CEMENT STABILIZED STEEL FIBER REINFORCED SOIL FOR RAMMED EARTH BLOCK APPLICATIONS: A CASE STUDY

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Abstract: The development of affordable housing is the need of the present day. Building with Rammed Earth Block (REB) technology is becoming more popular in the western world, due to their low cost and relative abundance of materials. The proposed Steel Fiber Rammed Earth Blocks (SF-REB) possesses of compressed earth ingredients plus steel fibers. Steel fibers have important attributes such as low density, light weight, low cost, high tensile strength, as well as being fire resistant. Experimental studies on rammed earth blocks with varying percentages of stabilizers i.e. cement and steel fibers were performed. Steel fibers, thus present a wide array of opportunities for enhancing properties of construction materials. The results of this study will highlight the use of locally available soil for its use in rammed earth block applications.

Index Terms: **Steel fibers; Rammed Earth Block (REB); Steel Fiber-Rammed Earth Block (SF-REB); Low Cost**

I. INTRODUCTION

The demand for low cost housing materials is growing as social, economic and environmental issues evolve in today's society. The recent increase in using natural materials for construction is to decrease energy consumption in the construction industry. The utilization of earth in housing gives a very high fire and heat resistance with comfortably built living environment. It also offers various other benefits to the user. Earthen building techniques have been in use for thousands of years, and structures built with these blocks have sustained for a long time; one such example is the Great Wall of China.

In India, the cost of living is increasing day-by-day. Majority of the current construction is being spread vertically mostly made of reinforced concrete (RCC) which is also not affordable to the majority.

There are various types of natural and artificial fibers which can be used in rammed earth blocks, to increase their mechanical properties. The use of steel fibers in RCC have also proved to reduce 56% of carbon emission in the environment. The energy consumption in the industry can also be reduced by using fibers due to their low density and light weight.

Adding steel fibers to the mix design is intended to increase the internal strength of the SF-REB significantly. This study will focus on the use of locally available soil in rammed earth blocks and effect of steel fibers on mechanical properties of the block. An extensive literature review on rammed earth construction, suggests feasible ranges for parameters like consistency limits and compaction characteristics. Thus, to check the suitability of locally available soil, optimum moisture content, maximum dry density and plasticity index were performed.

II. LITERATURE REVIEW

Through the literature review it was found that **Daniela Ciancio et al (2018)** described the social and financial sustainability of the rammed earth technology. **Kandamby G.W.T.C. (2018), Steve Burroughs (2010)**, suggested the minimum sand content in the mix. The importance of consistency limits and compaction characteristics was given by **Suresh A. et al (2016), Gerardo Chang Recavarren et al (2013) and Steve Burroughs (2008) (2010).**. Whereas **Susana Serrano et al (2016)** described the difference between strengths of stabilized and non-stabilized rammed earth.

III. METHODOLOGY

- *General* – Need for Study, Objective, Scope of work, Problem Statement.
- *Literature Review* – In this research work, literature review was collected by various national and international journal research papers.
- *Data Collection* – Soil for the research study and the composition of the soil was collected from the site.
- *Data Analysis* – Compression test was performed on various block samples and compared.
- *Probable Conclusion* – The study will help in selecting appropriate combination of soil, cement and steel fibers for optimum compressive strength.

IV. DATA COLLECTION

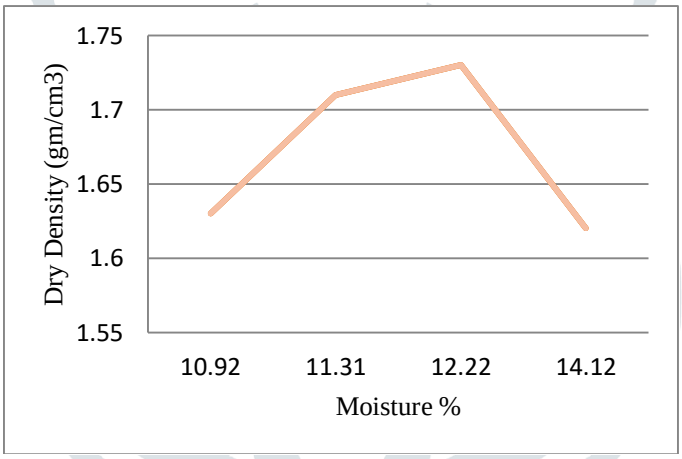
The local soil used in this research was sourced from the excavated soil at a construction site in Bibvewadi area in south Pune district. The grain size distribution, Consistency Limits and OMC and MDD of the soil under study, as obtained from the site data is as shown in Table 1.

Table 1. Properties of soil collected from site

Sr. No.	Property	%
1	**Grain Size Distribution**	
	Sand	23
	Clay	42
	Silt	35
2	**Consistency Limits**	
	Liquid Limit	51.50
	Plastic Limit	21.24
	Plasticity Index	30.26
3	**Compaction Characteristics**	
	OMC	12.22
	MDD (gm/cm^3)	1.73

The OMC and MDD were obtained from a graph plotted by considering four random experimented samples conducted on site.

Graph 1. OMC Vs MDD from soil data collected



V. DATA ANALYSIS

A. Introduction

In the data analysis, the consistency limits and compaction characteristics were checked when soil is added with varying percentages of Ordinary Portland Cement 53 grade (2%, 4%, 6%). Further, varying percentages of steel fibers (0.5%, 1%, 1.5%) were added to the samples respectively and rammed earth blocks were casted. Compression strength test of these sample blocks was performed and the data was compared.

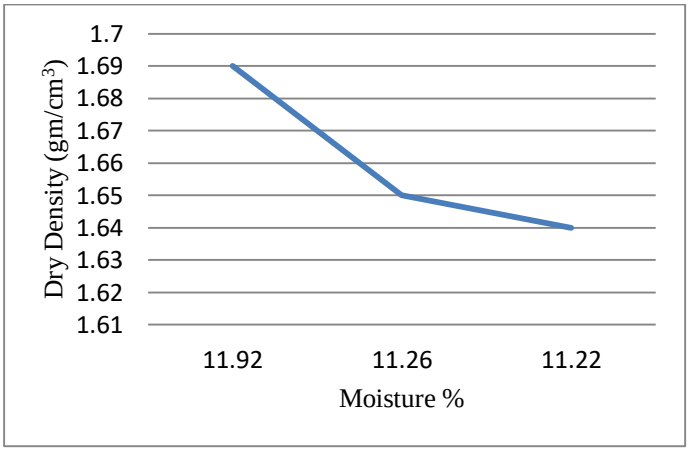
B. Consistency Limits of Stabilized Soil

There were variations in the values of the consistency limits and compaction characteristics, when the soil was added with cement. The following table illustrates the variations of OMC and MDD when added with varying percentages of cement.

Table 2. OMC and MDD when added with cement

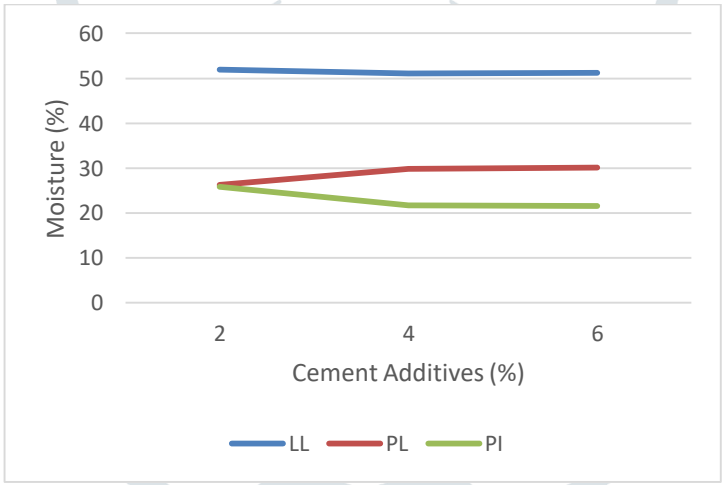
Sample No.	Cement (%)	OMC (%)	MDD (gm/cm^3)
1	2	11.92	1.69
2	4	11.26	1.65
3	6	11.22	1.64

Graph 2. OMC Vs MDD with Cement Additives



Thus, it is clear that there is slight decrease in the OMC as cement is added in the mixture. But, further increase in the cement does not satisfy the purpose of low cost housing. Thus, 4% cement can be considered to get the required moisture content and dry density.

Graph 3. Consistency Limits with Cement Additives



The liquid limit of the soil does not show any changes when added with cement additives. But the plastic limit gradually increases with 4% cement which eventually decreases plasticity index. The consistency limits when added with 4% cement are Liquid Limit – 51.10%, Plastic Limit—29.80% and Plasticity Index – 21.70%.

C. Compressive Strength Test of Blocks

The soil under study thus satisfies the condition for use in rammed earth construction. The condition to use it in rammed earth, as studied in literature review is to have plasticity index between 10-30%. Thus it can be used for rammed earth blocks. Preliminary compression test was performed to evaluate the optimum percentage of cement and steel fibers. Cement used was OPC 53 grade and steel fibers used were loose hook end steel fibers with aspect ratio 60. External sand was added so that the soil satisfies the parameter of minimum sand content in the soil.

Table 3. Percentage of Additives

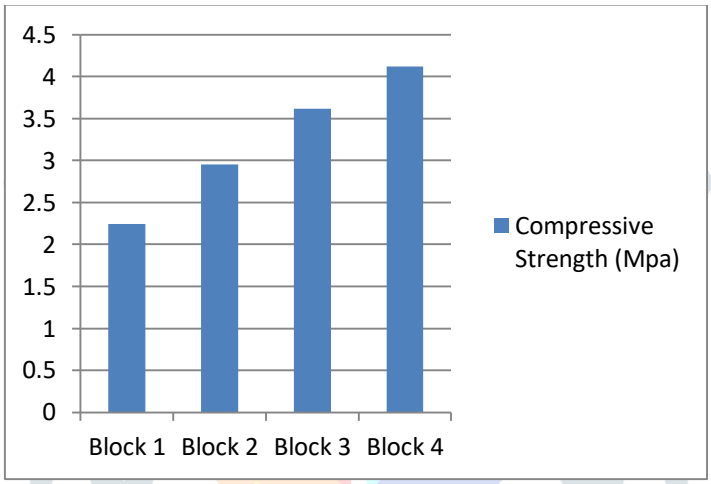
Block No.	Additives (%)		Sand (%)
	Cement	Steel Fibers	
1	0	0	30
2	2	0.5	30
3	4	1	30
4	6	1.5	30

Casting Procedure –

1. The soil at first is passed through IS 20mm sieve.
2. Percentages of cement and steel fibers to be added in the soil, is according to the dry weight of the soil.
3. The ingredients are then mixed thoroughly.
4. Optimum water is added to the mixture so that the ingredients bonds together.
5. This well mixed soil sample is then filled in the mold in three layers.
6. Each layer is compacted thoroughly so that further compaction of the soil is not possible.
7. Top layer of the soil is chopped off to get a leveled surface.
8. The mold is removed within an hour of compaction. The end product is little moist and as time passes; the sample block dries and hardens.

The compression test was then taken on the blocks casted, after 28 days of curing. Following are the results obtained.

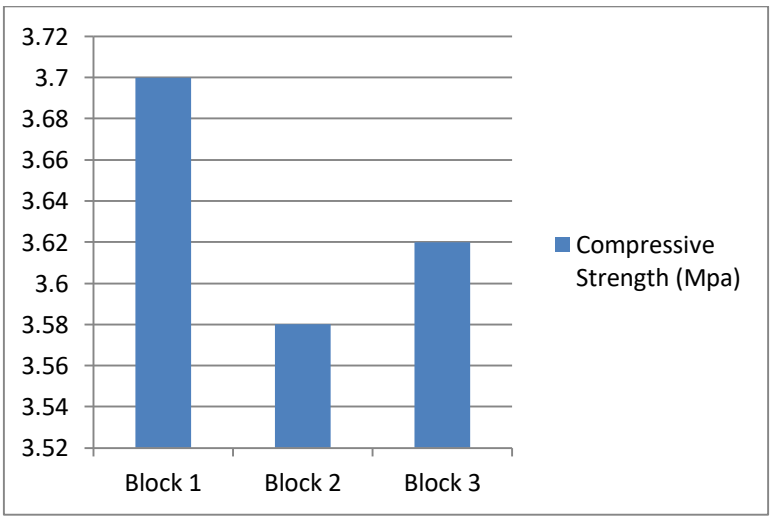
Graph 4. Compressive Strength (MPa)



Compressive strength of block no. 4, having cement 6% and steel fibers 1.5%, showed the highest compressive strength of 4.12 MPa. The graph suggests the compressive strength of the rammed earth block increases with increase in cement and steel fibers. But for the economic consideration, maximum 4% cement and 1% steel fibers were selected, which also satisfies the minimum compressive strength requirement of rammed earth blocks.

Further, to have an accurate value of the compressive strength of the selected composition, three SF-REB with 4% cement and 1% steel fibers, were casted. This is required to confirm the compressive strength of the selected block. Following were the results obtained.

Graph 5. Compressive Strength Comparison (MPa)



Graph shows that there is ±0.1MPa deviation in the compressive strength of the selected SF-REB. Thus this confirms that 4% cement and 1% steel fibers when added in rammed earth block gives the acceptable results.

D. Economic Feasibility

Economic feasibility of this project is required to determine its efficiency in using it in various construction projects. Following is the comparison between bricks and SF-REB.

For this $1m^3$ of work is considered. The quantities of material are calculated by standard practice considering wastages. Labor requirement is calculated by considering the labor productivity and labor constants.

Table 4. Brickwork

Particulars	**Quantity**	**Unit**	**Rate**	**Cost**
Cement	1.60	Bags	350	560
Sand	0.3210	Cum	1350	433.35
Bricks	525	Nos	4.50	2362.50
Total				3355.85
Labor				
Mason	1	Per day	550	550
Male Mazdoor	1	Per day	500	500
Female Mazdoor	1	Per day	450	450
Bhisti	0.5	Per day	400	200
Total				3237.5
Total Cost				5055.85

Add 1.5% for water cost = 75.83
Add 1.5% for tools & plants = 75.83
Add 3% for lumpsum = 151.67
Add 10% for contractor's profit = 505.58
Rate per m^3 = Rs. 5864.78

Table 5. SF-REB

Particulars	**Quantity**	**Unit**	**Rate**	**Cost**
Cement	1.28	Bags	350	448
Steel Fibers	16	Kg	120	1920
Sand	0.32	Cum	1350	432
Total				2800
Labor				
Mason	1	Per day	550	550
Male Mazdoor	1	Per day	500	500
Bhisti	0.5	Per day	400	200
Total				1350
Total Cost				4150

Add 1.5% for water cost = 62.25
Add 1.5% for tools & plants = 62.25
Add 3% for lumpsum = 124.5
Add 10% for contractor's profit = 415
Rate per m^3 = Rs. 4814

Thus, SF-REB can be constructed in Rs.1050.78 per cum less than that of the conventional brickwork. Moreover, rammed earth walls do not need plastering. Thus, the cost of material and labour required for plastering is also saved, eventually.

VI. CONCLUSION

The locally available soil was found to be suitable in plasticity index criteria, but was not suitable in percentage of clay it holds. But still the preliminary results obtained after the mixture of additives are satisfactory. The accurate results obtained from 4% cement and 1% steel fibers also shows that only ±0.1MPa deviation occurs in the compressive strength of the block. Though the compressive strength of the rammed earth blocks is less than those of the concrete cubes, they satisfy the minimum requirement of compressive strength of the block. The compressive strength of rammed earth blocks also depends on the percentage of compaction done. How well the compaction of the earth is done, gives the final results.

SF-REB containing 6% cement and 1.5% steel fibers by weight of soil, gives the highest compressive strength. However, for economic feasibility, 4% cement and 1% steel fibers are selected.

When compared with conventional brickwork, SF-REB construction proved to be Rs. 1050.78 per cum less. Thus, it proves to be cost effective too.

Material properties of SF-REB are largely influenced by fiber type, fiber volume, fiber geometry and length. Consequently, varying the percentages of additives, using different types of artificial and natural fibers can be used to evaluate the initial findings.

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