RESEARCH CORPORATION OF THAILAND

RESEARCH PROGRAMME NO. 21
MATERIALS FOR CONCRETE

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ROOFING ELEMENT IN FERROCEMENT

REPORT NO. 2
FERROCEMENT ROOFING ELEMENT II

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JENS OVERGAARD
NARONG SUKAPADDHANADHI
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ASRCT, BANGKOK 1973
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FERROCEMENT ROOFING ELEMENT II

By Jens Overgaard* and Narong Sukapaddhanadhi*

SUMMARY

In extension of the previous test on ferrocement roofing, another element was made in the same mould but only 18 mm thick and without transverse reinforcement bars. The wire mesh reinforcement which is the most costly item of the material components was reduced to 3 layers only. This was done to reduce the cost of materials as well as labour inputs.

Due to the simplicity of the reinforcement it was not necessary to tie it together before placing in the mould. Mesh and longitudinal bars could be placed directly in the mould and they were only tied where the mesh was not flat enough to fit to the sides of the mould. Bars were held in place by stretching and fastening them at each end of the mould. In comparison with previous experience this technique proved considerably easier. Also the plastering was greatly facilitated by the more open reinforcement in this element. It took only one fifth of the time that was spent on plastering the previous element which was more heavily reinforced. This meant that the whole 7.30 x 1.20 m element could be plastered in one operation, thus avoiding cold joints. As in the previous test a vibrating trowel was used. This seems essential for a good compaction.

The element was exposed to a load test after 21 days curing under wet gunny bags, and it collapsed due to lacking stability of the sides at mid-span. The load at the critical load was equivalent to an evenly distributed pay-load of 360 kg/m^2 on a 7.00 m span. Related to the requirements of the building practice in Thailand of 50 kg/m^2 this means the factor of safty was 7.

INTRODUCTION

Report No. 1 in Research Project No. 21/17 describes problems in the making of and the results of testing a 7.30 x 1.20 m folded plate ferrocement roofing element. Due to a rather dense reinforcement, it was very labour consuming to prepare the reinforcement as well as to work the plaster into the reinforcement. The load test proved that the

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*Minerals and Metals Group, Technological Research Institute, ASRCT.

Sand

In order to obtain a good workability of the mortar at the low water/cement ratio needed, a sand with a fair amount of coarse grains was used. It's grain size distribution is shown in Table 1. This sand has fineness modulus which is higher than that of the sand used in the previous test (3.02).

Cement

Ordinary Portland cement (Type I) was used.

Additives

A commercial plasticizer was added for improved workability, and a metal oxide was added to improve the bond of the round bars.

Reinforcement

Two kinds of round bars were used. A nominal 6 mm for skeletal steel and a nominal 9 mm for stringers in the extreme tensile and compressive zones. The element also contained 3 layers of zinc coated hexagonal wire mesh, gauge 25 with ½" openings. The location of the reinforcement is shown on the section in Figure 2, and yield point, modulus of elasticity, and other characteristics are indicated in Table 2. The three layers of wire mesh were all oriented in the same direction as shown in Figure 3.

TABLE 1. GRAIN SIZE DISTRIBUTION OF SAND

Sieve opening (mm)	.125	.2	.5	1	2	4	8	Fineness modulus
Passing (%)	0	2	28	61	87	98	100	3.24

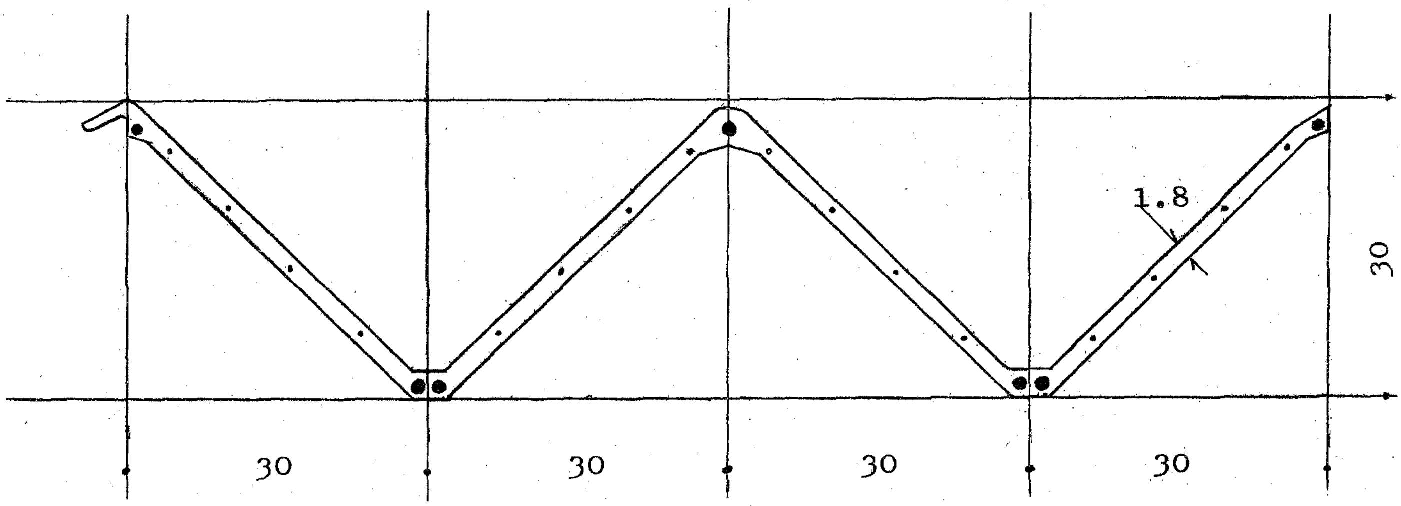
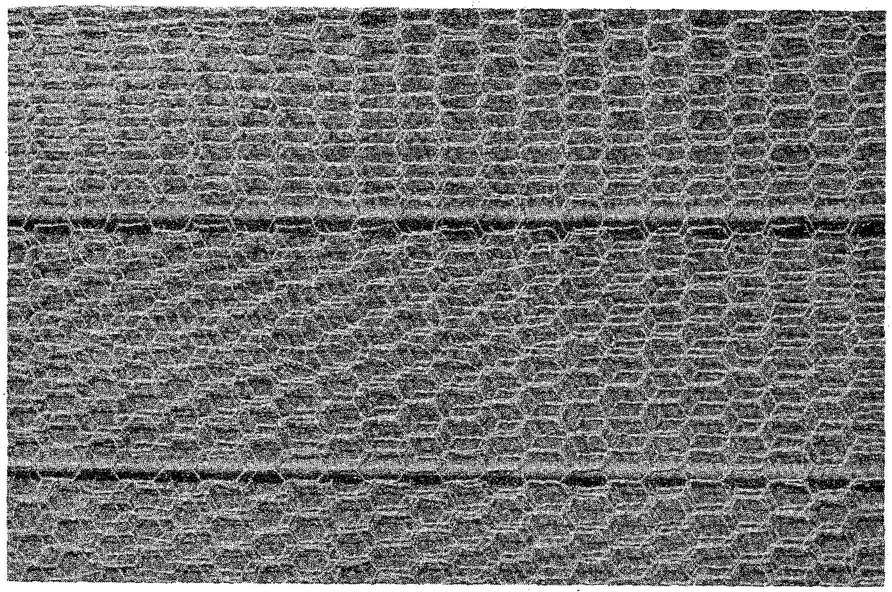


Figure 2. Section with location of reinforcement. (Measures are in cm.)

TABLE 2. DATA FOR REINFORCEMENT

Weight per m^2 wire mesh:	350 g/m^2
Zinc content:	310 g/kg
Steel content:	690 g/kg
Diameter of naked wire:	0.41 mm
Yield stress of wire:	4,270 kg/cm^2
Tensile strength of wire:	6,080 kg/cm^2
Modulus of elasticity of wire: E_t	89×10^4 kg/cm^2
Diameter of thin rods:	5.8 mm
Yield stress of thin rods:	3,800 kg/cm^2
Tensile strength of thin rods:	4,700 kg/cm^2
Diameter of thick rods:	8.6 mm
Yield stress of thick rods: no pronounced yield point	
Tensile strength of thick rods:	9,400 kg/cm^2
Modulus of elasticity of rods: E_s	= 210×10^4 kg/cm^2



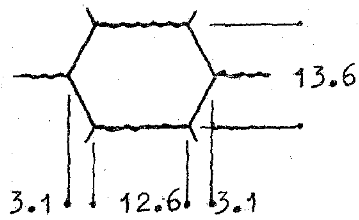


Figure 3. Orientation of wire mesh. (Measures are in mm.)

Mortar

As in previous ferrocement experiments at ASRCT a cement/sand ratio of 1:1.75 was used, and due to the sands slightly lower content of fines it was possible to obtain a mortar with good workability at a water/cement ratio of only 0.35. This gave a mortar with a compressive strength at 21 days of 652 kg/cm^2 as average. Individual results varied from 510–800 kg/cm^2.

Since earlier experience has shown that the concrete mixer available in the laboratory is unsuitable for this type of mortar, it was mixed by hand in a one by two metre mixing pan. Considering the results of the compressive strength test (5 cm cubes) this seems to be adequate.

The improved plasticity of the mortar resulted in a much better penetration into the mesh as compared with the previous test.

Design of element

The element was designed in the shape of a folded plate, see section in Figure 2. It had an effective width of 120 cm and a length of 732 cm. Each bay had 2 diaphragms located 60 cm from the ends of the elements. They serve to give the element rigidity and they are also used when lifting and handling the element. The long edges were shaped to form an overlapping joint.

Quantity and cost of materials

The results of effort to bring down the cost of reinforcement, by reducing the amount of mesh to half and the amount of rods by 27%, were to some extent offset by the rising steel prizes when compared directly to Table 4 in report No. 1 of this series. However, it was possible to bring down the materials cost by 20% to about 100 baht/m or about 83 baht/m^2. This compares to the materials cost of an asbestos-cement roof on wooden trusses, without gutters or ceiling and spanning no more than 6 metres. On longer spans the ferrocement roof is the most economical.

TABLE 3. QUANTITIES AND MATERIALS COST IN BAHT/METRE*
(Note that the element is 1.20 m wide)

3 layers of mesh, 5 m^2,	1.75 kg	26 baht
ø 6 mm rods, 15 m,	3.30 kg	23 baht
ø 9 mm rods, 7 m,	3.50 kg	21 baht
Subtotal	8.55 kg	70 baht
Cement	22 kg	12 baht
Sand	39 kg	2 baht
Water and additives etc.	8 kg	1 baht
Subtotal		15 baht
Formwork, formoil etc.		15 baht
	Total	100 baht

*Prices refer to October 1973.

Labour input

At the laboratory scale and with people who were familiar with the work from an earlier test the entire labour input did not exceed 7 man-hours per metre. However on a commercial scale this figure can be reduced considerably depending on the degree of mechanization.

Load test

The element was cured under wet gunny bags for 21 days, after which it was transferred to two concrete supports placed 7 m apart. The side which had been facing the mould was given a lime-wash in order to facilitate the detection of cracks during the load test. However this proved futile. Although the formation of cracks was audible, it was not possible to locate any cracks by the naked eye due to their small width.

Load was applied by sand bags placed symmetrically around the middle of the element and corresponding deflexion at mid-span was measured to nearest 10 micrometres.

RESULTS AND DISCUSSION

At the initial stage of the test the deflexion followed the load in a linear relationship where $EI = 9.5 \times 10^9$ kg.cm^2 (E being modulus of elasticity of the composite and I the moment of inertia of the uncracked section). When a bending moment of about 800 kg.m was reached, cracking was clearly audible. By the formation of cracks the forces in the section were redistributed and the deflexion now followed the load in a linear relationship where $EI = 3.0 \times 10^9$ kg.cm^2 (see Figure 4).

This continued until the element collapsed at a bending moment of 2,680 kg.m which, with analogy to a simple supported beam, is equivalent to an evenly distributed live load of 360 kg/m^2. Failure was due to the result of lacking stability of the two free sides which both collapsed suddenly (Figure 5). Under conditions in which the element would be used, this would not happen as the sides would be supported by neighbouring elements. It could also have been delayed by placing a diaphragm at mid-span.

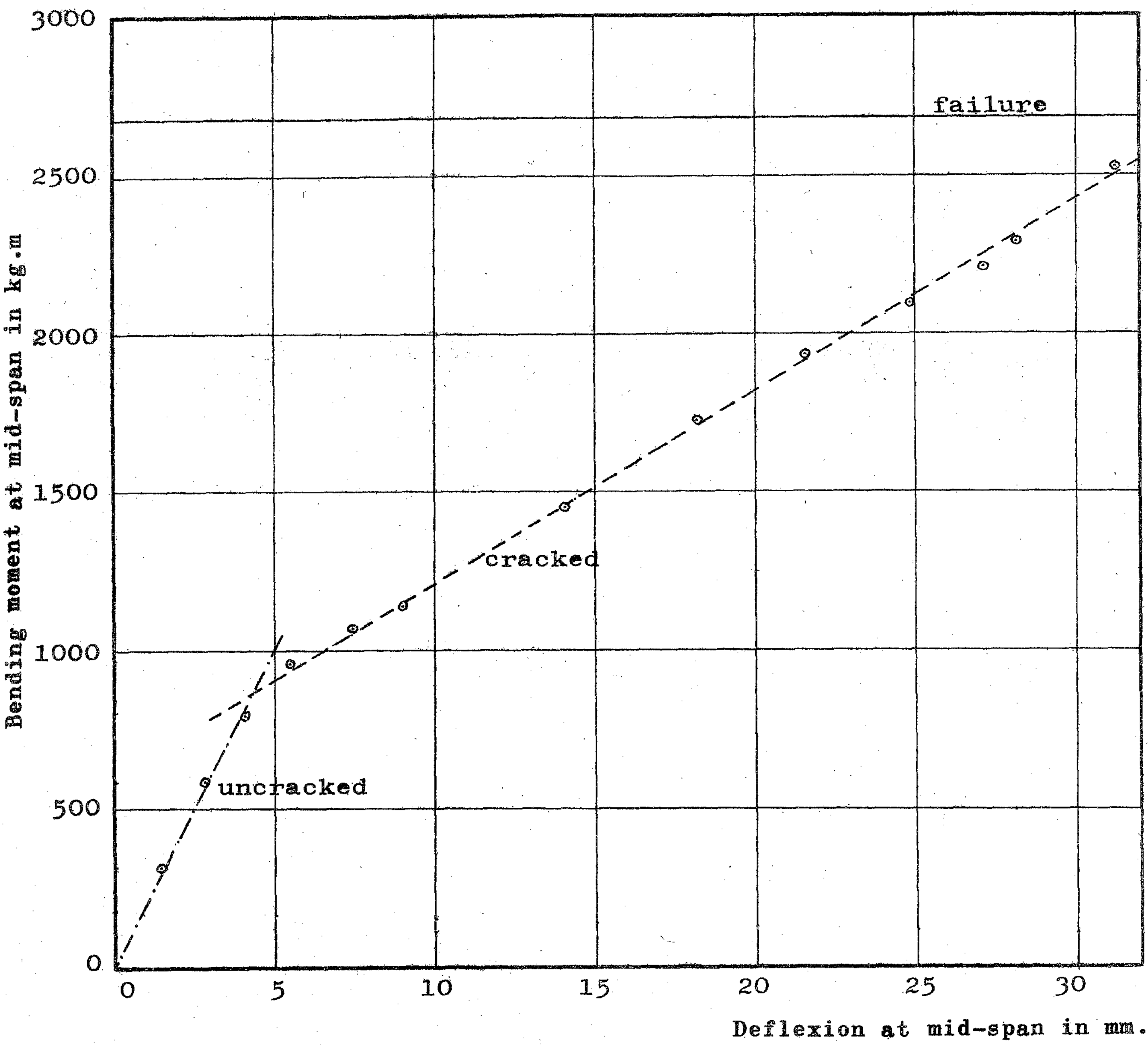


Figure 4. Deflexion at mid-span in relation to the bending moment resulting from the live load only.

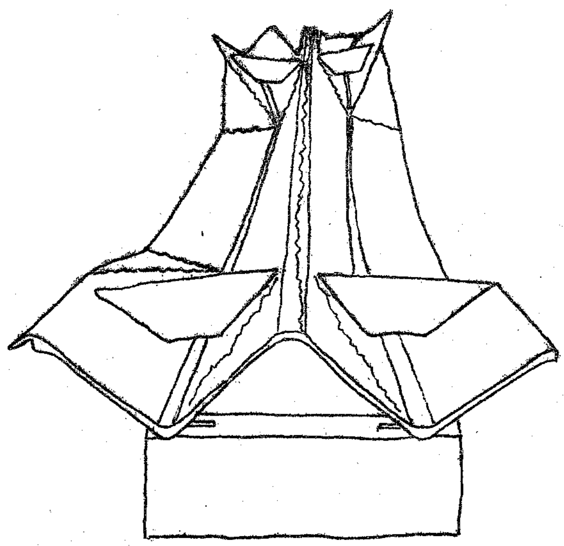


Figure 5. Sketch of the element after collapse.

The modulus of elasticity of the composite can be assumed equivalent to that of the mortar alone, $Em = 30 \times 10^4$ kg/cm^2, since the volume fraction of the mesh is as low as 0.006. The moment of inertia I for the section <u>in the uncracked range</u> is 3×10^4 cm^4. This includes the rods and the mesh. Rods are converted into effective mortar area at a rate of $\frac{E_s}{E_m} = \frac{210 \times 10^4}{30 \times 10^4} = 7$ and mesh is converted at a rate of $\frac{E_f}{E_m} = \frac{89 \times 10^4}{30 \times 10^4} = 3$. <u>In the cracked range</u> the neutral axis moves towards the compressed zone. This leads to a reduced I of about 1.1×10^4 cm^4 and at this stage the compressive stress of the mortar has reached a level where E_m should not be considered higher than 27×10^4 kg/cm^2. The bending moment resulting from the element's own weight is at midspan 465 kg.m. It is now possible to calculate the stresses at the extreme fibres.

The maximum stress in the mortar at first crack:

$$\sigma m = \pm \frac{(M_g + M_p)\ h/2}{I} = \pm \frac{(465 + 800)\ 10^2 \times 15}{3 \times 10^4} = \pm 63\ kg/cm^2$$

The maximum stress in the mortar, σ m and the maximum stress in the reinforcing rods, σ s at the point of failure:

$$\sigma m = \frac{-(M_g + M_p)\ h_c}{I} = \frac{-(465 + 2,680)\ 10^2 \times 8}{1.1 \times 10^4} = -230\ kg/cm^2$$

$$\sigma s = \frac{(M_g + M_p)\ h_t\ E_s}{I.E_m} = \frac{(465 + 2,680)\ 10^2 \times 20 \times 210 \times 10^4}{1.1 \times 10^4 \times 27 \times 10^4} =$$

$$= 4,450\ kg/cm^2$$

These stresses are high, and it shows that even if the sides had not collapsed the loadbearing capacity was almost exhausted anyway.

Considering two thirds of the ultimate bending moment as a reasonable design criteria and safety coefficients of 1.0 and 1.5 for dead load and live load respectively, it is possible to determine the maximum span at which this type of roofing element would carry 50 kg/m^2, which is the required live load for roofs in Thailand.

The dead load being 76 kg/m^2 we have

$$\text{Span} = \sqrt{\frac{2 \times 2,680 \times 8}{3\ (50 \times 1.2 \times 1.5 + 76)}} = 9.25\ m$$

The deflexion at this span due to live load only will be one centimetre or less than 1/900 x span. However the deflexion due to total load over a period would be about 3.5 cm.

CONCLUSION

The folded plate design is very suitable for roofing purposes. Its geometry is simple and it is aesthetically satisfying. As there is no double curvature, formwork is easy to manufacture.

Due to the thin sections obtainable in ferrocement, the weight of even quite large elements can be kept at a level where simple lifting equipment will suffice. Light weight is an important factor in areas where foundations require piling.

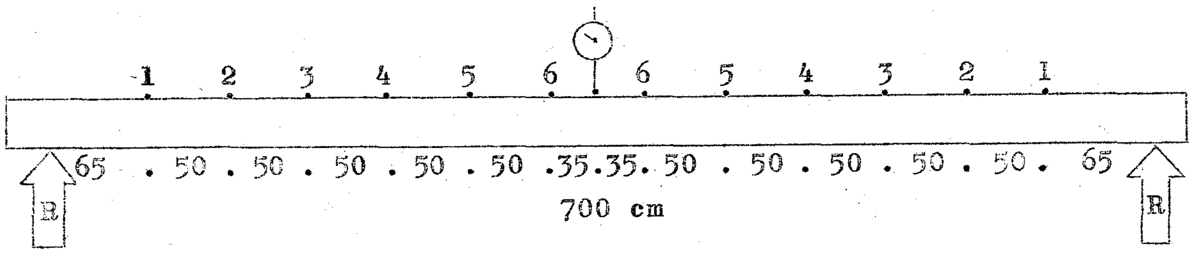
The design makes arrangement of a flat ceiling simple and it provides a ventilated space between ceiling and roof which is desirable in warm climates.

The material is very durable and resistant to the attack of rot, fungus, termites and other pests.

In all, the roofing element has qualities that make it applicable for low cost housing in warm climates.

APPENDIX

LOAD, BENDING MOMENT, AND DEFLEXION RECORDED DURING LOAD TEST



Reaction R at support (kg)	Load in kg at various positions						Bending moment at mid-span (kg.m)	Deflexion at mid-span (mm)
	1	2	3	4	5	6		
100						100	315	1.46
200					100	100	580	2.83
300				100	100	100	795	4.10
400			100	100	100	100	960	5.45
500		100	100	100	100	100	1075	7.44
600	100	100	100	100	100	100	1140	9.00
700	100	100	100	100	100	200	1455	14.03
800	100	100	100	100	200	200	1720	18.20
900	100	100	100	200	200	200	1935	21.55
1000	100	100	200	200	200	200	2100	24.85
1100	100	200	200	200	200	200	2215	27.17
1200	200	200	200	200	200	200	2280	28.15
1200	100	200	200	200	200	300	2530	31.29
1200	100	100	200	200	300	300	2680	FAIL