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UNDERSTANDING FERROCEMENT

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PREFACE

This paper is one of a series published by Volunteers in Technical Assistance to provide an introduction to specific state-of-the-art technologies of interest to people in developing countries. The papers are intended to be used as guidelines to help people choose technologies that are suitable to their situations. They are not intended to provide construction or implementation details. People are urged to contact VITA or a similar organization for further information and technical assistance if they find that a particular technology seems to meet their needs.

The papers in the series were written, reviewed, and illustrated almost entirely by VITA Volunteer technical experts on a purely voluntary basis. Some 500 volunteers were involved in the production of the first 100 titles issued, contributing approximately 5,000 hours of their time. VITA staff included Patrice Matthews and Suzanne Brooks handling typesetting and layout, and Margaret Crouch as project manager.

J.P. Hartog, the author of this paper and a native of Holland, has worked over the past 30 years in naval architecture. Mr. Hartog is experienced in the areas of boat building and design, and has an extensive knowledge of Ferrocement design and construction. He received his degree in structural engineering from the Technical University in Delft. He is presently employed by Holland Marine Design located in San Francisco, California.

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UNDERSTANDING FERROCEMENT CONSTRUCTION

By VITA Volunteer J.P. Hartog

I. INTRODUCTION

BASIC THEORY OF FERROCEMENT CONSTRUCTION

Ferrocement is a building material composed of a relatively thin layer of concrete covering a steel reinforcing material such as wire mesh. Since these materials are widely available and are relatively low in cost, and since the building techniques are simple enough to be done by unskilled labor, ferrocement is an attractive type of construction for many developing countries. Sand, cement, and water can be obtained locally, and the cost of the reinforcing material (steel rods, mesh, pipe, chicken wire, or expanded metal) can be kept to a minimum. There is no need for the complicated formwork of reinforced concrete construction, or welding which is done in steel construction. Virtually everything can be done by hand, and no expensive machinery is needed.

Ferrocement can be shaped to any form. It can be formed into sections less than an inch (2.5 cm) thick, and assembled over a light framework. It is lightweight, but very dense. It is also rot- and vermin-proof, impervious to worms and borers, and water-tight.

Ferrocement is more versatile than reinforced concrete and can be formed into simple or compound curves. Reinforced concrete construction is cast in sections, and needs extensive and very solid formwork to support the weight of the cement.

And ferrocment is almost always economically competitive with steel, wood, or glass-fiber reinforced plastic (FRP) construction in developing countries, as steel and FRP are expensive, and wood is becoming more and more scarce.

APPLICATIONS

Ferrocement's low cost, its weight-to-strength ratio, and other features make it useful in a wide range of applications, including boats, buildings, and food and water storage containers. In its final cured stage, ferrocement is somewhat flexible, and can be bent or flexed slightly without developing cracks. Ferrocement can be used in compound-curved structures such as domes, roofs, ship hulls, etc. Compound curvature adds to the strength, stiffness, and impact resistance of these structures, which can be built over a minimum of internal forms. Round or conical tanks, silos, and pontoons can also be constructed very satisfactorily with thin-wall ferrocement.

The least desirable designs for ferrocement construction are those that have large flat surfaces combined with angles of 90 degrees or less. However, non-bearing walls, partitions, dock floats and septic tanks, with or without internal or external stiffening, have been successfully constructed. Large, flat-bottom barges can also be built with ferrocement in combination with precast reinforced concrete frames and girders.

HISTORY

The practice of mixing burnt lime with water to make cement goes back into antiquity. Its use was confined mainly to patching irregularities in walls and as a mortar between building blocks. However, for a very long time the Chinese have used cement in combination with bamboo rod reinforcing for building boats.

The Romans were the first to use cement as a construction material. They made a hard-setting concrete by adding crushed volcanic powder (pozzolan) to the mixture.

In the nineteenth century, modern hydraulic (Portland) cements came into use. Portland cements set hard, and can withstand a load of up to 6,000 pounds per square inch (84,000 kilograms per square centimeter).

In the 1840s, Joseph Louis Lambot of France began to put metal reinforcing inside cement. He built two boats of cement with woven mesh reinforcing.

In the early 1940s, Professor Pier Luigi Nervi of Italy experimented with cement reinforcement by superimposing layers of wire mesh and thin steel rods. He noted that thin slabs made this way were somewhat flexible and acted like a homogeneous material. They were also capable of withstanding severe impact.

The use of ferrocement as a boat-building material was demonstrated by Nervi in 1945, when his firm built the 165-ton motor sailer **Irene**. The hull was only 1.37 inches (3.48 cm) thick, and was reinforced with three layers of 1/4" inch (6.3 mm) rods. Four layers of mesh were on each side of the rods. The hull weighed five percent less than a comparable wooden hull, and the price (at that time) was 40 percent less. The **Irene** proved to be a seaworthy vessel, with very little maintenance, and survived two serious accidents that required only simple plastering to repair.

In the early 1960s, ferrocement as a boat-building material finally attained wide acceptance. New Zealand, Australia, the United Kingdom, Canada, China, the USSR, and the West Coast of the United States produced thousands of sail boats and motor yachts, commercial fishing vessels, etc. After 1970, this production slowed, due to increased prices for cement, steel and, especially, labor. Ferrocement construction, however, continues to offer unlimited possibilities for both boats and land uses in countries where the cost of labor is not of prime importance.

II. TECHNOLOGY

Ferrocement can be described as a dense, reinforced cement mixture formed into thin shells or slabs, in which the cement absorbs most of the compression, and the steel reinforcing absorbs the tensile and shear stresses (see Figure 1).

REINFORCING

Many different kinds of reinforcing steel can be used. The material must be flexible; the tighter the curves of the structure to be constructed, the more flexible the reinforcing material must be. Chicken wire may be the cheapest abd easiest to use. It is adequate for most boats and for all uses on land, but is not recommended for high performance structures such as deepwater marine hulls. Wire mesh could be woven on site from coils of straight wire, using a hand loom adapted for the purpose.

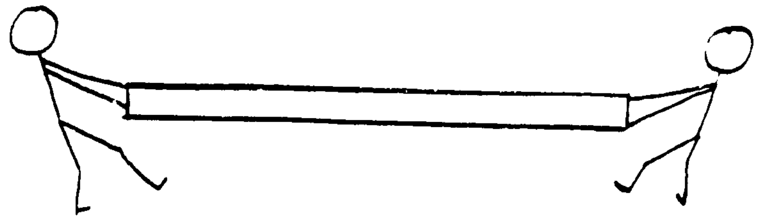
For adequate crack-resistance, stiffness, and strength, a minimum of 30 pounds of steel to one cubic foot of ferrocement (13.6 kg to .028 m^3) is required. This works out to:

2.5 lbs. of steel for a 1" thick slab, per sq. ft.
(1.13 kg of steel for a 2.54cm thick slab, per .093 sq. m)

1.9 " " " for a 3/4" " " " " "

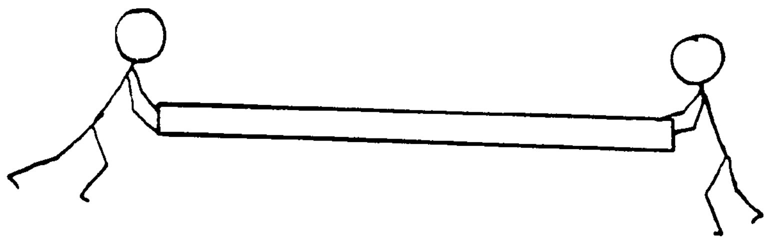
1.56 " " " for a 5/8" " " " " "

The adhesion between the mortar (the cement, sand, and water mixture) and the steel is of utmost importance. The specific reinforcing surface (the circumferences of the rods, mesh, and/or expanded metal) should be a minimum of five square inches per cubic inch of mortar (32 square cm per xx cubic cm):



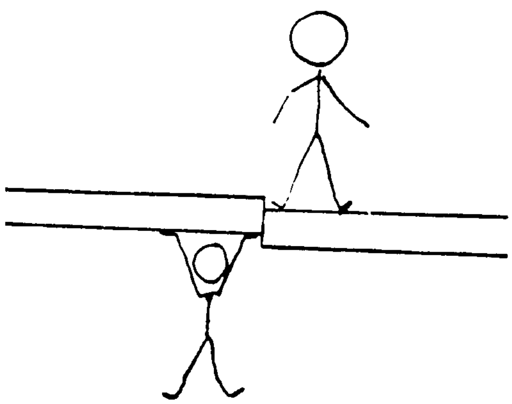
TENSION - PULL APART

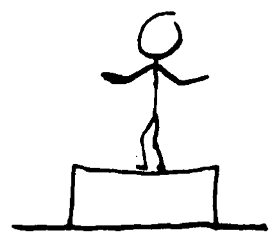
Tensile forces producing tensile stresses. Forces tending to pull the object apart.



COMPRESSION - COMPRESSING THE OBJECT

Compressive forces producing compressive stresses. Forces tending to compress the object. The opposite to tensile forces.





CRUSH - CRUSHING THE OBJECT

Crushing force. A special type of compressive force that causes surface deformation; a tendency to crush.

SHEAR - SHEARING THE OBJECT

Shear forces producing shear stresses. Forces tending to show the object.

Figure 1: Forces on Ferrocement Structures

1 sq.ft. of ferrocement,				3/4" thick,	wgt.	appr.		11 lbs.	:540 sq.in.	
(.093m^2 ferrocement,				1.9cm thick,	weight	approx.		5kg:	3.48m^2	
"	"	"	"	7/8"	"	"	"	12 "	:630	" "
"	"	"	"	1"	"	"	"	14 "	:720	" "
"	"	"	"	1-1/8"	"	"	"	15.5"	:810	" "

Because the maximum tensile and/or shearing stresses occur at the surfaces of the ferrocement slab, the mesh layers should be positioned as close to the surface as possible. At the same time, it is important that the steel is completely covered to protect it from corrosion. In thin wall ferrocement small diameter wires are used in the outer layers, and the lowest possible cement to water ratio is used, in order to give the greatest protection against corrosion.

To prevent cracking, the mortar cover should be a maximum 3/32 inch (2mm) thick over the mesh. Rods are used to space the mesh and hold it in place, and to give added stiffness and impact-resistance, after the mesh and rods have been tied together with wire ties.

If galvanized rods or mesh are used, a very small amount of chromium trioxide (Cr03) should be mixed in the mortar water, to prevent the formation of gas bubbles along the galvanized surfaces. These bubbles would adversely affect the bond between mortar and steel.

Instead of the conventional mesh and rods design, several layers of expanded metal have been used with considerable success. They are a little more difficult to form over compound curvatures, but they have sufficient adhesive surface, impact-resistance, and stiffness.

A minimum of two layers of 3/8 inch (9 mm) expanded metal, or equivalent weight in mesh or chicken wire, is used on each side.

The weight of	3/8"	expanded metal, galvanized		=		.380 lbs/sq.ft. (9mmm = .078 kg/sq.m)
" " "	1/2"	square welded mesh		"	19gage:	.235
" " "	1 "	stucco wire		"	20 "	: .100
" " "	1 "	chicken wire		"	18 "	: .190
" " "	1/2"	"	"	"	22 "	: .126

Two layers of rods, spaced a maximum of 3 1/2 inches (8.9 cm) center-on center, both horizontally and vertically, are used (see Figure 2).

For continuous strength, the mesh sections should be tied with a minimum overlap of 3/8-inch (9mm), and the rods should have a minimum overlap of 40 times their own diameter (a 10-inch overlap for 1/4-inch rods and 8 inches for 3/16-inch rods--25.4cm overlap for 6.3mm rods and 20cm for 4mm rods). Extra rods and mesh may have to be incorporated in certain areas, for example, at the stem and keel of boats.

FORMWORK

The formwork can either be removable or it can be incorporated into the finished product. The forms should be strong enough to support the weight of the structure with wet mortar, before it has set and is strong enough to support itself. Wooden frames are removable, and can be made collapsible if more than one identical structure is going to be made.

The Wooden Frame Method

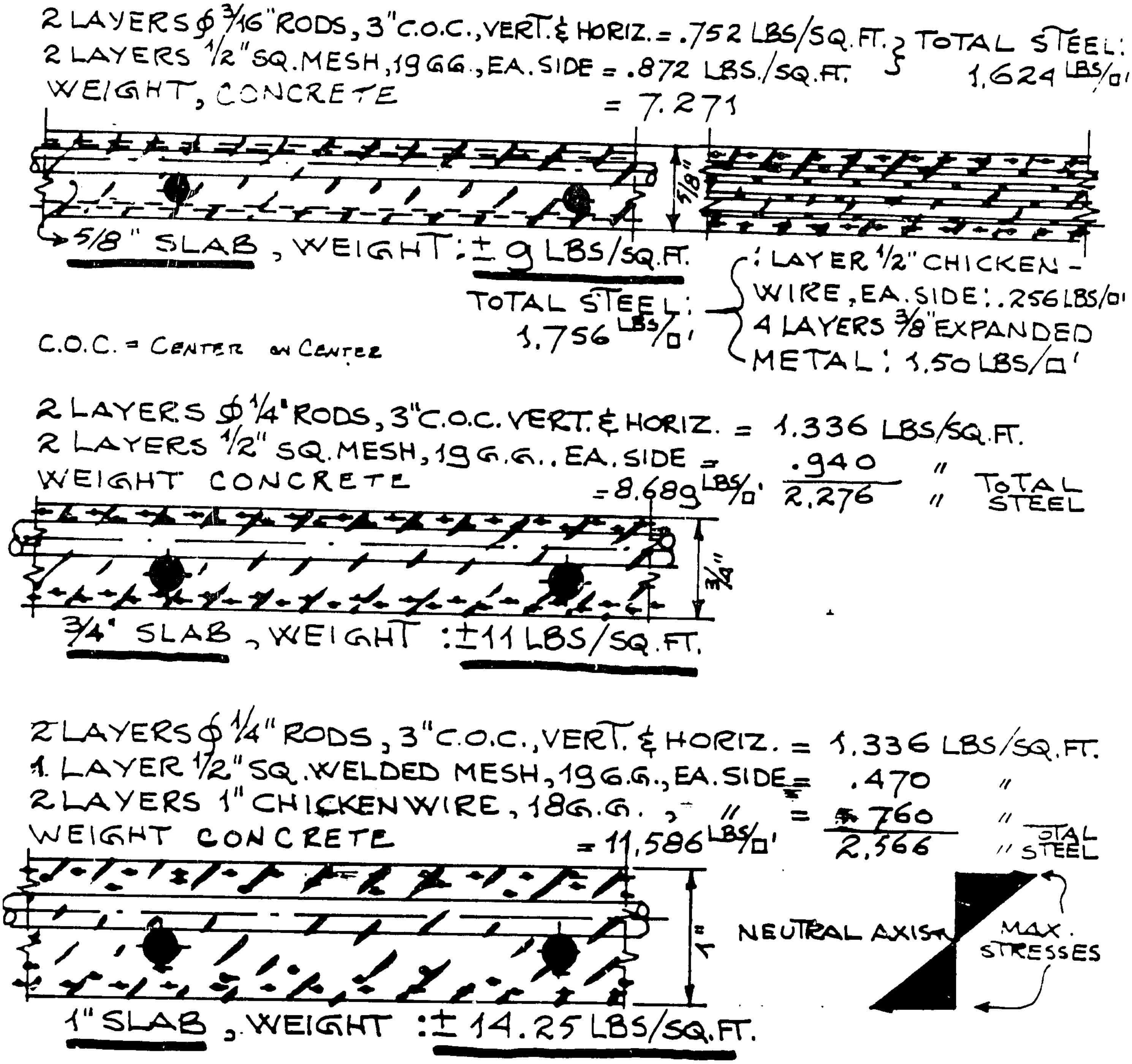
For boats, the open wooden frame method is in common use. The advantage of this technique is that the boat can be built with simple woodworking hand tools. Disadvantages are that it requires a large quantity of wood, that it must be done carefully in order to get a good finish on the interior, and that the wood is sometimes difficult to remove and may not be able to be re-used.

The method consists of nailing spaced wooden battens over fairly widely-spaced wooden transverse forms or frames.

The first inside layers of mesh are positioned over these battens and tied or stapled to them. Stainless steel wires or staples are preferable for this purpose, as the wire has to be cut before lifting the hull off the form, and rust spots might occur at these places if ordinary mild steel tie wire is used.

The other layers of mesh and rods are then solidly tied to the inside layers and to each other, and the entire form is checked for smoothness before applying mortar. If the boat is built upside down (recommended only for small boats--less than 30 feet or 10 meters), enough mesh and rods should be sticking out to provide for a sufficient overlap at the deck edge.

After the hull has cured, it can be lifted off the form, which may be used again. The deck may be constructed of wood or ferrocement. For ferrocement, deck reinforcing can be constructed over a temporary open mold (fore- and -aft battens over deck beams) which is fastened to the hull. The rods and mesh for the decking are tied to the overlap provided. After the deck has cured, the



Figures 2: Typical Ferrocement Lay-ups

deck mold has to be destroyed in most cases, since it is difficult to remove.

Pipe Frame Method

In the pipe framing method, steel water pipe takes the place of wooden frames. In this method, the pipes are incorporated in the ferrocement structure, and act as transverse stiffness. Food and water storage silos are constructed in Thailand using ferrocement with pipes or bamboo struts. The base of the cone-shaped silo is constructed first. Then mesh from the base is worked into the water pipe- or bamboo-framed walls. Hoops of reinforcing rod are positioned horizontally and are wired to the pipes. One layer of wire mesh is placed on the outside of the frame, and one on the inside. Mesh, rods, and pipe are then fastened together with short lengths of wire threaded through the wall and twisted with pliers.

For more complex structures such as boat hulls, construction of the pipe frame can require welding and pipe-bending equipment (which can be as simple as two 1-1/2" diameter--3.8 cm--fixed pins in a solid mounting). Temporary reinforcing should be welded in as the pipe frames are very floppy. A disadvantage of the pipes is that unless filled with a thin mortar, they can rust out from the inside and leave a void.

The Trussed or Webbed Frame Method

Instead of pipes, trussed or webbed frames made of reinforced bars and rods can be used. The frames are covered with steel mesh. An advantage of this and the pipe frame method for boat building is that deck beams and frames can be constructed together, saving time and efffort and reducing the amount of lumber needed.

APPLYING MORTAR

A rich mortar is used in ferrocement construction. This means a much higher cement to sand ratio--about one part cement to two parts sand--than normal. The mortar is made from a good grade of Portland cement, well-graded sharp sand, clean water, and optionally, a small amount of additives, to achieve a higher early strength or for plasticizing.

The sand used in the mortar should be clean, dry, and sharp; 10-15 percent should pass through a #100 mesh sieve, and 100 percent through a #8 sieve. One cubic foot (.028 cubic metersd) of sand weighs approximately 100 pounds dry, and 120 pounds wet (45 kg dry, 54 wet). One cubic foot of Portland cement weighs approximately 90 pounds (41 kg). Only fresh water should be used for mixing. One cubic foot weighs 62.4 pounds (28.3 kg). Up to 15

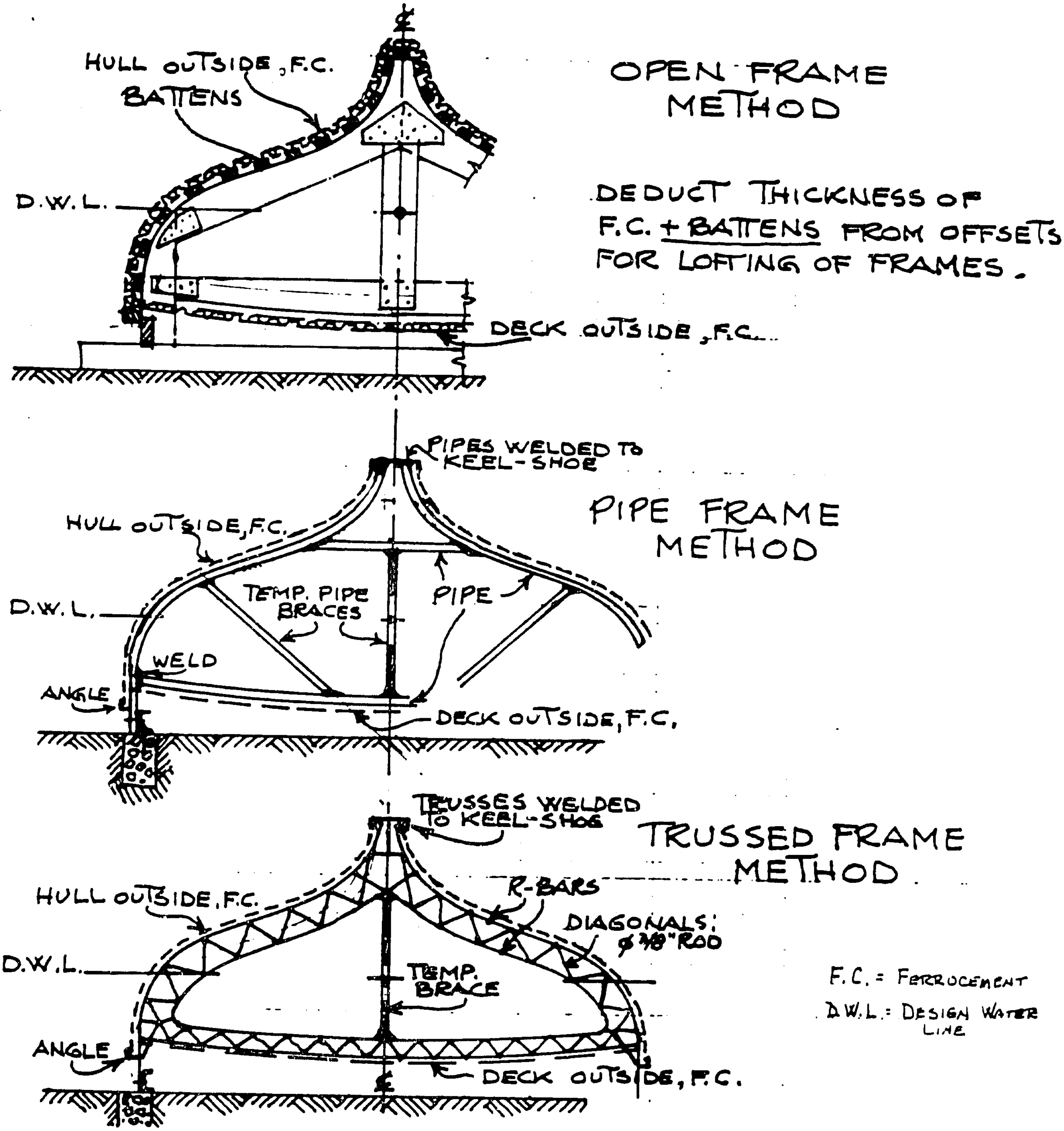


Figure 3. Open frame, pipe frame, and trussed frame methods for boat construction

percent of the cement may be replaced by plasticizing and air-entraining agents, for example, pozzolan, diatomaceous earth, or fly ash. For most purposes, one cubic foot (.028 cubic meters) of mortar should consist of 50 pounds (22.7 kg) of cement, approximately 75 pounds (34 kg) of sand, and approximately 2.20 gallons (8.3 liters) of water.

In some circumstances the use of a high-early-strength Portland cement is advantageous, for example in production line work, where it is desirable to remove the structures from the forms as soon as possible, or in cold climates, to reduce the period needed for protection against low temperatures. Type III Portland cement, which is used primarily for mass production by commercial ferrocement builders, fulfills these requirements. However, its alkaline (salt water) resistance is low. Type V Portland cement, although slower set ing than Type III, is preferred for ferrocement construction, because of its high resistance to sulfate and alkaline actions.

The chemical reaction between the cement and water (called hydration) makes the mortar set hard. The hardening (and strengthening) of the mortar is rapid in the beginning. It reaches near-maximum strength by the time curing is complete--usually 28 to 30 days. Great care should be taken that the mortar be kept moist during the application and curing process.

The temperature when the mortar is applied and cured plays a very important role in the ultimate strength of the structure. At 32 degrees Fahrenheit (0 C) or below, the freezing water particles will destroy the bond between sand and cement, causing the structure to fail. Near the boiling point, the early hardening will occur too fast. The hydration process also produces some heat. However, in thin-walled ferrocement structures the effect is negligible. The mortar will, in general, achieve a compression strength of 4,400 pounds per square inch (61,700 kg/cm^2) in 28 days when the temperature is 60 degrees F (xx C); in 23 days at 70 degrees F (xx C); and in 18 days at 80 degrees F (xx C).

The amount of water in the mortar also plays an important part in the ultimate strength of the concrete. The water to cement ratio is the weight of the water divided by the weight of the cement used.

Water-Cement Ratio	Gallons of Water per 100 pounds of cement-sand mix	Pounds of Water per 100 pounds of cement-sand mix
.40	4.75+	40
.50	6.+	50
.60	7.25	60

In general, a low water to cement ratio increases strength, and a high water to cement ratio decreases strength. A .40 water-cement ratio will produce a compression strength of approximately 6,500 pounds/square inch (91,000 kg/cm^2; a .50 ratio will produce a 5,000 pounds/square inch (70,000 kg/cm^2) compression strength; and .60 will produce a 4,000 pounds/square inch (56,000 kg/cm^2) compression strength.

For most ferrocement construction a .40 water-cement ratio should be used for a workable mix and high strength. The above quantities and weights of water (to be added to the cement-sand mix) for the different water to cement ratios are calculated on the assumption that the sand in the mix is bone-dry before the water is added. As this is practically never the case, allowance should be made for the water already contained in the sand, and the volume or weight of the water to be added should be adjusted. This can be done by taking two identical samples of the sand, weighing one sample on site, and drying the other one in an oven. The weight difference between the two samples shows the amount of water already in the mix. That weight should be subtracted from the amount of water to be added to the same volume of cemnt-sand mix as used in the sample.

The best test of a mortar mixture is to use a trial mix on a mock up section of the structure to be formed. Use the same rods and mesh lay-up that will be used in the structure. Another method, giving more approximate results, is the so-called slump test. A sheet metal cone approximately 18 inches (45 cm) in height is made and set on a flat, horizontal surface. The cone is filled with several layers of mortar and rods. The last layer is trowelled flat, level with the top, and the cone is carefully pulled upward. The degree of wetness of the mix will show in the difference in the height of the metal cone and the height of the mortar. This is called the slump. A good dry mix, as used for ferrocement, should show very little slump, with a maximum of 2-1/2 inches (6.5 cm). Any more would indicate excessive wetness and could result in shrinkage and cracks.

Compromises are sometimes necessary in the composition of ferrocement mortars. A high cement to sand ratio makes a strong, rich mortar, which is more workable, produces a better finish, and is far more impermeable than a weaker mortar with a lower cement to sand ratio. However, a rich mixture shrinks more than a weaker mortar, causing hair cracks, and sometimes large cracks as well.

As mentioned earlier, a small amount of plasticizers may be added to make a dry mortar more workable, and also, if desired, to accelerate the early setting strength of the Portland cement. For important projects, test panels should be made and, after curing, can be laboratory tested to determine crushing-, compression-, tensile-, shear-, and flexing-strengths, as well as impact resistance.

In general, a mortar made with a cement to sand ratio of approximately .50 (2 parts sand to 1 part cement) and a water to cement ratio of .40 will produce the least amount of shrinkage and a workable mix.

For large structures and where the distance from the mixing site to the construction site is considerable, it may be advantageous to pump the mortar to the construction area. A so-called plasterer's pump is used to transport the mortar through tubes or pipes to the work site. For a better flow through the pipes, the water to cement ratio should be slightly higher than normal, with a slump of 3 inches or more. A disadvantage of this method is that incomplete mixing or separation of the cement-sand mix during travel can clog the pipes. They must then be taken apart, cleaned out, and reassembled, resulting in substantial time and labor loss. Using mortar guns, or gunniting, has been tried, but not with much success, because the heavier parts of the cement-sand mix tend to separate out at the hose nozzles. Research may lead to improvements in this technique.

After checking the reinforcing for smoothness (and pounding out flat spots, retying loose mesh, etc.), the structure is ready for mortar. All loose rust should be wire-brushed off; oily and dirty surfaces should be sprayed with a muriatic (hydrochloric) acid solution and, after cleaning, neutralized with fresh water.

The mortar should be applied in one operation, and should be shaded from direct sunlight and winds, protected from frost, and done at an even temperature. A few simple tools are needed: buckets to carry the mortar; hods (troughs); steel and wooden floats; soft brooms for erasing float marks; and screeds (long flexible battens for finishing long curved surfaces).

The stiff mortar is pushed by hand through the reinforcing; as this is done, great care must be taken to avoid leaving air pockets, which might occur in back of the rods or the expanded metal. In places where penetration is very difficult, a pencil vibrator or an orbital sander with a metal plate substituted for the sandpaper pad can be employed to ensure complete covering of the reinforcing by the mortar. Localized vibration can also be created by using a piece of wood with a handle attached.

Should any air pockets be suspected, they can be located by tapping the structure with a hammer after curing. These places should be drilled out and filled with a cement and water grout, or an epoxy compound. The worker(s) on one side of the structure push the mortar through the mesh and rods until it appears on the other side, where the other worker(s) finish it off smoothly with approximately 3/32-inch (2 mm) of mortar protruding beyond the mesh. The same finishing is then done on the opposite side.

It is of the utmost importance that none of the work that has been completed be allowed to dry out while the workers are completing another part of the structure. In direct sunlight, or during hot weather, moistened gunnysacks or other coarsely woven cloth should cover completed areas. If the work cannot be finished in one operation, the finished work should be kept moist, and a bond of thick cement grout or epoxy compound should be put on between the old and the new work. Several polyvinyl acetate bonding products are also available. If a concrete mixer is available, a paddle-wheel type is greatly preferred over the conventional tilting-drum mixer, because of the stiffness of the mortar used for ferrocement construction.

CURING

Curing reduces shrinkage, and increases strength and water tightness. There are two types of curing: wet curing and steam curing.

The ideal method of wet curing is to immerse the structure completely in water for a certain time, which is dependent on the temperature of the water. However, immersion is not possible in most circumstances. The accepted alternative is to cover the structure, after all the mortar has been applied, with gunnysacks, tar paper, or other fabrics, which are kept moist continuously. Sprinklers or soaker hoses can also be used for this purpose. This procedure must be done for a minimum of 14 days. It is desirable not to let the temperature fall below 68 degrees F (xx degress C) during the curing process.

Steam curing provides a moist atmosphere as well as increasing the temperature. It is necessary to build a polyethylene tent over the structure and move a steam-producing engine (a steam-cleaning plant or boiler) under this tent, close to (or under) the structure. No steam should be applied before the initial mortar set has taken place. After that, wet steam, at atmospheric pressure only, should be applied slowly for approximately three hours until the temperature inside the tent reaches 180 degrees F (xx degress C). This temperature should be held for a minimum of four hours, after which it can be allowed to fall slowly. The advantage of steam curing is that the mortar achieves its 28-day strength in 12 hours, and the structure can be moved and worked on within 24 hours, compared with a minimum 14 days for wet curing. However steam curing may result in a less durable, more porous structure, especially if it is done by an inexperienced person.

A quality control test used in the construction of ferrocement grain storage bins in Thailand is to fill them with water for one week. Any cracks or weak sections are discovered as leaks.

FINISHING AND PAINTING

After curing, the surface is rubbed down with carborundum stone to achieve a smooth finish, and then rinsed thoroughly with fresh water. Because well-made ferrocement is impermeable (waterproof), there is theoretically no need for painting. However, if painting is desired, the structure should be scrubbed with a 5 to 10 percent solution of muriatic (hydrochloric) acid, flushed with clean, fresh water, and scrubbed again with a weak solution of caustic soda, after which it has to be rinsed again.

The ferrocement can then be sealed with a coat of epoxy resin, and one or more coats of epoxy paint applied as a finish. It has been personal experience that after sealing one side of the ferrocement slab, it is best to wait as long as possible before sealing the other side. Due to continuous hydration and curing, the lower surface(s) on the untreated side will show a white powder for a long time. Even after careful removing of this powder and rinsing, it will take years before paint will form a good bond with these surfaces.

For boats that will be left continuously in salt water, an anti-fouling paint should be applied below the waterline. For storage of diesel fuel in ferrocement tanks (not recommended because of the adverse effect of the alkaline action of the ferrocement upon the diesel fuel), the inside of the tanks should be sprayed with a polysulfide compound. Several kinds of epoxy resins and compounds are also available for the protection of bare metal, bonding cement to any other material, filling in voids, etc. Ferrocement tanks intended for water storage should be given a cement wash inside and stored with a little water inside them.

Underground ferrocement grain silos in Ethiopia are waterproofed with bitumen. After curing, the surface is cleaned with a wire brush, and a coat of bitumen emulsion (diluted 1 volume of emulsion to 1 volume of water) is scrubbed into the surface. After it dries, a cement/ emulsion mixture (1 volume of water to 1 volume of cement to 10 volumes of emulsion) is brushed on.

III. SUMMARY

The advantages of ferrocement construction are:

- It is highly versatile and can be formed into almost any shape for a wide range of uses;
- Its simple techniques require a minimum of skilled labor;
- The materials are relatively inexpensive, and can usually be obtained locally;

- Only a few simple hand tools are needed to build uncomplicated structures;
- Repairs are easy and inexpensive;
- No upkeep is necessary;
- Structures are rot-, insect-, and rat-proof;
- Structures are non-flammable;
- Structures are highly waterproof, and give off no odors in a moist environment;
- Structures have unobstructed interior room; and
- Structures are strong and have good impact resistance.

The main disadvantage of ferrocement for smaller structures and boats is its high density (+/- 150 pounds/cubic foot). Density is not a problem, however, for larger structures (for example, large domes, tanks, and boats over 45 feet long). Large, internally-unsuppported domes and curved roofs have been built which could not have been constructed with other materials without elaborate ribs, trusses, and tie rods.

The large amount of labor required for ferrocement construction is a disadvantage in countries where the cost of unskilled or semi-skilled labor is high. Tying the rods and mesh together is especially tedious and time consuming.

Another disadvantage is the impossiblity of nailing, screwing or welding to ferrocement. If anything is to be attached it has to be bolted in place, and many carborundum bits can be broken when rods are hit while drilling the bolt holes.

BIBLIOGRAPHY

Benford, J.R., and Husen, H. Practical Ferro-Cement Boat Building. Camden, Maine: International Marine, 1970.

Bezukladov, V.F. et Al. Translated by L.G. Robbins, U.S. Navy. "Ship Hulls Made of Reinforced Concrete." (NAV SHIPS Translation #1148), 1968.

Fyson, J., Editor. FAO Looks at Ferrocement. Rome, Italy: UN Food and Agriculture Organisation.

Hartley, R., and Reid. Hartley's Ferro-Cement Boat Building. Auckland, New Zealand: Bogtwood Printing House, 1971.

Jackson, G.W., Jr., and Sutherland, W.M. Concrete Boat Building: Its Technique and Its Future. Tuchahoe, New York: John Graff, Inc., 1969.

National Academy of Sciences. "Ferrocement: Applications in Developing Countries." Washington, D.C.: Academy Press, 1973.

Pama, R.P., Seng-Lip Lee, S.L.; and Vietmeyer, N.D., eds. "Ferrocement, a Versatile Construction Material: Its Increasing Use in Asia." Bangkok, Thailand: Asian Institute of Technology, 1976.

Roberts, W.H. Guide to Ferro-Cement Sail and Power Boats and Design, 1970.

Samson, J., and Wellens, G. How to Build a Ferro-Cement Boat. P.O. Box 98, Ladner, British Columbia, Canada: Samson Marine Design Enterprises, Ltd., 1968.

Whitener, J.R. Ferro-Cement Boat Construction. Cambridge, Maryland: Cornell Maritime Press, 1971.