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Design and Construction of Ferrocement Water Tanks

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Abstract

Ferrocement is proposed to construct of water tanks with high strength, crack resistance, high ductility, impact resistance and energy absorption properties suitable for rise buildings. This paper presents the results of an analytical study of proposed ferrocement water tanks. The cement sand matrix of the ferrocement composite was designed to achieve high compressive, tensile and flexural strengths for the produced ferrocement tanks. This was achieved by employing silica fume as replacement percentage of the cement content. The results of an experimental investigation of the effect of silica fume on the strength of the matrix are also included. The complete analysis and design of twelve ferrocement water tanks with different capacities and their estimated costs are also included. The optimum limit of partial replacement of cement with silica fume was found to be 15%, which exhibited the highest increase in strength. The structural analysis and design of ferrocement water tanks were determined. The developed ferrocement tanks are four times cheaper compared with the other constructed tanks. The developed ferrocement tanks could be used successfully for the developed and developing countries alike.

Keywords: *Ferrocement; development; Silica fume; Ferrocement tanks; Design; Fabrication techniques; Water tightness; Economic assessment; Cost competitiveness*.

1. Introduction

The American Concrete Institute (ACI) Committee 549 on ferrocement has given as "Ferrocement is a type of thin wall reinforced concrete construction, whereas usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh, mesh may be made of metallic materials or other suitable materials". The ferrocement concept is an excitingly simple idea, which has found wide-ranging applications in many countries. It was observed that in some of the water tanks cracks occur in the wall of tanks in both horizontal and vertical directions. In addition to leaking problems, corrosion of steel reinforcement is a major concern in these tanks. The use of large amounts of small diameter meshes distributed uniformly within a concrete section provides a very efficient and simple form of crack control, that is superior to many other forms of crack arrest obtained in concrete structure elements by using conventional reinforcement.

The adaptability of the concept to both semi-skilled technologies in developing countries, as well as to highly develop concrete technology in the developed countries, makes it a very unique construction material, the full potentialities of which are not yet wholly recognized. Several factors have contributed in wide spread use of ferrocement- its mechanical properties, the possibility of using elements without using formwork, high impact resistance and toughness, the economic advantages due to reduced element thickness, durability, crack resistance and simplified repair operations. Ferrocement could be used successfully in a variety of applications such as water tanks for high-rise buildings. Low –cost small sized circular cylindrical ferrocement tanks constructed for domestic use in India and abroad [1] are conventionally designed for hoop tension. The ferrocement members are usually very thin and therefore by following a conventional practice, a tank larger than 75 m^3 cannot be built. An alternative approach was first developed by Hanai [2], exploring which S. Carlos Group has constructed a number of large sized ferrocement tanks for various industrial uses in Brazil, which could claim substantial economy over reinforced concrete tanks [2].

Mansur [3] introduced the concept of constructing a ferrocement – brick sandwich water tanks. In this type of water tanks construction, the wall of the tank consists of a thick brick wall as a core and thin ferrocement layers as facing material. Such type of tanks has been designed and constructed and showed good performance, high ductility and energy absorption suitable for rise buildings. This paper presents the results of an analytical study of proposed ferrocement tanks. The optimum limit of partial replacement of cement with silica fume was found to be 15%, which exhibited the highest increase in strength. The structural analysis and design of ferrocement water tanks was determined. The developed ferrocement tanks are four times cheaper compared with the other constructed tanks. The developed ferrocement tanks could be used successfully for the developed and developing countries alike.

Tanks made of ferrocement are used in many countries for the collection and storage of water for drinking, washing, for animal use and irrigation. Ferrocement tanks vary in capacity, size, and shape [2]. They are built by hand-toweling layers of cement mortar onto a wire frame which is either free-standing or held in place by temporary or permanent structures known as 'formwork'. Ferrocement is only needed for tanks of capacities greater than 1000 liters as seen in Figure 1. Below this size, cement mortar alone is strong enough to withstand the applied loads.

Ferrocement tanks have several advantages over than tanks made of concrete or brick. Ferrocement tanks are usually cheaper than fiber reinforced plastic or steel tanks because these other materials have high manufacturing costs. Ferrocement has better corrosion resistance and lower maintenance costs than steel [3].

For ferrocement tanks, there is no need to purchase and transport large quantities of masonry stones, aggregates or bricks (However there will be the additional expense of purchasing reinforcing mesh for the ferrocement). The cost of reinforcing bars needed for large concrete and block work tanks will be saved. This money can be used towards the purchase of wires and meshes for the ferrocement tank. Additionally, ferrocement construction is labor intensive it requires relatively low levels of skill and few tools. Thus it is ideal for use in many developing countries. The tanks can be rapidly constructed. Typically, a 30m3 tank can be completed in 10 -13 days with a team of 10 or less workers.

Some of these structures (tanks and pipes) are exposed to the damage effect accumulating from environmental loadings such as wind, earthquake, and corrosion. Damage in a structure can be defined as changing that is introduced into a system causes reduction of its load-bearing capacity.

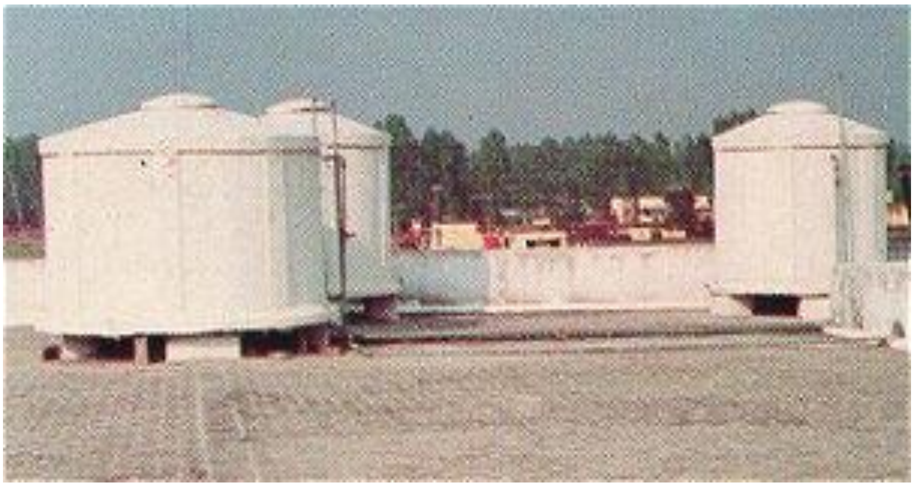


Figure 1: The application of ferrocement water tank.

Monitoring a structure and detect damage occurs with a large civil engineering structure such as water tanks is very important. Damage in a structure alters its dynamic characteristics [4]. The change is characterized by changes in the Eigen-parameters, natural frequency, damping values and the mode shapes associated with each natural frequency. Considerable effort has been spent in obtaining a relationship between the changes in Eigen parameters, the damage location and the damage size. Most of the emphasis has been used the changes in the natural frequencies and the damping values to determine the location and the size of the damage.

Curvature mode shape is investigated as a possible candidate for identifying and locating damage in a structure. Many researches submit that the absolute changes in the curvature mode shapes are localized in the region of damage and hence can be used to detect damage in the structure. Also, the changes in the curvature mode shape increase with increasing size of damage. This information can be used to obtain the amount of damage in the structure.

The characteristics of the impact load are a high loading rate and very short period that cause high strain rate in the structure [5]. Meanwhile, the mechanical properties of structures are different under impact loading compared with static loading. Impact properties of concrete are of interest where there is the possibility of impact loading in the foreseeable service life of a concrete structure.

Wide ranges of situations exist where structures may be subject to some type of impact loading. These include many different forms of missile impact, gas explosions, construction accidents, vehicle impacts and pile driving. Impact from an object colliding with a concrete structure can be divided into hard and soft impact depending upon the relative characteristics of the projectile (or Striking object) and the target (or structure) [6]. Different forms of damage can occur during hard impact of concrete structure. The contact zone is subject to intense dynamic stresses producing crushing, shear failure and tensile fracturing [7]. These may result in spilling and crater formation, penetration, back-face scabbing, perforation or shear failure and flexural failure of the target [8].

2. Experimental Investigation and Results

An experimental investigation was conducted to determine the effect of silica fume on the mechanical properties of the hardened cement-sand matrix to be used in the fabrication of the proposed ferrocement tanks. The matrix was designed to have high strength, low water to binder ratio, flow characteristics and high durability. To achieve these properties, silica fume was added to the mix. Different dosages of silica fume were considered namely: 10%, 15% and 20% replacement of the cement. The mix had sand to silica fume-cement, binder, ratio of 1.8. A ratio of 2% of super plasticizer was added to the mix to obtain the required workability while maintaining the water to binder ratio of 0.35 to provide adequate protection against corrosion and chemical attack. The 28 days compressive strength results showed that for the used water-content ratio, the optimum silica fume ratio was 15%. Table 1 shows chemical composition and physical properties of silica fume. Table 2 shows details of mix proportions and fresh mortar properties.

Figure 2 shows the variation of compressive strength with the age of the mix for the silica fume ratio. For the mix with 15% silica fume, the average 28 days compressive strength was 64.6 MPa and the average of three indirect tensile strength tests after 28 days was 5.8 MPa. The 28 days flexural strength was determined by loading the test plates with line loading applied at the third points on a span of 400 mm. The average flexural strength of the three specimens was 5.95 MPa. The average elastic modulus at the same age 35 GPA.

Table 1: Chemical Composition and Physical Properties of Silica Fume (SF).

Chemical Analysis	%	Physical Property	Value
Silicon dioxide (SiO_2)	97.10	Fineness, cm^2/gm	167000
Ferric oxide (Fe_2O_3)	0.50	particle size > 0.045mm, %	0.25
Calcium oxide (CaO)	0.20	Bulk Density	
Magnesium oxide (MgO)	0.50	(undensified), ton/m3	0.35
Sulfur dioxide (SO_2)	0.15		
Sodium oxide (Na_2O)	0.20		
Potassium oxide (K_2O)	0.50		
Water (H_2O)	0.55		
PH fresh	6.00		

Table 2: Details of Mix Proportions and Fresh Mortar Properties.

Series Designation	Mix No	W / C+SF	C / SF	S / C+SF	SP / C+SF	Slump (mm)
C	Cc	0.35	100/0	2.0	2%	55
	C1	0.35	95/5	2.0	2%	49
	C2	0.35	90/10	2.0	2%	35
	C3	0.35	85/15	2.0	2%	22
	C4	0.35	80/20	2.0	2%	12
	C5	0.35	75/25	2.0	2%	3

The compressive strength was found to increase with the increase in the of SF percentage up to 15%, subsequently it decreases. At 3-months age, the compressive strength for the 15% SF mix was markedly higher than that of the control mix. From Table 3, it is clear that there is a moderate drop in the early strength up to 7 days compared with the control mix. The explanation for this may be that the pozzolanic reaction took relatively longer time to show effect on strength; while, in the same time, the amount of cement was reduced by the replacement percentage of SF.

The flexure strength was found to be affected by the replacement level of SF in the same manner as the compressive strength as shown in Table 3. Also, it was found that the static modulus of elasticity increased compared to the control mix up to 15% replacement level; subsequently it decreased. The variation of the static modulus was in a complete agreement with the compressive strength behavior and most probably for the same previously mentioned reasons.

Table 3: The Effect of SF as Cement Replacement on the Hardened Mortar Properties.

Mix No	Compressive Strength, (MPa)							Flexure Strength (MPa)	Young′s Modulus (GPa)
	3-d	7-d	14-d	28-d	90-d	180-d	365-d		
Cc	30.3	37.4	45.0	50.5	58.6	61.5	63.2	5.40	26.4
C1	29.6	41.3	52.0	57.8	61.2	64.5	64.8	6.00	30.5
C2	28.0	43.0	56.2	61.9	70.7	72.6	71.3	6.20	33.3
C3	27.4	45.7	59.2	64.6	87.0	90.7	92.5	5.95	35.0
C4	26.2	42.1	54.0	61.0	66.8	70.9	70.1	5.40	32.6
C5	24.7	39.0	48.0	56.0	65.3	65.2	63.7	4.90	28.0

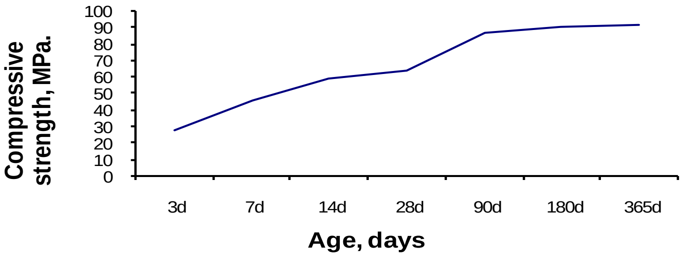


Fig.2 Variation of compressive strength with age

3. Development of Ferrocement Water Tanks

For rise buildings, steel tanks are commonly used to store water for domestic use. This may be to the availability of steel tanks in prefabricated form. However, the use of such tanks has many disadvantages like rusting and consequent deterioration of the quality of stored water, frequent maintenance and limited life span due to corrosion. In this section a design for precast cylindrical water tanks is proposed and recommendations for the construction technique are presented. The circular shape was chosen because it attracts less wind pressure, produces smaller bending moment in the wall due to water pressure, and is relatively less to leak as compared to an equivalent rectangular tank. However, circular tanks are more difficult to build if cast against a mold, so a unique design feature was incorporated to eliminate the need for a mold. A study was carried out to propose a suitable and durable design for use in high rise buildings by adapting available mechanized production methods, e.g. spinning technique, and the proper choice of reinforcement to ensure cost competitiveness.

The adopted water tank design consists of a cylindrical wall rigidly connected to a ring beam with a domed base. The tank has a height of 2.25 m. The diameter of the tank at the cylindrical wall is equal to 2 m. From the strength as well as practical viewpoint, a thickness of 35 mm is recommended for the roof and 40 mm to 100 mm for the cylindrical wall. The thickness of the base should be slightly larger and a value of 60 mm to 120 mm is recommended. The base is 3.60 m in diameter, for design calculations, the tank is assumed filled to a height 0.4 m below the top. Required thickness for the base, wall and roof are determined by checking the strength of each component against the maximum stress results acting on it. The construction procedure was carried out according to the results obtained from the analytical studies presented in Table 4.

Table 4 Details and results of designed ferrocement water tanks

Tank Design.	Volum.	Dimensions,					Reinforcement			Maximum stresses, MPa				M.T.D.	M.C.W	F.S.
	m3	D	H	twall	tbase	troof	No.of layers	V_R, %	Sr mm'[1]	Hoop*	Crack'	Tensi.#	Com.[+]	mm.	mm.	
Tank 1	1.0	1.02	1.22	0.025	0.05"	0.0225	2	0.035	0.0545	0.189	0.474	1.729	0.174	0.0023	0.0387	33.40
Tank 2	2.0	1.29	1.54	0.025	0.05	0.0225	2	0.274	0.054	0.316	0.791	2.882	0.264	0.0048	0.0387	20.03
Tank 3	3.0	1.47	1.77	0.025	0.05	0.0225	?	0.274	0.054	0.429	1.073	3.909	0.336	0.0075	0.0387	14.77
Tank 4	4.0	1.62	1.94	0.025	0.05	0.0225	2	0.274	0.054	0.527	1.317	4.801	0.396	0.0101	0.0387	12.02
Tank 5	5.0	1.74	2.09	0.025	0.05	0.0225	2	0.274	0.054	0.620	1.551	5.652	0.456	0.0128	0.0387	10.21
Tank 6	6.0	1.85	2.22	0.025	0.05	0.0225	2	0.274	0.054	0.702	1.754	6.393	0.499	0.0154	0.0387	9.03
Tank 7	7.0	1.95	2.34	0.025	0.05	0.0225	2	0.274	0.054	0.784	1.959	7.141	0.546	0.0181	0.0387	8.08
Tank 8	8.0	2.04	2.54	0.025	0.05	0.0225	2	0.274	0.054	0.862	2.154	7.851	0.591	0.0209	0.0387	7.35
Tank 9	9.0	2.12	2.55	0.025	0.05	0.0225	2	0.274	0.054	0.934	2.336	8.515	0.632	0.0235	0.0387	6.78
Tank 10	10.0	2.20	2.64	0.025	0.05	0.0225	2	0.274	0.054	1.006	2.515	9.165	0.619	0.0263	0.0387	6.30
Tank 11	11.0	2.41	2.41	0.030	0.060	0.027	2	0.272	0.045	0.812	2.029	7.452	0.573	0.0232	0.0464	7.53
Tank 12	12.0	2.48	2.48	0.030	0.060	0.027	2	0.272	0.0454	0.864	2.159	7.932	0.602	0.0254	0.0464	7.08

• Maximum hoop stress, Mpa. - Max. first crack stress of section # Max.t ensile stresses developed in mesh

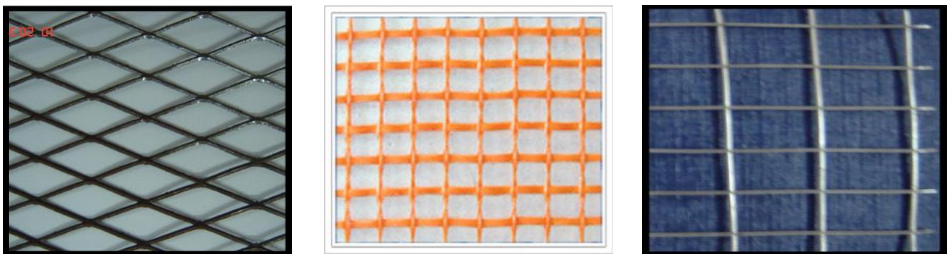
. Maximum Transverse Displacement. M.C.W. Maximum crack width at first crack F.S. Factor of safety against cracking.

4. Water tightness in Ferrocement

An increase in water tightness and durability of ferrocement at service load level can be achieved by using very low permeable mortar and by limiting the width of tensile cracks. The matrix was designed with low water to binder ratio to achieve low permeability. A super plasticizer was used to obtain the required workability at this low water to binder ratio of the mortar contributes not only to the reduction of the permeability but also to the improvement in crack resistance of ferrocement[9-18].

The replacement of cement by silica fume and the addition of a super plasticizer increase the strength of the mortar. The inclusion of silica fume in the mortar mix has two main effects: 1) it has the role of filler for the spaces between cement and sand grains and 2) it acts as a binder component. This results in a reduction in the size of the individual pores and voids. The size of the steel mesh opening has a dominant effect in controlling the crack width; the smaller the opening the better the results. Figure 3 shows the types of meshes used.

The small opening of the mesh reinforcement has a beneficial effect in strengthening the surrounding matrix and increasing its strength.



Expanded Metal Mesh Welded Metal Mesh. Fiberglass Mesh.

Figure 3. The Types of Meshes used

5. Results and Discussions

Twelve ferrocement circular water tanks having different capacities up to 12 m^3 were designed and tested. The results obtained are summarized in Table 4. It is interesting to note that high factor of safety could be achieved. Table 5 presents cost comparison of the designed ferrocement water tanks. Figure 4 shows relationship between volume of designed tanks and maximum hoop stresses.

Figure 5 shows relationship between volume of designed tanks and maximum first crack stress of section. Figure 6 emphasizes relationship between volume of designed tanks and maximum stresses developed in steel mesh.

Figure 7 shows relationship between volume of designed tanks and maximum transverse displacement. Figure 8 emphasizes relationship between volume of designed tanks and total cost. It is interesting to note that safe stresses could be obtained in the designed water tanks and four times cheaper could be achieved by the developed method.

It is interesting to note from Table 1 that the maximum hoop stresses are varied from 0.189 MPa to 1.006 MPa while the maximum cracking stresses are varying from 0.474 MPa to 2.515 MPa beyond the maximum limit of tensile strength of the matrix is predominant. The obtained maximum tensile stresses of the steel mesh achieved 9.165 MPa is superior and over more safe.

Table 5 Cost comparison of designed ferrocement water tanks

Tank Design	Volume m^3	Mortar					Wire steel mesh and Skeletal steel bars details									Total Cost
		Vol.,m^3	Weight, Kg-	Cement, Kg.	" S.F* Kg-	Sand, m^3	No.of layers	Area, m^2	Tranv. bars,D=10 m Spaci., mm	No.of bars	Length of bars ,m	Total length, m	Longi. bars.D - 6mm, Spaci., mm	No.of bars	Total length m	L.E.
Tank 1	1.0	0.19	437.12	157.37	17.48	0.13	2	14.16	300	5.0	3.7	22.2	450	8.0	22.0	242
Tank 2	2.0	0.30	690.18	248.46	27.61	0.21	2	22.33	300	6	4.6	33.3	450	10	34.6	382
Tank 3	3.0	0.39	895.36	322.33	35.82	0.27	2	29.0	300	7.0	5.3	44.1	450	12.0	47.4	497
Tank 4	4.0	0.47	1080.3	388.9	43.21	0.32	2	34.94	300	7.0	5.8	48.5	450	13.0	56.3	595
Tank 5	5.0	0.54	1245.2	448.25	49.81	0.37	2	40.29	300	8.0	6.2	59.4	450	13.0	60.5	677
Tank 6	6.0	0.61	1404.1	505.45	56.16	0.42	2	45.41	300	8.0	6.6	63.0	450	14.0	69.2	772
Tank 7	7.0	0.68	1557.4	560.66	62.3	0.47	2	50.37	300	9.0	6.9	74.6	450	15.0	78.1	861
Tank 8	8.0	0.74	1703	613.07	68.12	0.51	2	55.08	300	9.0	7.2	78.0	450	16.0	87.2	939
Tank 9	9.0	0.80	1838.7	661.92	73.55	0.55	2	59.47	300	9.0	7.5	81.0	450	16.0	90.6	878
Tank 10	10.0	0.86	1975.6	711.21	79.02	0.59	2	63.87	300	10.0	7.8	93.3	450	17.0	99.8	949
Tank11	11.0	1.13	2597.2	934.98	103.89	0.78	2	67.88	300	9.0	8.5	92.2	450	18.0	105.4	1193
Tank 12	12.0	1.19	2747.9	989.23	109.91	0.82	2	71.82	300	9	8.8	94.8	450	19.0	114.5	1283

* S.F. Si ilika Fume

The total cost includes cost of materials and cost of construction.

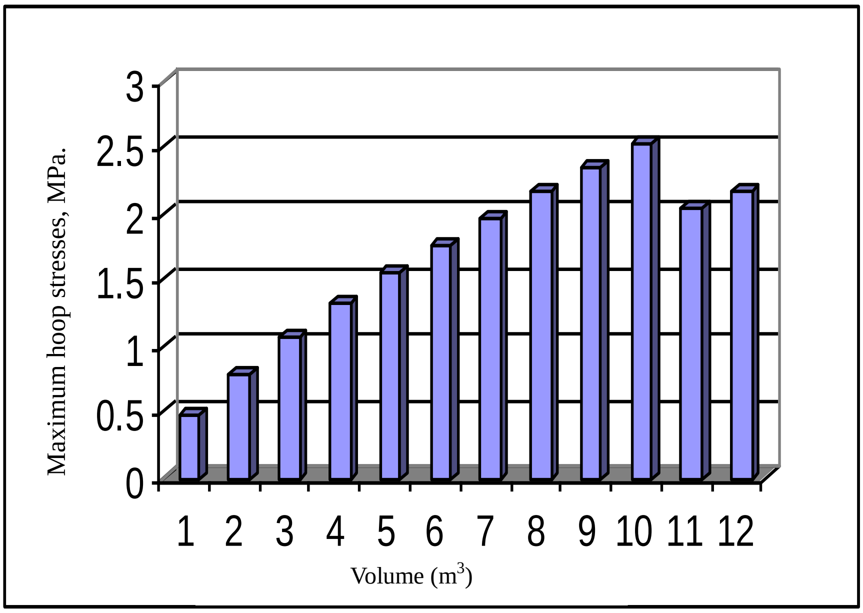


Figure 4: Relationship between volume of designed tanks and maximum hoop stresses.

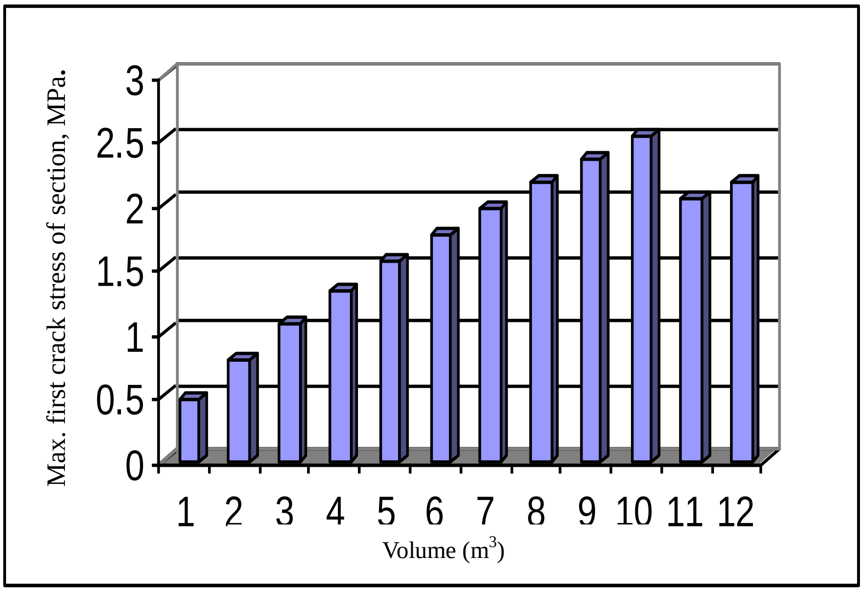


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Figure 5: Relationship between volume of designed tanks and maximum crack stress of section.

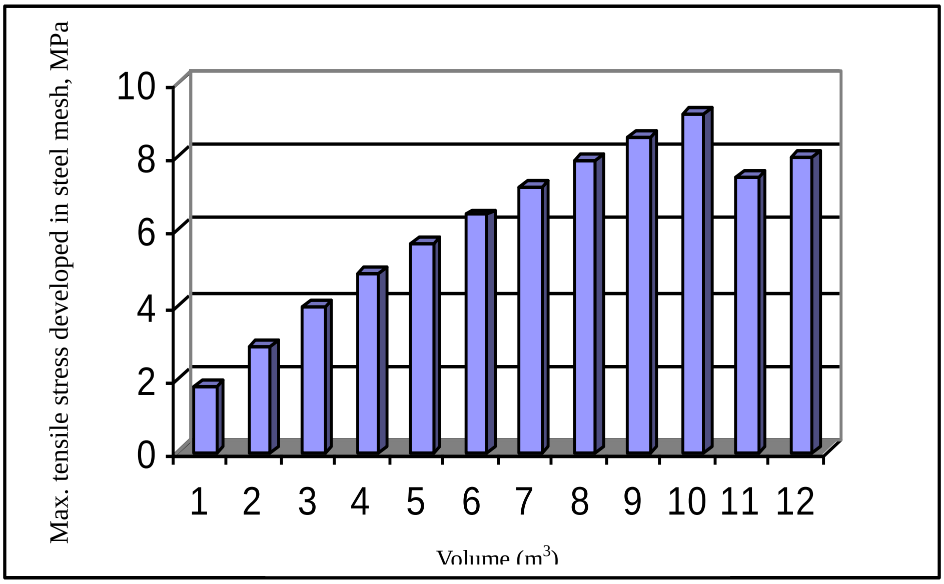

Fig. 6 Relationship between volume of designed tanks and maximum stresses developed in steel mesh**.**

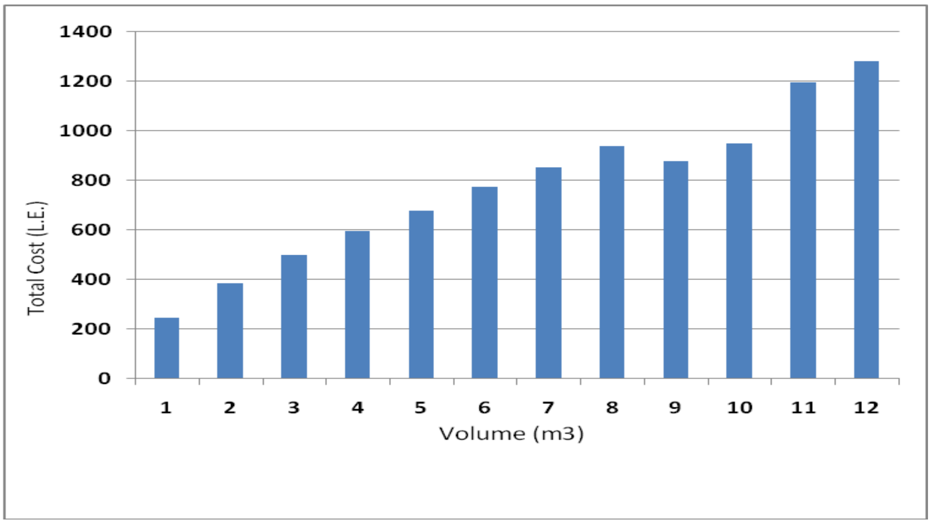

Figure 7: Relationship between the volume of designed tanks and maximum transverse displacement.

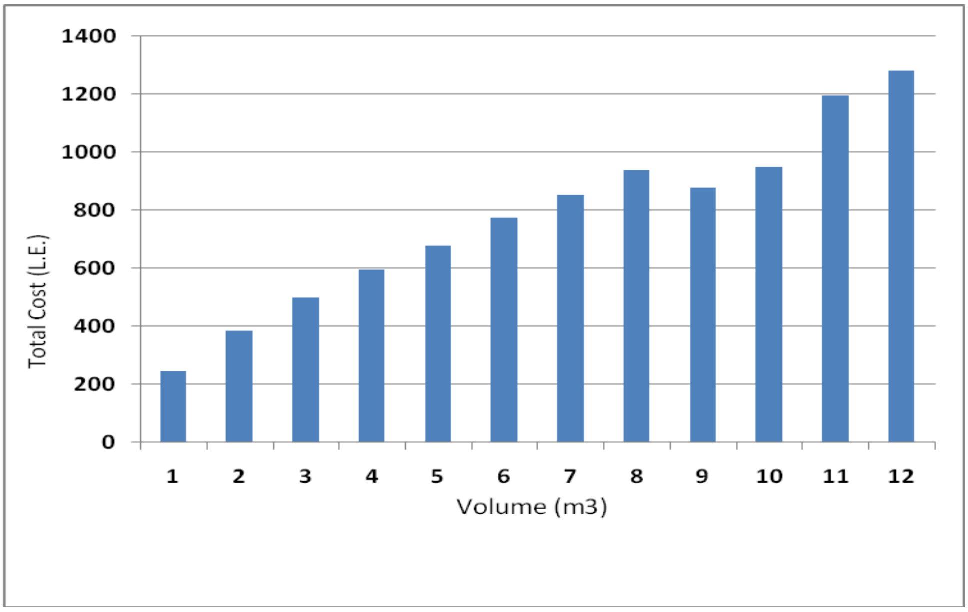

Figure 8: Relationship between the volume of designed tanks and total cost.

5.1 *Economic assessment of ferrocement*

It can be observed that the reinforcement represents the major cost factor in ferrocement, followed by the labor cost. Labor cost can be reduced through efficient planning and mechanized production processes. High cost of the steel mesh is mostly due to the cost of production of the mesh system itself and to the limited demand. With increasing market, steel mesh system can be produced more efficiently and at a lower cost. Therefore, resulting in a remarkable reduction of the ferrocement cost.

Among the more significant qualities of the ferrocement mentioned earlier:

- Low consumption of materials.
- It can take any shape most of the times without using form working.
- When worked correctly, it is practically impermeable.
- Good behavior to cracking.
- Easy to be repaired.
- It can be prefabricated.

6. Conclusions

The following conclusions could be drawn:

- Ferrocement is an up-and-coming construction material of the future. The interaction between the closely spaced mesh elements and the cementitious binder results in producing a new kind of material which is versatile, strong, durable and easily maintained. Ferrocement is not meant to suit all applications but for those applications where ferrocement is recommended, the material appears to perform in an excellent manner.
- The optimum limit of partial replacement of cement with silica fume was found to be 15%, which exhibited the highest increase in strength. The structural analysis and design of ferrocement water tanks were determined.
- Ferrocement water tanks were developed with high strength, crack resistance, high ductility, impact resistance and energy absorption suitable for rise buildings.
- The developed ferrocement tanks are four times cheaper compared with the other

constructed tanks

- There is also a need to encourage more use of ferrocement as a low cost construction material in many potential applications in the developed and developing countries alike.

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