FERROCEMENT-LGS COMPOSITE CONSTRUCTION: A VIABLE ALTERNATIVE TO RCC

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Abstract— **A novel construction form namely Ferro-cement Light gauge steel (LGS) Composite Construction has been proposed recently as an alternative to traditional Reinforced Cement Concrete (RCC) construction. In the present study G+3 residential building has been designed invoking principles of limit state RCC design. The same building has also been designed using Ferrocement-LGS composite form. A comparison is presented with respect to design philosophy, dead weight of the building, quantities of cement, steel, curing water, chemically bound water, and emission of CO_2. The present study confirms that the novel composite form results in 50% to 60% dead weight reduction, 30% to 35% reduction in cement quantity, 50% to 55% reduction in quantity of curing water, 50% to 60% reduction in quantity of chemically bound water, additionally 25% to 30% reduction in emission of CO_2. In a nutshell, Ferrocement-LGS composite construction is a lightweight, seismically advantageous, sustainable, and cost effective alternative to RCC buildings.**

Keywords— **Ferrocement LGS composite construction, dead load reduction, emission of CO_2 reduction, sustainable**

1. INTRODUCTION

Government of India is pushing for construction systems optimizing cement, sand and steel with less dependence on water, sand, aggregates during construction, zero construction & demolition waste, dust free technologies, materials & systems based on renewable resources. As a policy decision therefore, the Ministry of Housing and Urban affairs, vide Office Memorandum dated 30.05.2016 has included use of LGS framed structures in its construction works in metropolitan cities (Schedule of Rates 2018). Deriving motivation from it, Ferrocement-LGS composite construction has been recently proposed for construction of (up to G+5) buildings (by Dr. Arun Purandre, Structural Consultant, Pune). Interestingly this form eliminates brickwork altogether. **PROCEDURE FOR PAPER SUBMISSION**

This form of construction is multifold times faster and lighter, cost effective than traditional RCC framed construction.

In the available literature on LGS construction, three forms of load bearing LGS applications namely, framing, metal buildings and racks have been reviewed (Schafer, 2011).

In the available literature on LGS construction, three forms of load bearing LGS applications namely, framing, metal buildings and racks have been reviewed (Schafer, 2011). These forms employ plywood, gypsum board, steel sheets as cladding. An interesting form of steel sheeted LGS shear walls cladded with Gypsum and fiber cement boards has been examined by Mohebbi et.al. (2016) for its performance under in-plane lateral cyclic load.

The study concludes that the cladding material significantly alters in-plane strength, stiffness and hysteretic behavior of LGS framed shear walls. Seismic performance of full scale building made up of LGS wall with Gypsum board cladding is explored by Wang et.al. (2015). Usefi (2019) details the concise summary of numerical modelling of in-plane behavior of LGS framed shear walls covered with sheets of steel, wood, gypsum, cement board, etc.

In present study, factory cast Ferrocement panels, are employed as cladding on either sides of LGS framing members owing to their excellent tension and flexure carrying capacity. This construction form involves two constituents, namely,

a) Factory cast Ferrocement panels (600 mm X 900 mm X18 mm) (refer Figure-1)

b) Light Gauge Steel (LGS)

Ferrocement is thin reinforced cement mortar. It involves closely spaced small diameter reinforcement mostly in the form of mesh. The reinforcement details of the Ferrocement- panels employed in the present work are shown in Figure-1. LGS steel is cold form steel. Due to slender cross sectional elements it is susceptible to local instability, if not stiffened. Figure-2 presents the plan view of Ferrocement-LGS composite wall. The wall has LGS section sandwiched between two Ferrocement panels. As per construction sequence, LGS column-beam framing is erected at the site, Ferrocement panels are subsequently attached (with 900 mm side vertical) from both sides employing self-taping screws at regular spacing along the length and polymer based binder (refer Figure 2). The thickness of the wall works out to be 125 mm if LGS leap channel of 89mm X 40 mm X 1mm is employed.

Figure-3 provides a typical photograph of partially complete Ferrocement-LGS composite building. Under lateral loads, walls in such form of construction would behave more like a shear wall than infill in framed buildings, thus ensuring box action.

The present work compares RCC construction and Ferrocement-LGS composite construction pertaining to design philosophy, quantities of various construction and allied materials, deadweight of the building and emission of CO_2.

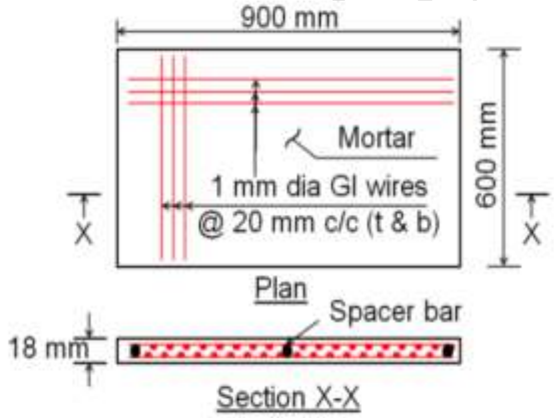


Fig. 1. Reinforcement details of Ferrocement panels

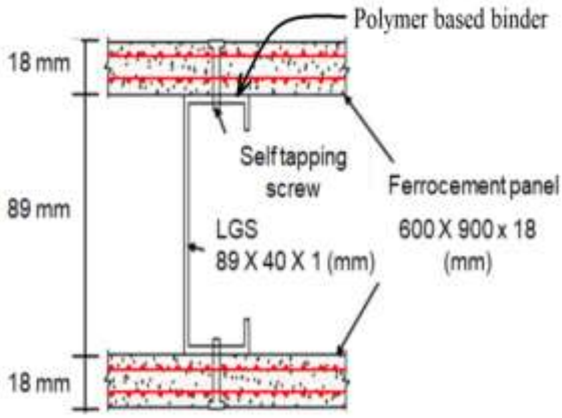


Fig. 2. Plan of Ferrocement-LGS wall section

Fig. 3. Photographic view of partially completed composite building.

2. SCOPE AND OBJECTIVES

In the present work, G+3 building with architectural plan as shown in Figure-4 has been designed invoking principles of limit state design in RCC and principles of working stress design in Ferrocement-LGS composites. Few of the important details of the building and employed materials are listed in Table 1. Objectives of the present work can be stated as below,

Demonstrating principles of working stress design of Ferrocement-LGS wall-slab-beam system.

Comparison of RCC design and composite design pertaining to dead weight, quantities of materials, water and CO_2 emission.

Table- I: Details G+3 building and material

Plan Dimension	39.73m x 13.32m
No. of Stories	4
No of flats on each floor	12
Height of floor	3.0m
Height of parapet	0.9m
Wall thickness	130mm

Grade of Concrete	M20
Grade of steel	Fe 415
GI wire	Fe 250
LGS Steel	Fe 500
Mortar crushing strength	40MPa

3. DESIGN IN RCC

Figure-4 presents architectural drawing of the typical floor plan of building to be designed. Figure-5A and 5B present the layout of beams and columns of typical floor of G+3 building. This building was analyzed and designed for gravity loads in **ETABS Ultimate 18.1.0**. Figure 6 shows schematic of ETAB model of G+3 building. Live loads on floors and dead loads due to slab, floor finish, wall, beams and columns are considered in the design in accordance with IS 875: Part I and II. Few details of various members are listed below

a) Typical beam size: 230 mm X 450 mm
b) Typical column size: 230 mm X 450 mm
c) Slab depth (by design): 120 mm
d) Wall thickness: 130 mm

The building members were designed invoking principles of limit sate design (IS 456:2000) Schedule of beams, slab and columns is provided in Annexure-I of this paper.

4. DESIGN IN FERROCEMENT-LGS FORM

The building with architectural plan as shown in Figure-4 is also designed employing Ferrocement-LGS composite construction. The arrangement of LGS channel columns (89 mm X 40 mm X 1 mm) and LGS box beams (80 mm X 89 mm X1 mm) is shown in Figure-7.

Description of slab beam system: In this form box LGS sections (Figure-7) are employed as beams placed at 600 mm c/c distance. On these beams Ferrocement panels are fixed using partially drilled self-tapping screws. These Ferrocement panels work as permanent shuttering on which 40 mm thick concrete topping is provided. . Box section beams rest on the brackets taken out from LGS columns. Working stress design philosophy as explained in IS-456:2000 has been employed in design of composite building owing to the unavailability of experimental data on near failure behavior of Ferrocement-LGS composite elements subjected to various actions. Typical calculation of slab, beam and wall capacity is furnished in Annexure-II of this paper.

5. DEAD WEIGHT AND QUANTITY ESTIMATION

Mass of the building, quantities of various construction and allied materials and CO2 emission are calculated for RCC as well as Ferrocement-LGS composite construction form of G+3 building. For RCC, M20 nominal mix of 1:1.5:3 is considered for calculation of cement quantity in concreting. 1:6 cement mortar is employed in brickwork. Ferrocement panels are considered to be cast with 1:3 cement mortar. For calculation of chemically bound water, water cement ratio was considered to be 0.5 in RCC. To cast Ferrocement panels water cement ratio of 0.34 was employed. Table 2 furnishes the details of the same.

Table- II: Comparison of RCC and Composite Construction

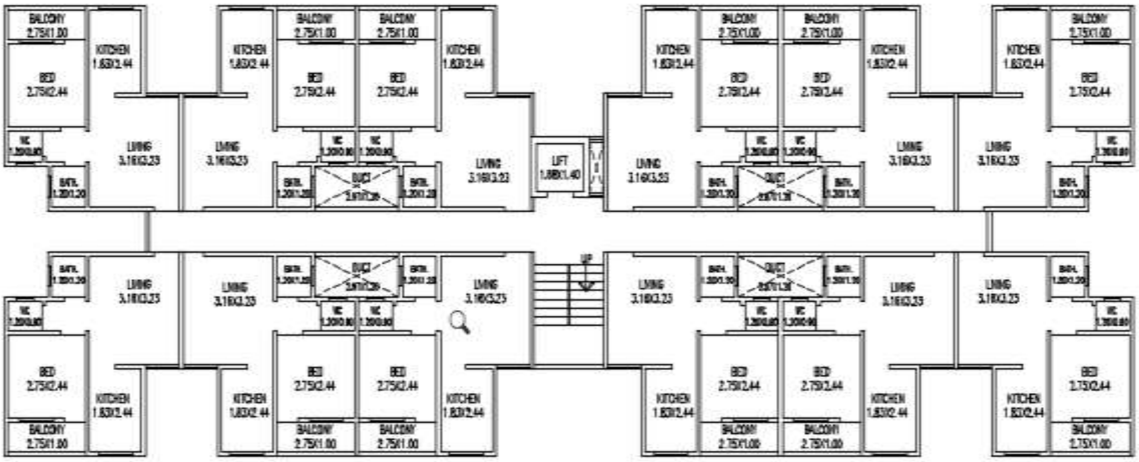
Description	RCC building	Ferrocement LGS building	Reduction
Dead weight(KN)	11011.49	5769.319	60%
Cement(Kg)	342750	235000	30%
Steel(Kg)	44514	32000	28%
Brickwork(Kg)	1083000	0	100%
Chemically bound water	171375	50000	70%
CO2 emission	501.8	354.55	30%

6. CONCLUSION

Following conclusions are evident from the present work,

1. The novel composite form of construction reduces deadweight of the structure by around 60% in comparison with traditional RCC framed construction.
2. The novel composite form of construction reduces cement and steel consumption by 30 to 35 % in comparison with traditional RCC framed construction.
3. The novel composite form of construction reduces required quantity of curing and chemically bound water by 50 to 55 % in comparison with traditional RCC framed construction.
4. The novel composite form of construction reduces CO2 emissions by 30 % in comparison with traditional RCC framed construction.
5. Significant reduction in dead weight indicates proportional reduction in seismic force.

In a nutshell, Ferrocement-LGS composite construction is a lightweight, seismically advantageous, sustainable, and cost effective alternative to RCC buildings



FIRST,SECOND,THIRD,FOURTH FLOOR PLAN

Fig. 4. Architectural plan of G+3 building

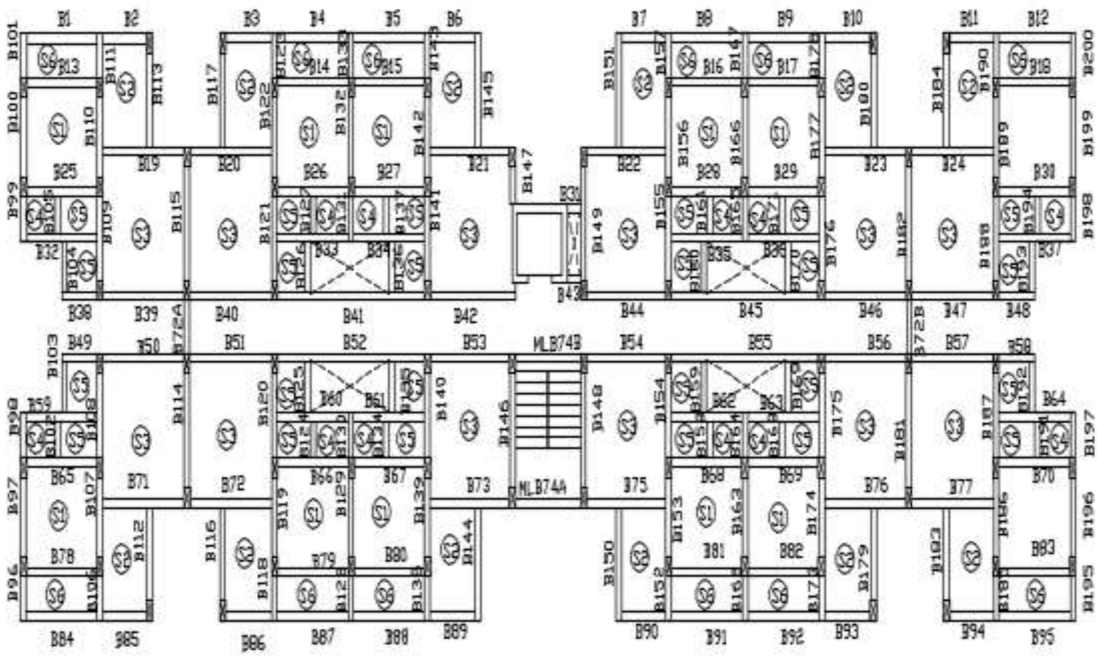


Fig. 5A. Layout of Slabs and Beams

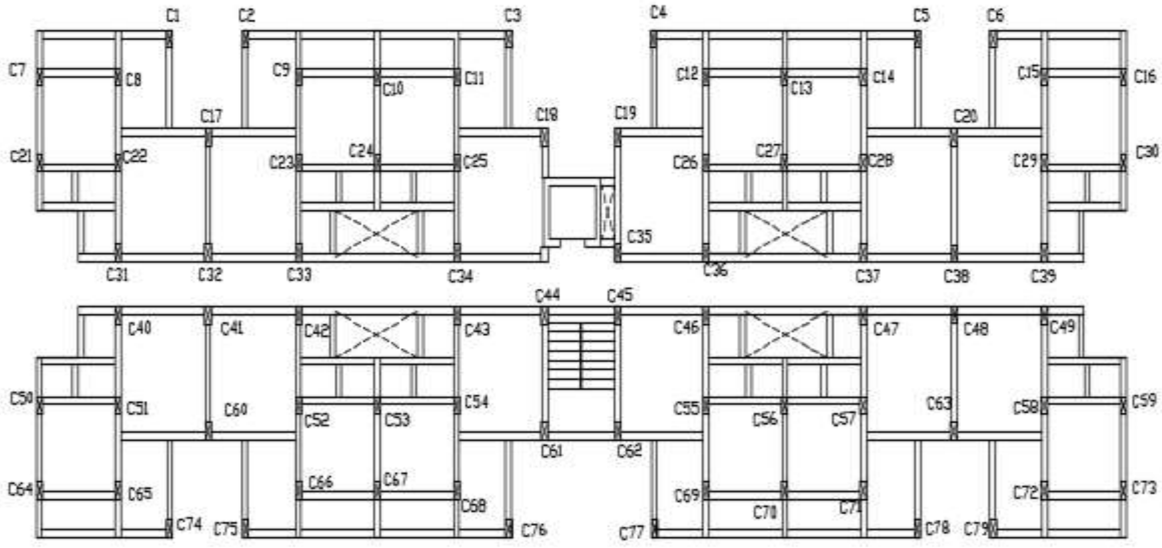


Fig. 5B. Layout of Columns

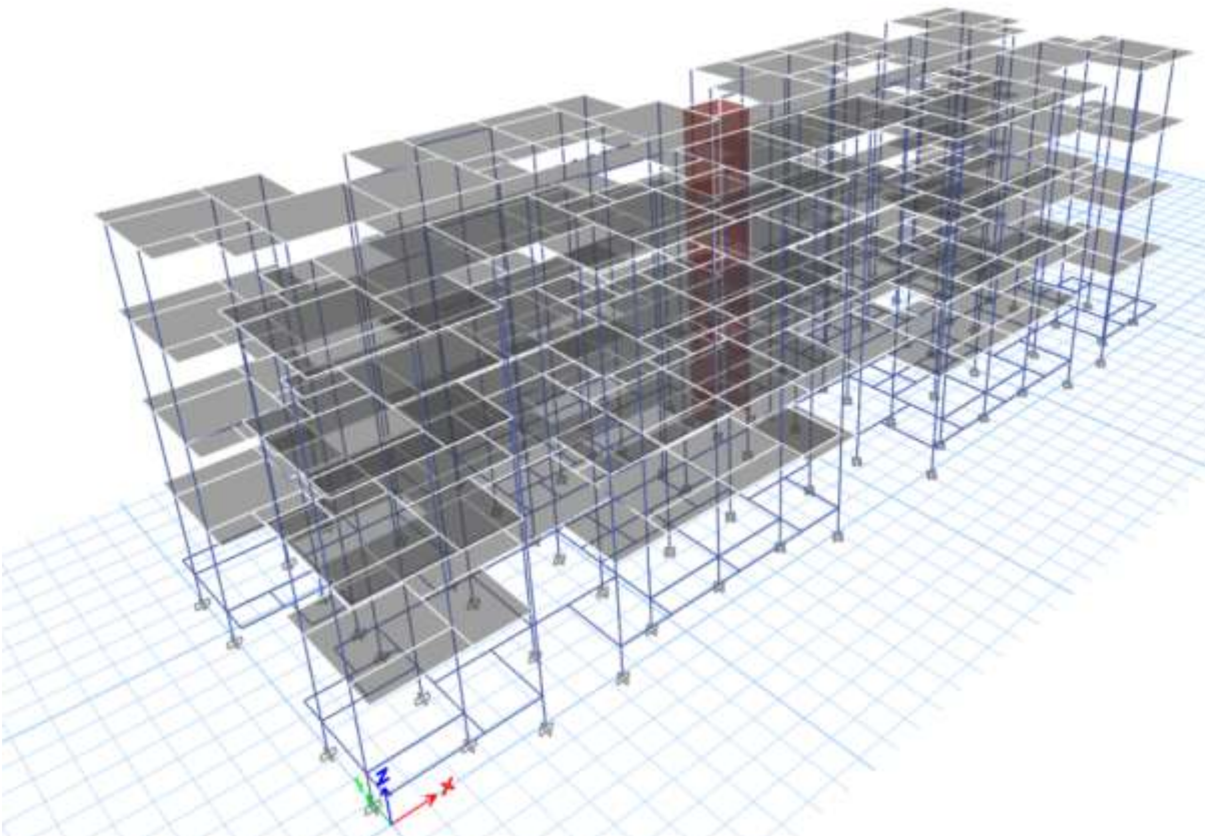


Fig. 6. Schematic of ETAB model of G+3 building

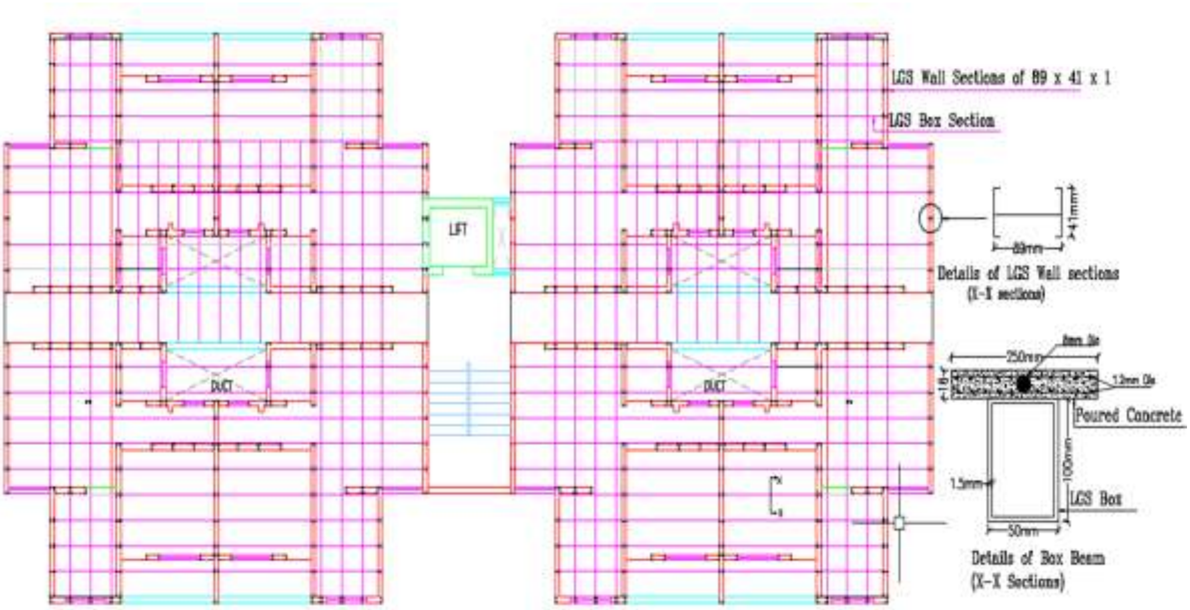


Fig. 7.LGS beam and column locations for Ferrocement- LGS construction

(**Note:** This figure presents only a part of floor plan shown in Figure-4)

ANNEXURE I

Schedule of beams, slabs and columns in RCC construction

A) Schedule of slabs in accordance with Figure-5A:

Table -III: Slab schedule

Designation	Depth(mm)	Short span reinforcement	Long span reinforcement
S1, S3	125	8#250mm c/c	8#250mm c/c
S2	115	8#250mm c/c	8#250mm c/c
S4(200mm sunk- toilet)	115	8#250mm c/c	8#250mm c/c
S5	115	8#250mm c/c	8#250mm c/c
S6 (150mm sunk- gallery)	115	8#250mm c/c	8#250mm c/c

Note: 8#250 mm c/c denotes 8 mm diameter Fe415 bars placed at center to center spacing of 250 mm

B) Schedule of beams in accordance with Figure-5A:

Table- IV: Beam schedule

Designation	Beam size (B x D)	Bottom reinforcement	Top reinforcement	Stirrups	Additional top reinforcement at support for beams
B1 TO B12,B31,B43, B84 TO B95,B102 TO B105,B112, B113,B116,B117,B124 TO B127, B134 TO B137, B144, B145, B150,B151, B158 TO B161, B168 TO B171, B179,B180, B183, B184, B191 TO B194	230 x 450	2-12#	2-8#	8#250mm c/c	B1, B94
B13 TO B18,B39, B40,B42,B44, B46, B47,B50,B51, B53, B54,B56, B57, B78 TO B83	230 x 450	2-16#	2-8#	8#250mm c/c	
B19TOB24,B42,B45,B52, B55,B71 TO B73 ,B75 TO B77	230 x 450	2-20#+ 2-12#	2-8#	8#250mm c/c	
B25 TO B30,B69 TO B70	230 x 450	2-16#+ 2-12#	2-8#	8#250mm c/c	
B32 TO B37,B147,B149	230 x 450	2-16#+ 2-8#	2-8#	8#250mm c/c	
B38, B48, B49,B58	230 x 450	2-8#	2-12#+ 2-8#	8#250mm c/c	B38
B74A, B74B ,B107,B110, B114, B115, B119,B122,B139, B142, B153, B156, B174,B177, B181,B182, B186,B189	230 x 450	2-20#	2-8#	8#250mm c/c	
B96,B98, B99, B101, B195, B197, B198,B200	230 x 450	2-8#	2-16#	8#250mm c/c	B96,B195, B197, B200
B97, B100,B108, B109,B120, B121, B129,B132,B140,B141,B146,B148, B154, B155, B163, B166,B175,B176, B187, B188, B196,B199	230 x 450	2-12#+ 2-8#	2-8#	8#250mm c/c	
B106,B111,B118, B123, B128, B133, B138, B143,B152,B157, B162, B167, B173,B178,B185,B190	230 x 450	2-8#	2-20#+ 2-8#	8#250mm c/c	ALL

B130,B131,B164, B165	230 x 450	2-8#	2-25#+ 2-20#	8#250mm c/c	B130, B131
B172	230 x 450	2-8#	2-8#	8#250mm c/c	

C) Schedule of columns in accordance with Figure-5B

Table- V: Column schedule

Designation	**Column size B x D (mm x mm)**	**Longitudinal reinforcement**	**Ties**
C1 TO C7, C64, C73 TO C79	230 x 450	10-12#	8#150mm c/c
C8 TO C63, C65 TO C72	230 x 450	8-12#+ 2-16#	8#150mm c/c

ANNEXURE II

This annexure focuses on analyzing capacities of slabs, beams and walls to ensure safety of LGS-Ferrocement-LGS composite construction (working stress method)

A) Slab

Mortar employed to cast Ferrocement panels is designed to have compressive strength of 35 MPa. GI wire has yield strength of 250 MPa.

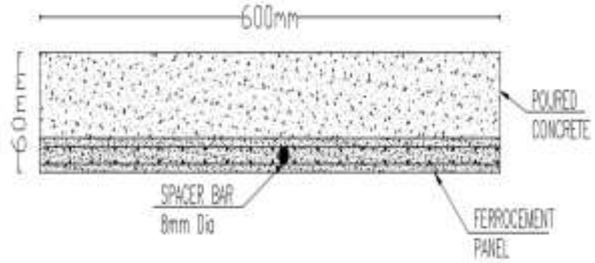


Fig. 8. Ferrocement Slab Section

m= 280/(3 X Ϭcbc) =280/(3 X 11.5)

= 8.115

K (neutral axis factor) for balanced section

=(m X Ϭcbc)/ (m X Ϭcbc + Ϭst)

= (8.115 X 11.5)/(8.115 X 11.5+140)

= 0.399 mm

Stress in concrete= 140/8.115=17.26MPa

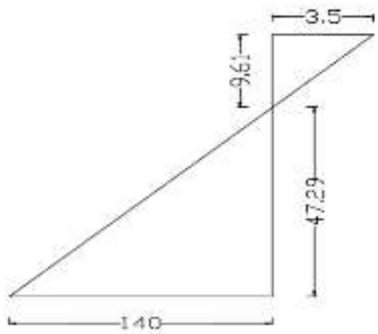


Fig. 9.Stress distribution diagram

Number of GI Wires=1000/20=50

Let's assume the section is under reinforced,

Let Xa be the distance of neutral axis from extreme compression fiber

$B \times Xa^2/2 = m \times Ast\,(d-Xa)$

$Xa^2 = (2 \times 8.115 \times 113.09 \times (60-Xa))/1000$

Xa= 9.6166mm > 0.399 X 60= 23.94mm

Moment carrying capacity

= 0.5 X b X Xa X Ϭcbc(d-(Xa/3))

= 0.5 X 1000 X 9.601 X 3.5 X (56.9-9.6166/3)

= 0.903 KN.m

Total Load: DL= 25 X 0.06=1.5KN/m^2

LL= 2 KN/m^2

FF= 1 KN/m^2

Moment = $wl^2/8 = 4.5 \times 0.6^2/8 = 0.2025$KN.m

Hence, moment carrying of slab is greater than design moment by substantial margin.

B) Beam

Mortar employed to cast Ferrocement panels is designed to have compressive strength of 35 MPa. Grade of steel for LGS section is 500 MPa

For M35, Ϭcbc= 11.5N/mm^2

For Fe500, Ϭst=230N/mm^2

(IS 456:2000 Clause B-2 , Table No. 21 and 22)

Stress in concrete (Ferrocement panel)

Ϭst/m=230/8.115=28.34

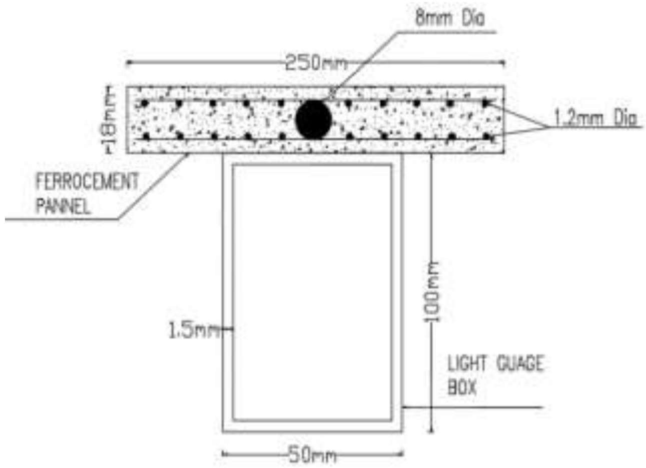


Fig. 10. Ferrocement- LGS beam section

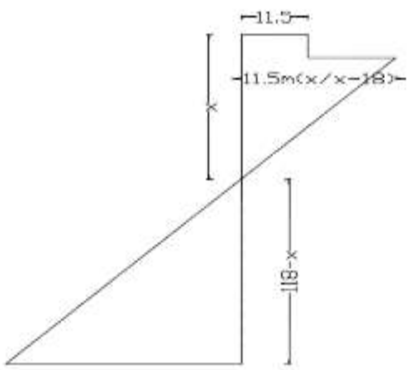


Fig. 11.Stress distribution diagram in Beam

Stress in concrete (above steel section) =11.5 X m X (x-118)/x

Compressive Force= 0.5 X [11.5+(x-18/x) X 11.5] X 18 X 250+ 0.5 X [m X (x-18)/x X 11.5 X 3 X (x-18)]+ [(x-18/x) X 11.5 X m X 50 X 1.5]

Tension Force= 0.5 X [11.5 X m X (118-x)/x X (118-x) X 3]+ [50 X 1.5 X 11.5 X m(118-x)/x]

Equating Compression and Tension Force X=26.527 mm

Locations of tensile and compressive forces from neutral axis turn out to be 73.075 mm and 16.77 mm respectively.

Tensile force act at a distance

=91.48-(36.81/2)=73.075mm

Compressive force act at a distance

= 26.52-(19.5/2)=16.77mm

Therefore, Lever Arm= 73.075+16.77

= 89.845mm

Moment carrying capacity= 89.845 X 68.2

= 6.135 KN.m

Loads on Beam:

Center to center span of beams is 0.6 m.

DL= 0.6 X 0.06 X 25

= 0.9KN/m

LL= 2 X 0.6=1.2 KN/m

FF= 0.6 X 1 KN/m

Hence total load= 2.7 KN/m

Moment =2.7 X 2.865^2/8=2.77 KN.m

(Note: 2.865 m is the largest span of beam as per the layout shown in Figure-7)

Hence, moment Carrying Capacity of the beam is greater than design moment by substantial margin.

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