Experimental and Analytical Studies on Prototype Water Tank Constructed Using Flowable Cement Composites

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***Abstract*— Ferrocement elements are being used for water tank construction because of their strong and durable nature. The construction of water tank using ferrocement technology requires highly skilled manpower of artisan type. In the recent day's labour cost is very high and also the availability of artisans is very difficult which increases the cost of the ferrocement water tank. To overcome these difficulties, an attempt is made to develop a composite of flowable nature without compromising its strength by suitably modifying the mix proportion. Cube specimens were cast to determine the compressive strength of the composite and slab specimens were cast using different types of steel wire meshes to study their flexural behaviour. Prototype water tank was cast using the composite and its structural behaviour was studied experimentally under hydraulic loading. The behaviour of the tank subjected to hydraulic loading was monitored using LVDTs and strain gauges. The analytical study indicates that the predictions are comparable with the test results. The outcome of this study may be useful to formulate guidelines to design water tank of various capacities.**

***Keywords*— Composites, Ferrocement, Water tank, Hydraulic loading, Experiment.**

I. INTRODUCTION

Ferrocement is a construction material that is proved to have superior qualities of crack control, impact resistance and toughness, largely due to the closer spacing and uniform dispersion of the reinforcement within the material. It can be constructed with a wide spectrum of qualities, properties, and cost according to customer's demand and budget. The ACI committee 549 defines ferrocement as a type of thin wall reinforced concrete construction using hydraulic cement mortar reinforced with closely spaced and relatively small sized wire mesh, the mesh may be made of metallic or other suitable materials[1].

The materials generally used as reinforcement are steel, synthetic woven fibres, glass fibres or fibre reinforced polymers, which are commonly called wire mesh [2]. Although it uses small sized meshes, they function successfully. The closely arranged and uniformly distributed wires in ferrocement change the brittle material into strong ductile material [3]. Provision of sufficient mesh reinforcement also improves the ultimate load carrying capacity of structural member [4]. The influence of ferrocement with wire mesh as reinforcements with various mesh size and volume fractions has shown a great improvement in resisting the tensile cracking[5]. The improved property of ferrocement allows thin walled construction which promotes reduced thickness of structural members and thereby reducing the cost of construction. The thickness of ferrocement usually ranges from 25 to 50mm.

Research studies with respect to the structural behaviour of ferrocement slabs may be found elsewhere. Its high degree of impermeability and resistance to cracking makes it ideally suitable for the construction of water tank and other liquid retaining structures. The construction of water tank with ferrocement technology requires skilled labours of artesian type. In the recent days, the availability of skilled labours is less which thereby increases the cost of construction. One of the ways to avoid the requirement of skilled labours is to modify the mortar so that it would flow and fill the mould to take the required shape of the structure.

In this present study, the conventional cement mortar mix proportion is suitably modified to make the mortar flowable. This is achieved by using superplasticizer and replacing 30% of cement using ground granulated blast furnace slag. The hardened properties of the flowable cement composite developed are determined to ensure that the mix satisfies the required strength properties. The flexural behaviour of the slab cast using this flowable cement composite is also studied using a small-scale specimen subjected to four-point bending. After these preliminary studies and ensuring the satisfactory structural performance of the composite developed, it was used to cast a prototype water tank. The tank was subjected to hydraulic loading and its structural behaviour was studied.

II. EXPERIMENTAL STUDY

A. Material Properties

The materials used for casting the specimens include locally available Portland Pozzolana Cement (PPC) of 53grade, Fine Aggregate passing through 4.75mm sieve, Ground Granulated Blast Furnace Slag (GGBS), Water and Super Plasticizer. The proportion of mortar mix (Cement

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+Fine Aggregate + GGBS) used in this investigation is 1:2:0.5 with a water-binder ratio of 0.38. The amount of Super Plasticizer used was 0.8% by weight of cement. The mortar was designed to give a 28-day compressive strength of 30Mpa. Welded Wire Mesh (WWM) locally available in the market was used as the reinforcement. Steel welded square wire mesh of 2.36mm diameter and 36mm openings are used. The tensile strength of the wire mesh was found using the method proposed by ACI committee 549 [9]. The yield strength of the wire mesh was found to be 415N/mm^2.

B. Experimental Program

The main objective of this investigation is to study the flexural response of slab panels fabricated using welded wire mesh and behaviour of prototype water tank cast using the developed flowable cement composite. The experimental program explained in this paper has been divided into two stages. The first stage involves the determination of material properties (both fresh and hardened property) of flowable cement composite (FCC) further, it involves studying the flexural behaviour of small-scale slab specimens. Fresh property of the composite was studied by conducting flow table test whereas the hardened property i.e. Characteristic compressive strength of mortar is obtained by conducting compressive strength test. To study the flexural behaviour of the slab, small scale slab panels were cast. A total of six slab panels were tested under flexure. It comprises of two slab specimens S1 and S2 of size 1300mmx270mmx40mm were cast. Slab panel S1 is incorporated with Welded Wire Mesh (WWM) having 36mm mesh spacing running throughout the longitudinal and transverse direction of the panel. WWM is provided in two layer and shear connectors made up of same the material are used to connect both the wire mesh. The diameter of wires used was 2.36mm. While Slab panel S2 is a Plain mortar. In the experiment, the load was increased until the specimen fails. The deformation and strains were recorded for every load increment.

The second stage involves construction and testing of prototype water tank. The water tank was designed for a capacity of a 1cubic meter. For this, Water tank of size 1230mmx1020mmx910mm (outer dimension) were cast for experimental study. The thickness of the base slab is 40mm, whereas the thickness of walls is 35mm and 40mm along shorter and longer direction respectively. A single layer of welded wire mesh with wire spacing of 36mm running in both longitudinal and transverse direction of the specimen is provided, with a cover of 10mm from the extreme tensile zone on each wall face and base slab. Prototype water tank was subjected to hydraulic loading condition. Similarly, deformation and strains were recorded for every load increment.

C. Fabrication and Casting

For casting the slab specimen, the formwork was cleaned and placed on the floor. A part of cement composite was poured into the mould. The WWM was then inserted inside the formwork by maintaining a cover of 10mm from the extreme tensile zone. The remaining area is then filled and fully compacted; its surface was toweled to obtain a smooth finish. Six cube specimens were cast at the same time. Similarly, the water tank is cast by pouring the composite into the mould setup for the water tank. The specimens were covered with wet hessian and plastic sheeting. Water was sprinkled twice a day to keep the specimens moist. The formwork is dismantled seven days after concreting and the specimens left to cure under ambient condition for 28days.

III. TEST SETUP AND PROCEDURE

A. Flow Table Test

In order to determine the workability of mortar, flow table test was performed. The flow test for the mixes was performed according to ASTM C230[6] with a targeted flow of 150 ± 10mm. Place the cylinder of diameter 7.5cm and height 14.6cm at the center of a flat, smooth and leveled steel plate. Pour the mortar into the cylinder until the cylinder is completely filled up and trowel flattens the top surface of the mortar with a straight edge. Lift the cylinder gently and allow the mortar to flow and spread for 30sec. Measure two perpendicular diameters of the mortar formed and calculate the average diameter.

B. Compressive Strength Test

The cube specimens are tested by Compression testing machine after 28days of curing to obtain the compressive cube strength of mortar. Place the specimen on the bearing surface of the testing machine. Align the specimen such that it is at the center of the base plate of the machine. The load should be applied gradually at a rate of 2.3kN/s till the specimen fails. Load at which the specimen fails divided by cross sectional area of specimen gives the Compressive strength of mortar.

C. Flexure Test

Slab panels were tested in a Universal testing machine. The test set-up used for carrying out flexural strength test on the panels is shown in the Fig.2. The panels were subjected to two point loading. The panel was placed in the loading frame in the correct position. The panel was simply supported by two steel pedestals. At one end of the panel, hinge condition was provided and roller support was provided at the other end. A hydraulic jack of 100kN capacity was used to apply the load at mid-span and equally distributed line loads at 900 mm from the supports. The load was increased in 0.1kN increment and was increased until the specimens fail. Electrical strain gauges for recording strains were fixed. Deflection at the mid-span of the slab panel was almost continuously overseer using linear variable displacement transducer (LVDT). The position of the strain gauge and LVDT is shown in the Fig.1. The deformation and strain were recorded for every increment in load. The load at which the first crack appears and the ultimate load were observed and noted down. Ultimate flexural strength was obtained using the following general equation based on the theory of simple bending.

$$f_{cu} = \frac{wl}{bd^2}$$

Where f_{cu} is ultimate flexural strength N/mm^2, w is load at failure in N, l is effective span in mm, b is width of the specimen in mm and d is effective depth of specimen in mm.

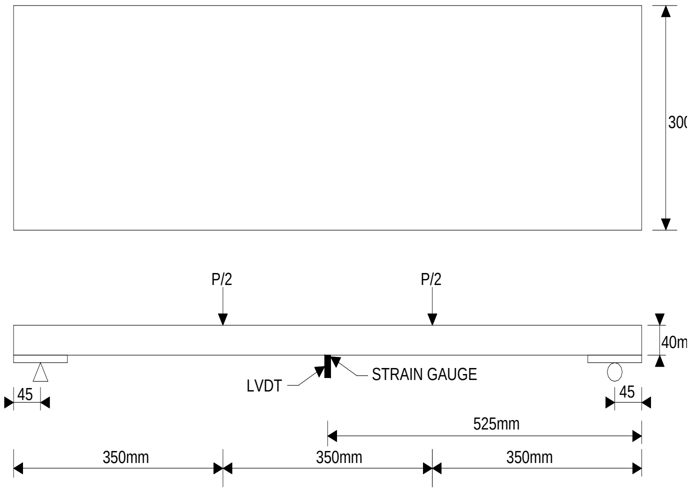
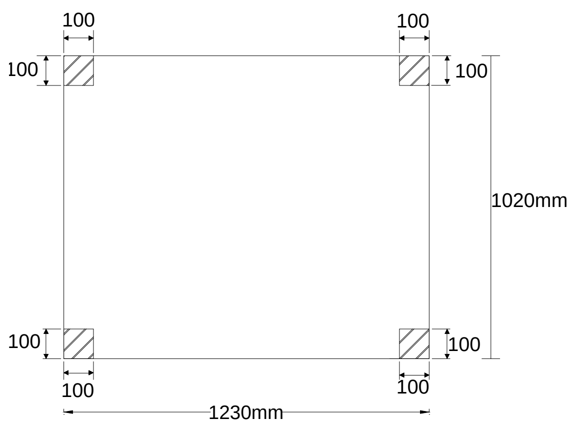


Fig. 1. Supports, loading and position of LVDT

D. Testing of Water Tank

The water tank was tested under hydraulic loading, for the support condition shown in the Fig.2. The water tank was kept fixed, supported only at the four corners. Electrical strain gauges are used for recording strains were fixed on the walls and base slab. Similarly, LVDT's were also placed to measure the displacement. The position and location of the strain gauge and LVDT at the base slab and walls are shown in the Fig.3, 4. The water tank was subjected to water pressure by filling the tank with water and its corresponding displacement and strains were recorded for every increment in load.



Bottom four corners are fixed

Fig. 2. Support Condition

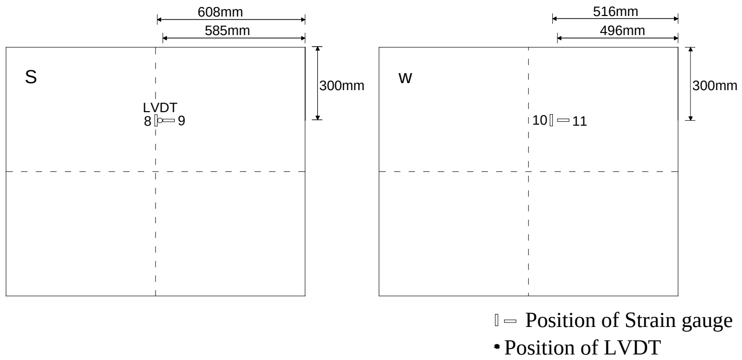


Fig. 3. Location and Position of LVDT and Strain gauge at Walls

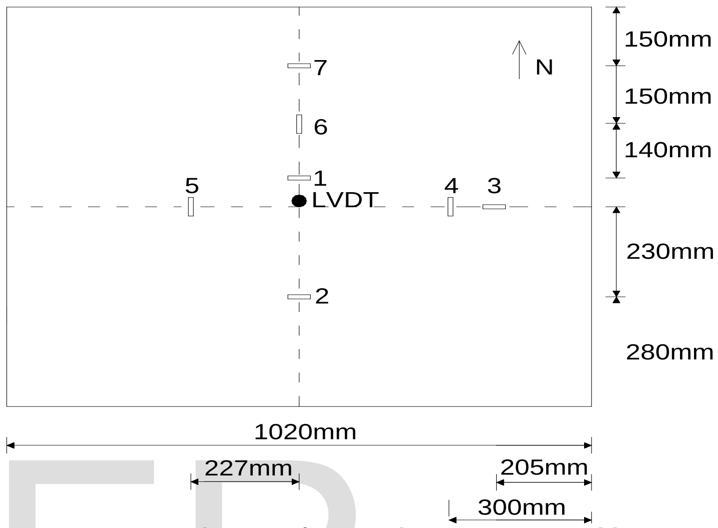


Fig. 4. Location and Position of LVDT and Strain gauge at Base slab

IV. DISCUSSION OF EXPERIMENTAL RESULTS

A. Fresh and Hardened properties

1) Flow index

The determination of the optimum dosage of super-plasticizer for the flowable cement composite is generally carried out by flow table test. The flow index of the mortar sample obtained from the test result is 35mm for 30sec, which indicates that the mortar is highly flowable and it can flow through the mould without any complication. Hence it is identified to be a suitable material.

2) *Compressive strength*

The compressive strength for the flowable cement mortar cube of size 100x100mm achieved is 30MPa at 28days of curing. This achieved strength is feasible for the construction of thin-walled ferrocement structures.

B. Behavior of slab panel

The experimental and predicted first crack, ultimate failure load and its corresponding deflection of the slab panels tested are presented in Table 1. In the case of slab panel S1, the first crack occurred approximately at a load of 60% of the ultimate load. Specimen S2 doesn't show any warning and failed at a load of 0.91kN. At the failure load, all the readings dropped to zero accompanied by a breaking sound, followed by dropping of load and deflection suddenly increases. This sudden failure is due to the absences of tensile steel wires. Thus, the slab specimen S1 proved to be very ductile, expending large deformation prior to failure.

Table I
EXPERIMENTAL RESULT ON SLAB SPECIMENS

Description	First crack load (kN)	First crack location (cm) from South side	Ultimate Load (kN)	Ultimate Moment (kN.m)	Max Deflection (mm)
S1	2.1	40.7	3.48	0.71	35.33
S2	0.91	53.2	0.91	0.24	0.94

1) Ultimate load and Crack pattern

Fig. 5. Typical crack pattern for slab specimen S1

Fig. 5. Illustrates the typical crack pattern which occurred at the tensile surface of the slab panel S1. The slab panel exhibit classical flexural cracking. The cracks are developed in the tensile zone (flexural zone) along the width of the panel. Failure of tested slab panel was observed to occur when the extreme layer of wire mesh failed under tensile stress. No spalling of the mortar was observed for any tested slab panels. It should be noted that small cracks were observed on the top face and the majority of the cracks occurred within the loading area.

2) Stress - Deflection profile for slab panel

In order to compare the slab panels with a bottom slab of the water tank, the stress verses deflection curves are plotted. The result of the flexure test is presented in the form of a flexural stress verses mid-span deflection and the curve is shown in Fig. Load-Deflection curve so obtained is also shown in the Fig.6. From the curve obtained for slab panel S1, it is observed that the panel deflected elastically on the application of load and therefore during the pre-cracking stage, the bending load increases linearly with corresponding mid-span deflection up to the load point of 1.25kN. Beyond this, the curve behaves non-linearly. The panel behaved non-linearly even before the occurrence of first crack. It was observed that the non-linear stage ceases with the initiation of cracking in mortar on the tensile zone. The first crack was seen at a load of 2.1kN at a distance of 40.7cm from the South side. The load carrying capacity of the specimen, however, continues to increase because the mesh starts carrying the additional load.

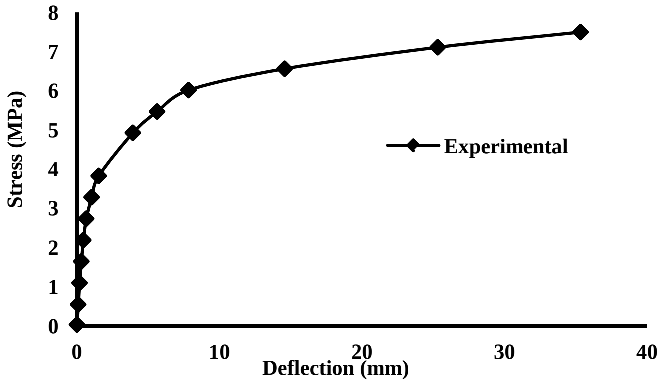


Fig. 6. Stress-Deflection profile for Slab panels at Mid-Span.

With further increase in load, the tension face of the specimen starts cracking followed by cracking of the compression face and finally forming a major failure crack occurs under the two loading point. The ultimate state of the specimen is shown in the Fig.6. The panel fails at the ultimate load of 3.48kN. The first crack occurred approximately at a load of 60% of the ultimate load. From the curve obtained for slab panel S2, it is observed that the load-deflection curve is linear up to the failure load of 0.91kN. On application of load, it is observed that plain specimen without mesh limits the number of fine parallel cracks evenly distributed developed in the central portion of the specimen followed by sudden failure of the specimen. Failure of the specimen occurred by the delamination of the extreme tensile layers. It was observed that flexural strength of the specimen increases with the provision of wire mesh.

3) Stress - Strain profile for slab panel

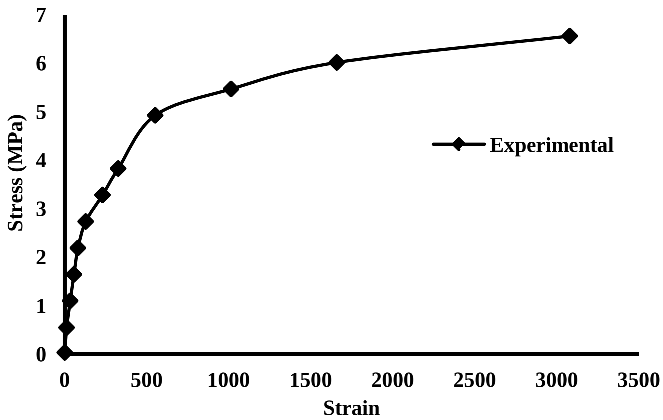


Fig. 7. Load-Strain profile for Slab panels at Mid-Span.

The measured variation of strain with the increase in load is shown in the Fig.7. Typical strains are obtained by

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increasing loads at the mid span for the slab panels. The results clearly indicate a parabolic relationship between load and mortar with wire mesh compressive strain similar to the load-mid span deflection behaviour. The turning point of the load-compressive strain curve indicates the cracking of the concrete in the tension zone. With reference to the concrete stress-strain relationship, at the initial level of deformation under compressive load, the compressive stress varies linearly with the corresponding concrete strain. At this stage of deformation, the concrete material behaves like an elastic material with a virtually full recovery of displacement, when the exerted compressive load is removed. On further application of load beyond the elastic range, the concrete behaves more like a plastic material whereby full recovery of displacement would not take place even after the removal of compressive load and a permanent deformation take place. At the cracking stage of flexural deformation, it was observed that the rate of increment in compressive strain with exerted bending load increased drastically. From the curve obtained for slab panel S1, it is observed that the load-strain curve is linear up to the load point of 1kN. Beyond this, the curve behaves non-linearly.

C. Behavior of water tank

1) Stress-Deflection profile for the Bottom slab of the Water tank

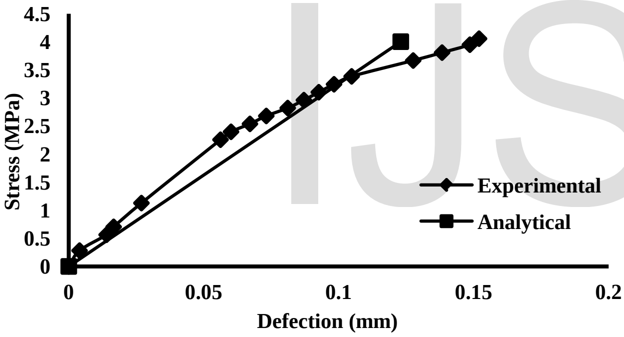

Fig. 8. Stress-Deflection Curve at Mid-Span.

Load versus Displacement curve obtained from the experiment is shown in the Fig.8. From the curve, it is observed that the bottom slab deflects elastically and therefore the stress deflection curve obtained is approximately linear. No crack formation was observed throughout the test and therefore no leakages were detected. An analytical study was also made on the bottom slab, considering the base slab to be subjected under hydraulic loading condition and the deflection at the mid-span is calculated and is found to be 0.123mm. The deflection profile is plotted for comparison with the experimental study. The analytical curve is found to be in good agreement with the experimental curve. Thus, the flowable cement composite is found to be an effective material for the construction of Leak-proof and cost-effective structures.

D. Analytical study

In this section, deflection at mid-span of the slab panel and bottom slab of prototype water tank is predicted analytically. The prediction is made until first crack loading and hence linear elastic analysis is used.

1) Analytical Calculation for the Bottom slab of water tank

An analytical study is carried on the base slab of the water tank. It can be carried out by assuming the edges of the base slab to be fixed.

Weight of water = 0.87 × 1.158 × 0.952 × 10= 9.59KN (1)

Pressure acting on the base slab $= \frac{9.59}{1.158 \times 0.952} = 8.7kN/m^2$ (2)

Pressure to be applied as udl $= \frac{8.7}{1.194} = 7.28N/mm$ (3)

Young's Modulus, E [7] $= 5000\sqrt{f_{ck}} = 27386MPa$ (4)

Moment of Inertia, I $= \frac{1000 \times 40 \times 40 \times 40}{12}$

$= 5.33 \times 10^6\ mm^4$ (5)

Deflection at Mid span, δ $= \frac{w \times l^4}{384EI}$

$= \frac{7.28 \times 986^4}{384 \times 27386 \times 5.33 \times 10^6} = 0.123mm$ (6)

2) Determination of Ultimate Capacity of Base Slab

An analytical study is made for determining the ultimate load acting on the base slab of the water tank. The base slab is subjected to uniformly distributed load assuming, all the edges fixed. Additionally, it is also designed for simply supported edge condition. The design of slabs results in the inelastic behaviour when subjected to factored load. At collapse loads, the slab begins to crack as they are mostly under-reinforced, with the yielding of reinforcement at points of the high bending moment. With the propagation of cracks, the yield lines are developed gradually. The crack pattern varies based on the support condition adopted. A mechanism is formed when the slab collapses due to uncontrolled rotation of members. Yield lines are the lines of maximum yielding moments of the reinforcement of slab. So it is necessary to design the slab for its ultimate load. The ultimate load acting on the base slab is calculated based on Yield line theory.

Size of Base slab = 1.23m x 1.02m x 0.04m (7)

No of bars provided $= \frac{1.23}{0.025}$ =50bars (8)

Where 25mm being the spacing between the steel wires.

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A_{st} provided $= 50\times\frac{\pi}{4}\times 2^2 = 157\text{mm}^2$ (9)

$$M_u = 0.87 f_y A_{st} d\left[1-\left(\frac{A_{st}\times f_y}{b\times d\times f_{ck}}\right)\right] \text{[7]} \quad (10)$$

$$= 0.87\times 415\times 157\times 25\left[1-\left(\frac{157\times 415}{1020\times 25\times 30}\right)\right]$$

$= 1.28$ kN.m/m (11)

Similarly $m_{ux} = m_{uy} = m'_{ux} = m'_{uy} = 1.28$ kN.m/m (12)

Where m_{ux} and m'_{ux} are positive and negative ultimate moment of resistance in x direction; m_{uy} and m'_{uy} are positive and negative ultimate moment of resistance in y direction.

The ultimate load per unit area is given by,

$$w_u = \frac{12}{l_y^2\left[3\left(\frac{l_x}{l_y}\right)-1\right]}\left[2\left(m_{ux}+\frac{l_x}{l_y}m_{uy}\right)+m_1\right] \text{[8]} \quad (13)$$

Where m_1 depends on the support condition

For all the four edges to be fixed, $m_1 = 2\left(m'_{ux}+\frac{l_x}{l_y}m'_{uy}\right)$ [8]

$$= 2\left(1.28+\frac{1.23}{1.02}1.28\right)$$

$= 5.632$ kN.m/m (14)

$$w_u = \frac{12}{l_y^2\left[3\left(\frac{l_x}{l_y}\right)-1\right]}\left[2\left(m_{ux}+\frac{l_x}{l_y}m_{uy}\right)+m_1\right] \text{[8]} \quad (15)$$

$$= \frac{12}{1.02^2\left[3\left(\frac{1.23}{1.02}\right)-1\right]}\left[2\left(1.28+\frac{1.23}{1.02}1.28\right)+5.632\right]$$

$= 49.96$ kN/m^2 (16)

The ultimate load, $w_u = 49.96 \times 1.23 \times 1.02 = 62.62$ kN (17)

For all the four edges to be simply supported, $m_1 = 0$ (18)

$$w_u = \frac{12}{l_y^2\left[3\left(\frac{l_x}{l_y}\right)-1\right]}\left[2\left(m_{ux}+\frac{l_x}{l_y}m_{uy}\right)+m_1\right] \text{[8]} \quad (19)$$

$$= \frac{12}{1.02^2\left[3\left(\frac{1.23}{1.02}\right)-1\right]}\left[2\left(1.28+\frac{1.23}{1.02}1.28\right)+0\right]$$

$= 24.98$ kN/m^2 (20)

The ultimate load, w_u $= 24.98 \times 1.23 \times 1.02$
$= 31.33$ kN (21)

The ultimate capacity of the base slab subjected to hydraulic loading estimated based on the theoretical study is found to be in between 3 and 6.3 tones. The result indicates that the base slab can withstand load up to 6.3tonnes, whereas in the experimental analysis the applied load was 1ton. This infers that the water tank is safe within the elastic limit and it shows that it can be designed for increased capacity, by increasing the height or by increasing the longitudinal and transverse dimensions of the water tank.

V. SUMMARY AND CONCLUSION

This paper presented the experimental and analytical investigation carried out to study the flexural behavior of ferrocement water tank for the bottom slab. The results of this investigation led to the following conclusions:

1. The flexural behaviour of conventional slab panel shows that the first crack occurred at 60% of its ultimate load, which proves to be very ductile expending large deformation prior to failure.
2. The ferrocement water tank tested under hydraulic loading condition shows no occurrence of crack and no leakage of water was detected throughout the test.
3. An analytical study was made for the bottom slab of the ferrocement water tank under same hydraulic loading condition is found to be in a good correlation with the experimental study.
4. Comparing the experimental with the analytical study, the maximum defection at mid-span of the bottom slab is found to be 0.123mm, which is negligible.
5. Thus, flowable cement composite proves to be an effective material for the construction of leak-proof and cost effective structures.

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