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A Review of the Repair of Reinforced Concrete Beams

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Abstract: This paper reviews works on repairing of deteriorated reinforced concrete beams. Every structural element should be designed for a particular type of loading as well as for adopting of different types of environment. However many civil structural elements, like reinforced concrete beams are often required to be repaired to restore the structural integrity and to protect the reinforcement from sever weathering condition. Recently repairing is gradually increasing with the increase of age of concrete structures. In some instances it may be more economical to accept the need for maintenance or repair at suitable intervals than to attempt to build a structure that will be maintenance-free under severe conditions for a long period. Several types of materials and techniques are available for repairing of exiting deteriorated reinforced concrete beams. In this paper, causes of deterioration of concrete as well as repairing by using cement grout, mortar, concrete, sprayed concrete or shotcrete, epoxy, ferrocement with mortar, Fiber Reinforced Polymer (FRP) Sprayed Fiber Reinforced Polymer (SFRP) and the techniques of applying of these materials and also some resin based materials for bonding agent between interface of old concrete and new concrete are reported. The advantages and disadvantages of these materials, causes of debonding between concrete substrate and new concrete applied on substrate and preventive measures are also discussed.

Keywords: Reinforced concrete beam, deterioration, repairing, mortar and concrete, sprayed concrete or shotcrete, epoxy resin, fiber reinforced polymer, sprayed fiber reinforced polymer, debonding.

INTRODUCTION

Reinforced concrete is the most frequently applied structural material because of its good durability, which has been used for many years to build a wide variety of structures from houses to bridges. Consequently little maintenance or repair work is usually required on concrete structures that have been designed and built well, with materials of quality, unless they are exposed to particularly aggressive conditions. A period of dynamic growth in its use came during the 1960s as a result of chronic shortage of housing[20]. The commonly held view, that concrete is a durable, maintenance-free construction material has been changed in recent years. Several examples can be shown where concrete did not perform as well as it was expected[14]. Although hundreds of thousands of successful reinforced concrete structures are annually constructed worldwide, there are large numbers of concrete structures that deteriorate, or become unsafe due to inadequacy of design detailing, construction and quality of maintenance, overloading, chemical attacks, corrosion of rebar, foundation settlement, abrasion, fatigue effect, atmospheric effects, abnormal floods[13], changes in use, changes in configuration and natural disaster (recent earthquake of Gujarat), etc. All of these factors affecting the durability of concrete structures[18].

In recent years, the growing need to maintain and repair structures has brought about a definite variation in the expenditure for restoration compared to the investment for new structures. It has been estimated that, at present, in Europe (and particularly in Italy) the investments in maintenance and repair work on old structures, represent about 50% of the total expenditure in construction. The expenditure for restoration, therefore, has nearly doubled compared to the last decade, when it was seen to be between 25 to 30%. Some estimates have indicated that in 2010 the expenditure for maintenance and repair work will represent about 85% of the total expenditure in the construction field. It has been forecast that, in the same year in the USA, 50 billion dollars will be spent for the restoration of deteriorated bridges and viaducts[8].

Repair and rehabilitation of deteriorated concrete structures are essential not only to use them for their intended service life but also to assure the safety and serviceability of the associated components so that they meet the same requirements of the structures built today and in future[2]. A good repair improves the function and performance of structures, restore and increase its strength and stiffness, enhances the appearance of the concrete surface, provide water tightness, preventing ingress of the aggressive species to the steel surface durability. Of course the repairing methods rather than replacement structures should become both environmentally and economically preferable. One of the current interests in the field of repairing is reinforced concrete beams for

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repeated loading condition. This is required for structures such as bridges and offshore structures.

Objective: The objectives of this paper are attaining knowledge on the following subjects,

- to find the causes of deterioration of reinforced concrete.
- to select the repairing materials and techniques.
- to highlights the advantages and disadvantages of each method.

Literature review: Concrete today is an indispensable part of the fabric of modern society, used for everything from mundane road pavements and high rise building structures. Despite its long history of use, our understanding of the material has only really developed in very recent times, particularly with respect to its durability. There was common view that concrete is a durable as well as a maintenance-free constructional material. In recent years this concept has been changed. Many investigations have shown that concrete does not perform as well as it was expected due to the effect of many factors which contribute to or cause the deterioration of concrete structures. The causes of deterioration, repair materials and techniques are described in brief in this section.

Causes of deterioration of concrete: Cracking and spalling are the most common phenomenon of deterioration of concrete. Cracks in concrete may occur in both the plastic state (Fig. 2.1-2.4) as well as hardened state owing to the internal stresses that arise from the response of the constituent's materials to the external excitation as well as their environment[1].

Cracks in hardened state occurs due to design errors (misconception of the structural action, inadequate reinforcement detailing, errors in designing calculation); construction defects (incorrect placement of steel, inadequate cover to reinforcement, incorrectly made construction joints, poor compaction, segregation, poor curing, too high water content); the loading of the structure in excess of the design load, due to change in use, unforeseen accident, such as explosion, impact and accidental effect due to fire[6,21]. ACI Committee 224[1] also reported that cracks may occur in hardened concrete due to chemical reaction, weathering action and corrosion of reinforcement, poor construction practice, Construction overloads and errors in design and detailing.

Macginley[17], has described the causes of main external, physical and mechanical factors causing concrete structures to cracks as well as fail. These are restraint against movement, abrasion, wetting and drying, freezing and thawing, overloading, structural alteration, fire resistance and settlement.

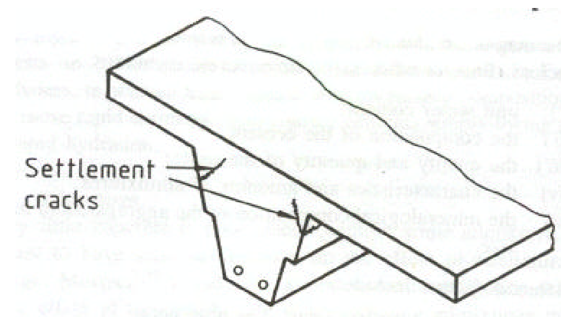

Fig. 2.1: Settlement cracks restrained by formwork[6].

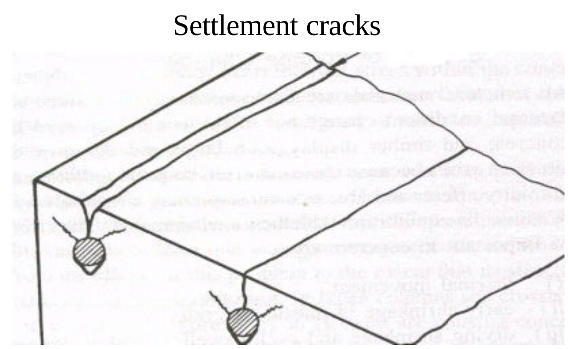

Fig. 2.2: Settlement cracks restrained by reinforcing[6].

Fig. 2.3: Plastic shrinkage cracking in RC slab[21].

Fig. 2.4: Thermal contraction crack in balcony slab[21].

Fig. 2.5: R.C structures after deteriorated concrete has been cut away[3].

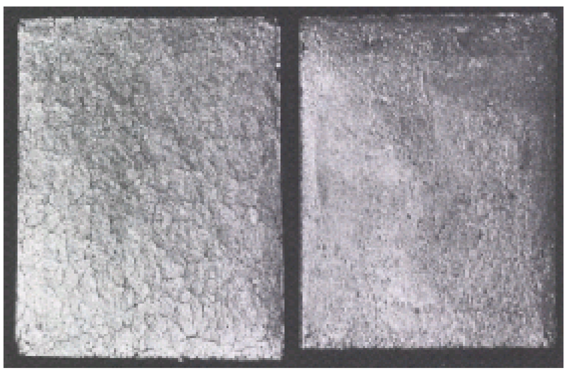

Fig. 2.6: The effect of sulphate solution on OPC mortar[21].

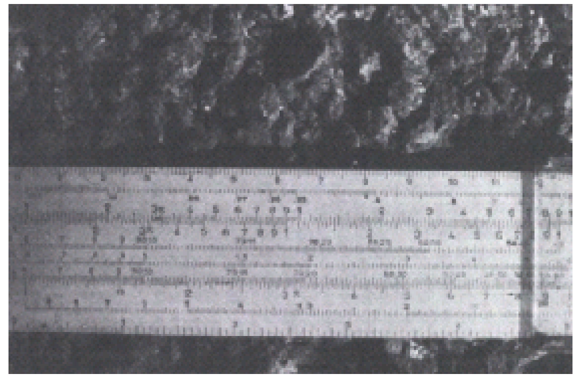

Fig. 2.7: Concrete attacked by sulphuric acid[21].

Fig. 2.8: View of fire damage to soffit of ware house floor[21].

Spalling may occur due to corrosion of rebar (Fig. 2.5), sulphate attack (Fig. 2.6), sea-water attack, acid attacks (Fig. 2.7), alkali-aggregate reaction, abrasion to concrete, high velocity water jet and accidental effect due to fire (Fig. 2.8). The most widespread cause of the spalling of concrete structures is corrosion of reinforcement. Chloride ions and carbon dioxide play an active role in this scenario. Inadequate clear cover and crack in concrete accelerate the corrosion process.

Carbonation occurs as a result of penetration of carbon dioxide from the atmosphere. In the presence of moisture this forms carbonic acid which reduces the alkalinity of the cement matrix. If the alkalinity fall bellow about P^H 10, the passivating layer is destroyed, in the presence of oxygen and moisture, the steel starts to corrode. Chloride induced corrosion of reinforcement occurs principally in older structures or in those which are exposed to the chloride containing materials such as sea water or de-icing salts. Chloride ions penetrate the concrete cover and break down the protective oxide layer around the reinforcements, thus depassivating the steel and permitting corrosion. As the corrosion proceeds, it not only results in significant loss of cross-section of the reinforcement but corrosion products may also cause the concrete cover to spall. Arya[4] has mentioned that cracks significantly reduce the service life of structures by permitting access of carbon dioxide, chloride, water and oxygen to the reinforcing steel. He also formulated the guide lines which will help identify those types that could potentially give raise to corrosion. During removing corrosion products it is necessary to measure the diameter of rebar. Replacement of steel is necessary if it has lost more than 20 percent of area but many specifies require replacement if more than 10 percent of the area is lost[6]**.** Sulphate attack is actually a rather complex process. Sulphate salts, when in solution, reacts with harden cement paste and accompanied by a very increase in solid volume, which causes a volume expansion, generates internal stresses and ultimately leads to cracks[15,17]. Sea water is composed of sulphate and chlorides of sodium and magnesium. The salts penetrate the concrete when in solution. As water is lost by evaporation, the salts begin to crystallize out. This form of attack occurs in concrete above the water line and particularly in the splash zone, where alternating wetting and drying occurs. This causes a build up of salt concentration and cycles of hydration of the salt crystals. This occur large force in concrete and exerted stress which can be sufficient to disrupt the concrete. Concrete is chemically basic, having a p^H of about 13 and therefore is attacked by acids, which have p^H

value less than 7. Concrete is not resistant to strong solutions of sulphuric, sulfurous, hydrochloric, nitric, hydrobromic, or hydrofluoric acids and will be destroyed by prolonged contact with any of these showing cracking and finally spall the concrete. Concrete is naturally alkaline (P^H 12.5 to 14) and the cement paste binder itself is not attacked by alkalise. Some sands and aggregates, however can react with alkalise either from the cement paste itself or from alkalise that penetrate the concrete from the surface and it may disintegrate the concrete[22].

The existing cracked or damaged or spalled concrete structures may require repairing to restore the structural integrity, to protect the reinforcement from sever weathering condition and the further crack propagation. For that purpose various types of materials and techniques had been used from the early age. Among these, patch repair is one of the oldest techniques and it is applied for the repair of spalled concrete. Patching is done using mortar, concrete, resin based mortar, sprayed concrete. The sprayed concrete is especially suitable for of those spalled concrete, which damaged due to fire. The sprayed technique itself originated in the U.S.A in 1907 and patented under the name 'Gunite' in 1910 by Allentown[3,27]. Choppola[8] has analyzed the properties of shrinkage-compensating mortar and highlighted how, to achieve successful repair of deteriorated concrete structures. It is composed of normal ingredients (water, cement and sand), water reducer, silica fume & expansive agents. Shrinkage-compensating mortars have high compressive strength and elastic modulus. The aim of these mortars was to eliminate problems caused by dimensional incompatibility which exists between old concrete substrate and repair materials. Nounu[20] has repaired the spalled beams using ordinary Portland cement and free flowing micro concrete and compared the load carrying capacity after repairing. For long-term situation, the beams repaired with free flowing micro concrete restored approximately 90% of its initial capacity whereas the beam repaired with OPC mortar restored 60-70%.

ACI Committee 224 1R-93[1] has discussed elaborately the types, causes, evaluation and repair of cracks in concrete. Arya[4] has mentioned that cracks significantly reduce the service life of structures by permitting access of carbon dioxide, chloride, water and oxygen to the reinforcing steel. The sealing of cracks of a concrete beam using epoxy was practiced by Allen[3]. NAHB Research Center, Inc[19] used low viscous, mixture of medium and high viscous epoxy for sealing cracks of slabs and stem walls.

In the last two decades the attempt on rehabilitation of damaged RC structures have been mainly concentrated into two methods, external post tensioning and the addition of epoxy bonded steel plate to the tension flanges. High strength steel strands are used in external post tensioning to increase the strength of damaged concrete structures[18].

An alternative to the post-tensioning method is the use of epoxy bonded steel plates. This method has been applied to increase the load carrying capacity of the existing structures and to repair damaged structures as well. Several cracks slabs and girders of the elevated highway bridges in Japan have been repaired using this method. A number of damaged concrete reinforced concrete bridges in Poland and erstwhile USSR have been repaired by bonding steel plates[18].

The use of composite materials represents an alternative to steel as it can avoid the corrosion of the plate. Fiber Reinforced Polymers (FRP) are one of the most common composite materials, which have been used for repairing as well as strengthening of reinforced concrete beams and columns[16]. He has used sprayed fiber reinforced polymer for repairing of pre cracked beams. The first repair work of a concrete bridge using carbon fiber composites laminates has been carried out at Ibach Bridge, Lucerne, Switzerland. The technique has been; largely investigated especially in Switzerland where existing structures have been retrofitted by epoxy-bonded composite materials[9].

However the effectiveness of repairing systems depend on the property of repairing materials, applying methods, property matching of old and new concrete, preparation of substrates and applying bonding agents. The properties of applied materials of old concrete should be as close as possible to protect the dimensional variation (creep, strain, drying shrinkage, coefficient of thermal expansion etc.) between old concrete and new concrete[24]. Especially for the case of sprayed concrete and epoxy injection, the quality of repair work depends on the experience of nozzle man. In recent years, durability problems, poor performance and, most of all, repair failure has tarnished the public image of concrete. Repair failure and endless "repair of repairs" make a substantial contribution to the current perception of concrete. Concrete often gets a bad name because premature repair failure is one of the most visible manifestations of poor design decisions and details, lack of quality construction practices and quality control; and the choice of repair materials (that may be incompatible with the exiting substrate). It is necessary to reconsider some recent viewpoints about concrete repairs if we wish to extend their service lives[24].

Repair materials: The International Concrete Repair Institute (ICRI) was founded to improve the durability of concrete repair and enhances its value structures owners. Concrete repair materials can be formulated to provide a wide variety of properties. Because the properties affect the performance of the repair, choosing the right material requires careful study. A repair material has value only when it permits an engineered product–a concrete structure-to fulfill its intended use, its function,[24]. In recent year, durability problem of the repaired structures is the major problem. The repair material should have such properties so that it can resist weathering action, chemical attack, abrasion or another process of deterioration. A durable concrete will retain its original form, quality and serviceability when exposed to its environment[15]. ICRI Technical Guideline Committee-03733[12] has described the selection process for the durable repair of reinforced concrete structures. The selection of the appropriate repair materials was based on its intrinsic properties as well as its compatibility between the repair material and the existing concrete substrates[13]. ACI Committee 224[11], ICRI[11], Tan[26], Allen[3] and Perkins[21] have discussed the various types of repair materials which have been recently used for the many successful renovation operations. According to them, materials can be classified in to cement based materials (Ordinary Portland cement grout, Nonshrink grout, Ordinary Portland cement mortar, Shrinkage compensating mortar, Hand applying concrete, Sprayed concrete or shotcrete and Free flowing micro concrete), Polymer mortar based materials (Light/medium weight polymer modified mortar, High strength polymer modified mortar), Polymer concrete based materials (Polymer concrete, Polymer Portland cement concrete, Polymer impregnated concrete), Organic polymer based materials (Epoxide resins, Polyurethanes, Polyester resins, Styrene, Butadiene), Composites materials (Fiber reinforced polymer, Sprayed fiber reinforced polymer composites). For concrete substrate and reinforcing bar priming, cement-mortar slurry, polymer resin and emulsion, Acrylic resin, Polymer modified cement slurry, Non passivating and Passivating epoxy are available.

Repair methods: The several methodologies had been shown to be feasible for repairing of existing cracked and spalled reinforced concrete beams. The brief discussion on repairing techniques of spalled and cracked concrete is as follows,

Substrate preparation: The first step of a repair work is substrate preparation. According to ICRI Technical Guideline Committe-03730[1] Tan[26] and Allen[3], before sealing cracks, the first step is to clean the cracks to the extent that is possible and practical. All loose aggregates, cement-based materials, soil inside of and adjacent to the cracked area, grease or other contaminations are removed by hand wire brushing, compressed air, flushing with water or other solvents. For repairing spalled concrete, all defects, loose or unsound concrete is removed or cut away along the length of the reinforcement up to 50-70 mm beyond the limit of corrosion. The concrete should also be removed a further 20-30 mm behind the repair zone. All edges should be cut to a minimum of 10 mm depth with a diamond cutter. Substrate shall be clean and free from dust. Particular care is necessary in the preparation of work that has been exposed to sea water or other aggressive liquids. The second step is to prepare reinforcing bars. Expose full circumference of the steel in areas to be repaired and it shall be mechanically cleaned to remove rust or loose mill scale. Where exposed reinforcement shows signs of corrosion deterioration, it shall be cleaned by grit blasting or other approved means. The replacement of steel is necessary if it has lost more than 20 percent of area but many specifies require replacement if more than 10 percent of the area is lost[6]. As soon as possible after preparatory cleaning has been completed and a sound surface obtained, the resin bonding agent is applied to all surfaces of concrete and steel to which the repair material is to be bonded and then, while the bonding agent is still sticky, the patching mortar or concrete is applied.

Patch repair process: This method is done for the repair of spalled concrete. If some concrete is removed from a structure, or has been become loose so that it has to be removed, it is usually necessary to restore the affected member to its original section and to provide adequate protection to any reinforcement that it may contain, is called the patching of reinforced concrete[3]. The patch repair process consists of the removal of damaged concrete, substrate and steel preparation and application of the repair materials. The removal of damaged concrete and steel preparation is discussed above. The application of the repair be through one of the following processes:

Hand applied mortar or concrete: This is suitable for patching of relatively small and isolated area. If a sufficiently large portion of concrete is removed, it can best be replaced with concrete placed in forms (Fig. 2.9, 2.10). US Bureau of Reclamation suggests that this method should be used, when the depth of repair exceeds 150 mm. After preparing surface, bonding agent is used prior to application of repair material. The mortar or concrete (cement based or resin based) should be mixed according to the manufacturer's instructions. The mortar is then worked around and behind the reinforcement by hand. The thickness of the layer built up and application procedure can vary greatly depending upon the material used and the orientation of the surfaced being repaired. A typical procedure is to apply layers of 25-50 mm thick for vertical work and 20-30 mm thick for overheads areas in each layer. Care should be taken when additional layers to ensure that the previous mortar has gained sufficient strength, but has not set. If the following layer is delayed then the surface can be scoured and dampened with water before the next layer is applied, or bonding bridge applied. The repair can be finished with a trowel using the surrounding concrete as a guide[5].

Recasting with mortar or concrete: This technique is usually most suitable for large-volume or where large areas of dense reinforcement present. Access of vibration is often a problem and so flowable grout and free flowing self-compacting micro concretes have been developed to minimize the vibration required. Where bonding agents are used the shutters and pouring sequence have to be carefully designed so that they can be rapidly positioned before the bonding agent dries. The concrete or mortar has to be carefully placed to avoid the entrapment of air. Pumping is usually employed although conventional

Fig. 2.9: R.C structures after deteriorated concrete has been cut away[3].

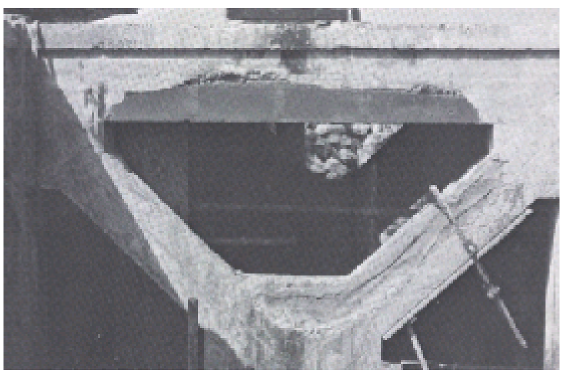

Fig. 2.10: Hand-applied mortars in progress[3].

Fig. 2.11: Cement gun[3].

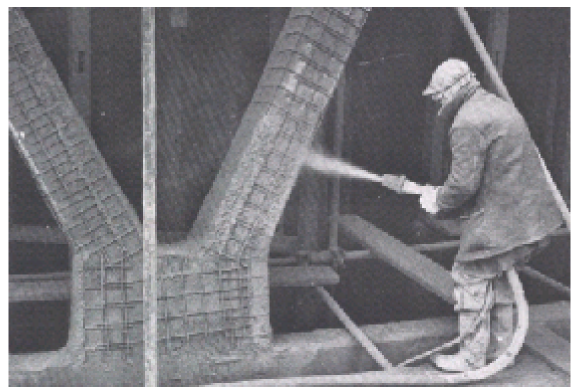

Fig. 2.12: Spraying concrete on surface[3].

'letter box' type shutter can be used on smaller pours. When pumping is used, the delivery hoseshould be at low position in the pour to allow the air to be displaced[5].

A large portion of patch repairs may fail in long term due to property mismatch of old and new concrete or anticipant anode phenomenon, requiring further repair. The durability of patch repair greatly depends both on its adherence to the substrate concrete and the protection it can afford to the steel reinforcement against corrosion. It must therefore physical and chemical properties are consistent with the substrate concrete and with the design and use of the structure to which it is applied[20]. It is difficult to maintain it during the repair work. Another draw back of patch repair is color matching between old and new concrete. For mortar repair, shrinkage is the main problem. Due to shrinkage, a hair crack occurs along the interface of patching material and old concrete. For resin based repair, it is not possible to match the color.

Repair using sprayed concrete, shotcrete or gunite: The name 'Gunite' was originally a trade mark, but it has now become accepted as a general term for spray-applied concrete. In the USA it is known as 'Shotcrete[3]. According to ACI definition; "Shotcrete is a mortar or concrete pneumatically projected at high velocity into a surface'. The method of placing concrete or mortar with high velocity is called shotcreting. The shotcrete machine or gun (Fig. 2.11) is used for shotcreting. Sprayed concrete has been widely used in many applications, including: bridge soffits, beams, concrete damaged by reinforcement corrosion, parapets and abutments, steel and reinforced concrete buildings, industrial chimneys, cooling towers, tunnel linings, cathodic protection over layers, water-retaining structures, jetties, sea walls and other marine structures. Shotcreting is not generally an economical process for repairing isolated member. If they are less than about 100 mm wide, too much material will be wasted even if a small nozzle is used[3]. There are two processes for applying shotcrete. One is dry-mix and another is wet-mix shotcrete. The use of dry-mix shotcrete is common and it has been used for about 90 years, while wet –mix shotcrete has been in use about half that long. This is due to fact that many repair jobs involve small quantities of dry-mix shotcrete and most wet-mix guns are designed for high production[23].

Surface to which shotcrete is to be applied must be prepared and wetted before applying shotcrete (Fig. 2.12). For thin repairs (say 25 mm or less) in relatively small areas, a light wire reinforcing mesh should be pinned to the prepared surface. Before applying shotcrete, adjacent sheets of mesh being lapped at least 100 mm. The adequate curing of sprayed concrete is essential as its relatively high cement content, low water/cement ratio. This method is especially suitable for fire damaged structures. If the water/cement ratio is properly maintained, the shotcrete adheres strongly to sound concrete surface because of the high velocity. The inner layers are compacted by the force of subsequent gunite striking them, so a dense, well-compacted covering can be built up. Minimum amount of form work is required, the ability to stick to vertical and overhead surfaces, the ability to produce varied and unusual shapes and the ability to placement in areas of different access, all make the shotcrete versatile material for concrete repair. If the mixture is too dry, a large amount of material will rebound from the concrete substrate. For good repairing, special nozzle man required to prevent inclusion of rebound and to completely encapsulate the reinforcing bar. Another draw back is that, it is not suitable for a small patch because of wasting too much material even a small nozzle is used.

Repair using dry-pack mortar : Dry-pack is suitable for filling holes of depth at least 25 mm. Dry-pack mortar is usually a mix of one part-Portland cement to 2.5 times of fine sand, which passes through the 1.18 mm screen. Sufficient water is added to produce a mortar that will stick together while it is being mounded in to a ball in the hands. The whole should be prepared as that they are sharp and square at the surface edges but corner within the holes should be rounded. Most dry-pack repair the surface should be dry. Immediately before starting to place the dry-pack, the surface should be brushed with a 1:1 cement-fine sand bond coat, which has been mixed to a fluid past. Dry-pack should be packed in several layers which have a compacted thickness of about 10 mm. One layer may be placed immediately after another. Each layer should be solidly compacted over the entire layer by a hard wood stick and hammer. Water curing at least 24 hours, is essential[6].

Repair using prepack: Preplaced aggregate concrete, sometimes referred to as prepacked concrete or prepack, is made by forcing cement grout into the voids of a compacted mass of course aggregate. Prepack is especially adaptable to underground construction and repair. Where it is difficult to place conventional concrete, especially where air would easily be trapped with conventional concrete procedure, it is suitable. Prepack contains a higher portion of coarse aggregate and this aggregate is in point-to-point contact as placed. Drying shrinkage is therefore one-half that of conventional concrete made from the same material. Prepack has better bond with old concrete than is found with conventional concrete repair. Resistance to freezing and thawing can be achieved by air entraining in the grout. The prepacked aggregate, which must be cleaned and well-graded, is washed and screened to remove fines immediately before it is placed and compacted. The aggregate surface must remain moist while grout is being injected as otherwise water will be absorbed from the grout and incomplete filling may occur[6].

Methods of repair cracks in concrete: ACI Committee 224 1R-93[1] has presented the twelve methods of crack repair depending upon their characteristics, including the techniques, advantages and disadvantages and areas of application of each. An appropriate method of crack repair depends on whether the crack is still actively moving or not. If some small movement presents at the crack, it may be possible to restrain this movement by bonding with epoxy, providing the resultant stress does not exceed the strength of the concrete, which is being bonded[21]. The cracks, which are not actively moving, can be repaired, depending upon the width of cracks. For cracks up to 0.5 mm wide, there is generally no needed to cut out the crack. The recommended procedure is to tap lightly along the crack with a chisel, clean out all grit and dust with compressed air and then brush into the crack cement latex grout, or a polymer resin[21]. Cracks, which are not active and maximum width of crack is about 20 mm, can be repaired by mortar[6]. For wider cracks, particularly when the edges have spalled, the crack should be cut out. After cutting out, the crack should be carefully cleaned. If cement/sand SBR latex mortar is used, it is advisable to wet the crack overnight and to cure the mortar for four days, starting 24 h after completion[21].

According to ACI Committee 224 1R-93[1], cracks as narrow as 0.05 mm can be bounded by the injection of low viscous epoxy. The techniques generally consist of establishing entry port and venting ports (Fig. 2.13-2.16) at close interval along the cracks, sealing the cracks on exposed surface and injection the epoxy under pressure. Epoxy injection has been successfully used in the repair of cracks in buildings, bridges, dams and other type of concrete structures.

Epoxide resin has very strong adhesion to sound surface, strength resistance to chemical attack and impermeability. This method is expensive but labor cost usually makes up by far the greater part of the cost of repair work and this method is suitable for quick repairing. The repair by epoxy is suitable for direct tension zone area, but strength under bending or shear is relatively low. This method is very much more expensive than cement based repair. Where access to the work is difficulties, this method is not suitable and all epoxide resins are very weak to fire[3].

External post tensioning and Epoxy bonded steel plate: High strength steel strands are used in external post tensioning to increase the strength of damaged concrete structures. The main obstacle faced in this method is difficulty in providing anchorage in post-tensioning strands. The lateral stability of the girder may become critical due to post-tensioning. Moreover, the strands are to be protected very carefully against corrosion. An alternative to the post-tensioning method is the use of epoxy bonded steel plates. This method has been applied

Fig. 2.13: Insertion entry ports for cracked slab specimen[19].

Fig. 2.14: Surface seal paste and ports along the crack plane of a typical slab specimen[19].

Fig. 2.15: Automatic metering, mixing and dispensing device used in a cracked slab specimen[19].

Fig. 2.16: Caulk gun used manually dispense the epoxy mixture in cracked slab specimen[19]

Fig. 2.17: Spray gun[16].

Fig. 2.18: Application of SFRP[16].

to increase the load carrying capacity of the existing structures and to repair damaged structures as well. Several cracks slabs and girders of the elevated highway bridges in Japan have been repaired using this method. The steel plate reinforced beam increases the allowable load on the structures and delay the usual cracks. The disadvantages of steel plate are that considerable corrosion takes place in steel plates with natural exposure causing a less of strength at the interface. Handling of heavy steel plates for long span beams can be very difficult problems were faced in forming clean butt joints in steel plates at small intervals, In addition, they also reported the possibility of high corrosion at the steel epoxy interface[18].

Repair using composite materials: The use of composite materials represents an alternative to steel as it can avoid the corrosion of the plate. FRP are composed of unidirectional fibers (Primarily glass and carbon) in an environmentally durable epoxy resin. FRP have desirable engineering properties (e.g., high strength and stiffness, low density, long fatigue life and high resistance to corrosion) and offer great potential for cost effective retrofitting of concrete structures. Among these, continuous fiber-reinforced laminates have been widely used to strengthen and repairing concrete beams and columns[16]**.** The price of these materials, specially of Carbon Fiber Reinforced Plastics (CFRP), could represents a draw back but the ease in handling the materials on construction sites, due to the light weight, helps to reduce labor cost[9]. The technique has been; largely investigated especially in Switzerland where existing structures have been retrofitted by epoxy-bonded composite materials. The composite materials, which have been recently used, are as follows:

Fiber reinforced polymer (FRP composites): The first step is grinding the beam surface, which is to remove the outer weak surface of the concrete. Flap disk are used in this beam grinding procedure. The second is washing the repaired surface with acetone to clean the surface before a layer of resin primer is applied on the surface. The surface is wiped over with acetone just before application of FRP materials. The reason for this is to remove the carbonization layer of the hardened primer. The one layer of epoxy was painted on the surface followed by a layer of FRP material. Secondly, before the application of the second layer of FRP, another layer of resin was painted on the face of the previous layer. These processes are repeated for all layers until the last layer of material are applied. Then the fibers are cut with scissors and a layer of resin was applied on the surface of the last bandage layer[10].

Sprayed fiber reinforced polymer (SFRP composites): SFRP consist of randomly oriented chopped fibers of controlled length in a polymer matrix. For the application of the SFRP, a spray gun with a chopper unit and epoxy containers are needed and these equipments have been used in the boat building and automotive industries for some time. SFRP are produced by combining the stream of resin from a spray gun with the chopped fibers from a chop gun. After spraying the fiber/resin mixture on the concrete surface to the required thickness, a ribbed aluminum rolled is used to roll out any entrapped air[16]. Banthia[27] indicated that the FRP wrapped specimen produced a 33% increase in the ultimate load over the un-retrofitted specimen while the SFRP.

Conclusion: Repairing of reinforced concrete beams is one of the important works normally associated with the rehabilitation of concrete structures. The reinforced concrete structures deteriorate due to several internal, external, physical and environmental effects and there by reduce their load carrying capacity. It is possible to restore the load carrying capacity up to a certain limit. Recently the repairing cost is gradually increasing with increasing of construction. It is important to make sure the bonding between old concrete and the applied materials and this purpose several bonding agents are used just before applying the repairing materials. Different types of repairing materials are available such as grout, mortar, concrete, sprayed concrete, resin based material and externally bonded steel plate and composite materials. Among these, cement based materials are more suitable. The effectiveness of a repair work depends upon the quality of material, implementation techniques and finally the work to be carried out by the experienced operators, working under experienced supervisors who full understand the reasons behind the techniques that are being used.

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REFERENCES

1. ACI Committee 224 1R-93 1998. Causes, Evaluation and Repair of Cracks in Concrete Structures. Concrete Repair Manua, 2nd Edn. Published jointly by ACI International, Building Research Establishment, Concrete Society and International Concrete Repair Institute in the year 2003, ISBN: 0-87031-105-0. Vol. 1. 1: 485-550.
2. Al-Dulaijan, S.U., M.M. Al-Zahrani, H. Saricimen, M. Maslehuddin, M. Shameem and T.A. Abbasi, 2002. Effect of rebar cleanliness and repair materials on reinforcement corrosion and flexural strength of repaired concrete beams. Cement and Concrete Composite, 24: 139-149.
3. Allen, R.T.L., 1974. The repair of concrete structures. Cement and Concrete Association, London SWIW 0AQ.
4. Arya, C. and L.A. Wood, 1995. The Relevance of Cracking in Concrete to Corrosion of Reinforcement.. Concrete Repair Manua, 2nd edn. Published jointly by ACI International, Building Research Establishment, Concrete Society and International Concrete Repair Institute in the year 2003, ISBN: 0-87031-105-0. Vol. 1: 553-584.
5. ACI International, BRE,Concrete Society and ICRI. 2003. Guide to the Maintenance, Repair and Monitoring of Reinforced Concrete Structures. Concrete Repair Manual, 2nd Edn, May. ISBN: 0-87031-105-0, 1: 691-736.

6. Cambel-Allen, D. and H. Roper, 1991. Concrete structures: Material, Maintenance and Repair. Concrete Design and Construction Series. 1st edn. New York.: John Wiley and Sons pp: 58-101, 118-120, 139-151, 243-285.
7. Celebi, Dr. M. Professor of Civil Engineering, Middle East Technical University, Ankara, Turkey. Research on Exopy Repaired Reinforced Concrete Beams.
8. Choppola, L. 2000. Concrete Durability and Repair Technology. ENCO Engineering and Concrete Spresiano (TV).
9. David, E., C. Djelal and F. Buyle-Bodin, 1998. Repair and Strengthening of Reinforced Concrete Beams Using Composite Materials. 2nd Int. PhD Symposium in Civil Engineering, Budapest.
10. Hadi, M.N.S., 2003. Retrofitting of shear failed reinforced concrete beams. Composite Structures, 62: 1-6.
11. ICRI Technical Guideline Committe-03730, 1996. Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion. Concrete Repair Manual, 2nd end. Published jointly by ACI International, Building Research Establishment, Concrete Society and International Concrete Repair Institute in the year 2003, ISBN: 0-87031-105-0, Vol. 1, pp: 916-921.
12. ICRI Technical Guideline Committee-03733, 1996. Guide for Selecting and Specifying for Repair of Concrete Surfaces. Concrete Repair Manual, 2nd edn. Published jointly by ACI International, Building Research Establishment, Concrete Society and International Concrete Repair Institute in the year 2003. ISBN: 0-87031-105-0, Vol. 1, pp: 835-912
13. Kenai, S. and Bahar, R.(2003). Evaluation and repair of Algiers new airport building, Cement and Concrete Composites, 25: 633-641.
14. Kovács, T., 2000. Deterioration of Reinforced Concrete Repair Mortar Layers. Periodica Polytechnica Ser. Civ. Eng., 44: 197–206.
15. Kum, W. and Tham, 1992. Durability of Concrete Structures. Continuing Educational Workshop on Rehabilitaton and Repair of Structures, IEB, Malaysia, 16th to 17th April.
16. Lee, H.K. and L.R. Hausmann, 2004. Structural Repair and Strengthening of Damaged R.C Beams with Sprayed FRP. Composite Structures, 63: 201-209.
17. Macginley, T.J. and B.S. Choo, 1990. Reinforced Concrete, Design Theory and Example, 2nd Edn. London SE1 8HN, UK. E & FN Spon, an imprint of Chapman and Hall
18. Mukherjee, A. and M. Joshi, 2000. Recent Advances in Repair and Rehabilitation of RCC Structures with Nonmetallic Fibers.
19. NAHB Research Center, Inc., 2000. Testing and Assessment of Epoxy Injection Crack Repair for Residential Concrete Stem Walls and Slabs-On-Grade.
20. Nounu, G. and Z. Chaudhary, 1999. Reinforced Concrete Repairs in Beams. Construction and Building Materials, 13: 195-212
21. Perkins, P.H., 1976. Concrete Structures: Repair, Waterproofing and Protection..London, ISBN: 0 85334 697. Applied Science Publishers LTD.
22. Prichard, B., W.S. Atkins and England, 1992. Concrete Deterioration. Continuing Educational Workshop on Rehabilitation and Repair of Structures, IEB, Malaysia, 16th to 17th April.
23. Rutenbeck, T., 1999. Repairing Concrete with Shotcrete. Bureau of Reclamation, TSC, Civil Engineering Services. Metal Engineering and Research Laboratory. Denver, Colorado.. R -90-10.
24. Vaysurd, M., P.H. Emmons and N.P. Mailvaganam, 2004. Concrete Repair Technology- A Revised Approach Is Needed. The Magazine of American Concrete Institute. Concrete International.Vol. 26 No. 1.
25. American Concrete Institute Publication, 1976. Shotcrete for Ground Support. Proceedings of the Engineering Foundation Conference Tidewater Inn. Easton, Maryland, October 4-8.
26. Tan, H., 1992. A systematic Approach to Concrete Repair. Continuing Educational Workshop on Rehabilitation and Repair of Structures, IEB, Malaysia, 16th to 17th April.
27. Banthia, N., N. Nandakumar and A. Boyd, 2002. Sprayed Fiber-Reinforced Polymers: Fromlaboratory to a real bridge. Concr Int. pp: 47- 52.