Experimental and Analytical Investigation of Ferro Cement Silo for Various H/D Ratios and Wall Thickness

Chetan S. Deshpande, N. V. Deshpande

***Abstract*—Ferrocement being a versatile construction material, its applicability in case of silos which can be used for food grain storage creates an area of research. Its cracking or tensile strength and corresponding strains are the key parameters of ferrocement silo designing. In this paper an attempt has been made to investigate tensile strength and strains of ferrocement flats of particular thickness, reinforced with single layer of square welded wire mesh and to calculate, predict and compare the hoop tensions for different silo wall thicknesses and H/D ratios using the equations developed graphically which are based on analytically developed parameters derived from the test results.**

***Index Terms*—Ferrocement, Hoop tension, Silo, Tensile strength**

I. INTRODUCTION

Ferrocement is a very well known construction material for its superior tensile strength along with its light weight characteristic. Due to the closely and uniformly placed steel wire meshes, ferrocement shows flexibility and a better cracking behavior as compared to conventional reinforced cement concrete material. Therefore, it has applications in the areas where either provision of light weight and thin components, is the requirement or waterproof crack less structure is the necessity of a project. Water tanks, Silos, Boats etc. are the applications of ferrocement where crack less waterproof structure is the governing factor. [1]

Silos used for food grain storage are one of the applications of ferrocement. Due to its better crack resistant property, food grains can be stored in dry state without losing its calorific value. Thus, ferrocement, which is usually recognized for its small thickness, can be studied for its feasibility as a construction material for silos to be used for grain storage. Therefore, analytical study of dimensions of a ferrocement silo of specified thickness without cracking has become the matter of investigation.

II. RELATED WORKS

Ferrocement being not a very new construction material, its various properties have been studied and investigated by the researchers. In case of design of silos, tensile strength and cracking behavior of ferrocement are the governing properties.

Researchers have carried out Brazilian test on ferrocement discs for their split tensile strength and flexural analysis to understand load – deflection behavior of ferrocement slabs. They have suggested an equation to determine tensile strength of ferrocement which is dependent on compressive strength of ferrocement and wire mesh ratio. [2] A few researchers have investigated axial tension carrying capacity of ferrocement, when sand is replaced by blast furnace slag to certain extent with the objective of making ferrocement as an eco – friendly material. Authors have cast dumb bell shaped test specimens with different percentage of Blast Furnace slag replacing the sand in ferrocement matrix. They have observed that at 20 % replacement of sand with Blast Furnace Slag, ultimate tensile strength of ferrocement has increased with further reduction in the tensile strength with the increase in the percentage of blast furnace slag. [3] A few investigators have also emphasized that axial tension carrying capacity is shouldered not only by area of wire mesh reinforcement provided along the direction of loading but also the specific surface of wire mesh causing the bonding between them and the cement mortar. [4] Ferrocement has been used to construct silo and small bins to hold 4 – 10 MT of food grains in Thailand. It is constructed in the form of frustum of a cone placed on a saucer. Due to its typical conical shape, walls of the silo do not carry considerable horizontal pressure and hoop tension. [5] Using minimum reinforcement in ferrocement, cylindrical silo walls have been analyzed for maximum horizontal pressure and maximum crack width criteria for different Height to Diameter ratios in filling and emptying condition using Janssen's theory. The authors have observed that a crack width criterion in silo emptying condition governs the dimensions of ferrocement silo. [6] For silo application, very limited investigation has been carried. Therefore, in this paper, an attempt has been made to investigate limiting dimensions of a cylindrical silo for different Silo wall Height to Diameter ratios based on the design parameters obtained through experimentation.

III. METHODOLOGY

Silo walls are subject to hoop stress due to the horizontal pressure exerted by the stored material and vertical compressive stress due to self weight of the walls and friction between the stored material and the wall. Therefore, to determine axial tensile strength of Ferrocement composite, three ferrocement flats of 450 mm x 90 mm x 20 mm with single layer of wire mesh placed at the centre of the thickness have been cast with Cement Mortar (1:2).

Manuscript Received on October 2014.

Chetan S. Deshpande, Department of Applied of Mechanics, St. Vincent Pallotti College of Engineering & Technology, Gavsi Manapur, Nagpur, Maharashtra, India.

Dr. N. V. Deshpande, Principal, Guru Nanak Institute of Engineering & Technology, Nagpur, India.

Using the same cement mortar, three companion cubes (50 Sq.mm.) have been cast for determining its compressive strength after 28 days of curing. The ferrocement flats also have been tested after 28 days of curing for axial tensile force carrying capacity until first crack is appeared on their surface. Using the values of axial tensile strength, composite modulus of elasticity and compressive strength of ferrocement, limiting dimensions of cylindrical silo for different H/D ratios varying from 2.00 to 3.00 for 20 mm thickness of silo wall have been calculated. Further, maintaining same percentage of wire mesh reinforcement, limiting dimensions of ferrocement cylindrical silo for the above mentioned range of H/D rations with 25 mm, 30 mm, 35 mm and 40 mm wall thickness have been predicted and compared with analytically obtained dimensions. Also, the equations have been proposed to obtain hoop tension for any H/D ratio and ferrocement silo wall thickness, for constant percentage of reinforcement in silo wall.

IV. EXPERIMENTATION

A. Test Specimen

According to the possible arrangement for testing and with the objective of depicting the applicability of 20 mm thickness of ferrocement silo wall, the sizes of the ferrocement test specimens have been decided. Therefore, using cement mortar (1:2) and water cement ratio 0.5, three specimens have been cast of 450 mm x 90 x 20 mm size. The Galvanised Iron wire mesh with 1.27 mm wire diameter and 17 mm spacing has been used. Its yield stress and ultimate tensile strength are 303.6 MPa and 543 MPa respectively.

Cement mortar (1:2) cubes have been cast and tested after 28 days of curing for compressive strength.

a) Mould for casting flats with glass at the bottom   b) Single layer of wire mesh   c) Test specimen

Fig. 1 Ferrocement Flat with 1 Layer of Wire Mesh

Fig. 2 Cube Specimen for Compressive Strength

B. Test Set - up

Ferrocement flat specimens have been tested for the determination of first crack load. Test set – up included Loading Frame of 50 kN capacity, Proving ring 1t, 8 channel digital strain indicator and 4 - strain gauges for each specimen (gauge length: 5 mm and resistance: 120 Ω).

Fig. 3 Tensile Test Set – up with Test Specimens

Three ferrocement flat specimens (1-1, 1-2 and 1-3) have been tested with rate of loading as 0.12 mm/min and first crack load and stress – strain relation has been plotted for them.

C. Test results

Three cement mortar (1:2) cubes tested for compressive strength have given following values after 28 days of curing.

Table: I Compressive Strength of Cement Mortar After 28 days

S.N.	Cube No.	f_c (MPa)	Average f_c (MPa)
1	C1	19.41	19.84
2	C2	19.80	
3	C3	20.31	

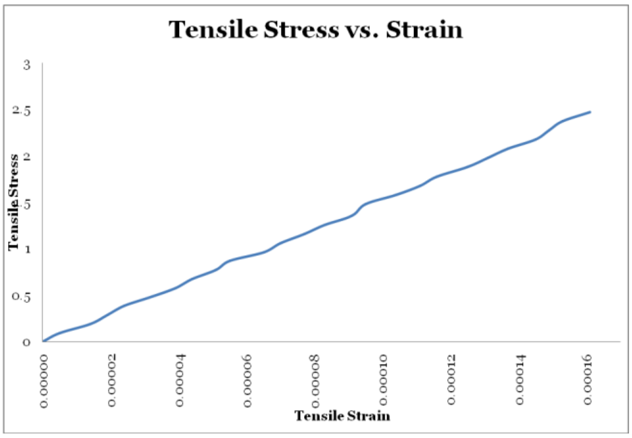

Fig. 4 Stress - Strain Graph for Test Specimen 1-3

As per ACI building code 318 – 83, Young's modulus of normal weight concrete is

$$E_c = 4700x\,(f_c')^{0.5} \quad (1)$$

As the composite modulus of elasticity of ferrocement obtained for specimen 1-3 (i.e. 15226 MPa) is the nearest value to that expected for (i.e. 18725 MPa from (1)), it has been considered for further calculation of strains. The cracking stress for the ferrocement flat 1- 3 has been observed to be 2.47 MPa and corresponding cracking strain as 162 x 10^{-6}.

V. DISCUSSION

Tensile strength of Ferrocement composite so obtained has been considered as permissible hoop stress in 20 mm thick ferrocement silo wall per metre height, reinforced with single layer of the wire mesh. Now, for further analysis of ferrocement silo wall following specifications have been used

- MESH AREA = 70.37 MM^2/M HEIGHT OF WALL
- Thickness of Silo wall = t = 20 mm
- Unit weight of stored sand = w = 18.05 kN/m^3
- Angle of Internal Friction of sand = $\Phi = 30^0$
- Pressure ratio, Filling condition = $\lambda_f = 0.50$
  Emptying condition = $\lambda_e = 1.00$
- Coefficient of for wall friction,
  Filling condition = μ_f = 0.414 (tan(0.75 Φ))
  Emptying condition = μ_e = 0.325 (tan(0.60 Φ))

After obtaining permissible hoop tension for 20 mm thick ferrocement silo wall from the permissible tensile stress obtained from the test (2), maximum permissible horizontal pressure has been obtained in terms of internal diameter of silo (3). As horizontal pressure due to stored material gives maximum value in case of emptying condition of silo, using Janssen's theory (4) horizontal pressure has been obtained in terms of H and D.

$$T = f_t \times (1000 \times t) \quad (2)$$
$$P_h = 2T/D \quad (3)$$
$$P_h = (wr/\mu_e)[1 - e^{-(\mu_e \lambda_e H/r)}] \quad (4)$$

In this way, for various H/D ratios varying from 2 to 3 height of the ferrocement silo wall (H) and internal diameter of the ferrocement silo have been obtained as shown in table no. 1. These dimensions satisfy not only the horizontal pressure criterion but also take into account initiation of first crack in ferrocement composite. Emptying condition in combination with crack width criterion has governed the design of a ferrocement silo. [6] The crack width formula used in the analytical study by the authors is basically referred from I.S. 4995(II) – 1974, which is used for Reinforced Cement Concrete Silos. Whereas in this investigation, maximum permissible tensile stress in the ferrocement flat has been calculated using load at first crack observed in experimentation.

Table: II Maximum Limiting Dimensions of Cylindrical Ferrocement silo for different H/D

S.N.	H/D	D (m)	H (m)	Capacity (cu.m.)
1	2.00	2.77	5.54	33.38
2	2.20	2.74	6.04	35.61
3	2.40	2.73	6.55	38.34
4	2.60	2.71	7.06	40.72
5	2.80	2.70	7.56	43.28
6	3.00	2.69	8.07	45.86

Further, for studying the variation of horizontal pressure **(P_h)**, hoop tension **(T)**, vertical pressure on a horizontal plane **(P_v)** and pressure transferred to the ferrocement silo wall due to friction **(P_w)**, H/D = 2.00 has been considered. The corresponding height of the ferrocement silo wall has been divided into six segments as shown in fig. 5 and the above mentioned parameters have been calculated (table III).

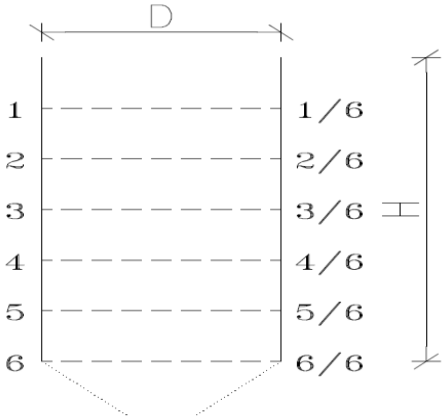

Fig. 5 Segments in Height of a Ferrocement Silo

Table: III Pressures, Hoop tension, Hoop stress and strain for a ferrocement silo with H/D = 2.00 for emptying condition

Level	P_h	P_v	P_w	T	f_t	ε_t (1×10^{-6})
6-Jan	13.6	13.6	2.2	18.94	0.95	62.18
6-Feb	22.41	22.41	7.73	31.21	1.56	102.5
6-Mar	28.13	28.13	15.41	39.17	1.96	128.63
6-Apr	31.84	31.84	24.5	44.33	2.22	145.58
6-May	34.24	34.24	34.49	47.68	2.38	156.57
6-Jun	35.51	35.51	45.27	49.4	2.47	162

When wire mesh reinforcement percentage is calculated in terms of area of ferrocement composite in tension, it comes out to be 0.36%. If the percentage of steel is maintained, tensile strength of the ferrocement composite will remain constant. Therefore, dimensions of ferrocement silo for various H/D ratio and thicknesses can be analytically worked out as mentioned in (table IV).

Now, for various H/D ratios varying from 2.00 to 3.00 and 20 mm thickness of ferrocement silo wall, hoop tensions expressed in per unit thickness of silo wall have been calculated at various levels as shown in fig.6. Using these values a graph has been plotted and equations have been obtained to predict and compare hoop tensions in ferrocement silo walls of different thicknesses varying from 25 mm to 40 mm.

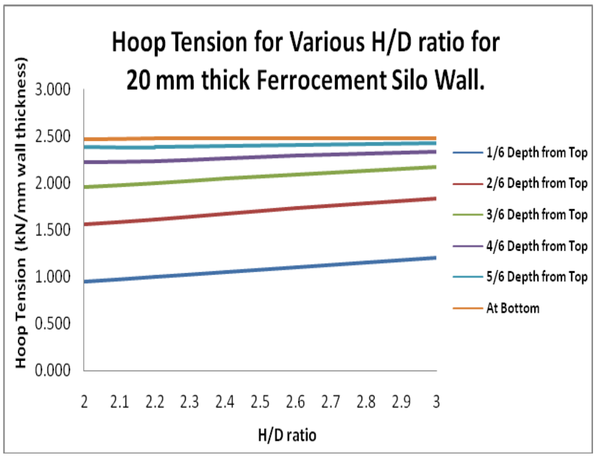

Fig. 6 Hoop Tension for Various H/D ratios for 20 mm thick Ferrocement Silo Wall

Table: 4 Dimensions of Ferro Cement silos for various H/D ratios and different thicknesses

H/D	t = 25 mm		t = 30 mm		t = 35 mm		t = 40 mm	
	D (m)	H (m)	D (m)	H (m)	D (m)	H (m)	D (m)	H (m)
2	3.1	6.2	3.4	6.8	3.67	7.34	3.92	7.84
2.2	3.07	6.75	3.36	7.41	3.63	8	3.88	8.54
2.4	3.05	7.32	3.34	8.03	3.61	8.67	3.86	9.26
2.6	3.03	7.87	3.32	8.64	3.59	9.34	3.83	9.98
2.8	3.02	8.45	3.31	9.27	3.57	10	3.82	10.7
3	3.01	9.03	3.3	9.9	3.56	10.7	3.81	11.44

Equations have been obtained which calculate the hoop tensions at various depths of a ferrocement silo for any given H/D ratio and thickness of a ferrocement silo (refer fig. 5 & 6).

T_1 = t x [(0.262H/D) + 0.42] (5)

T_2 = t x [(0.279H/D) + 1.00] (6)

T_3 = t x [(0.211H/D) + 1.535] (7)

T_4 = t x [(0.125H/D) + 1.963] (8)

T_5= t x [(0.047H/D) + 2.282] (9)

T_6 = t x [(0.002H/D) + 2.465] (10)

The hoop tensions calculated analytically and graphically for various thicknesses and H/D = 2 are as tabulated in table no. V.

Table: V Hoop Tensions at different Depths of Ferrocement Silo Wall of H/D = 2.00 of Varying Wall Thickness

S. N.	Level	Hoop tension (kN) for 25 mm			Hoop tension (kN) for 30 mm			Hoop tension (kN) for 35 mm			Hoop tension (kN) for 40 mm		
		Ana	Gra	% Dev	Ana	Gra	% Dev	Ana	Gra	% Dev	Ana	Gra	% Dev
1	1/6	23.46	23.60	**-0.59**	28.22	29.89	**-5.90**	32.88	33.04	**-0.48**	37.51	37.76	**-0.67**
2	2/6	38.67	38.95	**-0.72**	46.52	48.41	**- 4.00**	54.20	54.53	**-0.61**	61.84	62.32	**-0.77**
3	3/6	48.53	48.92	**-0.81**	58.8	59.98	**-2.73**	68.02	68.49	**-0.70**	77.61	78.28	**-0.86**
4	4/6	54.93	55.33	**-0.72**	66.07	67.14	**-1.62**	76.98	77.45	**-0.62**	87.83	88.52	**-0.78**
5	5/6	59.07	59.63	**-0.96**	71.06	71.56	**-0.70**	82.79	83.16	**-0.45**	94.46	95.04	**-0.61**
6	6/6	61.76	61.78	**-0.03**	74.29	74.13	**-0.21**	86.56	86.45	**0.13**	98.75	98.8	**-0.05**

VI. RESULT

While designing silo walls, it is assumed that complete hoop tension is taken care by circumferential reinforcement in the wall. But at the same time, silo walls are required to be checked for permissible crack width. Therefore, tensile stress obtained at the intiation of first crack in the ferrocement flats has been considered for the calculation of permissible hoop tension in a ferrocement silo. Also, composite modulus of elasticity of ferrocement composite obtained from the experiment has been compared with its expected value and the closest value has been considered for the calculation of hoop strains. The compressive strength of the cement mortar cubes (1:2 by weight) for water cement ratio = 0.50, has been found to be 19.84 MPa which is almost equivalent to M20 grade concrete.

The tensile strength of the ferrocement flats under axial loading has been observed to be 2.47 MPa which is generally assumed to be 10 % of the compressive strength in case of concrete. Tensile strain at first crack has been observed to be 162 x 10^{-6}. Here, area percentage of reiforcement is 0.36%. thus, increase in percentage of steel can definitely improve the tensile strength of ferrocement.

It is evident from table no. 5 that using equations 5 to 9, hoop tensions can be predicted almost precisely with less than 1% deviation for any given thickness and H/D ratio. Thus, using equation 9, maximum permissible hoop tension can be worked out for any H/D ratio for a given thickness or vice - versa, which in turn can be used to determine the dimensions of a ferrocement silo which will not only satify the tensile strength criteria but also take care of formation of cracks.

FUTURE SCOPE

In this investigation, ferrocement reinforced with only single layer of square welded mesh layer has been studied. Effect of increase in number of mesh layers is to be investigated in relation to its tensile strength and composite modulus of elasticity. Also the study of effect of using different combinations of wire meshes on the aforementioned parameters need to be addressed. Although, ferrocement shows compressive strength quite comparable with conventional reinforced cement concrete, ferrocement silo walls are required to be analysed for compressive stresses.

ACKNOWLEDGMENT

We would like to thank Er. Amol Shingare and Sudhanwa Shingare, Geotech Services, Nagpur, M.S., India for providing lab facilities to carry out the experimentation.

REFERENCES

1. *ACI 549R – 97, State – of – the – Art Report on Ferrocement*
2. Azad A. Mohammed and Dunyazad K. Assi, *Tensile Stress – Strain Relationship For Ferrocement Structures, Al – Rafidain Engineering, Volume 20, No. 2, March 2012,* pp 27 – 40.
3. Gangadharappa B. M., Prakash K. E., Suresh G. S. and Shesha Prakash M. N. "Studies of Light Weight Ferrocement Subjected to Axial Tension", *International Journal of Emerging Technologies in Computational and Applied Sciences, 2013,* pp 239 – 245.
4. Sayyed Shoheb Navid, Swayambhu S. Bhalsing and Pankaj B. Autad "Tensile Strength of Ferrocement with Respect to Specific Surface", *International Journal of Engineering and Advanced Technology, December 2013,Volume - 3, Issue – 2,* pp 473 – 475.
5. "*A report on Ferrocement: Applications in Developing Countries", National Academy of Sciences.*
6. Chetan S. Deshpande, Dr. N. V. Deshpande, "Study of Ferrocement Silo used for Bulk Material Storage", International Journal of Application or Innovation in Engineering & Management", *Special Issue for National Conference on Recent Advances in Technology and Management for Integrated Growth 2013.*
7. *I.S. 4995 (I) – 1974, "Criteria for Design of Reinforced Concrete Bins for the Storage of Granular & Powdery Materials, General Requirements and Assessment of Bin Loads".*
8. *I.S. 4995 (II) – 1974, "Criteria for Design of Reinforced Concrete Bins for the Storage of Granular & Powdery Materials, Design Criteria".*

AUTHORS PROFILE

Chetan S. Deshpande, has passed Diploma in Civil Engineering from Government Polytechnic, Nagpur (An autonomous institute of Maharashtra) in 2000, B.E. in Structural Engineering from V.N.I.T.(formerly known as V.R.C.E.), Nagpur in 2003 and M. Tech. in Geotechnical Engineering from Shri Ramdeobaba Kamla Nehru Engineering College, Nagpur in 2007 and is presently working as an Assistant Professor in the Department of Applied Mechanics, St. Vincent Pallotti College of Engineering & Technology, Nagpur. First author is a life member of Association of Consulting Civil Engineers (ACCE), India and Ferrocement Society of India.

N. V. Deshpande, did his Ph.D. from V.N.I.T.(formerly known as V.R.C.E.), Nagpur and is presently working as Principal, Guru Nanak Institute of Engineering & Technology, Nagpur.