DEVELOPMENT OF THIN SECTION CONCRETE FOR MARINE AND AQUACULTURE APPLICATIONS

by

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ABSTRACT

Aquaculture in Atlantic Canada has become an important industry in the last two decades. The marine setting where aquaculture activities are carried out demands durable construction products that can withstand a harsh environment. Reinforced concrete and ferrocement have been used for marine structures in the past and have performed well which argues favourably for their use in our local aquaculture industry.

Floating facilities made from thin section concrete and ferrocement should meet the requirements of this rapidly growing sector of the economy. Unfortunately the aquaculture industry has had minimal experience with ferrocement. There is a need for a pilot project to manufacture a floating structure so that the industry can be exposed to ferrocement and they can judge its effectiveness. In this way sufficient confidence can be acquired so that its full potential can be realized in structures such as cages, docks, boats and barges. Experience in the last one hundred years with construction of ferrocement boats has been positive and has demonstrated that they are competitive in terms of construction costs and durability when compared with other construction materials.

Ferrocement is now produced using a variety of new construction techniques that have been developed on the west coast of North America. These techniques result in significant reduction in cost and improved performance.

A service vessel (barge) was designed in this report to investigate, from a cost and serviceability point of view, whether a structure made of ferrocement could meet local needs, and at the same time demonstrate the uses of a ferrocement barge to the

local aquaculture industry.

Based on the cost estimate and the apparent serviceability of the barge design, thin section concrete for marine and aquaculture applications appears to be worthy of further investigation. The production of a prototype unit should demonstrate the value of this type of construction to the Atlantic Canada aquaculture industry.

ACKNOWLEDGEMENT

I would like to thank Professor Bremner for his help and guidance in preparing this thesis. I greatly appreciated being able to meet with Martin Iorns during the preparation of this thesis. Martin expressed interest in the potential applications for ferrocement during his visit to St. Andrews, NB. It should be noted that Martin Iorns has spent his lifetime working with ferrocement and has come up with several advancements and patents related to ferrocement. I would also like to thank my wife Mindi for her help and encouragement.

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1.0 INTRODUCTION AND BACKGROUND

1.1 Processes and Applications of Thin Section Concrete

Thin section concrete products are a variation of reinforced concrete. The materials used are very similar to those used for other concrete structures. The main difference is that the thin section requires a much closer spacing of smaller size reinforcement than does normal reinforced concrete. The close spacing of the reinforcement produces a product that is significantly different from the material known as reinforced concrete.

The processes used to produce thin section concrete are as varied as the types of thin section concrete themselves. Reinforcements include continuous metal mesh, randomly dispersed individual fibers, small diameter reinforcing rods, and numerous other materials including plastics. Many methods can be used to produce an acceptable product with the process selected depending on the properties of the concrete required.

Ferrocement is the most common thin section concrete composite that is used for marine applications. Boats and floating wharves have been constructed of ferrocement and have given a long service life with very little maintenance cost. Ferrocement has also been used to build low cost land structures including houses, water tanks, and bridges. Concrete has proven itself successfully in the marine environment and ferrocement is no exception. To date, very few other forms of thin section concrete have been used in the marine environment as extensively as ferrocement (1).

1.2 Applications and Uses of Thin Section Concrete for Marine and Aquaculture Related Uses in Atlantic Canada

The aquaculture industry requires many new and innovative products that are specifically suited to its needs. The marine environment in Atlantic Canada is a very harsh and aggressive one both in terms of loads applied to the structure and severity of exposure of the concrete product. It is important that units have a long service life of at least several decades.

Floating wharves, service vessels and boats, storage barges, and cages are all possible immediate uses for thin section concrete. As the aquaculture industry advances there is the possibility of building integrated structures to contain all aspects of a modern fish farm. This would include cages, feed stores, living quarters, service equipment, and mooring and docking areas. As the industry becomes more accustomed to the use of this material, it will be able to identify other areas where the material can be used effectively.

The construction of a prototype that could demonstrate the properties of thin section concrete to the industry would be desirable. It would allow government and industry personnel to see first hand how the product performs when subjected to Bay of Fundy conditions. The product should be highly visible and allow various sections of the aquaculture industry access to it at the early stage of product development.

1.3 Slipforming Thin Section Concrete to Reduce Cost of Production

The major drawback to the use of ferrocement is the high labour cost required to produce it. Materials for construction are relatively inexpensive as they consist mainly of basic materials familiar to the local work force. The large amount of labour required to produce ferrocement products is the reason it is used extensively in countries where labour costs are low. But by using modern techniques in constructing thin section concrete, labour costs can be reduced substantially.

Iorns (2,3) has proposed several methods of slipforming concrete sections. These include methods for making ferrocement pipes and long continuous wharf sections. These methods reduce the amount of formwork that needs to be constructed and allow structures to be cast into the water thus eliminating the need to use heavy lifting equipment to place it.

1.4 Life Cycle Cost of Thin Section Concrete.

It is important to determine the life cycle cost of any product constructed for the aquaculture industry and the first step is to determine the expected service life of the product. The service life can come to an end for several reasons. If the purpose for which the product was built has disappeared the service life of the product has ended even if the product is in excellent condition. The other extreme would be a product that has deteriorated so badly it no longer performs to suit its purpose, although it is still required. Set up and removal costs must also be taken into account. Therefore it is essential that the length of time products are being compared reflect as near as possible the expected conditions of use. An accurate economic analysis must be performed using actual financial data. Inflation, interest rates and time frame must all be taken into account.

Ferrocement has been shown to have a long service life and maintenance and repair costs are relatively low (1).

2.0 ATLANTIC FINFISH AQUACULTURE INDUSTRY

2.1 Aquaculture Past and Present

Aquaculture is not a new concept. It began in China approximately 2000 years ago. Aquaculture began in Canada 100 years ago for enhancement purposes and began commercially in the 1950s. However it was not until 1979 that the first farmed salmon were harvested in New Brunswick.

Aquaculture in Atlantic Canada is a rapidly expanding industry. It is gaining importance with the decrease of fish stocks and the decline in the eastern fisheries. In 1992 almost 92% of the 11,224 tonnes of aquaculture production was from Atlantic Salmon (4).

2.2 Aquaculture in Atlantic Canada

Aquaculture in Atlantic Canada is very competitive with low profit margins. This is causing a need for more economical methods of raising fish including improving genetics, feeding methods and infrastructure. The industry is rapidly expanding and there are moves to produce various new marketable species.

The industry has experimented with various types of construction materials and there are possibilities to use other new material including thin section reinforced concrete.

2.3 Future Developments in Aquaculture

Over the last several years the Atlantic finfish industry has experienced problems such as disease and pests. The large number of fish that are kept in the few well sheltered bays plays a role in these problems. The need for the industry to move to more open water sites is becoming apparent.

The materials that are used at the present time to produce cages such as high density plastics have not been applied to the items that are required at open water sites. Ferrocement and thin section reinforced concrete can be developed for various structures that would allow the industry to move to more exposed offshore sites. This would eliminate the problems associated with fouling of the bottom and decline in water quality.

3.0 MARINE ENVIRONMENT AND INFRASTRUCTURE

3.1 Conditions in Marine Environments

The marine environment experiences some of the worst climatic conditions in the world. These conditions are not always well understood and it is difficult to collect accurate data on a location that is distant and hard to monitor. Therefore facilities are frequently over-designed. Cyclic loadings caused by wind and waves create serious loads on structures. Strong winds produce large forces on exposed surfaces of floating structures. Floating debris and ice can do tremendous damage to structures in the water. Ice build up and biological fouling can lead to increased weight and deterioration. Waves of various sizes and frequencies produce cyclic loadings that result in both horizontal and vertical loads. This produces high impact loads on the structure and on mooring lines.

The direction of the wind, flow of the current and other climate conditions are always changing. Tidal currents, especially in the Bay of Fundy, contribute to even higher forces. Mooring forces change direction regularly and the angle of the lines change with the tide as well. The tide in the Bay of Fundy causes problems for finfish aquaculture. The mooring and positioning of the cages is made difficult by the constantly changing water depth. In order for a cage to be held in an exact position, several mooring lines must be used. If the depth of water where the cage is located becomes too shallow, problems with the fish can occur. During the changing of tides the currents in some of the channels can increase which causes the net to move. Instead of the net hanging vertically it will tend to be pulled horizontally causing a reduction in enclosed area and increasing the stress on the fish.

The marine environment has many effects on aquaculture sites. Many of the sites are located where conditions are favourable for growing aquatic organisms. Under certain conditions the nets used to contain the fish become fouled by growth of marine organisms including seaweed and other marine vegetation. This requires cleaning at regular intervals to ensure adequate conditions are maintained. This is a difficult task to carry out and often requires removing the net from the cage and replacing it with another so the fouled nets can be taken to land to be dried and cleaned.

A major threat to farmed species is the loss of fish to natural predators. Seals are the most common attackers that lead to fish loss. They will attempt to catch fish that swim too close to the net, which results in damaging fish which are unmarketable. Many fish also escape through holes torn in the net by seals. Exterior predator nets are used to prevent seals from getting too near the net containing the fish but maintaining a proper separation between the fish net and the predator net is difficult.

Despite all these negative environmental factors, the mixing caused by the tidal action in the Bay of Fundy has positive effects. The high flow helps to flush the area below the cage of fecal matter and leftover food. This helps to improve water quality for the fish and provide oxygen-rich water for them. The tidal mixing also helps to maintain a uniform temperature throughout the tidal basin. If the water temperature drops below the freezing point ice can form in the gills of the fish resulting in their death.

Ferrocement's flexibility of design will allow the incorporation of features that will combat these negative environmental aspects. Design shapes are not restricted by available section sizes as in the case of products built out of plastic pipe. Ferrocement can be constructed to any section shape and strength to meet the product requirements. Features can be incorporated in the design which will increase the survival rate of fish contained within the cages. Ballast tanks can easily be added to allow the operator to lower the cage below the surface during storms and cold periods to avoid the adverse surface conditions that can kill the fish. Ferrocement cages can be constructed as a rigid structure that would maintain a consistent volume unlike the hanging net concept that is used in the floatation type collars. This would reduce the stress on the fish that would occur during tide changes due to the reduction in net volume caused by the currents. The rigid shape would also allow for the incorporation of effective predator protection for the fish. This would reduce both the stress on the fish and damage and loss caused by predators.

3.2 Infrastructure

The aquaculture industry requires a great deal of equipment for the production of marketable fish. Much of the equipment that is required for saltwater rearing must be used on a regular basis in a very harsh environment. The nature of most of the infrastructure used in aquaculture is floating structures that can support the nets and the associated equipment placed upon them.

3.2.1 Cages

Perhaps the most critical part of the infrastructure is the cage or net pen in which the fish are contained. The cage is continually exposed to wind, waves, tidal currents, ice, biological build ups and other adverse factors. These cages contain fish that are all of the same age and that will be ready for market at the same time. Damage to the cage can allow the fish to escape and lead to financial difficulties. This emphasizes the need for reliable and durable cages to resist the environment. Cages have evolved considerably for protected since the birth of aquaculture. Materials, designs and mooring arrangements now in use have all been tried and tested by the industry and are continuing to change and improve. Plastic circular cages appear to have performed well and are gaining popularity in Atlantic Canada, but ferrocement could be easily adapted for more exposed locations to produce a durable cage complete with a safe working platform for storing and distributing the daily feed ration and tending the fish.

A variety of cages are currently in use for finfish aquaculture, with the main requirement being that the needs of the fish be met in a manner not likely to expose them to excessive stress. There are several classification schemes for describing cages.

Sedgwick (5) places cages into three main groups which include inflexible cages, large flotation collars, and flexible multi-sided cages. New cage types and concepts are continually being developed as can be seen with the development of the

Ocean Spar net pen system shown in figure 1. There are also a variety of concepts that have been proposed, including modified oil tankers and integrated offshore vessels that include cages, feed stores and living quarters as shown in figure 2.

Cages of circular or multi-sided shapes allow the fish to use the entire contained volume. Salmon tend to swim in circular patterns and the corners of a square cage are utilized ineffectively. However it appears to be cheaper to construct and operate a square cage.

Originally cages were constructed of timber to produce a floating collar to which nets were attached. These cages performed reasonably well for the investment required but tended to fail in storm conditions. Metal cages are also being used both on the east and west coast of North America. They consist of metal walkways and have plastic floats supporting them. They are usually square in construction and range in size from 10 to 30 meters per side. However past experience with steel cages has lead to the industry moving away from them because of high costs.

The circular plastic cages shown in figure 3 are currently the most popular in the Atlantic region. They are large in size and are much less expensive than a system of net pens.

The performance of cages now in use is varied and largely undocumented. The performance is largely dependent on location, service and upkeep, and on storms and other climatic conditions. The circular plastic cages tend to perform well and are corrosion resistant, flexible and can be constructed locally to keep production costs to a minimum. This could also be done with ferrocement structures.

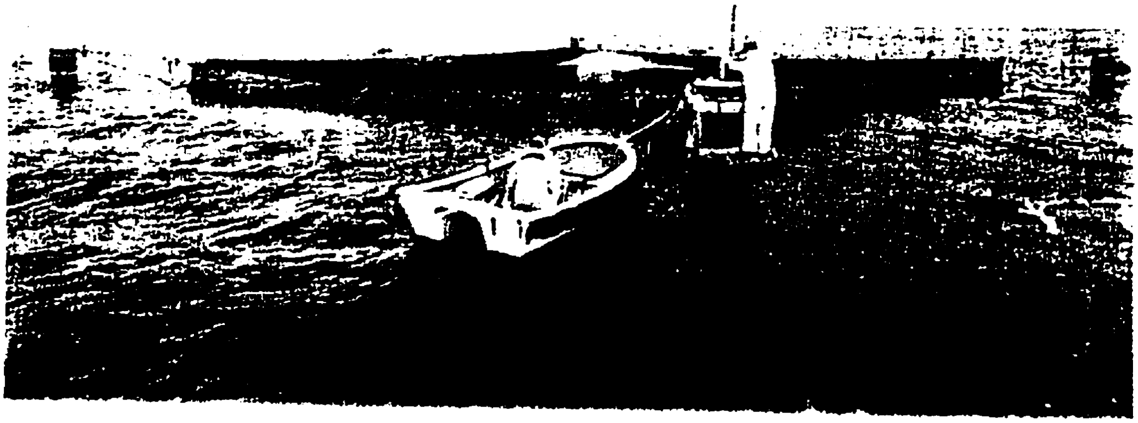


Figure 1 Ocean Spar Net Pen System (20)

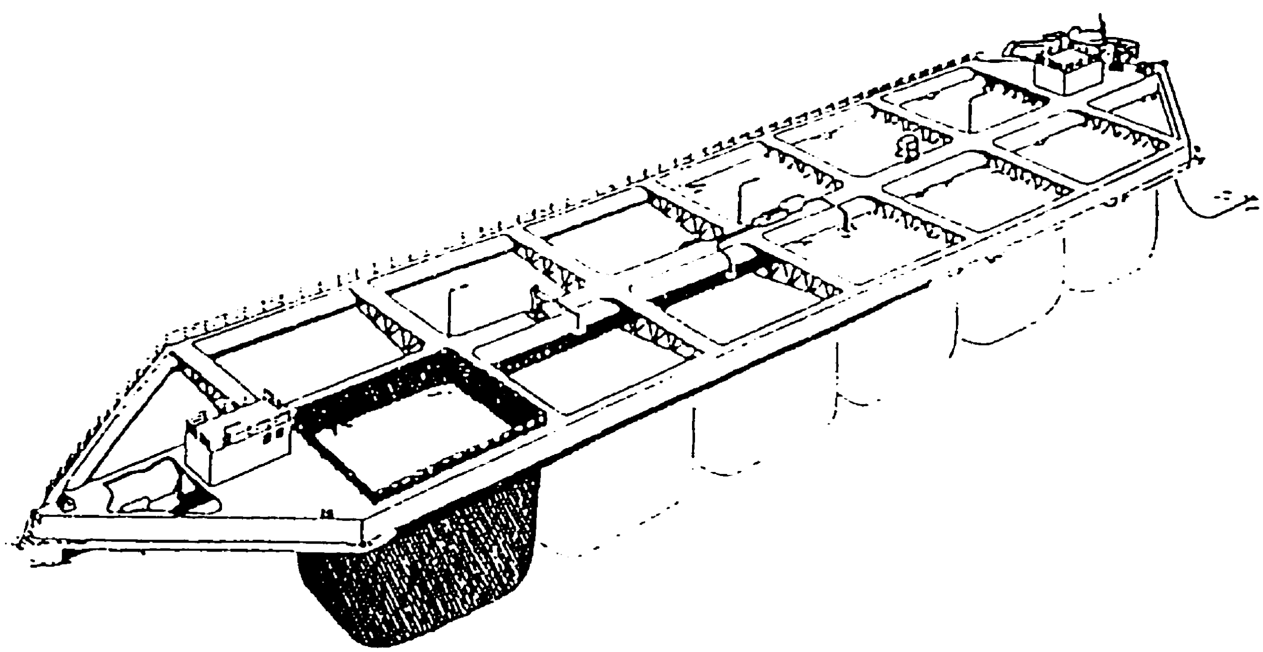


Figure 2 Conceptual Integrated Cage System (21)

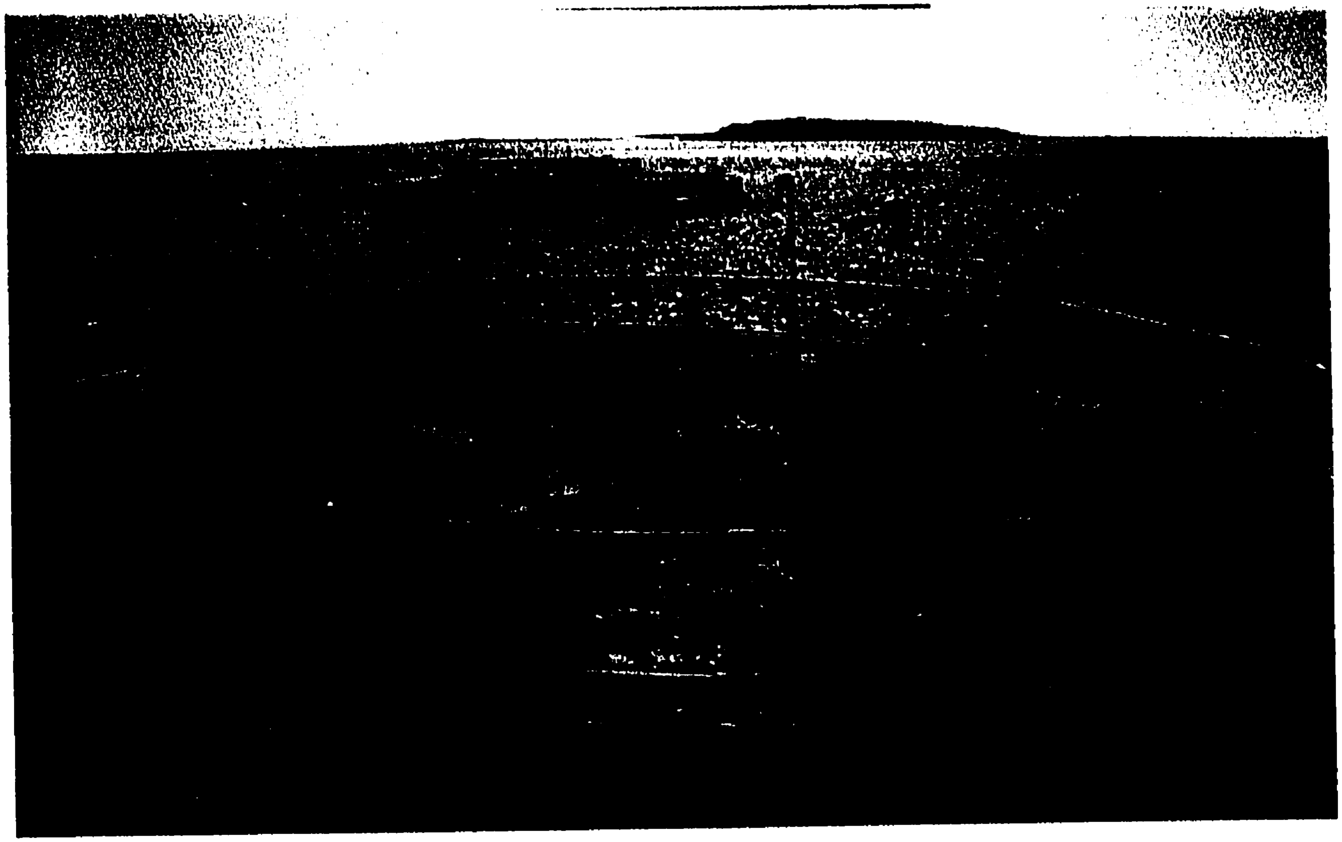


Figure 3 Circular Plastic Cages (22)

3.2.2 Support Vessels

Access to the cages is required on a daily basis for feeding and general care which requires a vessel that is durable and stable in all sea conditions with a good working area. Many of the suitable sites for net pens are a distance from land points of service and the necessity of transporting efficiently both feed and product is essential. Many of the vessels currently used are existing fishing boats which are nearing the end of their service life. Construction of new service vessels will require more purpose-built boats designed to serve the users more effectively. This is where a ferrocement vessel could prove beneficial.

More remote sites increases the need to leave workers out on barges in living quarters. This requires durable structures that could house a service crew including divers and biologists especially during stocking and harvesting. The possibility of moving to locations that are more offshore and exposed may require crews to stay with the cages to decrease the chances of loss due to vandalism and predator attack. Safe and functional ferrocement barges that could be moored at the net pen site without fear of damage would increase the productivity of the industry.

As the size of aquaculture enterprises expands it will become necessary to store feed close to the site of the sea cages. This will require floating warehouses that are either part of the cage or individual units moored nearby with the ability to withstand the same exposure conditions as the cage. A typical warehouse design is shown in figure 4.

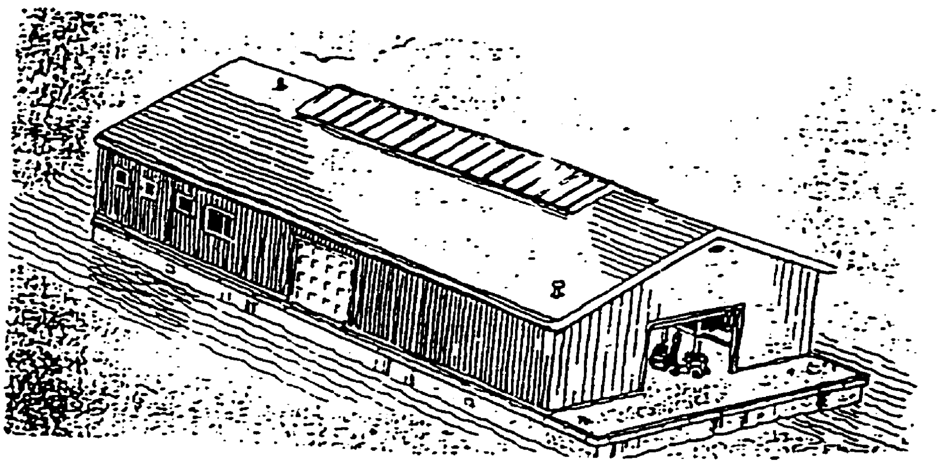


Figure 4 Floating Warehouse

4.0 CONCRETE IN A MARINE ENVIRONMENT

A great deal of research has been carried out on concrete in a marine environment (6) where it has been used extensively in marine structures like bridges piers, dams and sea ports. It is a relatively inexpensive and durable material that withstands extremely harsh conditions. Salt water, and freezing and thawing produce the greatest deterioration in the tidal zone.

4.1 Thin Section Concrete

Thin section concrete includes a wide variety of Portland cement concretes and mortars reinforced with a variety of materials.

The use of thin section fibrous cement products is in the range of 2.5 million tons/year around the world (7). The thickness can be as little as several millimeters. Meshes and continuous networks as well as fibers can be used effectively to improve the tensile strength of the concrete mortar. Fabric and mesh in various forms as well as fiber made of metals, polymers and natural materials have been used.

Two important factors in the properties of thin section reinforced concrete are the volume fraction of reinforcement and the specific surface of reinforcement. The volume fraction is the volume of reinforcement per unit volume of product. The specific surface is the bond area per unit volume of composite and is directly related to surface area.

Thin Section Concrete can be categorized into three main types; ferrocement, fibre reinforced concrete, and reinforced concrete.

Ferrocement is a specialized form of reinforced concrete. The American Concrete Institute defines it as " a form of reinforced concrete using closely spaced multiple layers of mesh and / or small diameter rods completely infiltrated with, or encapsulated in mortar" (8). Ferrocement reinforcement can vary considerably. Expanded metal , woven wire mesh, welded wire mesh, and chicken wire have all been used effectively. The spacing of mesh in the matrix is a critical factor in the strength of the material. The number of layers required varies depending on the required strength and impact resistance. The thickness of the cross section also varies from 10 mm to 40 mm. The material has small closely spaced cracks that provide a durable surface. Waterproofing finishes can also be placed on the surface to decrease permeability. Ferrocement has performed well in marine applications and boats are routinely built of ferrocement.

According to the American Concrete Institute (7) thin section fiber reinforced concretes can be broken down into three main groups. The classification is based on the type of fibers used for reinforcing. The first type employs synthetic fibers made of polyethylene, carbon, aramid and polypropylene. Glass fibers make up another group of materials used to reinforce thin section concrete, and this class includes new alkali resistant glass fibers. The third type employs steel fibers to reinforce the concrete. Research done with steel fibers in a marine environment shows that they perform well. The fibres are relatively short in length and are usually quite flexible. Therefore they do not change the properties of fluid concrete significantly. Most of these fibers are used to reinforce sheet products and because they are randomly distributed in a three-dimensional space they are not as effective in reinforcing thin sheet products as the two-dimensional mesh used in ferrocement.

Traditional reinforced concrete can be made in thin sections constructed using normal reinforcing bars. However, because of the cover requirement for the reinforcing, it is not possible to cast sections that are as thin as ferrocement and fiber reinforced concretes. The use of thin reinforced concrete is possible when the sections are in the range of 100 mm to 200mm thick.

The strength of thin section concrete varies considerably depending on the type of reinforcing that is used. Fiber reinforced products differ greatly from ferrocement and other thin section concretes produced using continuous mesh. Ferrocement can differ considerable depending on the type of reinforcing mesh and also the orientation of the mesh. Some mesh including expanded metal lath are very strong in the direction of the original sheet but very weak in the opposite direction.

4.2 Floating Concrete Products

Perhaps the first floating concrete product was a boat built by Louis Lambot in 1849 and described in the book "Concrete Afloat" (9) (Figure 5). Since then concrete has been used for a variety of floating products including ships, boats, wharves, and navigation buoys, and during World Wars I and II reinforced concrete was used as a emergency material for building ship hulls. The performance of these structures is varied but they proved conclusively that concrete could be used to construct floating marine products.

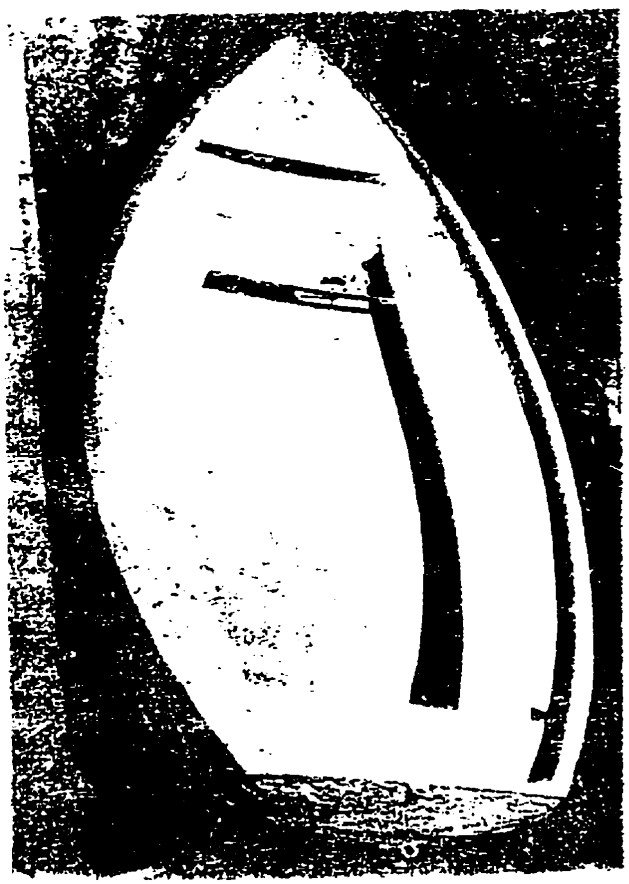


Figure 5 Lambot's Boat of 1849 in Paris 1974 (24)

According to Paul and Palma (10) ferrocement has been used extensively for constructing boats in the range of 12 to 15 meters in length. It is used mainly in countries where labour costs are low as is the case in China where thousands have been built. Fishing and small pleasure boats are the most common use of ferrocement but it has also been used for barges and fuel storage.

Most work with floating reinforced concrete was done during World War I and World War II during emergency boat building programs (11). The largest concrete ship ever built was the one hundred and thirty meter long Selma which was constructed of reinforced lightweight concrete. Floating docks, barges and pontoons were also built of reinforced concrete. Foundations for floating houses and floating barges continue to be built today, but prestressed concrete has become a more economical material for large vessels.

4.3 Ferrocement

Paul and Palma state "In general, ferrocement is considered as a highly versatile form of composite material made of cement mortar and layers of wire mesh or similar small diameter steel mesh closely bound together to create a stiff structural form. This material which is a special form of reinforced concrete, exhibits a behaviour so different from conventional reinforced concrete in performance, strength and potential application that it must be classed as a separate material" (10).

For our purposes it is important that we do not think of ferrocement as normal reinforced concrete as it has many advantages that make it more appealing for marine applications. Ferrocement is a composite material and therefore its behaviour is typical of a composite. It has a high tensile strength to weight ratio, and can be made relatively watertight.

The most common types of reinforcement used for ferrocement are welded and woven wire meshes and expanded metal as shown in figure 6. Several layers of this mesh are usually impregnated with a cement-based matrix to produce a material with high strength.

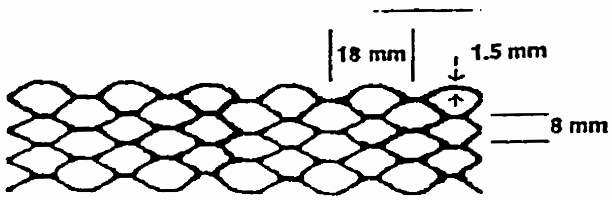
The matrix amounts to around 95% of the section volume and therefore its properties are important. It is comprised of hydrated cement and an inert filler which is usually sand. The matrix can also include fibers, but the size of the mesh opening must allow penetration of the fibre into the reinforcement.

4.4 Applications of Ferrocement

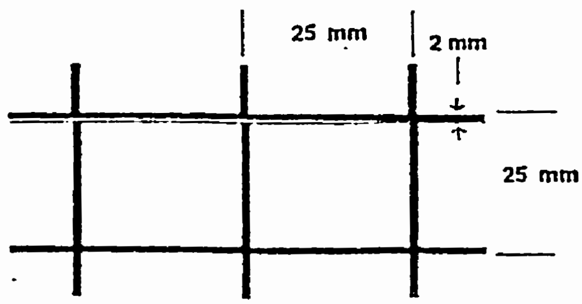
The uses of ferrocement has developed over many years. The main areas of use of this composite material are for boats, silos, tanks, and pipes. Ferrocement is very labour intensive and therefore tends to be used only for thin specialized applications (12).

Ferrocement boats are used extensively in Asia. They are cheaper then steel, are more durable than wood, and can be formed in virtually any shape. Ferrocement boats are heavier than wooden boats but at low speeds this does not affect operating costs to a great extent.

In developing countries tanks for storing grain and water have been built using ferrocement. It has a ductile failure mode which is beneficial. Corrugated ferrocement sheets have been used for roofing materials where they can be constructed on site.



3.4# EXPANDED METAL LATH (not galvanized)
Made from 9 in. (229 mm) wide strip of 24 GA. (.0329 In./0.6 mm) thick sheet steel expanded to 27 in. (686 mm) width and cut into 96 in. (2.4 m) lengths.



1"x1" 14 GAUGE WELDED WIRE MESH
Used in various gauges and openings for interior reinforcing under at least one layer of expanded metal lath near the surface for crack control.

Figure 6 Ferrocement Mesh Types (25)

which makes them economical as transportation costs for raw materials are relatively low.

Some problems have been noted with ferrocement boats after several decades of service. In particular poor application of mortar has led to voids and improper penetration of the matrix into the steel mesh. The steel in the area of these voids often corrodes and leads to failure while the steel in dense mortar adjacent to these improperly compacted regions is still in its original state. Corrosion is due to the creation of a galvanic cell with the improperly compacted concrete acting as the anode.

The fact that the reinforcement corrodes in these circumstances stems from the use of too thin a section leaving very little room for cover over the reinforcement. Many layers of reinforcement are also used which can make it difficult to force the stiff mortar through and around the reinforcing mesh. With hand placement a great deal of care is required during the construction phase.

The mortar used in marine applications must also be capable of withstanding the actions of the seawater. The matrix used in ferrocement has a sand to cement ratio of 1.5 to 2.5 by weight and a water to cement ratio of 0.35 to 0.5. A fine well graded sand is required with 100 % passing a # 16 sieve (7). A very dense impermeable mortar is desirable to prevent deterioration because the section can be as little as 25 mm in thickness. Any loss of material will lead to loss of cover followed by corrosion of the reinforcement. Also the matrix must be impermeable to prevent water from passing through it, although making boats that are essentially water tight has not been a problem. Paints and other coatings have been used to protect the reinforcement but this can be avoided with a durable mortar and stainless steel reinforcement.

The use of reinforcement that will not corrode can be a great advantage in this environment. Although polypropylene mesh and fibrillated plastic fibers can be used they are not very effective as their modulus of elasticity is low. Consequently they are not widely used in construction. Stainless steel meshes have been used but they lead to higher production costs.

4.5 Physical Characteristics of Ferrocement

The properties of ferrocement are associated with a relatively large amount of two dimensional reinforcement with small diameters and large surface areas. Since the reinforcement is distributed extensively throughout the entire matrix, there is a great increase in elasticity and resistance to cracking. This is related to the volume fraction and the specific surface of the reinforcement.

Tensile stresses cause three stages of behaviour in ferrocement elements as discussed in Nedwell and Swamy (12). The composite first behaves as a linear elastic solid until the first crack in the matrix. The next stage is the multiple cracking stage which starts at the first crack in the matrix and continues to the point where the matrix begins to fail. At this stage the number of cracks tends to increase but the crack width remains constant. This can be of benefit when used for water tight elements. The cracks widen in the third stage but few new cracks are observed. At this time the reinforcement is yielding and will continue until failure. Fig 7 shows the various

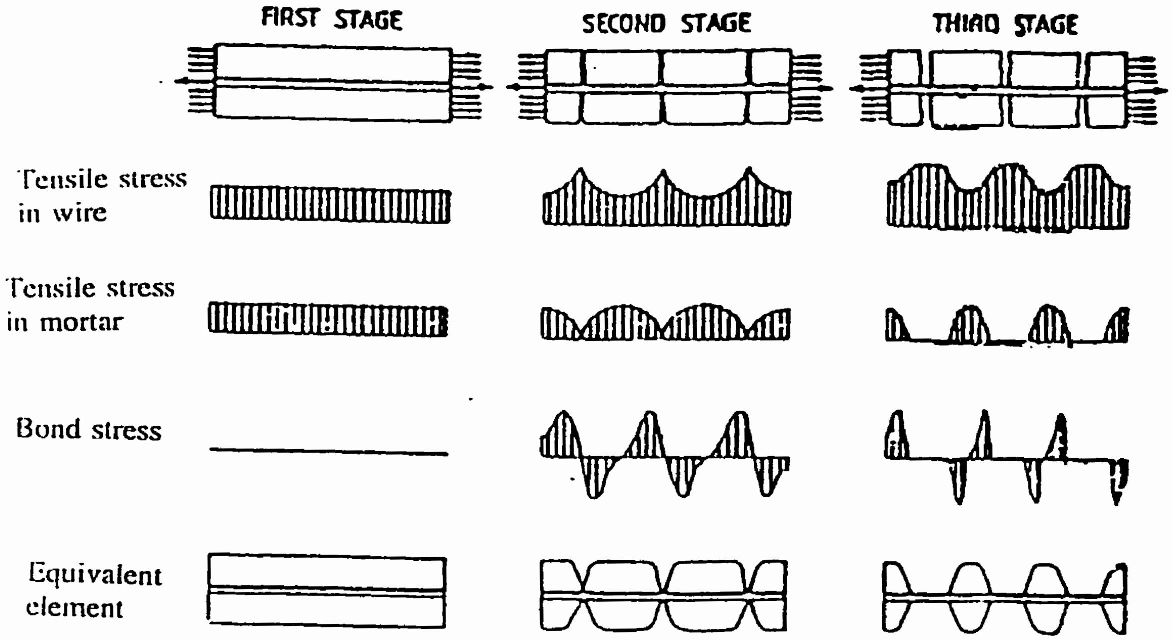


Figure 7 Stages in Ferrocement Cracking (25)

stages of cracking in a ferrocement slab subject to an increasing tensile stress.

Flexural behaviour is similar to tensile behaviour in that it is divided into three regions as shown in the load - deflection curve in Fig 8. The lower dashed line in Fig 8 represents the theoretical stress - strain curve if the composite was modified to an equivalent area of steel. The three regions are pre-cracking, post-cracking, and post-yielding stages. The most common stage seen in service is the post-cracking stage at this point. There is assumed to be no tensile strength in the mortar and all the tensile load is carried by the reinforcement. The composite behaviour can be approximated by formulas used for common reinforced concrete and good agreement is realized. The reinforcement provides improvements in the flexural strength of cement composites(12).

The resistance to impact loading can be increased with increase in the specific surface and the volume fraction of reinforcement. Welded wire mesh provides higher impact strength then chicken wire type reinforcement. The type and shape of the impact load also has an effect on the failure pattern.

4.6 Durability of Ferrocement in a Marine Environment

Ferrocement is a durable material in the marine environment and has performed well in past applications. The most important factor in producing a durable product is the quality of the mortar. Due to the thin section of the ferrocement, it is essential that a low permeability mortar be produced to resist the ingress of moisture. Admixtures can be added to the mortar that will produce a more impermeable product. Generally, the factors that produce a mass concrete that is durable in the marine environment also produce a durable matrix for ferrocement. These admixtures include silica fume and high range water reducers.

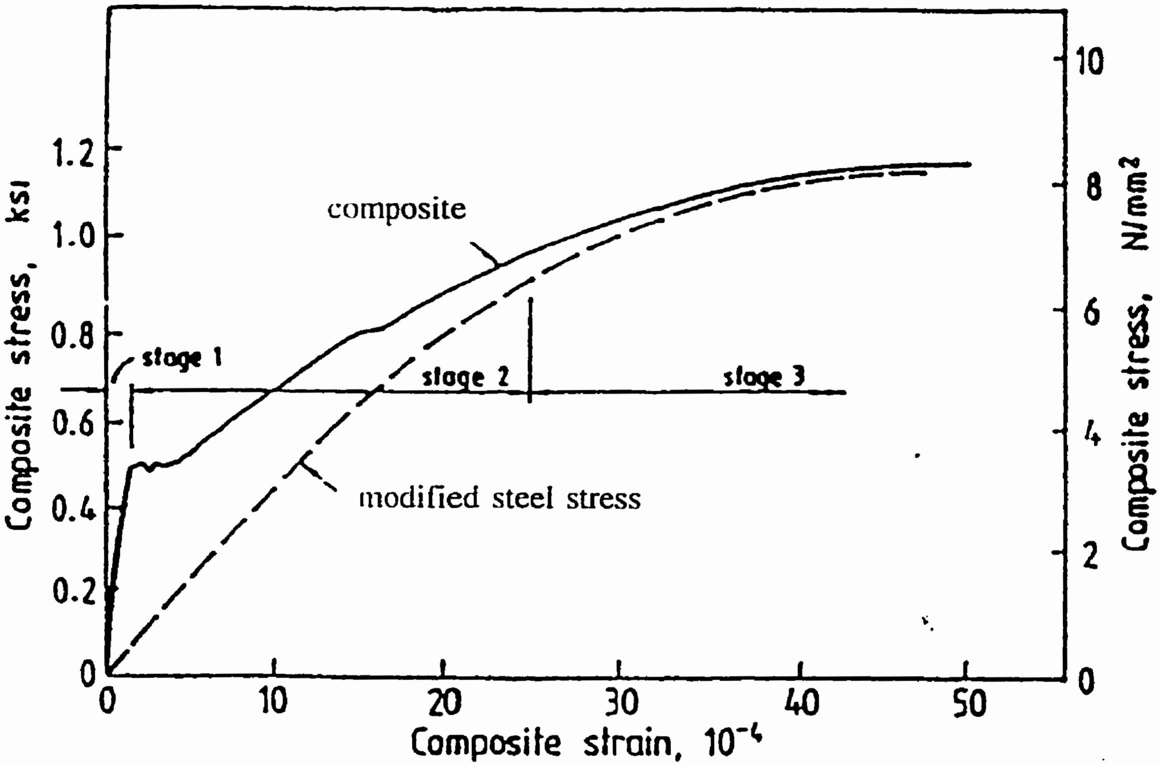


Figure 8

Stress Strain Diagram Showing the Stages of Ferrocement Cracking (27)

5.0 POSSIBLE APPLICATIONS OF THIN SECTION CONCRETE PRODUCTS IN AQUACULTURE

The demand for products that will meet the requirements of the industry is continually growing. Concrete products can prove to be very suitable for aquaculture uses due to their known durability in the marine environment. Floating concrete structures including barges, cages, boats and feed storage bins can be very beneficial to the fish farmer.

Cage structures are presently being constructed of a variety of materials including plastics, metals and wood. Designs of these cages are diverse both in appearance and function. The concept of a cage structure that could be constructed of some type of pozzolanic cement composite appears to have merit. Proper planning and design would be required to ensure that the product is durable and stands up to the conditions placed on it.

Floating docks, warehouses, and service vessels are also possible areas of use for concrete products. In these structures the full advantage of using thin section concrete products can be most easily realized. Structures that are a single, relatively rigid unit might produce a better facility then the products currently used. These concrete structures would be convenient to construct and would demonstrate the performance of thin section concrete and provide experience that would lead to the construction of products of a more complicated shape. For example, a floating feed storage facility would appear to be suitable for thin section concrete.

The initial cost and service life will play a major role in deciding the future of concrete products for aquaculture. To enter the market, products must be competitively priced or exhibit characteristics that make them superior to competing products. The aquaculture industry is so young in Atlantic Canada that existing products that last as few as five years are thought to be durable. Long term needs for facilities must be ascertained and the requirement that they need to have a long service life must be appreciated by the industry before thin section concrete structures can be marketed competitively. Concrete products are likely to be competitive only after they have been demonstrated to be able to provide this long service life at an economically competitive price to the local aquaculture community.

5.1 Favourable Applications for Thin Section Concrete

The properties of thin section concrete make it ideal for use in certain marine structures. Due to the corrosive nature of the marine environment, the durability of the product plays a very important role. Generally this type of construction is noted for good long term performance (12). One of the main advantages of thin section concrete is it weight. Due to the fact that the cross section is thin there is a minimal amount of material and therefore a low dead weight with the result that the vessel floats high in the water.

Also, thin section concrete can be constructed from basic raw materials by a local labour force. The shape of the finished product can be very complex and still be easily constructed of thin section concrete.

5.1.1 Barges

Barges are simple structures that could be constructed effectively out of concrete products. Depending on the size of the barge different materials are used. For a barge to be useful to the aquaculture industry, ferrocement appears to be the most appropriate form to use. The thin section would allow for a vessel of high capacity and still provide durable deck and sides to handle the impacts of landing materials and mooring. A proper engineering design would need to be carried out to ensure that the barge can withstand all the loads imposed on it. With ferrocement construction the size or shape are not limitations as in the case with wood and steel. Also the surfaces of the ferrocement can be finished to produce an anti-slip deck and smooth surfaces in the water.

5.1.2 Service Vessels

The variety of vessels used in the aquaculture industry includes scows, fishing boats, and flat deck service boats. Most new boats built specifically for the aquaculture industry are being built from conventional materials like wood, steel and fiberglass. A few ferrocement boats over ten meters in length have been constructed, and are less costly and last longer than those built of traditional materials (13,14).

5.1.3 Marine Wharves

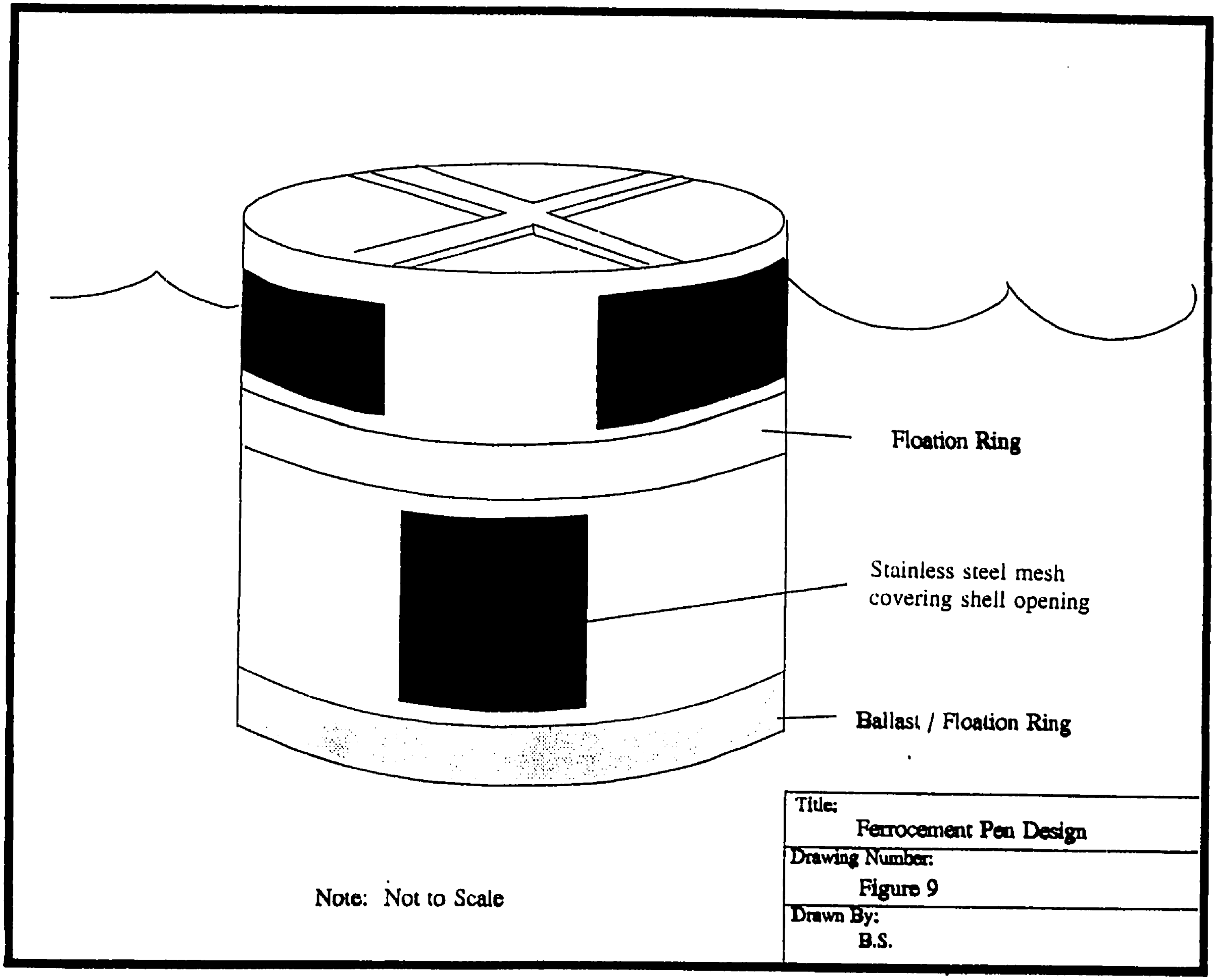
Reinforced concrete has been used extensively for industrial and public wharves, but it tends to be very heavy with a high initial cost. Pressure treated wood products have been used extensively for marina mooring facilities. This is a very light building material, is also very versatile, and employs well known construction techniques; however it tends to have a short service life (13,14).

Ferrocement has a very thin cross section resulting in a significant reduction of weight which is desirable for a floating wharf. It is also a very durable material for marine applications making it more appealing then most other materials. Furthermore its construction techniques require mainly unskilled labour and construction can take place on site. It has been used effectively for marine wharves to serve both the aquaculture industry and the commercial fishery on the Pacific coast (14).

5.1.4 Design of Appropriate Cages

As experience with ferrocement products is gained in the Atlantic aquaculture industry, it is hoped the industry will gain sufficient confidence to try various new designs using ferrocement. New species that are being promoted will require new cage designs and these new cages might be built more effectively out of ferrocement.

Ferrocement net pens can be constructed based on designs that produce a rigid structure. To do this the movement caused by the surface waves must be avoided by positioning the main buoyancy collar below the ocean waves and using a system of ballast tanks below the water line that can be flooded or filled with air to control the pen elevation in the water. The vertical struts above the buoyancy collar would be constructed of double walled ferrocement with sufficient buoyancy from inside to provide stability for the overall floating structure. Figure 9 shows a preliminary design of a net pen complete with a foam filled flotation ring at an elevation below the maximum wave height and a ballast / floatation ring at the bottom of the tank. The plan view of this structure shows ferrocement beams at the top and bottom of the vertical cylinder shaped pen to provide structural stability. The sides of the pen would need to have exposed stainless steel expanded metal to allow for circulation of water

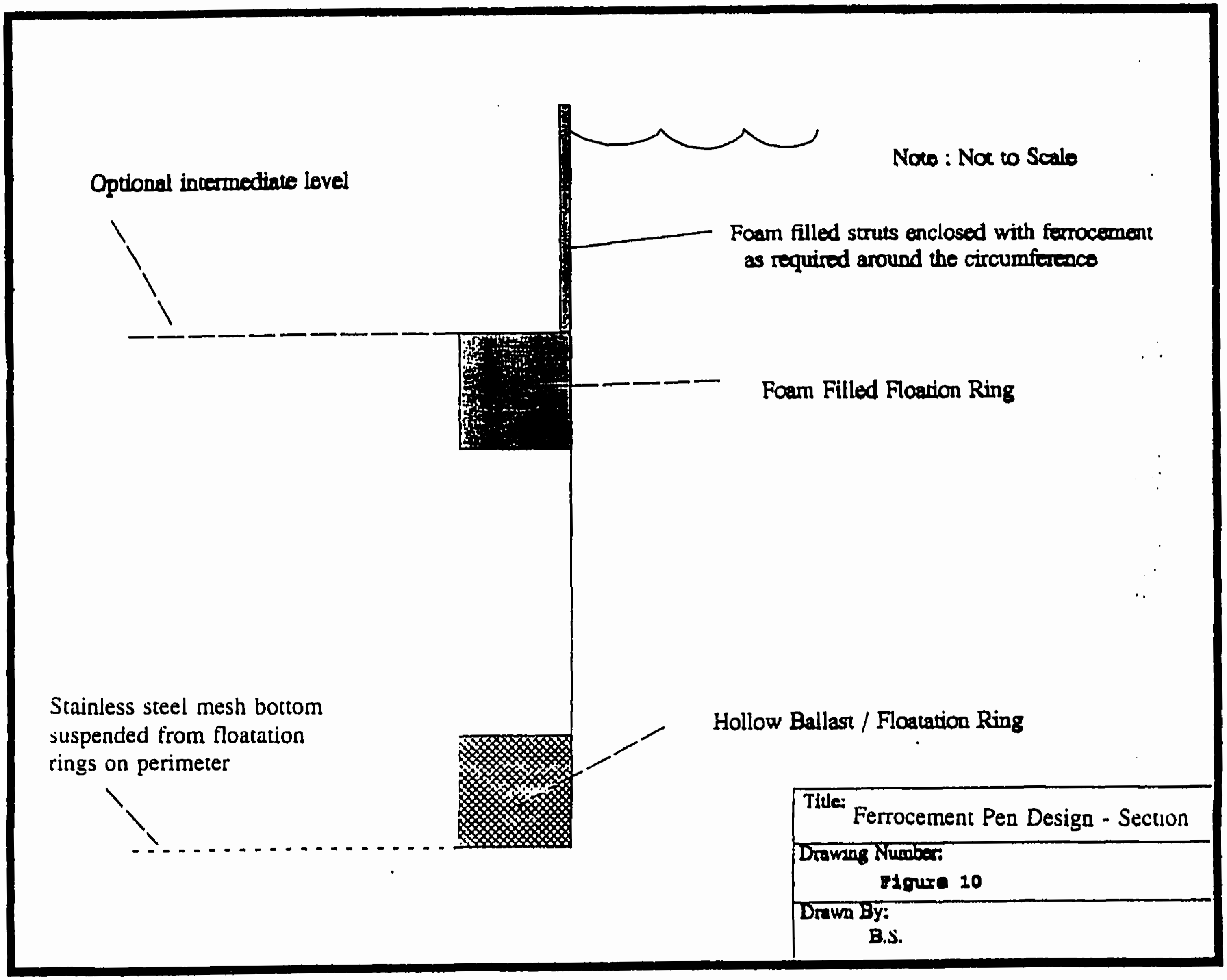


Floation Ring
Stainless steel mesh
covering shell opening
Ballast / Floation Ring
Note: Not to Scale
Title:
Ferrocement Pen Design
Drawing Number:
Figure 9
Drawn By:
B.S.

through the pen to maintain water quality. These openings would be constructed by not applying mortar to areas of the reinforcement. Since the mesh in the openings would extend into the ferrocement section there would be no concern for fastening the mesh at the perimeter of the openings. Openings would need to be distributed in a manner that will maintain the strength of the complete pen. A stainless steel mesh could also be used to seal the bottom of the cage while a traditional net would likely be used to seal the top of the cage.

The benefits of this type of a structure over traditional pens are numerous. The pen is a rigid structure that will provide a stable water volume for the contained fish and allow for the lowering of the cage below the water surface during bad weather thus increasing the security of the fish. However, the traditional net covering the cage must be replaced with a predator net and a fish net. Ferrocement creates no constraints in producing this type of structure due to its ability to be formed in any shape or thickness. Vertical slipforming could be used to produce this pen system on the water greatly reducing construction costs.

Ferrocement is a very versatile material that could easily meet the changes necessary to meet the future needs of the industry as new fish species are farmed. The cage described above could easily be modified to handle benthic species by making a portion of the bottom of the cage solid and perhaps adding intermediate levels as shown in figure 10 . It would be very difficult to mimic the geometry of the existing cage designs that are based on the flexibility of plastic with ferrocement and still produce an acceptable product.


Note : Not to Scale
Optional intermediate level
Foam filled struts enclosed with ferrocement as required around the circumference
Foam Filled Floation Ring
Stainless steel mesh bottom suspended from floatation rings on perimeter
Hollow Ballast / Floatation Ring
Title: Ferrocement Pen Design - Section
Drawing Number: Figure 10
Drawn By: B.S.

5.2 Applications Unsuitable for Thin Section Concrete

It is essential that applications for which thin section concrete are unsuitable be recognized. The production of products that fail because the material is simply unsuitable for that end use would tarnish the reputation of thin section concrete and make it much more difficult to promote it for other applications. Large surfaces made from thin section material are likely to buckle unless they have intermediate stiffeners which fortunately are easy to incorporate into the design. Also long slender shapes may not develop significant strength to resist bending moments and in this case the use of prestressing should be considered.

It is important to determine the loads imposed in a particular application and design the structure to resist them.

5.3 Production Methods of Thin Section Concrete

Basically ferrocement is produced either by forcing layers of mesh into the matrix or by forcing the matrix through a preassembled reinforcing mesh. If the matrix is applied from two sides of the mesh, care must be taken to ensure that no voids are left as this will lead to a poor bond between the mesh and the matrix resulting in a weak material.

Depending on the construction method, the product can either be constructed on site or close to the site of final use, or produced in a factory and shipped to the site. There are advantages to both types of production. Factory production makes it easier to maintain high quality control and allow trained labour to work very efficiently. Constructing the finished product on site allows for lower transportation costs and less handling of the finished product. Each situation would need to be analyzed on an individual basis.

5.3.1 Preformed Reinforcing and Mortar Packing

Hand plastering or shotcreting can be used to place the matrix around the mesh network that has been formed to the desired shape of the product. This is a relatively simple process as no formwork is required. This process can be enhanced by using a mould on one side and forcing the matrix through the reinforcing against the mould.

5.3.2 Laminating Process for Ferrocement

The laminating technique involves forcing the mesh into the plastic mortar. A layer of matrix is applied and allowed to set partially; this is to ensure proper cover. A second layer of mortar is then spread and one or two layers of reinforcing mesh is rolled into it. This layering process is continued until the desired thickness is reached.

5.3.3 Slipform Process for Ferrocement

One possible method of producing ferrocement is a slipform process. It would be most effective for uniform cross sections and for shapes where a slipform could be easily constructed. A one-sided form is constructed long enough to support the ferrocement for a period of time that will allow placing and curing. The construction is done on a continuous basis and the product is advanced out of the form at regular intervals. In slipforming ferrocement, the form is stationary on a beach and the product is extended out into the water. Because only a small part of the product is in the form at any one interval, a considerably smaller amount of formwork is required.

This method of construction was developed by Iorns (2).

6.0 DEVELOPMENT OF A THIN SECTION CONCRETE PRODUCT SUITABLE FOR AQUACULTURE AND THE MARINE ENVIRONMENT

6.1 Selection and Requirements of Trial Product

As an inducement to the industry to invest in the concrete net pen system, there is a need for a demonstration project to be carried out whereby a simple structure is built using similar material and procedures and then exposed to conditions in the Bay of Fundy.

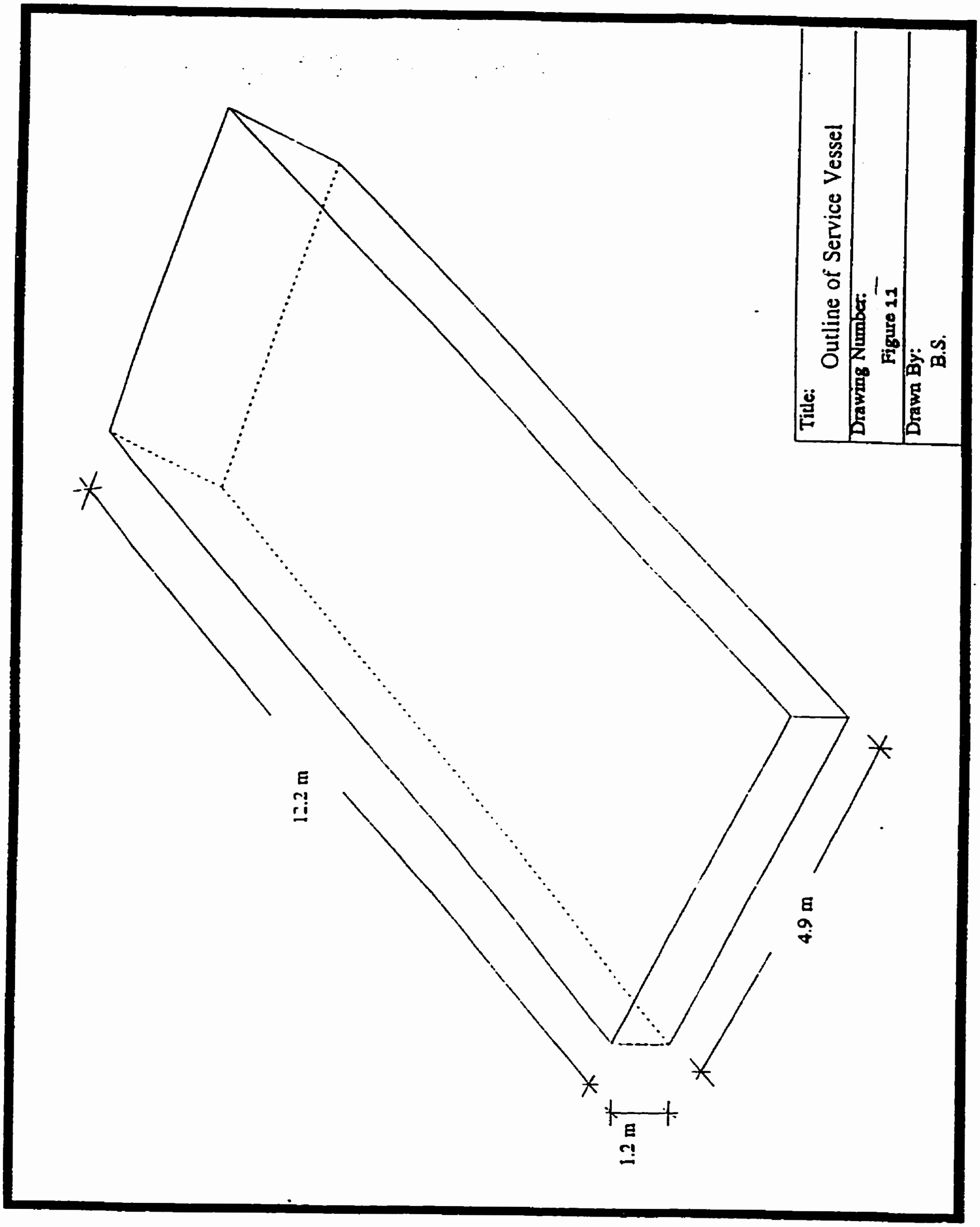
This demonstration project could be a floating concrete product for use in the aquaculture industry that must be selected, built and operated to demonstrate that it can be used effectively. The trial product should be readily accessible to as many members of the local industry as possible so they can see first hand the performance of the product. A structure that is similar to something already in service allows for an easy comparison between the old construction materials and ferrocement under the same loads and conditions.

The loading on the demonstration project should be typical for the location and conditions of use and include impact, wind, wave, icing, abrasion and other various effects. The trial structure should be exposed to known forces so that an accurate calculation of the internal stresses can be determined thereby increasing the knowledge gained from the trial project.

Based on these considerations possible suitable projects would be a floating wharf structure, a floating barge, or a service vessel. All of these structures would face impact loads from boats bumping the sides during docking. Exposure to marine conditions would be possible by placing the structure at a suitable location where marine loads are placed on it. Industry could have access to the structure if it were a public wharf or a feed storage barge owned by a fish feed supply company.

A survey of periodicals related to the aquaculture industry shows there is an increasing interest in the production of service vessels (15). Service vessels are being produced from various materials including plastics, wood and metals. The possibility of using thin section concrete to produce a marketable service vessel appears promising. It would require making the industry aware of the product and also showing that the product could be produced at a reasonable cost. The fact that ferrocement can be produced locally and is easily adapted to different designs and requirements will draw interest to it in the developing production of service vessels. The cost analysis in this report will focus on a service vessel. This will show after a few years if it is comparable in cost and superior in performance and durability compared to other construction materials.

The base structure of the service vessel is shown in figure 11 complete with dimensions. A boat of this size and shape was chosen as it reflects the average size and shape of those produced to date, and the size and shape lends itself well to ferrocement construction techniques. Also a vessel of this size is more likely to be to be constructed at this stage of development than a larger vessel. This vessel might


Title:
Outline of Service Vessel
Drawing Number:
Figure 11
Drawn By:
B.S.
12.2 m
4.9 m
1.2 m

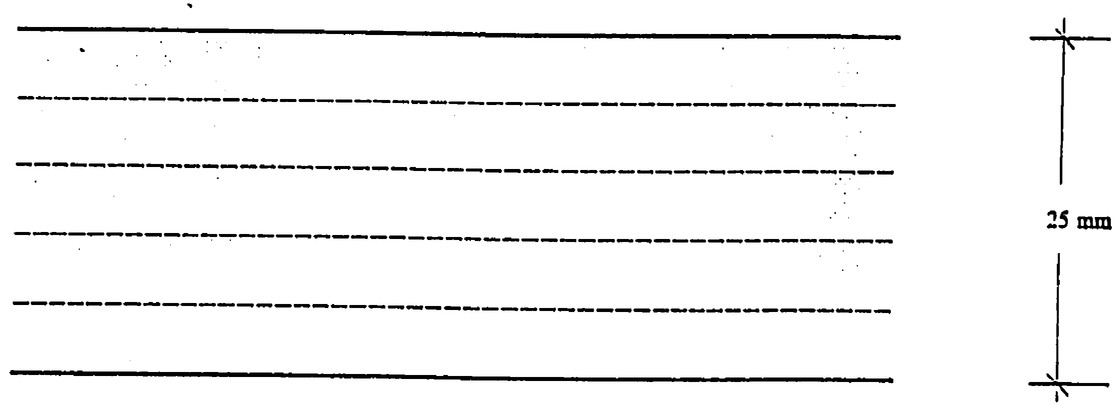
need to be modified to suit the attachment of special equipment but items such as a wheel house will not require major changes. The additional equipment was not considered due to the various requirements from different owners.

The vessel shown in the preliminary drawing was used for the cost estimate in section 6.6., which will address the vessel from a construction and economic point of view. The size chosen, 4.9 m (16 ft) by 12.2 m (40 ft), is an appropriate size for a Bay of Fundy service vessel.

In the aquaculture industry vessels are required to carry materials to and from cage sites and to provide a stable working platform from which to carry out daily activities. This necessitates a large deck area and a high load carrying capacity which the proposed vessel meets.

The cross section of the hull of the vessel is shown in figure 12. The 25 mm thickness is a typical section thickness for a ferrocement vessel of this shape and size. The number of layers of reinforcement can be up to five layers in a section of this thickness however three layers has been selected for cost analysis.

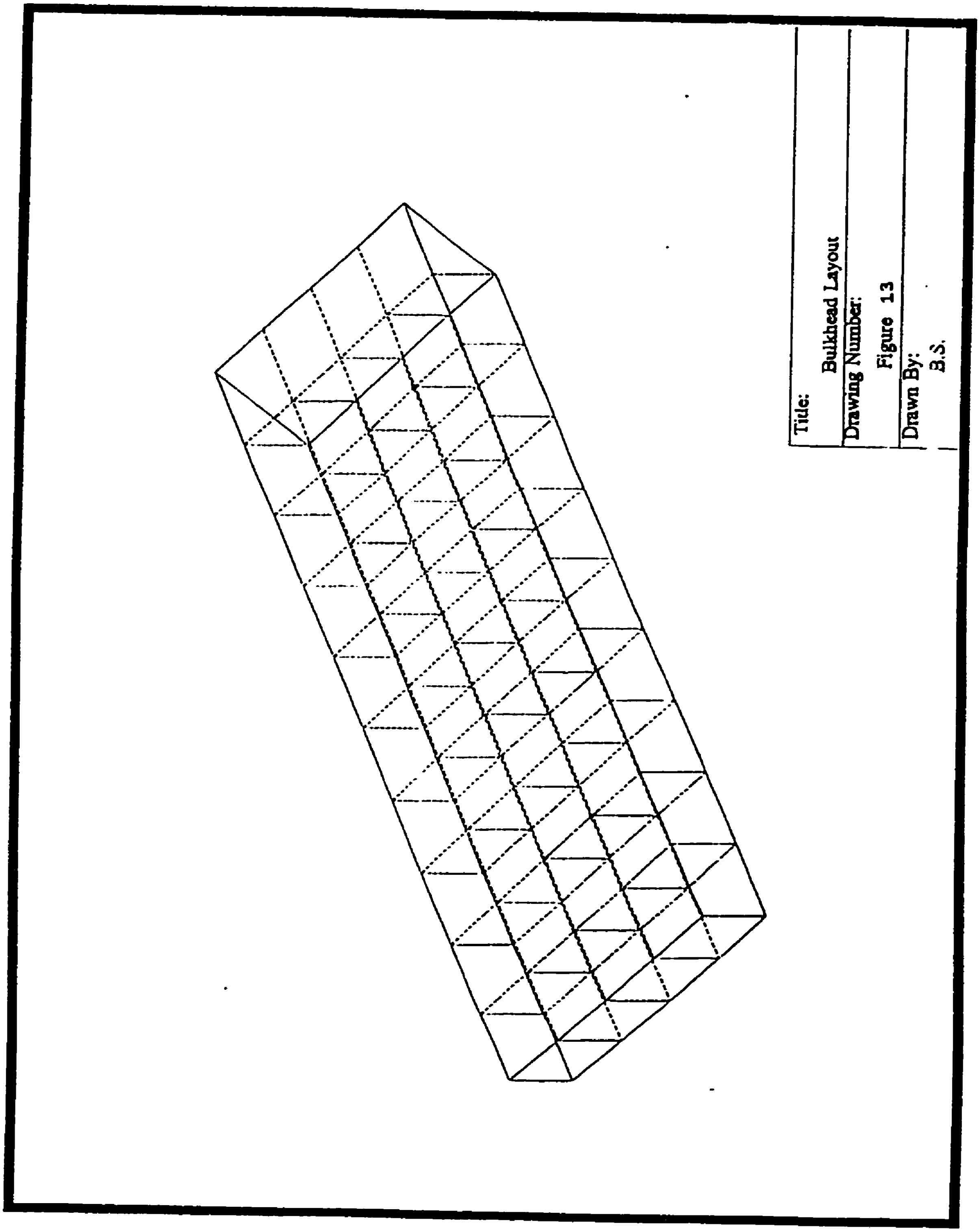
To increase the deck load capacity and to resist the water pressure beneath the boat it may be necessary to include internal stiffeners between the bulkheads depending on the applied loads. A barge type vessel constructed of thin section concrete will require the inclusion of internal bulkheads. In the prototype these bulkheads are spaced at 1.2 m in both directions as shown in figure 13. These compartments will be accessible via a watertight hatch to allow for inspection. Some of these cells could be constructed to allow for storage of a variety of materials such



Typical cross section showing 4 layers of expanded mesh and mortar. The outer layer of mortar constitutes the cover.

----- Wire Mesh Reinforcement

Title:	Ferrocement Cross Section
Drawing Number:	Figure 12
Drawn By:	B.S.


Title:
Bulkhead Layout
Drawing Number:
Figure 13
Drawn By:
B.S.

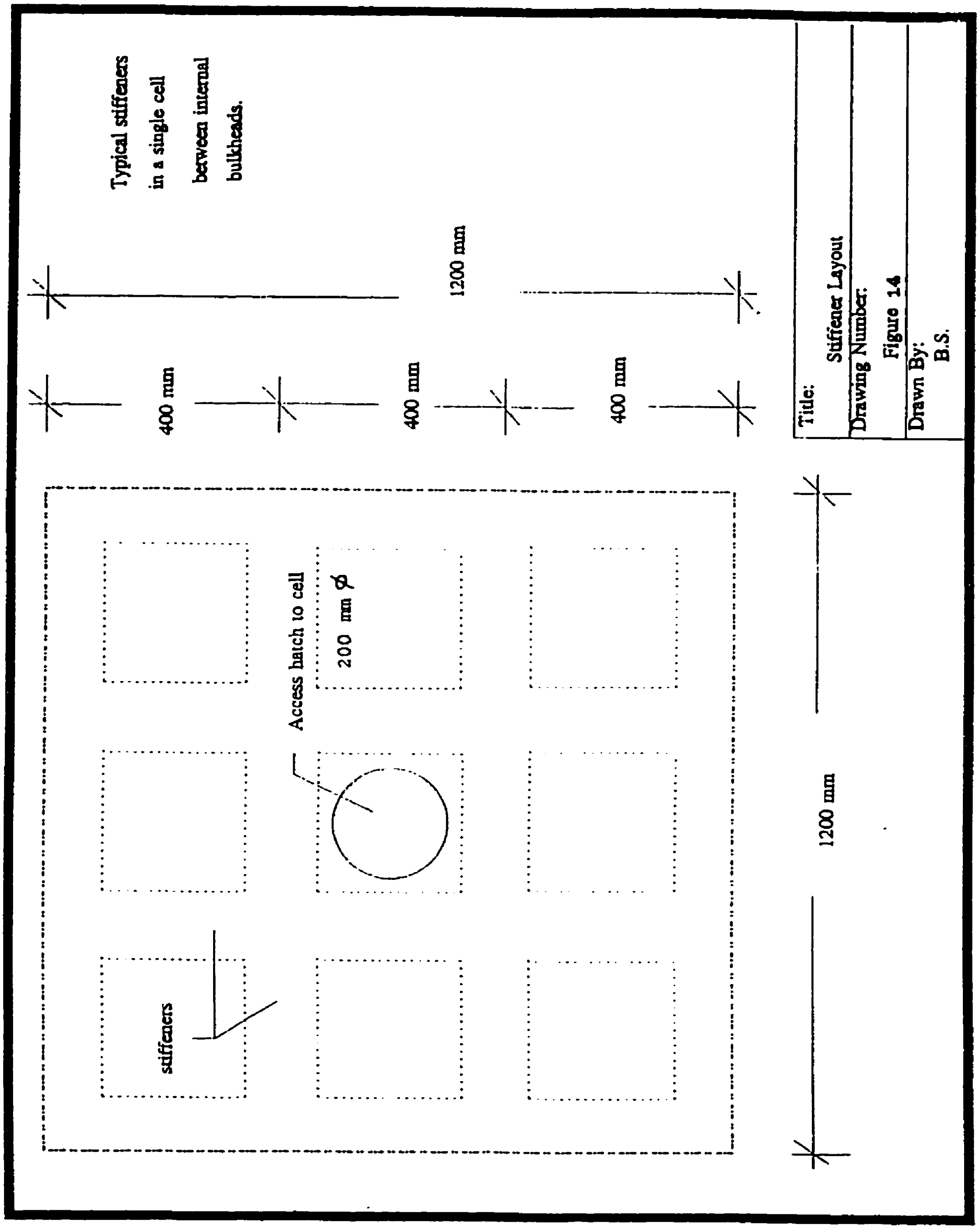
as wet wells for live fish. Figure 14 shows these spaced at third points between the internal bulkheads. A typical detail for the stiffeners is included in figure 15. This particular detail shows the inclusion of 10 M reinforcing bars. The section is thicker at the stiffeners and because of this the reinforcing bars can be included as there is adequate cover to prevent corrosion.

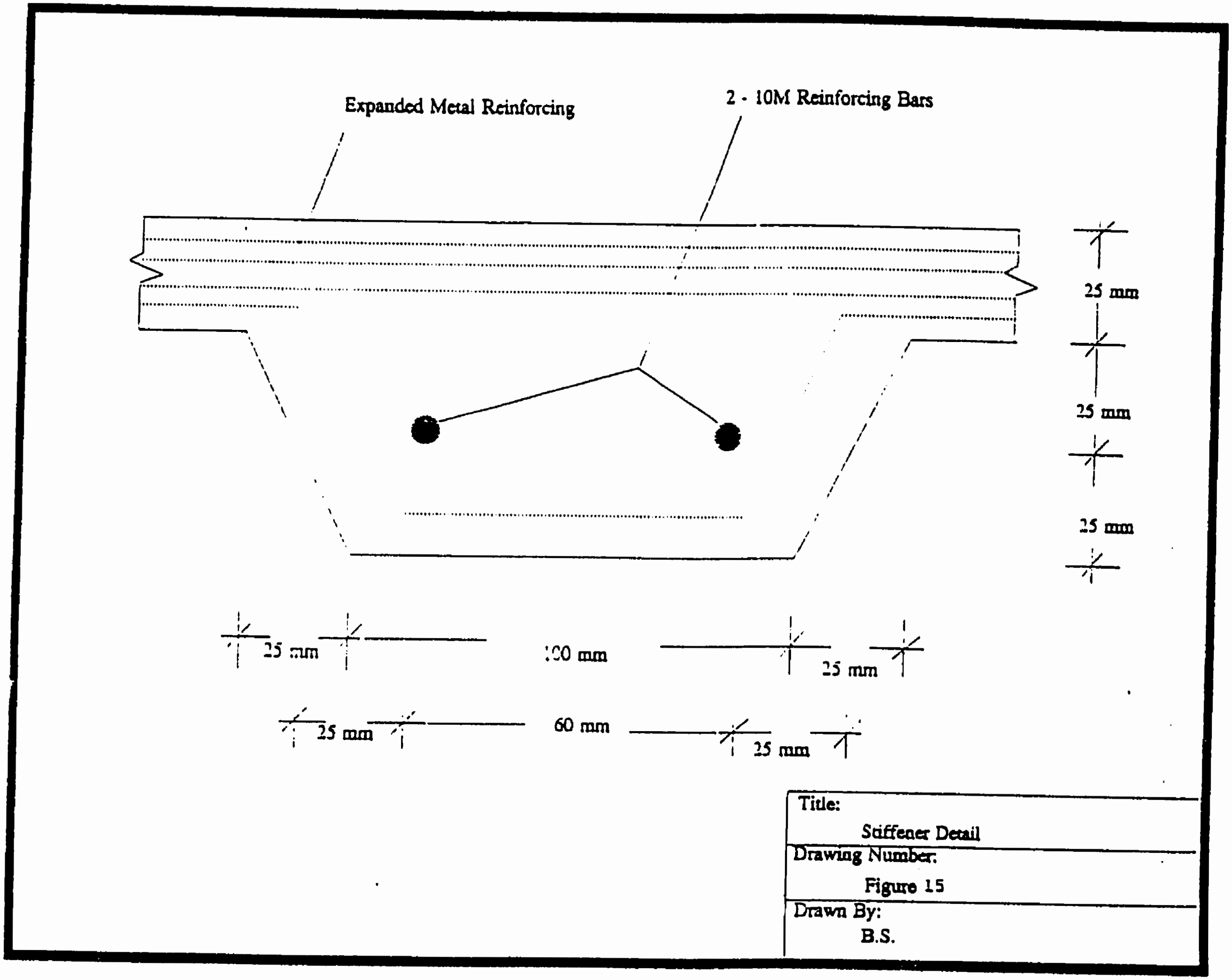
The construction procedure that will be used for the trial product will require the use of construction joints at several locations where precast panels are joined to the main structure. Figure 16 shows details of how this joint is constructed and where the expanded metal reinforcing is overlapped and tied. The workmanship at these joints is extremely critical to ensure proper tying of the reinforcing and complete filling of the joints with mortar.

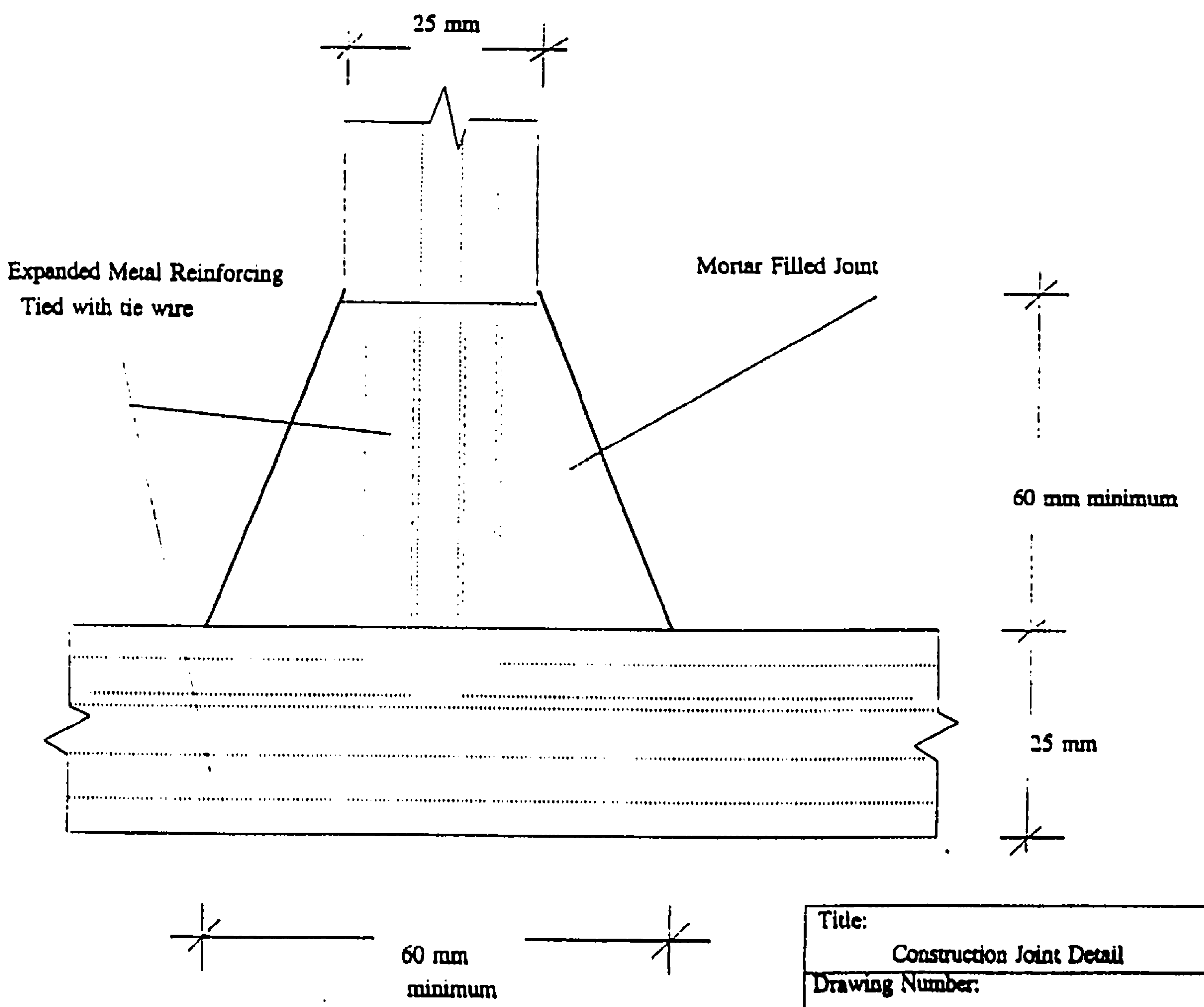
The construction of the barge could be carried out near the site where it would be deployed. In the past floating forms have been used for ferrocement thus eliminating the need for a dry dock (16). Ferrocement also lends itself well to unskilled labour which would allow it to be built locally without increased cost.

6.1.1 Prove Suitability of Product for Aquaculture Uses

To convince the industry that a ferrocement product is suitable for aquaculture use will require producing a cost effective product that is durable and performs well in its environment. Also different areas of the fish farming industry may require different properties in the service product. A trial product should exhibit the various surface textures of ferrocement. Safety concerns for slippery walkways can be combated with a broom finish on the topside of a ferrocement float. The long term


Typical stiffeners in a single cell between internal bulkheads.
1200 mm
400 mm
400 mm
400 mm
Access hatch to cell
200 mm ⌀
stiffeners
1200 mm
Title:
Stiffener Layout
Drawing Number:
Figure 14
Drawn By:
B.S.


Expanded Metal Reinforcing
2 - 10M Reinforcing Bars
25 mm
25 mm
25 mm
25 mm
100 mm
25 mm
25 mm
60 mm
25 mm
Title:
Stiffener Detail
Drawing Number:
Figure 15
Drawn By:
B.S.



Title:
Construction Joint Detail
Drawing Number:
Figure 16
Drawn By:
B.S.

durability of ferrocement will be difficult to demonstrate when exposed to sea water in a short time span. Therefore accelerated testing in a laboratory would be helpful in evaluating the product. The diversity of applications for which ferrocement has already been used in the past should provide confidence in its suitability for aquaculture uses. (11)

6.1.2 Gain Industry Confidence in the Product

The most effective way to gain confidence in a structure is to construct it. put it in service and let its performance speak for its self. Therefore it is essential that the initial trial product performs as well as the material allows. The design must incorporate all the considerations that might exhibit themselves during the life of the structure. Connections between various sections of the product or attached equipment must be evaluated to prevent premature failure of minor or major components. Selling the idea to larger aquaculture companies with sufficient capital to build a prototype and use it regularly would be the next logical step. This would give them exposure to ferrocement and concrete products. As the products become visible and popular the industry will propose new uses. It is imperative that proper engineering design practices continue to be followed to ensure that ferrocement products perform well and do not develop a poor service record.

6.2 Design Process

The design process must take into consideration all aspects of the project. Loadings on the product, material properties. service conditions, and expected service life are special considerations. The design addresses ease of construction of the product so that it can be efficiently built at a competitive cost.

A preliminary design which was used to provide information on which to base an initial budget was completed. It should be noted that before any prototype is constructed a detailed and thorough design must be completed by a marine architect and engineer with a good deal of experience the marine environment. A thorough structural design was not conducted by the author because this would be dependent on the service conditions that the owner would be looking for and the local marine conditions. Also the detailed design should be completed by an engineer with experience with this type of a vessel.

The preliminary vessel described in section 6.1 is a typical size that would be constructed. Based on the size of vessel, and the calculations included in section 6.2.5, the required amount of steel reinforcing for the vessel was determined for budget purposes. The preliminary design is based on the vessel acting simply as an end supported beam with a uniformly distributed load. The worst case situations of sagging and hogging were also used in the calculations.

The reinforcing steel was incorporated into the structure at the location of the bulkheads and the internal stiffeners. The reinforcing bars shown would complement the expanded metal mesh that is included in the thin section ferrocement construction. Various similar structures built by M. Iorns (shown in Appendix B) demonstrate the adequacy of the structure design.

6.2.1 Loadings on the Barge

The loadings on a marine structure are considerable in magnitude and diverse in application. Evaluation of environmental conditions specific to the region where the vessel will be used are of utmost importance. Fouling of a floating structure must be considered as it can greatly increase the dead weight of the product.

FIP Recommendations for The Design and Construction of Floating Concrete Terminals lists the following loads (17).

R2.2 Load Categories

- R2.2.1 Standard service load
- R2.2.2 Maximum design load
- R2.2.3 Theoretical cracking load
- R2.2.4 Ultimate load
- R2.2.5 Deformation loads
- R2.2.6 Accidental loads
- R2.2.7 Local loads

R2.3 Determination of Environmental Load

- R2.3.1 Wave loads
- R2.3.2 Ice and iceberg impact loads

R2.4 Mooring loads

R2.5 Sloshing loads

This breakdown of loads shows the variety of loadings that must be considered and even this is not necessarily a complete list in all situations. Each project must be assessed on an individual basis to ensure that no possible loads or combinations of loads have been overlooked. In the Bay of Fundy loads such as currents and biological fouling have substantial effects on design values.

6.2.2 Major Design Requirements

In addition to the loadings on the product, the service requirements of the vessel must be considered. This would include features like mounted equipment, access and storage requirements and lifting capabilities. Blood water containment is a problem during harvesting and the barge could be used to store blood in individual cells. These requirements must be identified before an effective and complete design can be produced.

As stated above the loadings on the product are a key consideration in any design. The design life of the structure must be determined so design loads and included components can reflect this. The projected design life will determine what loads the structure will be built to resist. The design life also is related to the purpose for which the product is built; in the case of a service vessel an ideal service life would be more than 20 years. Hull shape and construction will determine the sea worthiness and performance in rough water. This should be investigated thoroughly and related to existing shapes and their performance.

The material properties required for durability and service need to be addressed so that the design and construction procedure can be selected to reflect this. This includes items such as reinforcing material, cement type and surface finishes. For marine structures such as a service vessel Martin Iorns (2) recommended galvanized expanded metal mesh based on his experience.

It is important that the design reflects construction procedures that are available. The location, type and frequency of construction joints must be recognized because it will have a bearing on the design of the vessel. Care must be taken to prevent problems from occurring during the construction phase which would include a detailed and complete design complete with sufficient drawings and details to allow for construction efficiency. The proposed location of construction will have a bearing on the design as well. If the structure is to be built at a suitable location for floating formwork, the design can reflect this, but if it is built at a land based construction site, loads incurred while transporting the vessel to the water must be built into the design.

With any concrete structure in a marine environment it is important to assess the effects of freezing and thawing on the structure. In producing a vessel for Atlantic Canada it is important to ensure that the vessel has good freeze/thaw resistance.

Prestressing is a form of reinforcing that is used for many concrete marine structures and could be used for thin section concrete also. Prestressing makes use of the compressive strength of concrete products by applying a compressive load on the concrete during construction. This helps to limit cracking in the structure and ultimately leads to higher load capacity. Prestressing can be beneficial in larger structures provided it is carried out according to accepted procedures and as the structures developed for the aquaculture industry increase in size and complexity, prestressing could be used effectively. The small size of the service vessel described in this report does not allow for much benefit to be realized from prestressing. The finely spaced reinforcement in ferrocement is effective in controlling cracking in structures built from the material.

6.2.3 Corrosion Protection

The marine environment is hostile to concrete reinforcing materials. Special considerations must be incorporated into the design to ensure corrosion does not lead to premature failure. Permeability is one of the main characteristics influencing durability of concrete (17). Ferrocement is a relatively impermeable concrete product but due to the minimal cross section thickness precautions need to be taken. Adding silica fume and fly ash to the mortar will decrease permeability. Physical coatings also can be applied to produce a protective coating on the outer surface.

The corrosion of mechanical fasteners or equipment can also be a problem. Any exposed metal should at least be hot dipped galvanized and wearing parts should be made of non-corrosive metals. The corrosion potential of dissimilar metals must be considered. Metals and dissimilar metals showing poor performance in the marine environment should be avoided if a durable vessel is to be produced that matches the durability of ferrocement.

6.2.4 Design of Special Components and Considerations

The force required to moor a service vessel to a wharf is an important factor. Handrails, cleats, tie down rings and various other items must be connected to the vessel at various locations. In most cases these will be connected to the shell of the vessel. Components such as mooring connections or towing hooks must be fully integrated into the design. Ferrocement makes use of very thin sections, and reinforcing the areas around these connection sites is critical.

Major equipment including lifting hoists, motors and drive mounts must be considered. The hull design and the addition of a wheel house are important as well. These are rather large loads applied to specific points on the vessel, and the craft must be reinforced appropriately to prevent breaking of the shell.

6.2.5 Section Properties

The calculations for a 25 mm thick ferrocement section reinforced with 4 layers of expanded metal are shown below. These calculations are approximate and test specimens should be constructed and tested to get accurate design information. The formulas used have been obtained from Xiong and Singh (19) and they have been shown to correlate well in laboratory structural testing.

Assumptions used for the design:

- Based on a 1 m wide strip
- Section is cracked below the neutral axis and therefore the reinforcement is resisting all tensile forces
- There will be two layers of expanded metal lath (1.85 kg / m^2) reinforcement below the neutral axis. Figure 17 is not to scale
- The strength of the mortar is 30 MPa

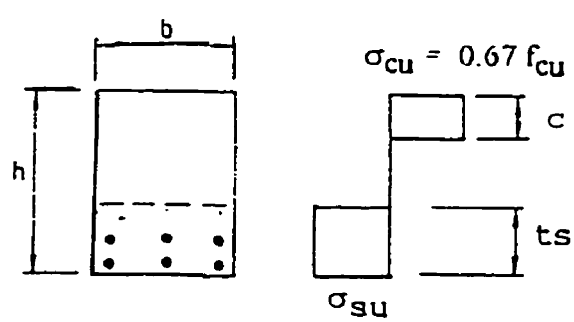


Fig. 17 Model for Predicting Ultimate Moment Capacity (19)

As = reinforcement area = 460 mm^2

fsu = ultimate steel strength = 400 MPa

b = width of the beam = 1000 mm (design is based on a 1 m strip)

ts = the height of the reinforced zone = 12.5 mm

σcu = the mortar stress

fcu = ultimate mortar strength = 30 MPa

σctu = converted steel ultimate stress

fcu = 30 MPa

fsu = 400 MPa

<u>Calculations to determine the moment capacity.</u>

$\sigma cu = 0.67\ fcu = 0.67 \times 30$ MPa = 20.1 MPa

$\sigma ctu = (As \times fsu) / (b \times ts) = (460\ mm^2 \times 0.4\ kN/mm^2) / (1000\ mm \times 12.5\ mm)$

$\sigma ctu = 0.0147\ kN/mm^2 = 14.7$ MPa

c = height of the compressive zone

$c = \sigma ctu \times ts / \sigma cu$

$c = 14.7\ MPa \times (12.5\ mm / 20.1\ MPa) = 9.14$ mm

<u>Calculation of the moment capacity of a 1 m section of ferrocement</u>

$M = \sigma ctu \times ts \times b \times (h - (ts/2) - (c/2))$

$M = 0.0147\ kN/mm^2 \times 12.5\ mm \times 1000\ mm \times (25\ mm - 6.25\ mm - 4.57\ mm)$

$M = 2605.6\ kN\ mm = 2.6\ kN\ m$

6.2.6 Product Design

The design of a prototype should not be taken lightly and would involve consulting specialists in the field of ferrocement and naval architecture and other experts in marine structures who have the knowledge and expertise. At this stage potential problems with the design would be identified and corrective action taken. A complete structural design of the product is involved and very important. The design must begin by identifying the intended uses of the service vessel which would include feeding, harvesting, net changing and cleaning, maintenance of site, cage mooring, and smolt transport. The detailed design of this prototype is beyond the scope of the thesis. This is because the design is one of the most important aspects of new product development and it should be completed by designers that have extensive experience in this field. Vessels in the past have been built based solely on experience and the results have been good which shows the importance of experience (2). Section sizes and the amount of reinforcing have been investigated to enable a realistic cost estimate to be made.

The allowable loading on the deck and sides of the vessel is calculated below based on a uniformly distributed loading using the span of 1.2 m and a moment capacity of the 25 mm section of ferrocement of 2.6 kN m as calculated above.

M = Moment capacity

w = Uniformly distributed live load

w_{all} = Allowable uniformly distributed load based on the calculated moment capacity.

$M = wl^2 / 8$ for uniformly distributed,

therefore $w_{all} = M \times 8 / l^2 = (2.6 \text{ kN m} \times 8) / (1.2 \text{ m} \times 1.2 \text{ m}) = 14.4 \text{ kN/m}$.

Because the moment capacity is based on a 1 m strip, the allowable load is 14.4 kN/m^2. Converting this to an allowable head of salt water with a mass of 10.1 kN/m^3 gives 14.4 kN/m^2 / 10.1 kN/m^3 = 1.43 m of water.

Therefore the sides can withstand a pressure of 14.4 kN/m^2 (1.43 m of water) and this would relate to a head on the deck during refloating after a beaching of 1.43 m. These calculations are conservative because the stiffeners are not taken into account and the deck and sides would act as a two-way slab continuous over many supports as shown.

Boats that have been built from ferrocement in the past have shown exceptional impact resistance on their sides over considerable spans. The vessel described here has a clear span of 1.05 m between internal bulkheads. A detailed design would determine the expected impact loads and if these exceed the capacity of the section it would need to be strengthened with internal stiffeners similar to the top and bottom sections. It should be noted that ferrocement properties regarding cracking usually lead to failures that are not catastrophic and can easily be repaired using simple techniques.

The maximum bending moment was calculated based on simply supported conditions with a uniformly distributed load applied to the deck. This would resemble the situation where the loaded vessel would be exposed to sagging conditions. Figure 18 and the following calculations depict this.

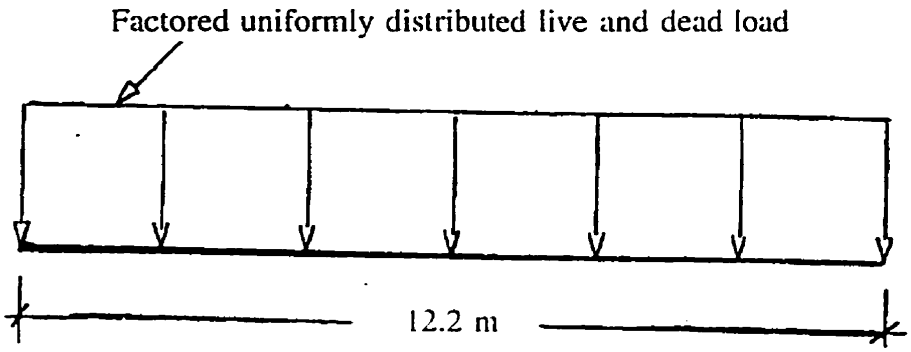


Figure 18 Load Distribution

Dead load per meter of length of the vessel:

Calculation of the volume of concrete in the vessel for each meter of length produces: Volume of the top slab plus volume of the bottom slab plus the volume of the bulkheads in both directions equals the volume of concrete. A ferrocement section thickness of 25 mm will be used for these calculations.

Bottom = (5 m (wide) x .025 m) = 0.125 m^2

Top = (5 m (wide) x .025 m) = 0.125 m^2

Longitudinal Bulkheads = (5 (bulkheads) x .025 m x 1.2 m (high)) = 0.15 m^2

Transverse Bulkheads = ((1 (bulkhead) / 1.2 m (length of the vessel)) x 5 m (wide) x 1.2 m (high) x .025 m = 0.125 m^2

Total = 0.125 + 0.125 + 0.15 + 0.125 = 0.525 m^2

The volume of concrete per meter of length of the vessel is .525 m^3/m.

Factored dead load = 0.525 m^3/m x 23.5 kN/m^3 x 1.25 (dead load factor) = 15.4 kN per meter of length of the vessel.

Live Load per meter of length of the vessel:

Use a Deck load of 4.8 kN/m^2

4.8 kN/m^2 x 5 m (wide) = 24 kN per meter of length of the vessel

Factored live load = 24 kN/m x 1.5 (live load factor) = 36 kN/m

Factored total load = factored live load + factored dead load = 51.4 kN/m

Calculation of the maximum bending moment:

The following calculation is based on the barge being supported only at each end.

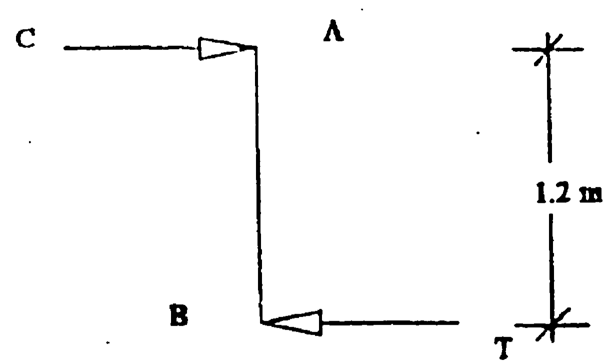
M max $= wl^2/8$

=(51.4 kN/m x 12.2 m x 12.2 m)/8

= 956 kN m

The maximum moment is 956 kN m for these conditions.

The force couple required to produce this moment in a 1.2 m deep section which was used for this vessel was determined based on figure 19 and the following calculations. The area of steel required is also calculated below.



C=Compressive Force
T=Tensile Force

Figure 19 Balancing Forces

Calculation of force couple and area of steel required:

Sum of the moments at A = 0

1.2 m x (T) = 956 kN m

T = 797 kN

C = T

Using fy = 400 MPa

As = T/(ϕs x fy)

= 797 kN / (.85 x 400000 kN / m^2)

= 0.002344 m^2

= 2344 mm^2

From the above calculations the amount of steel required is approximately 2500 mm^2

By using 10 M bars with an area of 100 mm^2. 25 bars would be required.

2-10 M bars would be placed in both directions both in the top and bottom slab at the internal stiffeners and at the internal bulkheads. A section view of a cell is shown in figure 20 and a plan view of this layout in each of the cells formed by the internal bulkheads is shown in figure 21.

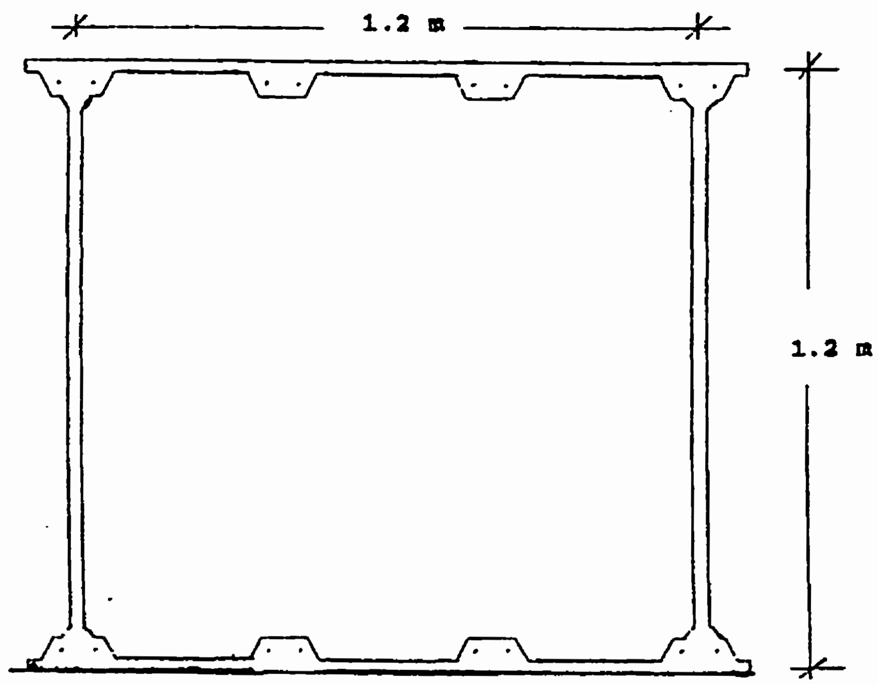
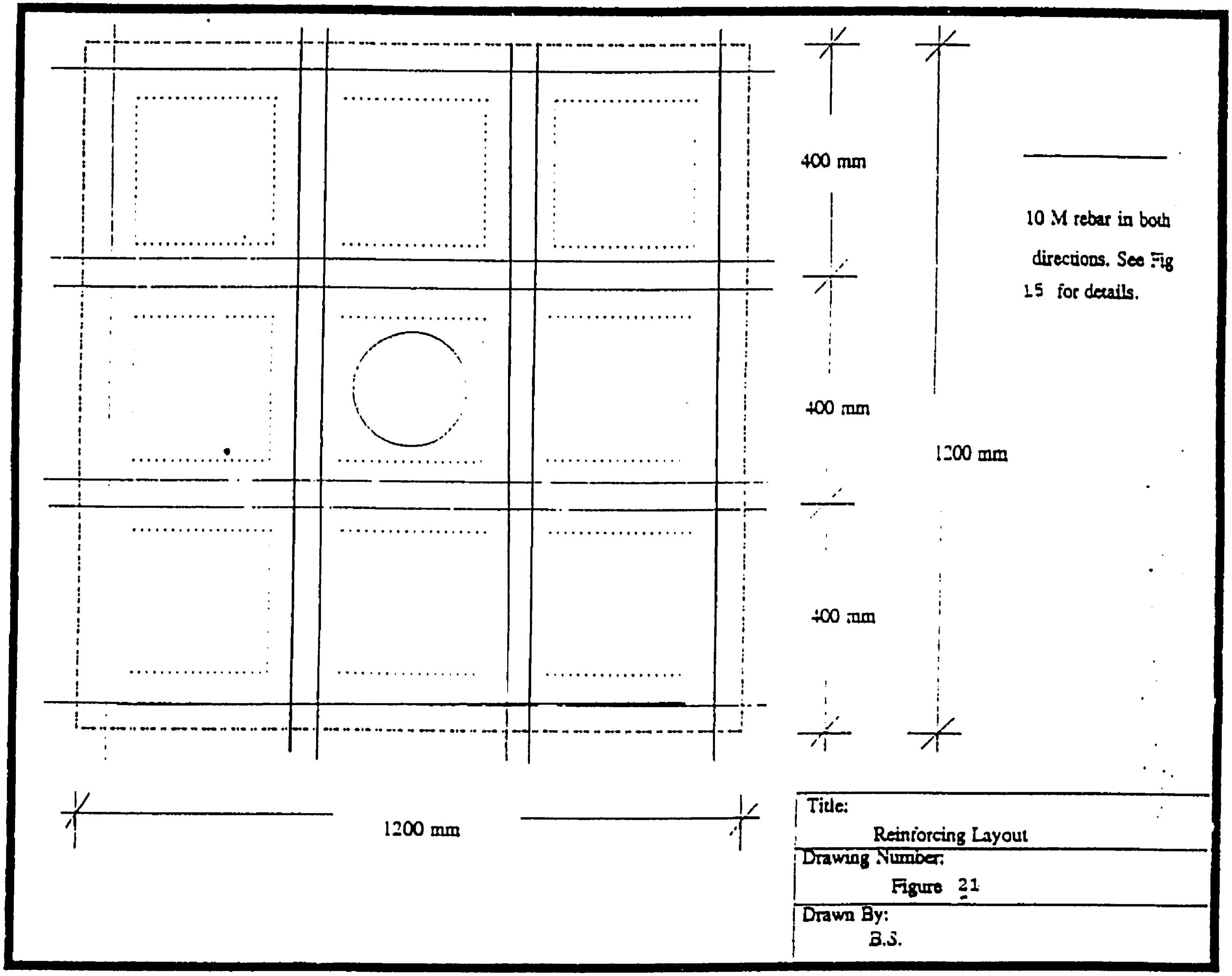


Figure 20 Section of Cell Showing Reinforcement


400 mm
400 mm
400 mm
1200 mm
1200 mm
10 M rebar in both directions. See Fig 15 for details.
Title:
Reinforcing Layout
Drawing Number:
Figure 21
Drawn By:
B.S.

The freeboard of the vessel was checked to ensure that the vessel floated high enough in the water to be seaworthy and that the preliminary size and depth of the vessel was reasonable. The calculations are shown below.

Mass displacement of the vessel at a depth d in meters.

12.2 m x 4.9 m x d x 1000 kg/m^3 = 59780 d kg

Mass of the vessel

The quantities are calculated on the quantity takeoff sheet in Appendix B.

Concrete	8 m^3 x 2310 kg/m^3 =	18480 kg
Expanded Metal	312 m^2 x 1.85 kg/m^2 =	577 kg
Reinforcing bars	1032 m x 0.785 kg/m =	810 kg
Total		19867 kg

Equate the mass and the displacement

59780 d = 19867

d = 19867/59780

d = 0.33 m

This shows that the vessel of the dimensions 12.2 m long by 4.9 m wide by 1.2 m deep will draw .33 m of water when floating. Therefore the freeboard is 1.2 m minus 0.33 m which is equal to 0.87 m. This is reasonable freeboard for this type of vessel and indicates that the dimensions chosen are appropriate.

6.3 Construction Method

6.3.1 Product Consistency and Quality

The construction method used must allow for a structure of consistent quality to be produced. The strength and durability of the product are highly dependent on the method of manufacture.

To best control these factors an open mould using a laminating procedure with hand layup and plastering would be the best method for the trial product. After experience has been gained and larger and more repetitive projects are constructed. a system to pump and spray the mortar would show cost benefits over hand work.

The construction of a barge would involve several steps. The process could be broken down into three major stages. First. an outer formwork would be constructed in the shape of the hull, and the bottom and sides of the vessel's shell would be constructed. After this. the internal baffles and supports would be constructed and put into place. They would be prefabricated on land and moved into the main structure and connected. Then the top deck would be built over the internal baffles to form the working platform of the service vessel. The forming of the top deck would involve the construction of an inexpensive form that could be disassembled and removed through the access hatch. It may be more cost effective to simply leave the formwork for the top deck in the cell if the cell is not required for any type of storage. This would complete the main structure and the wheel house and power house could be added as desired. Additional items such as equipment. mooring cleats and other attachments could then be added to complete the vessel.

6.3.2 Labour Requirements

The construction process selected will determine the amount of labour and the type of labour required to construct the product. Minimizing labour will help keep production costs low and allow for the construction of a cost effective product. Skilled labour and unskilled labour and the amount of each used will determine costs.

Production of a 4.9 m (16 feet) by 12.2 m (40 feet) Service Vessel as described in section 6.2 would require the following labour contingent.

A formwork crew to construct the outer shell form work and any additional formwork that is required. They also would strip the formwork after placing. The crew would consist of carpenters and skilled labourers. the number of each depending on the construction schedule.

The second crew would be responsible for mixing and placing the mortar. This is a critical phase of construction and the crew should receive some training to develop their skills before they start placing the concrete. This crew would consist of a minimum of four persons preferably with concrete or masonry experience.

The third crew would directly follow the mortar crew and would place the reinforcing mesh in the mortar. The size of this crew would need to be adequate to keep pace with the mortar crew and ensure accurate placement of the mesh.

A fourth crew would do the finishing work as the reinforcing crew completes its task. This would include completing the surface finishes and ensuring proper mortar cover. Also if the final layer requires special treatments or if the outer layer requires the application of waterproofing membrane or curing compound after striping it would be done by this crew.

Supervision will be required to oversee the process. Also the designer may need to have some input and verification of the process at the time of construction.

6.3.3 Machinery Requirements

Machinery and equipment will be required for producing and placing the finished product. Pumping of the mortar may be required as well as cranes for transporting and placing. If a floating formwork is used it will need to be constructed at the site. The machinery required can change considerably depending on the construction process selected.

The laminating process would require specific machinery to produce a service vessel. A mortar mixer would be required on site. A system for pumping the mortar will need to be developed that will include a hopper, a mortar pump, an air compressor, hoses and a spray nozzle. This nozzle is the key to the success of the process and it can resemble the one shown in figure 22.

6.4 Testing of Components and Structure

It is essential that testing is conducted on the finished product or segments of it to determine the properties of the structure. In order to test all the factors that affect the performance of the product, more than one element must be tested, and therefore many similar sections must be produced for test purposes.

6.4.1 Strength

Strength is one of the most important properties used to compare thin section concrete of various types and dimensions.

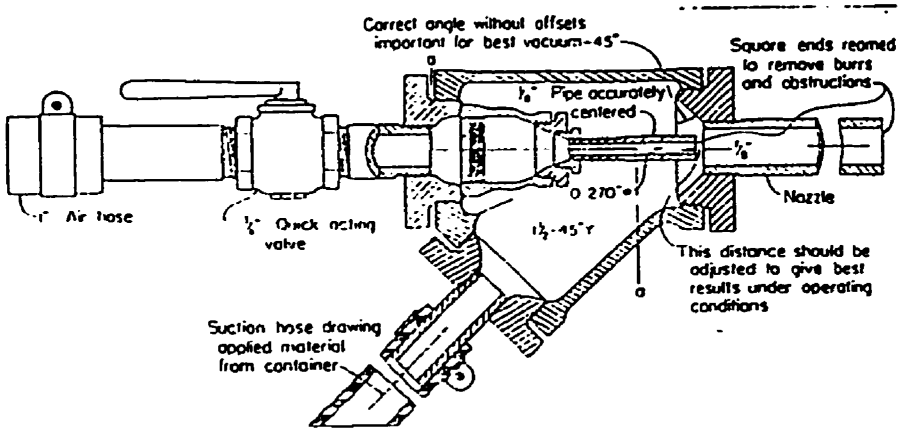


Figure 22 Mortar Spray Nozzle (28)

In the laboratory strength can be determined very accurately using conventional testing techniques. Various cross sections can be tested to determine the most efficient layout for ferrocement under given loads. Numerous similar sized specimens can be constructed and tested so that accurate numbers for strength can be determined. This should be done prior to construction to determine the best mix proportions. Samples should be taken during construction so that actual mix proportions can be tested.

6.4.2 Flexibility

Flexibility is another property of thin section concrete that can be accurately tested in the laboratory. The flexibility of the material is an important property to determine because it gives an idea of the deformation of the material under various loading conditions.

6.4.3 Durability

The durability of concrete products can be viewed in two separate ways, either with the entire project as a whole or with the durability of the concrete structure at the material level. Durability must be tested to determine how well the material will stand up to the environment in which it is to be used. Accelerated testing can be performed in a laboratory to give an indication of how durable the product will be in actual environment conditions particularly as it relates to the corrosion of the embedded steel.

Determining the durability of a particular marine structure in field conditions is difficult to do because information must be collected and processed over a period of time at a particular location. Durability is a very qualitative area of study, and therefore it is important that a rating system be developed and inspections carried out by the same people throughout the test period.

6.4.4 Corrosion Resistance

Corrosion resistance is closely related to durability. The corrosion resistance of a concrete product is dependent on the materials used for the structure. Corrosion is caused mainly by interaction between the environment and the product.

Corrosion of items such as reinforcing and connecting brackets can be identified through proper testing, and accurate measurements of the rate of corrosion can be determined using linear polarization. It may be desirable to eliminate corrosion by using materials such as stainless steel that are not prone to corrosion in the marine environment.

6.5 Product Life

The useful life of a structure is an important factor when comparing the performance and economic benefits of particular technologies. The longer the product life the better chance the product has of being economically feasible.

Many factors must be considered in estimating the life cycle of the product. Durability, strength, loading conditions, frequency of impacts and other conditions will affect the service life. It is important to estimate the expected service life as accurately as possible as this forms the basis for comparisons with other products and materials.

6.6 Cost Analysis

An accurate cost analysis is required to determine if a product and the construction material can replace existing structures. An excellent product that will last indefinitely will not be acceptable if the initial costs are too high. An economic balance must be achieved. Labour costs to construct the product, including training in new construction techniques, must be factored into the cost of a prototype but these costs can be expected to decrease as the construction process becomes more routine.

The raw materials required to construct thin section concrete are readily available in Atlantic Canada so in this case the production method will have the largest impact on the cost of production.

The detailed results of the cost estimate for the ferrocement service vessel discussed are included in table 1. Estimation software from Sunny Corner Enterprises was used to prepare the table. A detailed breakdown of the costs are presented in the work sheets in Appendix B. The estimate is a budget price only and this number should be reviewed once a final detailed design is complete. Various options may add to this price to reflect additional equipment and options deemed necessary by the owner. This cost estimate assumes the following conditions:

* A bare vessel with no drive or additional equipment.
* Preliminary drawings.
* A ferrocement section 25 millimeters in thickness.
* Special additives and coatings excluded.

Table 1 shows a summary of the material and labour required for construction in the various stages. The cost of the material is combined with a production rate for carrying out the activity and this produces a cost for the given activity. This can be seen in more detail in Appendix B.

Table 1 summarizes the estimate for the cost of construction in various areas including design, general requirements, equipment, formwork, shell construction, installation of baffles. All of these costs are broken down into various cost categories including labour, materials and equipment. Anticipated markups and overhead are calculated and an estimate total given. The estimated cost to construct the vessel is $26,152.00 as shown on the last page of table 1 .

It should be noted that this cost estimate is based on preliminary drawings and expected construction costs. If the pilot project progresses further and construction drawings are produced it would be possible to make a more precise prediction of costs.

6.6.1 Engineering and Design Costs

The development of thin section concrete products for the aquaculture industry will require a great deal of preliminary design to ensure an acceptable end product. These design costs must be taken into account when we consider the cost of the finished structure. Especially with a new technology, design and engineering are very important aspects that must not be compromised in an effort to keep costs down. The damage to the reputation of thin section concrete caused by the failure of poorly designed products would be very difficult if not impossible to overcome. An estimated cost of $3500.00 before markup was allowed to do the design work for the vessel including construction drawings based on typical industry standards.

Table 1 Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Legend: WKS=Week HRS=Hours GM=Global Markup LS=Lump Sum SF=Square Feet CF=Cubic Feet

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
WorkSheet Number: 001 · DESIGN												
COSTDESIGN DESIGN COSTS	3500 00	LS						3,500				3,500
001 · DESIGN	3500.00	LS						3,500				3,500
WorkSheet Number: 002 GENERAL REQUIREMENTS												
023150-01 EXCAVATION ~ SUB CONTRACT	500 00	LS						500				500
COSTSUPERVISOR SUPERVISOR RATE	2.00	WK	80	2,400								2,400
EQTK W 1/2 TON 1/2 TON TRUCK WEEKLY RENTAL	2.00	WEEK					720					720
EQTR W CANCAR 40' WEEKLY CAN CAR 40' TRAILERS	2 00	WK					184					184
MISCMATERIALS												

Table 1 (cont) Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
MISCELLANEOUS MATERIALS	500.00	LS			500							500
MISCSMALLTOOLS SMALL TOOLS FOR LABOR RESOURCES	1000.00	HRS									1,000	1,000
002 · GENERAL REQUIREMENTS			80	2,400	500		904	500			1,000	5,304
WorkSheet Number: 003 · EQUIPMENT												
COSTMORTAR PUMP MORTAR PUMP AND NOZZLE	2.00	WK					1,000					1,000
EQAC W AIR COMP 185 185 CFM Air compressor weekly rental	2.00	WEEK					800					800
EQTK D 15 TON 15 TON TRUCK DAILY RENTAL	2.00	DAY					1,280					1,280
IRCE W MORTAR MIXER MORTAR MIXER WEEKLY	2.00	WK				120						120
003 : EQUIPMENT						120	3,080					3,200

Table 1 (cont) Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
WorkSheet Number: 004 : FORMWORK												
COSTCARPENTER CARPENTER REGULAR TIME	26.00	HRS	26	442								442
COSTFORMWORK FORMWORK MATERIAL COST	2210.00	SF			3,315							3,315
COSTLABOURER LABOURER REGULAR TIME	52.00	HRS	52	624								624
004 · FORMWORK			78	1,066	3,315							4,381
WorkSheet Number: 005 · SHELL CONSTRUCTION												
COST FINISHING PROD FINISHING PRODUCTION CREW	2850.00	SF	29	428								428
COST PLACING PRODUCT PLACING PRODUCTION CREW	3330.00	SF	100	1,299	1,036							2,335
COST REINFORCING PRO REINFORCING PRODUCTION CREW	3330.00	SF	67	799	1,665							2,464

G2 ESTIMATOR (TM) GLOBAL-03 Date: 9/16/97 Time: 2:22:10 PM

Table 1 (cont) Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
MISCMATERIALS MISCELLANEOUS MATERIALS	1100.00	LS			1,100							1,100
005 · SHELL CONSTRUCTION			195	2,525	3,801							6,327
WorkSheet Number 006 : INSTALL AND GROUT SMALL BAFFLES												
COSTCONCRETE FINISHE CONCRETE FINISHER REGULAR TIME	20.00	HRS	20	300								300
COSTLABOURER LABOURER REGULAR TIME	20.00	HRS	20	240								240
COSTMORTAR READY MIXED MORTAR	160.00	CF			600							600
006 : INSTALL AND GROUT SMAL BAFFLES			40	540	600							1,140

Table 1 (cont) Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Page 6

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
GM Line: 005.00 5% SUBCONTRACTING - OVERHEAD AND P (Allowanc								200				200
GM Line: 006.00 TAX (Allowance)												
GM Line: 007.00 BOND (Allowance)												
Grand Total			393	7,511	9,038	120	4,183	4,200			1,100	26,152

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Table 1 (cont) Summary of Budget Cost Estimate

COST ESTIMATE (BUDGET)
ESTIMATOR -

Global Markups summarized after Grand Total

Resource Code	Quantity	Unit	Manhours	Labour	Materials	Rentals	Rentals (out)	Subcontracts	SUB (internal)	Consumables	Small Tools	Total Cost
Project Subtotal			393	6,531	8,216	120	3,984	4,000			1,000	23,852
GM Line: 001.00 CONTINGENCY (Allowance)				327								327
GM Line: 002.00 10% MAT- OVERHEAD AND PROFIT (Allowance)					822							822
GM Line: 003.00 5% OUTSIDE RENTALS -OH & P (Allowance)							199					199
GM Line: 004.00 10% LABOUR - OVERHEAD AND PROFIT (Allowance)				653							100	753

6.6.2 Material and Labour Costs

Direct costs in the production of thin section concrete products can vary considerably from one area to another. Material and labour costs in isolated areas may be considerably higher then costs in more populated places. Fortunately the materials required for production of thin section concrete are readily available in Atlantic Canada. Cement and suitable aggregate can be found locally as well as the timber required for forming.

The production techniques chosen will determine the amount and type of labour required. Both skilled and unskilled labour is readily available in southern New Brunswick but the cost associated with skilled labour would raise the production costs substantially. Labour costs could be minimized if local workers were trained in the production techniques used. This also could help to speed up the development of thin section concrete for marine applications as local entrepreneurs might be tempted to develop the product.

For the purpose of this estimate, skilled labour was used to avoid the uncertainty of training costs. The trades used include carpenters, labourers, and masons who are in the lower end of the skilled tradesmen pay range. This should produce a reasonable estimation of the labour costs.

Labour and material comprise a large portion of the cost of production. Combined they amount to $14,747.00 before markup or 56% of the budget price.

6.6.3 Production Costs

The cost of the finished product is one of the key factors in promoting a new type of construction. In order to enter a market competitively it is essential that the purchase price of the finished product be in the price range of similar products with similar service lives. The cost must reflect production costs, overhead and profit as well as any incurred costs that may be included in development and production. The overhead and profit were kept to a minimum in this cost estimate with total markups amounting to $ 2,300.00 which is less then 10 % of the total cost. The cost of the finished product will play a major role in determining whether it will be purchased by the prospective buyer or whether it will be rejected as a replacement to products currently in use.

6.6.4 Cost Comparison of Alternate Materials

There is a wide variety of materials currently being used in the aquaculture industry. These include wood, plastics, and various metals. These materials all have different service expectations and therefore cost comparison with thin section concrete would be difficult to do given the lack of service and cost records for the various structures. Various types of structures should be compared as one material may be cost competitive for one type of structure while thin section concrete may be more cost effective in another type of structure.

The framework for comparison must address several factors so that the best economic comparison can be established. This would require complete and detailed specifications and design from the owner. At this point the cost of the product could be estimated by going out to tender to contractors specializing in the various materials. More than one contractor in each material should be selected so that competitive bids are received. The life cycle of the product would need to be estimated as accurately as possible and this would be used to perform a detailed financial analysis of the product.

It is important that the contractors selected to prepare budget prices for the various materials have considerable experience and expertise to ensure that budget price is accurate and any potential problem with the design can be identified. The individuals chosen to predict the service life must also have exceptional credentials and experience to ensure that the life cycles used are reasonable.

Operation and maintenance costs for the various materials also need to be taken into account. The durability of the materials, repair methods, operational requirements, and special features will all play a part in determining operation and maintenance costs. Some of these costs will be determined by the original designs while others will result from service conditions.

All these factors will play a roll in the detailed financial analysis that would be required for each product. The financial analysis will demonstrate which applications of ferrocement would be suitable from a financial point of view.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The development of thin section concrete for marine aquaculture applications in Atlantic Canada appears to be a prospect worth investigating. Aquaculture production in this area of the country has expanded greatly over the past two decades and further growth is expected. With the development of new fish species for aquaculture production, new products will be needed to meet the requirements of these species. Growth in aquaculture will create a need for new wharves and facilities to serve this industry.

Aquaculture has developed innovative uses of plastics for marine applications. The majority of these uses are based on construction using circular sections which is not always the best section to be used. The sections available are determined by what the manufacturers produce to meet other markets as the aquaculture industry requirements do not justify mass producing a product. Thin section concrete can easily be produced to meet any section requirement and in no place would this be more advantageous than in the aquaculture industry.

Thin section concrete has already proven itself in the construction of boats and other marine structures. The extension of this technology to the aquaculture industry could benefit both further development of the product and the aquaculture industry itself. The potential for a good market for thin section concrete products makes it an area that deserves more attention.

7.1.1 Viability of Thin Section Concrete for the Aquaculture Industry

Thin section concrete may prove to be a viable material for a wide range of products that will be developed or are presently in use in the aquaculture industry. The flexibility and various construction methods of ferrocement may prove beneficial to the promotion and development of thin section concrete products. A technology that can be used by a local labour force in the off season may result in the speedy development and expansion of the product.

The variety of structures that can be built including cages, barges and access wharves show the flexibility of this marine construction material. Provided good production methods are followed, a very durable product with excellent service life can be constructed with this material.

7.1.2 Prototype Unit

The production of a prototype unit at a cost of $ 26,152.00 will demonstrate the effectiveness of thin section concrete as a marine construction material for the aquaculture industry in Atlantic Canada. It is necessary for members of this industry to have an opportunity to see the product in a working form and personally assess its physical properties. The prototype should be comparable to products built out of other materials that serve the same purpose. It should demonstrate the properties of thin section concrete and prove the suitability of the product for aquaculture purposes.

7.1.3 Long Term Potential

The long term potential of thin section concrete will be determined by the reputation it gains in the first several years of development. It is important to ensure that early development follows good engineering practice and that the structures built demonstrate the best possible performance of the product.

The long term potential will depend on the demand for the product in the future from the aquaculture industry and other marine users. The cost to produce products made out of ferrocement will have the largest influence on the potential development of the material. Products constructed with ferrocement must be competitive in cost and performance with other construction materials if it is going to have a future in the industry. Provided there is continued expansion of aquaculture there is an excellent potential for the expanded use of thin section concrete products in this field.

7.2 Recommendations

The development of new products to meet the requirements of the aquaculture industry is worth exploring. It is important that the development of floating thin section concrete products be carried out in a controlled and systematic manner to ensure that the benefits are maximized and a bad reputation does not develop through poor production techniques.

7.2.1 Assessing the Interest in and Demand for Thin Section Concrete Products for the Aquaculture Industry.

Determining the aquaculture industry's interest in the development of a new material such as ferrocement is important before development commences. Members of the industry must first be informed of the properties, applications, and various other aspects of the materials in question so they can form an opinion.

If the survival rate of fish kept in cages can be improved with new designs that are produced in ferrocement, the industry will look more favourably on the product. Increasing the survival rate of the fish will result in significant financial advantages to the owner and will reduce the cost of production.

The economic life of the structure will be a key consideration to the industry. It will be important to determine if the life of the asset will be extended substantially over the life of the products built with current building materials.

Sufficient information must be provided so that an educated decision can be made on whether or not to develop the product for use in this industry. Because the members of the aquaculture industry are the end users it is essential that their interest and backing be secured early in the development of the product. A scale model would be an effective method of presenting a ferrocement service vessel to the aquaculture industry. It would provide a physical representation of the product and samples could be produced that would show the material's properties. The completion of this report and its release to the industry will hopefully achieve some discussion and awareness of ferrocement. Channels will be developed through which the industry can make comments. If the industry receives this report with interest it may be possible to proceed with design and development.

7.2.2 Funding and Construction Management

Financial aspects of the development of a new product must be considered. Funding to aid in the development should be pursued from various sources including the aquaculture industry. The development of floating thin section concrete structures would be beneficial to the cement industry and funding from this group should be explored as well. It may be possible for boat manufacturers to receive grants and subsidies to develop a prototype. This may include tax credits and loan guarantees.

It is important to ensure that management of the construction process in the initial stages is of high quality. This will produce a product built to the specifications and completed in an efficient manner.

7.2.3 Monitoring Performance

A monitoring program should be carried out to keep track of the performance of the product after it is put in service. This will allow facts to be collected on the performance of the product and identify areas where redesign may be necessary. Long term monitoring and accelerated testing will be important in proving durability.

Also economic performance must be monitored as well. It is important that a reputable agency keeps these records so that the industry has faith in the economic results that are produced.

A laboratory test program would be beneficial in testing and monitoring various mix designs and types of reinforcement. Numerous factors could be tested to ascertain their effects on the finished product and the performance of that product. Due to the numerous construction techniques for ferrocement, a comparison between the performance of products built using various techniques also could be investigated.

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Figure References

20 Figure 1
National Fisherman, P.O. Box 622 Mount Morris IL. 61054-9915vv July 1995

21 Figure 2
BARNABÉ, G. (1990.) Aquaculture: volume 2. Ellis Horwood Limited, West Sussex, England.

22 Figure 3
The Royal Canadian Geographical Society. (1993) Silver Harvest in Canadian Geographic, July/August 1993. Vanier, Ontario, Canada.

23 Figure 4
From International Marine Floatation Systems Inc. Company Brochure

24 Figure 5
TELFORD, T. (1977) Concrete Afloat. Proceedings of the Conference on Concrete Ships and Floating Structures Organized by the Concrete Society in Association with the Royal Institution of Navel Architects. Thomas Telford Ltd. London. pp 3.

25 Figure 6
From information received from Martin Iorns.

26 Figure 7
NEDWELL, P.J. and SWAMY, R.N. (1994) Ferrocement. Proceedings of the Fifth International Symposium on Ferrocement. Chapman and Hall. London.

27 Figure 8
NEDWELL, P.J. and SWAMY, R.N. (1994) Ferrocement. Proceedings of the Fifth International Symposium on Ferrocement. Chapman and Hall. London.

28 Figure 9
From Concrete manual. A water resources publication. Eight Edition 1975. Published by the U.S. Government Printing Office Washington D.C.

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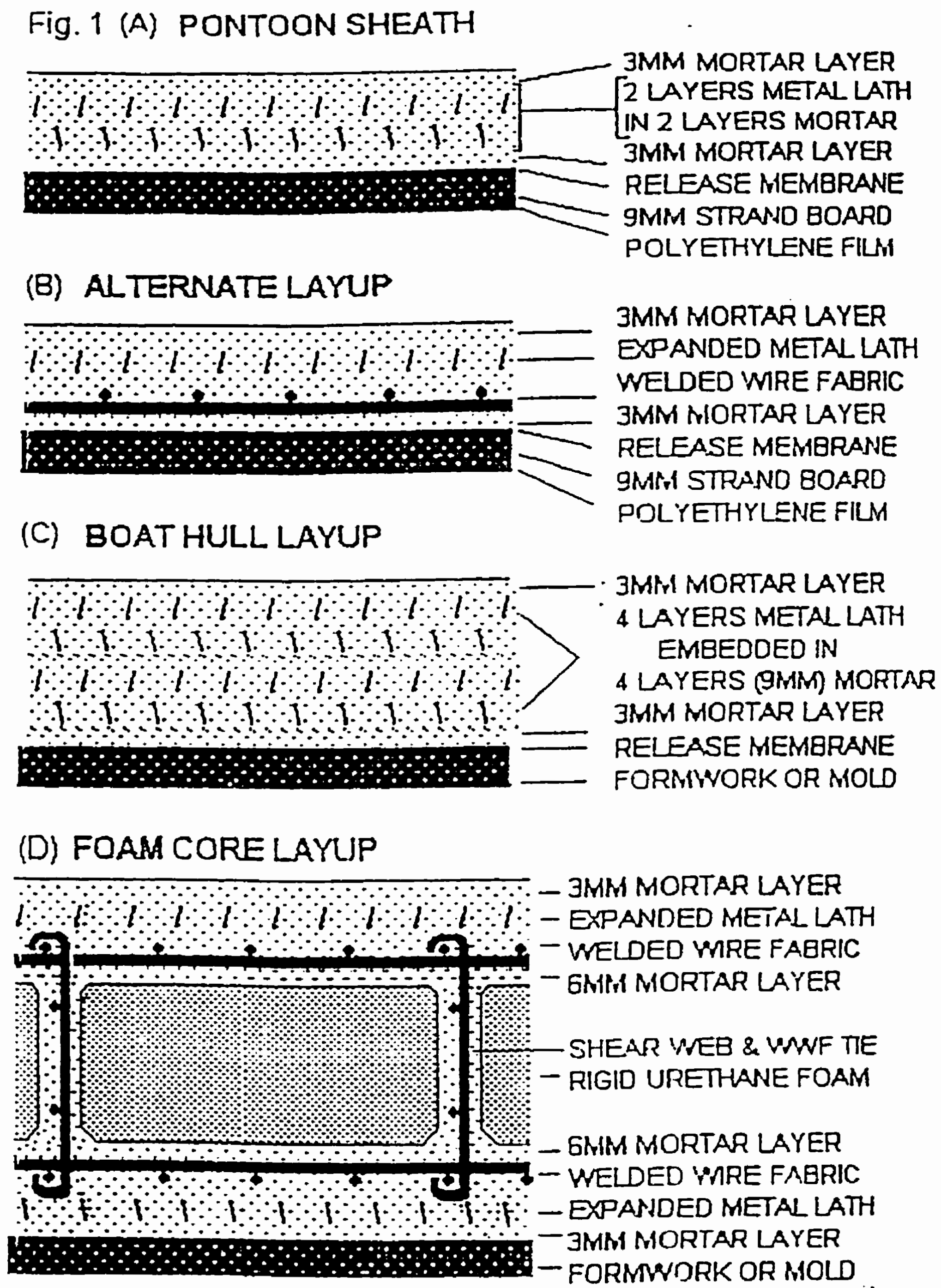
Appendix A

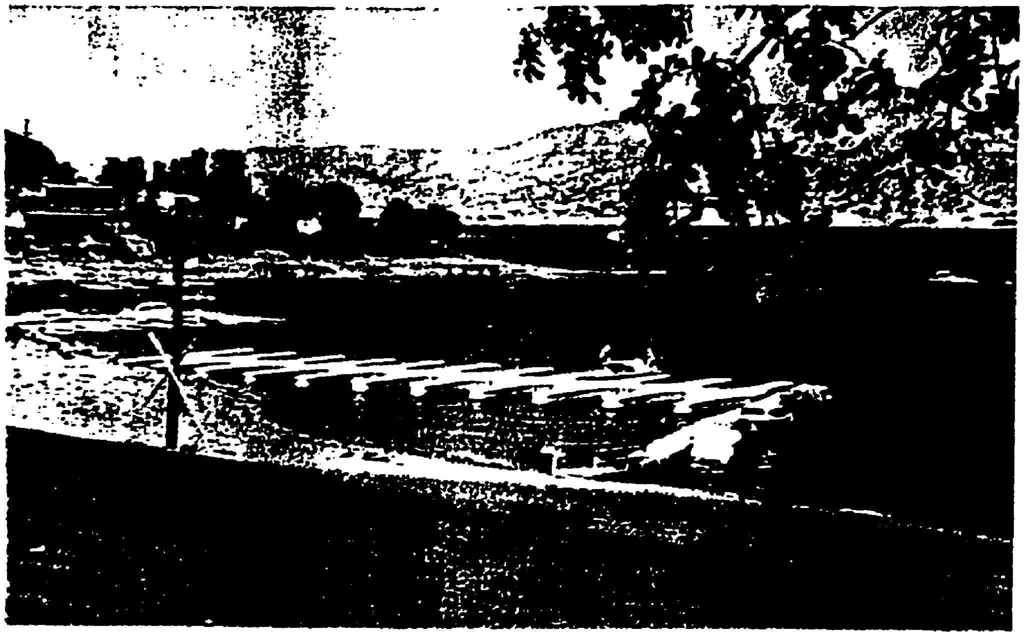
Other Figures

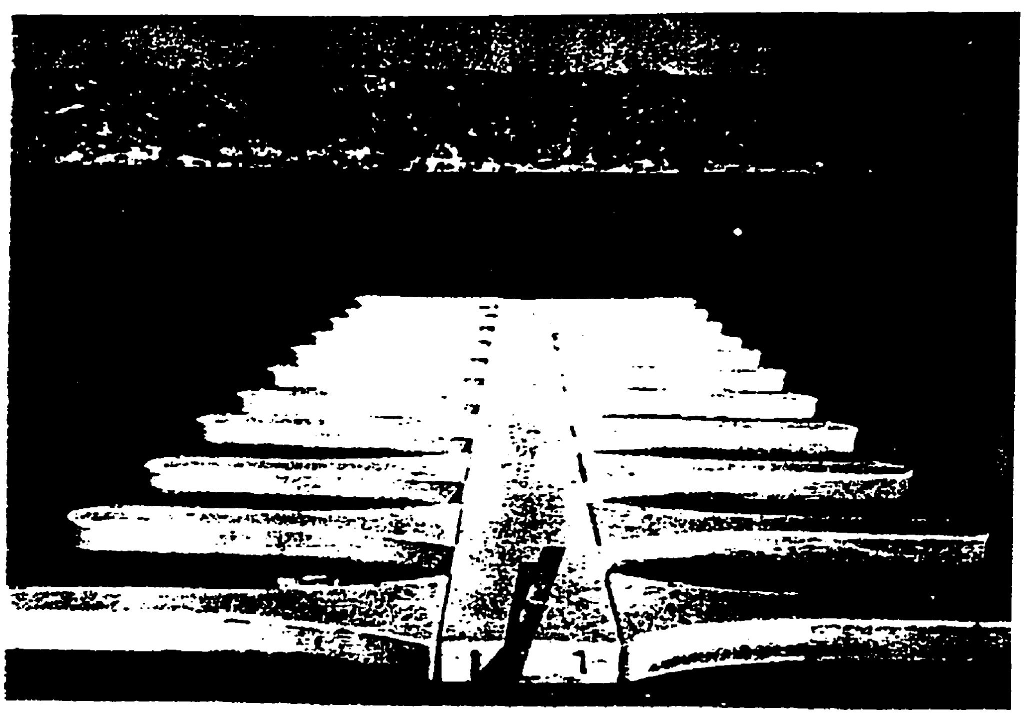
LAMINATED FERROCEMENT SECTIONS

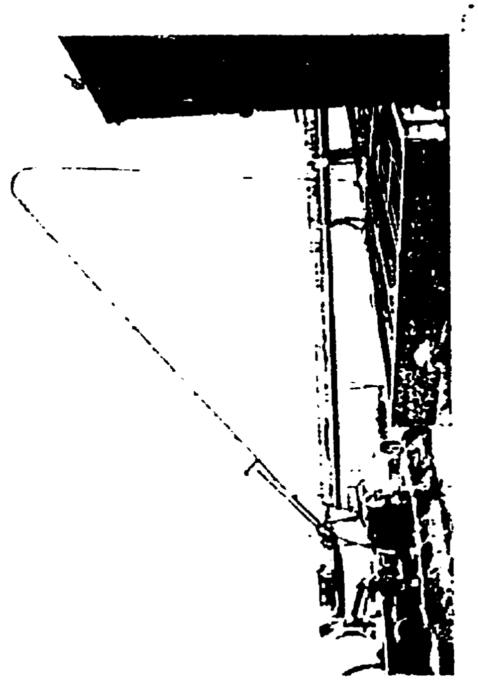


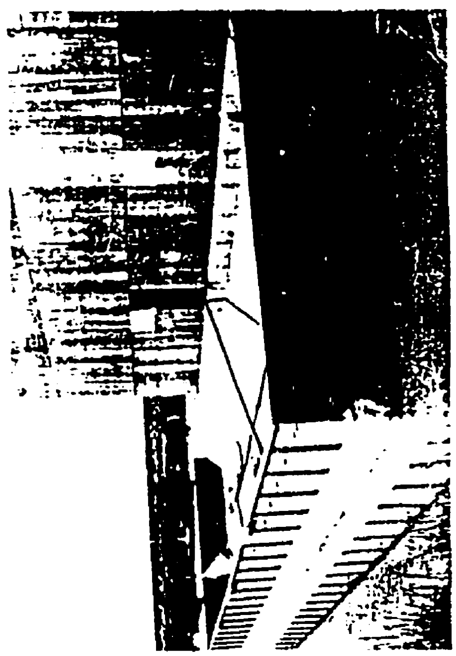
ALL THESE LAYUPS HAVE BEEN SUCCESSFULLY USED FOR PONTOONS AND BOATS

Ferrocement Sections Used For Boats and Pontoons (25)



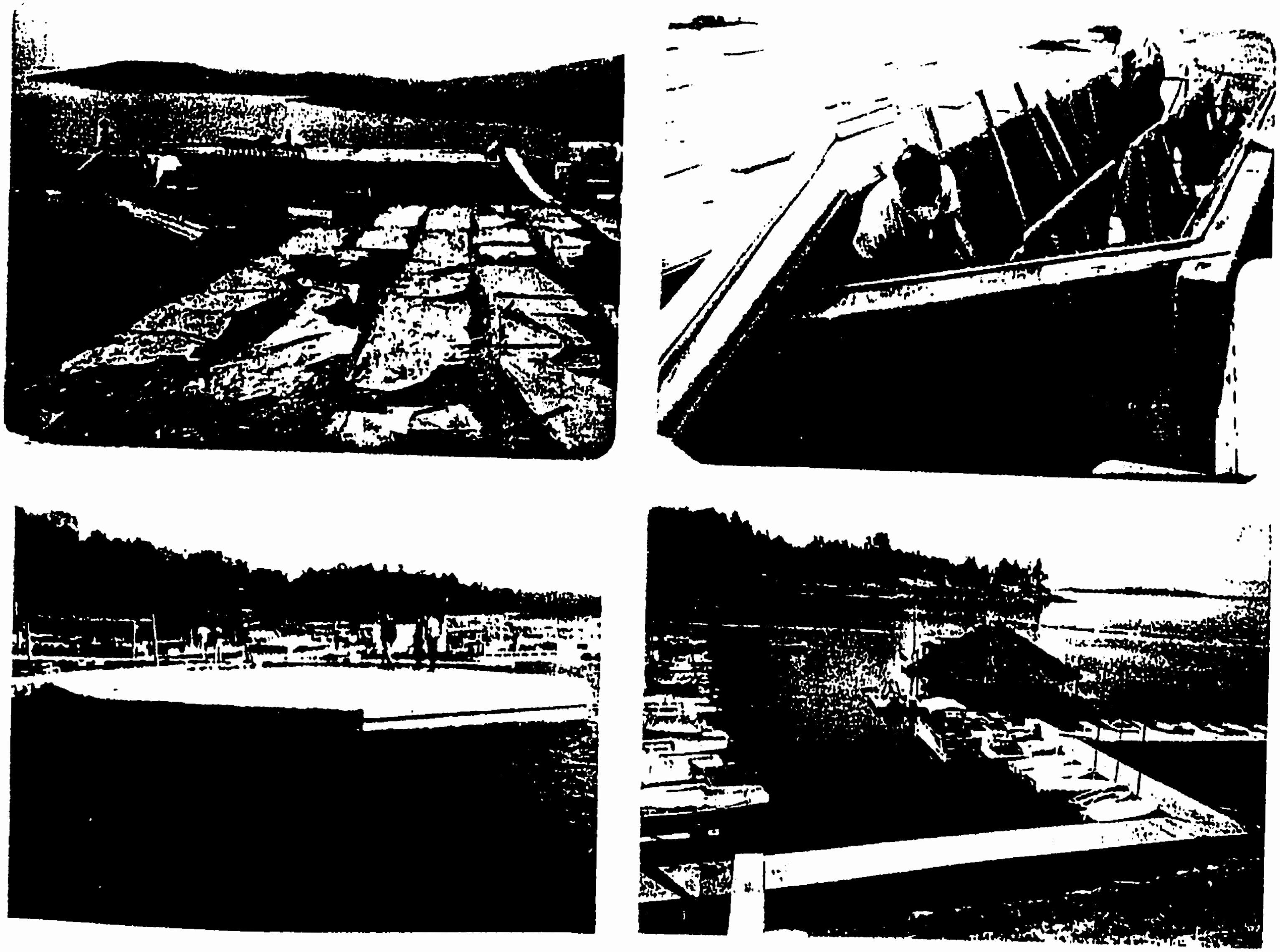






(25)

LAMINATED CONCRETE MARINA HEADQUARTERS FOLSOM CA (25)



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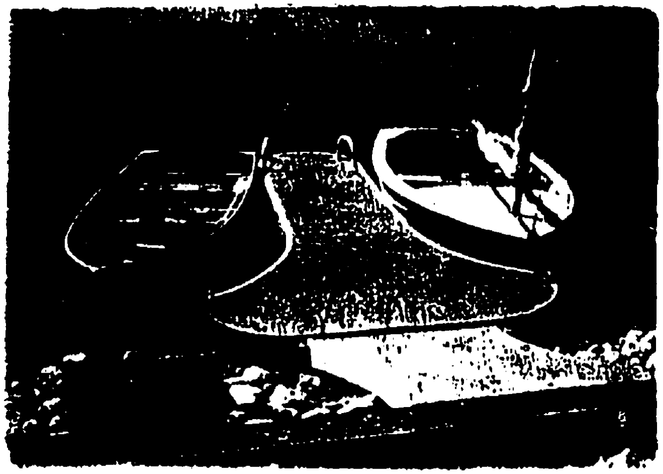

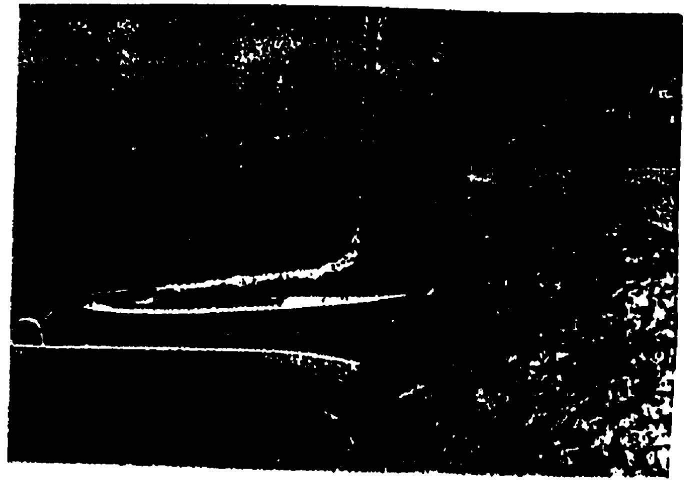

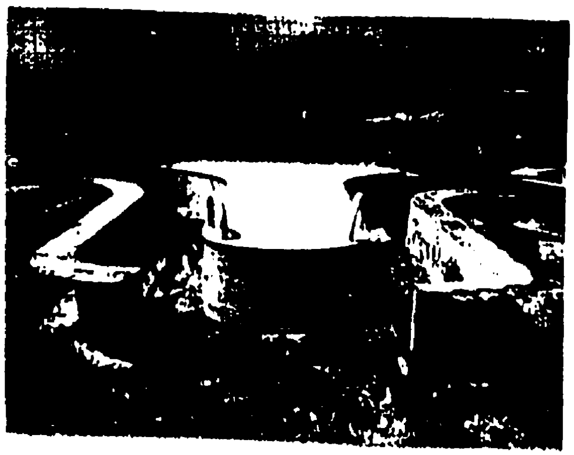

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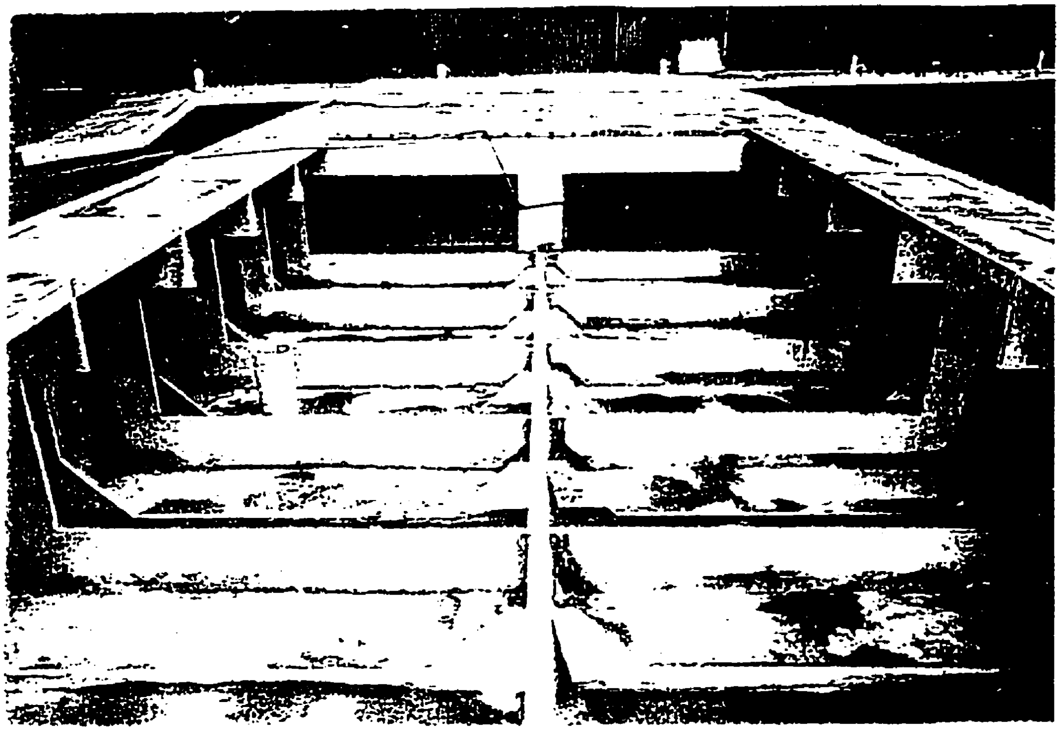

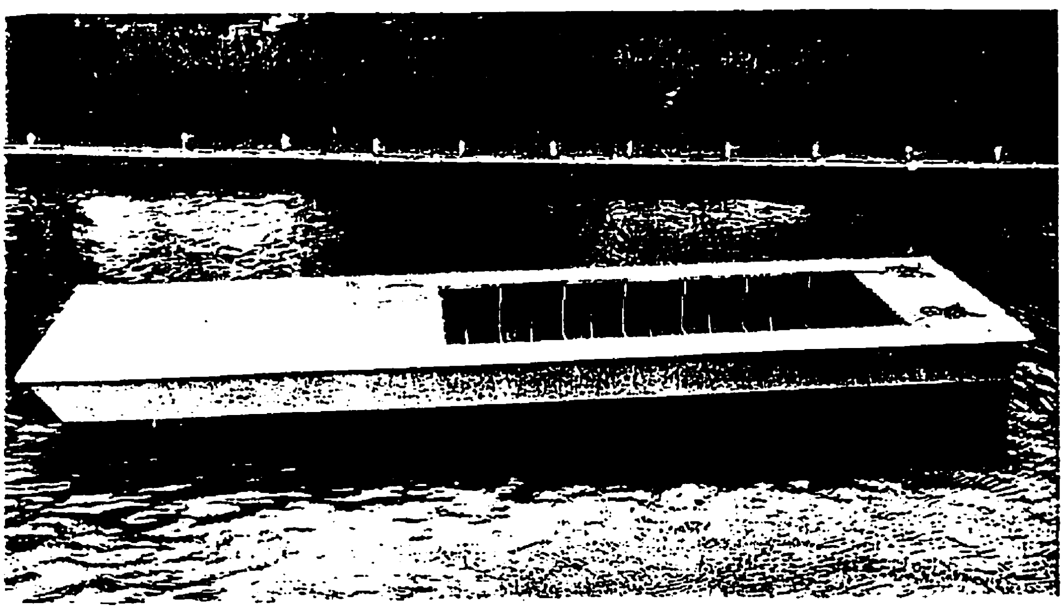

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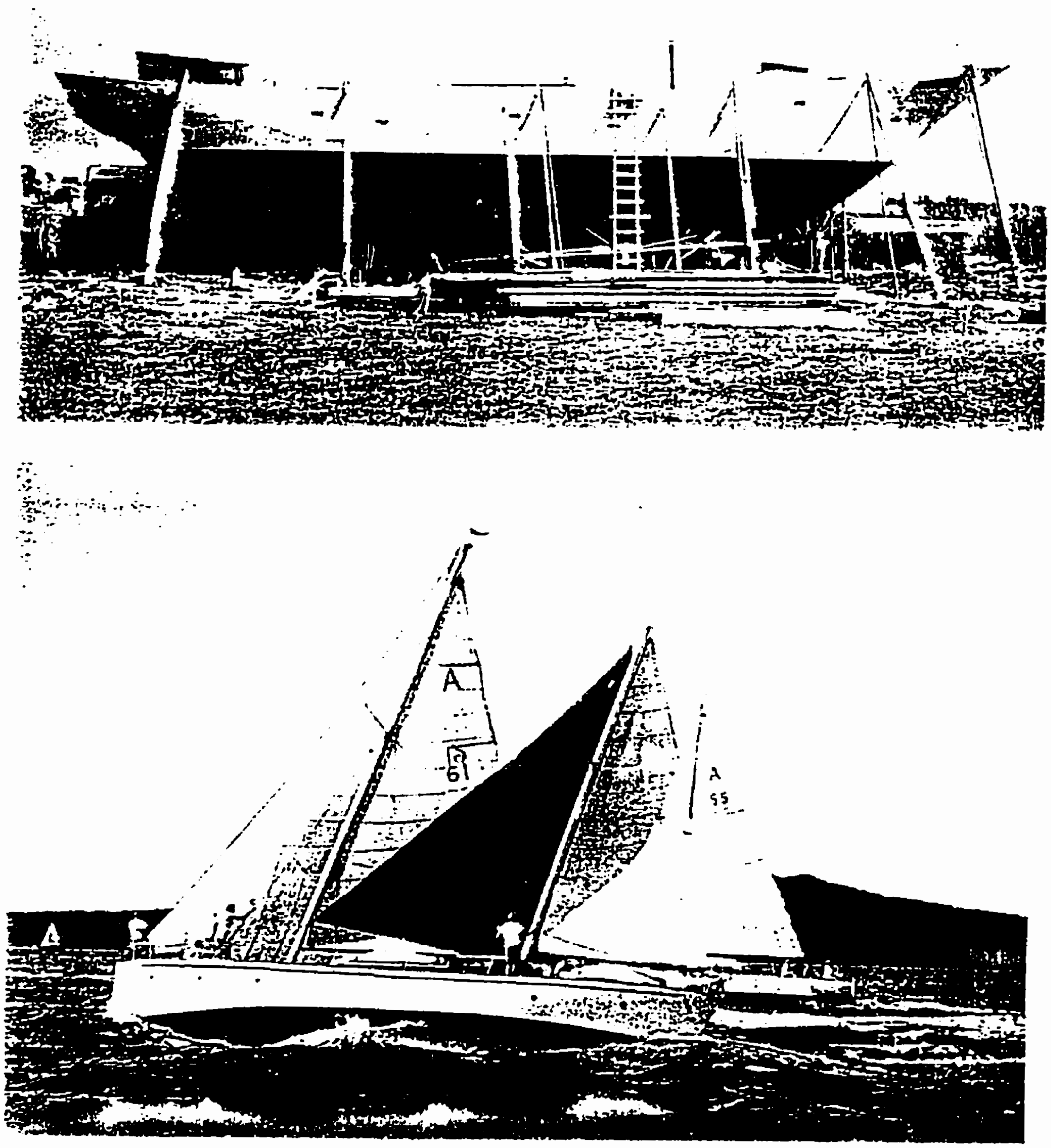
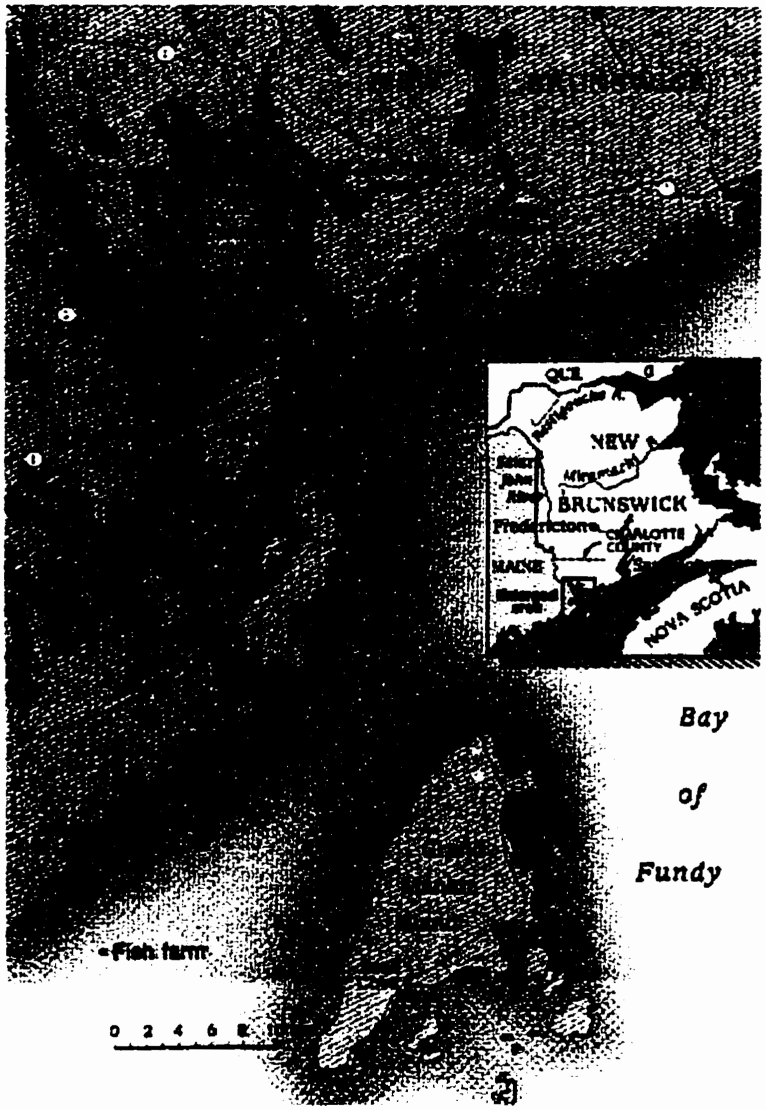
Ferrocement House Boat Foundation

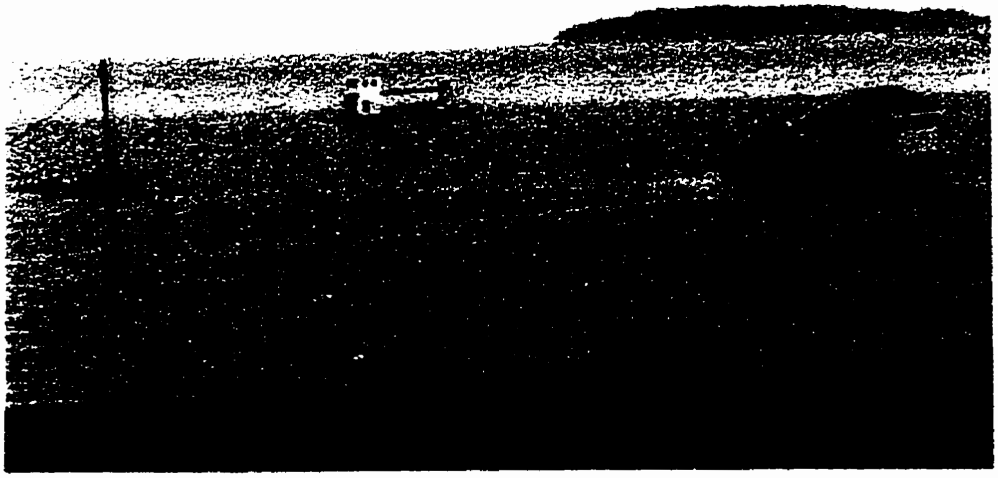


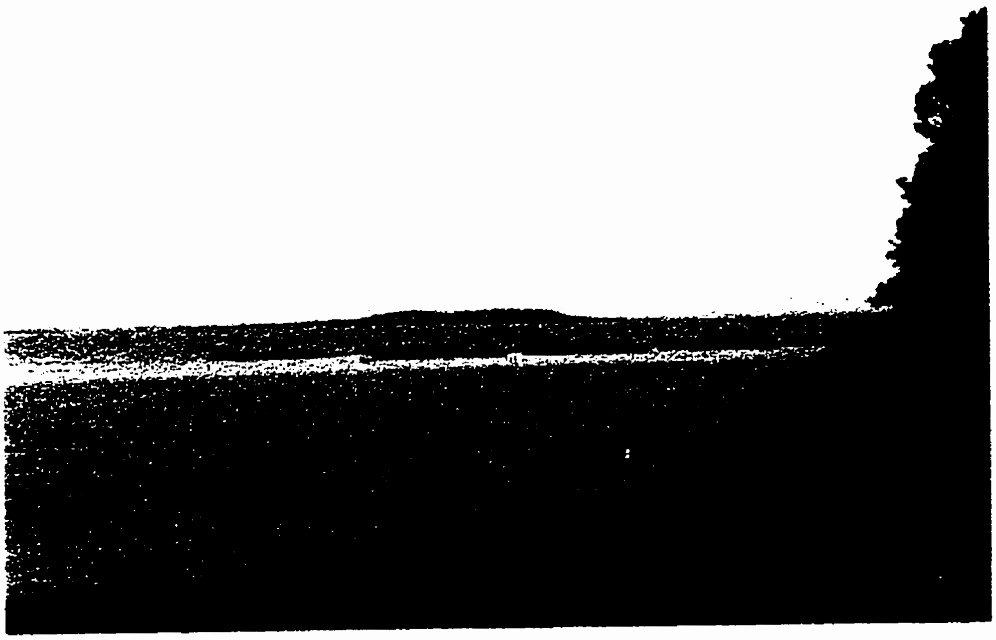
Sailboats Constructed of Ferrocement (29)



Aquaculture Sites in the Bay of Fundy (22)

Aquaculture Service Vessel Developed in Atlantic Canada (30)





Pictures from the Bay of Fundy

Appendix B

Cost Estimate Data and Information

Quantity Take Off

	Length Meter (Feet)	Width Meter (Feet)	Thickness Millimeter (Inches)	Area Sq Meter (Sq Ft)	Volume Cubic Meter (Cubic Feet)
Formwork					
Bottom	12.2 (40)	4.9 (16)		60 (640)	
Perimeter	34.1 (112)	1.2 (4)		41 (448)	
Long Int. Baffles	36.6 (120)	1.2 (4)		44 (480)	
Small Baffles	N/A	To be cast flat			
Deck	12.2 (40)	4.9 (16)		60 (640)	
Ferrocement Shell					
Bottom	12.2 (40)	4.9 (16)	25 (1)	60 (640)	1.5 (53)
Perimeter	34.1 (112)	1.2 (4)	25 (1)	41 (448)	1 (37)
Long Int. Baffles	36.6 (120)	1.2 (4)	25 (1)	44 (480)	1.1 (40)
Small Baffles	48.3 (160)	1.2 (4)	25 (1)	60 (640)	1.5 (53)
Deck	12.2 (40)	4.9 (16)	25 (1)	60 (640)	1.5 (53)
Stiffeners	442 (1450)	0.1 (.33)	50 (2)	44 (480)	1.1 (40)
Expanded Metal					
3 layers				312 (3360)	
Reinforcing Bars (10M)	1032 (3385)				

COST ESTIMATE (BUDGET)
Worksheet: 001 - DESIGN

Worksheet Header

Quantity: **Unit:** **Estimator:** BS **Revision:** **Start Date:** **End Date:**

Work Codes

Formula Variables

Global Variables	
DEPTH	0.000
LENGHT	0.000
WIDTH	0.000

Notes

Line Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
1.00 COSTDESIGN	DESIGN COSTS	3,000.00	LS						3,000				3,000
2.00 COSTDESIGN	INSPECTION AND TESTING ON SITE.	500.00	LS						500				500
	Sheet Totals	.00							3,500				3,500

COST ESTIMATE (BUDGET)
Worksheet: 002 - GENERAL REQUIREMENTS

Worksheet Header

Quantity: Unit: Estimator: BS Revision: Start Date: End Date:

Work Codes

Formula Variables | **Notes**

Global Variables	
DEPTH	0.000
LENGHT	0.000
WIDTH	0.000

Line Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
1.00 EQTR W CANCAR 40'	WEEKLY CAN CAR 40' TRAILERS	2.00	WK					184					184
2.00 EQTK W 1/2 TON	1/2 TON TRUCK WEEKLY RENTAL	2.00	WEEK					720					720
3.00 COSTSUPERVISOR	SUPERVISOR RATE	2.00	WK	40.00	2,400								2,400
4.00 MISCMATERIALS	MISCELLANEOUS MATERIALS	500.00	LS			500							500
5.00 MISCSMALLTOOLS	SMALL TOOLS FOR LABOR RESOURCES	1,000.00	HRS									1,000	1,000
6.00	SITE WORK												
7.00 023150-01	EXCAVATION – SUB CONTRACT	500.00	LS						500				500
	Sheet Totals	.00		80	2,400	500		904	500			1,000	6,304

COST ESTIMATE (BUDGET)
Worksheet: 003 - EQUIPMENT

Worksheet Header

Quantity: **Unit:** **Estimator:** BS **Revision:** **Start Date:** **End Date:**

Work Codes

Formula Variables

Global Variables	
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Notes

Line	Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
1.00	EQAC W AIR COMP 185	185 CFM Air compressor weekly rental	2.00	WEEK					800					800
2.00	IRCE W MORTAR MIXER	MORTAR MIXER WEEKLY	2.00	WK				120						120
3.00	COSTMORTAR PUMP	MORTAR PUMP AND NOZZLE	2.00	WK					1,000					1,000
4.00	EQTK D 15 TON	15 TON TRUCK DAILY RENTAL	2.00	DAY					1,280					1,280
		Sheet Totals	00					120	3,080					3,200

COST ESTIMATE (BUDGET)
Worksheet: 004 - FORMWORK

Worksheet Header

Quantity: **Unit:** **Estimator:** BS **Revision:** **Start Date:** **End Date:**

Work Codes

Formula Variables

Global Variables	
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WIDTH	0 000

Notes

Line	Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
1.00		BOTTOM FORMS												
2.00	COSTCARPENTER	CARPENTER REGULAR TIME	4.00	HRS	1.00	68								68
3.00	COSTLABOURER	LABOURER REGULAR TIME	8.00	HRS	1.00	96								96
4.00	COSTFORMWORK	FORMWORK MATERIAL COST	640.00	SF			960							960
5.00		PERIMETER FORMS												
6.00	COSTCARPENTER	CARPENTER REGULAR TIME	8.00	HRS	1.00	136								136
7.00	COSTLABOURER	LABOURER REGULAR TIME	16.00	HRS	1.00	192								192
8.00	COSTFORMWORK	FORMWORK MATERIAL COST	450.00	SF			675							675
9.00		INTERNAL BAFFLES												
10.00	COSTCARPENTER	CARPENTER REGULAR TIME	6.00	HRS	1.00	102								102
11.00	COSTLABOURER	LABOURER REGULAR TIME	12.00	HRS	1.00	144								144
12.00	COSTFORMWORK	FORMWORK MATERIAL COST	480.00	SF			720							720

COST ESTIMATE (BUDGET)
Worksheet: 004 - FORMWORK

Page 2

Line Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
13.00	DECK FORMS												
14.00 COSTCARPENTER	CARPENTER REGULAR TIME	8.00	HRS	1.00	136								
15.00 COSTLABOURER	LABOURER REGULAR TIME	16.00	HRS	1.00	192								136
16.00 COSTFORMWORK	FORMWORK MATERIAL COST	640.00	SF			960							192
													960
	Sheet Totals	.00		78	1,066	3,315							4,381

G2 ESTIMATOR (TM)

Date: 9/16/97 Time: 3:51:49 PM

COST ESTIMATE (BUDGET)
Worksheet: 005 - SHELL CONSTRUCTION

Worksheet Header

Quantity: **Unit:** **Estimator:** BS **Revision:** **Start Date:** **End Date:**

Work Codes

Formula Variables		Notes
Global Variables		
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LENGHT	0.000	
WIDTH	0.000	

Line	Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (Internal	onsumable	Small Tools	Total Cost
1.00		BOTTOM SHELL CONSTRUCTION												
2.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	640.00	SF	03	250	199							449
3.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	640.00	SF	02	154	320							474
4.00	COST FINISHING PROD	FINISHING PRODUCTION CREW	640.00	SF	01	96								96
5.00		PERIMETER SECTIONS												
6.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	450.00	SF	03	176	140							316
7.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	450.00	SF	02	108	225							333
8.00	COST FINISHING PROD	FINISHING PRODUCTION CREW	450.00	SF	01	68								68
9.00		LONG INTERNAL BAFFLES (3 AT 40' LONG)												
10.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	480.00	SF	.03	187	149							337
11.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	480.00	SF	.02	115	240							366

COST ESTIMATE (BUDGET)
Worksheet: 006 - INSTALL AND GROUT SMALL BAFFLES

Worksheet Header

Quantity: 1.00 Unit: EA Estimator: BS Revision: Start Date: End Date:

Work Codes

Formula Variables		Notes
Global Variables		
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LENGHT	0 000	
WIDTH	0 000	

Line Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals tout	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
1 00 COSTLABCURER	LABCURER REGULAR TIME	20 00	HRS	1 00	240								240
2.00 COSTCONCRETE FINISHE	CONCRETE FINISHER REGULAR TIME	20 00	HRS	1 00	300								300
3.00 COSTMORTAR	READY MIXED MORTAR	160 00	CF			600							600
	Sheet Totals	1 00	EA	40	540	600							1,140

COST ESTIMATE (BUDGET)
Worksheet: 005 - SHELL CONSTRUCTION

Line	Resource	Description	Quantity	Unit	Manhours	Labour	Materials	Rentals	entals (out	ubcontract	UB (internal	onsumable	Small Tools	Total Cost
12.00	COST FINISHING PROD	FINISHING PRODUCTION CREW	480.00	SF	.01	72								72
13.00		SMALL INTERNAL BAFFLES												
14.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	640.00	SF	.03	250	199							449
15.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	640.00	SF	.02	154	320							474
16.00	COST FINISHING PROD	FINISHING PRODUCTION CREW	640.00	SF	.01	96								96
17.00		DECK CONSTRUCTION												
18.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	640.00	SF	.03	250	199							449
19.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	640.00	SF	.02	154	320							474
20.00	COST FINISHING PROD	FINISHING PRODUCTION CREW	640.00	SF	.01	96								96
21.00		INTERNAL STIFFENERS												
22.00	COST PLACING PRODUCT	PLACING PRODUCTION CREW	480.00	SF	.03	187	149							337
23.00	COST REINFORCING PRO	REINFORCING PRODUCTION CREW	480.00	SF	.02	115	240							355
24.00	MISCMATERIALS	10 M REBAR AT $1.05 PER METER	1,100.00	LS			1,100							1,100
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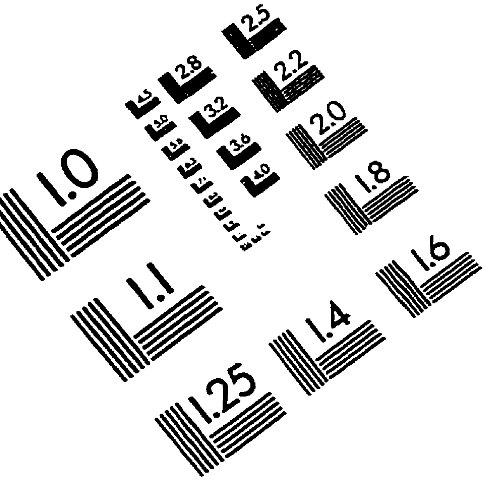
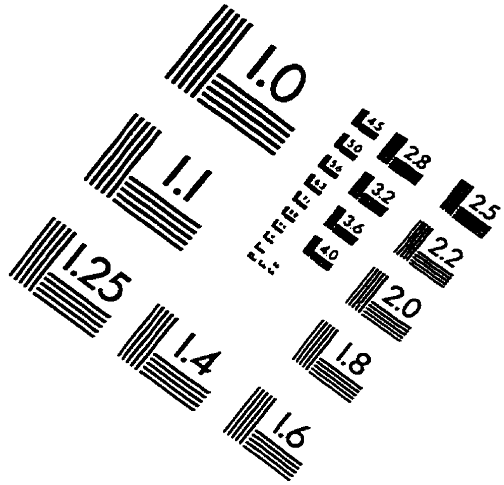
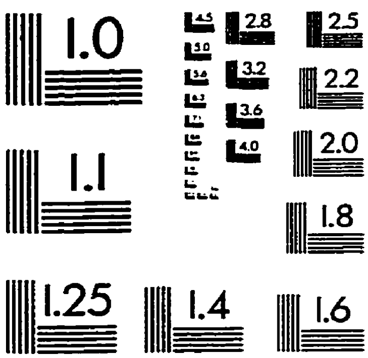
IMAGE EVALUATION TEST TARGET (QA-3)







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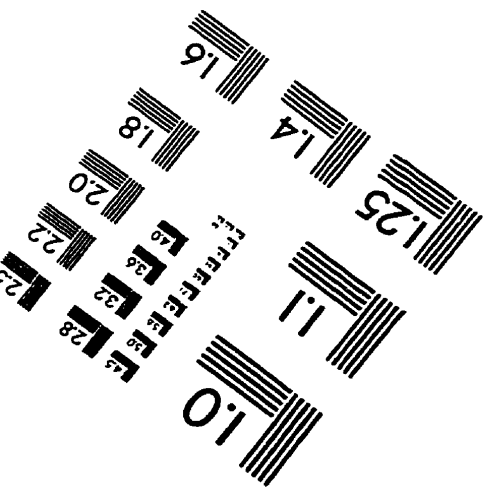

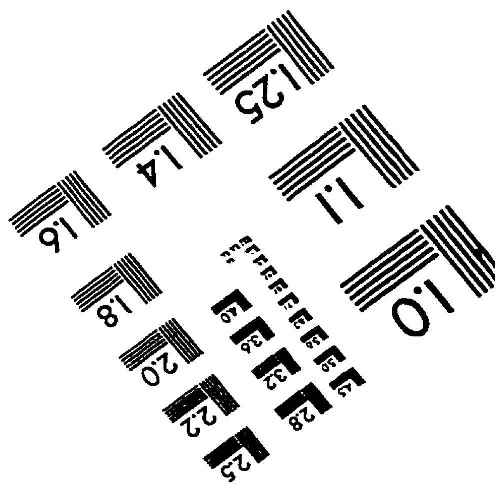

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