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CONTENTS

Discussion of the technical materials published in this issue is open until **April 1980** for publication in the Journal.

IFIC

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 Sciences's Advisory Committee on Technological Innovation (ACTI). IFIC receives financial support from the **United States Agency for International Development (USAID), the Government of New Zealand and the International Development Research Center (IDRC) of Canada.**

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EDITORIAL

The Editors of the Journal of Ferrocement are planning to devote the next July issue to **"Marine Applications of Ferrocement"**. It will be a special issue focusing on construction of boats, barges, canoes, pontoons, caissons, bouys, etc. Contributions for the special issue are earnestly requested from ferrocement builders active in the field of marine applications. That appeal is also addressed to "amateur" boat builders who once more are requested to send us short articles, notes, stories on their achievements, experiences, successes and misfortunes (with whenever possible some photographs or sketches).

The Editors hope that the preparation of a special issue on ferrocement marine applications will quell the fears of some readers, who seemed to think that we are not interested in boat building. The fact is that ferrocement first nearly exclusively used for the construction of vessels has recently gained popularity for many terrestrial applications. The Journal of Ferrocement has considered its duty to cover those new applications especially as they are of immediate interest to the rural communities of developing countries and therefore ferrocement boat construction may have appeared overlooked or at least diluted amidst many papers dealing either with other applications or with basic properties of ferrocement as construction material. This does not mean the Editors underestimate the importance of ferrocement for boat building which remains even today one of the major applications of that so versatile construction material. Boat builders who believe more emphasis on their work ought to be given in the Journal of Ferrocement will always be welcomed to submit for publicaion any papers, news, notes, stories they believe of interest to their colleagues worldwide. If they do not participate actively to the input in the Journal they will be partly responsible for what they will feel as a lack of information published on ferrocement boats. The Journal of Ferrocement is meant to cover all aspects of all applications of ferrocement and related materials and boat construction is certainly one of its major applications.

The Editors

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Flexural Rigidity of Ferrocement

G.V. Surya Kumar*, V.K. Gupta* and P.C. Sharma*

Experimental Deflection values of 28 ferrocement beams are compared with deflection values obtained using ACI and CEB Code formulae for prediction of short term deflections of reinfored concrete members in the working load range. The agreement between the experimental and code values is observed to be quite satisfactory. Thus ACI and CEB formuale seem to be quite suitable for prediction of effective flexural rigidity of ferrocment in cracked stage.

INTRODUCTION

Ferrocement, of late, is being investigated by various researchers because of its potentialities for wide ranging applications [1-2]. Investigations dealing with deflection characteristics and prediction of flexural rigidity of ferrocement are limited. Prediction of flexural rigidity becomes an important aspect wherein ferrocement is subjected to bending stresses. The available investigations on behaviour of ferrocement in direct tension have established that law of mixtures holds good fairly reasonably for prediction of modulus of elasticity of ferrocement in direct tension [3]. A similar formula is needed for prediction of flexural rigidity. Flexural rigidity of ferrocement varies with the moment existing on the section because of cracking of mortar in tension zone and the consequent shift of neutral axis. It can be obtained by taking into consideration the contributions of the individual components viz. cement mortar and steel wires.

Some of the recent investigations [4, 5, 11] reported that accurate prediction of load-deflection characteristics are possible by rigorous analysis. The object of this paper is to examine whether any approximate formulae could be used for prediction of deflections without going into rigorous analysis. The ACI and CEB [6, 7] code methods of evaluation of short term deflections for reinforced concrete members are used to predict the deflections of ferrocement beams. The experimental values from a previous investigation [9-10] are used for comparison with the predicted values. These formulae lead to approximation of effective flexural rigidity of ferrocement in cracked stage.

GENERAL FLEXURAL BEHAVIOUR

In general the load-deflection curve for ferrocement beams may have three distinct ranges [5];

(a) before cracking of mortar;

(b) after the first cracking of mortar but before yielding of steel and

(c) after yielding of steel.

In the first stage, there is no cracking and the flexural rigidity of the uncracked composite may be used directly. In the second stage, the mortar is cracked and the cracks are in the process of widening. The flexural rigidity values based on cracked section normally give conservative values and only at high loading stages the values are in agreement with experimental results. It is in this stage a need for effective flexural rigidity exists, which can give a fairly

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reasonable prediction of deflections close to experimental values. The third stage is when the steel starts yielding. Ferrocement differs in this stage from reinforced concrete, as the yielding takes place layer after layer resulting in large increase of deflection as well as some increase in load carrying capacity of the member. In this stage the flexural rigidity may be assumed to be that of cracked section alone and the contribution of yielded layers to flexural rigidity may be neglected.

FLEXURAL RIGIDITY

The flexural rigidity of ferrocement is given by

$$(EI)_{composite} = (EI)_{mortar} + (EI)_{steel} \qquad \ldots\ldots\ldots\ldots (1)$$

$$(EI)_{mortar} = E_c \left((bd^3/12) + bd\, n_1^2 \right)$$

$$(EI)_{steel} = (E_s - E_c) \sum_{1}^{n_c} A_s\, d_s^2 + E_s \sum_{1}^{n_t} A_s\, d_s^2$$

where

b = breadth of section

d = depth of mortar section upto cracking strain of mortar

n_1 = distance of c.g. of uncracked mortar section from neutral axis

n_c = number of wiremesh layers in the uncracked mortar zone

n_t = number of wiremesh layers in the cracked mortar zone

d_s = distance of wiremesh layer from neutral axis

A_s = area of steel in the respective layer

The following assumptions and values are used in the investigation:

1. E_c = modulus of elasticity of mortar in bending compression = $15{,}000\sqrt{f_c}$ in kg/cm^2
   = $13{,}900\sqrt{f_{cu}}$ in kg/cm^2

   where

   f_c = cylinder strength in kg/cm^2

   f_{cu} = cube strength in kg/cm^2

   $f_c = 0.85\, f_{cu}$

2. f_r = modulus of rupture of mortar = $1.85\sqrt{f_{cu}}$ in kg/cm^2
3. Modulus of elasticity of mortar in bending tension = E_c
4. Strain at which mortar cracks in tension = $\dfrac{1.85}{13{,}900} = 133 \times 10^{-6}$
5. E_s = modulus of elasticity of steel = 2.0×10^6 kg/cm^2
6. The contribution of mortar beyond cracking strain is neglected.

7. If any steel layer starts yielding, the rigidity of the corresponding layer is taken to be zero in Equation (1).

The ACI Code values for E_c and f_r are used as given above in this investigation. The cube strength values in the experimental investigation are obtained on 5 cms. cubes and the same values are used in evaluating E_c and f_r.

The validity of these expressions for mortar may be open to question. However, their application has given satisfactory correlation with experimental results for deflections.

A total number of 28 specimens are studied for comparison. The experimental values of deflection are taken from an earlier investigation [8-9]. Out of this, five representative specimens (Fig. 1) and their moment vs. deflection graphs (Figs. 2 to 6) are presented here. It may be seen from these figures that the cracked section assumption overestimates the deflections in the working range. This may be due to the variation of flexural rigidity along the span and also due to a higher tension carrying capacity of mortar than what has been assumed. The stiffening effect of mortar in between cracks may also have some effect as in the case of concrete. To take into acount the above effects, the formulae suggested by ACI and CEB for prediction of deflection of concrete members are used for prediction of deflections of ferrocement specimens. These formulae are as follows:

a) ACI Formula

Deflection at any moment 'M' is

$$\delta = \frac{\beta\, l^2\, M}{(EI)_{\text{eff}}} \qquad \ldots\ldots\ldots (2)$$

where

β = constant depending on type of loading

l = span

$(EI)_{\text{eff}}$ = effective flexural rigidity

$$(EI)_{\text{eff}} = \left(\frac{M_r}{M}\right)^3 (EI)_{\text{uncracked}} + \left[1-\left(\frac{M_r}{M}\right)^3\right] (EI)_{\text{cracked}} \qquad \ldots\ldots\ldots (3)$$

where

M_r = moment at cracking ($<M$)

Flexural rigidity values at uncracked and cracked stages obtained using Equation (1) are used in evaluating the effective flexural rigidity. Flexural rigidity values of cracked section are nearly constant till any one of the wiremesh layer yields. When a wiremesh layer yields then the flexural rigidity of the cracked section changes and the corresponding value at that stage is to be used in obtaining the effective flexural rigidity.

b) CEB Formula

Deflection at any moment 'M' is given by

$$\delta = \frac{\beta\, l^2\, M_r}{(EI)_{\text{uncracked}}} + \frac{\beta\, l^2\, (M - M_r)}{0.85\, (EI)_{\text{cracked}}} \qquad \ldots\ldots\ldots (4)$$

Flexural rigidities of cracked and uncracked sections are obtained using Equation (1).

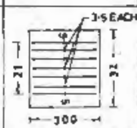
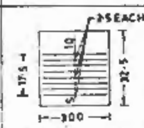
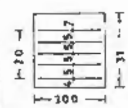
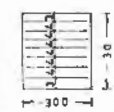
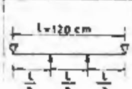
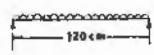
SPECIMEN NUMBER	I A/7	I B/8	I C/8	II A/5	III A/7
CROSS-SECTION (DIMENSIONS IN mm)					
TYPE OF REINFORCEMENT.	20 GAGE AT 10mm C/C UNGALVANISED MESH	20 GAGE AT 10 mm C/C UNGALVANISED MESH	20 GAGE AT 10 mm UNGALVANISED MESH	18 GAGE AT 12·5 mm C/C UNGALVANISED MESH	20 GAGE AT 10 mm C/C GALVANISED MESH
AREA OF STEEL/LAYER (IN cm^2)	0·195	0·195	0·195	0·28	0·195
% REINFORCEMENT IN CROSS SECTION	1·4	1·6	1·6	1·6	1·4
f_{cu} IN kg/cm^2 (5 cm CUBE STRENGTH)	300	200	300	240	296
f_{su} IN kg/cm^2 (STEEL STRENGTH)	3600	10,000	3600	8600	4500
TYPE OF LOADING	 2 POINT LOADING	 U·D·L·			SAME AS I A/7

Fig. 1 Details of some test specimens

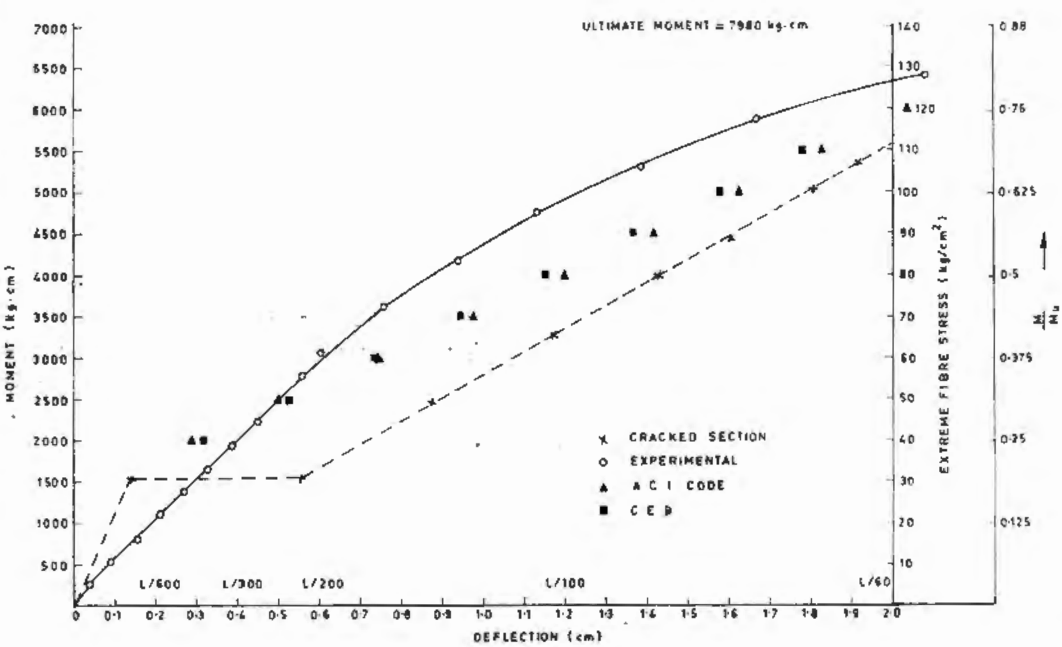


Fig. 2 Moment Vs Deflection (III A/7)-(Conservative)

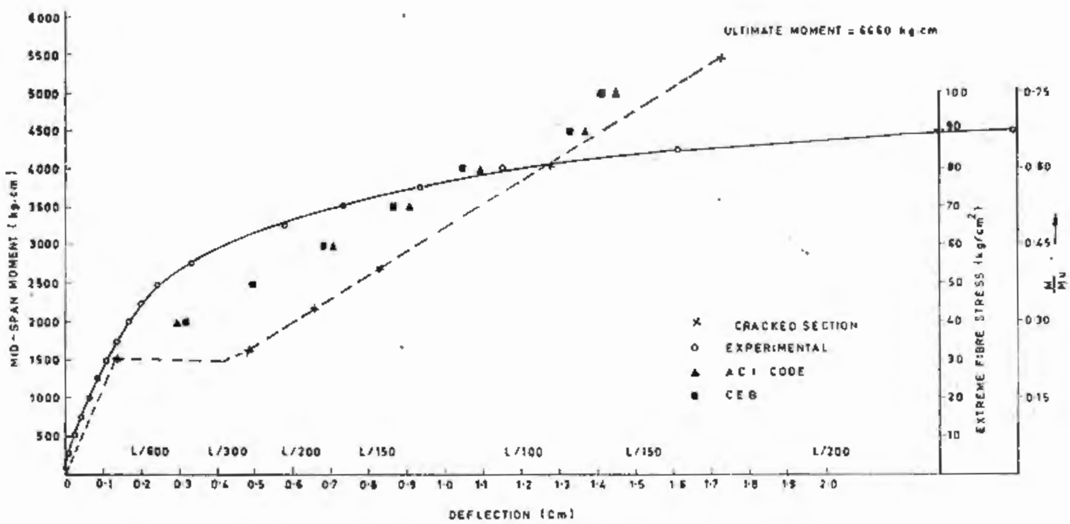


Fig. 3 Moment Vs Deflection (II A/5)-(Conservative)

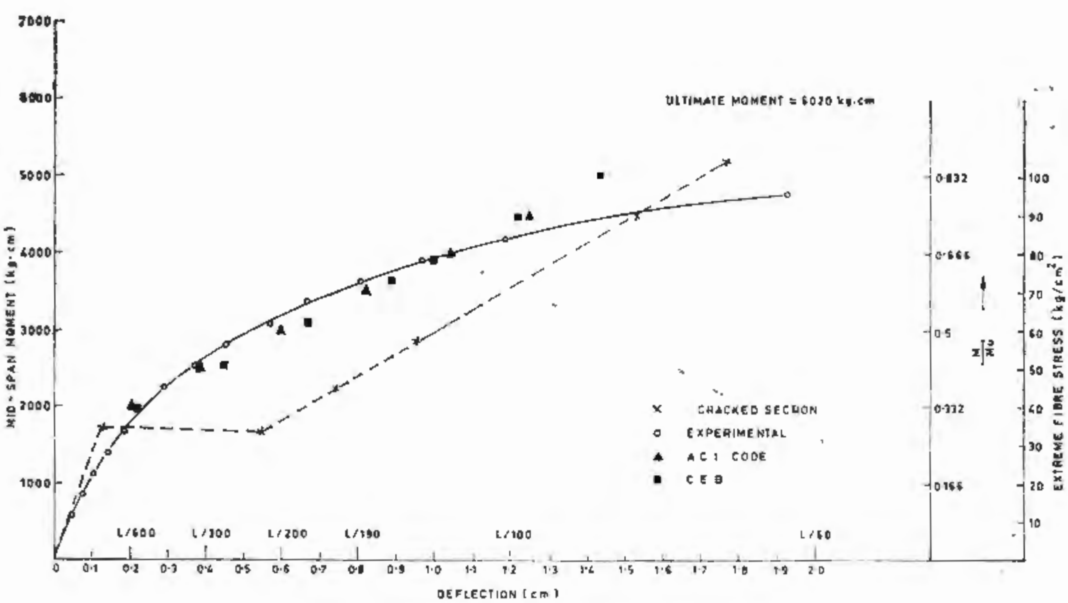


Fig. 4 Moment Vs Deflection (I A/7)-(Good)

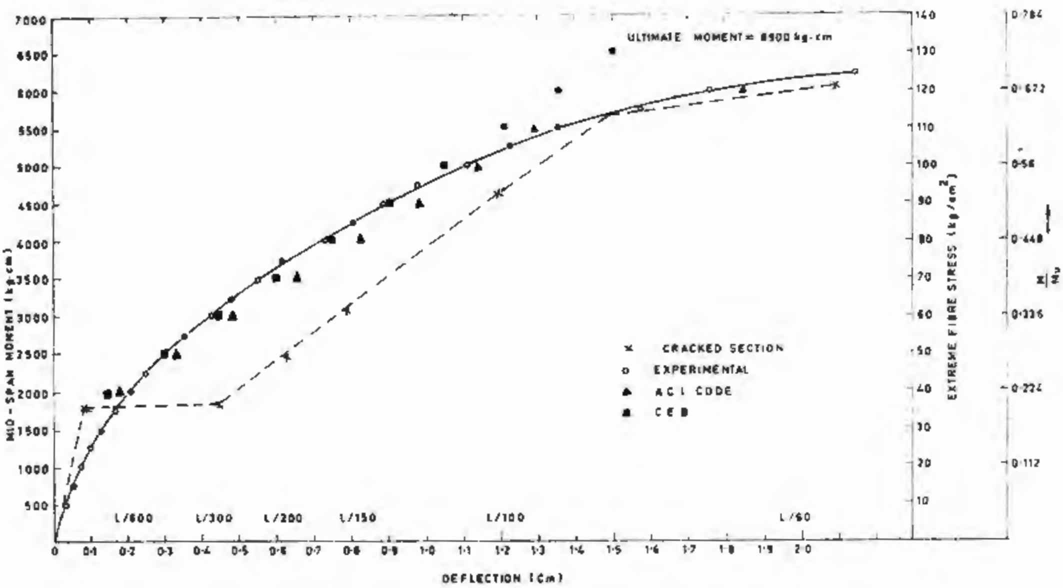


Fig. 5 Moment Vs Deflection (I C/8)-(Good)

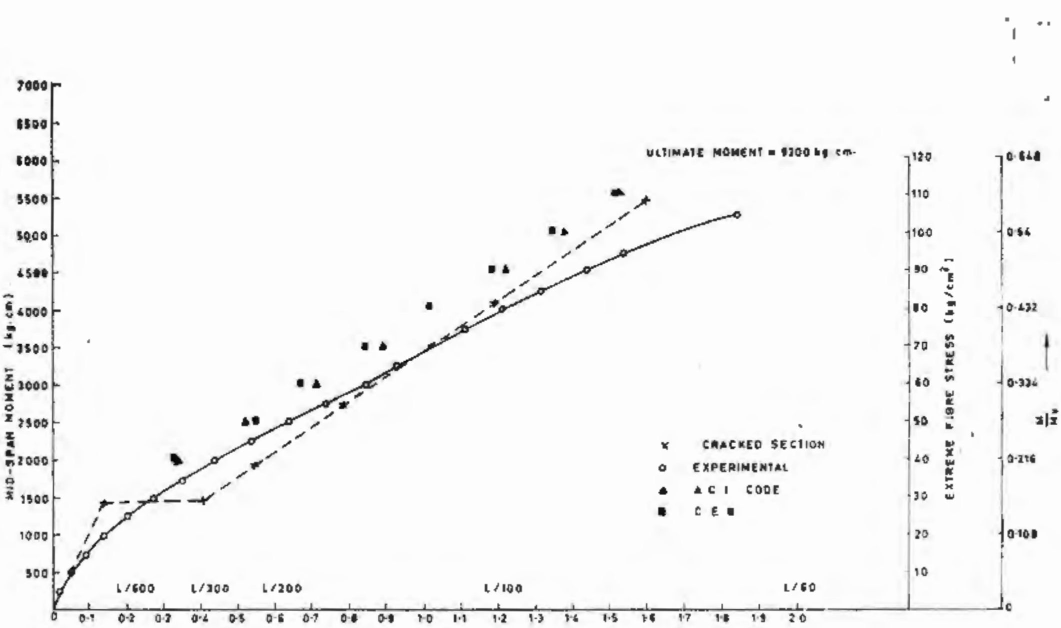


Fig. 6 Moment Vs Deflection (I B/8)-(Unconservative)

DISCUSSION

The deflection values obtained in the uncracked stage are to some extent in agreement with the experimental values. The experimental curves in this stage are observed to be nonlinear by and large. The deviation from linear predictions are tolerable and also the deflections in this stage are not of primary importance. Hence the flexural rigidity in this range may be predicted using the conventional theory.

The experimental deflection values in the cracked stage are compared with

1. Linear curve using flexural rigidity of cracked section.
2. ACI Code formula giving due consideration to evaluation of effective flexural rigidity of a section at any at any given moment and
3. CEB Code formula using bilinear expression for deflections in the working range.

It is observed that the linear curves using flexural rigidity of cracked section overestimate the deflections in the working range and compares well with experimental values only in the higher load ranges. The ACI and CEB Code predictions are close to the experimental values and appear to be more suitable for prediction of flexural rigidity and deflection values of ferrocement in the working load range (say up to $M = 0.6\ M_u$, where M_u = ultimate moment).

The agreement between the experimental and code deflection values is classified and a summary is presented in Tables 1-3. A representative graph from each classification for the three types are presented in Figs. 2 to 6. It may be observed from Tables 2 and 3 that nearly 70 to 80% of the specimens fall into the category of acceptable results (0.8 x Experimental values and above).

An attempt was made to see whether the type of loading or reinforcement content have any influence as parameters. From Tables 2 and 3 it may be seen that the variations observed in the results are random and are not due to different types of loading or variation in reinforcement content. The scatter observed may be due to the possible improper compaction of mortar in tension zone and due to the uncertainity of the wiremesh positions to a certain extent. The other factors that might have contributed to the scatter are the variations in material properties, especially the modulus of elasticity of mortar and steel both of which are assumed.

The formulae may also be used to predict deflections even after yielding of the last layer of steel. A typical deflection calculation where steel layer yields is presented in appendix for specimen IA-7 layers, which shows the comparison of experimental and Code values at higher loads. However, use of cracked section assumption for this stage is advisable to be on the safer side.

CONCLUSIONS

Based on the above discussion, the following conclusions may be drawn:

1. The ACI and CEB formulae for prediction of deflection of concrete members may be used for predicting deflection of ferrocement members in working range.
2. Expression similar to the one proposed by ACI for effective moment of inertia of a section at any moment may be used for predicting flexural rigidity of ferrocement (Equation 3).

Table 1. ACI Deflection/Experimental Deflection Ratios

Series	Number of layers	Reinforcement (%)	A		B		C	
			$M = 0.5\ M_{ult}$	$M = 0.6\ M_{ult}$	$M = 0.5\ M_{ult}$	$M = 0.5\ M_{ult}$	$M = 0.5\ M_{ult}$	$M = 0.6\ M_{ult}$
I								
Ungalvanised square	4	0.8	0.55	0.76	1.19	1.19	1.31	1.38
mesh (20 gage, 10 mm	5	1.0	0.90	0.96	1.25	1.03	1.05	1.20
mesh opening)	6	1.2	0.98	1.08	1.14	1.16	0.86	0.84
	7	1.4	1.13	1.08	-	-	-	-
	8	1.6	-	-	0.84	0.76	1.10	0.98
II								
Ungalvanised square	4	1.3	0.91	0.81	0.76	0.78	1.08	0.94
mesh (18 gage, 12 mm	5	1.6	1.42	0.94	0.64	0.60	-	-
mesh opening)	6	1.9	1.19	1.04	0.73	0.65	-	-
	7	2.2	0.82	0.74	0.90	0.78	0.92	0.81
III								
Galvanised square	4	0.8	1.04	1.05	0.92	1.67	-	-
mesh (20 gage, 10 mm	6	1.2	-	-	-	-	1.31	1.21
mesh opening)	7	1.4	1.36	1.34	-	-	-	-
	8	1.6	-	-	-	-	1.23	1.18

Note; Series IA 2-point loading with $f_{cu} = 300$ kg/cm^2 and $f_{su} = 3{,}600$ kg/cm^2

Series IB Uniformly distributed loading with $f_{cu} = 200$ kg/cm^2 and $f_{su} = 10{,}000$ kg/cm^2

Series IC Uniformly distributed loading with $f_{cu} = 300$ kg/cm^2 and $f_{su} = 3{,}600$ kg/cm^2

Series IIA Uniformly distributed loading with $f_{cu} = 240$ kg/cm^2 and $f_{su} = 8{,}600$ kg/cm^2

Series IIB Uniformly distributed loading with $f_{cu} = 180$ kg/cm^2 and $f_{su} = 8{,}600$ kg/cm^2

Series IIC 2-point laoding with $f_{cu} = 190$ kg/cm^2 and $f_{su} = 3{,}900$ kg/cm^2

Series IIIA 2-point loading with $f_{cu} = 296$ kg/cm^2 and $f_{su} = 4{,}500$ kg/cm^2

Series IIIB Uniformly distributed loading with $f_{cu} = 220$ kg/cm^2 and $f_{su} = 4{,}500$ kg/cm^2

Series IIIC 2-point loading with $f_{cu} = 260$ kg/cm^2 and $f_{su} = 4{,}500$ kg/cm^2

Table 2. Summary of Comparison (Deflections in the Working Range)

$\frac{ACI \text{ deflection}}{\text{Experimental deflection}}$	Agreement	At $M = 0.5\ M_{ult}$		At $M = 0.6\ M_{ult}$	
		Number of specimens	Approximate cumulative %	Number of specimens	Approximate cumulative %
Specimens tested under 2-point loading					
1.21 to 1.50	Conservative	3	27	2	18
1.00 to 1.20	Good	4	63	5	63
0.80 to 1.00*	Good	3	90*	3	90*
0.50 to 0.79	Unconservative	1	100	1	100
	Total	11		11	
Specimens tested under UDL					
1.21 to 1.50	Conservative	4	24	2	12
1.00 to 1.20	Good	4	48	5	42
0.80 to 1.00*	Good	6	84*	4	66*
0.50 to 0.79	Unconservative	3	100	6	100
	Total	17		17	
All Specimens Combined					
1.21 to 1.50	Conservative	7	25	4	14
1.00 to 1.20	Good	8	54	10	50
0.80 to 1.00*	Good	9	86*	7	75*
0.50 to 0.79	Unconservative	4	100	7	100
	Total	28		28	

* Results acceptable up to this level.

Table 3. Summary of Comparison (Deflections in the Working Range at $M = 0.5\ M_{ult}$)

$\frac{ACI \text{ deflection}}{\text{Experimental deflection}}$	Agreement	Specimens with % reinforcement					
		0.80 to 1.00		1.20 to 1.60		1.80 to 2.20	
		Number of specimens	Cumulative %	Number of specimens	Cumulative %	Number of specimens	Cumulative %
1.21 to 1.50	Conservative	3	37	4	28	-	-
1.00 to 1.20	Good	2	63	4	56	3	50
0.80 to 1.00*	Good	2	88*	4	84*	2	84*
0.50 to 0.79	Unconservative	1	100	2	100	1	100
Total		8		14		6	

* Results acceptable up to this level.

3. It may be advisable to use flexural rigidity of cracked section (neglecting the contribution of layers yielded) for prediction of deflections beyond the working load level.

ACKNOWLEDGEMENTS

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APPENDIX

Typical Deflection Calculations

Specimen : IA-7 layers

f_{cu} : 300 kg/cm^2

E_c : 2.41 × 10^5 kg/cm^2

f_r : 32.1 kg/cm^2

f_{su} : 3600 kg/cm^2

E_s : 2.0 × 10^6 kg/cm^2

Area of steel in each layer : 0.195 cm^2

Neutral axis from compression face (assumed) = 0.79 cm

Strain at top : 1000×10^{-6}

Strain at bottom: 3050×10^{-6}

Tensile strain of 133×10^{-6} at 0.105 cm from Neutral Axis

Compressive force : $\dfrac{0.79 \times 30 \times 241}{2} = 2860$ kg

Tensile force (mortar) : $\dfrac{0.105 \times 32.1 \times 30}{2} = 50.5$ kg.

The moment calculation is given in Table 4.

Table 4. Calculation of Moments

Component	c.g. from N.A (cm)	Strain ($\times 10^{-6}$)	Stress (kg/cm^2)	Force (kg)	Moment (kg.cm)
Compression					
Mortar	0.526	-	-	2,860.0	1.505.0
Steel (1)	0.190	240	421.0	82.0	15.6
Total for compression	-	-	-	2,942.0	1,520.5
Tension					
Steel (2)	0.16	202	404.0	78.6	12.6
Steel (3)	0.51	635	1,270.0	248.0	126.3
Steel (4)	0.86	1,090	2,180.0	425.0	366.0
Steel (5)	1.21	1,530	3,060.0*	600.0	726.0
Steel (6)	1.56	1,975	3,600.0*	700.0	1,090.2
Steel (7)	1.91	2,420	3,600.0*	700.0	1,339.0
Mortar	0.07	-	-	50.5	3.5
Total for tension	-	-	-	2,802.1	3,663.6
Total moment	-	-	-	-	5,184.1

* Layers yielded

Calculation of flexural rigidity:

Area : $b \times d$; here $b = 30$ cm

$= 26.85$ cm^2 $\quad (d = 0.79 + 0.105 = 0.895)$

Now $(n_1)^2$ for uncracked concrete = $\left(0.79 - \dfrac{0.89}{2}\right)^2 = 0.1085$

$\therefore \quad A \times n_1^2 = 26.85 \times 0.1085 = 2.92$ cm^4

and $bd^3/12 = (1/12) \times 30 \times (0.895)^3 = 1.74$ cm^4

$\therefore$ *EI* for uncracked concrete : $4.66 \times 2.41 \times 10^5 = 11.22 \times 10^5$ kg cm^2

now *EI* for steel in uncracked concrete : $A_s \times \sum (d_s)^2 \times (E_s - E_c)$

$$= 0.195 \times 0.036 \times 1.759 \times 10^6$$

$$= 0.123 \times 10^5 \text{ kg cm}^2$$

and *EI* steel in cracked concrete:

Here $\sum d_s^2$ =	0.0256	Layer (2)
	0.26	Layer (3)
	0.74	Layer (4)
	1.46	Layer (5)
	0.0	Layer (6) & (7) (as they have yielded)
	2.4856	

$$A_s \times \sum d_s^2 \times E_s = 0.195 \times 2.4856 \times 2.0 \times 10^6$$

$$= 9.7 \times 10^5 \text{ kg cm}^2$$

$$\text{Total } [EI]_{\text{Cracked}} = (11.22 + 0.123 + 9.7)\ 10^5$$

$$= 21.043 \times 10^5 \text{ kg cm}^2$$

EI for uncracked section and M_r (Moment at first crack) obtained in similar manner, are given below:

EI uncracked section : 209.3×10^5 kg cm^2

M_r : 1729 kg cm

At Moment M = 5184 kg cm

i) *Deflection based on cracked section alone*

= 3.78 cm

ii) *Deflection based on ACI Code:*

$$(EI)_{eff} = (EI)_{uncracked} \left(\frac{M_r}{M_{max}}\right)^3 + (EI)_{cracked} \left[1 - \left(\frac{M_r}{M_{max}}\right)^3\right]$$

$$= 209.3 \times 10^5 \left(\frac{1729}{5184}\right)^3 + 21.043 \left[1 - \left(\frac{1729}{5184}\right)^3\right]$$

$$= 27.9 \times 10^5 \text{ kg cm}^2$$

Deflection based on *ACI* formula = 2.95 cm

iii) *Deflection based on CEB* :

$$\sigma = \frac{\beta . l.^2 M_r}{(EI)_{uncracked}} + \frac{\beta . l.^2 (M - M_r)}{0.85\ (EI)_{cracked}} = 3.097 \text{ cms}$$

iv) *Deflection based on experiments = 3.36 cms*

Similarly the deflection are calculated at different values of moments using the three methods. All these values are tabulated in Table 5.

Table 5. Comparison of Deflections (IA/7)

Moment (kg. cm)	Deflections (cm)		
	Experimental	ACI code	CEB
2,000	0.240	0.202	0.234
2,500	0.362	0.385	0.431
3,000	0.535	0.600	0.628
3,500	0.735	0.820	0.825
4,000	1.038	1.040	1.022
4,500	1.650	1.250	1.217

Ribbed Slabs Made of Ferrocement*

M. Sarid+, E.Z. Tatsa† and F. Bljuger‡

This article presents a new type of slab to be applied in semiprefabricated construction. The slab is made of a thin 15mm flat layer of ferrocement stiffened by a set of ribs. The paper describes the main advantages of this type of slab in comparison to well known techniques of building with skins. It also reports a series of experiments which indicate the potential of the proposed element as a building component.

INTRODUCTION

The aim of this article is to develop a low cost slab which is easy to handle and erect. To acheive this goal an element with minimum weight during handling and erection is required. At the final stage of the completed building the elements must not necessarily be light because of a number of factors of which at least the following two cannot be avoided:

a) The requirement for a monolitic structure.
b) The requirement for non-structural properties like acoustic and thermal insulation.

With this view in mind a large number of construction methods have been developed in recent years. The common features of these methods are:

a) The skin requires additional temporary supports during errection. (Fig. 1a)
b) The final product is nothing else but a solid concrete slab (Fig. 1b)
c) The thickness of the precast part is relatively large in comparison to the overall depth (Fig. 1b)

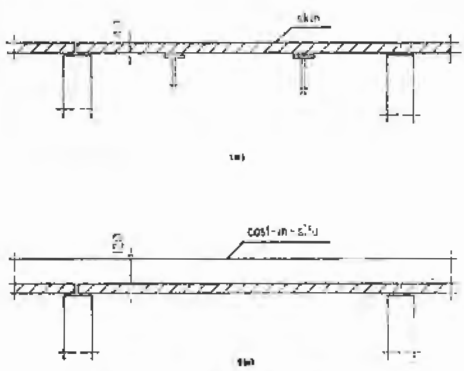

Fig. 1. Skinned slabs

PROPOSAL FOR A NEW SLAB

The properties which feature skin type construction prevent the realization of the great advantage of using the skin as a layer of a sandwich type element where it provides the struc-

* First published in the International Conference on Concerte Slabs, Dundee. U.K., April 1979.
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tural properties while an appropriate fill or additional layer provide the required non-structural properties. To overcome this difficulty the use of a ferrocement ribbed skin is proposed. (Fig. 2). The advantages of this solution are:

a) The weight of the prefabricated part of the slab is reduced considerably.
b) There is no need for temporary supports.
c) Because of the ductility of ferrocement breakage during handling is reduced.
d) The upper slab and cast-in-situ joints create a monolitic structure.
e) Non-structural properties are provided to the already built structure by filling the space between the skin and the cast-in-situ concrete layer. This space may also be used for various instalations.
f) The lower face of the slab is smooth and ready to paint without additional plastering.
g) Openings may be cut in the thin ferrocement layer at any stage and so is the case with repairs.
h) The skin may be used also as a wall panel and thus a higher degree of standardization is acheived.

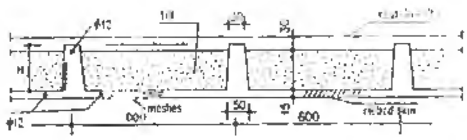


Fig. 2. Proposal for a ribbed ferrocement slab

PRELIMINARY RESEARCH

As a first stage in order to realize the anticipated advantages of the proposed slab a series of experiments was carried out. The experiments included:

a) Flexural tests on 400 x 100 x 15 mm ferrocement plates (Fig. 3). Three plates reinforced by four meshes and three plates with two meshes. The meshes were woven of 0.55 mm wires at 5 mm distances apart. The compressive strength of the mortar was 50 N/mm^2 after 28 days.

b) A series of ribbed slabs in bending, the details of which are given in Fig. 4. Casting of the slabs using steel forms was done in two stages but with no timelag in between. First the ribs were cast and then a flat mesh was placed and the flat 15 mm thick layer cast. The mortar compressive strength was 50 N/mm^2 after 28 days.

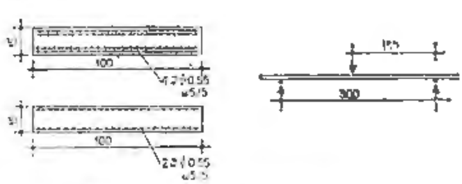


Fig. 3. Ferrocement plate

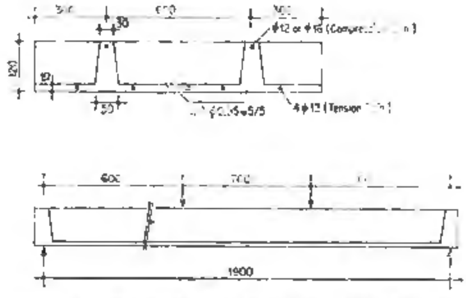


Fig. 4. Ribbed slabs for experimental study

TEST RESULTS

a) *Thin plates*

The results are shown in Fig. 5 (moment deflection curves) and in Fig. 6 (crack patterns) and summarized in Table 1.

Table 1. Test Results for Thin Plates

Parameter	Four Mesh Plate 4#0. 55w5/5mm	Two Mesh Plate 2#0.55w5/5mm
Ultimate moment-M_u (N-mm/mm)	490	356
$\frac{\text{Defl.}}{\text{Span}}$ at failure	$\frac{1}{28}$	$\frac{1}{75}$
At $\frac{2}{3}$ of ultimate load	$\frac{1}{320}$	$\frac{1}{500}$
Average distance between cracks at failure (mm)	8	10
Crack width at failure (mm)	0.2	0.2
Cracking moment Nmm/mm	300	300

b) *Ribbed Slabs*

The results are shown in Fig. 7 (moment-deflection curves), Fig. 8 (moment-elongation at the external face) and Fig. 1 (tensile stress distrubution). In addition the following observations were made:

a) The average distance between cracks was 35 mm and the maximum crack width before failure 0.2 mm. The crack width at 70% of the ultimate moment did not exceed 0.1 mm (Fig. 10)

b) Cracking moment to ultimate moment ratio was about 0.50 which is high in comparison to ordinary reinforced concrete.

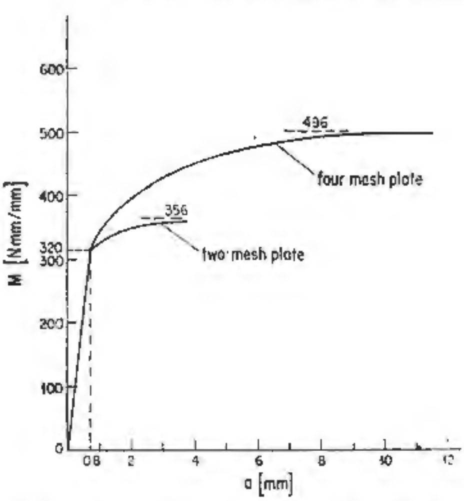


Fig. 5. Ferrocement plates - moment deflection curves.

Fig. 6. Ferrocement plates - crack pattern

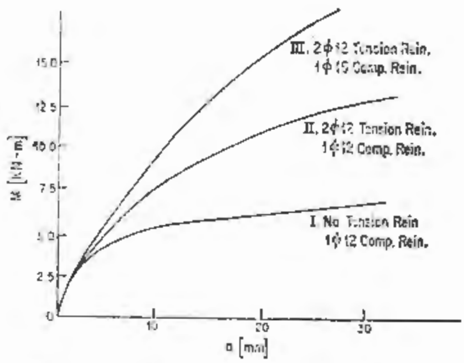


Fig. 7. Ribbed slabs - moment deflection curves

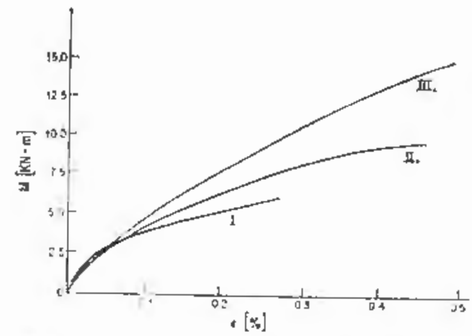


Fig. 8. Ribbed slabs - moment elongation curves

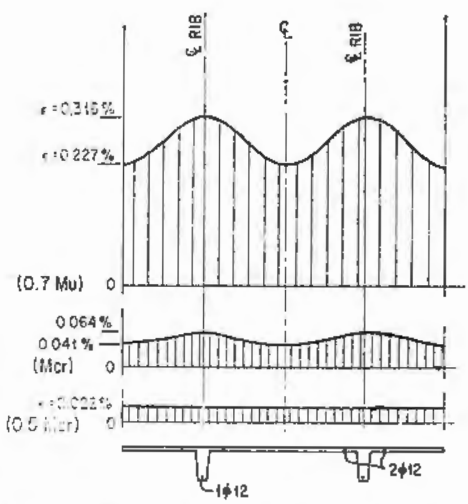


Fig. 9. Ribbed slabs - tensile stress distrubution

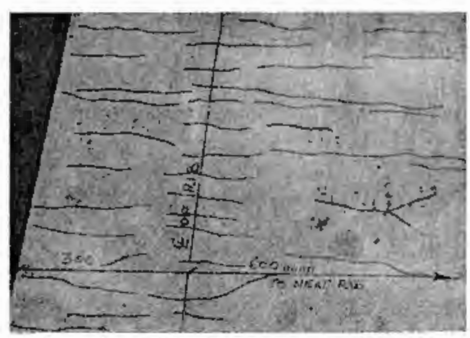


Fig. 10. Ribbed slabs - crack pattern

ECONOMIC ASSESSMENT

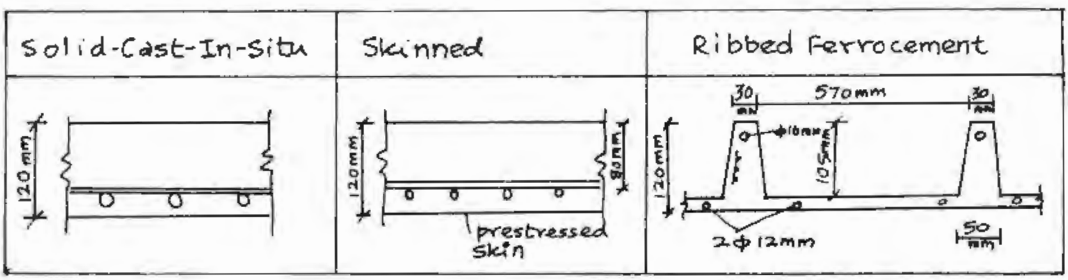
To assess the economic advantages of the proposed slab a comparison based on material quantities between a solid slab, a prestressed skin slab and a ferrocement ribbed slab was made (Table 2). The three slabs are of 3. 6 m span, simply supported and carry a liveload of 0.15 tons per m^2. The results are given in Table 2. The comparison is made on a base unit which is the price of Concrete Grade 20 and of mild steel with a yield strength of 240 N/mm^2. This price ratio are taken as:

Concrete Grade 20 : Grade 40 : Grade 50- 1:1.15:1.20
Mild Steel: Meshes: Prestressing Wires- 1:4:4

Table 2. Comparison Between the Three Types of Slabs

Type / Parameter	Solid-cast-in-situ+	Skinned+	Ribbed ferrocement+
Grade of concrete	20	20 (cast-in-situ) 40 (skin)	50
Reinforcement	12 mm dia. at 200 mm (main) 8 mm dia. at 250 mm (shrinkage)	157 mm^2/m wires 8 mm dia. at 250 mm (shrinkage)	2 layers 0.55 mm wire, $\frac{1}{2}$ in. mesh 2 x 12 mm dia. at 600 mm (tensile) 16 mm dia at 600 mm (compressive)
Equivalent Gr 20 concrete m^3/m^2	0.12	0.12	0.026
Equivalent mild steel kg/m^2	6.10	7.90	12
Unit cost* (Cost ratio)	465 (1.00)	510** (1.10)	362 (0.78)

\+ See figures below, showing section details
* Unit price for steel taken as 4% of unit price for Grade 20 concrete.
** Price should be increased due to need for temporary supports.



DISCUSSION AND CONCLUSIONS

Comparison betweeen the behaviour of the two types of ferrocement plates shows that the main advantage of the four mesh plate is in the much larger inelastic range it has got. In ordinary slab structures this is not essential property and therefore one may use the less expensive two mesh plate. The small number of meshes (low specific area of steel) will result in a different crack pattern than in ordinary ferrocement but again, as long as the cracks are not wider than a specified width to prevent excessive deflections and corrosion they can be tolerated. The reduced ultimate strength of the two mesh plate can be compensated for by shortening the space between the ribs or by transfering the loads directly to the ribs. The behaviour of the model ribbed slabs indicated that the required stiffness and ultimate strength can be provided with no much difficulty by providing the appropriate total depth of the section. Since the depth is controlled by the height of the ribs only economical sections are easy to obtain.

Ferrocement in Relation to the RC Code*

D. Alexander+

A great deal of research on ferrocement is now accumulated without its practice being resolved in terms of a code of practice to guide engineers in the use of the material. Not the least of the difficulies surrounding the material is its definition which has largely and probably erroneously attached itself to multi layer mesh reinforced ferrocement. The emergence of mono layered high tensile wire reinforced fibrous ferrocement which produces parallel properties puts point to this assertion. The aim of this article is to argue a simplified objective view of the material as belonging essentially and in detail to the reinforced concrete family of composites. Objectively the applicable criteria are strength performance and crack width which govern corrosion susceptibility. Subjectively we have the configuration and quantities of steel and surface requirements which govern the objective criteria, and these may have led to difficulties of definition as the means of achieving the objectives of ferrocement diversified in usage.

THE NATURE OF FERROCEMENT

Ferrocement is basically a form of reinforced concrete with the same composite assemblage of cement aggregate matrix and reinforcing steel. The difference lies in the use of a fine grained matrix and fine mesh reinforcement which has historically been devised for specialized applications typified by thin shell structures. It has been relatively difficult to extend this concept into the beam and slab field of reinforced concrete because of economic constraints which arise from the inefficient use of steel reinforcement in the form of layered mesh.

In reinforced concrete the things we design for are flexural strength, shear resistance and protection of the substrate steel from corrosion, and each of these constraints has also to be resolved for ferrocement together with the two other important criteria, economic sensibility and the ability to construct sections as designed.

Concrete composites using steel reinforcement have tended to be broken into three categories: reinforced concrete, reinforced mortar and ferrocement. Codes of practice have been attached to the first two but ferrocement remains without recognition in this sense.

There is a tendency to forget that they are all the same composite. In comment it can be said that:

1. Ferrocement devises its flexural strength from the inter action of steel against compressive concrete in exactly the same manner in which reinforced concrete obtains its competence, and the calculations of strength have been shown by computer backed analysis of test data to obey the same rules as reinforced concrete.

2. For shear the same principles apply as for reinforced concrete with, however, a higher reliance on the steel.

3. In respect to corrosion it is necessary to ensure the integrity of the steel. Devices common to all forms of reinforced concrete are employed for this purpose.

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+ Alexander and Poore Consulting Engineers, Auckland, New Zealand.

The first two statements are self evident but the last deserves elaboration for some special quality of corrosion resistance is generally attributed to ferrocement.

Corrosion of tensile reinforcing steel can be prevented primarily by restricting cracks to the critical width above which ingress of moisture can occur.

CONTROL OF CRACKING

It is generally accepted that crack widths below 0.05 mm are acceptable in non-aggressive but wet conditions and 0.1 mm in interior conditions. With protective covers greater widths may be tolerable.

Crack control can be explained with the aid of simplified concepts. When cracks are initiated, the tensile force exerted by the concrete across what is now the crack interface, is transferred to the steel at that section and in turn is transferred elastically back into the concrete by a bond mechanism.

Bond is a function of surface hence a discrete length of rod or wire is required to develop sufficient force to restore the concrete stress.

This can be illustrated diagrammatically (see Fig. 1).

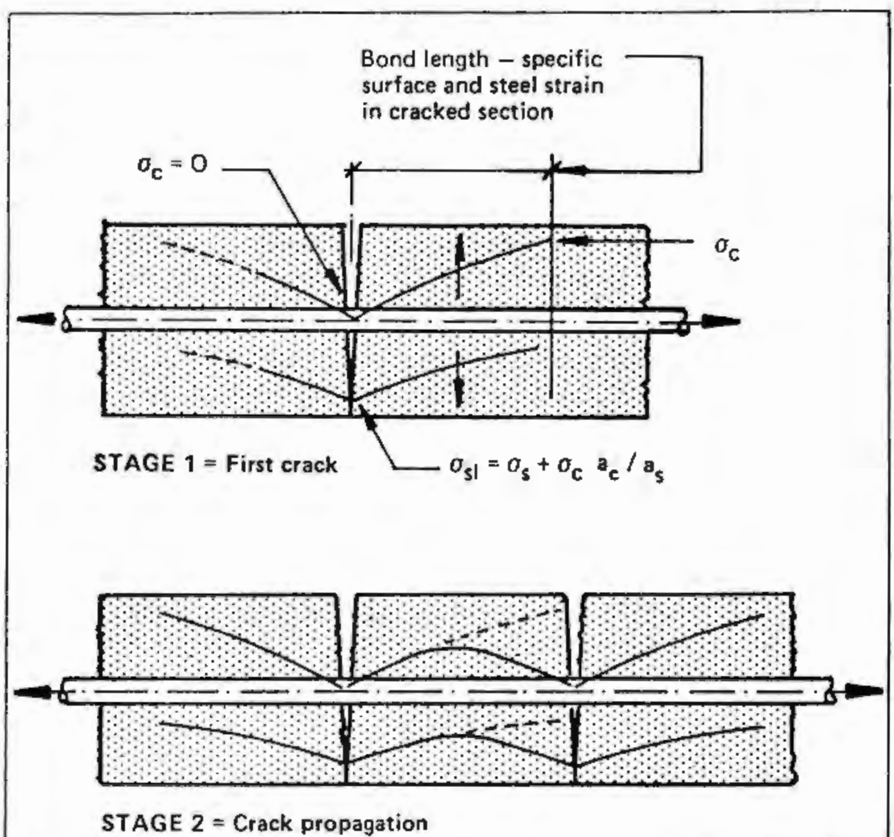

Fig. 1.

The length in which the stress in the concrete is restored is called the characteristic bond length beyond which cracking can again be initiated repetitively to give a characteristic crack spacing.

Remembering that the phenomena is surface dependent, crack spacing is wide for rod and close for fine wire, for the same steel area.

The spacing may be dominant or it may be subordinated to crack inducers the best examples of which are deformed bar in reinforced concrete and the transverse wires of mesh reinforcement in ferrocement which induce their own periodicity.

Some theories developed for ferrocement give crack spacing in terms of transverse steel which may obscure the basic cracking mechanism outlined above, and this is demonstrated in the crack behaviour of the newer form of ferrocement in which high tensile wire reinforcement is used in conjunction with wire fibres [4] in which transverse steel may be omitted. Nevertheless a characteristic crack spacing comparable with that induced in much finer wire mesh reinforced ferrocement occurs.

In terms of the simplified concept discussed above, residual forces at the crack site are now shared by the fibres bridging the interface and the continuous tensile reinforcement so that a lesser bond length is required to restore the stress in the concrete.

Ferrocement has been considered a distinctive material because it requires multi layers of fine mesh to achieve a significant control of cracking, but high tensile wire reinforced fibrous ferrocement achieves similar crack spacing with coarser mono layered wire. Therefore, the important function is the characteristic bond length not the physical means of achieving it.

In considering corrosion, crack width is a specifying parameter and is the product of the strain in the steel by a factored bond length (which is the controlling parameter ofthe crack spacing), and is expressed as follows:

$$t_c = \sigma_s/E_s \ l_b$$

where t_c = crack width

σ_s = steel stress

E_s = elastic modulus for steel

l_b = characteristic bond length (factored)

The most significant characteristic of ferrocement which differentiates it from conventional reinforced concrete, is its use of higher percentage of small diameter wires which results in increased specific surface which is aimed at producing a reduced characteristic bond lengh resulting in diminished crack widths, and it is this feature that accounts for the low level of corrosion of the steel despite the thin covers employed. At the same time it is necessary to ensure a low absorbency by using dense, fine grained concrete (mortar) whilst corrosion is further inhibited by the alkali environment of the cement enriched concrete (mortar).

From the foregoing discussion it may be concluded that ferrocement shares the characteristics of flexural resistance, shear properties and crack formation phenomena of the reinforced concrete composite, although emphasis on the latter characteristic differentiates it from conventional reinforced concrete. It follows therefore that in order to unify the code of practice approach it may be prudent to abandon the definition of ferrocement in subjective terms of steel quantity (volume fraction) and surface per unit volume (specific surface), layers of mesh, etc., and revert the material to the objective discipline of reinforced concrete criteria of strength and crack control.

A code of practice devised for ferrocement should therefore primarily define the requirement of protection of steel from corrosion whilst leaving the strength determinants to the present theories applicable to reinforced concrete (see Appendices)

It could define:

(a) minimum covers;
(b) maximum crack widths for various environments;
(c) porosity of the concrete or mortar;
(d) mortar design in terms of high free lime content;
(e) additives to enhance corrosion resistance and other properties of the material;
(f) coatings to add protection in severe environments.

It is not anticipated that the goal of a code will be realized in the short term, but the directions suggested herein may assist in giving direction to the effort required to achieve it.

DESIGN OF FERROCEMENT IN FLEXURE

It can be shown by back analysis of test panel results that reinforced concrete theory is applicable to ferrocement as may be expected for a non-synergistic composite.

Therefore, ferrocement sections can be designed using one of the methods applicable to reinforced concrete:

A Ultimate Load Design—Balanced Section Method
B Elastic Analysis—Working Stress Method for linear concrete
C Elastic Analysis—Yield Stress Ultimate Design Method for linear concrete

Case 1: Mild steel mesh reinforced ferrocement

Mild steel mesh reinforced ferrocement which is the common and historical form of ferrocement is invariably severely under reinforced and Elastic Analysis must be used.

Case 2: High tensile wire reinforced ferrocement

High tensile wire reinforced ferrocement is necessary for economic optimization to use the Ultimate Load Method for balanced sections. Therefore, the required area of steel as is obtained from the equation:

$$A_s f_y = 0.85 \, f'_c \, a \, b + A_{sl} E_s \frac{c-d_l}{c} \in_c$$

If a practical assembly of wires can be devised within 5% of the area obtained then the actual area decided upon can be re-inserted in the equation without sensible error. The moment capacity M_u can then be found using the new 'a' thus

$$M_u = \phi \, 0.85 \, f'_{cl} \, a \, b \, (d - \tfrac{1}{2} a) + A_{sl} E_s \frac{c-d_l}{c} \in_c (d - d_l)$$

where ϕ is the capacity reduction factor.

Case 3: High tensile wire reinforced fibrous ferrocement (under-reinforced)

High tensile wire reinforced fibrous ferrocement (under-reinforced), in practice a great many design sections need not be fully reinforced and such sections most frequently fall into the area of non-linear — elastic concrete as shown below.

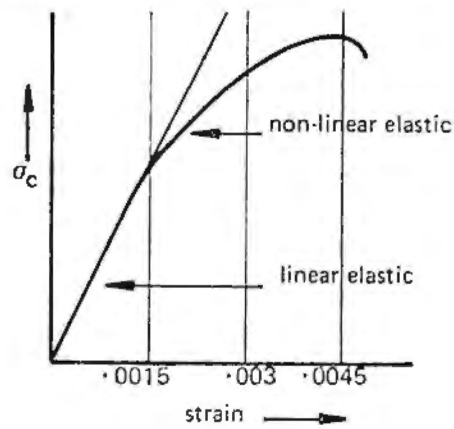

Fig. 2.

The design calculations must be adapted to monitor the changing stress block in this zone, i.e. the coefficient for the modified Whitney Stress block must be introduced into the calculations.

A modified Whitney Stress block would satisfy most applications.

Research projects may, however, need a more refined approach which would require both the concrete and the high tensile steel to be treated as nonlinear elastic at their approach to high strains.

The mathematics of this may be better resolved by fitting theoretical curves to experimentally derived curves to obtain a match, and programming the data to handle the various inputs.

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APPENDIX I - DERIVATION OF FORMULA

A. Ultimate moment design—Balanced Section Method (high tensile wire reinforced fibrous ferrocement)

Symbols

f_y = yield stress of steel (typically 164,000 psi)

$\in_y$ = steel strain (typically 0.0056)

f'_c = compressive strength of concrete (typically 8,000 psi)

$\in_c$ = concrete strain (typically 0.004 psi)

b = unit width

$\beta = 0.85 + 0.05 \left[\dfrac{-f'_c + 4{,}000}{1{,}000}\right]$ (typically 0.65 psi)

$a = \beta c$

c = distance to neutral axis from compression face

d = depth of tensile steel from compression face

d' = depth of compressive steel from compressive face

ϕ = capacity reduction factor

$C = \in_c d/(\in_y + \in_c)$

A_s and A'_s = area of tensile and compressive steel

Forces balance

$$A_s f_y = 0.85\, f'_c\, a\, b + A'_s E_s \in'_s \qquad (1)$$

$$\in'_s = \frac{c-d'}{c} \times \in_c = \frac{c-d'}{c} \times c/d\,(\in_c + \in_y)$$

$$A_s f_y = 0.85\, f'_c\, a\, b + A'_s E_s \frac{c-d'}{c} \in_c \qquad (2)$$

$$M_u = \phi \left(0.85\, f'_c\, a\, b\,(d - \tfrac{1}{2}a) - A'_s E_s \frac{c-d'}{c} \in_c (d-d')\right) \qquad (3)$$

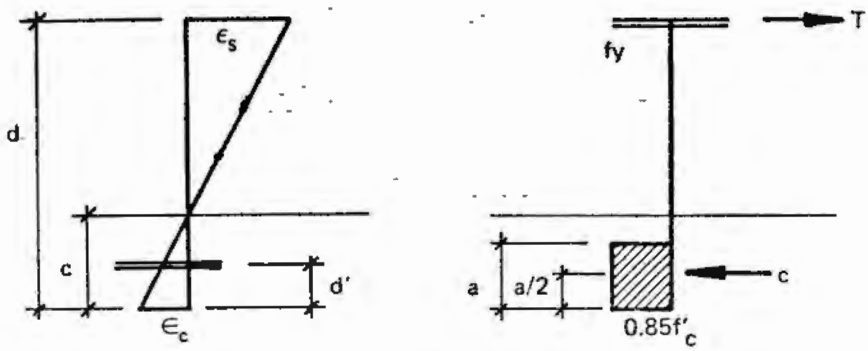


Fig. 3.

B. Elastic analysis—Working Stress Method

Linear concrete $\in_c < 0.0015$

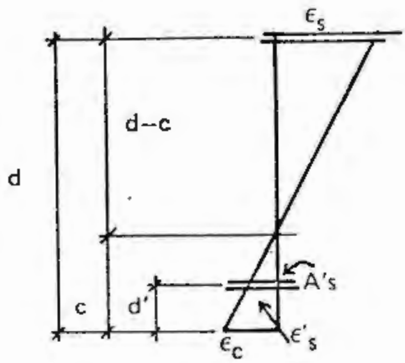


Fig. 4.

$$\frac{\in_c}{\in_s} = \frac{c}{d-c}$$

$$\frac{\in'_s}{\in_s} = \frac{c-d'}{d-c}$$

$$\in_c = \frac{c}{d-c}\in_s$$

$$\in'_s = \frac{c-d'}{d-c}\in_s$$

$$\frac{\in'_s}{\in_c} = \frac{c-d'}{c}$$

Forces balance

$$A_s f_s = f_c \times c/2 \times b + A'_s \times f'_s$$

$$A_s E_s \in_s = E_c \in_c \frac{c\,b}{2} + E'_s \in'_s A'_s$$

$$= E_c \frac{c}{d-c} \in_s \frac{cb}{2} + E_s \frac{c-d'}{d-c} A_s' \in_s$$

$$A_s E_s \in_s = M_r E_s \frac{c}{d-c} \in_s \frac{cb}{2} + E_s \in_s \frac{c-d}{d-c}$$

$$A_s = M_r \frac{c}{d-c} \frac{cb}{2} + \frac{c-d'}{d-c} A_s'$$

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

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

Moment capacity

Moments about tension steel

$$M = \in_c E_c \frac{cb}{2} \times \left(d - \frac{c}{3}\right)$$
$$+ E_s' \in_s' A_s' (d-d')$$
$$= E_c \in_c \frac{cb}{2} \left(d - \frac{c}{3}\right)$$
$$+ E_s \frac{(c-d')}{c} \in_c A_s' \times (d-d')$$

C. Elastic analysis—Yield Stress Ultimate Moment Method

Linear concrete $\in_c < 0.0015$

(Heavily under reinforced high tensile wire reinforced fibrous ferrocement)

From elastic design

Solve

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

Assume:

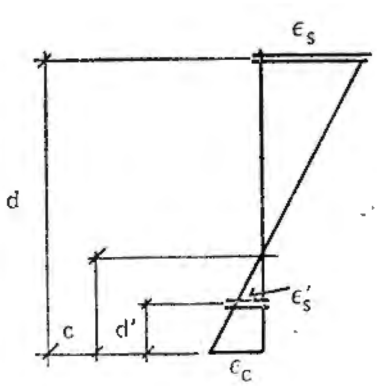


Fig. 5.

$$\in_s = \frac{\sigma_{yield}}{E_s}$$

$$\in_c = \frac{c}{d-c} \in_s$$

$$\in_s' = \frac{c-d'}{d-c} \in_s$$

(Check to ensure that $\in_c < \frac{1}{2} \times 0.003$ assumption of linear strain)

$$M_u = \phi \left(E_c \in_c \frac{c \times b}{2} \times \left(d - \frac{c}{3}\right) + A_s' E_s \in_s' (d-d') \right)$$

In terms of tension steel strain

$$\frac{M}{\in_s} = E_c \times \frac{c}{a-c} \frac{c\,b}{2} \left(d - \frac{c}{3}\right) + E_s \frac{c-d'}{d-c} A_s' (d-d')$$

$$M = \left(M_r \frac{c}{d-c} \frac{c\,b}{2} \left(d - \frac{c}{3}\right) + A_s' \frac{c-d'}{d-c} (d-d') \right) f_s$$

Symbols

f_s = tensile stress in steel
f_c = concrete stress
f_s' = compressive stress in steel
M_r = modular ratio $\frac{E_c}{E_s}$

Other symbols used are same as for ultimate moment design.

APPENDIX II - DEFINITIONS

Mesh reinforced ferrocement :

A thin plate material consisting of a cement mortar matrix and reinforced with multi layers of mild steel mesh generally in a woven or welded form. The size of wire mesh commonly used is 1 mm and 0.8 mm and the aperture size 25 mm. The resulting composite is severely under-reinforced.

High tensile wire reinforced fibrous ferrocement :

Generally made in this plate form using a fibrous mortar matrix and employing 2.5 mm to 3.0 mm high tensile wire (UTS 12,000-16,500 MPa), as reinforcement disposed in one or two near surface layers. This assemblage results in substantial increases in strength a diminition of crack width compared with mesh reinforced ferrocement and has a favourable cost strength ratio. It is best designed in the near balanced section range for optimum economy.

Square Welded Mesh*

Ian Baugh+

The object of this article is to bring to light some pitfalls in the use of square welded mesh, and to describe a method of applying it which works satisfactorily.

New Zealand remains the stronghold of hexagonal mesh as far as amateur and most professional boat builders are concerned. Only a couple of amateur boats have been built with square mesh in the Auckland area. The reason why this mesh should be considered is the fact that research investigation by Shah & Key, indicates that high tensile meshes greatly improve the strength characteristics of ferrocement panels and shells. The reasons why it has not been used in New Zealand have probably, however, got a lot more to do with price, and the old bogey that it is hard to work. The price differential is now considerably less, if not eliminated on an equal weight basis, if the latest prices are compared; and on the basis of my own experience I would say that the problem of workability is far from insurmountable if suitable techniques are used.

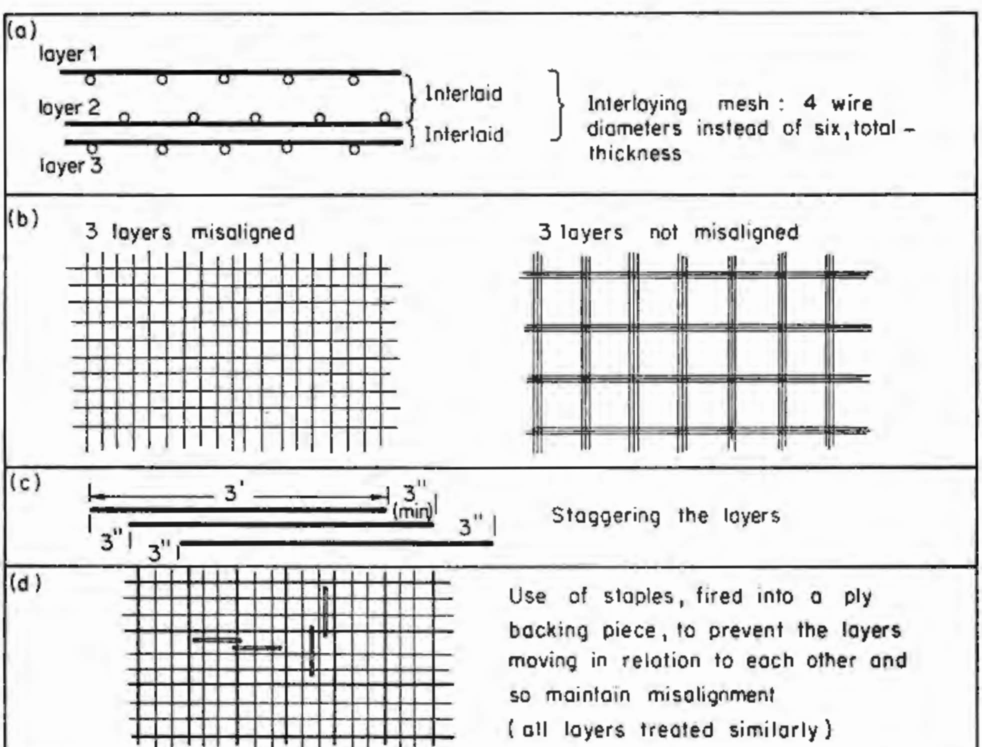


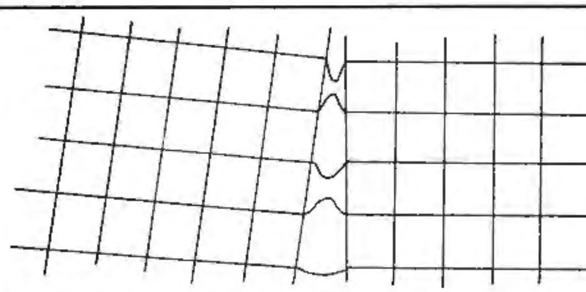
Fig. 1

* Reprinted from Journal of Ferrocement (NZFCMA).
+ Associate Editor, Journal of Ferrocement (IFIC).

Having decided to use welded mesh (the variety available in New Zealand), and having committed myself by buying it, I could find only one published source of information on its application - Benford and Husen's Practical Ferro-Cement Boatbuilding- although I did later read the "Flicka" articles by Bruce Bingham in Rudder, which cover the subject.

Benford, in brief, recommends that the mesh be applied longitudinally in multilayered "strakes". The mesh is laid out on a flat floor to make up these strakes. Layers are placed so that the top strands of wire on the lower layer are running in the same direction as the bottom strands of wire on the upper layer, in order that the layers may intermesh, and so take up less thickness. Also, the edges of the layers are staggered a minimum of 3", so that joints do not coincide; and the layers of mesh are "misaligned", so that individual wires and joints do not lie together and thus reduce the effective dispersion of the steel. These points are illustrated in Fig. 1. The layers are wired together on the ground in this position, and then the strake is stretched into place on the hull using wire strainers.

I was advised that this system would not be satisfactory: the mesh would align, no matter what precautions I took (this had been observed on one of the boats built locally), and in order to make the mesh lie fair it would need to be cut extensively. It was suggested that I apply each layer individually, on opposing diagonals (to increase dispersion, since the wires would be criss-crossing), crimping the wires with needle nose pliers instead (see Fig. 2). Using this method would stop me from interlaying the mesh, and would theoretically result in a considerable increase in thickness, but my advisers did not think the interlaying would work anyway.



Crimping wires with needle - nose pliers to avoid cutting darts. In general where there are small bulges (i.e. locally the mesh is "loose") the bulge can be removed by "shortening" the wires in this way.

Fig. 2

I decided to ignore the men of little faith, however, and follow the book. I laid the mesh on the ground and spent literally hours tying it together every couple of feet in an effort to interlay, stagger and misalign the layers, and keep them that way. Then I stretched the strake against the frames ... and the layers promptly aligned themselves over about three-quarters of the hull, so that I could poke a finger through almost anywhere I liked.

The Doubting Thomases having won the day, I took the strake back off and applied the inside layers on one side diagonally, one at a time. This too was far from a satisfactory job. Each layer needed to be perfectly fair if the next layer was not to bulge alarmingly on top of the high spots of the layer underneath. Fairing each layer turned out to be a very lengthy process, so in the end I simply laid one layer on another as best, I could and placed my faith on typing the layup back onto the battens, aided of course by a few strategic darts. (Crimping the wires was far too lengthy a process to be used on a 36′ hull, and in fact not many darts were necessary).

These unsatisfactory efforts did suggest a few conclusions. The more rigid welded mesh must be applied as tightly and as fair as possible if the rods are to lie fairly over top of the inside layers. Benford's system seemed on the face of it the most logical approach to this, if the problem of misalignment could be overcome. By applying all the layers at once, only one fairing job needs to be done, and use of wire strainers will get the layers as tight as possible, thus eliminating unnecessary bulges. It is also quite essential that the strakes be applied in the plane of the hull, as described by Graeme Kenyon in Journal of Ferrocement Vol. 2, No. 9, to minimise bulging. Finally, if the hull is built over solid timber battens (not necessarily a full mould) to which the mesh can be stapled, much working and cutting of the mesh to fair it can be avoided altogether.

Having thought up a few solutions to the problems I had struck with the Benford system, I proceeded with the modification of their ideas described below.

To lay up the strake in this manner, a flat floor or piece of ground is required, preferably right alongside the hull. About every three feet place on the ground a small, fairly soft ply pad into which staples can be fired. Roll the first layer of mesh out on this, and staple it to the ply backing pieces using a pattern similar to that illustrated in Fig. 1. After stapling there must be very little if any movement between the ply and mesh.

The next layer is then laid over with the opposite face down, so that the wires can interlay. The layer is offset to one side by the desired amount, and adjusted so that layers are misaligned, and then stapled to the backing pieces in the same way as the first layer. After turning the roll upside down again the remaining layer (s) are then treated in the same way. The backing pieces should hold the layers in the misaligned position quite securely until can they be stapled onto the boat.

Any short lengths of mesh should be used in the centre layer of the strake, so the joint does not pull apart, or catch on anything.

At each end of the strake a piece of, say, 3″ × 1″ is bolted onto each side of the layup with say, three $\frac{3}{8}$″ coach bolts. These will be used as the anchor points when the strake is strained onto the hull. Anything less substantial will simply rip through the mesh.

The strakes are now ready to apply to the hull. Here another change from the Benford system was made.

Benford applies the strakes in order from the keel up to sheer, and arranges the staggered edges as in Fig. 3 (a). The edge of each layer in the following strake must then be trimmed to butt against the equivalent layer in the lower strake. To do the inner layers the outer layers of the second strake must be somehow lifted up to get behind them with a pair of cutters. This is a difficult, bloody job, especially since the strake is under tension, and tends to be curved in section.

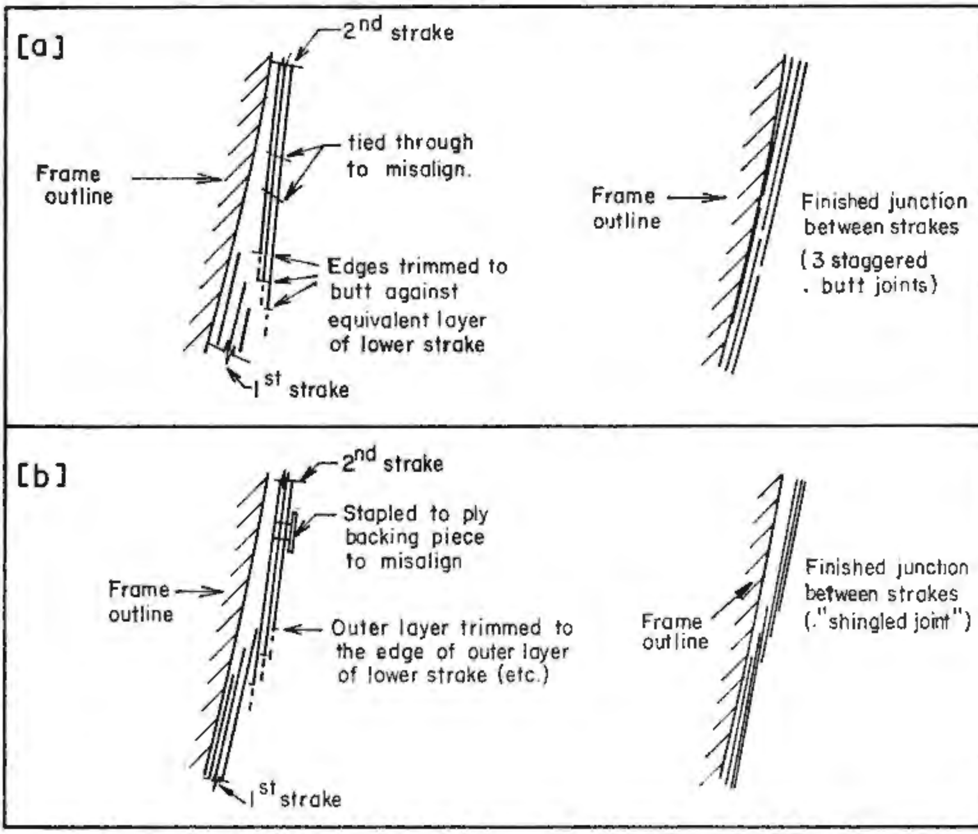


Fig. 3

To overcome this I adopted the system shown in Fig. 3 (b), the benefit of which is that no layer has to be trimmed while covered up by an overlapping layer on top of it. Whereas the Benford method gives three staggered butt joints (Fig. 3 (a), the modification gives a "shingled" joint (Fig. 3(b)). I could think of no structural disadvantage to this, since (as with the other method) at any point there are always at least two complete layers of mesh. Possibly there might be extra thickness. The disadvantage that there are now three raw edges of mesh showing instead of one can be overcome by trimming the edges as in Fig. 4, so that there are no short ends to stick out. Certainly this modification saves a lot of effort.

With the aid of hooks to hold it roughly in place, the strake is held against the hull. The tension is taken with the wire strainer and the strake is manoeuvred into its final position. Its centre should be tight against the hull at all points. Ensure that there are no unplanned gaps between strakes.

Once in position, strain it as tight as possible, and staple the centre of the strake to the battens and frames. Then staple all areas where the mesh is lying against the hull and start stapling out from these into the places where it is bulging. When the bulges are thus isolated (but not so localised that you can't get shears in to cut the mesh) you can begin cutting darts so that the mesh can lay flat. Remember that the cuts must be staggered between layers here too. Where the bulges are small it may be possible to avoid cutting, and remove excess material by squeezing the wires together with needle nose pliers (see Fig. 2). If you are stapling down on to battens, not much cutting will be necessary. Any overlaps which occur when a dart is cut should of course be removed to avoid extra mesh buildup.

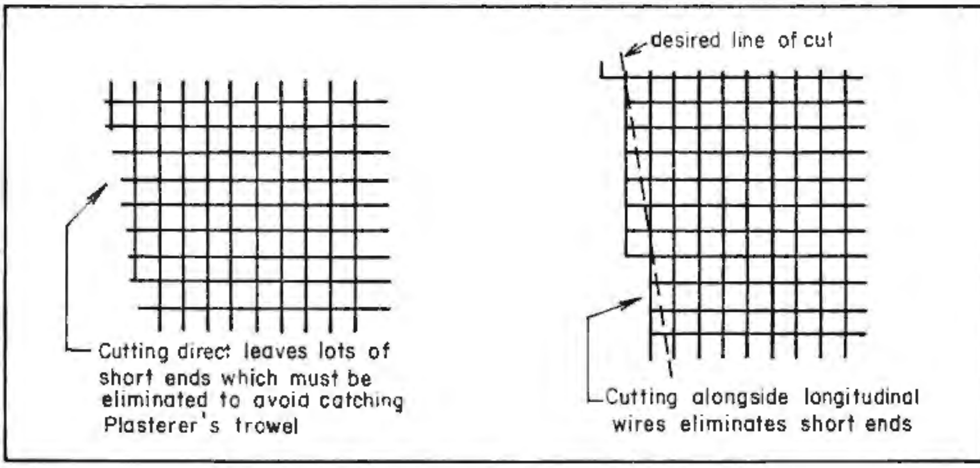


Fig. 4

One the strake has been shaped to the hull in this way, the edge between this strake and the one below should be trimmed to fit. When the strake is securely stapled and the layers can no longer move relative to each other, the ply backing pieces can be levered off for use on the next pass-but not before. Misalignment should be good over most of the hull.

One further practical point: the strake should not be rolled up for any reason before it is applied to the hull. This will put kinks in it which will not pull out when the wire strainers are used.

Finally, it is not possible to simply substitute square welded mesh for hexagonal in your existing design, if that is your wish. For one thing, as mentioned earlier, this would result in a thicker hull, as the 19 ga. square mesh is bulkier for an equivalent layup (although also, perhaps, stronger). Thus, to make up for this, the transverse and longitudinal rod configuration might have to be altered to reduce the overall thickness by using a greater number of smaller wires? or by use of high tensile mesh without transverse wires? (Benford's practice). Clearly this is a case where consultation with the designer is essential.

A Training Program on Ferrocement Technology for Indonesia*

(A summary report submitted to Development Technology Center, Institute Technology Bandung, Indonesia and USAID/Indonesia)

P. Karasudhi+, R.P. Pama+, P. Nimityongskul‡ and V.P. Narayanaswamy**

A training program on ferrocement technology for Indonesia was conducted by the Division of Structural Engineering and Construction, Asian Institute of Technology and sponsored by USAID/Indonesia. Nine engineers chosen from different institutions and universities in Indonesia had undergone the training at AIT which lasted four months. The course consisted of lectures, laboratory experiments and field demonstration projects. The trainees were given instruction on the theoretical, experimental and constructional aspects of ferrocement technology. For the field demonstration project nine different applications which were in the areas of immediate concern to Indonesia, especially for rural development, were selected. Prior to the training program the majority of the trainees did not have much familiarity with the subject of ferrocement. Nevertheless, it was found that the knowledge gained during the training course enabled them to carry out the field demonstration projects with confidence. It is believed that they, in turn, would be able to train their fellow-engineers and technicians in their own country so that the benefits of this new technology are fully realized. With their well-balanced program, it is expected that they would act as effective agents for the transfer of this technology to Indonesia.

INTRODUCTION

At the invitation of USAID/Indonesia, a study was conducted to determine the potential applications of ferrocement in Indonesia. A team consisting of Dr. Ricardo P. Pama and Mr. Opas Phromratanapongse of Siam Cement Company Limited visited Indonesia during October 4-18, 1977. The visit was prompted by the recognition of ferrocement as an appropriate technology material with many potential applications in developing countries, especially in the rural areas [1, 2]. The major constituents of ferrocement, namely cement and steel wire mesh were being produced in sufficient quantities in Indonesia and it was expected that there would be a surplus of one million tons of cement by 1979 with the expansion of the cement industry in Indonesia.

The team visited several institutions and universities and conducted field trips to various places in Indonesia to study the potentials and feasibility of introducing ferrocement, especially for application in rural areas. They submitted a report entitled "The Potentials of Ferrocement and Related Materials for Rural Indonesia -A Feasibility Study" [3].

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During their visit to Indonesia the AIT team noted that the people were not fully aware of the enormous potentials of ferrocement. However, when they were shown slides indicating the various ferrocement applications they were enthusiastic and convinced of its potential. The team observed that the task of introducing ferrocement in Indonesia could be enhanced if key individuals who will be involved in the project are given the proper training in ferrocement technology so that they can effectively demonstrate the technology and train the local people in its many application.

The team recommended that the most effective way for the transfer of ferrocement technology to Indonesia was to train staff members of national institutions such as Institute Technology Bandung, Universitas Hasanudin and Syiah Kuala, which have rural development centres and which can become the focal points for the introduction of this technology in this respective areas. It was recommended that a selected team of engineers from the above institutions should be given specialized training for a period of approximately four months at the Asian Institute of Technology, in all aspects of ferrocement technology and applicaions. It was further recommended that the training program should consist of lectures, laboratory experiments and field trials. The following applications were singled out as being appropriate for field trials:

Dug-out canoes
Building boards with indigenous fibers as reinforcement
Toilet bowls
Well casings
Grain storage bins
Domes for village mosques

Following the above recommendations a team of nine engineers chosen from different national institutions of Indonesia were sent to the Asian Institute of Technology, Bangkok, for a four-month training program starting from June 26, 1978.

ORGANIZATION OF THE TRAINING COURSE

The training course was planned for a duration of four months and consisted of theoretical studies, laboratory experiments, field demonstration projects and field trips. This approach was considered to be the most appropriate, as it allowed for the exposure of the trainees to both the theoretical and the practical aspects of ferrocement technology.

Theoretical Component

This aspect of the training was in the form of lectures on the various aspects of ferrocement, comprising of historical developments, constituent materials, construction methods, mechanical properties, physical properties and potential applications. The lectures included a section on the technology and application of related construction materials such as fiber-reinforced concrete and mortar, organic fiber reinforcement, etc. It was considered desirable to expose the trainees to the theoretical aspects of ferrocement, since a good understanding of the theory is essential for good design, especially as the material is still in the development stage. A series of lectures on the fundamentals of structural analysis of plates and shells was included, since most of the ferrocement applications are in the form of plate and shell elements. The above lectures were supplemented by a series of lectures on special constructional techniques of ferrocement structures. The topics covered under the theoretical component are listed in Appendix A.

Experimental Component

The experimental component comprised the study of the various types of tests on ferrocement and its constituent materials (cement mortar, wire mesh, skeletal steel) to determine their mechanical properties in tension, compression, flexure, etc. Lectures on the experimental component covered in detail the different types of tests, types of test specimens, test variables and test results, reported in the literature. This was followed by laboratory experiments in which the trainees themselves performed the fabricaion and testing of the specimens and analyzed the test results. The topics covered under this component are also listed in Appendix A.

The course material for the above two components was drawn mainly from the book which was specially written for this training program and was subsequently published by the International Ferrocement Information Center [4]. A copy of the above book was supplied to each of the trainee as textbook.

Field Demonstration Projects

The core of the training programme was the field demonstration project in which each of the trainee was assigned a particular ferrocement application. The demonstration projects were chosen in such a way as to broadly represent all the major areas of application, namely marine structures, building and bridge components, storage structures and sanitary engineering structures. Suggestions were sought from the trainees as to their areas of interest and the projects were assigned to them on this basis. The projects chosen were all highly relevant to the needs of the rural areas in Indonesia as recommended in the Feasibility Study. The list of projects selected for field demonstration along with a brief desdcription of each of the projects is given in Appendix B.

After the selection of the projects for field demonstration, the trainees were asked to prepare a project outline describing the nature of the problem, its relevance to the needs of Indonesia, suitability of ferrocement for the particular application, choice of design data and approximate dimensions, proposed method of fabrication, work schedule chart, etc. After the project outline had been approved, the trainees were assigned to carry out the detailed design (functional and structural) of the structure and to prepare the necessary drawings and estimate of the quantity of materials and labour required. While designing the prototype structures every effort was made to retain the traditional forms, as it was felt that the potential users would accept them more readily, if these traditional shapes are retained.

The various stages of fabrication of the protype, such as preparation of the mould, preparation of the skeletal frame work, tying of the wire mesh, weighing of the materials (cement, sand and water) for the mortar, mixing, placing and compacting of mortar, finishing, curing and painting of the specimens were carried out under the direct supervision of the trainees. The trainees were encouraged to do the application of mortar themselves so as to get the "feel" of the material and its fabrication. Before commencing the fabrication, tests were carried out on the skeletal steel and wire mesh samples and on trial mortar mixes to establish their properties for use in the design. For each project the various stages of fabrication took from two to three weeks followed by two weeks of curing.

After the completion of the field demonstration project each trainee was asked to prepare a project report which contains such information as to its relevance to the needs of Indonesia, the reasons for the choice of the material and the construction techique, detailed design calculations, and working drawings description of the various stages of fabrication, special difficulties encountered if any during the fabrication, estimate of the actual cost of fabrication including materials and labour and comparison of cost using alternative materials.

As part of the field demonstration, the trainees visited the Ferrocement Boat Construction Yard at Sriracha to see the actual construction of ferrocement fishing boats. The trainees were shown around the yard and the actual method of construction was explained.

During the course of the training program, an International Conference on Materials of Construction for Developing Countries was held at the Asian Institute of Technology, Bangkok. The Conference devoted several sessions for papers dealing with ferrocement and other low-cost construction materials. The trainees were all asked to attend the above Conference as delegates and were each supplied with a copy of the Proceedings.

Evaluation of the Trainees

The evaluation of the trainees was conducted in the form of a seminar lasting one to two hours for each of the trainee. The trainees were asked to present in details all aspects of the field demonstration project. Questions relating to their projects were asked as well as questions relating to ferrocement technology and applications in general.

CONCLUSIONS AND RECOMMENDATIONS

One of the major recommendations made in the feasibility study on the "Potential Applications of Ferrocement and Related Materials for Rural Indonesia" was that a training course in Ferrocement Technology should be organized at the Asian Institute of Technology for engineers from Indonesia. Following the acceptance of this recommendation by the USAID/ Indonesia, nine engineers chosen from different institutions and universities in Indonesia had undergone the training at AIT. The training lasted four months with the course consisting of lectures, laboratory experiments and field demonstration projects. The trainees were given instruction on the theoretical, experimental and constructional aspects of ferrocement technology. For the field demonstration project nine different applications which were in the areas of immediate concern to Indonesia, especially for rural development, were selected. The work undertaken for the field demonstration project was compiled by each of the trainee in the form of a Project Report and was presented in the seminar. The trainees had, in addition, visited a ferrocement boat building yard and also participated in the International Conference on Materials of Construction for Developing Countries, held at AIT.

Prior to the training program the majority of the trainees did not have much familiarity with the subject of ferrocement. Nevertheless, it was found that the knowledge gained during the training course enabled them to carry out the field demonstration projects with confidence. It is believed that they, in turn, would be able to train their fellow-enginners and technicians in their own country so that the benefits of this new technology are fully realized. With their well-balanced program, it is expected that they would act as effective agents for the transfer of this technology to Indonesia.

The evaluation of the trainees was based on their participation in discussions, during the lectures, the laboratory experiments that they had carried out, the field investigation project and the seminar itself. It was observed that some of the trainees lacked the ability to communicate effectively in English both orally and in writing. The training program, however, has enabled the trainees to work independently and to develop self-confidence. These are important facets that only a training program of this kind can instill to the participants which in turn will make them effective agents for the transfer of ferrocement technology to a wider group of people in Indonesia.

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APPENDIX A

Ferrocement Technology Training Program

PART I : THEORETICAL COMPONENT

1. Introduction
   (a) Definition of Ferrocement
   (b) Historical Background
2. Constituent Materials
   (a) Cement
   (b) Wire Mesh
   (c) Water
   (d) Additives
3. Construction Methods
   (a) General Procedures
      (i) mix proportion
      (ii) mixing
      (iii) plastering
      (iv) curing
   (b) Concrete Mix Design
      (i) characteristic strength
      (ii) water-cement ratio law
      (iii) slump
      (iv) maximum size of aggregate
      (v) concrete density
      (vi) grading of fine and coarse aggregate

4. Mechanical Properties
   (a) Uncracked Range- Tension and Compression
      (i) strength
      (ii) moduli of elasticity
      (iii) Poisson's ratio
   (b) Cracked Range-Tension and Compression
      (i) strength
      (ii) moduli of elasticity
      (iii) Poisson's ratio
   (c) Ultimate Condition-Tension and Compression
      (i) strength
   (d) Moment-Curvature Relations
      (i) uncracked range
      (ii) cracked range
      (iii) ultimate condition
   (e) Moment - Deflection Relations
      (i) uncracked range
      (ii) cracked range
      (iii) ultimate condition
   (f) Properties in Shear
   (g) Design of Ferrocement
   (h) Impact and Fatigue
   (i) Durability
   (j) Corrosion Resistance

5. Potential Applications
   (a) Boats
   (b) Water jars and tanks
   (c) Rice storage bins
   (d) Canal linings
   (e) Well casings
   (f) Roofing
   (g) Wall panels, etc.

6. Related Materials
   (a) Properties of composite with short steel fibers
   (b) Properties of coir-fiber boards
   (c) Properties of sugar cane baggase-cement composite
   (d) Properties of bamboo fiber-cement composite
   (e) Properties of rice hull-ash-lime mixture

7. Theory and Design Criteria of Plate and Shell Structures
   (a) Simplified basic theory of plates.
   (b) Design criteria of reinforced concrete plates, and common plate structures.
   (c) Design charts for plates subjected to uniform and hydrostatic loads [1]:
      (i) simply supported rectangular plates;
      (ii) rectangular plates with two opposite edges simply supported and the other edges clamped;
      (iii) rectangular plates with three edges simply supported and one edge built in;

(iv) rectangular plates with all edges built in;
(v) rectangular plates with one edge or two adjacent edges simply supported and other edges built in;
(vi) rectangular plates with two opposite edges simply supported, the third edge free, and the fourth edge built in or simply supported;
(vii) rectangular plates with three edges built in and the fourth edge free; and
(viii) rectangular plates with two opposite edges simply supported and other two edges free or supported elastically.

(d) Type of shells; shells of revolution, and shells of translation.
(e) Simplified membrane analysis of shells of revolution with intention to apply to concrete water tanks, shell roofs, rice bins, etc.
(f) Reinforced concrete shell roofs, and their design charts [2].
(g) Design of hyperbolic paraboloid shell roof.

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PART II: EXPERIMENTAL COMPONENT

1. Experiment on mix design
2. Compression test of concrete cylinders and cubes
3. Splitting test of concrete cylinders
4. Rupture test of concrete beams
5. Tension test of wire mesh
6. Tension test of skeletal steel
7. Tension test of ferrocement specimen
8. Compression test of ferrocement specimen
9. Cylindrical bending of ferrocement specimen
10. Anticlastic test of ferrocement plate

PART III: FIELD DEMONSTRATION PROJECTS

1. Canoe
2. Pipe Culvert
3. Cylindrical Water Tank
4. Sampan
5. Cylindrical Pontoon
6. Dome Shell Roof

7. Rectangular Pontoon for Pump House
8. Folded Plate Roofing Element
9. Septic Tank

PART IV: FIELD TRIP AND CONFERENCE

1. A field trip to see ferrocement boat construction at Sriracha.
2. Participation in International Conference on Materials of Construction for Developing Countries, August 22-24, 1978, Bangkok, Thailand.

APPENDIX B

Canoe

Investigator: John B. Manga
Advisors: Dr. V.P. Narayanaswamy and Prof. P. Karasudhi
Project Description:

Wooden dug-out canoes are one of the most common modes of transport of goods and people across rivers and streams in Indonesia. The wood for canoes are those which on an average take 20 to 30 years to grow. The wood used for typical dug-out canoe, if processed and exported, could fetch an income several times that of the cost of the canoe. The use of ferrocement for canoes could save much valuable timber which can be diverted to other uses. This project has been recommended in the feasibility report mentioned earlier [3].

The ferrocement canoe selected for fabrication under the project was of the type commonly used in the South Sulawesi region. It was 3.6 m. long, 0.8 m. wide and 0.6m. deep. It was designed to carry a total load of 800 kg. excluding its own weight. The main framework consisted of 10 mm. diameter mild steel bars along the top edge and along the longitudinal centre line. The skeletal reinforcement consisted of 6 mm. diameter mild steel bars in the transverse and longitudinal directions. The mesh reinforcement consisted of G.I. hexagonal wire mesh gauge 19 with a mesh size of 20 mm. with two layers on each side of the skeletal reinforcement. The thickness of the section was 20 mm. and the total weight of the canoe was 353 kg.

Fig. 1. Hauling the completed ferrocement canoe for launching.

After welding the framework in position, the skeletal bars were tied to it and the wire mesh was tied to the skeletal bars. Cement mortar with a cement/sand ratio of 1:1.75 and a water/cement ratio of 0.35 was mixed in a pan type mixer. The mortar was applied on the wire mesh from the outside first and then eventually on the inside. After the plastering was completed, the canoe was cured for two weeks with wet gunny bags and them painted with waterproof paint. The canoe was tested by floating it in a pond. The cost of the ferrocement canoe including materials and labour was B 2,400 (US. $ 120) which was slightly less than the estimated cost of a wooden canoe. The life of the ferrocement canoe is expected to be several times that of a wooden canoe.

Dome shell Roof

Investigator: M.S. Bandaro

Advisors: Dr. P. Nimityongskul and Prof. R.P. Pama

Project Description:

Indonesia, with its overwhelmingly muslim population has the need to build mosques in large numbers in the villages. Building of domes for these mosques using conventional materials such as clay tiles, teak-wood tiles, etc. is prohibitively expensive. Ferrocement is an ideal material for constructing dome shell roofs as the whole structure can be constructed monolithically without using formwork. Building ferrocement domes for mosques is an ideal way to popularize the material, as the mosque is a holy place of worship and a place where the community meets socially. This particular application has been recommended for investigation in the feasibility report.

Fig. 2. Model dome for a mosque in the finishing stage.

The dome selected for fabrication under the project was hemispherical in shape with a diameter of 2.5 m. It has been designed to carry the forces due to its own weight, wind load of 60 kg/m^2 and a live load of 100 kg/m^2. The stress resultants were determined using the membrane theory for thin shells. A shell thickness of 25 mm. was adopted. The skeletal reinforcement consisting of mild steel bars 6 mm. diameter were laid in the meridinal and circumferential directions. The meridinal bars were welded to a ring made of 20 mm, diameter pipe provided at the base of the dome and to a ring made of 6 mm. diameter mild steel bar provided near the apex. The bottom ring was stiffened by four struts connected to the top of the dome. Two layers of galvanized iron hexagonal wire mesh gauge 21 with a mesh size of

12 mm. were provided on each side of the skeletal reinforcement. The mortar with a cement/sand ratio of 1:1.75 and a water/cement ratio of 0.35 was applied on both sides of the dome and cured for two weeks with wet gunny bags.

Pipe Culvert

Investigator:: Iskandar
Advisors: Dr. V.P. Narayanaswamy and Prof. R.P. Pama
Project Description:

Culverts are provided for drainage of water across highways. These are normally constructed of reinforced concrete and are in the form or pipe or box sections. As they are required to carry heavy loads, the thickness of the section becomes very large resulting in heavy sections. Besides, the high cost of the materials and the cost of transportation over long distances make them uneconomical. On the other hand, if ferrocement is used for pipe culverts the sections could be made lighter, as the thickness required would be one-half of the former or even less. The pipe sections can be standardized, mass-produced under controlled conditions and transported to the site.

The pipe section selected was circular in cross secton with a diameter of 1 m. and a length of 1m. It was designed for loads corresponding to the ASTM class I pipe culverts. the pipe thickness selected was 54 mm. The pipe section was provided with tongues at either

Fig. 3. Plastering a ferrocement pipe element.

ends for making joints. The total weight of the pipe section was 470 kg. The skeletal reinforcement for the pipe consisted of an inner cage of 2 layers of 10 mm. diameter mild steel bars and an outer cage consisting of 2 layers of 6 mm. diameter mild steel bars, one layer laid in the longitudinal direction and the other in the circumferential direction. The mesh reinforcement consisted of G.I. hexagonal wire mesh gauge 19 with a mesh size of 20 mm. One layer was laid on each face. A wooden template was used for forming the tongue at the ends of the pipe section. The mortar had a cement/sand ratio of 1:1.75 and a water/cement ratio of 0.35.

After preparing the skeletal reinforcement, the wire mesh was tied to it. The distance between the outer and the inner cages was maintained by using a spacer. After the mortar had been applied, the pipe section was cured for two weeks with wet gunny bags. The total cost (materials and labour) of the pipe section worked out to B 1,008 (U.S. $50), which was about 70 percent less than the cost of reinforced concrete pipe.

Folded Plate Roofing Element

Investigator: A. Djausal
Advisors: Dr. P. Nimityongskul and Prof. P. Karasudhi
Project Description:

Like other developing countries, Indonesia is engaged in large scale construction of low-cost buildings for housing. The conventional roofing materials such as timber, tiles, thatch, etc. although cheap are not very durable and therefore the houses made of such materials do not have a long life. Besides, large scale use of timber leads to the cutting down of forests which is not desirable in Indonesia especially in Java. Ferrocement offers a better choice as roofing material in view of its high strength and durability, its ability to be moulded into efficient structural forms and the ready availability of constituent materials. Standardized roofing elements could be mass-produced under controlled conditions. The erection of the roofing elements can be done manually since the elements are light.

The roofing element investigated under this project was of the folded plate type. This shape is structurally very efficient and simpler to cast as it is made up of flat surfaces. Since the roof will comprise several identical elements, it is advantageous to use a mould for casting the

Fig. 4. Ferrocement folded plate roofing element being weighed.

unit. Besides, the use of a mould ensures better compaction and thickness control. The mould was constructed from plywood sheets stiffened with wooden strips and was in the form of a female mould. The reinforcement consisting of mild steel bars and wire mesh is laid out on the surface of the mould to the desired shape and mortar applied on to the exposed surface.

The element was in the form of a trough with a length of 5.0 m. It is 0.66 m. wide at the top and 0.164 m. deep. The skeletal reinforcement consisted at 6 mm. diameter mild steel bars in the longitudinal direction only. Distributed reinforcement consisted of galvanized iron hezagonal wire mesh gauge 19 with mesh size of 20 mm. Two layers of wire mesh were tied on each side of the skeletal reinforcement. The thickness of the element was 12 mm. and its weight was 160 kg. The cost of the element excluding the cost of the mould is about B 100 (U.S. $5) per sq.m. of covered area.

Rectangular Pontoon for Pump House

Investigator: Arifin Taher
Advisors: Dr. P. Nimityongskul and Prof, R.P. Pama
Project Description:

Rivers are a major source of water in Indonesia. For pumping water from rivers it is necessary to have a pump house, which could be fixed or of a floating type. Floating type pump houses have the advantage that the end of the inlet pipe is always submerged, irrespective of the level of water in the river. Such floating pump houses are at present made of steel in Indonesia. These pump houses, if made of ferrocement, would be cheaper and have a longer life. The fabrication of the pump house could be done nearer to the site and therefore the transportation is reduced to a minimum.

Fig. 5. Floatation test of a rectangular pontoon.

The ferrocement pontoon that was fabricated had overall dimensions of 1.20m. by 1.20 m. and 0.75 m. high. The inner chamber where the pumpset was proposed to be installed was 0.35 m. by 0.35 m. by 0.75 m. high. The average wall thickness was 25 mm. and therefore the total weight, excluding the pump set was 580 kg. and the depth of immersion was 0.40 m. Ribs were cast diagonally in the space between the outer and the inner chamber.

The reinforcement of the pontoon consisted of mild steel skeletal bars and galvanized iron hexagonal wire mesh. The edges were reinforced with 10 mm. size bars and between these 6 mm. diameter bars were provided in two orthogonal directions. The wire mesh was of 19 gauge with 20 mm. mesh size, two layers on each side of the skeletal reinforcement. The mortar used had a cement to sand ratio of 1:1.75 with a water cement ratio of 0.35. The mortar was applied and finished from the inside and outside. The finished pontoon was cured for two weeks with wet gunny bags and painted with waterproof paint. The pontoon was tested by floating it in a pond.

Cylindrical Water Tank

Investigator: M. Amin Hayat
Advisors: Dr. V.P. Narayanaswamy and Prof. R.P. Pama
Project Description:

Public buildings in Indonesia are normally provided with steel tanks for storing water. These tanks are expensive, require frequent painting and have limited life. The use of ferrocement for water tanks leads to reduction in overall cost, utilizes indigenous materials and labour and increases the life of the tanks. There is therefore considerable scope for large-scale production of small-capacity ferrocement tanks for use in urban and rural areas.

The water tank designed and fabricated for this project was cylindrical in shape, as this shape is the most efficient to resist the forces caused by the stored water. The tank was designed with a storage capacity of 2 cu.m. and had a diameter of 1.32 m. and a height of 1.5 m. A constant thickness of 25 mm. was provided for the wall, the base slab and the roof slab. The roof was provided with an opening 0.6 m. diameter and a ferrocement cover was also built.

Fig. 6. Completed ferrocement cylindrical water tank.

The skeletal reinforcement consisted of mild steel bars 10 mm. diameter for the base and 6 mm diameter for the wall, laid in orthogonal directions. The top slab was reinforced with 10 mm. diameter bar along the outer edge and 6 mm. diameter bars in the remaining portions. The mesh reinforcement consisted of G.I. hexagonal wire mesh gauge 19 with a mesh size of 20 mm. Two layers of wire mesh were tied on each side of the skeletal reinforcement. The mortar had a cement/sand ratio 1:1.75 with a water/cement ratio of 0.35.

After casting the base slab, the wall portion was cast from the bottom upwards. The roof slab was the last to be cast. The cover for the roof opening was cast separately. Special care was required to cast the junctions between the base and the wall and the roof and the wall. The mortar was applied from the inside and then from the outside and finished. The tank was cured for two weeks with wet gunny bags and painted with waterproof paint. The total cost of the tank (materials and labour) was estimated to be B 1,860 (U.S.$ 90). The costs of reinforced concrete and steel tanks of the same capacity were found to be several times higher.

Sampan

Investigator: Syarifuddin Harahap
Advisors: Dr. V.P. Narayanaswamy and Prof. P. Karasudhi
Project Description:

Indonesia has many islands and rivers and waterways are therefore a major means of transport for people and goods. Wooden sampans have been traditionally used in Indonesia for transport for centuries. The use of wood for sampans on a large scale leads to denudation of forests. Besides, the life of wooden sampans is very short as the wood deteriorates in water and is also attacked by marine organisms. Ferrocement can be used for building sampans to advantage, as it can be produced at comparable cost and has longer life. Ferrocement sampans have been built successfully on a large scale in the People's Republic of China.

Fig. 7. Ferrocement sampan under trial.

The ferrocement sampan built for the project had a length of 4.8 m., a width of 0.82 m. at the beam and a depth of 0.38 m. The hull thickness was about 25 mm. and the total weight was 200 kg. It was designed to carry a total load of 200 kg in addition to its own weight·

The framework for the sampan consisted if mild steel bars 10 mm. diameter along the top and bottom edges and for the transverse frames. The longitudinal reinforcement consisted of 6 mm. diameter bars. The mesh reinforcement consisted of G.I. hexagonal wire mesh gauge 19 with a mesh size of 20 mm. with two layers on each side of the skeletal reinforcement. The mortar had a cement/sand ratio of 1:1.75 and a water/cement ratio of 0.35 and was applied from both sides of the reinforcement cage. The finished sampan was cured for two weeks with wet gunny bags and painted with waterproof paint. The total cost of the sampan (material and labour) was B 2,225 (U.S. $ 110) compared to the cost of a wooden sampan of B 2,750 (U.S. $ 135). The life of a ferrocement sampan is espected to be at least two to three times that of a wooden sampan. The ferrocement sampan was tested by floating it in a pond.

Septic Tank

Investigator: B. Husin
Advisors: Dr. P. Nimityongskul and Prof. R.P. Pama
Project Description:

The rural areas of Indonesia, especially the Aceh province, lacks facilities for sewage disposal. It is well-known that the incidence of certain diseases such as cholera and typhoid is directly related to the pollution of drinking water due to the absence of scientific sewage disposal facilities. Fabrication and installation of septic tanks of steel or reinforced concrete is very expensive. Ferrocement can be used to advantage for septic tanks, as these can be prefabricated and installed underground. Their performance is superior to that of steel and reinforced concrete especially in the corrosive environment encountered.

Fig. 8. Reinforcement cage being prepared for a rectangular septic tank.

The septic tank fabricated for the project was designed for a family of five persons and had a capacity of 1.60 cu.m^3. It was rectangular in shape with a length of 1.20 m., breadth 1.20 m. and height 1.10 m. The wall thickness was 20 mm.

Cylindrical Pontoon

Investigator: Winarto
Advisors: Dr. V.P. Narayanasamy and Prof. P. Karasudhi
Project Description:

Pontoons are often used in Indonesia for crossing several rivers as it is not economical to build permanent bridges across those rivers. A pair of pontoons supporting a platform can be used to transport heavy goods such as trucks using the velocity of the stream for motive power. Such pontoons are at present made of steel which makes them very expensive, Wooden pontoons, though cheaper, have been found to be susceptible to attack by marine borers leading to frequent failures resulting in disruption of the traffic. Ferrocement is an ideal substitute for steel as it is cheaper and will last longer.

The ferrocement pontoon fabricated for the project was a cylinder 6 m. long and 0.9 m. diameter with conical ends. It was designed to carry a total load of 8000 kg. including its own weight, distributed uniformly over a number of points along its length. Circular diaphragms were provided at three intermediate sections to improve the stiffness of the pontoon. The thickness of the shell and the diaphragms was 25 mm. and the total weight of the pontoon 510 kg.

Fig. 9. Completed ferrocement cylindrical pontoon undergoing floatation test.

The skeletal reinforcement for the pontoon consisted of mild steel bars 6 mm. diameter laid in the longitudinal and circumferential directions of the shell and 8 mm. diameter for the diaphragms. The mesh reinforcement consisted of G.I. hexagonal wire mesh gauge 19 with a mesh size of 20 mm. Two layers of wire mesh were attached on each side of the skeletal steel. The mortar had a cement/sand ratio of 1:1.75 with a water/cement ratio of 0.35.

As the pontoon was a closed structure, it was necessary to leave a part of the top surface open so that the interior portion was accessible for plastering. After the mortar had been applied to both sides of the pontoon, a plywood sheet was laid across the opening, reinforcement was placed on it and the plastering done leaving the sheet in position. The finished pontoon was cured for two weeks and painted with waterproof paint.

The pontoon was tested by floating it in a pond. The total cost of the pontoon (materials and labour) was B 3,330 (U.S. $ 165).

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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 (rates mentioned elsewhere in this issue). Please quote the serial number of the list at the time of request.

This issue contains a list of references on Fiber Reinforced Composites for the first time. IFIC has decided to incorporate this field primarily because the engineering behaviour of Fiber Reinforced Composites are somewhat similar in nature to that of ferrocement. Earlier parts of the bibliography have been published in the past issues of the Journal.

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NEWS AND NOTES

IFIC NEWS

New Zealand Support

The New Zealand Ambassador to Thailand, Mr. Richard B. Taylor recently presented a grant of 2 million Baht (U.S. $ 100,000) as New Zealand's contribution to support the International Ferrocement Information Center (IFIC) and the scholarship programme.

Photograph below shows Ambassador Taylor (right) congratulating Mr. Theodore Varpiam (left) of Paua New Guinea who is one of the recipients of the New Zealand scholarship. Onlooking are Mr. V.S. Gopalaratnam, Senior Information Scientist (IFIC) and Mr. Rene Wilson (partially hidden), Second Secretary at the New Zealand Embassy.

Technical Specialist Joins IFIC

Mr. Prem Chandra Sharma, the Journal of Ferrocement Correspondent from India joined IFIC on a second two month stint. He has come under an Intermediate Technology Development Group (ITDG) sponsored project to write two more booklets in the Do it yourself series that IFIC has undertaken to publish. The first such booklet on Ferrocement Grain Storage Bin, readers will recall was published in May this year. Publication of the second booklet on Water Tanks has been kept in abeyance pending availibility of reviewers comments on the first booklet. This would enable IFIC to make such booklets more purposeful. The current booklets under draft are on Biogas Holders and Canoes. Mr. Sharma, a Scientist at the Structural Engineering Research Centre, Roorkee is expected to complete his task by November this year. These booklets will be available for sale around March 1980.

Special Issue Planned for July 1980

The Editorial Board has decided to devote the July 1980 issue (Volume 10, Number 3) entirely to the Marine Applications of Ferrocement. A separate brochure calling for papers and other contributions has already been widely circulated to prospective contributors. The Editorial Board believes this action would serve as a stimulant to boat-builders, the world over, at a time when interest in ferrocement boat-building seems to be wanning. IFIC is confident of a more than favourable response from boat-building enthusiasts, both commercial and the amateurs alike. If need be, IFIC will bring out two special issues (also October 1980) depending upon the quality and quantity of articles received. Write to the Editor requesting for more details on the Special

Issue, if you have for some reason not received your copy of the brochure (also refer to the Editorial in this issue).

INDONESIA

Feed-back from Ferrocement Technology Trainee

In May this year IFIC got its first feed-back from a trainee in the four month Ferrocement Technology Programme held at AIT last year. A summary report on the training submitted to the participating organization Development Technology Center (DTC) Bandung and the programme sponsors USAID, Indonesia is published elsewhere in this issue.

Mr. J.B. Manga, a participant wrote to inform us of his post-training activities in Indonesia. Working in South Salawesi under a development project for rural Tonrokkassi Jeneponto (Indonesia) conducted jointly by Hassanuddin University, DTC and USAID, Mr. Manga and his associates have successfully promoted the use of ferrocement for water tanks, septic tanks, well casings, canoes (similar to wooden dug-out types used locally) and a dome for a community mosque.

Photographs alongside show some of the strutures built by the group.

Mr. William H. Littlewood, Science and Technology Advisor, USAID, Indonesia who is primarily responsible for promoting the widespread use of this technology in Indonesia expresses great enthusiasm over progress made in the recent past. The team has also published an informative project report in May 1979 reviewing its activities. Copies of the report (in Bhasa Indonesia can be obtained on request from:

Prof. A. Amiruddin
Rektor, Universitas Hasanuddin
Ujung Pandang, Indonesia.

According to Mr. Littlewood, the Syiah Kuala University which also sent two engineers for the AIT training, has also been actively involved in another ferrocement project. A copy of their report on the Syiah Kuala University Ferrocement Project which contains details of the project description can be obtained from Mr. Littlewood of USAID, Indonesia.

Fig. 1. First canoe built at the Hassanuddin University "FERROHAS I UNHAS"

Fig. 2. Finishing a ferrocement septic tank in Tonrokkassi Jeneponto. Villager also participated actively in the construction.

Fig. 3. Canoe completed by Mr. Manga at Hussanuddin University after attending the training course at AIT.

Fig. 4. Cylindrical water tank for community in Tonrokkassi Jeneponto.

INTERNATIONAL MEETINGS

International convention on Concrete Ships and Floating Structures, Rotterdam. Holland, November 12-14, 1979

A major conference on "Concrete Ships and Floating Structures" will be held at the Hilton Hotel in Rotterdam, Holland. It is expected that the conference will cover all aspects of the topic and for the first time in Europe an entire session will be devoted to ferrocement structures.

IFIC will be presenting a paper entitled A Review of Marine Applications of Ferrocement in Asia" while another contribution from Ferrocement Marine Services of England will review recent developments in Africa and the Indian Ocean. Besides these two informative articles, it is expected that a few other contributions will make the session on ferrocement interesting. The conference is planned as a major event, and its proceedings will subsequently be published in full for the benefit of those who might not be able to attend.

The conference is being organised by Thomas Reed Publications Ltd., of 36 Cock Lane, London ECLA 9BY, who are already well-known in marine engineering circles for their highly successful series of conferences on tugs and on offshore crafts. For further information contact.

Mr. F.H. Turner,
Conference Organiser,
International Conference on Concrete Ships and Floating Structures,
3. Leyburn Close, Woodley,
Reading RG5 4PX, Berkshire, U.K.

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

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

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

Participants are invited to present papers within the scope of the Symposium as outlined a bove. Authors are asked to provide a summary not exceeding 300 words, accompained by such drawings and/or photographs as might be appropriate. The abstracts should sent be in two copies before October 15, 1979, to:

The Finnish Academy of Technical Sciences
The IASS-Symposium Committee
Lönnrotinkatu 37
00180 Helsinki 18
Finland

On the basis of abstracts submitted, the authors are requested to prepare, in three copies, final manuscripts not exceeding the 6000-word model in length and send them addressed as above before January 15, 1980. Instructions on the preparation of papers will be sent to authors so as to facilitate reprocuction and preprinting before the Symposium.

All abstracts and papers should be submited in English. For further information, contact:

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

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

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

CERILH,
23, rue de Cronstadt,
75015 Paris, France.

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

The Committee on Experimental Analysis and Instrumentation will sponsor a session at the ASCE Annual Convention, October 27-31, 1980 in Hollywood, Florida. The theme is "Experimental Wind Engineering on Structures". However, other outstanding papers ralated to special projects will also be considered.

Abstracts (apperoximate 500 words) should be sent to Prof. Leon R.L. Wang or Prof. James Colville (addresses mentioned along side) Deadline for receiving abstracts is October 1, 1979.

Prof. Leon R.L. Wang
Department of Civil Engineering
Rensselaer Polytechnic Institute
Troy, New York 12181
U.S.A.
Prof. James Colville
Department of Civil Engineering
University of Maryland
College Park, Md. 20742
U.S.A.

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

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

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

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

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

Further information can be obtained from:

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

Abstract

JFP18 FLEXURAL RIGIDITY OF FERROCEMENT

KEYWORDS: Cracking, Deflections, Flexural Rigidity, Flexure, Testing

ABSTRACT: Experimental deflection values of 28 ferrocement beams are compared with deflection values obtained using ACI and CEB Code formulae for prediction of short term deflections of reinforced concrete members in the working load range. The agreement between the experimental and code values is observed to be quite satisfactory. Thus ACI and CEB formulae seem to be quite suitable for prediction of effective flexural rigidity of ferrocement in cracked stage.

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

The Widening Applications of Ferrocement

DOUGLAS ALEXANDER
B.E., F.N.Z.I.E., M. (AUST) I.M.M., M.A.I.M.E.

This is a book published privately by an author of considerable experience in construction in Ferrocement in its earlier forms. This experience has crystallised in the development of an entirely new form of Ferrocement termed High Tensile Wire Reinforced Fibrous Ferrocement in which discrete layers of medium diameter (2 mm to 5 mm) high tensile wire supply the primary reinforcement whilst steel fibres provide the crack control normally associated with the high steel surface area in traditional Mesh Reinforced Ferrocement. The resulting material cannot only substantially exceed the strength of equivalent weight mild steel plate in flexure at substantially less cost, but also allows for the determination of its engineering properties in the same manner as orthodox reinforced concrete since it is but an extension of the same.

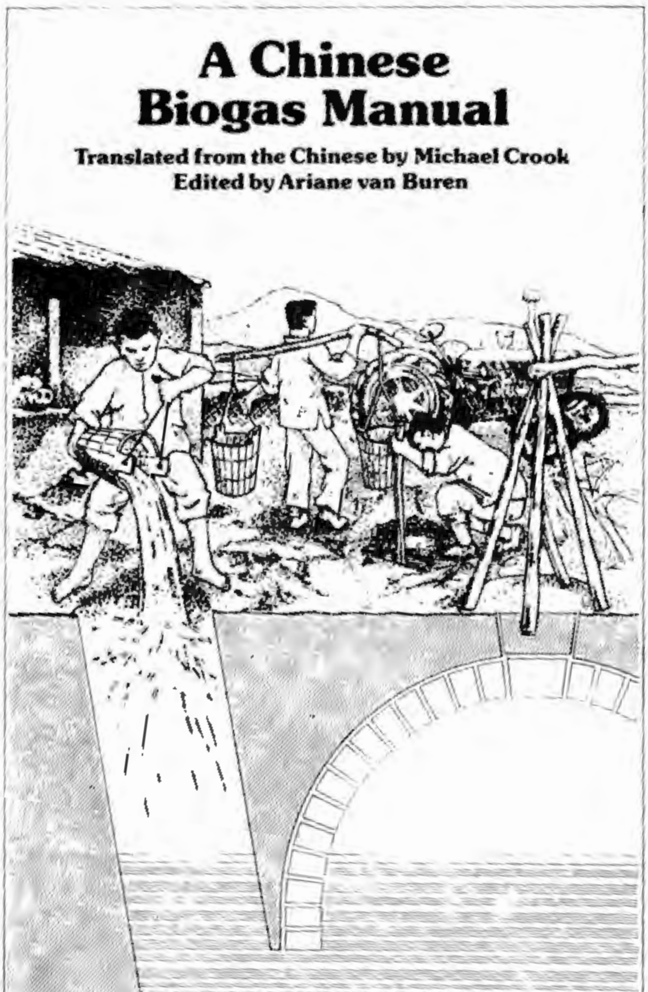
The book compares the properties of the newer fibrous form of Ferrocement with its progenitor, Mesh Reinforced Ferrocement, and collates technical aspects of the material from articles and papers previously published by the author in divers journals. The papers include, amongst others:

The Development of Fibrous Ferrocement;
Ferrocement in Relation to the Reinforced Concrete Code;
The Protection of Substrate Steel in Ferrocement Composites;

and are supplemented by photographs, sketches and drawings of barges, pontoon wharfs, tugs, fishing vessels, tanks, etc. which have been designed by the author's Consulting Practice and built in many countries. Some of these illustrate the detail of construction. This book can be ordered by remitting $22 (includes airmail potage) to: **D. Alexander, Box 28265, Remuera, Auckland 5, New Zealand.**

New From IT Publications

A Chinese Biogas Manual



Since the 1950's China has experimented with the production of biogas from agricultural wastes, a practice based upon an age-old Chinese tradition of composting human, animal and plant wastes to produce an organic fertilizer of high quality. The breakthrough came in 1978 when a process was developed to ferment the materials in an airtight and watertight container in order to produce methane gas. This was then collected for use as a fuel for motors, cooking and lighting.

The production of biogas, which is regarded in many countries as a by-product of an efficient system of waste disposal, has become in China a comprehensive, controlled method of recycling resources, supplying energy and fertilizer and improving rural health, as the digesting of wastes in a closed container kills many of the pathogens responsible for common human diseases.

There are already approximately seven million bigas pits in operation, with Sichuan (Szechuan) province leading the country in a movement to extend the practice throughout the countryside. This manual describes in detail how to build the pit, and covers a full range of designs to suit various soils from from sandstone to sheer rock.

To be published in May 1979 by Intermediate Technology Publications Limited, 9 King Street, London WC2E 8HN, U.K.
160 pp. Illustrated.
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ISBN 0 903031 65 5

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