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AN APPRAISAL OF THE SHEAR RESISTANCE OF FERROCEMENT ELEMENTS

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ABSTRACT

This paper deals with the shear strength of simply supported ferrocement rectangular plates subjected to four points loading. Limited literature is available on the shear behavior of ferrocement elements, as the span to depth ratio of these elements is very high. However, studies on the shear response of ferrocement assume importance to understand the material behavior. In the present study, tests on ferrocement elements varying the shear span to depth ratio (a/d) and different layers of mesh are conducted. It is observed that increase in the volume fraction of the mesh reinforcement (number of layers of mesh) increased the shear capacity of the member. It is also found that up to Shear span to depth ratio 3, shear behavior is predominant. Beyond shear span to depth ratio 3, the flexural behavior is predominant and design of the elements based on flexure is sufficient.

Keywords: Composite-shear resistance-shear span-ferrocement-web shear

1. INTRODUCTION

Ferro cement is a composite material constructed by cement mortar reinforced with closely spaced layers of wire mesh. The ultimate tensile resistance of ferrocement is provided solely by the reinforcement in the direction of loading. The compressive strength is equal that of the un reinforced mortar. However, in case of flexure and shear, the analysis and design of ferrocement elements are complex and are based primarily on the reinforced concrete analysis using principle of equilibrium and compatibility. Unlike studies on the behavior of ferrocement elements undert flexure very limited research reports are available on the shear behavior of ferrocement elements. The reason for this may be due to the fact that the span to depth ratio of these elements is very high. But the use of ferrocement is not limited to stressed skin elements alone and it finds application in the construction of compound structural sections like I, T, C and L etc., Thus, there is a need for the understanding of this material under shear loading.

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Literature Review: Abdul Samad, Rashid, Megat Johari, and Abang Abdulla [1] investigated on the ferrocement box beams subjected two point load tests which induces pure bending moment with shear force. The modes of failures and crack pattern were observed. The lower the a/d ratio (≤ 1) the more prominent is the diagonal tension failure, for the higher value of 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).

Al-Kubaisy and Ned Well [2] 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_c'. 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_c' 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 under estimates the location for ferrocement beams with a/d = 1.0 and over estimates the location for beams with a/d ≥ 1.5.

Mansur [3] conducted shear tests on the ferrocement Channel sections and concluded that, the behavior of these structural sections is similar to that of structural reinforced concrete sections. It is also mentioned that the ferrocement beams exhibit numerous cracks and sections are serviceable up to 90% of the ultimate load.

Desayi [4] proposed a semi empirical formula for predicting the shear strength of ferrocement elements.

Till today no codal formula is available to assess the shear strength of ferrocement elements. Thus there is a need to verify, where the shear resistance equations given by existing codes of practice for reinforced concrete can be extended to ferrocement also? This is because; ferrocement can be visualized as a variety of concrete having aligned reinforcing mesh in place of coarse aggregates of conventional concrete.

2. OUTLINE OF EXPERIMENTAL PROGRAMME

The experimental investigation consists of casting and testing six series (A, B, C, D, E, and F) of plates. The six series of plates were tested for different shear span to depth ratios viz., 1, 2, 3, 4, 5 and 6 respectively. In each series number of mesh layers were varied as 0 (un reinforced), 3,4,5 and 6. For each shear span–depth ratio (a/d ratio) two plates were tested and the average was taken as the representative capacity of the corresponding plate. The Dimension of each plate is 600mmx150mmx25mm. The dimensions and details of plates were shown in Figure 1. Thus plates are designated accordingly. A plate of designation C4 represents that the plate consists of 4 layers of mesh wire and is tested for shear span to depth ratio of 3.

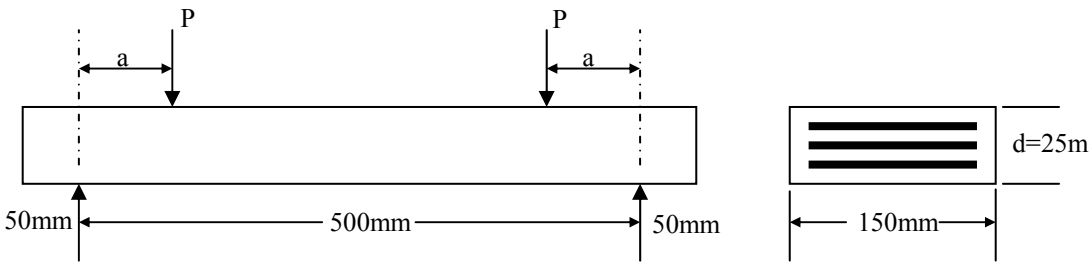

Figure 1. Cross section details for specimen

2.1 Materials used

The cement used in this work was Portland Pozzolona Cement conforming to the requirements of IS 1489:1991. Fine aggregate used in this work was river sand obtained from a local source, sand passing through IS sieve 4.75mm was used in the investigation. The mortar used in this investigation is 1:2 with a water cement ratio of 0.45. The compressive strength of the mortar found to be 32.2Mpa while the splitting tensile strength of the same was found to be 2.85 MPa.

2.2 Mesh reinforcement

Galvanised woven mesh was used as reinforcement to the ferrocement elements. The wire diameter was found to be 0.55mm. The yield strength of the wires of the mesh was found to be 380 Mpa. The openings in the mesh measures 2mm×2mm.

2.3 Fabrication of the test specimens

Wooden moulds of required size are used as formwork for casting the plates. 3mm GI wires were used as separators for the meshes. The required numbers of layers of meshes in the required size were placed in the wooden formwork, and then the cement mortar was applied intermittently. The whole formwork was placed on a horizontal platform. For better compaction, the formwork was vibrated until the mortar slurry started coming out of the formwork. Clamps were used to prevent the bulging of the moulds. For each series of casting, mortar cubes and cylinders were also cast. The ferrocement plates, companion cylinders and cubes were removed from the moulds one day after casting. The ferrocement plates and auxiliary specimens were placed in curing tank for curing. All these specimens were cured up to 28 days. They were kept in a cool dry place until they were tested.

2.4 Testing procedure

All the plates were tested on testing machine. The Load was applied by means of a proving ring. The load was transferred as a two point symmetrical load by means of steel rods as shown in Figure 2. The test plates were launched on to the cross head of the machine, and were centered over the supports. The load points were marked as per requirement of a/d ratios. The beams were subjected to two symmetrical point loads. The deflection gauges of 0.01mm least count and 50mm range were fixed under load points, which were marked previously. The crosshead of the machine was raised until the fixed head of the machine just

touches the roller placed at the center of loading beam. Experimental setup is shown in Figure 2.

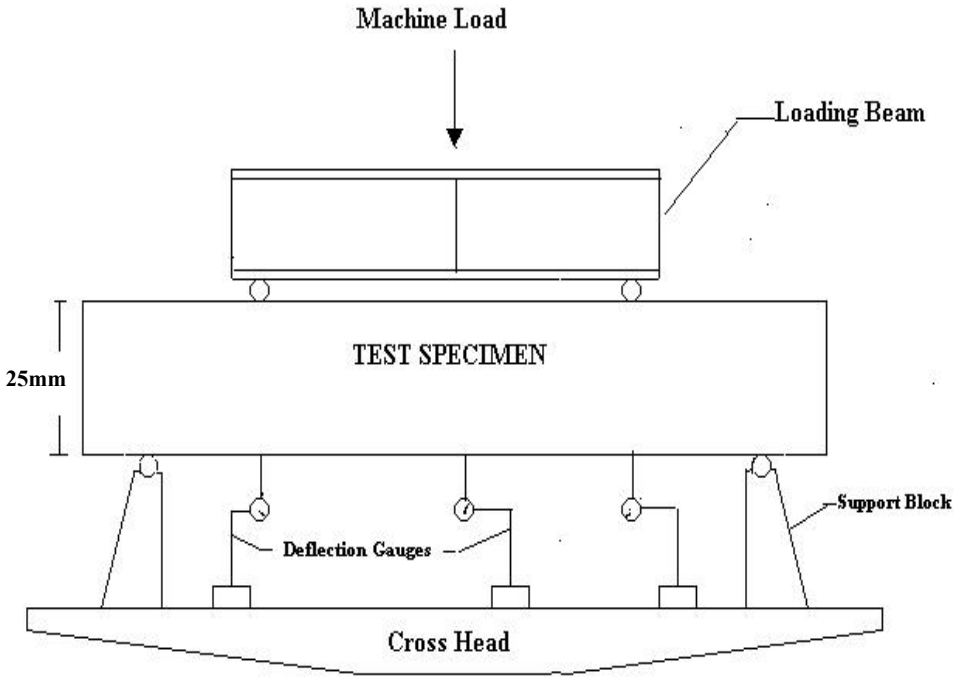

Figure 2. Experimental Setup

The deflection gauges reading were noted for each interval of load increment. The crack patterns were drawn. Every care has been exercised to obtain the drooping portion of the load response of the testing specimen during the testing. Loads that produced the initial diagonal crack and the ultimate load were recorded. The load at which visible cracking has occurred was considered as cracking load. Table 1 shows the test results of the all tested elements.

2.5 Test results and discussions

All un reinforced plates having failed all of a sudden without giving any prior information. The failure is brittle in nature. However, at shear span to depth ratio 5 and 6 the specimens failed in flexure. A single major crack developed in the constant moment region.

All the ferrocement specimens failed in shear, in all the plates and no visible cracks were observed until 20% to 25% of the ultimate load. The behavior of all elements was linear until tension cracks formed. Tension cracks were initiated on the bottom surface of the beams and spread vertically upward. Around at 40% to 50% of ultimate load new cracks initiated between the supports and the nearest load points. Further increase in load increased the cracks and reached the load point. In case of plates with shear span to depth ratio 4 more number of flexural cracks in the region of constant moment region also along with the diagonal cracks, indicating shear flexure mode of failure. Once the inclined crack initiated, flexure cracks stopped propagating and the inclined cracks started moving towards the top.

Table 1. Test results

Designation of the Specimen	a/d ratio	A_{ls} (mm^2)	v_f	V_u (N)	V_{cr} (N)	V_u/V_{cr},	Failure mode
A0	1	0	0	1839.4	1839.4	1	S
A3	1	53.454	1.425	8240.4	1840	4.48	S
A4	1	71.272	1.90	9932.6	1855	5.35	S
A5	1	89.090	2.375	12017	1862	6.45	S
A6	1	106.908	2.850	13489	1875	7.19	S
B0	2	0	0	931.95	931.95	1	S
B3	2	53.454	1.425	3924	932.15	4.21	S
B4	2	71.272	1.90	4954.1	934.21	5.3	S
B5	2	89.090	2.375	5787.9	938.42	6.17	S
B6	2	106.908	2.850	6572.7	942.21	6.98	S
C0	3	0	0	490.5	490.5	1	S
C3	3	53.454	1.425	2207.3	492.32	4.48	S
C4	3	71.272	1.90	2550.6	496.12	5.14	S
C5	3	89.090	2.375	2967.5	498.32	5.96	S
C6	3	106.908	2.850	3359.9	502.23	6.69	S
D0	4	0	0	441.45	441.45	1	FS
D3	4	53.454	1.425	1594.1	442.23	3.6	FS
D4	4	71.272	1.90	1986.5	444.81	4.47	FS
D5	4	89.090	2.375	2354.4	447.01	5.27	FS
D6	4	106.908	2.850	2648.7	449.28	5.9	FS
E0	5	0	0	402.21	402.21	1	F
E3	5	53.454	1.425	1422.5	402.81	3.53	F
E4	5	71.272	1.90	1863.9	403.75	4.62	F
E5	5	89.090	2.375	2158.2	404.15	5.34	F
E6	5	106.908	2.850	2403.5	404.82	5.94	F
F0	6	0	0	338.45	338.45	1	F
F3	6	53.454	1.425	1373.4	339.21	4.05	F
F4	6	71.272	1.90	1839.4	340.05	5.41	F
F5	6	89.090	2.375	2148.4	340.95	6.3	F
F6	6	106.908	2.850	2393.6	341.65	7.01	F

Several diagonal tension cracks have formed in ferrocement plates before the ultimate load is reached. The one that forms first is referred to the initial diagonal tension crack and the corresponding load is called the initial diagonal tension-cracking load. The ratio of the ultimate load to the cracking load is presented in Table 1. First crack load and ultimate load were almost same for the plain mortar elements. For ferrocement elements ultimate load was higher than the cracking load. It can be understood that, till the initial crack form reinforcement will not come in resisting the external forces, while after initial cracking the effect of mesh present in the ferrocement elements was pronouncing.

In most elements with a/d ratio 1 to 3, the elements failed with a single shear crack. The diagonal cracks started from the midst of the shear span and propagated towards the load point. The elements tested for a/d ratios 5 and 6 major cracks, leading to the ultimate failure, formed in the constant moment zone and multiple cracks were observed. The formation of multiple cracks reflects the enhanced ductility of the ferrocement elements. The ultimate load carrying capacity increased with the increase in the number of layers. The increase in the shear load carrying capacity of the ferrocement elements with increase in the volume of mesh (v_f) was presented in Figure 3.

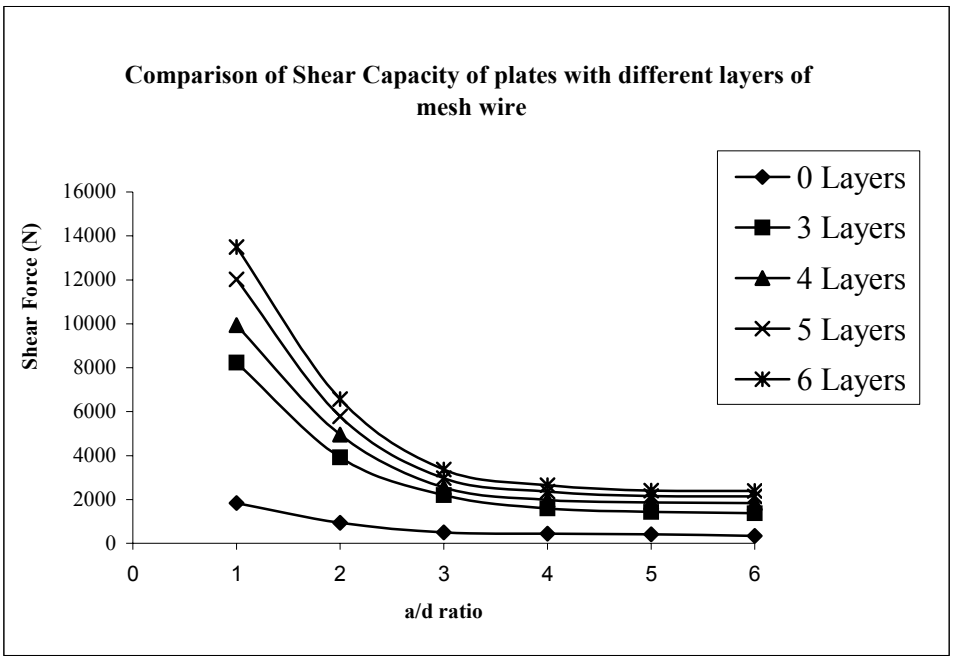

Figure 3. Comparison of shear capacity of plates with different layers of mesh wire

From this variation it can be understood that the shear load carrying capacity of the ferrocement elements improves with the increase in the longitudinal reinforcement (mesh reinforcement), which is similar to the improvement of shear strength of conventional reinforced concrete members with increase in the longitudinal reinforcement. This argument seems to be acceptable as the ferrocement also one variety of concrete, where in coarse

aggregates of ferrocement are replaced by aligned woven wire mesh. Thus to predict the shear capacity of ferrocement elements, equations used for reinforced concrete can be adopted with or without any modifications. The ultimate shear load of the tested ferrocement plates were compared with the shear capacity calculated based on two codes of practice, which were prepared for reinforced concrete.

2.6 Comparison of test results with codal predictions

The two codes of practice considered in this study are Australian code (AS 3600-1994) and American Code (ACI Committee 318-95). The shear resistance of the section is influenced by the tension reinforcement. In ferrocement mesh reinforcement is placed in layers. Thus to find the percentage tension reinforcement, flexural analysis was carried out using strain compatibility and equilibrium. The comparison of ultimate shear strength of ferrocement elements with the ultimate shear strength of the same using the guidelines given in the mentioned codes was presented in Table 2. The ratio of experimental shear strength to predicted shear strength based on the code provisions ($V_{exp.}/V_{aus.}$) reveals that Australian code overestimates the shear strength of ferrocement elements. The reason for this may be attributed to the presence of longitudinal reinforcement in layers over the entire depth of the ferrocement element, while it is not in the case of reinforced concrete elements. However the average, coefficient of variation and standard deviation of $V_{exp.}/V_{aus}$ of all tested ferrocement elements was found to be 0.94, 0.22 and 0.05 respectively. Thus with suitable modifications to Australian code formula for predicting shear strength of RCC elements can be extended to even ferrocement also. The ratio of experimental shear strength to predicted shear strength based on the code provisions ($V_{exp.}/V_{aci.}$) reveals that ACI code also overestimates the shear strength of ferrocement elements. This overestimation is very high in case of plain ferrocement elements. The reason for this may be attributed to the smooth fracture plane during the failure of plain ferrocement element. In case un reinforced concrete members the aggregate particles increase the friction along the failure plane, increasing the ultimate shear strength of the member. The average, coefficient of variation and standard deviation of $V_{exp.}/V_{aci.}$of all tested ferrocement elements was found to be 0.97, 0.81 and 0.66 respectively. Thus there is a need for a separate expression for predicting shear strength of ferrocement elements.

2.7 Load deflection curves

A typical shear load and deflection (measured under the shear load point) response of the series of plates tested for a/d ratio 2 and 6 were presented in Figure 4 and Figure 5 respectively. From these Figures, it can be concluded that ductility of ferrocement elements are of many folds compared to the plain cement mortar elements. It is also observed that the plates failing in shear (a/d=2) had low ductility compared to the plates failing in flexure (a/d=6).

Table 2. Comparison of experimental results with predicted values using codes

Designation of the Specimen	a/d ratio	ACI Formula (N)	Australian Code (N)	Experimental Shear (N)	Exp./ACI ($V_{exp}/V_{aci.}$)	Exp./AUS ($V_{exp}/V_{aus.}$)
A0L	1	3039.91	NA	1839.4	0.61	NA
A3L	1	3345.5	6452.43	8240.4	2.46	1.28
A4L	1	3956.67	13421.59	9932.6	2.51	0.74
A5L	1	4210	15792.35	12017	2.85	0.76
A6L	1	4332.54	16876.54	13489	3.11	0.80
B0L	2	3039.91	NA	931.95	0.31	NA
B3L	2	3192.71	3226.21	3924	1.23	1.22
B4L	2	3498.29	6710.8	4954.1	1.42	0.74
B5L	2	3624.96	7896.17	5787.9	1.60	0.73
B6L	2	3686.23	8438.27	6572.7	1.78	0.78
C0L	3	3039.91	NA	490.5	0.16	NA
C3L	3	3141.78	2150.81	2207.3	0.70	1.03
C4L	3	3345.5	4473.86	2550.6	0.76	0.57
C5L	3	3429.94	5264.12	2967.5	0.87	0.56
C6L	3	3470.79	5625.51	3359.9	0.97	0.60
D0L	4	3039.91	NA	441.45	0.15	NA
D3L	4	3116.31	1613.11	1594.1	0.51	0.99
D4L	4	3269.1	3355.4	1986.5	0.61	0.59
D5L	4	3332.44	3948.09	2354.4	0.71	0.60
D6L	4	3363.07	4219.13	2648.7	0.79	0.63
E0L	5	3039.91	NA	402.21	0.13	NA
E3L	5	3101.03	1290.49	1422.5	0.46	1.10
E4L	5	3223.27	2684.32	1863.9	0.58	0.69
E5L	5	3273.93	3158.47	2158.2	0.66	0.68
E6L	5	3298.44	3375.31	2403.5	0.73	0.71
F0L	6	3039.91	NA	338.45	0.11	NA
F3L	6	3090.84	1075.4	1373.4	0.44	1.28
F4L	6	3192.71	2236.93	1839.4	0.58	0.82
F5L	6	3234.93	2632.06	2148.4	0.66	0.82
F6L	6	3255.35	2812.76	2393.6	0.74	0.85
				Average	0.97	0.94
				SD	0.81	0.22
				COV	0.66	0.05

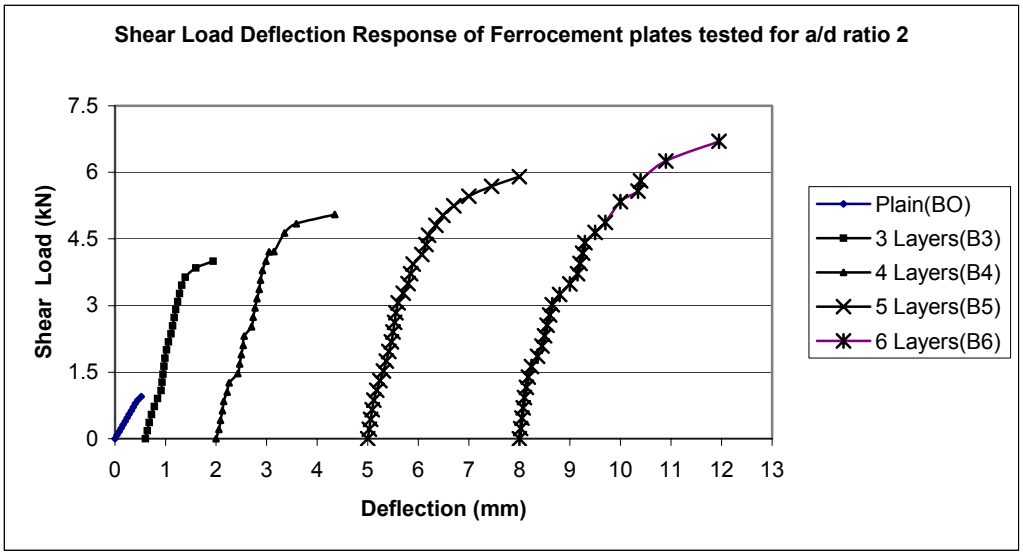

Figure 4. Shear load deflection response of ferrocement plates tested for a/d ratio 2

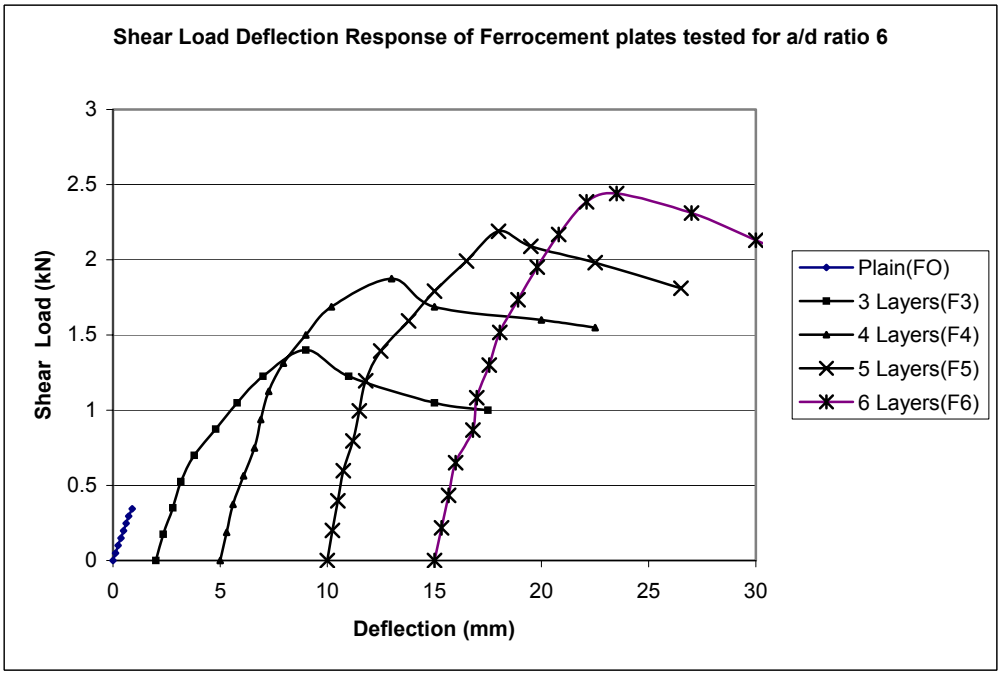

Figure 5. Shear load deflection response of ferrocement plates tested for a/d ratio 2

2.8 Empirical Formula for the shear capacity of Ferrocement Elements:

From the earlier discussion it is clear that, a separate formula for predicting the shear

capacity of ferrocement elements is necessary. Shear resistance of ferrocement elements is mainly due contribution of matrix (mortar) and longitudinal reinforcement. Shear resistance has been expressed as

$$\frac{V_u}{bd} = k\frac{\sqrt{f_{cm}}}{a/d}$$

In the above expression a/d is the shear span ratio, V_u is shear capacity of the cross section, b is the breadth of the cross section, f_{cm} is the compressive strength of the mortar and k is a constant. From the experimental result of plain mortar elements as shown in Figure 6 the k value found to be 0.0856. Thus for plain elements shear strength can be expressed as

$$\frac{V_u}{bd} = 0.0856\frac{\sqrt{f_{cm}}}{a/d} \tag{1}$$

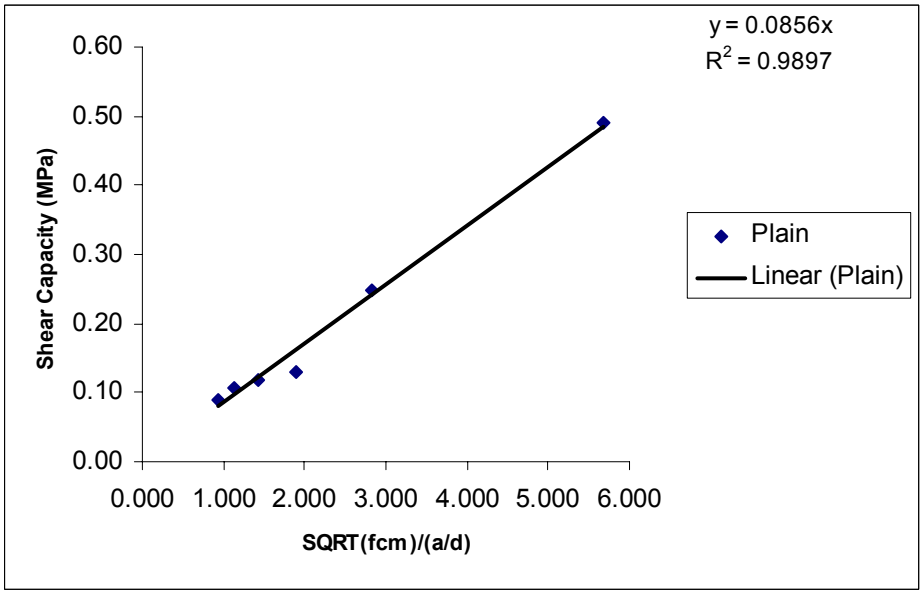

Figure 6. Regression between the parameters $\frac{V_u}{bd}$ and $\frac{\sqrt{f_{cm}}}{a/d}$

Shear resistance of ferrocement elements can be expressed as the sum of shear resistance due to mortar and aligned fiber. Thus from the experimental data regression analysis has been performed between the terms (Vu-Vm)/bd, i.e., shear strength excluding mortar

contribution, and $v_f \frac{f_y}{a/d}$. A linear regression between these two parameters, shown in Figure 7, revealed that the mesh contribution toward shear resistance of ferrocement elements could be predicted as

$$\frac{V_u - V_m}{bd} = 0.0028 v_f \frac{f_y}{a/d} \tag{2}$$

From the equations (1) and (2) the shear resistance of a ferrocement element can be estimated as

$$\frac{V_u}{bd} = \frac{\sqrt{f_{cm}}}{a/d}\left\{0.0856 + 0.0028\frac{v_f f_f}{\sqrt{f_{cm}}}\right\} \tag{3}$$

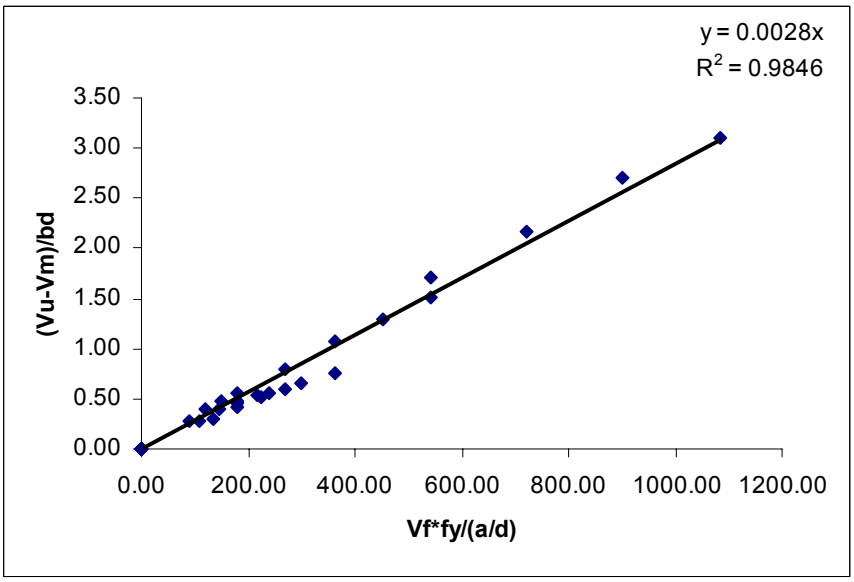

Figure 7. Regression between the parameters $\frac{V_u - V_m}{bd}$ and $v_f \frac{f_y}{a/d}$

3. CONCLUSIONS

Based on the limited test results on the ferrocement elements the following conclusions were drawn.

1. The load carrying capacity and ductility of plain ferrocement elements improved by

several folds with the inclusion of aligned wire mesh. Increase in the number of mesh layers increase both the shear load carrying capacity as well as the ductility of the composite.

2. Shear behavior of ferrocement elements is almost similar to the shear behavior of reinforced concrete elements.
3. Up to Shear span to depth ratio 3, shear behavior is predominant and thereafter-flexural behavior is predominant.
4. The proposed empirical expression can estimate the shear strength of ferrocement elements.

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NOTATIONS:

a/d ratio: shear span to depth ratio
A_{ls}: Cross sectional area of the longitudinal aligned reinforcing mesh
v_f : Volume fraction of the mesh reinforcement ($100*A_{ls}/bd$).
b: Breadth of the plate (150mm)
d: Depth of the plate (25mm).
V_u: Ultimate shear load
V_m: Ultimate shear load of mortar elements
V_{cr}: Cracking shear Load.
f_m: Compressive strength of mortar.
f_y: Yield strength of the mesh wire.
S: Shear mode failure
FS: Flexure shear mode failure

F: Flexure mode failure