JOURNAL OF FERROCEMENT

SPECIAL ISSUE
FERROCEMENT
WATER RESOURCES
STRUCTURES

International Ferrocement Information Center

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The International Ferrocement Information Center (IFIC) was founded in October 1976 at the Asian Institute of Technology under the joint sponsorship of the Institute's Division of Structural Engineering and Construction and the Library and Regional Documentation Center. The IFIC was established as a result of the recommendations made in 1972 by the U.S. National Academy of Science's Advisory Committee on Technological Innovation (ACTI). IFIC receives financial support from the Government of Australia, Canadian International Development Agency (CIDA), Government of France, Government of New Zealand, and the International Development Research Center (IDRC) of Canada.

Basically, IFIC serves as a clearing house for information on ferrocement and related materials. In cooperation with national societies, universities, libraries, information centers, government agencies, research organizations, engineering and consulting firms all over the world, IFIC attempts to collect information on all forms of ferrocement applications either published or unpublished. This information is identified and sorted before it is repackaged and disseminated as widely as possible through IFIC's publications and IFIC's reference and reprographic services. All information collected by IFIC are entered into a computerized data base using ISIS system. These information are available on request. In addition, IFIC offers referral services.

A quarterly publication, the Journal of Ferrocement, is the main disseminating tool of IFIC. IFIC has also published the monograph "Ferrocement", Do it Yourself Booklets, Slide Presentation Series, State-of-the-Art Reviews, bibliography and reports. FOCUS, the information brochure of IFIC, is published in 15 languages as part of IFIC's attempt to reach out to the rural areas of the developing countries. IFIC is compiling a directory of IFIC consultants and ferrocement experts.

To transfer ferrocement technology to the rural areas of developing countries, IFIC organizes training programs, seminars, study-tours, conferences and symposia. For these activities, IFIC acts as an initiator; identifying needs, finding funding and experts, and bringing people together. So far, IFIC has successfully undertaken training programs for Indonesia and Malaysia; a seminar to introduce ferrocement in Malaysia; another seminar to introduce ferrocement to Africans; and a study-tour in Thailand and Indonesia for African officials. IFIC has initiated the establishment of a national research and training center in Malaysia. Currently IFIC is involved in organizing a regional symposium and training course in India (1984) and an international symposium and short course at AIT (1985).
In keeping with the practice of publishing a special issue annually, initiated in 1980, the Journal of Ferrocement offers its readers for 1984 this special issue dedicated to “Ferrocement Water Resources Structures”.

The vital importance of water supply and water storage has been and is being underlined by so many dramatic situations and spectacular events that it need not be demonstrated any further. The urgency of finding adequate solutions to this crucial problem has also triggered the launching of the “Water Supply and Sanitation Decade” by the United Nations Organization.

It was, therefore, most appropriate for IFIC to bring its modest contribution by emphasizing through this special issue the potential of ferrocement and related materials for building structures used for water supply and storage such as water tanks, tube well casings, pipes and irrigation conduits, hydraulic gates, reservoirs, earth dam casings, etc.

It is worthwhile mentioning here that the concern of IFIC for water resources problems is also reflected by other activities such as the Study-Tour in Southeast Asia organized by IFIC, with UNESCO support, for African Officials. This project consists of organizing a seminar and field visit to areas where ferrocement and bamboo reinforced cement rainwater collecting cisterns are widely used. The objective is to introduce the technology in the draught stricken Sahel region of Africa.

The Editors
Cracking and Leakage of Fibre Reinforced Ferrocement Tank: An Experimental Study

S. C. Natesan* and S. Rajasekaran*

An experimental investigation on the cracking and leakage behaviour of ferrocement circular tanks are reported in this paper. Tests on nine tanks under short-term loadings and five under long-term loadings are described. Reinforcement consisted of weld mesh and round straight steel fibres. The test results are presented in the form of graphs from which the variation of hoop stress, deformation of tank, cracking and leakage behaviour can be studied. The variables considered are the volume content and aspect ratio of fibres.

INTRODUCTION

Ferrocement has received much attention as a possible building material for developing countries. The material has wide ranging applications in sandwich panel construction, roofs, shells, silos, pipes and small water tanks. Some studies have been made on the cracking and leakage behaviour of ferrocement cylindrical tanks [1, 2]. It has been established that when mortar or concrete is reinforced by short, closely spaced fibres, the cracking strength is increased by the closely spaced fibres acting as "crack arrestors" [3]. As the use of steel fibres in mortar/concrete results in improved cracking resistance, an investigation was undertaken to study the cracking and leakage behaviour of ferrocement tanks reinforced with short steel fibres [4]. The primary purpose of this investigation was to study the effect of steel fibres on the cracking and leakage behaviour of ferrocement cylindrical water tanks under both short term and long-term pressure loadings. The variables considered were the quantity and aspect ratio of the fibres. The present paper briefly reports some of the findings of the experimental investigation.

EXPERIMENTAL WORK

Materials

Cement conforming to IS 289, river sand sieved through ASTM sieve No. 16 and rain water were used in casting the tanks. Wire weldmesh of 3.6 mm diameter and 50 mm spacing in each direction, having an ultimate tensile strength of 602 N/mm² was used. Fig. 1 shows the weldmesh used in casting the tank. Steel fibres of 0.4 mm diameter and lengths of 28, 32 having an ultimate tensile strength of 1080 N/mm² were also mixed with the mortar and used in casting. A view of the different sizes of fibres used in this investigation is shown in Fig. 2. One part of cement, two parts of sand and 0.6 parts of water by weight were adopted for the mix.

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Specimen Fabrication

All tanks were of cylindrical shape with 395 mm internal diameter, 600 mm height and average thickness of 25 mm. Seven tanks were cast for short-term loadings in which five were of fibre reinforced with weldmesh as main reinforcement, one with weldmesh alone and the other with fibres alone. For long-term loadings, five tanks were cast, four with fibres and weldmesh and the fifth with weldmesh alone. For casting the tank, two moulds (one inner mould and one outer mould) as shown in Fig. 3 were used. Both inner and outer moulds can be split up into two halves. The casting of each tank was done in three layers. Each layer of fibre reinforced mortar filled in the annular ring of the mould, was vibrated using table vibrator. Along with the tank, three cubes, three cylinders and three tensile specimens were also cast using the same mix. The specimens were removed from the respective moulds after 24 hours and kept in a curing tank for 28 days. After curing, they were taken out, air dried and kept ready for testing.

Fig. 1. Weldmesh for the tank.
Fig. 2. A view of the fibres.
Fig. 3. Mould details.
Test Setup

The air dried tanks were coated with thick hydraulic lime on their outer surfaces and painted using emulsion paint on their inner surfaces. Four electrical strain gauges were glued in the middle part of the cylinder, each two diametrically opposed, one being vertical and the other being horizontal. The ends of the tanks were smoothed using a grinding stone. First one rubber sheet was placed on the prepared steel plate and the tank was placed on the rubber sheet after the araldite coat was given to the ends. Now the ‘O’ ring was placed on the other end and over that the other steel plate was also placed. Now the bolts connecting the bottom and top steel plates were slightly tightened. Fig. 4 shows a view of the test set-up.

![Fig. 4. A view of the test setup.](image)

Test Procedure

The tank was filled with water up to the top. Two pipe holes were provided in the top plate, one for the pressure gauge and other for connecting the air compressor. The accuracy of the pressure gauge used was 0.005 N/mm². Eight dial gauges were placed in equal spacings around the tank at diametrically opposite points to measure the radial deflections at the mid-height of the tank. The longitudinal deformations of the tank were measured using dial gauges at top and bottom steel plates. The pressure was applied at increments of 0.01 N/mm² until leakage occurred. At each increment, dial and strain gauge readings were noted. In the case of short-term loadings, the pressure was kept constant at each level for approximately 3 to 4 minutes and then the readings were taken.

In the case of long-term loadings, the pressure was kept constant at each level for about 24 hours and then the necessary readings were taken.

An internally illuminated microscope fitted with a micrometer was used to measure the crack width. The measuring accuracy of the microscope was 0.01 mm. At each level of pressure, crack-widths were measured after formation of cracks. Because of increase in the number of cracks that may develop under high pressure, at least two representative cracks including the largest one were kept under observation until substantial leakage which corresponds to failure. The leakage water was collected in a tray and the quantity leaked for a particular time under a given internal pressure was measured using calibrated vessels.
RESULTS

Results on the cracking and leakage behaviour of fibre reinforced concrete tanks are summarized in Tables 1 and 2. These results are given as function of hoop stresses instead of internal pressures in order to eliminate the effect of the wall thickness. The hoop stress $\sigma_\phi$ in the tank described in Tables 1 and 2 is derived from the following simple formula assuming negligible end effects:

$$\sigma_\phi = \frac{pR}{t} \quad \ldots \ldots \ldots \ldots \ldots (1)$$

where
- $p$ = internal pressure
- $R$ = radius of the tank
- $t$ = thickness of the tank

It can be noted that the vertical stress at a given pressure is half that of the hoop stress. The stress in the circumferential steel $\sigma$, assuming a cracked section is given by

$$\sigma = \frac{\sigma_\phi}{V_{wv}} \quad \ldots \ldots \ldots \ldots \ldots (2)$$

where $V_{wv}$ = volume fraction of weldmesh reinforcement.

<table>
<thead>
<tr>
<th>Type of loading</th>
<th>Tank designation</th>
<th>Volume of fibres (%)</th>
<th>Aspect ratio of fibres</th>
<th>Internal pressure (N/mm²)</th>
<th>Hoop stress (N/mm²)</th>
<th>Crack width (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term loading</td>
<td>FRCPTT (Trial)</td>
<td>1.0</td>
<td>80</td>
<td>0.125</td>
<td>0.969</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 1</td>
<td>1.5</td>
<td>80</td>
<td>0.150</td>
<td>1.160</td>
<td>0.01</td>
</tr>
<tr>
<td></td>
<td>FRCPT 2</td>
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<td>0.125</td>
<td>0.968</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 3</td>
<td>1.0</td>
<td>70</td>
<td>0.125</td>
<td>0.968</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 4</td>
<td>1.5</td>
<td>70</td>
<td>0.150</td>
<td>1.160</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 5</td>
<td>1.0</td>
<td>120</td>
<td>0.125</td>
<td>0.968</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 6</td>
<td>1.5</td>
<td>120</td>
<td>0.125</td>
<td>0.968</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPT 7**</td>
<td>0</td>
<td>0</td>
<td>0.040</td>
<td>0.310</td>
<td>0.04</td>
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<tr>
<td></td>
<td>FRCPT 8*</td>
<td>1.5</td>
<td>70</td>
<td>0.075</td>
<td>0.580</td>
<td>0.03</td>
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<tr>
<td>Long-term loading</td>
<td>FRCPTL 1</td>
<td>1.0</td>
<td>70</td>
<td>0.100</td>
<td>0.775</td>
<td>0.03</td>
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<tr>
<td></td>
<td>FRCPTL 2</td>
<td>1.5</td>
<td>120</td>
<td>0.150</td>
<td>1.160</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>FRCPTL 3**</td>
<td>0</td>
<td>0</td>
<td>0.050</td>
<td>0.390</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>FRCPTL 4*</td>
<td>1.5</td>
<td>70</td>
<td>0.100</td>
<td>0.775</td>
<td>0.03</td>
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<tr>
<td></td>
<td>FRCPTL 5</td>
<td>1.5</td>
<td>70</td>
<td>0.100</td>
<td>0.775</td>
<td>0.02</td>
</tr>
</tbody>
</table>

** Weldmesh alone as reinforcement
* Fibre alone as reinforcement
Table 2. Results observed at onset of leakage.

<table>
<thead>
<tr>
<th>Type of loading</th>
<th>Tank designation</th>
<th>Internal pressure (N/mm²)</th>
<th>Hoop stress (N/mm²)</th>
<th>Hoop steel stress (N/mm²)</th>
<th>Minimum crack width in leaking cracks (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-term</td>
<td>FRCPTT (Trial)</td>
<td>0.188</td>
<td>1.45</td>
<td>0.016</td>
<td>0.10</td>
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<tr>
<td></td>
<td>FRCPT 1</td>
<td>0.200</td>
<td>1.55</td>
<td>0.017</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>FRCPT 2</td>
<td>0.250</td>
<td>1.94</td>
<td>0.021</td>
<td>0.09</td>
</tr>
<tr>
<td></td>
<td>FRCPT 3</td>
<td>0.200</td>
<td>1.55</td>
<td>0.017</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>FRCPT 4</td>
<td>0.200</td>
<td>1.55</td>
<td>0.017</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FRCPT 5</td>
<td>0.125</td>
<td>0.968</td>
<td>0.011</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>FRCPT 6</td>
<td>0.150</td>
<td>0.163</td>
<td>0.013</td>
<td>0.10</td>
</tr>
<tr>
<td></td>
<td>FRCPT 7**</td>
<td>0.140</td>
<td>0.160</td>
<td>0.012</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>FRCPT 8*</td>
<td>0.110</td>
<td>0.853</td>
<td>0.009</td>
<td>0.05</td>
</tr>
<tr>
<td>Long-term</td>
<td>FRCPTL 1</td>
<td>0.150</td>
<td>1.050</td>
<td>0.021</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td>FRCPTL 2</td>
<td>0.157</td>
<td>1.240</td>
<td>0.013</td>
<td>0.12</td>
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<tr>
<td></td>
<td>FRCPTL 3**</td>
<td>0.050</td>
<td>0.390</td>
<td>0.004</td>
<td>0.09</td>
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<tr>
<td></td>
<td>FRCPTL 4*</td>
<td>0.104</td>
<td>0.780</td>
<td>0.008</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>FRCPTL 5</td>
<td>0.100</td>
<td>0.775</td>
<td>0.008</td>
<td>0.06</td>
</tr>
</tbody>
</table>

** Weldmesh alone as reinforcement
* Fibre alone as reinforcement

Cracking Behaviour

Since cracking was predominantly in the vertical direction, crack widths and leakage behaviour refer to the vertical cracking. The following observations were made:

a. First vertical cracks generally occurred at hoop stresses varying from 0.310 to 1.160 N/mm² depending on the fibre content and aspect ratios. The number of cracks and their lengths kept increasing with increasing stresses.

Fig. 5.a Typical crack patterns for tanks under short-term loadings.
b. The crack openings and the crack width increased with increasing pressure or hoop stress. It was generally observed that the higher the volume fraction of fibres, the smaller the crack width at a given stress.

c. It was observed that the stress at first cracking is essentially similar for specimens under short-term and long-term loadings. The typical crack patterns for the tanks under short-term loadings are shown in Fig. 5. The variation of average crack width for different hoop stresses for FRCPT-3 and FRCPT-7 is shown in Fig. 6.

**Fig. 5.** A closer view of the crack patterns.

**Fig. 6.** Variation of average crack width.

**Fig. 7.** Variation of ultimate internal pressure.

**Leakage Behaviour**

The term leakage is used here in two ways, one qualitative and one quantitative. The onset of leakage was qualitatively observed with the naked eye when the lime coated exterior surface of the tank along a crack darkened in colour as it became wet. Quantitative leakage
was defined as the loss of water per unit wall area per hour of loading under a specified internal pressure. The following observations were made:

a. Fibre reinforced concrete ferrocement tanks did not leak before cracking unlike tanks without fibres even during long-term loadings.

b. The stress at the onset of leakage increases with the increase of fibre content and aspect ratio for a given amount of weldmesh reinforcement.

c. All other things being constant, tanks under long-term loading showed high leakage when compared to short-term loading.

Effect of Fibre Content on Ultimate Internal Pressure

Fig. 7 shows the variation of internal pressure at ultimate stage with increasing fibre content for fibres of aspect ratio 80. It is seen that for a given amount of weldmesh, the internal pressure at ultimate stage increases with fibre content up to 1.5 percent by volume. After 1.5 percent, there is not much increase in the ultimate internal pressure. This may be attributed to the non-uniform distribution of fibres in the mix at higher fibre contents.

Deformation Characteristics

Fig. 8 shows a typical hoop stress-deflection curve for FRCPT-8 under short-term loading. The initial portions of these curves are linear and there is a significant change in slope at the onset of cracking or leakage. The tanks with fibres failed gradually whereas those without fibres failed suddenly without much warning. This shows the increase in the ductility of the tank when fibres are included. In all cases fibres pulled out. Generally after unloading (relieving the internal pressure), cracks closed and remained almost invisible to the naked eye.

![Fig. 8. Hoop stress vs. deflection for FRCPT-8.](image)

Fig. 9 shows typical deformation curves for FRCPT-5 at each pressure level. These were drawn from the deflection readings taken at different pressure levels. From the deformation curves, it was found that some portions bulge out and some other portions contract. This may
be due to non-uniform thickness of the tank and the non-uniform cover for the weldmesh because of the smaller thickness of the tank.

CONCLUSIONS

On the basis of the observation made in the experimental study, the following conclusions are reached:

1. Both fibre content and aspect ratio of fibres affect the formation of first vertical cracks in the ferrocement tanks but to a lesser extent.

2. The crack width is generally smaller with increase of fibre content at a given internal pressure.

3. The stress at first cracking is essentially similar for tanks under short-term and long-term loadings.

4. The fibre content and aspect ratio affect the internal pressure at which the leakage starts. That is, with increasing fibre content and aspect ratio (for a given amount of weldmesh), the internal pressure at the onset of leakage increases.

5. Tanks with fibre reinforcement undergo large deformations and fail gradually when compared to tanks without fibre reinforcement which normally fail by bursting and without any warning.

ACKNOWLEDGEMENTS

The investigation described herein was sponsored by the Board of Research in Nuclear Sciences (BRNS), Department of Atomic Energy, Government of India. The authors wish to
thank the BRNS for sponsoring and financing this project. They are highly indebted to the authorities of P.S.G. College of Technology, Coimbatore for providing the necessary facilities to carry out the investigation.

REFERENCES


Watertightness in Ferrocement

R.S. Ravindrarajah* and C.T. Tam*

An increase in watertightness and durability for ferrocement in service may be achieved by using very low permeable mortar and by limiting the width of tensile cracks. This paper reports the results of an investigation into the properties of ferrocement suitable for water retaining structures. A superplasticizer was used to achieve the workability of low water to cement ratio mortar. Stability of mortar in the fresh state is also discussed. An attempt is made to define the working load of ferrocement in bending for watertightness control.

INTRODUCTION

The most important property of any construction material used for water retaining structures is low permeability. In ferrocement, permeability is basically due to interconnected pore system and internal cracks in the mortar matrix. Two main factors influencing the permeability coefficient of cement paste are initial porosity and degree of hydration. The former is directly governed by the water to cement ratio of the mortar while the latter is influenced by the age and curing conditions.

In ferrocement, the use of a low water to cement ratio mortar has dual advantages. These are namely, reduction in the initial porosity needed for impermeability and improvement in tensile strength needed for crack resistance. Since the cover giver to the reinforcement in ferrocement is generally as low as 2 to 4 mm, mortar having low permeability is desired to minimise the steel corrosion.

Disadvantages arising from the reduction in the water to cement ratio of the mortar are as follows: (i) reduction in workability of the mix causing difficulty in placing; (ii) increase in cement content resulting in retrogression of strength, due to internal cracking, and high cost; and (iii) reduction in the degree of hydration of cement due to lack of space for gel growth.

The aim of this paper is to discuss the production of ferrocement with low water to cement ratio and the mechanical properties of such ferrocement. In this investigation, the water to cement ratio, by weight, was limited to 0.30 for the technical and economical reasons mentioned. A superplasticiser, also known as high-range water reducing admixture, was used in the mortar to achieve the necessary degree of workability for full compaction.

EXPERIMENTAL INVESTIGATION

The experimental investigation was carried out in two parts. In the first part, the properties of mortar component of the ferrocement in its fresh and hardened states were studied whereas in the second part, strength and deformational behaviour of ferrocement as a function of the volume fraction of reinforcement were studied.

* Department of Civil Engineering, National University of Singapore, Kent Ridge, Singapore.
Mix Details

The mix proportions of the mortar by weight were 1:1.50:0.30 (cement:sand:water). The cement content of the mortar mix was about 840 kg/m³. Locally available ordinary portland cement and natural sand, passing BS No. 7 (2.36 mm) sieve and retaining on BS No. 100 (150 µm) sieve, were used in making the mortar. Sulphonated melamine-formaldehyde condensate type superplasticiser was used at the recommended dosage (0.33% solid by weight of cement) by the manufacturer. Mixing was carried out in a conventional pan mixer. The superplasticiser was added to the freshly mixed mortar and mixed thoroughly for 5 minutes.

Reinforcement Details

Square woven mesh steel was used as reinforcement for the ferrocement specimens. The grid size of the wire-mesh was 8.5 mm x 8.5 mm. The average diameter of wire was 0.92 mm. The ultimate tensile strength and the modulus of elasticity were 360 N/mm² and 188 kN/mm² respectively.

The arrangement of the reinforcement in the ferrocement specimens is such that a uniform distribution of steel about the centre line of the specimens was obtained. The number of reinforcement layers was varied from 0, 1, 2, 3 to 4. In all cases, except for the specimens with 0 and 1 layer, the cover to the reinforcement was maintained at 3 mm on both external faces. When a single layer was used, the wiremesh reinforcement was placed at mid-depth of the section.

Testing of Mortar

Tests were conducted on mortar in both fresh and hardened states. Freshly mixed mortar was tested for its consistency from the time of mixing for a period of up to 2 hours after mixing. Slump in accordance with BS 1881 [1], and flow in accordance with ASTM C230 [2] were determined. In addition, the temperature and wet density of mortar at the end of mixing were measured.

For the properties of hardened mortar, the following specimens were cast for each batch: 9 Nos. of 100 mm cubes; 5 Nos. of 150 mm diameter by 300 mm long cylinders; and 3 Nos. 100 x 100 x 500 mm prisms. These specimens were used to determine the development of compressive strength with age, modulus of elasticity, indirect tensile strength and flexural strength of mortar. All the specimens were moist cured until the age of testing and the details of testing procedures are given in BS 1881 [1].

Testing of Ferrocement

The ferrocement specimens were tested at the age of 7 days in direct tension and bending. Nominal thickness of the specimens was 19 mm. The tensile specimens are similar in shape to that described earlier [3]. The flexural specimens had dimensions of 100 mm x 375 mm x 19 mm. All specimens were compacted by means of a vibrating table. The tests were carried out on an Instron Testing Machine at a constant strain rate. Flexural specimens were tested over a span of 300 mm with loading at middle third points.

The electrical strain gauges having a gauge length of 25 mm were used to monitor the strains in the tensile specimens up to first crack stress. The strain measurements were continued
with a "democ" mechanical strain gauge, having a gauge length of 50 mm, until failure. For the flexural specimens, the above electrical and mechanical strain gauges were used to measure the tensile strain on the bottom tensile face. In addition, the mid-span deflection was monitored with a dial gauge.

RESULTS AND DISCUSSION

Properties of Fresh Mortar

The mortar in its fresh state was found to be dry and the workability improved considerably on the addition of the superplasticiser. The slump and flow values at the end of mixing were 30 mm and 35% respectively. Fig. 1 shows the variation of workability with time up to a period of 2 hours after mixing.

![Fig. 1. Change of workability with time.](image)

The mortar lost its workability with time and within 30 minutes the relative loss of consistency was 50%. This indicates that the fluidising action of superplasticiser is of short duration. The rate of loss of workability for a superplasticised mortar may be influenced by the temperature of the mix and dosage level. The maximum temperature of the mortar was about 3°C higher than the ambient temperature of 28°C. The wet density of the mix was 2275 kg/m³.

Properties of Hardened Mortar

Table 1 summarises the strength and modulus of elasticity of the mortar component of the ferrocement. At early ages, significant parts of the later strength were developed in this high strength mortar. The relative cube strengths at 3 and 7 days are 76 and 87 per cents of 28 days strength respectively. Since the modulus of elasticity is directly related to strength [4], it may be assumed that the mortar has sufficient stiffness at early ages. Results showed that the modulus of elasticity of mortar at 7 days was 28.0 kN/mm².

Modulus of Elasticity of Ferrocement

Table 2 gives the modulus of elasticity of ferrocement obtained from direct tensile and bending tests. In direct tension the stress-strain diagram was used for the determination of the modulus of elasticity whereas in bending, the stress-strain diagram of the extreme tension
Table 1. Properties of hardened mortar.

<table>
<thead>
<tr>
<th>Mix proportions by weight (Cement : sand : water)</th>
<th>1 : 1.5 : 0.30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cube strength (N/mm²) at</td>
<td></td>
</tr>
<tr>
<td>3 days</td>
<td>43.0</td>
</tr>
<tr>
<td>7 days</td>
<td>49.0</td>
</tr>
<tr>
<td>28 days</td>
<td>56.5</td>
</tr>
<tr>
<td>Cylinder strength at 7 days (N/mm²)</td>
<td>39.5</td>
</tr>
<tr>
<td>Tensile strength at 7 days (N/mm²)</td>
<td></td>
</tr>
<tr>
<td>Modulus of rupture</td>
<td>4.00</td>
</tr>
<tr>
<td>Indirect tension</td>
<td>2.45</td>
</tr>
<tr>
<td>Modulus of elasticity at 7 days (kN/mm²)</td>
<td>27.80</td>
</tr>
</tbody>
</table>

Table 2. Modulus of elasticity of ferrocement.

<table>
<thead>
<tr>
<th>No. of reinforcement layer</th>
<th>V_f</th>
<th>Experimental (kN/mm²)</th>
<th>Theoretical (kN/mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tensile test</td>
<td>Bending test</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stress-strain</td>
<td>Load-deflection</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>27.0</td>
<td>26.0</td>
</tr>
<tr>
<td>1</td>
<td>0.39</td>
<td>28.2</td>
<td>28.0</td>
</tr>
<tr>
<td>2</td>
<td>0.78</td>
<td>25.3</td>
<td>28.0</td>
</tr>
<tr>
<td>3</td>
<td>1.16</td>
<td>29.9</td>
<td>30.0</td>
</tr>
<tr>
<td>4</td>
<td>1.54</td>
<td>31.2</td>
<td>32.0</td>
</tr>
</tbody>
</table>

* Volume fraction of reinforcement in per cent

fibre and load-deflection curve were used with equations for simple beam bending to determine the modulus of elasticity. The modulus of ferrocement was also predicted using the following equation, based on the law of mixture:

$$ E_c = E_s(A_s/A_c) + E_m(A_m/A_c) $$

where \( E_c \), \( E_s \) and \( E_m \) are the modulus of elasticity of the ferrocement composite, steel and mortar respectively; and

\( A_c, A_s \) and \( A_m \) are the area of ferrocement composite, steel and mortar respectively.

The predicted values for the modulus are included in Table 2.

In general, the predicted values for the modulus of ferrocement are in close agreement with the experimental values. Also, the modulus is independent of the method of determination, indicating the homogenity of the ferrocement composite.
First Crack Strength of Ferrocement in Direct Tension

Fig. 2 shows the first crack strength of ferrocement in direct tension as a function of the volume fraction of reinforcement. The first crack load corresponds to the point at which deviation from linearity occurred in the plot of load-deformation curve. As the volume fraction of reinforcement increases, the first crack strength of the ferrocement is increased.

The simplified theoretical model proposed by Nathan and Paramasivam [3] is used to predict the first crack strength of ferrocement in direct tension. The general expression for the first crack strength is given by the following equation:

\[ \sigma'_c = \sigma'_s \left( \frac{A_s}{A_c} \right)^n + \sigma'_m \]  

\[ \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2) \]

where \( \sigma'_c, \sigma'_s \), and \( \sigma'_m \) are the proof stresses at 0.01% strain for the ferrocement composite, steel and mortar respectively;

\( A_c \) and \( A_s \) are the area of composite and steel respectively; and

\( n \) is a constant independent of the specimen thickness.

The results have indicated that the values for \( \sigma'_s \) and \( \sigma'_m \) were 203 N/mm² and 2.44 N/mm² respectively.

In the above equation the value of "\( n \)" was found empirically to be 1.1 for the ferrocement made with medium strength of 28 N/mm² for mortar [3]. However the limited test results in this study for the ferrocement made with mortar strength of 49 N/mm² indicate that the value of "\( n \)" is increased to 1.3. A comparison of theoretical (\( n = 1.3 \) in equation (2)) and experimental values for the first crack strength is shown in Fig. 2. Further investigations are needed to quantify the effect of mortar strength on the value of "\( n \)". The effects of mortar strength on the first crack strength of ferrocement is also reported by others [5].

Strength and Deformational Characteristics of Ferrocement in Bending

Fig. 3 shows the first crack moment of ferrocement in bending as a function of the volume fraction of wire-mesh reinforcement. A typical relationship between the maximum tensile strain of ferrocement in bending and the applied moment is shown in Fig. 4. The load-deflection curve for ferrocement in bending is shown in Fig. 5.
Similar to direct tension, the first crack strength of ferrocement in bending is influenced by the quality of the mortar component [5]. In addition, the mortar strength greatly influences the ultimate strength of ferrocement in bending [5, 6]. It was also reported that the thicker the specimen the more the effect of mortar strength on ultimate strength [6].

From Fig. 4, the existence of three stages of deformation for ferrocement in bending is evident. Walkus and Kowalski [7] described these stages in relation to the width of cracks and serviceability [Table 3]. In Stage I, the width of the cracks is below 20 microns and invisible to the naked eye. In addition, the stress-strain relationship is linearly elastic. The working stress of ferrocement for the water retaining structures should be within the Stage I to achieve complete watertightness in service [7].

**First Crack Strain of Ferrocement in Bending**

Fig. 6 shows the influence of the concentration of reinforcement in the first crack tensile strain of ferrocement in bending. The first crack becomes visible when the width of cracks is sufficiently large. This will occur when the stress-strain curve is either quasi-elastic or plastic state (i.e. Stages II or III in Fig. 4). The role of reinforcement is to delay the cracking of mortar component and to limit the width of the cracks. Therefore, the stress and strain at
the onset of first crack increase with the concentration of reinforcement as shown in Fig. 3 and 6 respectively.

Allowable Width of Cracks for Water Retaining Structures

The maximum crack width for the water retaining reinforced concrete structures as recommended by CP 110 [8] and ACI Committee 224 [9] is 100 microns under severe exposure conditions. This value may not be applicable to ferrocement which is much thinner than reinforced concrete and having a reinforcement cover, as low as 2 to 4 mm. Based on the experimental study, Guerra, Naaman and Shah [10] proposed the limiting average crack width of 40 microns. Walkus and Kowalski [7] suggested an even lower limit for complete watertightness in ferrocement of 20 microns.

A recent study by the authors [11] indicated that ferrocement in sustained flexure deflects significantly with time. When the sustained load intensity was 30% of the first crack moment, the ratio of time-dependent deflection to instantaneous deflection varied from 1.45 to 2.65. It is possible that a part of this time-dependent deflection is due to propagation of existing microcracks. This is indirectly noted by a reduction in first crack strength for the pre-sustained loaded specimens when compared with non-loaded specimens at the same age [12].

Therefore, considering the absolute necessity of watertightness and time-dependent behaviour of ferrocement in bending, the limiting value for crack width under short-term flexural loading is taken as 20 microns for severe exposure conditions. For less severe exposure conditions, this limit may be relaxed to 50 microns for water retaining structures as recommended by Shah [13].

Permissible Tensile Stress of Ferrocement for Water Retaining Structures

Since excellent watertightness of ferrocement is expected in Stage I of the stress-strain curve, the permissible stress corresponds to the end of Stage I of the curve. Using the linearly elastic stress-strain relationship during Stage I, the working stress of ferrocement in bending can be estimated. The permissible tensile stress ($\sigma_t$) of ferrocement in bending is given by the following equation:
\[ \sigma_f = E_r \varepsilon_f \]  

where \( E_r \) is the modulus of elasticity of the ferrocement composite (using equation (2)); and  
\( \varepsilon_f \) is the tensile strain corresponding to the end of Stage I (limit of proportionality).

The permissible moment \( M_f \) is given by the following equation:

\[ M_f = Z_c (E_r \varepsilon_f) \]  

where \( Z_c \) is the section modulus of the ferrocement composite. For a rectangular cross-section of ferrocement specimens in bending, \( M_f = (bh^2/6) E_r \varepsilon_f \) where \( b \) and \( t \) are the width and thickness of the specimens.

The results shown in Table 4 indicate that the values of \( \varepsilon_f \) vary between 220 and 300 microstrains for the ferrocement specimens with up to 4 layers of wire-mesh reinforcement. The increase in the strain value with the volume fraction of reinforcement is due to the improvement in the resistance to cracking of the composite.

| No. of reinforcement layers | \( \nu_f^* \) (x 10\(^{-6}\)) | \( \varepsilon_f^* \) (N/mm\(^2\)) | \( \sigma_f^* \) (N/mm\(^2\)) | \( M_f^* \) (Nm/m) | First crack** strain (x 10\(^{-6}\)) | First crack** moment per unit width (Nm/m) | \( M_f \) First crack moment |
|-----------------------------|----------------|----------------|----------------|----------------|----------------------------------|----------------------------------------|----------------|----------------|
| 2                           | 0.72           | 250            | 7.25           | 436            | 300                             | 490                                    | 0.89           |
| 3                           | 1.08           | 280            | 8.32           | 501            | 560                             | 735                                    | 0.68           |
| 4                           | 1.44           | 300            | 9.09           | 547            | 730                             | 905                                    | 0.60           |

* Volume fraction of reinforcement in per cent  
** \( \varepsilon_f, \sigma_f, M_f \) are tensile strain, stress and permissible moment respectively, corresponding to the limit of proportionality for ferrocement composite in bending.  
** First crack corresponds to visible cracking.

Table 4 also shows the ratio of permissible moment of ferrocement, with respect to the first crack moment. As the concentration of reinforcement increased, the permissible moment and first crack moment are increased. However, the ratio of permissible moment to first crack moment is decreased. Therefore, the effect of reinforcement concentration is to increase the first crack moment (visible cracking) more significantly than the permissible moment. With increased volume fraction of reinforcement, the width of the cracks is decreased and difficulty may arise in detecting the cracks visually at early stage. For the ferrocement with 4 layers of reinforcement this ratio is 0.60.

CONCLUDING REMARKS

The use of ferrocement for the water retaining structures requires a high degree of watertightness in service. This may be achieved by having a low permeability mortar component
and by limiting the working stress. A low water to cement ratio of the mortar contributes not only to the reduction in permeability of mortar but also to the improvement in crack resistance of ferrocement.

In this paper, the production of low water to cement ratio mortar and the properties of ferrocement made with this mortar were discussed. Superplasticiser was used to achieve the required degree of workability necessary for full compaction. This degree of workability lasted for about 30 minutes. The experimental results for the modulus of elasticity and strength of ferrocement in direct tension indicate that they may be reasonably predicted by established models [3].

The results showed the existence of three distinct stages of deformation for ferrocement in bending. For water retaining structures, assuming the limiting value of crack width to be 20 microns, the Stage I (linearly elastic) part of the load-strain curve is important. The method of prediction for the working moment of ferrocement in bending for water retaining structures based on the modulus of elasticity of the ferrocement, section modulus and the strain corresponding to the limit of proportionality is presented. It is recommended that investigations should be directed to study strain at the limit of proportionality as a function of mortar quality, volume fraction of reinforcement and distribution of reinforcement.

ACKNOWLEDGEMENT

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REFERENCES


Ferrocement for Hydraulic Gates†

Chinese National Committee on Large Dams*

Hydraulic gates with ferrocement facing and reinforced concrete support system have been in use in several provinces in China. The types of gates include: vertical-lift gates, radial gates, bow gates, shell gates, trussed gates, three-hinged arch gates and gates of box-type shell structure for wave protection and repair works. A brief description of each type is given. The advantages and disadvantages of using these types of structures are discussed.

INTRODUCTION

Reinforced concrete gates and ferrocement gates are being explored and tried out in recent years for low head barrages, flood diversion barrages and tide protection barrages. Rapid development has been made in Anhui, Jiangsu, Zhejiang, Henan, Heilongjiang, Guangdong, Guangxi and Hunan provinces (autonomous region). In the Zhanjiang Prefecture of Guangdong Province, the technology of prestressing is also applied in the manufacture of reinforced concrete gates and ferrocement gates. The types of gates are manifold, including vertical-lift gates, radial gates, bow gates, shell gates, trussed gates, three-hinged arch gates and others. The largest span is up to 16.2 m, while the largest head reaches around 10 m.

The advantages claimed in favour of reinforced concrete gates and ferrocement gates are:

a. Economy in steel: Under the conditions of equal heads and similar openings, such gates can economize 30-50% of steel as compared with the steel gates. When prestressing method is applied, the amount of steel saved may even reach 40-60%.

b. Reduction in project cost: The total cost of gates can be cut down by 30-60% as compared with that of steel structures because the gates requires less amount of steel and welding materials, and simple on-site fabrication.

c. Economy in maintenance expenses and in labour: When steel gates function either under water or in moist state for a long period, the steel facings and bracings are susceptible to rusting. Hence, involving a great deal of expense and labour. The use of good quality reinforced concrete gates or ferrocement gates will reduce regular maintenance work such as rust clearing, painting, etc.

d. Suitable to the openings where the sinking of gates requires surplus weight to overcome buoyancy.

Nevertheless, reinforced concrete gates and ferrocement gates also have their disadvantages and defects as against steel gates:

a. Such gates are heavier, being generally twice or thrice the weight of steel structures. This will require greater capacity and higher cost of lifting equipments.

† Excerpt from Chinese National Committee on Large Dams "Dam Construction by the Chinese People" Undated.
* The Ministry of Hydraulics and Electricity Industry, Bai Gurung Lu, Beijing, China.
b. The behaviour to resist earthquake and the behaviour to withstand gate vibration and impact of floating objects on the gate both caused by flowing water, are inferior to those of steel gates.

c. On account of the above-mentioned defects, such gates require strict and careful management, and the control of their operation is not so convenient and secure as the steel gates.

Taken as a whole, despite the aforementioned defects of the reinforced concrete gates and ferrocement gates, it is still worthy to promote them to local projects of medium-sized and small barrages or dams, because their total cost and steel consumption are smaller, and they are suitable for self-help using indigenous construction methods.

TYPES OF HYDRAULIC GATES

A brief description of several types of such gates are as follows:

Vertical-lift Gate with Cantilevers at Two Edges

This gate can be used as a water-retaining gate (Fig. 1) for a low head barrage. Its net length is 8 m and its height 1.9 m. The gate is supported on 2 main precast reinforced concrete cross-beams and on the upper and lower framed beams. The load is then transferred to the main longitudinal beams, on which the fixed wheels can move vertically along the rails on the piers. The facing is only 18 mm thick, using ferrocement with 3 layers of wire mesh (wire diameter 0.9 mm, mesh opening 10 mm x 10 mm) and 2 steel-bar meshes (bar diameter 4 mm, mesh opening 100 mm x 100 mm). This type of gate had experienced overtopping at a surcharge head of 1 m during its service and suffered no damage.

![Diagram of Vertical-lift Gate with Cantilevers at Two Edges](image)

1 - Face slab of wire mesh cement
   (3 layers of wire meshes and 2 layers of reinforced bars)
2 - Prestressed main beam
3 - Fixed wheel
4 - Guide wheel

(Dimensions in cm)

Fig. 1. Vertical-lift gate with cantilevers at two edges.
Fig. 2. Radial gate of beam-slab type.

Radial Gate of Beam-Slab Type

Fig. 2 shows a radial gate of beam-slab type for the flood diversion barrage of a reservoir. A prestressed reinforced concrete parapet wall is provided above the gate, which has a net span of 10 m and a height of 4.5 m, capable of withstanding a maximum head of 9.75 m. The structure and internal stresses of the gate are designed and calculated in a similar way as a steel gate. A precast reinforced concrete beam system is adopted to form the skeleton of the gate flap. The face slab of the gate is made of ferrocement (4 layers of wire mesh and 3 layers steel bar meshes), with coating of glass fibres and epoxy resin for water tightness. The gate arms are also reinforced concrete structures, which are accurately and securely connected to the gate flap by steel plate splices (shoes of the gate arms) embedded in advance. The gate flap and the gate arms are separately precast on the ground and then assembled at the work site.
Bow Gate

A bow gate can be constructed by changing the face slab of a vertical-lift gate into a bow facing of vertical arc surface. Fig. 3 shows a service gate of such type installed at a regulating barrage on a canal. Its facing is ferrocement while its cross beams and edge struts are reinforced concrete structures. The facing of the gate assumes a vertical cylinder wall. The water pressure acting on the gate is normal to the wall face, and so the facing will bear only tangential stresses which produce no moment. In this way, economy in materials can be effected. Under a given span length of the gate, the tangential stresses in the facing is proportional to the radius of the arc surface but inversely proportional to its central angle. Therefore, the greater the central angle of the arc surface, the smaller the radius, and the smaller the tangential stresses of the facing. Consequently, its thickness can be reduced. However, if the central angle is too great, the arc surface will be lengthened and the chord height increased. This will then lead to difficulty in the arrangement of the supporting structure at the two ends. Hence, a suitable central angle of about 60°-90° is to be selected. When the facing is made of materials with a high tensile strength (e.g., steel plate or ferrocement with high percentage of reinforcement), the arc surface should bow towards downstream so that the facing will be subjected to tensile stress in the tangential direction and the cross beams will become tension rods. Conversely, when the facing is built of materials with a high compressive strength (e.g., concrete or ferrocement with low percentage of reinforcement), the arc surface

![Diagram of Bow Gate](image)

1 - Face slab of wire mesh cement
   (3 wire meshes and 2 bar meshes)
2 - Transverse reinforced concrete beam
3 - Steel tie rod
4 - Fixed wheel
5 - Guide wheel
6 - Hoisting eyes

(Dimensions in cm)

Fig. 3. Bow gate.
has to be bowed towards upstream, but the cross beams will still be tension units. For a bow gate, in addition to using cross beams for resisting the tangential stresses of the facing, it is also necessary to use rigid edge struts to form the gate frame. At the rear part of the edge struts the sliding blocks or the fixed wheels are provided for the gate to move vertically along the rails in the grooves.

Shell Gate

A shell gate refers to a gate whose facing is arranged into an arc surface in both vertical and horizontal directions to form a facing of spherical shell structure (Fig. 4). Its ratio of rise to span is relatively small (generally being 1:8 to 1:12). The facing of such gate is clamped at the edges by rigid units to prevent damage or deformation. Very small or essentially no moment will be produced in the facing. Thus, a thin facing will be adequate. The ratio of height to length of the gate should be controlled within the range of 0.5-2 according to the requirements of uniform loading on the facing in the two directions and of its structural shape. The shell gate illustrated in Fig. 4 is used in a regulating barrage. Its facing is ferrocement, and its frame which is formed by perimeter units is reinforced concrete.

![Diagram of Shell Gate](image)

1. Shell face of wire mesh cement
   (6 wire meshes and 2 bar meshes)
2. Shell face of wire mesh cement
   (8 wire meshes and 2 bar meshes)
3. Edge beam
4. Sliding support

(Dimensions in cm)

Fig. 4. Shell gate.
Three-Hinged Arch Gate with Twin Flaps

This type of gate can be made as follows: A bow gate is divided vertically from its centre into two flaps, they are then separately stiffening ribs and gate post units. The edge posts are provided with pivots at their upper and lower ends and the gate slots are changed into concave arc slots. To be in open position, the two flaps of the gate can rotate, one to the left and the other right. When closed, the gate forms an arc in plan, having three hinges, one is the contact part between the posts of the two flaps, and the other two are the pivots where the edge posts are connected at the gate slots. Such is a three-hinged arch gate with twin flaps (Fig. 5). Because the gate is a cylindrical arc which is bowed towards upstream, the water pressure acts perpendicularly to the gate and its resultant passes through the centre of the arc surface, therefore, the moment of the flap structures will be zero, and the tangential compressive stresses will be transmitted to the abutment walls or the piers. This type of gate makes rational use of the superior behaviour of the cylindrical structure, effecting great economy over the ordinary miter gates with twin flaps and so is applicable to navigation locks and to barrages for tide-protection and drainage. The three-hinged arch gate with twin flaps shown in Fig. 5 is the one used in a navigation lock on Nantu River in Haikang County, Zhanjiang Prefecture. The headwork of the lock is 9 m in net width, and the gate 7.9 m in height, capable of passing 150 t ships. The facing of the gate is a ferrocement structure, and the gate frame and the stiffening ribs are reinforced concrete structures.

![Diagram of Three-Hinged Arch Gate with Twin Flaps](image)

**Fig. 5.** Three-hinged arch gate with twin flaps.

Gates of Box-Type Shell Structure Used for Wave Protection and Repair Works

At No. 1 Spillway of Hedi Reservoir in Zhanjiang Prefecture, Guangdong Province, there were originally 5 steel gates, each of 10 m in net span and 4.5 m in height. The vast reservoir surface and long fetch distance caused very large wave action during the attack of a typhoon. In 1965, one steel gate was damaged at the gate arms and at the gate flap which lost their stability under the strong wave action. In order to lessen the wave action and prevent the service gates from shock damage, wave-protection gates are provided upstream of the
service gates. These gates were constructed of prestressed units of thin shell boxes. The upper and lower edge beams are I-shaped reinforced concrete beams with webs, and the upstream and downstream facings are shells of ferrocement. When several shell box units are put together one over the other, they will form the emergency gate for repair work (Fig. 6). This box-type shell gate for wave protection and repair work can resist a maximum moment of 73 t-m. During prestressing, the total tension force had reached as high as 341 t. Under ordinary circumstances, the gate is in suspension on the water surface, and has good effectiveness in wave protection.

![Fig. 6. Gate of shell box type used for wave protection and repair work.](image)

**Stoplog Trusses**

In case of stoplogs with a large span, steel stoplogs will consume a great deal of steel, while wooden stoplogs will present difficulty in lowering to the required position, besides using a large quantity of timber. If ordinary reinforced concrete stoplogs are adopted, the operation will be very clumsy owing to their large volume. In Fig. 7, the stoplog truss is composed of a pair of prestressed reinforced concrete trusses and a ferrocement facing. It is used for closing a barrage opening with a net span of 10 m. The maximum head is 7.5 m. Such gate has a comparatively small volume and small dead weight, and good flexibility in operation.
CONCLUSION

Using ferrocement for the face slab of hydraulic gates, requiring surplus weight to overcome buoyancy, has realized economy in steel, maintenance and labor. This reduced project cost 30-60% compared with that of steel structures.
Ferrocement Water Tanks

F.C. Tarran*

A detailed description of the construction of ferrocement water tanks, up to 50 m$^3$ capacity, is presented. Practical problems involved in the placement of reinforcement and mortar are emphasized. Roof construction and water-proofing are also discussed.

LIST OF SYMBOLS

- $A_s$ = area of steel reinforcement
- $N$ = tension forces
- $d$ = diameter of tank
- $f_{yk}$ = maximum allowable steel tension stress
- $f_{yk}$ = reinforcement yield strength
- $h$ = height of water tank
- $\gamma$ = density of stored liquid

INTRODUCTION

This ferrocement liquid storage tank design was developed, primarily, for alcohol storage. The same design was used for water storage, the only difference was the elimination of the special internal coating needed for the alcohol reservoir.

GEOMETRY OF THE TANK

The tank was cylindrical and ground bearing. The cylindrical form is very convenient in the sense that there are no bending moments, except in the boundary regions.

The height of the tank was made equal to 2.5 m which is compatible with welded grid mesh (2.4 m wide). Two internal diameters were used: 3.6 m for 25 m$^3$ and 5.2 m for 50 m$^3$ capacity, respectively. The wall thickness, in both cases, was 30 mm (Fig. 1).

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Only the 50 m$^3$ capacity water tank will be described as the smaller one is similar in geometry and design.

**DESIGN**

For the design it was assumed that:

1. All tension forces are resisted by the reinforcement, which means that the tensile strength of the mortar is neglected.
2. There are no bending moments over the entire reservoir, including the tube-slab connection region. This is an acceptable assumption as the boundary disturbance affects only a few centimeters of the cylindrical tube and bottom slab.
3. The reinforcement due to the wire meshes is neglected, its function being to allow the placement of mortar without formwork.
4. The maximum allowable tensile stress in the reinforcement steel is 200 MPa for high grade steel ($f_{sh} \geq 400$ MPa) and 120 MPa for low grade steel ($f_{sh} \geq 240$ MPa).
5. There are no bending moments acting upon the bottom slab. This means the soil reaction is supposed to be uniform over the entire bottom slab.

With the above assumptions the design of the reservoir is very simple (Fig. 2), using the relationships:

\[ N = \gamma \cdot h^2 \]
\[ A_s = \frac{N}{f_t} \]

Substituting $h = 2.5\ m$, $d = 5.2\ m$ and $A_s = 520\ mm^2/m$ or $330\ mm^2/m$ for low and high grade steel reinforcement, respectively, then the tension force $N$ is obtained as $N = 65\ kN/m$.

![Fig. 2. Distribution of water pressure.](image)

![Fig. 3. Alternative roof slab.](image)
CONSTRUCTION MATERIALS

Steel Reinforcement

The reinforcement may be either welded wire mesh or reinforcement bars. The former one is simplest to assemble but not available all over Brazil. Steel reinforcement may be either low or high grade, wherever possible, choose one with the highest bond.

The steel bars should be of small diameter (4 to 6 mm) spaced no more than 200 mm for hoop bars, 300 mm for the vertical reinforcement and 150 mm for the bottom slab.

When isolated bars are utilised, the height of the tank is divided in three sections of equal length. In each section the horizontal bars are equally spaced.

The minimum recommended steel area for the bottom slab is 0.005% in each direction (square mesh). This reinforcement is placed at mid-height of a 30 mm thick mortar.

Instead of ferrocement the bottom slab may be made of reinforced concrete with a minimum thickness of 60 mm.

There are the following possibilities for roof construction:

• Asbestos-cement roof plates
• Pre-fabricated reinforced concrete slab
• Ferrocement ribbed slab with or without central column

The choice of either solution will depend on local availability of components. The first possibility is the easiest while the last one is the more time consuming.

Only the ferrocement slab calls for a design. Its geometry is given in Fig. 1 and it consists of eight radial beams and six segmental slabs. The slabs are 30 mm thick and the beams are 60 mm wide and 150 mm in height.

A more simple design would be the one shown in Fig. 3, but it will be more expensive as it calls for more wood formwork than the ribbed slab.

Wire Mesh

Wire meshes may be either chicken wire meshes (galvanized) or stucco wire meshes. The latter is not galvanized and so is cheaper than the former one.

Mortar

The mortar consisted of portland cement and coarse washed sand in a ratio of 1 to 2 (by volume) and the water: cement ratio was about 0.36 to 0.40.

A mortar may be considered good for placement when a ball of it loses no water when pressed in the hand and maintains its shape when the pressure is released.

CONSTRUCTION PROCEDURE

The ground, at the site where the tank will be constructed, must be compacted. Care must be taken to deviate rain water from the base of the tank.
The mortar, or the concrete, must not be poured directly over the soil. A better way is to lay over the soil a plastic sheet (PVC or polyethylene) prior to mortar or concrete pouring.

![Diagram of construction details of tanks reinforced with isolated bars.](image)

Fig. 4. Construction details of tanks reinforced with isolated bars.

**Tanks Reinforced with Isolated Bars**

1. After the ground has been prepared, a circular trench 150 mm by 150 mm with a medium radius of 2.61 m should be excavated (Fig. 4a).

2. To support the reinforcement erect about 10 timber struts (50 mm x 50 mm x 2.80 m or round lumber, diameter = 70 mm) 1.6 m apart, center to center. These struts are located externally to a circle of radius 2.60 m. It’s upper ends are attached to 18 gage steel wires which are fixed to stakes driven in the ground (Fig. 4b).

3. The square mesh (welded or not) is laid over the plastic sheet with the ends of bars bent upward (Figs. 4c and 6). The mortar or concrete is poured just to the border of the trench.

4. Wall reinforcement

To support the hoop bars, drive nails into the timber struts. Lay two layers of chicken or stucco wire mesh (Fig. 4d). Place the hoop bars in between the nails spaced no more
than 200 mm (Fig. 4e). Then position the vertical bars at 300 mm on centers (Fig. 4f) and the second layer of hoop bars at 200 mm on centers (Fig. 4g). Two layers of wire meshes are wrapped around the steel reinforcement (Fig. 4g).

To tie together the reinforcement bars and the wire meshes it is convenient to utilise threaded nylon ropes like those sold for masonry works. Wire ties are inconvenient in the sense that they hurt the hands during mortar placement. The threaded nylon rope is either knotted or utilised to "sew" the reinforcement. In the latter case a big hand sewing needle is very useful.

5. Molding of walls

The pouring of wall begins at the trenches. Care must be taken in the connection between wall and bottom slab (Fig. 4h). Provide voids around the struts to make its removal easier.

The mortar placement is done in the usual way, remembering that they must have no interruptions and that the maximum delay between old and new mortar must not be greater than half an hour (in hot climates at least).

For the 50 m³ tank, a crew of 10 men to lay the mortar is recommended.

In the region of the struts it is not possible to cover internally the reinforcement. This may be done after the removal of the timber some 3 days after the pouring of the mortar. About 3 to 5 hours after the beginning of mortar application one must start to wet the mortar. The wet curing must continue for five days at least.
6. Central column

A square footing 400 mm x 400 mm x 100 mm is poured over the center of the tank. It will support a column molded inside PVC tube of 150 mm diameter. This column is reinforced with 4 to 6 mm diameter bars. There is no need for stirrups (Figs. 4i, 4j, 4k and 5).

7. Roof slab

The dimensions of the roof slab are shown in Fig. 1. In order to reduce formwork cost, the slab may be constructed in parts. However, it may be built one eightieth at a time as a permissible minimum.

The formwork may be withdrawn 48 hours after the application of the mortar.

![Diagram](image)

**Fig. 7.** Construction details of tanks reinforced with wire meshes.

### Tanks Reinforced with Welded Wire Meshes

When welded wire meshes are used, the wall reinforcement is simplified and there is no need for timber struts; in this case, the reinforcement is supported horizontally by means of radial wires and stakes (Figs. 5, 6 and 7).
WATERTIGHTNESS

If for some reason certain areas develop strong leakage due to faulty molding, these areas must be repaired with mortar applied from inside. To eliminate leakages other than those due to large voids it suffices to apply two coatings of cement-water admixture. This may be done on the inside face of walls with a minimum delay of 8 hours between applications.

It is recommended to apply the same coating on the outer face of wall in order to prevent rusting of wire meshes.

Fig. 8. Finished 25 m$^3$ water tank with a conical ferrocement roof.

Fig. 9. 50 m$^3$ ferrocement water tank under construction.

CONCLUSION

Two water tanks of 25 m$^3$ (Fig. 8) and one of 50 m$^3$ (Fig. 9) capacities were built during 1979 and early 1980. To date they are in good condition showing no leakage nor steel corrosion. When stucco wire mesh is used instead of chicken-wire mesh, the total cost of the reservoir is greatly reduced.
Ferrocement Water Tanks With Precast Barrel Vault Elements*

J.B. de Hanai** D.A.O. Martinelli† I. Montanari++ and M.K. El Debs†

A peculiar type of water tank, featuring an undulated circular wall composed of ferrocement precast cylindrical vertical elements is presented, mainly through the description of the already built 2700 m³ and 900 m³ ground reservoirs.

INTRODUCTION

A short account of the "S. Carlos Group" adaptation of Nervi’s "ferro-cemento" basic idea is given in a previous panoramic paper [1], where the ferrocement applications of the Group to silos, swimming pools and water tanks are shortly commented together with a number of other structural applications. The idea of moulding a watertight ferrocement "membrane" all over the sloping faces and the bottom of a ground excavation has allowed the economical construction of swimming pools up to 1000 m² projection, water tanks up to 3000 m³ volume and grain silos 12 m in diameter.

The basic idea of the undulated wall goes back to M. and A. Reimbert [2]. They proposed—and at least one large application was realized—to cast the undulated wall, then wrapping it all with a prestressing wire girdle, which would be tensioned on filling the reservoir, then the wire girdle would be encased in concrete, thus eliminating any danger of cracking. The undulated wall, on its side, would be essentially compressed, an idea retained in the undulated wall reservoirs already built by the S. Carlos Group, which nonetheless, have dispensed with the continuous wall wrapping, concentrating the hoop tension resistance in a top ring and in the tank bottom.

DESCRIPTION OF TANK

A peculiar type of ground water tank, featuring an undulated circular wall composed of precast cylindrical vertical elements, is hereafter described in some details. This type may be adopted also for water towers; two of them, initially intended to be built assembling precast ferrocement elements were, for contingent reasons, executed with cast-in-place concrete in Araraquara, SP, Brazil (1972 and 1974), respectively to 1200 m³ and 500 m³ storage capacity (Figs. 1 and 2); in both reservoirs the cast-in-place undulated wall was made up of sixteen cylindrical barrel vaults 100 mm thick.

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Fig. 1. 1200 m$^3$ water tower using precast barrel vault elements.

Fig. 2. 500 m$^3$ water tower also using precast barrel vault elements.

The opportunity for precast ferrocement elements was seized at the construction of a ground reservoir of 2700 m$^3$ volume for S. Carlos (1981-82) and, almost simultaneously, of two smaller (900 m$^3$) reservoirs at Americana (some 100 km from S. Carlos) [3]. Figs. 3 and 4 show the main features of the S. Carlos reservoir.

The two water tanks, each of 900 m$^3$ volume, built in the town of Americana, have their walls composed by 30 barrel vaults whose dimensions are practically the same as those of the S. Carlos reservoir. It is noteworthy to mention the possibility of using only one type of element for reservoirs of such differentiated volumes. The construction procedure was exactly the same, but for the different roof solution, which consists of precast prestressed concrete slab elements, supported by the wall top ring and by interior beams on columns.

**ANALYSIS**

For practical applications, the wall analysis may be essentially reduced to the analysis of a number of representative horizontal arches; however, a beam-arch analysis was also developed [4], as an adaptation of the beam-arch method for roof barrel vaults.

The bending moments, shearing and normal forces computed with the beam-arch approximation are low, as can be observed in Fig. 5, where the horizontal bending moments and normal compressive forces at the critical points are shown. As could be expected, the higher bending moments occur near the built-in sections of the vaults in the vertical ribs, with tension stresses at the inner side. However, the tension band (with maximum thickness of 45 mm) is only 0.35 m wide. A measure of the small importance of the computed transverse bending moments was obtained using the formulae proposed by Logan and Shah [5] and by Surya Kumar and Sharma [6] for the estimate of the moment corresponding to the first visible
Fig. 3. Main features of S. Carlos reservoir.
Fig. 4. Details of S. Carlos reservoir.
crack. The results were respectively 2660 Nm/m and 1870 Nm/m, neglecting the chicken meshes and the favourable effect of the normal compressive force. Assuming homogeneous section, the maximum tension stresses were approximately 4.0 MPa, indicating low probability of crack formation. The same occurred with the vertical stresses, the maximum being now of the order of 3.0 MPa. These values, purposely conservative, and the good behavior observed, suggest the reduction of the dimensions adopted for these initial accomplishments.

Fig. 5. Transverse bending moments and normal forces.

METHOD OF CONSTRUCTION

The undulated wall of this reservoir is composed of 48 precast barrel vaults of approximately 2 m chord. They are erected side-by-side, vertical reinforced concrete ribs being then cast in place embodying the juxtaposed sides (Fig. 6). The wall rests on a continuous reinforced concrete ring supported by piles placed in correspondence to the vertical wall ribs. The barrel vault tops are embodied in a cast-in-place reinforced concrete, which also supports the 96 precast ferrocement roof Y beams (Fig. 7).

These 96 roof beams lay at their other extremity on the central portion of the roof, a circular cast-in-place reinforced concrete slab on columns, 10 m in diameter (Fig. 8).

The tank bottom is a reinforced concrete slab on a regular plain concrete layer laid on the compacted ground, independent from the wall ring.
The major portion of the precast barrel vaults, 35 mm thick, embodies two welded fabrics of 2.77 mm diameter wires (yield strength $f_{yk} = 600$ MPa) and 50 mm square meshes (steel content of welded fabrics about 108 kg/m$^3$), plus two chicken galvanized screens of 12.7 mm (1/2 in) with BWG 22 wires (0.71 mm diameter). In the lateral bands of the vaults, 250 mm, the thickness increases from 35 mm to 45 mm, embodying four welded wire fabrics instead of two. At the top and bottom sites of the vaults, the diaphragms are 45 mm thick, with four welded wire fabrics plus two chicken meshes.

The vaults were moulded on brick forms, (Fig. 9) and after three days curing were moved by means of a small rolling crane either to the stocking yard or directly to their assembling position (Fig. 10). A second crane was used for the erection of the vaults weighing 8 kN (Fig. 11). As already stated, a reinforced concrete vertical rib was then cast-in-place, assembling each pair of vaults.

The roof beams are reinforced only with welded wire fabrics, four in the web and two in the upper portion (steel content about 150 kg/m$^3$). They were moulded on steel forms, weighing approximately 10 kN, and were erected after casting of a portion of the wall top ring.
A protective and waterproofing layer of chlorinated rubber resin was applied to the inner face of the structure.

The construction procedure has shown great flexibility, allowing for the simultaneous execution of different parts of the structure, with reduced consumption of forms and scaffolding. In most cases, the traditional building methods go on only by total horizontal sections: the whole foundation, then the whole basis, then the whole wall, and finally the whole roof. Here, on the contrary, the construction could proceed by independent circular sectors, at their turn split into horizontal sections, thus adding one more time dimension to the flexibility of the construction procedure. So, in each of the several independent circular sectors, the casting and the erection proceeded continuously from bottom to top of the wall, irrespective of the construction stage of the adjacent sectors.

CONCLUSIONS

The filling tests have shown only a few moisture speckles near the joints, easily corrected by improving the internal protective coating, as none of them got to be real leakage points.

The different contractors of S. Carlos and Americana have manifested great interest in the ferrocement solution and, in spite of the lack of experience with the system, estimated a cost saving of approximately 30% with regard to the conventional reinforced concrete solution. As a matter of fact, the Americana contractor has already begun the construction of two new 900 m³ volume tanks, repeating the two previously built.

Presently, the "S. Carlos Group" is studying the possibility of improving the construction procedure. It is now planning a research on a prototype of 120 m³, which will also give the opportunity of testing some new features for alcohol storage.

Another research project is devoted to the ferrocement application for small water treatment facilities. In connection to the large underground tank and swimming pool achievements, all these projects follow the course in order to complete an extended ferrocement construction system to be applied to water resource structures.
REFERENCES


Ferrocement Well Mounting Rings for Shallow Surface Wells

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Shallow surface wells have great potential for economy irrigation techniques for barren lands in Pakistan. These wells can be produced rapidly and at comparatively lower cost. To ensure optimum utilization of such wells, it is essential to use well-lining to prevent collapse. Prefabricated ferrocement well mounting ring, a very good alternative to the traditional masonry wall, is discussed including advantages and construction technique.

INTRODUCTION

Economy irrigation techniques for agricultural production have reached a very advanced stage. This system consists of low-cost perforated PVC pipes laid in ridges of soft soil with crops on both sides of the ridges. Water is fed to these pipes through a hose under low pressure. This technique can make a useful contribution in winning the battle against food shortage.

The best strategy to win this battle is to grow the food where it is required. This is in the poorer countries where soil, sunshine and a hardy peasantry co-exist. The problem—the soil is barren because massive water supplies are not available and economy irrigation has still to become popular.

In such regions, small diameter surface wells have a great potential because they can be produced rapidly and at comparatively lower cost. However, in order to ensure optimum utilisation of such wells, it is essential to raise a permanent structure for them, in order to prevent collapse. The traditional method of building masonry walls has become so expensive and time consuming that it is no longer a practical possibility.

PREFABRICATED FERROCEMENT WELL MOUNTING RINGS

Advantages

A very good alternative to masonry walls is that of prefabricated ferrocement well mounting rings (w.m. ring) which can be mounted, one upon another, in an incredibly short time, resulting in a neat and strong structure which affords complete protection to the well at a fraction of the cost and time which other alternative methods would involve. These rings also offer the following advantages compared to masonry walls:

a. Eliminate the need for any foundation. Well mounting rings make it impossible for the well to collapse even during the excavation process.

b. Economy in construction materials, transportation and total volume of excavation. Masonry walls are normally at least 9 in (229 mm) or 12 in (305 mm) thick while the thickness of the w.m. rings vary from 1 1 in (32 mm) to 3 in (76 mm).

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c. Eliminate the need for skilled labour at the construction site. W.m. rings also eliminate the risk which is inherent in masonry walls, namely, that weak spots may exist in the construction, due to defective quality of sand or cement or inadequate mixing of the mortar. With these rings, a completely built-up well becomes available as soon as the excavation is over, whereas with the masonry wall the expensive and time consuming task of wall construction can only begin after the excavation is over and adequate water supply has been reached.

d. Ensure correct dimensions of the well. The w.m. rings ensure that the well is truly circular in shape and that its walls are correctly vertical. Both these factors provide optimum strength to the well construction.

e. If it is desired at any time to deepen the well, which is very often the case, this can very easily be done by digging the soil and rock below the bottom ring, as a result of which the entire structure slips down a fraction of an inch at a time. In the case of masonry walls, however, it is only possible to deepen the inner portion of the well, and this naturally is able to provide a much smaller storage capacity.

**Materials for Construction**

- Mild steel rod 3/8 in (9.5 mm) diameter ~ 60 r.f.t.
- Mild steel rod 1/4 in (6.35 mm) diameter ~ 30 r.f.t.
- Wire mesh ~ 30 ft² (2.8 m²)
- Jute cloth ~ 30 ft² (2.8 m²)
- Cement ~ one bag
- Sand ~ 5 bags (same size as cement bag)

**Construction Technique**

The construction method described is for 10 ft (3.05 m) diameter w.m. rings, however, the same method is applicable for the other dimensions.

1. Roll the 3/8 in (9.5 mm) diameter rod into two 10 ft (3.05 m) diameter circles, one for the top and the other for the bottom of the w.m. ring. Join the two rings by means of tie rods 1 ft (0.305 m) long and 1/4 in (6.35 mm) diameter. All joints have to be welded (Fig. 1).

![Skeletal steel reinforcement for the w.m. ring](image1)

![Wire mesh tied tightly to the skeletal steel reinforcement](image2)
2. Cover the entire ring with a layer of chicken wire mesh. The mesh is to be tied to the mild steel rods with mild steel wires (Fig. 2). The mesh must be stretched taut.

3. Cover the mesh with a layer of thin jute cloth, tying this tightly at suitable intervals. The jute cloth provides a good backing surface to hold the plaster (Fig. 3).

4. Prepare a well mixed mortar for plaster, using one part of cement to four or five parts of screened sand. The sand must be free from dust and other impurities, and in case this is not available, it must be washed to remove the dust and other impurities.

First apply a thin mixture of cement and water on the jute cloth (neelu), and over this apply a layer of plaster, from 1/4 in (12.7 mm) to 5/8 in (15.9 mm) thick. After this has set, which may take a few hours, apply a second coat of plaster, this time from the inside. After completion of plastering, it should be well cured by keeping it moist for at least 3 days. Thereafter the rings are ready for installation.

The thickness of the completed ring can vary from 1.25 in (31.8 mm) to 2.5 in (63.5 mm) or even 3 in (76.2 mm) depending on the application required as well as in the skill of the workmen concerned. Completed w.m. rings are shown in Fig. 4.

Fig. 3. Jute cloth laid on.   Fig. 4. Completed ferrocement w.m. ring of different diameters.

Fig. 5. Ring ready for transport.   Fig. 6. Ferrocement w.m. ring, 6 ft. (1.8 m) diameter used for a 12 ft. (3.7 m) deepwell.
Transportation Technique

The thicker size of ring will need nearly 8 men to lift and carry. The best way to do this is to coil a thick strong rope around the entire ring as shown in Fig. 5 and for the men to hold on to the ropes, which provide a much better grip.

For transport by vehicle, the best position for stowing the w.m. ring is to keep it at an incline and fixed position. It should never be transported in the vertical position as it may crack if the full load comes on one side.

CONCLUSION

Shallow surface wells were constructed about five years ago with w.m. rings of 4 ft. (1.2 m), 6 ft (1.8 m) (Fig. 6) and 10 ft. (3.05 m) diameters. The maximum depth of these wells were about 40 ft (12.2 m), however, the rings were only installed at the lower part of the well, i.e. 3 ft (0.9 m) or 4 ft (1.2 m) above the water level. Even this limited cover has given excellent results, but it is obvious that the best course is to install the rings along the whole depth of the well. In such a case, of course, the compressive and shearing stresses in the rings will be in proportion to the depth of the well and the rings will have to be so designed. The maximum number of rings mounted so far has been ten ring layers and work has been started for about twenty ring layers.
Review of Design Considerations and Construction Techniques for Ferrocement Water Resources Structures


An overview of the basic design considerations in the construction of ferrocement water resources structures is presented. Since very little analytical work has been done, an attempt has been made to identify parameters that will be essential to the design process. Particular attention has been given to water tanks which constitute a major area of application. A brief description of construction practices is also outlined.

INTRODUCTION

The development of systems to effectively store, transport, control and transform water and water power is crucial to national growth. Water storage tanks, reservoirs, pipes for penstocks, drainage and well-linings, canal networks, sluices, hydraulic gates, water filters etc. are all independent yet integrated components of such a system.

The growing need for water-resources structures in the region is plainly evidenced by the enormous loss to life and property as a consequence of the inability to harness water power following heavy rains and floods. However, most developing countries lack the sophistication, technique and resources to build as many of these systems as ideally required. It is in this context that an appropriate material of construction which affords simpler and less sophisticated construction at reduced costs assumes significance.

Ferrocement has long been used as an appropriate technology material for strong, durable and economical construction. But the majority of applications have remained confined to small-scale construction requiring no elaborate analytical methods and hence no adequate guide-lines exist for designing ferrocement structures.

The primary aim of this paper, therefore, is to identify essential design parameters and discuss the feasibility of using ferrocement for a range of water-resources applications. Particular emphasis has been given to water storage tanks since they constitute an area where most of the work has been done. Important factors pertaining to construction procedures are also discussed.

MECHANICAL PROPERTIES

The mechanical properties of ferrocement that are essential to the design process are briefly listed below:

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1. The Young's modulus of the composite may be determined from the law of mixtures.

\[ E_{\text{comp}} = E_m v_m + E_f v_f + E_s v_s \] ........................ (1)

where \( E_m, v_m, E_f, v_f, \) and \( E_s, v_s \) are the elastic moduli and volume fractions of the mortar, wire-mesh fibres and steel respectively. However, if the overall percentage of reinforcement provided is rather small, i.e. much less than 1.8 percent [1], then the value of \( E_{\text{comp}} \) may be assumed to be the same as for plain mortar.

2. Laboratory results, if available, or validated empirical relations may be used to establish the first-crack strength of ferrocement, e.g. the formula given by Naaman [2]:

\[ \sigma_{fr} = 24.52 S_{f_1} + \sigma_{mu} (\text{MPa}) \] ........................ (2)

where \( \sigma_{fr} \) is the required first-crack strength, \( S_{f_1} \) is the specific surface of the reinforcement in the loading direction (mm\(^2\)/mm\(^3\)) and \( \sigma_{mu} \) is the ultimate strength of the mortar in direct tension.

3. The net cover of the reinforcement should not exceed 1/5 the thickness of the element nor should it be greater than 5 mm [1].

4. All water-retaining structures must be designed for crack-free service, i.e. the stresses developed during the service life of the structure under maximum load must not exceed the established first crack strength. However, a maximum crack width of 0.005 mm is sometimes recommended for water retaining structures [1].

WATER TANKS

Water tanks account for a major share of ferrocement applications in water resources structures. The greatest advantage of ferrocement over ordinary reinforced concrete in water tank construction comes from its ability to resist both shrinkage cracking during curing and normal cracking under tensile loads during service. In addition it is easier to construct, cheaper in cost and has also proven to be relatively more water-tight.

Design Considerations

Cylindrical Tanks

Though no general analytical procedure is employed in designing ferrocement cylindrical tanks, the linear elastic theory for axisymmetric shells is sometimes used in determining the displacements and stresses developed. A procedure used by Watt [3] assumes the tank foundation to be sufficiently rigid and continuous with the shell wall. This would imply fixed-end conditions with both moment and shear occurring at the base. However, the characteristic slenderness of the ferrocement shell wall may not satisfactorily permit such an approximation.

There are hence a number of alternative options in attempting to understand the exact behavior at the base of the tank wall. The need for such a precise prediction of the stresses developed in the tank will arise when ferrocement is to be considered in the design of large-scale storage tanks since only a rigorous analysis will yield a structure with optimal dimensions and reinforcement thereby making it more competitive to other conventional materials used in the construction of such structures.
1. Considering the fact that the shell wall may be extremely thin compared to the baseplate, it would be more appropriate to idealize the walls as being elastically restrained by means of moment-resisting coil springs (Fig. 1). The stiffness of the springs in such an idealization is a function of the foundation thickness and may be computed from an analysis of the base plate. The tanks designed at the University of Singapore are based on the above assumptions [4].

Fig. 1. Boundary condition at base of tank wall idealized as moment-resisting coil spring.

Fig. 2. Analysis assuming partial restraint at base.

2. Cylindrical tanks may also be analyzed assuming only partial restraint at the base. When the base slab is not thick enough (a base to wall thickness ratio of 1.6 is considered normal), the lateral loads which cause rotation of the shell walls may simultaneously tend to lift the base plate upward. However, the water pressure on the plate will counter this effect, though not necessarily sufficient to keep it horizontal (Fig. 2).

A rigorous analysis of this effect is treated by Timoshenko [5].

The primary load carried by the shell of a cylindrical tank is the tensile hoop stress due to hydrostatic pressure acting normal to the tank wall around its circumference. The consequences of removing the base restraint is to increase the hoop stress induced. While this may yield a more conservative design of the tank wall, it is also prone to underestimating the moment developed at the toe.

Rectangular Tanks

Most ferrocement rectangular water tanks, like cylindrical ones, follow no regular design procedure whatsoever. The tank dimensions and reinforcement requirements are arrived at by approximation on the basis of available data on tanks constructed in the past.

A typical wall element of a rectangular water tank may, however, be analysed as a thin walled structure using the linear elastic theory of thin plates [4]. The analysis would require the solution of the classical plate equation where water pressure may be treated as a linearly varying load. Once again, an appropriate use of boundary conditions is crucial. Only the longer side wall need be analysed if the thickness of this element is retained for the remaining walls as well.

It is common to assume the top edges of the wall free and the side-edges continuous with each other so that they may be regarded as fixed (Fig. 3). Such an idealization of the side walls
is reasonable if suitable rigid frames are provided at the connections (Fig. 4). An analysis of this nature was used in the design of rectangular tanks at the University of Singapore [4].

Fig. 3. Boundary and loading conditions used in standard analysis of rectangular tanks.  Fig. 4. Rigid concrete frames ensuring continuity of ferrocement tank walls.

In investigating the behavior of large-scale rectangular storage tanks, a similar approach as for cylindrical tanks may be followed in choosing boundary conditions at the junction of the base plate and the tank wall. If a more rigorous analysis is required, the restraining action of the roof slab may be introduced. A similar assumption may also be extended to the analysis of the side walls.

**Design Procedure**

A basic step-by-step procedure for designing ferrocement tanks is suggested below:

1. Given the capacity, establish the dimensions of the tank.

2. Assume a suitable thickness and estimate the number of wire-mesh layers required.
   Use the guide-line given below which is obtained by equating the stress on the tank wall due to static liquid pressure and the resisting force per unit of the wall height.

\[
I = \frac{WHR}{\sigma_m} 
\]

where
- \( I \) = thickness
- \( W \) = unit weight of liquid
- \( H \) = depth of water in the tank
- \( \sigma_m \) = allowable tensile stress of the composite which may be taken as equal to the ultimate tensile strength of plain mortar
- \( R \) = radius of the cylindrical tank or larger dimension of the rectangular tank

3. Determine the Young’s modulus of the composite. The value of Poisson ratio is sometimes taken as zero [3] though the normal range of the value is 0.12-0.18 and is dependent upon the percentage of mesh reinforcement provided.

4. Choose an appropriate set of boundary conditions as discussed and solve the governing plate or shell equation as the case may be.

5. Compute the maximum hoop stress and bending moment and check against the corresponding permissible values at first crack.
6. If the factor of safety obtained is too large or too small then decrease or increase the thickness and/or number of mesh layers accordingly. The choice will depend upon the minimum cover available. Repeat the above process till satisfactory results are obtained.

7. The critical stresses in the roofs of tanks are a consequence of temperature changes governed by climatic factors and must be accounted for in the design [6].

Construction Techniques

The traditional method begins with the fabrication of the reinforcement cage using skeletal steel over which the mesh layers are wrapped around and tied. If an even number of layers are to be placed, then an equal number is provided on both sides of the skeletal steel. However, if the number is odd, it is advisable to place the extra layer on the outer side. The application of mortar may vary depending upon the resources available. The simplest method is hand-trowelling. Better compaction can be achieved with the use of a vibrator, if available. The rectangular and cylindrical tanks cast at SERC (Madras) in India [7] and the University of Singapore [4] use this familiar procedure. Shotcreting, another method of mortar application, which consists of mortar applied pneumatically, is expensive and requires skilled labor, therefore making it less attractive in developing countries.

It is customary to cast the base slab before the tank walls. However, some of the utility tanks constructed in New Zealand [8] began with the fabrication of the walls. The order is merely a matter of convenience and neither approach has any particular advantage.

If a large number of tanks have to be built, it is preferable to resort to prefabrication because of the ease in construction using standard moulds. A large structure may thus be fabricated as a number of components which can be assembled at site by jointing. Most of the cylindrical water tanks fabricated at the Structural Engineering Research Center, Roorkee, India were assembled from independent components fabricated using a semi-mechanized process [9]. Here, the base slab, the wall elements and the dome-shaped roof are cast separately and assembled on site (Fig. 5). Such tanks have become immensely popular in several regions in India and are presently being used as ground-surface tanks, overhead tanks, rainwater...
cisterns and underground tanks. Likewise, the storage tanks installed in several buildings in Japan to assist fire-fighting were assembled from prefabricated components [10]. Fig. 6. shows details of one such tank.

Whenever the vertical wall of a tank is fabricated in parts, i.e. as a set of separate elements, it is essential that the wire reinforcement at the edges of the plate or shell unit be left exposed for overlapping and casting at the site itself. The construction of panels [11] marketed by the Housing and Building Research Institute, Bangladesh for the construction of rectangular water tanks (Fig. 7) and the wall elements described earlier for the cylindrical tanks developed at Roorkee (Fig. 8) are examples of this technique.

Another method, similar to the semi-mechanized process developed at Roorkee, is outlined by Alexander [12] and consists of rolling flat plates into cylindrical ones. Here, the main longitudinal wires are prestressed before casting. A more recent paper [13] discusses a new technique of assembling prefabricated shell elements which are in a state of constant compression owing to their inward curvature.

The construction of ferrocement water tanks normally requires no formwork. Plastering of average-sized tanks may proceed with a short wooden plank on one side which can be shifted as the mortar application progresses. When a number of tanks have to be fabricated, an internal formwork can be used which serves as a partial mould [14]. In this case, the need for skeletal framework is also eliminated though additional circumferential wires to resist hoop stresses may be provided. The wire mesh is applied in separate layers, i.e. after the first mesh layer is placed it is plastered completely to a proportional mortar thickness before the next layer is placed. Since continuity of the wall with the base slab is important, care must be taken to extend the reinforcing layers of both the slab and the tank wall adequately into each other [15].

In designing floor slabs, a distinction can be made between large and small tanks. For tanks with diameters exceeding 10 m, it is essential to cast the base slab in smaller sections with suitable joints to allow for crack-free expansion and contraction.
In all cases it is advisable to avoid sharp corners and angles at the junctions of the wall with the roof and base respectively. Since such angularities tend to concentrate stresses and initiate cracks, all corners must be lined with additional mortar filling.

For large tanks it is safer to make pipe connections (for inlet and outlet) at the base of the tank since cut-outs in the vertical wall are undesirable. However, adequate (or additional) reinforcement should be provided around cut-outs and holes to avoid stress concentration.

The construction of water tanks using ferrocement has always proven to be overall more economical than reinforced concrete [3,4,8,11,16]. While most of the tanks that have been constructed do not exceed capacities of 20 m³, there are some, like the ones built by the Sao Carlos group in Brazil which have a storage capacity of 2700 m³ [17]. Such large water towers require more elaborate and sophisticated techniques for analysis, design, fabrication and assembling.

### Bamboo-Cement Water Tanks

Though several bamboo-reinforced cement mortar tanks have been built in Indonesia and Thailand, it is best to consider them as 'experimental' because no conclusive results on their long-term behavior is yet available.

The most important criteria in designing bamboo-reinforced structures would be the effectiveness of the bamboo-mortar bond. Even granting that there is no long-term deterioration of the bamboo reinforcement, a more immediate requirement would be the strength of its composite action with the mortar matrix. If composite behavior is assumed then the process of designing bamboo-cement tanks would be identical to that described for ferrocement with only a change in material properties.

However, since the chief factor affecting the use of bamboo in concrete is its water-absorption capacity, it would be worthwhile to experiment on the effects of treated bamboo as a reinforcing material. The liquid-sulphur treatment discussed by Fang and Fay [18] is reported to reduce the water-absorbing capacity of bamboo considerably. Another study [19] using varnish and a hydrocarbon sealer showed no appreciable effect on the tensile strength of the bamboo. However, the use of the sealer alone seemed to indicate a better bond while the treatment of the bamboo with varnish alone increased its modulus of elasticity. It, therefore, appears that better water proofing methods should be developed to solve the problem of water-absorption though not at the cost of losing bond strength.

The construction technique involved is similar to ferrocement with the exception that the bamboo reinforcement has to be first woven and properly treated before it is placed around the skeletal steel cage. The top soft ends of the bamboo stalk must be discarded. The stalks are then split and their inner core removed to make them more flexible. These splits are then woven into a mat (Fig. 9). The spacing between splits can be determined from the volume of reinforcement to be used. Fig. 10 shows the application of mortar to a bamboo-reinforcement cage.

In the construction of a bamboo-cement tank at the Asian Institute of Technology using this technique, a locally available impermeable resin “chan” mixed with rubber oil and hardened with hydrated lime was used to treat the bamboo [20].
CANAL LININGS AND AQUEDUCTS

It is reported that almost one-third of the water diverted to farms and fields through canals is lost due to seepage and evaporation [21]. The purpose of lining a canal, however, is not merely to control seepage loss but also to prevent weed growth and reduce maintenance costs. For example, a concrete lining can effectively double the capacity of a canal, i.e. a canal lined with concrete will require only half the cross-sectional area required for an unlined one.

Ferrocement has still to be used extensively in lining canals. But there are a number of feasible areas where ferrocement can be put to effective use.

1. Ferrocement can be used as a facing for large irrigation canals that are lined with an initial layer of concrete.

2. Ferrocement can replace concrete altogether in lining large canals especially if prefabricated components are desirable.

3. Small-scale irrigation channels units can be constructed with considerable efficiency and ease using unskilled labor.

Of the various types of linings that are commonly used nowadays, concrete is the most popular. However, it is also the most expensive in terms of initial cost. The use of ferrocement linings in concrete canals is not a new concept. The 4 inch (0.1 m) concrete lining of the Highline Canal in Utah (USA) has a 10-gage wire mesh along its entire length of 9.6 kms [21].
A concrete canal lining with ferrocement facings may be treated as a sandwich plate. The Reissner small displacement solution for the bending of isotropic sandwich plates may be used for analysis [22]. A study using such a technique was conducted at AIT to analyse the axisymmetric bending of a concrete canal lined with ferrocement facings idealized as an elastic sandwich plate resting in Winkler-type elastic foundation.

The primary loads which a canal lining must effectively resist are:

1. Hydrostatic pressure as a consequence of the difference in head of the water level inside and outside the canal. This pressure causes the maximum moment at the toe of the lining and in the bottom slab.

2. Swelling pressure such as the bulging action of expansive clays. The magnitude of this pressure will depend upon soil type, its moisture content, dry density, etc.

3. Patch load due to an inspection vehicle travelling along the embankment of the canal.

The parabolic cross-section is hydraulically more efficient and structurally more stronger than its trapezoidal counterpart [23]. However, the construction of large parabolic canal systems using reinforced concrete poses several difficulties in terms of the formwork required. It is likely that ferrocement will prove to be a superior material in such construction and is well worth investigating.

In order to prevent excessive expansion, canal linings should be built in slabs not exceeding 10 m². Suitable joints between adjoining slabs must be provided to permit free expansion and contraction without undue leakage. A coal tar pitch filling is normally found to be adequate.

Any canal lining must be provided with adequate weep holes. They serve to relieve water pressure differences that exist inside and outside the canal. Sometimes, weepholes are so constructed so as to allow water to flow only into the canal. The diameter and spacing of such weepholes depend on numerous factors including capacity of the canal, permeability of the soil, differential pressure head, etc.

The use of ferrocement channels as prefabricated units for small-scale irrigation holds immense potential. Irrigation and drainage sections of various shapes can be constructed.

Fig. 11. Mould for construction of trapezoidal channel unit.

Fig. 12. Ferrocement aqueduct with tension beams.
though the semi-circular and trapezoidal trough-shaped ones have been found to be the easiest to produce [24]. An added advantage in using these light-weight units (about 2.5 to 4 m long) is that they can be easily transported and assembled by unskilled labor. The most efficient method to produce these units on a large scale is to fabricate them on moulds. Fig. 11 shows the cross-section of a typical mould for a trapezoidal section. Here the elevated portion at one longitudinal end is provided to facilitate overlap when the units are being joined at site.

Several precast ferrocement shell elements for use as aqueducts have been fabricated in the People's Republic of China [25]. If the shell element is sufficiently long (L/B > 3) then the internal forces in the longitudinal direction may be analysed as a U-beam. If tension beams are added to the top as shown in Fig. 12, a more rigorous indeterminate analysis is necessary.

HYDRAULIC GATES

Ferro cement has been used in the construction of hydraulic gates for mini-hydropower in the People's Republic of China since 1960s [25]. More recently, they have extended its application to higher head hydraulic installation as well.

Some feasible types of hydraulic gates using ferrocement are: slab-beam gates, folded plate gates, wave-plate gates, cylindrical shell gates, prestressed slab gates, etc. The main factor affecting the choice of gates is determined by the size of the structure and the hydraulic head.

Folded plate gates, by virtue of the strength derived from their shape are strong enough to resist considerable pressure thereby eliminating the need for cross-beams or additional reinforcing columns. An approximate analysis of the plate can be obtained by idealizing it as an I-section.

Slab-beam gates are the simplest types and can be used when the hydraulic head is relatively small. A modification of the slab-beam arrangement is achieved by adopting a curved section with a greater moment of inertia. The wave plate (Fig. 13) and cylindrical shell gates are examples of this modification.

Fig. 13. A ferrocement hydraulic wave-plate gate.
More details on hydraulic gate construction in the People's Republic of China appears in a separate paper in this issue.

PIPS FOR WATER RESOURCES APPLICATIONS

The design of pipes varies with its function. Though the basic analysis is based on the theory of axi-symmetric thin shells, the associated load and boundary conditions depend upon the nature, location and purpose of the structure. Hence, water-supply pipes, sewers, culverts, penstocks, well-linings, etc. are each unique in design and installation.

Pipes

The most commonly used material in pipe construction is reinforced concrete. However, being comparatively heavy, they are often damaged during transportation and crack easily under tensile loads. The use of a lighter, ductile and better crack-resistant material like ferrocement could, therefore, prove to be a better alternative especially for small and medium-sized pipes.

As with other structures, ferrocement pipes have so far been designed using empirical knowledge and thus restricted to small scale elements prefabricated to suit the needs of the user. However, two analytic studies [26, 27] were conducted at the Asian Institute of Technology on the performance and behavior of ferrocement pipes. While the former is concerned with ultimate strength behavior, the latter makes a comparative analysis of reinforced concrete and ferrocement pipes. It was observed that for a given diameter and load, ferrocement can be made more competitive to reinforced concrete by increasing the thickness and reducing the steel ratio. Ferrocement also satisfies the ASTM 3-edge bearing test that are normally required for pipes of acceptable standard.

Outlined below are some feasible ferrocement hydraulic pipes and design approaches for their construction.

1. Ferrocement can be utilized as a sanitary sewer carrying domestic and/or industrial waste. However, the effects of chemical affluents on ferrocement has yet to be studied in detail.
2. Ferrocement could likewise be a competitive alternative in the construction of small-scale culverts.

The important factors to be accounted for in the design of pipes include:

1. The earth load which is dependent on the nature of the installation. Some pipes are put in place after an open excavation following which the cut-outs are back-filled. Some pipes, on the other hand, may be installed by tunnelling methods if the installations have to be extremely deep.
2. The effect of critical live-loads especially when the pipe is laid with shallow cover under the influence line of railroads, highways, etc.
3. The strength of the subgrade around the lower exterior surface of the pipe since all loads must be effectively transmitted to the soil below without inducing undue stress concentration.

The American Society for Testing and Materials have developed standard specifications for concrete pipes (28). These criteria may be suitably modified and adapted for ferrocement
pipes as well. From a design point of view, it would also be interesting to analyse the strength of elliptic pipes (both horizontal elliptic and vertical elliptic) as compared to circular ones since such pipes are sometimes required when minimum cover available and the existing structures around become design restrictions.

The fabrication of ferrocement pipes is best achieved using a mould. However, the centrifuging process used for concrete pipes can be extended with advantage in the construction of ferrocement pipes as well. A trial casting of pipes by centrifuging using wire-mesh is reported by Surya Kumar [29]. Another technique, the vibropressing method discussed by Walkus [30] is in used in Poland for the construction of numerous thin shell elements including pipes (Fig. 14).

Ferrocement pipes may also be used as culverts. An experimental pipe culvert was constructed during the training program for Indonesian technologists at the Asian Institute of Technology [16]. The circular pipe with a diameter of 1.0 m and designed to resist loads corresponding to ASTM class I pipe culverts was 54 mm thick and cost 70 percent less than a comparative reinforced concrete pipe.

**Well Lining**

Ferrocement well linings may be constructed at site on self-help basis or used directly as prefabricated units for hand-dug wells. Several precast units for this purpose have already been built in India, Indonesia (Fig. 15) and Pakistan [31]. The two types of loading to be resisted by well-linings are:

1. earth pressure
2. self-weight causing buckling

Of these, the latter presents no problem since ferrocement elements are generally lightweight. Earth pressure considerations become critical only in water-logged soils and expansive clays.
When prefabricated well-linings are used, a short length at one end with enlarged diameter must be provided to facilitate jointing. The pipes can be placed as the excavation progresses since they also serve to retain the soil above the excavation. The minimum diameter for hand-dug wells should be kept at 1.0 m if a single person is to work inside it and 1.33 m if two people wish to work inside.

Penstocks

Ferrocement penstocks are feasible when:

i. the penstock maintains a constant and regular gradient without vertical curves and bends that may cause cavitation.

ii. the total head is reasonably low (upto 30 metres)

The use of ferrocement penstocks for larger heads should be preceded by rigorous analysis and scale-model testing. When the length of the penstock is considerable, suitable surge tanks or large open stand-pipes must be provided to relieve water hammer.

Another application is the lining of reinforced concrete penstocks using a layer of ferrocement. The Castelbello reinforced concrete penstock in Italy was lined along its entire interior length of over 450 m with ferrocement [32]. The purpose of this layer was to prevent crack formation or at least reduce possible serious cracks into minute ones so that the total head losses would be reduced to a minimum. An additional advantage in using ferrocement comes from its inelastic material property which permits large elasto-plastic deformations before final yield.

FERROCEMENT WATER SUPPLY SYSTEMS IN INDONESIA

It was necessary to treat the above topic under a separate heading since such relatively large-scale applications of ferrocement is a feature characteristic of Indonesia alone where ferrocement technology has met with the approval of both the government and its people.

The first development was the construction of rainwater collectors. Encouraged by the success of these storage tanks, which proved to be superior to concrete cisterns [33], the use of ferrocement was gradually extended to other applications—slow-sand filters, water reservoirs and treatment plants. The 10 m³ slow-sand filter (Fig. 16) was built at half the cost compared to the original design in reinforced concrete of the same capacity [33].

Fig. 16. The 10 m³ slow-sand filter.

Fig. 17. A low-cost water supply system for 300 people.
An entire community water-supply system using ferrocement was also successfully implemented in the northern coast of West Java. The system which consists of facilities for bathing and washing also contains a sanitary and filtering unit. Two types of units were constructed: the first serving a community of 2000 people and the second for a smaller community of about 500 people (Fig. 17). A more complete and improved system incorporating a surface-water treatment plant and storage reservoir was later built in Kuta Ampel [34].

These low-cost projects which are now in full operation can be described as an immensely successful rural development effort.

CONCLUSION

Design procedures for the construction of ferrocement water resources structures are either inadequate or totally absent. As a consequence, their applications have been limited to small-scale structures with few exceptions. This highlights the need for coordinated experimental work in the development of an efficient material model. In particular, the elastoplastic behavior of ferrocement needs careful study if this non-linear property can be used to advantage in the design of elements subject to large tensile strain. Work in this direction is essential if ferrocement is to emerge as an alternative to reinforced concrete in the construction of major water resources structures.

Ferrocement offers an immense scope for prefabrication. Its light weight can ensure better transportability than concrete. And even when cast on site, the construction can proceed rapidly and efficiently without need for skilled labor or heavy equipment.

Presently the widest possible potential for using ferrocement in water resources structures still remains with small-scale construction. Having already found wide application in water-tanks and rain water cisterns, ferrocement should soon be in use for numerous other applications as well: penstocks for micro and mini-hydros, overflow weirs for canal drops, precast pipes for drains, irrigation channels and well-linings, sluices, hydraulic gates, water-filters etc. With the abundance of labor in most developing countries it should not be long before this unique composite can effectively be used in a wide range of applications.

REFERENCES


Ferrocement Applications for Water Supply System in Nepal

B.G. Rajbhandari

INTRODUCTION

In the hilly area of Nepal, the Water Supply Systems built are gravity flow type. Generally the source is spring or stream. The drinking water supply programme is under the Ministry of Panchayat and Local Development (MPLD) in cooperation with UNICEF. The programme is operating all over the country, trying to provide the villages with safe drinking water within a reasonable distance.

One important part of a water supply project is the storage tank, to collect water during night time which can be used in day time. A storage tank will only be built if the water quantity of the source is not sufficient to guarantee enough water during the peak hours.

Till 1979, MPLD was using stone and cement for the wall of the reservoir tank and slates or corrugated sheet for the roof. MPLD tested 20 m³ capacity ferrocement reservoir tank in November 1979. Since then, the reservoir tank has come into practice all over Nepal, where the sand is fairly good.

FERROCEMENT APPLICATIONS

Ferrocement Tank

Two diameters have been adapted for this project: 2.5 m for capacities 2.0 m³ to 9 m³ and 4.0 m for capacities 10 m³ to 20 m³. The height of the tank is varied to obtain the desired capacity (Figs. 1-2).

![Fig. 1. 4.0 m diameter ferrocement tank.](image-url)
The reinforcement detail of the tank wall is shown in Fig. 3. The mortar of 1:2 cement:sand ratio by volume was plastered to 10 mm cover outside.

The wall was cured for one to two weeks depending on the climate of the place. Then the formwork was removed and the inside was plastered to 10 mm thickness with mortar of 1:3 cement:sand ratio by volume (Fig. 4). The roof was plastered to 30 mm thickness with 1:2 cement:sand ratio by volume. After 24 hours the roof was plastered from the inside after removal of formwork. The tank wall and roof were cured for two weeks.

The formwork for this tank is unique. It consists of a 32 mm high density polyethylene (HDP) pipe coiled to form a cylinder (Fig. 5). The pipe is removed to be used as formwork for the roof (Fig. 6) and later as distribution pipe. Grooves made by the HDP formwork provide better bond (Fig. 7).
Valve-Box

As the tank wall was being cured, the walls of the valve-box are built by stone masonry (Fig. 1) or mud masonry (Fig. 2). Ferrocement manhole cover (0.60 m x 0.60 m) plastered with 1:2 mortar was used. The detail of the valve-box is shown in Fig. 8.
Valve-boxes fabricated out of ferrocement are now in use as it is easier to construct than stone masonry. The cost difference between the ferrocement valve-box and the stone masonry valve-box is not much per unit, however, for large number, ferrocement is more advantageous to use.
Break Pressure Tank and Pit Latrine Slab

Ferrocement is also used to build break pressure tank and pit latrine slab. The details of the break pressure tank piping is shown in Figs. 9 and 10. Cement:sand ratio used is 1:3 for the break pressure tank and 1:2 for pit latrine slab. The pit latrine slabs are used in schools. Ferrocement has been found to be an appropriate construction material for these utility structures because it is easy to control during construction.

Fig. 9. Detail of the break pressure tank.
CONCLUSION

There are now 31 ferrocement tanks built in Nepal. The common problem encountered is cracks. Cracks appear after filling up with water in the area facing the sun. This is solved effectively by plastering with 1:1 cement mortar. The cracks may be due to very old cement (cement reaches the villagers after one year from the date of manufacture) and not well graded and unclean sand.

All the tanks built in Nepal were based on the test tank built in November 1979. No structural design has been undertaken and control of grading the sand in the field is poor. However, no structural defects has been observed except for the cracks with can be easily repaired.
Ferrocement Well-Lining for Village Wells

G.L. Bowen*

Generally, well-lining serves several purposes: to prevent well collapse or slumping; to keep burrowing animals and insects out and if the water bearing aquifer is under artesian pressure, it can prevent locally charging the water table. In the interest of public health, the lining is also intended to exclude vegetable or animal matter as well as dirty or polluted surface water.

The proposed section with fabrication and installation details are shown in Figs. 1-4. The vertical dimension of the well-lining is about 900 mm but adjust to suit width of mesh. Use three layers of 22 ga chicken wire mesh on each side of rod. Tie and twitch to make tight. Use 6 mm rod at 50 mm centers running vertically. Tie except weld toggles. Plaster inside first using 2:1 sand to cement ratio.

Fig. 1. Plan view of lifting spider (for lining placement using tripod at surface).

Fig. 2. Lining placement detail.

* Correspondent of the Journal of Ferrocement.
The material per section are:

- cement: 37.7 kg
- sand: 67.4 kg
- water: 16.8 kg
- rod: 69.3 m
- mesh: 16.7 m

The total weight of the section is 110 kg.

The advantages of the ferrocement well-lining compared to concrete culverts are: it can be manufactured at the village site with the participation of the villagers themselves, it is cheaper and easier to construct, much lighter and safer to handle at the wellhead, easy to transport and provides climbing rungs for access to cleaning and repair.

This procedure was suggested to the CARE Mission in Liberia for the rural environmental health program of the Government of Liberia.
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 where copyright laws permit, are available at a nominal cost (see page 117). 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.

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MARINE


MORTAR


MATERIALS AND RESEARCH


PROTECTION AND RELATED TOPICS


TERRESTRIAL APPLICATIONS

T1559 "All India Coordinated Project on Biogas (Phase II)", Final Report, Structural Engineering Research Centre, Roorkee, India, April 1983, 21 pp.


IFIC NEWS

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AIT Rainwater Storage Tank Project

The AITAA Thailand chapter have undertaken the AIT Rainwater Storage Tank project to increase domestic water supply in rural areas. The AITAA project will be introduced in provinces suffering from severe water supply shortage in Thailand.

Surin and Srisaket provinces were the first provinces to receive three ferrocement rainwater storage tanks each. The rainwater storage tank has a diameter of 2.50 m, a height of 2.20 m, and a storage capacity of 10 m³. Estimated cost is Baht 5,000 to 6,000 per tank. Loei and Kanchanaburi have been lined up as the next two recipients. The tanks are located in schools, temple grounds and public health centers. The location is selected by the provinces giving top priority to the poorest villages of the province.

Mr. Prida Thimakorn, Associate Professor of the Water Resources Engineering Division of AIT, is the coordinator of the project. Construction of each water tank serves as demonstration to the villagers and training for the people elected by the villagers to assist in the construction. Since skills in ferrocement construction can be easily acquired, it is expected that these villagers trainees will be able to construct the structure on their own. For this project, IFIC provides technical information.

Ferrocement Tank for Solar Ice-Making Machine

A solar-powered ice-making machine suitable for rural areas has been recently developed at the Asian Institute of Technology. Solar energy received by solar collectors is used to generate ammonia from an ammonia-water solution contained in the collectors. The subsequent condensation of the ammonia vapor takes place in a condenser immersed in a tank for stagnant water. During the
first phase of the project, a reinforced concrete tank 100 mm thick was built for immersing the condenser. However, for the second phase, a ferrocement tank was proposed for this purpose owing to its ease in construction and overall cost-effectiveness. The tank should have a capacity large enough so that the heat transferred as a result of the latent heat of condensation of ammonia does not raise the temperature of the water by more than 1°C.

The Swiss Government provided the grant for the Asian Institute of Technology (AIT) to participate. AIT was represented by Dr. Chongrak Polprasert, Associate Professor of the Division of Environmental Engineering; Mrs. Lilia Robles-Austriaco, Senior Information Scientist of IFIC and Mr. Peter Swan, Coordinator of Media and Information Services.

The Technology for the People (TFTP) is the only international fair of its kind specializing in helping developing nations find products, technical processes and support services which effectively match their limited capital resources, labor requirements and social development goals. TFTP is a place where everything is done to facilitate contacts in a “people to people” basis. TFTP also offers insights into some critical areas of development such as training management consultancy, marketing, information processing and maintenance, all of which are integral to the acquisition of new technologies.

IFIC participated in the third Technology for the People International Fair held in Manila, Philippines 21-27 November 1983. IFIC exhibits include complete set of publications, eight posters and small-scale models of water tanks, biogas digester and canoe (Fig. 1).

Mrs. Austriaco also attended the forum on the role of Asia-Pacific women in the development, utilization and transfer of technology. The forum, conducted in conjunction with TFTP, was called “Asia-Pacific Womens’ Small Technologies and Business Forum”.

Fig. 1. The solar collectors on left, the ferrocement tank and the receiver below.

Fig. 2. Another view of solar ice-making machine.

The system consisting of the solar collectors, the ferrocement water tank and the receiver, shown in Figs. 1 and 2, is presently being studied for its performance characteristics.

Third Technology for the People International Fair

IFIC participated in the third Technology for the People International Fair held in Manila, Philippines 21-27 November 1983. IFIC exhibits include complete set of publications, eight posters and small-scale models of water tanks, biogas digester and canoe (Fig. 1).
The participants were women inventors, technology users, heads or representatives of women's associations, development groups and business establishments from Asia-Pacific Region.

RILEM NEWS

On the RILEM Technical Committee 48-FC third meeting at the Civil Engineering Institute, University of Liege, 8 July 1983, all members agreed to prepare a final report “State-of-the-Art Report with Recommendations”. The report is divided in seven chapters as follows:

1. Introduction (Shah)
2. Design
   2.1 Collapse state design according to USSR recommendations (Winokur).
   2.2 Collapse state design: comparison between USSR and U.S.A. recommendations (Dieterle-Goffi).
   2.3 Service state design (Kuczinski).
3. Durability and Repair (Dieterle, Gamski, Paillere).
4. Survey on Ferrocement (Ronzoni).
5. Fabrication (Sandowicz, Swamy).
6. Applications (Sub, Mejia).

The members whose names are in italic have the primary responsibility of completing the report. The report will be discussed and improved during the next meeting of 48-FC in Delft, May 17-18, 1984.

CUBA

Ferrocement for Small-Scale Ships

The Expert Group Meeting on Small-Scale Shipbuilding and Shiprepair for Latin American and Caribbean Countries was held in Havana, 9 to 12 November 1982 under the auspices of UNIDO, with the support of the Action Committee for Sea and Fresh Water Products of SELA, in cooperation with the Government of the host country, the Republic of Cuba.

The meeting was conducted in five technical sessions over four days. It consisted of presentations and discussions in technical reports prepared by the 16 experts from participating countries, as well as observers from the host country and other countries.

From the reports and discussion it was gathered that for small-scale shipbuilding in developing countries of Latin America different materials are used, namely, timber, steel, reinforced plastic and ferrocement. Great potential for the development of small-scale ships was created, as shown in the example of Cuba, with the introduction of ferrocement which requires a much smaller time period for labor training and is based on the use of raw materials readily available in most countries.

As a result, one of the recommendations of the participants is to recognize the possibilities of using the Cuban Research and Design Maritime Centre for providing a regional service in design and production of small ships, particularly those to be made of ferrocement, and in analyzing the related economics and technical problems within the framework of a regional programme, making the best possible use of expertise from other countries of the region.


INDIA

Ferrocement Lining for Leaking Overhead Reinforced Concrete Tank

Leakage of water through the walls and base of overhead reinforced concrete tanks due to poor workmanship, improper compaction or cracking is a common defect
noticeable in several tanks following the first few years of their construction. Though these tanks do not exhibit any structural failure, they have to be abandoned due to their inability to hold water.

An experimental project to repair a 50,000 gallon capacity tank of the Military Engineering Service (MES), Roorkee was recently undertaken by the Structural Engineering Research Center (SERC). The tank with an internal diameter of 9.19 meters was constructed in 1971. It was abandoned only a few months after construction following excessive leakage through the tank walls. The tank was repaired using a 30 mm thick ferrocement lining applied uniformly over the walls and base. Three layers of mesh (20 gage x 12 mm) was used as reinforcement. The mortar thickness was built up in three layers of 10 mm with mesh reinforcement provided in each layer.

The repair was completed by SERC and the MES staff in October 1982 and since then the tank has been performing satisfactorily.

Ferrocement Tanks Replace Steel

A large number of ferrocement water tanks (capacity: 5000 litres) has replaced leaking, corroded steel tanks over the ministry buildings of Yojna and Transport Bhavan in New Delhi during the past few years. Two types of tanks viz., those having a diameter of 2.05 m and height 1.65 m and those with a diameter of 1.60 m and height 2.60 m were constructed using the SERC semi-mechanized process. Fig. 3 shows one such battery of interconnected tanks.

Fig. 1. The 50,000 gallon reinforced concrete water tank repaired with ferrocement lining Roorkee (India).

Fig. 2. Mortar application inside the tank.

Fig. 3. 5000 litre capacity tanks over Ministry Buildings, New Delhi.

The Central Public Works Department of the Government of India has, in addition,
recently ordered a number of ferrocement tanks for installation over government flats in Chanakyapuri, New Delhi. The above works were executed by M/s. Building Construction and Repair Corporation, Ghaziabad.

**Ferrocement Tanks for American Embassy School**

Three underground ferrocement water tanks each with a capacity of 5000 litres were constructed for the American Embassy school in New Delhi. The static head of the municipal water supply was not adequate to reach the underground reinforced concrete reservoir provided in the school thereby creating an acute shortage of potable water on campus. The ferrocement tanks were therefore located at a lower level in order to receive the municipal supply from where it is pumped to the main reservoir. The tanks have a diameter of 2.05 m and height 1.65 m with a wall thickness of 20 mm. Produced using the SERC semi-mechanized process, these units were constructed and installed by M/s. Building Construction and Repair Corporation, Ghaziabad. (Fig. 4)

(Reported by Mr. P.C. Sharma, Correspondent of the Journal of Ferrocement).

**PAKISTAN**

**Design and Construction Techniques of Pakistan Biogas Tanks**

The two designs mainly used in Asia are the Indian pattern, which uses a vertically mobile steel shell as the gas collector, and the Chinese pattern, which is completely of masonry, and has no moving parts. Both these designs are subject to factors which somewhat discourage their production in vast numbers in Pakistan. The Merin Ltd. have undertaken to produce a design and construction technique which will by-pass most of these discouraging factors. The result is the Pakistan design. It incorporates a static digestion chamber made of easily portable prefabricated segments, to be assembled on site on a firm foundation, and thereafter plastered to produce a thin but strong ferrocement shell. The critical requirement of making the shell completely proof against gas leakage has been fulfilled by means of a special compound which have been developed, and given the trade name 'Merinplast'. A single 1/8" (3.2 mm) thick coat of this material, mixed with cement, makes the surface completely proof against gas leakage. One of the tanks using this plaster had been in use for the past two and a half years without any problems. Recently, a 45 m² tank has been constructed and performing excellently.

Another innovation being used is a sealing compound called Merinoid, which is more or less immune to atmospheric heat and cold, and which enables the manhole cover at the top of the tank to be hermetically sealed, after which it is weighted down with

![Fig. 4. Underground tanks being installed at the American Embassy School.](image-url)
heavy stones to prevent its being pushed up by gas pressure.

The lessons which have been learnt from the first two biogas tanks of Pakistan design have produced techniques which will enable these tanks to be completed within a fortnight. The cost factor is very competitive. It is interesting to note that the prefabricated construction method enables the easy production of much larger tanks and the next objective will be to build a 140 m³ capacity tank, which will make organic farming possible for somewhat larger farms and will also enable Pakistan's vast resources of dung to contribute more substantially to rural energy and fertiliser requirements. This will help to provide animal husbandry as a profitable enterprise.

The recently constructed large Pakistan pattern biogas tank is for use on the Merin farm, and also for test and demonstration purposes. This was charged with poultry droppings (16 Suzuki loads of 600 kg. vehicles) in early January, and gas production has commenced on 2nd February. It has not yet been possible to correctly measure gas output, but a single cylinder 3½ h.p. four stroke Clinton engine is being fuelled to pump water, with a head of 5.5 m (approx. 18ft). The necessary kit for gas adaption is still in process of being perfected, but indications are that a daily pumping for at least four hours will be possible, with a daily input of 200-250 kg. poultry droppings.

Specifications of this tank are as follows:

Internal volume of digester tank .......... 45 m³ (1620 ft³)
Shape: Dome, with flat concrete foundation. Internal diameter at base : 7 m (23 ft) Internal height : 2.9 m (9 ft-6 ft)
Dome wall construction :
22 curved conical ferrocement segments, plastered with Merinoplast to render gas proof.

Manhole cover :
600 mm x 600 mm (2ft x 2ft), hermetically sealed with Merinoid, and weighted down with 50 kg. stones.

Input tank :
Cylindrical ferrocement tank - 1.2 m diameter x 1.5 m height.

Output container :
Shallow cement plastered pond, approx. 20 m² x 300 mm

Input and output connections :
9 ft R.C.C. pipes.

Surface scum breaker :
Rope operated wooden float.

Maximum pressure observed :
300 mm (12 in) high water column.

An extremely interesting phenomenon which has come about, after the installation of the bigger size biogas plant, is that the farm workers have clearly realised the extreme importance of dung, both as a supplier of fuel to the engine, and fertiliser to the crops. They have begun to scrounge about for every bit of dung which can be gathered, and, almost without prompting, the idea has gathered momentum that night soil can add vastly to the resources. It seems clear that within a matter of days, there will be unanimous consent to the building of public latrines in the neighbourhood, and the development of ways and means whereby this raw material can be neatly transferred to the biogas tank. For a heavily populated country like Pakistan, the advantages of processing night soil in biogas tanks are truly immesurable, in terms of increased fuel resources, control of numerous diseases, and increased agricultural production. Obviously, the problem has to be approached with great tact, and the finest approach will be that which comes from the people themselves, and brings them immediate and visible benefits.

(Excerpt from FUTEHALLY, M., "A Commercial Approach to the Development of
Profitable Small Farm on Hitherto Barren Lands in Pakistan*).

PAPUA NEW GUINEA

Village Water Supply and Sanitation Program

The aim of this program is to provide safer and more adequate supplies of water for Papua New Guinea communities.

Some of the projects under this program in 1982 include a small gravity feed system with a bamboo cement tank as storage in Buakap village. The bamboo cement is the first of its kind in PNG so occasional checks are required to observe its performance. Ferrocement tank construction was also demonstrated during the Buakap village water supply construction to University students and the village community. Ferrocement water tank was also demonstrated in community workshops such as the Bosadi Workshop, the National Youth Workshop at the Appropriate Technology Development Institute (ATDI) and the Peace Corps Workshop held in Wau.

Based from the 1983 experience, one of the projects given emphasis is the rainwater catchment storage. ATDI staff continue to improve and acquire new skills by experimenting with and developing first a kind of storage such as bamboo-cement tanks and cement water jars. Acquired skills are demonstrated during the community workshops. It is felt that demonstration is an effective way of transferring ideas and practical skills to community groups.

During two workshops, two ferrocement and a bamboo-cement water tank were constructed. ATDI has received funds and have undertaken the construction of several ferrocement tanks in Malasiga and Tami Island. (Condensed from Appropriate Technology Development Institute “1982 Annual Review and 1983 Program Plan” Papua New Guinea University of Technology, PNG).

PHILIPPINES

Ferrocrete Penstock for Mini-Hydro Project

In remote villages, where wood is the primary source of heat, the social and ecological problems caused by deforestation are forcing a search for alternative sources of energy. And small hydro often is the solution. In the Philippines, development of small hydro system has been assigned to the National Electrification Administration (NEA). NEA has developed a nationwide system of locally owned and operated distribution cooperatives like the Camarines Sur Electric Cooperative IV (CASURECO IV).

CASURECO IV has 10 towns in its jurisdiction. Its first mini-hydro was constructed in Baliguian, Presentation, Camarines Sur. This mini-hydro project cost P500,000 (US$50,000) in 1979 and has a capacity of 100 kw.

The emphasis of the program is to use local engineering and manufacturing to reduce the overall cost of small hydropower systems. To achieve this objective Engr. Percival Favoreal designed a ferrocement penstock as a substitute for the steel penstock usually used.

The ferrocement penstock was fabricated in one meter length with inside diameter of 16 in (406.4 mm) and outside of 24 in (609.6 mm). The fabrication of the skeletal steel of 1/2 in (12.7 mm) diameter is shown in Fig. 1.

Fig. 1. Fabrication of skeletal steel cage.
Each penstock was fabricated using a mould of 1 m height (Fig. 2) with the bars protruding 4" (101.6 mm). These bars were welded and plastered on site.

The proportion of cement-sand used was 1:1 and the water : cement ratio was maintained at nearly 0.4 by weight to insure impermeability of the structures.

Two persons with daily wage of 17/day (US$1.7/day) could finish two penstock per day.

The Baliguian Mini-hydro has a 300 m ferrocement penstock operating under 20 m head of water. This mini-hydro has been in operation for four years and no structural damage has been observed on the ferrocement penstock.

THAILAND

Khon Kaen University-New Zealand Water Resource Project

The Government has contributed advisers, vehicles and an annual budget to bridge the gap between local contributions and the total cost of each structure. The advisers are attached to the Khon Kaen University’s Office of Water Resources Development in the Faculty of Engineering.

The Water Resource Office conducts training on several levels as well as produce engineering designs and supervise the construction program. Engineering students are also involved in field activities, seminars and training courses for officials and farmers.

Since 1979 the Water Resource project includes construction of irrigation weirs, windwell pumping systems, village reservoirs, roof water storage project and other small projects.

The roof water storage project started with the construction of 3 m diameter reinforced concrete, cast in circular steel forms which are raised in half meter lifts. Construction time is about ten days and labor was provided by the villagers free. The cost of a tank, 3 m diameter and 3.5 m high, range from $10,000.00-11,500.00 (US$500.00-575.00). This includes the cost of all materials, transport to site and any other materials required such as formwork and guttering. This cost is equivalent to $450.00 per m³ storage.

To reduce the cost, bamboo reinforcement was used and this reduces the cost by $405/m³ for a 3 m high tank. Approximately 23 reinforced concrete tanks and three bamboo reinforced tanks have been constructed.

Starting 1982, ferrocement tanks were used for rainwater storage. These tanks are 3.2 m in diameter and are made with ferrocement. The cost (1982), inclusive of transport, materials is about $6,300.00 per tank. This is definitely cheaper than the reinforced tanks, and nine tanks have been built by the village technicians to-date.
Ferrocement Project of the Maejo Institute of Agricultural Technology

The Maejo Institute of Agricultural Technology (MIAT) under the direction of His Majesty, King Bhumibol Adulayadej, has undertaken a project with the objective of upgrading the quality of life of the people in Ban Pong. Ban Pong is a village near the MIAT and the village major problem is clean water for household use.

The project is under the supervision of Dr. Thep Phongparnich, Head of the Department of Agricultural Extension. The scheme of the MIAT project is to build a ferrocement rainwater storage tank 10 m³ for every five families. Two tanks have been constructed, one for the use of 5 families and another one for the community school. Shown below is the tank for the community school under construction. MIAT plans to build more.

USA

Hydraulic Applications of Fiber Reinforced Concrete

Fiber reinforced cement (FRC) has superior impact-resistance, toughness, tensile strain and fatigue performance. These are the major reasons for using FRC in spillway channels, tunnels through dams and their abutments, and stilling basins. These hydraulic structures are subjected to water flows of great velocity, and sometimes cavitation results which can rip out the concrete and bedrock beneath.

Two successful applications of this type in U.S.A. were at Dworshak Dam in Idaho and Libby Dam in Montana. At Dworshak, large debris flows moving at high velocity in the stilling basin dug through the concrete lining and 9 ft (2.7 m) into the granite bedrock. Repairs consisted of concrete backfill to replace the eroded granite and concrete, plus a 15-in. (375 mm) topping slab of FRC to replace the lost concrete lining. This corrective construction has withstood the damaging water and debris loads for several years.

About 1972, when the Libby Dam had been in use about a year or two, water ringing through an open outlet in the dam led to vibrations felt throughout the dam. The shaking was caused by high velocity cavitation resulting after some concrete was ripped away. Repairs were made using FRC. Geometry of the structure was not changed in the remedial construction.

Steel fibres were used to reinforce hundreds of unusual concrete shapes named "dollosse" that protect jetties at Humboldt Bay, Eureka, California. The dollosse are impressive—each weighs 42 tons, measures 15 ft (4.5 m) in each direction, has 40 day compressive strength up to 8,500 psi (59 MPa). Some of the dollosse were not reinforced and many of these were broken within 10 years of those reinforced with fibers, inspection after eight years revealed that only two or three had broken.


WEST INDIES

Atech'82

"Atech'82" was a workshop held in May 1982 in the village of Anse-la-Raye in Saint Lucia. This workshop was organized by the National Appropriate Technology and Energy
Committee (NATEC), to promote exchange of ideas and technologies.

The workshop participants were divided into fourteen (14) groups. Individual groups discussed what form of activity to undertake to solve existing community problems, modify any existing plans to suit the requirements of the community and construct the structure with the help of the villagers.

The low-cost housing was constructed out of bamboo-cement and ferrocement using usual reinforced cement roofing sheets. The demonstration house, which was erected on site provided by the Government, was designed to withstand winds of 100 mph.

Among the many activities undertaken was the constitution of bamboo forms which were later plastered with cement to make low-cost water tanks. Several young men of the village took part and it was hoped that a small business enterprise would emerge using this technique.

It was estimated that approximately 500 people benefited from the workshop and all those involved agreed that there was a need for follow-up programmes to maintain the interest that had been generated.

One of the most important things to emerge from Atech'82 was the identification of a regional group of resource people and their technologies and their introduction to each other. With this pool of knowledge and personnel, even the smallest territory in the region will have an adequate source from which to draw.


TUVALU

Save the Children Programs

Save the Children began its work in rural Appalachia during the worldwide depression of the 1930s. Since that time Save the Children programs have expanded to many impoverished areas of the United States and 33 other countries. Over the past five decades Save the Children's experience has shown that assisting people to achieve a permanent change in their lives is most effectively accomplished when they are involved from the beginning in making decisions for themselves and their communities. Learning additional skills as they are needed, the local people contribute their time and labor. This process leaves them not only with a school or well or garden but with the skills necessary to maintain, share and expand the projects which help them create a better life.

In Tuvalu, Save the Children and the island people identified the need for water catchment and storage facilities as one of the priority needs on all the eight islands. During frequent periods of drought the women and children spent long hours getting potable water from community cisterns, which often times had to be rationed.

In May 1980, Save the Children was invited by the government of Tuvalu to implement a community-based integrated rural development program of which the ferrocement water tank project is a part (Fig. 1). Although a large part of the Save the Children effort is being funded by the Agency for International Development (USAID), the water tank project has also been supported by community contributions and the EEC.

The purpose of the initial project was to show that a permanent household water system could be constructed using less than $250 worth of imported materials. However, because the people of Tuvalu participated in the need identification and in the planning and construction, the project has reached a national scale. To date, 750 tanks have been built (Fig. 2). The goal is 1000, a substantial amount considering there are only about 1200 households in the country.
Fig. 1. The completed tank of 2.0 m diameter and 1.52 m weight.

Fig. 2. One village in Tuvalu with ferrocement water tanks to every household.

Fig. 3. Forming the ferrocement tank in the Kiribati.

The program has been extended to Kiribati and Dominica (Caribbean). The tanks constructed in Kiribati are of two capacities: 400 gallon and 850 gallon. The tanks are fabricated in sections and three sections forms a single tank (Fig. 3). The joints are plastered with 1:3 cement mortar. The tank cover is fabricated separately then installed in the tank wall taking care that the opening is in line with the gutter. Then the top of the tank wall is sealed with mortar.

The effort was carried out in collaboration with Peace Corps volunteers posted on the islands. Save the Children provided the technical assistance training, tools and some imported materials. Due to the tremendous enthusiasm and hard work of the local people, the Peace Corps volunteers and Save the Children staff, today many homes have easy access to clean water throughout the entire year.

(Information and photographs sent by Mr. Jeffrey D. Saussier, Technical Resources Unit, Department of Programming and Planning, Save the Children).
FIRST ANNOUNCEMENT

SECOND INTERNATIONAL SYMPOSIUM ON FERROCEMENT
14-16 January 1985

ORGANIZED BY: ASIAN INSTITUTE OF TECHNOLOGY
UNDER THE AUSPICES OF: RILEM, ACI AND IASS

OBJECTIVES
- to provide an opportunity to review and update the existing knowledge and further understand the latest development and progress made in ferrocement technology.
- to discuss corrosion problems and recommended practices.
- to highlight the need for ferrocement standards.
- to focus on the technology transfer of ferrocement to the rural areas of developing countries.

CALL FOR PAPERS
Papers are invited on the following subjects of ferrocement:
- Mechanical properties
- Research and development
- Housing applications
- Rural applications
- Marine applications
- Corrosion problems
- Ferrocement standard
- Technology transfer

OBJECTIVES
The objectives of the short course are: to provide an opportunity for ferrocement users in developing countries to update their existing knowledge of ferrocement technology and to understand the latest development and progress on the applications of ferrocement relevant to their needs.

COURSE DESCRIPTION
The course consists of three broad areas: mechanical properties of ferrocement, analysis and design of ferrocement structures and field demonstration of various construction stages of ferrocement structures.

LANGUAGE
The official language of the symposium and short course is English.

VENUE
All technical sessions will be held at the Asian Institute of Technology.

Correspondence:
All correspondence relating to the symposium and short course should be addressed to:

Mrs. Lilia R. Austriaco
Secretary
Second International Symposium on Ferrocement and Short Course on Design and Construction of Ferrocement Structures
IFIC/AIT, G.P.O. Box 2754
Bangkok 10501, Thailand
Telex: 84276 TH
Cable Address: AIT Bangkok.
FINAL ANNOUNCEMENT

ASIA-PACIFIC SYMPOSIUM ON
FERROCEMENT APPLICATIONS
FOR RURAL DEVELOPMENT
April 23-25, 1984

Organized by: ASIAN INSTITUTE OF TECHNOLOGY, BANGKOK, THAILAND
UNIVERSITY OF ROORKEE, ROORKEE, INDIA

Venue: UNIVERSITY OF ROORKEE, ROORKEE, INDIA

Objectives:
- To promote the use of ferrocement for rural development in the region.
- To promote interaction among government officials in construction and rural development, ferrocement scientists and builders in the Asia-Pacific region.
- To give opportunity to participants to present the latest developments in ferrocement technology.

Papers are invited on the following subjects: mechanical properties of ferrocement; research and development; housing application, rural applications, marine application of ferrocement; national experiences, prospects and trends on ferrocement.

Registration fees:

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For further information write to:
IFIC/AIT
G.P.O. Box 2754 or
Bangkok 10501
Thailand

TRAINING COURSE IN
FERROCEMENT CONSTRUCTION
April 26-30, 1984

Objectives
To train participants in the underlying principles, safe design procedures and proper construction of ferrocement structures which will improve the quality of life in the rural areas to the extent that subsequently, they can serve as trainers.

Course description:
The course consists of three broad areas: fundamentals of ferrocement as a construction material, detailed field demonstration of the various construction stages and underlying principles of analysis and design of ferrocement structures.

Registration Fees:

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Abstract

JFP 44 CRACKING AND LEAKAGE OF FIBRE REINFORCED FERROCEMENT TANKS: AN EXPERIMENTAL STUDY

KEYWORDS: Cracking, Crack width, Deformation, Fiber reinforced, Leakage, Water tank

ABSTRACT: An experimental investigation on the cracking and leakage behaviour of ferrocement circular tanks are reported in this paper. Tests on nine tanks under short-term loadings and five under long-term loadings are described. Reinforcement consisted of weld mesh and round straight steel fibres. The test results are presented in the form of graphs from which the variation of hoop stress, deformation of tank, cracking and leakage behaviour can be studied. The variables considered are the volume content and aspect ratio of fibres.


JFP 45 WATERTIGHTNESS IN FERROCEMENT

KEYWORDS: Crack width, Durability, Elastic modulus, Flexure, Mortar strength, Permeability, Strain, Tensile stress, Watertightness, Workability

ABSTRACT: An increase in watertightness and durability for ferrocement in service may be achieved by using very low permeable mortar and by limiting the width of tensile cracks. This paper reports on the results of an investigation into the properties of ferrocement suitable for water retaining structures. A superplasticiser was used to achieve the workability of low water to cement ratio mortar. Stability of mortar in the fresh state is also discussed. An attempt is made to define the working load of ferrocement in bending for watertightness control.

IFIC Consultants are individuals who are willing to entertain referral letters from IFIC on their field of expertise.

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Principal, Alexander and Poore Consulting Engineers  
2 Whitaker Place  
Auckland 7, New Zealand

Mr. Russell J. Bartell  
Rt. 1, Box 153  
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Mr. Colin Brookes  
Hartley & Brookes Boat Design Ltd.  
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Mr. Jim Dielenberg  
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Mr. Brain William Donovan  
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Auckland, New Zealand

Mr. Peter E. Ellen  
Director, Peter Ellen and Associates Ltd.  
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156-7 Connaught Rd.  
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Mr. Peter Finch  
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Mr. John Forbes Fyson  
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Fishery Industries Division  
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Mr. Hajime Inoue  
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MARINE APPLICATIONS
Mr. Martin E. Iorns
1512 Lakewood Drive
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Mr. Robert Gowan MacAlister
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Mr. Everard Ralph Sayer
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Onerahi, Whangarei
New Zealand

Mr. Stevie Smith
1500 Channel Ave.,
Richmond CA 94804
U.S.A.

Mr. Jeremy Martin Morrison Turner
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32 Hayes Terrace
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HOUSING APPLICATIONS

Mr. Denis Backhouse
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Mr. Horacio Berretta
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Villa Siburu, 5000
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Mr. James Douglas Couston
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Mr. V.G. Gokhale
Chief Executive Officer
Bombay Chemicals Pvt. Ltd.
CASTONE-PreCast Concrete Division
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Mr. Ashok Kumar Jain
314/69 Mirza Mandi
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192-198 Vauxhall Bridge Road
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Mr. S.W. Norton
P.O. Box 168
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South Africa

Mr. Jens Overgaard
EAO, United Nations, Human Settlements
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and the Pacific (ESCAP)
Bangkok 2, Thailand

Mr. Edred Hiter Robinson III
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U.S.A.

Mr. Simcha Yom-Tov
Kibutz Dalia 18920
Israel
This is a partial list of ferrocement experts in the current survey conducted by IFIC on the current status of ferrocement scientists, designers, builders of ferrocement structures and manufacturers of ferrocement materials. The aim is to provide communication and collaboration within the field. Entries were received from July 1, 1983 to September 30, 1983.

Guide to Format

A. Scientists/Designers—Nine categories of information constitute each bibliographical entry of each individual. Each category of information is designated by a number and within each category the following format has been employed:
(1) sex; year of birth; country of birth; nationality; marital status; mailing address,
(2) degree, institution; field or discipline,
(3) current position, organization; (duration) previous position only related to ferrocement, organization.
(4) total number of papers published | five latest papers on ferrocement and related materials,
(5) title of current research project, (date of completion)
(6) name of language followed by A B C or D or all
   A means “ability to deliver lectures and speeches”
   B means “ability to converse with ease”
   C means “ability to conduct a very small group or one-to-one conversation”
   D means “ability to use written materials for research in his own field”.
(7) IFIC Consultant; IFIC Resource Speaker.
(8) awards,
(9) structures completed; professional experience.

B. Builders/Consultants/Manufacturers—Seven categories of information constitute each entry for each organization. Each category of information is designated by a number and within each category the following format has been employed:
(1) address; telephone number; telex number; cable address; contact person.
   location of organization; year of establishment; geographical coverage; location
   of production plants in operation
(3) scope of activities,
(4) description of structures/product,
(5) mechanical properties; advantages; construction method; production system; number
   of structures; location; date of completion; unit cost,
(6) patent and license situation.
ADEDEJI, Olusegun

(1) M; 1939; Nigeria; Nigerian; m; P.O. Box 4555, Lagos, Nigeria
(2) B.Sc., Washington State University, USA; M.Sc., New York University, USA: Civil Engineering
(3) Principal Partner; SSHWED Associates Consulting Civil/Structural Engineering Firm
(5) Theoretical consideration of application of ferrocement to precast housing units (walls, roofs and slabs); Water/grain storage tanks; Home applications such as wash hand basins, water closets, incinerators etc. using existing guidelines on structural properties.
(6) English ABCD
(7) IFIC Consultant; IFIC Resource Speaker

BALASUBRAMANIAN, N.

(1) M; 1939; India; Indian; m; Research Director, Asbestos Cement Ltd., 21B Peenya Phase II, Bangalore 560 058, India
(2) M.S. Met.E., Purdue University, USA; Ph.D. Columbia University, USA: Materials Science
(3) Director of Research, Asbestos Cement Ltd.; (1979-1982), Senior Research Associate, Materials Laboratory, Air Force Base, Ohio, USA; (1972-1979) Assistant Director (Materials) National Aeronautical Laboratory, Bangalore 560 017, India
(5) Fracture of Cement Composites, 1984
(6) English ABCD
(7) IFIC Consultant; IFIC Resource Speaker

BRIDGE, Russell Quinlin

(1) M; 1941; Australia; Australian; m; School of Civil & Mining Engineering, University of Sydney. NSW 2006, Australia
(2) B.E., University of New South Wales; Ph.D., University of Sydney: Civil Engineering
(3) Senior Lecturer, University of Sydney
(4) (30) “Viewpoint on Concrete Origami” (co-author), Australian Outdoors, Vol. 62, No. 12, August 1982
 “Orihune-A Folded Concrete Canoe” (co-author) Concrete. Vol. 16, No. 1, January 1982
 “Orihune-The World’s First Folded Concrete Canoe” (co-author) Journal of Ferrocement. Vol. 11. No. 4. October 1981. (published also in the Concrete International:

"Folded Concrete Canoe—New Concept in Concrete Construction" (co-author) Australian Sea Spray, 20 March, 1981

(5) The use of concrete origami techniques for commercial and industrial development (1986)

(6) English ABCD; French D

(7) IFIC Consultant; IFIC Resource Speaker

BROMBERGER, David

(1) M; 1922; Belgium; American; m; 3231 Spring Garden Ave., Pittsburgh PA 15212, USA

(2) M.E., Stevens Institute of Technology, USA; M.S. New York University, USA; Mechanical and Sanitary Engineering

(3) President, PPS Enterprises, Inc.

(6) French ABCD; Flemish ABCD; English ABCD: Portuguese B; Spanish C; German C; Hebrew C

(7) IFIC Resource Speaker

CZARNECKI, Lech

(1) M; 1941; Poland; Polish; m; Institute of Technology and Organization of Building Production, Civil Engineering Department, Warsaw Technical University, Al. Armii Ludowej 16, 00-637 Warszawa, Poland

(2) M.Sc., D.Sc/Ph.D., Warsaw Technical University; Chemical Technology, Plastic Engineering, Technology of Building Materials

(3) Scientific Director, Institute of Technology and Organization of Building Production; (1972-present) Leader, Polymer Concrete Group, Warsaw Technical University

(4) [100] "Resin Concrete and Polymer Impregnated Concrete: A Comparative Study" (co-author) Third International Congress in Polymers in Concrete, May 13-15, 1981, Koriyama, Fukushima, Japan

"Experimental Studies of the Influence of Particle and Fiber Reinforcement in the Rheological Properties of Polymer Melts" Rubber Chemistry and Technology, Vol. 53


(6) English ABCD; Russian B

(7) IFIC Consultant; IFIC Resource Speaker

LLOYD, Donald

(1) M; 1934; USA; American; m; Covington Technologies, 17811 Mitchell, Irvine, CA 92714, USA

(2) Associate of Arts, Orange Coast College, USA; Architecture

(3) Vice-President-International Marketing, Covington Technologies; (1955-1976) Reinforcing steel business

(6) English ABCD
NATESAN, S.C.

(1) M; 1944; India; Indian; m; Department of Civil Engineering, P.S.G. College of Technology, Coimbatore-4641004, India
(2) B.E. (Civil), M.Sc. (Structural Engineering), Ph.D. (Engineering), P.S.G. College of Technology, Coimbatore-4; Concrete Technology, Fibre Concrete and Ferrocement
(3) Assistant Professor of Civil Engineering, P.S.G. College of Technology, Coimbatore-4, India
"Cracking and Leakage Characteristics of Fibre Reinforced Concrete Tanks" (co-author) a report for the Board of Research in Nuclear Sciences, Department of Atomic Energy, Government of India
"Strength of Steel Fibre Reinforced Concrete" (co-author) Interlink, Graduate Journal of P.S.G. College of Technology, 1983
(5) Strength and behaviour of ferrocement slabs subject to UDL (June 1984); Ferrocement vessels for application in biogas production (June, 1984)
(6) English ABCD
(7) IFIC Consultant; IFIC Resource Speaker

PEVARNIK, Louis Jr.

(1) M; 1945; USA; American; m; P.O. Box 683, Latrobe, PA 15650, USA
(2) Fine Arts
(3) President, Ferrocement Development Corporation
(5) All areas of ferrocement
(6) English ABCD
(7) IFIC Consultant;

RAJASEKARAN, S.

(1) M; 1942; India; Indian; m; Dept. of Civil Engineering, P.S.G. College of Technology, Coimbatore-4, 641004, Tamil Nadu, India
(2) B.E., M.Sc, P.S.G. College of Technology; Ph.D. (Civil Engineering) University of Alberta, Canada; Structural Engineering
(3) Professor of Civil Engineering, P.S.G. College of Technology;
"Cracking and Leakage Characteristics of Fibre Reinforced Concrete Tanks" (co-author), A report for the Board of Research in Nuclear Sciences, Department of Atomic Energy, Government of India
"Strength of Steel Fibre Reinforced Concrete" (co-author), Interlink, Graduate Journal of P.S.G. College of Technology, 1983

(6) English ABCD; German D
(7) IFIC Consultant; IFIC Resource Speaker

ROMUALDI, James

(1) M; 1929; USA; American; m; 5737 Wilkins Ave., Pittsburgh, PA 15217, USA.
(2) B.S., M.S., Ph.D., Carnegie-Mellon University; Structures, Materials
(3) Professor of Civil Engineering, Carnegie-Mellon University
(4) [46] "Ferrocement: Applications in Developing Countries" (Chairman of Committee)
    National Academy of Sciences, February 1973
    "Research Needs and the Future of Ferrocement" Publications SP-61, American
    Concrete Institute, 1979
(5) Fracture of Brittle Materials; Ferrocement
(6) English ABCD
(7) IFIC Consultant;

BUILDERS/CONSULTANTS/MANUFACTURERS

CENTRO DE PROYECTOS NAVALES

(1) Oficinas No. 452, Esq. Acosta, Habana Vieja, Cuidad de la Habana, Cuba; 62-01-47:
    —; —; Ing. Marcel Menendez de la Terre, Director
(2) Government; 1976
(3) Undertake research on technologies for the construction of ferrocement fishing vessels;
    Design ferrocement fishing vessels

COVINGTON TECHNOLOGIES

(1) 17811 Mitchell, Irvine, CA 92714, USA; (714) 545-2288; 182255; —; Donald Lloyd,
    Vice-President, International Marketing
(2) Public owned corporation; 1962; worldwide; Mexico, Singapore, England, USA
(3) Builder/Developer, General Contractor, Manufacturer of Therml-Impac Panel
(4) Therml-Impac Panel
(5) Advantages: Savings in time and materials; low-cost and speedy erection; unskilled labor
    can learn the necessary construction technique in only three days; construction quieter;
    polystyrene insulation keeps the homes cool in summer and warm in winter; excellent seismic
    properties; load-bearing; fire proof; good accoustical properties; vermin-proof; no heavy
    equipment or high technology

    Construction Method: Thermal-Impac Panel composite sections consist of steel wire
    meshes interlaced with expanded polystyrene insulation and wire cage on
    each face. A coat of Portland cement plaster is gun or hand applied both
    sides of panels. A finishing colored waterproof stain is then applied to the
    exterior surface
Production system: Prefabrication process can be accomplished in the plant or jobsite
(6) Patents worldwide; License in several countries

FERROCEMENT DEVELOPMENT CORPORATION

(1) P.O. Box 683, Latrobe, PA 2565D, USA; 412-537-5887; —; —; Louis Pevnik, Jr., President
(2) Private Company; 1983; USA
(3) Application of ferrocement for the relining of water containing structures and developing other areas for its application.
(5) Advantages: ferrocement is highly competitive for relining of water containing structures; liner is not bonded to the old wall.
Construction method: Layer of Watson mesh stapled to pool wall at discrete intervals with spacer. Apply matrix and the finish coat.
Project executed: Six pools

PPS Enterprises Inc.

(1) 3231 Spring Garden Ave., Pittsburgh, PA 15212, USA; 412-322-7100; —; —; Mr. D. Bromberger, President
(2) Private company; 1956; Pittsburgh, PA:
(3) Construction
(4) six ferrocement pools.
Mounir Khalil El DEBS

Mr. Debs is assistant professor at the Engineering School of São Carlos, University of São Paulo. His main interests are concrete bridges and research. He obtained Master of Science in 1976 from the University of São Paulo and Civil Engineer in 1972 from the Engineering School of São Carlos, University of São Paulo. After a few years of practice as structural designer, he joined the Engineering School of São Carlos in 1980.

Mahmood FUTEHALLY

Mr. Futehally is managing director and principal of the Merin Ltd. He established the firm in 1948 in Karachi, Pakistan and in 1978 set up the Agrotool and Forestation Department of the firm. The department produces equipments and techniques for regeneration of barren lands at low-cost and in shortest possible time. The equipments and techniques are studied and developed in the five acre land owned by the firm. Mr. Futehally is also interested in philosophy, religion and Islamic history and has organized a number of discussion groups in these subjects.

João Bento de HANAI

Dr. Hanai is assistant professor and coordinator of the Laboratory for Construction Systems at the Federal University of São Carlos. He obtained from the University of São Paulo, his Doctor of Civil Engineering in 1982, Master of Science in 1977 and Civil Engineer in 1972. He has served as assistant professor at the Engineering School of São Carlos, and researcher and head of the Laboratory of Structures, Engineering School of São Carlos, University of São Paulo. His main activities is on prestressed concrete and concrete bridges and research.

K. SASHI KUMAR

Mr. Sashi Kumar is the information scientist of the International Ferrocement Information Center. He obtained his Master of Engineering, major in structural engineering from the Asian Institute of Technology, Thailand in 1982 and his Bachelor of Engineering (Civil Engineering) from Bangalore University, India in 1980.
Dante A.O. MARTINELLI

Dr. Martinelli is a professor in the Structural Engineering Department of the Engineering School of the São Carlos Campus, University of São Paulo. He obtained his Doctor of Engineering from the University of São Paulo in 1961 and Civil Engineer from the Polytechnic School, University of São Paulo in 1951. He was assistant professor at the Polytechnic School of São Paulo before joining the Engineering School of the São Carlos, University of São Paulo as assistant professor, then associate professor and professor. Dr. Martinelli has been a structural design consultant to government agencies and private companies. Among his designs are the Italper Hydroelectric Plant, São Paulo first subway line, the 32,000 m² São Cristovao hanging roof and two prestressed concrete shell hanging roofs of the Montevideo type. He has been actively involved in the organization of structural laboratory. His main interests are bridge and shells.

S. RAJASEKARAN

Dr. Rajasekaran is professor of Civil Engineering at P.S.G. College of Technology, Coimbatore, India. He had doctoral and post-doctoral work at the University of Alberta, Edmonton, Canada (1968-1973). While serving as visiting professor at the University of Alberta (1979-1980), he was appointed member of the committee to investigate the causes of failure of light rail transport bridge in Canada. He was the Alexander van Humboldt guest professor at the of University Stuttgart, W. Germany (1982-1983). He has published one book in computer programming, an invited chapter in “Theory of Beam Columns, Vol. 11” published by McGraw-Hill, Book Co., U.S.A. and more than 60 publications in symposia proceedings and journals. His interest include finite element nonlinear analysis of steel and concrete structures, ferrocement and fibre reinforced concrete structures, and optimum structural designs.

S.C. NATESAN

Dr. Natesan is teaching at the Department of Civil Engineering, P.S.G. College of Technology, Coimbatore, India for the past twelve years. He obtained his B.E., M.Sc. (Engg.) and Ph.D. from the University of Madras. He worked as senior research fellow, Council of Scientific and Industrial Research (CSIR), Government of India for one year. His field of interest are concrete technology, fibrous concrete and ferrocement. He has published three research reports, 10 research papers and 20 discussions.

Rasiah Sri RAVINDRARAJAH

Dr. Ravindrarajah is a teaching and research lecturer of the Department of Civil Engineering, National University of Singapore. Before joining the National University of Singapore, he was a lecturer at the University of Malaysia (1977-1981); research assistant at the Department of Civil and Structural Engineering, University of Sheffield, England (1974-1977) and assistant lecturer, Department of Civil Engineering, University of Sri Lanka, Katabedde Campus (1971-1973). In 1971, he was the recipient of the UNESCO
Gold Medal for being the "Best Engineering Student of 1971" in the Faculty of Engineering and Architecture, University of Sri Lanka, Katabedde Campus.

Dr. Ravindrarajah obtained his B.Sc. (Engineering, Hons.) from the University of Sri Lanka in 1971 and his Ph.D. from the University of Sheffield, England in 1977. He is a member of the American Concrete Institute, Concrete Society, London and Singapore Concrete Institute. He also served as member of the National Standard drafting committee's in Sri Lanka and Malaysia for cement and concrete.

Lilia ROBLES-AUSTRIACO

Mrs. Austriaco is the senior information scientist of the International Ferrocement Information Center. She obtained a Bachelor of Science in Civil Engineering (Cum Laude) from the Mapua Institute of Technology and a Master of Engineering, major in Structural Engineering from the Asian Institute of Technology. Mrs. Austriaco served as civil engineer, Bureau of Public Works, Philippines; associate professor and reviewer, School of Civil Engineering, Mapua Institute of Technology, Philippines; information scientist, Asian Information Center for Geotechnical Engineering, Asian Institute of Technology, Thailand and lecturer in the undergraduate and graduate program of the School of Housing, Building and Planning, Universiti Sains Malaysia, Malaysia. She is a member of the Philippine Institute of Civil Engineers and the American Society for Engineering Education.

Prem Chandra SHARMA

Mr. Sharma is a Scientist at the Structural Engineering Research Centre (SERC), Roorkee, India and India correspondent of the Journal of Ferrocement. He obtained his Bachelor of Engineering (Civil) from Roorkee (India) and later received Advanced Training in Construction Management and Quality Control. Prior to joining SERC, he had been a Construction Engineer at Bhilai Steel Project and carried out research work for Central Building Research Institute, Roorkee. He is author and co-author of numerous papers in ferrocement. Currently, he is engaged in research in the field of ferrocement technology.

TAM Chat Tim

Dr. Tam is an associate professor of the Department of Civil Engineering, National University of Singapore since 1979. He has served as assistant lecturer, lecturer, associate professor and head, Department of Civil Engineering, University of Malaya (1963-1979); design engineer with M/s Steen Schested & Partners, Malaysia (1962-1963); assistant engineer, Hydro-Electric Commission of Tasmania (1960-1962) and research student University of Adelaide Australia (1959-1960). He obtained his B.E. (Hons.) and M.E. from the University of Adelaide and his Ph.D. major in Materials Science from the University of Calgary. He is a chartered engineer in U.K. and registered professional engineer in Malaysia. He is a fellow of the Institution of Engineers, Malaysia and member of: the Institution of Engineers in Singapore and
Australia: Institution of Civil Engineers in London; American Concrete Institute; American Society for Testing and Materials; Concrete Society, London and Singapore Concrete Institute. Dr. Tam has published over 25 papers in local and international journals and conferences.

Bijaya B. RAJBHANDARI

Mr. Rajbhandari is the project officer of UNICEF in the mid and far western region of Nepal.

Fausto C. TARRAN

Mr. Tarran is a senior research engineer at the Instituto de Pesquisas Tecnológicas, São Paulo, Brazil. He received his BE in civil engineering in 1956 from Universidade do Paraná, Curitiba, Brazil. Before joining the IPT staff he has worked several years in the design of reinforced concrete structures.
INTERNATIONAL MEETINGS

March 4-9, 1984: Symposium on Deflections of Concrete Structures, ACI Convention, Phoenix, Arizona. Contact: G.K. Sabnis, FKC Engineering, Inc., 8720 Georgia Avenue, Suite 605, Silver Spring, Maryland 20910, U.S.A.

March 28-30, 1984: International Symposium on Earthquake Relief in Less Industrialized Countries, Zurich, Switzerland. Contact: SIA Schweiz. Ingenieur und Architekten Verein, Postfach, CH-8039, Zurich, Switzerland.

April 10-12, 1984: Second International Conference on Concrete Block Paving, Delft Institute of Technology, Netherlands. Contact: CBP c/o Klv, P.O. Box 30424, 2500 GK The Hague, The Netherlands.

April 12-14, 1984: Second Congress of Civil Engineers on 'The Engineer in Society', Brighton, Sussex, U.K. Contact: Conference Office, ICE, 1-7 Great George Street, London SW1P 3AA, U.K.

April 23-25, 1984: Asia-Pacific Symposium on Ferrocement Applications, Roorkee, India. Contact: Dr. D.N. Trikha, Organising Secretary, Room 113, Civil Engineering Department, University of Roorkee, Roorkee 247667, India.

April 25-27, 1984: Eighth Symposium on Advances in Reliability Technology, University of Bradford, U.K. Contact: Dr. G.P. Libberton, NCSR, Wigswa Lane, Culcheth, Warrington WA3 4NE, U.K.


July 16-20, 1984: International Conference on Structural Impact and Crashworthiness, Imperial College, London. Contact: Dr. G.A.O. Davies, Department of Aeronautics, Imperial College, London SW7 2BY, U.K.

July 21-28, 1984: 8th World Conference on Earthquake Engineering. San Francisco, California, U.S.A. Contact: EERI, 2620 Telegraph Ave., Berkeley, CA 94704, USA.

August 12-15, 1984: International Conference on Durability of Building Materials and Components, Espoo, Finland. Contact: Conference Secretary, Anneli Kaarresalo, Technical Research Centre for Finland, Division of Building Technology and Community Development, 02150 Espoo 15, Finland.

August 25-31, 1984: International Symposia on Concrete Pressure and Storage Vessels, Sea Structures in Arctic Regions and Prefabrication, Calgary, Alberta, Canada. Contact: F.LP. '84, c/o Genstar Structures Limited, 1000, 1520-4th Street S.W., Calgary, Alberta, T2R 1H5, Canada.

September 3-7, 1984: 12th International Congress of the IABSE on Structural Engineering Today and Tomorrow, Vancouver,
B.C., Canada. Contact: IABSE Headquarters, ETH-Honggerberg, CH-8093 Zurich, Switzerland or 1984 Vancouver Congress, c/o Dr. P.F. Adams, Faculty of Engineering, University of Alberta, S-1 Mechanical Engineering Building, Edmonton, Alta., Canada T6G 2G8 or 1984 Vancouver Congress, c/o Dr. R.A. Dorton, Structural Office, Ministry of Transportation and Communications, 3501 Dufferin Street, 4th Floor, Downsview, Ont., Canada M3K 1N6.

September 10-14, 1984: Symposium and Exhibition on Spatial Roof Structures, Dortmund, West Germany. Contact: Abteilung Bauwesen, Universitat Dortmund, Postfach 50 05 00, D-4600, Dortmund 50, West Germany.

September 11-14, 1984: Third International Conference on Space Structures, Guildford, U.K. Contact: Dr. H. Nooshin, SSRC, University of Surrey, Guildford GU2 5XH, U.K.

September 17-20, 1984: International Symposium on Long-Term Observation of Concrete Structures, Budapest-Balaton, Hungary. Contact: Dr. M. Heiner, EMI, Dioszegi ut 37, Budapest, Hungary. Sponsored by RILEM, ACI and the Institute for Quality Control of Buildings (Budapest).

September 17-21, 1984: International Conference on Computer Aided Analysis and Design of Concrete Structures, Split, Yugoslavia. Contact: Dr. E. Hinton, Department of Civil Engineering, University College of Swansea, Singleton Park, Swansea, SA2 8PP, U.K.

September 17-21, 1984: Fourth Triennial World Congress and Exhibition on Finite Element Methods, Interlaken, Switzerland. Contact: Dr. J. Robinson, Robinson and Associates, Horntown Road, Woodlands, Winborne, Dorset BH21 6NB, U.K.

October 2-5, 1984: International Conference on In Situ Nondestructive Testing of Concrete, Westin Hotel, Ottawa, Canada. Contact: V. Mohan Malhotra, Chairman, Conference Organising Committee, CANMET, EMR, 405 Rochester Street, Ottawa, Ontario, Canada K1A OG1.

October 11-12, 1984: Conference on Progress in the Formulation of the Structural Analysis Problem Since Castiglano, Torino, Italy. Organized by Turin Polytechnic to mark the 100th death anniversary of Alberto Castiglano. Contact: Dipartimento di Ingegneria Strutturale, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy.

October 16-19, 1984: International Conference on Concrete Technology for Developing Countries, Irbid, Jordan. Contact: Mohamed A. Abdel-Halim, Yarmouk University, Irbid, Jordan.

October 28-November 2 1984: ACI Convention on Strength Evaluation of Existing Concrete Bridges, New York, U.S.A. Contact: C.A. Carnegie, PEng, Structural Branch, Transportation Department, Regional Municipality of Ottawa-Carleton, 222 Queen Street, Ottawa, Ontario K1P 5Z3, Canada.

December 4-10, 1984: Sixth International Conference on Fracture, New Delhi, India. Contact: Dr. K.N. Raju, General Secretary, ICF 6, Deputy Director, National Aeronautical Laboratory, Bangalore 560017, India.
001 FERROCEMENT
B.K. Paul and R.P. Pama

This publication discusses every aspect of ferrocement technology: historical background, constituent materials, construction procedures, mechanical properties and potential applications. The flexicover edition includes over 75 literature references on the subject. 149 pp., 74 illus.

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002 THE POTENTIALS OF FERROCEMENT AND RELATED MATERIALS FOR RURAL INDONESIA - A FEASIBILITY STUDY
R.P. Pama and Opas Phromratanapongse

The report recommends seven potential applications of ferrocement and related materials found particularly suitable for rural Indonesia. Good reference for volunteer groups and government officers involved with rural development.

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003 FERROCEMENT, A VERSATILE CONSTRUCTION MATERIAL: IT'S INCREASING USE IN ASIA
Edited by R.P. Pama, Seng-Lip Lee and Noel D. Vietmeyer

This report is the product of the workshop "Introduction of Technologies in Asia - Ferrocement, A Case Study", jointly sponsored by the Asian Institute of Technology (AIT) and the U.S. National Academy of Sciences (NAS). Thirteen case studies on the 'State-of-the-Art' of ferrocement technology and applications in nine countries in Asia and Australia are presented. 106 pp., 59 illus.

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004 FERROCEMENT AND ITS APPLICATIONS - A BIBLIOGRAPHY,
Volume 1

It presents a comprehensive list of references covering all aspects of ferrocement technology and its applications. This first volume lists 736 references classified according to subject and author indices. All listed references are available at IFIC which can provide photocopies on request at nominal cost. Ideal for researchers and amateur builders. 56 pp.

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005 DO IT YOURSELF SERIES

To accelerate transfer of ferrocement technology to developing countries, IFIC has published the following six Booklets in the Do it yourself series:

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Booklet No. 2
Ferrocement Water Tank

Booklet No. 3
Ferrocement Biogas Holder

Booklet No. 4
Ferrocement Canoe

Booklet No. 5
Ferrocement Roofing Element

Booklet No. 6
Ferrocement Biogas Digester

The descriptive text in each booklet is in a non-technical language. Material specifications, material estimations, construction and post-construction operation of each utility structure are well discussed. Construction drawings and construction guidelines to ensure better workmanship and finished structures are presented. Also included are additional readings and sample calculations.

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006 FOCUS

This pamphlet introduces ferrocement as a highly versatile form of reinforced concrete used for construction with a minimum of skilled labour. Published in Bengali, Burmese, Chinese, English, French, Hindi, Indonesian, Japanese, Nepalese, Filipino, Sinhalese, Spanish, Swahili, Tamil, Thai, Urdu. These pamphlets could be obtained FREE of charge.
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