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Research Paper

Structural Analysis and Simulation of Innovative Composite Building Consisting of LGS and Load Bearing Ferrocast Wall Panels Using FEM

Mrudula S. Kulkarni [a,*], ***Arun Purandare*** [b], ***Saarim Momin*** [c], ***Sumant Shinde*** [c]

[a] *Professor, Civil Engineering, Dr.Vishwanath Karad MIT, World Peace University Pune, Maharashtra, India*

[b] *Senior Structural Consultant, member ASCE,*

[c] *Research Assistant,Dr.Vishwanath Karad MIT, World Peace University Pune, Maharashtra, India*

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ABSTRACT

In the construction of any structure, the most important factor considered today are cost of construction and ability of the building to resist loads and earthquakes. Research is going on about various precast composite technologies to get a structurally strong system yet with reduced time and cost of construction, thus making it an affordable structural system for modular construction. Considering these factors, light gauge steel or commonly known as cold formed steel and precast ferrocement composite structures are gaining popularity in the Indian construction industry. This article is an attempt to review structural behaviour of innovative use of LGS and Ferrocement, sandwich panel composite construction. In the present research work, Finite Element analysis is done for typical residential building made of precast ferrocement panels combined with light gauge steel composite structure. Finally, stresses in the ferrocement element are checked with experimental values thus determining the load carrying capacity of the structure subjected to dead, live and seismic loads. Overall proving this load bearing composite construction system to be more effective with respect to speed of construction, cost of construction and affordability at the same time enhanced structural performance. Thus, a practically enhanced solution to substitute the conventional RCC structure is possible using this LGS Ferrocast/ferrocement composite construction technology. The assumption for this composite technology is that all ferrocement structural components are factory made in custom sizes under strict quality control as to achieve desired permissible stresses.

1 Introduction

The cost of RCC construction in India is increasing exponentially day by day. Also, a major amount of resources are wasted during its construction and after its demolition [1]. For the low rise buildings light gauge steel framing structure can be effectively used for residential as well as commercial buildings and industrial sheds [2-4]. This type of construction is also

* *Corresponding author.*
E-mail address: mrudula.kulkarni@mitwpu.edu.in

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used for non-structural framing, such as interior partitions or cladding for external walls [5, 6]. This form of construction was actually developed for interior partitions generally at commercial office spaces. The basic needs of the construction industry are fulfilled by such types of structures and thus they have a considerable acceptance in the industry in various structural and non structural ways [3-6].

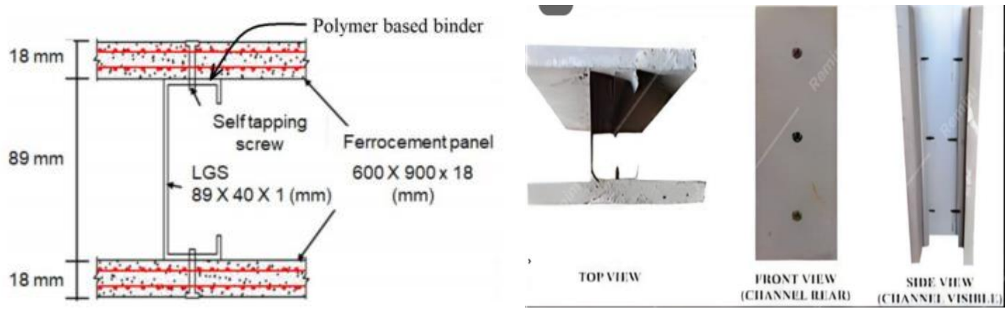

Fig. 1(a) – Section of Ferrocement-LGS panel sandwich wall unit

Various codes can be used to design light gauge steel framed structures as per local requirements and are based on factory made galvanised light gauge steel. As no heat is utilised while creating light gauge steel section, which is through a cold formed method, this method creates high tensile and light weight sheets [7, 8]. The surface of the sheet is covered with a zinc alloy which covers the steel surface completely and thus seals it from corrosive action of the environment. This framing of light gauge steel can be covered by various types of claddings depending upon the requirement and/or availability. These claddings will act as wall panels of the system [9]. They include gypsum boards, metal insulated panels, reinforced concrete panels, wood panels, fibre cement sheets, ferrocement composites and many more. Of all the mentioned varieties, ferrocement composite sheets are being widely researched and used today. A Ferrocast panel is a thin cement mortar precast panel, reinforced with closely spaced weld mesh layers [10].

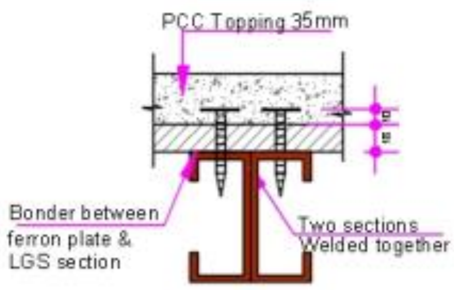

Fig. 1(b) – Floor Beam to slab connection details.

The LGS ferrocement panel wall system is produced by LGS section and Ferrocast panels assembled at site thus forming structural wall system and framework of a building eg. Varying sizes of walls and floors. The Ferrocast panels are factory manufactured in standard dimensions [3, 4, 6]. The framing of LGS is erected on site. The panels are connected to LGS frame on either side of LGS section using various methods for connection [6]. The assembly of this wall is done using various special types of self tapping screws and bolts. After assembling Ferrocast panels on either side of LGS the total thickness of wall unit is 125 mm.

In the present study, finite element modelling is done for ferrocement/ Ferrocast panel and light gauge steel, composite wall unit. It is subjected to loads combination. The proposed wall is LGS section placed between two panels made of ferrocement with design and sectional details as shown in figure1(a). The proposed dimensions of the LGS section 89x40x1 mm with yield strength higher than 450 MPa and ferrocement panel are 600x900x18 mm precast in factory as customised product.

The study is carried out using STAAD PRO software. A complete line model is created of typical G+5 storied structure, as shown in part line diagram fig No.2. The finite element model of a representative single load bearing wall, which is subjected to the total loads which act at the ground floor of the same G+5 building is done. The load combination of dead load, live load are applied as uniformly distributed intensity on composite wall, as line load on wall panel units as walls are designed as load bearing. The boundary condition at applied at connection of wall panel unit and plinths with all degrees of freedom constrained. At mutually perpendicular wall panels, boundary conditions allow translation in horizontal plane due to lateral force at each floor level. Thus the entire model acts as box structure and utilises strength by virtue of stiffness of box. The stresses that will thus occur in the ferrocement plates and LGS section will be checked for its capacity which is obtained by laboratory experimentation and published by the author earlier [6, 7, 9-12]. The discussion over the obtained results gives fare idea of structural behaviour of this innovative composite construction and utilisation of composite material strength for G+ 5 constructions.

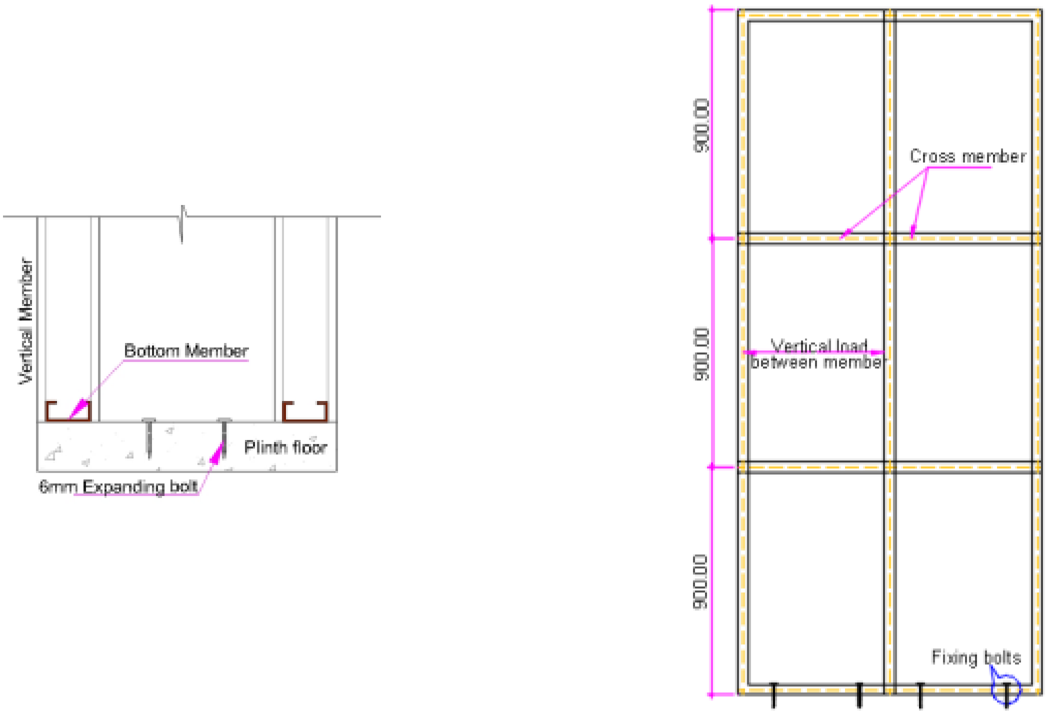

Fig. 1(c) – LGS Frame and floor fixing details

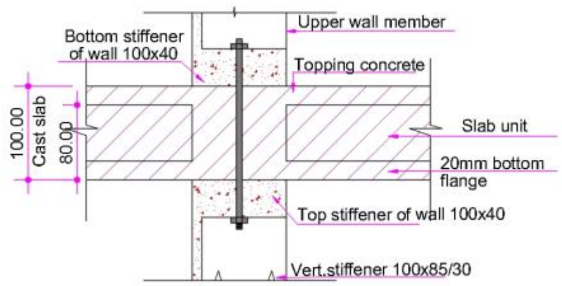

Fig. 1(d) – Details of wall connection

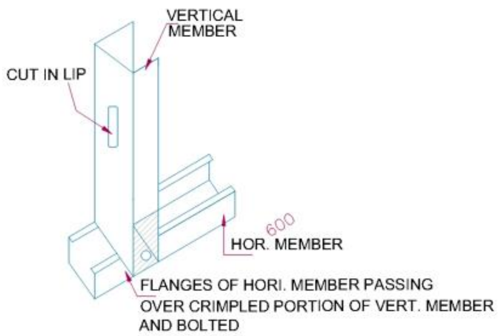

Fig. 1(e) – Details of LGS Cross members

2 Materials and Methods

Modelling approach of G+5 model and the finite element wall model are described in this section. Two main materials are considered in this study light gauge steel and ferrocement. The specifications of these materials vary according to the requirements of the structure and studies conducted in the past. Mainly the ferrocement panels used in the structure will be observed.

2.1 Light gauge steel

The strength of steel used for plates in the early 1960s was 250MPa. Strengths of 550MPa are now possible thanks to advancements in the production of steel and its alloys [7]. We are using yield strength of steel as minimum 450 MPa. Galvanized sheets are also an option for longer life. In LGS sections, these plates serve as the primary material input for softwear. The steel plate thickness that is available to the manufacturer determines the thickness of the sections. The thicknesses range from 0.7 mm to 2.3 mm, though they do vary slightly depending on the source [8]. Self-tapping screws are used to join the vertical and horizontal wall portions together [9]. The CVC former machine is used to make hole on the outer section. The screws that are often used for this connection are 4mm in diameter and of appropriate length [2, 4, 6]. Capacities of typical sections are given in IS code 801. For instance, 89x41x1.2 mm is 3502 kg and for 89x41x1.5 mm is 4800 kg. Here we have used Indian standard section details only because author intends to target Indian construction scenario at present. Similar section details can be available in any other code of standards.

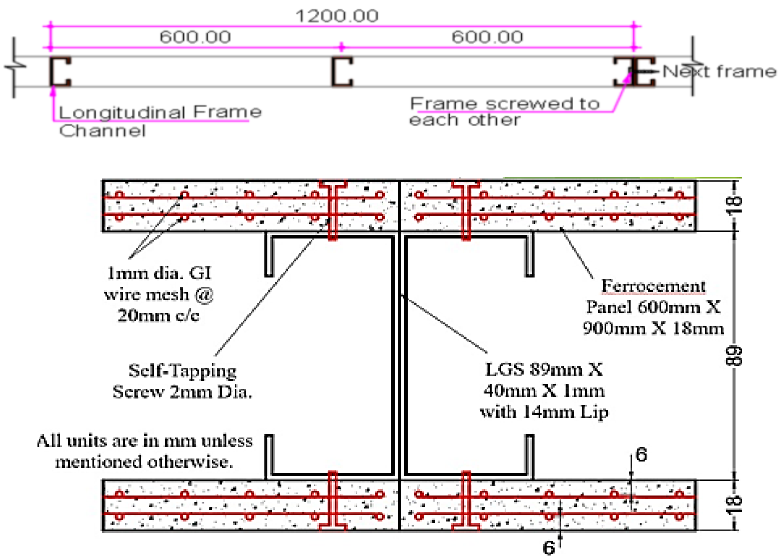

Fig. 1(f) – Section of typical Ferrocement-LGS frame

2.2 Precast Ferrocement panels: Ferrocast or Ferrocast

The author in their previous research have extensively experimented with mix design of mortar for precasting process of Ferrocast panels [6, 11]. The preferred cement is regular Portland cement in grades 41 or 53. Pozzolana cement is not recommended since the mortar needs to develop early strength. Given the strength-gain characteristics of the cement and the additives used in the mortar mix, the mix design is appropriately modified. The strength and workability during casting are the most crucial factors for creating the mortar mixture for the Ferrocast panels. Concrete's plastic qualities, such as workability, setting time, and early strength increase, can be altered using additives [6, 11]. A variety of steel mesh types have been employed throughout the years to create ferrocement products. We are using weld mesh [12]. The optimum range for wire diameters is from 1.0mm to 1.5mm [13]. The ideal wire spacing is between 15 mm and 25 mm. For typical application, a mean value of 20 mm x 20 mm spacing in both directions is chosen. These requirements are used to make Ferrocast panels. The capacity of a single ferrocement panel will be 12x18x1200=21744 kg per panel.

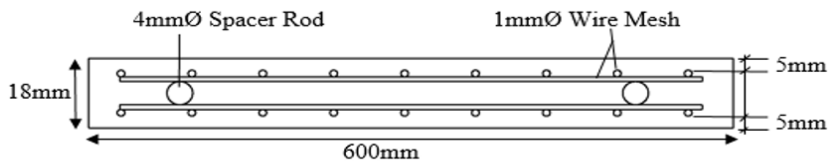

Fig. 1(g) – Reinforcement details of ferrocement pane

3 Finite Element Method modelling and analysis

An approved working drawing of a G+5 typical building is modelled in STAAD Pro. The part framing plan is shown in the figure 2a,2b which shows cold rolled channel sections 90x40x1.6 mm used as columns and 150x50x3.15 mm used as beam sections. The entire structure consists of light gauge steel frames. The vertical LGS sections in load bearing walls are placed at a distance of 600 mm or less as per the required dimension for connection purpose.

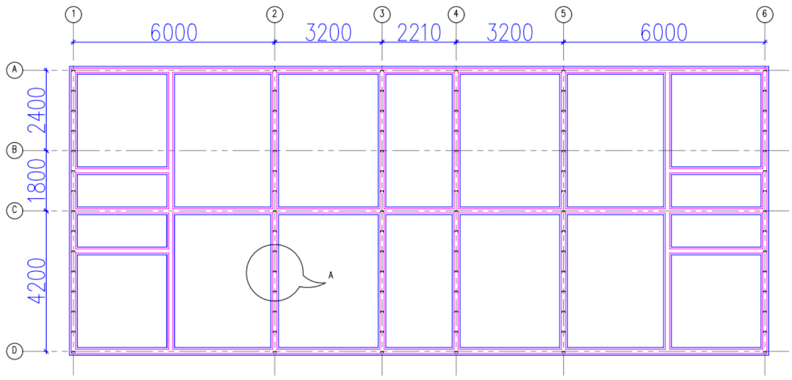

Fig. 2(a) – Ground floor framing plan used for G+5 building (Refer detail 'A' fig. 2 (c) for clarity

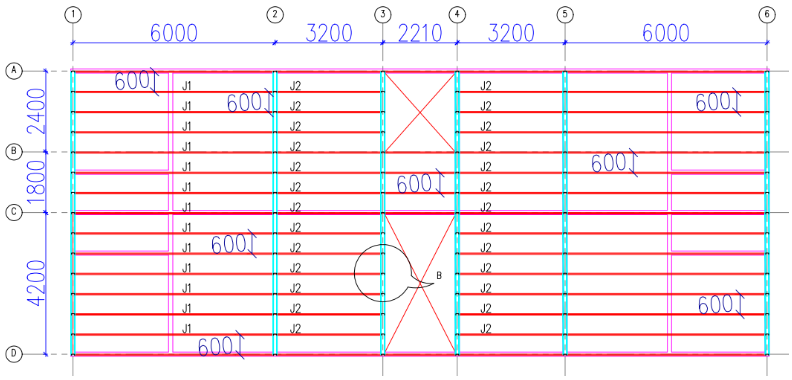

Fig. 2(b) – First floor framing plan used for G+5 building (Refer detail 'B' fig. 2 (c) for clarity

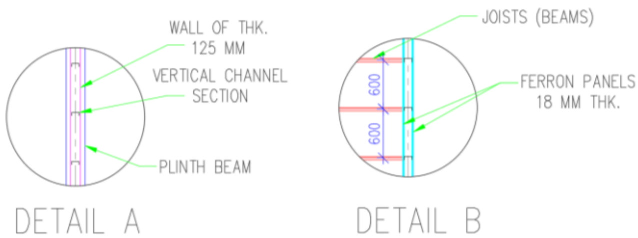

Fig. 2(c) – Details from floor plans use

The input loading conditions for the model are as stated below:

(1) Dead load, consisting of Self weight – Generated from STAAD Pro, Wall load – 1 kN/m, Slab load – 2 kN/m^2

(Slab – 1.25 kN/m^2& Floor finish – 0.75 kN/m^2)

(2) Live load, in accordance with IS 875 part 2, live load – 2 kN/m^2

(3) Seismic load in accordance with IS 1893 – 2016, Earthquake Zone – III (Pune, India region), response reduction factor – 5, importance factor – 1.2, earthquake directions – X & Z, seismic loads generated by inputs given to the software.

Following thirteen load combinations used in the model as per Indian standards code of practice.

1.5(DL+LL), 1.2(DL+LL+EQX), 1.2(DL+LL+EQZ), 1.2(DL+LL-EQX), 1.2(DL+LL-EQZ), 1.5(DL+EQX), 1.5(DL+EQZ), 1.5(DL-EQX), 1.5(DL-EQZ), 0.9DL+1.5EQX, 0.9DL+1.5EQZ, 0.9DL-1.5EQX, 0.9DL-1.5EQZ.

Country wise these load combinations may vary but not much. The local earthquake parameters will have impact on load combinations.

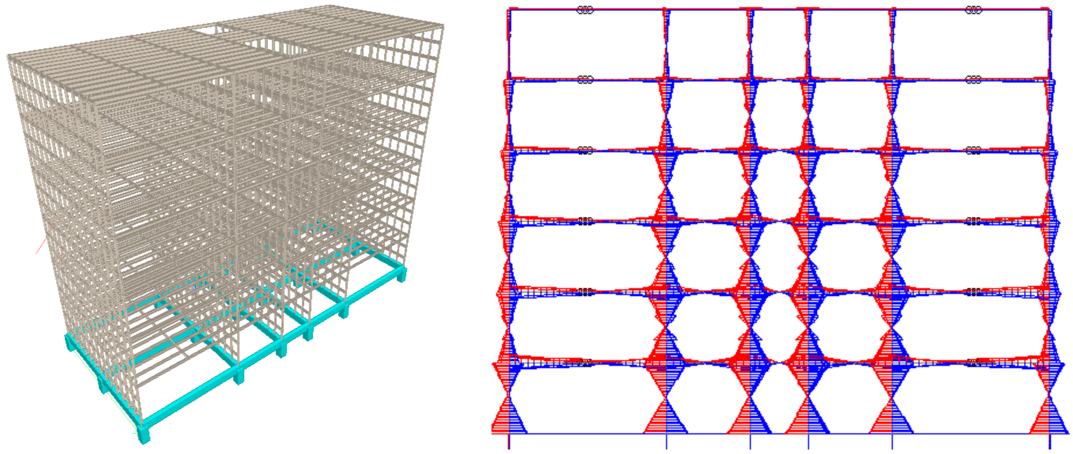

Fig. 3 – 3D view of G+5 model and stress indicators

3.1 Finite element wall model

A ferrocement and LGS composite load bearing wall is modelled for second phase of finite element analysis. The loads which are acting on the ground floor load bearing wall, of the main G+5 model are entirely transferred to the finite element wall model. In meshing the elements of size is maintained as 60 mm x 90 mm. Ferrocement plate elements are assigned thickness of 18 mm and light gauge steel plate elements are assigned thickness of 1 mm. Their respective material properties like Modulus of elasticity, yield stress poisons ratio are assigned. The load bearing cross-section of LGS and Ferrocement panels resting on plinth beam, transfer the load to plinth beam below. Accordingly, the common nodes of wall panel system and plinth beam are applied with boundary conditions to constrain the all the displacements as shown in figure 6. The analysis is run to obtain parameters at each node like displacements, stresses in LGS as well as Ferrocement panels at each node.

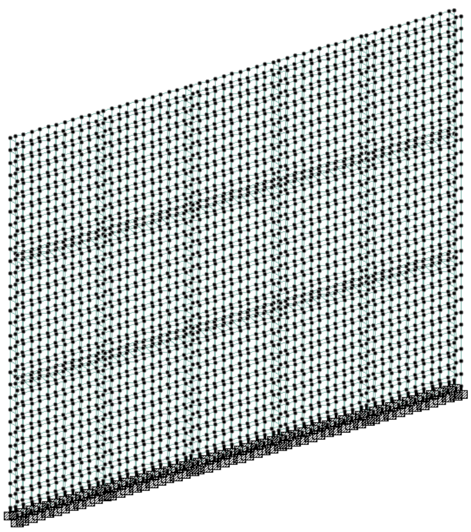

Fig. 6 – Finite element meshed sandwich wall model

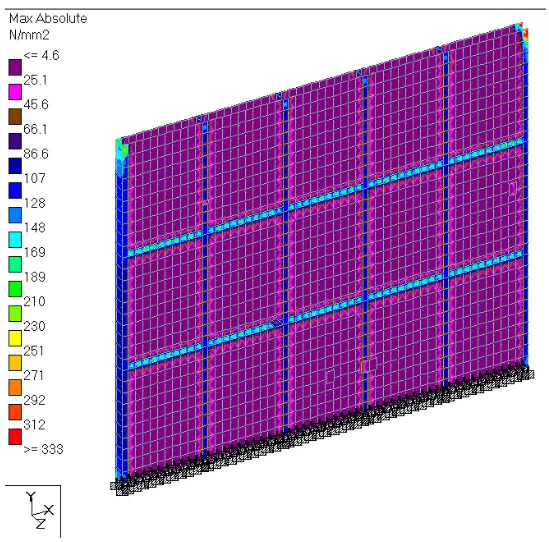

Fig. 7: Analysis of wall, stress contour plot

The post processing indicates the results of displacements and stresses in ferrocement panel and LGS sections in the form of output list as well as in the form of coloured contour plot for easy understanding. The colour contour plot gives idea of level of stresses as indicated in fig 7. The model is thus checked for stresses obtained after analyzing it and are compared with the available experimental values. Thus we have analysis of entire G+5 system and from this analysis the part analysis of panel at ground floor is carried out for in-plane loading obtained from G +5 analysis. Both the models were analyzed one after the other. Modelling was done simultaneously. Output of one model was the input of the second model. Results obtained from G+5 model include, the maximum load observed at the ground floor wall of the structure. The maximum load will be the reaction offered at the top of ground floor wall to the majorly contributing loads which include dead, live and seismic loads. The worst possible scenario was thus obtained by using thirteen load combinations as stated above. The maximum concentrated load thus obtained at column was 213 kN. This point load was acting when the columns were spaced at 0.6 meter centre to centre. Hence, this load was further converted to distribute on small plates as uniformly distributed load where the nodes were created at 0.06 meters centre to centre distance. This load is further equally distributed on both panels of the load bearing ferrocement LGS composite wall. Thus a nodal load of 10.65 kN was applied on every node of the finite element wall

4 Discussion

Results obtained from finite element wall model include, the stresses developed in the ferrocement and light gauge steel plates. The maximum stresses are checked for exceeding the limiting value. The maximum stress obtained as per Von Mises failure theory. The flexural stress in light gauge steel section is observed to reach 335.61 N/mm^2 at top and 334.61 N/mm^2 at the bottom. While the capacity of one LGS channel section 89 * 41*1 mm LGS section as per IS code is 47 KN (4800 kg). The yield stress of steel is 450 MPa, hence only 60% capacity of LGS steel section is used leaving 40% spare capacity [14, 15]. Similarly, the maximum obtained Von Mises failure stresses in ferrocement plate is evaluated by experimental study, and is observed to be 13.01 N/mm^2 at top and 14.017 N/mm^2 at the bottom, while tensile strength of ferrocement of M30 grade is 25 MPa, without surface crack [14]. These stresses are seen near the edges of the panels as indicated by corresponding colour code given in fig no. 7. The capacity of one ferrocement panel having two layers of square weld mesh, each strand 25 mm centre to centre, 3 mm cover to reinforcement and 18 mm overall thickness of panel is found to be 21.33 KN (21744 kg) per panel. Hence the total load carrying capacity of one composite sandwich wall panel (600 mm by 900 mm by 125 mm thick) is approximately 89 KN. Thus with this load bearing composite utilises 60% all tensile capacity of ferrocement leaving more than 40% spare capacity for G +5 construction. This gives us enough space for getting some factor of safety for unforeseen parameters that may affect the overall stability of structure. In the same manner authors developed a G+8 model and analysed it. The utilization of LGS and ferrocement panel in the composite structure showed that the LGS steel section's capacity was almost entirely utilized. This was demonstrated by the flexural stress in the light gauge steel section reaching 528.81 N/mm^2 at the top and 526.93 N/mm^2 at the bottom, which is near the yield stress of the steel at 550 MPa.The experimental studies carried out on the ferrocement plate showed that it also utilized almost complete capacity. The maximum Von Mises failure stresses in the ferrocement plate were observed to be 22.49 N/mm^2 at the top and 24.38 N/mm^2 at the bottom, which is well within the tensile strength of ferrocement of M30 grade at 25 MPa without surface crack.

The permutation and combination of structural form and use of strength capacity of composite material, this technology and design approach may give us useful solution for future development. The authors hope for future in this technology development [3, 4].

In the above study, considered stresses in the finite element analysis are the Von Mises failure stresses. The importance of considering these stresses is that this criteria states that if the Von Mises stresses of the material when acted upon by a set of loads are less than the yield stress of the material, then the material will not yield. The grade of ferrocement used in our study is M30 which provides a yield stress of 25 N/mm^2 according to the extensive tests carried out by author in MIT, World Peace University (Pune) [12, 13, 15-19]. The stresses obtained through the finite element analysis are less than the yield stress, thus ensuring safety of the structure as a whole. Similarly, the light gauge steel plates in the model show Von Mises stresses less than the typical yield stress of steel that is 550 N/mm^2.Thus both the material properties considered and used for G+5 storied model turn out to be analytically safe for further research, prototypes, full scale construction.

5 Conclusion

(1) Due to variety of steel with 450- 550 MPa yield stress, only 60% of the LGS steel section's capacity is being utilized, leaving 40% available. Also, as from the experimental studies conducted, which gives us a result of 25 MPa strength for M30 concrete grade used, only 60% of ferrocement capacity is utilized, leaving 40% spare capacity. Results obtained are satisfactory according the tests conducted in the earlier studies, leaving sufficient factor of safety. The analytical viability of the structure is thus established and validated with experimental results for the contemplated loads and other technical considerations.

(2) This keeps enough scope for any unforeseen circumstances or variability in loading and/or environmental conditions. Also, the study shows that this composite structure analytically safe for the building in given circumstances based on the parameters considered. This composite technology allows us to construct G+8 building. At this level the entire strength of LGS and Ferrocement panels is utilised hence with G+8 there is no spare capacity available or there is no factor of safety remaining. While with G+5 building, we still have spare load bearing capacity (almost 40%)available that gives with factor of safety upto 1.6.

(3) This analytical study and its mapping with experimental stress values is useful step to establish this method of construction as innovative technology. This method ensures quality and speed of construction along with structural stability as per prevailing code of practice.

(4) This technology definitely is futuristic and meets SDG goals in many ways like no wastage of water and other materials at site, low over heads, reduced transportation cost, low carbon footprint, less housekeeping and less hazardous and better safety at site.

(5) Detailed further research and typical cases, actual constructed case studiesare needed to establish this composite technology to prove and promote its effectiveness. Hence this method of construction surely showcases futuristic trend to follow.

6 Future scope

The authors are also involved in full size actual construction of this structure. It is a matter of time that this method of construction is adopted as innovative technique and many structures are seen around using this construction method. Thus authors are hopeful of progressive and futuristic scope of this composite construction technology. In this research, authors have solely checked the analytical viability of the materials and building as a whole. Further research can be conducted with different building plans and different loading conditions. Also, further full scale experimental research can be done supporting this theory which has been put forward in the paper. Experimental research and supporting the analysis will lead to overall more impact about the concept and viability. As main requirements in today's construction industry are earthquake resistance, reduction in construction cost, environmental impact and quick assembly, the concept used in the project happens to be beneficial to the future construction practices. These being all the advantages of the technology used in the above study, it holds a greater importance for developing a new technology in the near future.

Fig 8 a – LGS frame

Fig8 b – Ferrocement panels fixed on LGS frame

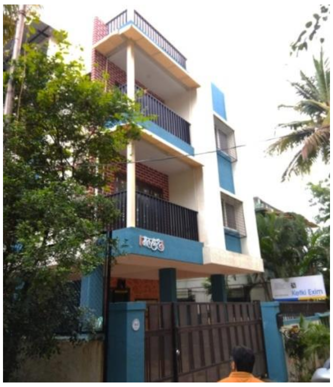

Fig 8c – Full scale construction of G+2 and a completed vila using LGS Ferrocast composite technology

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REFERENCES

[1]- M. Rashmi, N. Jayaramappa, B. Annapurna, Experimental Study on Ferrocement Panels Under Static Loading, in Impact of global atmospheric changes on natural resources. (2018). 335-338.

[2]- A.N. Purandare, M. Kulkarni. Ferrocast Structural Elements For Mass Housing For Low Income Group In India. in 3 rd Residential Building Design & Construction Conference. Penn state University USA. (2016).

[3]- P. Pawar, P. Minde, M. Kulkarni, Analysis of challenges and opportunities of prefabricated sandwich panel system: A solution for affordable housing in India. Materials Today: Proceedings, 65 (2022) 1946-1955. doi:10.1016/j.matpr.2022.05.193.

[4]- S. Shinde, P. Minde, M. Kulkarni, Analysis of LGS- ferrocement composite construction technology as a cost-effective & sustainable alternative to RCC. Materials Today: Proceedings, 65 (2022) 1011-1018. doi:10.1016/j.matpr.2022.04.122.

[5]- C. Londhe, P. Minde, Ferrocement: Cost Effective & Sustainable Construction Material for Low Cost Urban Housing in India. Gis Science Journal, 8(3) (2021).

[6]- Arun Purandare, M. Kulkarni, Theory and behaviour of Ferrocement in Construction. Kindle Edition ed.: IIPE publications, 2020.

[7]- N. Usefi, P. Sharafi, H. Ronagh, Numerical models for lateral behaviour analysis of cold-formed steel framed walls: State of the art, evaluation and challenges. Thin-Walled Structures, 138 (2019) 252-285. doi:10.1016/j.tws.2019.02.019.

[8]- M. Lawan, M. Tahir, S. Ngian, A. Sulaiman, Structural performance of cold-formed steel section in composite structures: A review. Jurnal Teknologi, 74(4) (2015) 65-175.

[9]- A. Jayaraman, S. Athibaranan, A. Mohanraj, Flexural behaviour of light gauge cold formed steel members comparison of is code and euro code. International Journal of Research in Engineering and Technology, 4(06) (2015).

[10]- T.M.U. Skudai, A review study on cold-formed-ferrocement composites. Australian Journal of Basic and Applied Sciences, 7(9) (2013) 103-111.

[11]- S.N. Mhadeshwar, A.M. Naik, Experimental performance, mathematical modelling and development of stress block parameter of ferrocement beams with rectangular trough shaped skeletal steel. International Research Journal of Engineering and Technology (IRJET), 4(06) (2017) 1387-1393.

[12]- D.G. Gaidhankar, M. Kulkarni, S.K. Inamdar, Behavior of Ferrocement Panels Using Welded Square Mesh. International Journal for Research & Development Intechnology, 8(4) 2349-3585.

[13]- R.J. Phalke, D.G. Gaidhankar, Flexural Behaviour of Ferrocement Slab panels using welded square mesh by incorporating steel fibers. International Journal of Research in Engineering and Technology, 3(5) (2014) 756-763.

[14]- P.S. Parande, D.G. Gaidhankar, Behaviour of ferrocement composite in direct tension by using welded square mesh. International journal of research in advent technology, 2(7) (2014).

[15]- D. Gaidhankar, M. Kulkarni, A.R. Jaiswal, Ferrocement composite beams under flexure. International Research Journal of Engineering and Technology, 4(10) (2017) 117-124.

[16]- N.M. Kulkarni, D. Gaidhankar, Analysis and design of ferrocement panels an experimental study. Volume-1, Issue-5, pg, (2013) 2319-9598.

[17]- A. Kale, D.M.S. KULKARNI, In plane shear behaviour of ferro-cement panels using finite element method. International Research Journal of Engineering and Technology (IRJET), 7 (2020) 604-614.

[18]- B.Y. Desai, J. Patel, Experimental analysis of ferrocement panels in flexure. International Journal of Innovative Research in Science, Engineering and Technology, 5 (2016) 12.

[19]- D.G. Gaidhankar, M. Kulkarni, A. Akhtar, Behaviour of Ferrocement Panel under Impact Loading. International Refereed Journal of Engineering and Science (IRJES), 7(7) 1-11.