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Design and Analytical Investigation of Confined Ferrocrete Cross-Beams under Flexure

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***Abstract*— The research investigates flexural strength of new box-section cross-beams through testing which uses a restricted ferrocrete matrix. Ferrocement, which is a specialized cementitious composite, provides better ductility and structural efficiency than standard reinforced concrete. The testing program involved casting and testing nine box-beams which had dimensions of 150 x 150 x 1000 mm and core longitudinal reinforcement that used 8 mm, 10 mm, and 12 mm HYSD 500 bars. The study evaluated ultimate load-bearing capacity and deflection parameters through four-point bending testing which occurred during the experimental phase. The researchers conducted analytical simulations through Finite Element Method (FEM) software which used ANSYS and STAAD Pro to create a computer model that predicts structural behavior. The study results demonstrate that increasing longitudinal steel quantities leads to higher flexural stiffness and ultimate capacity gains while restricting maximum displacement. The study proved that confined ferrocrete beams can function in modern lightweight high-performance structural systems which include infrastructure retrofitting based on model validation that showed strong agreement between analytical results and experimental data.**

***Index Terms*— Confinement Effect, Finite Element Analysis (FEA), Cross-Beams, Ferrocement Composite, Flexural Rigidity, Ultimate Capacity, and Structural Rehabilitation.**

I. INTRODUCTION

The civil engineering field is keen on advanced composite materials that offer dual advantages of reduced structural weight and mechanical properties. Ferrocement (also sometimes called ferro Crete) is a thin-walled highly reinforced cementitious material that meets this criteria [8], [11]. The material obtains higher tensile strength and avoids crack propagation through its design which includes dense cement-sand mortar with multiple tightly spaced wire mesh layers [1].

A. Context and Justification

Cross-beams function as key load transfer elements which are required by the operators to build building frames and bridge decks. Structural components need material properties that lead to an increased performance standard and a resultant reduction in foundation loads.

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The development of a constrained ferrocrete box-beam system consists of constructing a standard concrete core which the engineers will cover with a ferrocrete exterior. The ferrocement layer is the active confinement in conferring the compressive strength of the core concrete and the overall ductility of the cross section by its hollow box type [9].
The use of ferrocement for external strengthening of existing RC members has been extensively studied [2], [3], but there aren't many thorough studies in the literature that concentrate on the main structural behaviour of recently built, restricted box-section beams with different internal reinforcement ratios.

B. Research Goals

The purposes of the study is to achieve two objectives, which is the main research mission to overcome the information deficiency that has existed about the relationship between the final flexural capacity and serviceability performance of confined ferrocrete box-beams and their skeleton steel reinforcement diameter which use 8 mm 10 mm and 12 mm sizes reinforcement. The researchers used the linear models created using STAAD Pro software and the non-linear models created using ANSYS software to simulate the composite action and predict the failure envelope. The purpose of this project is to develop an economical design tool which will allow for the optimization of design for the future based on validation of the analytical models with experimental results.

IV. Literature Review

The research conducted over the last 30 years shows that ferrocrete allowed more beneficial properties than the traditional reinforced concrete (RC) as it offered better ductility and higher crack resistance and ensured to maintain a strong strength-to-weight ratio. The current study necessitates literature review utilizing basic physics and hollow section applications & analytical modelling methods.

A. Basic Ferrocement Research

The first research findings defined ferrocement as a material different from the ordinary reinforced concrete by its small diameter and tightly spaced reinforcement system. The study performed by Khan showed that material performance (in tension and flexure) is dependent upon the specific surface area of the reinforcement [10], [11]. Researchers have been examining the priority of coir and the synthetic fibres as additives for the mortar matrix (an additive or supplement) to afford better tensile toughness and impact resistance of their materials. The organization shows its dedication to improving the composition of materials with the continual development work from their team.

B. Ferrocement Elements' Flexural and Shear Behavior

The existing research mainly focuses at the bending and cutting strength characteristics of ferrocement structural components [8], [10], [11] which have distinct structural designs. Al-Sulaimani et al. [5] carried out the first research study about the behavior of ferrocement box beam under shear loads which revealed that the hollow section of the beam had good shear strength and structural behavior [14]. The study proved that the use of hollow ferrocement components allows designers to have reduced dead weight of the building while maintaining their structural strength. The researchers El-Sayed and Erfan [4] performed experimental and analytical tests for the study of shear strength of composite box-section concrete beams and found that the addition of ferrocement resulted in the enhancement of both shear strength and ductility of the beams. The results were confirmed by the process of finite element analysis.

C. Ferrocement in Applications for Strengthening and Retrofitting

The material Ferrocement allows structural retrofitting because it has ductility and high surface hardness and application methods simple. Research by Raghunath apandian et al. [1] prove that Ferrocement laminations can enhance ultimate load capacity of the pre-damaged RC Tee beams with the help of enhancement in their flexural strength [9], [13]. The researches ElSbaya et al. [3] not only studied the use of ferrocement jacketing to square reinforced concrete columns but it superior axial load capacity while also reducing the lateral and vertical movement [12]. The investigations confirm that the material can provide good external confinement which the suggested confined ferrocrete cross-beams do implement through their internal design.

D. Numerical and Analytical Modeling

Ferrocements composite structure require advanced analytical methods as its behaviour depend on three materials i.e wire mesh and skeleton steel and mortar. The impact of the Finite Element Method (FEM) on the modeling of these materials is often used in research to model the non-linear response of these materials accurately. El-Sayed et al. [2] successfully verified their experimental results with the help of numerical tools with FEM for the analysis of ferrocement composite slabs. The study indicated that ANSYS and other commercial FEA programs could be used to accurately simulate the specific material properties and interface between materials to determine ultimate load capacity and cracking distribution [9], [12]. The total of the literature studied serves as an argument in favoring the methodological choice made to use the experimental validation in combination and the validation of the structural benefits of ferrocrete mentioned in hollow and constrained sections.

V. Methods: Fabrication and Experimental Program

It was aimed to reproduce, on the structural layout of the structure, the real loading phenomena - caused the variable cross-beams.

A. Specifications for Materials

The composite beam contained two different cementitious matrices in their construction.
Core Material: The concrete of grade M25 was developed in order to attain the required compressive strength during its compact dimensions.
The Ferrocrete Jacket used of M30 grade mortar which contains 1:3 ratio of cement and sand for the encapsulation of its mesh because of the high density and fineness properties [4], [10].
The main longitudinal steel used HYSD 500 grade steel for all reinforcement purpose [15]. The welded Galvanized Iron (GI) wire mesh performed two roles; confinement and fracture development control:

TABLE I: M25 CONCRETE DATA

Material	Description	Per m³	Per 50 Kg Cement bag
Cement [Kg]	OPC 53 Grade IS-269	370	50
Fine Aggregate [Kg]	Crushed Sand	834	113
Coarse Aggregate [Kg]	20 mm Angular	1132	153
Water [Lit]	Potable Water	185	25

B. Details of the Test Specimen

Nine box-type beam specimens with constant nominal size of 1000 mm in length and 150 mm * 150 mm in cross section were manufactured. The main tensile reinforcement diameter was used by the researchers to group the test specimens into 3 groups which included:
FCB-8: Beams of 8mm main bars for reinforcement.
FCB-10: Beams with main bars for reinforcement of 10 mm
FCB-12: Beams reinforced with main bars 12mm.
The outer layer of each specimen was mortar which became 20 mm thick. The material totally covered the wire mesh whereas the concrete core activated the synergistic force of the composite.

C. Method of Testing

Each of the beams was subjected to a four-point bending test after 28 days of curing using a Universal Testing Machine (UTM). The system applied concentrated loads via symmetrical build up at the middle span. The UTM load measurement and the mid-span vertical deflection measurement by the Linear Variable Differential Transducer (LVDT) were the basic data to conduct the study. The three key aspects of the flexural behavior was recorded in this study, which were the first cracking load, ultimate failure load and the formation of crack patterns.

Figure 1. Compression Testing Machine

VI. FRAMEWORK FOR ANALYTICAL MODELING

One analytical technique was used more than the other during the misinterpretation cues stage.

A. ANSYS, or Finite Element Modeling

The team used ANSYS software to perform a complete non-linear analysis which dealt with the intricate material characteristics of yielding and crushing and crack. The concrete core and mortar jacket were modeled as SOLID65 elements that contain a non-linear material including shear transfer coefficients for fractured concrete. The LINK180 elements were used to show the discrete longitudinal and mesh steel reinforcement which ensured accurate simulation of the rebar yielding.

Boundary Conditions The models were constrained to replicate the experimental situation with is concentrated loads and located at the correct experimental positions, from supports approximating the simply supported situation:

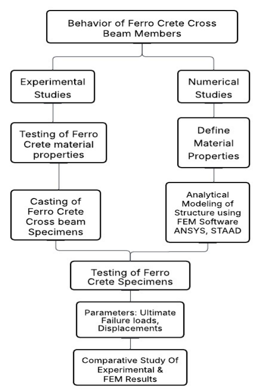

Figure.2. Flow Chart of Present Work

B. Constitutive Properties and Materials

The research focused on two primary techniques to determine the ways in which Confined Ferrocrete Cross-Beams retain their structural integrity. According to the experimental protocols researchers created and tested nine specimens to address their strengths and stability which were considered the basis for validation purposes. The ferrocrete cross-beam acts as a composite material as its constituent phases are interlinked with each other, which consists of core concrete, cement-sand mortar jacket, skeleton steel reinforcement and fine wire mesh layer. The Finite Element Method (FEM) analysis required that we use these specimens as real composite materials. The software kept all of the material properties and constitutive relations based on the experimental program requirements for numerical model development. Table 2 gives a comprehensive documentation of the exact value of the beam specimens and material characteristics used in FEM study such as modulus of elasticity, yield stress and compressive strength etc.

TABLE II. MATERIAL PROPERTY

Sr. No.	Material	Property	Value
1	HYSD 500	Yield stress fsy (MPa)	500
		Young's modulus Es (MPa)	2 x 105
		Poisson's ratio μ	0.3
		Density kg/m3	7830
2		Yield stress fsy (MPa)	250
		Young's modulus Es (MPa)	2 x 105
		Poisson's ratio μ	0.3
		Density kg/m3	7830
3		Compressive strength fsc (MPa)	25
		Tensile strength fsy (MPa)	3.5
		Young's modulus Ec (MPa	25000
		Poisson's ratio μ	0.18
4		Compressive strength fsc (MPa)	30
		Tensile strength fsy (MPa)	3.83
		Young's modulus Ec (MPa)	30000
		Poisson's ratio μ	0.18

C. Validation of STAAD Pro

The secondary model deployed in STAAD Pro was used as a validation tool since it provided the way to verify the initial stiffness and serviceability limit state tests via assessment of similar section characteristics. The design process used this competent standard as the basis for its early development.
The researchers developed a supplementary linear elastic model which modeled the box section as consisting of a homogeneous material characterized by the same stiffness characteristics as a means of validating initial stiffness and serviceability limit performances.

VII. OUTCOMES AND STRUCTURAL EVALUATION

The experimental results which illustrate the direct relation with the reinforcement ratio proved that ferrocrete confinement works as a while effective method in improving the flexural performance [11], [13].

A. Load-Deflection and Ultimate Capacity

The examined results of the experimental testing provide obvious trends of flexural parameters which are shown in tab I. The flexural performance indicators for confined ferrocrete box beams is presented in table 3 based on data gathered from previous research studies)

TABLE III

Specimen Designation	Core Reinforcement Diameter (mm)	Ultimate Flexural Load (Pu) (kN)	Maximum Mid-Span Deflection (δmax) (mm)	Flexural Rigidity (Pu/δmax) (kN/mm)
FCB-8	8	66	18	3.67
FCB-10	10	74.3	11.3	6.57
FCB-12	12	84.5	10.4	8.12

The results indicate that the use of longitudinal steel increases the final load capacity. The flexural rigidity of the beams from FCB-8 to FCB-12 grew to more than two times its previous value. The performance of an element under service loads getting improved with the help of this increased stiffness which obtains to cause a major reduction in the maximum deflection.

B. Conversation and Comparative Analysis

The Non-linear ANSYS model results are in excellent agreement with the experimental data. Final Load Forecast: The FEM simulations gave an accurate prediction of final flexural strength which showed less than 5% variation from experimental results for all the beam sets [9], [12].

TABLE IV

SampleType	Element Name	Ultimate Load (KN)	Deflection(mm)	Average Ultimate Load (KN)	Average Deflection(mm)
Set I	CB1 – 8 mm	63.43	22.3	65.92	17.98
	CB2 – 8 mm	65.01	12.9		
	CB3 – 8 mm	69.32	18.76		
Set II	CB1 – 10 mm	75.3	15.99	74.33	11.32
	CB2 – 10 mm	68.73	10.42		
	CB3 – 10 mm	78.96	7.56		
Set III	CB1 – 12 mm	87.87	5.19	88.44	5.93
	CB2 – 12 mm	90.45	6.54		
	CB3 – 12 mm	87	6.06		

The three specimen sets which were named consecutively as SET I and SET II and SET III showed the flexural performance with the experiment that tested Confined Ferrocrete Cross-Beams that used 8 mm and 10 mm and 12 mm HYSD 500 bars used for reinforcement. The researchers set out to achieve an accuracy measurement of the amount of ultimate failure load of each of the specimens which was the maximum amount of weight that could be placed on a specimen before structural failure occurred completely.
The FEM method for calculating mid-span deflection measurements reveals persistent underestimation and this is due to the fact that the software model neglects minor boundary condition changes, while the perfect bond assumption needs to be eliminated through proper testing. The total flexural strength of all beams failed when tension steel hit its yielding point and when concrete at the compression zone crushed. The restricting ferrocrete jacket was successful in containing cored concrete which led to delayed collapse usually expected of unconfined

RC sections whereas it induced a controlled slow failure process [8], [11]. The multiple tiny crack existed in the shear span area is a typical characteristic of ferrocement material.

VIII. CONCLUSIONS

The research has shown that constrained ferrocrete box section cross-beams have better structural characteristics when compared with other structural systems with its extensive assessment. The creative composite design manages to achieve the goal because it supplies building materials that are light and extremely strong [8], [9], [11]. The main findings are:

- Direct Proportionality: Amount of primary longitudinal reinforcement take effect directly on the ultimate flexural capacity and rigidity structural beams of constrained ferrocrete.
- Enhancement of Rigidity: Increased diameter of reinforcement increases the flexural stiffness which reduces the maximum deflection by 42% and improves the serviceability.
- Model Reliability: The non-linear FEM technique of ANSYS offers a reliable framework [12] which enables an accurate prediction of composite system flexural capacity while successful modeling of complex failure mechanism.

The research lays the foundations for the scientists to develop better structural materials [15]. The future research should study long term performance by testing creep and fatigue strength while determining best ferrocrete jacket materials which include mesh density and mortar grade).

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