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Performance of Existing Non-structural element and Selection of Ferrocement (Eco-friendly) for building construction

Zinat Hosain[1], Mosfiqur Rahman[2]
[1] *Institute of Earthquake Engineering and Research, Chittagong University of Engineering and Technology, Chittagong, Bangladesh.*
[2]*Department of Disaster and Environmental Engineering, Chittagong University of Engineering and Technology, Chittagong, Bangladesh.*

Abstract:
Urbanization and speedy growth of population results on the increasing demand for construction of building. Resource, energy, technology and manpower play a key role for the challenges of this demand. Sustainable development is a great challenge to overcome these issues. Environment-friendly technology can be reached by cost effectiveness and improving the life style of the inhabitant. So, a new approach should be introduced with in affordable cost in construction industry. Generally, the construction part plays two essential terms, such as structural and non-structural element. Mostly non-structural elements depend on the brick and it's by product. Beyond the significance of brick production, most of kilns are outdated and highly contaminating. This leads to harmful impact on environment and to the human health. Now it is appropriate time to replace the brick as per use as non-structural element which should be environment-friendly and accelerate to achieve the future goal with in sustainable environments. In this work, ferrocement is introduced as a lightweight thin element to control these problems by improving architectural and structural behavior as well as pre-cast and cast in situ construction of nonstructural elements. The main objective of this research is to discuss the behavior of ferrocement and compare the load with conventional elements in building design by software analysis program. It includes some recent different types of applications in civil construction. The study also aims for carbon reduction by using the ferrocement technologies in order to speed up the sustainable environment.
***Key Word**: Eco-friendly, Sustainability, Environment, Brick, Ferrocement.*

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I. Introduction

The growth rate of the urbanization depends upon the aerial perspective and basic needs of inhabitants; it occurs somewhere very rapidly or comparatively less than other part. Construction sector is the major part of urbanization and behind that civil work plays a superior part for the development. Civil Engineering plays a vital role in the construction sector. Most of the civil part may involve with two parts that is structural element (beam, column, footing etc.) and non-structural element (brick wall, furnishing elements etc.).

Bangladesh is now fastest developing country in the world. In 1980's & 1990's, the GDP of Bangladesh grew at about 4%, where the construction industry grew at 5.5%. The demand rate of brick is increasing 5.28% annually. As per demand the annual production of bricks is nearly 8.66 billion, where the sale value US$-450 million which is almost 1% of Bangladesh GDP.

The Brick making industry in Bangladesh is best described as a "Footloose" industry. Production period is seasonal confined only five to six dry months of the year. The technology is outdated where the labor productivity is low, capitalization non-existent and informal management. Most of the time, only 6-10 numbers of permanent workers in whole seasons and the quantity of labor reaches at 120-130 numbers during dry season were observed. Another observation of brick-field is, on their leased land no permanent sites and fixtures are found. Now-a-days in Bangladesh, there are 3,935 number of FCK and BTK kilns which together account for about 95% of operating kilns. These kilns are known as most polluting kiln in the world and an observation of UNDP of the PDF B exercise showed that BTKs and FCKs consume an average of 240 tonnes of coal to produce one million of bricks. The coals being used is imported from the Indian state of Meghalaya which specifications are shown in table-1.

Table 1: Scenario of Fixed Chimney Kiln (UNDP-2016)

Calorific Value of Coal	6,400 Kcal/kg
Coal Consumption per 1,00,000 bricks	30.00 Tonnes *
Brick weight	4.3 Kg
Specific Fuel Consumption	8.0-6 TJ/brick
Carbon emission factor for fuel	25.8 tC/TJ
Carbon to Co_2 Conversion factor	3.66
Average annual Kiln production	20,00,000 bricks
Tonnes CO_2 per Fixed Chimney Kiln per year	1,518 Tonnes

Areas such as at Cox's Bazar, Chittagong Hill track side which is far south of the country where the wood fuel accounts for almost 100% of the energy used in kilns. Denuding "protected" woodlands and forest areas. And at the rural areas where the availability of land beside the major road and cities like as Comilla, Feni, near Dhaka (Narayn-gonj, Condra) and some areas at North Bengal are also targeted as the area selection of brickfield. Most notable is the impact of brick making on land degradation and deforestation (shown in figure 2 & 3). In a country where the population growth rate is alarming as compared to the small amount of land, the farmland depletion rate is now alarming. Total farmland in Bangladesh is about 14 million hectares and this depleting by about 80,000 hectares every year, a 0.05% depletion rate. Moreover, wood fuel is used as a secondary fuel for brick making accelerating the depletion of scare carbon sinks in Bangladesh. A chart form is shown in figure: 1.

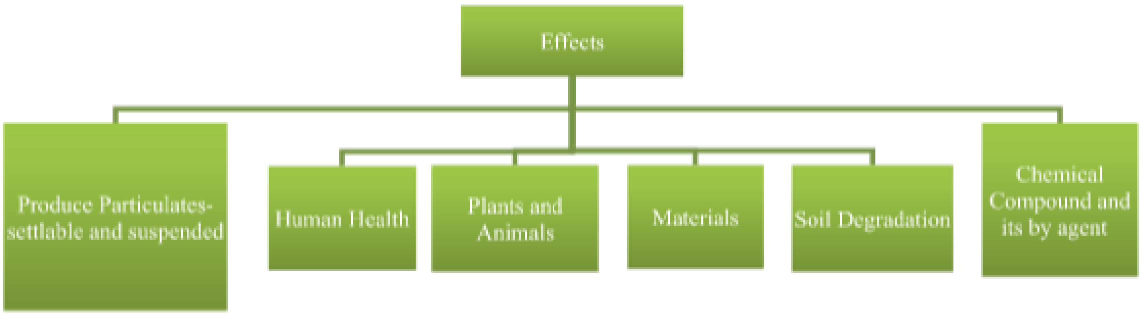

Figure: 1

Figure 2: Land is getting eroded due to manufacturing of bricks

Figure 3: Showing spoiled shrubs because emission of dust

Huge amounts of hazardous materials are discharged from the brick manufacturing industry, which would have great impact on the environment as well as on human health as shown in figure 4.

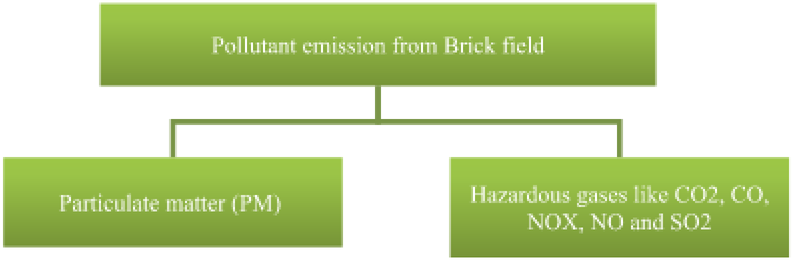

Figure 4: Pollutant emission from Brick field

A case study is taken of total emissions from the brick manufacturing in the Greater Dhaka region, to produce 3.5 billion bricks per year has been estimated shown in a table: 2.

Table 2: Pollutant Emission from Brick kiln in Dhaka

Product/ Pollutant	Amount/ Emission Rate
Brick per year	3.5 billion
$P.M._{2.5}$ (< 2.5 µm)	23,300 tonnes
SO_2	15,500 tonnes
CO	302,000 tonnes
BC	6,000 tonnes
CO_2	1.8 million tonnes

The emission of individual air pollutant from brick kilns varied significantly during a firing batch (seven days) and between kilns. Average emission factors per 1,000 bricks were 6.35 to 12.3 kg of CO, 0.52 to 5.9 kg of and 0.64 to 1.4 kg of particulate matter (PM). Presently sulphur dioxide (), oxides of nitrogen (NOx) and suspended particulate matter (SPM) are the main issue pertaining to air pollution problems in developing countries, where it contributes both to urban pollution and to regional acid depositions. A trend of Carbon emission from brick-field is shown in figure 5.

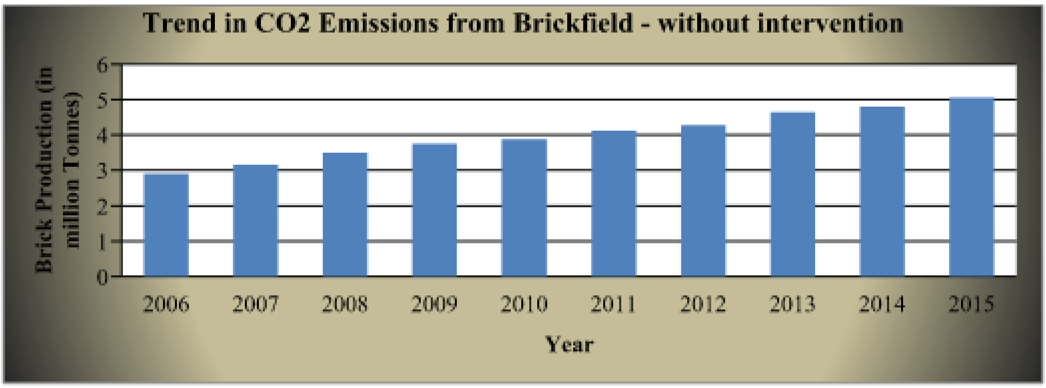

Figure 5: Trend in Emissions from Brickfield - without intervention

Fuel consumption, particulate emission and GHG emission from different kilns are given below Table 3. It is clear from the above table that fuel consumption, particulate emission and GHG emission are highest for FCK. FCK releases the highest level of PM and , primarily because of the high ash and sulfur content of the coal.

The main environmental impacts of operating brick kilns, which are particularly evident for the FCKs, include health, emissions and poor energy efficiency, Crop yields (from air pollution) and depletion of cropland. Evidence is inconclusive on PM emissions of the Zigzag kiln. In terms of pollutants, the Hoffmann kiln, fired by natural gas, is considerably superior to all coal-burning kilns. Unfortunately, due to natural-gas supply constraints, the expansion of this technology stopped and existing kilns are facing closure.

Table 3: Energy Consumption, Particulate Emission and GHG Emission from Brick Kilns (Source: BUET 2007)

Technologies	Coal per 100000 bricks (Tonnes)	Particulate (mg/m^3)	CO_2 per 100000 bricks (Tonnes)	GHG (CO_2) Reduction
Baseline				
FCK	20-22	1000+	50	--
Zigzag (poor kiln design and poor management)	18-20	1000+	45	10%
Zigzag (poor kiln design and medium management)	16-18	500-800	40	20%
Hoffman (Natural Gas)	16,000 m^3	< 100	30	40%
Alternatives				
Hoffman (Natural Gas)	16,000 m^3	< 100	30	40%
FCK (+ GSC + IF)	16-18	< 500	40	20%
Zigzag (good management)	16-18	400-600	40	20%
Coal Hoffman	12-14	< 400	30	40%
VSBK	10-12	200-400	25	50%

II. Ferrocement Work

Materials should satisfy the environmental sustainable product. In the research, non-structural element selection is essential to ensure the environment friendly material that should be adopted following these criteria and should be possessed like the characteristics shown in the following figure 6.

Figure 6: Eco-friendly construction criteria

Conventional Eco-friendly materials:
According to criteria shown in figure, here provided some materials name in following:

1. Bamboo, Bamboo Based Particle Board & Ply Board, Bamboo Matting
2. Bricks sun dried
3. Precast cement concrete blocks, lintels, slab. Structural and non-structural modular elements
4. Calcined Phospho Gypsum Wall Panels
5. Calcium silicate boards and Tiles
6. Cellular Light Weight Concrete Blocks
7. Cement Paint
8. Clay roofing tiles
9. Water, polyurethane and acrylic based chemical admixtures for corrosion removal, rust prevention, water proofing
10. Epoxy Resin System, Flooring, sealants, adhesives and admixtures
11. Ferro-cement boards for door and window shutters
12. Ferro-cement Roofing Channels
13. Fly-ash Sand Lime Bricks and Paver Blocks

14. Gypsum Board, Tiles, Plaster, Blocks, gypsum plaster fiber jute/sisal and glass fiber composites
15. Laminated Wood Plastic Components
16. Marble Mosaic Tiles
17. MDF Boards and Moulding
18. Micro Concrete Roofing Tiles
19. Particle Boards
20. Polymerized water proof compound
21. Portland Pozzolana Cement Fly ash / Calcined Clay Based
22. Portland Slag Cement
23. RCC Door Frames
24. Ready Mix Cement Concrete
25. Rubber Wood Finger Joint Board
26. Stone dust
27. Water proof compound, adhesive, Polymer, Powder

Material Selection:

Criteria as shown in figure 6 and according to judgement of engineering material, ferrocement might be feasible to use as non-structural element. The main reasons are, it is a light weight product and possess a greater strength in compression as compared with brick and have tensile strength (shown in figure 7 & 8), whereas brick do not have any strength at tension. Another one is higher lateral stiffness property than bricks. Ferrocement materials are usually durable, cost effective, do not need any extra plastering and can provide a great architect view at any place. Another advantage is, it can be made to any shape as per requirements. Although the total fabrication process is environment friendly, where emission of carbon is only from cement production rather than there is no carbon emission from its product. Other pollutant like as nitrogen, Sulphur and its bi-agent which are produced in brick production can be minimized by the use of ferrocement technique.

From the above observation, “Ferrocement” should be more convenient and reliable material in building construction as use of non-structural element.

Ferrocement Element:

Generally, ferrocement is a form of thin (around .75” ~2”) reinforced concrete using closely spaced multiple layers of mesh and/or small diameter skeleton steel completely infiltrated with, or encapsulated in mortar. The ratio of mortar depends on the construction objectives; roughly cement sand ratio is taken as 1:1.5~2. The skeleton steel (shown in figure 7) may use 5~6mm for two layer or use 10mm for single layer in both directions. And the wire mesh (shown in figure 8) should be square woven and the thickness should be 22~24 gage. At fixing stage, post (RCC/ Steel) should be providing at certain interval to control the slenderness problem.

Figure 9: Skeleton Steel (Various diameters)

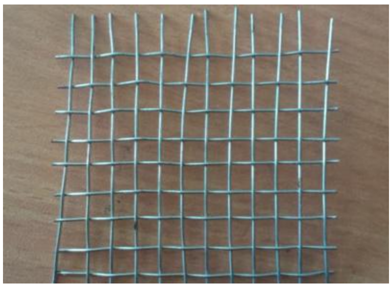

Figure 10: Chicken Wire Mesh

Properties of Ferrocement:

- It is a very durable, cheap and versatile material.
- Low w/c ratio produces an impermeable structure.
- Less shrinkage and low weight.
- High tensile strength and stiffness (shown in figure 8).
- Better impact and punching shear resistance.
- Undergo large deformations before cracking or high deflections.

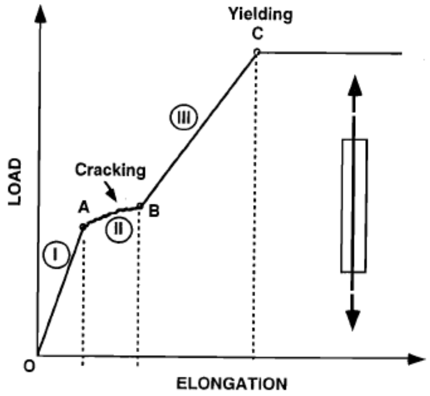

Figure 7: RC in tension

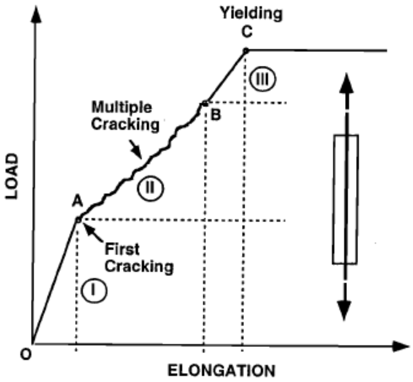

Figure 8: Ferro cement in tension

Advantage and Disadvantage of Ferrocement:

Every product has some merits and demerits. But it is convenient to know about their properties as per their specific usage. So it is essential to know about the product disadvantages for precaution taking in terms of use and as well as advantages to know about the features.

Advantage:

- It is highly versatile and can be formed into almost any shape for a wide range of uses
- 20% savings on materials and cost
- Suitability for pre-casting
- Flexibility in cutting, drilling and jointing
- Very appropriate for developing countries; labor intensive
- Good fire resistance
- Good impermeability
- Low maintenance costs
- Thin elements and light structures, reduction in self-weight & Its simple techniques require a minimum of skilled labor.
- Reduction in expensive form work so economy & speed can be achieved
- Only a few simple hand tools are needed to build any structures
- Structures are highly waterproof & Higher strength to weight ratio than R.C.C

Disadvantage:

- Low shear strength
- Low ductility
- Susceptibility to stress rupture failure.
- It can be punctured by collision with pointed objects.
- Corrosion of the reinforcing material due to the incomplete coverage of metal by mortar.
- It is difficult to fasten to ferrocement with bolt, screw, welding and nail etc.
- Large no of labors required.
- Tying rods and mesh together is especially tedious and time consuming.

Application of Ferrocement:

- Marine Applications:
- Boats, fishing vessels, barges, cargo tugs, flotation buoys
- Key criteria for marine applications: light weight, impact resistance, thickness and water tightness
- Water supply and sanitation:
- Water tanks, sedimentation tanks, swimming pool linings, well casings, septic tanks etc.
- Agricultural:
- Grain storage bins, silos, canal linings, pipes, shells for fish and poultry farms.
- Residential Buildings:
- Houses, community centers, precast housing elements, corrugated roofing sheets, wall panels etc.
- Rural Energy:
- Biogas digesters, biogas holders, incinerators, panels for solar energy collectors etc.
- Miscellaneous uses:

- Mobile homes
- Wind tunnel
- Silos and bins
- Bus shelters
- pedestrian bridges
- soil stabilization
- chemical resistant treatment
- Precast ferrocement structures
- Boats, fishing vessels, barges, cargo tugs

Existing Practice in Bangladesh:
A very rare application found in Bangladesh due to lack of the expert and some socio-economical aspect. Within a limited bounded, some work of ferrocement is running by self-founded organization. Some examples are shown in below by two segments.

A. Cast-in-situ Construction:

This one is for the 1st time in Bangladesh; a sample project named as “Fercem Inn & Suites” (shown in figure: 9) at kolatoli Cox’s Bazar is done by Engr. Shamsul Huq who is founder of FERCEM HOUSES & AMENITIES and wants to introduce low cost housing system in Bangladesh. In this structure the non-structural elements and slab were built with ferrocement. Thickness of wall is around 1.25”~1.50” due to precast element and slabs were made as “I” shape which was pre-cast and later jointing was done by the welding adjacent steel with some grouting.


Figure 9: Cast-in-situ Ferrocement non-structural element work

Another couple of figures show some ferrocement cast in situ work. These figures are for water tank construction. As from figure 10(a) it shows some small diameter steels placed vertically and horizontally at fixed intervals on the side wall and bottom of the tank. Next, wire meshes are placed on both side to increase lateral stiffness and as well to reduce the probability crack on the construction. Another couple of figure 10(b) and 10(c) shows the application of mortars (cement: sand = 1: 2) on the lateral wall. And figure 10(d) shows the finishing of the project with water storage. The total thickness of the lateral wall is 1.5” and the bottom slab 2.0”.

(a) (b)

Figure 10: Water storage by the application of Ferrocement (continue)

(c) (d)

Figure 10: Water storage by the application of Ferrocement

B. <u>Precast Work:</u>

Simple and easy solution is always important for any types of work. Specially for building construction it is always convenient to user. Precast element in building construction is that type of solution. A research work is continue in "Rahman Nagor, Chittagong", to build precast ferrocement elements. But it has some limitation in terms of fixing. Some portion of that research work is given in below:

i. Ferrocement Roof:

Low cost housing and long term sustainability rather than the existing practice of tin or mud house, roofing system of ferrocement has been introduced here. In figure: 12 show the cross section of roofing element. An ideal formwork is used for casting the unit. The fixing system is very simple, in figures 11, 13 & 14 shows the ultimate arrangement of roofing system after fixation by nuts and bolts the unit and overlaps them between two adjacent units.

Figure 11: Fabrications and Storage

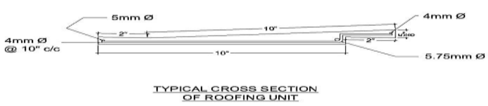

Figure 12: Roofing Element Cross Section

Figure 13: Roofing Unit Fixing

Figure 14: Ultimate Arrangement of Unit

ii. Precast Wall Unit:

Partition Wall is a non-structural element mostly covered by bricks. A full height (10’) of 5” thickness brick may produce 500 lb/ft whereas the ferrocement 1” thick wall produce 125~135 lb/ft. This may reduce 70~75% of partition wall loads. A typical cross section of ferrocement wall is shown in figure 15, and a completed project by precast ferrocement wall shown in figure 16 and the fixation work is done by 8mm dia nuts and bolts.

Figure 15: Cross Section of Wall Unit

Figure 16: Wall unit Fixation Arrangement

C. Composite type work:

River protection is a comprehensive work and lots of sophisticated issues are involved here. It can be simplified by the use of ferrocement and reduce lots of expenses. Examples are shown in figure 17 & 18. The river bank protection is in “Danghar-char, Karnaphuli”. It was built around 8 years ago and the main mechanism is to float with the tidal height and it can be up and down which works like as a finger nail. Here the ferrocement works on the sheet pile, slab and ferrocement bollis. For that the project cost reduced at 28~30% of any other types protection.

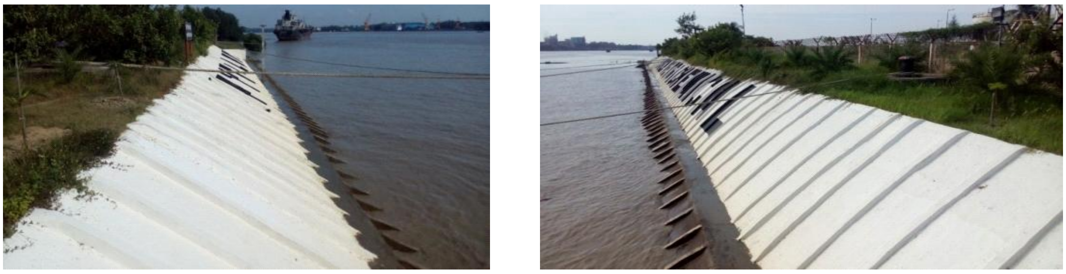

Figure 17: Side view of River Protection

Figure18: Part view of River Protection

III. Feasibility Study

Report recommendation is conducted sometimes after an exploratory work is performed into a large scale. This aim is to find out the existing product’s market analysis and shows the society the project that can be beneficial to the them and others.

Load Estimation:

From engineering point of view, load estimation is important role for any types of engineering construction. If lesser design load found from the structure or any objects it can reduce the total project cost and as well as the design complexity.

Here a typical analysis is shown in following tables where the wall dimension (shown in figure 19) are taken 8’-0” x 12’-0” constant with a varying thickness of 3”, 5” & 10” for brick walls and 1”, 1.25” & 1.5” for ferrocement walls.

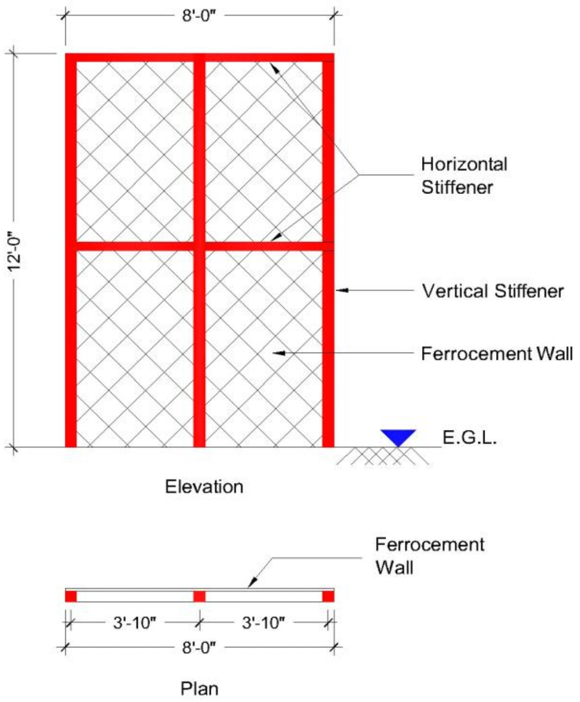

Figure 19: Plan and Elevation of a typical ferrocement non-structural element

Table 4: Brick Wall Load Calculation

Particulars	Dimensions			Volume	Unit Weight	Total Load	Load per length
	Length	width	thickness				
	ft	*ft*	*inch*	*cft*	*pcf*	*lb*	*lb/ft*
3" brick work	8	12	3	24	120	2880	360
5" brick work	8	12	5	40	121	4840	605
10" brick work	8	12	10	80	122	9760	1220

Table 5: Ferrocement Wall Load Calculation

Particulars	Dimensions			Volume	Unit Weight	Total Load	Load per length
	Length	width	thickness				
	ft	*ft*	*inch*	*cft*	*pcf*	*lb*	*lb/ft*
1.00" thick ferrocement wall	8	12	1	8	155	1240	155
1.25" thick ferrocement wall	8	12	1.25	10	155	1550	193.75
1.50" thick ferrocement wall	8	12	1.5	12	155	1860	232.5

From the above observations (table 4 & 5) the loads from ferrocement walls are found lesser than any other thickness of brick wall. If consider a 3" brick wall with compared with 1.5" thick ferrocement wall still the load from brick wall is higher. And it's around 35% higher than the ferrocement wall. From that point of view, the loads from the non-structural element can be effect on the total structural design.

IV. Cost Benefit Analysis

Low cost and eco housing is a big challenge for developing nation and poorer nation. It is big issue now-a-day. Ferrocement is a solution for those types of nation. But the problem is in its thickness. Due to lesser thickness as compared to other, some slender effect must be introduced. So, stiffener (post) should be essentially provided there, on both vertically and horizontally at a certain interval it can be reduced at a satisfactory stage. And for that, the costing has increased partially.

Here ferrocement wall considers for cost analysis where the wall is connected with three vertical stiffeners and two horizontal stiffeners as shown in figure 19. And a summarized cost analysis is given for two types of element in table 6 & 7.

Table 6: 1" thick ferrocement costing for specified element

SL#	Materials	Reqd.	Unit	Rate	Cost
1	Cement	5	bag	415	1961
2	Sand	12	cft	24	284
3	4mm reinforcement (Post Tie bar)	3	kg	45	118
4	5mm reinforcement	19	kg	45	833
5	5.75mm reinforcement	9	kg	45	422
6	Wire mesh 22 gage	2	nos.	1350	2325
Total Material Cost					5942
Per area Material cost					61.89695797
Labor Cost					2900
Per area Labor cost					30.20833333
Total Cost					**8842**
Total Cost per sft					**92.1052913**

Table 7: 5" brick costing for specified element

SL#	Materials	Reqd.	Unit	Rate	Cost
1	Cement	4	bag	415	1673
2	Sand	20	cft	24	484
3	brick	1	nos.	8000	4048
Total Material Cost					6205
Per area Material cost					64.63666667
Labor Cost					2200
Per area Labor cost					22.91666667
Total Cost					**8405**
Total Cost per sft					**87.55333333**

Here, slightly higher in ferrocement construction is shown. But due to lesser load found on structure, it can reduce the total project cost and simplify the project.

V. Conclusion

It is shown that ferrocement is beneficial to the building construction for non-structural element. Cost analysis is also shown though it is slightly higher but it will reduce the total cost of the project. Ferrocement can be the alternate solution to the brick which produces carbon emission and other hazardous gas emission. It is more convenient and reliable material.

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