Application of Ferrocement Technology for Construction of Water Storage Containers

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Abstract

The current study is to learn and know about ferrocement technology used in construction. The focus of this work is to design a prototype water storage tank made of ferrocement technology in the laboratory. Ferrocement gives a cost-effective sustainable solution for the design of durable structures to store large capacity of the water. It is required to understand the ferrocement technology in general, working with hands on materials and to understand the construction process by making the prototype for the cylindrical shape water storage tank in the laboratory. Initially, a review of ferrocement technology is given specifically for water storage containers. Using the locally available materials for design and fabrication, the simple technique is used to construct prototype water retaining structures. A small survey on awareness of ferrocement technology in rural and urban areas of Vadodara city is carried out to understand the scenario of use of technology. Cost calculation of larger capacity tanks is also being shown while working on the project.

Keywords

Ferrocement, Sustainable materials, Water tank, Durable structure

Introduction

Ferrocement is a material discovered in 1848 by French engineer Joseph Louis material, used first time for the construction of his boat. It is a versatile material that possesses excellent engineering property including flexural strength, toughness, fatigue, impact and most important the crack resistance due to fine wire mesh interlocking with cement mortar. It is an innovative composite material in the range of variety of construction materials. It is the material that is before proven to be considered to save cost of the materials and produce low carbon emission. It is proven to be one of the best construction materials for low cost, long lasting, energy efficient system with locally available materials and cheap labor in countries like Africa, Bangladesh, Thailand, Malesia and other Asian countries. The green housing effect of the structures built using ferrocement demonstrates a high standard of energy efficiency rating in the housing construction industry. Various construction panels, and low-cost affordable housing solutions using ferrocement gives the highest level of thermal performance. The applications of ferrocement are not limited to low-cost housing but also the other structures, water tanks, boats, swimming pools, shells roofs, pipelines and thin structures. The resulting product of a ferrocement gives a thin structure with mortar and wire mesh. The thickness of the ferrocement sections ranges from 10 mm to 40 mm and consists of layers of small diameter steel mesh with cement mortar. The structural behavior of ferrocement is uniquely different than conventional reinforced concrete sections in terms of strength and performance. Due to its unique property ferrocement has potential applications that separates it from a class of innovative building materials. Additionally, it requires minimum skilled labor and utilizes locally available materials. Its simplicity in construction procedure, easily moldable in various structural forms and economy are the prime attraction and popularity. In the past, attempt for experimental and numerical analysis of ferrocement of large size in Brazil is studied[1]. The literature shows the improvement in the current practice of design of ferrocement tanks. Detailed design and construction of ferrocement tanks are given in literature2 where the authors have added silica fumes to reduce the content of the cement. Comparative study of hybrid design of ferrocement tanks with conventional reinforced cement concrete material is shown[3]. Ferrocement design involves a large capacity of 1000 m^3 including hyperboloid of revolution in walls to improve structural behavior[4]. The testing and test methods are developed for ferrocement materials are given in the litrature[5].

American Concrete Institute code ACI PRC – 549 code[6] gives the information on the design guidelines, mechanical and physical properties of ferrocement. Also, it provides information on various testing standards to be performed on ferrocement specimens. Code describes data for choice of materials, for example, guidelines for choosing sand is cited in table 3.1, common types of sizes available for steel meshes used in ferrocement are cited in table 3.2, minimum values of steel wire mesh yield strength to be adopted in designing ferrocement components are cited in table 4.1, it cites various stress strain relationship obtained on the tested specimen in flexure, tension and compression for both steel wire meshes and mortar specimens. Also, Standard test methods for the ferrocement material have been described by many researchers. Scientific experiments and verification for the various tests have been given and provided the measurements of deformation and cracking for compression, axial tension and tension in bending as well as bending.[5]. Behavior of ferrocement water pipes as an alternative to steel water pipes have been studied[7]. In the article, pipes are cast and subjected to experimental testing to evaluate various properties such as cracking patterns, tensile and compressive stress, failure mechanism, elastic stiffness and energy absorption properties. Experimental programs to evaluate flexural performance of ferrocement focusing on high performer mortar have been studied[8]. Experimental results are given related to various flexural properties such as modules of rupture, elasticity, flexural toughness. Flexural behavior of septic tank wall panels reinforced with glass fibers are given[9]. Load deflection responses are given based on various glass fibers added in different volume fractions. Water leakage from water tank walls and base made of reinforced concrete and masonry tanks is a problem which is faced by the practiced engineers very frequently. Mostly, epoxy applications to repair this is a tedious task. In this comparison, ferrocement is a material known for its high impermeability and ease in application on any surface[10]. Experimental work related to seismic retrofit material for masonry walls is carried out[11]**.** Numerical study is also mentioned on the behavior and performance of composite and hybrid ferrocement tanks[12]. Ferrocement construction techniques for water tanks are studied by many researchers. The present work adopts some of the basic and feasible features suitable for construction of small tanks [2, 3, 4]. Typical load-deflection behavior of fiber-ferrocement sheet and conventional ferrocement arc shown[13]**.** Ferrocement is also used as a material which has numerous retrofitting applications and gained interest during recent times [14,15].

Force transfer mechanism

The force transfer mechanism of the ferrocement tank is qualitatively explained in this section. As in the water tank, water pressure acts on the walls and floors of the tank. The thickness of the walls should be such that it does not produce cracks generated due to the excessive hoop stresses which are prominent in the walls due to the water pressure. Hoop stresses are termed as forces on the cylinder which are acted in all directions including circumferential and axial direction inside the thickness walls of the tank and happen usually in the case of cylindrical body. Hoop stress is directly proportional to the water pressure, radius of the tank and inversely proportional to the thickness of the wall. Because of tank's curved shapes, it resists the stresses due to membrane stresses which gives primary action of force transfer mechanism to the wall. Such membrane stresses are much higher as compared to smaller tanks due to high water pressure as water pressure depends on the height of the tank. Fig. 1 shows the hoop stresses in the walls of the cylinder.

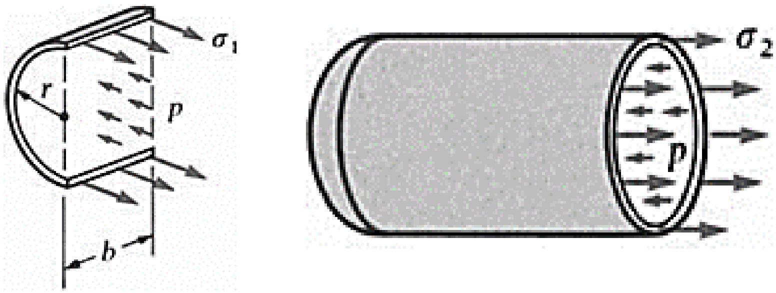

Figure 1: Hoop stress σ_1 and axial stress σ_2

Behavior of wire – reinforced mortar

It is known that concrete and mortar material are both stronger in compression and weak in resisting tensile load. Also, structures constructed using such materials are subjected to tensile loads mostly in practice. Additionally, the structure will bend and fracture without warning and develop fine cracks before failure. It is a brittle failure that can occur. Conventional reinforced cement concrete is used to overcome this difficulty by allowing tensile loads to be taken by reinforcements in the concrete. However, it is a complex phenomenon that how much a reinforcing bar is contributing to controlling the tensile cracks in the practice. This is the reason why the working stress method is used in designing RCC water tanks to prevent cracks in the structures which give conservative results and provide better factors of safety. Water tanks are subjected to high tensile hoop stress in the walls due to water pressure. In ferrocement material, if the wire mesh is densely distributed with the mortar, it allows to arrest the cracks produced due to critical tensile stresses generated in the walls. Also, if cracks are generated, those cracks are not wide enough to enter the wire mesh and support reinforcements to have corrosion in them.

In view of the literature, there have been successful attempts to design and construction large sizes of ferrocement water tanks. The objective of the present work is to understand the ferrocement technology, working with materials and gain hands on experience with the materials by constructing a very small size water container of cylindrical shape and size of nearly 3 liters. The work is carried out by a group of interdisciplinary students with the help of laboratory technician on social innovation KHOJ project conducted at Navrachana University. The aim is to introduce undergraduate students to work on a project and be familiar with the technology which is in demand in today's world of sustainability and sustainable materials. While working on the project, students learnt the simple techniques of construction, working with hands on materials of ferrocement and to know how efficiently the technology can be utilized as an affordable alternative to plastic and other artificial material tanks.

Materials and methods

The basic materials used for ferrocement construction are as follows (1) wire mesh, (2) cement (3) sand (4) mild steel rod. Steel rods are used to support the wire mesh and used as skeletal reinforcement. As mentioned previously, unlike other construction materials, ferrocement requires minimum labour and utilizes locally available materials. A detailed method and construction procedure is mentioned in the following section of the article.

Material Specifications

Wire mesh

Wire mesh is the primary important component in ferrocement technology. Wire mesh can be constructed in various shapes such as square, hexagon, or zigzag pattern, are usually 0.5 mm to 1 mm in diameter and, spaced at 5 mm to 25 mm apart. Wire mesh is manufactured in such a way that it is handled properly and bend easily for achieving the sharp corners. The basic function of the mesh is to provide and act as support to the mortar mix. It is important to know that wire mesh withstand mainly the tensile stresses of the structure which mortar is not able to withstand. In the present case mesh having square woven is used having 1 mm diameter with 5mm spacing is used. (Fig. 2).

Figure 2: Chicken wire mesh used in the project.

Steel rod (skeletal)

The main framework of the structure of steel bar is used on which the layers of meshes are laid. The rods are spaced with equal distance of 6 cm, centre to centre. Since cylindrical tank is used, the cage is made of total diameter of 15 cm and height of 30 cm for the prototype model. (Fig. 3). Inner steel skeletal after casting is shown in Fig. 4.

Figure 3: Steel Skeletal

Figure 4: Inner Steel Skeletal

Cement

Ordinary Portland cement, which is most common, is used in the present project work. (Fig. 5).

Cement Mortar

It is very important to mix the mortar ingredients water, cement and sand in such a way that it gives the consistency of proper strength. Material used for cement mortar is used is shown in Fig. 5. Imperviousness of ferrocement can be obtained by w/c (Water to cement) ratio less than 0.4.

Figure 5: Material used for ferrocement for cement mortar.

Sand

Utilised clean and dry sand that is well-graded, consisting of particles with varying sizes.

Cement-to-Sand Ratio

The standard volume ratio of cement to dry sand is 1:3. To achieve this specific ratio, a bucket can be employed for precise measurement of sand and cement proportions. It's important to note that damp sand from a stockpile occupies more volume than when it's dry. Considering the bulking of cement, it is advisable to utilise a complete bag of a known volume un cubic meter. In the entire process of mixing, sand and cement were mixed uniformly. After that water is added part by part in order to achieve the required workability of the mortar mix.

Water-to-Cement Ratio

The water-to-cement ratio significantly influences the ultimate strength of the mortar. An optimal ratio falls within the range of approximately 0.4:1 to 0.5:1 (water to cement by weight), corresponding to 20 to 25 litres of water per 50kg bag of cement.

Methods of Construction

The ferrocement structure was fabricated in the Civil Engineering Material Testing Laboratory of Navrachana University. As per main outer dimensions of the structures, the amount of longitudinal and transverse direction steel was separated and cut for various segments. Once the steel was cut to the desired length, the skeletal frame was constructed as per the shapes of the structures, which is, cylindrical tank in the present case. Connection between steel bars was made by welding and through steel ties. Following the shape of the structures, two layers of wire mesh - one inside and one outside of the steel frame, were placed and tied with steel wire maintaining the thickness as minimum as possible, which is, a crucial and challenging component in the entire construction process. Since this is the prototype work of student's project work, it is limited till the construction with the basic ingredient and plastering work was not carried out. Primary objective of the present study is to obtain the hands-on experience with the materials of prototype made by the students.

In this approach, a sturdy wire frame is needed. Surrounding sturdy frame, flexible mesh-like 'chicken wire,' is wrapped. To make the prototype on this work, students applied a layer of mortar on both the inside and outside of the tank. While one student worked on one side, the other student worked on the other side holding a plastering float to keep the mortar in place and compacted without it slipping through the mesh. Since this is a smaller prototype the formwork of wood was not needed. Final product is seen in Fig. 6.

Curing

The main objective of curing is to keep the cement mortar in moist and saturated condition and to promote the hydration of cement. There were many options for the curing, however, jute mat was used, and it was kept for about 5 days. The prototype structure which is a cylindrical tank is of capacity of about 3 litre capacity. It is shown in Fig. 6. The cylindrical tank was easily shifted from one place to another as it was light in weight. Depending on the capacity of water to be stored in the tank, the structure size can be expanded to 5 to 8 litres for household and domestic purpose. So larger tank can be built based on the capacity of water to be stored.

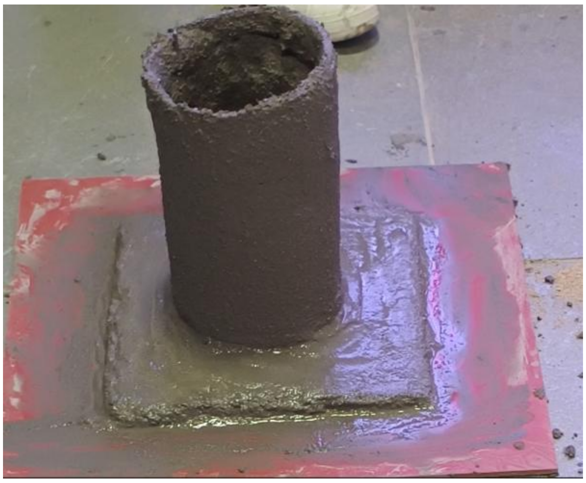

Figure 6: Final prototype of ferrocement cylindrical tank

Due to flexibility in forming shape, the tank can be made of any desired shape. In the present work, cylindrical shape which is chosen as it is convenient while constructing the tank. The schematic of entire construction steps with material specification are shown in Table 1. Also, Fig. 7 shows the images of various construction steps.

Sequence	Tasks
1	Decide the dimensions according to the size in litres to store water
2	Decide depth and diameter (300 mm, 150 mm)
3	Lay out plan and drawing
4	Calculate the material quantities required as per the size of the tank
	Material specification
	Cement (Standard ordinary Portland Cement)
	Sand (Clean, dry and well graded)
	Wire mesh (0.5 mm to 1 mm in diameter and, spaced at 5 mm to 25 mm apart)
	Steel rods (6 mm to 8 mm)
	Tie wires (1 mm)
	Water to cement ratio (0.4), Clean Water
5	Prepare cement mortar mix (The standard volume ratio of cement to dry sand is 1:3)
6	Prepare base of the tank (15 mm to 20 mm)
7	Lay out wire mesh with rods and tie based on the thickness (Thin shells are designed between10 mm to 15 mm)
8	Apply cement mortar from outside through in such as way wire mesh is covered
9	Apply curing as per the standard
10	Store

Table 2: Schematic of construction stages with material specifications

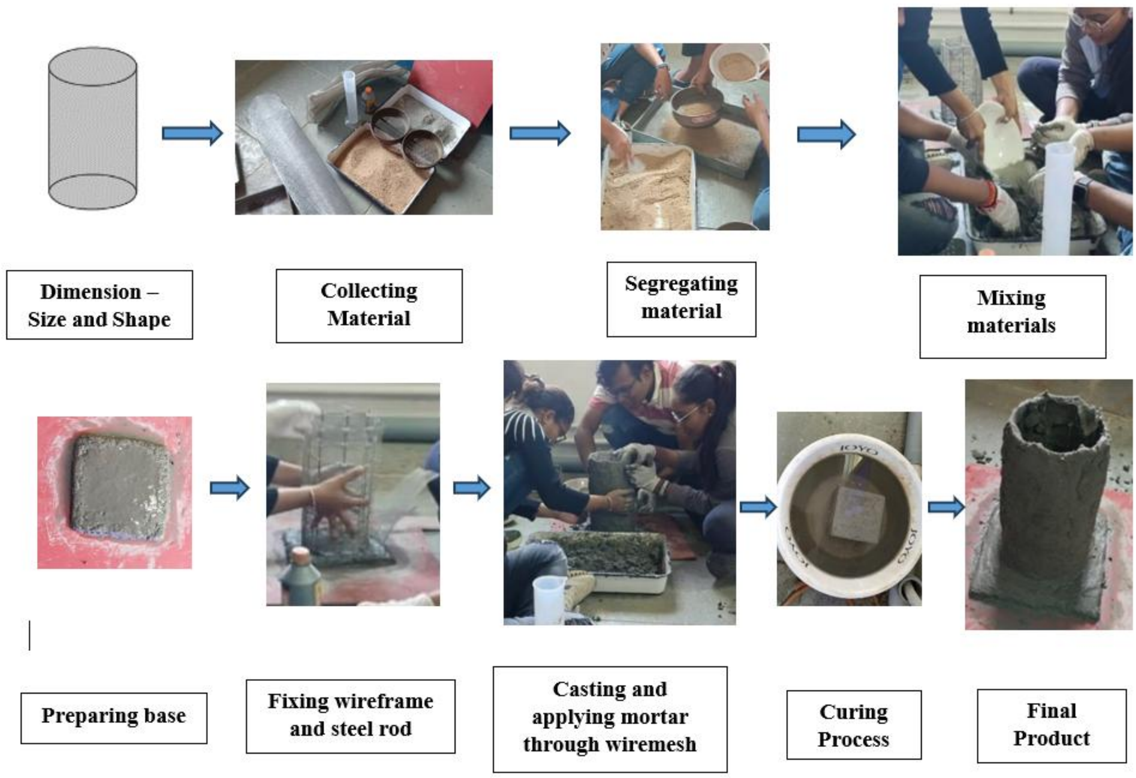

Figure 7: Construction Stages of the process

Promotion effort for sustainable solution

Also, promotion effort was made for creating awareness of ferrocement technology as one of the storage sustainable solutions. A survey was conducted by students in rural and urban localities in Vadodara to learn and understand the conditions and requirements for water storage. Responses were received from civilian surveys from both rural and urban areas on percentage of residents that have considered using Ferrocement water storage. The chart shown in Fig. 8 shows an observation that very few communities in urban and rural areas in Vadodara city in Gujarat were aware of such technologies. The primary and important related to the present work survey questions are listed in Table 2. The first two questions are related to the chart shown in Fig. 8. Fig. 9 shows the primary source of water being used by communities is municipal water supply (question 3 in table 2), however, little community is aware about rainwater harvesting and knowing the techniques available. From Fig. 10, most communities depend on the water tank available in society rather than storing water in drums as question 4 in Table 2. Fig. 11 shows the type of water treatment the community prefers before using it. It is mentioned as question 5 in table 2. From the survey results, it is understood that special efforts and awareness programs are required to be pressed upon to know about sustainable technologies, storing water in emergencies especially during calamities and optimum usage of water by storing it and using it in small quantities to save the resources.

Question Number	Question
1	Are you aware of ferrocement water storage systems?
2	If yes, have you considered using ferrocement for water storage?
3	What is your primary source of water?
4	How do you store water at home?
5	What methods do you use for water treatment?

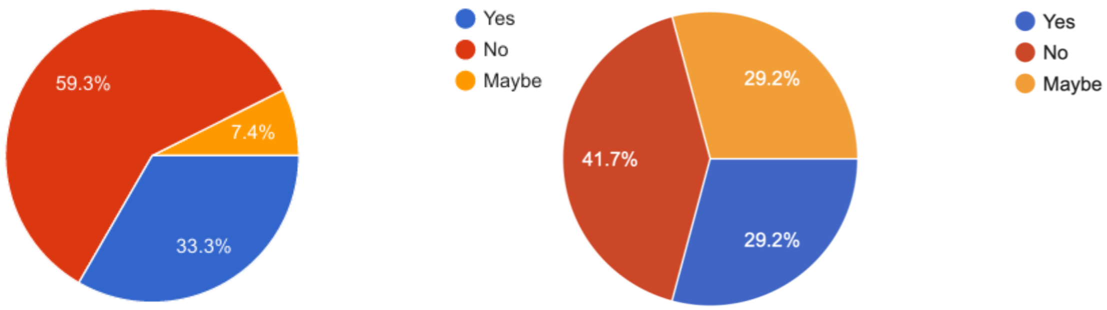

Figure 8: Survey on awareness of ferrocement technology

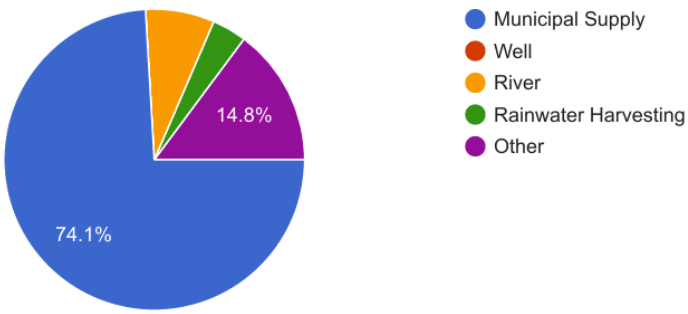

Figure 9: Survey on primary sources of water

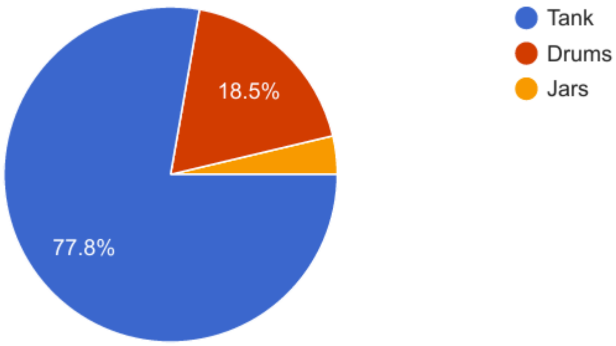

Figure 10: Survey of water storage devices

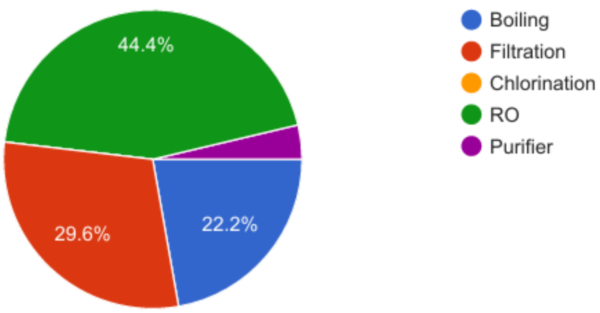

Figure 11: Method of water treatment

Sr. No.	Material	Cost in INR
1	Weld mesh 7.00 m^2 at INR 8.85/ m^2	61.95
2	Chicken mesh 13.0 m^2at INR 26 /m^2	338
3	6 mm M.S rod 0.7Kg at INR 43 /M.T.	30.1
4	Cement 2.2 bags at INR 385 /bag	847
5	Sand 0.147m^2 at INR 42/ m^2	6.01
6	Labour L.S.	40
7	Welding of fins for outlets and scour	10
8	Oil, grease, mixer, etc. L.S.	12
	Total	**1344.95**

Table 3: Cost of ingredients used in Ferrocement

The cost calculation is done to arrive at the cost of per litre tank. Table 3 shows the cost of various ferrocement materials estimated based on cost of materials and labour. The cost mentioned above are calculated as per 800 litre capacity. The purpose of cost analysis is to show that it is a cheaper material as compared to other costly material such as timber, steel etc.

Conclusion

The prototype of ferrocement cylindrical tank has been made in the laboratory. Using a simple construction process which utilizes the readily available materials, it is shown that ferrocement is easily handled material which can be moulded in various shapes. It also gives structurally sound product which carries water without any cracks arising in the thick walls of the tank. It is a good alternative source of storing the water in hygienic condition to the tank made of plastics. From the field survey carried out, it has been found that ferrocement technology is not known to the community in villages as well as urban areas. A recent study by the Gujarat Ecological Society (GES) has revealed that the quality and quantity of groundwater is affected due to contamination of total dissolved solids as well as the lower position of water table and deeper bore wells respectively. A major step in the direction of water harvesting is necessary to reduce dependence on the condition of ground water tables only in such a situation, it is also important to provide a sustainable solution to water scarcity as well as supply of good quality clean water especially in the rural areas of the city. Ferrocement material is a sustainable technology and a good way to store water. A cost analysis and material methods have been developed to construct the small cylindrical tank in the laboratory. Cylindrical ferrocement water storage containers, a structure identified in the present work, can be constructed for domestic larger capacity water storage using ferrocement technology. It is understood that the observations made from this work will carry new concept of ferrocement technology used for the construction. It is a low-cost technology yet gives strong and sustainable structures for domestic rural and urban water storage uses.

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References

1. Moita, G. F., de Las Casas, E. B., Carrasco, E. V. M., & Bonifácio, S. N. (2003). Experimental and numerical analysis of large ferrocement water tanks. *Cement and Concrete Composites*, *25*(2), 243-251.
2. Shaheen, Y. B. I., & Elsayed, A. A. (2013). Design and Construction of Ferrocement Water Tanks. *Concrete Research Letters*, *4*(4).
3. Saxena, S., & Pathak, K. K. (2024). Conventional and ferrocement-based hybrid design of RCC tanks: a comparative study. *Innovative Infrastructure Solutions*, *9*(4), 122.
4. Martirena Hernandez, J. F. (1993). Analysis, design and construction of ferrocement water tanks in Cuba. *Journal of Ferrocement*, *23*, 25-25.
5. Walkus, B. R. (1986). Testing and test methods for ferrocement. *Journal of ferrocement*, *16*(1), 27-37.
6. ACI PRC-549.1-18: Design Guide for Ferrocement
7. El-Sayed, T. A., Shaheen, Y. B., AbouBakr, M. M., & Abdelnaby, R. M. (2023). Behavior of ferrocement water pipes as an alternative solution for steel water pipes. *Case Studies in Construction Materials*, *18*, e01806.
8. Dawood, E. T., Shawkat, A. S., & Abdullah, M. H. (2021). Flexural performance of ferrocement based on sustainable high-performance mortar. *Case Studies in Construction Materials*, *15*, e00566.
9. Gifta, C. C., Bharathi, L. V., & Vimal, A. (2021). Flexural behavior of ferrocement septic tank wall panels reinforced with glass fibers. *Materials Today: Proceedings*, *47*, 6664-6669.

10. Sharma, S. P., Sharma, P. C., Singh, K. P., & Bhatia, S. S. (1984). Ferrocement treatment for repairing a 50, 000-gallon overhead water tank. *Journal of Ferrocement* , *14*(3), 241-248.
11. Reinhorn, A. M., Prawel, S. P., & Jia, Z. H. (1985). Experimental study of ferrocement as a seismic retrofit material for masonry walls. *Journal of ferrocement*, *15*(3), 247-260.
12. El-Sayed, T. A., Shaheen, Y. B., Mohamed, F. H., & Abdelnaby, R. M. (2023). Performance of ferrocement composites circular tanks as a new approach for RC tanks. *Case Studies in Construction Materials*, *19*, e02228.
13. Hussin, M. W. (1991). Deflection and cracking performance of fibrous ferrocement thin sheets. *Journal of Ferrocement*, *21*(1), 31-41.
14. Kaish, A. B. M. A., Jamil, M., Raman, S. N., & Zain, M. F. M. (2015). Axial behavior of ferrocement confined cylindrical concrete specimens with different sizes. *Construction and Building Materials*, *78*, 50-59.
15. Kaish, A. B. M. A., Jamil, M., Raman, S. N., Zain, M. F. M., & Nahar, L. (2018). Ferrocement composites for strengthening concrete columns: A review. *Construction and Building Materials*, *160*, 326-340.

Glossary

Ferrocement – Ferrocement is a building construction material made of thin cement layer reinforced with steel wire mesh

Cement – cement is a binder, a chemical substance used for construction that hardens and binds other materials to bind together

Cement Mortar – It is a mixer of cement, sand and water used to bind various blocks in construction such as bricks. It is also used for plastering.

Reinforcement – It is a steel rod used with concrete in construction for providing tensile strength in concrete

Concrete – It is a binding material which is made of mixing broken stones, sand, cement and water

Wiremesh – It is a two-dimensional lattice made from two or more smaller diameter metallic wires

Cylinder – It is a long solid body having two parallel side along the axis with a circular cross section

Cylindrical Shell – It is a thin structural element shaped in a cylinder defines relatively having lesser thickness to its diameter has widely usage in industrial applications

Hoop Stress – It is the internal intensity of the force distributed around the circumference of the pipe due to pressure

Circumferential Stress – It is same as hoop stress

Axial Stress – It is the intensity of the forces distributed along the axis of the solid body

Water Cement Ratio – It is the ratio of the mass of the water to the mass of the cement added to the concrete. The typical water cement ratio varies between 0.40 – 0.60 for different mixes of concrete

Cement to Sand Ratio – Example 1: 3, It is the proportion mix indicates one part of the cement and 3 parts of the sand as per the ratio given

Sustainable Solution – It is the innovative practices of the technologies that provides the long-term solution to improve upon social, economic and environmental impacts.

Curing – Curing is the process of maintaining adequate moisture in concrete in order to aid cement hydration process to gain strength in the concrete

Hydration – Hydration of the cement refers to the chemical reaction that occurs when water is added to cement helps to obtain the hardened mass of the concrete.

Prototype – A first preliminary basic version of a device from which higher versions are formed and developed

Low-Cost Technology – They are the design principles used for the development of solution replaces costlier version by not compromising the quality of the technical features

Compressive Stress – It is the maximum intensity of the force distributed over the body or material that can support without failure when it is being compressed

Tensile Stress - It is the maximum intensity of the force distributed over the body or material that can support without failure when it is being stretched

Pressure – It is the physical force exerted on the object and vice versa

Structural Behavior – It is the phenomena, the way a structure or a body responds to the external forces. It can be measured in the form of internal forces or the displacements

Forces – It is the physical action of the push or pull on an object

Retrofit – It is the process of modifying the part of the body for the improvement and its performance

Force Transfer – It is the mechanism of transferring force from one part of the body to another part through its connection or joints

Mild Steel – It is the low carbon steel which is more flexible compared to other class of steel suitable for many industrial applications