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Generation of Behaviour and Strength Statistics of Brick Beams with Shear Reinforcement Using Ferrocement

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Abstract: ***Ferrocement is a versatile construction material and confidence in the material is building up resulting in its wider application especially in developing countries such as for housing, sanitation, agriculture, fisheries, water resources, water transportation both in freshwater and marine environment, biogas structure, repair and strengthening of older structures, and others. However there have been many structural applications in different parts of the world especially in eastern hemisphere considerable efforts have been made by many individuals and research organization around the world to study the engineering of ferrocement. Such studies include tensile, compressive, impact and fatigue strength and mainly cracking behaviour. In spite of that very less attention has been given to the shear strength of ferrocement beams. These study presents on the behaviour of ferrocement brick beams under central point load. A total of 6 rectangular brick beams have been casted of length 1450mm and width varying between 130mm to 170mm and depth varying between 380mm to 430mm. These beams have been cured for 28 days and on the 28th day they were removed from the water tank and tested. Along with these beams 6 cubes have been casted with the dimensions 7.06 cm x 7.06 cm x 7.06 cm. The compressive strength of mortar is determined used for the mason work. The beams were tested under centre point loading in a loading frame. Ferrocement coatings applied to reinforced brickwork beams help to reduce deflection and increased shear strengths of the members.***

Keywords: Brick Beams, Ferro-cement, Mesh, Load-Deflection, Bricks.

I. INTRODUCTION

Over the past 20 years ferrocement has been used in a number of applications for the strengthening and repair of existing reinforced concrete, steel and concrete water tanks, sewers, swimming pools and the seismic retrofitting of masonry walls. Advantages of ferrocement for this type of work include its enhanced crack control, durability and toughness properties. Brick work is weak in shear, unlike concrete or grouted cavity masonry sections it is generally not feasible to incorporate transverse shear reinforcement into solid brickwork sections.

Abdul Samad, Rashid, Megat Johari, and Abang Abdullla investigated on the ferrocement box beams subjected two points load tests which induce pure bending moment with shear force. The modes of failure and track pattern were observed. The lower the a/d ratio (a/d< 1) the more prominent is the diagonal tension failure, for the higher value of a/d (a/d>1) tends to develop flexural failure of the beam. The ferrocement box section beams have very high shear capacity with very low a/d ratio (0.7) [1]. Abdulla and Katsuki Takiguchi have conducted experimental study on wear of concrete by Ferrocement boxes. The test results indicate that ferrocement boxes offer significant enhancement in stiffness, strength and ductility[2]. Al-Kubaisy and Ned Well studied on the location of the diagonal crack in ferrocement rectangular beams. The variables covered in the study were, a/d volume fraction and compressive strength of the mortar 'f_{cu}'. The results indicated that the location of the critical diagonal crack as measured from the nearest support increases as the a/d ratio is increased and to a lesser extent as 'f_{cu}' is decreased. The effect of the volume fraction, V_f on the location critical diagonal crack is not well defined. It is also concluded that the ACI-ASCE committee 326 expression for predicting the location of the diagonal crack in conventional reinforced concrete beams underestimates the location for ferrocement beams with a/d = 1.0 and over estimates the location for beams with a/d $\geq$ 1.5[3]. Mansur, M.A. and Ong, K.C.G. 1987 conducted shear tests on the ferrocement beam sections and concluded that, the behaviour of these structural sections is similar to that of structural reinforced ferrocement beams. It is also mentioned that the ferrocement beams exhibit numerous cracks and sections are serviceable up to 90% of the ultimate load[4]. P.J. Walker and M. Damo they had shown the feasibility of using ferrocement coating to provide shear strength for the brickworks[5].

Brick work is weak in shear, unlike concrete or grouted cavity masonry sections it is generally not feasible to incorporate transverse shear reinforcement into solid brickwork sections. This paper considers coating as an alternative method of providing shear reinforcement. It is anticipated that a ferrocement coating might also offer improved durability, cracking control, ductility and allow more efficient positioning of tensile steel in the cross section. This paper has undertaken to assess the feasibility of ferrocement for the shear strengthening of reinforced brickwork beams. The results from a series of six beams tests are presented, in which the amount of tensile reinforcement and details of the ferrocement coating were varied. It is anticipated that a ferrocement coating might also offer improved durability, cracking control, ductility and allow more efficient positioning of tensile steel in the cross section.

II. MATERIALS

The materials used in this paper are bricks, cement, sand, water, wire meshes and steel. Details of each constituent are as follows:

A. Bricks: All test beams were fabricated using well burnt locally available clay bricks.

Table-1: Brick properties

Brick properties	Test values
Characteristics compressive strength (N/mm^2)	3.368 n/mm^2
Average absorption (%)	20%
Average dimension	
Length	21.5mm
Breadth	10mm
Height	7mm

B. Wire mesh: Wire mesh is one of the important constituent of Ferrocement. This generally consists of thin wires. The mechanical properties of ferrocement depend upon the type, quantity and strength properties of mesh reinforcement. The wire mesh used in this project is of hexagonal pattern with a diameter of 1mm with mesh opening 12.5mm. The different types of wire mesh are chicken (Hexagonal/aviary) wire mesh, square woven or welded mesh, expanded metal mesh lath etc. Except for expanded metal mesh, generally all the meshes used are galvanized. The properties of wire mesh are tabulated in table-2.

Table-2: Properties of Wire Mesh

Wire mesh type	Properties	Value
Welded wire mesh	Average diameter	1.2mm
	Opening size of mesh	12.5mmx12.5mm
	Yield strength	410 N/mm^2
	Tension Modules of elasticity	10000 N/mm^2

C. Steel: The tensile reinforcement for the brickworks beams comprised plain 10mm diameter mild steel bars. For the reinforcement coating nominal 4mm diameter galvanized mild steel fencing wire is used.

Table-3: Reinforcement details

Type of reinforcement	Average diameter in (mm)	Yield stress N/mm^2	Ultimate stress N/mm^2
Plain mild steel reinforcing bar	10mm	415	520
Galvanized mild steel wire	4mm	415	510

D. Water: Water used for both mixing and curing should be free from injurious amounts of deteriorous materials. Potable water is generally considered satisfactory for mixing and curing of concrete. In the present work potable tap water is used.

E. Cement: Ordinary Portland cement (OPC-53 grade) of Grasim industries Ltd. from a single batch was used throughout the course of the investigation.

F. Sand: Well graded locally available river sand from Shahpur taluka of 2.36mm size was used; lumps of clay were separated out from the sand. The sand having fineness modulus between 4-4.6 is suitable for ferrocement brick beam construction. The grading of sand for mortar mixes becomes very important to get workable cement mortar with low w/c ratio.

III. TEST PROGRAM

A. **Brick work:** All beams were rectangular in cross section with 1450mm length or span, width varying between 130mm to 170mm and depth varying between 380mm to 430mm. The cement used for brickwork was ordinary Portland cement and the sand was the specially graded sand with cement to sand ratio 1:6 and the water cement ratio 0.4 for A-Series beams and 0.35 for B-Series beams. In all, six bed joint reinforced brick beams were fabricated as given in table-4. The bricks were laid in running bond. All tensile reinforcement was placed in the lower most bed joint. The tensile reinforcement for beam series 'A' comprised 2No of 10mm diameter bars as shown in figure and for beam 'B' series it was doubled to 4 No. of 10mm bars as shown in figure-1. The overall length of each beam was normally 1450mm. To account for their high suction the bricks were briefly wetted prior to laying. The brickwork was moist cured under polythene sheeting for 28 days. Six cubes of dimensions 70 x 70 x 70mm have been casted to determine the compressive strength of brickwork mortar.

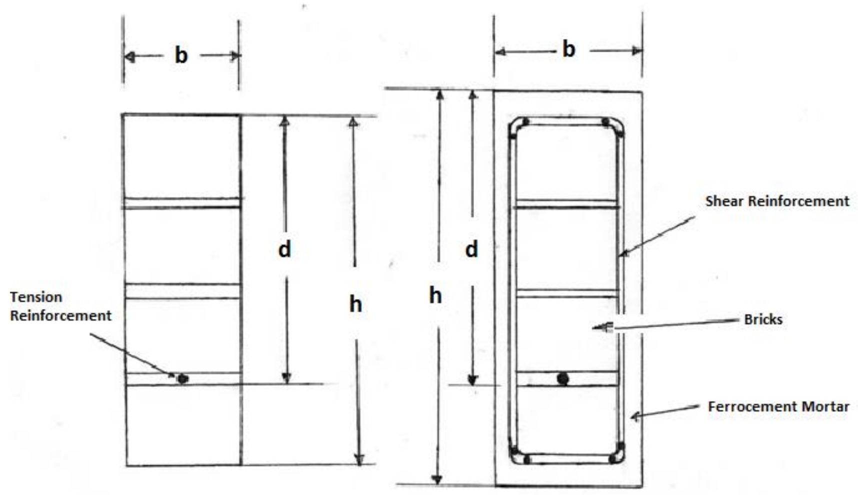

Fig.1: Cross sectional details

B. **Ferrocement Work:** Two beams A-II and A-III were selected to be strengthened using stirrups and ferrocement respectively. Initially beams were prepared by fixing the 4mm wire stirrups at 90mm centres. Stirrups were separated from the face of the brickwork using 2.4mm diameter wire spacers. One layer of wire mesh of 1.0mm diameter and 12.5mm opening was used in beam A-III. Wire mesh was wrapped around the outside of the stirrups tightly by using binding wire. For beam B-II, a layer of wire mesh is wrapped around the beam. For beam B-III 4mm wire stirrups at 50mm centres and one layer of wire mesh wrapped around the outside of stirrups. The cement sand ratio 1:2 with water cement ratio 0.5. The ferrocement mortar nominally 15mm thick was applied in one continuous operation around the perimeter of each beam. The ferrocement mortar was subsequently cured under polythene sheeting for further 7 days.

C. **Test Setup:** The side faces of the beam were painted with white emulsion to assist in crack detection. All the beams were simply supported on the two edges. All specimens were tested under a single concentrated load with a circular attachment applied at the mid-span of the beam using a hydraulic jack. The load is increased gradually by operating hydraulic jack. The deflection under the load point was measured by using an attachment of dial gauge. The load was applied with an increment of approximately 2kN. After each increment of the load the dial gauge reading was taken and a search was made for the appearance of cracks. The load at initial crack for each test specimen is noted. After the failure the ultimate load, mode of failure and cracking pattern were recorded.

Table-4: Brick Beams Details

Beams No.	Dimension (mm)			A_{st} mm²	Shear reinforcement
	B	L	D		
A I	130	1450	380	157	None
A II	140	1480	410	157	Wire stirrup @ 90mm c/c
A III	155	1460	420	157	Wire stirrup @ 90mm + 1 layer mesh
B I	130	1435	380	314	None
B II	150	1440	420	314	1 layer mesh
B III	170	1450	430	314	Wire stirrup @ 50mm c/c + 1 layer mesh

IV. RESULTS AND DISCUSSIONS

The ultimate loads and corresponding shear strengths for each beam is outlined in Table-5 and the load deflection relationships are shown in Fig-2.

Table-5: Test Results

Beams No.	Mortar compressive strength(N/mm²)		Mode of failure	Maximum load(kN)	Shear Strength τ_v (N/mm²)	Total Shear Strength with stirrups τ_{sv} (N/mm²)
	Brickwork	Ferrocement				
A I	11.63	-	Shear	20	0.203	0.203
A II	11.63	30.61	Primary tension + shear	38	0.337	5.81
A III	11.63	30.61	Primary tension + shear	54	0.430	5.38
B I	11.63	-	Shear	32	0.344	0.344
B II	11.63	30.61	Primary tension + shear	50	0.413	0.413
B III	6.6	30.61	Primary tension + shear	74	0.520	16.77

The total shear strength of sections with vertical stirrups τ_{sv}

$$\tau_{sv} = (\tau_v + A_{sv}\,\sigma_y / b_{sv})$$

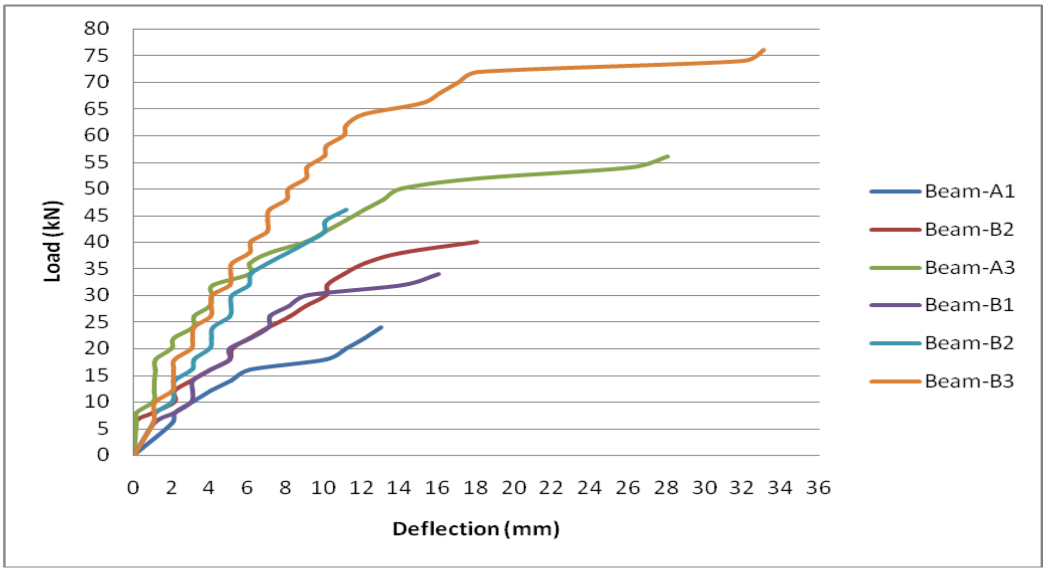

Fig-2: Load-Deflection Relationship for different Beams.

Application of a ferrocement coating increased shear strength significantly. Wire stirrups at 90mm centres increased shear strength of beam series A and including one layer of wire mesh further increased shear strength with respect of beam A-I. Similarly the shear strengths of beam series B were increased. Interestingly application of a plain high strength mortar rendering alone increased shear strength of beam B-II, with respect to B-I. The inclusion of wire stirrups at 50 mm centres further increase capacity beam B-III.

3 phases have been observed from load deflection graph

1) Up to first crack the load deflection response was linear, which indicates that the tensile steel was elastic.
2) On further increase in the load. The load deflection response was found linear and increase rate of deflection.
3) On further increase in the load, the load defection response was found non-linear. After reaching yield point by tensile steel there was large increase in deformation.

Beams A-I and B-I without ferrocement coating have shown first two phases of behaviour. This is due to premature shear failure. Ferrocement coatings increases beam stiffness and the load at the first cracking. Inclusion of wire stirrups improved beam ductility.

V. Conclusions

1) Ferrocement coatings may be used to provide effective shear reinforcement for brickwork sections.
2) A plain high strength mortar render alone can significantly improve shear strength. However, without shear reinforcement the plain mortar coating is very brittle.
3) Increasing steel content in the ferrocement coating enhances shear capacity.
4) Ferrocement coatings applied to reinforced brickwork beams help to reduce deflection, increase loading at first cracking, and enhanced section ductility.
5) To improve efficiency of the technique, there is a need to ensure an effective anchorage for the wire stirrups.

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