Full Length Research Paper

Experimental and analytical investigation of ferrocement water pipe

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The main objective of this research is to investigate the possibility of using ferrocement concrete in constructing water supply pipe. The current work presents the comparison between the performance of ferrocement pipe and reinforcement concrete pipe under static load as starting step to study the performance of this type of pipe under impact load. The current paper presents an experimental models of ferrocement and concrete water pipes and their numerical models using the finite element method. Finite element models were developed to simulate the behavior of the pipes through nonlinear response and up to failure, using the ANSYS Package. Additionally, the comparison between the theoretical and experimental models results is presented and discussed.

Key words: Ferrocment, water pipe, nonlinear analysis, finite element analysis.

INTRODUCTION

Ferrocement is type of reinforcement concrete. It commonly composed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small size wire mesh. The mesh may be made of metallic or other suitable materials (Blake, 2001). It is low cost, durable, weather-resistance, lightweight and particularly its versatility comparing to the reinforced concrete (Ali, 1995). Robles-Austriaco et al. (1981) indicated that ferrocement is an excellent material for housing construction. Also Al-Kubaisy and Jumaat (2000) studied the possibility of using ferrocement cover in the tension zone of reinforced concrete slab.

This material is also used in repairing the reinforcement element such as beams, slabs or walls (Fahmy et al. 1997; Elavenil and Chandrasekar, 2007; Jumaat, 2006). Mourad and Shang (2012) used ferrocement jacket in repairing reinforced concrete column. Their test results indicated that using the ferreement jacket increases 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) investigated the possibility of using ferrocement jacket in strengthening of square reinforced concrete short column. Their results indicated that using this method of strengthening improved the column behavior. Various researches were carried out to study ferrocement elements (beam, slabs and column) to investigate its behavior under applied loads up to failure. Ibrahim (2011) and Hago et al. (2005) studied the ultimate capacity of wired mesh-reinforced cementations slabs and simply supported slab panels; respectively with different types of reinforced wired mesh. Nassif and Najm (2004) investigated an experimental and a theoretical model for ferrocement–concrete composite beams. Various types of reinforced concrete beam overlaid on a thin section of ferrocement (cement paste and wire mesh) were tested

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| a-Polypropylene fiber | b- Expanded steel mesh | c- Welded steel mesh |

Figure 1. Reinforcement steel meshes and fibers used.

up to failure under two-point loading system. Their results showed that the proposed composite beam has good ductility, cracking strength and ultimate capacity more than reinforced concrete beam. Shannag and Ziyyad (2007) increased the strength of ferrocement mortar by adding discontinuous fibers glass. Shannag and Mourad (2012) developed high strength mortar matrices contain various combinations of silica fume and fly ash, and provide a good balance between workability and strength. Chandrasekhar et al. (2006) studied the shear strength of simply supported ferrocement rectangular plates. In their study, tests on ferrocement elements with different layers of mesh were conducted. They observed that increase in the number of layers of the mesh reinforcement increases the shear capacity of the plate. An experimental study on simply supported ferrocement plates was conducted by Ibrahim (2011). In his study, flexural steel was designed to preclude failure in modes due to shear other than flexure. A good agreement between the classical shear equations prediction and his experimental results is obtained water supply pipe is very important structure that is used to supply water to individual buildings. Supply pipes should be strength and durable. There are several types of these pipes according to their constructed material; metallic pipes, cement pipes and plastic pipes. The main objective of this study is studying the performance of ferrocement pipe and reinforcement pipe under line load. Also this research presents a theoretical finite element model using ANSYS (2006) program and a comparison between the experimental and theoretical results.

EXPERIMENTAL MODEL

Five different types of pipes with 300 and 30 mm internal diameter and thickness; respectively was cast and tested under static load in reinforcement laboratory in Faculty of Engineering-Minufiya University. The first type is reinforcement concrete pipe and the anther types are ferrocement pipes with different in the type of

reinforcement system. Two types of steel wire meshes (welded wire mesh and expanded metal mesh) as shown in Figure 1 were used in the reinforcement of the ferrocement pipes. The two types are locally produced and available in the Egyptian market on commercial scale. The expanded wire mesh type with 1.5×2.1 mm diameter and 19.7×43.7 mm grid size and welded wire mesh type with 0.72 mm diameter and 12×12 mm grid size were used. In the five types of pipes, the weight of reinforcement was constant as shown in Table 1.

Properties of the used materials

The sieve analysis was done on the used sand for the ferrocement mortar mix and its results are presented in Table 2 was done on the used aggregate for the concrete mix. Also properties of both of the used sand and aggregate satisfied the Egyptian Standard Specifications (E.S.S.) requirements (2007). The chemical and physical properties of the cement were analyzed according to E.S.S. (2007) for concrete works. Fresh drinking water and free from impurities was used for mixing and curing of the test specimens. Fiber, silica fume with a powder form and a light-gray color and its chemical composition is given in Table 3 and super plasticizer EDECRETE DM2, complies with ASTM C494-86, with a specific weight of 1.05 at 20°C were used to increase the strength and the workability of the mortar mix.

Six ferrocement mortar mixes were designed and tested under compression load to select the best proportions of the ferrocement constituent's materials. The selecting mortar mix based on achieving the maximum compressive strength and the moderate workability has a sand/cement ratio and water/cement ratio of 2 and 0.35; respectively and fiber with ratio of 900 g/m^3 of the mortar matrix and silica fume were added as indicated in Table 4.

Compression and tensile tests were carried out for the hardened mortar according to E.S.S (2007). From the tests results, the compressive stress (F_{cu}) is considered as 33.4 and 47 MPa after 7 and 28 days; respectively and the tensile stress is considered as 3.6 MPa after 28 days. The modulus of elasticity of concrete and stress-strain curve were employed the Egyptian Code for design and construction the reinforced concrete structures (2001) and Kaewunruen and Remennikov work (2006). The modulus of elasticity of concrete (E_c) can be calculated from equation 1 by considering the compressive strength of concrete at 28 days (F_{cu}). The multi-linear isotropic stress-strain curve for the concrete can be computed by Equation 2. The stress-strain curve for the used ferrocement mortar is presented in Figure 2.

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 %

$$E_c = 139140.22\sqrt{F_{cu}} \tag{1}$$

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

$$\varepsilon_0 = \frac{2F_{cu}}{E_c} \tag{3}$$

Where, f is stress at any strain (ε) and ε_0 is the strain at the ultimate compressive strength at 28 days and can be found from Equation (3).

The control pipe was reinforced with conventionally mild steel and has an ordinary concrete mixture. This mixture is the same as that was used in Egyptian pipes factories. The conventionally mixture was consisted of 0.8 gravel, 0.4 m^3 sand, 350 kg cement and 160 L of water. Twelve cubes 100 × 100 × 100 mm were cast and tested according to E.S.S (2007) to determine the compressive strength of the mixture after 7, and 28. Table 5 shows the compressive strength and the tensile splitting strength of the concrete mixture. Figure 3 presents the stress-strain curve for the used concrete mixture. Three samples of each type of the steel meshes were tested using the Universal Testing Machine as shown in Figure 4. The specification and the mechanical properties of the steel meshes are illustrated and shown in Table 6. For the mild steel, the modulus of elasticity and yield strength were considered as 210 GPa and 2240 MPa; respectively.

Testing of pipes

A Gibson form was constructed with an outside diameter equal 300 mm and has top and bottom cylinder to control the thickness of pipes. The casting processes were done as following steps. At the beginning, the reinforcements were prepared by their required diameters. Then they were put in the forms in their position (in the middle of the section) as shown in Figure 5. At the second, the concrete was casted by plastering as shown in Figure 6. Finally, the final face was finished. Within 24 h the specimens were turned upside down to allow the sides to harden. The specimens were stored in the laboratory atmosphere until testing after 28 days. The specimens were covered using a wet cloth while water was sprinkled twice a day for curing. The faces of each specimen were painted in white to facilitate crack detection before the testing. The specimen was placed in the testing position on steel frame as shown in Figure 7. Two rigid steel beams were used under pipe as supports and another one was used up to pipe under the increasable load to distribute the concentrated load along pipe.

THEORETICAL MODEL

In the current theoretical work, finite element ANSYS program (2006) was used to study theoretically the behavior of the tested pipes up to failure. Solid65 element was used in the modeling of ferrocement and concrete mix (Hoque, 2006; Singh, 2006; Aboul-Anen et al., 2009). The Solid 65 element is defined by eight nodes.
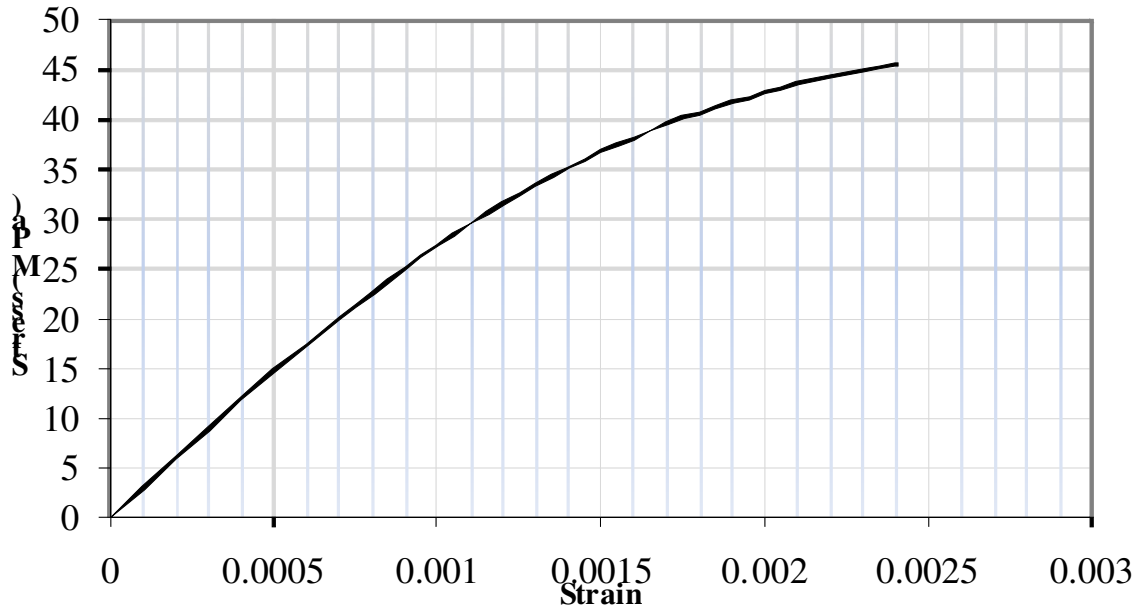
Figure 2. Stress-strain curve of the selected ferrocement mortar.

Table 5. Properties of the used concrete mixture.

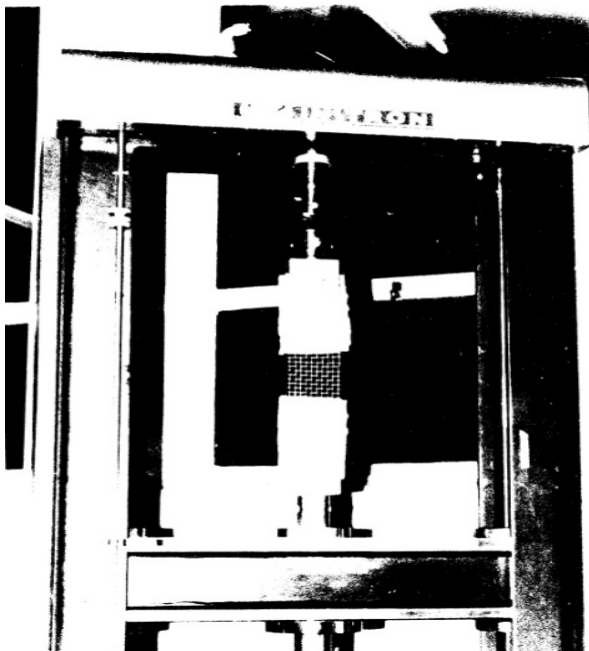| Age (days)	Compressive strength (MPa)	Tensile splitting strength (MPa)	Modulus of elasticity (GPa)
7	17	1.9	---
28	28.5	2.4	23.5

Figure 3. Testing of steel mesh by using Instron Testing Machine.

Each node has three degrees of freedom (translations in the nodal x, y, and z directions). Link 8 element was used to represent steel bar and stirrups. It has three degrees of freedom at each node (translations in the nodal x, y, and z directions). Theoretical model is indicated in Figure 8.

RESULTS AND DISCUSSION

In this part, the results of the experimental program are presented and discussed. The load at the first crack and the failure load are shown in Table 7. The experimental detected crack patterns of the tested pipes are shown in Figure 9. The experimental relationship between the total applied load and the deflection of the five types of pipes are shown in Figure 10. From this table and the two figures, it can be seen that the four ferrocement pipes failed at total load greater than the reinforced pipes. Also it can be concluded that the fifth type of pipes (FP4) failed at greatest failure load.

The comparison between the results of the experimental program and the current theoretical model are exposed and discussed in this part of the work. The total applied load - deflection curves of the five types of
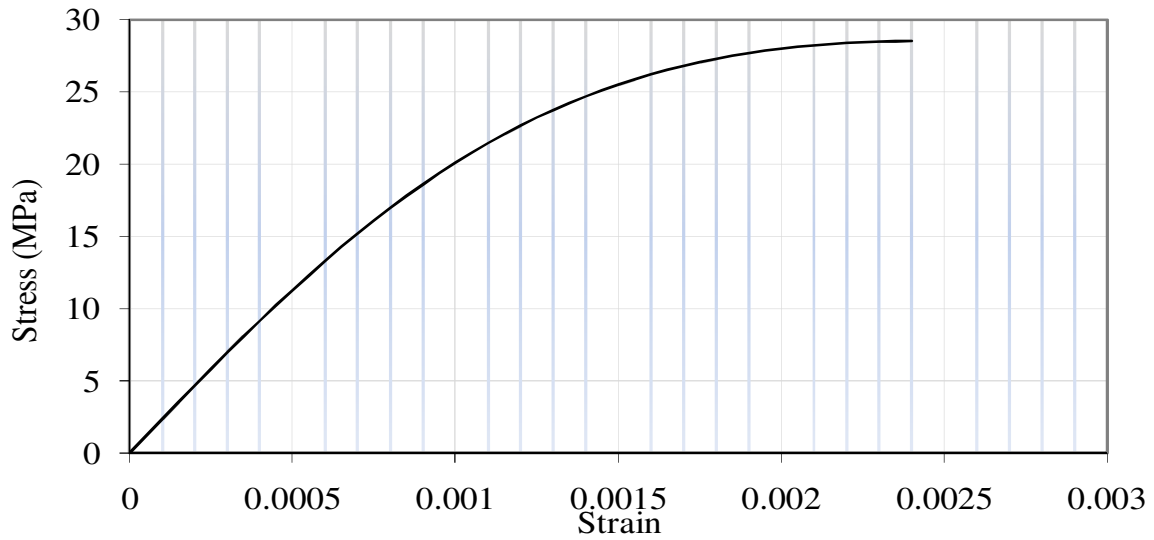
Figure 4. Stress-strain curve of the used concrete.

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.

pipes that were obtained from the experimental work and the theoretical models are indicated in Figures 11 to 15. From these curves, it can be concluded that the response obtained from theoretical work was quite similar to the actual response of the experimental results, especially in the initial region.

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
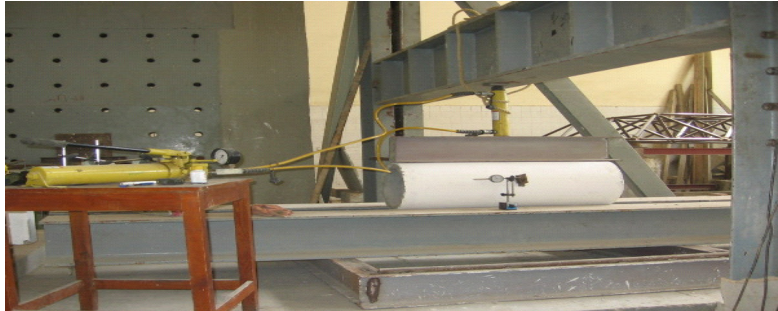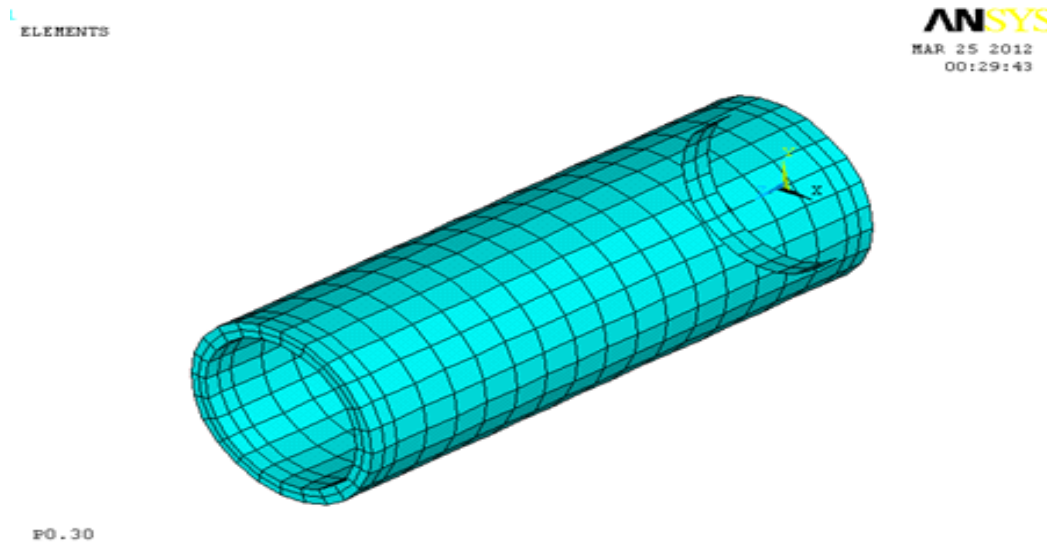
Figure 7. Pipe testing and loading system.

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

(i) Low consumption of materials.
(ii) It can take any shape most of the times without using form working.
(iii) When worked correctly, it is practically impermeable.

a) Good behavior to cracking.
b) Easy to be repaired.
c) It can be prefabricated.

It is interesting to note from Table 8 that there is high cost saving by employing ferrocement pipes for all developed ferrocemen pipes, FP1, FP2, FP3 and FP4 compared with conventional reinforcement pipe, RCP. The average cost saving of ferrocement pipes is approximately equal 25% compared with that of conventional reinforced concrete pipe. The ultimate strength of pipe FP4 is approximately twice of that of reinforced control pipe with significant deformation characteristics and cracking behavior.
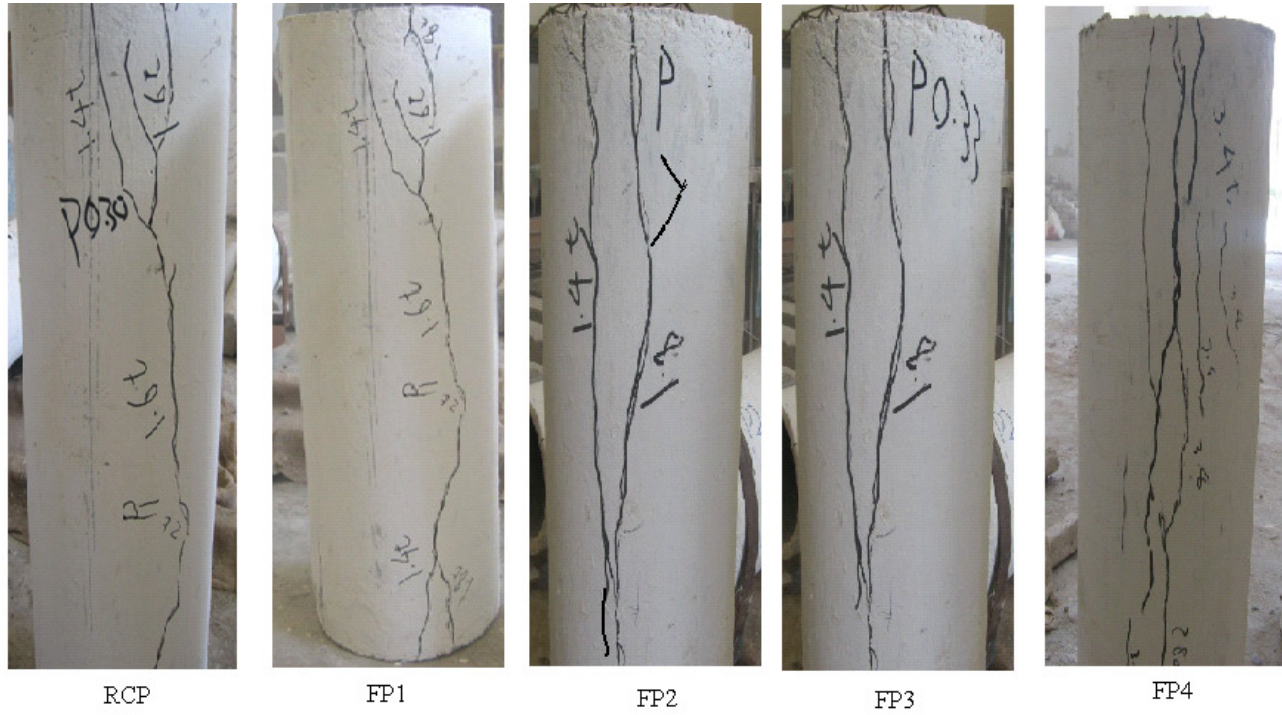
cost of the steel mesh is mostly due to the cost of production of the mesh system itself and to the limited demand. With increasing market, steel mesh system can be produced more efficiently and at a lower cost. Therefore, resulting in a remarkable reduction of the ferrocement cost among the more significant qualities of the ferrocement mentioned earlier:

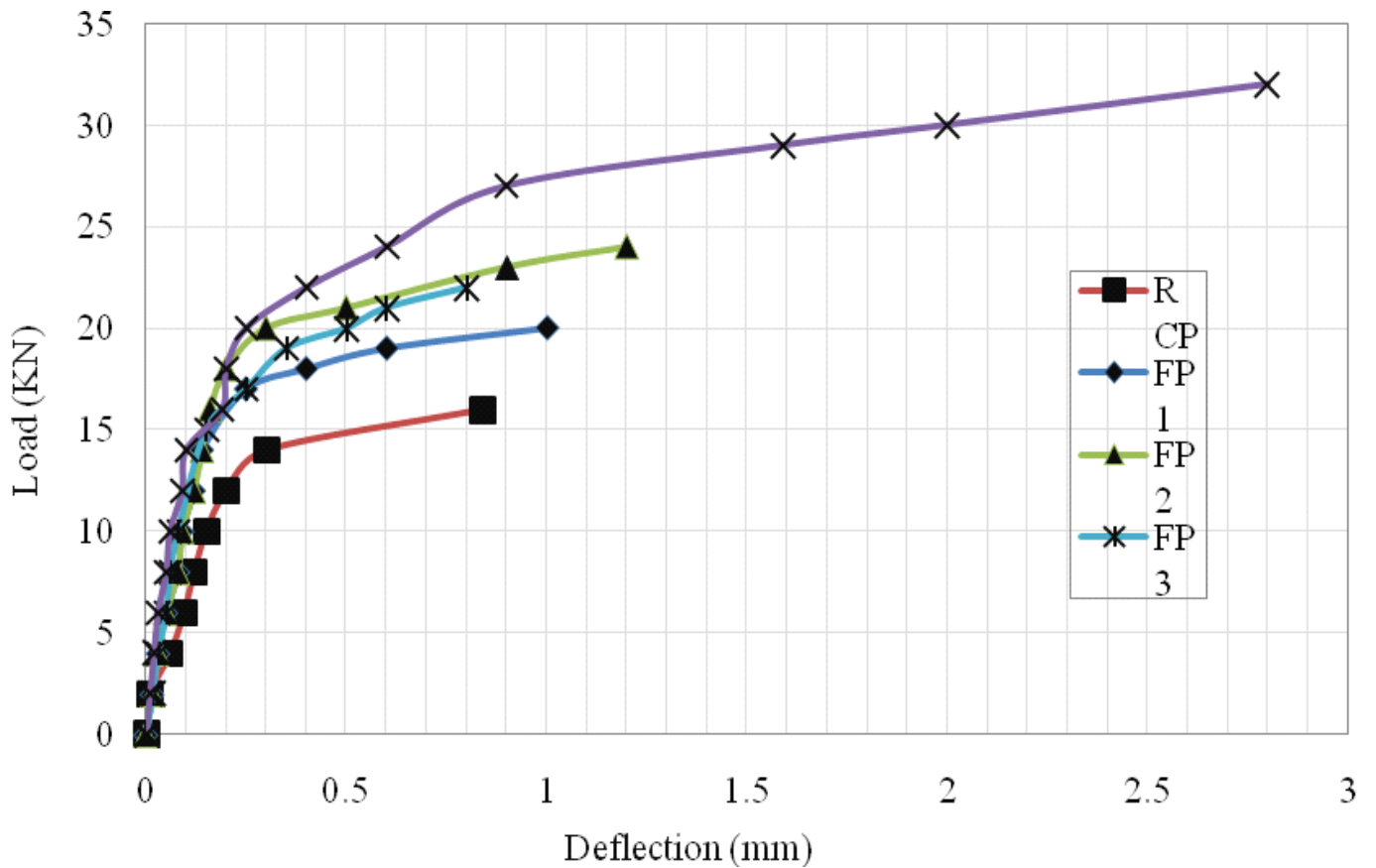Figure 9. cracking patterns of tested pipes.

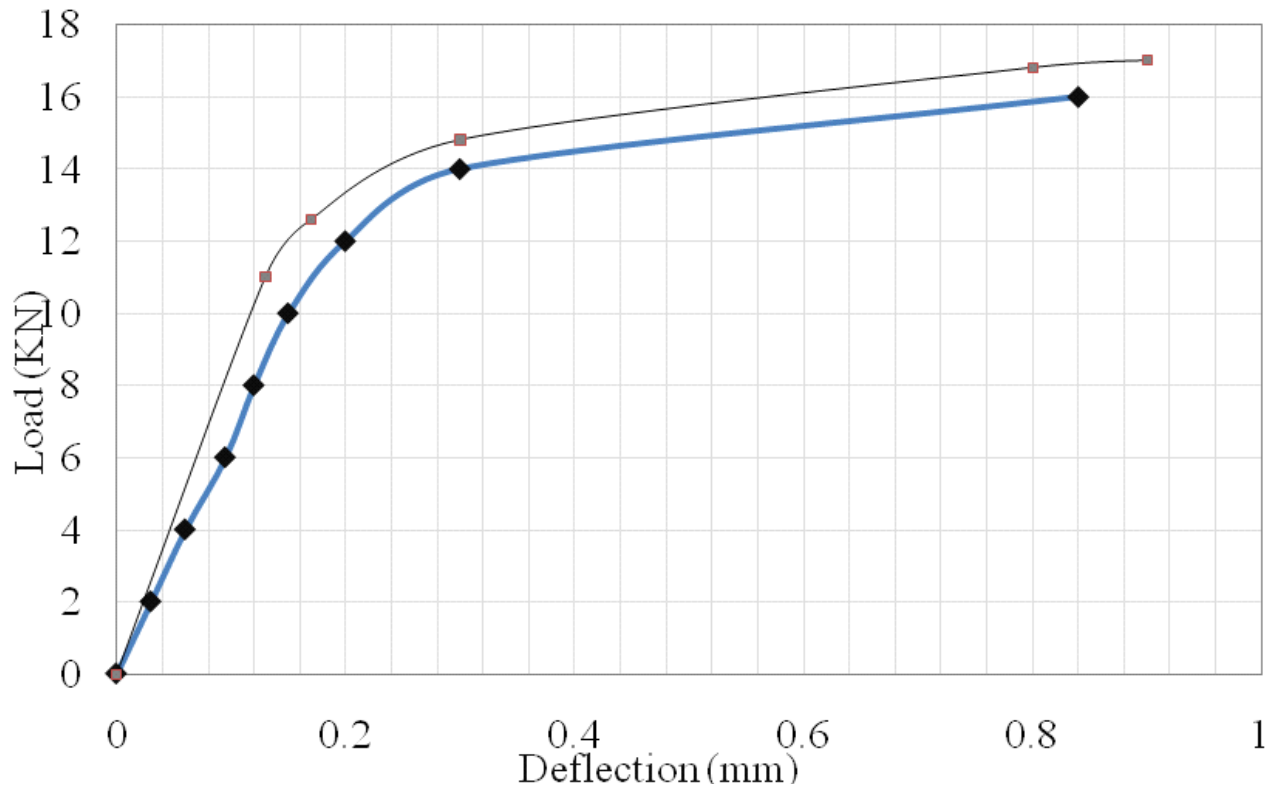**Figure 10.** Experimental load-deflection curve.

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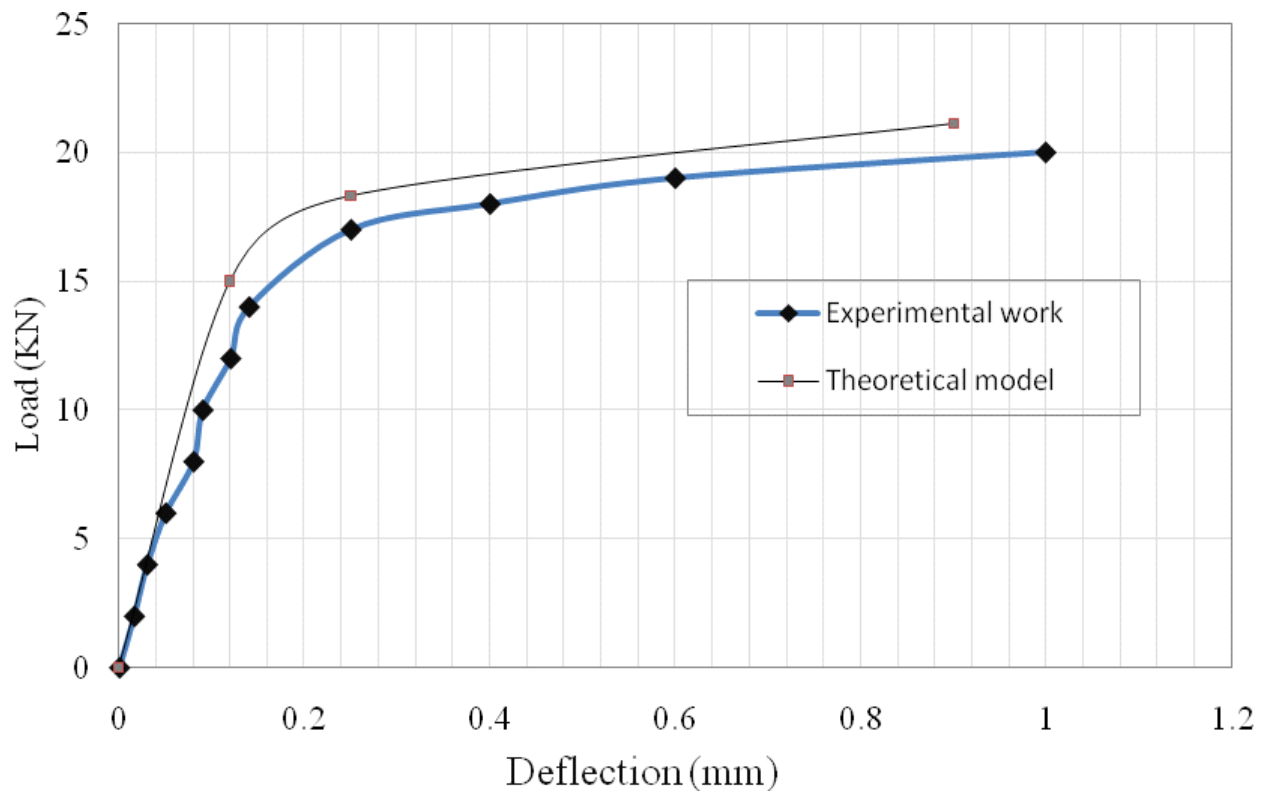

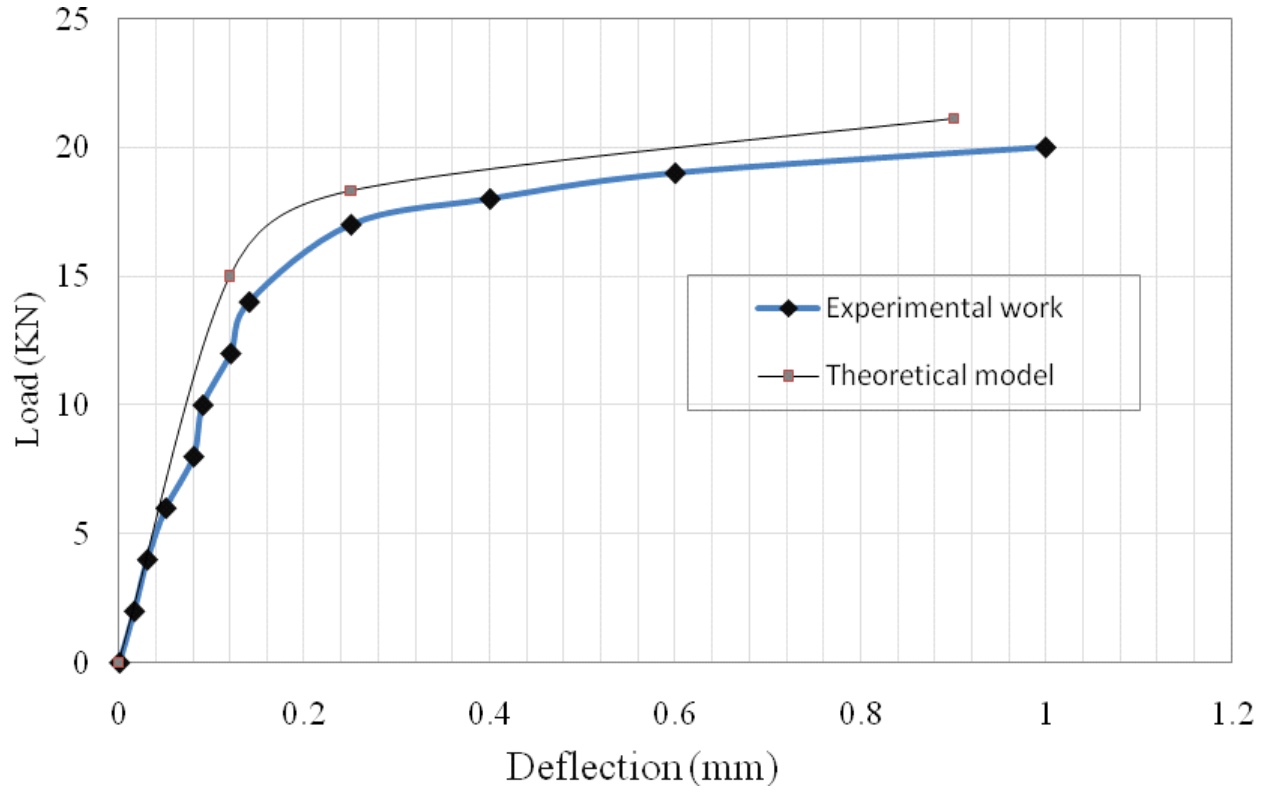**Figure 12.** Experimental and theoretical load-deflection curve of FP1.

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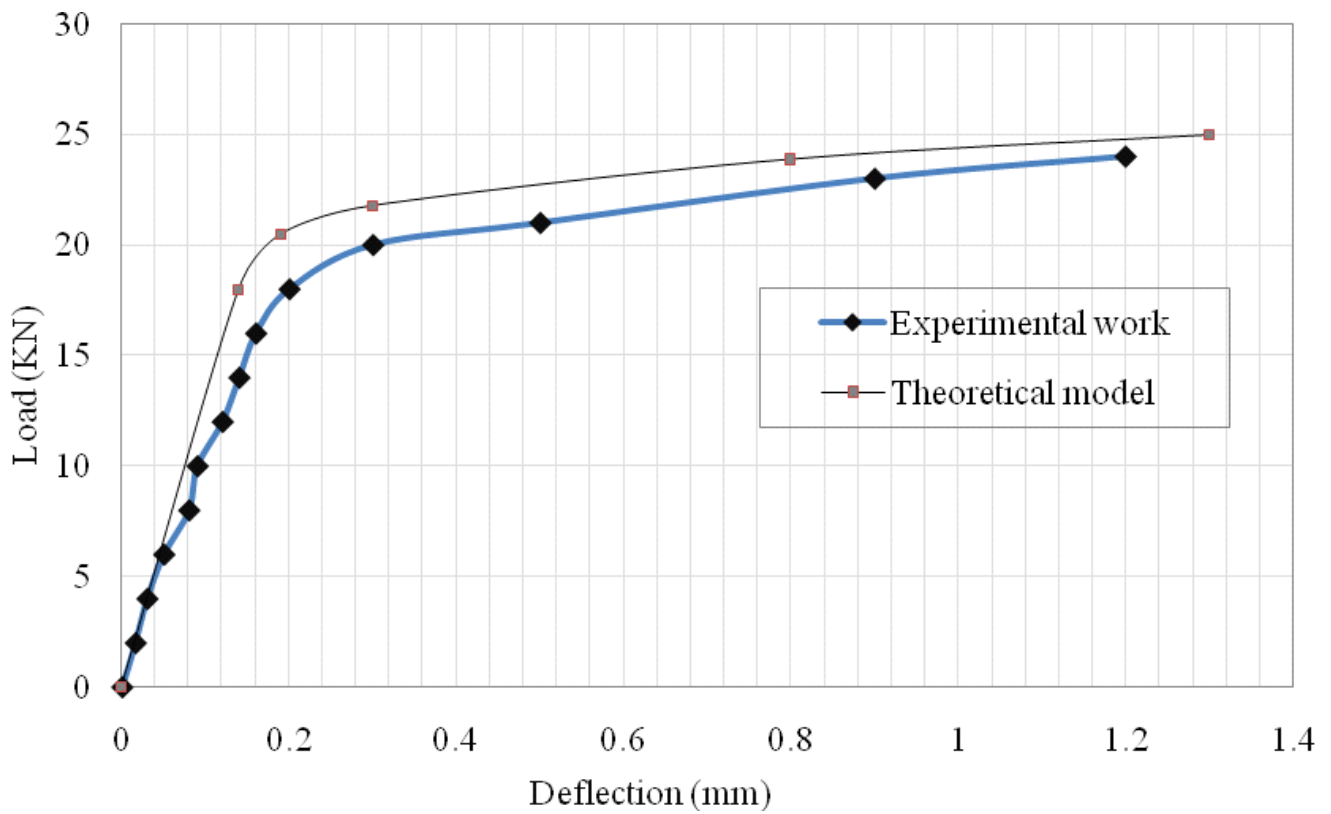

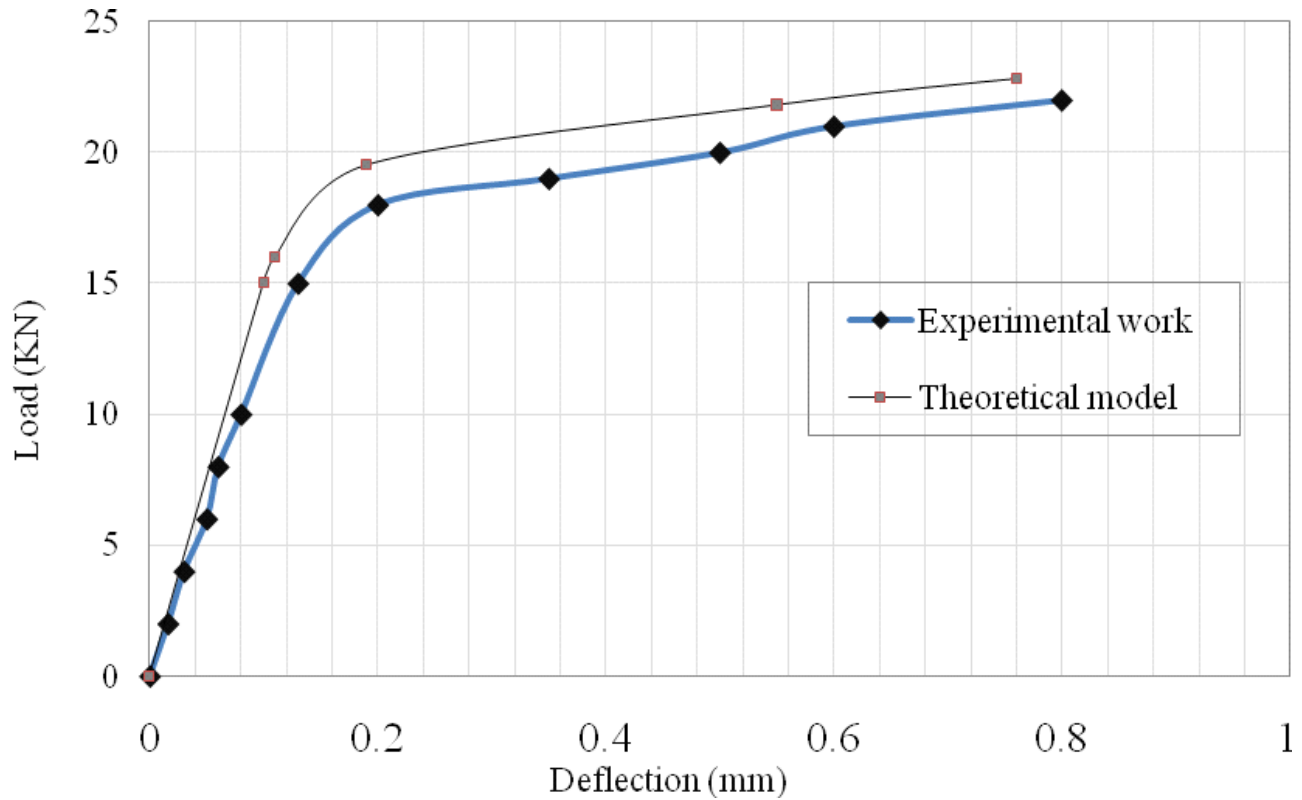**Figure 13.** Experimental and theoretical load-deflection curve of FP2

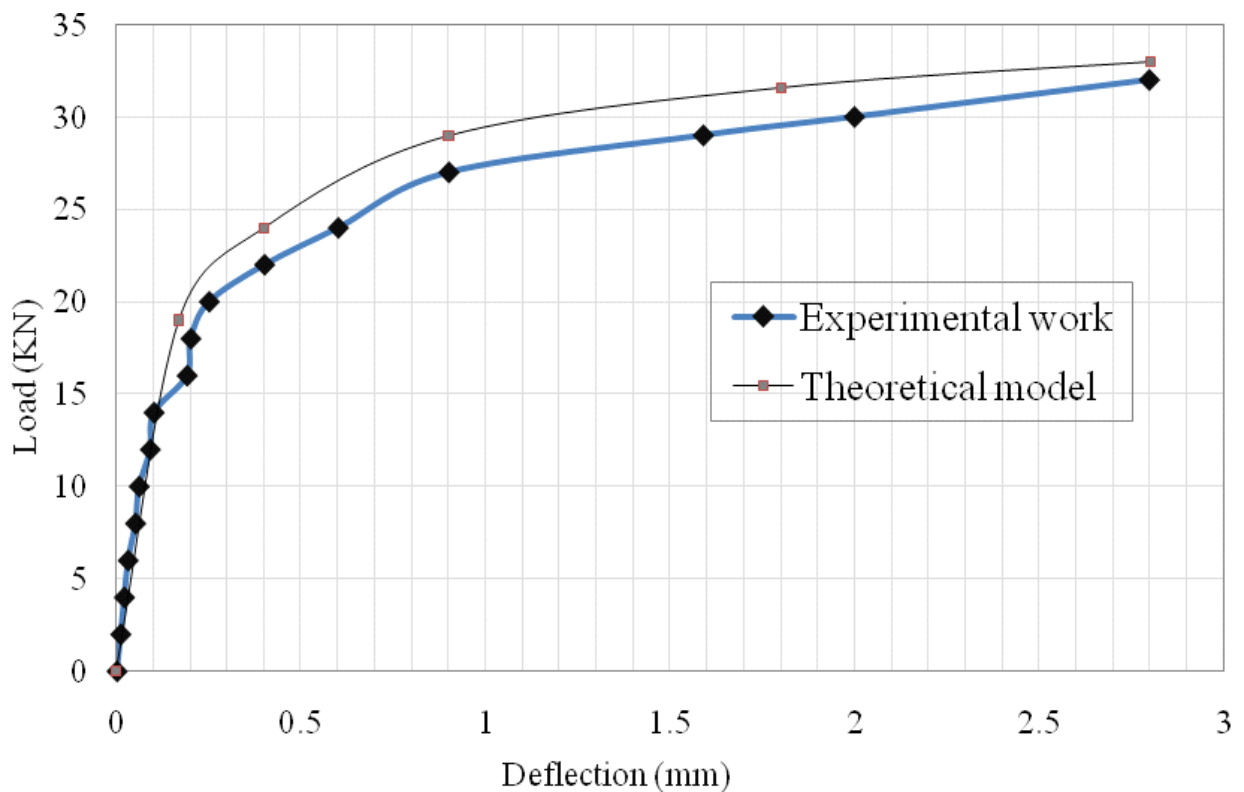**Figure 14.** Experimental and theoretical load-deflection curve of FP3.

Figure 15. Experimental and theoretical load-deflection curve of FP4.

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

The main goal of the current research is studying the ability of using ferrocement concrete in design and construction of the water supply pipes. Four ferrocment pipes that were different in the reinforcement system were casted and tested up to failure and their results were compared with anther casted and tested reinforced concrete pipe. Also theoretical models were developed using ANSYS program and their results were compared with the experimental results. From the current results, it can be concluded that the investigation finite element models for the five types of pipes give accurate results in comparison with the experimental results. Furthermore it can be clearly seen that the ferrocement pipes behaves under the applied load better than the reinforced pipes. Also it can be concluded that the fifth type of pipes (FP4) that was reinforced with welded wire meshes collapsed at greatest failure load.

Ferrocement pipes were produced with high strength, crack resistance and 25% economic saving could be useful for developed and developing countries alike.

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