A STUDY ON BENDING BEHAVIOUR OF REINFORCED CONCRETE BEAMS STRENGTHEN BY FERROCEMENT LAMINATES

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ABSTRACT

Starting with the premise that the choice of the optimal method for strengthening reinforced concrete (RC) structures is a complex task and that ferrocement strengthening is comparable to other advanced strengthening technologies due to its cost-effectiveness, ease of construction, and durability, this paper presents a comparative study of the flexural bearing capacity of RC beams strengthened with ferrocement strips applied by gluing. An overview of the life cycle assessment (LCA) based on embodied energy or CO2 is presented in the introduction, based on the existing literature review. The research includes tests of 15 RC beams of identical cross-sections (150/250 mm) and a span of 3000 mm. Strengthening was conducted by applying four types of ferrocement strips (different widths and wire mesh layers). Two factors were examined: the verification of the comprehensive FEM numerical model against the experimental results and the applicability of existing simplified calculation methods for sufficiently accurate results which could be used in regular practice. The results show that the failure forces obtained from numerical models and experimental models differ by no more than 3.94%. The increase in the bearing capacity of the strengthened models is up to 21.4%. The transformed area method for the cracked section showed good results when compared to the FEM and experimental models. The analytically calculated failure force is contingent upon the partial factor for variable action, which was explored within the 1.5–1.7 range.

Keywords: strengthening; micro-reinforced concrete; ferrocement; reinforced concrete (RC) beams; flexure; numerical simulation.

I. INTRODUCTION

1.1 GENERAL

The factors affecting deterioration of reinforced concrete structures, pre-stressed concrete structures and the mechanisms of deterioration are well understood today. The major factors responsible for the deterioration of structures are faulty design, unsuitable materials, improper workmanship, overloading and exposure to an abnormally aggressive environment. The main causes of deterioration of concrete structures are:

- Cracking and spalling of concrete
- Environmental conditions such as corrosion and
- Extremely heavy loads

Once a structure is built in concrete, it is more or less considered permanent and does not need much attention for maintenance. However, over the years a number of structures have manifested deterioration thereby exploding this myth. The concept of durability and serviceability of a structure has been considered by Indian engineers during design and construction. New materials, methodologies and construction techniques have been developed and used to ensure durability of structures.

1.2 DAMAGE ASSESSMENT

Damage can be defined as the change in structural performance which can be identified in terms of discrete cracks or a weak zone formation and a consequent stiffness reduction. Damage can be of any physical form and its growth under a particular type of loading differs based on various factors like the type of material, location and intensity of loading. The investigation of reasons for damaged structures is largely a matter of gathering information by observation, studying earlier records, doing preliminary testing and then interpreting the information thus obtained. A systematic study on concrete structures is highly important and essential in order to find the cause of damage, to assess the condition of the structures in its damaged state and to formulate recommendations for repair and restoration. A wide range of approaches are available, for estimating the strength of concrete. A conventional destructive test method enables the strength of the is not possible in all cases and especially for slender members. In non-destructive testing, the strength properties are not measured directly but the other related properties are analysed and the strength can be estimated by calibration. Naturally, in these methods, the great advantage is that the concrete is not damaged. In partially destructive tests, the concrete is tested to failure but the destructive resulting in much localized and the member under the tests is not weakened to any significant extend.

1.3 OVERLOADING DAMAGE

The excess of load above the design loads on structural members is called overloading and it causes basic symptoms of cracking. Subsequently, it leads to spalling and disintegration. Deterioration of reinforced concrete structures is frequently caused by a combination of various factors. It may result from physical damage, chemical attack and from material degradation on exposure to severe environment. Physical damage to reinforced concrete can arise from the number of causes like fire damage, explosive damage, impact damage and damage from natural calamities such as floods, cyclones and earthquakes. The chemical causes of concrete deterioration are alkali-silica reaction, alkali-carbonate reaction, carbonation, sulphate attack and steel corrosion. The other factors contributing to concrete degradation include high structural stress, thermal stress, shrinkage and poor quality of materials.

1.4 WHY REHABILITATION?

Repair is the technical aspect of rehabilitation which refers to the identification of a structure partly or wholly which is damaged in appearance and serviceability. Rehabilitation consists of restoring the structure to service level, it once had and that too at low cost. The rehabilitation envisages restoration of structural system as close to the original configurations as possible. The structures in distress are to be brought in line and require strength so that they could be put back in service without endangering their safety and utility.

The basic aims of rehabilitation work would be as under:

- To prevent harmful development to restore the integrity of the structure and to provide effective protection.
- To improve functional utility and service life.
- To reduce distress and remove defects which involve hazards to life and affect durability of a structure.
- To improve the aesthetic appearance.

The repair of the structural damage and rehabilitation is possible by a number of methods. These methods include:

- Use of steel plates or FRP in the damaged regions to increase the load carrying capacity of the structure.
- Removal of the corroded steel bars and damaged concrete and their substitution by fresh materials of the same type.
- Use of epoxy mortar alone or in combination with the above mentioned two methods.
- Use of ferrocement in the damaged portion to restore the performance of the structure.

1.5 NEED FOR STUDY

This study considers ferrocement as a rehabilitation material in plate bonding technique to bond in the tension face of the RC beam. The main constituents of ferrocement are mortar and reinforcement in the form of steel wire mesh. The cementing mix is made of cement and sand mortar while the reinforcement steel wire mesh has openings large enough for adequate bonding. The closer distribution and uniform dispersion of reinforcement, transform the otherwise brittle mortar into a high performance material distinctly different from reinforced concrete.

The present study aims to study the effect of ferrocement laminates attached to reinforced concrete beams by plate bonding technique. This study also aims at studying the effect of ferrocement laminates attached to reinforced concrete beams by cast in situ bonding technique. This study also examines the effects of different volume fraction of ferrocement laminate reinforcement in both plate bonding technique and cast in situ bonding technique. A comparative study on performance of laminated and rehabilitated beams has been made on both plate bonding technique and cast in situ bonding technique. This has been planned to be achieved by conducting extensive experimental studies and analytical studies on reinforced concrete beams under the undamaged and predamaged rehabilitated status.

II. LITERATURE REVIEW

2.1 GENERAL

Many scientists and researchers have studied the aspects of causes of damages in structures and the required remedial measures to bring it into the satisfied level. The assessments of damages due to various causes and the novel rehabilitation techniques can be made in many ways. A brief review of the works done by various authors is presented in this chapter.

2.2 STUDIES ON EPOXY BONDED STEEL PLATES

MacDonald and Calder (1982), studied the behaviour of concrete beams externally reinforced with steel plates bonded to their tension flanges. They tested a series of beams under four point loading. Results showed that full composite action was provided by the adhesive and that significant improvements in performance could be achieved in terms of load, crack control, and stiffness. Exposure tests were carried out on unreinforced concrete beams with steel plate bonded to one face. Results showed that significant amounts of corrosion of the steel plate may take place due to natural exposure. Also loss in bond strength at the steel-epoxy interface was observed resulting from the corrosion of the steel plate. The reduction in the overall strength of the exposed beams was attributed to the corrosion.

Van Gemert and Vanden Bosch (1985), reported the results of durability tests on concrete beams with epoxy bonded steel reinforcements. They studied the effects of long term exposure, fatigue, and temperature loading and concluded that the effects of atmospheric corrosion depended for the greater part on the preparation of concrete and steel plate surfaces and on the workmanship of the repair crew. Therefore more specialized personal and a careful control of the preparation work would be necessary.

2.3 STUDIES ON EPOXY BONDED FRP PLATES

Hamid Saadatmanesh and Ehsani (1996), experimentally investigated the static strength of reinforced concrete beams strengthened by gluing glass fiber reinforced polymer (GFRP) plates to their tension face of the beams. The measured load versus strain in GFRP plates, steel rebar, extreme compression fiber of concrete, and the load versus deflection for the section at mid span of the beams were plotted and compared to the predicted values. The results indicated that the flexural strength of RC beams could be significantly increased by gluing GFRP plates to the tension face. In addition the epoxy bonded plates had improved the cracking behaviour of the beams by delaying the formation of visible cracks and reducing crack widths at higher load levels.

Garden and Hollaway (1998), studied and reported that carbon fiber reinforced polymer (CFRP) materials were all suited to the rehabilitation of civil engineering structures due to their corrosion resistance, high strength to the weight ratio, and high stiffness to weight ratio. The anchorage system for the plate had more structural benefit under low shear span/ depth ratio.

Houssam Toutanji and Yue Zhang (2000), studied external bonding fibre reinforced polymer (FRP) sheets with epoxy matrix which had an effective technique for strengthening and repairing reinforced concrete beams under flexure. The variables in that study were the reinforcement ratios the type of epoxy matrices and the concrete-FRP interface conditions. All the beams were subjected to four point bending test under load control while the crack width, deflection, and mid span strain at both compression and tension faces were measured. An analytical method for predicting the ultimate moment and moment strain curves of the strengthened beams were developed. Both experimental and theoretical results were presented and compared. Results showed that there was a good agreement between the experimental and analytical result. They concluded that externally bonded CFRP sheets significantly enhanced the flexural strength capacity of RC beams by 50%.

2.4 STUDIES ON EPOXY BONDED FERROCEMENT COMPOSITES

Suryakumar and Sharma (1976), presented a comparison of the results of tests of thirty five specimens with the theoretical values of ultimate strength, predicted by the conventional reinforced concrete theory. They concluded from the study that, conventional reinforced concrete theory could be adopted for predicting the ultimate flexural strength of ferrocement. The ultimate strength and first crack strength of ferrocement was found to increase linearly with increase in the percentage area of reinforcement.

Perumalsamy et.al (1979) carried out experiments on ferrocement beams reinforced with volume fraction varying from 2% to 6% with variety of square steel meshes which were subjected to fatigue flexure with three levels of loading corresponding to approximately 40%, 50% and 60% of static yield load. Based on the observed experimental results linear regression equations were proposed by them to predict fatigue life of ferrocement as a function of the stress range in the outermost layer of steel mesh. Also, an exponential relation with two parameters was built to predict the increase in deflection, average and maximum crack widths as a function of applied load and number of loading cycles. The proceeding relations established by them are carefully adaptable to reinforced concrete subjected to fatigue flexure.

III. SCOPE AND OBJECTIVES

The reinforced concrete structures may be subjected to many types of damage and distress. But, the scope of this study is limited to damages of reinforced concrete beams due to overloading alone. The damaged structures could be repaired and rehabilitated to a satisfactory level of performance at a reasonable cost by different methods. This study proposes two methods of repairing, rehabilitating, and restrengthening of reinforced concrete beams by plate bonding technique and also by cast-in situ bonding technique at reasonable cost. A comparative study was made on the two techniques based on the performance on reinforced concrete beams. This objective was planned to be achieved by an experimental study on reinforced concrete beam elements. After rehabilitation, the depth of cracks was reduced and the deflections were arrested with restoring the load carrying capacity of the damaged beams because ferrocement laminate was a highly ductile material with better crack arresting mechanism.

Accordingly, the scope and objective of this work have been set as follows:

- To study the static behaviour of reinforced concrete beams as perfect beams, undamaged laminated beams and predamaged rehabilitated beams experimentally by plate bonding technique.
- To study the static behaviour of reinforced concrete beams as perfect beams, undamaged laminated beams and predamaged rehabilitated beams experimentally by cast insitu bonding technique.
- To study the comparative performance and behaviour of laminated beams by plate bonding technique and cast insitu bonding technique.
- To study the comparative performance and behaviour of rehabilitated

beams by plate bonding technique and cast insitu bonding technique.

- To study the crack propagation, and maximum crack spacing on beams perfect, undamaged laminated beams and predamaged rehabilitated beams
- To evaluate the overall performance of undamaged laminated beams and predamaged rehabilitated beams with respect to perfect beams.
- To perform a non-linear finite element analysis for reinforced concrete beams perfect, undamaged laminated beams and predamaged rehabilitated beams using ANSYS software.
- To study the composite action of the ferrocement laminates during load spectrum and to understand the cracking failure mechanism.
- To predict the flexural properties strength, deformation, ductility and energy capacity of the beams based on regression analysis.
- To validate the experimental results with previous investigations
- To assess the characteristics of ferrocement as a rehabilitation materials.

The specific conclusions on the static behaviour of perfect, undamaged laminated and predamaged rehabilitated beams will be drawn based on the experimental investigation and analytical investigation.

IV. EXPERIMENTAL INVESTIGATION

4.1 INTRODUCTION

In general, cracking in reinforced concrete structural elements is not a damage, but an expected natural phenomenon due to inherent low tensile strength. At the same time, cracks that were caused due to overloading, poor quality of concrete, poor workmanship were parameters that could lead to unacceptable cracking which further leads to an increased level of damage. In this study damages caused due to overloading of reinforced concrete elements were considered. In recent years, there was a growing need for rehabilitation of structures. Many methods of rehabilitation of structures were developed by researchers and adopted over the years. Plate bonding technique of ferrocement laminates had been introduced as normal repair and strengthening method. Another method for repair and strengthening of reinforced concrete elements was cast insitu bonding technique of ferrocement laminates. A detailed experimental programme was finalized after assessing the percentage of overloading and type of rehabilitation procedures.

4.2 EXPERIMENTAL PROGRAMME

A total of fifty beams of size 125 mm width, 250 mm depth and 3200 mm overall length were cast and tested. All the beams were tested in two points loading over an effective span of 3000 mm. Out of 50 beams two beams (BP1 and BP2) were used as perfect beams, another six beams (BRP1 to BRP6) were strengthened with ferrocement laminates with three different volume fraction (Vr) of ferrocement reinforcement in virgin condition by plate bonding technique. Another eighteen beams (BOP1-BOP18) were damaged by subjecting three different levels of overloading and were repaired and rehabilitated with ferrocement laminates by plate bonding technique having three different volume fraction of ferrocement reinforcement. Another six beams (BRC1 to BRC6) were strengthened with ferrocement laminates with three different volume fraction of ferrocement reinforcement in virgin condition by cast insitu bonding technique. Another eighteen beams (BOC1-BOC18) were damaged by subjecting three different levels of overloading and were repaired and rehabilitated with ferrocement laminates by cast insitu bonding technique, having three different volume fraction of ferrocement reinforcement.

The variables considered in this study include different levels of damages, different volume fraction of reinforcement in ferrocement laminates as rehabilitation material and different methods of laminating the ferrocement laminates. A comparative study was made between the perfect beams, undamaged laminated beams and predamaged rehabilitated beams by both plate bonding technique and cast insitu bonding technique.

4.3 DETAILS OF TEST PROGRAMME

A total of fifty beams were categorized into nine series and tested in the laboratory. Series1 consists of 2 beams BP1 and BP2 and these beams were tested upto ultimate load carrying capacity Pu. They were tested under static monotonic loading. Series2 and series 6 consist of six beams under each category. Under each series (BRP1 to BRP6 and BRC1 to BRC6) they were strengthened by ferrocement laminates having three different volume fractions of ferrocement reinforcements viz Vr=2.192%, Vr=4.384%, and Vr=6.576% respectively for two beams in each volume fraction Vr in virgin condition by plate bonding technique and cast insitu bonding technique. Series 3 and series 7 consist of 6 beams under each series namely BOP1 to BOP6 and BOC1 to BOC6 were damaged by overloading by subjecting the beams to a preloading which corresponds to 67% of the ultimate load carrying capacity (Pu) of the perfect beams (BP1 and BP2) and rehabilitated with ferrocement laminates with three different volume fraction (Vr) of ferrocement reinforcement, two beams in each category by both plate bonding technique and cast in situ bonding technique. Similarly, series 4 and series 8 consist of 6 beams in each series namely BOP7 to BOP12 and BOC7 to BOC12 were damaged by overloading by subjecting the beams to a preloading which corresponds to 75% of the ultimate load carrying capacity (Pu) of the perfect beams (BP1 and BP2) and rehabilitated with ferrocement laminates with three different volume fraction (Vr) of ferrocement reinforcement and two beams in each category by both plate bonding technique and cast insitu bonding technique. Series 5 and series 9 consist of 6 beams in each series namely BOP13 to BOP18 and BOC13 to BOC18 were damaged by overloading by subjecting the beams to a preloading which corresponds to 85% of the ultimate load carrying capacity (Pu) of the perfect beams (BP1 and BP2) and rehabilitated with ferrocement laminates with three different volume fraction (Vr) of ferrocement reinforcement and two beams in each category by both plate bonding technique and cast insitu bonding technique. The summary of the test plan is presented in Table 4.1.

Table 4.1 Summary of Test Plan

S. No	Beam code	Damage level % P_u	V_r %	Technique adopted	Performance evaluation
1	BP1&BP2	Perfect beam	----	---	Strength and deflection under static test
2	BRP1&BRP2	Undamaged beam	2.192	Plate bonding technique	Effect of undamaged beams, strengthened by ferrocement laminates
	BRP3&BRP4		4.384		
	BRP5&BRP6		6.576		
3	BOP1&BOP2	67	2.192	Plate bonding technique	Effect of predamaged beams, strengthened by ferrocement laminates
	BOP3&BOP4	67	4.384		
	BOP5&BOP6	67	6.576		
4	BOP7&BOP8	75	2.192		
	BOP9&BOP10	75	4.384		
	BOP11&BOP12	75	6.576		
5	BOP13&BOP14	85	2.192		
	BOP15&BOP16	85	4.384		
	BOP17&BOP18	85	6.576		
6	BRC1&BRC2	Undamaged beam	2.192	Cast insitu bonding technique	Effect of undamaged beams, strengthened by ferrocement laminates
	BRC3&BRC4		4.384		
	BRC5&BRC6		6.576		
7	BOC1&BOC2	67	2.192	Cast insitu bonding technique	Effect of predamaged beams, strengthened by ferrocement laminates
	BOC3&BOC4	67	4.384		
	BOC5&BOC6	67	6.576		
8	BOC7&BOC8	75	2.192		
	BOC9&BOC10	75	4.384		
	BOC11&BOC12	75	6.576		
9	BOC13&BOC14	85	2.192		
	BOC15&BOC16	85	4.384		
	BOC17&BOC18	85	6.576		

4.4 MATERIALS USED

The mean strength of concrete used for the beams was 29.11 N/mm2. The concrete mix used for the beam was 1:1.52:3.42 with water cement ratio of 0.50. The concrete mix proportions was designed by IS method to achieve the mean strength of 20N/mm2. Ordinary Portland Cement of 53 grades, fine aggregate of locally available river sand passing through 4.75mm sieve and retained on 600 microns conforming to zone II of IS 383 (1970) with specific gravity 2.48, coarse aggregate of crushed granite type passing through 20 mm sieve and retaining on 10 mm sieve conforming to IS-383 (1970) with specific gravity 2.91, were used as the concrete ingredients. Ordinary portable water free from impurities was used for preparing and curing of concrete.

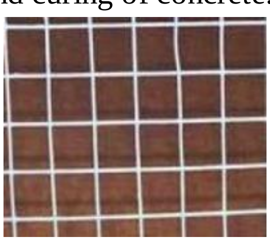

Figure 4.1 Welded wire mesh

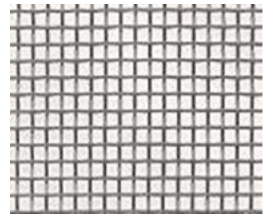

Figure 4.2 Woven mesh

4.5 FABRICATION OF BEAMS

The beam reinforcement along with shear reinforcements of cross section of the beam and longitudinal section of the beam are shown in Figure 4.3 and Figure 4.4. The form work of size 125 mm width, 250 mm depth and 3200 mm length for the beam was made up of teak wooden blanks. A thin layer of waste oil was applied to facilitate easy removal of form work after 24 hours of casting. Required quantities of fine aggregate, coarse aggregates and cement were mixed thoroughly and the measured quantity of water was poured on the dry mix and mixed thoroughly to get uniform colour and the required consistency. The steel reinforcement was kept inside the mould. The thoroughly mixed concrete was poured inside the mould and vibrated using a high frequency needle vibrator. Control specimens in the forms of cubes and cylinders were also cast under the identical condition as that of the beam. The beam mould was removed after 24 hours from the time of casting and the specimens were cured using wet gunny bags for 28 days.

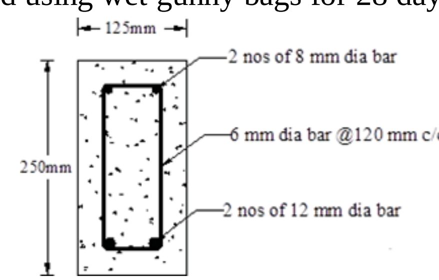

Figure 4.3 Cross section of the beam

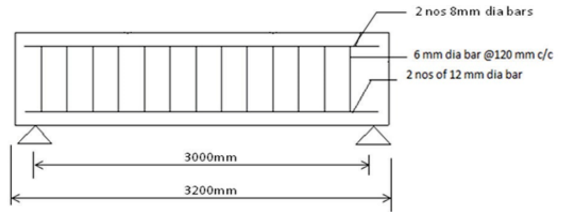

Figure 4.4 Longitudinal section of the beam

4.6 TESTING OF BEAMS

All the beams were placed over the loading platform according to the specifications. The load was applied by means of manually operated hydraulic jack. The deflectometer readings were observed under the loading point and also at the centre for every 2.0 kN load increment and were recorded. According to the test programme the first two beams were tested upto failure and the failure load was Pu. The other sets of beams, series 3 to series 5 and series 7 to series 9 were loaded to different predetermined damage level of 67%Pu, 75%Pu, and 85%Pu. These predamaged beams were strengthened by ferrocement laminates having three different volume fractions (Vr=2.192%, Vr=4.384% and Vr=6.576%) of ferrocement reinforcements both by plate bonding technique and cast in situ bonding technique. The series 2 and series 6 were undamaged and strengthened by ferrocement laminates having three different volume fractions of reinforcements both by plate bonding technique and cast insitu bonding technique.

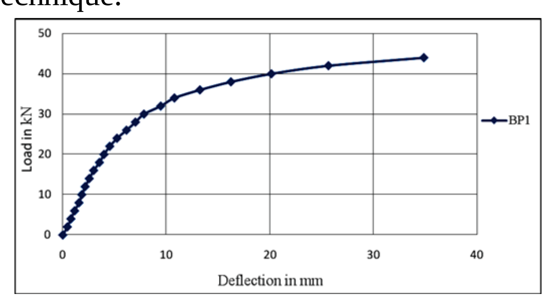

Figure 4.6 Load-deflection behaviour of perfect beam (series 1)

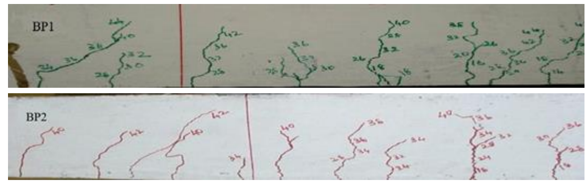

Figure 4.7 Crack patterns of perfect beams (series 1)

4.7 FABRICATION OF FERROCEMENT LAMINATES FOR PLATE BONDING

Cement and sand were mixed in 1:2 ratio, with water cement ratio 0.42. The wooden mould of 3000 mm length, 125 mm width and 25 mm thick was arranged as per requirement. A thin mortar layer was applied for required thickness. One layer of welded wire mesh and one layer of woven mesh tied together having volume fraction Vr=2.192% was placed over it. Again a thin mortar layer was applied. The top surface was finished properly and the moulds were removed after the specified time and the sides were finished, as shown in Figure 4.8 and Figure 4.9. The same procedure was repeated to fabricate ferrocement laminate having volume fraction Vr=4.384% and Vr=6.576%. The arrangements of ferrocement reinforcement conforming to volume fractions Vr=2.192%, Vr=4.384% and Vr=6.576% are shown in Figure 4.10.

Figure 4.8 Reinforcement placed over the mortar

Figure 4.9 Finished top surface of the laminate

V. CONCLUSION

The following were the major findings derived from the study.

1. Ferrocement laminates properly bonded to the tension face of reinforced concrete beams could enhance the flexural strength capacity substantially. Ferrocement laminates with 2.192% volume fraction (Vr) of ferrocement reinforcement behaves in a superior way when compared with ferrocement laminates with 4.384% and 6.576% volume fraction (Vr) of ferrocement reinforcement. Therefore the following conclusions are mainly drawn from the behaviour of beams laminated and rehabilitated with laminates having Vr = 2.192%.
2. The undamaged laminated beams, laminated with ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by plate bonding technique exhibit an increase in load carrying capacity of 8.3%, but the beams laminated by cast insitu bonding technique exhibit an increase of 16.7% at the initial cracking stage when compared with perfect beams. The plate bonded undamaged laminated beams with volume fraction Vr=2.192% exhibit an increase of 15% and 9.1% at the yield stage and ultimate stage while the cast insitu bonded undamaged laminated beams with same volume fraction exhibit an increase of 30% and 27.3% at the yield stage and ultimate stage, with respect to perfect beams.
3. The undamaged laminated beams, laminated with ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by cast insitu bonding technique exhibit an increase of 7.7%, 13% and 12% respectively at the initial cracking stage, yield stage and ultimate stage with respect to the identical beams laminated by plate bonding technique. The same performance exits for other beams laminated with ferrocement having Vr=4.384% and Vr=6.576%.
4. The 67%Pu predamaged rehabilitated beams, rehabilitated by ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by plate bonding technique, exhibit an increase of 16.7%, 40% and 20% respectively at the initial cracking, yield and ultimate stage with respect to perfect beams, while the 67%Pu predamaged rehabilitated beams, rehabilitated by ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by cast insitu bonding exhibit an increase of 33.3%, 60% and 22.7% respectively at initial cracking stage, yield stage and ultimate stage with respect to perfect beams.
5. The 67%Pu predamaged rehabilitated beams, rehabilitated by ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by cast insitu bonding technique, exhibit an increase of 14.3%, 14.3% and 12.5% respectively at the initial cracking stage, yield stage and ultimate stage compared with identical beams rehabilitated by plate bonding technique. The same condition prevails for 75%Pu and 85%Pu predamaged rehabilitated beams by ferrocement having 2.192%, 4.384% and 6.576% volume fraction (Vr) of ferrocement reinforcement.
6. The undamaged laminated beams, laminated with ferrocement having 2.192% volume fraction (Vr) of ferrocement

reinforcement by plate bonding technique exhibit a decrease in deflection of 12.5% at the initial cracking stage, while the undamaged laminated beams, laminated with ferrocement having 2.192% volume fraction (Vr) by cast insitu bonding technique exhibit an decrease of 21.4% at the initial cracking stage with respect to perfect beams. The plate bonded undamaged laminated beams exhibit a decrease of 16.7% and 12.3% at the yield stage and ultimate stage respectively, while the cast insitu bonded undamaged laminated beams exhibit a decrease of 22.8% and 12.0% at the yield stage and ultimate stage respectively with respect to perfect beams.

7. The undamaged laminated beams laminated with ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by cast insitu bonding technique, exhibit a decrease in deflection of 10.2%, 7.1% and a marginal decrease in deflection at the initial cracking stage, yield stage and ultimate stage respectively with respect to the identical beams laminated by plate bonding technique. The same performance exhibits for other beams laminated with ferrocement having Vr=4.384% and Vr=6.576%.

8. The 67%Pu predamaged beams rehabilitated by ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by plate bonding technique, exhibit a decrease in deflection of 5.4%, 7.6% and 14.6% at the initial cracking, yield and ultimate stage with respect to perfect beams, while for the identical beams rehabilitated by cast insitu bonding exhibit an decrease in deflection of 21.4%, 9.5% and 13.6% at initial cracking stage, yield stage and ultimate stage with respect to perfect beams.

9. The 67%Pu predamaged beams rehabilitated by ferrocement having 2.192% volume fraction (Vr) of ferrocement reinforcement by cast insitu bonding technique, exhibit a decrease in deflection 17.0%, 2.0% and a marginal decrease in deflection at the initial cracking stage, yield stage and ultimate stage with respect to the identical beams laminated by plate bonding technique. The same performance exhibits for other predamaged beams laminated with ferrocement having 2.192%, 4.384% and 6.576% volume fraction (Vr) of ferrocement reinforcement.

10. The perfect beam recorded an ultimate load of 44kN load. For the same load the undamaged laminated beams laminated by ferrocement laminates with Vr=2.192% by using plate bonding technique showed a decrease in deflection of 51.7%, while the undamaged beams with same volume fraction by cast insitu bonding technique exhibit a decrease in deflection of 57.9% with respect to perfect beams for the same load. Also there is a decrease in deflection of 11.5% for undamaged laminated beams by cast insitu bonding compared with undamaged laminated beams by plate bonding. The same condition extends for other undamaged laminated beams with volume fraction Vr=4.348% and Vr=6.576%.

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