Journal of Contemporary Issues in Business and Government Vol. 26, No. 03, 2020
https://cibgp.com/

P-ISSN: 2204-1990; E-ISSN: 1323-6903
DOI: 10.47750/cibg.2020.26.03.002

Experimental and analytical investigation of ferrocement water pipe

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INTRODUCTION

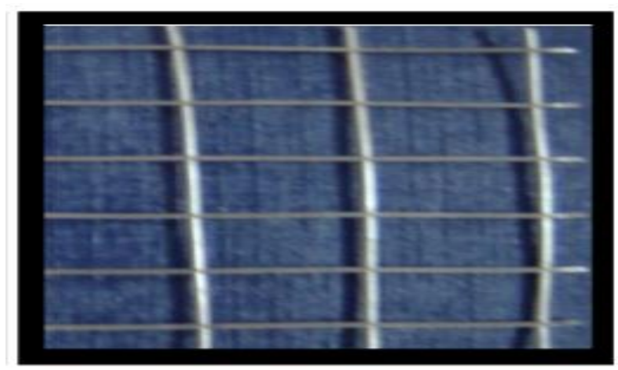
Ferrocement is kind of reinforcing concrete. It generally comprised of hydraulic cement mortar reinforced with closely spaced layers of continuous and very tiny size wire mesh. The mesh may be composed of metallic or other appropriate materials (Blake, 2001). (Blake, 2001). It is cheap cost, robust, weather-resistance, lightweight and notably its adaptability compared to the reinforced concrete (Ali, 1995). (Ali, 1995). Robles-Austriaco et al. (1981) revealed that ferrocement is an effective material for home building. Also Al-Kubaisy and Jumaat (2000) explored the feasibility of utilizing ferrocement cover in the stress zone of reinforced concrete slab. This material is also utilized in mending the reinforcing element such as beams, slabs or walls (Fahmy et al. 1997; Elavenil and Chandrasekar, 2007; Jumaat, 2006). (Fahmy et al. 1997; Elavenil and Chandrasekar, 2007; Jumaat, 2006). Mourad and Shang (2012) employed ferrocement jacket in restoring reinforced concrete column.

Their test findings suggested that employing the ferrecement jacket enhances the axial load capacity and the axial stiffness of repairing reinforced concrete column compared to the control columns. Kaish et al. (2011) and Xiong (2004) explored the possibilities of employing ferrocement jacket in strengthening of square reinforced concrete short column. Their findings suggested that utilizing this way of strengthening enhanced the column behavior. Various investigations were carried out to explore ferrocement elements (beam, slabs and column) to evaluate its behavior under applied stresses up to failure. Ibrahim (2011) and Hago et al. (2005) examined the ultimate capacity of wires mesh-reinforced cementations slabs and simply supported slab panels; respectively using various kinds of reinforced wiring mesh. Nassif and Najm (2004) studied an experimental and a theoretical model for ferrocement–concrete composite beams. Various kinds of reinforced concrete beam superimposed over

a thin sheet of ferrocement (cement paste and wire mesh) were tested

a-Polypropylene fiber

b- Expanded steel mesh



c- Welded steel mesh

Figure 1. Reinforcement steel meshes and fibers used.

under a two-point loading mechanism, till failure. They found that the suggested composite beam

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outperformed the reinforced concrete beam in terms of ductility, cracking strength, and ultimate capacity. In 2007, Shannag and Ziyad added discontinuous fibres of glass to ferrocement mortar to boost its strength. Various mixtures of silica fume and fly ash were used by Shannag and Mourad (2012) to build high-strength mortar matrices that are both workable and strong. Ferrocement rectangular plates were tested by Chandrasekhar et al. (2006) for their shear strength. Ferrocement components with various thicknesses of mesh were tested in this investigation. When the number of mesh reinforcing layers is increased, shear capacity of the plate rises. Ibrahim carried out an experiment on ferrocement plates supported by a simple structure (2011). To prevent failure in mechanisms other than flexure, flexural steel was devised in his research. The classical shear equations prediction and his practical findings are in excellent agreement with the water supply pipe, which is a highly crucial structure. Supply pipes must be sturdy and long-lasting. " These pipes come in a variety of materials, including metallic pipes, cement pipes, and plastic pipes, depending on their construction. Ferrocement pipe and reinforcement pipe performance under line load is the primary goal of this investigation. A theoretical finite element model using ANSYS (2006) and a comparison of experimental and theoretical data is also presented in this study.

TEST BANQUET MODEL

Cast and tested under static stress at the reinforcing laboratory of the Faculty of Engineering-Minufiya University were five different kinds of pipes with diameters of 300 mm and thicknesses of 30 mm. Reinforcing concrete pipe is the first kind, whereas ferrocement pipes include a variety of reinforcement systems. The ferrocement pipes were reinforced with two kinds of steel wire meshes (welded wire mesh and expanded metal mesh) as indicated in Figure 1. Both kinds are made in Egypt and sold on a large scale in the local market. Expanded wire mesh with 1.5 mm diameter and 19.7 mm grid size and welded wire mesh with 0.72 mm diameter and 12 mm grid size were employed. Table 1 shows that the weight of reinforcement was the same for each of the five kinds of pipes.

The characteristics of the materials utilised

The concrete mix's aggregate was subjected to a sieve analysis, with the findings shown in Table 2. The sand used in the ferrocement mortar mix was the subject of the sieve analysis. both sand and aggregate met the Egyptian Standard Specifications (E.S.S.) standards for their qualities (2007). According to E.S.S. (2007) for concrete works, the chemical and physical qualities of the cement were evaluated. The test specimens were mixed and cured in fresh drinking water that was free of contaminants. EDECRETE DM2, an ASTM C494-86-compliant super plasticizer with a specific weight of 1.05 at 20°C, was employed to boost the mortar mix's strength and workability. It comes in powder form and has a light grey hue. A total of six ferrocement mortar mixtures were developed and tested under compression stress in order to find the appropriate proportions of the ferrocement component elements. The optimum sand/cement and water/cement ratios are 2 and 0.35, respectively, and fibre with a ratio of 900 g/m3 of the mortar matrix and silica fume were added as shown in Table 4 to achieve the greatest compressive strength while maintaining reasonable workability. According to E.S.S., the hardened mortar was subjected to compression and tensile testing (2007). The compressive stress (Fcu) is estimated to be 33.4 and 47 MPa after 7 and 28 days, respectively, whereas the tensile stress is estimated to be 3.6 MPa after 28 days. The Egyptian Code (2001) and the work of Kaewunruen and Remennikov used concrete's modulus of elasticity and stress-strain curve to design and build reinforced concrete structures (2006). With respect to concrete's 28-day compressive strength, the modulus of elasticity (Ec) may be computed using equation 1. (Fcu). To determine the concrete's multi-linear, isotropic stress-strain curve, use Equation 2. Figure 2 depicts the stress-strain relationship for the ferrocement mortar used in the experiment.

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Table 1. Reinforcement system of the tested pipes.

Model No.	Type of reinforcement	Mortar	Weight of Steel (kg/m)
RCP	(6 Bars + 6 Stirrups) Ø 6 mm	Conc.	
FP1	(6 Bars + 6 Stirrups) Ø 6 mm	Ferro.	
FP2	One layer of welded metal + One expanded metal	Ferro.	3.0
FP3	Two stirrups Ø6 mm + One layer of expanded metal	Ferro.	
FP4	Three stirrups Ø6 mm + Three layers of welded metal	Ferro.	

Table 2. Sieve analysis results for the used sand.

Sieve size (mm)	% Passing by weight	Limits of (E.E.S.)
4.75	100	100
2.83	95	100-85
1.4	79	100-75
0.7	68	80-60
0.35	17	30-10
0.15	2	10-0

Table 3. Chemical composition of silica fume.

Chemical composition	Weight %
SiO_2	92 - 94
Carbon	3 - 5
Fe_2O3	0.1 - 0.5
CaO	0.1 - 0.15
AL_2O_3	0.2 - 0.3
MgO	0.1 - 0.2
MnO	0.008
K_2O	0.1
Na_2O	0.1

Table 4. Consisted material of the ferrocement mixture.

Material	Ratio related to cement
Cement	0.9
Silica fume	0.1
Sand	2
Fiber	900 g/m^3
Water	0.35
Adecrete DM2	1 %

$$E_c = 139140.22\sqrt{F_{cu}}$$

$$f = \frac{E_c \varepsilon}{1 + (\varepsilon / \varepsilon_0)^2}$$

At any strain (), f is the stress, and 0 is the strain at the ultimate compressive strength at 28 days (3). The control pipe was strengthened with mild steel and a normal concrete mix. This is exactly the same combination that was used in Egyptian pipe-making companies. – To make a typical batch, 350 kg of cement and 160 litres of water were added to 8 m3 of gravel and 4 m3 of sand. After 7, and 28, a total of twelve 100 100 100 mm cubes were formed and tested to assess the mixture's compressive strength according to E.S.S (2007) The concrete mixture's compressive and tensile breaking strengths are shown in Table 5. The stress-strain curve for the employed concrete mixture is shown in Figure 3. Using the Universal Testing Machine, three samples of each kind of steel mesh were examined. Table 6 shows the specifications and mechanical characteristics of the steel meshes. For the mild steel, the modulus of elasticity and yield strength were calculated to be 210 GPa and 2240 MPa.

Pipe inspection and testing

To regulate the thickness of the pipes, a Gibson form was built with an outer diameter of 300 mm and a top and bottom cylinder. The following stages outlined the casting process. The reinforcements were first made according to the appropriate diameters. After that, they were inserted into the forms as indicated in Figure 5 (in the section's centre). After that, as illustrated in Figure 6, the concrete was cast using a plastering technique. As a result, the last face was completed. Turned over within 24 hours, the

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specimens' sides had hardened. Tests on the specimens were place 28 days after they were kept in the laboratory. For curing, the specimens were covered with a moist towel, and water was sprayed on them every two days. Prior to testing, the faces of each specimen were painted white to make cracks easier to see. Figure 7 shows the specimen in its testing position on a steel frame. The pipe was supported by two hard steel beams, and a third was employed up to the pipe to diffuse the concentrated load as the load increased.

THEORETICAL MODEL

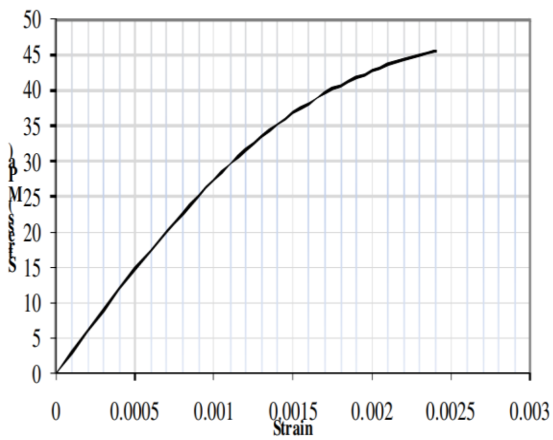
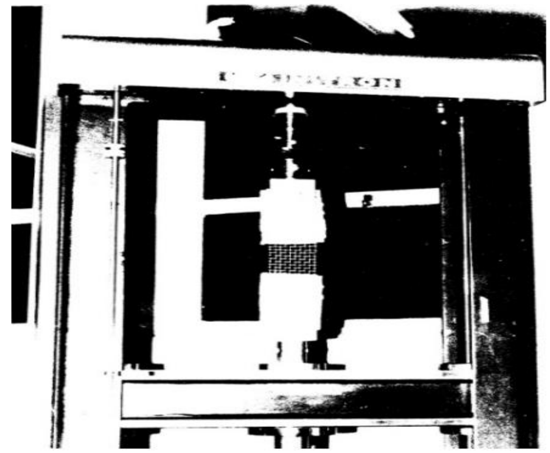


Figure 2. Stress-strain curve of the selected ferrocement mortar.

Table 5. Properties of the used concrete mixture.

Age (days)	Compressive strength (MPa)	Tensile splitting strength (MPa)	Modulus of elasticity (GPa)
7	17	1.9	---
28	28.5	2.4	23.5



Three degrees of freedom are available to each node in the network (translations in the nodal x, y, and z directions). Steel bar and stirrups were shown using the Link 8 element. A three-degree-of-freedom system (translations in the nodal x, y, and z directions). Figure 8 depicts the theoretical model.

REPORTS AND COMMENTS

The outcomes of the experiment are detailed in this section. Table 7 displays the load at the first fracture and the failure load. Figure 9 depicts the experimentally discovered fracture patterns in the tested pipes. There is an experimental correlation between total applied load and pipe deflection demonstrated in Figure 10 This table and the two figures show that the four ferrocement pipes collapsed at a total load larger than the reinforced pipes. They are shown to have failed. That the fifth kind (FP4) of pipes failed at the highest rate of failure may be determined. This section of the paper examines and discusses the differences between the experimental findings and those predicted by the existing theoretical model. The deflection curves of the five kinds of applied loads

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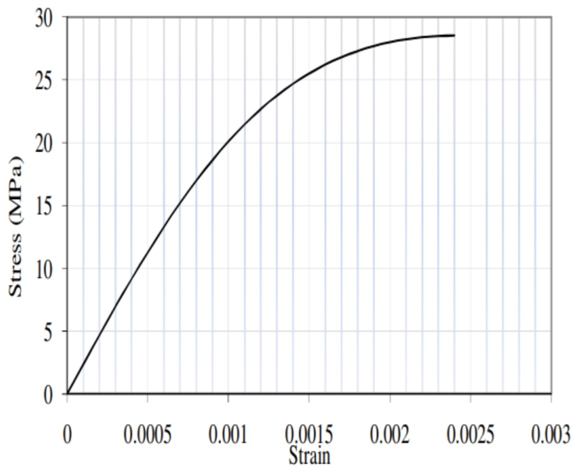

Figure 4. Stress-strain curve of the used concrete

Table 6. Mechanical properties of the used steel meshes.

Mesh type	F_y (MPa)	F_u (MPa)	Modulusof elasticity (GPa)
Expanded metal mesh	250	350	120
Welded wire mesh	400	600	170

Figure 5. Steel in the form.

Figure 6. Casting the pipe by plastering.

ECONOMIC ASSESSMENT OF FERROCEMENT

As can be seen, the most expensive part of ferrocement is the reinforcing, followed closely by the cost of labour. The cost of labour may be decreased by using robotic manufacturing methods and better planning. HighJ. Civ. Eng. & Constr. Tech.

Figure 7. Pipe testing and loading system.

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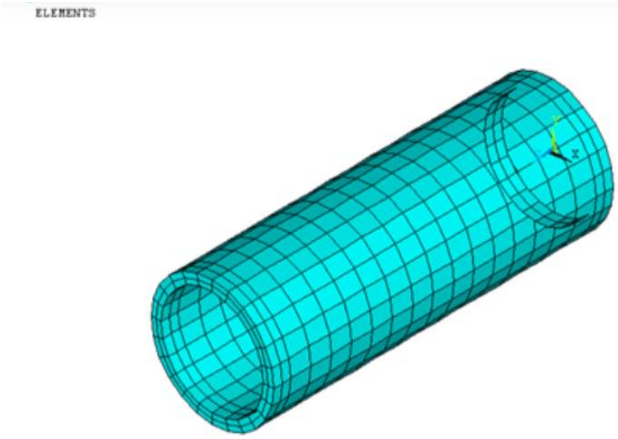

Figure 8. Theoretical model.

Table 7. Experimental first cracking and failure loads.

Model No.	First cracking load (KN)	Failure load (KN)
RCP	10	16
FP1	14	20
FP2	16	24
FP3	15	22
FP4	18	32

In part, steel mesh prices are driven up by the high manufacturing costs of the mesh system itself, as well as by a dearth of customers. When demand for steel mesh systems grows, it becomes easier and cheaper to build it. As a consequence, the cost of the ferrocement has been greatly reduced as one of the most important attributes of the ferrocement:

Materials are used sparingly. When it doesn't need form functioning, it can take on whatever shape it wants. (iii) It's virtually impenetrable when done properly. First and foremost, cracking should be treated with respect. Repairs are simple to do. c) It may be made in advance.

Table 8 shows that using ferrocement pipes instead of the more traditional RCP reinforcement pipe saves a significant amount of money for all of the developed ferrocement pipes (FP1, FP2, FP3, and FP4). Ferrocement pipes save an average of 25% over ordinary reinforced concrete pipes in terms of cost. Pipe FP4 has double the maximum strength of reinforced control pipe with substantial deformation and cracking characteristics.

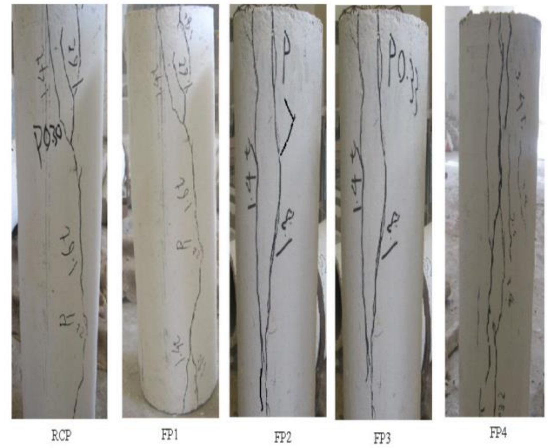

Figure 9. cracking patterns of tested pipes.

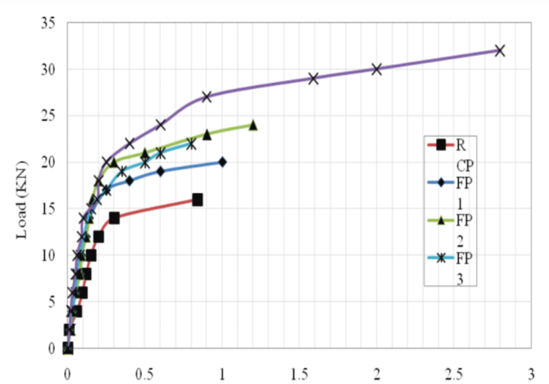

Figure 10. Experimental load-deflection curve.

J. Civ. Eng. Constr. Technol

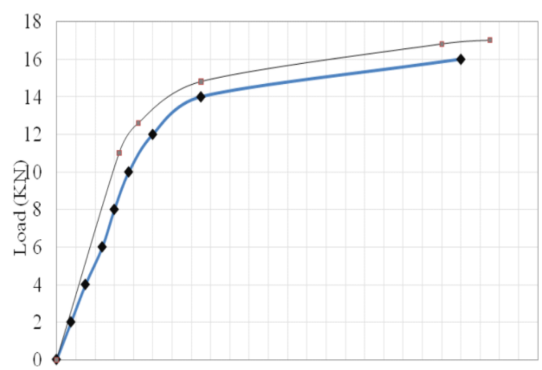

Figure 11. Experimental and theoretical load-deflection curve of RCPP.

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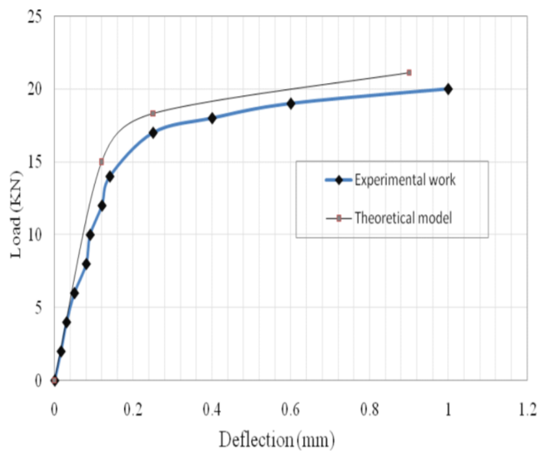


Figure 12. Experimental and theoretical load-deflection curve of FP1.

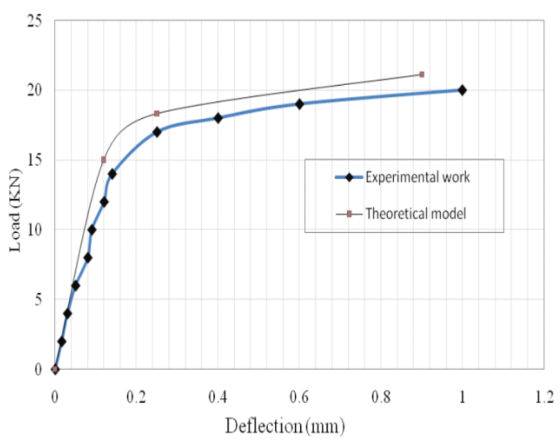


Figure 12. Experimental and theoretical load-deflection curve of FP1.

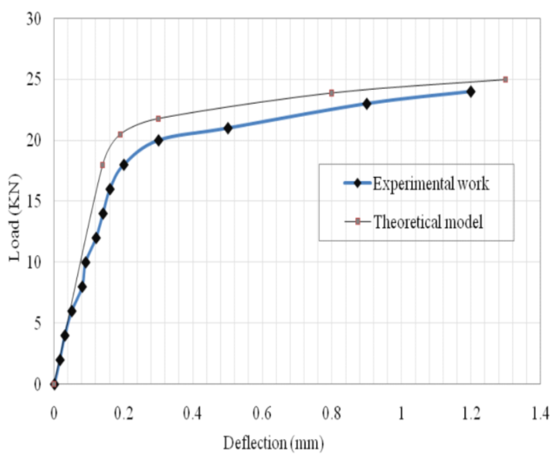


Figure 13. Experimental and theoretical load-deflection curve of FP2

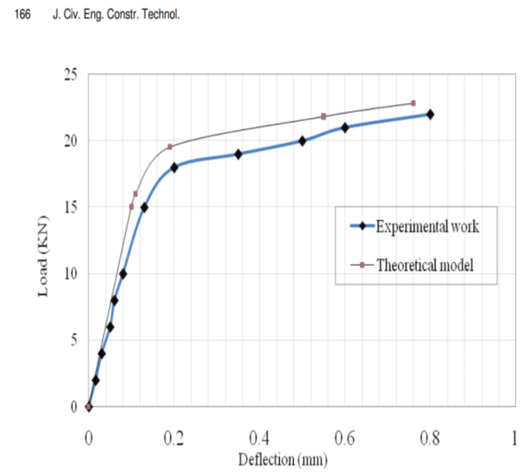
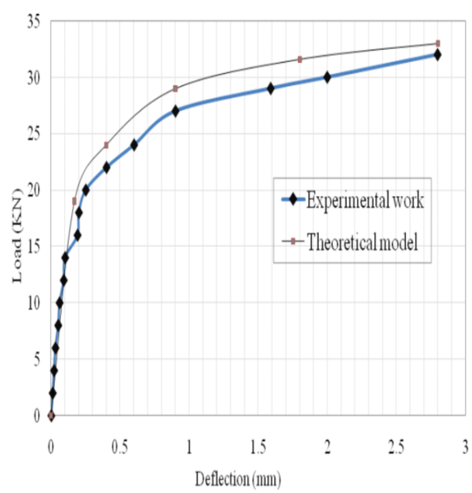


Figure 14. Experimental and theoretical load-deflection curve of FP3.



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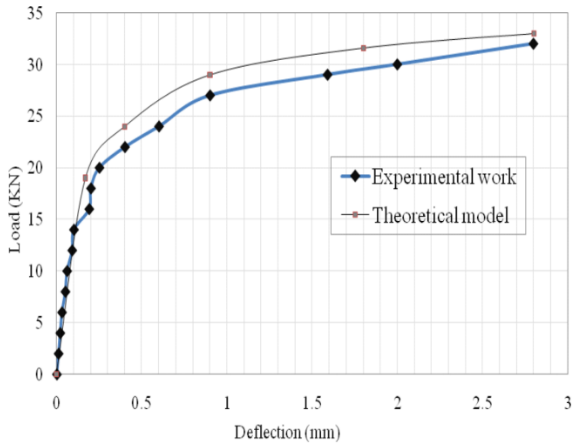

Table 8. Cost comparison and strengths of developed concrete and ferrocement pipes.

Model No.	Type of reinforcement	Cost of mortar matrix	Cost of reinforcement	Total cost Egyptian pound	First crack load (KN)	Ultimate load (KN)
RCP	(6 Bars + 6 Stirrups) Ø 6 mm	20 (concrete)	21.3	41.3	10	16
FP1	(6 Bars + 6 Stirrups) Ø 6 mm	14.6	21.30	35.9	14	20
FP2	One layer of welded metal + One expanded metal	14.6	14	28.6	16	24
FP3	Two stirrups Ø6 mm + One layer of expanded metal	14.6	12.1	26.7	15	22
FP4	Three stirrups Ø6 mm + Three layers of welded metal	14.6	19.06	33.66	18	32

Conclusions

Ferrocement concrete is now being studied for its potential use in water supply pipe design and construction. We cast and tested four reinforced concrete pipes, each with a different strengthening technique, to see how they would do in comparison to another similarly reinforced concrete pipe. There was also an ANSYS application used to construct theoretical models that were compared with the experimental data. Results from this study have shown that the five different kinds of pipes may be accurately predicted using finite element models. It is also obvious that the ferrocement pipes perform better than the reinforced pipes when subjected to an applied load. FP4 pipes reinforced with welded wire meshes fell at the highest failure stress, according to the results of this study. For both rich and developing nations, ferrocement pipes with high strength, fracture resistance, and a 25 percent savings in cost might be advantageous.

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