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# Repair and Rehabilitation of Flexure-Failed RC Beam

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***Abstract*—The increase in damage due to fast deterioration of concrete in RC-structures has led to the need for cost effective and reliable rehabilitation methods. The purpose of rehabilitation is to restore the structural capacity and undo the damage caused to the structure. This paper discusses the method of rehabilitation of a beam, which failed in flexure and had undergone loss of rebar cover. The rehabilitation process restored the structural capacity of the beam and the results are compared with the results of a virgin beam of similar dimensions. The methods discussed in the paper are a reliable solution to the rehabilitation of RC beams with flexural damage and loss of dimensions.**

***Index Terms*— RC beam, repair, rehabilitation, micro concrete.**

## I. INTRODUCTION

The dynamic construction boom in the Arabian Gulf has led to a rapid increase in the number of buildings constructed. Due to the extreme climatic conditions prevailing in the region, these buildings are deteriorating at an alarming rate[1]. The deterioration is accelerated by unruly construction practices such as poor mix-design and insufficient curing of concrete accompanied by damage phenomenon like chloride attack and sulphate attack on the concrete [2]. Loss of concrete cover, flexural cracks, shrinkage cracks and corrosion of reinforcement are some of the results of such deterioration. The need for repair and rehabilitation of concrete structures is increasing because of the deterioration of these structures. Many researchers have experimented on different types of rehabilitation methods such as jacketing [3], retrofitting with fibre reinforced polymer [4,5], strengthening with high performance concrete [6,7], epoxy resins [8], and cementitious composites [9]. This paper suggests and examines the repair of concrete beams that has failed due to flexural loading and have flexural cracks with loss of rebar cover, exposing the tension steel reinforcement. The repair is being done using micro-concrete, epoxy crack sealers and epoxy bonding agents.

This paper elaborates the rehabilitation of a beam with dimensions 140 x 280 x 2000 mm that has failed due to flexural loading causing the loss of rebar cover. The details of two beams are discussed in this paper, which are, the control beam named CB; and the rehabilitated beam named REMB, before and after rehabilitation. The beam to be rehabilitated had been tested under four-point loading. Upon failure, the beam experienced concrete separation from the rebar cover level, exposing the tension reinforcements (Fig-1). The objective of this experiment is to rehabilitate this beam, which had failed due to flexure and rebar-cover

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separation and restore its original dimensions and flexural capacity. The control beam, CB is a virgin beam similar to REMB in dimensions and is used to compare the flexural capacity of REMB to its original flexural capacity.

## II. Sample Preperation And Test Procedure

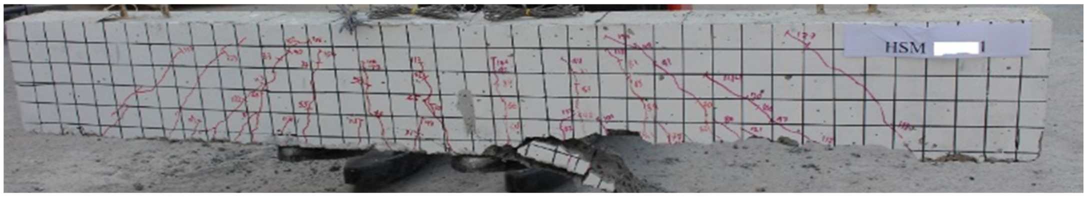


Figure 1- Beam REMB before Rehabilitation

Figure 2-Form work for concreting

Figure 3-Removal of lose

Figure 4-Post compaction of concrete

Figure 5-Bonding Agent and Micro-concrete

Since the flexural failure in the beam REMB had resulted in the rebar cover removal, the primary objective is to provide additional concrete material for the rebar steel to bond with, and to restore the lost height of the beam. The secondary objective is to provide adequate bond strength between the old concrete and the new concrete. The flexural cracks are to be sealed and stopped from propagating further as well.

The primary step of the rehabilitation process is to remove loose concrete material from the tension side of the beam (Fig-2). The concrete is chiselled out until the concrete cover level, exposing at least 50% of the tension rebar steel. The remaining debris is cleaned using a water jet with high pressure. Secondly, the cracks on the surfaces of the beam are sealed with FOSROC NITO-MORTAR FC, which is a high strength trowel grade epoxy repair mortar. The epoxy and resin are mixed according to the design criteria mentioned by FOSROC and applied with pressure over the cracks to make sure that the material has penetrated the cracks to a significant level. The irregularities/loss of concrete on the lateral surfaces of the beam were also filled with the epoxy. The epoxy is left to dry for two days at an ambient temperature of $36^{o}$C. Thirdly, the beam is placed with tension side facing upwards, and a wooden formwork (Fig-3) is built around the beam to cast the new layer of concrete. The formwork for the beam would extend the clear cover of the beam to 40mm. Strain gauges are attached on the tension steel rebars at the midspan of the beam.

Prior to concreting, a coating of FOSROC NITO-BOND EP, an epoxy based concrete bonding agent is applied (Fig-4). This is to ensure the proper bond between the old concrete and the new concrete. Immediately after the application of NITO-BOND EP, FOSROC RENDEROC LA XTRA, a fluid micro-concrete is poured and compacted using hand compaction technique (Fig-5). After 24 Hours, the formwork is removed, and the new concrete is cured for 28 days.

After 28 days of curing with wet burlap and polyethene sheet covering, the rehabilitated beam is prepared for flexural loading. Strain gauges are fixed on the compression fibres of the beam at the midspan. Additional strain gauges are fixed on the lateral face of the beam at the interface of the bond between the old and new concrete. This is to measure the bond slippage, if any. A crack transducer is fixed on the other lateral face at the bond interface to check if the beam cracks at the bond interface. The beam is prepared for four-point flexural loading on INSTRON Universal testing machine with a capacity of 1500kN, with a loading rate of 1 mm per minute. The displacement at the midspan are measured with additional two LVDTs for precision. Strain Gauges are attached to the lateral face of the beam and the interface of the bond between old and new concrete. This location is assumed to be the weakest point where a probable bond separation is possible. Two strain gauges, vertical and angular in orientation is placed to measure the vertical and angular separation.

## III. Results and Discussion

The beams REMB and CB are tested until the beam could not take any more load. The rehabilitated beam reached a maximum load of 114.25 kN with a maximum midspan deflection of 19.2 mm. Whereas, the control beam had reached a maximum load of 100.40 kN with a maximum midspan deflection of 13.9 mm. The maximum midspan deflection of the beam before being rehabilitated was 16.13 mm, which had retracted back to 8.5 mm when the load was released. The load deflection curves of the beam CB and REMB (Fig-6) compares the behaviour of rehabilitated beam to the control beam. The rehabilitated beam had restored the strength of the beam to 112% of the previous beam i.e. 1.14 times stronger than CB, indicating the successful restoration of the ultimate load capacity of the beam. However, the midspan deflection of the rehabilitated beam (REMB) was larger than the control beam (CB) by 5 mm. This is due to the increase in ductility of the beam because of preloading.

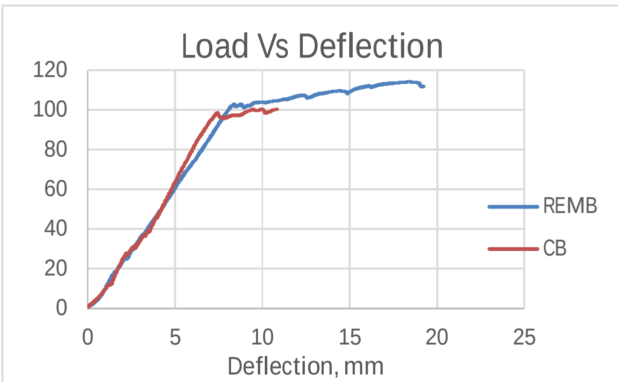


Figure 6- Load Vs Deflection Curves

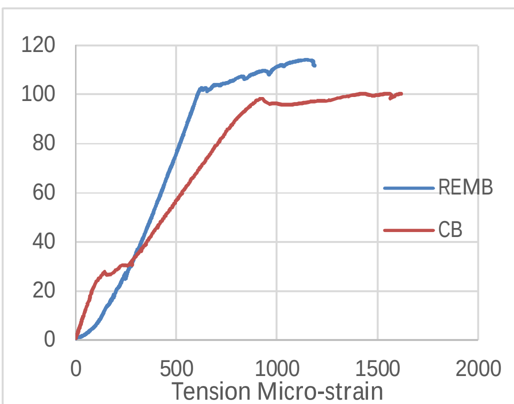


Figure 7-Load Vs Steel Tension Strain

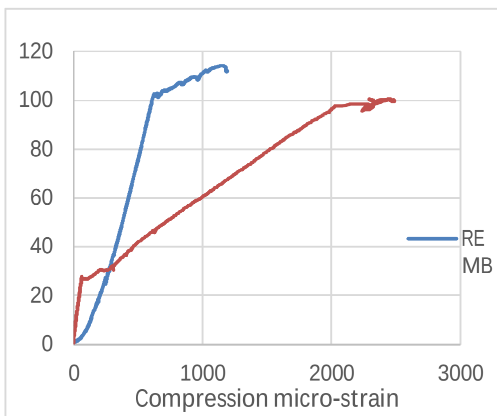


Figure 8-Load Vs Concrete Compression Strain

The strain in the tension steel of REMB and CB compared in the Fig-7 shows that the maximum strain in the tension steel rebar of the rehabilitated beam (REMB) is lesser than the maximum strain of the control beam (CB). This could be because the beam was subjected to repeated loading, replicating the effect of cyclic loading on the tension steel rebars. The maximum strain on the extreme compression face of the concrete were same in both REMB and CB as shown in Fig-8. However, the graph of compression strain in REMB is stiffer than that of CB.

The cracks propagation (Fig-9) in the rehabilitated beam is similar to the beam CB. The cracks in the new micro-concrete were mostly continuation of the previous cracks in the old concrete. Although new cracks were formed, it was less in number. The continuity in propagation of cracks from the new concrete to the old concrete is an evidence to the excellent bonding between the old and the new concrete. The strain gauges attached at the interface of the bond between the new and old concrete exhibited a better understanding of the bond behaviour. The reading on the strain gauges indicate there is not much displacement between the old and new concrete.

## IV. Conclusion

The following conclusions could be drawn:

1. The rehabilitation process restored 112% strength of the beam, thus confirming the credibility of the rehabilitation process.
2. The restoration of the strength is due to the combined effect of the bonding agent used and the strength of micro concrete used to repair the beam.
3. The majority of the cracks were due to the propagation of old cracks from the beam onto the micro-concrete layer, although new cracks were also formed in the micro-concrete layer and travelled though the old concrete beam.
4. The crack propagation and the strain gauges reading from the interface of the new and old concrete indicates that the two layers have bonded and acted as a single material.
5. The tension steel rebars in the rehabilitated beam had a lower strain than the control beam. The compression strain readings for both beams were the same.

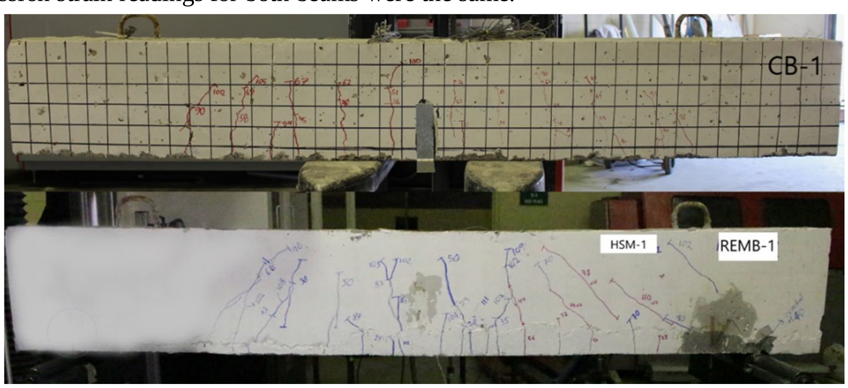


Figure 9-Crack Propagation in CB and REMB

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