WORLD HEALTH ORGANIZATION
REGIONAL OFFICE FOR THE WESTERN PACIFIC

MANUAL FOR THE CONSTRUCTION OF WATER TANKS USING HIGH TENSILE WIRE REINFORCED FIBROUS FERROCEMENT

MANILA, 1980

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Prepared for the
WHO Regional Office for the Western Pacific
by
Alexander & Poore, Consulting Engineers

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INDEX

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Section I. INTRODUCTION

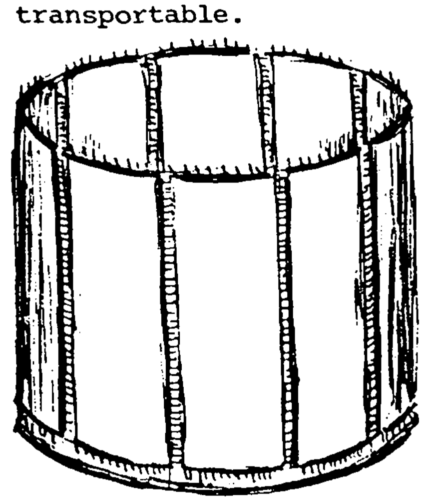
A. Purpose of the Manual

The purpose of this manual is to set out methods by which water tanks can be constructed using High Tensile Wire Reinforced Fibrous Ferrocement. This technology is a newly developed, lower cost variant of the mesh reinforced ferrocement which may be familiar to many people.

It is a matter of decision how ferrocement technology should be introduced and what degree of organization is desirable to introduce this technology. The simplest introduction to ferrocement water tank technology is to build them using moulds, because this results in a more predictable product, both visually and in performance. This is very important if the product is to compare favourably with the more familiar (and more expensive) tank structures employing steel or fibreglass.

Two methods of ferrocement water tank construction are described in this manual, designed to satisfy the probable needs in the Pacific area. One method produces segmental tank components which are light enough to transport and man-handle to the site for erection. The other method is for insitu construction of the tank using a simple cylindrical mould.

The first method produces a series of panels from which the tank can be assembled and thereafter completed by hand plastering the joints. (See Figure 1) This satisfies two very important needs; it produces concrete panels by simple casting methods, and the product is easily transportable.

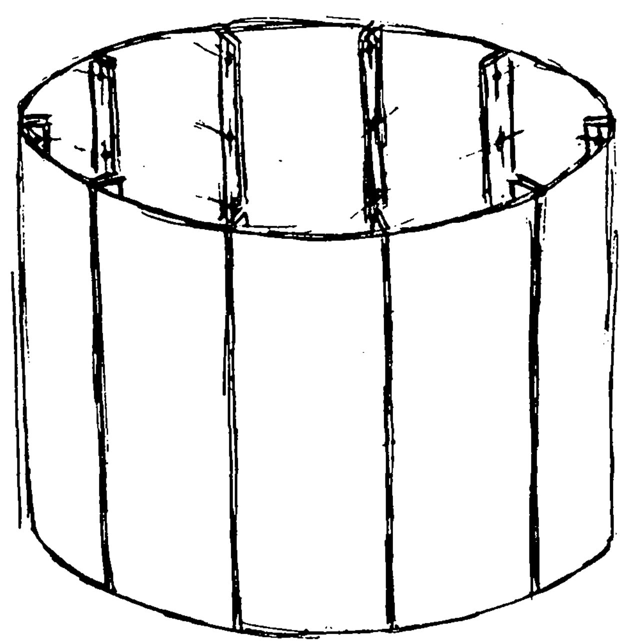


Segmental Tank

Fig. 1

The second method is very similar in result but can only be done on site. In this method, an internal liner (See Fig. 2) mould is built and the wire reinforcement for the tank sides is assembled prior to plastering. The tank walls are then formed in a single stage operation, instead of segmenting them for subsequent joining as in the first method. It is probable that this is more appropriate for larger tanks, and it would be the method of choice where a tank making facility is established. It would or course be necessary to dispatch the mould together with the trained personnel to the site for this form of tank construction. A base facility would supply a nucleus of trained people and organize the dispatch of mould and material to its surrounding region.

Beyond a limited range it is probable that a segmental form of tank would be preferred!



Liner for Internal Moulder Tank - Fig. 2

B. What is Ferrocement?

Ferrocement is a material which uses very fine wire reinforcement rather than coarse rods used in conventional concrete and results in a much lighter and cheaper structure. It is consequently a more practical material for tank making under most circumstances.

The basic materials used in ferrocement construction are sand, cement and fine wire. The mortar is composed of cement, sand and water and can be mixed with no other equipment other than shovels. The wire may be imported but its placement is a pure labour function and no machines are necessary.

For these reasons ferrocement has become one of the more important materials for the construction of water tanks. This technology is especially important because it provides employment at village level using readily available materials (such as sand which is obtained from local sources using community labour) and requires a low level of investment in plant and equipment which suits it to non industrial environments.

Tanks holding fresh water are a very basic need in village life so that means to make them from simple materials using local labour as described above, constitutes a saving of limited funds which would otherwise be expended on importing steel tanks. Mixing mortar is surely one of the most simple skills and the skill of placing the wire is readily learned by observation.

C. Ferrocment Water Tank Technologies

There are many ways of forming ferrocement water tanks. These have been the subject of several papers, a short list of which is given in the reference section of the Manual for those wishing to enquire further.

Ferrocement water tanks, in general, are built by forming a skeleton covered with a fabric of fine wire mesh which is plastered from both sides with a cement mortar. The skeleton may commonly be 6 mm high tensile rods set at 100 mm centres in two directions and the fabric, galvanised wire chicken mesh with a 12 mm aperture or 19 gauge weld mesh with a similar aperture. Two, three or four layers of the finer mesh are used in the construction, depending on the size of the tank. These are either supported on a cylinder mould, or a barrel may be formed from 150 mm x 150 mm x 6 mm weld mesh for free form construction on which the layers of fine mesh are wound and tied.

1 - Skeleton with Mould

When a mould is used, the skeleton and fabric assembly is first plastered with mortar from the outside. The mould is removed after the mortar is semi-cured, and the inside is then plastered to provide a cover to the mesh.

2 - Free Form Skeleton

The second method or free form style requires more skill as it is necessary to plaster the mortar from both sides into the mesh without a back-up support. Initially the flexibility of the unsupported mesh is disturbing to the operator, and the technique requires development of skills in order to master it. This is however a relatively simple operation and is widely used in boat building.

Variations on these methods are common. For example, rotating cylinder moulds may be devised. The wire is first wound on the mould and plastering is undertaken while turning the cylinder slowly, thus enabling mortar to be placed 'downhand', that is by the operator working under the level of his hands. For small tanks this method is easy to do, but larger tanks require expensive equipment due to their increasing size and weight.

3 - New Zealand Cement Mortar Tanks

The cement mortar tank, widely used in New Zealand and Australia does not use multi-layer mesh. One layer only of 'pig' netting is wrapped around a cylinder mould and then given a further wrap-on of No. 8 fencing wire at 50 mm centres prior to plastering. Plastering is done by hand or by shotcreting methods, until a wall thickness of 35 mm to 40 mm is obtained. After partial curing the lining is stripped and the inside plastered to give cover to the steel, similar to true ferrocement tanks. These New Zealand tanks are properly termed cement mortar tanks, since they are designed in the uncracked range (i.e. within the tensile strength of the mortar itself whereas ferrocement can be used in the cracked range because the cracks formed are fine and impervious to water. The disadvantage of the cement mortar tank whose construction is otherwise simple is its weight which is at least twice that of a ferrocement tank. It is less expensive than mesh reinforced tanks but more expensive than the high tensile wire reinforced fibrous ferrocement tank.

4 - High Tensile Wire Reinforced Fibrous Ferrocement Tanks

The materials used in this type of construction differ from the mesh reinforced ferrocement in so far as they use wire fibres together with fairly coarse high tensile wire usually in the form of fencing wire. Mesh reinforced ferrocement fabric shown diagramatically in Fig. 3, consists of layers of mesh typically 12 x 12 x 1 mm weld mesh layed one on top of the other.

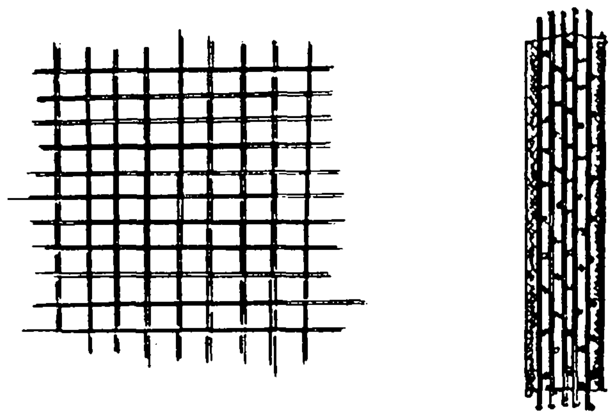


Fig. 3

High tensile wire reinforced ferrocement differs from this assembly in that a much coarser wire in fewer layers replaces the many layers of mesh, see Fig. 4. Typically the wire used would be 2.5 mm diameter spaced 25 mm apart whilst 14.5 mm x 0.4 mm fibres (Fig. 5) would be incorporated in the mortar during the mixing operation.

Symetrical Moment Configuration

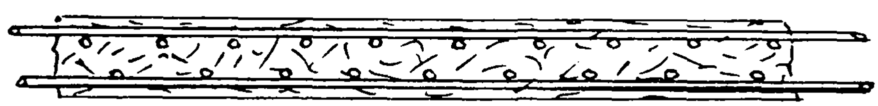
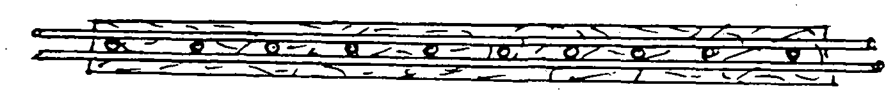


Fig. 4

Asymetrical Moment Configuration



The methods of construction for high tensile wire reinforced fibrous ferrocement tanks are similar to those used for mesh reinforced ferrocement when cylindrical moulds are used, but precast panels or segments can be used in the tank construction and subsequently joined by hand plastering the joints since suitable fingering can be formed at panel edges to give 'binding' across the joints, see Fig. 6.

Actual size

Magnified size

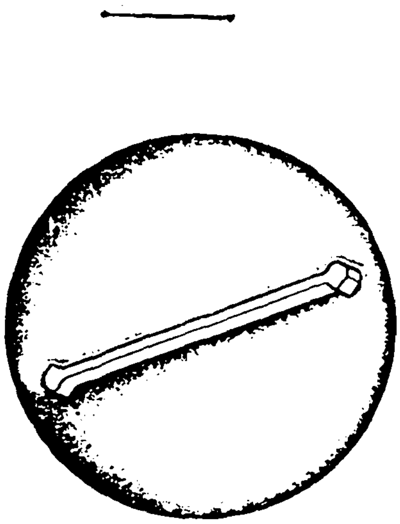


Fig. 5

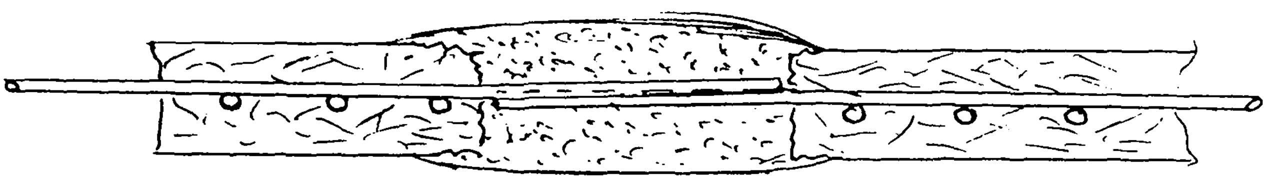


Fig. 6

This latter technology also requires only limited skills for plastering vertical surfaces, as the plates are cast in moulds and when assembled leave only narrow bands to be mortared.

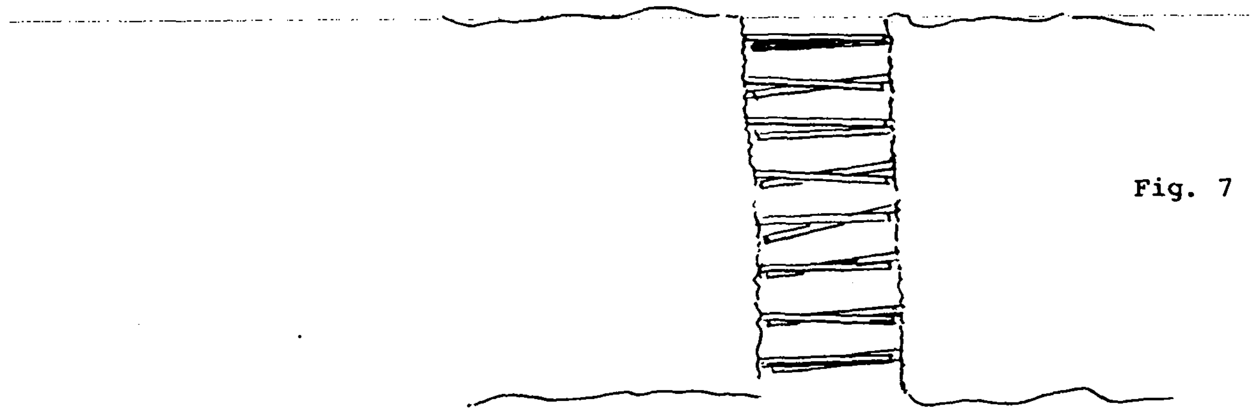


Fig. 7

Two methods of constructing round tanks are immediately available.

i The tank is constructed of precast panels which are subsequently erected and joint reinforcement fingered together before mortaring the joint to render it water tight which is the method referred to above.

ii The tank side is constructed on a cylindrical mould upon which the wire is assembled by first setting up vertical wires after which circumferential wires are wound on top of these. The side is then plastered by vertical application of fibrous mortar.

This latter operation however requires the development of more skill than will first be available but competence develops with experience. (Vertical plastering methods are for instance, widely used in boat building.)

This manual will place emphasis on the simpler precast panel method of construction as an early phase of development but once a training facility exists the skills required for the alternative form of construction can be incorporated into the teaching scheme. Both methods of construction are detailed in the test of this manual.

Other methods:-

Other methods of forming high tensile wire reinforced fibrous ferrocement tanks consist of casting long planks and rolling them into cylinders or casting continuously hinged plates and folding them into a polygonal shape. This latter method is similar to the precast panel method but avoids the complication of fingering all the joints together as only terminal joints need be fingered.

These last methods are however better suited to industrial production and will not be considered again in this manual.

D. Cost Comparison for Various Ferrocement Water Tanks

A series of unit costs have been established for the purposes of comparing tank costs and determining them too. These are given in Table I.

TABLE I - UNIT COST OF MATERIAL - November 1979

Material	Unit Cost
Cement	US$110 per tonne (5¢/lb)
Sand	10 " " (½¢/lb)
Fibre	880 " " (40¢/lb)
High Tensile Wire:	
- in Coil Form	920 " " (42¢/lb)
- in Straightened Form	975 " " (45¢/lb)

TABLE II illustrates the difference in the cost of materials between traditional mesh type ferrocement and high tensile wire reinforced fibrous ferrocement. (Figures must be continuously revised to adjust for price increases and relative changes.)

The costs of materials are compared for a 1,500 mm diameter x 1,800 mm high tank of approximately 2,500 litre capacity.

TABLE II

Material	Mesh Reinforced Tank		High Tensile Wire/Fibre Tank	
Cement	182 Kg @ 11¢/Kg	20.02	154 Kg @ 11¢/Kg	16.94
Sand	364 Kg @ 1.1¢/Kg	4.00	308 Kg @ 1.1¢/Kg	3.39
Water	45 Kg @ 2¢/Kg	.90	40 Kg @ 2¢/Kg	.80
Mesh	40 sq.m.@ $3/sq.m.	120.00		
Tie Wire		2.50		
Additive		1.20		1.10
Fibre			28 Kg @ $88 /Kg	24.64
HT Wire			24 Kg @ 99¢/Kg	23.76
		US$148.62		US$70.63

In Section II B-6 data is given on dimensions, areas and wire configurations for two sizes of tanks, namely 9,000 & 18,000 litre. Table III in this section gives the cost of material. The examples given are for the construction using a cylindrical mould. The segmental construction used more wire and is marginally more expensive.

TABLE III - COST OF MATERIALS FOR 9,000 & 18,000 LITRE TANK

9,000 Litre Tank				18,000 Litre Tank			
	Unit Cost	Weight	Cost	Weight	Cost	Weight	Cost
Cement	@ 11¢/Kg	340 Kg	37.40	568 Kg	62.50	168 Kg	18.48
Sand	@ 1.1¢/Kg	680 Kg	7.48	1,136 Kg	12.50	336 Kg	3.69
Water							
Fibre	@ 88¢/Kg	62 Kg	54.00	103 Kg	90.50	30 Kg	28.40
HT Wire	@ 96¢/Kg	64 Kg	61.44	100 Kg	96.00	12 Kg	11.52
Tie Wire	@ 120¢/Kg	1 Kg	1.20	2 Kg	2.40	.3 Kg	0.36
Additive			3.00		6.00		1.20
			US$164.52		US$269.90		

Section II. PREPARATIONS

A. How to Choose the Best Design for the Tank

So far a series of methods of construction of tanks has been discussed.

Because of the clear cut cost advantage of high tensile wire reinforced fibrous ferrocement, this material should be selected for all sizes of tank construction.

For larger tanks a great deal of wire is needed as reinforcing in order to resist the greater head of water but for smaller tanks, say up to 600 gallons capacity, the wire reinforcing can be left out and fibre alone used. The wall thickness would however need to be increased when the main reinforcing is left out but the sheer simplicity of the product warrants this. When the panels are precast it is necessary to provide reinforcing across the joints so that short pieces of wire are inserted through the side bars of the mould and left sticking out of the panel when cast in order to provide for 'fingering' the joint.

The actual selection of wire to be used and its placement is a function of designed strength which is beyond the scope of this manual and therefore must be specified for each size of tank. Generally 2.5 mm diameter galvanised high tensile wire will be used at 25 mm centres in one direction at least and the mortar will contain 5% by weight of fibres in its mix.

However, for any particular size of tank where the wire placement is known, the method of construction can be selected from two possibilities.

a) The construction can be from precast panels which are subsequently fingered together and the joints mortared to complete the tank.

b) The tank can be constructed by wrapping reinforcement on a form work and plastering this in situ.

The former should be used for all tanks where insufficient skills exist at the site, but the latter method may be used when skilled labour is available on site, in which case the materials would have to be transported to the site along with a segmental mould.

Where precast panels are supplied on site, only the simplest of tools are needed to mortar the joints after the pieces are assembled into the form of a tank.

B. Materials

The principal materials used in constructing high tensile wire reinforced fibrous ferrocement are listed as follows:-

1. Cement: Any Portland cement is acceptable for construction of water tanks. Most cements comply with Standard Type II Portland Cement to NZS 3122 : 1974. It is necessary however to maintain it in good condition, free from lumps and in any case cement over six months old should not be used.

2. Sand: Most sands are acceptable. The size range recommended usually lies between 7 to 10 mesh screen size. Generally the sands should comply with New Zealand Standard 3111 : 1974 and 3121 : 1974 which require the sand to have the following range of sizes of particles in its sand used, viz:

- passing	4 mm aperture	100%
	7 BS Screen	95 - 100%
	14 BS Screen	75 - 98%
	25 BS Screen	80 - 79%
	50 BS Screen	12 - 14%
	100 BS Screen	0 - 15%

In the event that the sand does not appear to satisfy this specification it should be tested in a mix using the Standard Concrete Mix Design. In this test at least 2 compression test cylinders must be cast from the mix and cured for 28 days in humid conditions before testing. Assistance of the Ministry of Works should be sought for this work. If the resulting compression cylinder test value for a 28 day cure exceeds 30 MPa strength the sand will be acceptable. It is possible to get a coral sand to give this result in which case it is perfectly satisfactory for use. The use of beach sand with a high salt content should however be avoided, but if it is the only sand available locally and it passes the strength requirement it may be used after it is leached by rain for a period of three months. For this purpose it should be raked out into a thickness of 24 inches on a free draining base to allow the rain water to leach out the salts.

3. Fibre: The fibre used is obtained from Australian Wire Industries Pty. Ltd., P.O. Box 55, Five Dock, N.S.W. 2046, Australia and is a 14.55 mm or 18 mm long chopped wire fibre with enlarged ends. The 14.5 mm size is superior and mixes well, but the 18 mm is cheaper and is suitable. Few other wire fibres are successful in practice. When the wire fibre is ordered, reference should be made to its intended use in high tensile wire reinforced fibrous ferrocement.

4. High Tensile Wire: This wire is obtained from the same source as the fibre. It is specified as 2.5 mm diameter galvanized high tensile spring wire with an ultimate tensile strength of between 1650 and 1850 MPa. The form in which the wire is ordered depends on the type of tank construction method adopted.

   a. When it is intended to use an internal cylindrical mould, some of the wire can be ordered in rolls and some in straightened lengths. In the case of the 9,000 and 18,000 litre tanks, 25 kilo and 40 kilo respectively is ordered in rolls and 39 kilo and 50 kilo respectively ordered in straightened lengths of 6 metres.

   b. In the case of the segmental tank construction, all the steel is ordered in 6 metre straightened lengths.

5. Additives: Where galvanized wire or mesh is used as reinforcement it will be necessary to add approximately 20 grammes of Chromium Trioxide per bag of cement in order to prevent gas generation within the wet mortar.

   With the development of technical competence, the use of additives, such as air entraining agents and plasticizers, can be investigated and adopted where clear benefits occur. Both air entraining agents and plasticizers increase the workability of the mortar and make it easier to get a dense air bubble free concrete.

6. Materials Table for Various Tank Designs

TABLE IV - DATA FOR VARIOUS TANKS

	9,000 Litre Tank	18,000 Litre Tank	2,250 Litre Tank
Internal Diameter	2430 mm	3044 mm	(Rectangular) 1200 x 1500
Height	1950 mm	2500 mm	1200
Circumference	7618 mm		-
Area of Sides	18.04 sq.m.	24.00 sq.m.	6.48 sq.m.
Area of Top	4.93 sq.m.	7.72 sq.m.	1.80 sq.m.
Area of Bottom	4.93 sq.m.	7.72 sq.m.	1.80 sq.m.
Weight of Sides	723 Kg	1290 Kg	393 Kg
Weight of Top	193 Kg	301 Kg	110 Kg
Weight of Bottom	286 Kg	286 Kg	73 Kg

TABLE V - MATERIALS ASSOCIATED WITH TANKS IN TABLE 1 (In Kilograms)

	9,000 Litre Tank	18,000 Litre Tank	2,250 Litre Tank
Cement	340	568	168
Sand	80	1136	336
Water			
Fibre	62	103	30
HT Wire	64	100	12
Tie Wire	.1	2	.3
Additive			

C. Tools & Equipment:

Very few tools are necessary for the construction of the tanks. The following items are required:-

a) A flat area such as a concrete slab or ply sheet for mixing the mortar.

b) A 4 mm sieve to screen sand which may have over-sized pebbles or other material in it.

c) Shovels for mixing the mortar.

d) Selection of flat trowels and pointer trowels for application of the mortar.

e) Hammers for tapping moulds to help in the placement of the mortar.

f) A set of measuring boxes for the materials as defined in the specification Section III.

g) Tamping rod and base board.

h) Buckets for transfer of the mortar to the moulding position.

i) At least two sets of bolt cutters. Small size are suitable.

j) A slump cone. Base plate and tamping rod.

D. Moulds:

A complete set of accurately made moulds for each size of tank must be available. Good moulds will make for precision casting and ease of construction so care should be taken with the manufacture and the surfaces should be finished with a polyurethane resin such as floor lacquer and subsequently lightly oiled to give easy release to the casting.

The moulds needed are:-

No. 1	Base mould for assembling lower level reinforceing wires:	Drawings No. 1552-11
No. 2	Base mould for assembling upper level radial reinforcing wire:	Drawing No. 1552-12
No. 3	Tank side wall segmental moulds:	Drawing No. 1552-13, 14, 15.
No. 4	Tank top mould:	Drawing No. 1552-16
No. 5	Centre post mould:	Drawing No. 1552-24
No. 6	Cap mould:	Drawing No. 1552-24
No. 7	Manhole mould:	DRawing No. 1552-24

The details of construction of these appear in the drawings section of this Manual.

Section III. CONSTRUCTION OF SEGMENTAL SIDED WATER TANK

A. Materials List:

The quantities of materials required for the 9,000 and 18,000 litre tanks are given in Table V Section II B.6 but it must be kept in mind that these weights are not in position and so the amount ordered should be 10% greater to allow for waste.

The following tables set out the configuration of wire employed and the weight in each configuration category. All wires are 2.5 mm High Tensile Sprung Steel.

TABLE VI 9,000 LITRE TANK

Location	Layer	No. of Pieces	Length Meters	Total Length Meters	Weight
Bottom Drwg. 1552-12	1st Layer	56		140	
	2nd Layer	56		140	
	3rd Layer	150	650 mm	98	
Sides Drwg. 1552-13	Circumferential	765	0.920	703	
	Circumferential Doubling				
	Vertical Wires	100	2.1	210	
	Doubling Wires	90	0.275	27.5	
Top Drwg. No. 1552-16	1st Layer	56		140	
	2nd Layer	56		140	
				1198.5	60 Kilo

TABLE VII 18,000 LITRE TANK

Location	Layer	No. of Pieces	Length Meters	Total Length Meters	Weight
Bottom Drwg. No. 1552-12	1st Layer	74		228	
	2nd Layer	74		228	
	3rd (radial)	198	750	150	
Sides Drwg. No. 1552-13	Circumferential	1155	0.939	1490	
	Circumferential Doubling	451	0.130	59	
	Vertical Wires	121	2.600	315	
	Doubling Wires	110	0.275	31	
Top Drwg. No. 1552-16	1st Layer	74		228	
	2nd Layer	74		228	
				2,957	110 Kilo

Miscellaneous: Manhole Ring

Centre Post

Allow - 1 Kilo

B. Site Preparation:

The site requirements for the construction of the Tank are simple enough and can take many forms. The materials used are cement, sand, water, fibre, high tensile wire, tie wire and additive so the first requirement of a site is a suitable store area to keep the materials dry.

The sand poses its own problem and should be brought into a dump from which it is processed if necessary to the required sieve sizes to remove debris and over-sized materials. If the sand contains very fine material or mud it may need washing to remove the mud. After this processing the sand must be dried and stored dry under cover.

So far the remarks apply equally to on site construction or to a base facility.

For on site construction the proposed tank site must be prepared by flattening and draining and then laying a suitable sand base upon which to construct the tank. As the base is constructed in this position in the case of an insitu pour, or assembled in the case of a segmented tank, no other working floor is necessary. However a mortar mixing base adjacent to the construction site is necessary. An area 3 meters square is suitable and wherever possible a timber mixing floor should be provided.

The mould is erected on top of the base once it is formed or in the case of the segmented tanks the segments are erected on the base once formed.

The only other preparation required on site for casting a tank is the provision of tools and a means of measuring the quantities of material which may consist of gauge boxes for the various materials so they can be accurately mixed in the proper proportions.

Finally, a proper set of instructions should be supplied to site together with a trained tank maker.

C. Mixing of Cement:

1. Measuring Boxes: The materials used to make the cement mix or mortar require to be accurately proportioned. For this purpose square boxes should be made for each material and cut down to the exact size required to hold the specified weight. The material to which it applies should be clearly painted on each of these boxes together with the weight involved. Generally the proportions should be based on 1 bag of cement, approximately 40 kg - hence:-

for cement	use 1 bag holding 40 kg
for sand	use 1 box holding 80 kg
for water	use 1 box holding 16 litre
for fibre	use 1 box holding 7.6 kg
for chromium trioxide	use 1 box holding 21 gram

2. Concrete Mix Design: The mix design shall be such that a minimum 28 day compression strength of 35 MPa is obtained. This will generally be met with the following mix:-

Cement	1.00 part	by weight
Sand	2.00 parts	by weight
Water	0.40 part	by weight
Wire Fibre	0.19 part	by weight

If the sand is finer than the grading given it will be necessary to increase the cement ratio.

3. Control of Mix: The mix is controlled by systematic checking of the slump obtained; first before the wire fibre is added and then after. This is done by using a slump cone, the dimensions of which are as follows:

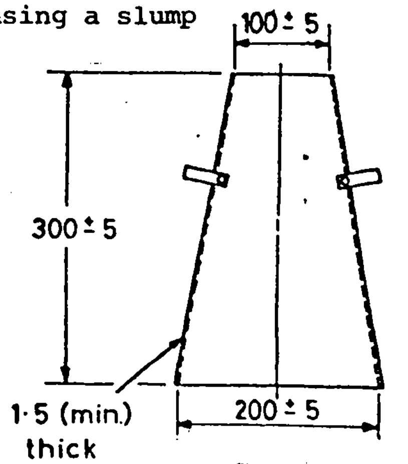
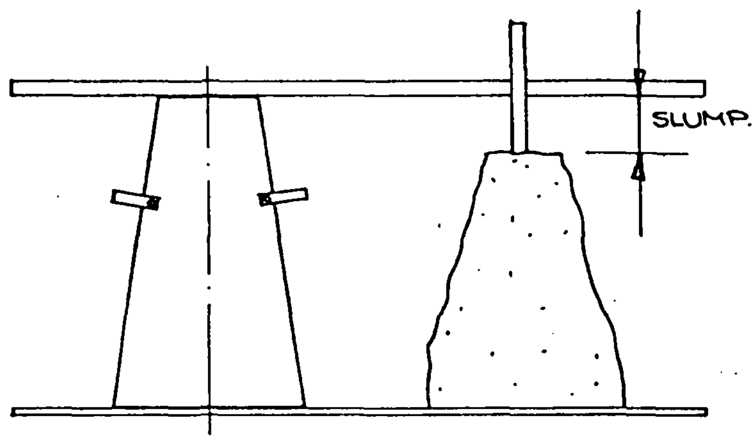


Fig. 8

The cone should be placed on a flat board and filled to above half height before rodding with a 250 mm long by 15 mm diameter steel rod. A specific number of strokes should be used to prevent operator error. Normally ten strokes is sufficient, but whatever number is selected should be consistently used. The cone is then topped up and 'rodded' again and this repeated a third time before levelling the cone. The cone is then lifted clearly away from the mortar and the slump measured.

Fig. 9



The slump of the mortar before fibre is added should be about 75 to 85 mm otherwise add small amount of water. After the fibre is added this should reduce it to approximately 25 to 35 mm slump.

4. Mixing the Mortar: This should be done on a clean flat base and the sand should be screened through a 4 mm mesh to remove large lumps and debris if it contains such material as these will 'tear' the mortar during plastering.

The sand should be dry where ever possible and water added cautiously until the correct slump is obtained. With wet sand this is more difficult to achieve. Mixing must be thorough and continued for about 10 minutes before slump testing is done otherwise results are misleading. Once the correct slump is obtained the wire fibre is added by holding handfulls of the fibre in two hands and shredding the wire over the mix with a rolling action to obtain even distribution. Dumping handfulls into the mix leads to 'balling' and faulty distribution of the fibres.

5. Curing: Whenever mortar is placed, care must be taken to see that too rapid a cure does not take place and this requires that the surface be kept wet for several days usually by placing wet sacking on the surface and sprinkling this from time to time with water. This ensures the curing takes place in humid conditions and that correct strengths are obtained. Wetting the surface must be delayed for six hours after casting to allow for the initial set of the mortar.

Where components are being systematically manufactured they can be stored in water troughs after 24 hours in the mould.

D. Casting the Tank Bottom: In-situ Construction

There are two methods of casting the bottom:-

1) It may be done in-situ;
2) It can be cast in segments and these transported to site for joining in position.

This section III D. deals with in-situ casting. Reference should be made to the drawings when reading the following instructions.

Operations:

a. The first operation is to cut the wire required for the two bottom layers of reinforcement in the base into lengths and to assemble them in the No. 1 base mould by dropping them in the slots formed in the side members of the mould. Drawing No. 1552-11.

b. Before placing these wires in the base mould, however, thin support strips can be prepared by casting them in mould boxes formed with a series of 25 mm flat grooves 3 mm deep. 600 mm is a convenient length of strip.

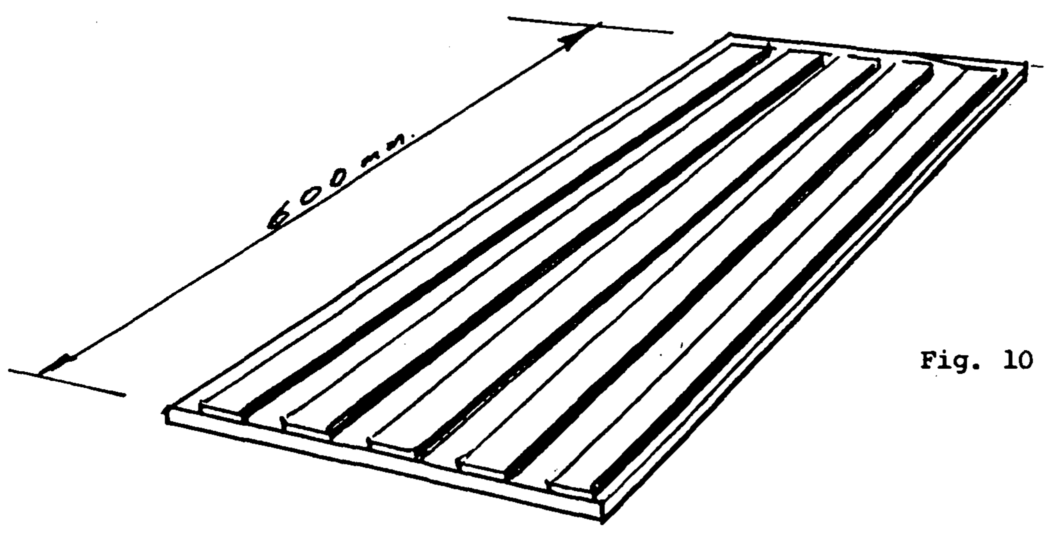


Fig. 10

Well compacted mortar is placed in these mould boxes and left to set for about two to three hours. At that point in time a fine wire in the form of a hook should be drawn down the sides to roughen the edges and the top surface also roughened by brooming. This makes sure the spacer strips will bond into the cast material. Twenty-four hours after casting the strips should be stored in water until required.

c. The assembled wires in the base mould are then held in position with a 12 mm depth of well compacted fibrous mortar which is flooded across the central area of wires. Drawing No. 1552-11

d. This mortar is left for two to three hours prior to raking out the edges to feather them and brooming the top surface also to obtain proper adhesion for the subsequent placing of mortar used to complete the bottom of the tank.

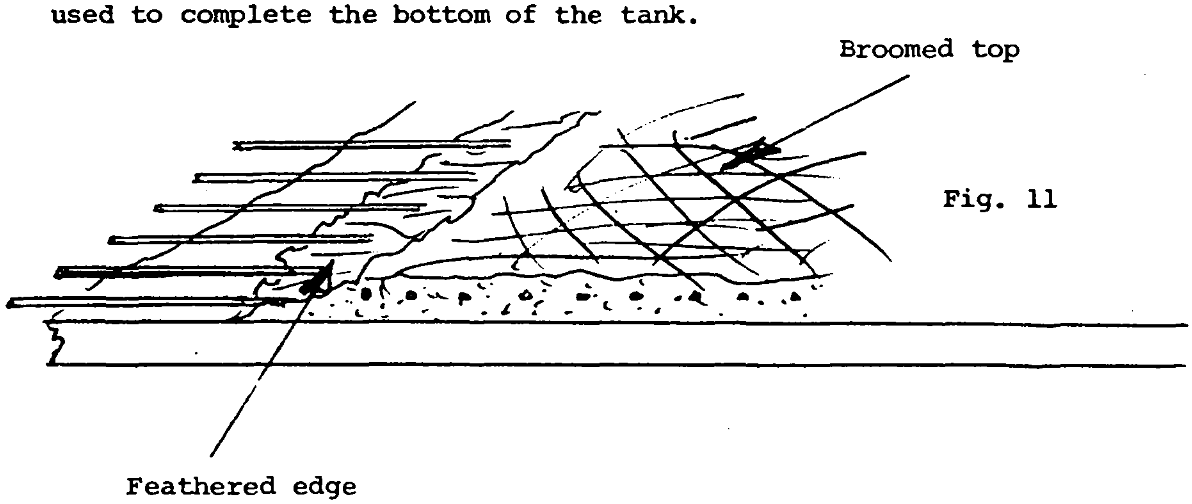


Fig. 11

e. Six hours after this partial casting of the bottom, wet sacks are placed over the mortar to provide humid curing conditions. These are kept wet until the bottom is required for further erection. It may be stripped after two days.

f. The partially formed bottom is next placed on a round disc, (which may be a painted circle on the floor), cut to the size of the exterior diameter of the tank less 6 mm all round and the wires are then trimmed to a circle using bolt cutters.

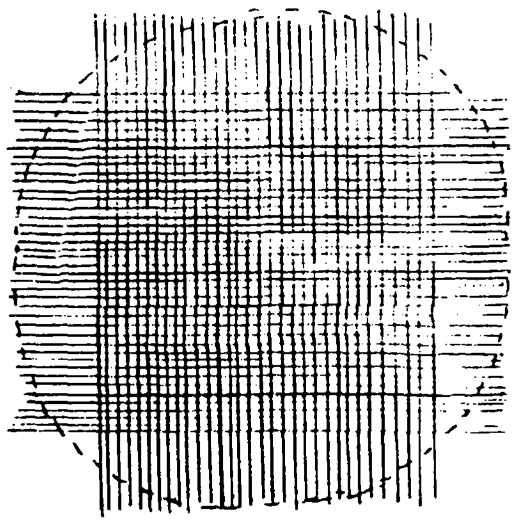


Fig. 12

This enables the bottom wire assembly to be dropped onto the next mould in preparation for the placing of the radial reinforcing wires.

g. This mould consists of a circumferential boxing, the perimeter lip of which is slotted to allow the wires to be accurately located. See Drawing No. 1552-12. The wires rest in these slots at one end and on the precast centre at the other.

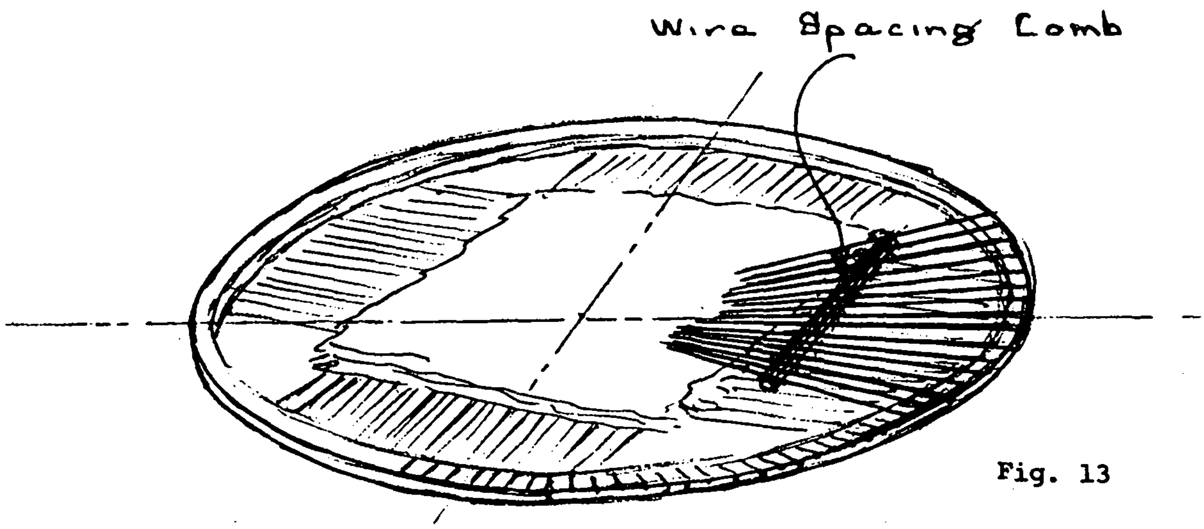


Fig. 13

Combs are used to keep the inner ends reasonably in position during casting operations which do not, however, take place until the tank wall elements are in position.

It is proper to note that this procedure is applicable to the construction of a transportable tank.

If the tank is to be constructed in-situ this mould need not be used.

Instead the first mould is reduced to a perimeter mould by cutting a circle out of the centre to permit the wires to be cast into the bottom which is itself cast against a prepared base of well tamped sand or gravel. When this initial casting is cured, the perimeter mould is dismantled which is very simple to do if the end strips are screwed down to the perimeter mould base which is itself sectional.

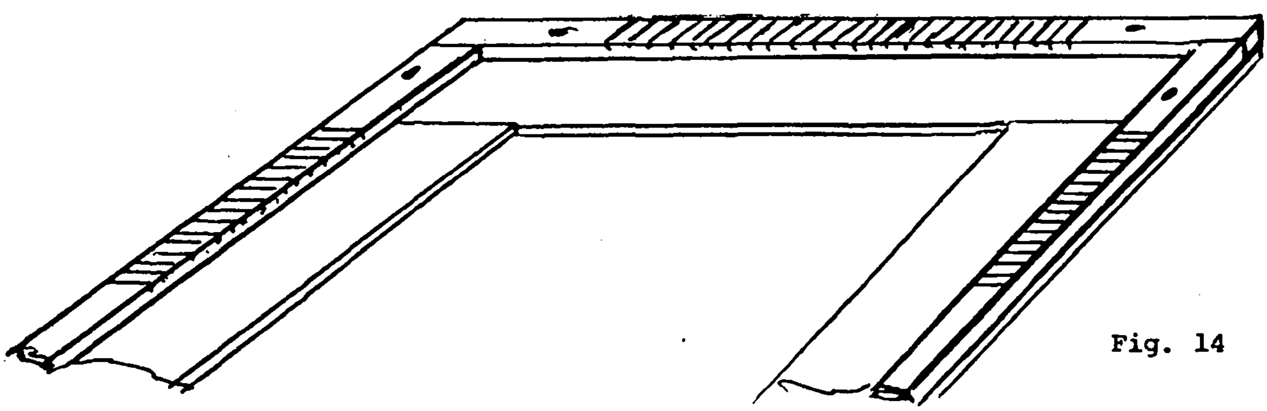


Fig. 14

When the in-situ method of casting the bottom is used the wires themselves are made 50 mm longer all round so they overlap the tank walls.

Once the first (perimeter) mould is removed, mortar is placed roughly around the perimeter at a greater diameter than the tank and radial wires pressed into the still plastic mortar to the correct level and at the required distance apart and allowed to cure for a day or so.

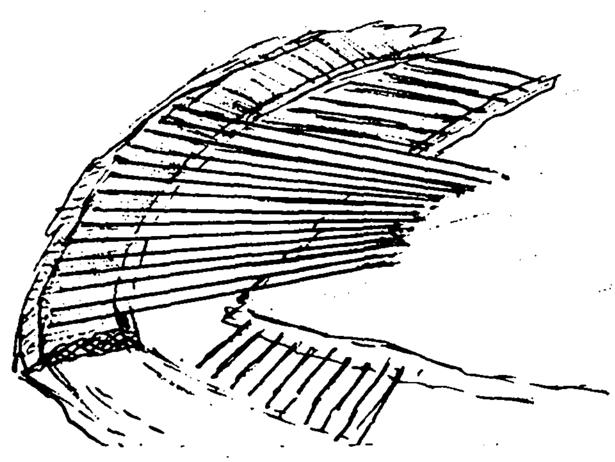


Fig. 15

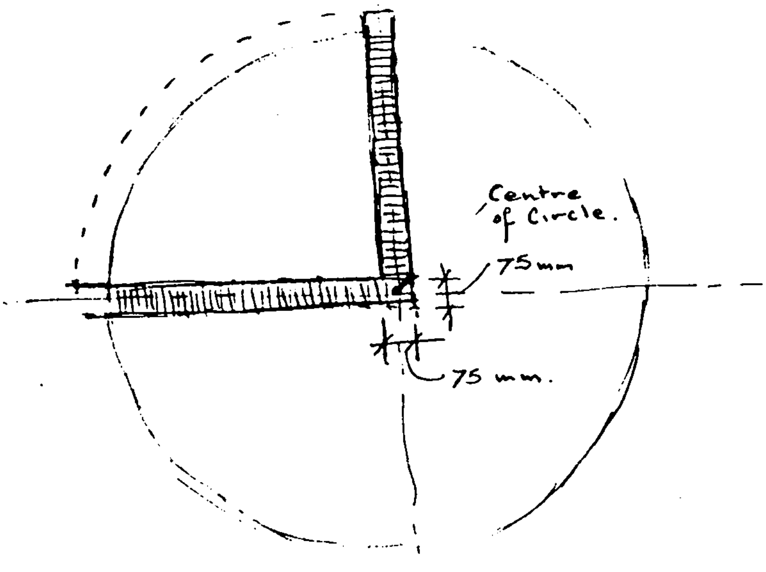
The tank walls can then be erected and the whole base flooded to its finished level. However, this method should not be used in the training phase but has obvious advantages when the technology is transferred to outlying districts when the method may well be used in conjunction with the interior cylindrical wall moulds instead of the precast segments. This method is not part of this manual, but is outlined to show one of the areas of development that can take place after establishment of the technology.

E. Casting the Tank Bottom: Transportable Type

This method is similar to the segmental casting of the top which is dealt with in detail in Section III H.

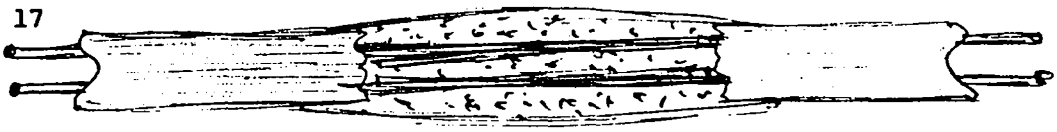
The configuration of wire lay-down in III D. is retained except that only one quarter of the mould is constructed as illustrated for the Tank Top in Drawing No. 1552-16 and the edges on the radii finished off with 75 mm strips with the wire slots cut in them.

Fig. 16



This provides for a 75 mm overlap of the wires when they are fingered together on site where the joints are cast in.

Fig. 17



It must be note that all edges to be cast in-situ in this manner should be roughened in the mould before the mortar sets to improve the bond of the new mortar applied to the joint.

F. Casting the Tank Wall Segments:

When the base is prepared the tank wall segments can be cast. The drawing section shows how the reinforcing is assembled in the mould formwork ready for mortaring. The mortar must be thoroughly placed and compacted by trowel edge stirring. Curved screeds can also be made to work backwards and forwards along the mould to finish the segment to an accurate thickness and to smooth the surface evenly. After setting off for four to six hours the segment should be covered with wet sacks and tripped from the mould two days after casting for erection. Whilst this Manual sets out to record all the particulars of construction, there is an area of manual dexterity which can only be obtained from a training programme. The screeding referred to above is one of these instances.

G. Erection of the Tank Wall:

When withdrawn from the mould the bottom wire reinforcement is bent out by pulling them free from the mortar. Every eighth wire is, however, left in place but cut back to 10 mm to act as a support for the segment. A rebate has been formed in the mould to make this operation easy as the wires occur at the surface in this area and are readily broken free.

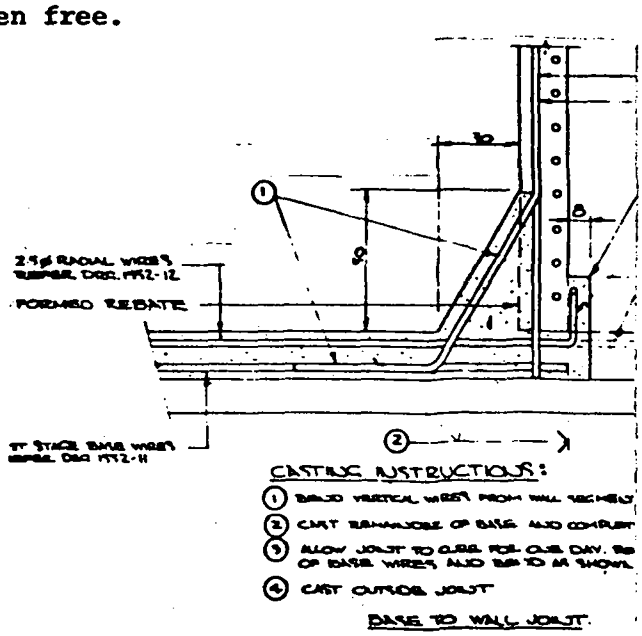


Fig. 17a

Once the wires are set as described above, the segment is lowered into the bottom mould. The segments are successively installed with the mesh fingered at each joint. This leaves an unmortared joint area 62 mm wide between each segment which is mortared from the outside after tying on a thick plywood backing strip to make plastering easier. However, once the plasterers are sufficiently skilled this strip can be done without.

Two other devices will be found useful in erecting the segments. Clamps can be used at each vertical joint to help grip the segments and hold them during the finishing operation or plastic strapping can be used to tighten the segments together using standard warehouse equipment. The mortar used for vertical plastering should contain 5% by weight of steel fibres as for the tank mortar but the cement sand ratio can be increased to 1 - 1.5 parts if desired.

Once mortared, the joints should be wetted down at least three times daily for the first two days. After that the backing strips can be removed.

The tank can now be water tested by adding 300 mm of water per day until full. This also assists in the cure of the mortar.

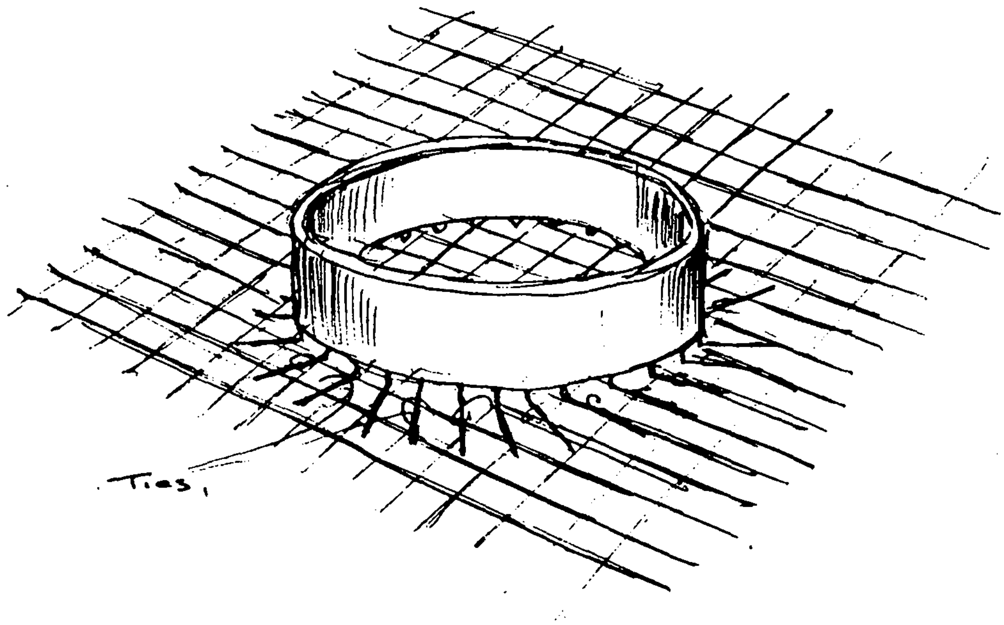
H. Casting the Tank Top:

During the construction of the tank walls the tank top can be prepared. This is cast in segments to enable it to be transported and lifted on to the top of the tank without any undue difficulty as the total weight of the top is 190 Kg and 300 Kg. The quarter segments can be handled by two or three men. The details of the mould for this quarter casting of the tank top are shown in Drwg. No. 1552-16.

Only bottom wires are provided in two directions and these are placed in the slots provided along the perimeter of the mould.

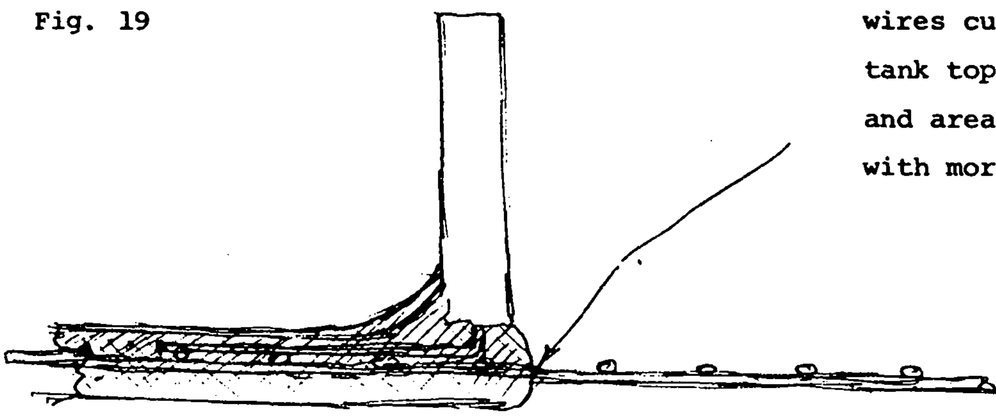
One segment is provided with a precast manhole ring which is set down on the mould surface and incorporated by mortaring. The details of this are shown in Drwg. No. 1552-17 where it will be noted that the protruding wires of the manhole ring are bent outward before the ring is set down on the wired up top segment mould.

Fig. 18



The wires set up in the top segment mould are not cut off at this juncture but left until the mortar is cured.

Fig. 19



wires cut after tank top is cured and area sealed with mortar

I. Casting the Centre Support Pole:

The centre post has a simple square section down the centre of which four 2.5 mm wires are located as reinforcement.

The mould detail is shown in 1552-24 and is a simple long box one side of which should be screwed on so it can be loosened to free the post once cast and cured. An alternative is to tape the mould so that the post could be ejected without dismantling the mould box.

J. Erection of the Tank Top:

When the segments are sufficiently cured they are placed on the top of the tank walls and supported in the middle by a 75 mm square precast post which has wires protruding top and bottom to locate it.

The segments should be set down on the wall perimeter and be fingered together ready for mortaring in-situ.

The first three segments can be positioned and the centre post located with the assistance of a man inside the tank. A 75mm wide piece of ply is wired up underneath each joint as a backing strip for the subsequent mortaring of the joints.

The last two side strips can also be fixed in position before the man climbs out from inside and finally the last segment is dropped in position.

The joints can be mortared using a 5% wire fibre mortar which is then cured in the usual manner. The mortar may be enriched with cement if desired and the joint area built up to a greater thickness.

Finally the perimeter of the tank top is secured by turning down and trimming the protruding wires. When this is done a thin 75 mm x 12 mm plank is warped round the top of the tank and the edge of the tank top cast in. See Drawing No.1552-17.

Notes: The centre support post is located at the bottom in a recessed area formed when the bottom is cast. The wires left sticking out of the bottom are first cut off and then hammered over to allow the post to sit in the recess.

The top wires protrude through the tank top joints and are used to secure the top of the post in position and are cast in when the joint mortaring is done.

In order to give sufficient landing to the segments as they are placed, a 200 mm square plate 15 mm thick is placed on top of the post but is provided with holes to let the post wires through.

Section IV. CONSTRUCTION OF CYLINDRICALLY MOUDED TANK

A. Materials List:

The quantity of materials required for the 9,000 and 18,000 litre tanks is given in Table V, Section II B.6 which records the net weight in position.

The following tables set out the configuration of the wire employed and the weight of each configuration cagegory.

TABLE VIII   9,000 LITRE TANK

Location	Layer	No. of Pieces	Length Meters	Total Length Meters	Weight
Bottom Drwg. No. 1552-12	1st Layer	56		140	
	2nd Layer	56		140	
	3rd Layer	150	0.650	98	
Sides Drwg. No. 1552-13	Circumferential	85	8	680	
	Vertical Wires	100	2.1	210	
	Doubling Wires	100	0.275	28	
Top Drwg. No. 1552-16	1st Layer	56		140	
	2nd Layer	56		140	
				1,576	60 Kilo

TABLE IX 18,000 LITRE TANK

Location	Layer	No. of Pieces	Length Meters	Total Length Meters	Weight
Bottom Drwg. No. 1552-12	1st Layer	74		228	
	2nd Layer	74		228	
	3rd Layer	198	0.750	129	
Sides Drwg. No. 1552-13	Circumferential	110	10	1,100	
	Vertical Wires		2.6	315	
	Doubling Wires		0.275	34	
Top Drwg. No. 1552-16	1st Layer	74		228	
	2nd Layer	74		228	
				2,490	97 Kilo

Miscellaneous:

Manhole

Centre Post Allow 1 Kilo

B. Construction:

This is an alternative method of construction to the segmental method described above in that it uses a cylindrical former instead of a segmental mould for making the tank walls. Drawing Nos. 1552-20, 21, 22, 23.

This form of construction should not be initiated until all the skills of construction of the segmental method have been mastered, and is a method most likely to be used where a tank making centre is established

The procedures for casting the bottom are the same as for the segmental tank but differ for tank wall forming which is done by positioning a cylindrical mould on the base instead of the precast segments.

The cylindrical mould in itself consists of a number of segments which are bolted together with a strip of timber between each part. These timber strips can be withdrawn after plastering is completed in order to release the segments of the mould for removal. Drawing Nos. 1552-20 & 21.

When the cylinder mould is assembled and positioned on the prepared base, placing of the wire reinforcement can begin. This starts with the fixing of the internal spacer wires used to give the correct cover of mortar to the main steel. This is the first step shown in Drawing No. 1552-22 & 23.
This is the first step shown in Drawing
This layer consists of a number of widely spaced wires which are bound tightly round the mould. To do this loops should be formed at the end of each wire hoop which are levered up tightly and tied in position by means of tie wire. (The wire is a soft 16 or 18 gauge wire.)

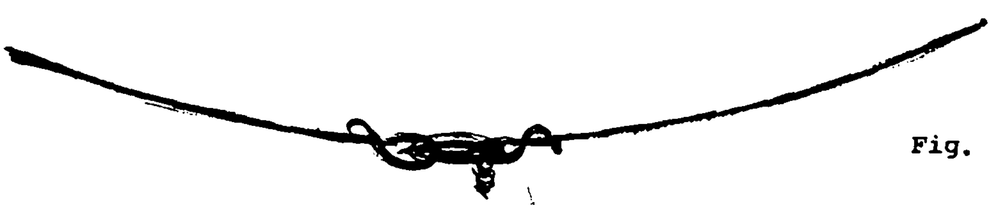
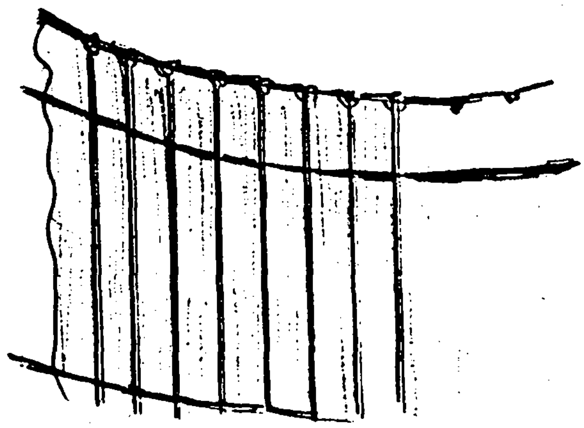


Fig. 20

In the next operation vertical wires are placed at 3" centres around the mould and may be temporarily suspended by looping them over the top of the mould. In fact the top of the mould can be notched to locate them.

Fig. 21



When these wires are located further spacer hoops are added as shown in the appropriate stage of Drawing No. 1552-22 and on top of these, further widely spaced vertical rods are placed. At this point, for the purposes of spacing, tie wire can be used to tighten up and positively locate the wires.

Then the final circumferential layer of wire is wound on continuously starting with 14 coils of 2.5 mm wire spaced at 12 mm. At this point short doubling wires should be inserted at the bottom between the wires of the first layer of vertical steel, as shown in Drawing Nos. 1552-22 and 23.

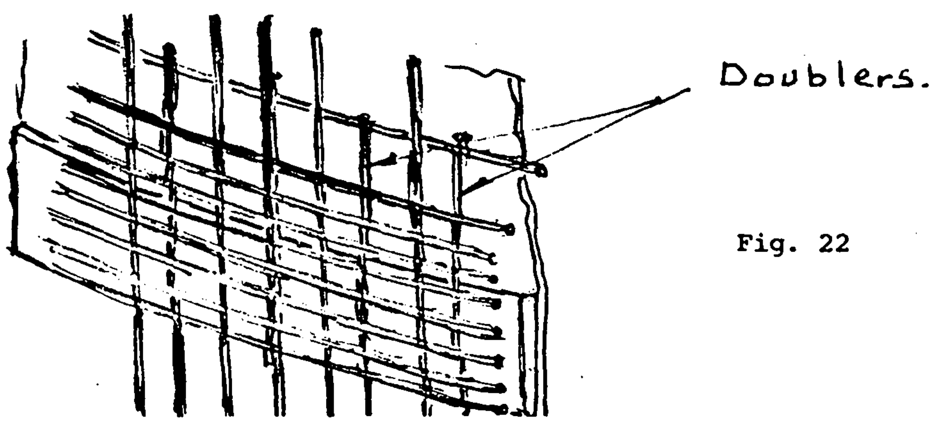


Fig. 22

Winding should then continue at 25 mm spacing which can be increased to 30 mm spacing and finally 35 mm in the last 900 mm towards the top of the tank. Again tie wire should be used to secure the hoop wire, care being taken to keep this tight during the winding operation.

A coil unwinder device mounted on wheels to permit it being towed round the tank greatly facilitates the operation.

It should also be noted that wherever it proves necessary, nails can be driven into the inter-segment timbers of the mould in order to hold the specing of winding more or less accurately. These nails are withdrawn progressively during the mortaring operation.

Mortaring:

Vertical mortaring is not a difficult operation when a wire fabric exists to support the mortar. The mortar itself must be kept relatively stiff to prevent slump occurring and for this reason well mixed mortar is required as poorly mixed mortar tends to increase its slump with elapsed time and can lead to eratic results.

During the mortaring operation care must be taken to progressively compact the mortar to obtain a dense material. A varying degree of porosity will occur inside dependent upon the skill of the operators, but this can be fixed later by touching up the areas affected with plain mortar trowelled across the surface. As skills develop porosity will become insignificant.

Mortaring is continued until an even coating up to 18 mm thickness is obtained. Once complete the mortar is allowed to set off and thereafter for two days the surface is kept moist. At the end of twenty-four hours the cylindrical mould can be stripped off.

One point in the above procedure to be noted is that care must be taken to avoid the mortar dropping into the tank bottom reinforcement at this stage, which can be done by slipping a piece of emery cloth under the bottom during the commencing of mortaring away from the bottom.

When this cloth is withdrawn the under surface is left roughened for subsequent bonding of the base mortar.

The reason for this care is that the vertical wires of the side wall have to be spread backward after the mould is stripped out in order to increase the leverage of the wire at the joint.

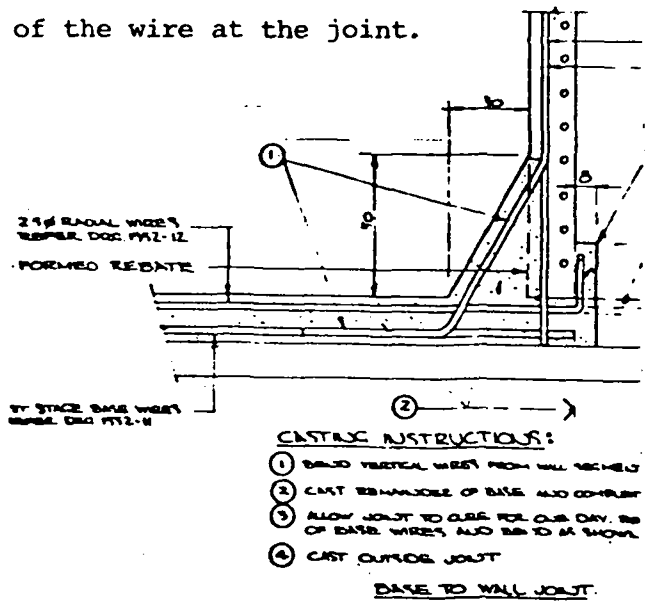


Fig. 23

When this is done the bottom can be plastered and coved up the walls using a 5% weight of wire fibre in the mortar but increasing the slump for ease of placement and finishing.

Section V. CONSTRUCTION OF SMALL PRECAST FLAT PLATE TANK

A. Materials List:

The quantity of materials required for the 2,250 litre tank illustrated in this section is given in Table V, Section II B.6.

The wire configurations follow clearly from the text so are given in calculated form.

TABLE X - APPROXIMATE COST OF MATERIAL

Cement	168 lb	@	11¢	18.48
Sand	336 lb	@	1.1¢	3.70
Water	45 lb	@	2¢	.90
Fibre	30 lb	@	97¢	29.10
H.T. Steel	12 lb	@	110¢	13.20
Tie Wire				.50
Additives				1.20
				$67.08

B. Construction of Tanks Without High Tensile Reinforcing except for Fingering Steel:

This tank is used to illustrate a precast flat plate type of construction. It specifically omits full wire reinforcing and restricts the use of reinforcing other than fibres, to joint steel and edge reinforcing. This leads to a simplified and less costly construction but can only be used for small tanks. In larger tanks full wire reinforcing should not be used. Whether or not wire should be omitted is not to be arbitrarily decided as substantial design considerations are involved in such a decision.

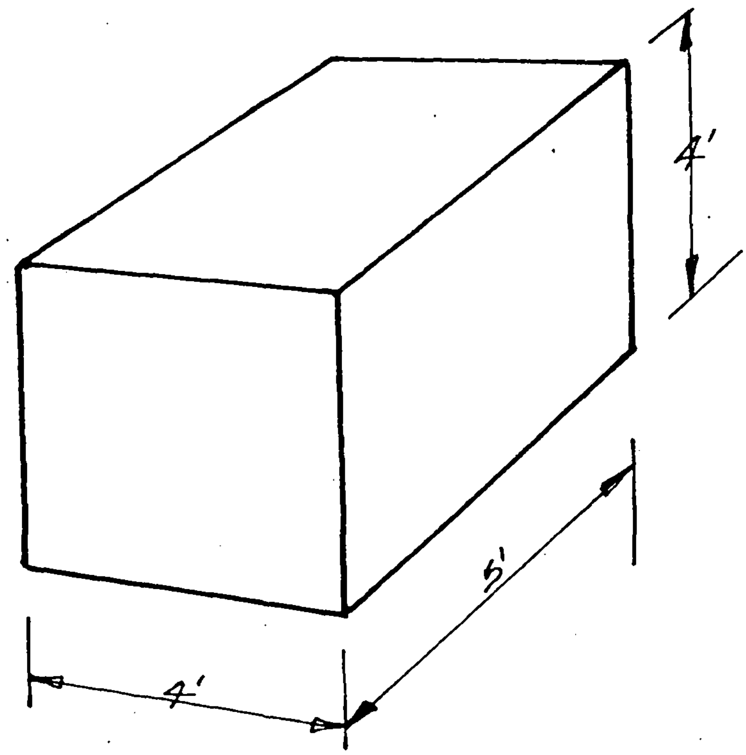


Fig. 24

Fig. 24 shows the shape of the tank. As this section is excerpted from other work all dimensions have been left in inches, but metric sizes can be put alongside these figures if desired.

The construction sequence has been set out in the following form:

1. Tank Plates

2. Preparation of Plates for Assembly of Tank

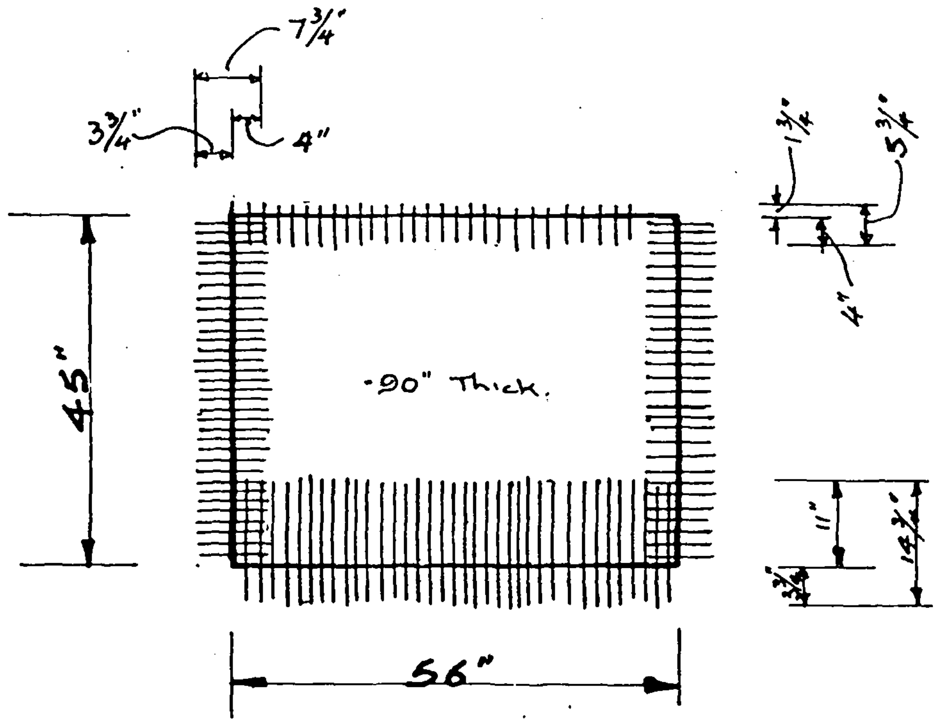
3. Moulds for Forming the Plates

4. Preparation for Casting the Plates

5. Assembly of the Tank

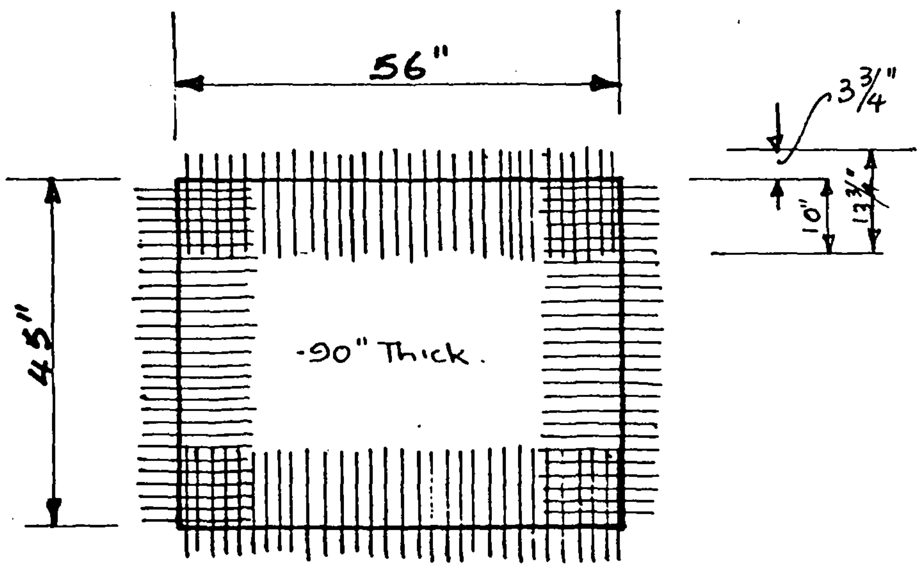
B. 1. Tank Plates

a) Long Side Plates:

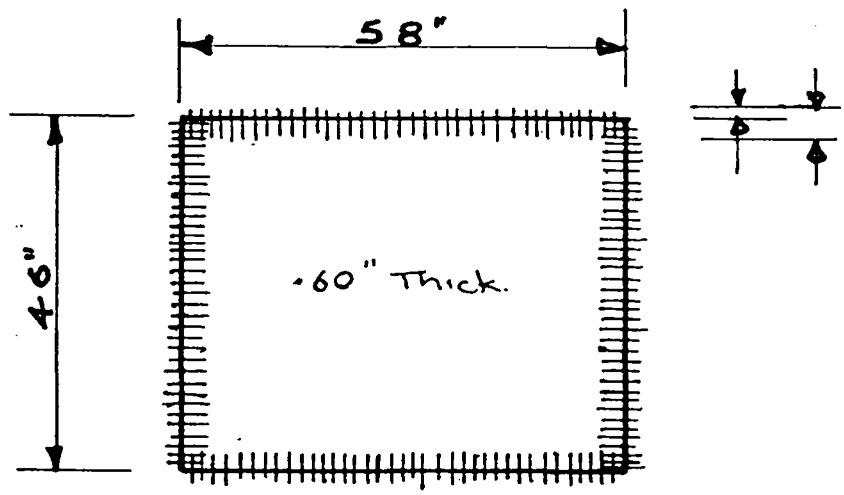


2 off required.

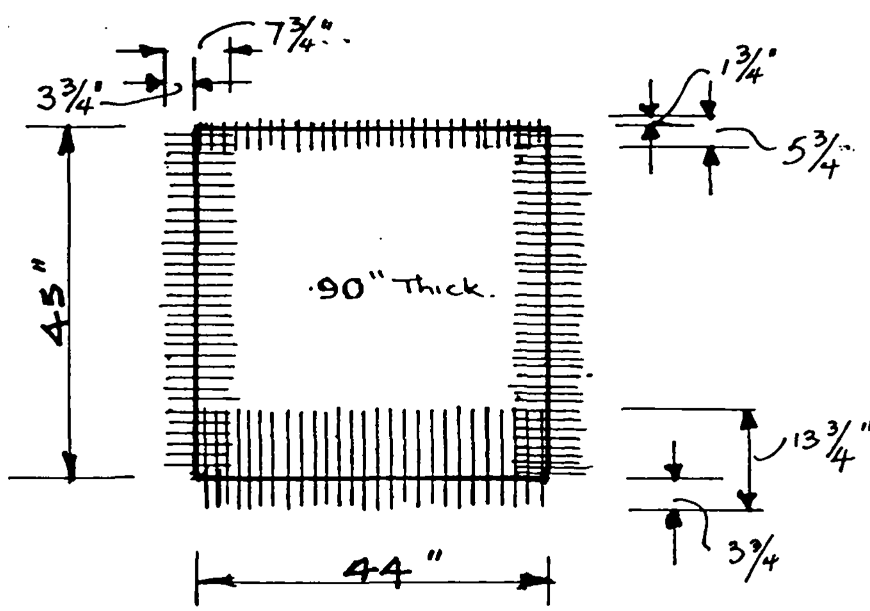
b) Bottom:



c) Top:



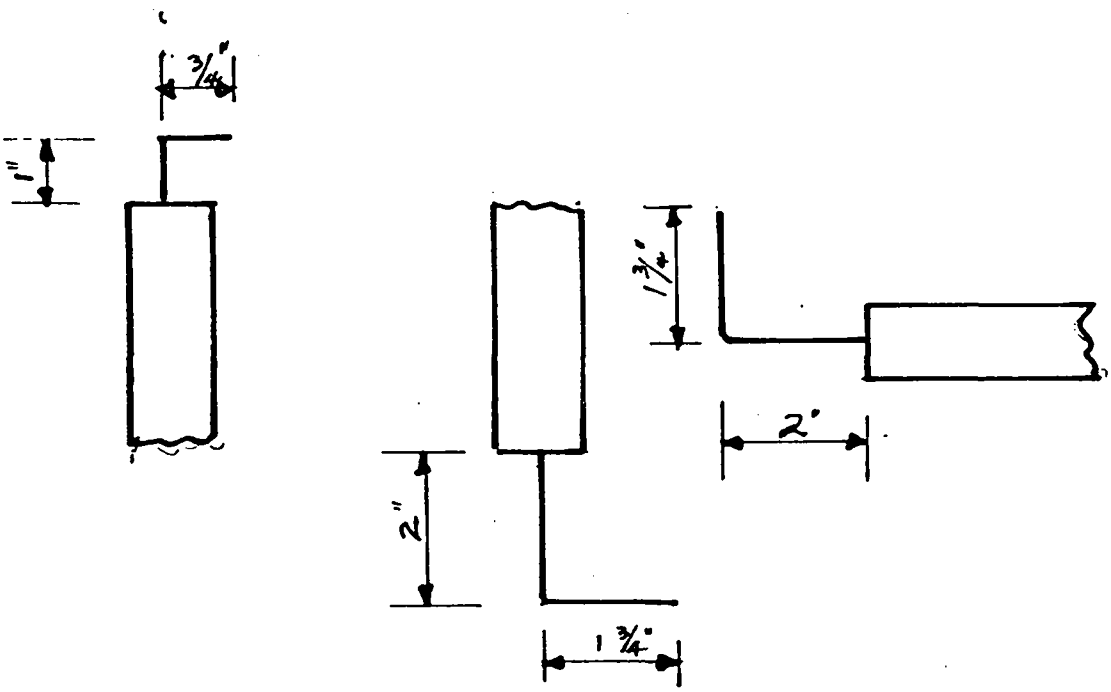
d) Short Sides:



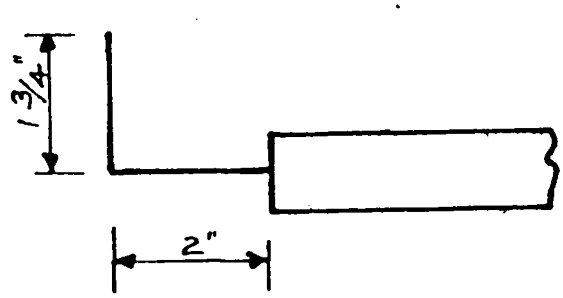
B. 2. <u>Preparation of Plates for Assembly of Tank</u>

The wires which extend out from the edges of the plates must be bent as shown in the following sketches:

a) Long Side Plate:

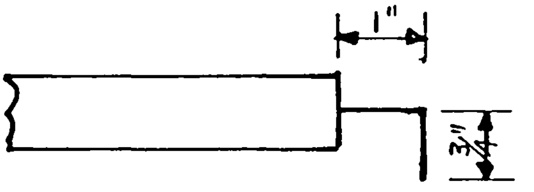


b) Bottom Plate:



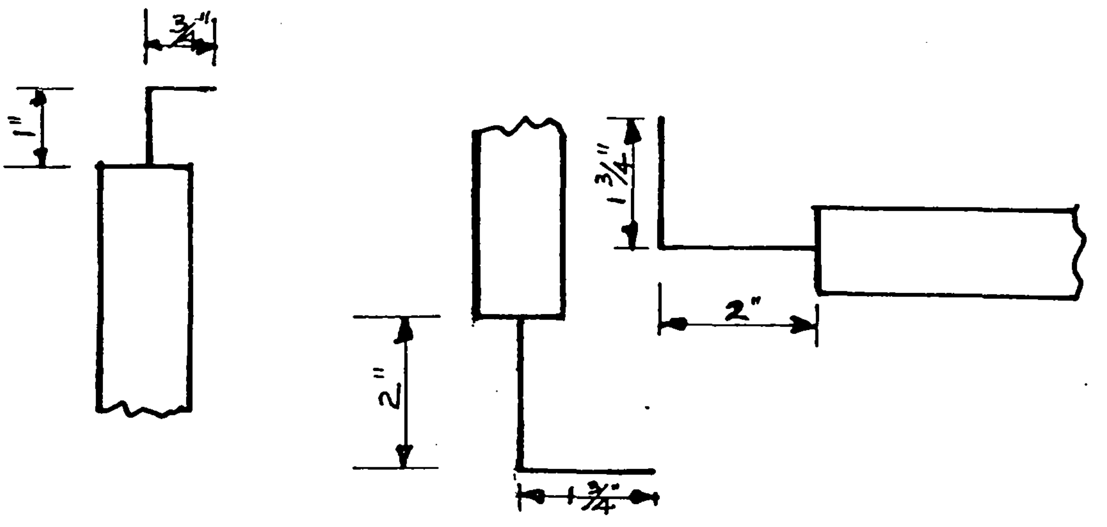
all around

c) Top Plate:



all around

d) Short Side Plates:



V. B. 3 Moulds for Forming the Plates

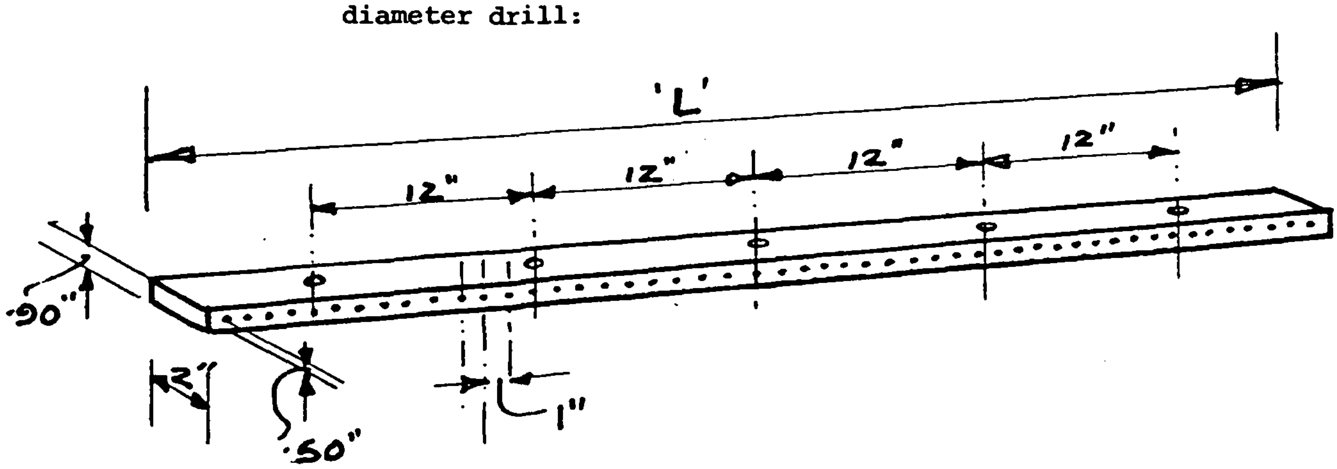
Three moulds are required for casting the plates for making a flat sided tank:

A. Long Side Moulds & Bottom Mould

B. Short Side Mould

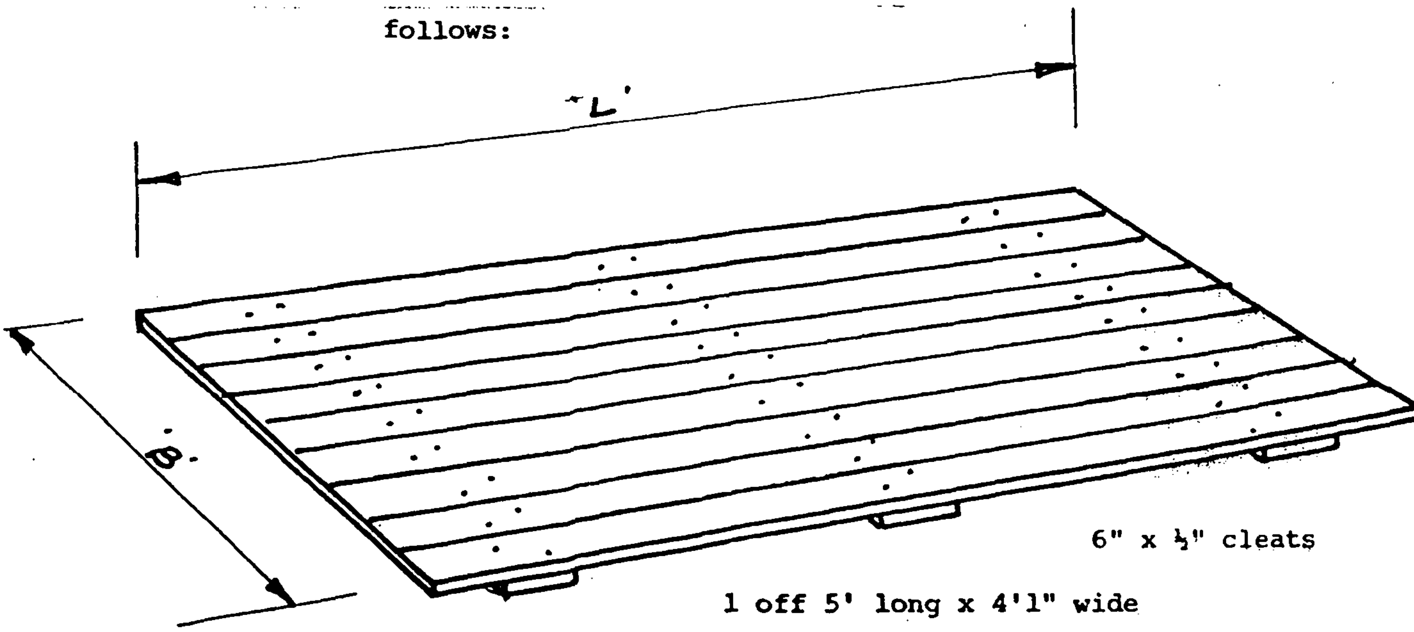
C. Top Mould

The moulds for A & B are made by preparing strips of 2" x .90" timber - which are drilled at 1" centres, slightly off-centre, using a 3/16" diameter drill:



Vertical countersunk holes ¼" diameter are also drilled in these edge strips for securing them with wood screws to the base.

The bases are made up of 6" x ½" dressed timber as follows:

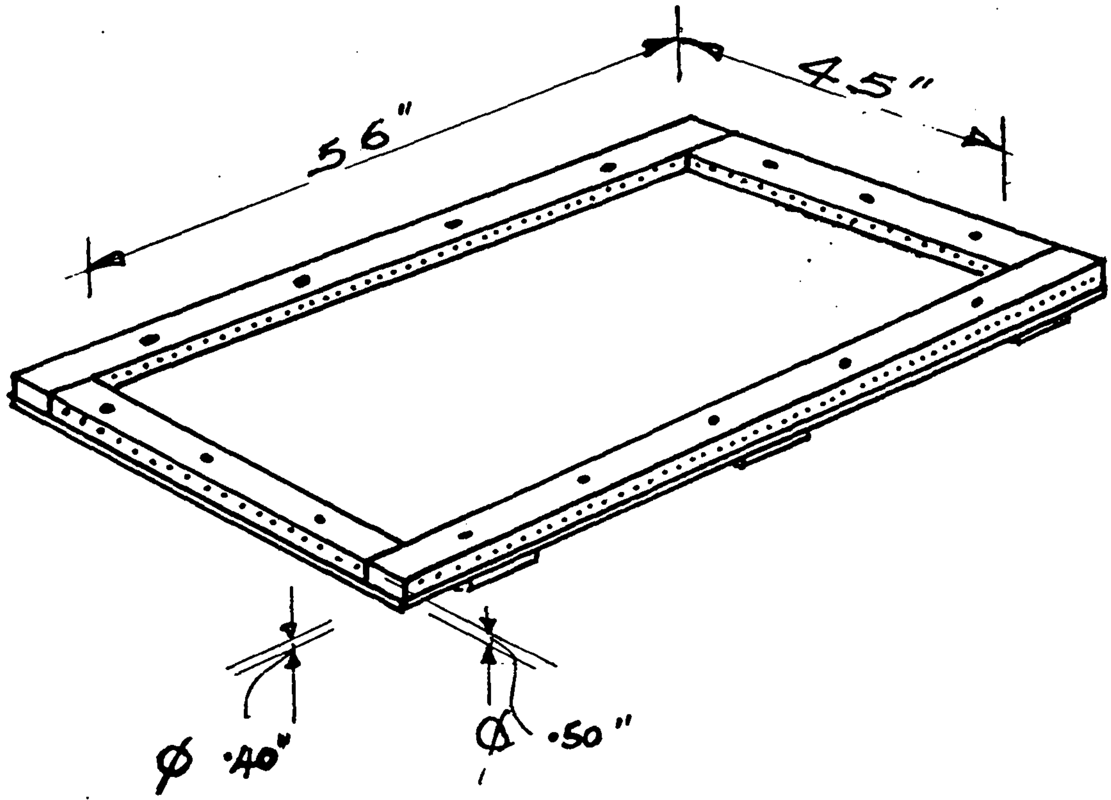


1 off 5' long x 4'1" wide

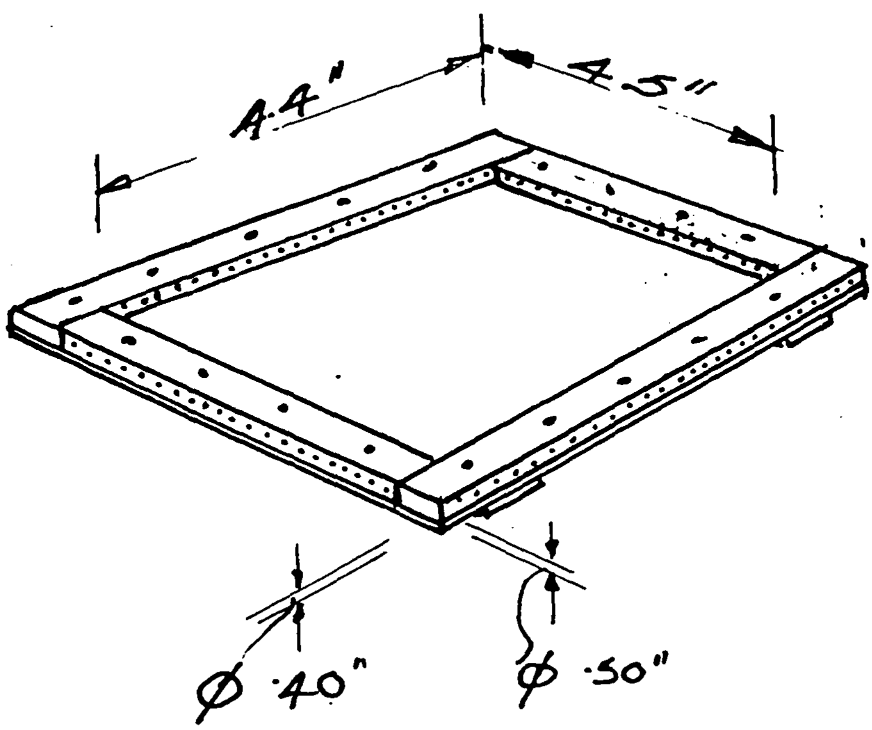
1 off 4' long x 4'1" wide

The edge strips are then screwed onto this base as follows:

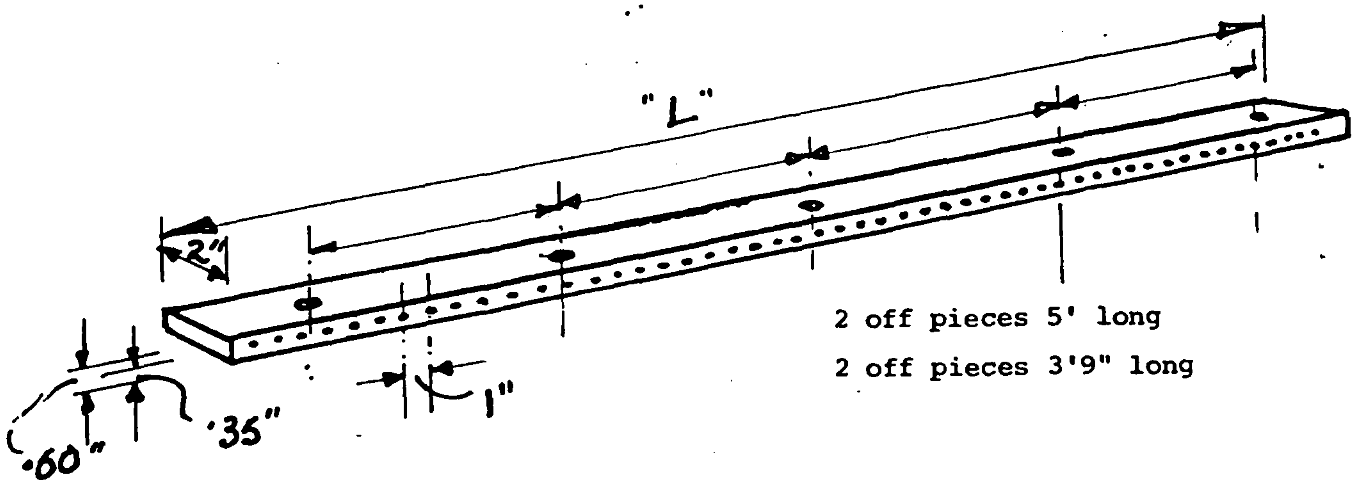
A. Long Side Moulds & Bottom Mould:



B. Short Side Mould:



C. The Top Mould edge strips are made as follows;

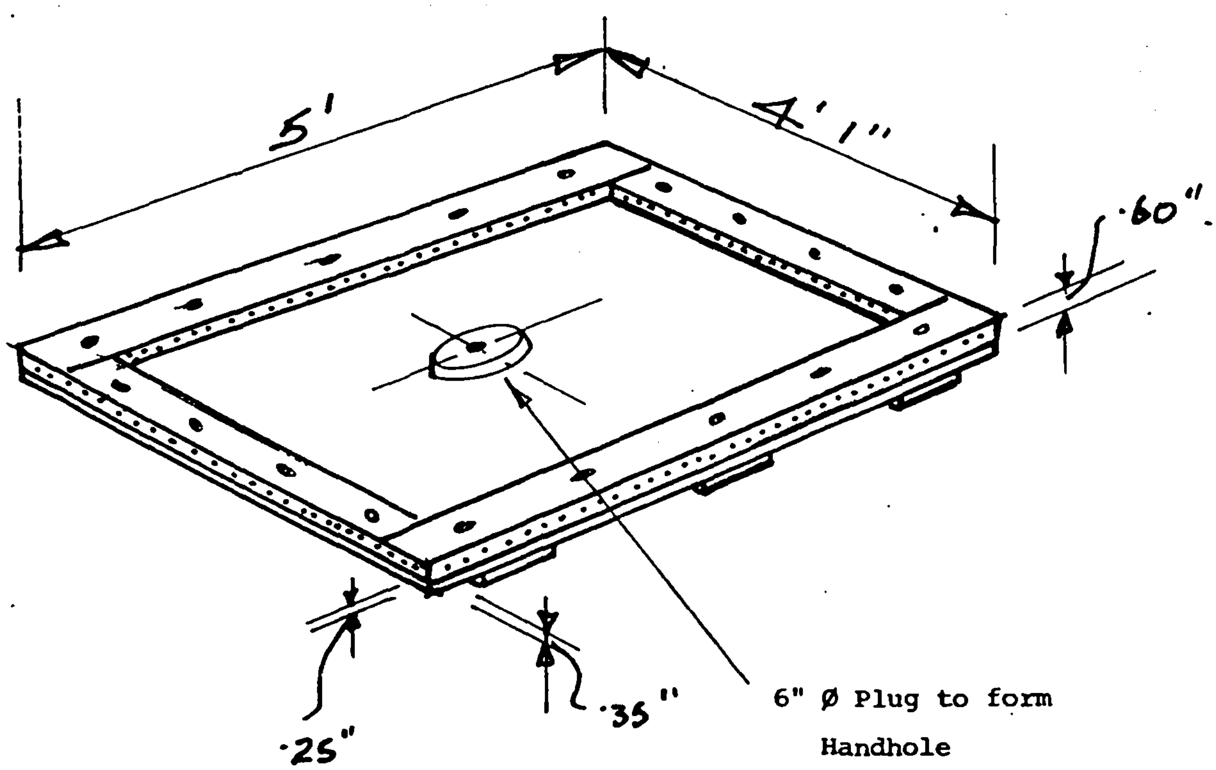


2 off pieces 5' long

2 off pieces 3'9" long

The top mould edge strips are screwed onto a 5' x 4'1" base.

A plug to form a hole should be secured to the mould.

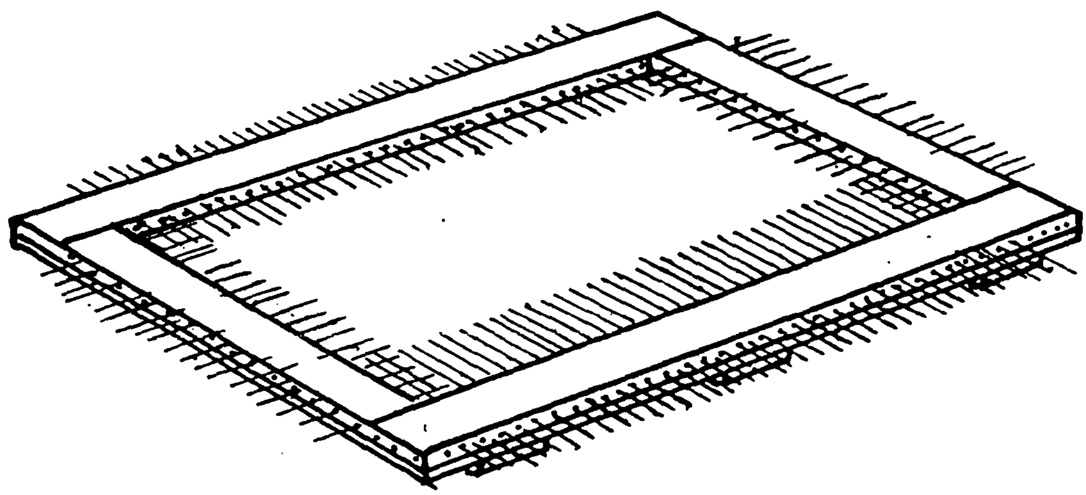


6" Ø Plug to form Handhole

B. 4 <u>Preparation for Casting the Plate</u>

1) The moulds are first lightly oiled. Care must be taken to wipe the surfaces to free them from excess oil, then set up on trestles so the under side can be tapped during casting.

2) The edge reinforcing wires must then be inserted in the mould to the correct depth as shown in Section III.



3) The mould is then ready to add the mortar and level it.

4) The mortar is then prepared as set out in the appropriate section of this manual except that the slump obtained from the slump cone test is different to that used for hand mortaring vertical surfaces. The slump, before adding the wire fibres, should be 4" (compared with 2.5" for hand mortaring) and the slump after addition of fibres between 1½" and 2".

5) The mortar is added to the mould and roughly levelled with trowels and then the under side of the mould is tapped moderately with a hammer to vibrate the mortar free of blow holes and to fill the mould to the edges. After this the mould is again levelled and the surfaces 'floated'.

6) The mould is then left for 8 hours to set and then damp sacking placed over the surface and kept moist for 2 days.

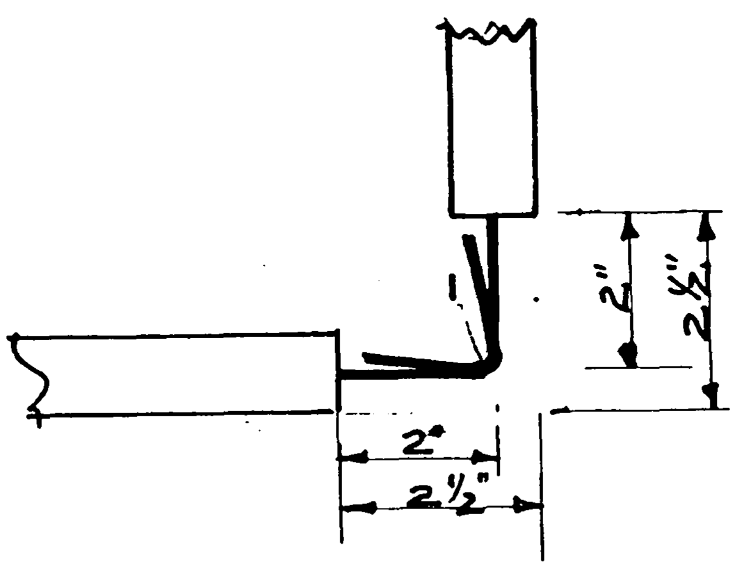
7) After two days curing the mould can be dismantled and the plate removed.

8) It is then placed in water or again covered by damp sack for several more days.

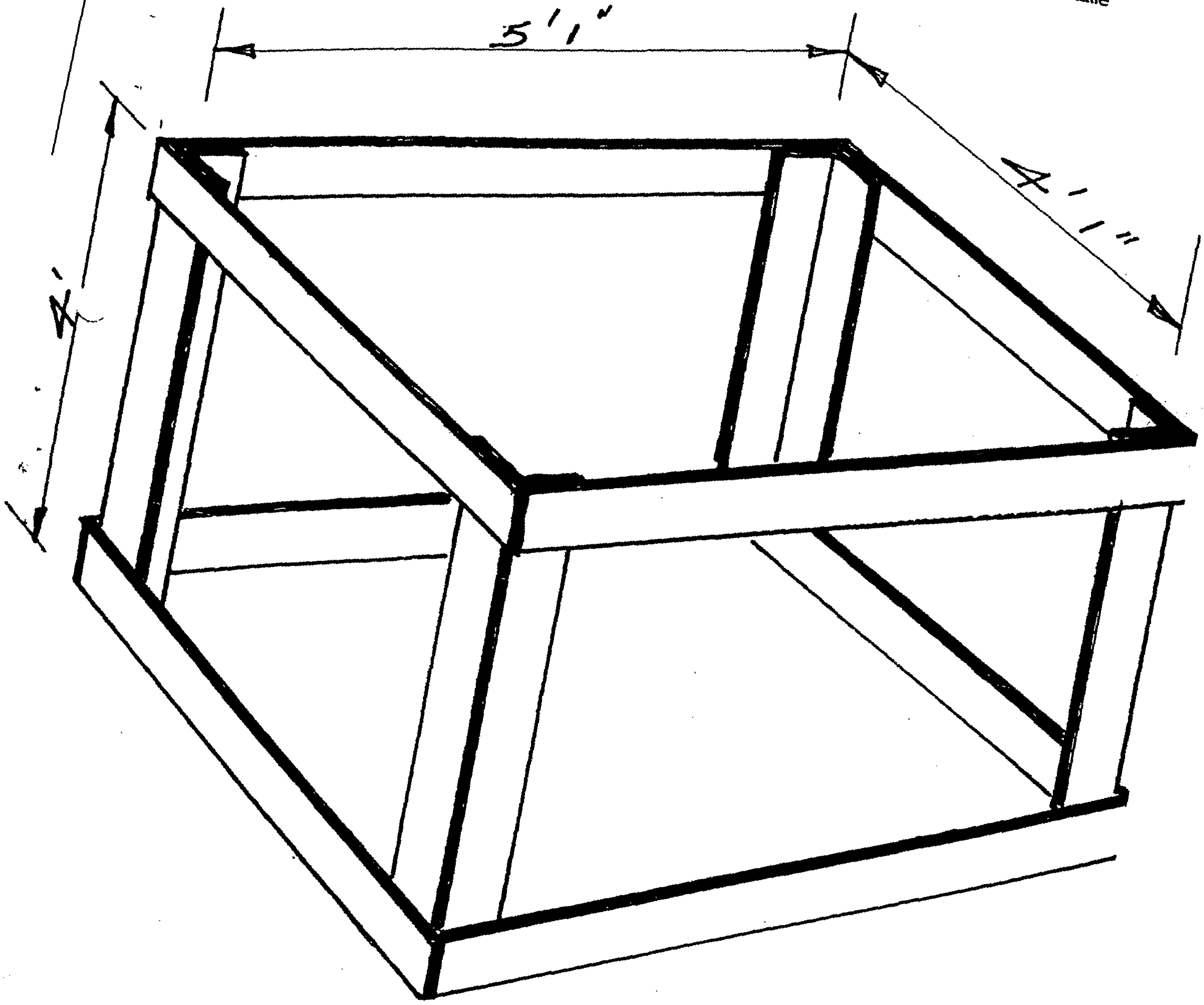
When a set of plates are made they can be assembled into a tank.

B. 5. <u>Assembly of the Tank</u>

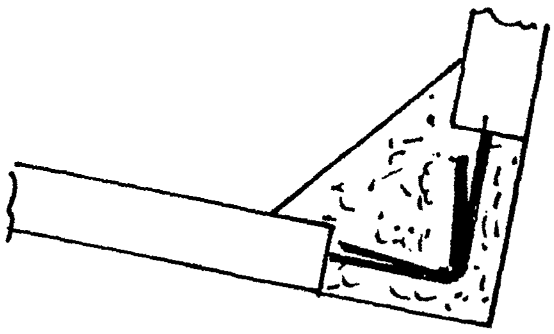
When the plates are prepared as set out in Section IV they are set up for corner mortaring.



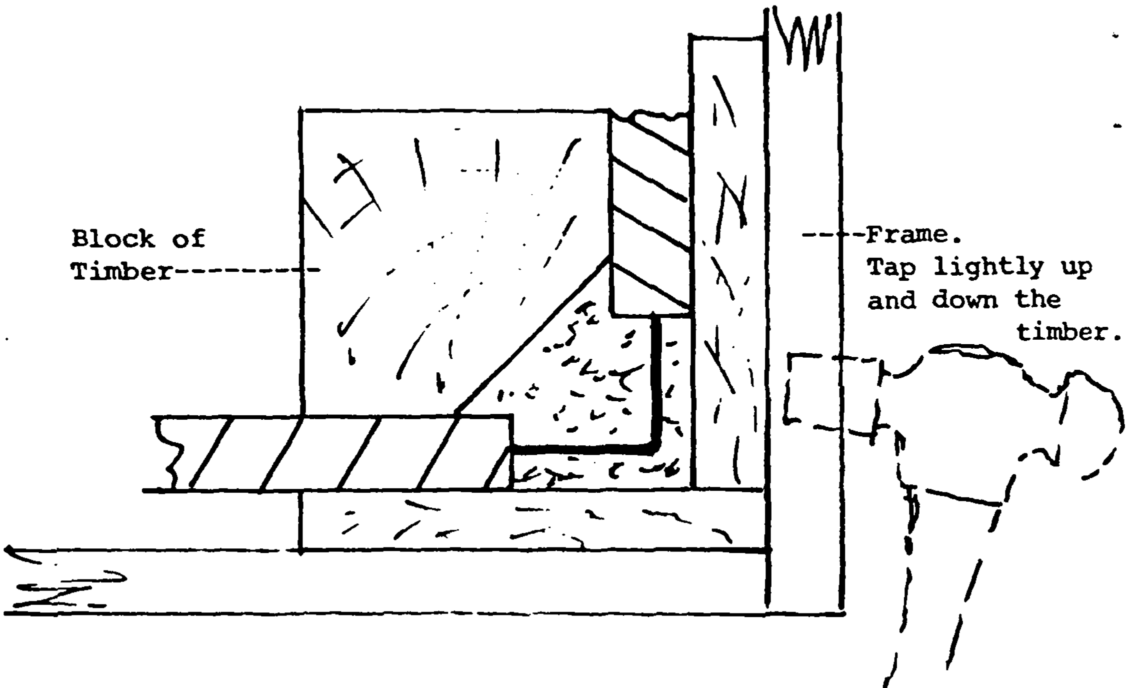
This is best done by placing the four sides in a frame made up as follows:-



The corners of the side are then mortared from the inside:

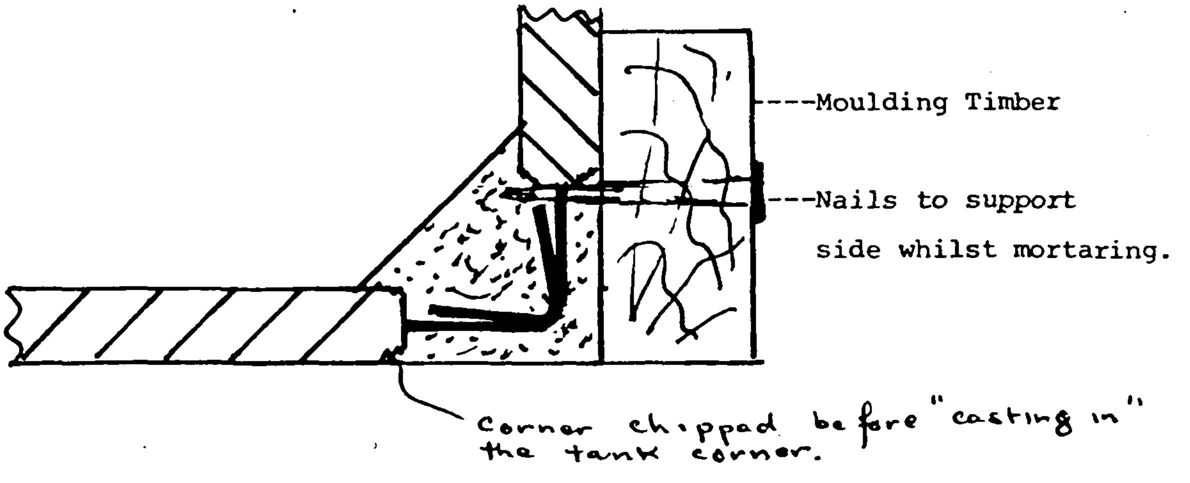


The mortar used for this purpose should have a slump of 2.0" which may however be varied to suit the operators convenience. When the mortar is placed up the joint a piece of timber is then held in place by one man while a second taps up and down the corner to compact the mortar.

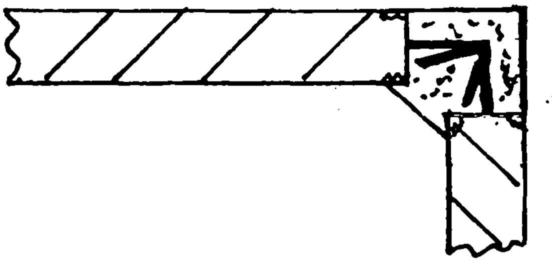


When this is done the mortar will slump away from the top and this should then be topped up.

When the corners are complete the sides are left in the frame for one day to cure. Water should be sprinkled onto the corner mortar every four to five hours. After this period the sides of the tank can be lifted, still in the frame, and placed on top of the bottom plate which is laid on a flat floor which has been greased or painted to prevent sticking:



The bottom corner can then be mortared in the same way as the sides:



The top can be placed and mortared from the outside.

Section VI. TANK REPAIR PROCEDURE

Two types of repair may be required in the case of damage to the tanks.

1. Cracking due to impact and minor shattering. No damage to fabric. Repairs are undertaken as follows:

   A. For shattering:

      (i) Mix a mortar of:
      1.0 of sand,
      1.0 of cement,
      0.45 of water,
      to a trowelling consistency.

      (ii) Clean up area and remove loose debris. Straighten if necessary.

      (iii) Trowel on the mortar and finish the surface.

   B. For cracking:

      (i) Chip out the line of crack with a cold chisel or scrape it out with a sharp blade instrument.

      (ii) Fill the crack with an epoxy resin cement. These repair kits are almost universally obtainable at hardware stores.

2. Pierced and holed tanks with fabric damage.

   A. Mix mortar as for (i).

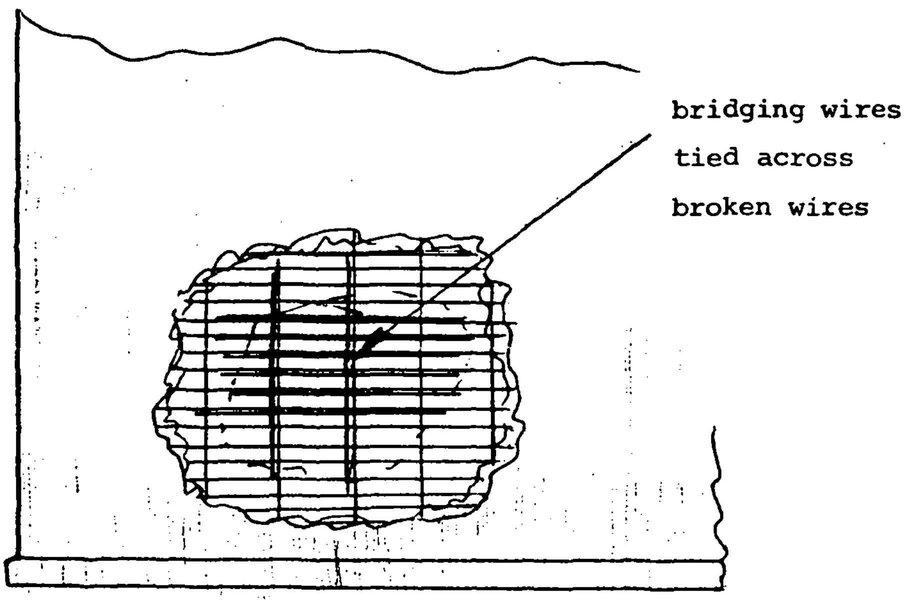
   B. Pulverize the area of damage to free the wires from the concrete until a clean looking area is obtained, in which the intact perimeter wire is uncovered.

C. Straighten up the reinforcement as well as possible and then tie on new bridging reinforcement or tie in two pieces of mesh.

D. Paste the edges of the old concrete with a neat cement wash:

1.0 of cement and water to make
a liquid paste.

E. Mortar the area to complete the repair. A back up piece of ply can be used if practical.



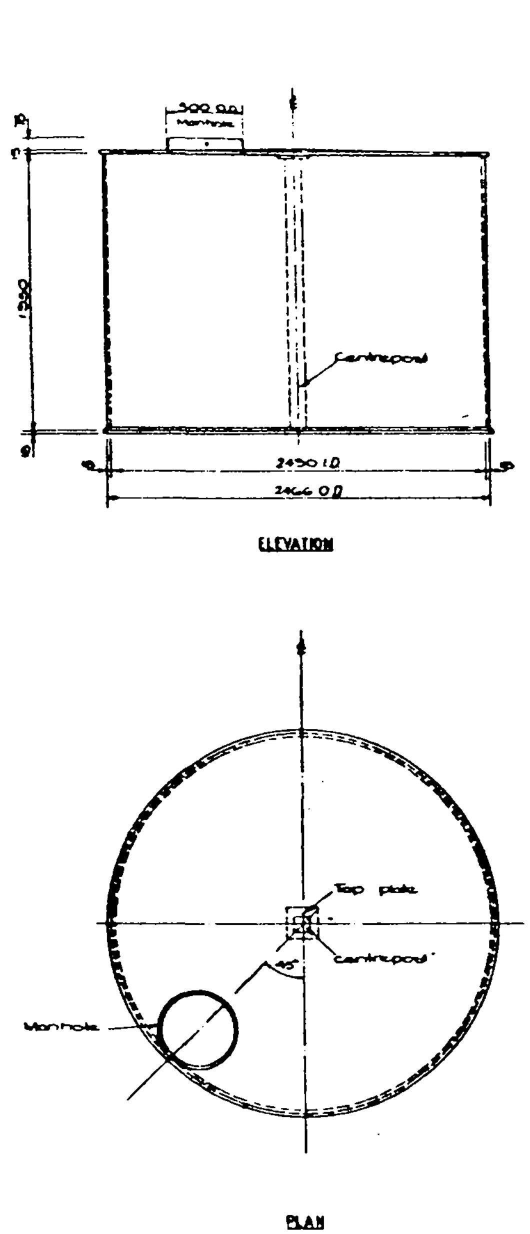
Internal Porosity:

After mortaring some porosity may be found on interior surfaces at the mould interface. If these are small they may be filled by 'bag' washing the surface which is done by rubbing in a neat cement mortar using a piece of coarse hemp sacking.

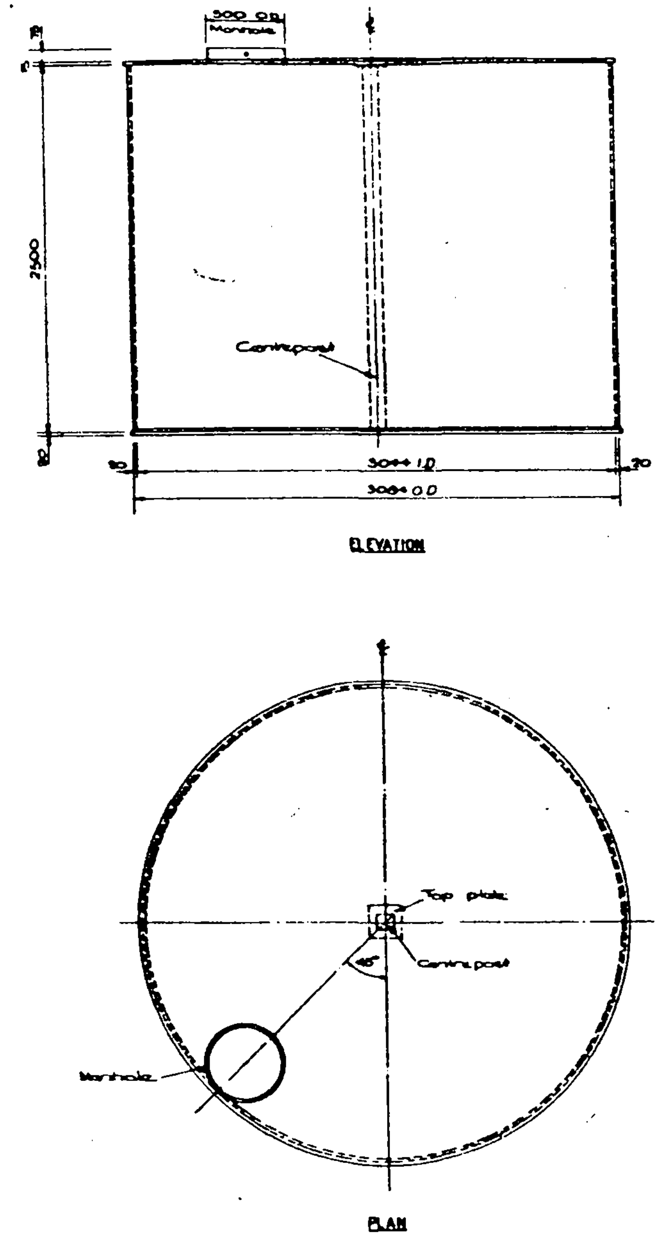
For larger clusters of holes filling should be done with the aid of a pointed trowel to work the cement into the holes.

Annex 1: Engineering Drawings

Drawing No. 1552-10	9,000 and 18,000 Litre Tanks General Arrangement
Drawing No. 1552-11	Bases - 9,000 and 18,000 Litre Tanks Moulds and Wire Lay-up 1st Stage Cast
Drawing No. 1552-12	Bases - Mould for Casting Base to Wall Joint. Plans and Details
Drawing No. 1552-13	Sides - 9,000 Litre Tanks Mould and Wire Lay-up. 9 Required
Drawing No. 1552-14	Sides - 18,000 Litre Tank Mould and Wire Lay-up. 11 Required
Drawing No. 1552-15	Sides - 9,000 and 18,000 Litre Tanks Mould Details
Drawing No. 1552-16	Top - 9,000 and 18,000 Litre Tanks Sector Moulds and Wire Lay-up
Drawing No. 1552-17	9,000 and 18,000 Litre Tanks Construction Joints Details
Drawing No. 1552-20	9,000 Litre Tank Internal Cylindrical Mould for Alternative Method of Casting Walls
Drawing No. 1552-21	18,000 Litre Tank Internal Cylindrical Mould for Alternative Method of Casting Walls
Drawing No. 1552-22	9,000 Litre Tank Wire Lay-up Sequence for Alternative Method of Casting Walls
Drawing No. 1552-23	18,000 Litre Tank Wire Lay-up Sequence for Alternative Method of Casting Walls
Drawing No. 1552-24	Centre-Post, Top Plate, Manhole Reinforcement and Mould Details



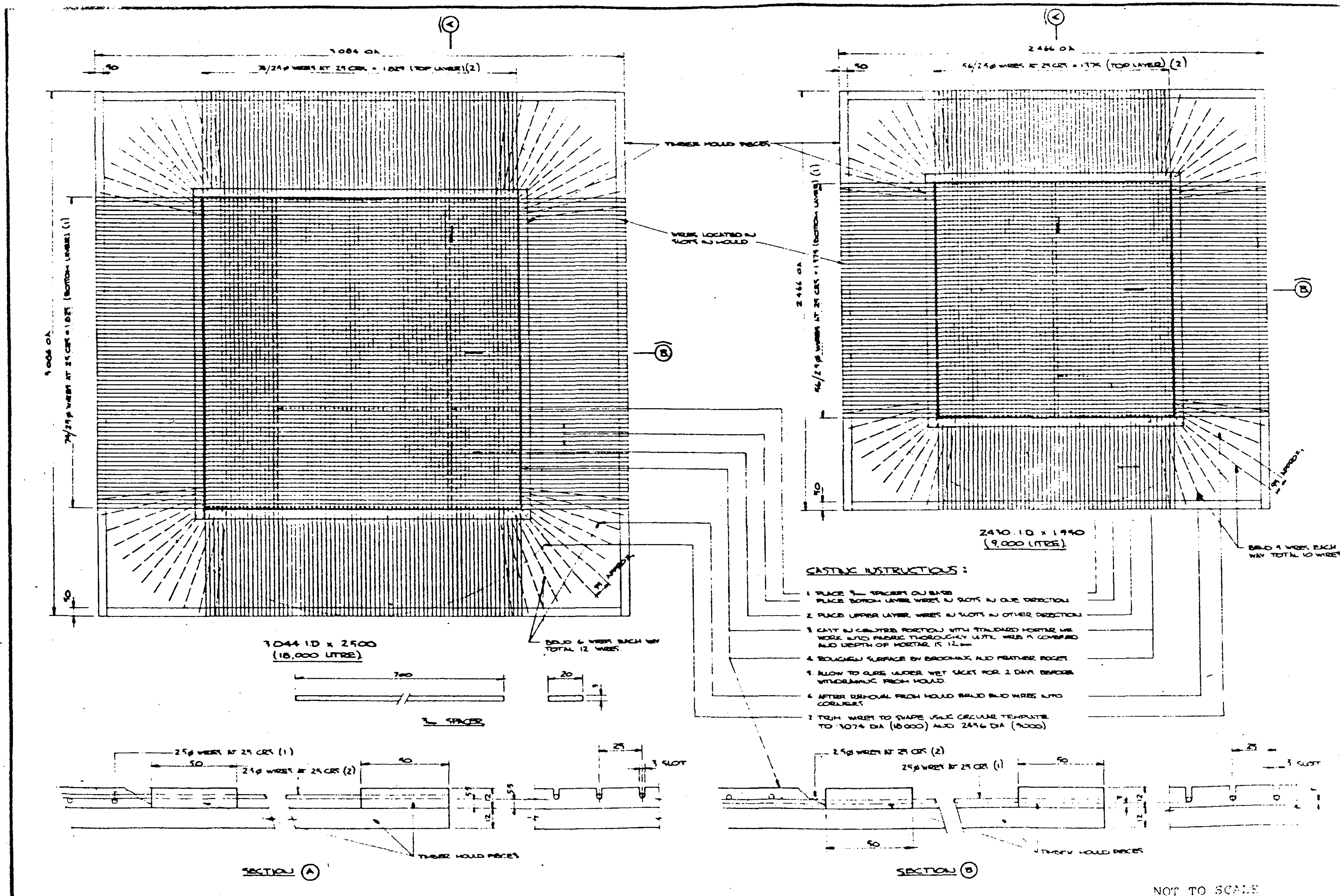
9000 LITRE TANK



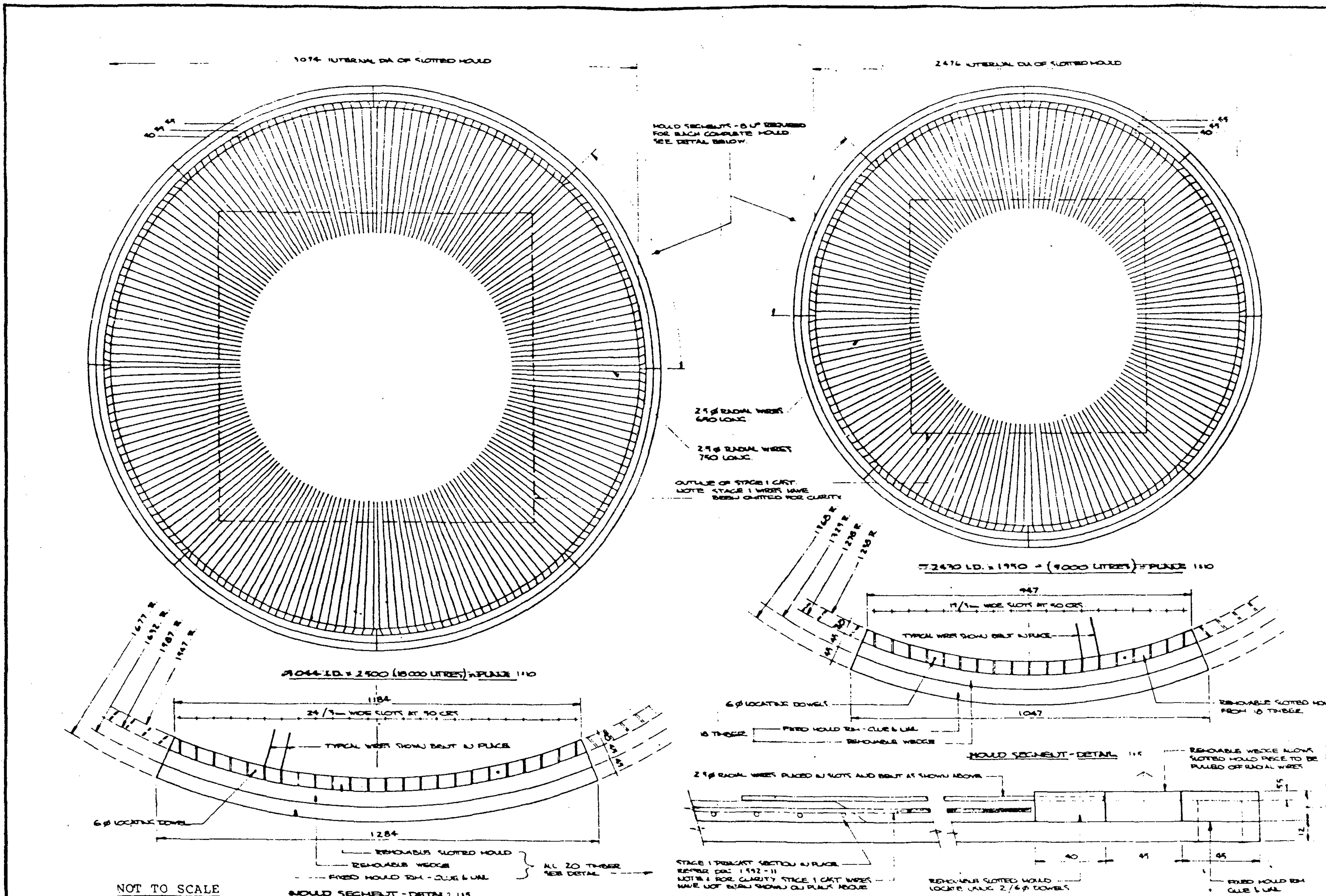
18000 LITRE TANK

NOT TO SCALE

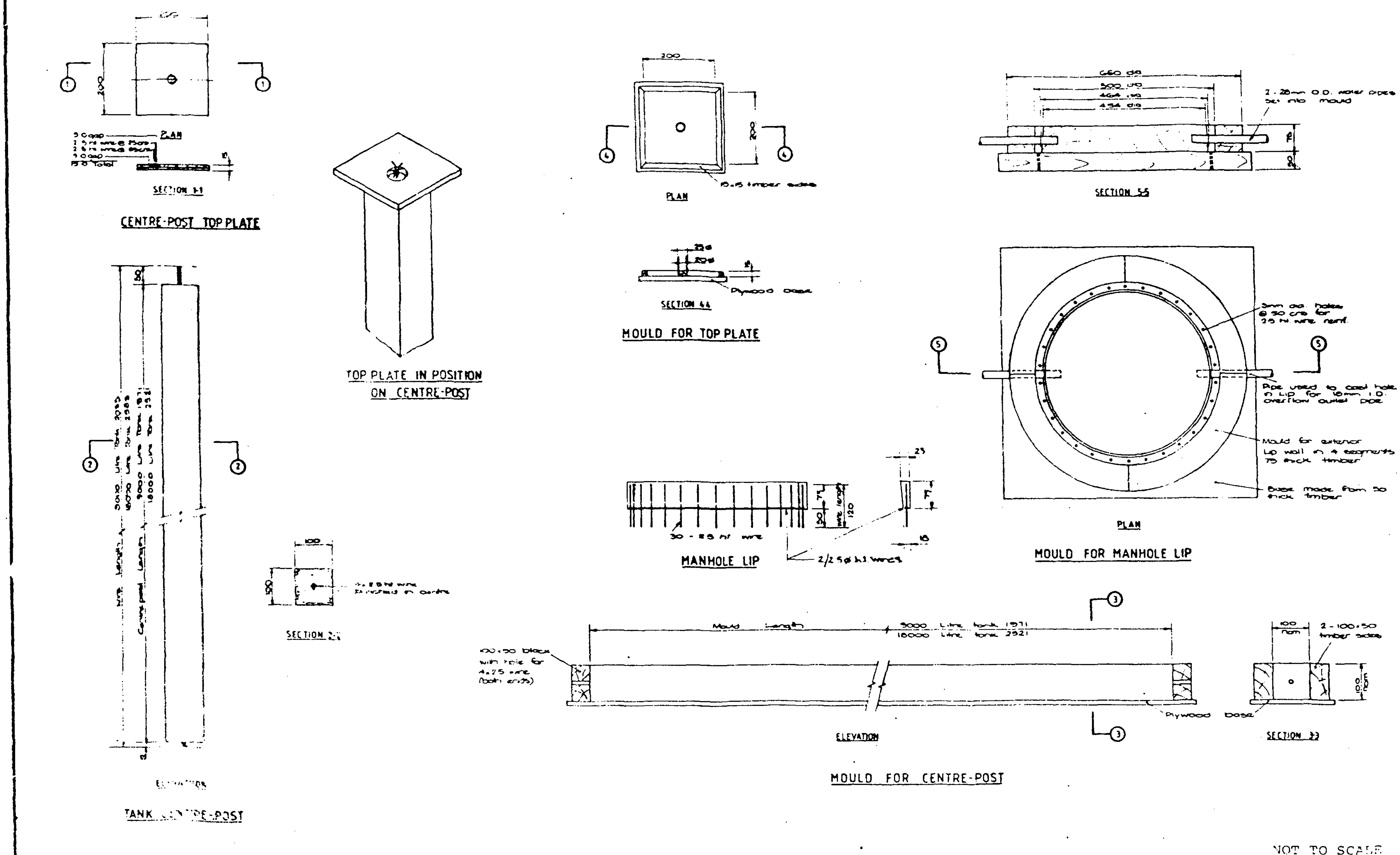
WHO PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	9000 & 18000 LITRE TANKS GENERAL ARRANGEMENT	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 10



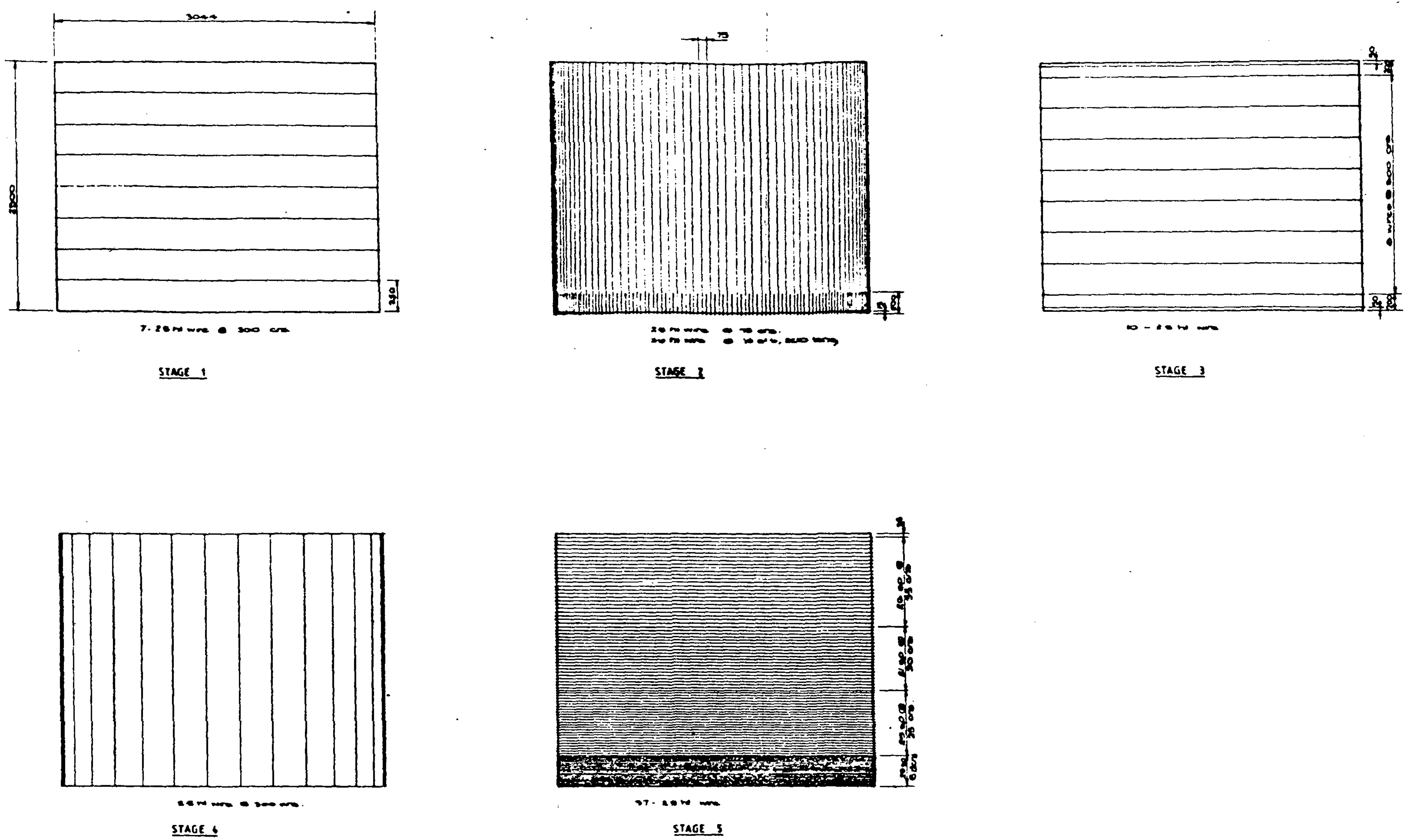
W.H.O. PACIFIC REGION.	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS.	BASES - 9,000 and 18,000 LITRE TANKS. MOULDS & WIRE LAY-UP. 1st STAGE CAST.	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 11



W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	BASES - MOULD FOR CASTING BASE TO WALL JOINT. PLANS and DETAILS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 12



WHO PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	CENTRE-POST, TOP PLATE, MANHOLE REINFORCEMENT & MOULD DETAILS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 24



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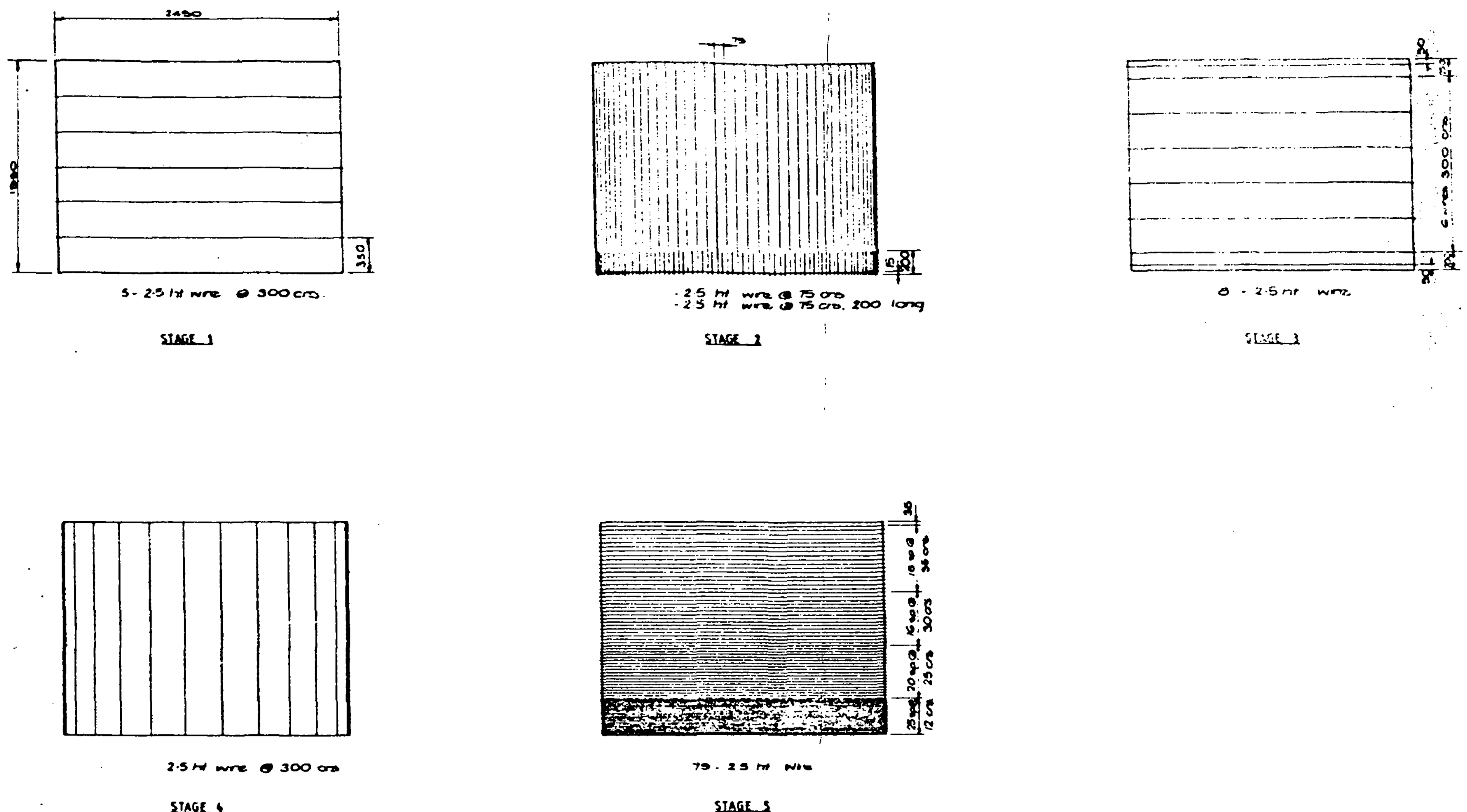
W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	18,000 LITRE TANK. WIRE LAY-UP SEQUENCE FOR ALTERNATIVE METHOD OF CASTING WALLS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 23



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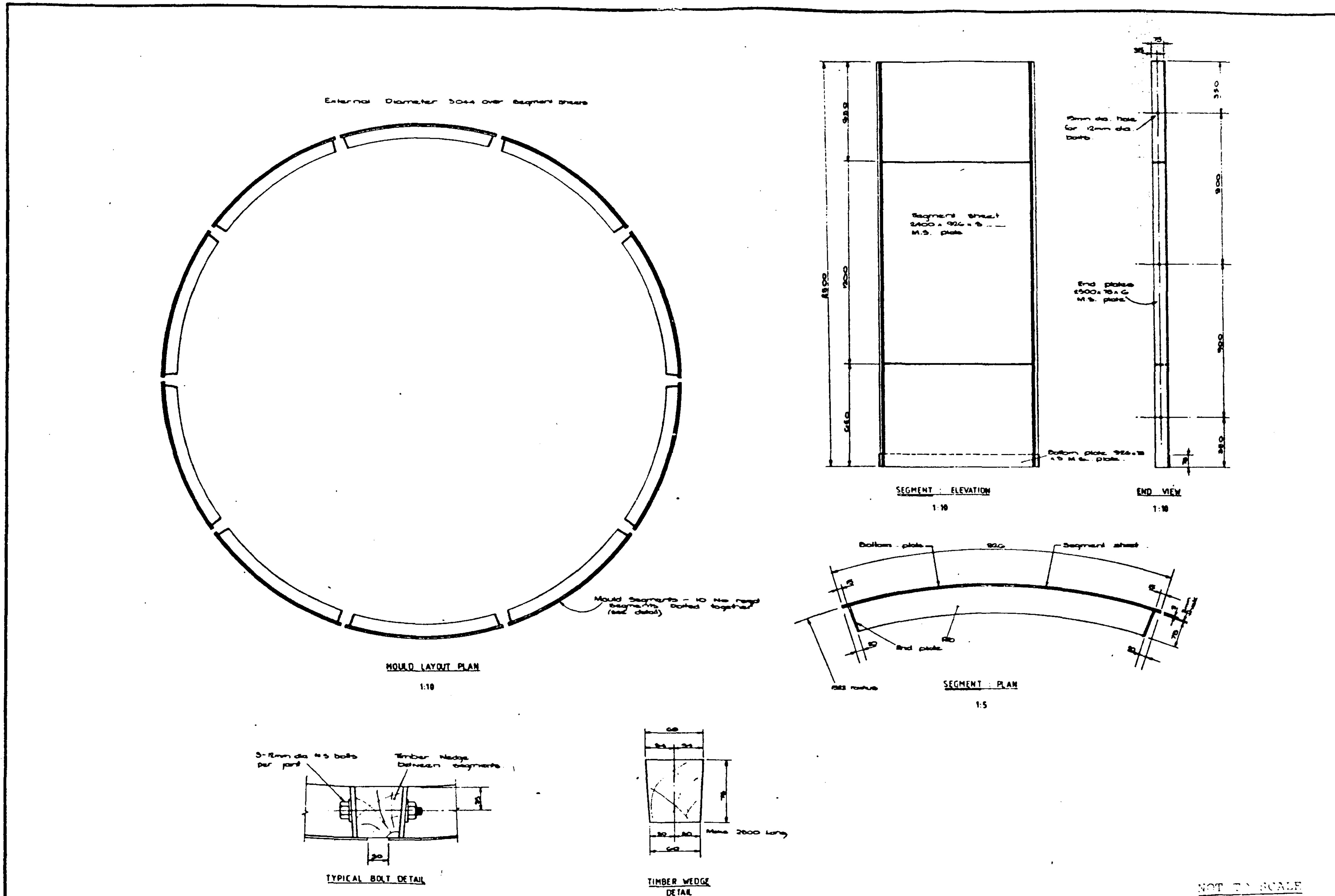
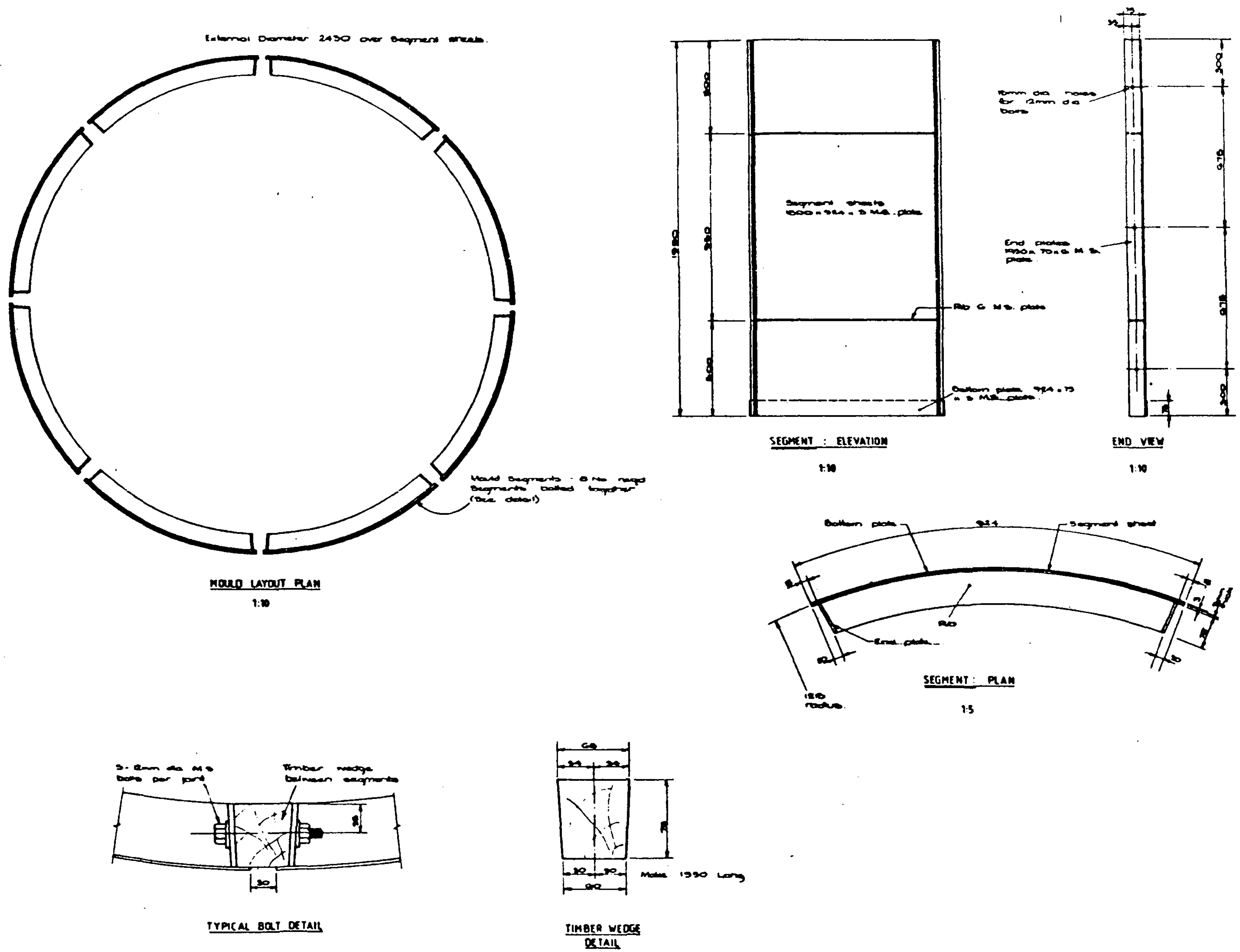
W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	9,000 LITRE TANK WIRE LAY-UP SEQUENCE FOR ALTERNATIVE METHOD OF CASTING WALLS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 22



W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	18,000 LITRE TANK. INTERNAL CYLINDRICAL MOULD FOR ALTERNATIVE METHOD OF CASTING WALLS.	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 21



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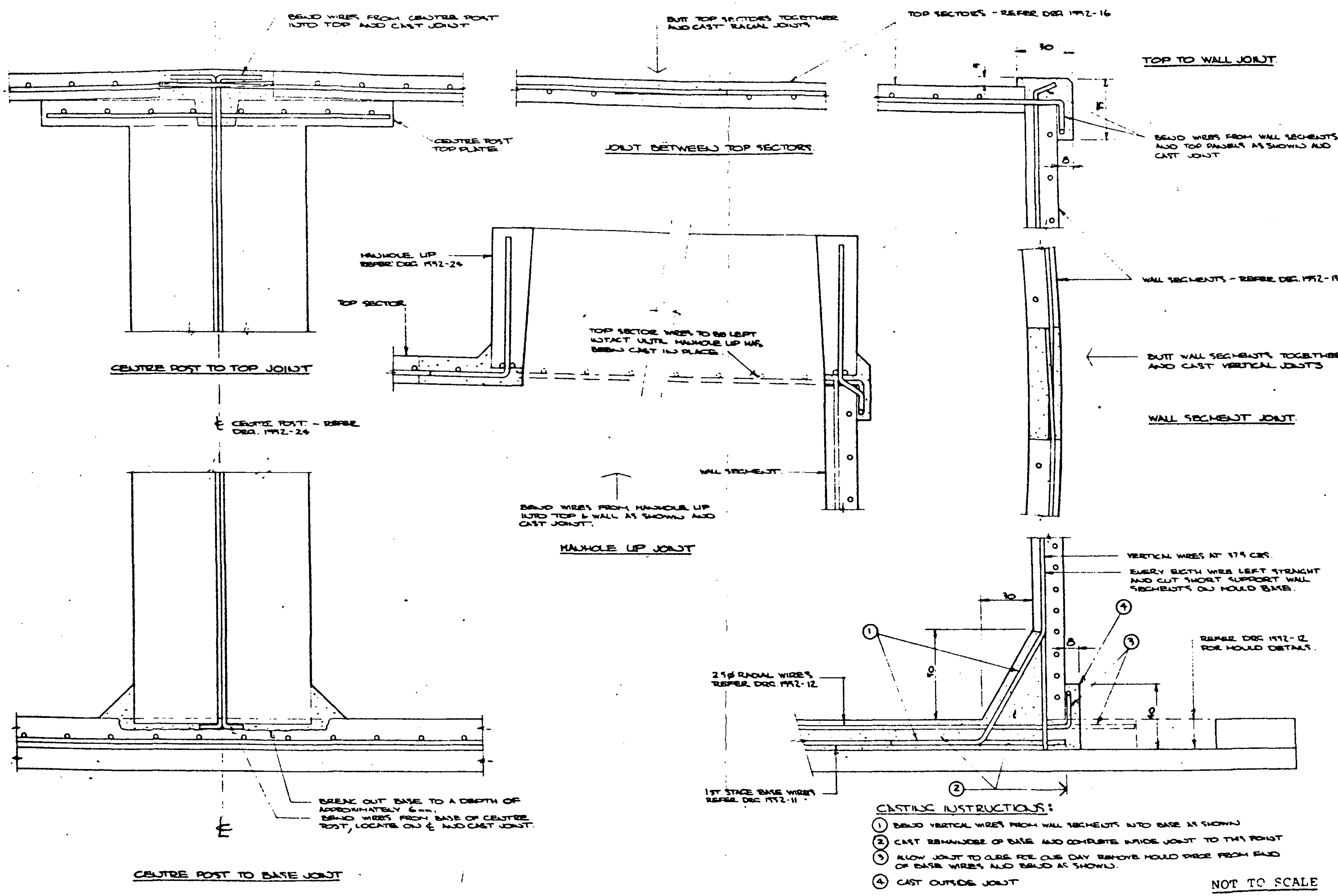
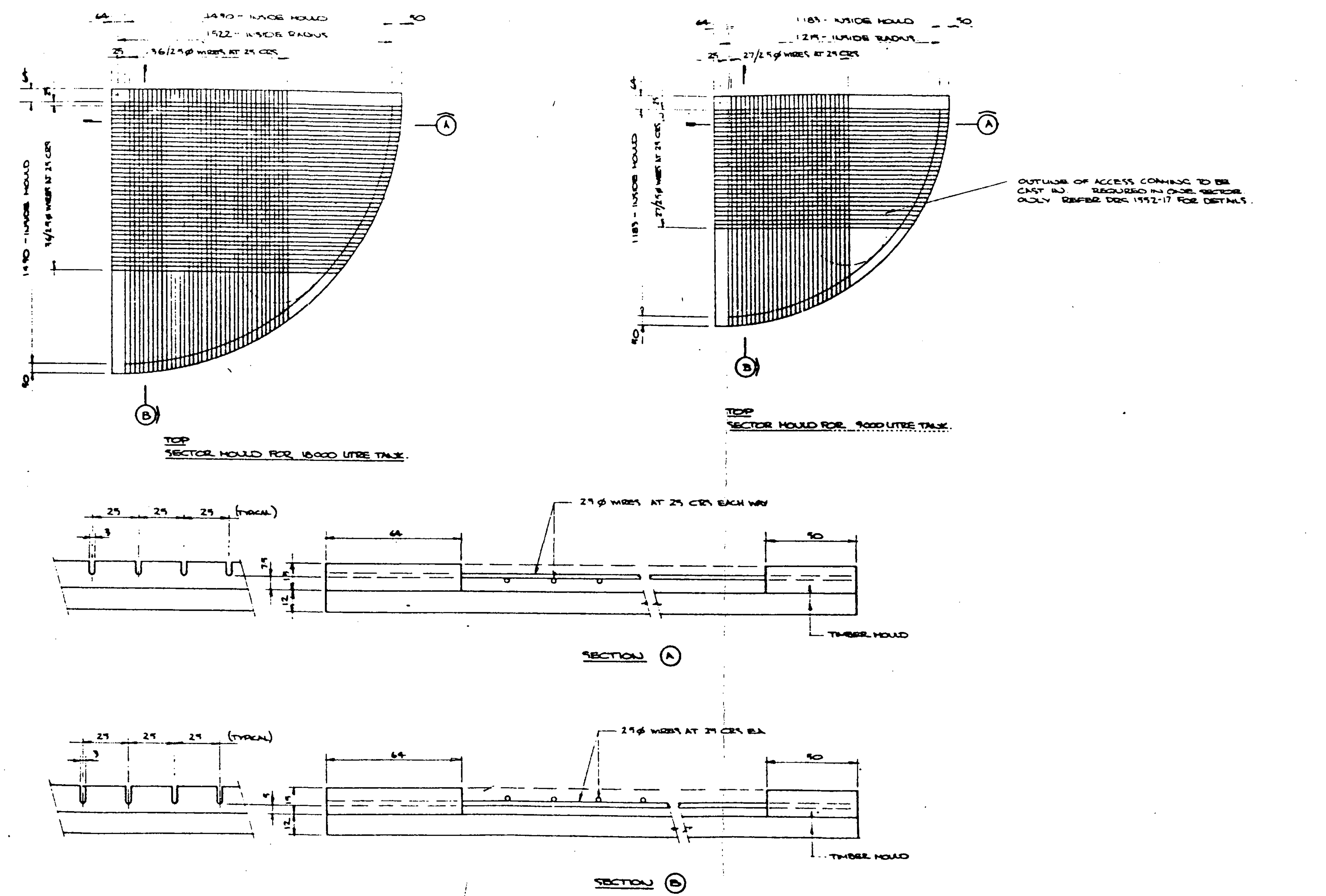
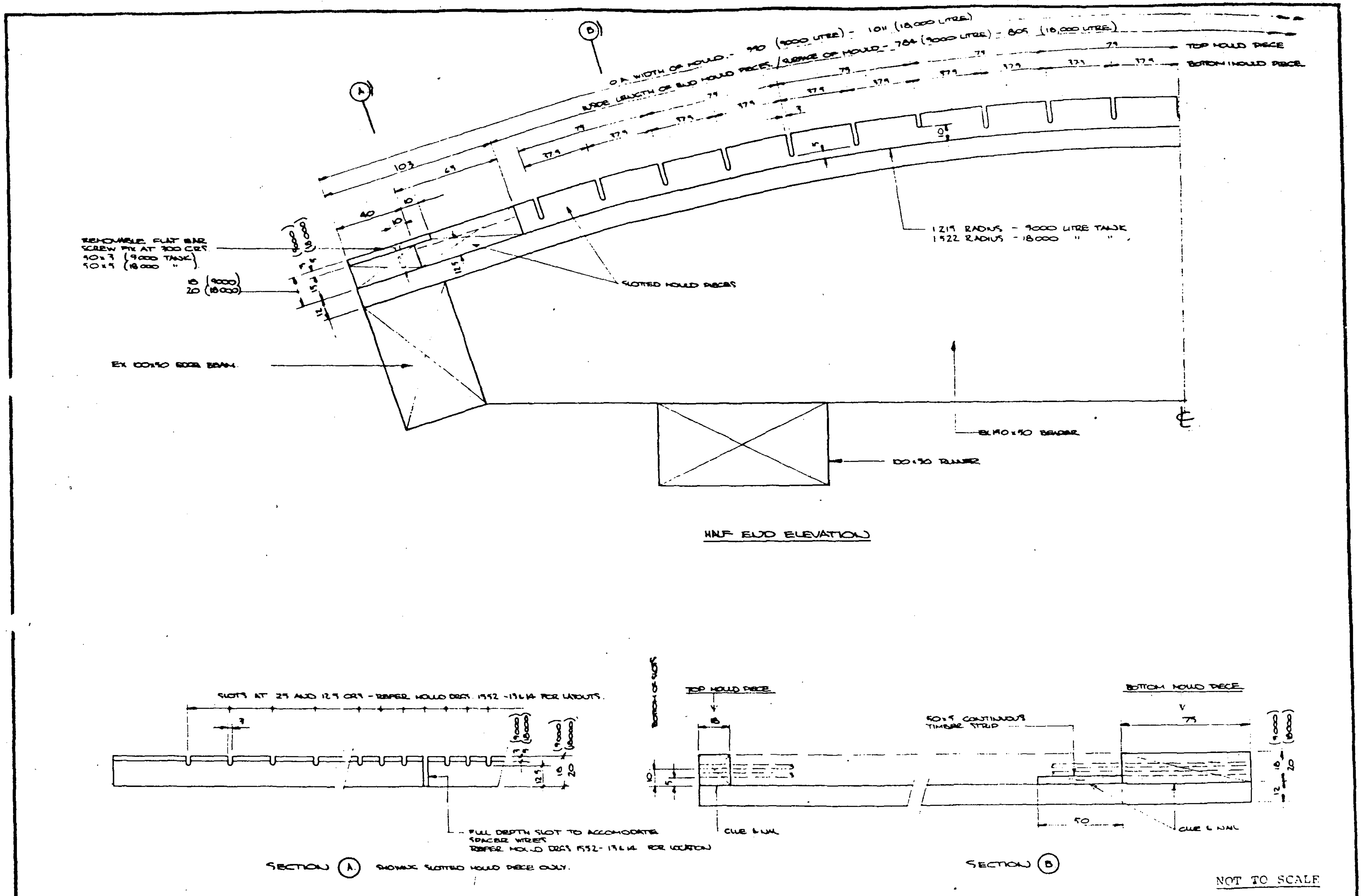
W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	9,000 LITRE TANK. INTERNAL CYLINDRICAL MOULD FOR ALTERNATIVE METHOD OF CASTING WALLS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 20



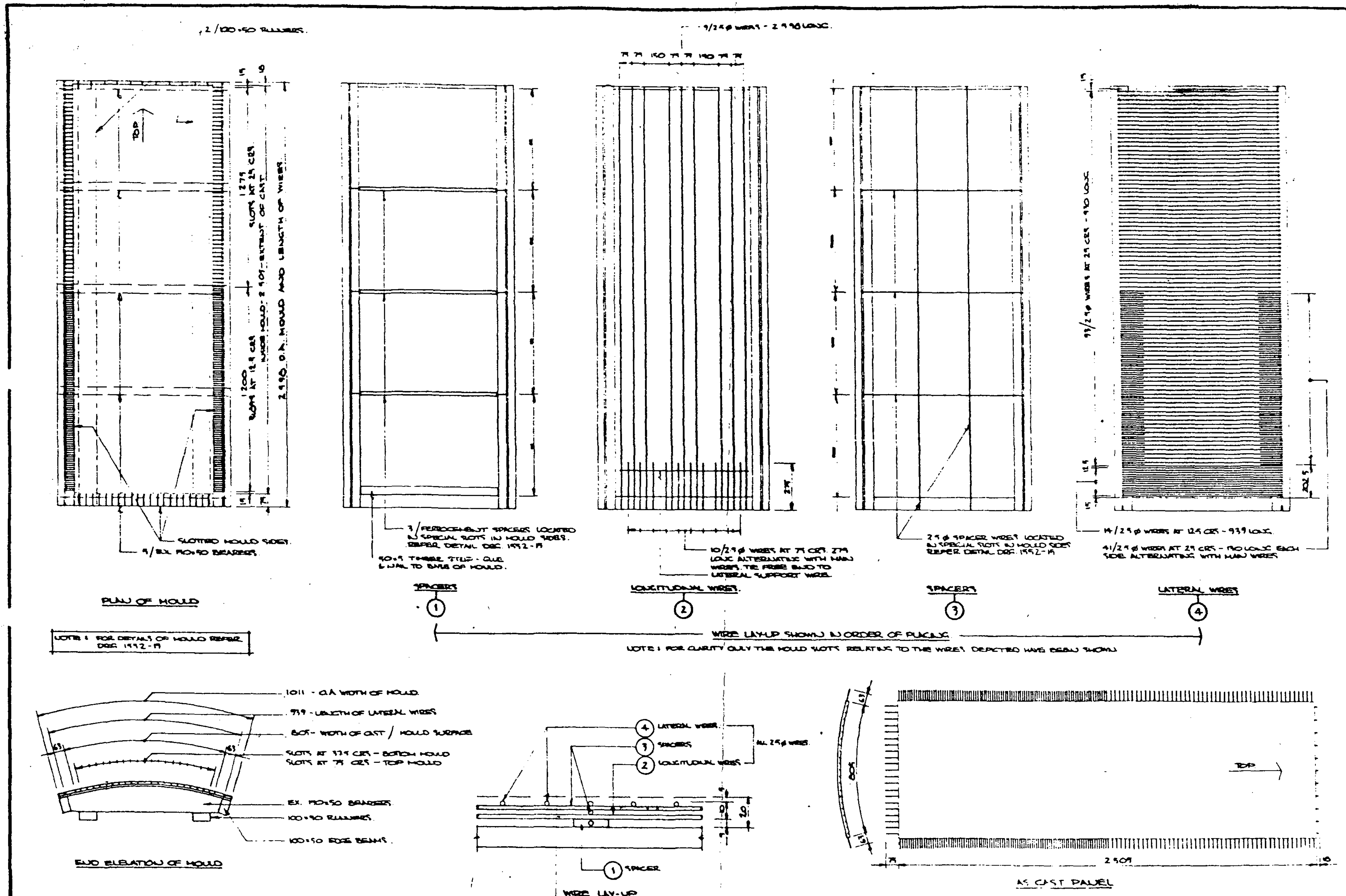
W.H.O PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	9,000 and 18,000 LITRE TANKS CONSTRUCTION JOINTS. DETAILS	ALEXANDER & POORE CONSULTING ENGINEERS	1552-17



W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE REINFORCED FIBRE FERROCEMENT WATER TANKS	TOP - 9,000 and 18,000 LITRE TANKS SECTOR MOULDS and WIRE LAY UP	ALEXANDER & POORE CONSULTING ENGINEERS	1552-16



W.H.O. PACIFIC REGION.	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS.	SIDES - 9,000 and 18,000 LITRE TANKS MOULD DETAILS	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 15



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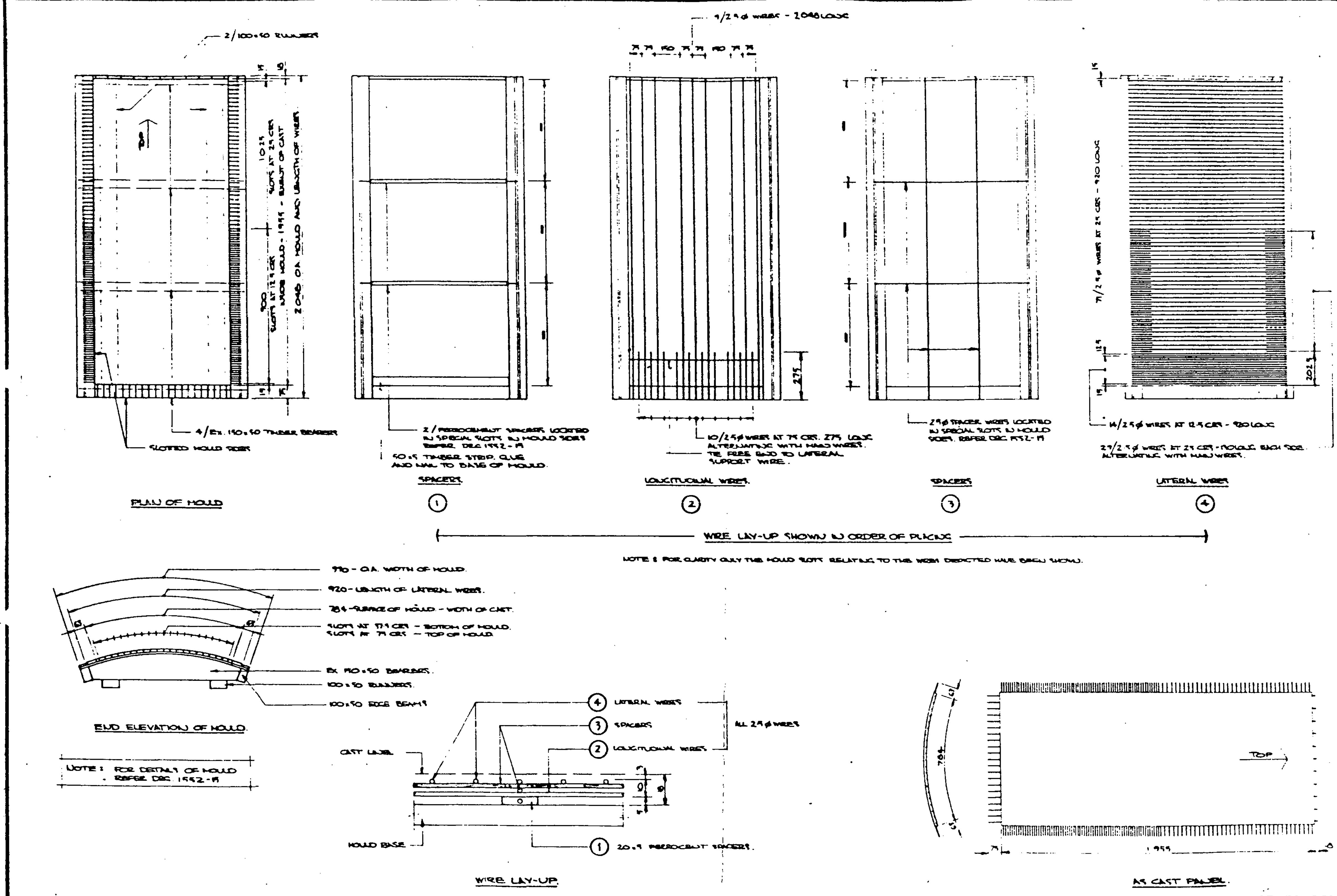
W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS	SIDES - 18,000 LITRE TANK MOULD and WIRE LAY-UP. 11 REQUIRED	ALEXANDER & POORE CONSULTING ENGINEERS	1552 - 14



W.H.O. PACIFIC REGION	MANUAL OF CONSTRUCTION FOR HIGH TENSILE WIRE REINFORCED FIBRE FERROCEMENT WATER TANKS.	SIDES - 9,000 LITRE TANK MOULD and WIRE LAYUP. 9 REQUIRED.	ALEXANDER & POORE CONSULTING ENGINEERS	1552-13

Annex 2: References

N.Z. Portland Cement Association
C.P.O. Box 2797 Wellington
Ferro-Cement Tanks and Utility Buildings

Ferrocement Cylindrical Tanks:
Cracking and Leakage Behaviour
Guerra, Naaman and Shah
Published A.C.I. Journal January 1978

Ferrocement Water Tanks and Their Construction
S.B. Watts
Intermediate Technology Publications Ltd.
London United Kingdom

Ferrocement Applications in Developing Countries
National Academy of Sciences
Washington DC February 1973

A D D E N D U M

Journal of Ferrocement : Vol. 10, No. 2, April 1980

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

D.J. Alexander*

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

LIST OF NOTATIONS

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

INTRODUCTION

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

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

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

CRACKING CHARACTERISTICS

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

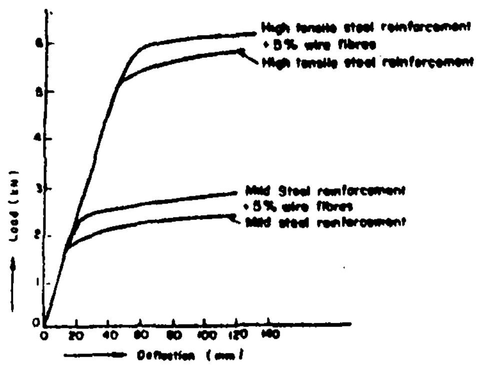

Fig. 1. Effect of use of steel fibres and high tensile wire reinforcement.

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

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

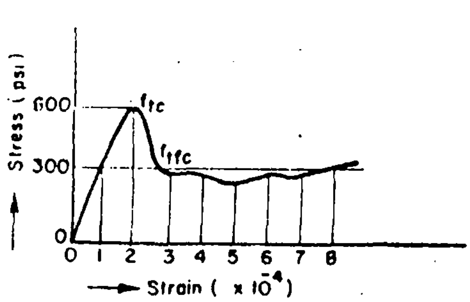

Fig. 2. Increased first crack stress.

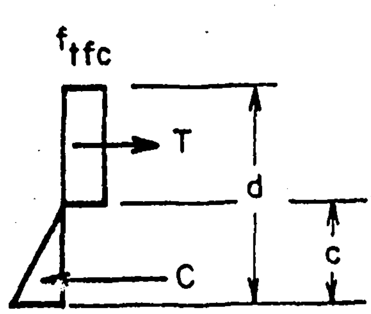

Fig. 3. Stress block diagram.

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

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

FACTORS AFFECTING THE STRENGTH OF FERROCEMENT AND FIBROUS FERROCEMENT

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

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

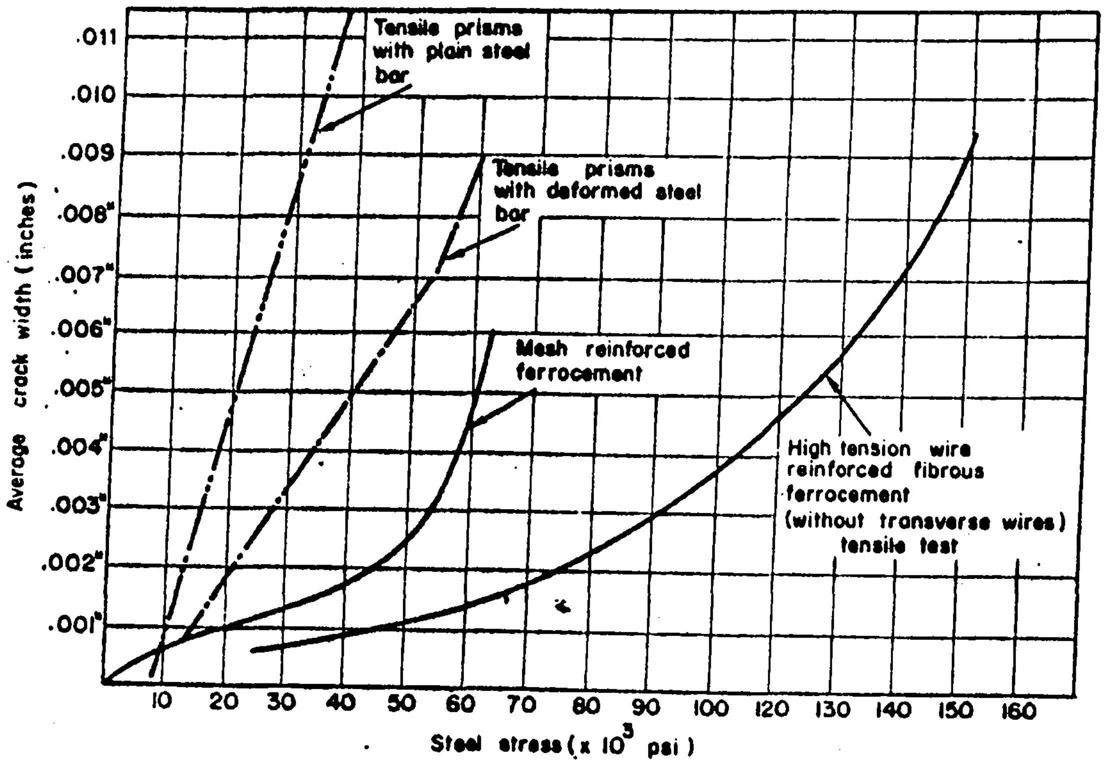

Fig. 4. Comparison of average crack width versus steel stress in direct tension for reinforced concrete and ferrocement.

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

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

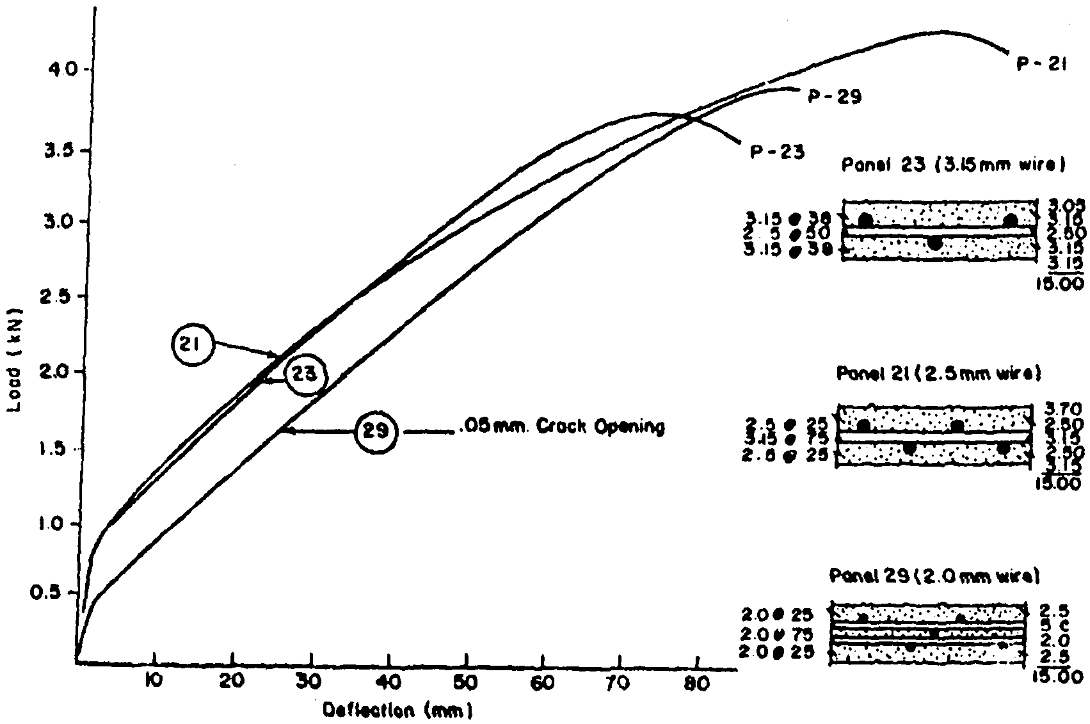

Fig. 5. Flexural tests on 15 mm high tensile wire reinforced fibrous ferrocement using 5% by weight 14 mm wire fibres.

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

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

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

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

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

Case (A)

R... s to a typical mesh assemblage of 12 layers of ½" x ½" x 19 gauge weld mesh. This has been chosen to roughly approximate the example given in 'Ferrocement' by B.K. Paul & R.P. Pama [2]: Design in Flexure (4-B); using, however, square weld mesh at a lower yield. The choice is related to some unsatisfactory aspects of woven mesh and the cost of placement difficulties of high yield wire woven mesh. Details of the assemblage are shown in the Fig. 6a.

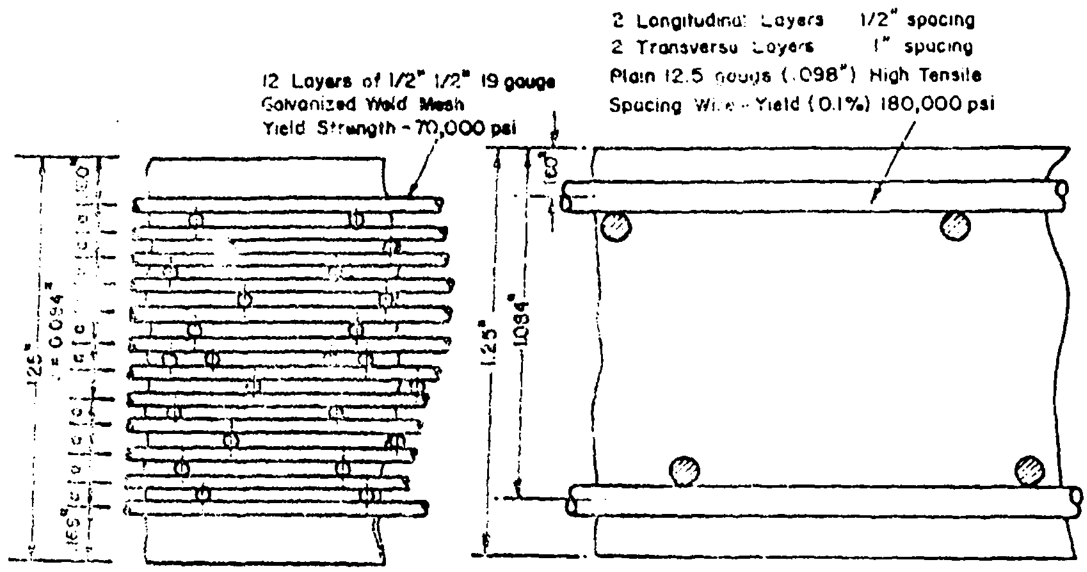

Fig. 6. Details of assemblages for mesh reinforced ferrocement and high tensile wire reinforced fibrous ferrocement (examples discussed in the text).

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

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

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

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

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

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

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

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

Case (B)

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

where c is obtained from the quadratic

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

and moment from

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

This results in:

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

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

These examples illustrate the following points:

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

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

Table 1. Stress at Visible Cracking

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

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

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

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

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

FACTORS LIMITING THE USE OF FERROCEMENT

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

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

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

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

$$\lambda = \frac{k\sigma_{mu} V_{in}}{S_L}$$

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

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

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

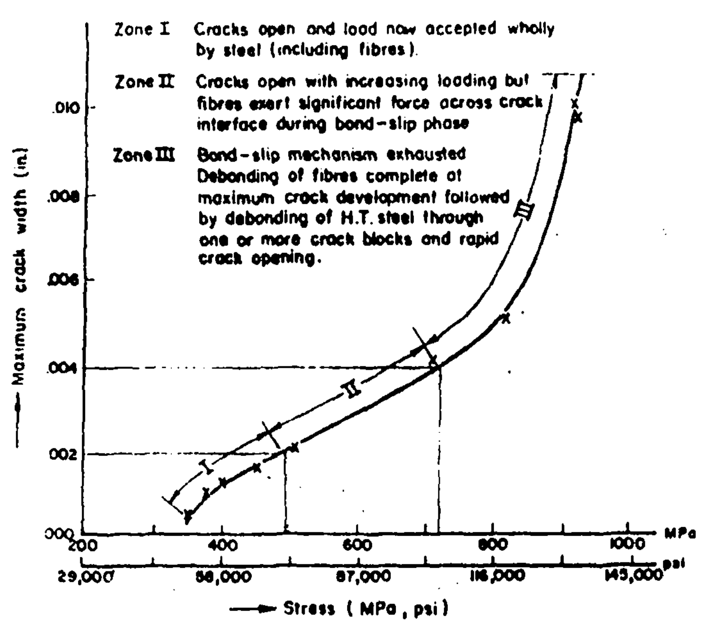

Fig. 7. Curve for maximum crack width versus steel stress. The test panel contains 1.5% high tensile steel wires and 1.6% wire fibres (by volume). Note, however, that no transverse wires have been used.

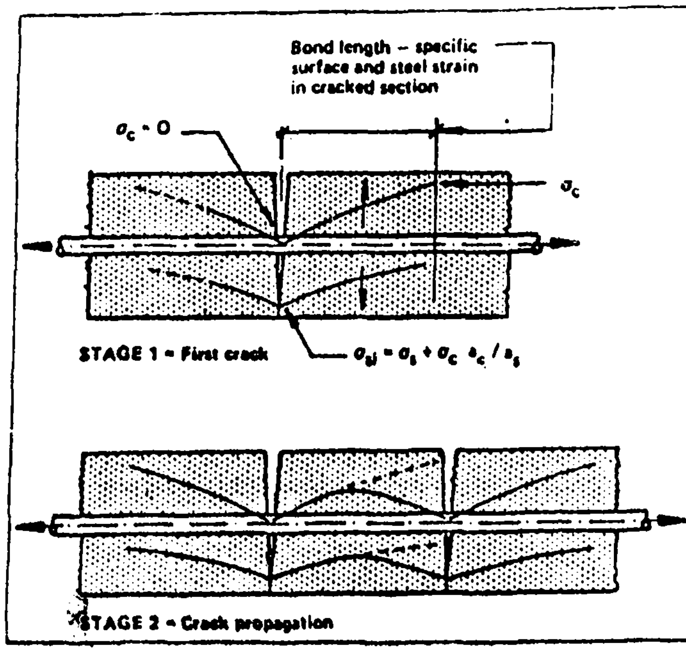

Fig. 8. Crack behaviour in ferrocement explained with respect to bond length.

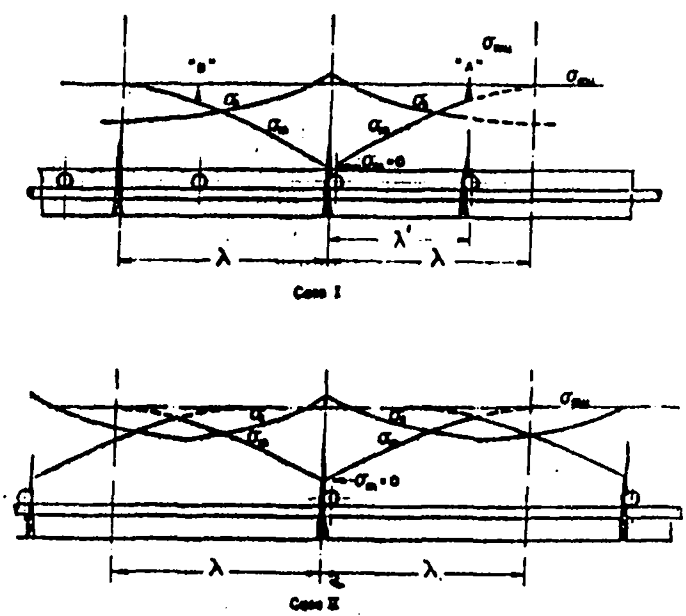

Fig. 9. Crack behaviour of high tensile wire reinforced fibrous ferrocement in notched condition. Case I- stress peaks inside bond determined bond spacing. "A" stress peak exceeds σ_{mu}. "B" stress Peak falls below σ_{mu}. Case II - Mortar stress development arrested by stress regression from notch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

MECHANICS OF CRACKING

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

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

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

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

METHODS OF ANALYSIS FOR FERROCEMENT

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

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

Method A

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

Method B

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

Method C

This employs standard concrete design methods based upon forces summation.

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

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

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

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

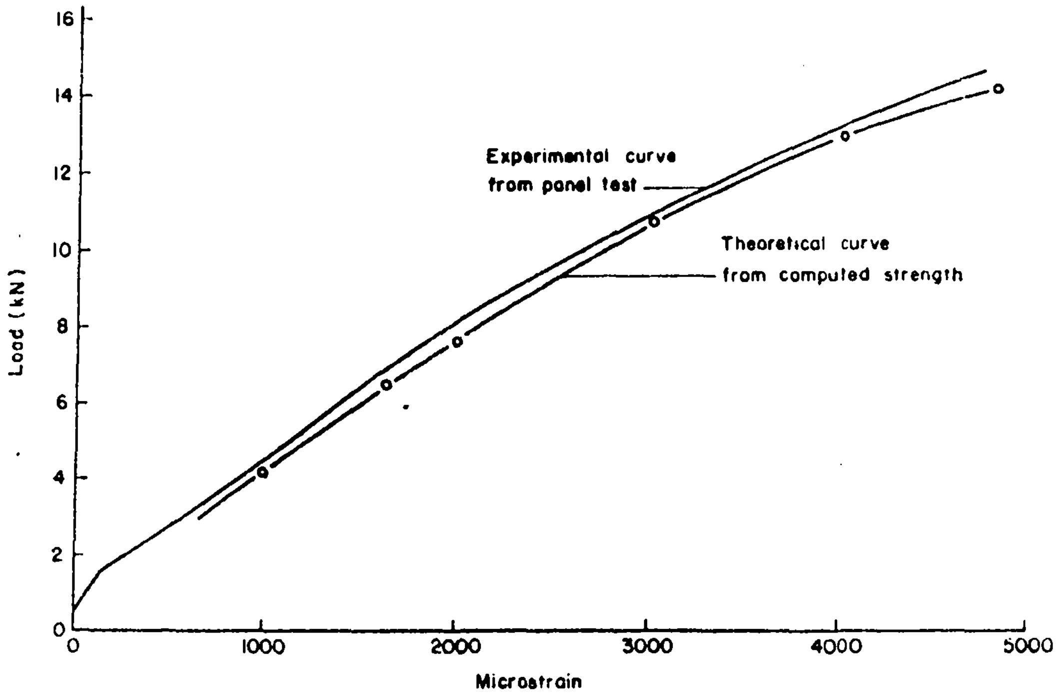

Fig. 10. Correlation between experimental and theoritical curves showing a high level of accuracy in predicting the behaviour of high tensile wire reinforced fibrous ferrocement (Panel 22).

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APPLICATIONS

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

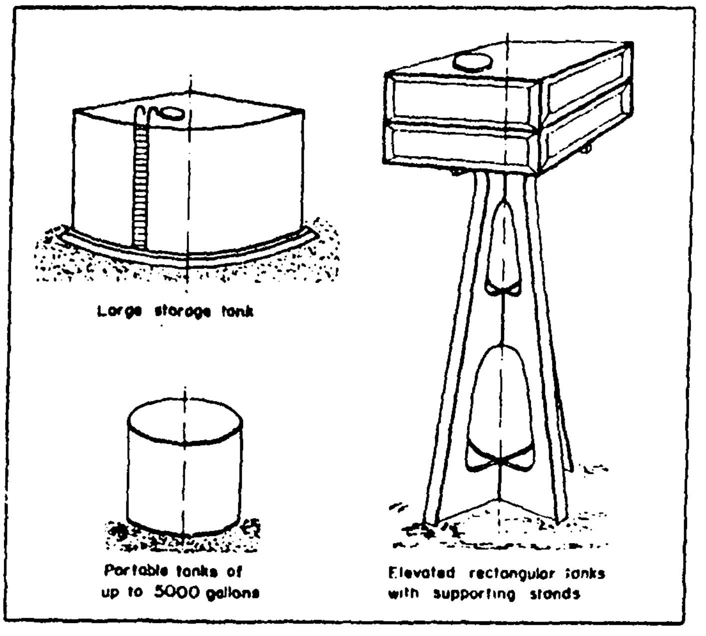

Fig. 11. Water retaining structures made from high tensile wire reinforced fibrous ferrocement.

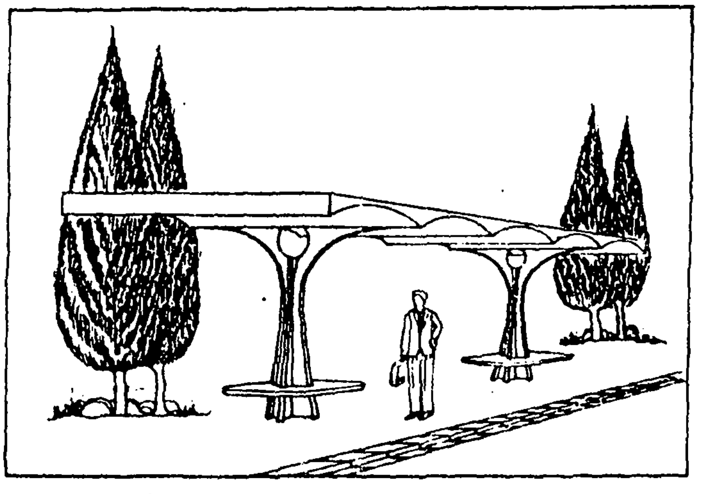

Fig. 12. Bus-shelters constructed in fibrous ferrocement, Singapore.

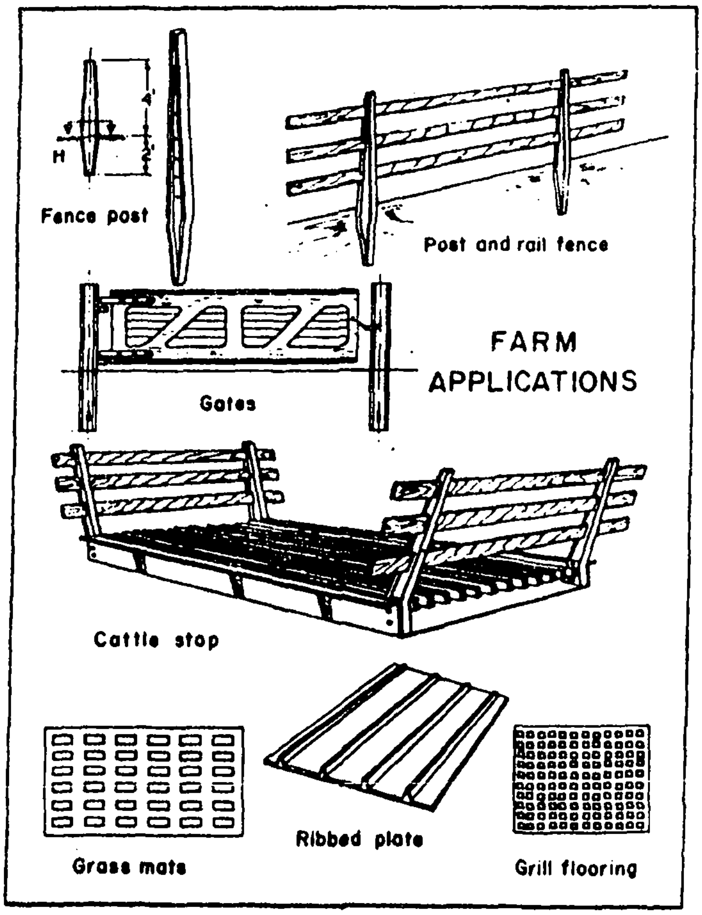

Fig. 13. Some typical applications of fibrous ferrocement for farm structures.

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

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

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

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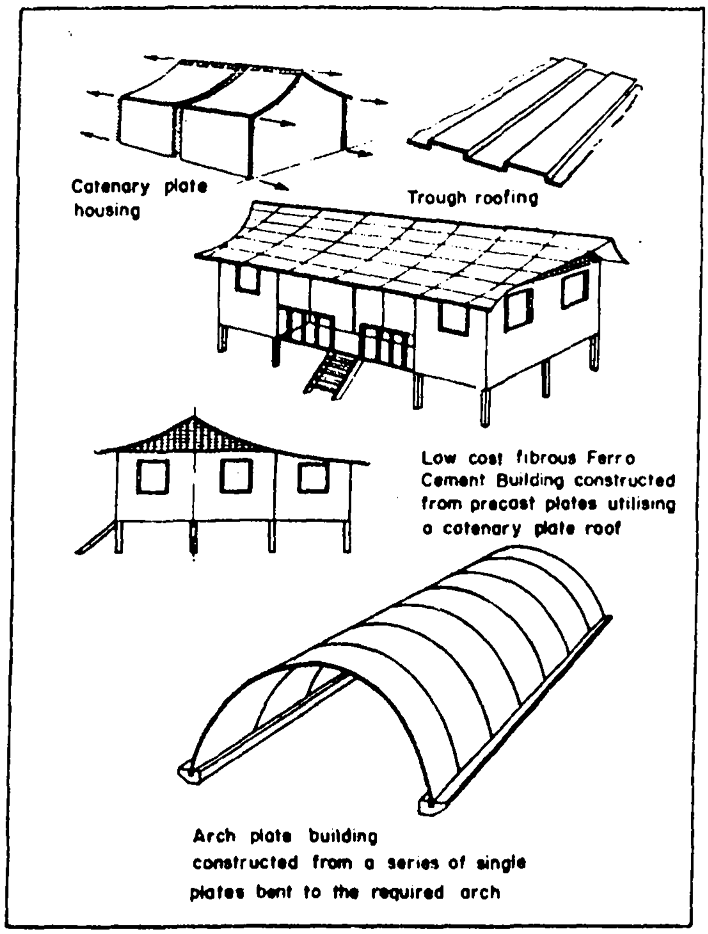


Fig. 14. A few proposals for use of precast fibrous ferrocement panels in housing.

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

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

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

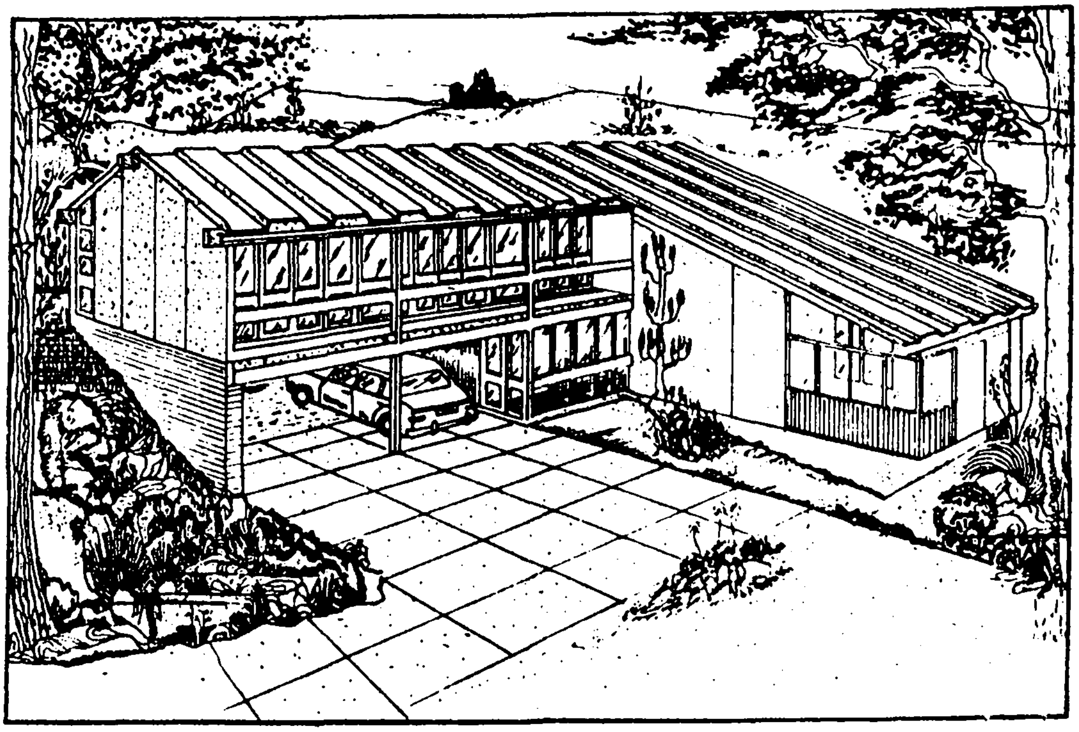
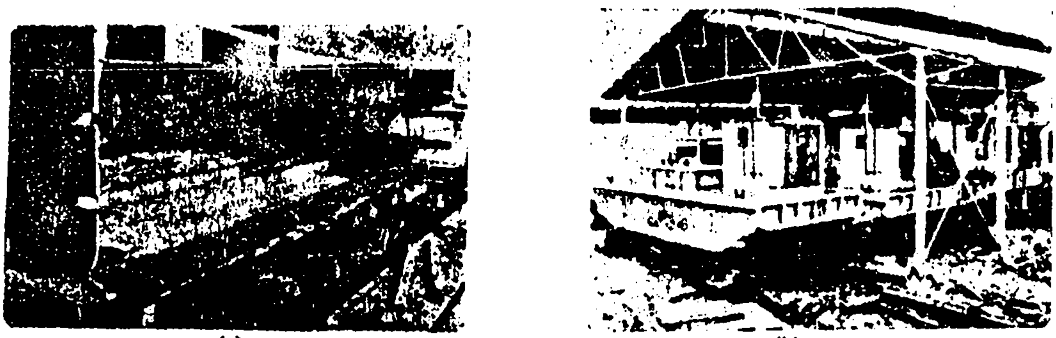


Fig. 15. A proposed house using floor, wall and roof panels made from fibrous ferrocement.



(a) (b)

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

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

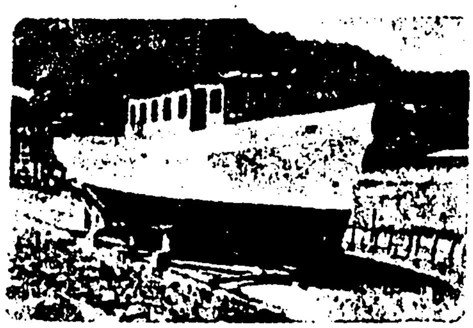


Fig. 18. 22 m Prestressed fibrous ferrocement tugs for coastal log hauling and general cargo handling constructed in Sabah, Malaysia.

REFERENCES

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