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CONTENTS

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EDITORIAL

The paper included in the present issue, entitled "Ferrocement in India—At the Threshold of Commercial Production" highlights in a remarkable way both the versatility of ferrocement and the amazing development of its utilization as construction material. For a long time confined to research work ferrocement has now reached in India the commercial production level for many different types of applications such as the building of boats, of water and grain storage structures, of biogas holders of housing elements (folded plates, domes, kiosks, etc.), of pipes, fence posts, sanitary equipment, waterproofed ponds, etc. The Indian example clearly proves that ferrocement utilization has now undoubtedly gone further then the purely research and testing stages and really entered commercial production for many diversified application both terrestrial and marine.

Such achievements amply justify the objectives of the Journal of Ferrocement to cover all types of ferrocement applications and to encourage all types of ferrocement users—not an easy task considering the great variety of utilizations and of users! In keeping with that policy the Journal which we are preparing for this July, is a special issue on "Marine Applications", and will publish in January 1981 another special issue devoted to "Housing Application" of ferrocement.

As far as users are concerned the Journal still requires increasing contributions from "amateur" ferrocement builders. Those "amateurs" who might have been somewhat scared by the high technical level of some of the Journal's papers must not be afraid to send in news items and short notes on their achievements or observations. The Journal of Ferrocement **is their** journal too and must ideally become the vehicle for communicating **all types of information on ferrocement** either sophisticated or very simple and practical. Much of the work done by "amateurs", much of the experience they gain through both successes and failures would be most useful to other people if properly communicated through the Journal. The Editors, therefore, earnestly request them to send in observation, stories of their achievements and difficulties, with whenever possible photographs or diagrams. The contributions of "amateurs" must become a major component of the Journal of Ferrocement.

The Editors

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Evaluation of Ferrocement Folded-Plate Roofing Panels

Rosemary Fernandes*, V.S. Gopalaratnam+ and P. Nimityongskul†

The paper presents results of a study conducted to evaluate the merits of ferrocement as a roofing material. Analysis, design and casting procedure adopted have been highlighted. Effect of the type of wiremesh and amount of transverse reinforcement have been studied. Test results of six panels are presented and compared with results from a similar study on asbestos panels. It has been concluded that ferrocement folded-plate panel is a stronger, more durable and cost-competitive alternative to asbestos roofing.

LIST OF SYMBOLS

$A_{1m1}, \ldots\ldots, A_{4m4}$ = constants of integration;
a = span length;
$B_{1m1}, \ldots\ldots, B_{4m4}$ = constants of integration;
b_1, b_2, b_3, b_4 = widths of the plates;
D = flexural rigidity of plate = $Eh^3/12(1-\mu^2)$;
D_{ij} = matrix of order $i \times j$;
E = modulus of elasticity;
h = thickness of the plates;
I = moment of inertia;
K, L = factors which non–dimensionalize the constants of integration;
M_x, M_y = longitudinal and transverse bending moments per unit length respectively;
$M_{xy} = M_{yx}$ = torsional moment per unit length;
$m, n,$ = integers defining the harmonic of the Fourier series in the x and y directions, respectively;
$N_x N_y$ = longitudinal and transverse normal forces per unit length, respetively;
$N_{xy} = N_{yx}$ = membrane shearing force per unit length;
P_i = load matrix;
p = intensity of uniform live load per unit area of horizontal projection;
q = intensity of dead load per unit area of the middle surface of the plate;
Q_x, Q_y = longitudinal and transverse shear forces per unit length, respectively;
R_x, R_y = longitudinal and transverse edge reactions per unit length, respectively;
T_j = column matrix denoting the constants of integration;

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u, v, w = displacement components in the x, y and z directions, respectively;
W_{mn} = Fourier coefficients;
X, Y, Z = load components in the x, y and z directions, respectively;
x, y, z = coordinate axes in the longitudinal, transverse, and normal directions, respectively;
Y_{mn}, Z_{mn} = Fourier coefficients for load components X and Y, respectively
α = $m\pi_a$;
β = $n\pi_{b_i}$, $i = 1$ to 4;
$\varepsilon_x, \varepsilon_y$ = the longitudinal and transverse normal strains, respectively;
μ = Poisson's ratio;
ϕ = Airy stress function;
ϕ_{mn} = Fourier coefficients;
$\theta_1, \theta_2, \theta_3, \theta_4$ = angle between the horizontal plane and the plane of the plate containing the positive y axis measured clockwise;
$\theta_1', \theta_2', \theta_3', \theta_4'$ = absolute values of the acute angle between the horizontal plane and the plane of the plate;
Δ = vertical displacement component;

INTRODUCTION

Most developing countries where nearly 80% of the population live in rural areas, face the problem of providing housing and other essential services of adequate standard within available resources. Survey and analysis conducted in developing countries show that in the rural areas, maximum emphasis should be placed on the roof as the basic shelter form. However, a permanent roof is beyond the reach of most people and consequently, they resort to materials which require maintenance and frequent replacement. Though asbestos sheet roofs, which have been widely used in some developing countries, have advantages over thatched, tiled or galvanized sheet roofs, they have many disadvantages, namely the health hazards encountered in the fabrication of asbestos cement, their lack of ductility and inadequate heat insulation. Ferrocement has in the recent past found wide application as a roofing material in numerous developing countries mainly because it lends itself well to meet most of the essential structural and functional requirements at competitive costs [1].

Some of the earlier investigations [2-7] identified ferrocement as a material suitable for specific housing applications. More recently Naaman [8] presented a set of guidelines for the analysis, design and construction of ferrocement structures which is expected to serve as a generalized code of practice until such a document is available. Analytical investigations by Huq and Pama [9-10] explored the exact behaviour of ferrocement in tension and in flexure. The investigation also exacted design procedures for ferrocement elements subjected to tension and bending in all the stress ranges. By virtue of the above investigations, it is now possible to rationally design housing components of ferrocement.

ANALYSIS

Co-ordinate System and Sign Convention

Fig. 1 illustrates the idealized cross-sectional profile of the folded-plate panel that is considered in this study. A set of orthogonal co-ordinate axes x, y and z in the longitudinal,

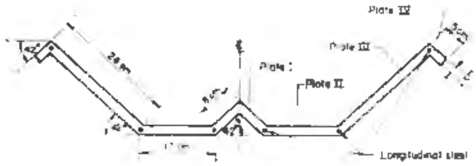


Fig. 1. Cross-sectional profile of the ferrocement panel showing location of longitudinal steel.

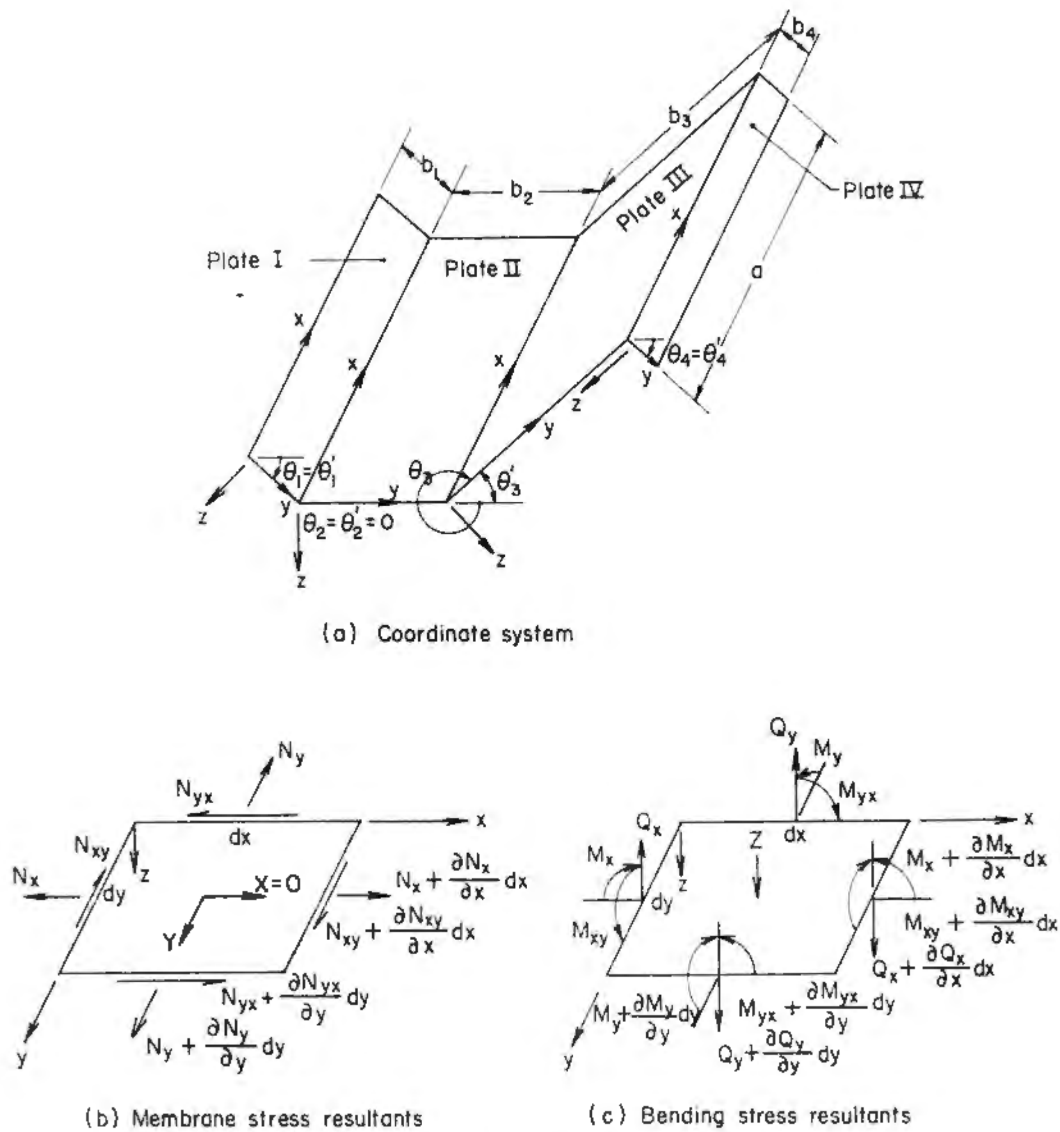


Fig. 2. Coordinate system and positive directions of stress resultants.

transverse and normal directions respectively, is defined with the origin at the corner of the individual plate as shown in Fig. 2. The displacements u, v and w measured in the x, y and z directions respectively, are positive in the positive directions of the co-ordinate axes. The slope of the individual plate is defined by the angle θ. It is measured clockwise from a horizontal plane passing through the origin to the positive y axis. The absolute value of the acute angle between the horizontal plane and the plane of the plate is denoted by θ'. Positive directions of all the stress resultants are denoted in Fig. 2.

Assumptions

Based on earlier investigations a few practically justified assumptions have been made which simplify the analysis to a great extent

(1) Ferrocement is treated as a homogeneous, isotropic material in the elastic range
(2) Basic assumptions of the theory of pure bending are valid.
(3) The influence of membrane forces on the bending of the plate is neglected.
(4) The slope in the longitudinal direction of the panel is small and can be neglected.

These assumptions result in two fourth-order differential equations which govern the bending of the plate under the action of the normal load component and the membrane action of the plate under in-plane load component.

Bending Action

The generalized differential equation governing the bending of plates subjected to lateral load Z is given by,

$$\nabla^4 w = Z/D \qquad \ldots\ldots\ldots\ldots (1)$$

With the application of appropriate boundary conditions at the two transverse edges $x = o$ and $x = a$, expansion into a double Fourier series and addition of the complimentary solution satisfying the homogeneous part of Equation 1, yields the total solution for w as,

$$w = \sum_{m=1}^{\infty} \sum_{n=0}^{\infty} W_{mn} \sin\alpha x \cos\beta y + K \sum_{m=1}^{\infty} [B_{1m} e^{\alpha y} + B_{2m} e^{-\alpha y}$$

$$+ B_{3m}\, \alpha y e^{\alpha y} + B_{4m}\, \alpha y e y^{-\alpha y}] \sin\alpha x \qquad \ldots\ldots\ldots\ldots (2)$$

where, all notations used are defined earlier. All the bending stress resultants can be computed from Equation 2.

Membrane Action

For the case where the longitudinal in-plane component is zero, the differential equation governing the plane stress problem of plates subjected to transverse load component Y is given by,

$$\Delta^4 \phi = \frac{\partial^2}{dx^2} (\int Y dy) - \mu \frac{\partial Y}{\partial y} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Again with the application of appropriate boundary conditions at the two transverse edges x = 0 and x = a, expansion into a double Fourier series and addition of the complimentary solution satisfying the homogeneous part of Equation 3, the completed solution can be obtained as,

$$\phi = \sum_{m=1}^{\infty}\sum_{n=0}^{\infty} \phi_{mn}\sin\alpha x \cos\beta y + L\sum_{m=1}^{\infty}\Big\{A_{1m}e^{\alpha y} + A_{2m}e^{-\alpha y} + A_{3m}\alpha y e^{\alpha y} + A_{4m}\alpha y e^{-\alpha y}\Big\}\sin\alpha x \quad \ldots\ldots\ldots\ldots (4)$$

where, all notations used are defined earlier. Membrane stress resultants can be computed by using Equation 4.

It can be readily verified that solutions of Equations 2 and 4, and stress resultants and displacements that are computed from them, satisfy the boundary conditions at the simply supported edges.

Solution for Applied Loads

The solution for a simply-supported folded-plate panel subjected to uniformly distributed live and dead can be obtained by substituting the appropriate displacements and stress resultants in the boundary conditions listed below (Equations 5-7).

The roof panel, shown in Fig. 1, is symmetrical with respect to the vertical plane passing through the central longitudinal edge, hence, only one-half of the structure consisting of four plates need be considered.

The boundary conditions for the longitudinal edge on the plane of summetry, i.e. left edge of Plate 1, are.

$$\left.\begin{aligned} N_{xy} &= 0 \\ \frac{\partial w}{\partial y} &= 0 \\ v\cos\theta_1 - w\sin\theta_1 &= 0 \\ N_y\sin\theta_1 + R_y\cos\theta_1 &= 0 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (5)$$

For the free edge, i.e. right edge of Plate IV

$$\left.\begin{aligned} N_y &= 0 \\ N_{xy} &= 0 \\ M_y &= 0 \\ R_y &= 0 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (6)$$

For each of the other three continous longitudinal edges

$$\begin{aligned} [N_y\cos\theta - R_y\sin\theta]^i_{y=b} &= [N_y\cos\theta - R_y\sin\theta]^j_{y=0} \\ [M_y]^i_{y=b} &= [M_y]^j_{y=0} \\ [u]^i_{y=b} &= [u]^j_{y=0} \\ [v\cos\theta - w\sin\theta]^i_{y=b} &= [v\cos\theta - \sin\theta]^j_{y=0} \\ [v\sin\theta + w\cos\theta]^i_{y=b} &= [v\sin\theta + w\cos\theta]^j_{y=0} \\ \left[\frac{\partial w}{\partial y}\right]^i_{y=b} &= \left[\frac{\partial w}{\partial y}\right]^j_{y=0} \end{aligned} \quad \ldots\ldots\ldots\ldots (7)$$

where superscripts i and j denote two consecutive plates forming the edge (e.g. 1 and 2, 2 and 3, 3 and 4). These Equations (5, 6 and 7) result in 32 simultaneous equations which can be expressed in the matrix form

$$\left[D_{ij}\right]\left\{T_j\right\} = \left\{P_i\right\} \qquad \text{(8)}$$

in which $\left[D_{ij}\right]$ is the square matrix of order 32 x 32, representing the coefficients of integration; $\left\{T_j\right\}$ is the column matrix denoting the constants of integration to be determined, and $\left\{P_i\right\}$ is the column matrix which are functions of the applied loads.

For uniformly distributed load in the longitudinal and transverse directions, the Fourier coefficients Z_{mn} and Y_{mn} are given by

$$\left.\begin{aligned} Z_{mn} &= 0 && \text{for even } m, n > 1 \\ Z_{mo} &= \frac{4Z}{m\pi} && \text{for odd } m, n = 0 \end{aligned}\right\} \qquad \text{(9)}$$

$$\left.\begin{aligned} Y_{mn} &= 0 && \text{for even } m, n \\ Y_{mn} &= \frac{16Y}{mn\pi^2} && \text{for odd } m, n \end{aligned}\right\} \qquad \text{(10)}$$

For uniformly distributed dead load of the middle surface, the load components are defined by

$$\left.\begin{aligned} Y &= q \sin \theta \\ Z &= q \cos \theta \end{aligned}\right\} \qquad \text{(11)}$$

The corresponding load factors K and L are

$$\left.\begin{aligned} K &= a^4 q/D \\ L &= a^3 q \end{aligned}\right\} \qquad \text{(12)}$$

The components of a uniformly distributed live load p per unit area of horizontal projection are

$$\left.\begin{aligned} Y &= p \sin \theta \cos \theta \\ Z &= p \cos^2 \theta \end{aligned}\right\} \qquad \text{(13)}$$

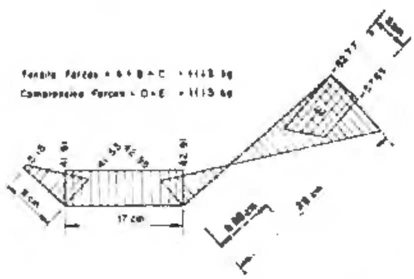
and the corresponding load factors K and L are

$$\left.\begin{aligned} K &= a^4 p/D \\ L &= a^3 p \end{aligned}\right\} \qquad \text{(14)}$$

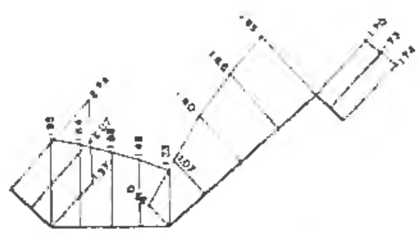
An iterative computer program is developed to carry out the above analysis and to determine the stress resultants and displacements at various points in the longitudinal and transverse directions for each of the four plates. The solutions for the panel subjected to dead load and live load are examined separately and superimposed later.

DESIGN

The ferrocement folded-plate panel is designed to resist an uniform live load of 75 kg/m^2. Panel thickness is assumed at 2 cm in view of practical construction constraints. This results in an uniformly distributed (along the middle surface of the panel) dead load of 48 kg/m^2.



a) Longitudinal normal force, N_x, Due to total load at midspan



b) Longitudinal bending moment, M_x, Due to total load at midspan

Fig. 3. Distribution of N_x and M_x at midspan.

The above analysis showed that the values of stress resultants N_x and M_x at midspan governed the design of the folded-plate panel (Fig. 3). The moment produced by the normal forces about an axis lying on Plate II, the bottom plate in Fig. 3a equals 17.09 kg-m. The total moment due to longitudinal bending moment M_x equals 0.92 kg-m. Total moment at the midspan section is 17.18 kg-m. The total tensile force at midspan section equals 113 kg. The maximum tensile force at midspan occurs in Plate II and equals 42.91 kg/cm^2. Assuming the total tensile stress is taken by wiremesh reinforcement alone, the total area of wiremesh required equals 0.33 cm^2 (an allowable tensile stress of 1300 kg/cm^2 is assumed for the wiremesh). Two layers of 20 gage, 12 mm ($\frac{1}{2}$ in) opening, galvanized square welded mesh or two layers of 20 gage, 18 mm (3/4 in) opening, galvanized hexagonal mesh adequately meet the steel requirements of 0.33 cm^2. Location of longitudinal steel (6 mm diameter mild steel bars) is shown in Fig. 1. Transverse steel (6 mm diameter mild steel bars) were provided at 50, 60 and 70 cm spacings along the lengths of both the sets of panels reinforced with square and hexagonal wiremesh. Details of the test specimens that were designed are presented in Table I.

CONSTRUCTION

In view of the fact that six test panels were to be constructed in a time bound study, 2 reusable plywood "female moulds" were fabricated with 10 mm thick plywood sheets and 20 mm thick plywood used as supporting diaphragms at intervals of 1.80-1.85 m (Fig. 4). As mentioned earlier, a panel thickness of 2 cm was adopted (6 mm ϕ longitudinal steel + 6 mm ϕ transverse steel + 2 mm for the two layers of mesh + 3 mm cover on either side of the reinforcement cage = 20 mm). However, while plastering attempt was made to reduce excessive

Table 1. Details of Test Panels.

Panel no.	Type of mesh	Total volume of wiremesh, cm^3	Transverse steel, $p_t\%$	Longitudinal steel, $p_l\%$	Design thickness mm	Panel weight kg
1	Square	1143.4	.31	.74	20	300.5
2	Square	1143.4	.26	.74	20	309.0
3	Square	1143.4	.23	.74	20	314.8
4	Hexagonal	1118.5	.31	.74	20	320.5
5	Hexagonal	1118.5	.26	.74	20	292.5
6	Hexagonal	1118.5	.23	.74	20	294.5

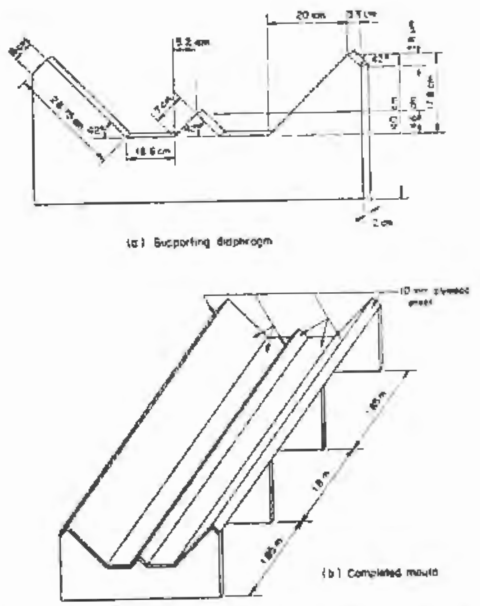
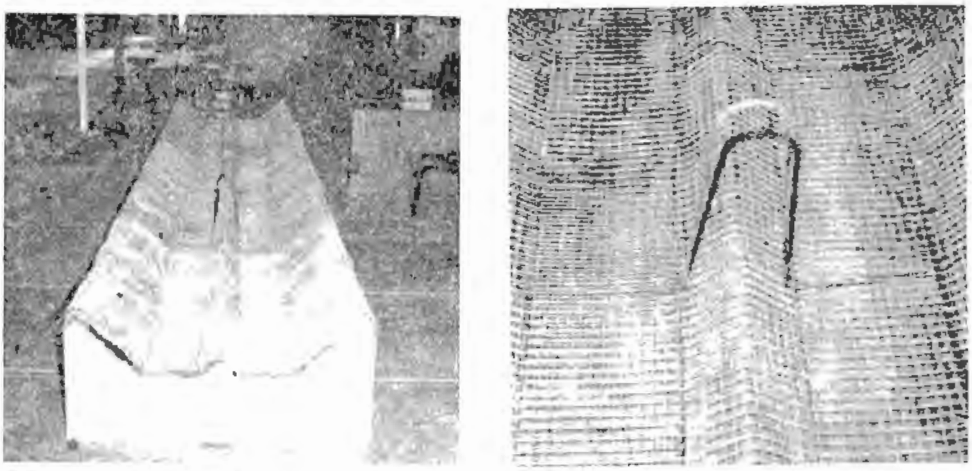


Fig. 4. Details of mould and supporting diaphragm.

build-up of mortar as well as reducing average thickness of panel by providing a 'just-adequate' cover to the meshes. Reinforcement consisted of a skeletal steel grid of 6 mm ϕ longitudinal bars (along six main fold lines) and 6 mm ϕ transverse bars (at 50, 60 and 70 cm spacings). Two layers of mesh, one on each side of this grid was provided for each panel. Two lifting hooks of 6 mm ϕ were provided as shown in Fig. 5 to facilitate handling of the panels. Mortar was dry-mixed prior to wet-mixing and was undertaken in two batches. Control specimens were prepared for each batch primarily to ascertain mortar properties and ensure the consistency



(a) (b)

Fig. 5. Folded plate panel before plastering.

Table 2. Properties of Materials Used

Item		Mean value
Cylinder crushing strength of mortar	kg/cm^2	356.00
Modulus of elasticity of mortar	kg/cm^2	2.94×10^5
Poisson's ratio of mortar		0.18
Yield strength of wire	kg/cm^2	2180.00
Modulus of elasticity of wire	kg/cm^2	8.22×10^5
Yield strength of skeletal steel	kg/cm^2	2757.00
Ultimate strength of skeletal steel	kg/cm^2	4800.00
Modulus of elasticity of skeletal steel	kg/cm^2	2.13×10^6

Table 3. Properties of Ferrocement Roof Panel

Item		Mean value
Modulus of elasticity of uncracked ferrocement	kg/cm^2	3.09×10^5
Modulus of elasticity of cracked ferrocement	kg/cm^2	0.40×10^4
Poisson's ratio		0.17
Span length 'a'	cm	450.00 (550)
Average thickness	cm	2.00
Angles of inclination θ'_1 θ'_3		42°
Dead load	kg/cm^2	0.0048
Width of plate I, b_1	cm	8.00
Width of plate II, b_2	cm	17.00
Width of plate III, b_3	cm	28.00
Width of plate IV, b_4	cm	5.00
Allowable tensile strength = 0.60 f_y	kg/cm^2	1300.00
Allowable compressive stress = 0.45 f_c	kg/cm^2	160.00
Total surface area	m^2	4.8128

of the mix. Tables 2 and 3 give detail of the properties of constituent materials and details of the ferrocement panel. Fig. 6 gives the gradation of sand that was used. The cement, sand and water ratio of 1.0:2.0:0.4 (by weight) was used for the mortar. Plastering (Fig. 7) of the 5.5 m panel was completed in one operation. Finishing of the top surface was done using a combination of wooden and metal floats, after which the folded-plate panel was covered with polyethylene sheet for 24 hours. The panels were later demoulded and moist cured for 14 days by covering them with wet burlaps.

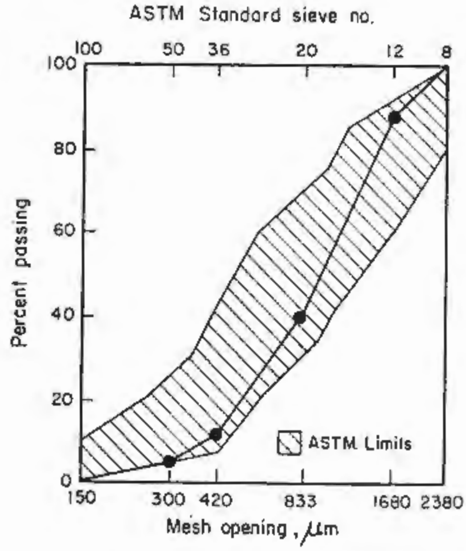


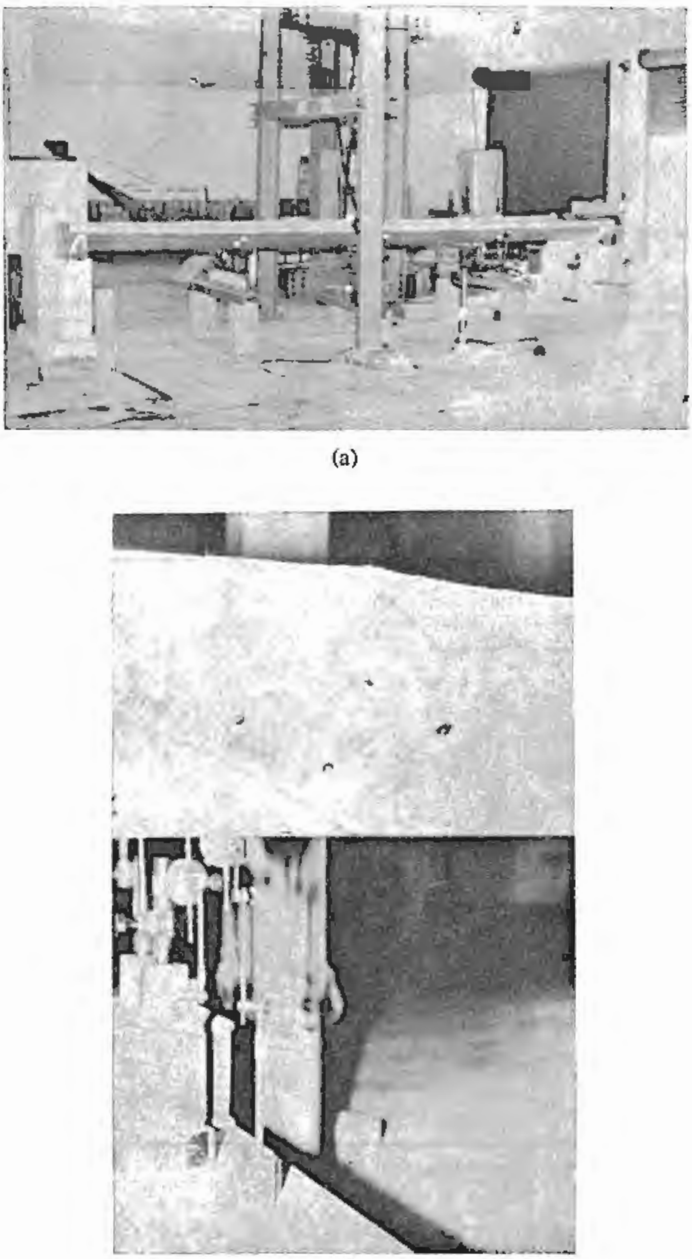
Fig. 6. Gradation of sand.

(a) (b)

Fig. 7. Plastering of folded-plate panel.

TEST PROGRAM

The panels were simply supported over a span of 4.5 m (except panel 6 which spanned 5.3 m) and subjected to uniform loading, which was simulated by loading with sand in increments of 200 kg until maximum permissible deflection was observed. Deflections were measured at 18 points along the length and width of the panels (Fig. 8). Strain was measured, both in the longitudinal and transverse directions at 4 locations using demec points. During loading crack development, crack location and cracking pattern were observed by visual inspection and recorded on the panel. Results of the loading tests conducted are illustrated in Figs. 9-13 and in Table 4. Cracking pattern for panels reinforced with square and hexagonal meshes are presented in Fig. 15.



(a)

(b)

Fig. 8. Experimental set up.

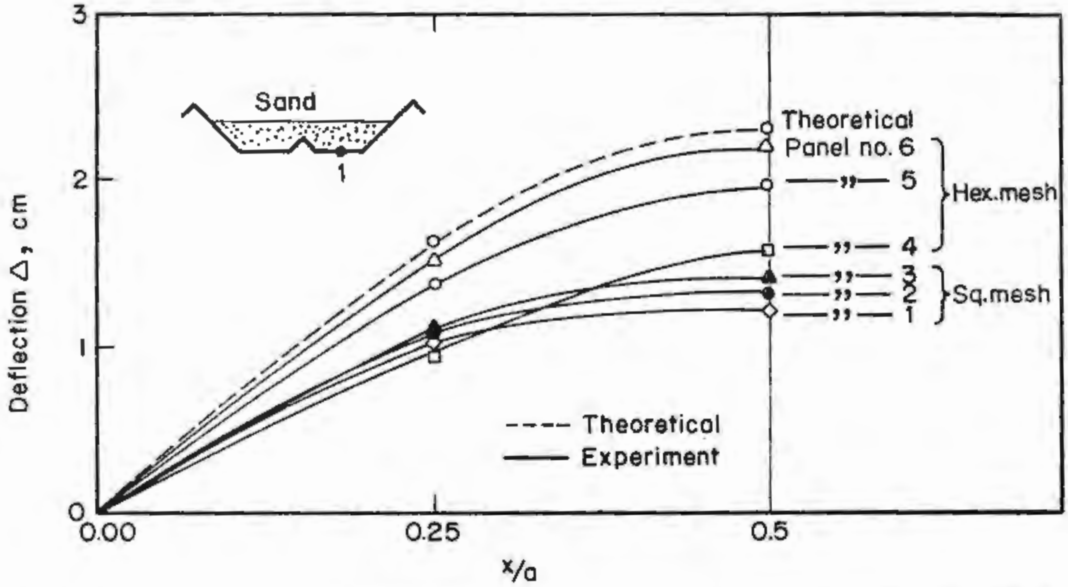


Fig. 9. Distribution of vertical deflections along the span of point 1 for all roof panels due to a live load of 75 kg/m^2.

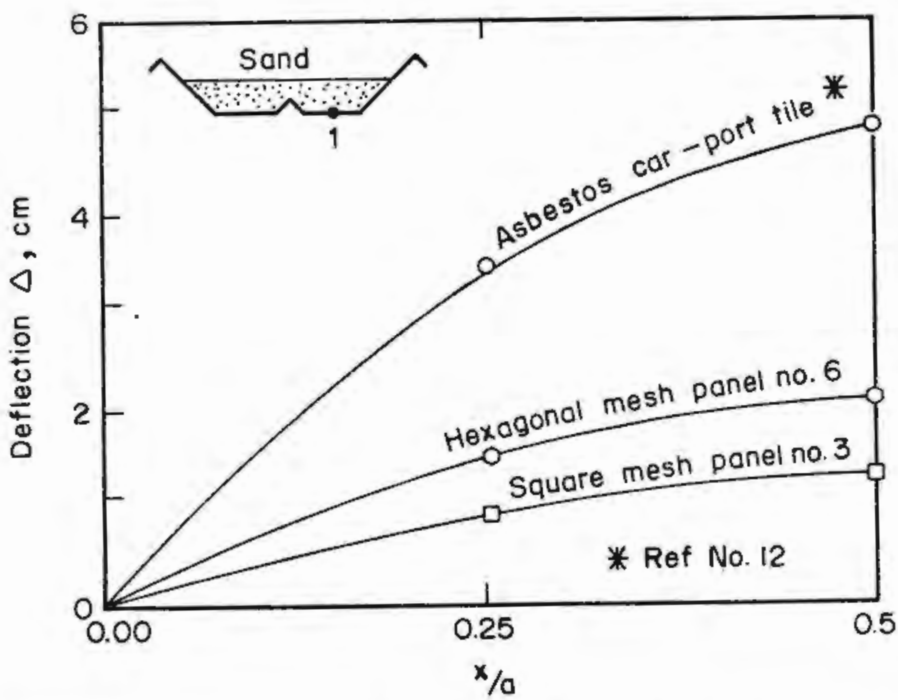


Fig. 10. Comparison of distribution of vertical deflections along the span, of point 1 between asbestos carport tile and ferrocement roof panels.

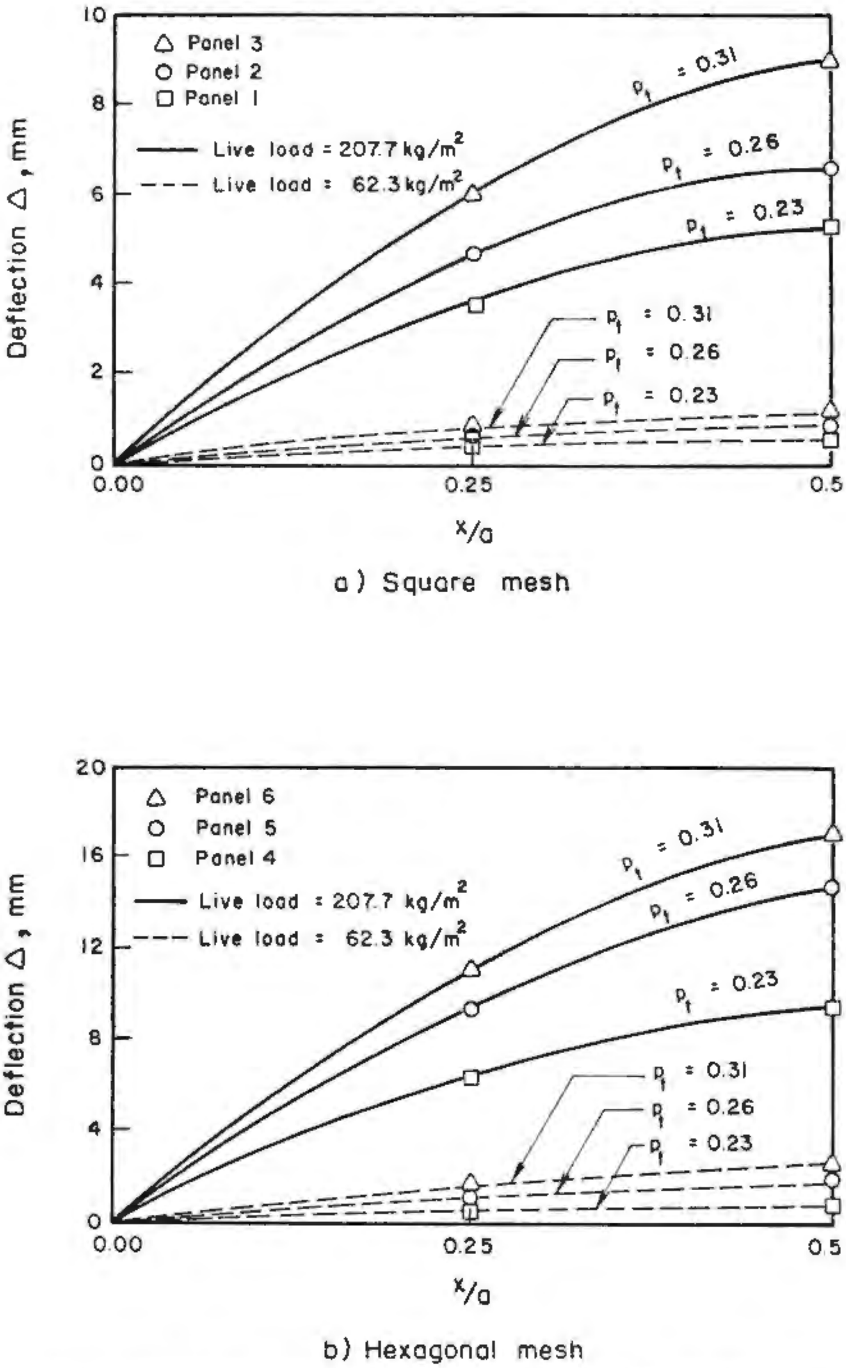
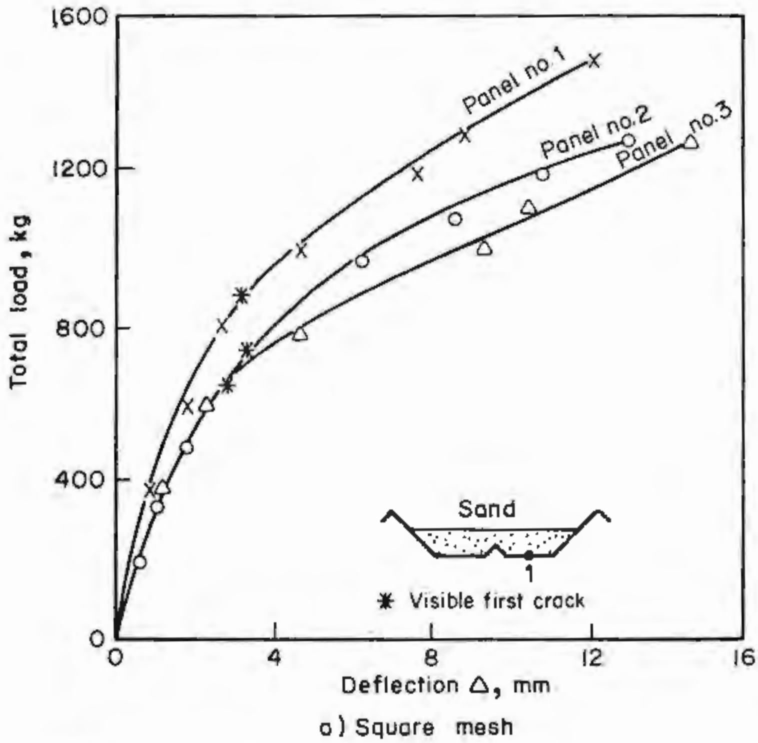


Fig. 11. Effect of transverse reinforcement on deflections at different load levels.



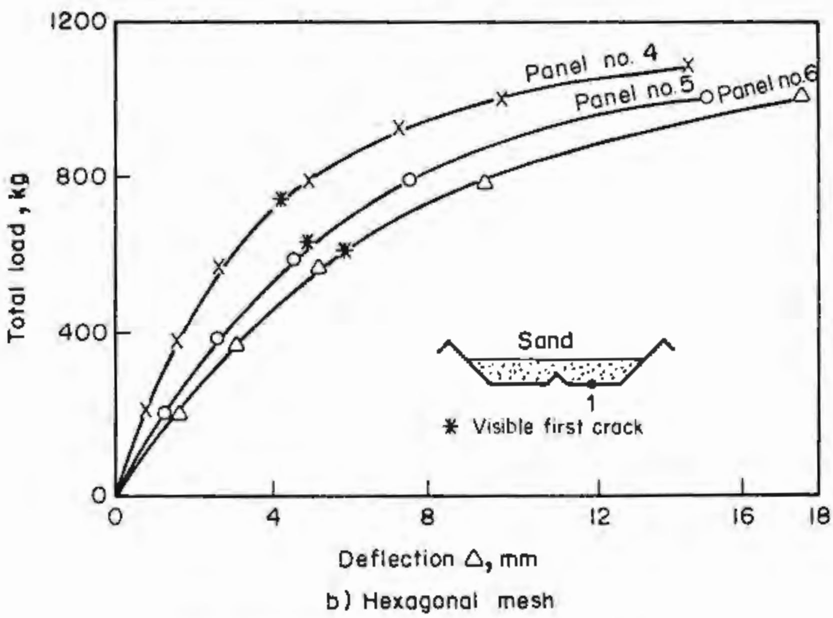
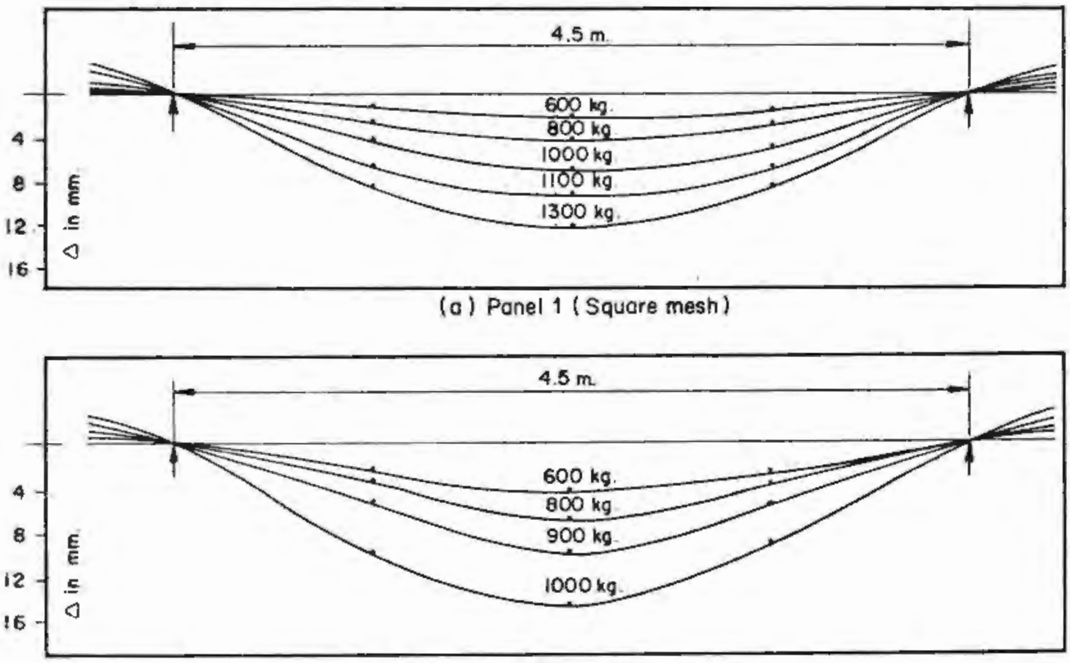


Fig. 12. Load-deflection at midspan ($Y/b_2 = 0.5$).



(b) Panel 4 (Hexagonal mesh)

Fig. 13. Typical deflection profiles for panels reinforced with square and hexagonal meshes.

Table 4. Live Load Carrying Capacity of Panels.

Panel no.	Type of mesh	Transverse reinforcement, %	Total live load at maximum allowable deflection, kg	Equivalent live load kg/m^2	Safety factor
1		.31	1500	311.60	4.16
2	Square	.26	1260	261.80	3.49
3		.23	1180	245.17	3.27
4	Hexagonal	.31	1080	224.40	2.99
5		.26	1000	207.80	2.77
6		.23	920	191.15	2.55

DISCUSSION

Structural Evaluation

Deflections predicted by the suggested analysis are marginally higher than those observed during experimental investigation. This is attributed mainly to ineffective simulation of the loading condition that was analysed. Firstly, because of the cross-sectional profile, it was not possible to achieve an uniformly distributed loading condition and secondly, reduced deflection was partially due to negative moments contributed from loading the overhanging portions of the panel.

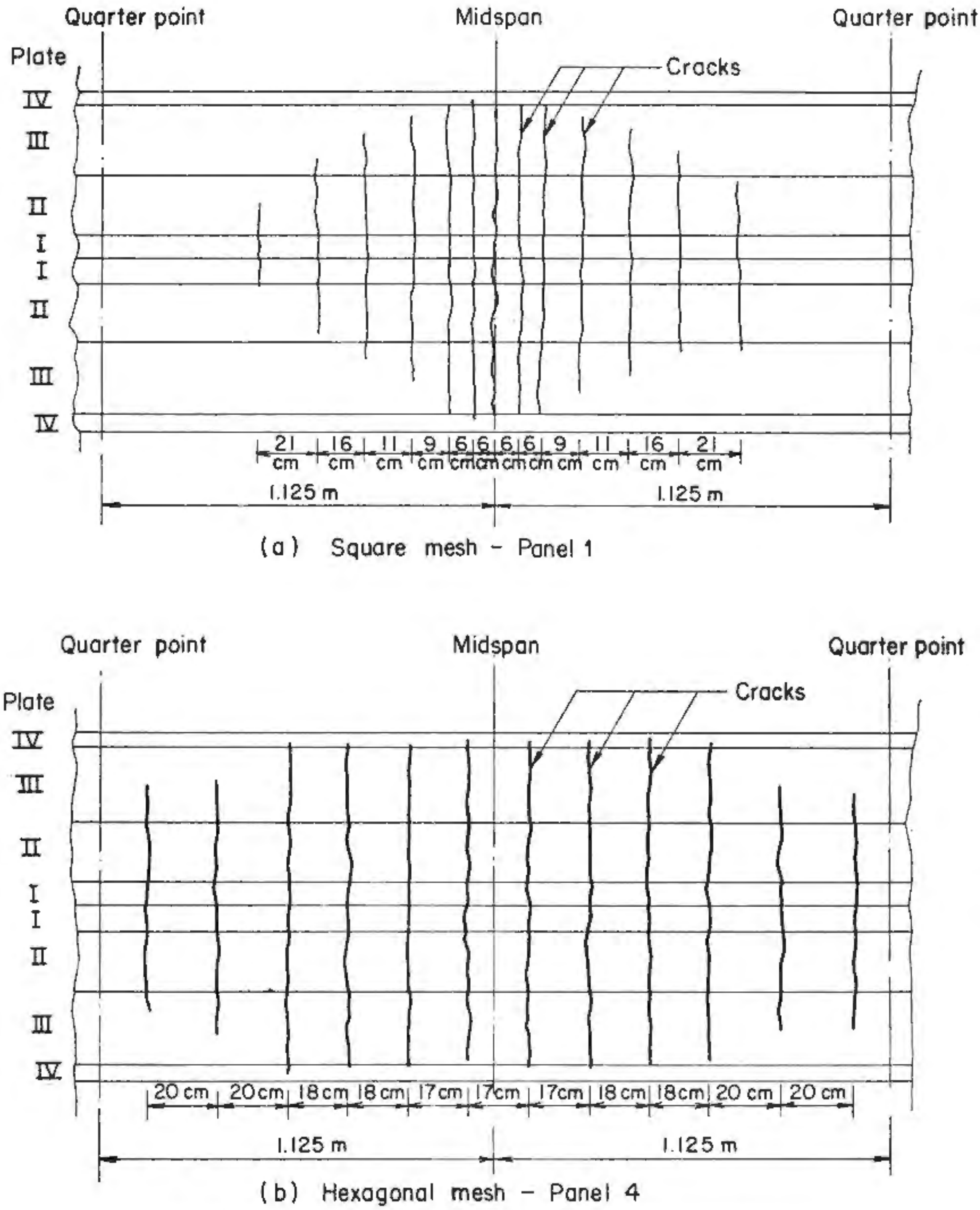


Fig. 14. Plan of the bottom surface of the panels showing cracking pattern.

It can be observed from Fig. 10 that panels made of hexagonal mesh yield larger deflections for the same load as when compared to square mesh, even though panels made from hexagonal mesh have a higher volume fraction of steel. This is due to lack of stiffness and the interwoven nature of the hexagonal mesh. It can thus be concluded that panels reinforced with square mesh have greater load carrying capacity considering maximum allowable mid-span deflections. The average safety factor (at maximum allowable deflection for the six panels tested was 3.2 (designed live load capacity being 75 kg/m^2).

Crack development for the two types of panels were studied from first appearance of cracks to the stage were maximum allowable mid-span deflection were recorded. Cracks were initiated at higher loads for panels with square mesh than those for panels with hexagonal mesh. Crack spacing and crack widths were smaller for panels with square mesh than for panels with hexagonal mesh. All these observations confirm the fact that a more uniform spatial distribution of reinforcing steel provides for a superior cracking mechanism.

The influence of transverse reinforcement can be analysed from Figs. 12 and 13. With a reduction in spacing of transverse reinforcement there is a relatively small decrease in deflection. The effect of transverse reinforcement is more pronounced in the higher load ranges than in the lower load ranges. It was also observed that crack development is initiated at the location of transverse reinforcements, nearer to the mid-span. On further loading, however, cracks develop at other locations as shown in Fig. 15. The present study confirms the mechanism fact that of crack formation as described by Paul and Pama [11].

From Fig. 11 and Lee [12], it can be seen that for the same load, asbestos panels of same dimensions and profile deflect more than ferrocement panels made either of hexagonal or square mesh. At maximum allowable deflection, the load carrying capacity of ferrocement panel is much higher than that of asbestos panel. Additionally, it is a now well established ferrocement panels have a much higher resistance to impact than asbestos panels.

Economical Evaluation

A comparitive cost analysis is presented in Table 5, while an overall comparison is presented in Table 6.

The analysis reveals that aside from being stronger, ferrocement panels are more economical (US\$4.5-5.0/m^2 for ferrocement panels as against US\$6.5-7.0/m^2 for asbestos panels). Besides, since ferrocement panels can be produced at site, losses due to breakages can be avoided (it has been estimated that 15-25% of the asbestos panels are prone to breakages or critical cracking during transportation). Fabrication of ferrocement panels at site also offers employment opportunities for rural labour. Another plus point for ferrocement panel is that its fabrication does not require skilled labour or input energy. Fabrication of asbestos panels, on the other hand, is mechanized and requires a power input of the order of 190 kva/24 hrs [6].

Table 5. Cost Analysis of Asbestos Car-Port Tiles and Ferrocement Panels.

	Quantity	Unit cost (B)*	Total cost (B)
Ferrocement panels using hexagonal mesh			
Materials:			
Cement, kg	90.00	0.80	72.00
Sand, m^3	0.072	110.00	8.00
Steel bar 10 m long pieces	4.50**	16.00	72.00
Wiremesh, 36″ width, ft	52.80	5.00	264.00
Sub-total			416.00
Labour:			
Skilled (man-hour)	3.00	8.00	24.00
Unskilled (man-hour)	12.00	5.00	60.00
Sub-total			84.00
Total			500.00
Cost per square meter of projected area			91.00
Ferrocement panels using square mesh			
Materials:			
Cement, kg	90.00	0.80	72.00
Sand, m^3	0.072	110.00	8.00
Steel bar 10 m, long pieces	4.50**	16.00	72.00
Wiremesh, 36″ width, ft	52.80	5.70	301.00
Sub-total			453.00
Labour:			
Skilled (man-hour)	3.00	8.00	24.00
Unskilled (man-hour)	12.00	5.00	60.00
Sub-total			84.00
Total			537.00
Cost per square meter of projected area			98.00
Asbestos carport tile+			
Cost per tile			400.00
Transportation			80.00
Total			480.00
Cost per square meter of projected area			133.00

*Cost of materials and labour in July 1979, US$ 1 = B 20.00.

**Based on transverse reinforcement percentage = .23.

+ Commercially available in Thailand in 4 m lengths (approximately same cross-sectional profile).

Table 6. Comparative Study of Ferrocement and Asbestos Panels of Same Cross-Sectional Profile.

Property	Ferrocement panels	Asbestos panel
Raw materials	Wiremesh, skeletal steel cement, sand	Asbestos fiber, cement
Thickness	20.00 mm	8.00 mm
Length	5.50 m	4.00 m
Projected area	5.445 m^2	3.60m^2
Self weight	51.95 kg/m^2	18.30 kg/m^2
Fabrication	Labour intensive	Mechanized
Power required	Nil	190 kva/24 hrs
Health hazard	None	Causes lung damage
Ductility	High	Very low
Cost per m^2 of projected area	Baht 90.00-100.00	Baht 133.00

CONCLUSIONS

Based on the study the following conclusions can be drawn:

(1) Ferrocement folded-plate panels offer a feasible solution to meet the requirements of a strong, durable and economical roofing in developing countries.

(2) While the type of mesh influences the strength of the panel to a great extent, the amount of transverse steel does not have an appreciable effect on the strength. Panels made with square welded mesh are stronger than those made with hexagonal mesh.

(3) For comparable deflections, it is observed that ferrocement panels had a greater load carrying capacity as when compared to asbestos panels.

(4) Cost analysis reveals that unit cost of ferrocement roofing is lesser than that of asbestos roofing.

ACKNOWLEDGEMENTS

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REFERENCES

1. ROSEMARY THOMAS, "Application of Ferrocement in Low-Cost Undulated Roofing, Elements", M.Eng. Thesis, Asian Institute of Technology, July 1979.
2. BASAVARAJIAH, B.S., VENKATA KRISHNA, H.V. and RAGHOTHAM, U.R. "Experimental Study of the Applicability of Ferrocement for Precast Folded Plate Element", Journal of Structural Engineering, Vol. 2, No. 4, January 1975, pp. 193-198.

3. HAYNES, H.H. and GUTHRIE, G.S., "Ferrocement Construction Panels", Civil Engineering Laboratory (Navy), Port Hueneme, California, Report No.TN-1341, April 1975, AD 781 644.

4. PAMA, R.P., LEE, S.L. and VIETMEYER, N.D., "Ferrocement, a Versatile Construction Material: Its Increasing Use in Asia", A Report of the Workshop on Introduction of Technologies in Asia—Ferrocement, A Case Study (November 1974), Asian Institute of Technology, 1976, 106 pp.

5. NAAMAN, A.E. and SHAH, S.P., "Evaluation of Ferrocement in Some Structural Applications", Proceedings of the IAHS International Symposium on Housing Problems-1976, Atlanta, Georgia, U.S.A. pp. 1069-1085.

6. FERNANDO, U.G., "Development of a Ferrocement ('Wirecon') Substitute for the Asbestos Cement Corrugated Roofing Sheet", Paper presented at the Seminar on Building Research and Its Application in Developing Countries, New Delhi, India, February 1977.

7. MIRONKOV, B.A., "Ferrocement Applications in the USSR", Journal of Ferrocement, Vol. 8, No. 3, 1978 pp. 203-208.

8. NAAMAN, A.E., "Performance Criteria for Ferrocement", Journal of Ferrocement, Vol. 9, No. 2, April 1979, pp. 75-92.

9. HUQ, S. and PAMA, R.P., "Ferrocement in Tension: Analysis and Design", Journal of Ferrocement, Vol. 8, No. 3, July 1978, pp. 143-168.

10. HUQ, S. and PAMA, R.P., "Ferrocement in Flexure: Analysis and Design", Journal of Ferrocement, Vol. 8, No. 3, July 1978, pp. 169-194.

11. PAUL, B.K. and PAMA, R.P., "Ferrocement", Published by the International Ferrocement Information Center, Asian Institute of Technology, August 1978, 149 pp.

12. LEE, P.S., "Evaluation of a Corrugated Asbestos Cement Roof Panel", M.Eng. Thesis No. 817, Asian Institute of Technology,

High Tensile Wire Reinforced Fibrous Ferrocement-It's Theory and Practice

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Variations in the form and use of conventional ferrocement made with multiple layers of wiremesh and plain cement mortar, are limited by the requirement for meshes to be finer in order to reduce concrete cracking. The paper reports of a series of experiments with mono-layered high tensile steel mesh encased in a fibrous (steel) cement mortar matrix. The outcome is a high strength material for which flexural properties can be designed and predicted with acceptable accuracy. The material has a superior cracking mechanism, offers improved energy absorption and impact resistance. The paper also highlights various other characteristics of the material and its applications, besides reporting its cost-effective edge over conventional ferrocement.

LIST OF NOTATIONS

A_s = area of tensile steel
A'_s = area of compressive steel
A_{si} = area of steel in the i th layer of mesh
b = width of the section
c = distance of the neutral axis from the compression face
d = depth of tensile steel from the compression face
d' = depth of compression steel from the compression face
d_i = depth of the i th layer of mesh from the compression face
E_c = modulus of elasticity of concrete
E_s = modulus of elasticity of steel
ε_c = concrete strain (typically 0.004 psi)
ε_t = steel strain (tension)
F = fibre pull out force
f_{tc} = ultimate concrete stress in tension
f_{tfc} = concrete stress in the tension face
f_{ws} = working stress
k = factorized average bond stress
M_r = resisting moment
M_u = ultimate moment
M_{ws} = moment at working stress
M_y = yield moment
S_L = specific surface of steel mesh
V_m = volume fraction of steel
λ = crack spacing
σ_{mu} = matrix stress at ultimate
ϕ = capacity reduction factor

INTRODUCTION

The finer crack pattern of ferrocement as when compared to familiar forms of reinforced concrete is attributed to an uniform dispersion of reinforcing steel. This results from the inter-relationship between bond and the specific surface of the reinforcement. Thus crack spacing and crack width diminish with the increasing specific surface of reinforcement. Several other factors, however, govern the frequency of occurrence and crack width in the composite, noteworthy the notch effect of the transverse wires of the mesh which generally dominate in determining initial crack location and development. It is also interesting to note location of coarse wiremesh near the surface results in smaller crack widths than produced by several layers of finer mesh, as this surface layer reduces strain below that, which results in more ineffectual layers of steel, each successively operating at reduced stress and lever arm.

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This prompted Alexander and Poore [1] to experiment with mono-layered wire without transverse wire employing both mild steel and high tensile steel, with and without wire fibres incorporated in the mortar. The following sections highlight some of the salient characteristics of High Tensile Wire Reinforced Fibrous Ferrocement (hereafter referred to as fibrous ferrocement) and a comparison with conventional mesh reinforced ferrocement.

CRACKING CHARACTERISTICS

Experiments show an improved cracking mechanism with a decreasing gauge of wire used as may be expected, although wires used are substantially coarser than mesh gauges. Detailed mechanics of cracking is explained elsewhere in this article. It was also observed that the high tensile wire delayed rapid opening of cracks which is a natural consequence of the greatly increased yield of the material (Fig. 1). Stress at which cracking occurred increased when fibre was incorporated in the mortar.

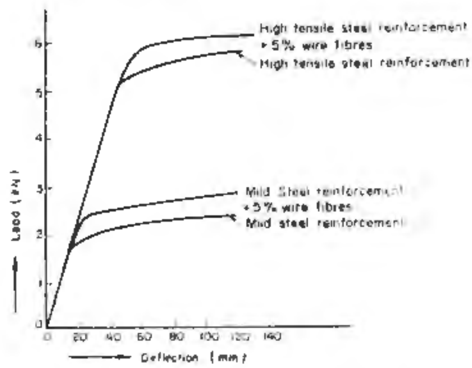

Fig. 1. Effect of use of steel fibres and high tensile wire reinforcement.

The effect of the wire fibres in controlling crack initiation and development can be explained, based on current literature [1-8] thus:

Although wire fibres in acceptable percentage is not as strong in tension as the natural tensile strength of the concrete itself, it has a sustained stress, as strain increases during fibre pull out. As a result fibres continue to exercise a cohesive force across crack interfaces. Quantitatively this cohesive force can be expressed as $F = (d-c)b f_{tfc}$ (Fig. 2) and constitutes a substantial load sharing with the reinforcing steel across the crack interface (Fig. 3).

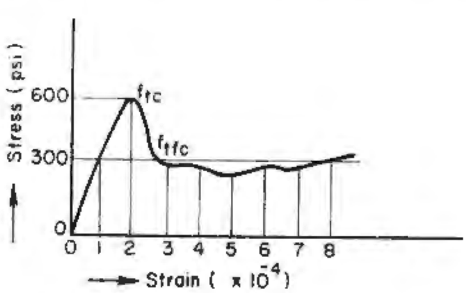

Fig. 2. Increased first crack stress.

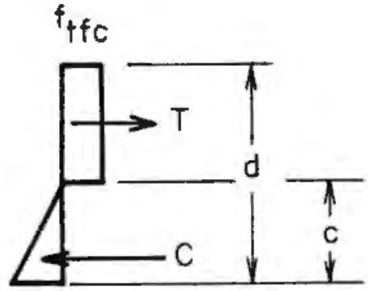

Fig. 3. Stress block diagram.

This load sharing also has an effect in decreasing bond length required to re-establish concrete stress and therefore induce further crack formation. As a consequence, crack spacing was reduced so that comparatively coarse wires in combination with wire fibres had a characteristic crack spacing of the same order as the conventional mesh reinforced ferrocement.

Coupled with the greater area of steel now disposed at maximum lever arm, it is apparent that much stronger composites can be obtained at lower levels of reinforcing whilst maintaining tolerable ranges of crack widths. Also, in high stress areas, the high tensile wire alone could sustain the stress and arrest crack propagation. A detailed correlation of crack width to steel stress, elastic modulus of steel and characteristic bond length has been presented in [1].

FACTORS AFFECTING THE STRENGTH OF FERROCEMENT AND FIBROUS FERROCEMENT

The strength of ferrocement in flexure is determined by the interaction of tensile steel with compressive concrete in common with all reinforced steel composites whilst the strength of ferrocement in tension is solely due to the steel. These postulates assume that concrete can only be usefully employed in its cracked condition. In practice the usefulness of ferrocement is entirely predicated by the degree of cracking which occurs and the term ferrocement has no other material connotation than the effect finer reinforcement has on crack control.

This crack criteria is illustrated in the following (Fig. 4) which plots crack width versus stress for the various groups of reinforced concrete which are listed on the next page.

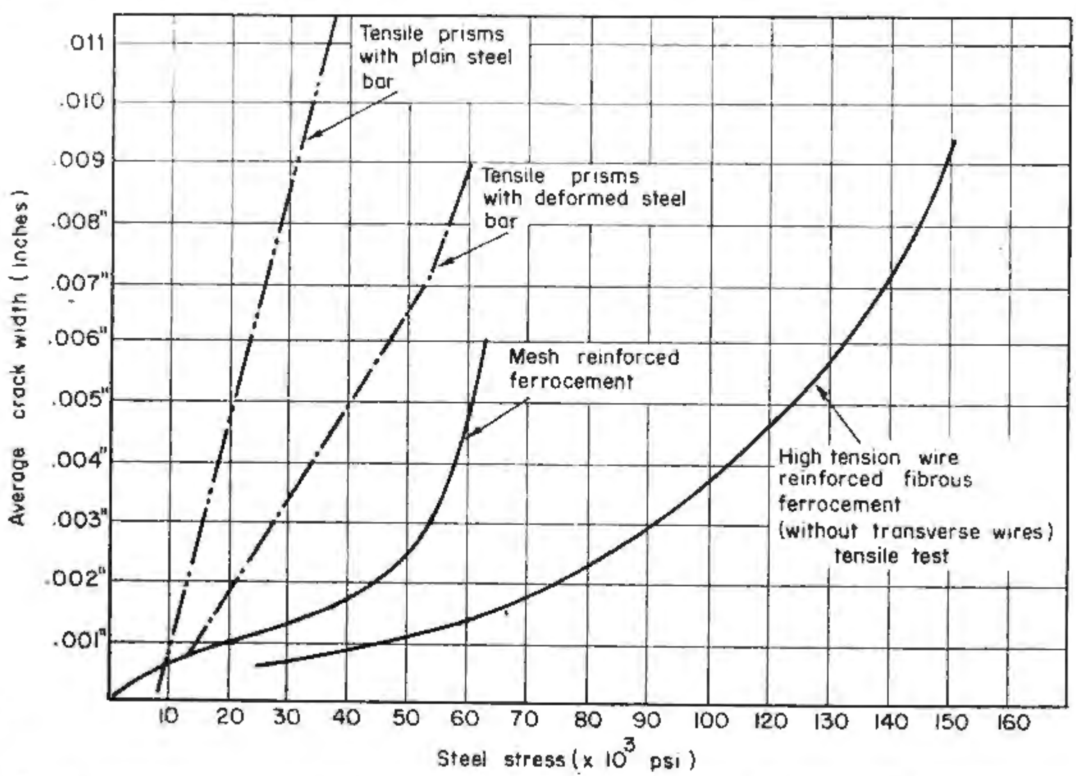

Fig. 4. Comparison of average crack width versus steel stress in direct tension for reinforced concrete and ferrocement.

(a) Plain reinforced concrete,
(b) Deformed bar reinforced concrete,
(c) Finely reinforced concrete (ferrocement),
(d) Finely reinforced fibrous concrete (high tensile wire reinforced fibrous ferrocement).

The data for the high tensile wire reinforced fibrous ferrocement is extracted from current research as yet unpublished, relating to tensile testing. Data for flexural testing is presented in Fig. 5 and derives from a paper published in The Widening Application of Ferrocement [4].

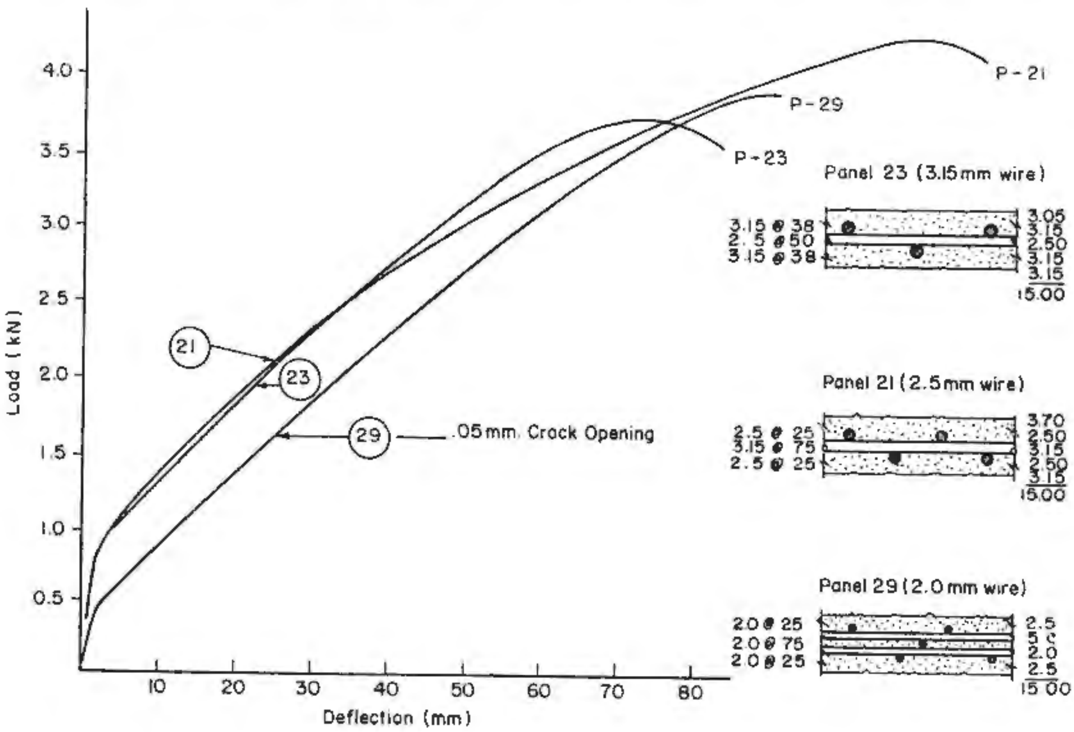

Fig. 5. Flexural tests on 15 mm high tensile wire reinforced fibrous ferrocement using 5% by weight 14 mm wire fibres.

Factors influencing the strength of ferrocement may be divided into two classes:

(a) Dominant determinants,
(b) Subordinate determinants.

The first grouping encompasses the quantity and quality of the steel reinforcements and the strength of the mortar and the second concerns such esoteric matters as neutral axis determinants, surface containment of compressive concrete and the influence of non-linear stress strain relationships in steel and mortar. Only dominant determinants are reviewed here.

In order to illustrate the function of the steel reinforcement as it relates to economy of location in achieving strength, two disparate reinforcing assemblages are examined:

(a) Mesh reinforced ferrocement,
(b) High tensile wire reinforced fibrous ferrocement.

Case (A)

Relates to a typical mesh assemblage of 12 layers of ½" x ½" x 19 gauge weld mesh. This has been chosen to roughly approximate the example given in 'Ferrocement' by B.K. Paul & R.P. Pama [3]: Design in Flexure (4-B); using, however, square weld mesh at a lower yield. The choice is related to some unsatisfactory aspects of woven mesh and the cost of placement difficulties of high yield wire woven mesh. Details of the assemblage are shown in the Fig. 6a.

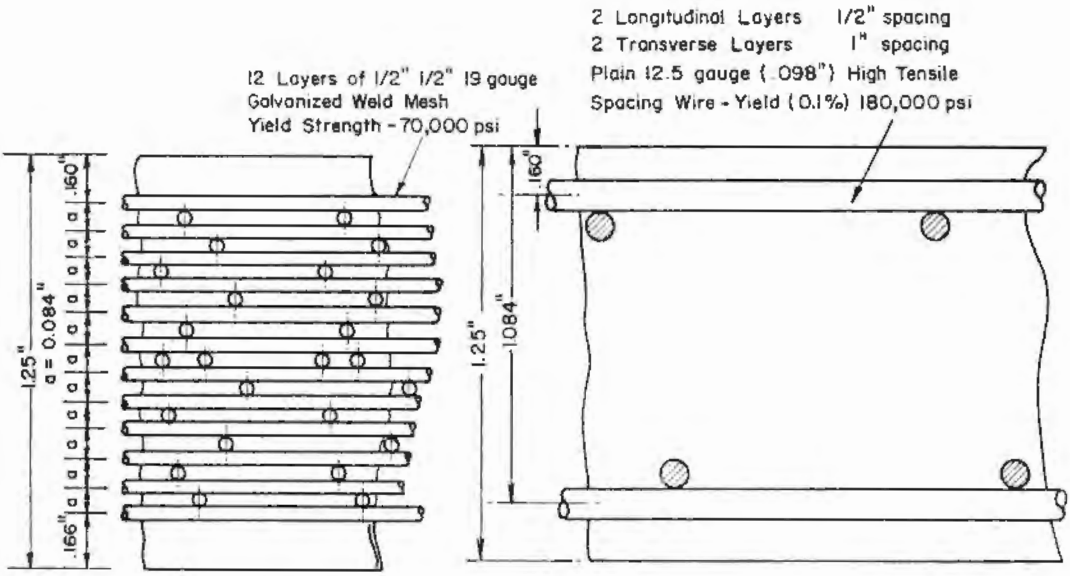

Fig. 6. Details of assemblages for mesh reinforced ferrocement and high tensile wire reinforced fibrous ferrocement (examples discussed in the text).

The resultant moment capacity of the section is derived by standard design methods. which gives $M_y = 7{,}950$ lb. in.
when c is determined from

$$\frac{E_c}{E_s}\frac{bc^2}{2} + c\sum_{i=1}^{n} A_{si} - \sum_{i=1}^{n} A_{si}\, d_i = 0$$

and c equals 0.391", and the moment is determined from

$$M = \frac{E_s\varepsilon_t}{(d-c)}\left(\sum_{i=1}^{n} A_{si}\, d_i^2 - c\sum_{i=1}^{n} A_{si}\, d_i - \frac{M_r bc^3}{6}\right)$$

and $\varepsilon_c = .0013$ (where symbols used appear in the list of notations).
This latter strain illustrates the nature of under-reinforcement arising from employing fine mesh assemblages.

From other sources it is noted that the stress at .002" crack opening is 45,000 psi, i.e., $f_{ws} = 45{,}000$ psi

$$M_{ws} = 7{,}950 \times \frac{45{,}000}{70{,}000} \left(\frac{f_{ws}}{f_{sy}}\right) = 5{,}110 \text{ lb. in.}$$

when f_{ws} and M_{ws} are the working stress and moment respectively.

Case (B)

This case employs mono-layer reinforcement typical of high tensile wire reinforced fibrous ferrocement [5]. The parameters of thickness and steel content are identical to that of Case (a). The assemblage is given in Fig. 6b. The steel content of Case (a) is 2.88 lb. and in Case (b) 2.82 lb. including 6% fibre additions. The computed result derives from formulation for Design of High Tensile Wire Reinforced Fibrous Ferrocement—under-reinforced linear, concrete, given in [5], but to compensate (without significant error) for the non-linear concrete at steel yield the secant value of E_c is reduced to 3×10^6.

where c is obtained from the quadratic

$$\frac{M_r bc^2}{2} + (A_s' + A_s)\, c - (A_s' d' + A_s d) = 0$$

and moment from

$$M_u = \phi \left[E_c\ \varepsilon_c\ \frac{cb}{2}\ (d - \frac{c}{3})\right] + \left[A_s' E_s \varepsilon_s'\ (d - d')\right]$$

This results in:

M_y = 30,674 lb.in.
c = 0.370 in.
ε_c = .0033

where working stress = f_{ws} = 58,600 psi (stress at .002" crack) moment at working stress = M_{ws} = 10,000 lb.in. As in Case (a) f_{ws} is derived from other sources (in this case, experi mental data from similarly reinforced test pieces). Typical data on stress at visible crack is presented in Table 1 [4]. These figures refer to the panel condition at the point where cracks were first observed with the naked eye. Checks indicated that the cracks seen would have been of the order of .02 to .05 mm, i.e. approximately .001 to .002 inches. These results for the mesh and high tensile wire reinforced fibrous ferrocement assemblages are compared in the following Table 2.

These examples illustrate the following points:

i) That each level of mesh functions at a lower stress level and a lesser moment arm and multi-layered reinforcement is, therefore, a comparatively inefficient use of reinforcement.

ii) The efficient use of reinforcing is best carried out as monolayers of increased diameter wire (the decreased specific surface area resulting from the unit area increase, however, increases the crack spacing and crack width so that wire fibres or some other such device must be employed to control crack width).

Table 1. Stress at Visible Cracking

Section thickness (mm)	Wire diameter (mm)	Specimen number	Load (kN)	Bending moment		Calculated steel stress (MPa)
				Experimental (Nm)	Calculated (Nm)	
15	2.0	29	1.7	260	269	489
	2.5	21	2.0	305	235	317
	3.15	23	1.8	274	246	303
25	2.0	30	2.9	442	487	375
	2.5	22	6.7	1,021	979	504
	3.15	24	4.9	747	770	350
	5.0	26	3.2	488	440	172
35	2.5	28	8.0	1,220	1,240	430
	3.15	25	7.0	1,067	950	279
	5.0	27	5.5	840	769	174

Table 2. Comparitive Study of Mesh Reinforced Ferrocement With High Tensile Wire Reinforced Fibrous Ferrocement.

Property	Mesh reinforced ferrocement	High tensile wire fibrous ferrocement
Yield moment capacity	7,950.00 lb.in.	30,674.00 lb.in.
Working moment	5,110.00 lb.in.	10,000.00 lb.in.
Weight of steel employed per sq.ft	2.88 lb.	2.82 lb.
Cost of steel employed per sq.ft	$ 2.56	$ 1.02
Cost of equivalent strength steel (nearest size)	$ 3.85 for 3/8" plate	$ 5.00 for 1/2" plate
Comparative cost of ferrocement per sq.ft	$ 2.84	$ 1.31

(Cost data derived from current New Zealand prices as listed in [1]).

iii) For a given volume fraction of steel reinforcement high tensile steel is much more cost effective than low carbon steels in mesh form.

FACTORS LIMITING THE USE OF FERROCEMENT

Various codes of practice limit crack width in terms of environment. Typically the Russian Structural Code [7] uses 0.05 mm (.002") for external exposure and 0.1 mm for internal exppsure below which thresholds, corrosion does not normally occur. Guerra, Naaman & Shah [8] are specific in terms of leakage permeability to water in tanks.

Cracks occur in patterns or regimes which are dependent on matrix stress, specific surface area of reinforcement and volume fraction of reinforcement for their characteristic spacing and width, both of which are interdependent but which are, however, frequently modified or dominated by stress raisers such as transverse reinforcing wires.

In multi-layer mesh reinforced ferrocements marked stress peaks do not occur but marked cracking arising from stress concentration occurs when skeletal steel is substituted for the centrally disposed layers of mesh. High tensile wire reinforced fibrous ferrocement may also display similar characteristics.

For mesh reinforced non-skeletal steel assemblied, crack spacing may be determined by:

$$\lambda = \frac{k\sigma_{mu} \; V_m}{S_L}$$

where k is a factorized average bond stress determined from experimental values.

Where stress raisers exist, however, the determination of crack width cannot be theoretically derived. There is a widespread acceptance of formula which reflect transverse wire spacing as crack spacing determinants but experiments suggest that reasonable correlation occurs only when the transverse wire spacing approximates the characteristic bond length of the principle wire assemblage. This phenomena of transverse wire influence on cracking can be used as a design device to achieve a systematic crack regime.

Unlike mesh reinforced ferrocement, in high tensile wire reinforced fibrous ferrocement tranverse wire may frequently be omitted altogether. Where no transverse wire is used the crack regime takes on the characteristic bond length induced crack spacing, usually between 5/8" to 7/8" spacings which are the virtual optimum. Fig. 7 shows graphed data of an assembly without transverse wires with stresses reaching 112,000 psi at .004" crack width. Where transverse wires are required at spacings unsatisfactory in respect to crack width criteria (because notch effects are introduced) a layer of weld mesh can be introduced above the longitudinal wire to assist in the development of closer crack spacing. Fig. 8 & 9 highlight the mechanism of cracking in fibrous ferrocement [5].

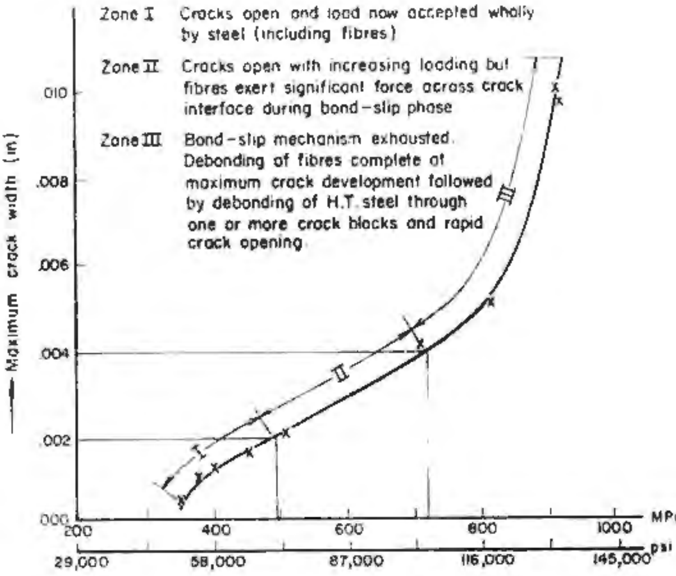

Fig. 7. Curve for maximum crack width versus steel stress. The test panel contains 1.5% high tensile steel wires and 1.6% wire fibres (by volume). Note, however, that no transverse wires have been used.

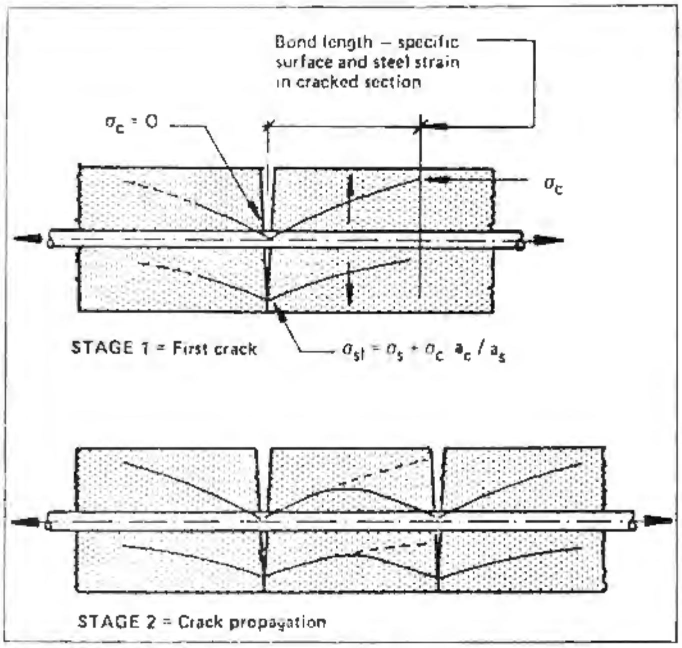

Fig. 8. Crack behaviour in ferrocement explained with respect to bond length.

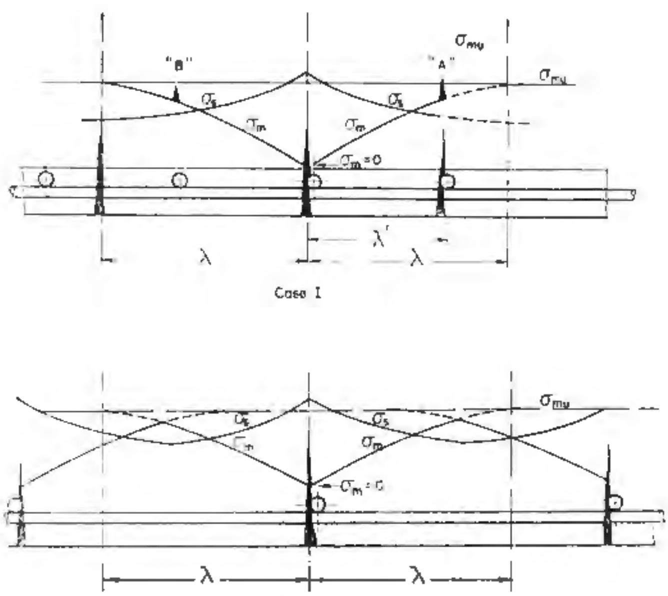

Fig. 9. Crack behaviour of high tensile wire reinforced fibrous ferrocement in notched condition. Case I-stress peaks inside bond determined bond spacing. "A" stress peak exceeds σ_{mu}. "B" stress Peak falls below σ_{mu}. Case II - Mortar stress development arrested by stress regression from notch initiated outside distance λ. No further cracking is possible within preemptive cracking.

MECHANICS OF CRACKING

Repetitive cracking proceeds from the first crack which occurs when the matrix stress σ_{mu} is exceeded. Once initiated the force originally in the mortar reverts to the steel at the crack interface but is progressively returned to the mortar by a bond mechanism which restores the mortar to its pre crack stress at a distance λ (crack spacing) from the initial crack. At this point cracking can recur (Fig. 8).

The crack pattern may be disturbed by notches or stress raisers which intercept the rising stress in the matrix and induce premature cracking (Fig. 9, Case I)

Alternately cracking may be induced at wider separation than the bond controlled spacing in which case the concrete stress may not be restored to its initial stress level and no intermediate cracking can occur. This leads to increased crack width at the induced crack sites as loading proceeds (Fig. 9, Case II).

It therefore follows that the crack spacing and techniques for controlling it play a large part in the design of ferrocement structures which would not be suggested by experience with mesh assemblages only.

METHODS OF ANALYSIS FOR FERROCEMENT

Three methods are used in the flexural analysis of ferrocement (tensile analysis flows from the same basic assumptions where applicable). These are namely:

a. The material is analysed as a composite;
b. Design parameters are entirely based upon simulation data;
c. Standard reinforced concrete analysis is employed.

Method A

The material is treated as a composite which has permitted the content to be defined in such subjective parameters as volume content of steel, specific surface of reinforcement, etc. Idealized stress strain curves are employed upon which to base derived formula which are predicated by performance factors in order to approximate experimental results. Crack spacing and widths are rationalized as a bond slip mechanism.

Method B

All methods of analysis are ultimately matched to experimentally obtained values. Although ill advised without understanding of the theoretical basis an empirical approach to design may be based on simulation derived data in which a standard test piece using the proposed fabric assembly is tested in bending in the proposed crack range. The resulting data is then employed in stress analysis in terms of modulus strength.

Method C

This employs standard concrete design methods based upon forces summation.

The appropriate design formula employed in the analysis of ferrocement sections by such standard concrete design methods are given in [1,5] criteria affecting crack spacing and crack width have been discussed earlier in the text.

The standard concrete design approach overcomes the difficulty inherent in dealing with asymmetrical wire assemblages and appears more applicable to high tensile wire reinforced fibrous ferrocement whilst the simplistic approach of the composite model which doubtless arises from the historical use of symmetrically disposed mesh reinforcement, and is readily globalized by composite assumptions, may well satisfy the indeterminancy of mesh assemblages.

The choice of design approach will probably lie in the type of reinforcing selected which in itself will depend on cost effectiveness. A unified design method to integrate ferrocement into the body of reinforced concrete practice may also influence design approach but will depend upon developing experience with the material.

Reverting to the comment on cost effectiveness the earlier section analysed the strengths and cost of two reinforcement assemblages using equal thickness of plate and equal weights of reinforcement, and demonstrated the large gains in strength and the cost advantage obtained with high tensile wire reinforced fibrous ferrocements relative to mesh reinforced ferrocements. This contrast can become even more disparate when the reinforcing assemblages are varied to match the stresses arising from moment distribution and crack criteria which differs internally and externally to which matching is simpler to implement in high tensile wire reinforced fibrous ferrocements. These diverse constraints are typically met in ship and barge hulls. Increased knowledge of the factors controlling strength, crack width and relevant parameters now allow more precise design for optimum performance. Fig. 10 gives a comparison between experimental and theoretical curve for load versus strain which shows a precise correlation between them.

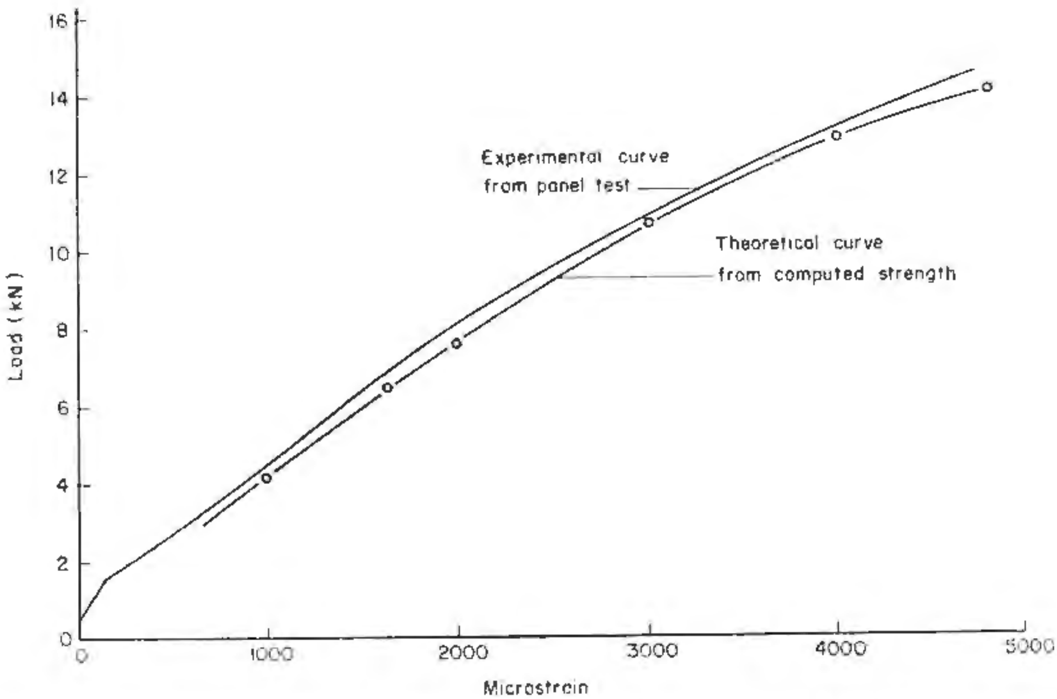

Fig. 10. Correlation between experimental and theoritical curves showing a high level of accuracy in predicting the behaviour of high tensile wire reinforced fibrous ferrocement (Panel 22).

APPLICATIONS

High tensile wire reinforced fibrous ferrocement has wide ranging applications. The more immediate applications have been in boats and barges, but the stiff fibrous mortar permits construction of shapes such as ventilation cowls and any such free form. These applications are outlined in the book 'The Widening Applications of Ferrocement' (Figs. 11-18). The applications of the composite in plate form are, however, the area of greatest anticipation. Its most obvious use is to displace mild steel plate in many applications and currently this is in producing thin wall precast plates for deckhouses and small stores.

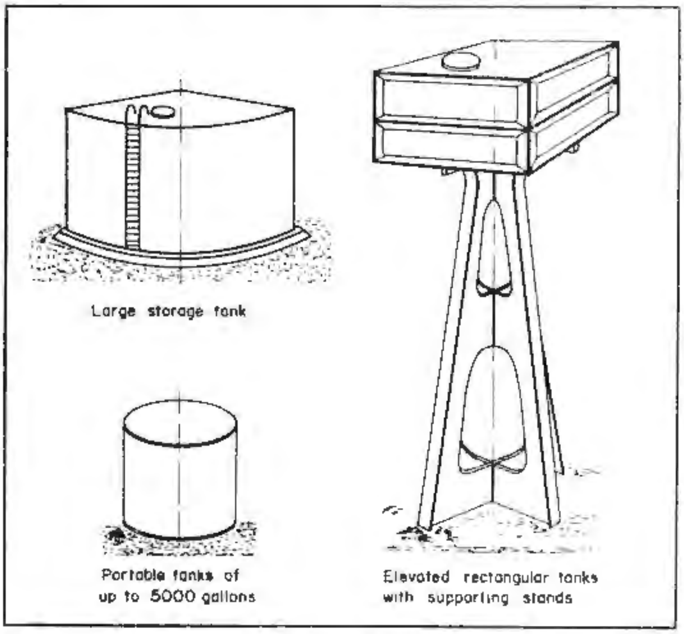

Fig. 11. Water retaining structures made from high tensile wire reinforced fibrous ferrocement.

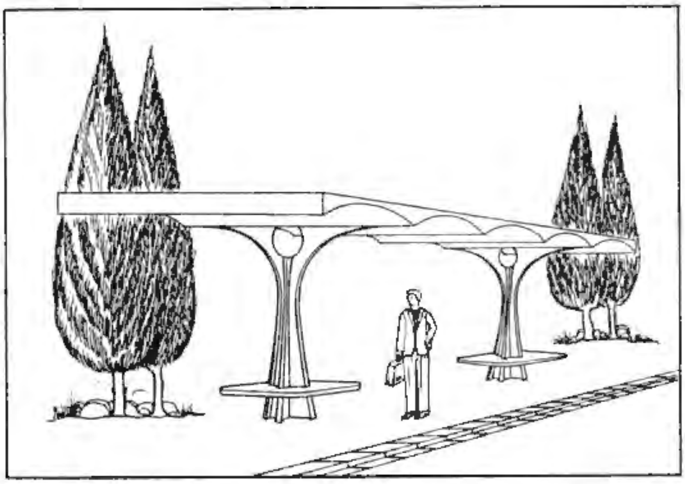

Fig. 12. Bus-shelters constructed in fibrous ferrocement, Singapore.

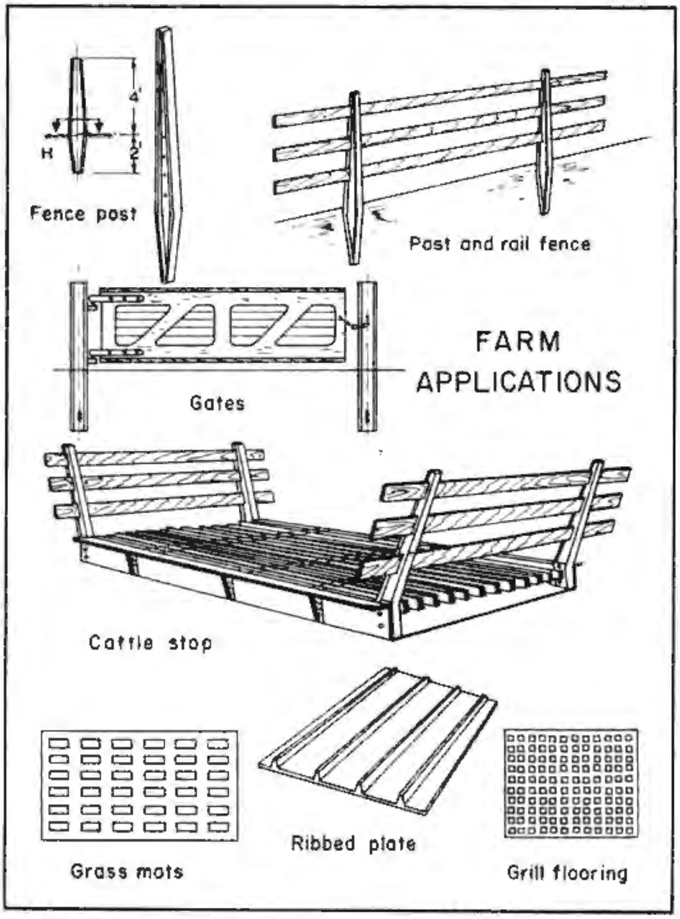

Fig. 13. Some typical applications of fibrous ferrocement for farm structures.

Plate can be made in continuous lengths in existing long casting beds in which placement of the mortar and the vibration of it are substantially mechanised. The wires themselves are prestressed accurately into position in the longitudinal direction and transverse wires held in combs during casting.

Such plates can be employed to form barges and pontoons for which purpose the planks are made the full length of the vessel and fingered together transversely with or without the assistance of prestress.

Water tanks are currently being manufactured by precasting the walls as planks. For instance 5,000 gallon tanks employ two 33 ft x 5 ft wide planks which are rolled without visible cracking into their circular form and assembled into precast tops and bottoms to form a tank at substantially less cost than other methods of manufacture.

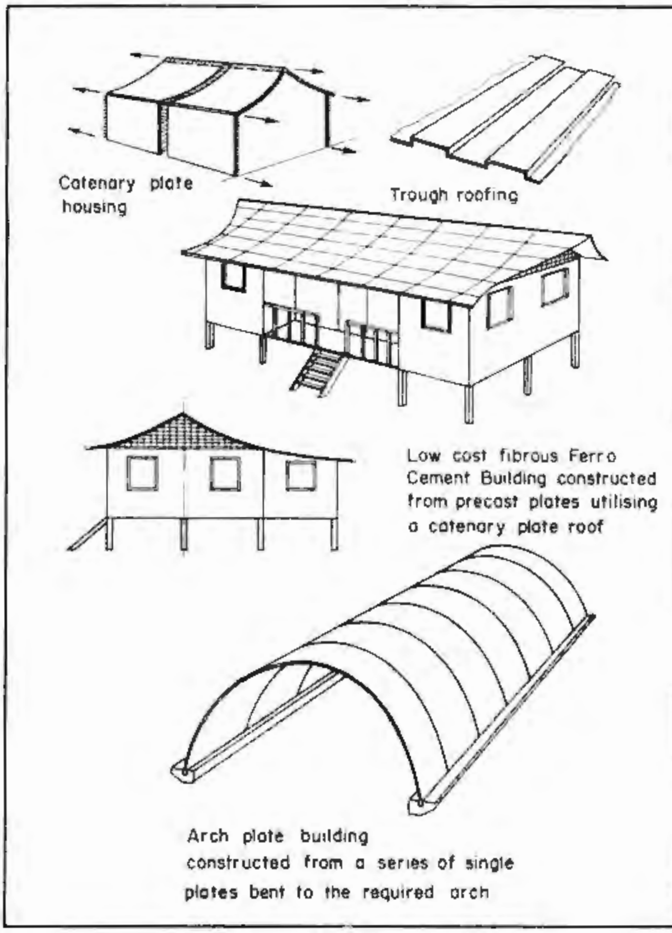

Fig. 14. A few proposals for use of precast fibrous ferrocement panels in housing.

Large diameter arch culverts formerly the domain of Armco type corrugated sheet iron arches, can be made by similar rolling of high tensile wire reinforced fibrous ferrocement plates into the arch form and this too is in current production.

As sheets from .30 to 3 inches thickness can be made by production methods with concurrent precision and finish, it is now possible to produce precision planks and plates suitable for use in buildings at a cost comparable, if not less than competitor materials. Typical of this is its ability to displace asbestos fibre sheet in its applications.

In a more general sense its field of application encompasses both free form and plate work where high strength and low cost are prerequisites.

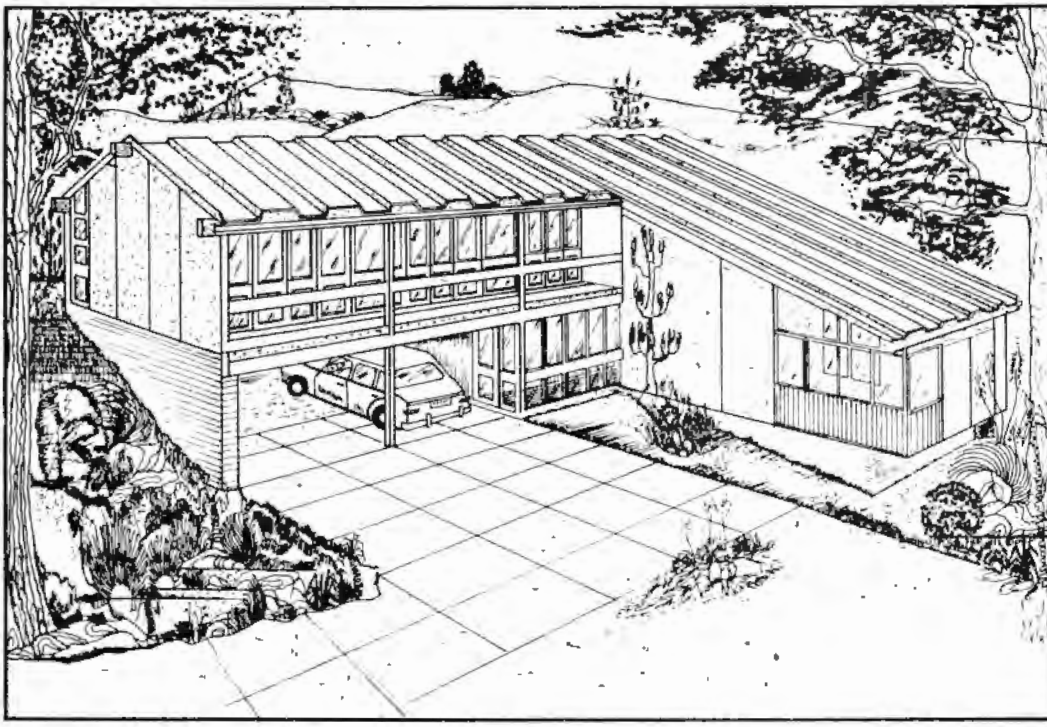

Fig. 15. A proposed house using floor, wall and roof panels made from fibrous ferrocement.

(a) (b)

Fig. 16. 12 m Prestressed high tensile wire reinforced fibrous ferrocement motorized barges being built in a Jakarta yard. Note use of precast parts for the construction. Over 60 such barges have been built in a 2-year period.

Fig. 17. Prestressed fibrous ferrocement barge for the transport of palm oil (410 tonnes), Sabah, Malaysia.

Fig. 18. 22 m Prestressed fibrous ferrocement tugs for coastal log hauling and general cargo handling constructed in Sabah, Malaysia.

REFERENCES

1. ALEXANDER, D.J., "High Tensile Wire Reinforced Fibrous Ferrocement—Its Theory and Practice", A Report prepared by Alexander & Poore Consulting Engineers, Auckland, New Zealand, 34 pp.
2. ALEXANDER D.J. and ATCHESON, M.G.A., "Development of Fibrous Ferrocement", Proceedings of the ACI Committee 549 on Ferrocement, Toronto, 1978.
3. PAUL, B.K. and PAMA, R.P., "Ferrocement", Published by the International Ferrocement Information Center, Asian Institute of Technology, Bangkok, Thailand, August 1978, 149 pp.
4. ALEXANDER, D.J., "The Widening Applications of Ferrocement", Published by the author himself, 1979, 120 pp.
5. ALEXANDER, D.J., "Ferrocement in Relation to the RC Code", New Zealand Concrete Construction, December 1978, pp. 20-23 (also reprinted in the Journal of Ferrocement, Vol. 9, No. 4, October 1979, pp. 191-199).
6. ALEXANDER, D.J., "The Protection of Substrate Steel in Ferrocement", New Zealand Concrete Construction, September 1979.
7. Scientific Research Institute on Concrete & Ferrocement, Soviet State Committee on Construction, Leningrad Regional Scientific Research Institute of Experimental Design.
8. GUERRA, A.J., NAAMAN, A.E. and SHAH, S.P., "Ferrocement Cylindrical, Tanks—Cracking and Leakage Behaviour", ACI Journal, Proceedings, Vol. 75, No. 1, January 1978, pp. 22-30.

Influence of Discrete Fibres on Behaviour of Ferrocement*

P. Paramasivam⁺, G.K. Nathan† and S.L. Lee‡

Fibre reinforced ferrocement, which is made up of plain mortar, wire mesh, and randomly distributed short steel fibres, is studied to determine the interaction between the two forms of reinforcement in the behaviour of the composites. The tensile and flexural properties of composites made of fibre reinforced mortar, ferrocement and fibre reinforced ferrocement are experimentally investigated with various volume fractions of reinforcement.

INTRODUCTION

It has been recognised that the introduction of wire mesh or fibres would appreciably increase the tensile strength of mortar. The inclusion of short steel fibres in the concrete resists the propagation of cracks, improves the tensile strength, toughness and ductility of mortar. Ferrocement exhibits relatively higher ductility and ultimate strength compared to fibre reinforced concrete. Earlier studies were limited to either wire mesh [1,2] or fibre reinforcement [3-7]. An earlier investigation by Paramasivam et al [8] showed that in a fibre reinforced ferrocement made of plain mortar with one layer of wire mesh and randomly distributed fibres, the interaction between the two forms of reinforcement gives improved first crack tensile stress. In this paper, an experimental investigation conducted to compare the mechanical properties of fibre reinforced mortar, ferrocement, and fibre reinforced ferrocement is reported.

EXPERIMENTAL INVESTIGATION

Tensile and flexural tests were conducted on three composites, fibre reinforced mortar, fibre reinforced ferrocement and ferrocement with different volume fractions of reinforcement. The details of the test specimens are listed in Table 1. Specimen sizes used for tensile and flexural tests were identical to those used in earlier investigations [2,7]. Three specimens were cast for each series and the average value of the three was reported in the test results. Cement, sand and water ratio of 1.0:1.5:0.5 by weight was used. Fine aggregates consisting of dry sand passing through BS No. 14 and greater than BS No. 200 were used. The properties of the reinforcement and matrix obtained from standard tests are presented in Table 2. A preliminary investigation was carried out with steel fibres and plain mortar to determine a suitable fibre length from the consideration of strength, workability and aspect ratio [4,5] and it was found that a length of 50 mm fibre was suitable from the above considerations.

Preparation of Specimens

The sand and cement were mixed, and the fibres were then added in small quantities and mixed further. When the required quantity of fibres was thoroughly mixed, water was added

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Table 1. Summary of Test Program.

Type	Total Vol. Fraction of Steel	No. of Layers of Wire Mesh	Vol. Fraction of WireMesh	Vol. fraction of Fibre	Identification
Fibre reinforced ferrocement	0.022	1	0.011	0.011	A1
	0.044	2	0.022	0.022	A2
	0.066	3	0.033	0.033	A3
	0.088	4	0.044	0.044	A4
Fibre reinforced mortar	0.02	0	0.0	0.02	B1
	0.04	0	0.0	0.04	B2
	0.06	0	0.0	0.06	B3
	0.08	0	0.0	0.08	B4
Ferrocement	0.022	2	0.022	0.0	C1
	0.044	4	0.044	0.0	C2
	0.066	6	0.066	0.0	C3
	0.088	8	0.088	0.0	C4

Table 2. Properties of Reinforcement and Matrix.

Item	Mean Value
Galvanised Wire Fibre	
Diameter	1.07 mm
Ultimate tensile stress	331.0 N/mm^2
Modulus of elasticity	1.73×10^5 N/mm^2
Length of fibre	50.0 mm
Galvanised Square Wire Mesh (6.35 mm × 6.35 mm)	
Diameter	1.07 mm
Ultimate tensile stress	331.0 N/mm^2
Modulus of elasticity	1.73×10^5 N/mm^2
Plain Mortar	
Ultimate tensile stress	0.80 N/mm^2
Modulus of elasticity	1.62×10^4 N/mm^2
Cylinder crushing strength	28.0 MN/mm^2
Modulus of rupture	2.9 MN/mm^2

and the mix was worked to a uniform consistency to obtain a mortar-fibre mix. For fibre reinforced mortar specimens, the composite was placed in a mould made up of perspex material and compacted on a vibrating table. Fibre reinforced ferrocement specimens were prepared by having alternate layers of mortar-fibre mix and wire mesh. The specimens were compacted alternately after every pair of layers of mortar-fibre mix and wire mesh. Ferrocement specimens were prepared by keeping the required amount of layers of wire mesh equally spaced in the mould and plain mortar was added and compacted continuously. The specimens were stripped after 24 hours and cured in water at a temperature of 28°C for 6 days.

Tensile and Bending Tests

An Instron testing machine was used to carry out the tensile and bending tests. The dimensions of the specimens for tensile and bending tests are shown in Figs. 1 and 2. Direct pull out tests were carried out to determine the first crack and ultimate tensile strength of the composites. Third-point loading on a span of 380 mm was used to determine the first crack bending stress and ultimate moment.

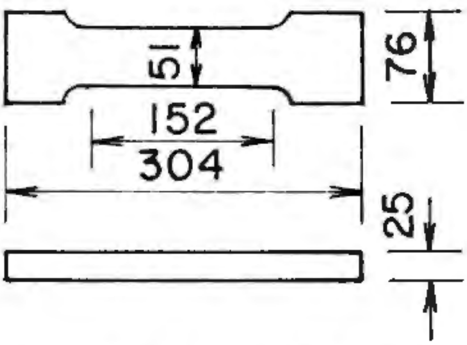

Fig. 1. Tensile specimen (all dimensions are in mm).

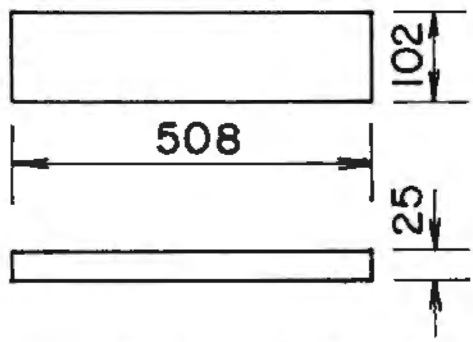

Fig. 2. Flexural specimen (all dimensions are in mm).

RESULTS AND DISCUSSIONS

The important variable that affects the mechanical properties of these composites is the total volume fraction of steel. Tensile and flexural tests were carried out with varying volume fraction in order to compare the reinforcing action of steel as continuous wire mesh, discrete fibres and the combination of both in plain mortar and the test results are presented in Table 3.

Table 3. Experimental Results.

Type	Identification	Tensile Test			Flexural Test	
		First Crack Stress N/mm²	Ultimate Stress N/mm²	Modulus of Elasticity N/mm²	First Crack Stress N/mm²	Ultimate Moment Nm
Fibre reinforced ferrocement	A1	2.42	2.95	1.73	3.80	98.0
	A2	2.88	4.32	1.75	7.00	117.0
	A3	5.58	6.75	1.80	8.30	118.0
	A4	7.85	9.75	1.86	11.10	171.0
Fibre reinforced mortar	B1	2.25	2.25	1.52	3.14	35.0
	B2	2.36	2.95	1.54	4.70	61.0
	B3	2.96	4.58	1.58	5.00	58.0
	B4	4.24	5.57	1.64	7.06	84.0
Ferrocement	C1	1.78	3.44	1.75	2.95	133.0
	C2	2.72	7.39	1.85	7.15	174.0
	C3	4.84	11.05	2.00	12.20	240.0
	C4	6.17	14.18	2.10	16.60	274.0

Tensile Strength

The variation of first crack tensile stress with total volume fraction of reinforcement for all three composites is shown in Fig. 3. The first crack tensile stress is defined as the tensile stress at which the length of first crack is about half the width of the specimen and the definition is chosen for consistency. The reinforcement ratio, which is defined as the ratio of volume fraction of wire mesh (V_W) to the total volume fraction of reinforcement (V_T), is plotted against the first crack tensile strength in Fig. 4 to compare the relative effectiveness of these composites. It can be seen from Figs. 3 and 4 that first crack tensile stress increases with increasing volume fraction of reinforcement for all three composites. For the same total volume fraction, the first crack tensile strength of fibre reinforced ferrocement is higher than the other two composites. Therefore it may be concluded that fibres combined with wire mesh are more effective in arresting the propagation of cracks.

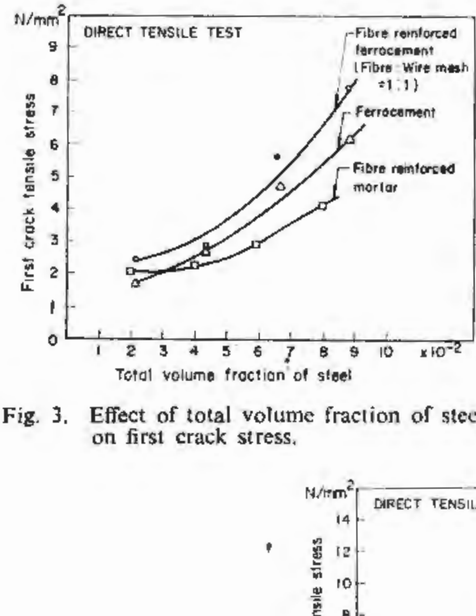

Fig. 3. Effect of total volume fraction of steel on first crack stress.

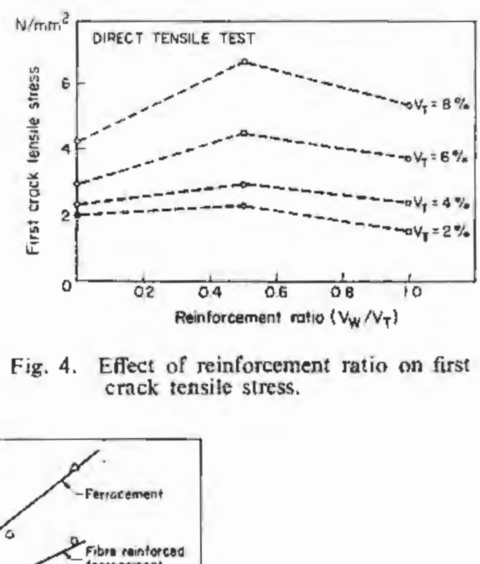

Fig. 4. Effect of reinforcement ratio on first crack tensile stress.

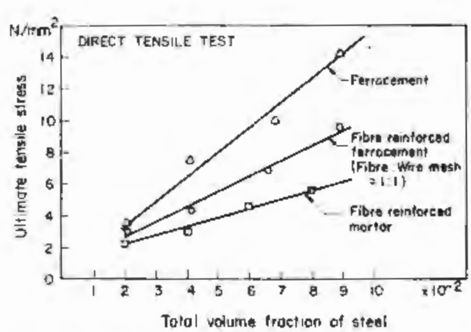

Fig. 5. Effect of total volume fraction of steel on ultimate tensile stress.

Fig. 5 shows the linear relationship between volume fraction of reinforcement and ultimate tensile strength of the three composites. The ferrocement material gives a higher ultimate strength for any volume fraction of steel in comparison to other composites. This is as expected because in ferrocement, the ultimate tensile strength is governed by the ultimate tensile strength of the wire mesh. In the case of the other composites, the fibres are not effective after the first crack. The moduli of elasticity of the composites were obtained from strain measurement during tensile test and are presented in Table 3. It can be seen that the modulus of elasticity increases with increasing volume fraction of steel content. However, there is no significant difference between the three composites.

Flexural Strength

The effect of total volume fraction of steel on the first crack bending stress and the ultimate moment for the three composites are presented in Figs. 6 and 7 respectively. Fibre reinforced ferrocement gives much higher values than the fibre reinforced mortar, but ferrocement gives higher values for the same volume fraction of steel. Similar trend is noticed in the case of ultimate moment capacity of the three composites. It can be seen from Figs. 6 and 7 that wire mesh is more effective in terms of flexural strength.

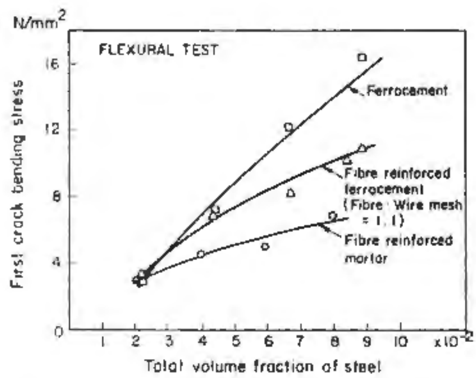

Fig. 6. Effect of total volume fraction of steel on first crack bending stress.

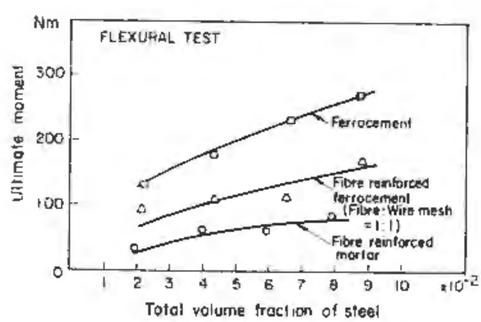

Fig. 7. Effect of total volume fraction of steel on ultimate moment.

CONCLUSION

This investigation studies the effect on the tensile and flexural strength of the interaction between wire mesh and steel fibres in fibre reinforced ferrocement. The results show that while the fibre increases the first crack tensile stress of the composite, the ultimate strength depends almost entirely upon the volume fraction of the wire mesh. For given total volume fraction of reinforcement, the trade off between the two properties should be optimized in the design of the composite for particular applications.

In bending, no benefit seems to be derived from the steel fibres in terms of the ultimate flexural strength. For given total volume fraction of reinforcement, the wire mesh is much more efficient in increasing the first crack bending stress.

ACKNOWLEDGEMENT

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REFERENCES

1. NAAMAN, A.E. and SHAH, S.P., "Tensile Tests of Ferrocement", Journal of American Concrete Institute, Vol. 68, 1971, pp. 693-698.
2. NATHAN, G.K. and PARAMASIVAM, P., "Mechanical Properties of Ferrocement Material", Proceedings of First Australian Conference on Engineering Materials, University of New South Wales, Sydney, 1974, pp. 309-332.
3. KAR, J.N, and PAL, A.K., "Strength of Fibre Reinforced Concrete", Journal of Structural Division, ASCE, Vol. 98, 1972, pp. 1053-1068.
4. PAKOTIPRAPHA, B., PAMA, R.P. and LEE, S.L., "Mechanical Properties of Cement Mortar with Randomly Oriented Short Steel Fibres", Magazine of Concrete Research, Vol. 26, 1974, pp. 3-15.
5. ROMUALDI, J.P. and BATSON, G.B., "The Behaviour of Reinforced Concrete Beams with Closely Spaced Reinforcement," Journal of American Concrete Institute, Vol. 68, 1971, pp. 775-789.
6. SHAH, S.P. and RANGAN, B.V., "Properties of Fibre Reinforced Concrete", Journal of American Concrete Institute, Vol. 68, 1971, pp. 126-135.
7. SWAMY, R.N., "Fibre Reinforced Concrete: Mechanics, Properties and Applications", Indian Concrete Journal, Vol. 48, 1974, pp. 7-12.
8. PARAMASIVAM, P., NATHAN, G.K., WONG, K.F. and LIU, P.P., "Study of Fibre Reinforced Concrete", Proceedings of First Australian Conference on Engineering Materials, University of New South Wales, Sydney, 1974, pp. 333-350.

Development of a Semicylindrical Ferrocement Roofing System

P.J. van Stekelenburg* J.C. Walraven* and M.S. Mathews+

The article describes an experimental research program on ferrocement cylindrical archshells for roofing carried out at the Stevin laboratory of the Delft University of Technology in cooperation with Mr. M.S. Mathews, a participant of the international course on building constructions of the Bouwcentrum in Rotterdam, Netherlands.

INTRODUCTION

The object of this research program was, to develop a ferrocement roofing system of light elements, which could be introduced in self help projects. Such a roof system should fulfill the following demands.

a. The elements must be such, that they are suited to man-handling and can be assemblied and/or erected by two persons.
b. The shape must be so, that easy production and mounting of the elements is possible.
c. The minimum span may not be smaller than 3 meters, being an appropriate span of a room in rural buildings in India.
d. Unit length the roof must be capable of carrying a load-equivalent of at least a man's weight without cracks being formed.
e. The erection of the elements and construction of the joints must be simple.

The above mentioned demands are fulfilled by choosing a semi-cylindrical shape of the roof, composed of three elements with a working-length of 0.9 meter and an inner radius of 1.50 meters (Fig. 1). The actual length in the field should then be 0.8 m wide with meshes of 1.0 meter width. The weight of the such elements is relatively low: a thickness of 12 mm results in a weight of about 50 kg.

The cylindrical shape permits the use of a single mould, made of cement stabilized earth, timber or steel, which may be used numerous times.

Fig. 1. Ferrocement roof unit.

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EXPERIMENTAL PROGRAM AND FABRICATION OF THE ELEMENTS

The specimens to be tested were supported on edge beams, which were clamped with bolts to the supporting construction. Horizontal displacements were restrained.

Several layers of hexagonal mesh (Fig. 2) were used to reinforce the roofing elements.

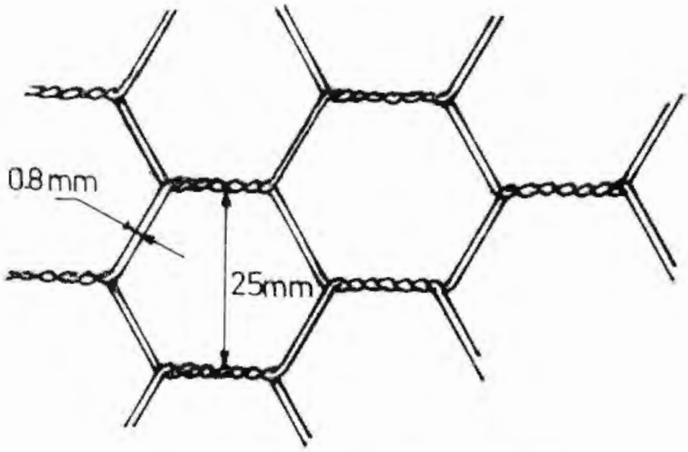


Fig. 2. Dimensions of the hexagonal mesh used.

One layer of mesh provides a total steel section of 40.2 mm^2/m. The specimens were made in lengths of 1 meter, being the width of the mesh. The parameters studied were:

a). The type of joint between the primary elements in tangential direction.
b). The number of layers of hexagonal mesh.

Four types of connections were tested (Fig. 4).

Type 1. A reinforcement overlap of 200 mm grouted in situ.

Type 2. A bolted connection, with element No. II (Fig. 1) overlapping both elements No. I.

Type 3. A bolted connection with an articulated element No. II, supported by two elements No. I.

Type 4. A so called bayonet connection, with the reinforcement of element No. II overlapping the elements No. I over a length of 200 mm in the exterior of the steel and the reinforcement of the elements No. I overlapping the element No. II over a length of 200 mm in the interior of the shell.

With respect to the number of layers of mesh two values were considered. The specimens with connection type 1, 2 and 3 were tested both with 4 meshes and with 6 meshes. These layers of mesh were placed in two phases. Half of the number was placed directly on the wooden mould used in the laboratory which was covered with a thin plastic sheet. The layers were stretched and tightly fixed at the edges. They were plastered with grout, using a vibrating rubbing board until a thickness of about 8 mm was obtained (Fig. 3).

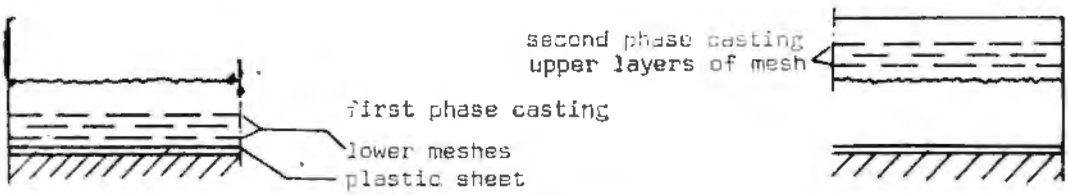


Fig. 3. Phases of casting.

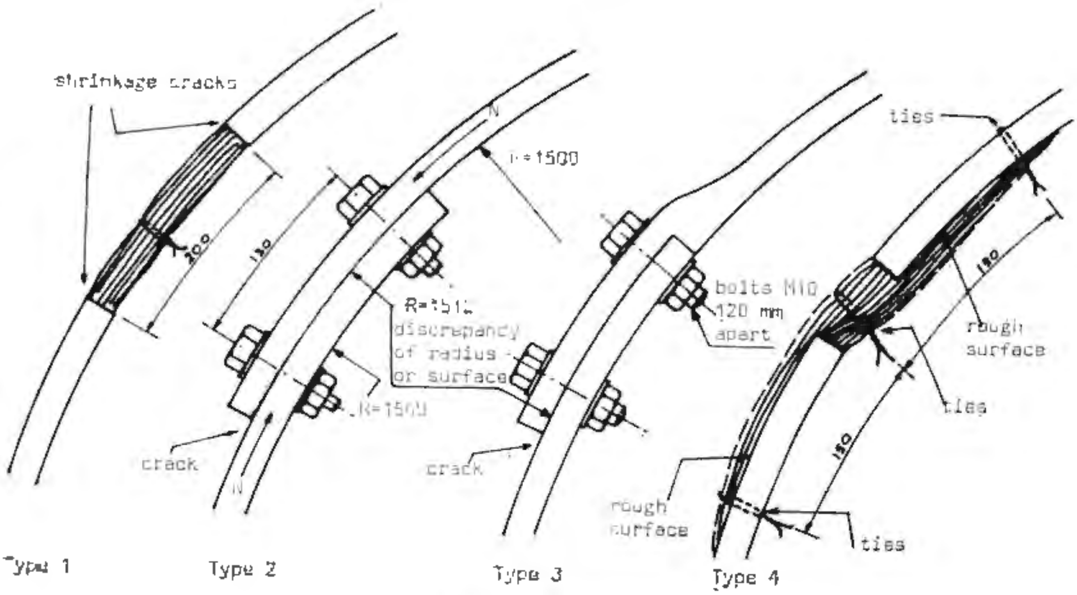


Fig. 4. Joint details.

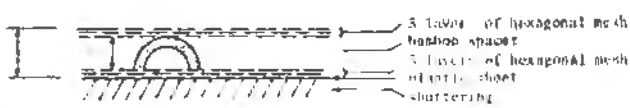


Fig. 5. Split bamboo rods as spacers to ensure greater lever arm.

In the second phase the other half of the mesh was placed on top of the 8 mm thick layer of grout, stretched and fixed properly, after which the second layer of 4 mm grout was plastered. In this way an efficient use of the reinforcement was expected. However, it appeared that the position of the stretched layers of hexagonal mesh was not always completely uniformly distributed over the cross section of the structure. Hence for the model with connections of type 4, soaked split bamboo rods were used as spacers (Fig. 5 and Fig. 7).

The elements could be lifted from the mould after 2 days. They were then cured for seven days by covering them with wet cloth and plastic sheets. Subsequently the elements were erected with the help of a scaffolding, after which the connections were grouted or bolted (Fig. 6). The strength of the mortar was measured using prisms of dimensions of 40 × 40 × 150 mm for the flexural strength and on cubes of 40 × 40 × 40 mm for the compressive strength. The edge beams had a reinforcement of 2, 6 mm diameter mild steel bars with a yield strength

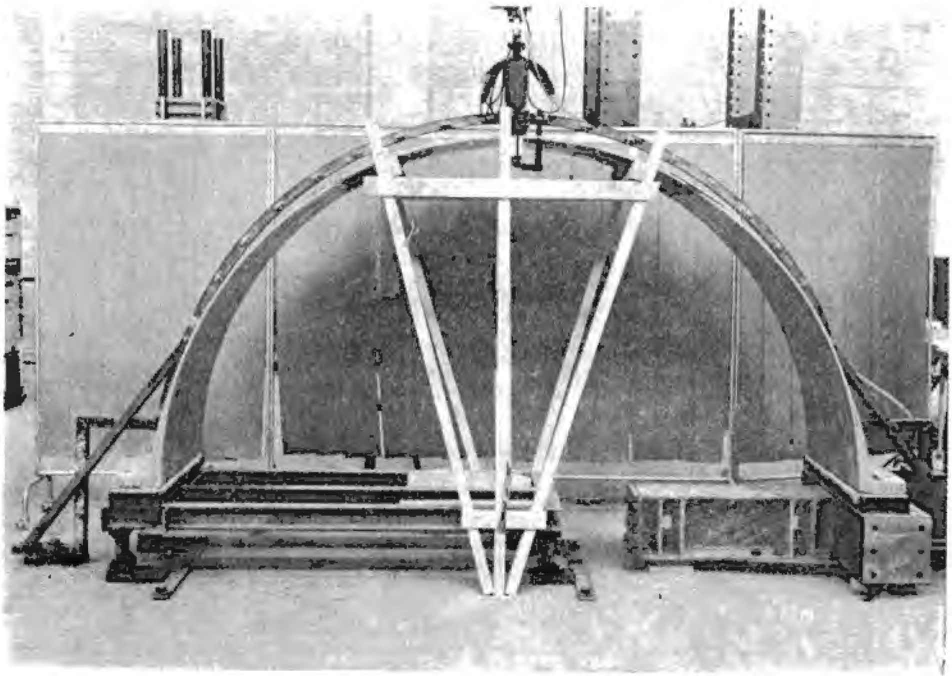


Fig. 6. Elements, supported by scaffolding.

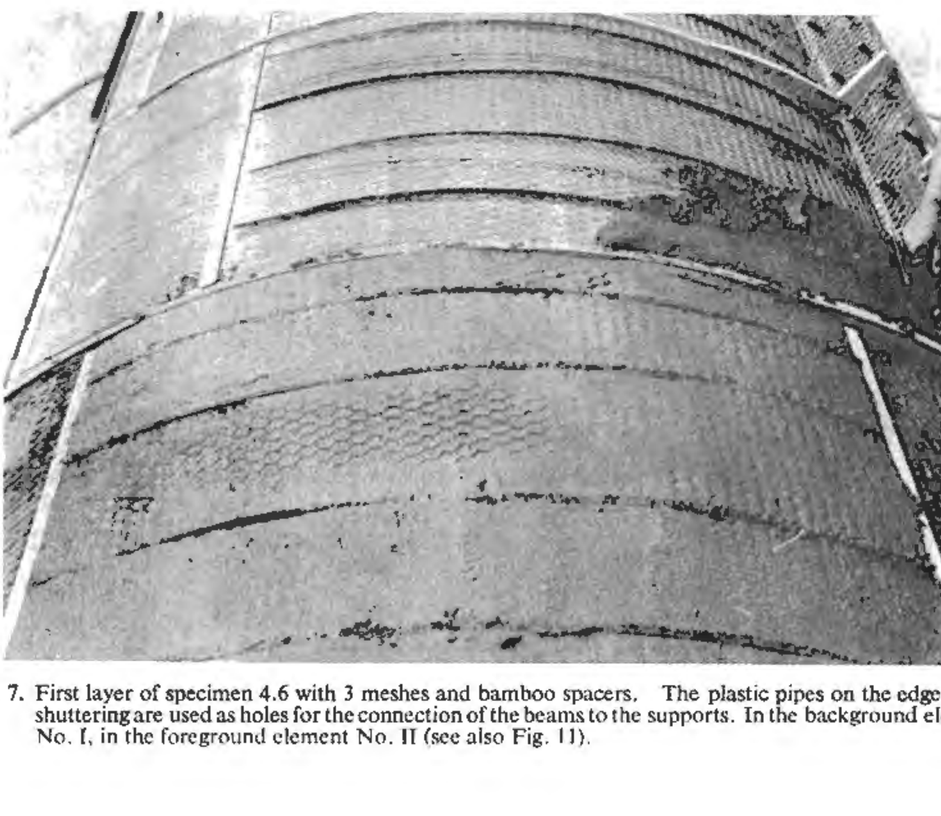


Fig. 7. First layer of specimen 4.6 with 3 meshes and bamboo spacers. The plastic pipes on the edge beam shuttering are used as holes for the connection of the beams to the supports. In the background element No. I, in the foreground element No. II (see also Fig. 11).

of 500 N/mm². The edge beams had bolted rigid connections with the supports. The loading system and measuring arrangements are shown in Fig. 8.

A survey of the test program in combination with the material properties and the actual thickness of the roof is given in Table 1.

Although the design thickness was 12 mm for all specimens, the specimens with 6 layers of mesh had a slightly greater thickness than the other ones.

Table 1. Details of the Test Program

Specimen No.	Joint type	Number of layers of mesh	Number of bolts or ties in 1 joint	Concrete		Thickness (mm)	Remarks
				Flexural strength N/mm²	Compressive strength N/mm²		
1.4	1	4	$2 \times 9\ \phi\ 1.25$	9.57	43.4	12	-
1.6	1	6	$2 \times 9\ \phi\ 1.25$	10.0	63.6	13	-
2.4	2	4	2×9 M12	10.5	63.6	12	-
2.6	2	6	2×9 M12	10.6	69.1	14	-
3.4	3	4	2×9 M12	10.2	66.1	12	-
3.6	3	6	2×9 M12	10.4	63.2	14	-
4.6	4	6	$3 \times 9\ \phi\ 1.25$	8.6	41.2	14	Bamboo spacers

TEST RESULTS

The load deflection curves are represented in Fig. 9 for the specimens with 4 layers of hexagonal mesh (Fig. 9a) and those with 6 layers of hexagonal mesh (Fig. 9b).

Table 2 presents characteristic values of the load during the test, where

P_{cr} = load at which the first cracks were observed in the top.

P_n = load at which cracks occur at the sides, near the joint connections.

P_u = ultimate load.

Table 2. Characteristic load capacities.

Specimen No.	P_{cr} kN	P_n kN	P_u kN	Condition before testing
1.4	0.7	1.2	1.3	Shrinkage cracking at joints
1.6	1.1	1.6	1.9	Shrinkage cracking at joints
2.4	1.0	1.4	1.7	Cracks caused by deviations of surface
2.6	1.4	2.0	2.6	curvature in joint, combined with the
3.4	1.45	1.9	2.0	stress in the connection bolts.
3.6	1.8	2.4	2.8	
4.6	1.5	2.7	3.5	Soaked bamboo spacers

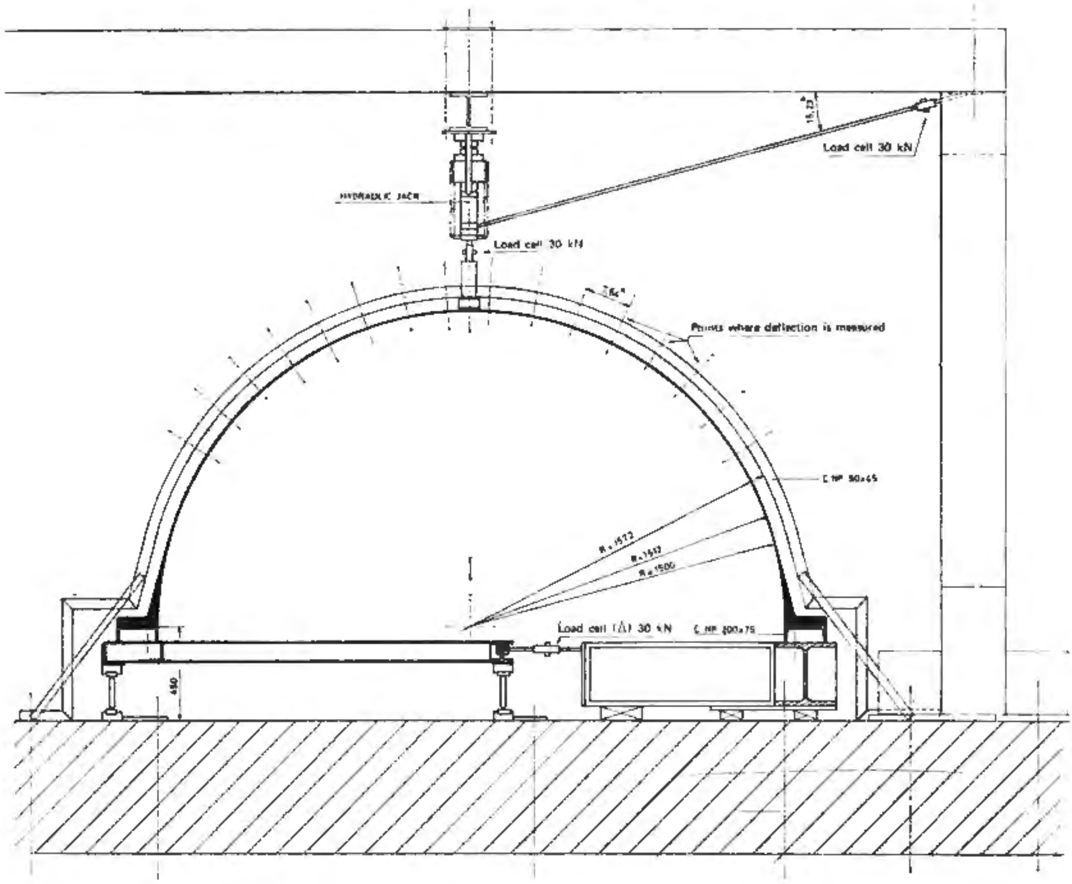


Fig. 8. Arrangements for the test of a ferrocement roof unit.

CONCLUSIONS AND SUGGESTIONS

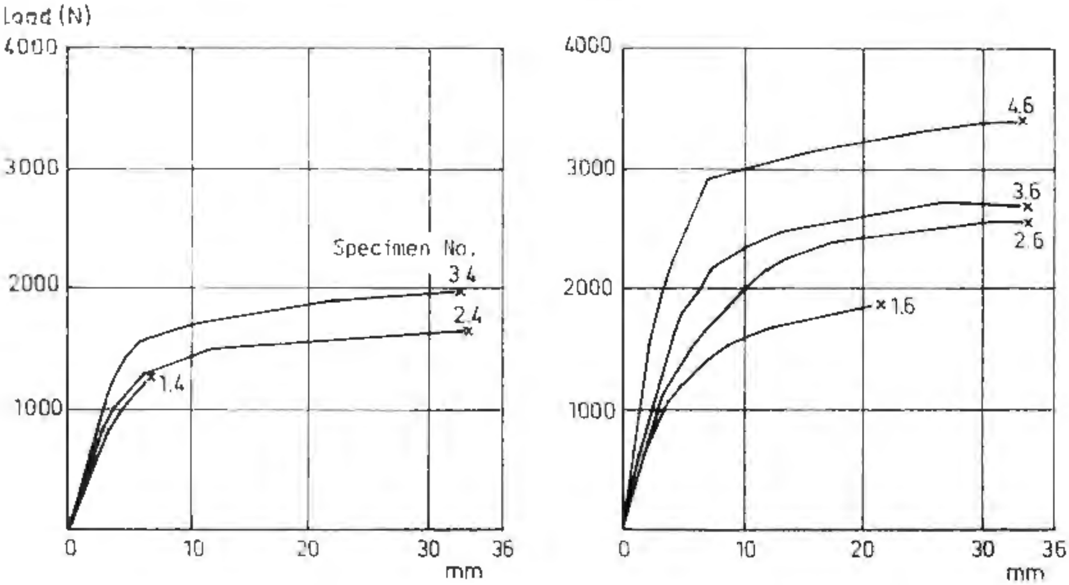
(a) The joint connections of Type 1 do not fulfill the demands because shrinkage cracks appear at the joint.

(b) The bolted connections do not fulfill the demands because of precracking due the concentrated bolt stresses combined with the differences in surface and curvature at the joints. (Outer radius = 1512 mm, Inner radius = 1500 mm).

(c) Adequate safety against cracking can only be obtained by using sufficient number of meshes. When a safety factor of 2 is required the number of meshes should be at least 6.

(d) The effect of bamboo spacers is two fold. It increases the stiffness after cracking and it increases the ultimate load.

(e) The bayonet connection gives the best result; it has none of the disadvantages of the other joint connections. It increases the stiffness of the structures in the elastic state and the value of the load at first crack. It is also more economical as when compared to bolted connections, and can be manufactured with unskilled labour.



Curves for the top deflection of the specimen with 4 layers of hexagonal mesh.

Curves for the top deflection of the specimen with 6 layers of hexagonal mesh.

Fig. 9. Load top-defleciton curves for the different series.

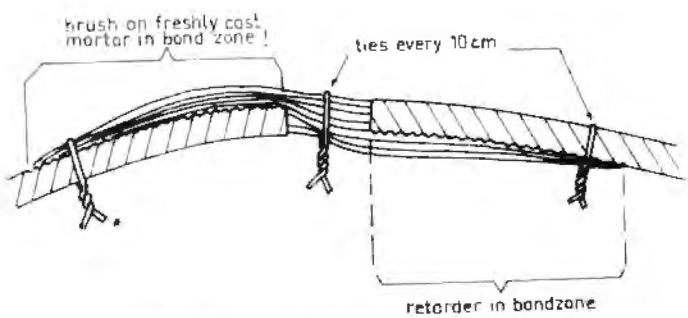


Fig. 10. Details of a proper bayonet joint.

(f) The load-deformation relation for the structure in the uncracked state can be analysed by Castigliano's method. To describe the behaviour of the structure in the cracked state, a basic theory for the behaviour of cracked ferrocement, reinforced with hexagonal mesh was developed by second author. This method is described in [1]. It appeared that good agreement between experiment and theoretical model was obtained.

(g) To obtain a proper bayonet joint connection the edges of element II should be grouted after the application of a retarder on the mould to obtain a coarse surface in the area where the reinforcement of the elements No. I and No. II overlap (Fig. 10). The elements No. I may be kept coarse in the bond zone by using a brush right after the first hardening of the mortar on the mould.

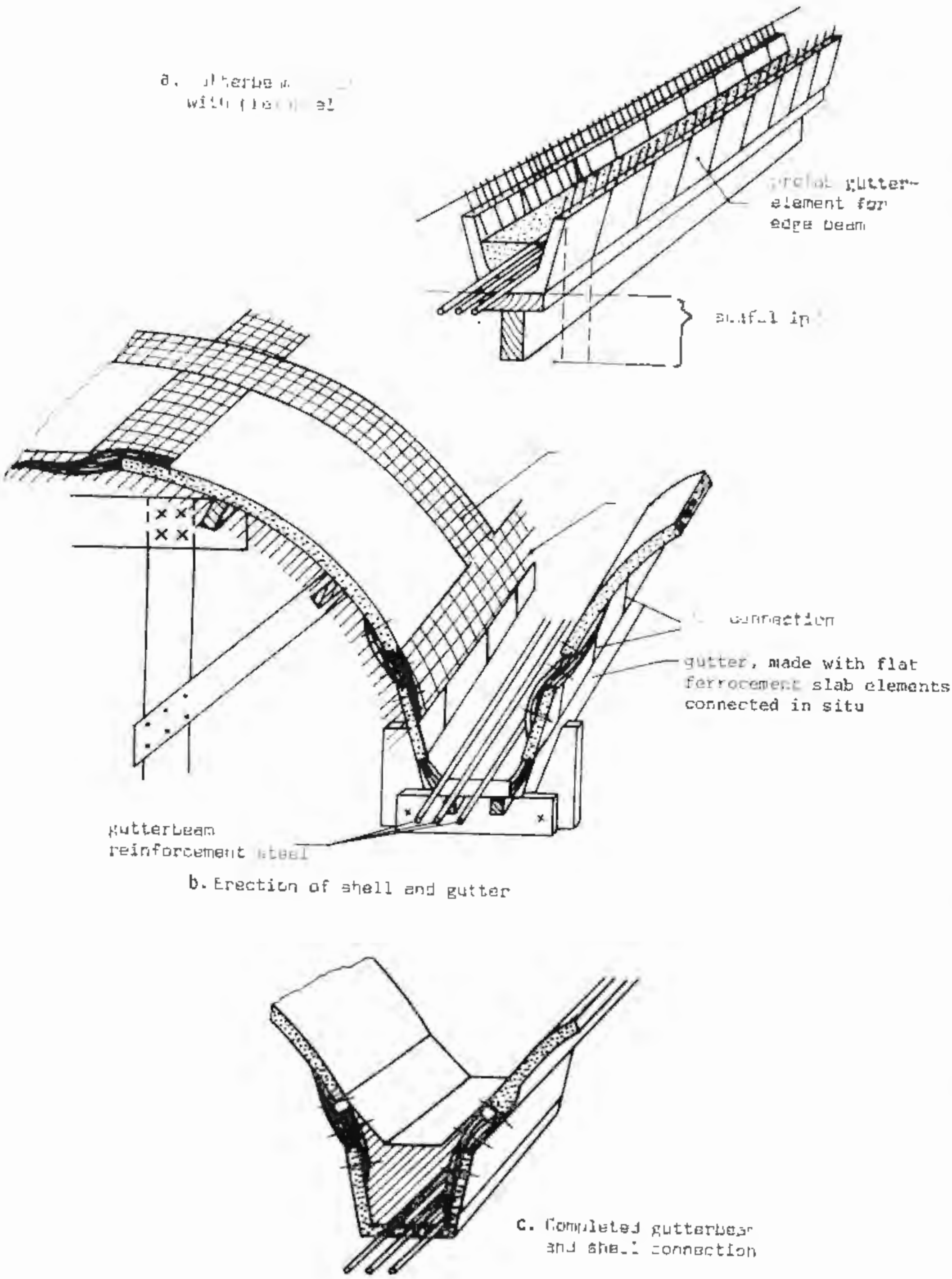


Fig. 11. Some ideas on the use of gutterbeams.

(h) The manufacturing of roof structures by using prefabricated portable elements, placed on a temporary scaffold, assembled on the site by grouting is practically feasible. The construction principle could be extended by the use of gutter elements, which may be transformed into edge beams later, Fig. 11.

REFERENCE

1. STEKELENBURG. P.J. VAN, MATHEWS. M.S. and WALRAVEN, J.C., "Development of a Semi-Cylindrical Roofing System in Ferrocement", Report No. 5-78-11, December 1978, Stevin Laboratory, Delft, University of Technology, Netherlands.

Studies in Ferrocement Applications

E.Z. Tatsa* and S.P. Prawel*

The article presents details of a multidisciplinary study being conducted by the authors at the State University of New York at Buffalo. Pooling in efforts of undergraduate and graduate level students and faculty from Architecture, Civil Engineering and Industrial Engineering, the team's acheivements in integrating education and research in identifying applications of ferrocement, are reported. It has been concluded that such multidisciplinary team undertakings initiates creative thinking and originates new and unconventional solutions to existing problems.

INTRODUCTION

Studies in ferrocement applications is a multidisciplinary project involving students at both the undergraduate and graduate levels and faculty in Architecture, Civil Engineering and Industrial Engineering. Its purpose is to provide a framework whereby students and educators can work together to achieve a meaningful educational and professional experience through the development of new and improved components for buildings and other engineered facilities using ferrocement as a material.

Traditional educational programs are usually limited to specific aspects of a partioular discipline. In reality, however very complex interconnections of apparently disjointed activities are involved. The construction industry is among the most complex of these. By bringing together in a single project several of these diverse components, the student becomes more aware of the realities of problem solving and achieves a more complete technical background because of exposure to other areas of technical activity.

The overall goal of the project is the development of useful products and corresponding construction methods using ferrocement. This material was selected for the project because of its versatility and the wide range of applications in which it can be used. The usual constraints associated with more conventional building materials are largely eliminated and more innovation on the part of the students is possible. This results from the use of relatively cheap and readily available raw materials and the simple techniques that can be used in the production process. It does not however preclude a high degree of sophistication in manufacturing.

Most of the structural applications of ferrocement that have been reported to date are relatively simple in nature and involve manual construction. Except for a few isolated cases, they do not make use of the real potential of the material as a basis for a large scale prefabricated structures industry. This project attempts to integrate education and research by examining ways whereby the full potential of ferrocement as a structural material can be exploited and how reinforced thin-walled elements should be used in construction.

PROJECT DESCRIPTION

By nature a project of the type described herein is quite wide ranging in scope. Project organization is therefore a problem. Our solution has been to first define problem type cate-

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gories. Within each category, a series of cycles are developed with each cycle, as work progresses, dealing in more detail with topics where a lack of knowledge has been identified in a previous cycle. The basic categories that have been defined are:

1. Definition of needs for new components and systems. This provides a general direction for research and development and sets the requirements for new components in terms of performance specifications.

2. Materials Investigations. This includes research dealing with basic information needed for the design of components; recommendations for materials preparation such as mixtures etc. and problems relating to production.

3. Analysis and design of individual structural elements and of structural systems employing these elements.

EXAMPLE PROJECTS

While staff interest and research in the use of ferrocement as a construction material has existed for quite some time, active student participation in the project at SUNY-Buffalo has been over the past two years. Because of this, some of the projects are still in the process of development and others continuations of work begun elsewhere. The topics are divided into two groups:

1. Projects leading to a completed product and an evaluation of its performance in use.

2. Projects involving the development of a structural system based on the use of ferrocement.

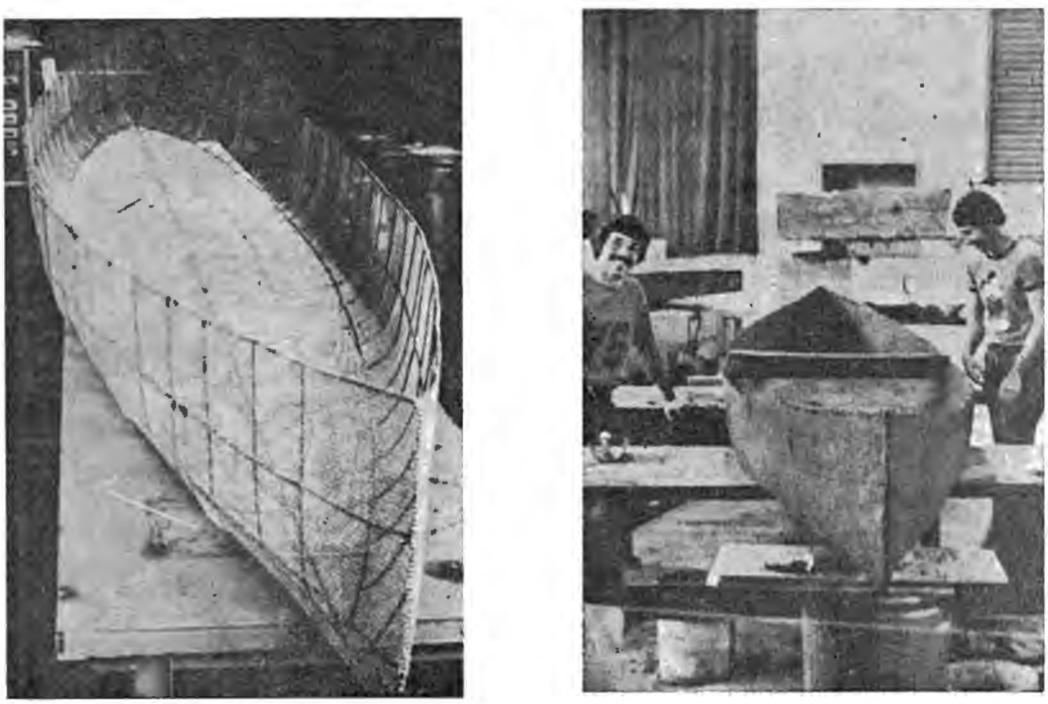
The end products of this second type are detailed research and development programs for interested industrial organizations. These projects include the design, construction and testing of prototype components.

As previously mentioned, this work is intended to satisfy more than one goal. It is not a research program as one is usually understood to be. It is also an educational vehicle for the participating students and faculty. This strongly influences both choice of specific topics and their method of execution. Some examples of projects that are either completed or well along the way are described in the following.

The Racing Canoe

The purpose of this project was to see if a group of well prepared and highly motivated students could, using only the available literature, determine the best way to design and build a competitive canoe from ferrocement. The boat was sixteen feet (4.80 m) with a 32 inch (0.80 m) beam. Two sixteen foot segments of a circle having a radius of twenty-nine feet (8.85 m) were used to define the boat. Appropriate node points were located on the shell structure and an analysis for various loading conditions carried out using the finite element method. To reduce the weight of the boat to a minimum, it was decided to use a lightweight aggregate. After selecting and testing ten mixtures with varying ratios of cement, sand and glass microspheres, a cement-aggregate ratio of 1:1.85 was selected in which the volume of glass spheres amounted to one-third of the total volume of the aggregate. The compression strength was 3780 psi (265 Kg/cm^2) which was considered to be acceptable.

The reinforcement consisted of a .135 inch wire frame with one layer of 23 gauge - 1/4 inch square galvanized mesh on each side of the frame. The overall wall thickness was approximately .25 inches and the total weight of the boat with stiffeners 175 pounds. The boat participated in races at the U.S. Military Academy at West Point and performed quite well in competition. The project in various stages of completion is shown in Fig. 1. The main technical achievement of the project was in the use of lightweight ferrocement for the construction of a boat. The idea is feasible and should be considered as a topic for further research. Information available in the literature was found to be useful but not complete.



(a) (b)

Fig. 1. Racing canoe. (a) Armature ready for plastering. (b) Plastering nearing completion.

Playgrounds for Children

This project was initiated by the Youth Conservation Council and the City of Buffalo, New York. The idea was to design and build a standardized twelve foot (3.60 m) diameter play unit for children's playgrounds which was at the same time functional and attractive. Ferrocement was chosen as the material of construction for the project because of the ease whereby unusual shapes could be attained. Holes and curves which are major obstacles in construction with many materials are easily realized with ferrocement. The prototype unit is now under construction by a group of Civil Engineering and Architecture students. A model of the structure is shown in Fig. 2.

Fig. 2. Playground project model.

Precast Housing Systems

Most of the reported applications of ferrocement in housing are based on modular roofing systems for single story units. This results from the need to attain the required stiffness by shaping the element into a shell type form. A possible use of flat ferrocement components for multi-storey prefabricated buildings was described by Bluger and Tatsa [1]. This project extends that prior work into the development of a building system using multi-purpose ferrocement components. The project can be described in the following steps:

1. Statement of the need for the new system.

2. Performance specifications.

   2a Functional - Typical floor design.
   Services supply - Transportation
   Water
   Energy conservation

   2b Structutal - Vertical elements (panels)
   Horizontal elements (slabs)
   Connections - Geometrical errors, Ductility

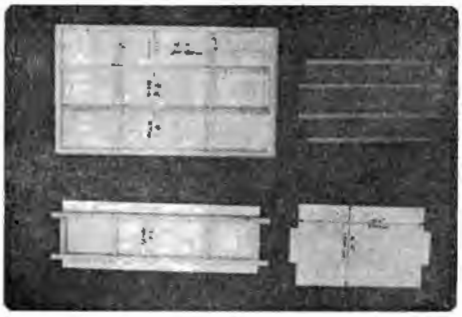
3. Feasibility -Methods of manufacturing
   Transportation
   Assembly

4. Economical Assessment

This general outline has already resulted in the definition of several problem areas which are in themselves subjects for new research. Some of these are typical of the prefabricated construction industry and could have been anticipated while others result from the new method. Some of these are (Fig. 3):

1. The use of ribbed ferrocement panels for slabs and walls. This has been partially reported by Sarid, Tatsa and Bluger [2].

2. The achievement of continuity in the new system and the need to minimize the use of cast-in place concrete while at the same time maintaining the required ductility of the structure.




(a) (b)
Fig. 3. Housing project model. (a) Component units. (b) Sample assembly

3. Material behaviour and properties of under-reinforced ferrocement. The optimization of material costs indicate the need to reduce the number of meshes in the ferrocement.
4. Long term behavior of ferrocement when underreinforced.
5. The automatic production of ribbed ferrocement panels.
6. The integration of non-structural components into the structural system. The influence of doors, windows, nonbearing walls etc.
7. Diaphragm action of shear panels of ferrocement.

These topics and others will lead to a final report dealing with the potential of ferrocement in high rise construction.

Other Topics

There are at this time a number of other topics that are also under investigation but have not reached the same stage of developments as those previously discussed. These include a ferrocement hypar unit, shown in Fig. 4, that will act as the basis for a long spanning composite roofing system.

Fig. 4. Hypar roofing unit.

SUMMARY AND CONCLUSIONS

The work described in this paper demonstrates that by bringing together a diversified group of students and faculty united in a common effort, a major change in attitude and use of a well known material such as ferrocement can be achieved. Entirely new concepts based on unprejudiced thinking can be made available for the benefit of all. A massive undertaking such as that described here can have many advantages. An educational experience integrated into a research and development program leads to creative thinking and the origination of new and unconventional solutions to existing problems in a time of decreasing financial resources. It is the hope of the authors that, in similar ways, further development of the traditionally conservative construction industry can be achieved.

ACKNOWLEDGEMENT

The authors wish to thank all students who participated in the project in past and those who take part at present. It is expected that these people will pursue the use of ferrocement in their professional carrers. Special thanks to M. Ader, K. Anderson, T. Omorodion, A. Moses, R. Spengler, S. Stevens, O. Gyebi, G. Bacile - students of the department of civil engineering at U.B. and to L. Riggs of YCC.

REFERENCES

1. BLUGER, F., and TATSA, E.Z., "Skinned Elements Made of Ferrocement for Building", Journal of Ferrocement, Vol. 9, No. 1, January 1979, pp. 35-40.
2. SARID, M., TATSA, E.Z., and BLUGER, F., "Ribbed Slabs Made of Ferrocement", Journal of Ferrocement, October 1979, Vol. 9, No. 4, October 1979, pp. 185-189.

Use of Ferrocement for Waterproofing

P.C. Sharma*

A rather unique application is discussed in the article—Waterproofing. Construction notes on this innovative application has been presented based on experiences with numerous practical applications of the process described. Economical and functional comparisions of ferrocement waterproofing layer with other conventional methods of waterproofing has also been presented.

INTRODUCTION

In tropical countries flat roofs constructed with reinforced cement concrete, reinforced brick work or assembled precast concrete components, often exhibit water leakage. The cause for such leakage may be a honeycombed or poorly compacted concrete surface or a defective water proofing layer over it. A faulty joint design, cracks developed due to various reasons or, water ponding due to improper slopes, may be other causes for the leakage. In India and neighbouring countries traditional water proofing is generally carried out by providing a layer of well compacted earth for providing insulation and drainage slopes, with a layer of 8 cm to 15 cm thick, lime : surkhi (pozzolana) : brick-bat concrete laid over it. Proper compaction of lime concrete is achieved by slow beating of the lime concrete layer. This is a very skilled job. Because of the high labour cost, poor labour output and non-availability of the traditional labour for this type of job at times of the compaction of lime, terracing is not proper and it fails to function and the roofs start leaking. Present-day roofs are also provided with waterproofing (Fig. 1) layers using tarfelt and mexafalt (bitumen). Success of this treatment also depends largely upon the skill and precautions used in laying the treatment, temperature and moisture content of roof surface, proper boiling of mexafalt/bitumen, quality of tarfelt and the hessian cloth used. In case the roof surface has more moisture content than desired or the bitumen is not properly boiled and carries air bubbles to the surface with it, separation of tarfelt layer from concrete surface may take place (because of moisture getting converted into vapours) with the formation of tarfelt domes filled with evaporated moisture. In such conditions pointed loads may mechanically damage the water proofing layer. Sometimes this happens within a short period of 2 to 3 years.

If adequate quantity of acceptable quality of bitumen is not used as glue for fixing the tarfelt over roof or the bitumen gets cold by the time tarfelt is pressed over the roof surface, this may also result in separation of tarfelt from roof and ultimately damage the water proofing layer.

Use of polythelene films and its laminates with paper have also been attempted for the purpose of water proofing treatment but have not gained much popularity because of its puncturing during laying and requirement of a separate protecting layer (additional) over the film treatment.

Ferrocement has very valuable characteristics in that, it is highly crack resistant, and it can withstand thermal changes very efficiently. It also obtains very good bond when laid over surfaces of concrete or brickwork. As a result of its crack resistant and impervious surface,

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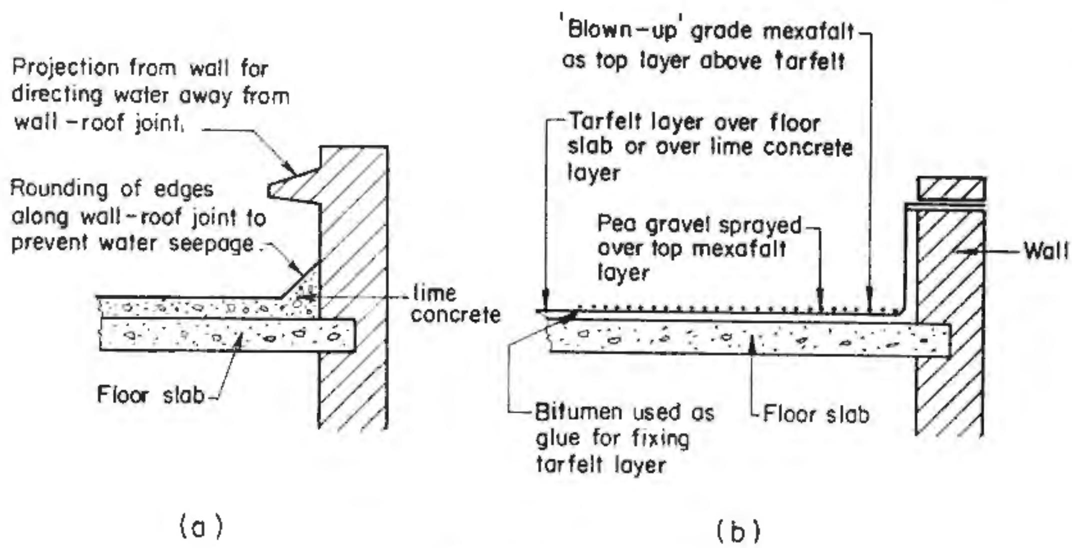


Fig. 1. Present waterproofing methods.

most of the ferrocement structures do not require separate water proofing treatment over them. Taking advantage of these characteristics, ferrocement has been successfully tried out for providing waterproofing treatment over other concrete/reinforced brick, stone and even wooden structures. First reported use of ferrocement, as a waterproofing layer was made by Architect Jorn Utzon, many years ago, over reinforced cement concrete roof of New Sydney Opera House in Australia. This sail shaped roof was covered with tile shaped surface panels of ferrocement which serves as waterproofing layer for the roof below.

Ferrocement is a form of reinforced concrete in which the matrix of cement and sand mortar, is reinforced with two or more closely spaced welded or woven steel wiremesh layers which are distributed throughout the depth and area of the structure (Fig. 2). Wherever extra rigidity and strength is required, M.S. rounds or G.I. wires of small diameter or welded wire fabric can be provided in addition to woven meshes.

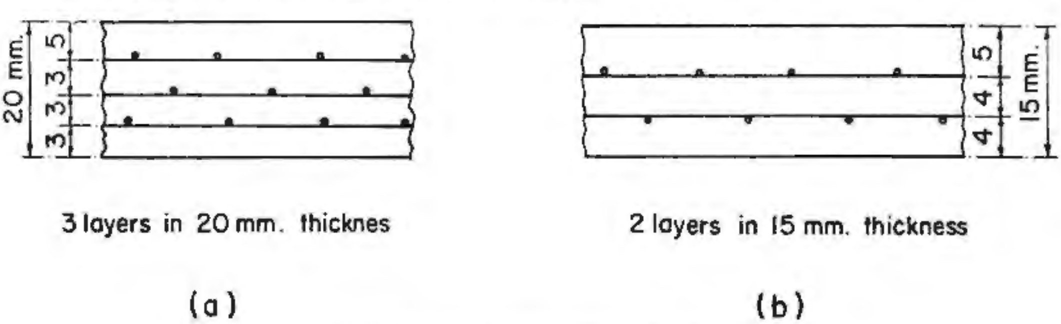


Fig. 2. Typical sections for ferrocement waterproofing layers.

WHY FERROCEMENT FOR WATERPROOFING?

Ferrocement exhibits quite different behaviour from reinforced cement concrete in performance and strength, because of its dispersed steel. It provides higher tensile and flexural strengths, better resistance to impact, fracture and fatigue. It also provides a crack free, tough, dependable surface free from danger of leakage and corrosion. These improvements in characteristics are due to the fact that concrete can undergo large deformations in the neighbourhood of its reinforcement. Since reinforcement in ferrocement structures is provided in the form of well distributed wiremesh layers, it can carry larger strains-deformations without cracking during its service. High specific surface and distribution of reinforcement also result in an efficient and improved crack arrest mechanism, which results in higher tensile strength. When this material is able to provide a surface free from danger of cracking and offers a highly impervious layer, it can be safely adopted for waterproofing treatment of other structures constructed with reinforced concrete, reinforced brick work and stone slabs. Especially, for the precast roofing systems which are susceptable to leakages at the joints.

Convinced by the excellent performance and the merits of ferrocement (established in the field and the results of the laboratory investigations carried out at the Structural Engineering Research Centre, Roorkee (India) and elsewhere), SERC recommended use of ferrocement for waterproofing of old and new structures. The technology was first tried out on various buildings belonging to various industrial and educational organizations at Ahmedabad (India) through M/s. Sarabhai Technological Development Syndicate in 1976. More than a dozen buildings including factories, offices, residences have been waterproofed with ferrocement and since then all these structures have been performing very well. Some of them even carry terrace gardens and lawns over the waterproofing treatment.

MATERIALS FOR FERROCEMENT WATERPROOFING

Material used in ferrocement waterproofing could be divided into two groups:

1. Materials used for matrix or the mortar.
2. Reinforcement.

The mortar binds and protects the wiremesh reinforcement of ferrocement. It is normally made with Portland cement and ordinary silica sand except in cases of structures to be built or used in corrosive atmosphere where sulphate resisting cement may be used) and its properties depend solely on the quality of its constituents (cement, sand, admixtures and water), mix proportions, climatic conditions and the method and procedure used for its making.

The aim of the selection for the constituents should be to achieve a composite which has highest possible: (1) compressive strength, (2) hardness, (3) impermeability, (4) compacted surface free from voids even behind reinforcement, and (5) resistance to normal chemical attack.

Cement

Ordinary Portland cement confirming to IS:269, ASTM C-150 can be used for ferrocement waterproofing layers. Cement should be free from lumps, adultration or partial setting. Pozzolana or flyash mixed cements may be used provided the percentage of these additives are within specified limits and the additives used satisfy requirements of ASTM class N pozzolana. Tests and checks may be carried out before use to ascertain the setting properties and strength. In case of very cold weather, rapid hardening cement can be used, but use of clacium chloride as additive in the mortar is avoided as an excessive dose of this chemical may initiate corrosion in meshes.

Sand

Sand selected should be well graded having particles of 1.2 mm to 0.3 mm size and confirm to ASTM C-33-74a. Hard and sharp silica sand is preferred. Natural sand is better than crushed stone powder. The percentage passing through B.S. sieve No. 100 should not be more than 5-10%. The sand is sieved (to remove larger particles above 1.2 mm) through a sieve having openings of 1.2 mm size. Sand should be free from organic matters. Chemical effects, silt/clay and vegetation, etc. It is better to wash the sand for removing silt and soluble salts. Porous sand should not be used for waterproofiing jobs. A sand with a fineness modulus between 2.2 to 2.4 is preferred as it gives an excellent dense mortar.

Waterproofiing Compound

Standard products available in market for use as waterproofiing admixtures for cement concrete can be used in the matrix at a rate specified by its manufacturer.

Admixtures in powder form may be sieved through B.S. 100 sieve and mixed thoroughly with the cement in the dry form for ensuring even distribution throughout the mortar.

Water

Water fit for human consumption may be used for mixing and curing. Water should be free from impurities like oil, grease, organic matters and chemicals.

Wiremesh

Galvanized woven square wiremesh made of 20, 22 or 24 gage wires spaced at 10 to 12 mm centers (both ways) is preferred but hexagonal woven mesh of 20 to 24 gage with 10 to 12 mm opening can also be used. Square mesh provides better rigidity. Hexagonal mesh may be used for waterproofing jobs for smaller buildings and water ponds, etc. For larger size roofs, basements and water storage structure linings woven square mesh is recommended.

The wires, with which the mesh is manufactured should have an ultimate tensile strength of at least 36 kg/mm^2. Mesh surface should be free from rust, grease and oil stains. The galvanized mesh may be sprayed with water 36 hours before use, so that the salts present at the surface are converted into oxides which can be brushed off.

MIXING OF MORTAR

Mixing of ingredients be weight is recommended. Cement is premixed with waterproofing compounds. Then this mixture is dry-mixed with sand thoroughly. Water-measures made of metal or plastic may be used for measuring and adding water. Use of a concrete mortar mixer is recommended. Small hand operated concrete mixers can also be used as materials handled are comparatively less in quantity. Hand mixing is not preferred but carefully carried out hand mixing has been observed to give satisfactory results.

CONSTRUCTION NOTES

Ferrocement Lining Over Old Flat Roofs

(a) Old waterproofing treatment like lime concrete, tarfelting, etc. is first removed and parent conctete surface is exposed.

(b) Surface is checked thoroughly and if there are any cracks in concrete surface these are marked. In case defective construction joints or honeycombed areas are located these are also to be marked carefully. Quite often dry surfaces do not reveal actual crack positions. In such a case water is sprayed over exposed surface for exposing crack positions.

(c) In case cracks, honeycombed areas or defective construction joints are located, mortar in the adjoining area is chiseled to get a 'V' shaped groove. The adjoining surface on both sides of the groove is made rough. Water is sprayed over the surface for saturating the dry mortar. The cement slurry is sprayed and brushed over the groove and rich cement sand mortar (1:2) is packed in it. Waterproofing and water reducing admixtures may be added both in the cement slurry and mortar.

(d) Roof slopes are checked, depressions are marked with chalk and slopes are corrected by filling and levelling the depressed areas with lean concrete or mortar. Correction of slopes is a very important step.

(e) Two layers of galvanized square or hexagonal mesh, made with 20 to 24 gage wires with 12 mm opening, is stretched and nailed over the cleaned and washed roof surface. 5 mm cover blocks or 5 mm G.I. wire pieces are inserted between roof and the mesh and in between the two mesh layers for keeping meshes at desired positions and for maintaining proper cover. Mesh surface is cleaned with hard steel wire brush. Earlier repaired cracks or slope defects are kept moist.

(f) Cement slurry is sprayed over the roof surface and 1:2.5 or 1:3 (cement:sand, by weight), mortar is mixed applied and trowelled in to the meshes and over the roof area. 2 to 4% waterproofing compound is added in the mortar used.

(g) Mortar is applied to cover the mesh layers completely with a top cover of 3 to 4 mm. Hard trowelling is carried out over the suface for levelling finishing is done using a wooden float.

(h) In case of roofs projection beyond walls. Waterproofing treatment is carried over the edges of the roof or parapet walls as shown in Fig. 3a. For roofs having parapet walls the lining is taken over the parapet top or inserted in the wall with one or two masonary layers above it as shown in Fig. 3a, b and c.

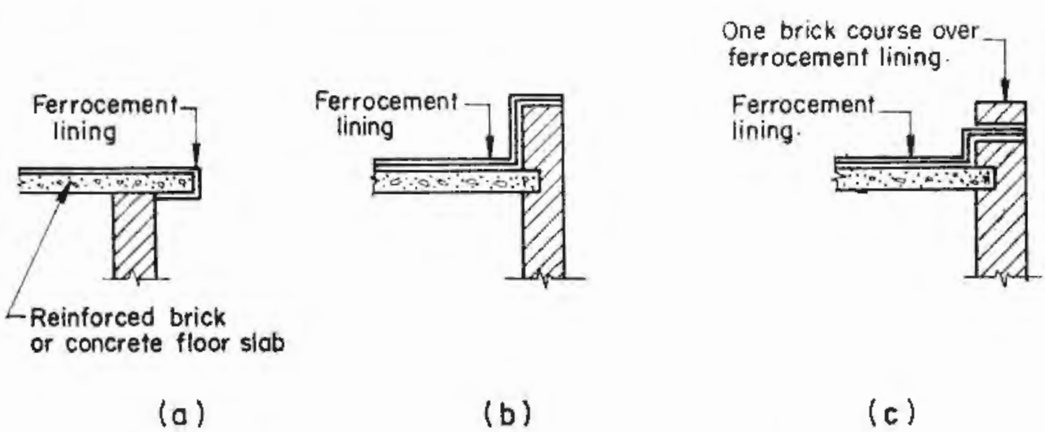


Fig. 3. Three types of waterproofing treatment (using ferrocement) over flat roofs.

(i) Curing is carried but for 14 days and only then it is permitted to dry slowly. Thin brick tiles or 2 cm thick cement concrete tiles may be laid and joints grouted and cured if desired. Figs. 4 to 9 show various stages of ferrocement waterproofing treatment of an old reinforced brick work roof at SERC, Roorkee.

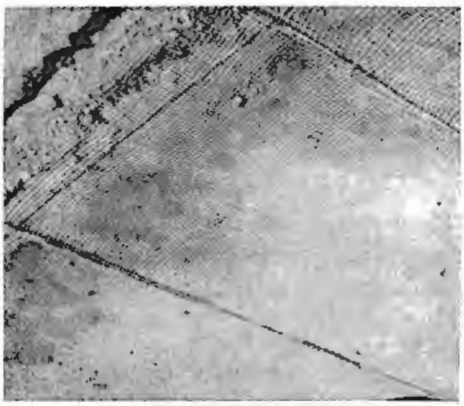


Fig. 4. Wiremesh laid over flat roof using mails and 6 mm ϕ mild steel bars at 1 m center (both ways)

Fig. 5. For intermediate columns, wiremesh from roof is taken over to columns for an effective waterproofing treatment.

Fig. 6. While plastering, wiremesh layers are lifted up using a hook so that a cover of 3-4 mm could be provided below the bottom layer of wiremesh.

Fig. 7. Mortar is to be pushed under the wiremesh layers using the lifting hook.

Fig. 8. If plastering cannot be finished within a day, the edge of a half-done job is tapered to improve adhesion with subsequent patch of mortar to be placed.

Fig. 9. Wooden float is used for levelling and finishing the ferrocement layer.

Ferrocement Layer Over New R.C.C., Reinforced Brick or Stone Block Slabs

Ferrocement can prove to be a very successful long term waterproofing treatment for new construction of reinforced cement concrete, reinforced brick slabs or stone block slabs. This can cut down unnecessary dead weight of lime terracing over roof structures. Ferrocement lining is only 15 to 20% in weight when compared to brick/lime concrete terracing. Cost-wise and weight-wise ferrocement treatment competes well with tarfelting when these are compared for their respective service lives.

The procedure for laying the lining remains same as already described as for old roofs, but in new construction the slopes can be set right at the time of laying of the slab. If the slopes are perfect then no additional material or labour is required for slope setting at the time of waterproofing.

Waterproofing of the structure can be carried out immediately when it is ensured that no further construction operations are going to be carried out over the roof. Surface of roof/slab to be treated should be left rough, at the time of casting of slab itself for better bond with ferrocement waterproofing.

Expansion joints may be treated as shown in Figs.10 and 11. Drain points or spout positions should be treated as shown in Fig. 12.

Ferrocement Waterproofing Over the Roofs Assembled with Precast Roofing Elements

The procedure adopted for preparation of surface remains same as in case of reinforced concrete flat roofs. The precast units are laid in position and joints are filled after adjusting the gaps, as per the construction practice for precast roofs. The joints are kept rough to improve ashesion of the subsequent mortar layer. Joints are cured for at least 3 days before wiremeshes are laid in the manner described in procedure for lining over flat roof. Wiremesh can be fixed on joints made of moncrete or mortar using nails that are driven when mortar is wet. Mortar is applied and finished as described earlier. Fig. 13 shows ferrocement lining over a precast channel roofing system.

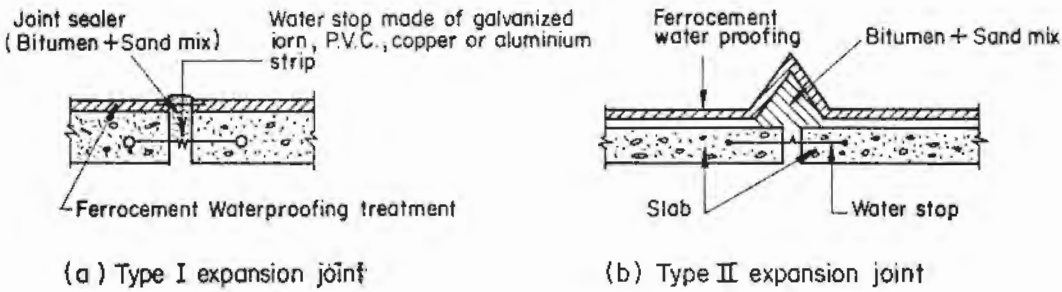


Fig. 10. Ordinary types of expansion joints to be used for the ferrocement waterproofing layer.

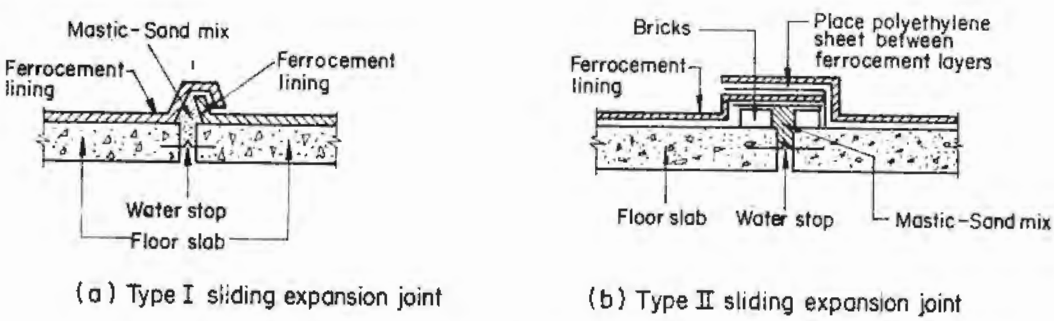


Fig. 11. Sliding types of expansion joints to be used for the ferrocement waterproofing layer.

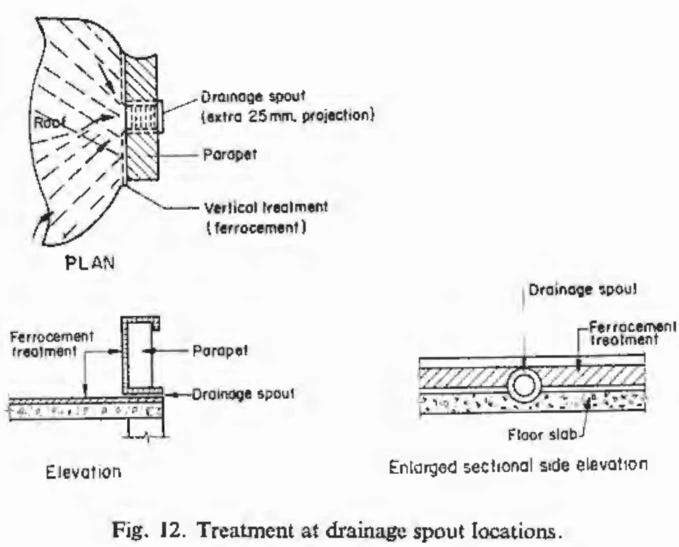


Fig. 12. Treatment at drainage spout locations.

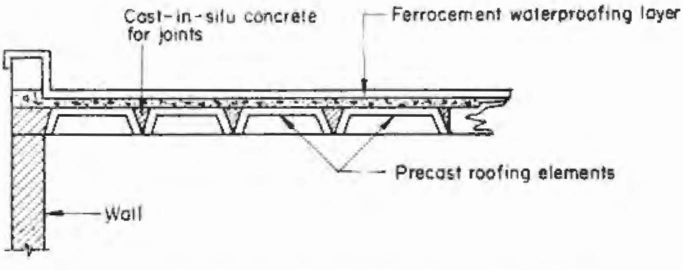


Fig. 13. Ferrocement waterproofing over precast roofs

Waterproofing of Earthen Water Ponds with Ferrocement

The work carried out in Ethiopia for construction of underground pit silos provide a good guideline for waterproofing of such ponds. The work is carried out in the following steps:

(a) If an existing pond or pit is to be lined then its base and walls are thoroughly cleaned, levelled and all loose earth is removed.

(b) 5 to 8 cm thick layer of hard-core is laid on the floor of the pit with lean concrete 1:3:6 cement:sand:aggregate or lime concrete 1:2:4) (lime:pozzolona:brick aggregate 3/4" and down.)

(c) A plaster coat of cement:sand mortar (1:4) is applied with trowel or hand on the vertical or slopy earthen wall surface of the pit.

(d) When the mortar layer is green, galvanized iron wire nails are fixed in the mortar by keeping the head projecting out by 6 to 12 mm in a zig zag pattern as shown in Fig. 14. The surface of mortar is made rough and is permitted to set for 24 hours.

(e) Minimum two layers of hexagonal or square mesh are fixed on the wall (depending upon the size) and base surface with the help of the nails fixed in the mortar layer. A lap of

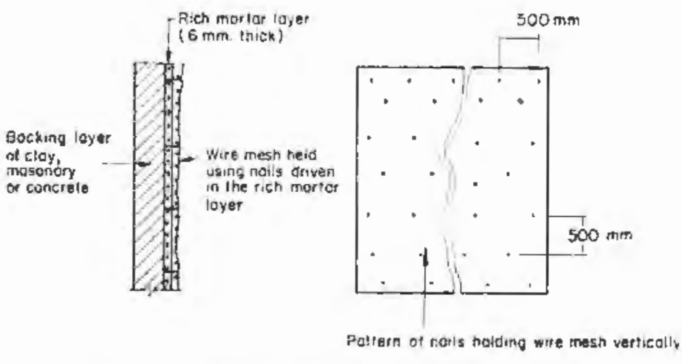
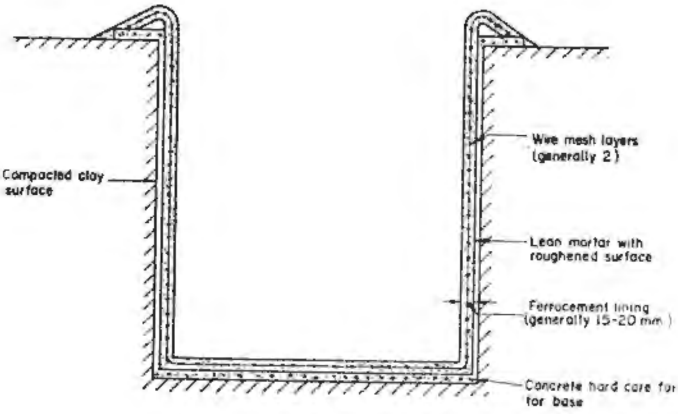


Fig. 14. Use of nails for fixing of meshes on vertical surfaces.

minimum 15 cm is provided at the wall-base junction by taking the wall mesh over to the base and vice versa (Fig. 15a).



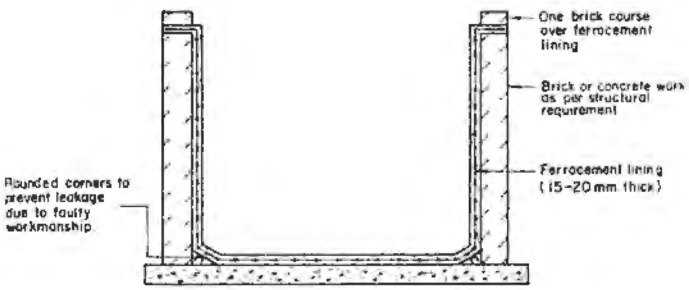


Fig. 15. Ferrocement treatment of pits: (a) Earthen pit, (b) Masonary pond.

(f) Mortar is applied in one or two layers, obtaining a 2 to 3 cm thickness. Thickness and number of meshes will depend upon site conditions and size of the pond. In most cases it is preferable to avoid sharp corners.

Lining of Masonry Tanks with Ferrocement

The method is similar to the one described for lining earthen water ponds. The masonry surface is thoroughly washed, cleaned and chieselled to remove all loose or decayed material which may reduce bond between masonry and ferrocement surfaces. In case of very old structures, surface chieselling is essential as the inner face of pond may have algae or fungal growth on its surface. Nails may be driven in the mortar joints of the masonry over vertical walls as shown in Fig. 14. This is required to hold the treatment during application and also provide mechanical anchorage. Fig. 15b and Fig. 16 shows the ferrocement waterproofing treatment for masonry tanks and a swiming pool respectively. Old water ponds have been treated using ferrocement as waterproofing treatment at Ahmedabad few years ago and their performance is encouraging.

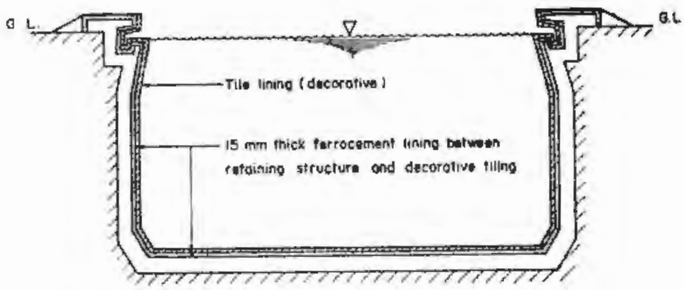


Fig. 16. Ferrocement treatment of a swimming pool.

Ferrocement Used as Protecting-Cum-Waterproofiing Layer for Wooden Structures

Old wooden structures having historical value or new wooden structures (requiring perfect protection from weathering for increasing the life and also for keeping these in the original shape) can be easily protected with the help of ferrocement lining at an economical cost.

Fig. 17 shows one of the wooden structures, in Hansol Village near Ahmedabad waterproofed with ferrocement. The roof shells are made with marine plywood panels supported on a steel framework. The original waterproofing treatment suggested was tarfelting, but 1 cm thick ferrocement layer reinforced with two layers of hexagonal mesh24 g 3/8", proved to be more economical and was used over these roofs in 1976. The surface could also be painted to

Fig. 17. Ferrocement waterproofing and protective layer over wooden roof, Ahmedabad, India.

improve the asthetics. This treatment is expected to serve for over 20 years as against 3 to 4 years for tarfelt. Observations made in the past 3 years have encouraged the users in adopting it for many more structures of this type.

Ferrocement Waterproofing Treatment for Basement

Waterproofing treatment of basements require special care as during rainy seasons the rising water table contributes to seepage of water through walls. Ferrocement has been successfully used for treatment of basements walls as shown in Fig. 18. After curing and drying of ferrocement layer a thick coat of mexafalt hot boiled is applied over the ferrocement layer before back filling of earth.

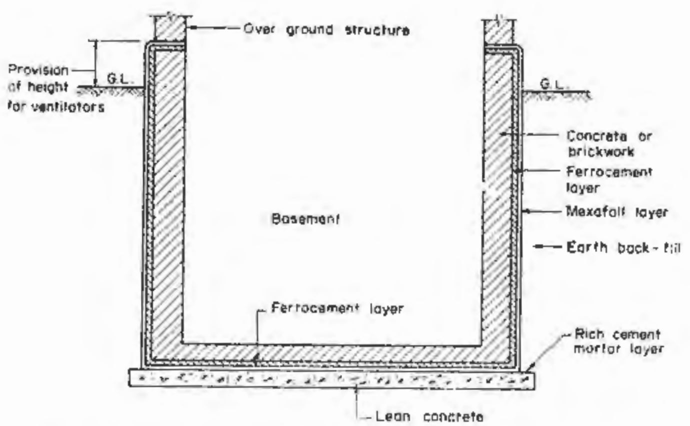


Fig. 18. External ferrocement waterproofing layer for basements.

PRECAUTIONS

Although certain precautions have been mentioned earlier in the construction notes, the author believes that the following additional precautions are essential for perfect ferrocement construction:

(a) Mesh layers should be nailed to hold the mesh taut. A frame of 6 mm diameter mild steel bars at 1 m centres (both ways) should be provided for larger roof areas to hold the mesh taut. A minimum of 10-15 cm overlap should be provided at all mesh joints. Mesh layers should be misaligned (staggered) so that the effective opening is reduced to half of the individual mesh openings.

(b) Proper impregnation of the mortar is essential for a good ferrocement construction. Wiremesh layers should have adequate covers. Final finish with a wooden float is suggested as a steel float tends to bring cement onto the surface thus disturbing the consistency of the mortar mix.

(c) If any tiling work is to be undertaken over the ferrocement waterproofing, it can be done immediately when the mortar layer is finished (Fig. 19).

(d) Proper curing is as important as proper application of the mortar, for all types of ferrocement construction. After about 12-14 hours depending upon climatic conditions, ferrocement layer can be cured. Curing could be done by either covering the entire exterior surface by

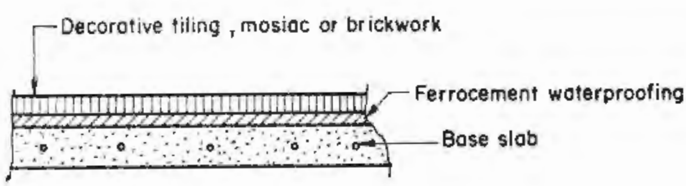


Fig. 19. Optional use of decorative tiles over ferrocement waterproofing layers.

polyethylene sheets or by using moist jute bags over it. In case moist jute bags are used, they should be kept continously moist by sprinkling water over them in regular intervals. Water can be ponded over flat surfaces by providing temporary sand or clay bunds, after 24 hours. The ferrocement surface should be kept wet for a period of not less than 14 days.

ACKNOWLEDGEMENTS

The author is thankful to Prof. G.S. Ramaswamy, Ex-Director, SERC, Roorkee for guidance and encouragement, Sri Gautam Sarabhai and Smt. Gira Sarabhai of Sarabhai Technological Development Syndicate, Ahmedabed (India) for the information and encouragement by trying out this material for waterproofing treatment. This paper is published with the permission of Scientist-in-Charge, SERC, Roorkee (India).

APPENDIX I

Some of the Structures in India Where Ferrocement has been Used for Waterproofing

Building	Location	Job description	Completed in
Calico Mills	Ahmedabad	Old RCC roof slab of the textile mill was waterproofed	November 1976
Glass House	Ahmedabad	Terrace at this retreat waterproofed. 6" soil layer over ferrocement is used for a terrace garden.	November 1976
		Precast floor units were covered with a layer of ferrocement and ferrocement tiles	November 1976
Shahibag House	Ahmedabad	Brick masonary spray pond for the airconditioning plant was lined with ferrocement.	November 1976
Steel House	Hansol	Servants' quarters flat slab was waterproofed	April 1977
B.M. Institute	Ahmedabad	RCC roof slab of the guest house waterproofed.	October 1977
Glass House	Ahmedabad	Porch wooden roof waterproofed	January 1978
Steel House	Hansol	Ferrocement on top of plywood shells with a layer (38 mm) of glass-wool insulation in-between	April 1978
SERC	Roorkee	Precast roof with prestressed burnt clay hollow block roofing of the testing machine annexe waterproofed.	April 1978

APPENDIX I (Cont'd)

Building	Location	Job description	Completed in
Raipur Haveli	Raipur	Old building roof waterproofed.	February 1979
Shantisadan	Ahmedabad	A 50-year old building roof treated with ferrocement.	March 1979
SERC	Roorkee	Casting shed annexe waterproofed	March 1979

APPENDIX II

Cost Analysis for Ferrocement Waterproofing of a Swimming Pool

For all the computations a-100 ft^2 area of 15 mm thick ferrocement layer has been assumed. Since vertical surfaces require additional reinforcement, the unit costs have been accordingly presented separately for horizontal and vertical surfaces. All costs listed are based on local conditions in India (August 1979) and could vary depending on location and time (Indian Rs. 8.20 = US$ 1).

Horizontal Surface

Item	Quantity required	Unit cost (Rs)	Cost (Rs)
Materials:			
Cement	1.3 bags	22.00/bag	28.60
Sand (sieved and graded)	4.0 cft	0.80/cft	3.20
Waterproofing compound	1.3 packs	4.00/pack	5.20
Water reducing/anti-shrinkage compound	1.3 packs	8.00 packs	10.00
Nails	-	-	5.00
Wiremesh (2 layers of 24 ga 12 mm hexagonal mesh)	200 ft^2	0.40/ft^2	80.00
Labour:			
Wiremesh fixing	-	-	15.00
Mortar application	-	-	30.00
Curing	-	-	5.00
Total cost (100 ft^2)			182.00

Vertical Surface

Item	Quantity required	Unit cost (Rs)	Dost (Rs)
Material:			
Cement	1.3 bags	22.00/bag	28.60
Sand (sieved and graded)	4.0 cft	0.80/cft	3.20
Waterproofing compound	1.3 packs	4.00/pack	5.20
Water reducing/anti-shrinkage compound	1.3 packs	8.00/pack	10.00
Nails	-	-	6.00
Wiremesh (2 layers of 22 ga 12 mm hexagonal mesh)	200 ft^2	0.60/ft^2	120.00
Labour:			
Wiremesh fixing	-	-	15.00
Mortar application	-	-	35.00
Curing	-	-	5.00
Total cost (100 ft^2)			228.00

These result in the following unit costs per m^2 of area to be waterproofed:

Horizontal surface : Rs. 19.56/m^2
Vertical surface : Rs. 23.80/m^2

APPENDIX III

Cost Comparison With Other Conventional Methods of Waterproofing

Material	Unit cost (Rs/m^2)
1.*12 mm thick ferrocement with 2 layer of 22 ga, 12 mm hexagonal mesh	26.00
2.*12 mm thick ferrocement with 2 layers of 24 ga, 12 mm hexagonal mesh	22.18
3. Lime concrete terracing	30.00
4. Four course tarfelt treatment	30.00
5. Lining with aluminium foil and rubberoid solution	28.00

*Rates quoted by Sarabhai Technological Development Syndicate during August 1979.

All other rates are also 1979 rates. Please also note that the service life of items 4 and 5 are only about 4 and 5 years respectively.

Ferrocement in India — At the Threshold of Commercial Production

V.S. Gopalaratnam*

India has made noteable headway in the development of ferrocement particularly for essential applications in housing and farm storage structures. Although trials with the material have been reported to be undertaken as early as 1970 [1] the imperative need for commercial exploitation of the versatile material has only recently gained momentum. Paul [2] reported of the work done by a number of institutions investigating the engineering behaviour of the material besides mentioning a few applications that had been developed on a proto-type scale. Since then, renewed optimism in the material has seen it through stages during which many of these applications have outgrown into competitive commercial products. The present article results from a first-hand survey by the author, of a few research institutions and numerous other commercial establishments in India. Although no claim to comprehensiveness of this report is made, it covers activities of most of the establishments in India involved in commercial production of ferrocement items. The following sections describe the primary activities of the organizations in chronological sequence of visits undertaken.

STRUCTURAL ENGINEERING RESEARCH CENTRE (SERC)

Located at Roorkee, this organization has been spearheading applications oriented research on ferrocement in India. Four of the applications developed by this centre (which also has a sister unit at Madras known by the same name) are now in commercial use. These applications have been reported in detail earlier in this Journal [3-4].

More recently, the organization has perfected a technique for manufacture of multipurpose segmental units. These units that could make up large cylindrical storage structures, make transportation and installation operations much less troublesome. Conceptually, a cylindrical structure of any diameter is divided into 4, 6 or 8 segments (depending upon the diameter). Each of these segments is cast seperately on a masonary mould with wiremesh and skeletal reinforcement projecting on both sides of the segment. After 10 days of curing, these are transported to site and errected by lapping wiremesh and skeletal steel reinforcements of adjacent segments and sealing the joint with a rich mortar mix. Joints could also be additionally reinforced with vertical ribs, if desired (Fig. 1-3). Alternately, these elements could be put to use as wall panels or roofing units.

In collaboration with the Central Buildings Research Institute, SERC has recently perfected a resin-based coating for biogas holders. This coating has undergone successful performance tests and as a result ferrocement can now be made totally impermeable to gas.

From earlier emphasis on farm storage structures, attention has now been focused on applications in housing. SERC is presently developing techniques for production of precast trough shaped folded-plate panels (Fig. 4). Research knowledge now accumulated the world over, on this subject, has proven beyond doubts that such panels could replace the popular panels made from asbestos cement.

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Fig. 1. Precast segmental unit with horizontal ribs. Note also mesh projections which facilitate construction of strong joints with similar other adjacent units.

The Center has also been responsible for conducting a training programme on ferrocement technology for polytechnic teachers in India (based on similar lines as the one conducted earlier at AIT for a group of Indonesian engineers). The activities of this pioneering research institution has gone a long way in effectively transferring this innovative infantile technology to the field.

Fig. 2. A 2.5 m diameter tank constructed with three 12 mm segmental units which has undergone water retaining tests successfully for over 5 years. The height of the tank is 1 m.

Fig. 3. A 6000 litre capacity tank made with ferrocement segmental units of 12 mm thickness. At joints vertical ribs of 25 mm are provided.

Fig. 4. Precast ferrocement folded-plate roofing element undergoing structural tests while the specimen is being water loaded.

SARABHAI TECHNOLOGICAL DEVELOPMENT SYNDICATE

With supporting technical assistance from SERC (Roorkee and Madras) this private group from Ahmedebad has over the recent years developed its own know-how for methods of construction of compoundly curved domes. They have constructed a marvellous inverted catenary dome (W shaped in plan) covering a column-free floor area of over 500 m^2. The method adopts a relatively easy mechanism of fabricating a planar network of tubular frame pinned down at the edges of the network. At various intermediate nodal points the frame is jacked up to predetermined heights by means of a simple pulley-chain arrangement. Vertical coordinates of the inverted catenary are measured directly from a scaled model of the dome. This profiled network then serves as the basic skeletal steel framework over which mesh layers can be laid. After plastering this tubular network become an integral part of the dome. If left exposed on the inside of the dome, these tubes also serve to improve the aesthetics of the interior (Fig. 5-6). Subsequent to this large structure two domes using a basic bamboo frame have also been constructed. Circular in plan these domes (Fig. 7) are of approximately 5 m in diameter with a central rise of about 1.5 m. Bamboo strips are left in place as earlier, so as to lend a beautiful grid pattern to the interior. The bamboo strips which are treated for resistance to termite attacks cut down the total roofing costs to as little as US$ 6.00/m^2.

Fig. 5. A complex shell. W shaped in plan constructed at Ahmedabad. Interesting to note is the provision for ornamental plants along the edge beam.

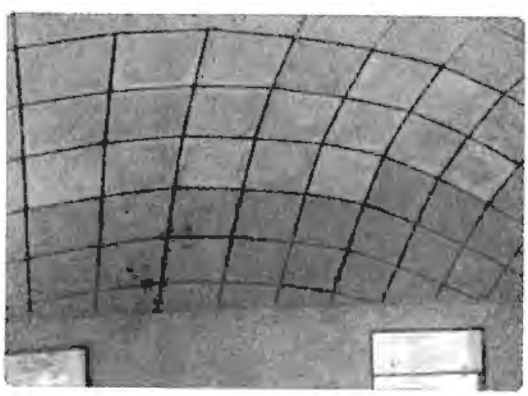


Fig. 6. Grid pattern of the exposed tubular network in the interior of the shell lends a beautiful geometric design.

The Syndicate also has the valuable experience of using ferrocement for waterproofing several of its existing buildings and water ponds [5]. It is one of the very few organizations using ferrocement that successfully blends functional aesthetics with essential structural integrity.

Fig. 7. Bamboo strips that are connected to each other orthogonally at junction facilitate profiling of the mesh into the desired dome shape at the same time cutting down on roofing costs.

KHADI AND VILLAGE INDUSTRIES COMMISSION (KVIC)

A centralized Government of India venture, the KVIC has been responsible for implementing the biogas utilization programme on a very large scale. Beginning in 1962, the Gobar Gas Scheme (biogas from cow dung) has until January 1979 installed over 70,000 gas plants which produce 131.22 million m^3 of gas [6]. Essentially the KVIC design of the plant, consists of two main units, the digester and the gas holder. The digester is constructed from brick masonary with foundations of cement concrete at the bottom. The digester is plastered on the inside by cement mortar. The gas holder, a floating stopper delivers gas at a constant pressure to the gas appliances through a pipeline. In a conventional design these gas holders were constructed of mild steel plates. In view of the high cost of steel and also to overcome the difficulty of corrosion, the KVIC is now in search of an alternative material. Ferrocement gas holders, the KVIC has established, are 20 to 30% cheaper than steel holders. It is presently testing the performance efficiency of these gas holders in numerous plants throughout India. While containment of gas in an improperly constructed holder still is a stumbling block in KVIC's large scale use of these, it envisages to licence over 300 manufacturing units for the fabrication of ferrocement cylindrical 'well casing' rings for its digesters. Additionally, it also has attempted to use ferrocement paddles for mixing of the dung with water in its waste input chamber. If the KVIC is successful in its inconclusive attempt to use ferrocement for all components of its biogas plants, it would qualify itself as being the single largest user of the technology for terrestrial applications.

SAINT PEDRO PRECAST UNIT

This company located in Goa, is one of the licencees of the SERC patent of the know-how for manufacturing cylindrical ferrocement units. The equipment used (Fig. 8), and the operational sequence has been described in [3]. Using segmental moulds (Fig. 9) made of a galvanized iron sheeting cover over wooden frames, the company produces these cylindrical units in a wide range of diameters (0.6 - 1.5 m). The standard height of these units is 1 m. Most commonly, these are reinforced with two layers of square woven mesh (18-22 ga., 12 mm opening). These are used along with other components cast seperately on masonary moulds, like the base unit, roof unit and inlet/outlet lids are assembled together at site to be used as either a water storage tank or a grain storage bin. Minor modifications in the stanard-ized cylindrical units provide for a flexible multipurpose use to these units. Figs. 10-12 below present a view of the casting yard and the various components.

Fig. 8. Process equipment for the casting of ferrocement cylindrical units developed by the SERC

Fig. 9. Segmental moulds of different diameters are made of a wooden frame that is covered with galvanized iron sheets.

Fig. 10. The production yard at St. Pedro Precast Unit lined up with tanks and grainstorage bins after they have been cured.

Fig. 11. Reinforced concrete base for the cylindrical units. Bases are provided with four lifting hooks to be used while handling the tanks and grain storage bins.

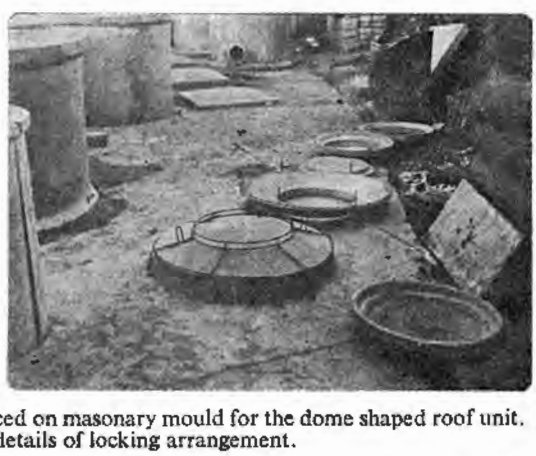


Fig. 12. Skeletal steel placed on masonary mould for the dome shaped roof unit. Photograph also shows lids for the roof and details of locking arrangement.

The company also envisages mass manufacturing 25 cm diameter ferrocement half-pipes to be used by local farmers as water conveying troughs.

Although an appreciable amount of effort has been successfully put into maintaining a good quality control of the company's products, it has been plagued by cement shortages and a lack lusture marketing effort. The outcome of public displays the company is now undertaking, is well worth watching — and is very likely that it can overcome its apparent impediments and launch a successful sales drive.

MARINECRETE SDIPBUILDERS

Also located in Goa, this successful company specializes in boat building. The firm has ventured into ferrocement boat building after having an enviable record a an experienced ship repairing yard in Goa.

The company undertakes salvaging operations of iron-ore barges and fishing trawlers. Using the frame of one such salvaged trawler, "the company has built a 9.5 m ferrocement hull. The hull reinforcement consists of two layers of 6 mm diameter mild steel rods diagonally placed at 75 mm centers, orthogonal to each other. Mesh reinforcement for the hull is made up of 7 layers, 4 on the outside (2 layers 19 ga., 12 mm square mesh and 2 layers 19 ga., 18 mm hexagonal mesh) of the skeletal steel reinforcement and 3 on the inside (2 layers 19 ga., 18 mm hexagonal mesh and 1 layer 19 ga., 12 mm square mesh). The deck, cabin and frame are 25 mm, 18 mm and 18 mm thick respectively (Fig. 13-14).

Fig. 13. 9.5 m hull is all meshed up and ready for plastering. Frames for the trawler were borrowed from a salvaged steel vessel.

The company is presently undertaking repair of a discarded wooden trawler by sheathing it with a layer of ferrocement. Its task is simplified greatly by the presence of an approving authority at hand (Bureau Aquafloat, Goa - a subsidary of Bureau Veritas). It also has over the course of its existance diversified into building deck structures of ferrocement, like, engine rooms and deck cabins (Fig. 15). It ultimately hopes to also use ferrocement bouys for a variety of marine applications like culture of mussels and other forms of marine growths.

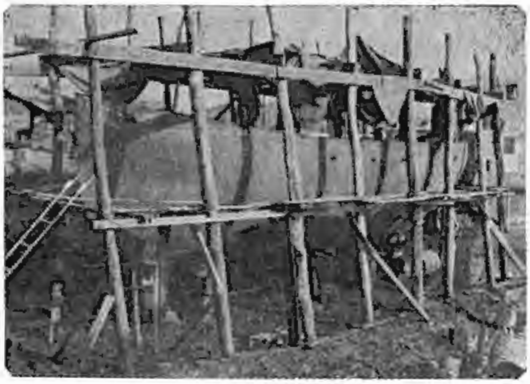


Fig. 14. Details of scaffolding and shed that protect the hull that is yet to be plastered.

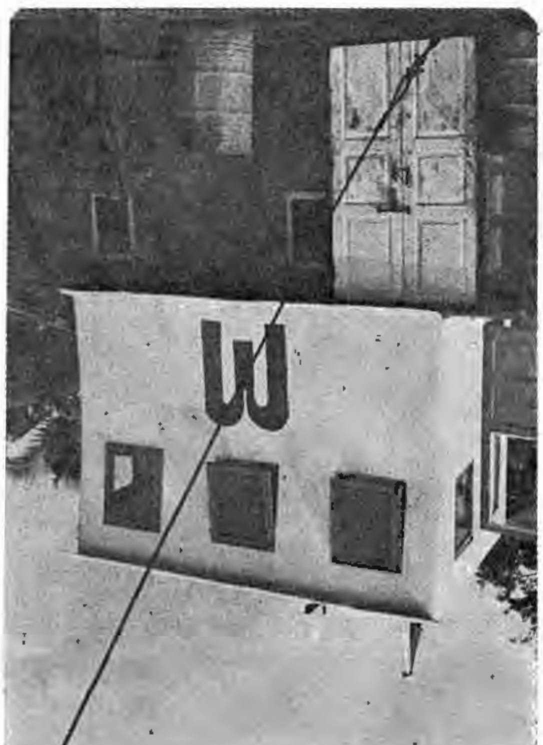


Fig. 15. Cabin and crew quarters fabricated in ferrocement (two storeyed) atop the deck of a steel salvage barge.

With the present level of diverse activities, it might not be long before the company gears itself towards series production of fishing trawlers, barges and smaller work boats.

SARANG FERROCRETE

Since its formation over 6 years ago, the Sarang Ferrocrete (Sarang literally meaning sea horse) has taken gaint strides in commercial production of its wide ranging products. The company is one of the very few in the world which exploits ferrocement to its fullest potentials. Its working force consists of about 50 unskilled workers with the most sophisticated equipment being a hand operated drum mixer! More than being a very successful ferrocement casting yard it is an unique non-profit making social movement to uplift an underdeveloped region in Western India. Pen, where it is located is exactly halfway between bigger cities Bombay and Poona, which serve as its sales outlets. At Sarang any 'major hurdle' is synonymus to 'minor challanges' and the very fact that this company being located where it is, has acheived a stable and ever increasing rate of production validates, beyond doubts the 'small is beautiful' concept. The company also has a one-man sales office at Poona which proudly claims that the sales orders at anytime could keep the yard working for over three months!

Among its diverse range of products are watertanks, grain storage bins, biogas plants, fence posts, gates, kiosks, lids for electrolytic cells, pipes, kitchen sinks and mechanized costal fishing boats.

Water tanks produced by the firm come in varied sizes and shapes. It has as of date produced and errected tanks of rectangular, cylindrical and spherical shapes, both on ground and elevated tanks in capacity ranges of 450-4000 liters (the storage capacity being limited only by transportation constraints and related economics) (Figs. 16-17). Amongst the present activities, production and sales of water tanks occupy a premier position.

Fig. 16. A line-up of armatures for rectangular water tanks of different capacities.

Fig. 17. Completed watertanks ready for delivery.

Fig. 18. Cylindrical grain storage bin of the Sarang Ferrocement design.

Cylindrical grain storage bins produced by the firm are very popular among the farmers in the area (Fig. 18). Sarang Ferrocrete has developed its own design for biogas plants. It is a modified design of the floating gas holder type but a water seal provided by the double walled digester makes its performance uniquely different. Besides it is the only organization thus far that has an entire biogas plant prefabricated from ferrocement (Fig. 19).

Fig. 19. A semi-underground biogas plant that is completely fabricated in ferrocement.

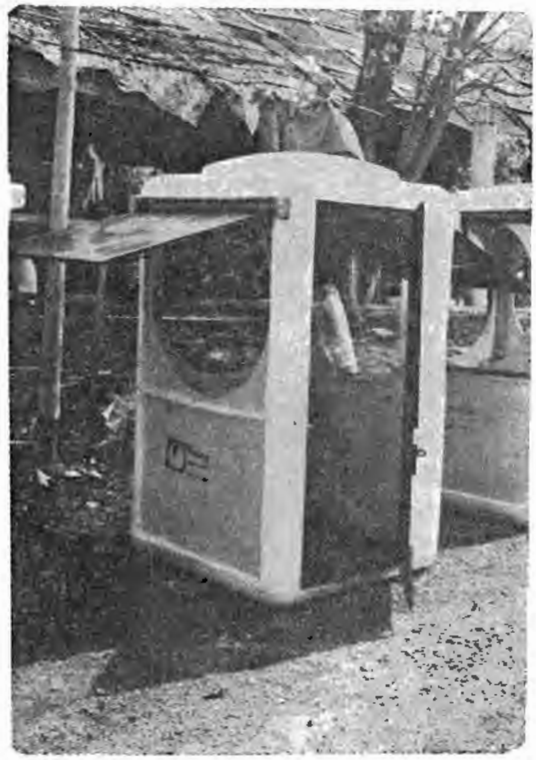


Fig. 20. Guard posts or mini kiosks made from ferrocement. Built-in steel frames for doors and windows make the design suitable for multipurpose use.

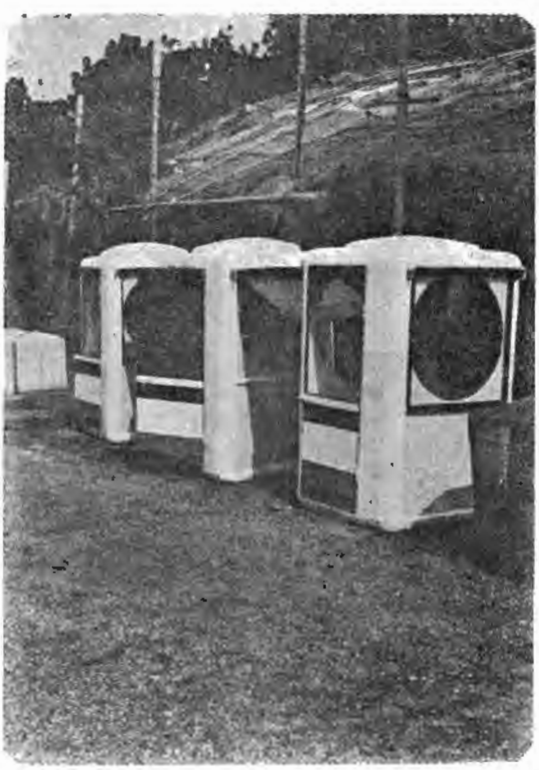


Fig. 21. A line of completed kiosks await to be transported.

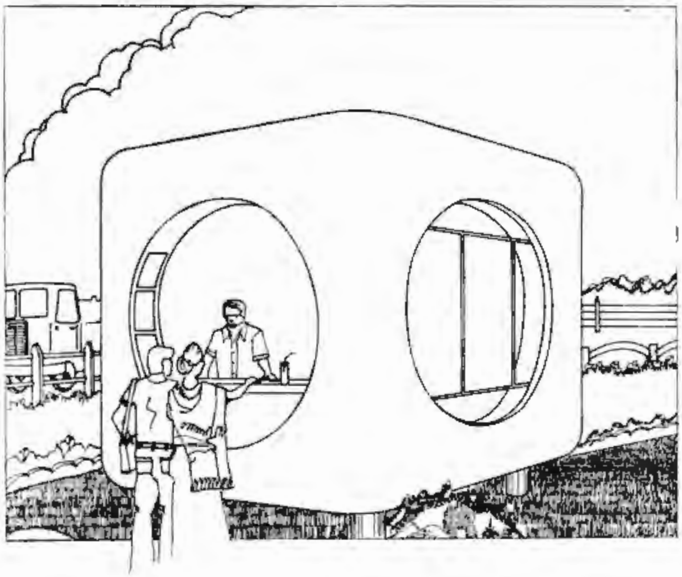
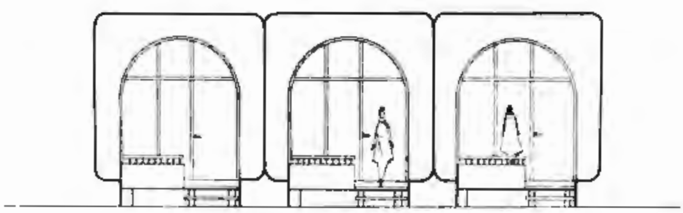


Fig. 22. A cuboid of 3m x 3m x 3m proposed to be used as a tea and soft drinks vending stall at a petrol pump.



(a)

(b)

Fig. 23. Two proposals for using modular kiosks of varying sizes in combination make up small dwelling units.

One very interesting application developed by Sarang Ferrocrete is a modular kiosk unit. The 3m x 3m x 3m cuboid has provisions for doors/windows on all the four vertical faces and it is designed to stand on four hollow cylindrical stumps made also of ferrocement (Figs. 20-22). The firm proposes to use the built-in flexibility to meet the varied requirements for independent dwelling units. Similar smaller units 2m x 2m x 3m and 1m x 1m x 3m have been designed serve as guard posts, newstands tea/cigarette vending booths and utilities for dwelling units (Fig. 23).

Interlock, a charitable trust to coordinate rural development and related activities worldwide, has financed the first mechanized costal fishing boat to be built by Sarang Ferrocrete.

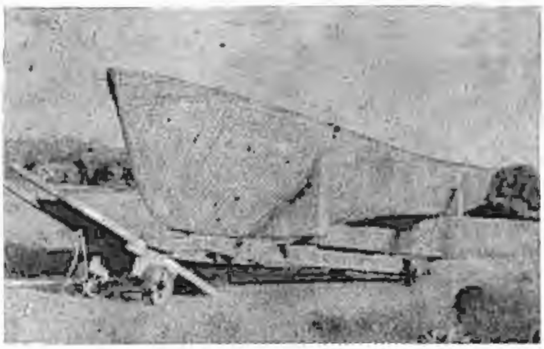


Fig. 24. The completed armature of a 7.8 m coastal fishing boat being transported to plastering site near a creek. A discarded truck chasis is effectively used in combination with a hand drawn cart.

The boat is a modified FAO design (UAR-1) whose principal specifications are: Length (overall) 7.80 m, length DWL 7.2m, Beam moulded 2.38m, Beam DWL 2.00m, Depth 1.15 m and Displacement to DWL (approx.) 2.40 tons. The boat has an in-board diesel engine (6-10 hp) and a proposed insulated fish hold of 0.5 m^3. Construction techniques adopted were labour-intensive and Figs. 24-27 show details of the hull construction. The boat is to be donated to a fisherman from Pen. Interlock which is already doing a commendable job soon envisages to go into a series production venture along with Sarang Ferrocrete. Plans are also afoot to set up a ferrocement vessel construction training center jointly. The author is staunchly inclined to believe that such a joint venture would be very a successful model to numerous other organizations primarily because Sarang Ferrocrete and Interlock are both commited to rural development and both have a firm belief that ferrocement is indeed an outstanding and appropriate material to meet their stringent requirements.

Fig. 25. A team of plasteres work on the hull under a temporary shed.

Fig. 26. Curing has been completed and minor finishing of the inside is undertaken.

Additionally Sarang Ferrocrete also produces lids for electrolytic cells (of a match box factory), cylindrical pipes, kitchen sinks and similar utility items on specific customer requests.

Fig. 27. The completed hull is painted and mounted on close fitting ferrocement supports. Note the supports are shaped complimentary to the hull profile to provide a perfect hold. The logo of the financing organization, the Interlock Charitable Trust adorns the hull.

CONCLUSION

Authenticated by rational design procedures and relevant performance tests, ferrocement in India is now at the threshold for commercial exploitation. This development in India over the last few years is a relief to most researchers who other-wise would have had to see their work only ardorning fancy bookshelves. The competence of the commercial producers leaves no room for earlier speculations that the technology might altogether be abandoned for lack of adequate expertise.

ACKNOWLEDGEMENTS

The author wishes to express his sincere thanks to all of the individuals mentioned below without whose assistance it would not have been possible to compile this report: Dr. V.P. Narayanasuramy, Mr. G.V. Surya Kumar, Mr. P.N. Zutshi, and Mr. H.B. Jayaraman, all from SERC, Roorkee, Ms. Gira Sarabhai and Mr. Patel of Sarabhai Technological Development Syndicate, Ahmedabad, Mr. H.S. Srinivasan, Mr. Y.N. Sharma, and Mr. Hanuman of KVIC, Bombay, Mr. Vasudeva Tamba of Saint Pedro Unit, Goa, Mr. Arun Madgavkar and

Mr. Anil Madgavkar of Marinecrete Shipbuilders, Goa, Mr. Vishnu Joshi of Sarang Ferrocrete and Mr. Terrence Mckee and Ms. Pamela Lobo of the Interlock charitable Trust, Bombay.

Grateful appreciation is also due to Dr. Jacques Valls, and Prof. Ricardo P. Pama, Director and Associate Director of IFIC respectively, for their encouragement and support, during the investigations.

REFERENCES

1. PAMA, R.P., LEE, S.L. and VIETMEYER, N.D., Ferrocement a Versatile Construction Material: Its Increasing Use in Asia", A Report of the Workshop on Introduction of Technologies in Asia - Ferrocement, A Case Study, International Ferrocement Information Center, Asian Institute of Technology, 1976, 106 pp.
2. PAUL, B.K., "Ferrocement Development in India and Bangladesh", Journal of Ferrocement, Vol. 8, No. 2, April 1978, pp. 104-113.
3. SHARMA, P.C., GOPALAKRISHNAN, S., RAMAN, N.V. and KUMAR, G.V.S., "Small Capacity Ferrocement Bins for Food Storage", Journal of Ferrocement, Vol. 9, No. 1, January 1979, pp. 21-34.
4. RAMAN, N.V., NARAYANASWAMY, V.P., SHARMA, P.C. and JAYARAMAN, H.B., "Ferrocement Gas Holder for Biogas Plants", Journal of Ferrocement, Vol. 9, No. 2, April 1979, pp. 93-102.
5. SHARMA, P.C., "Use of Ferrocement for Waterproofing", Journal of Ferrocement, Vol. 10, No. 2, April 1980, pp. 127-141.
6. SRINIVASAN, H.S., "Gobargas Retrospect and Prospects", published by the Directorate of Gobar Gas Scheme, Bombay, January 1979, 24 pp.

BIBLIOGRAPHIC LIST

This list includes a partial bibliography on ferrocement and related topics. The AIT Library and Regional Documentation Center has these articles and books. Reprints and reproductions when copyright laws permit, are available at a nominal cost (see page iv). Please quote the serial number of the list at the time of request. Earlier parts of the bibliography have been published in the past issues of the Journal and are also available in the first volume of "Ferrocement and its Applications—a Bibliography" which contains 736 references compiled from the list. Copies of this IFIC publication can be ordered at a cost of US$2.00 per copy (surface postage included). For air mail postage add an additional amount of US$2.00.

MARINE USES

M866. BARBERIO, V., "Barche in Ferrocement a Wellington (Nuova Zelanda)", L'Industria del Cemento, Anno XLIV, June 1974, pp. 351-369 (in Itallian).

M867. BARBERIO, V., "Caratteristiche e Possibilita Attuali del Ferrocemento Nelle Construzioni Economiche, Edili e Navali", Ingegneri Aac Litetti, Anno XXV, No. 2, April-June 1975, pp. 12-26 (in Itallian).

M868. GOPALARATNAM, V.S., PAMA, R.P. and VALLS, J., "A Review of Marine Applications of Ferrocement in Asia", Proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979, Thomas Reed Publications Ltd., U.K. (also reprinted in the Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 31-45).

M869. HODSDON, J.S., "Ferro Cement Construction in Developing Countries", Proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-24, 1979, Thomas Reed Publications Ltd., U.K.

M870. IORNS, M.E., "Cost Reduction and Quality Control in Ferrocement and Marine Concrete", Proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979, Thomas Reed Publications Ltd., U.K. (also reprinted in the Journal of Ferrocement, Vol. 10, No. 1, JFP20, January 1980, pp. 11-17).

M871 MACALISTER, R.G., "Ferrocement and the Development of Small Boats", Proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979, Thomas Reed Publications Ltd., U.K. (also reprinted in the Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 47-50).

M872. MAHAN, L., "Building of 24-feet Sloop", Journal of Ferrocement, Vol. 9, No. 3, July 1979, pp. 153-155.

M873. MAHAN, L., "Some Thoughts on Methods and Materials for Ferrocement Boat Construction—Part I", Journal of Ferrocement, Vol. 10, No. 1, January 1980, pp. 51-53.

M874. SPRADBROW, B.J. and WIKLUND, K.M., "Design, Series Production and Promotion of Ferrocement Vessels", Proceedings of the Concrete Ships and Floating Structures Convention, Rotterdam, November 12-14, 1979, Thomas Reed Publications Ltd., U.K. (also reprinted in the Journal of Ferrocement, Vol. 10, No. 1, JFP21, January 1980, pp. 19-29).

M875. TOLOSA, R.T., "Ferrocement Buoys for Mussel Culture," Journal of Ferrocement, Vol. 9, No. 3, July 1979, pp. 129-133.

MATERIALS AND RESEARCH

MR876. ABERCROMIBIE, S., "Ferrocement, Building with Cement, Sand and Wire Mesh", Robert Hale Limited, Clerkenwell House, London ECIR OHT, 1978, 192 pp.

MR877. ALEXANDER, D.J., "Ferrocement in Relation to RC Code", New Zealand Concrete Construction, Vol. 22, No. 11, December 1978, pp. 20-23 (also reprinted in the Journal of Ferrocement, Vol. 9, No. 4, October 1979, pp. 191-199.

MR878. ALEXANDER, D.J., "High Tensile Wire Reinforced Fibrous Ferrocement— It's Theory and Practice", Journal of Ferrocement, Vol. 10, No. 2, JFP23, April 1980, pp. 89-104

MR879. ALEXANDER, D.J., "The Widening Applications of Ferrocement", Published by the author, Box 28265, Remuera, Auckland 5, New Zealand, August 1979, 120 pp. — 7 drawings.

MR880. ALEXANDER, D.J., and ATCHESON, M., "Development of Fibrous Ferrocement", Proceedings of the ACI Symposium on Ferrocement Toronto, April 1978.

MR881. BALAGURU, P.N., NAAMAN, A.E. and SHAH, S.P., "Fatigue Behaviour and Design of Ferrocement Beams", Journal of Structural Division (ASCE), Vol. 105, No. ST7, July 1979, pp. 1333-1346.

MR882. BALAGURU, P.N., NAAMAN, A.E. and SHAH, S.P., "Serviceability of Ferrocement Subjected to Flexural Fatigue", International Journal of Cement Composites, Vol. 1, No. 1, May 1979, pp. 3-10.

MR883. BAUGH, I., "Square Welded Mesh", Journal of Ferrocement, Vol. 9, No. 4, October 1979, pp. 201-205.

MR884. BATSON, G.B., SABNIS, G.M. and NAAMAN, A.E., "Survey of Mechanical Properties of Ferrocement as a Structural Material", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

MR885. BUHAGIAR, C., "Ferrocement", B.E. & A Dissertation, New University of Malta, June 1979, 165 + vi pp.

MR886. GOPALARATNAM, V.S., "Ferrocement in India—At the Threshold of Commercial Production", Journal of Ferrocement, Vol. 10, No. 2, April 1980, pp. 143-158.

MR887. INTERNATIONAL FERROCEMENT INFORMATION CENTER, "Ferrocement and Its Applications—A Bibliography, Volume 1", IFIC Publication No. 8/78, November 1978, 58 pp.

MR888. KARASUDHI, P., PAMA, R.P., NIMITYONGSKUL, P. and NARAYANASWAMY, V.P., "A Training Program on Ferrocement Technology for Indonesia", Journal of Ferrocement, Vol. 9, No. 4, October 1979, pp. 207-222.

MR889. NAAMAN, A.E., "Design Predictions of Crack Widths in Ferrocement", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

MR890. NAAMAN, A.E., "Performance Criteria for Ferrocement", Journal of Ferrocement, Vol. 9, No. 2, April 1979, pp. 75-92.

MR891. NARAYANASWAMY, V.P., SURYA KUMAR, G.V. and SHARMA, P.C., "Lecture Notes for the Ferrocement Technology Training Course", S.E.R.C., Roorkee, June 1979, 129 pp.

MR892. NIMITYONGSKUL, P., CHEN BOR-SHIUN and KARASUDHI, P., "Impact Resistance of Ferrocement Boat Hulls", Journal of Ferrocement, Vol. 10, No. 1, Paper JFP19, January 1980, pp. 1-10.

MR893. PAMA, R.P. and GOPALARATNAM, V.S., "Ferrocement—Applications, Research and Developments", International Journal of Cement Composites, Vol. 1, No. 4, November 1979.

MR894. ROMUALDI, J.P., "Research Needs and the Future of Ferrocement as a Structural Material", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

MR895. ROSEMARY FERNANDES, GOPALARATNAM, V.S. and NIMITYONGSKUL, P., "Evaluation of Ferrocement Folded-Plate Roofing Panels", Journal of Ferrocement, Vol. 10, No. 2, JFP22, April 1980, pp. 69-88.

MR896. SABNIS, G.M., "Ferrocement—Past and Present", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

MR897. SABNIS, G.M., BATSON, G.B., NAAMAN, A.E. and PAMA, R.P., "Bibliography on Ferrocement", Proceedings of the ACI Symposium on Ferrocement, April 1978.

MR898. SURYA KUMAR, G.V., GUPTA, V.K. and SHARMA, P.C., "Flexural Rigidity of Ferrocement", Journal of Ferrocement, Vol. 9, No. 4, Paper JFP18, October 1979, pp. 171-184.

MR899. TATSA, E.Z. and PRAWEL, S.P., "Studies in Ferrocement Applications", Journal of Ferrocement, Vol. 10, No. 2, April 1980, pp 121-126.

MORTAR

MO900. RAICHVARGER, Z. and RAPHAEL, M., "Grading Design of Sand for Ferrocement Mixes", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

PROTECTION AND RELATED TOPICS

PR901. ALEXANDER, D.J., "The Protection of Substrate Steel in Mesh Reinforced Ferrocements and High Tensile Wire Reinforced Fibrous Ferrocement", New Zealand Concrete Construction.

TERRESTRIAL APPLICATIONS

T902. BARBERIO, V., "Cupole Sottili in Ferro-Cemento per un Impianto Ittico Sul Fiume Tirino", L'Industria Italiana del Cemento, Anno XLII, April 1972, pp. 261-272 (in Itallian).

T903. CASTRO, J., "Ferrocement Applications in Mexico City Low Cost Housing", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

T904. MADHAVA RAO, A.G., MURTHY, D.S.R., JAYARAMAN, R. and JOSEPH, G.D., "Ferrocement Service Modules for Housing", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

T905. MURTHY, D.S.R., MADHAVA RAO, A.G. and JAYARAMAN, R., "Ferrocement Service Core Units for Housing", The Indian Concrete Journal, Vol.53, No. 10, October 1979, pp. 263-267.

T906. PARAMASIVAM, P., NATHAN, G.K. and LEE, S.L., "Analysis, Design and Construction of Ferrocement Water Tanks", Journal of Ferrocement, Vol. 9, No. 3, Paper JFP17, July 1979, pp. 115-128.

T907. RAO, P.S. and MATHEWS, M.S., "Corrugated Ferrocement Sheets", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

T908. SARID, M., TATSA, E.Z. and BLJUGER, F., "Ribbed Slabs Made of Ferrocement", Proceedings of the International Conference on Concrete Slabs, Dundee, U.K., April 1979 (also reprinted in the Journal of Ferrocement, Vol. 9, No. 4, October 1979, pp. 185-189.)

T909. SHAH, S.P., "Tentative Recommendations for the Construction of Ferrocement Tanks", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

T910. SHARMA, P.C., "Use of Ferrocement for Waterproofing", Journal of Ferrocement, Vol. 10, No. 2, April 1980, pp 127-141.

T911. SHARMA, P.C. and GOPALARATNAM, V.S., "Ferrocement Grain Storage Bin", Do-it-yourself series, Booklet No. 1, IFIC Publication No. 11/79, May 1979, 28 pp.

T912. SHARMA, P.C., PAMA, R.P., VALLS, J. and GOPALARATNAM, V.S., "State-of-the-Art Review on Ferrocement Grain Storage Bins", Journal of Ferrocement, Vol. 9, No. 3, July 1979, pp. 135-151.

T913. STEKELENBURG P.J. VAN, WALRAVEN, J.C. and MATHEWS, M.S., "Development of a Semicylindrical Ferrocement Roofing System", Journal of Ferrocement, Vol. 10, No. 2, April 1980, pp 111-119.

T914. WALKUS, B.R., "The Efficient and Economical System for Producing Ferrocement Elements", Proceedings of the ACI Symposium on Ferrocement, Toronto, April 1978.

NEWS AND NOTES

NEWS AND NOTES

IFIC

Special Issue on Housing Applications Planned for January 1981.

The Editorial Board, following the overwhelming response for the July 1980 special issue on Marine Applications of Ferrocement, has decided to devote the January 1981 issue of the Journal of Ferrocement to Housing Applications. The 70's saw ferrocement qualify the world-over for varied applications in housing. The developments in the last decade has been note-worthy with the establishment of IFIC, the constitution of committees on ferrocement by the American Concrete Institute (ACI 549) and the International Association of Testing and Research (RILEM). Experience shows that the multipronged approach has been necessary for the promotion of any new construction material. Research institutions and professional and amateur builders have done their part in initiating and successfully completing many studies on ferrocement for housing applications. After a decade of such studies, it is essential that these individuals should share their findings and experiences with each other so that they could undertake further studies in the 80's based on the existing body of literature, to push the frontiers of knowledge further. IFIC once again has come forward to play its pioneering role in documenting all aspects and studies on ferrocement as a material for housing applications and thus offering an ideal forum for such discussions.

Contributions should be original and will be published on the understanding that they have not been published earlier. However, truly outstanding contributions published elsewhere will also be considered for possible publication. The International Editorial Board of the Journal of Ferrocement will be solely responsible for the selection of the articles.

Suggested topics for the contributions are listed below:

(a) Detailed construction information.

(b) Research and developments.

(c) New materials like fibrous ferrocement

(d) Innovative applications, prefab housing, modular housing, equipments and techniques.

(e) Surveys, case-studies and state-of-the-art reports.

(f) Material properties and performance.

(g) Additives, admixtures and coatings.

(h) Corrosion prevention.

(i) Building codes and associated developments.

(j) Design methods.

(k) Disaster housing and housing for earthquake prone zones.

(l) Projects proposed, underway or completed and,

(m) Envisaged applications and developments for the future.

The following deadlines would be strictly adhered to, for articles that are to be considered for possible publication:

Submission of title and abstracts : May 15, 1980.

Notification of preliminary acceptance : June 1, 1980.

Submission of completed manuscripts : August 1, 1980.

Notification of final acceptance : October 1, 1980.

INDONESIA

Innovative Rural Applications

Telling us once again of his activities in rural Indonesia (read also earlier reports in October 1979 and January 1980 issues) is Mr. J.B. Manga, our ever enthusiastic contributer. Indeed this time he has come up with a few novel and thought provoking applications.

Fig. 1 illustrates the skeletal steel frame for a lobster broodstock. Readers might be

Fig. 1

aware that we published an article from the South Eastasian Fisheries Development Center, Philippines way back in April 1978 on ferrocement tanks for prawn broodstock, but this seems to be the first large scale use of tanks made of ferrocement for such purposes The Department of fisheries have sponsored. construction of ferrocement lobster broodstocks in South Sulawesi province. Fig. 2 shows a row of such tanks (diameter 1.1 m, height 1 m and thickness 3 cm) undergoing curing. Fig. 3 shows a tank that is now ready for use. The central 1" PVC pipe serves to meet functional requirements for such tanks.

Fig. 2

Fig. 3

In the same province, villagers are thrashing the material to more adverse tests (literally and figuratively too!). Fig. 4 shows at compatible threesome, all made of ferrocement. Water is being drawn for a well sleeved with ferrocement casings. 4 casings each 1.25 m in height have been used for this 5m deep well. To the left of the well stands a 200 liter water tank made from ferrocement and uses braided bamboo mattings as reinforcement

Fig. 4

instead of conventional steel meshes (diameter 50 cm, height lm). In the foreground partially hidden by the shrubs is a plate made of ferrocement, also using bamboo matting which bears the brunt of the flogging while clothes are being washed.

Fig. 5-8 depict construction of a dome for the Takalar Mosque 45 kilometers south of Ujung Pandang. Since there was no access to electricity or welding equipments, the frame for the 10m diameter semi-spherical dome were prefabricated elsewhere and transported to site in 8 sections. Extensive bamboo scaffolding and simple pulley-chain winch mechanism permitted smooth errection of the sections to form the basic frame for the dome. A base ring made from galvanized iorn pipe facilitated anchoring of the dome onto a circular edge beam of conventional reinforced concrete.

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Another of the electrifying ideas is the sheathing of bamboo poles normally used as electric posts in the Ujung Pandang area. A layer of hexagonal mesh is nailed onto the bamboo (Fig. 9) and plastered with the usual mortar mix (Fig. 10). Besides greatly increasing the strength, the ferrocement sheathing increases the service life of the electric post, manifold.

Fig. 9

Fig. 10

Precast trough units 1.25 m in length, 20 cm high and 20/15 cm wide are used for lining irrigation ditches. Cast in open female moulds (Fig.11), these are reinforced with a layer of hexagonal mesh. Fig. 12 shows an array of such ready to use troughs along with precast well casing rings.

Fig. 11

Fig. 12

Indonesia is surely not a graveyard of ferrocement structures but they do for sure have the first known ferrocement grave! Fig. 13 illustrates a grave in Tanatoraja, 300 kilometers north of Ujung Pandung (deptd 1.6m, length 2m and width 0.9m). The deah man apparently consumed only 240 Kgs. of cement, the sand and bamboo available locally at no cost!

Fig. 13

ITALY

RILEM Symposium on Ferrocement — A Tribute to Nervi

Following the RILEM Committee 48FC meeting held in Delft last year, it has been proposed that a Symposium on Ferrocement be held at Bergamo, Italy in October 1981, subject to the approval of the RILEM Bureau this month.

Tentatively, it has been decided that the number of those taking part in the Symposium held as a tribute to Prof. Nervi, be limited to 70-80, while no restriction has been placed on the number of papers to be selected for the ocassion.

This notice is only for an advance preliminary information for would be authors and others interested and is not intended to serve as definitive program. Preliminary announcements inviting contributors to write a 200 word summary of their article will be circulated during summer 1980. Deadline for receiving these summaries would be around November

1980. Final announcement with definitive program is due in December 1980. Authors of papers accepted based on the summary submitted will be notified during that time and final manuscripts are due by April 1981. Subjects to be dealt with at the symposium include: the Mechanical properties of ferrocement; Structural analysis and testing of elements and structures, Production technologies, Applications and cost evaluation and Recommendations.

U.S.A.

New Crimped Steel Fibers for Concrete Reinforcement

Ribbon Technology Corporation of the USA has introduced into the market, a new crimped design for steel fibers. Used for reinforcing concrete, it is claimed that these fibers feature a new, irregular shape for better mechanical bonding and absence of tangling or balling together. Fibers act as arresters which restrain the growth of flaws within the concrete besides improving the overall tensile strength. They provide protection against cracking, abraiding and spalling. Fiber lengths of 1″ - 3″ are available and are suitable for varied precast and structural concrete applications. Shorter lengths are suitable for use in mixes that are pumped, gunnited, shotcreted or rammed.

INTERNATIONAL MEETINGS

Symposium on Wood, Ferrocement and Plastics in Shells and Spatial Structures, University of Oulu, Oulu, Finland, June 9-14, 1980.

The IASS Symposium 1980, organized by the International Association for Shell and Spatial Structures in collaboration with, the Finnish Academy of Technical Sciences will be devoted to two trends both central in the present development of thin-walled and spatial structures. The first half of the Symposium will concentrate upon the use of wood material in shells and spatial systems, the latter half dealing with more modern materials such as ferrocement and plastics.

The symposium is organized in three sessions each one offering ample scope for discussion. The first session treats wooden shells and spatial structures, and the appropriate theory. Although the Symposium will place most weight on the ingredients of a good structural solution, design fabrication and constructional technique, opinions about future development are also welcome. The second session is devoted to concrete-like composites such as fine-aggregate concrete with various binders or cement paste. These almost entirely thin-walled shell structures make use of microreinforcement, asbestos, glass, metal, plastics, etc. In this session the properties of the composites form an interesting part. The third session is reserved for structures of plastics, without more accurate specifications.

For details regarding the Symposium and further information, contact:

Prof. Dr. Paavo A. Tupamäki
Chairman, IASS Symposium 1980
Department of Civil Engineering,
Kasarminite 8
University of Oulu
90100 Oulu 10, Finland

The International Congress in the Chemistry of Cement, Paris, France, June 30-July 5, 1980.

The following themes have been selected for the above Congress: Influence of raw materials, fuels and manufacturing processes on clinker structure and properties; hydration of pure Portland cements; structure of slags and hydration of slag cements: structure of pozzolanas and fly-ash-hydration of pozzolanic and fly-ash cements; special cements' pastes-rheology; interface reaction between cement and aggregate in concrete mortar.

For further information, contact:

CERILH
23, rue de Cronstadt
75015 Paris, France

International Conference on the Performance of Concrete in a Marine Environment, St Andrews, Canada, August 17-21, 1980.

An international conference on the performance of concrete in a marine enviroment will be held at the Algonquin Hotel, St Andrews, New Brunswick, Canada, August 17-21, 1980.

The conference will cover:

1. Performance of normal and lightweight concretes in a marine environment;

2. Case histories and performance of concrete structures in cold and tropical sea water;

3. Durability in sea water of concrete made with different types of cement including high alumnina cement, blast furnace slag and fly ash blended cements;

4. Corrosion of reinforcing steel;

5. Current related research.

Further information can be obtained from:

Mohan Malhotra,
Conference Chairman,
CANMET,
405 Rochester Street,
Ottawa, Ontario,
CANADA K1A OG1.

Sixth International ERMCO Congress, Brussels, Belgium, September 22-26, 1980.

The Belgium Ready Mixed Concrete Association is to host the Sixth International European Ready Mixed Concrete Organization's (ERMCO) Congress at Brussels. It has chosen "the future" as the theme for the Congress "Horizon 2000 for the Ready Mixed Concrete Industry". It invites participants to view the situation for the year 2000 on the following topics:

The RMC Industry - its economic and industrial aspects.

High early strength concrete and the RMC Industry.

The RMC Industry - operational and management support.

The RMC Industry - Legal aspects.

The RMC Industry - Commercial aspects.

The Association also proposes to bring out a compendium for the RMC Industry which consists of the following chapters - Introduction, Production of RMC, Raw materials, Management equipment and systems, Transport, Handling of RMC at the job-site, Quality Control and other Miscellaneous aspects.

Further information could be obtained from:

APBP - BVSB
Mechelsesteenweg 363,
1950 Kraainerm,
Belgium.

Session on Experimental Wind Engineering on Structures, Florida, U.S.A., October 27-31, 1980.

The Committee on Experimental Analysis and Instrumentation will sponsor a session at the ASCE Annual Convention, October 27-31, 1980 in Hollywood, Florida. The theme is "Experimental Wind Engineering on Structures".

For further information, contact:

Prof. Leon R.L. Wang
Department of Civil Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181
U.S.A.

Prof. James Colville
Department of Civil Engineering
University of Maryland
College Park, Md. 20742
U.S.A.

Conference on Large Earthquakes, Napier, New Zealand, January 31-February 3, 1981.

A conference on large earthquakes will be held in Napier, 31 Jaunary to February 1981.

At the moment papers are being solicited—abstracts must be submitted by 3 February 1980 and papers by 1 January 1981.

The conference will embrace all aspects of before, during, and after the event. These will include:

Assessment of nature and extent of risk; Likelihood of forewarning; Engineering countermeasures; Political, legal, and economic countermeasures;

Immediate post-earthquake action;

Subsequent rehabilitation;

Individual and group response to the prediction of occurrence of, and recovery from a major earthquake;

Lessons from the Hawke's Bay earthquakes overseas.

The programme will take account of recent inter-governmental conferences and symposia with similar topics held in Paris under the auspices of UNESCO.

The breadth of the problem of large earthquakes requires an equally wide spectrum of approaches, including scientific, engineering, economic, legal, political, human, and social specialism.

Papers on any aspect of earthquake risk, countermeasures, and rehabilitation are invited for presentation at the conference. In addition a few theme papers may be invited, and it is expected that a speaker will be invited from overseas who has been involved in countermeasures following a recent earthquake.

Further information could be obtained from:

Dr. T. Hatherton
Convenor,
"Conference on Large Earthquakes",
Geophysics Division,
DSIR,
P.O. Box 1320,
Wellington,
New Zealand.

Third International Congress on Polymers in Concrete, Nihon University, Fukushima-ken, Japan, May 13-15, 1981.

Nihon University along with some other institutions will sponsor this Congress to be held in Japan in 1981. The main objective of the Congress is to provide for the dissemination of information on polymers in concrete through presentation of papers, and discussion related to the process technology, properties, and existing potential applications of polymer-modified concrete, resin concrete (or polymer concrete), ploymer impregnated concrete, gypsum-polymer composite, concrete-sulphur composite, polymeric admixture for concrete, and adhesives and coating used in concrete work.

A number of papers contributed related to polymers in concrete will be accepted for oral presentation. In addition to these, other papers will be considered for publication in the proceedings. Potential authors are invited to submit an abstract (in English) of about 300 words by July 1, 1980.

Papers or discussion comments may be presented at the Congress in either English or Japanese. Manuscripts of papers, however, should be written in English.

Further details concerning the final Congress Program and accommodations will be available early in 1981.

Further information can be obtained from:

Polymer Concrete Congress 1981
Secretariat
c/o Dr. Yoshihko Ohama
Department of Architecture
College of Engineering, Nihon University
Koriyama, Fukushima-ken 963
Japan

Second International Conference on Superplasticizers in Concrete, Ottawa, Canada June 10-12, 1981.

A call has been issued for papers for presentation at the Second International Conference on Superplasticizers in Concrete, to be held June 10-12, 1981 in Ottawa, Canada Original papers are invited on the following topics:

Role of superplasticizers in resource and energy conservation

New developments in superplasticizers

Physical/chemical interactions between cements and superplasticizers

Compatibility between super-plasticizers and air-entraining agents

Air void system of superplasticized concretes

Control of rapid slump loss in superplasticized concrete

Performance of superplasticizers in concrete made with cements other than normal portland

Superplasticizers as water reducers

Superplasticizers and the rheology of concrete; test methods and research

Case histories and other related topics

Four copies of a 200-word abstract of any paper to be submitted should be sent by May 15, 1980 to:

Mohan Malhotra,
CANMET,
405 Rochester Street,
Ottawa, Ontario,
Canada K1A OG1

BOOK REVIEWS

FERROCEMENT — BUILDING WITH CEMENT, SAND AND WIRE MESH

By Stanley Abercrombie

Published by Robert Hale Limited, Clerkenwell House, Clerkenwell Green, London EC1R OHT, U.K.

The book divided into four parts highlights the architectural and functional use of ferrocement. The first part on Characteristics and History describes in a story form, the basic properties of ferrocement, its apparent present day neglect, the pioneering work of Nervi and some of the more recent applications. The part on Materials and Techniques gives an assorted collection of ideas, though many of which do not strictly pertain to ferrocement. An interesting section on building codes in this part also brings to light foreseeable difficulties in official approval for the material. Amateurs would find the well illustrated third part, Examples of Actual Use of practical interest. The fourth part lists a summary of the merits and demerits of the material. The list of references used for the book could have been more comprehensive. In concluding that the facilities recommended by the National Academy of Sciences have gone unheeded, the author has apparently made no effort to review developments in the field beyond 1976. The book is highly recommended for all amateur builders particularly those interested in housing.

192 pp.	*240 mm × 160 mm*	*Hard Cover Edition*
English	*ISBN 0-7091-6693-1*	*1978*
		£ 4.50

FERROCEMENT — MATERIALS AND APPLICATIONS

Edited by Gajanan M. Sabnis

Published by American Concrete Institute, Box 19150, Detroit, Michigan, 48219 U.S.A.

The book contains papers presented at the ACI Symposium on this subject held in Toronto during April 1978. The first paper offers historical background and a current state-of-the-art appraisal of ferrocement. The last discusses its potential for future uses, and areas where more research is needed. Ten other papers in between cover the mechanical properties of ferrocement, the development of fibrous ferrocement, grading design of sand for ferrocement mixes, construction of ferrocement tanks, ferrocement service modules for housing, corrugated ferrocement sheets, and related laboratory tests and research on properties.

The volume presents information of value on ferrocement for researchers, designers, and engineers looking for new and practical materials for construction. A bibliography covers a wide selection of research papers and applications on ferrocement.

195 pp.	*230 mm × 150 mm*	*Hard Cover Edition*
English	*ACI-SP 61*	*February 1979*
		US$ 27.50

Abstract

JFP22 EVALUATION OF FERROCEMENT FOLDED-PLATE ROOFING PANELS

KEYWORDS: Analysis, Asbestos, Construction, Cost, Cracking, Design, Folded-Plate Roof, Testing.

ABSTRACT: The paper presents results of a study conducted to evaluate the merits of ferrocement as a roofing material. Analysis, design and casting procedure adopted have been highlighted. Effect of the type of wiremesh and amount of transverse reinforcement have been studied. Test results of six panels are presented and compared with results from a similar study on asbestos panels. It has been concluded that ferrocement folded-plate panel is a stronger, more durable and cost-competitive alternative to asbestos roofing.

REFERENCE: ROSEMARY FERNANDES, GOPALARATNAM, V.S. and NIMITYONGSKUL, P., "Evaluation of Ferrocement Folded-Plate Roofing Panels", Journal of Ferrocement, Vol. 10, No. 2, Paper JFP22, April 1980, pp. 69-88.

JFP23 HIGH TENSILE WIRE REINFORCED FIBROUS FERROCEMENT—IT'S THEORY AND PRACTICE

KEYWORDS: Analysis, Applications, Cracking, High-Tensile Wire, Ferrocement, Fiber, Flexure, Strength, Tension, Volume Fraction.

ABSTRACT: Variations in the form and use of conventional ferrocement made with multiple layers of wiremesh and plain cement mortar, are limited by the requirement for meshes to be finer in order to reduce concrete cracking. The paper reports of a series of experiments with mono-layered high tensile steel mesh encased in a fibrous (steel) cement mortar matrix. The outcome is a high strength material for which flexural properties can be designed and predicted with acceptable accuracy. The material has a superior cracking mechanism, offers improved energy absorption and impact resistance. The paper also highlights various other characteristics of the material and its applications, besides reporting its cost-effective edge over conventional ferrocement.

REFERENCE: ALEXANDER, D.J., "High Tensile Wire Reinforced Fibrous Ferrocement—It's Theory and Practice", Journal of Ferrocement, Vol. 10, No. 2, Paper JFP23, April 1980, pp. 89-104.

JFP25 INFLUENCE OF DISCRETE FIBRES ON BEHAVIOUR OF FERROCEMENT

KEYWORDS: Cracking, Ferrocement, Fiber, Flexure, Tension, Testing, Volume Fraction.

ABSTRACT: Fibre reinforced ferrocement, which is made up of plain mortar, wiremesh, and randomly distributed short steel fibres, is studied to determine the interaction between the two forms of reinforcement in the behaviour of the composites. The tensile and flexural properties of composites made of fibre reinforced mortar, ferrocement and fibre reinforced ferrocement are experimentally investigated with various volume fractions of reinforcement.

REFERENCE: PARAMASIVAM, P., NATHAN, G.K. and LEE, S.L., "Influence of Discrete Fibres on Behaviour of Ferrocement", Journal of Ferrocement, Vol. 10, No. 2, Paper JFP24. April 1980. pp. 105-110.