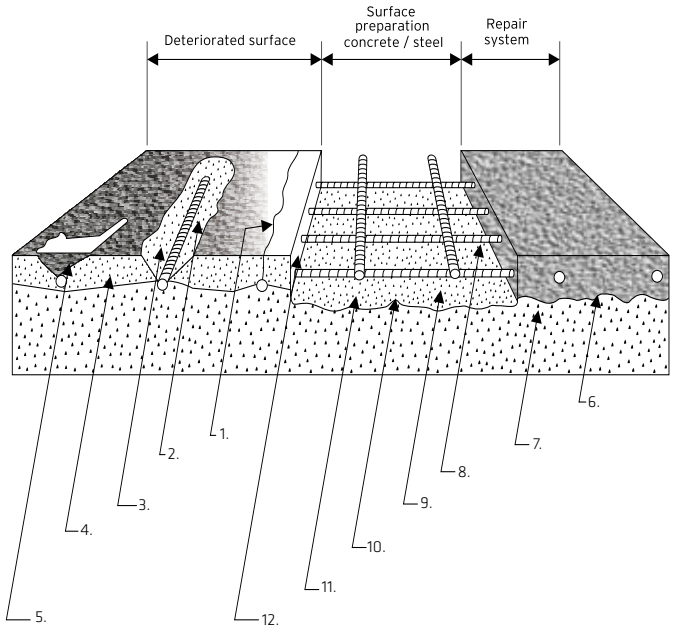
Rebar Corrosion Crack Repair

[Excerpts from Dr. Fixit Guide to Healthy Construction, Cracks & Crack Repair (Unpublished)]

1.0 Introduction

Cracks that run directly over reinforcing bars in such a position that they could not have been caused by shrinkage, plastic settlement, or thermal contraction, must have been caused by build up of rust forming on the reinforcement. These cracks are a symptom of deterioration which will eventually lead to spalling and complete loss of cover. Horizontal surface repair is common on slabs either elevated or on grade. Deterioration may be caused by corrosion of embedded reinforcement resulting in delamination and spalling. Other common causes include deterioration due to carbonation and chloride ion ingress and chemical attack. After an evaluation of the deterioration by an engineer, a plan should be developed including objectives and specifications for the repair. Steps for repairs that include layout, removals, edge preparation, mixing, bonding, placement, and curing have been included below as a step-by-step guide for use by field personnel (Fig. 1).



1. Crack
2. Heavily corroded reinforcing bar
3. Spall
4. Contaminated concrete with caddies or carbonation
5. Delamination
6. Durable repair material
7. Bonding new to old
8. Reinforcing steel protection
9. Reinforcing steel cleaning
10. Concrete surface conditioning
11. Removal of contaminated concrete undercutting of exposed reinforcing sheet
12. Edge conditioning

Fig. 1: Schematic diagram showing rebar corrosion crack repair

The purpose of spall repair is to repair deteriorated concrete, repair damaged reinforcing steel, and replace the lost concrete section. This method should be used for repairing spalls on horizontal surfaces such as structural slabs, exterior slabs on ground, balconies, and interior floors.

Damage of concrete due to corrosion cannot be treated without removing and renewing the concrete cover. The step by step approach for corrosion crack repair is given below.

1.1 Removal of Damage Concrete

The repair areas should be clearly defined and marked. All loose and damaged concrete should be broken to sound dense subsrtate. The edges at the periphery of repair should be saw cut to minimum 10 mm depth to avoid feather edging. The removal of concrete cover which constitutes the major damaged portion in a structural element to be repaired becomes essential at a time when the reinforcement is rusting enough to crack the concrete (Fig. 1 i). The cover is cut away to the level of reinforcement and usually up to 20 mm beyond it.

Fig. 1i : Breaking and removing damaged concrete

A method, hydro-demolition, (removing concrete with high pressure water jets), helps greatly in removing the bulk of the concrete behind the reinforcement. It offers dust free operation and produces the cleanest surface ready to receive new concrete. The removal of cover can also be carried out using power hammers which are cheap to use and widely available. However, if not kept properly sharpened, they suffer from the disadvantage of shattering aggregate which does not get removed. Power hammer and jack hammer can be justified for initial chipping and removal of large quantities of concrete. Final chipping to be done with light hand held hammer to avoid damage to the structure. Cutters are also used for removal of damaged concrete. The profile at edge of repair is prepared.

In the case of reinforcement corrosion, concrete removal must be carried out to a depth that includes all the affected reinforcement and leaves some room for replacement behind it as well. Concrete is usually specified to be removed around all exposed reinforcing

bar so that a distance of at least 20 mm popularly known as a finger gap is removed around each bar. This allows better cleaning of reinforcing bar and repair material to coat the entire perimeter of the bars. When carbonation is the cause of the problem, and carbonated concrete in contact with the reinforcement has to be removed. If the corrosion takes place due to chloride contamination, there are two cases to be considered. Firstly, if enough chloride contamination to cause corrosion comes from the original mix, any amount of further removal would not give complete protection as chloride can spread from contaminated concrete into new concrete. Hence if the new concrete is of sufficiently high quality, it is likely to provide protection to the reinforcement for a very long time. Secondly, if the chloride contamination is from an external environment, the chloride concentration would decrease as the distance from the surface increases and at some depth would be insignificant. Hence in this case, it is possible to remove the contaminated concrete altogether and replace it with highly impermeable concrete.

1.2 Surface Preparation

Once the unsound concrete has been removed, the existing surface may need further preparation to provide an appropriate platform for the repair. Surface preparation should include removal of dust particles and loose material by pressure washing, high pressure air or light abrasive blasting. An important aspect of surface preparation is wetting the concrete prior to application of cementitious repair materials.

When the affected concrete has been removed, the reinforcement is inspected and cleaned. This is carried out by water jetting or wire brushing. Water jetting is the best method of removing chlorides from the pits in rusting reinforcement.

Sand is introduced into water jets to provide sufficient abrasion to clean the steel properly. While cleaning reinforcement, it must be ensured that the rust deposited on the blind side of the reinforcement is completely removed. Sand blasting is also another method of cleaning the steel. After water jetting and wire brushing, the reinforcement is washed with potable water to remove all contaminants in the vicinity of the reinforcement. Phenolphthalein is being sprayed to find out the carbonation. If pink colour turns to white then carbonation is there. Rust remover is also being used for cleaning corroded reinforcement.

1.3 Addition of Reinforcement

If rusting has reduced the cross-sectional area of the reinforcement by more than 20%, extra reinforcement is provided before the repair is made good. When the loss of section is under 10%, no added steel is needed. When between 10% and 20% of bar section in lost, the answer requires some judgment and analysis. The usual method of adding reinforcement is to lap the weakened bars with additional bars or spliced by welding to restore the original cross-sectional area. In some situations, reinforcement is also added by drilling into the concrete or polyster and bonding new bars into the drilled holes with epoxy or polyster resin.

1.4 Coating on Reinforcement

Once the reinforcement has been cleaned, it is coated with zinc rich primer which provides active galvanic protection to steel (Fig. 1 ii). The zinc thus acts as a sacrificial anode and in addition to protecting the steel in the repair area; it corrodes in preference to adjacent steel thereby protecting it from further immediate corrosion. In addition to zinc primer, epoxy resins are also used to coat reinforcement especially in very aggressive environments.

The coated film should have a minimum dry film thickness of 40 microns. The film shall be continuous especially in the regions where pitting, imperfections etc., are present on the surface of the bars. It is important that the rear portion of the bars should not be left without coating. A second coat if needed may be provided to achieve a uniform and continuous film. The additional reinforcement provided and also the shear connectors shall be coated with epoxy zinc primer. The weld mesh if provided shall also be coated with epoxy zinc primer.

Fig. 1 ii: Priming the steel with zinc epoxy primer after rust removal

1.5 Application of Bonding Agent

Bonding agent is applied on the prepared concrete surface for better bonding of new concrete with substrate. When repair mortar is used as repair material, it should be used in, layer of 25 to 30 mm thick and bonding coat is applied on each layer.

The epoxy based bonding agent is most suitable as bond coat for structural repair. The base and hardener component of epoxy resin based bonding agent must be mixed well to get a uniform grey coloured mix. Apply the material to properly cleaned and dry concrete substrate using stiff nylon brush by scrubbing it well into the substrate. The coat should be uniform and well spread on the entire surface area of the repair patch. The mixed

material must be applied before the elapse of its pot life and the new repair mortar must be applied before the elapse of overlay time. As a fully dried epoxy resin coat acts as debonding layer, the repair material should be applied whilst the bonding coat is tacky. In case the applied epoxy bond coat gets dry, an extra coat should be applied before application of repair mortar.

1.6 Replacement of Concrete

The areas of concrete which have been cut away can be made good in the following ways: Patch repairing i) with cementitious mortar ii) with polymer modified repair mortar and iii) with resin mortar.

Polymer modified mortar/concrete is being applied tightly by hand trowel on prepared surfaces. (Fig. 1iii). Then the excess of materials are being striked out (Fig. 1 iv) and repaired area is finished with a trowel (Fig. 1 v). Finally the repaired area is cured with a curing compound.

Fig. iii: Application of polymer mortar

Fig. 1 iv: Striking of excess material

Fig. 1 v: Finishing with a trowel

The patch repair of a beam starting from surface preparation, cleaning, application of epoxy bonding agent and the additional reinforcements provided shown in (Fig. 2.i). The polymer mortar is placed by hand and followed by application of bonding agent on concrete surface for application of final layer of polymer mortar. The surface is finished by trowel.

Fig. 2i : Bonding agent applied

Fig. 2ii : Bonding agent applied for finishes

Fig. 2 iii : Finishing of patch repair

The other replacement of concrete for repair: Spraying new concrete for building more thickness and recasting (Fig. 3) and recasting with polymer modified concrete (Micro concreting).

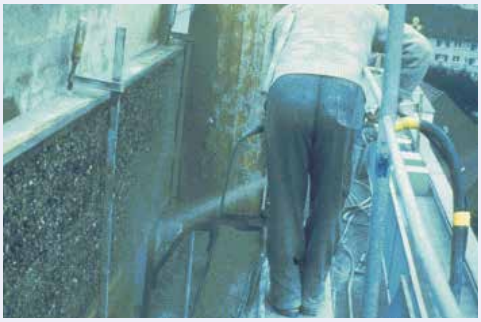


Fig. 3 : Spray concrete

1.7 Recasting with Polymer Modified Concrete (Micro Concreting)

Micro concrete is a free flow, self compacting with high early and final compressive strength used where hand applied PMM (polymer modified concrete) is not possible due to inaccessible and congested reinforcements. There are certain advantages of using micro concrete over normal concrete.

These are: flow-able grade micro concrete reaches in all corners easily as it can be used even without using vibrators. Use of epoxy based bonding agent provides better bonding with substrate. It provides more impermeable concrete. Curing time is reduced to great extent. When micro concreting is used, formwork should be very rigid without any leakage in shuttering. If there is enough repetitive work to justify the cost, permanent formwork of glass reinforced plastics can be useful in some applications. Pourring of micro concrete is made through a funnel or a hopper.

It can be applied for sections up to maximum 100 mm thick and addition of pre-calculated aggregates may be required if thickness is more than 100 mm. The step by step approach right from mixing to pouring of microconcrete are shown in (Fig. 4 i – v).

1.8 Formwork and shuttering

Slurry tight and strong form work shall be provided for micro concreting. The shuttering for encasement shall be kept ready such that the formwork shall be placed in position and fixed such that the micro concrete can be poured into the formwork within the overlay time of the bonding agent (5 hours). Adequate supports shall be provided for the formwork. Care should be taken to ensure leak proof shuttering. Under no circumstance the slurry should flow out of the shuttering during pouring of micro concrete.

Mixing of micro concrete: It should be mixed using the appropriate water powder ratio as mentioned in the product data sheet. The mixing shall be done mechanically and under no circumstance hand mixing shall be done. Mixing shall be carried out for 3 to 5 minutes to ensure that homogeneous mix is obtained without any bleeding or segregation. In hot climate ice cooled water shall be used to maintain the temperature of mixed material. If the encasing thickness is more than 100 mm, add stone aggregates up to 50 % by weight of micro concrete to the mixed micro concrete directly into the mixer hopper. The stone aggregates must be 12 mm and down and shall be clean, washed and dried. The mixing should be done for 3 minutes in mixer and then pre weighed stone aggregates into the mixer. Mix further for 2 minutes till lump free mix is obtained.

Deshuttering: The shuttering from the sides of the R C members shall be removed after a period of 24 hours. However, the formwork of the soffit shall be retained and removed after 3 days.

Pouring of micro concrete: The mixer should be poured into the formwork using a suitable funnel or through a hose pipe. It must be poured from one end only. A suitable hopper / funnel arrangement shall be made at site to facilitate the pouring operations. The pouring operation shall be continuous and it shall not be stopped unless the job is completed. To achieve this sufficient mixers / drilling machines and wok force shall be arranged at site.

Curing: All the repaired and encased area shall be fully cured as per standard concrete practices. Curing compound shall be used for effective curing of sides and soffits of beams. If a curing compound is applied, care shall be taken to ensure that proper surface preparation is carried out so as to remove any traces of curing compound on the surface. If this is not done, it may lead to debonding of any protective coating applied on top.

Fig. 4 i : Micro concrete for repair of a congested beam

Fig. 4 ii : Micro concrete for repair of a congested beam

Fig. 4 iii : Micro concrete for repair of a congested beam

Fig. 4 iv : Repair done by micro concrete

2.0 Bill of Quantities (BOQ) of Structural Repair

A standard bill of quantities of concrete structural repair is given in table below for a reference.

Sr.	Description	Unit
1.	Dismantling & Surface Preparation	
1.1	Dismantling and removing damaged core concrete by manually/ mechanically means in columns,beam,roof slab,chajja, lintels, etc complete including disposal of unserviceable debris	Cum
1.2	Diamond wire saw cutting making profile at edges and avoiding feather edges(measurement to be made on cut cross section of the area of surface).	Sqm
1.3	Hydro-demolition cutting with high-pressure water jetting of 80 – 240 MPa (measurement to be made on cut cross section of the area of surface).	Sqm
1.4	Chipping of loose concrete from surface to expose sound concrete beneath using light chisel & hammer & also preparing concrete surface to receive further treatment, disposing the unserviceable debris	Sqm
1.5	Sand blasting for cleaning of reinforcement and chipped surface of concrete so as to cause an intense abrading of the reinforcement and removal of rust from entire surface of reinforcement to achieve shining bright surface	Sqm
1.6	Reinforcement Cleaning: Cleaning reinforcement of total rust by tapping or using wire brush or any other suitable way including from behind and around the reinforcement bars to give it a totally rust free finished steel surface (measurement to be made on repair surface area).	Sqm
1.7	Rust remover of Dr. Fixit Rust Remover/equivalent: Providing and applying approved chemical rust remover with paint brush on corroded rebar and removing loose particles after 24 hours of its application and washed with sufficient quantity of water to make rebar free from corrosion (measurement to be made on repair surface area).	Sqm
1.8	Surface preparation to remove all dust, dirt, loose rust scales etc., with wire brush, emery papers, rotary wire bristle brushes and grinding (if required) to the concrete surfaces to receive further repair treatment	Sqm
Repair & Strengthening		
2.1	Fixing new reinforcement: Providing & fixing new reinforcement of various diameters as required at site in the form of mild steel and /or steel confirming to Fe 415 and lapping,welding,anchoring suitable to the old reinforcement including cutting, bending with all tools & tackles etc. complete as per direction of Engineer-in-charge	Kg
2.2	Shear keys: Providing and fixing 'L' type shear keys using 10mm diameter TMT bars after drilling holes of 12 mm diameter and minimum 100mm depth on the concrete substrate & 75 mm outside @ 500 mm c/c on all the faces of repaired surfaces in staggered form, cleaning and grouting the holes with approve polyester resin anchoring grouts of Dr. Fixit Anchorfix P/equivalent. Item rate is inclusive of the material, all labours, supervision, tools and tackles, transportation etc., complete as per direction of Engineer-in-charge.	Nos
2.3	Fixing GI weld mesh: Providing and fixing GI weld mesh (4" x 4" x 12 gauge) with 30 cm lap at junction, one layer around the cross section of beams and along the span length completed complete as per specification and as directed by Engineer-in-charge.	Sqm
2.4	**Anti-corrosive Treatment to steel:** Providing and applying approved epoxy zinc rich anti-corrosive coating of 40 micron dry film thick/approved thickness of Dr. Fixit Zinc Rich Primer/ equivalent to the exposed reinforcing bars after application of rust remover, on the shear connectors/welded mesh/additional reinforcement of entire concrete repair surface. Testing method of anti-corrosive treatment should pass the requirement of BS 6920/equivalent (Bond Strength). (measurement to be made on repair surface area) complete as directed by Engineer-in-charge.	Sqm
2.5	**Non-structural bonding:** Mixing and applying approved SBR/Acrylic polymer modified cementitious bond coat of Dr. Fixit Pidicrete URP/ Dr. Fixit Pidicrete MPB/equivalent to meet the requirement of ASTM C:952/equivalent, on prepared non-metallic / cleaned concrete surface with specified proportion of polymer to weight of cement as per specification etc. complete as directed by Engineer-in-charge.	Sqm
2.6	**Structural Bonding:** Providing and applying approved two components epoxy bond coat of Dr. Fixit Epoxy Bonding Agent/equivalent to meet the requirement of ASTM C:882/equivalent on the prepared surface to receive new polymer mortar / polymer modified concrete. Laying of reinstatement polymer mortar or micro concrete	
	shall be completed within the overlay time of bonding agent between old and new concrete. Item rate inclusive of all materials, labours, supervision, tools, tackles, transportation, fixing etc., complete as per specification and as directed by Engineer-in-charge.	Sqm

2.7	**Site mixed PMM treatment:** Providing, mixing by mechanical means and applying cement mortar mixed with Dr. Fixit Pidicrete URP/equivalent approved polymer modified cement mortar in layers having 28-days tensile strength to meet the requirement of ASTM C 190, each layer not exceeding 20 mm thick, up to 50 mm thick with a bond coat at 2nd layer, including trowelling with wooden tools etc. (Pre-measurement of average thickness shall be done before laying of repair mortar). Polymers shall be mixed in approved proportion or as specified and applied while bond coat is still tacky and as per direction of Engineer-in-charge.	Sqm
2.8	Single part PMM treatment: Providing and laying of approved polymer modified single component,fibre reinforced, shrinkage -compensated, cementitious patch repair mortar of PAGEL U40/equivalent having 28-days tensile strength to meet the requirement of ASTM C 190 and compacting the same around the rebars and finishing with trowel up to 40 mm thick (Pre-measurement of thickness shall be done before laying of repair mortar) after applying bonding coat while in tacky(bonding coat shall be payable separately), complete as per specification and as directed by Engineer-in-charge.	Cum
2.9	High-build polymer modified mortar: Providing & applying approved single component ready to use structural grade high build polymer modified repair mortar of Dr. Fixit Polymer mortar HB / equivalent having 28-days tensile strength to meet the requirement of BS : 6319 : part 7on prepared concrete surface for a maximum 50 mm thick as per specification and as directed by Engineer-in-charge.	Sqm
2.10	**Form work:** Providing, fixing 100 % water tight shuttering (form work) using film coated 12 mm thick plywood sheets brush applied with Dr. Fixit Deshuttering Oil/equivalent for micro-concreting to the structural members in line and level with proper prop supports inclusive of all materials,labours, tools, tackles, transportation, fixing etc. and removing as per specification and as directed by Engineer-in-charge.	Sqm
2.11	Circular Formwork: Providing, fixing 100% water tight circular steel shuttering brush applied with Dr. Fixit Deshuttering Oil/equivalent for the jacketing work in line & level with proper supports, etc. complete and removing as directed by Engineer-in-charge.	Sqm
2.12	**Micro-Concreting:** Providing concrete of Dr. Fixit Micro Concrete/ equivalent mixing approved polymer modified micro-concrete blended with washed, saturated surface dry (SSD), graded, low absorption, high density aggregates of size 10mm & below and water at 4 litres per 25 kg bag and pouring through hopper / funnel arrangement into the leak-proof shuttering formwork for concreting having properties of free-flowing, self-leveling , self-compacting and high early strength having 28-days tensile strength of 5-10 MPa to meet the requirement of BS : 6319 : part 7/equivalent and compressive strength of 30-60 MPa and ensuring proper bond between the micro concrete and existing concrete substrate	
	to meet the requirement of ASTM C:882/ equivalentand complete as per specification and as directed by Engineer-in-charge. (Form work will paid in separate item).	
	a) Up to 50 mm thick without addition of any aggregate in to the micro-concrete	Sqm
	b) 50 mm thick admixed with 10 mm down cleaned washed aggregates @ 50% by weight of micro-concrete.	Sqm
	c) 75 mm thick admixed with 10 mm down cleaned washed aggregates @ 50% by weight of micro-concrete.	Sqm
	d) 100 mm thick admixed with 10 mm down cleaned washed aggregates @ 50% by weight.	Sqm
2.13	Application of curing compound -Providing and applying approved water based curing compound of Dr. Fixit Curing Compound/equivalent to the newly provided concrete surface by spray applied/ brush applied as per manufacturer's specification immediately after removal of formwork or shuttering as directed by Engineer-in-charge.	Sqm
2.14	**Rebar:** Providing and fixing additional rebar for 300mm deep with Hilti HIT-HY150 as per structural drawing, manufactures instructions and as designed by Structural Consultant for anchoring of reinforcement bars including cost of drilling by mechanical means in concrete, cleaning the drilled holes, inspection of Hilti HIT HY-150, placing rebar and fixing with approved polyester resin grout of Dr. Fixit Anchorfix P/equivalent and allow adhesive to cure as directed by Engineer-in-charge.	Kg
3.0	Hilti/Fischer Anchors: Providing and fixing Hilti / Fischer Bolts/equivalent (anchor Fasteners) for connection, as per structural drawing and as instructed by Project Managers. Rate to include cost of drilling by mechanical means in concrete, cleaning the drilled holes, insertion of Epoxy cartridge, placing internally threaded sleeve, and driving of bolts, 2nos-4mm thick MS washers fastening screw and tightening with nuts and check nuts (various sizes as per requirement) as directed by Engineer-in-charge.	Nos
3.1	**Drilling holes in concrete**- Making holes of 75 mm dia in slab after scanning with rebar locator and without cutting the rebars by core cutting for pouring of micro concrete as directed by Engineer-in-charge.	Nos

3.0 Conclusion

Performance of a concrete repair needs to be measured in physical terms and other parameters such as environmental effects, safety and whole-life costs. The polymeric repair materials fail due to improper surface preparation, wrong application methods, incompatibility of the repair material with the original concrete etc.

The most of the failure takes place at the interface of the bonding for which bond strength is very important. All corrosion related cracks should be tested by corrosion analyzer etc. Structural crack repairs should be tested for an in-situ non destructive load testing to demonstrate satisfactory performance under an overload above the design working value after 28 days.