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Investigation of Ferro Cement Composite Beam Under Flexure

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Abstract – Ferro cement is a thin, versatile construction material, with several unique properties and suitable for wide range of applications in Civil Engineering. Generally concrete structures are designed for static loads but sometimes dynamic loads like blasts etc. Prefabricated elements are used in construction industry as an alternative system to overcome the formwork problems in addition to getting better quality control. The prefabricated elements made of reinforced concrete are extremely heavy and difficult to transport, placing in position and to construct. Because of its good structural performance and low cost ferrocement is used in construction industry. Ferrocement is suitable for the construction of roofing/floor elements, precast units, manhole covers, and construction of domes, vaults, grid surface and folded plates. So finding the flexural behavior of ferrocement is necessary. Therefore, the flexural strength is determined by varying the meshes in the U-section and varying the thickness of the beam. An experimental and finite element analysis on flexural behavior of ferrocement U-shape channel section reinforced with wire mesh with varying number of wire mesh layers is presented. Finite element analysis of U-shape ferrocement channel was carried out. The finite element analysis (FEA) has been also used to model the ferrocement U-shape channel for various span and thickness. Ferrocement U-shape channel with varies thickness and number of mesh layers analyzed in ANSYS.

Keywords: Ferrocement, U-shape channel section, Flexure.

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INTRODUCTION

The definition of ferrocement is given by ACI Committee 549: "Ferrocement is a type of thin wall reinforced concrete constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh". Mesh may be made of metallic or other suitable materials. The matrix may contain discontinuous fibers. This definition ignores as important type of reinforcement currently in use in ferrocement i.e. the combination of steel rods and wire mesh.

India has been identified as a developing economy which tends to give rise to a lot of infrastructure developments especially the building projects. RCC is most widely used in all over world because of its high load carrying capacity but the cost of cement and steel is increasing day-by-day. So, we require a substitute to concrete which gives se strength as that of RCC with low cost. In ferrocement, hydraulic cement mortar with closely spaced small diameter wire meshes is used. To improve certain characteristics of ferrocement various materials such as admixtures, silica fumes, fly ash and fibres are used. Generally, the thickness of ferrocement ranges from 20 – 50 mm.

APPLICATION OF FERROCEMENT

1. Ferrocement can be used in Agricultural work such as in storage bins, irrigation channels, pipes and pedestrian bridges.

2. It can be used in new structures and repair & rehabilitation works. It can also be used in case of marine for docks, submarine structures, etc.

3. It can be used in case of pothole repairs, lining of swimming pools and corroded steel water tanks.

4. Structural application of ferrocement were boats, tanks, silos, roofs and the high cost of traditional wooden or steel form work led to the idea of using ferrocement laminate as permanent forms in concrete construction.

DISADVANTAGES OF FERROCEMENT

1. It fails in compression due to absence of mass concrete.
2. Increment in weight due to skeleton steel.
3. Liable to corrosion due to bad compaction.
4. Because of distinctive shapes trouble in construction.
5. Time consuming technique.
6. Frequently suffers from intense spelling of matrix cover.
7. Labour demanding therefore excessive Labour cost.

CONSTITUENT MATERIALS OF FERROCEMENT

1. **Cement:** Cement is a material having adhesive and cohesive properties that helps in bonding mineral fragments into compact mass. Some forms of mortars are used to bind together stone, gravel and other material for structural functions. The cement should be clean, having equal consistency and free from lump.
2. **Fine Aggregate:** Fine aggregate must be clean and free from dust and silt. Fine aggregates should be natural sand which might be a mix of silica, basalt rock, limestone or even soft coral.
3. **Water:** The clean potable water should be used for mixing of mortar as well as curing of ferrocement elements. The water should be free from acids, gravel, silts, oils and chlorides.
4. **Admixture:** Chemical admixture can be used for water reduction with strength and reduce permeability, air voids which rises resistance to cold and thaw effect between wire mesh and cement. Admixtures are used to raise the workability, to minimize water demand and to increase mortar setting.
5. **Reinforcing mesh:** Reinforcing mesh is the essential components in ferrocement. Different kinds of wire mesh are available in market. Various steel meshes for ferrocement includes square welded or woven mesh, expanded Meta lathe sheet similar to those used in plaster, chicken wire mesh of hexagonal shape. The function of wire mesh is to hold the mortar and form in liquid state and in toughened state it should take the tensile stresses which mortar, on its own, could not withstand. Different types of wire mesh are listed below:

1. Square woven wire mesh: In this type of mesh, wire is bent in a zigzag shape and grid is formed by interlinking the wires without welding the intersections.
2. Square welded wire mesh: In this type of mesh, wires are straight and grid is obtained by welding the perpendicular wires at intersections.
3. Chicken wire mesh: In this type of mesh, the wire meshes are in hexagonal pattern. After weaving the cold drawn wire, the hexagonal pattern is obtained. This type of mesh is also called as Aviary wire mesh.
4. Expanded metal mesh: The expanded metal mesh is not so strong compared to others. This is formed by cutting a thin expanded metal sheet so as to form diamond shape openings. Different types of meshes are shown in Figure 1.

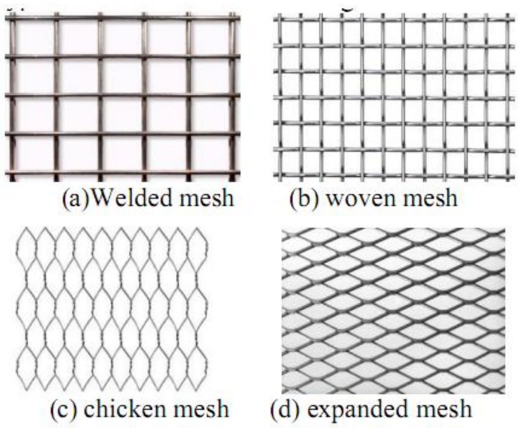

Figure 1. Types of meshes

FERROCEMENT COMPOSITE: -

1. Thickness 6 to 50 mm.
2. Steel cover 1.5 to 5 mm.
3. Ultimate tensile strength up to 34MPa.
4. Allowable tensile stress up to 10MPa.
5. Modulus of rupture up to 55MPa.
6. Compressive strength up to 28MPa to 69MPa.

CEMENT –MORTAR MATRIX

The main ingredients of ferrocement matrix are OPC (Ordinary Portland Cement), fine aggregate, water and admixture. Various additives such as silica fumes, fly ash, super-plasticizers and air-entraining agents are used in various ferrocement applications such as water reduction, good workability and improved permeability. For increasing the cracking behaviour of matrix fibres may be used. Some factors that have an effect on the properties of mortar are –

1. Water / Cement ratio: The water / cement ratio usually ranges from 0.35 to 0.60 by weight. For high strength and low shrinkage, water / cement ratio is kept low

2. Sand / Cement ratio: The ratio of sand / cement must lie between 1 to 1.25 by weight.

3. Grade of Sand: For workable mix, proper gradation of sand is needed. Sand must be free from silt, organic materials and it must pass through 2.36-millimeter sieve.

DIFFERENCE BETWEEN REINFORCED CEMENT CONCRETE (RCC) AND FERROCEMENT

Table 1. Difference Between Reinforced Cement Concrete And Ferrocement

No.	Titles	RCC	Ferrocement
1	Thickness	Minimum 75mm thick	Much thinner (25 to 50mm)
2	Reinforcement	Not distributed throughout thickness	Distributed throughout thickness
3	Reinforcement direction	May or may not be	Reinforced in two directions
4	Matrix composition	Cement, Fine aggregate,	Rich mix of cement and Fine aggregate
5	Reinforcement	Steel Bars > 6mm dia,	Continuous Fine Wire mesh
6	Specific Surface	Very High	Low
7	Strength	Weak in tension, bond, punching	High tensile strength, superior bond & better
8	Strength to Weight Ratio	Very Low	Very High
9	Ductility	It is Less	It is more
10	Formwork	Quite essential.	Wire meshes can be tied tightly which act as forms for mortar casting.
11	Labour cost	Moderate	Very high

EXPIREMENTAL PROGRAM

Material used

1. Cement

The cement used in the test was Ordinary Portland Cement (Grade 43) Birla Super Gold according to requirements of IS code IS 1489:1991.

Tests on Ordinary Portland cement: -

1. Setting Time
2. Soundness
3. Fineness
4. Compressive Strength

2. Water

Portable Municipal tap water was used as a hydration agent in concrete and mortar. The water was clean and free of any salts, silt, oil and organic matter.

3. Admixture

Perma Plast Super PS 34 is used which is a multicomponent liquid admixture based on high molecular weight polymers and naphthalene formaldehyde. The Perma plast Super PS 34 is used so as to produce self-compacting flowing mortar and to get high early strength concrete or mortar. It is used in a specify range of 0.5 to1.5 % of weight of cement for initiating trail based on type of mortar required.

4. Fine Aggregates

5. Reinforcing Steel Mesh

5. Moulds

For ferrocement channel section 200mm width 150mm height and 2000mm length are manufactured to cast channel section having varying thickness from 20-50mm. with different number of mesh layers.

Figure 2.Mould for U-shape beam

Fabrication of Specimens

This topic includes the information relating to test specimen from their specific dimensions to the process of fabrication.

Types of Specimen Used

In this study, four types of ferrocement channel sections are fabricated; total fourteen types of specimens are casted and tested. The four types of sections are as follows-

1. 20mm 2 layer (using welded and woven mesh)
2. 30mm 2 &4 layers (using welded and woven mesh)
3. 40mm 2 &4 layers (using welded and woven mesh)
4. 50mm 2 &4 layers(using welded and woven mesh)

The thickness of channel section is increased from inner side of channel section keeping the outer dimension constant to be 200mm X 150mm.

20 mm channel section with square welded and woven mesh**:**

Sectional Dimension: 200mm X 150mm X 2000mm

Thickness of web: 20mm

$\frac{l}{D}$: 13.4

Thickness of steel mesh: 1.6mm

No. of Mesh layers: 2

Clear cover for ferrocement steel mesh: 4 mm

Clear spacing between two steel meshes: 12 mm

Diameter steel mesh: 1.6mm

Thickness of flange: 20mm

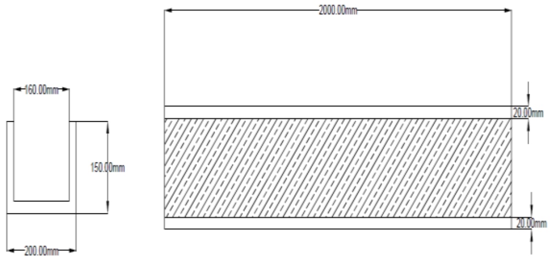

Figure 3. Detailing for 20mm thick channel section.

Experimental Setup

In this topic, the specifics of the experiment and its setup procedure are detailed.

1. **Universal Testing Machine**

Universal Testing Machine also known as UTM for short is a multifunction testing machine for various tests for compression, Tension, Flexure etc. The load in UTM is applied by hydraulic action. The UTM in Applied Mechanics Department of MIT College, Pune was utilized for experimental work conducted. The capacity of UTM was 100 tonne.

Deflection Gauge

The deflection gauge used in the experimental work was readily available in Applied Mechanics Department of MIT College, Pune. It has a least count of .01mm or 10micron.

Four-Point Bending Test

At the time of testing, the specimen was painted with white paint to facilitate the visual crack detection during testing process. The specimen was laid on a universal testing machine of maximum capacity of 100 kN where the test was conducted under a four-point loads system with a span of 1800 mm. one dial gauges with an accuracy of 0.01 mm were placed under the test specimen at the centre to measure the deflection versus load. Load was applied at 100 N increments on the specimen exactly at the centre. Concurrently, the beam deflections were determined by recording the dial gauge reading at each load increment. Cracks were traced throughout the sides of the specimen and then marked with white chalk markers. The first crack-load of each specimen was recorded. The load was increased until complete failure of the specimen was reached.

Calculation for Flexural Strength

The flexural strength formula is given by –

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$$\frac{M}{I} = \frac{f}{y} \#1$$

$$f = \frac{M}{Z} \times y \#2$$

Where,

M = Bending Moment (N.mm) = PL/6

I= Moment of Inertia

$$y = \frac{A_1 y_1 + A_2 y_2 + A_3 y_3}{A_1 + A_2 + A_3}$$

I=MomentofInertia= $\frac{b \times t^3}{12} \times b \times t \times (y - \frac{t}{2})^2 + 2 \times (\frac{t \times D^3}{12} + D(\frac{D}{2} - y)^2)$

Moment acting on channel section, M = $\frac{PL}{6}$

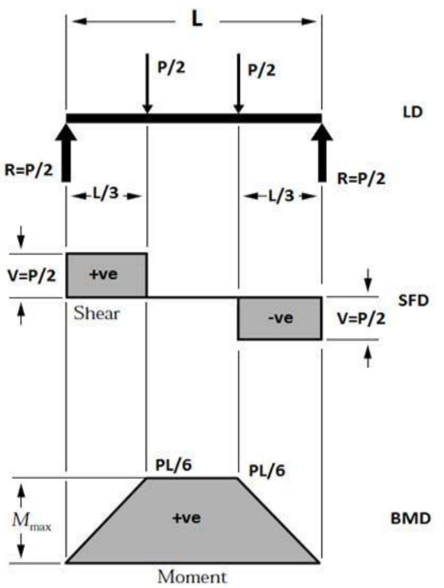


Figure 3.10 SFD and BMD of slab

20mm Thickness (200mm X 150mm X 2000mm) 2 Layers welded channel section:

Calculation of flexural strength: -

Thickness of section, t= 20mm, Outer Height of wed section, D = 150mm

Outer length of flange section, B= 200mm, Inner length of flange section, b = 160mm

Load acting on slab, P=2800N

$y = \frac{A_1 y_1 + A_2 y_2 + A_3 y_3}{A_1 + A_2 + A_3} = \frac{(160 \times 20 \times 10) + 2 \times [20 \times 150 \times 75]}{(160 \times 20) + 2 \times (20 \times 150)}$ = 52.391mm

I = Moment of Inertia = $\frac{b \times t^3}{12} \times b \times t \times (y - \frac{t}{2})^2 + 2 \times (\frac{t \times D^3}{12} + D(\frac{D}{2} - y)^2)$

$$= \frac{160 \times 20^3}{12} \times 160 \times 20 \times \left(52.391 - \frac{20}{2}\right)^2 + 2 \times \left[\frac{20 \times 150^3}{12} + 20 \times 150 \times \left(\frac{150}{2} - 52.391\right)^2\right]$$

$$= 20.17 \times 10^6 mm^4$$

Moment acting on channel section, M = $\frac{PL}{6} = \frac{2800 \times 1800}{6} = 840.0 \times 10^3\ Nmm$

Flexural strength, f = $\frac{M}{I} \times y = \frac{840.0 \times 10^3}{20.17 \times 10^6} \times 52.391 = 2.18\ MPa$

Flexural strength of ferrocement channel section = $2.18\ MPa$

30mm Thickness (200mm X 150mm X 2000mm) 2 Layers welded channel section:

Calculation of flexural strength: -

Thickness of section, t= 20mm, Outer Height of wed section, D = 150mm

Outer length of flange section, B= 200mm, Inner length of flange section, b = 160mm

Load acting on slab, P=3700N

$y = \frac{A_1 y_1 + A_2 y_2 + A_3 y_3}{A_1 + A_2 + A_3} = \frac{(140 \times 30 \times 15) + 2 \times [30 \times 150 \times 75]}{(140 \times 30) + 2 \times (30 \times 150)}$ = 55.09mm

I = Moment of Inertia = $\frac{b \times t^3}{12} \times b \times t \times (y - \frac{t}{2})^2 + 2 \times (\frac{t \times D^3}{12} + D(\frac{D}{2} - y)^2)$

$$= \frac{140 \times 30^3}{12} \times 140 \times 30 \times \left(55.09 - \frac{30}{2}\right)^2 + 2 \times \left[\frac{30 \times 150^3}{12} + 150 \times \left(\frac{150}{2} - 55.09\right)^2\right] = 27.49 \times 10^6 mm^4$$

Moment acting on channel section, M = $\frac{PL}{6} = \frac{3700 \times 1800}{6} = 1110 \times 10^3\ Nmm$

Flexural strength, f = $\frac{M}{I} \times y = \frac{1110.0 \times 10^3}{27.49 \times 10^6} \times 55.09 = 2.22\ MPa$

Flexural strength of ferrocement channel section = $2.22\ MPa$

30mm Thickness (200mm X 150mm X 2000mm) 4 Layers welded channel section:

Calculation of flexural strength: -

Thickness of section, t = 30mm, Outer Height of wed section, D = 150mm

Outer length of flange section, B = 200mm, Inner length of flange section, b = 140mm

Load acting on slab, P =4550N

$y = \frac{A_1y_1+A_2y_2+A_3y_3}{A_1+A_2+A_3} = \frac{(140\times30\times15)+2\times[30\times150\times75]}{(140\times30)+2\times(30\times150)}$ = 55.09mm

I = Moment of Inertia = $\frac{b\times t^3}{12}\times b\times t\times(y-\frac{t}{2})^2+2\times(\frac{t\times D^3}{12}+D(\frac{D}{2}-y)^2)$

$= \frac{140\times30^3}{12}\times140\times30\times\left(55.09-\frac{30}{2}\right)^2+2\times\left[\frac{30\times150^3}{12}+150\times\left(\frac{150}{2}-55.09\right)^2\right]=27.49\times10^6 mm^4$

Moment acting on channel section, M = $\frac{PL}{6} = \frac{4550\times1800}{6} = 1365\times10^3\ Nmm$

Flexural strength, f = $\frac{M}{I}\times y = \frac{1365\times10^3}{27.49\times10^6}\times55.09 = 2.73\ MPa$

Flexural strength of ferrocement channel section = $2.73\ MPa$

40mm Thickness (200mm X 150mm X 2000mm) 2 Layers welded channel section:

Calculation of flexural strength: -

Thickness of section, t = 40mm, Outer Height of wed section, D = 150mm

Outer length of flange section, B = 200mm, Inner length of flange section, b = 120mm

Load acting on slab, P =4300N

$y = \frac{A_1y_1+A_2y_2+A_3y_3}{A_1+A_2+A_3} = \frac{(120\times40\times20)+2\times[40\times150\times75]}{(120\times40)+2\times(40\times150)}$ = 59.286 mm

I = Moment of Inertia = $\frac{b\times t^3}{12}\times b\times t\times(y-\frac{t}{2})^2+2\times(\frac{t\times D^3}{12}+D(\frac{D}{2}-y)^2)$

$= \frac{120\times40^3}{12}\times120\times40\times\left(59.286-\frac{40}{2}\right)^2+2\times\left[\frac{40\times150^3}{12}+150\times\left(\frac{150}{2}-59.286\right)^2\right] = 33.51\times10^6 mm^4$

Moment acting on channel section, M = $\frac{PL}{6} = \frac{4300\times1800}{6} = 1290\times10^3\ Nmm$

Flexural strength, f = $\frac{M}{I}\times y = \frac{1290.0\times10^3}{27.49\times10^6}\times55.09 = 2.58\ MPa$

Flexural strength of ferrocement channel section = $2.58\ MPa$

Flexural Strength Test Results

The test results of the samples at the age of 28 days from the day of casting are presented in following tables and graphs and compared with FEM results –

1) 20mm Thickness (200mm X 150mm X 2000mm) 2 Layers welded channel section:

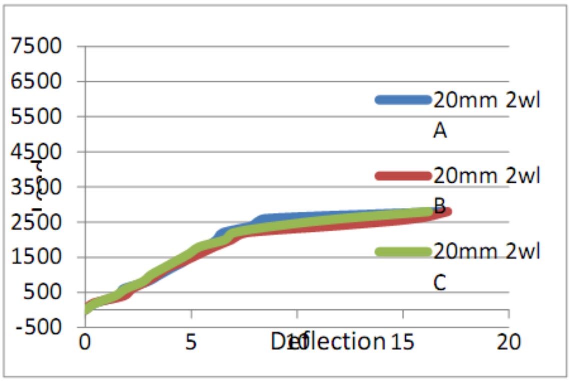
Table 1.Test results for 20mm 2-layer welded channel section

Sr No.	Load (N)	Deflection (mm)			Avg. defl mm	FEM mm
		Sam. 1	Sam. 2	Sam. 3		
1.	0	0	0	0	0	0
2.	200	0.5	0.4	0.5	0.5	0.7
3.	400	1.6	1.8	1.4	1.6	2.1
4.	600	1.8	2.2	1.9	2.0	2.9
5.	800	2.9	2.85	2.7	2.8	3.9
6.	1000	3.5	3.4	3.1	3.3	4.7
7.	1200	4.1	3.9	3.7	3.9	5.2
8.	1400	4.7	4.7	4.3	4.6	6.3
9.	1600	5	5.4	4.9	5.1	6.8
10.	1800	5.7	6.1	5.4	5.7	8.3
11.	2000	6.2	6.9	6.6	6.6	9.1
12.	2200	6.5	7.6	7	7.0	12.6
13.	2400	7.9	11.9	9.1	9.6	14.2
14.	2600	8.5	15.6	12.1	12.1	16.89
15.	2800	16.9	17.1	16.2	16.7	18.56
Ultimate load (N)		**2800**	**2850**	**2760**	--	

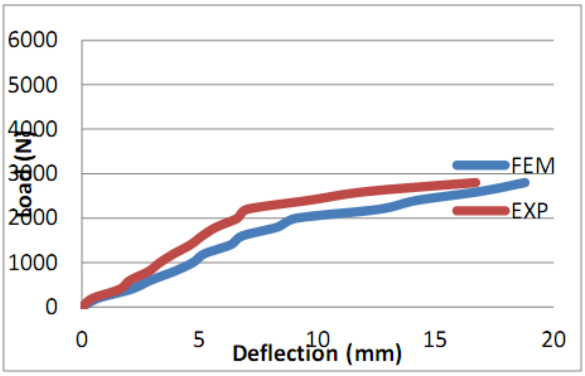
I = Moment of Inertia = $\frac{b\times t^3}{12}\times b\times t\times(y-\frac{t}{2})^2+2\times(\frac{t\times D^3}{12}+D(\frac{D}{2}-y)^2)$

$=\frac{120\times40^3}{12}\times120\times40\times\left(59.286-\frac{40}{2}\right)^2+2\times\left[\frac{40\times150^3}{12}+150\times\left(\frac{150}{2}-59.286\right)^2\right]$

$= 33.51\times10^6 mm^4$



Graph 1.Load-Deflection Curves using 2 Layer Welded mesh (20mm).



Graph 2.Comparing Experimental and FEM Results for 20 mm 2 Layer Welded Channel Section.

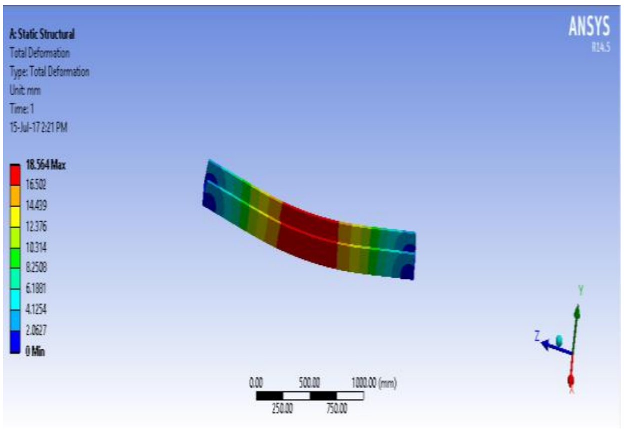


Figure 1.Loading condition for 20mm welded channel

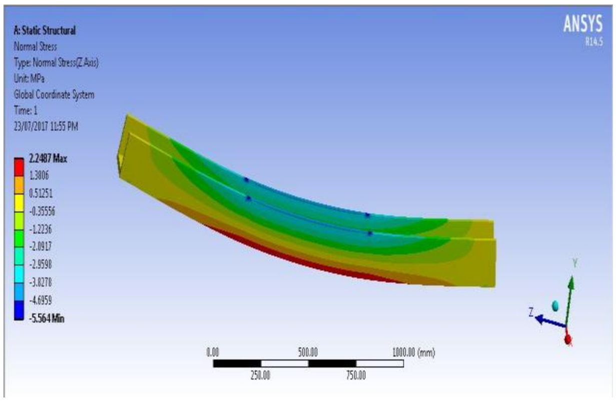


Figure 2.Maximum deflection using2-layer welded mesh.

CONCLUSIONS

Based on the experimental and FEM results following conclusions are made.

1. The load carrying capacity and flexural strength of ferrocement channel section reinforced with welded square mesh is found to be more than that of ferrocement channel section reinforced with woven square mesh.

2. Flexural strength and load carrying capacity increases when the number of mesh layers increases from 2 to 4 numbers.

3. The proposed finite element model can be used efficiently in characterizing the behavior of ferrocement channel section under the flexural behavior.

4. The increase in the thickness of ferrocement channel section shows an enhancement in the load carrying capacity and decrease in the deflection.

5. The experimental results are in good agreement with the FEM results.

FUTURE SCOPE

1. Very limited research reports are available on the behaviour of ferrocement compound structural sections like I, C, T, L etc.

2. Introducing nominal size of reinforcement at top and bottom of section would increase the load carrying capacity of channel section.

3. Using the different type of mesh (expanded wire mesh, fibre mesh) change in behaviour

of ferrocement channel section can be observed.

4. Flexure behaviour also can be check for Changing the loading condition as applying load on base and providing supports on web.

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