GUIDELINES FOR INSPECTION, MAINTENANCE AND REHABILITATION OF CONCRETE BRIDGES

CHAPTER V

MAINTENANCE AND REHABILITATION

5.1 GENERAL

After completion and commissioning of the bridge, various operations that may be required to do on it are:

- Maintenance and repair
- Rehabilitation
- Improvements
- Replacement or reconstruction

5.1.1 Maintenance and repair: This is the work needed to preserve the intended load carrying capacity of the bridge to ensure correct functioning, aesthetic appearance and continued safety. It excludes any work leading to improvement of the structure by strengthening or by widening to carry heavier loads or wider gauge. It consists of the prevention of deterioration by normal causes, wear, damage through accidents, vandalism and built-in imperfections. Maintenance deserves great attention. Maintenance is to be performed in a systematical way because it has been proved to be the most economical. All structures should be designed and constructed with consideration of both capital expenditure and predictable maintenance cost. The maintenance of engineering works begins from the day these have been constructed.

5.1.2 Rehabilitation: This activity also meets the above definition of maintenance and repair but is larger in scope and cost. Rehabilitation operations aim at restoring the bridge to its original service level it once had and has now lost. In some cases this consists of giving the bridge the service level which was intended, but could not be attained because of deficiencies in the original design and/or construction.

Rehabilitation or strengthening of bridges may become necessary under various conditions, such as:

(i) Aging, weathering, or deteriorating due to adverse environmental conditions

(ii) Inadequacies in the design and detailing and defects during construction

(iii) Damages due to external causes like accident, earthquake, floods, fire, etc. and foundation settlement

(iv) Change in live load pattern during service

5.1.3 Improvements: These aim at upgrading the level of service of a structure. Improvements can be for:

- Increasing the load carrying capacity
- Changing geometric parameters like increase in deck width etc.

5.1.4 Replacement or reconstruction: These works are required to be carried out when the whole structure or at least its major components are required to be replaced, being beyond the economic level of repairs/rehabilitation.

5.1.5 Improvements and replacements or reconstruction are not included in the scope of this guideline. In this chapter, repairs for maintenance and rehabilitation of concrete bridge superstructure only will be discussed with particular emphasis on analysis of cause of damage, remedial measures and the corresponding methods and techniques for engineering operations. Performing maintenance is a specialised job. Experience plays a predominant part in it, with regard to both inspection and the choice of measures for eliminating imperfections.

5.2 ANALYSIS OF CAUSE OF DAMAGE AND FORMULATION OF MAINTENANCE PLAN

5.2.1 Before any repair or rehabilitation work is taken up, the cause of damage and the extent of damage to the structure must be ascertained. This aspect is often disregarded with the result that further repairs have to be carried out within a short time. Sometimes the cause of damage or deterioration is obvious, but careful investigation of a deteriorated structure is essential. The investigation of the causes of the damages to the structure is largely a matter of gathering information by visual observations, studying records and asking questions, supplemented by a certain amount of laboratory and field testing and finally interpreting the information thus collected.

5.2.2 Investigations should cover defects relating to materials, construction, design or other aspects. All observed signs of damage must be analysed to determine their cause. The following questions should be answered:

(a) How long have signs of damage been noticed?

(b) Have the signs changed with time?

(c) Was the assumed loading and the design (including specifications) complete and correct?

(d) Were there any special occurrences, omissions during construction?

(e) Could some defects have been overlooked or unknown?

Only after thorough investigation and analysis any evidence of damage may be removed. During the repair itself, further information can be obtained and should be taken into consideration for necessary adjustment to the analysis, repair plan and its execution.

5.2.3 The analysis of results of condition survey, detailed investigation and structural assessment should enable the engineer to know:

(a) Whether there is a risk of failure of the damaged structure.

(b) Whether damages have established or likely to propagate further with time and repeated loading.

(c) Whether or not an economically effective repair plan can limit or contain damages and enhance the effective service life of a structure.

(d) Degree of urgency required in implementing a repair plan because of advanced stage of damage.

(e) Whether it is necessary to evaluate load carrying capacity of the bridge by load tests or otherwise.

5.2.4 The data from the investigations form the basis of decision regarding selection of an appropriate repair or rehabilitation plan out of the following available options:

- Total replacement in case the damages are found to be too extensive and the cost of repair is prohibitive.
- Partial replacement and repair based on the severity of localised damages in the structure.
- Extensive rehabilitation and/or strengthening.
- Minor repairs

5.2.5 Some of the important criteria for deciding the most appropriate repair/ rehabilitation plan from the available options may be identified as:

- Reliability and technical feasibility
- Cost of repairs/rehabilitation for both short term and long term measures.
- Importance of the bridge
- Estimated remaining life and life expectancy anticipated for various available options.
- Risk involved with any changes in safety level or reduction in load carrying capacity.
- Availability and efficacy of repair materials and equipment.
- Feasibility of having long duration traffic blocks, laying of temporary diversion and access for repairs.
- Time involved in implementing the repair plan
- Need for enhancing load capacity.
- Availability of expert supervision during implementation of rehabilitation measures.
- The technique should be robust and not too sensitive to implement.
- The technique and material should be resistant to environmental changes.
- The technique should involve preferably proven technology and new idea and novel methods should be introduced with care and on trial basis.

5.2.6 Many a time, accurate structural analysis may not be possible for the assessment of both the existing strength as well as extent of repairs or strengthening. The designer, therefore, has to be very judicious in his approach. Following two things should be clearly understood.

(a) Repairs do not necessarily have to reinstate initial or near initial level of quality and performance. A target quality of repair in terms of performance and extended service life should be fixed and the aim of repairs should be to achieve this target only.

(b) Deterioration mechanisms in the structure and influencing parameters must be identified in order to carry out repair works that can slow down or stop ongoing deterioration.

5.2.7 After results of investigation have been analysed and the elements of repair plan decided, detailed working drawings have to be prepared for carrying out the necessary repairs at site. The drawings should give clear and exhaustive instructions regarding various procedures to be followed during execution of the repair plan. In addition detailed specifications have to be drawn up for the materials and equipment to be used on the work. A scheme of quality assurance of the entire rehabilitation work should also be prepared.

5.2.8 **Site Survey:** Before any repair (other than temporary works) is carried out, a comprehensive site inspection and survey should be made. There are four basic objectives behind this survey:

i) To ensure that structure is safe to carry its imposed loading while waiting for the repairs to be carried.

ii) To establish the cause of deterioration/distress.

iii) Full recording of all cracking, spalling, discolouration, degree of corrosion of the steel and any other relevant factors to assess quantities and type of repairs.

iv) To enable identification of deterioration, which may not require immediate repair monitoring.

5.2.9 A flow chart for systematic approach for assessment of distressed/ deteriorated concrete structure is depicted in Figure 5.1.

5.3 REPAIR WORKS NOT REQUIRING STRENGTHENING

Concrete repair works not requiring strengthening may be categorized as below:

(i) Surface protection measures

(ii) Repair of the concrete surface

(iii) Repair of concrete cracks

(iv) Repair of corroded steel materials and repairs related to high tensile steel in prestressed concrete

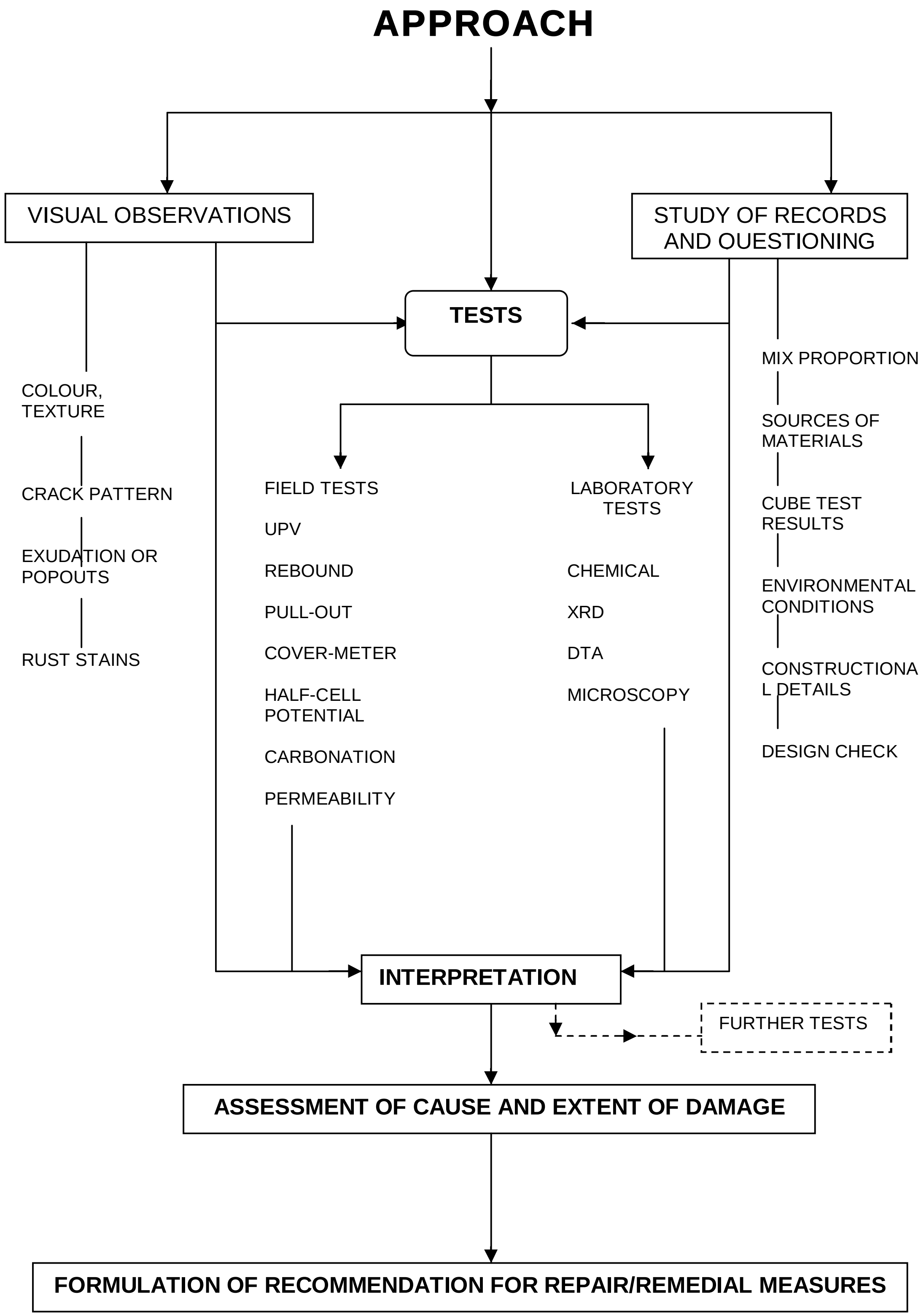

FIG. 5.1 ASSESSMENT OF RECOMMENDATION FOR REPAIR/REMEDIAL MEASURES

5.3.1 Surface protection measures: Where further development of an already existing weathering is of concern, following surface protection measures may be taken to minimize or stop this process.

- Hydrophobation
- Painting
- Impregnation
- Sealers
- Coating

The degree protection achieved from these measures increases in the order as they have been listed above. The difference between various measures lies in the process how protection is achieved. In the impregnation system, the protection is achieved through prevention of capillary absorption of water by the concrete. Depending upon the material used, this effect will be achieved by hydrophobation of the pores at the walls or by narrowing of the capillary ducts, which result due to film formation on these walls. Sealers or coatings lead to a closed thin film on the surface.

5.3.1.1 Materials for surface protection measures:

(a) The materials used for impregnation, hydrophobation are:

- silicon organic solutions
- resins
- oils

(i) Silicon organic impregnation materials are:

- siliconates
- silanes
- siloxanes and
- silicon resins

(ii) Resins:

In contrast to the silicon organic impregnation materials, the protection provided by the resins is mainly derived from a film formation on the surface of the pores and a narrowing of the capillaries. Types of materials used are:

- polymethylmetacrylates (PMMA) and
- epoxy resins

(iii) Oils

Low molecular, organic compounds in the form of oils may be used for impregnation. Linseed oil is most widely used oil for impregnation. Linseed oil may be used in the following forms:

- boiled (linseed) oil
- linseed stand oil and
- mixture products of boiled (linseed) oil or
- Linseed stand oil with not more than 15% unsaturated organic compounds.

(b) Sealers: In contrast to impregnation, a sealer forms a film on the concrete surface. This can be achieved by increasing the applied quantity of an impregnation agent, which tends to form a film, or through the choice of suitable resins. The following plastics are commonly used:

- epoxy resins (EP)
- polyurethane resins (PU)
- polymethylmetacrylate resins (PMMA); and
- unsaturated polyester resins (UP)

Sealers can also serve as a primer for coatings:

(c) Coatings: Coatings as compared to sealers provide an additional protection against mechanical influence. Consideration should also be given to the fact that coatings, as compared to sealers, have an increased resistance to the diffusion of internal moisture. A differentiation should be made between thin and thick coatings. Thin coatings, will follow the contour of any unevenness of the surface. Thick coatings should form as much as possible a plain surface with a thickness of 1mm or larger. Therefore, a thick coating will smooth out any unevenness of the surface.

Requirements of coating materials are as following:

- resistance against chemical attacks,
- resistance against temperature changes,
- good adhesion to the surface,
- sufficient tensile strength and elasticity,

- sufficient abrasive resistance,
- capability to bridge cracks; and
- coefficient of thermal expansion comparable to that of concrete.

Plastic modified cement systems and resins are suitable for coatings. Thick coating of resin mortars, upto thickness of 3mm can be produced by repeated wet-in-wet application of thin layers. Other coatings suitable for protection at concrete surfaces are epoxy resin, bituminous compound linseed oil, silicon preparation, rubber emulsion or even mere cement coating.

Coatings should also have the capability to bridge cracks. This requires a high elasticity of the coating materials. The epoxy systems are known to change their properties with variations in temperature and exposure to sunrays. For thinner layers bridging of cracks can only be achieved when a limited debonding of the coating adjacent to the crack is possible. With such coating, it is possible to bridge cracks upto 0.2mm in width. Bridging of larger crack widths can be achieved by the insertion of a fiber material into the coating, e.g. in the form of textile fabrics. Recently, two component liquid sealers have been developed which can be sprayed onto the concrete surface. They have the ability to bridge larger cracks as a result of their low modulus of elasticity and their improved elongation.

5.3.1.2 Technique of application: The efficiency of an impregnation basically depends on the preparation of the surface and on the required depth of impregnation. The impregnation liquid must be placed on the concrete surface in an amount to fill the voids. The application may be accomplished by means of a brush, lambskin roller or by spraying. Depending on the absorptive capacity of the surface, several repetitions may be necessary. For solvent containing impregnation systems, the concentration of the solution during the first application may require thinning to achieve a deeper penetration. Penetration depth is especially important where wearing of concrete surface is expected. Therefore, impregnation protection systems are only suitable where the concrete surface will not be removed by abrasion, damaged or locally disturbed by the formation of crack.

While impregnation with resins may be successfully used on horizontal surfaces, hydrophobizing impregnations are not suitable for horizontal surfaces where water will stay on the surface. Therefore, the primary field of application of hydrophobizing impregnations is on vertical or sloped surfaces, where the water can flow off easily.

5.3.2 Repair of Concrete Surface

5.3.2.1 Surface Preparation: The success of any repair depends on proper preparation of existing concrete surface. Regardless of the type or position of bridge member, or type of repair to be carried out, all unsound, damaged and fractured concrete must be removed. Concrete contaminated with chloride must be given special consideration for removal. Removal of all concrete that shows evidence of active or potential corrosion will guarantee a durable repair. Various methods available for surface preparation can be classified in four groups as under:

i) Mechanical Methods

ii) Thermal Methods

iii) Chemical Methods

iv) Hydraulic Methods

The choice of a suitable method depends on the situation, especially on the extent and thickness of the layer which is to be removed, as well as on the type, location and position of the damage in the structure. The thermal and chemical methods are rarely used in special circumstances and hence have not been described here.

5.3.2.1.1 Mechanical Methods: In general, Mechanical Method is preferable, as it is more intensive and reliable. While choosing and applying mechanical methods for removing the deteriorated concrete following care should be taken.

- Top edges of the areas to be patched should be sharp but corner should be rounded to make it easier to obtain good contact between the substrate and patch material.
- Edges of patched area should be undercut to eliminate feather edges and to provide keyed patch.
- The cut should not be so deep so that reinforcement are damaged.
- Chipping tools must be selected such that they do not damage surrounding areas and create additional areas of potential failure.
- Unnecessary heavy equipment and/or sharp-edged or pointed tools should be avoided.

- Ø The hammer weight should not be more than 14 kg.
- Ø Where only partial depth patching is required special instructions to hammer operation should be made to avoid breaking through the deck or fracturing the concrete below the partial – depth patch area.
- Ø Special care should be taken in removing unsound concrete from around reinforcing steel and embedded anchorages.
- Ø Scabbler, scarifier, or planner will be preferable to chipping hammers where large areas requiring the removal of relatively thin layer of concrete such as in shallow scaled decks.
- Ø If reinforcement is to be exposed for encasement with repair materials, the concrete behind reinforcement should be removed to a depth of at least 40 mm.
- Ø Where reinforcing steel is to be cut and replaced, lap splices with design lap length should be used.

5.3.2.1.2 Hydraulic Methods: Hydraulic Methods such as water jetting are also sometimes used and are considered preferable to jack hammer for preventing damage. A water jet with 10 to 40 MPa pressure at the jet will remove loose particles, scaled concrete or remove vegetation coatings. This is most efficient for removal of soft areas of concrete surface. This method is essentially free of vibration, but there will be deep penetration of moisture into the concrete.

5.3.2.2 Cleaning of area to be repaired: If removal of unsound concrete is done by mechanical methods, the area should be flushed with high-pressure water or vacuum cleaned to remove loose particles and dust. Air blowing may be effective, but the compressor should be equipped with a functioning oil trap to prevent contamination. The layer of bitumen on top of deck, if any, should be removed by mechanical methods and the surface should then be sandblasted. Any asphalt or oil will interfere with methyl methacrylate polymerization. Strong detergents, such as sodium metasilicate or trisodium phosphate, may be useful in removing surface oil contamination. However, oil that has penetrated the surface should be removed by chipping or scarification. The chipped surface often retains particles that have broken out but not dislodged. These particles should be removed by high-pressure water jetting or sandblasting. After cleaning and just prior to placing the repair material, the chipped surface should be moistened to surface dry conditions.

5.3.2.3 Bonding Aids for Old Concrete Surface to Fresh Repairs: Proper bond between repair work and old concrete is of utmost importance and it is this bond which determines the effectiveness of repairs. There are several types of bonding agents as given below:

(i) Cement paste: This bonding agent consist of a cement paste with a low water/cement ratio which is brushed into the surface to be repaired.

(ii) Cement slurry: Another bonding agent is cement mortar, which can be of high or low viscosity, consisting of equal parts of cement and sand along with water. It can, however, also consist of the repair mortar itself, from which the coarse aggregate has been removed.

(iii) Bonding system with polymer modified cement: Generally in theses systems, the polymer is mixed into the cement paste or cement mortar via mixing water. Dispersions free of plasticizers with certain portion of solid substances such as vinyl-propionate-copolymers or acrylic resin dispersions or poly-vinylacetate-dispersions may be added to the mix. In some instances emulsions may be used. The effect depends on the type of resin being used. These additives are often used not only to improve the bond strength, but also to improve workability and water retention capacity

(iv) Resins: There are two basic types of bonding agents made of two component resins: emulsifiable agents and normal agents. The first case consists of a combination of a water emulsifiable epoxy resin, a polyamide resin hardener and a filling material. The epoxy resin and the hardener are initially mixed together before placement. Filler may be permitted in a suitable designed ratio. If required, the mixture may be diluted with water. In the two component resin bonding agents, a pure resin-hardener-mixture is used, with or without fillers. Resins with filling materials are used in practice for the following reasons:

- filling materials prevent a deep penetration of resin into the old concrete,
- filling materials prevent a penetration of resin into the new concrete,
- filling materials are less expensive than epoxy resin; and
- resins with fillers can be placed in thicker layers.

In the latter case, the influence of possible heat development should be considered.

While considering the epoxy resin as bonding agent, it is essential to investigate the following aspects:-

- The components of the resin and their exact formulation in consultation with the experts.
- Detailed specifications for the materials and their application procedure.
- The quality acceptance standards and testing methods available based on international standards.
- Sensitivity of the material to temperature, ultra-violet rays and other external factors.
- Modulus of elasticity with and without proposed fillers.
- The cost effectiveness of the resin as compared to that of other materials. Cementitious based polymer modified materials are more economical, serve same purpose and sometimes better than epoxy resins.

5.3.2.4 Repair Materials: Selection of repair materials for repair concrete must be based on an evaluation of damage, characteristics of the repair material and local conditions. Repair material must be compatible with the concrete being repaired. A wide variety of materials differing in cost and performance are now a days available for repair and maintenance of concrete. These are low viscosity polymers, very rapid setting cement, special concrete for overlays apart from Portland Cement mortar or concrete. Before final selection, following properties of such materials should be checked or known:

- Bond with substrate
- Strength development (compressive, flexural and tensile)
- Co-efficient of thermal expansion
- Co-efficient of permeability
- Stress development at interface whether on shrinkage, temperature change, alternative cycles of wetting and drying
- Corrosion resistance
- Durability

Besides the above, speed of repair and appearance of finished surface should also be kept in mind. Basically, the repair materials can be grouped into:

i) Cementitious System

ii) Polymer Modified Cementitious System

iii) Polymer Concrete System

iv) Reactive Thermosetting Resin System

The following are some of the major repairing materials currently used for repair/rehabilitation or strengthening of concrete bridges:

(a) Unmodified Portland Cement Mortar or Grout: These are generally mixtures of ordinary Portland Cement and suitable aggregates. Cement mortar or concrete is very often selected because it is widely available and has low cost. Cement mortar is used for relatively small repairs, and cement concrete are commonly selected where large area is to be repaired.

(b) Latex Modified Portland Cement Mortar or Concrete: These are Portland Cement mortar or concrete modified by addition of a latex emulsion. Long term strength is same as conventional mortar or concrete with same quantity of cement but chloride ingress can be reduced due to lower water cement ratio.

Synthetic latex that have been found useful in Portland cement mortars or concrete are polyvinyl acetates, acrylics, styrene – butadene and vinylidene chloride. The last three are particularly suitable for wet environment.

The particular latex modifier will have an influence on the strength and durability of the cement. Selection of the modifier should be based on anticipated service conditions.

Latex modifier concrete recommended for sections upto 30mm deep, should have 1:3-3.5 as ratio of cement and fine aggregates. Water ratio should be 0.3 with latex solid-cement ratio of 0.1 to 0.2 by weight.

Latex modifier concrete recommended for sections deeper than 30mm should have proportions of 1 part of cement to 2.5-3 parts fine aggregate to 1.5-2 parts coarse aggregate. The water ratio and latex solid-cement ratio may be kept same as given above.

(c) Quick Setting Non-shrink Mortar: Shrinkage cracks may be better controlled and bond between new material and old concrete is better insured by use of expensive cement in the concrete mix. These products are combined with admixtures that increase strength and improve bond and workability while reducing curing time.

(d) Polymer Concrete: Although other materials have been used to make polymer concrete, the most successful has been either an epoxy system with curing agents or methyl methacrylate monomer with an inhibitor and promoter. Epoxy system is widely available in repaired formulations. Methyl methacrylate systems can be formulated by the user or prepackaged system can be used.

(e) Epoxy Mortar or Concrete: Epoxy compounds have been successfully used for more than three decades. A typical epoxy mortar consists of two components, the epoxy resin and curing agent. Considerable improvements have been possible due to elimination of short comings without sacrificing their desirable characteristics. Epoxies currently available have the same thermal coefficient as of concrete, but they exhibits a low modulus of elasticity that is not sensitive to temperature variations.

Material and proportions – type, grade and class must be chosen to satisfy job conditions and requirements. Aggregate should be as recommended by epoxy formulator. The most generally used aggregate is silica sand with little or no material passing through 100 micron sieve. The maximum aggregate size should be no more than 1/3rd the thickness of patch or overlay. The aggregate should be clean and dry with a maximum moisture content of 0.5% by weight.

Epoxy mortars generally consist of 4 to 7 parts of sand to 1 part resin by weight. The ratio may be increased by incorporating coarse aggregate proportioned with respect to sand. The ratio depends on combined gradation, particle shape and resin viscosity. Proportioning studies should determine density as well as strength. To ensure durability, air voids should not exceed 12 percent.

The two components of two compound resins are to be thoroughly mixed before the incorporation of aggregate. Chemical reactions start as soon as the resin components are combined and the working time will depend on the system, the temperature and the handling procedure. The user should be thoroughly familiar with the particular system being used before a large application is attempted.

(f) Methyle Methacrylate Concrete: Resin-based polymer concrete products were introduced in the 1970s. The initial version used methyle methacrylate monomer (MMM) that exhibits properties superior to most epoxies. This materials exhibited higher strength, faster curing time at low temperature, improved chemical resistance, and better overall compatibility with old concrete. However, products based on this constituent were found to have high vapor pressure, low flash point and a strong odor, hence they were discontinued. A current derivative of these products is the so-called Sika Pronto Monoma, a materials that is considerably improved.

The methyl methacrylate concrete is preferred to produce polymer concrete because of its low viscosity and high bond strength to concrete. The prepackaged systems are also available. The maximum size of aggregate should not exceed 1/3rd the depth of repair. 15 to 20mm maximum size coarse aggregates can be used with approximately same amount of fine aggregate.

Mortars and concrete can be rapidly mixed by hand or machine. If a rotating drum mixer is to be used to prepare materials, half of the coarse aggregate and all the monomer or resin system should be added to the mixer and mixed. The powders and fine aggregates, followed by the rest of the coarse aggregates are then added, and the entire blend is mixed for 2-3 minutes. The material can be placed directly into the repair area, consolidated by vibrating and tamping with conventional equipment and finished with a trowel.

5.3.2.4.1 Repair Materials Commonly Used: According to ACI-546 report, a low slump Portland cement concrete admixed with accelerating admixture (ASTM C 494 – Type F) is recommended for use in repair of partial depth patches along with some bonding agent. Bonding agent may be of LATEX-cement slurry or any epoxy system. W/C ratio of concrete mix shall be less than 0.45 and maximum size of aggregate shall be less than 1/3 of the patch depth. Concrete shall be laid while the bonding agent is still tacky.

Polymer modified mortars are readily available in the market in prebatched conditions and very easy to mix and apply in the field. Such materials should have compressive strength around 25 N/mm^2 and flexural strength around 5 to 6 N/mm^2. Small patch repair having a depth less than 13mm my be done using such mortar.

Around 4 to 6% (by weight of cement) SBR latex may be used to modify Portland cement-sand mortar or concrete. Such mortars will attain high flexural and bond strength and have minimum shrinkage on drying after application. For patch repair of depth 13-32 mm, latex modified mortars and over 32mm depth – Latex modified concrete is recommended by ACI-546.

Epoxy mortar or concrete may be used for repair of spall when time of repair is very short. ACI 503 report gives necessary guidelines for use of epoxy system in concrete superstructure. Epoxy system should conform to ASTM C 881-87. Type, grade and class must be chosen to satisfy job conditions and requirements. Epoxy mortars generally consists of 15-20 parts silica sand which shall be mixed slowly with a premixed resin-hardener formulation by using a slow speed drill fitted with a stirrer. Mortar shall be laid after application of an epoxy primer and shall be trowel finished within its pot life.

5.3.2.5 Repair Technology:

5.3.2.5.1 Sprayed Concrete, i.e. Shotcrete or Gunite: Sprayed concrete is a mixture of cement, aggregate (fine and coarse) and water projected at a high velocity from a nozzle into place against an existing structure of formwork where it is compacted by its own velocity to produce a dense homogeneous mass. The most commonly used terms are:

- Gunite, where maximum aggregate size is 10mm
- Shotcrete, where the maximum size of aggregate is beyond 10mm and less than 1/3 of the build up thickness.

According to the recommendation of ACI Committee report no. 546, Shotcrete or Gunite is especially adaptable for patching large areas of shallow scaled or spalled beams, pier caps, curbs and undersides of decks. Detail recommendations are given by ACI Committee 506.

Surface preparation is almost similar to that for any spalled repair. An area, which is to be repaired by guniting or shotcreting, should be prepared by chipping or sand blasting and then thorough washing with water.

Saturated surface dry (SSD) condition of the area is a must prior to application of shotcrete/gunite. Anchor bolts and suitable BRC/JRC fabric reinforcement may be used to tie new material to old concrete and for higher built up thickness respectively. For shotcreting in successive layers on overhead and vertical surfaces a gap of atleast 30 minutes should be given between two layers to avoid sagging and loss of bond. Also any defective application of previous layer shall be cut, removed and replaced with the succeeding layer. Proper curing condition either by using any membrane curing compound conforming to ASTM C 309 or by sufficient watering must be followed after completion of shotcreting.

Spraying of concrete/mortar may be done effectively either by Wet Process or by Dry Process. However both the systems have got advantage or disadvantage and shall be chosen as per specific site conditions.

Wet Process: The wet process is a technique where a pre-batched mix of cement, aggregate and water is transported to the site and pumped to the nozzle by a concrete pump through flexible hoses. Compressed air is introduced at the nozzle to project the concrete and compact the mix into the desired location. Since wet process needs larger volume to mix at a time and output is very high, it is generally less suitable than dry process in case of repair of any concrete structure.

Dry Process: In this system materials like cement, sand or coarse aggregate is batched at site without addition of water. In case it is decided to use powder accelerator, the same shall be mixed with the above prebatched material and to keep at site in dry condition prior going for shooting. The premixed material is then placed into a pneumatic gun where it is pressurised and allowed to flow through flexible hoses along with a high velocity compressed air stream upto the nozzle. At nozzle point water is added by using a controlled spary to hydrate the mix before it is projected at a high velocity to the prepared surface. Controlling of water-cement ratio is carried out by the nozzleman and may vary within a limited range. However too little water will create excessive dust and will not allow the mixture compacting into a homogeneous mass. Similarly, too much water will increase the workability and cause a reduction in strength and induce shrinkage. Use of suitable steel or other fibres, microsilica, polymers and powder admixture shall be able to render better result with respect to strength and durability.

The dry process is particularly favoured for repair work because the mix in its dry form can be batched as required and kept in stock at site prior to start of the shooting operation. Rebound loss is inherent in sprayed concrete and is unavoidable. Under no circumstance should rebound be reused. The amount of rebound is dependent on various factors such as nature of surface, direction of application, mix design and finally skill of the nozzleman. The optimum distance between the nozzlemen and the surface to be sprayed may be kept around 1.0 M. However, it is commonly seen that rebound loss in overhead shooting will always be higher than shooting on vertical surfaces.

Ready to use pre-bagged dry mix micro-concrete using 3 mm aggregate and admixed with polymers, micro silica and superplasticizer is now available in the market. Use of such material will always render better result than the conventional cement-aggregate mix by way of reducing shrinkage, attaining high flexural, compressive and tensile strength, reducing rebound loss and high build up thickness in one layer and thus improves the quality of the repair.

5.3.3 Repair to Cracks and Other Defects

5.3.3.1 General: Before deciding the most appropriate methods/material for repairing/sealing cracks, the cause of the cracks should be investigated. It should be determined whether they are active or dormant. The repair techniques generally applicable for the various types of damages, particularly in case of deterioration of concrete are as follows:

(a)	Active cracks	:	Caulking, jacketing, stitching, stressing, injection
(b)	Dormant cracks	:	Caulking, coatings, dry pack, grouting, jacketing, concrete replacement, pneumatically applied mortar, thin resurfacing.
(c)	Crazing	:	Grinding, coatings, sand blasting, pneumatically applied mortar.
(d)	Alkali aggregate	:	Injection, concrete replacement, total replacement.
(e)	Holes & honeycombs	:	Total replacement, combing pneumatically applied mortar, prepackaged concrete, replacement.
(f)	Exercise permeability	:	Coatings, jacketing, pneumatically applied mortar, prepackaged concrete, total replacement, grouting.

It is always desirable to attempt repairs to cracks at an early stage. However, in the case of cracks, which are the result of time-dependent constraints such as shrinkage or settlement, the repair should be delayed as much as possible, compatible with the use of structure, such that the effect of further deformation is minimized. Pressure (not too high to cause damage) injection of epoxy/cement can be effective even for an active crack (a cyclic opening and closing resulting from temperature changes or cyclic loading) when the objective is primarily corrosion protection of the reinforcement. However, if the crack is of a nature to adversely effect the structural integrity, strengthening will be required prior to crack repair.

5.3.3.2 Selection of Materials: The material used for crack repair must be such as to penetrate easily into the crack and provide a durable adhesion to the crack surfaces. The larger the modulus of elasticity of the material, the greater will be the obtainable adhesion strength. The interface of the material and the crack surfaces should be such as not to allow infiltration of water and to resist all physical and chemical attacks. Currently, the following fluid resins are used for crack injection:

- Epoxy resin (EP)
- Polyurethane resin (PUR)
- Acryl resin (PMMA) and
- Unsaturated polyester resin (UP)

The formulation of commercially available injection resins varies widely in their properties. Therefore, care must be exercised in making the proper selection. Manufacturers or applicators who are experienced in this method of repair should be consulted before the material is specified as there are large number of epoxy formulations available in the market. In general, the following properties of epoxy should be looked for:

i) Low viscosity

ii) Good compression and flexural strength

iii) Excellent bonding properties

iv) High heat deflection temperature (15-20^{0}C) above maximum service temperature.

v) Ability to bond even in presence of moisture

vi) Non-shrinking

vii) Adequate pot life; 30 minutes or more.

Table below gives general idea about selection of epoxy injection material for repair of cracks.

Type of cracks	**Width**	**Move -ment**	**Water**	**Type of material**	**Mode of application and/or principle**
1	**2**	**3**	**4**	**5**	**6**
Shrinkage cracks in concrete	<0.2 mm	No	No	Two component epoxy injection	Surface treatment, which works through capillary action.
Structural cracks in concrete	0.2-1 mm	No	No	Two component epoxy injection	Low pressure treatment, which works through capillary action.
Structural cracks in concrete	1-2 mm	No	No	Two component epoxy injection and solvent free epoxy.	Low pressure injection
Structural cracks in concrete	2-5mm	No	No	Solvent free epoxy thixotropic	Low pressure injection with hand pump
Structural cracks in Concrete	5-15mm	No	Dry/ Wet	Polymer modified cement based grout	Grout with injection by gravity or hand pump
Structural cracks in concrete	>15 mm	No	Dry/ Wet	Non shrink grout	Cut and fill non shrink grout
Moving cracks in concrete	0.2 – 1 mm	Due to temp. change	Dry/ Wet	Two component polyurethane injections & flexible paints when wet joint, primary injection with polyurethane gel forming	High pressure injection Coat with roller/brush
Moving cracks in concrete	<2mm	Vibrati on	Dry/ Wet	Sealant on different basis including flowable grades	Sealant gun or spatulas

5.3.3.3 Injection process: As a rule, the following steps are necessary during injection:

- Drilling of the injection-holes and blowing out of the holes and cracks

- Installation of packers
- Tamping of surface in the area of the cracks to be injected
- Mixing of the injection material
- Injection of the injection material and
- Re-injection and testing

5.3.3.3.1 Packer: Packers are auxiliary means by which the injection material is injected into the crack. Depending on the method of installation, they may be classified as an adhesive packer, drilling packer or a jet-packer.

Adhesive packers are pasted into the crack. The hose to the injection device is connected to the nozzle of the adhesive packer. In the case of drilling packers, holes are drilled in the plane of the crack or may be inclined to the crack plane. The packer consists of a threaded metal tube which is encased in a rubber-like sleeve and equipped with a nut. After insertion into the drill hole, the rubber sleeve is compressed by screwing down the nut. In this manner, the drill hole is sealed. A nipple, equipped with a ball valve to which the injection hose is attached, is screwed into the packer opening. The valve opens itself when subjected to the injection pressure.

5.3.3.3.2 Injection equipment: Injection equipment are differentiated as one-component or two-component equipment. In the case of one-component equipment, the resin is mixed first and subsequently injected into the crack. Typical representative one-component equipment are a hand grease gun, treadle press, air pressure tank, high-pressure tank and a hose pump. With these equipment, rather high pressures can be applied. However, the influence of the applied pressure on the packer, the tamping and the crack itself should be considered. The pot life of the material is an important parameter in the application of one-component equipment. Therefore, the length of crack that can be injected is related to the volume of material being used and its pot life.

In the case of two-component equipment, resin and hardener are separately transported to the mixing head by means of fully automatic dispensing equipment. Therefore, pot life is only of secondary importance. Errors in mixing two-component resins can have significant effect on the hardening of the resin. Therefore, the use of pre-packaged batches prepared by the manufacturer is recommended. Generally, in the case of two-component automatic dosing devices errors will not be discovered in sufficient time to apply corrective measures.

5.3.3.3.3 Injection: A distinction must be made between low-pressure (upto approximately 2.0 MPa) and high pressure injection (upto 30 MPa). The penetration speed of the injection resin does not increase proportionately with increasing pressure. The viscosity of the resin strongly influences the rate of injection, especially for small crack widths and in the area of the crack root.

The injection of a crack is completed when either the resin or hardener has been consumed from either of the containers or a back pressure has built up in such a manner that no further material can be injected into the crack.

For the low-pressure process, the resin has a relatively greater amount of time to penetrate gently into the crack. Because the injected resin may flow from the main crack into fine capillaries, a post-injection procedure may become necessary. This will be especially true for high-pressure injection. Therefore, it must be accomplished prior to hardening of the previously injected resin.

Flow capacity and hardening reaction of the resin is dependent on temperature. This factor must be considered for cold structural elements and for declining ambient temperatures. High resin temperatures shorten the processing time in one-component equipment. For crack widths upto 0.2mm, a thick sealing at the cracked surface with a resin is usually sufficient. It will be absorbed by capillary action in the crack.

5.3.3.4 Other methods of crack repair:

(a) **Stitching:** Stitching across the cracks by in-situ reinforced concrete is done either along the cracks or as a series of bands around the member. Reinforcement is placed across the cracks in suitable grooves that are suitably packed with wet concrete gunited. Alternatively, if geometry permits, bars grouted in holes could be used for stitching.

(b) **Jacketing:** This involves fastening of external material over the concrete to provide the required performance characteristics and restoring the structural value. The jacketing materials are secured to the old concrete by means of bolts and adhesives or by bond with existing concrete.

5.3.4 Testing after repair: The usual testing methods are drill core removal and ultrasonic testing described in Chapter IV.

5.3.5 Replacement of Concrete in a Prestressed Zone: The stress in the affected zone should be calculated as accurately as possible. When it is necessary the stresses should be re-established.

Consideration should be given to possibility of reducing the stresses while repairs are being carried out, by temporarily loading or supporting the structure. When defective concrete is to be removed from a stressed zone, it should be removed and replaced in stages so that not much concrete will be removed at one time.

The joints between old and new concrete should be normal to the direction of the principal compressive stresses. If this is not possible, the joints should be arranged in form of steps whereby one side of steps should always be situated normal to compressive stresses (see figure 5.2 below). The transfer area for compressive forces should never be skewed relative to the plane normal to the principal compressive direction, since the shear could cause a separation of the new and old concrete. In certain cases, the problem can be solved with a temporary prestressing in an area remote from the damage zone. This stress is eliminated once the repair is finished.

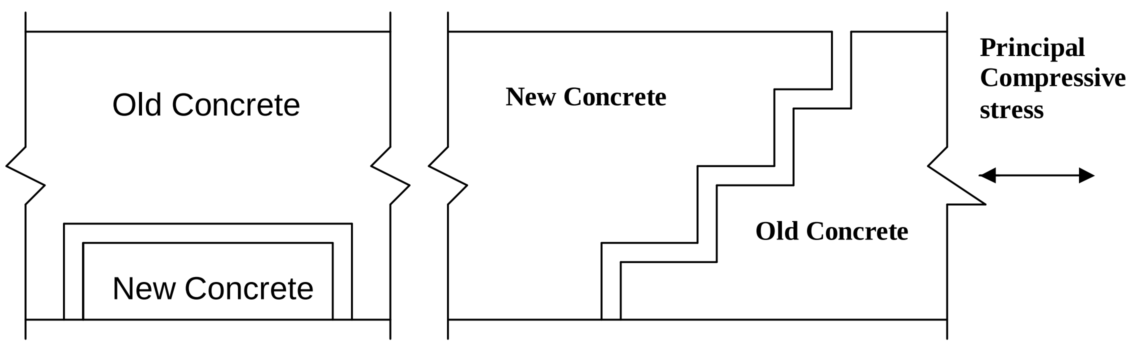

Figure 5.2 – Desirable arrangement of joints between Old & New concrete.

The joints between old and new concrete can also be prestressed using special short tendons. It is recommended that an expanding agent be added to the new concrete.

5.3.6 Repair of voids in Prestressing Cable Duct: Grouts inside the sheathing of prestressing cables may be irregular and voids may be present in the duct. The locations of the voids are to be identified using ultrasonic or radiographic or endoscopy equipment. For repair of voids in sheathing of prestressing cables, holes are to be drilled into the area. The grouting of voids are generally done by vacuum procedure with epoxy resin or cement grout. The equipment used sucks the air out of the cavity and then via a relay valve presses the injection material into the cavity. Vacuum machines form a definite vacuum within tendon duct and therefore volume to be grouted is measurable. The amount of cement grout or epoxy resin used can also be measured enabling to know if the void has been completely filled.

5.3.7 Corrosion Repair: Repair of corrosion of reinforcement or prestressing steel is a recent technology adopted in other country. In India this is only at research stage. Several electro- chemical techniques have been developed specially to repair and protect concrete suffering from deterioration in an environment conducive to corrosion. Two important techniques for corrosion repair are given below:

i) **Cathodic protection:** For detail reference may be made to Report No. BS-14 (Revised) issued by RDSO, Lucknow on “Durability of Concrete Structures”.

ii) **Electro-chemical Chloride Extraction:** Electrochemical Chloride Extraction (ECE) is based on a process of reducing chloride ions from around the reinforcing steel in contaminated concrete down to a level below the corrosion threshold. This works on a principle similar to impressed current cathodic protection, whereby a temporary, externally mounted metallic anode is embedded into an alkaline, electrolyte reservoir and a current in the range of $1A/m^2$ of concrete is applied to the rebars which become the cathode. The negatively charged chloride ions are repelled away from the negatively charged rebars and migrate towards the positively charged anode mesh. Simultaneously, the electrolytic production of hydroxyl ions at the steel surface results in the displacement of chloride ions and subsequent re-passivation of the steel with an effective buffer zone. Once the required number of ampere/hour has been delivered (as previously determined through treatment to trial on previous areas) and the chloride content reduced to the desired level, as evidenced by chemical chloride analysis, the current is switched off, and the external anode, with its electrolyte reservoir is removed and discarded. ECE produces no additional loading after treatment and there is no need to maintain a permanent installation. However, ECE is not suitable for use under certain circumstances, such as immersed or tidal zones.

5.4 STRENGTHENING AND REHABILITATION

5.4.1 General: The deterioration of concrete bridges occur due to corrosion of embedded reinforcement or prestressing steel, poor compaction of concrete or presence of harmful chemicals in the mix since its inception, honey combing, faulty detailing of reinforcement etc. Normally, the first sign of distress appears in form of cracking, which progresses to the stage of delamination and spalling of concrete. The general state of distress leads to reduction in cross sectional area and/or weight loss of principal steel. A combination of the two factors reduces the overall load carrying capacity of the structure necessitating strengthening. Strengthening of structural members can be achieved by:

- Replacing poor quality or defective material by better quality material.
- Providing additional load bearing material
- Re-distribution of loading actions through imposed deformation of the structural system

The new load bearing materials can be:

- High performance/quality concrete
- Reinforcing steel bars
- Thin steel plates or straps
- Post tensioning tendons
- Various combination of these materials

The main problem in strengthening is to achieve compatibility and continuity in the structural behaviour between the original material/structure and the new material/repaired structure. It may be noted that these strengthening measures improve the strength but not necessarily the durability of the original structure.

5.4.2 High Performance Concrete: The use of advanced composite materials using fiber-reinforced composites is one of the latest techniques for structural repair and rehabilitation. The limitations posed by conventional strengthening techniques have given an impetus to researchers to innovate and develop new materials/techniques for structural rehabilitation. The advent of advanced composite materials in the structural rehabilitation industry is a result of these efforts. Advanced Composite System (ACS) is one of the more popular and widely available commercial fibre reinforced composites with a proven performance record.

Compared to the conventional strengthening techniques, the use of ACS offers the following advantages:

1. It is lightweight and easy to install causing no distress to the member being strengthened.
2. No heavy machinery or equipment required for installation.
3. No appreciable increase in member sizes or corresponding dead weights.

4. It can be used in space constrained areas
5. It does not corrode and also inhibits the corrosion process in the member on which it is used.
6. Quick and easy application procedure results in time and cost savings.
7. Flexibility of application makes it suitable for use on member with any shape or profile.

5.4.3 Strengthening with reinforcing bars or structural steel:

In the simplest case, strengthening of concrete in tension zone is possible by addition of reinforcing steel. Reinforcement should be added after reducing the locked up stresses to the extent possible and after the concrete cover has been removed or after recess have been cut in the cover to accommodate the added reinforcement. Afterwards the concrete cover must be re-established. An effective anchoring of the ends of the reinforcing steel is required. This can either be done by providing sufficient anchorage length for the steel in the concrete or by steel plates and bolts with anchoring discs.

Some of strengthening technique under this scheme is given in figures 5.3

5.4.4 External Bonding of Steel Plates: As embedment of reinforcements involves partial dismantling of the load carrying members, an alternative approach will be to attach mild steel plates at the required location of the concrete member. This is a akin to welding/riveting of steel plates to rolled steel or built up sections to enhance the flexure or shear capacity of the section. This method is known as bonded plate technique, where mild steel plates are glued to the concrete surface with epoxy resin. The preliminary requirement will be to repair the cracked or sound concrete and make the surface as even s possible.

With a judicious choice of bonding media, dimensions of plates and ratio K, (neutral axis coefficient), a plated beam preserves both beam action and composite behaviour till failure. This technique controls cracking, rotation and crack width at service load, which is of practical interest. The main advantages of the technique are relatively quick execution and continuous use of the structure/during strengthening. The change in dimensions of the members if any would be in the order of a few millimeters.

The bonded plates need to be protected by a suitable method from corrosion during service life.

The resin bonded steel plates should only be used after careful structural appraisal of the problem and where frequent monitoring of their performance in use can be ensured. Resin bonded plates should not be used specially on concrete of unsatisfactory quality or which is deteriorating as a result, for example, of chloride or sulphate penetration or by alkali silica reaction.

If after careful structural appraisal of the problem it is decided to use the method, specialist advice should be obtained on the selection of the plate and resin types and thickness, standards of surface preparation and other details. Mechanical fixing must be provided as a construction expedient and to prevent the plates becoming a hazard, should they become detached by failure of the resin bond.

5.4.5 Strengthening with Carbon Fibre Plates: Strengthening of bridge elements in flexure using carbon fibre reinforced plates by bonding to the soffit of the girder has been successfully used in abroad. This has many inherent advantages over conventional steel plates like i) low weight high strength ii) excellent handling facilities iii) high resistance to corrosion iv) excellent fatigue, creep and fire resistance characteristics and v) good durability.

5.4.6 Jacketing around pier/abutment to increase load carrying capacity: For details of jacketing reference may be made to Para 513(b) of Indian Railway Bridge Manual, 1998.

5.4.7 External prestressing: External prestressing by unbonded tendon is a novel way of rehabilitating distressed bridge girders. The cost effectiveness of an external prestressed beam depends on the configuration and the number of tendons. As the bending moment diagram produced by prestressing force being similar to the tendon profile, a suitable configuration (i.e. straight, curved V shaped or through shape) could be chosen to counter the moments primarily due to deed load. In case of simply supported beam, the tendons need not to be placed through-out the length, as the bending moment close to the support will be too small. This can be achieved by anchoring the tendons into the deck slab, rather than at the end faces of the end beam. In case of box girder bridges with intermediate diaphragms, straight tendons anchored between pair of diaphragms can be chosen to achieve the required extent of prestressing.

A typical method for external prestressing of prestressed concrete I-girder is shown in Figure 5.4.

As the external prestressing primarily counteracts the live load moment, any loss of prestress or snapping of wire does not lead to collapse of strengthened members.

The corrosion protection of externally placed tendons poses no problems as they can be painted with epoxy or embedded in cable sheaths before prestressing, to be grouted later.

To obtain the desired uniform compressive stress distribution in each section throughout the entire length of bridge, resultant of the additional prestressing force should be located as close as possible to the centre of gravity of the cross-section. In case where actual losses that have occurred are suspected to be more than design losses, the additional tendons should be located close to the centre of gravity of existing prestressing tendons.

The sheathing for external tendons should be supported along its length and should be anchored to the reinforced concrete blocks projecting from the section of girder at close intervals with distance not more than 4m.

In a prestressed concrete bridge a typical sequence of operation will be as under:-

- Epoxy paint to bottom portion of girders and suitable paint to other areas of superstructure.
- Injection of epoxy grout in minor cracks.
- Strengthening by external prestressing.

GUIDELINES FOR INSPECTION, MAINTENANCE AND REHABILITATION OF CONCRETE BRIDGES

ANNEXURE - A

(SHEET – 1)

DESIGN AND CONSTRUCTION PARTICULARS OF RAILWAY/ROAD/FOOT-OVER BRIDGES OF RCC/PSC/COMPOSITES

1. Division
2. Section
3. Bridge no.
4. Km.
5. Between stations
6. Type of Crossing – Rail/Road Bridges/Road under bridge etc.
7. Name of River/Nallah/Canal/Road
8. Whether on curve and radius of curve
9. Angle of crossing
10. Rail level (if on gradient, rail level at each pier/abutment location may be given)

11a. Footpath/Manrefuge

11b. Trolley refuge Nos.

12. Level of underside of girder
13. Span details (No. of spans and clear and effective length of each span)
14. Number of tracks on bridge
15. Date of completion
16. Completion Drawing reference
17. Type of Concrete Components – Plain/Reinforced/ Prestressed/Concrete/Composite
18. Characteristic strength of concrete used
19. Type of cement used
20. Type of aggregate used
21. Admixtures used in concrete Mix
22. Type of reinforcement steel used – Plain/deformed bars, etc.
23. Type of strands/cables (for PSC components)
24. Prestressing system adopted
25. Prestressing system adopted
26. Anti-corrosive treatment of steel reinforcement, if any

27. Type of bearings
28. Details of bearings
29. Details of expansion joints, if any
30. Details of water proofing of deck slabs, if adopted
31. Details of protective painting, if done
32. Span-wise Camber (for PSC girders) just after completion
33. Calculated maximum deflection
34. Loading standard (both for Rail/Road bridges)
35. Special construction features, if any (e.g.segmental construction)
36. Special design features, if any
37. Permanent speed restrictions & infringements, if any
38. Any other information considered relevant by Engineer-in-charge

Note: For existing bridges above details may be recorded to the extent available.

For all new bridges full details must be recorded.