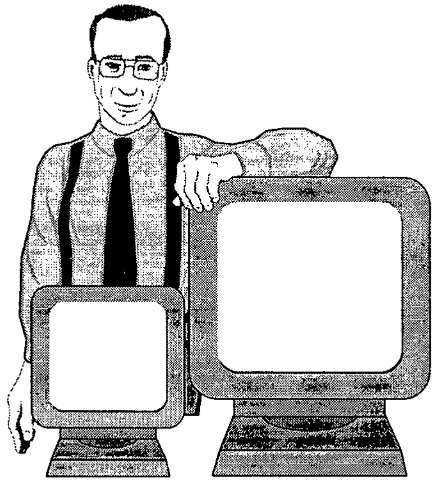

READ ME

(STEPS FOR USING EXPERT SYSTEM)

Read Me

C O N R E P is an expert system for step by step diagnosis of cause /causes of cracking in concrete structure and suggesting methods for repairs and strengthening of structure as required. In addition it provides the information on various corrosion protection methods available to prevent/ reduce corrosion in reinforcing bars, it also gives the user, information about various firms manufacturing epoxy compounds for concrete repairs.

If you want to find the cause /causes of distress in any given RCC structure, this system will help you diagnose the cause/ causes of cracking in the structure based on the given input data and will suggest the repair steps which can be undertaken for repairing or strengthening of the structure.

For using the this expert system you should have TC^{++} compiler loaded in your hard disk. Boot your system then go to TC^{++} by running TC.EXE file in BIN subdirectory, once the working window for TC^{++} comes, insert the CONREP diskette and type a: or b: as per your system configuration. Type **conrep** and enter. The title of the system appears with music in form of screen saver, press enter key, the information about the system will appear. On pressing enter you will be prompted with a menu and any of the required item can be selected by simply using ↑↓ keys and then press enter, for example if you press enter key by selecting first row you will go for diagnosis and repairs of cracking in RCC structure. Once option is selected then system will keep on asking certain information about the structure, and will suggest the expected cause of cracking in the structure based on the data given and will also give you the recommended repair methods, if more than one method is recommended than system will ask the choice of user and on giving the choice the system will provide the steps for implementing that repair method. You can exit out any time by simply pressing Esc, however don't try to Esc while programme is expecting some input data from you.

Photograph showing damaged columns and the encasing reinforcement.

Photograph showing Epoxy being coated on the unjacketed column.

Photograph showing columns being jacketed by jacketing concrete and additional reinforcement.

Photograph showing Schmidt hammer test being carried out to find out the rebound number.

DISKETTE CONTAINING THE EXPERT SYSTEM PROGRAM WHICH CAN BE RUN ON TURBO 'C++'

(Name of File : CONREP.C)