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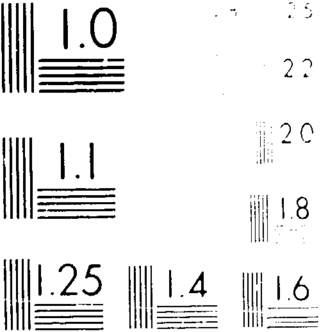
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ID/WG.347/23
29 October 1981

ENGLISH

United Nations Industrial Development Organization

Workshop on Cement and Concrete Products

Brisbane, Australia, 18 - 29 May 1981

FERRO-CEMENT - APPLICATIONS - TECHNOLOGY*

by

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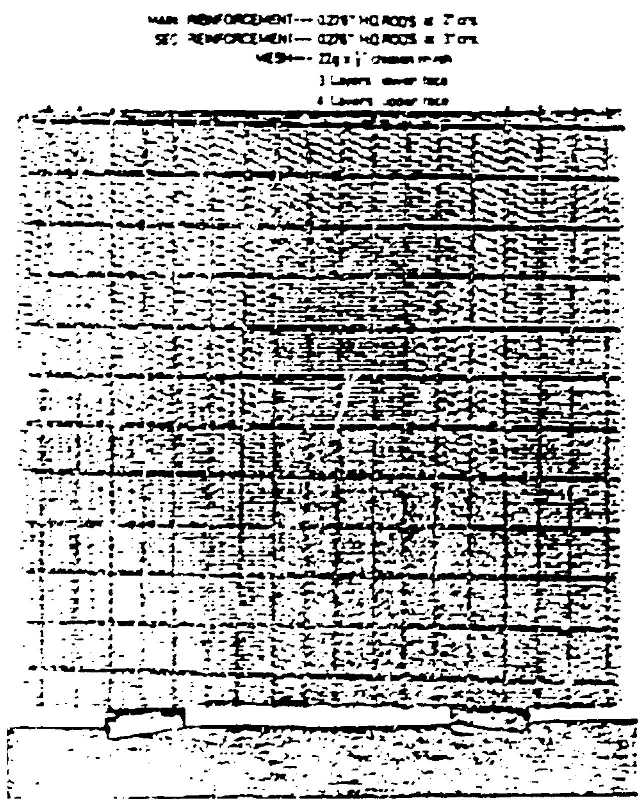
TABLE OF CONTENTS

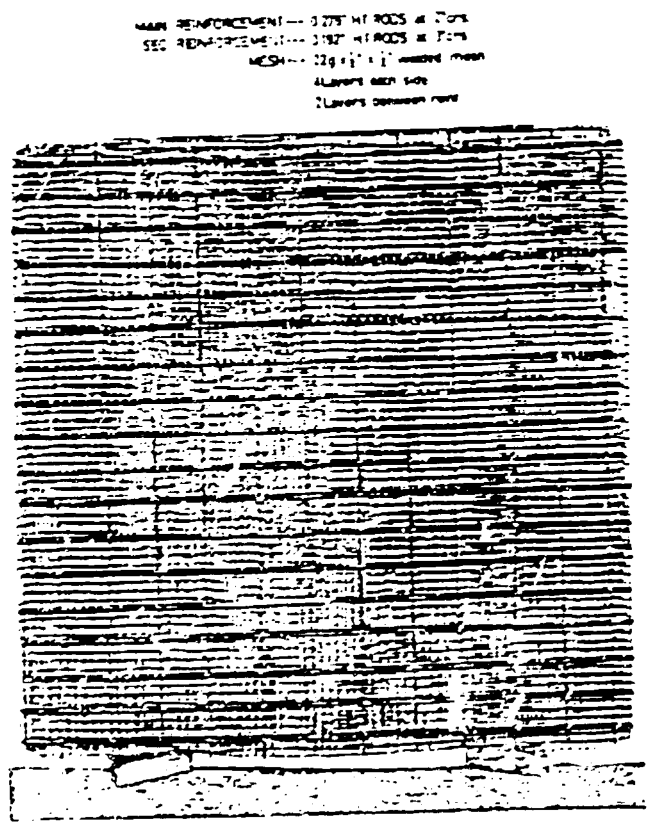
INTRODUCTION

Ferro-cement is the name that has been given to a type of reinforced concrete construction, and is a direct translation of 'ferro-cemento' used by Dr. Nervi about 40 years ago to describe the material.

Ferro-cement consists of a number of layers of fine steel mesh, that may have a sandwich of larger diameter steel bars between them, impregnated with a cement rich mortar. The mesh sizes range from 16g to 22g welded wire fabric or netting, and the steel bars from 4.5mm (3.16") to 8.0mm (5.16"). Typical rod and mesh arrangements are shown in Figure 1.



(a) Rods with 'chichen' mesh



(b) Rods with 22g welded wire fabric

Such construction is characterised by several features that distinguish it from normal reinforced concrete:-

(1) The steel is of small diameter (particularly the mesh), and is more or less evenly distributed throughout the matrix of mortar.

(2) The aggregate size is small with particles retained on 3mm (No. 7) sieve or larger excluded.

(3) The cover to the steel is kept to a minimum [being 1.5mm (1/16") to 3.0mm (1/8") maximum].

(4) The mortar is cement rich with a low water cement ratio. A pozzolana may be added to react with free lime present in the mortar in an attempt to improve the durability.

The resulting mortar-steel matrix has several interesting properties, although there is some doubt that it is synergistic in character as was first reported in the literature. The reduction of the area of mortar in relation to the steel area (particularly of unreinforced to reinforced area), means that the shrinkage forces must be considerably less than for normal reinforced concrete. Again, there are not large areas of plain concrete in which tension cracks can form and then propogate. It appears too, that concrete in tension adjacent to the finely divided mesh may be able to suffer larger tension strain than is normal for plain concrete with out cracking.

The Figure 2 shows a tee beam with a 12.5mm (½") rod in the tension zone, surrounded with 2 layers of welded wire fabric (1 layer 16g, 1 layer 22g). The beam was subjected to its ultimate load, and even at this load, no visible cracks appeared, nor was there any bond failure Because of the proximity of the tension steel to the free edge.

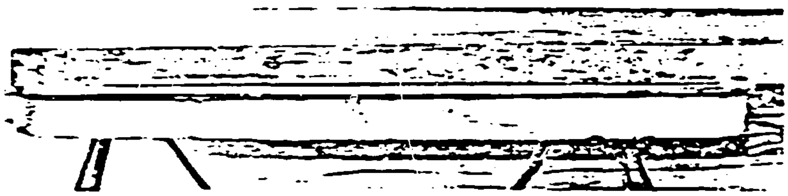


FIGURE 2 Ferro-cement beam loaded to ultimate

Photographs of typical slab flexure and ultimate failure are shown in Figures 3, 4 and 5.

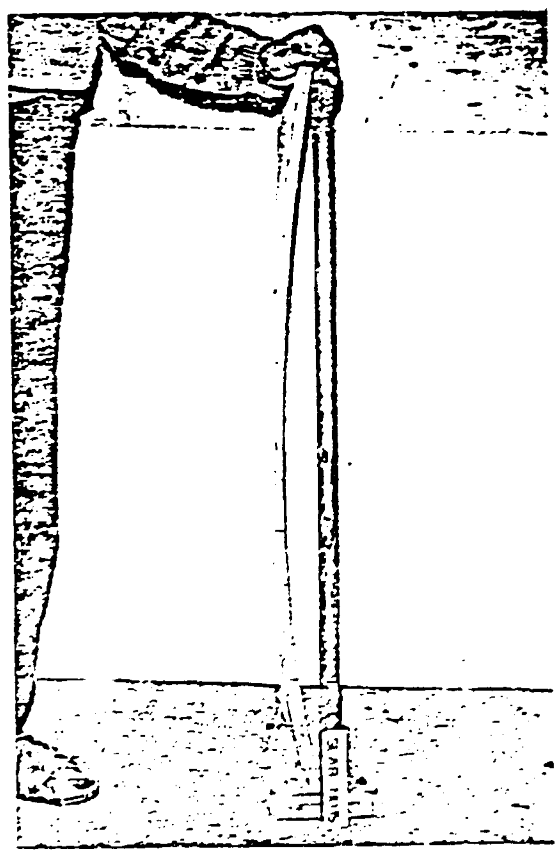


FIGURE 3 Slab cross-section after failure

FIGURE 4 Underside of slab reinforced with 'chicken' mesh and M.S. rods after failure.

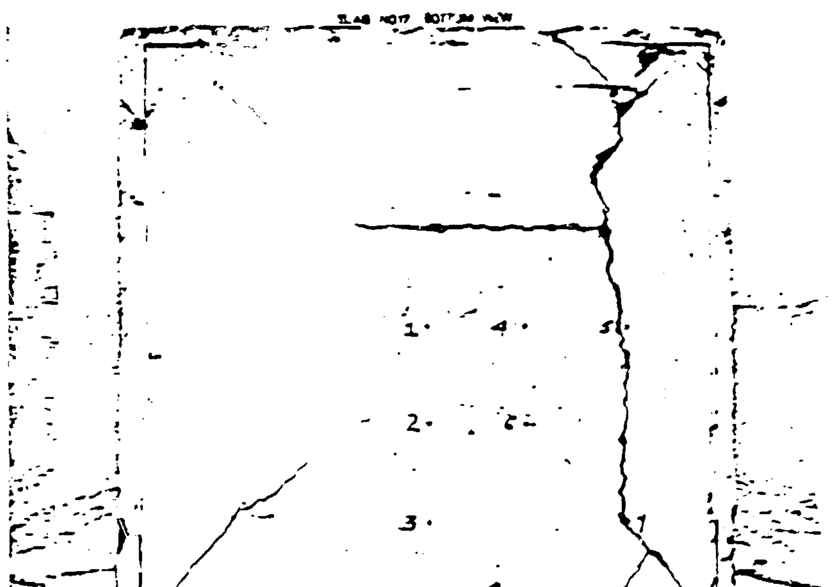
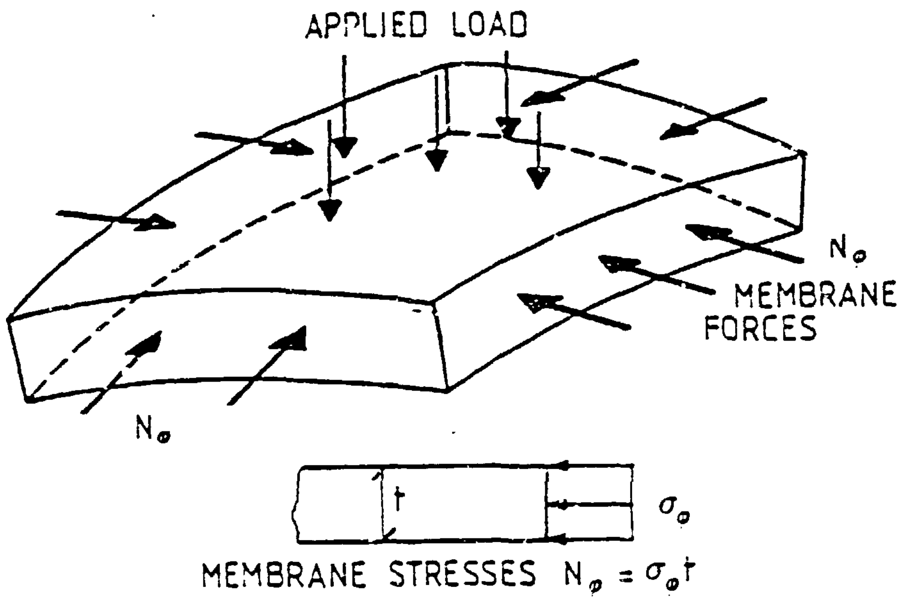
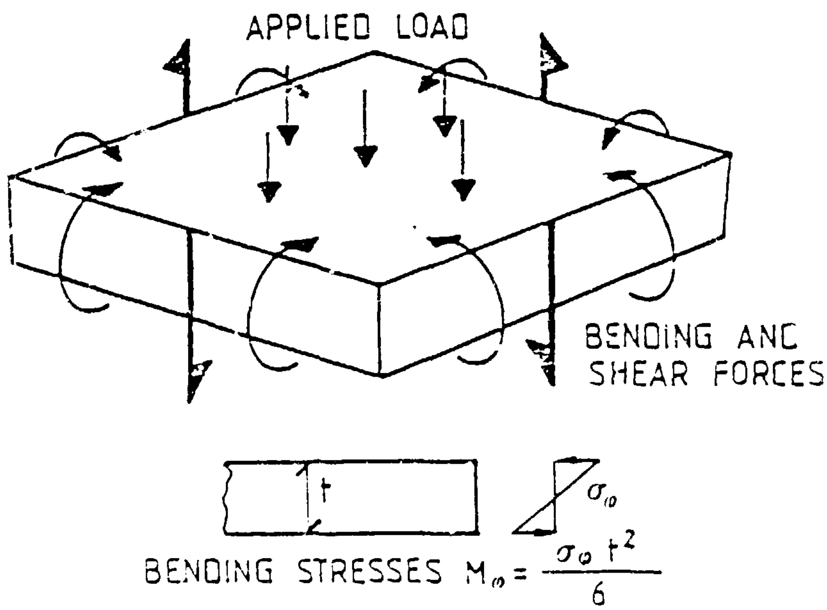


FIGURE 5 Underside of slab reinforced with 22g. welded wire fabric and M.S. rods after failure.

There are, in addition, structural advantages that help to produce a more economic use of material when form is used to express force path. Thus, when ferro-cement is used in shell shapes, much of the load can be carried by membrane action rather then bending action, hence minimizing cracking. The comparison between membrane and bending action is shown in Figure 6 (a) and (b).



(a) SHELL ACTION



(b) PLATE ACTION

It is seen in Figure 6(a), that the whole cross-section strength is utilized whereas in 6(b), the maximum stress is twice the maximum. Examples of shell shapes are shown in Figure 7 and 8.

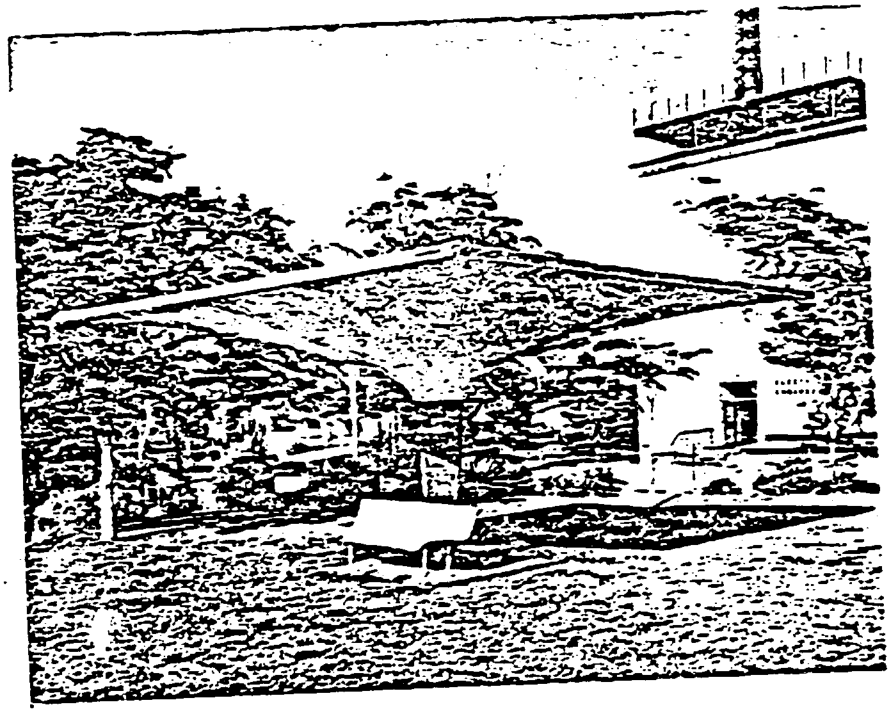


FIGURE 7 Hyperbolic Paraboloid ferro-cement shell (12.5) ½" thickness.

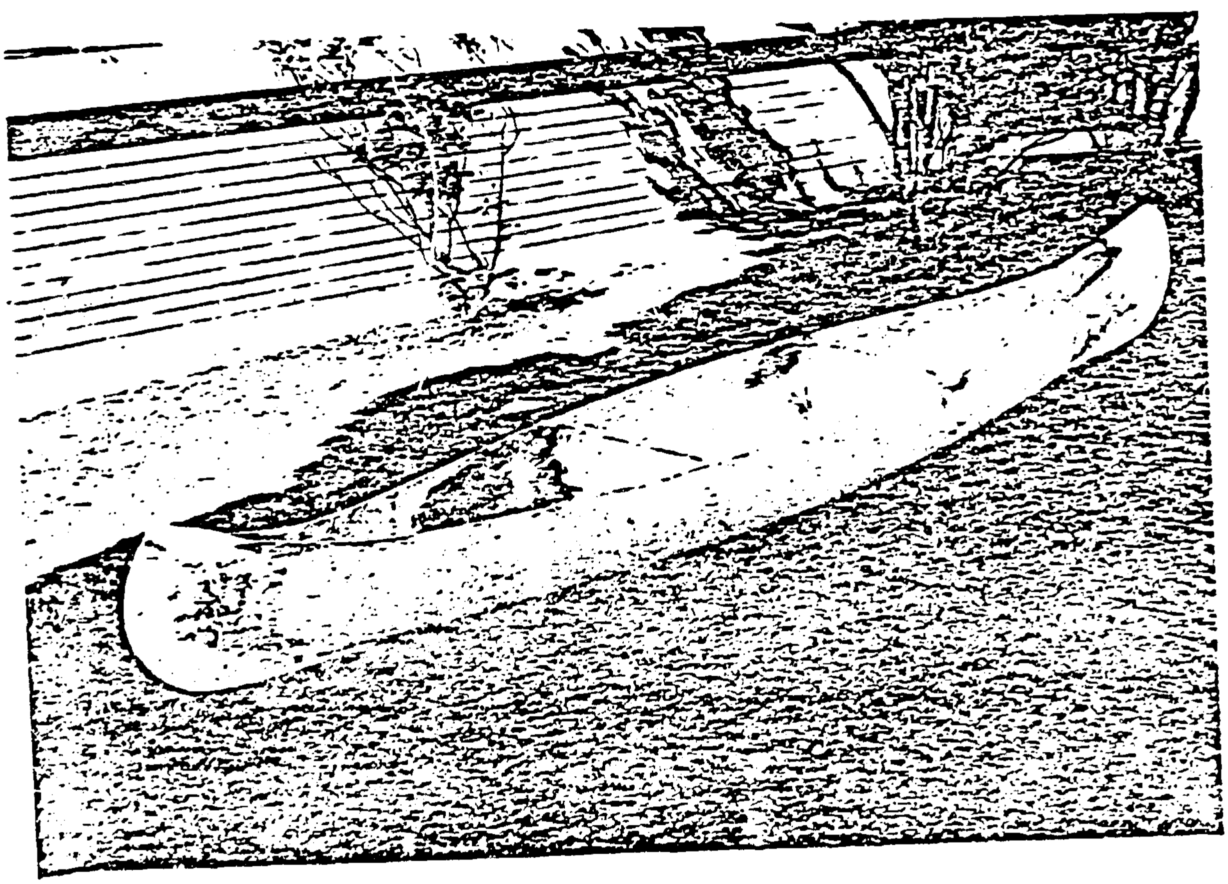


FIGURE 8 Ferro-cement canoe. Wall thickness 4.5mm (3/16")

Surprisingly, these membrane stresses will develop in thin, simply supported plates once deflections exceed 1/10th of the slab thickness. Evidence of these membrane tensions is shown in Figure 9. In Figure 9, the slab, with reinforcing steel in one direction only plus chicken mesh, has been split into two by membrane tensions. In properly reinforced slabs these membrane tensions allow the steel reinforcement to mobilize its full capacity and very high loads may be sustained.

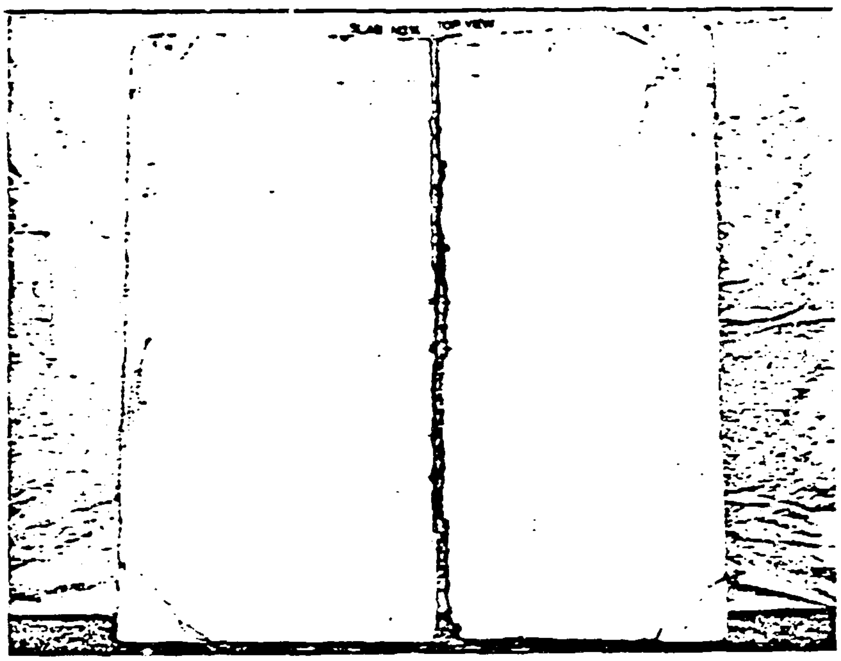


FIGURE 9 Slab split in two by membrane action

It must be mentioned at the outset, that ferro-cement is a relatively low strength structural material. A comparison of various material strengths and properties is given in Table I. The ferro-cement strength is based on 7 layers of 12.5 x 12.5 x 22g welded wire fabric plus one layer of 6.5mm steel rods at 50mm centres. A heavier mesh will improve the figures for ferro-cement.

	Mild steel	Aluminium alloy	Spruce	Hardwood	Glass Fibre Cloth	Glass Fibre Matt	Ferro Cement
U.T.S.	450	245	68	136	306	48	41
U.C.S.	450	245	54	68	-	-	41-68
S.G.	7.86	2.7	0.51	0.88	1.72	1.6	2.6
$\frac{U.T.S.}{S.G.}$	57	91	133	155	178	30	16

Strength in MPa

TABLE I

The other basic ingredient of ferro-cement is the cement mortar. This must satisfy the two conflicting requirements of,

(1) Workability in the placing phase

(2) Strength and durability in the hardened phase.

Because durability is of such importance, (particularly for marine applications), it is necessary to keep the water cement ratio below 0.4. This is consistent with concrete cylinder strengths in the range 50-70 MPa depending on the cement used. Because of the tight packing of the mesh, a fine sand < 3mm should be used, and to achieve the required workability, sand/cement ratio of about (1.8 - 2.0) is necessary. Approximately 10% of cement by weight can be replaced by a pozzolana such as fly ash, to help improve durability and entrainment, is quoted as being beneficial both for workability and durability.

One of the real difficulties that ferro-cement construction suffers is in the placing of the mortar because of the inherent tendency to trap air voids in the mesh. Great care must be taken at the plastering stage. Application must be from one side only, with finishing on the other side only when complete penetration has been achieved. Plastering against forms is to be avoided because air voids will always be trapped against the mesh.

Historical sketch

Ferro-cement was used from the very inception of the manufacture of Portland cement in small boat construction, and has been in and out of vogue ever since. The very beginnings can be attributed to Joseph Lambot who constructed a number of boats at Brignoles in France in about 1848-49. Lambot's boat were 3.6 metres long with 1.35 metre beam and hull thickness of 30 to 40mm. It will be seen that Lambot's boats were quite heavy and today's construction materials and techniques allow for a much thinner hull. Boats built nearly 100 years ago are still in good condition. The first part of the 20th century saw the building of many concrete boats and incidently, a tremendous expansion in the production of cement. An early pioneer was N.K. Fougner of Norway, and, in 1917 he built an 84ft boat, followed by two larger vessels. His work brought him recognition in the United States and he addressed the U.S. Shipping Board, who, in April 1918, published a "Special Report on the Advisability of Constructing Concrete Ships". Approximately a dozen vessels were built of more conventional reinforced concrete design. Presumably they were unsuccessful because the work was not continued.

One vessel built by the United States government in this period attracts attention. The boat, named "Concrete", was 18ft long with a hull thickness of 3/4". It was used by the U.S. Naval Reserves on the Great Lakes and had a cruising speed of 10 knots. Apparently, concrete barges were being built in China prior to the second world war but few details are available. Today, China has a considerable construction industry in manufacture of ferro-cement sampans. The modern phase of concrete boat building and the general use of ferro-cement most definitely has its origins in the work of Dr. Pier Luigi Nervi. Nervi built several notable structures and boats of ferro-cement.

Soon after the second world war, Nervi's company, built on their own account a 165 ton motor sailer 'Irene'. The hull of Irene is (1.4 inches) thick and consists of 3 layers of 6.4 (¼") steel bars at 100mm (4") spacing and 8 layers of mesh, 4 on either side. The mesh and bars were tied together and the whole plastered with a mixture of pozzolanic cement and sand (1.0 to 1.6).

Nervi's pioneering work appears to have passed almost unnoticed to the engineering profession. It was the roll of the amateur boat builders in New Zealand to rekindle the enthusiasm for his ideas. From there, they have spread world wide and gradually a technology of ferro-cement is emerging.

The 1970's have seen the vindication of Dr. Nervi's vision with now world wide interest in ferro-cement, particularly for fishing boat construction in developing countries. The Food and Agriculture Department of the United Nations has shown interest in ferro-cement construction of fishing vessels and several projects were started in Asia. In 1972, F.A.O. sponsored an International Seminar on the Design and Construction of Ferro-Cement Fishing Vessels in Wellington, New Zealand. Technical articles by selected authorities on various subjects were presented and formed the basis of an exchange of knowledge on ferro-cement boat design and construction.

In 1972, the N.A.S. of the United States of America set up an Ad-Hoc panel on the utilization of ferro-cement in developing countries under the chairmanship of Prof. J.P. Romuldi of Carnegie-Mellon University. The panel concentrated on three specific tasks

(1) Evaluating the current state of art on ferro-cement as an engineering material in order to identify its known properties.

(2) Evaluating the principal areas of applications on both land and water.

(3) Developing specific recommendations for promoting the use of ferro-cement in a logical effective manner.

The report was published in 1973 and identified ferro-cement as an overlooked appropriate technology material with wide potential applications. In October 1976, an International Ferro-cement Information Centre was established at the Asian Institute of Technology (address P.O. Box 2754, Bangkok, Thailand) with the support of the International Development Research Centre of Canada, The United States Agency for Government of New Zealand. The I.F.I.C. publishes quarterly the Journal of Ferro-cement and is now the main source of information as far as ferro-cement design and construction is concerned.

In early 1977, the American Concrete Institute set up a committee, No. 549, on ferro-cement to review the present state of the art and presumably to formulate a code of practice for the material. It is surprising that the engineering fraternity has been so late on the scene.

Potential for Development of Ferro-Cement

The purpose of this paper so far has been to introduce the reader to ferro-cement as a viable construction technique. Some of its deficiencies have been pointed out already, namely, its relatively low strength and the need for careful compaction of the concrete around the mesh. There is one further drawback to its use, particularly in countries with high labour costs and this is the labour content in tying the mesh. For satisfactory fairness of shape and tightness of the mesh, ties must be used on an approximately 100 x 100mm grid. Since each tie must be tightened and tacked in behind the mesh, the work involved is time consuming. This does not necessarily exclude the use of ferro-cement but it does mean that either (a) an efficient method of tying must be developed or (b) some way of overcoming the problem must be found. One of the themes of this talk is to explore this second possibility.

At the present time, the major development of ferro-cement has been in boat construction. As the cost of the petro-chemical based polyesther and epoxy resins rise, the cost benefit on materials is in favour of ferro-cement. If labour costs can be hidden or absorbed in some way (as they are for the amateur builder) then ferro-cement provides an extremely versetile construction material. Free-form structures can be built with ease once a skeleton frame work of pipes or truss-beams has been accurately constructed. The mesh and reinforcing rods can be tied in position by unskilled labour and the resulting surface made remarkably fair. With careful supervision, the same is true for the plastering operation which requires a team of unskilled labourers to push the mortar through the mesh and one or two skilled plasterers for the finishing operation.

At the present time, there would be nearly 1,000 ferro-cement boats from (10 to 20 metres in length) under construction in Australia. Nearly all of these are amateur built and unfortunately, this is reflected in many unattractive and poorly finished vessels that may be seen in nearly any harbour along the coast. Among the boat builders, there has been unfound belief that ferro-cement is a 'wonder' material. The result has been some failures of boats in service. For example, no one would think of constructing a timber work boat without adequate fender strips. Since ferro-cement is relatively weak in impact, the same is true for this material. Similarly, bilges should be protected with either internal or external stringers.

For developing countries, particularly those of South East Asia, ferro-cement provides an attractive alternative to other forms of small boat construction. The advantages are:-

(1) low first cost in materials

(2) low maintenance and complete immunity to teredo attack

The use of ferro-cement in the general civil engineering construction industry is vertually untouched and it is to this topic that I would like to devote the remainder of this talk.

FLEXCRETE

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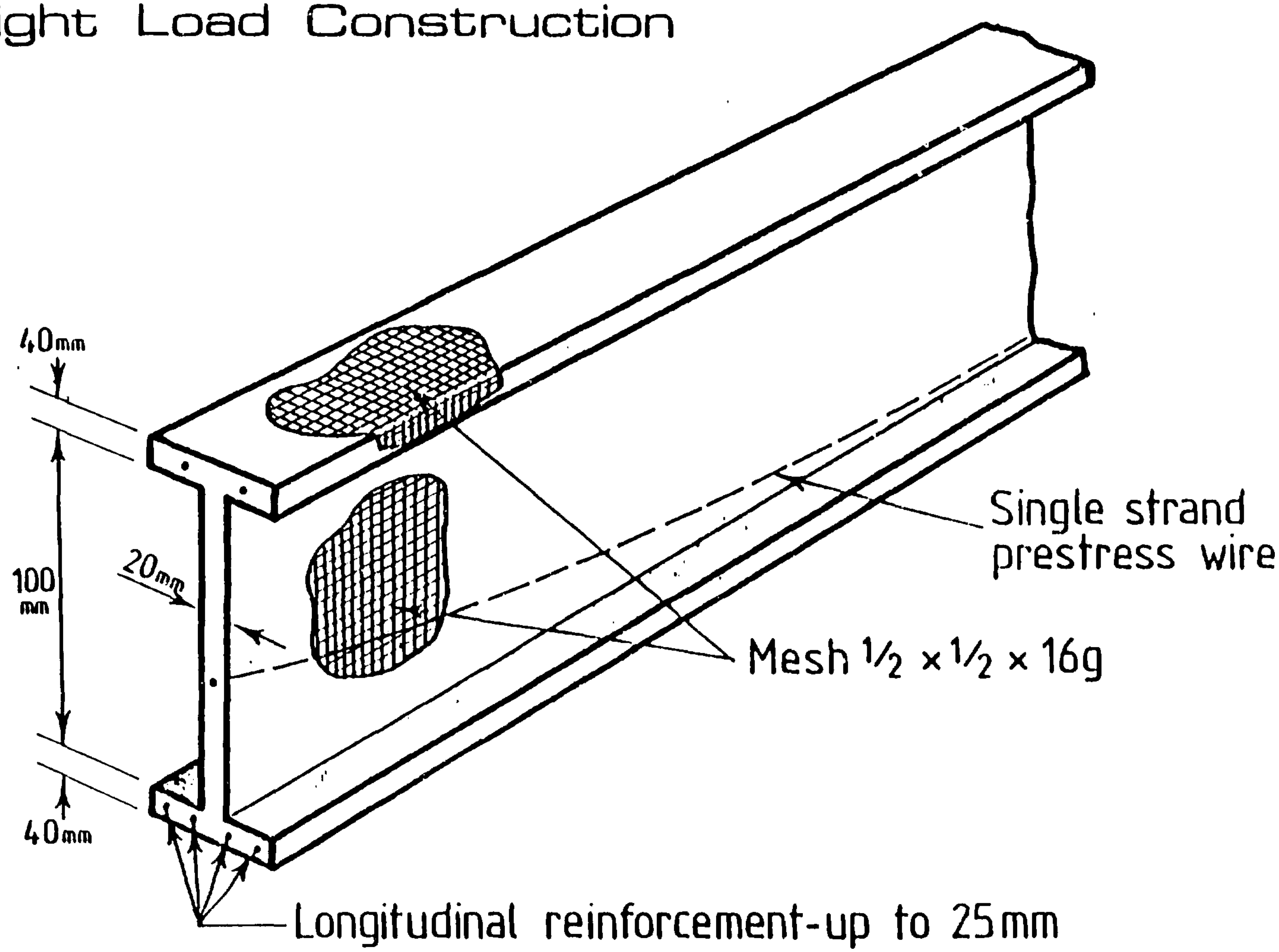
Partially Prestressed Beams

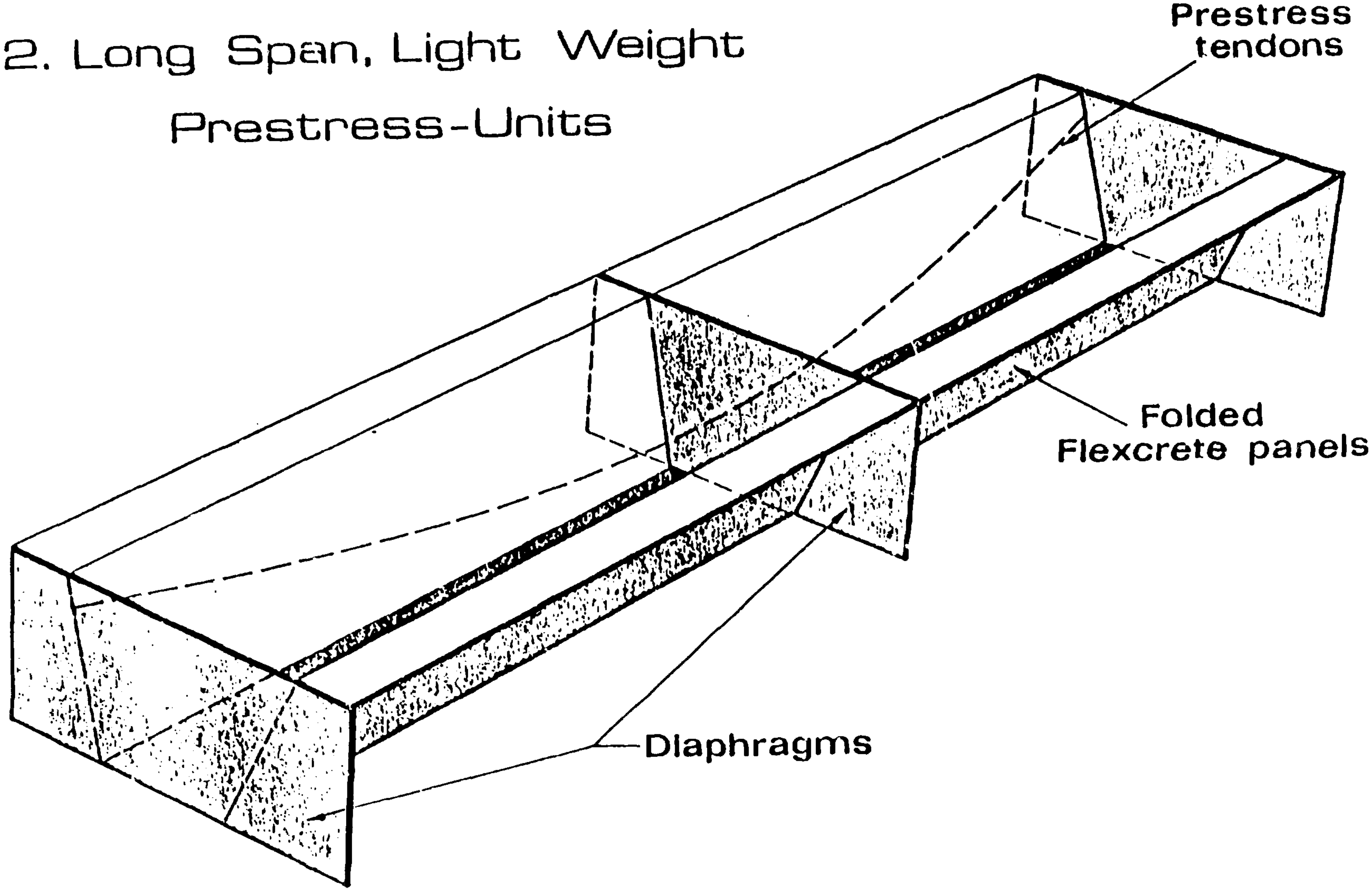
Light Load Construction

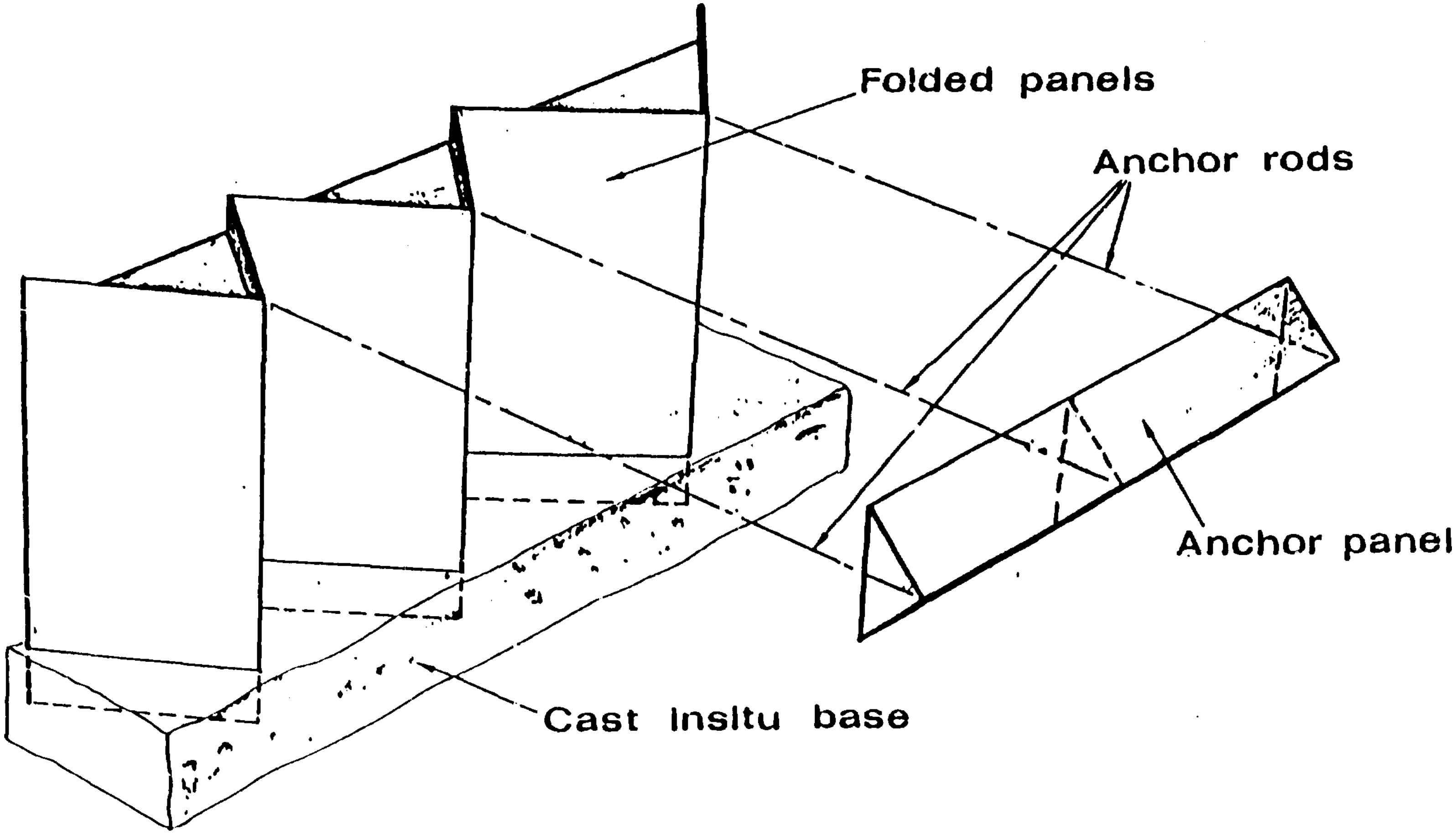


Folded Flexcrete

2. Long Span, Light Weight

Prestress-Units



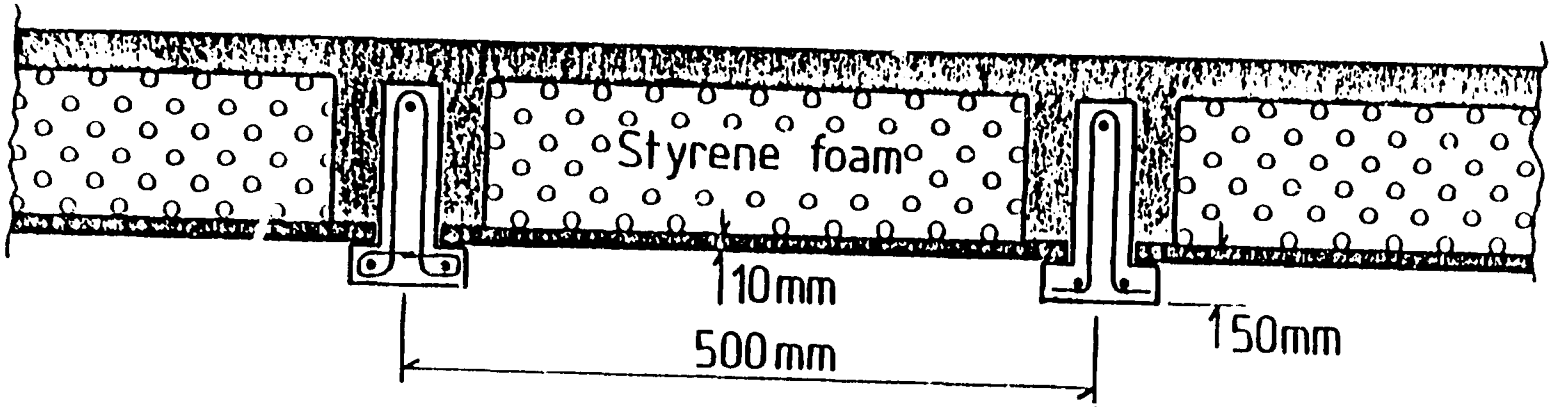


Folded Flexcrete

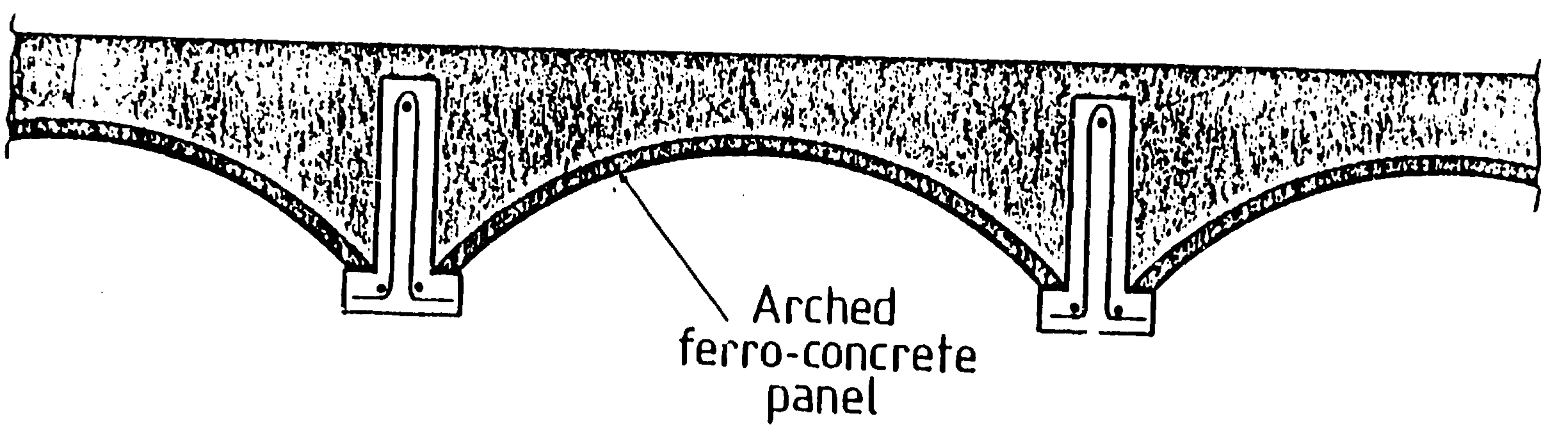
1. Precast Retaining Walls

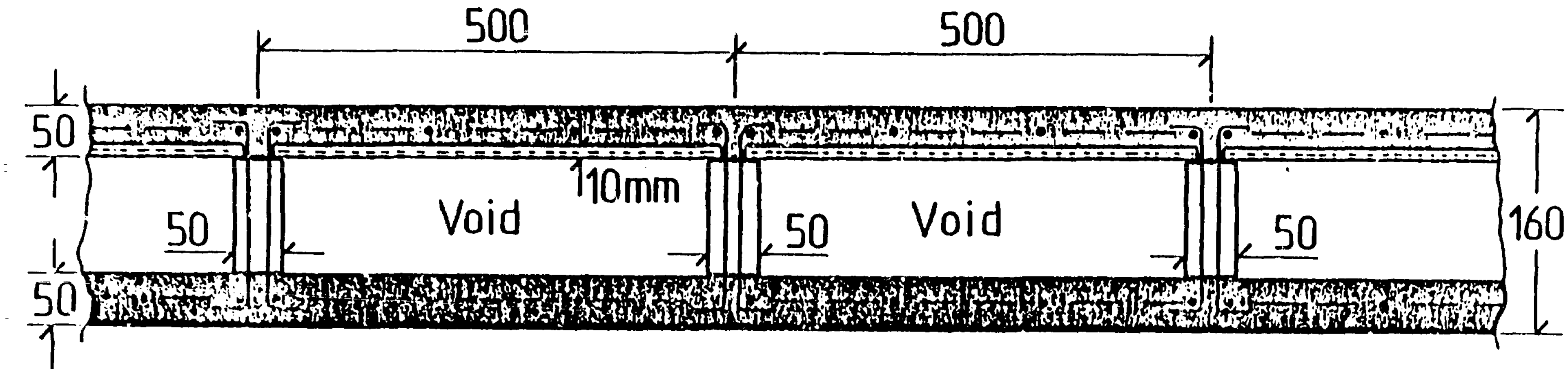
Light Weight Floor Units

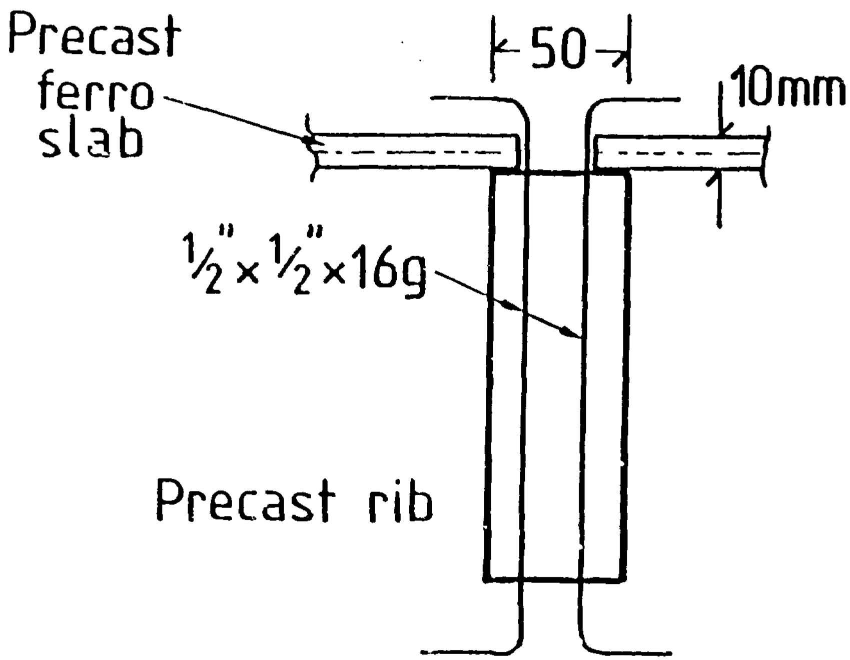
Scheme 2



Scheme 3



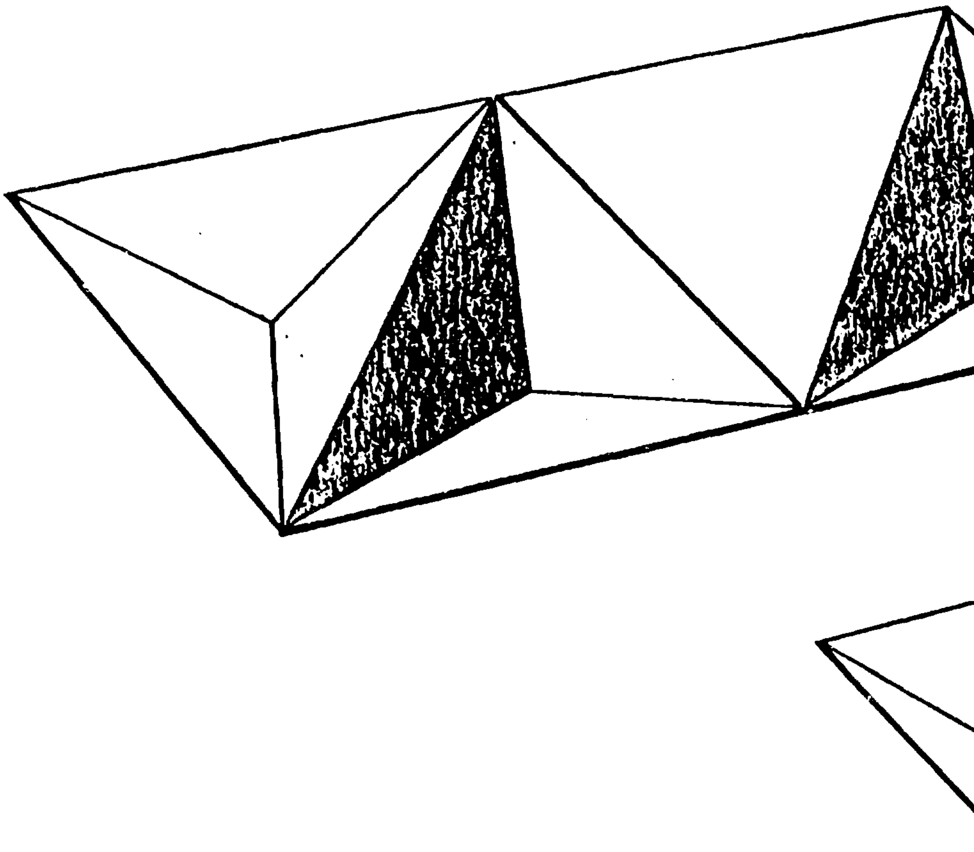




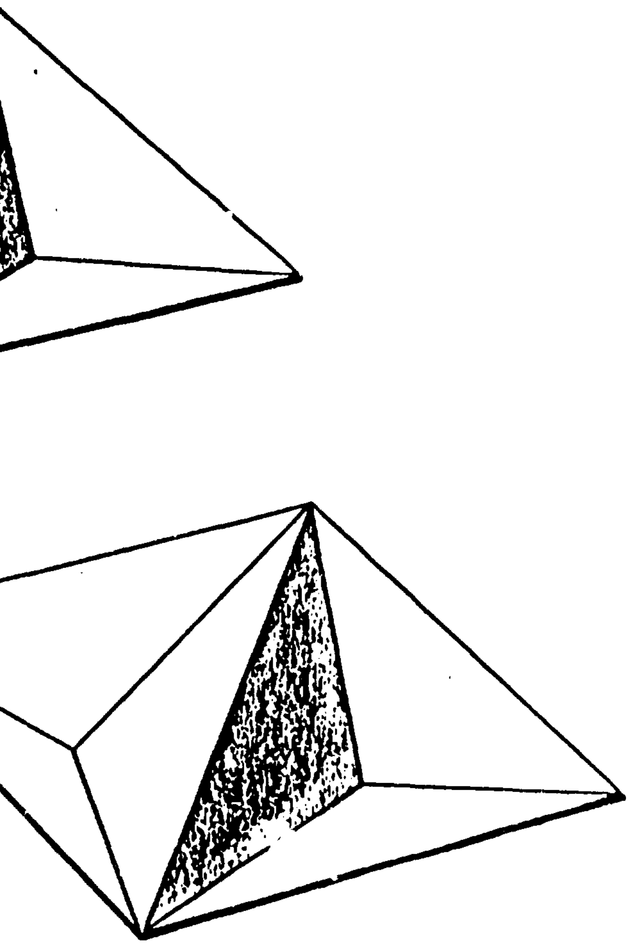
Light Weight Floor Units

Scheme 1

Folded Flexcrete

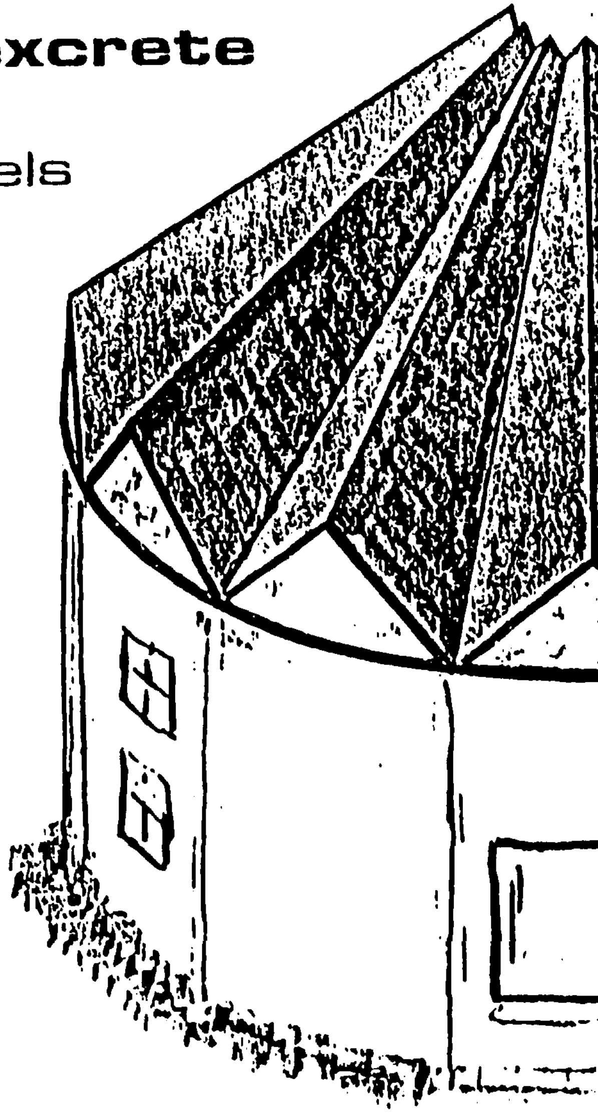


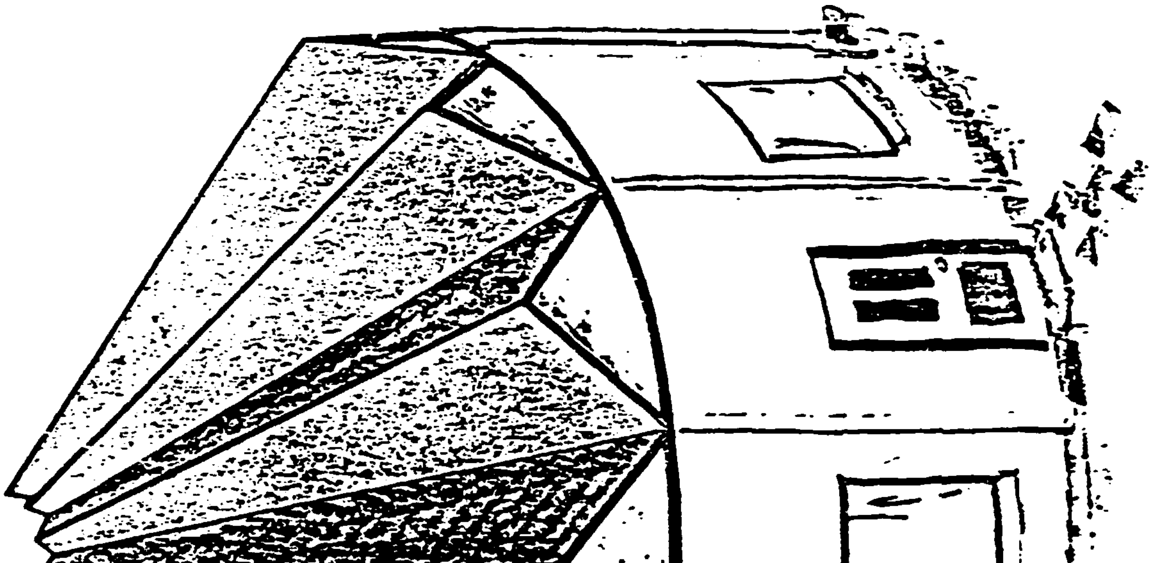
3a.Roof Panels

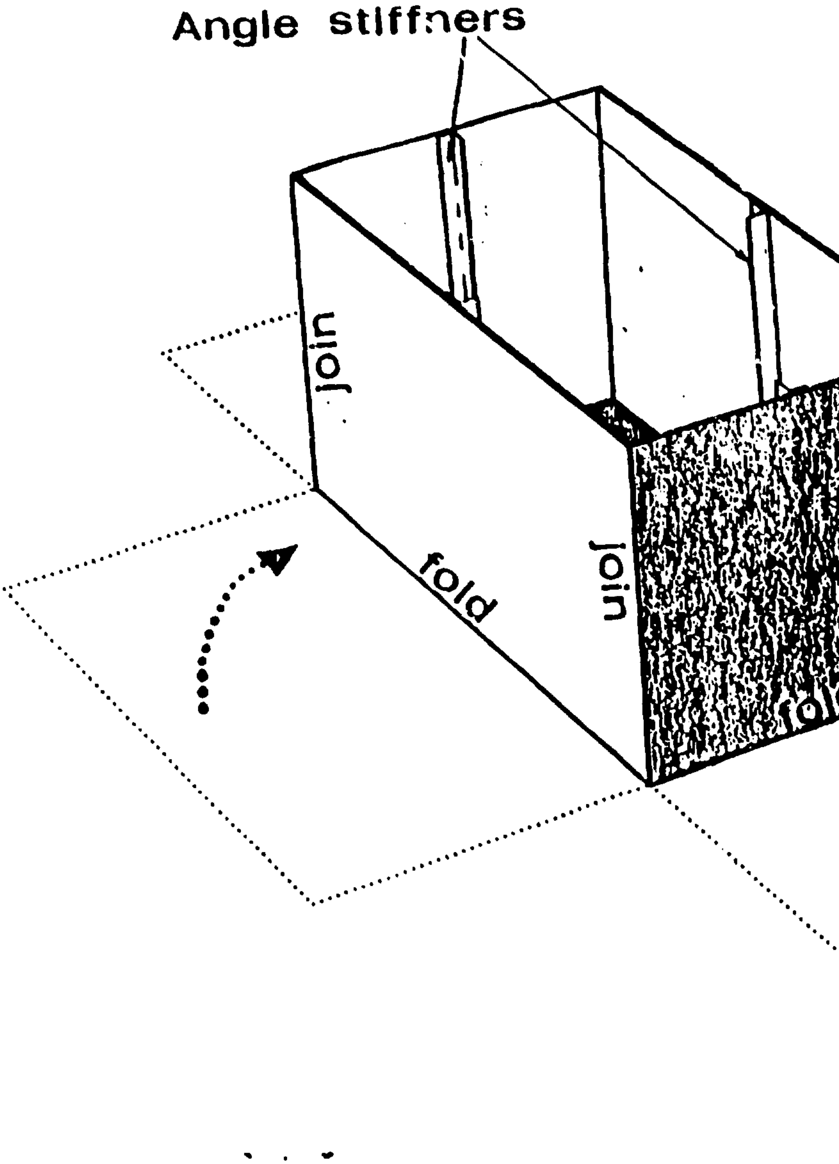


Folded Flexcrete

3b.Roof Panels






Angle stiffners
join
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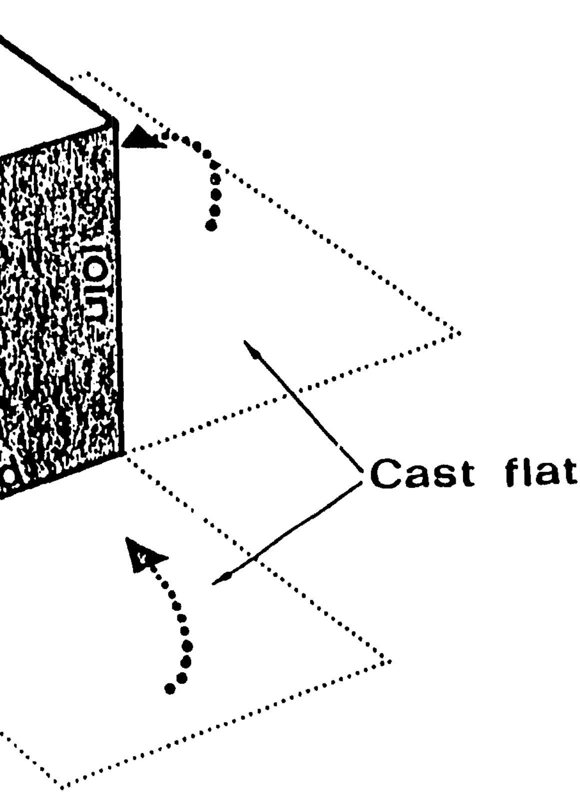
Folded Flexcrete

4. Bin Structures

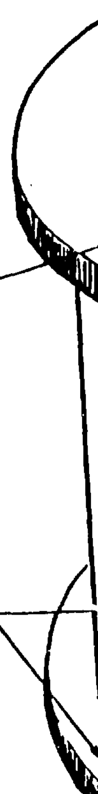


Water Storage Str

5. Compression Panels

Prestressed ring beams

Precast Flexcrete panels



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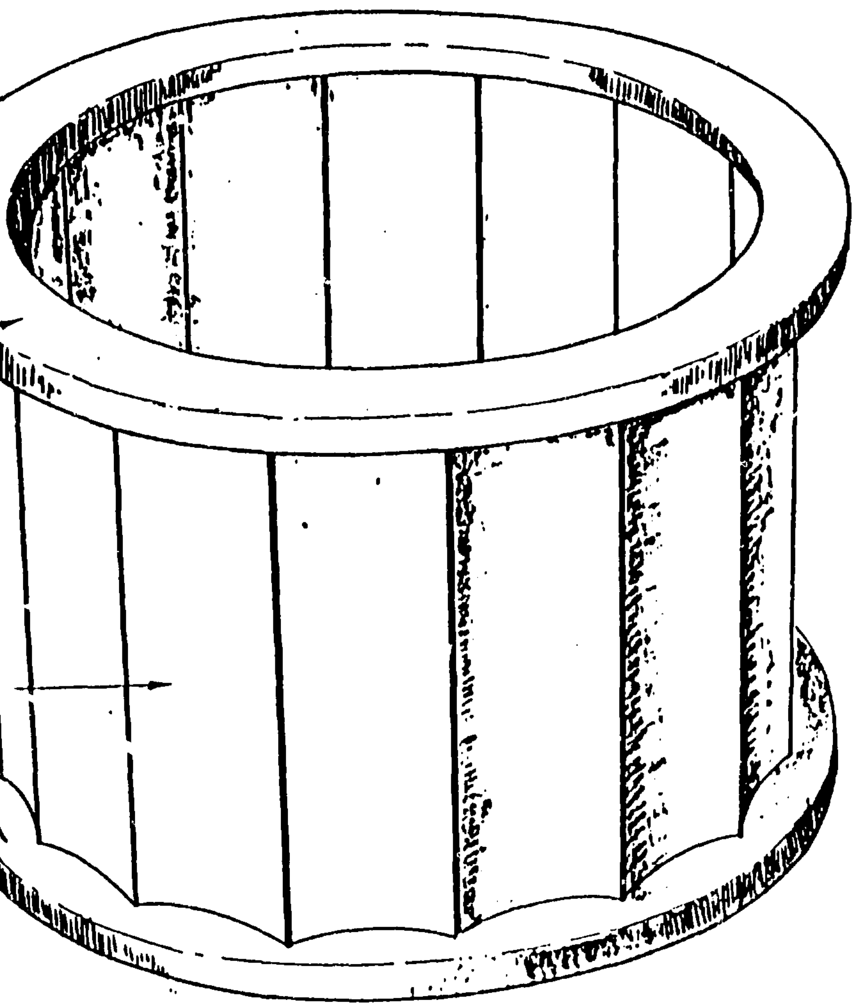
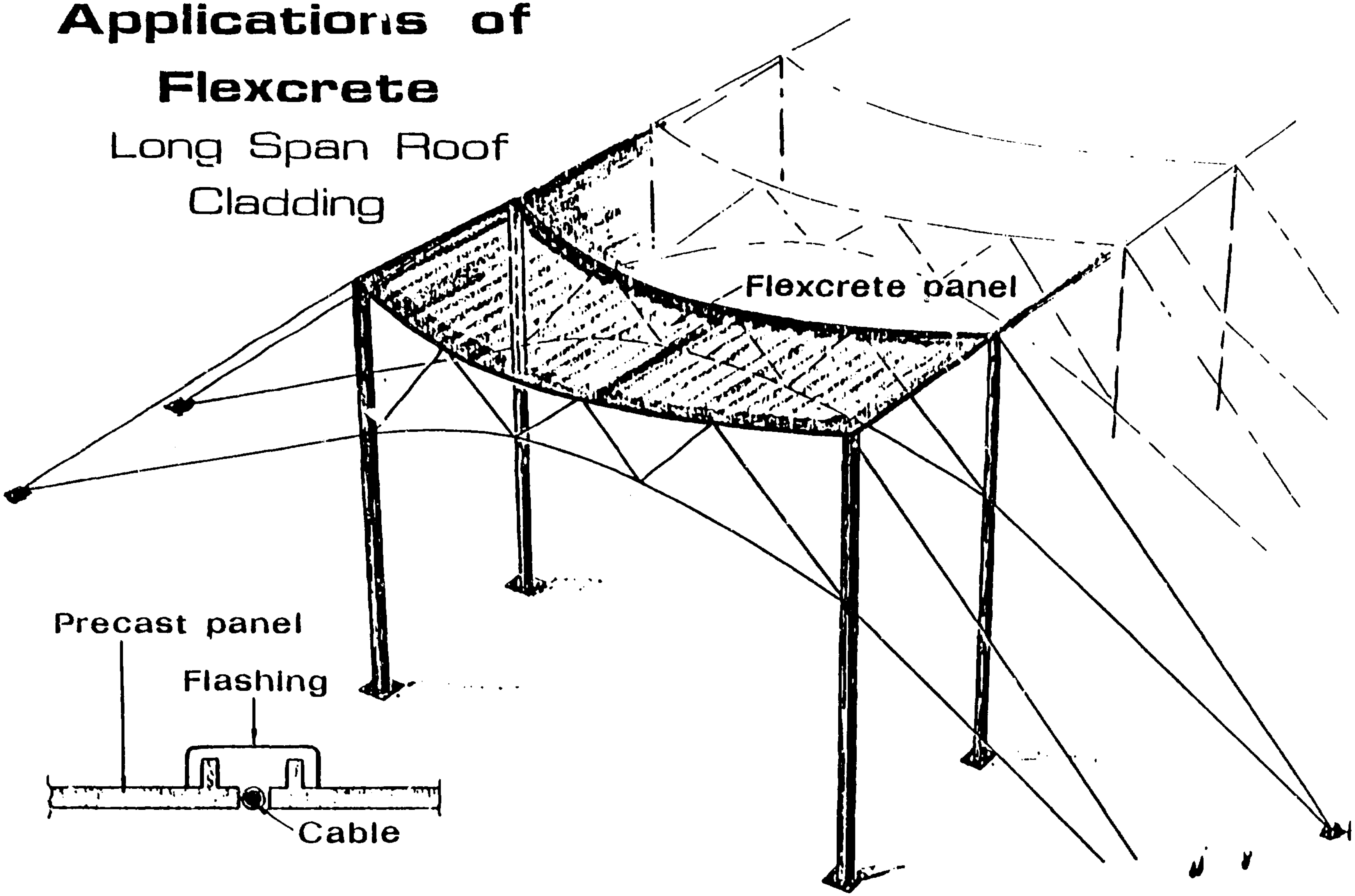


Applications of Flexcrete

Long Span Roof Cladding



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