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CONCRETE SHIPS AND VESSELS PAST, PRESENT, AND FUTURE

by

Tony C. Liu and James E. McDonald

Concrete Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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This report reviews the history of concrete ships and vessels over the past 130 years. The experience in the design, construction, and operation of concrete vessels is also examined. Future trends and potential applications of concrete vessels are presented.

The historical review and operational experience reveal that concrete is an ideal material for ships and vessels because it is economical, durable, water

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tight, easy to repair, excellent seaworthiness, and less affected by fire and explosion. The growing sophistication of prestressed concrete design and precasting construction techniques should improve confidence in the use of concrete and enhance prospects for the full utilization of its potential in many types of future concrete vessels.

PREFACE

This paper was prepared as part of the Concrete Laboratory's (CL) participation on the Federation Internationale de la Precontrainte (FIP) Commission on Concrete Ships. FIP is an international organization for the development of concrete, prestressing, and related materials and techniques with administrative offices in Wexham Springs, England. Mr. J. E. McDonald, Chief, Structures Branch, CL, is a member of the Commission on Concrete Ships.

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The Commander and Director of WES during the preparation and publication of this report was COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, US CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.30480	metres
inches	0.02540	metres
miles	1609.347	metres
pounds (force) per square foot	47.88026	pascals
tons (long, 2240 lb)	1016.047	kilograms
tons (register)	2.831685	cubic metres

CONCRETE SHIPS AND VESSELS - PAST, PRESENT, AND FUTURE

INTRODUCTION

The design and construction of concrete ships and vessels has been performed sporadically over the past 130 years. This report reviews the history of concrete ships and vessels and examines the experience gained in the design, construction, and operation of concrete ships and vessels. Future trends and the potential applications of concrete ships and vessels are also presented.

The biggest problem in getting the idea of concrete ships and vessels accepted is the lack of understanding and appreciation of concrete and its properties by marine architects and the public in general. Although the first concrete vessel was built in 1848, the first reinforced concrete 50-ton* lighter was constructed in 1902, and the first 500-ton prestressed concrete barge was launched in 1943, mention of concrete as a construction material for ships and barges still invites the skeptical comments that it is too heavy and will not float. It is also popularly thought to be so brittle that it will break in pieces in a collision - the same objections raised when iron was introduced for shipbuilding at the beginning of the 19th century.

It is argued that if concrete, not steel, was the conventional construction material for ships and barges, attempts to introduce steel would meet all sorts of criticisms - steel has three times the density of concrete; it buckles under heat; it tends to split on impact, rusts easily, and is more expensive. It is not as durable as concrete and has inferior fire and explosion resistance. It transmits vibrations far more readily, and can be more difficult to repair.

Therefore, this state-of-the-art report on concrete ships and vessels was prepared primarily for distribution to project managers, technical monitors, etc., in an attempt to inform those who might be in a position

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*A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

to influence future research on prefabricating multipurpose concrete barges for use for such purposes as expedient container pier modules or for the transport of either containerized or break bulk cargo.

HISTORICAL REVIEW

Pre-World War I Era

In 1848, in the south of France, Joseph Louis Lambot, a horticulturist, built a small row boat by plastering a sand-cement mortar over a framework of iron bars and mesh.[1] Not only was this the first concrete boat, but it heralded the advent of reinforced concrete as a structural material.

Many boat builders followed Lambot's techniques in the latter half of the 19th century, notably, Gabellini[2] and Boon,[3] who built the now famous sloop "Zeemeeuw" in 1887, the year Lambot died.

A few small boats and river craft were built in the 1900's including the first ferrocement concrete vessel used by the United States Government, appropriately named "Concrete." This boat was 18 ft long and had a hull thickness of 3/4 in. and was used by the US Naval Reserves on the Great Lakes.[4]

The first conventional reinforced concrete barge, a 50-ton lighter, was built by Gabellini[5] in 1902. Gabellini also built many barges, including the 150-ton Liguria, built in 1905 which was reported as giving good service 12 years later.[6] The year 1910 saw the first British reinforced concrete vessel, Sand Witch,[7] and the first North American barge, Pioneer,[8] and in 1912 a 500-ton barge was built in Baltimore.[9] Searle refers to many pontoons and barges built all over the world in the period leading up to the first world war.[9]

First World War Period

The first world war caused major losses in merchant shipping due to submarine action. Since plate steel was needed for military use, US and Britain turned to reinforced concrete as an alternative hull material, and emergency shipbuilding programs were established. During the war period, many large vessels were built in several countries. Most of the big ships came from the US, including the Selma (Figure 1), the largest ever built (6340 ton, 434 ft long), and the Faith, one of the most successful

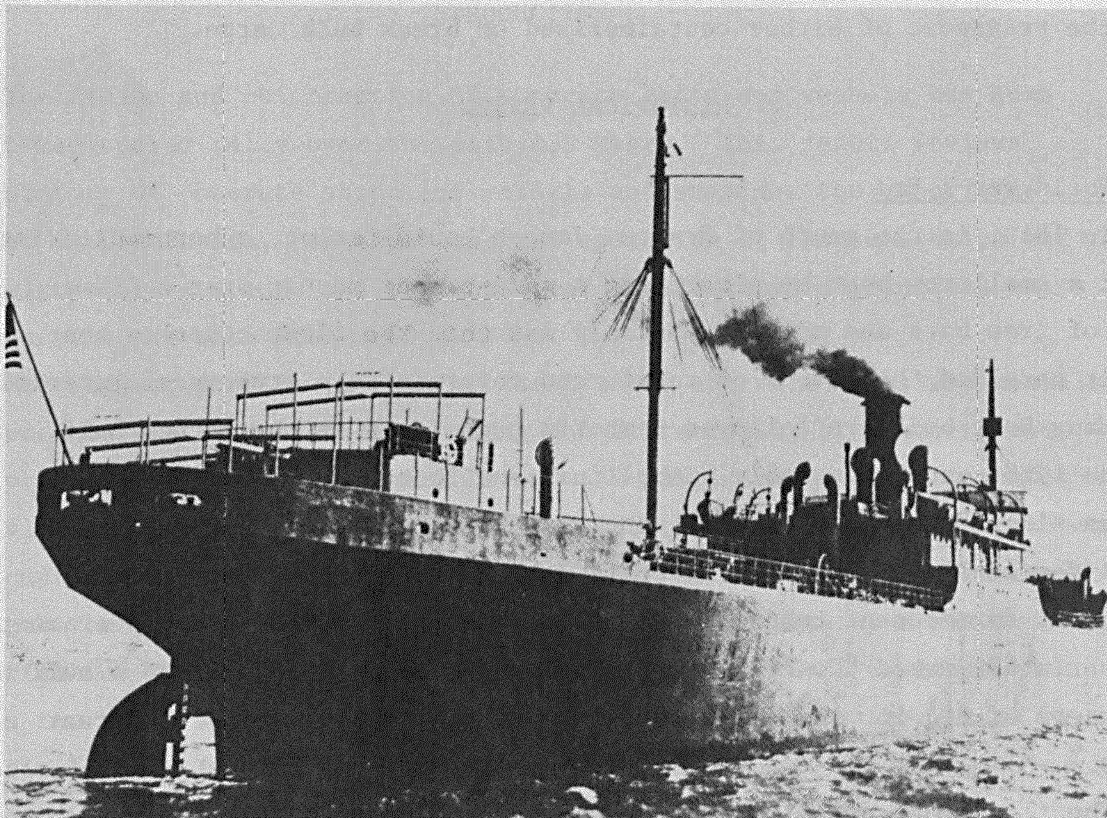

Figure 1. USS Selma, expanded shale lightweight concrete vessel.

(4188 ton, 320 ft long).[1] Unfortunately, these ships were designed along parallel lines to steel ships. As a result they were uneconomical due to excessive reinforcing steel and labor requirements, as well as heavy weight.[10] In Great Britain many ocean-going vessels were built, including the Armistice (1150 ton, 205 ft long), which was afloat and in use until a few years ago.[11] Shipyards were set up in many parts of the United Kingdom to build 1000-ton capacity barges, and one such barge, Creteravine, built in 1919 in Gloucester, is still afloat in a Norwegian fiord.[1]

About 85,000 tons of seagoing shipping was built in this period, not counting several hundred barges, lighters, pontoons, and a few floating docks.[1]

Post-First World War Era

Although a number of concrete hulls were constructed from 1918 to 1919, the end of hostilities resulted in a surplus of merchant ship tonnage, and the concrete ships were then unable to compete as cargo carriers.[12] Concrete ship building programs, therefore, came to an abrupt halt, and no further projects for concrete ships were considered after 1919.

Second World War Period

The second world war created a desperate need for more shipping and, again, reinforced concrete vessels were constructed. During this period, the US developed several types of vessels, mainly hulls to be towed by tugs, although 24 self-propelled dry cargo ships were included. A total of 104 seagoing concrete vessels (Figure 2) was put into service, with a total deadweight (DWT) capacity of 488,000 tons.[10,13,14]

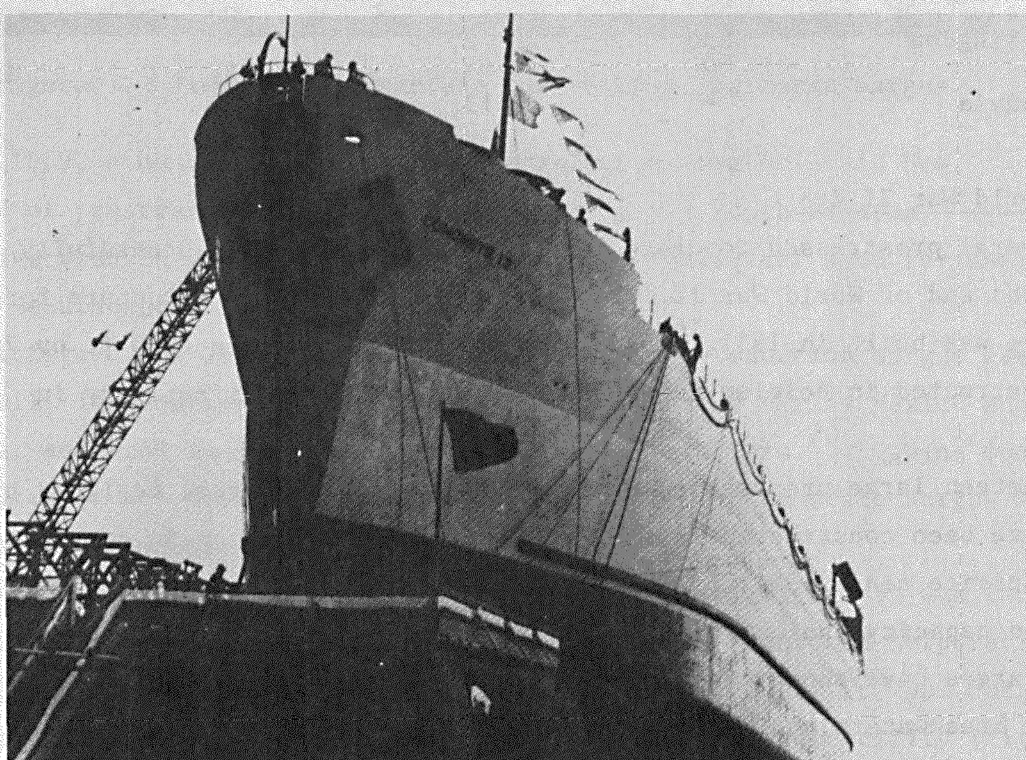

Figure 2. One of 104 concrete ships built during World War II.

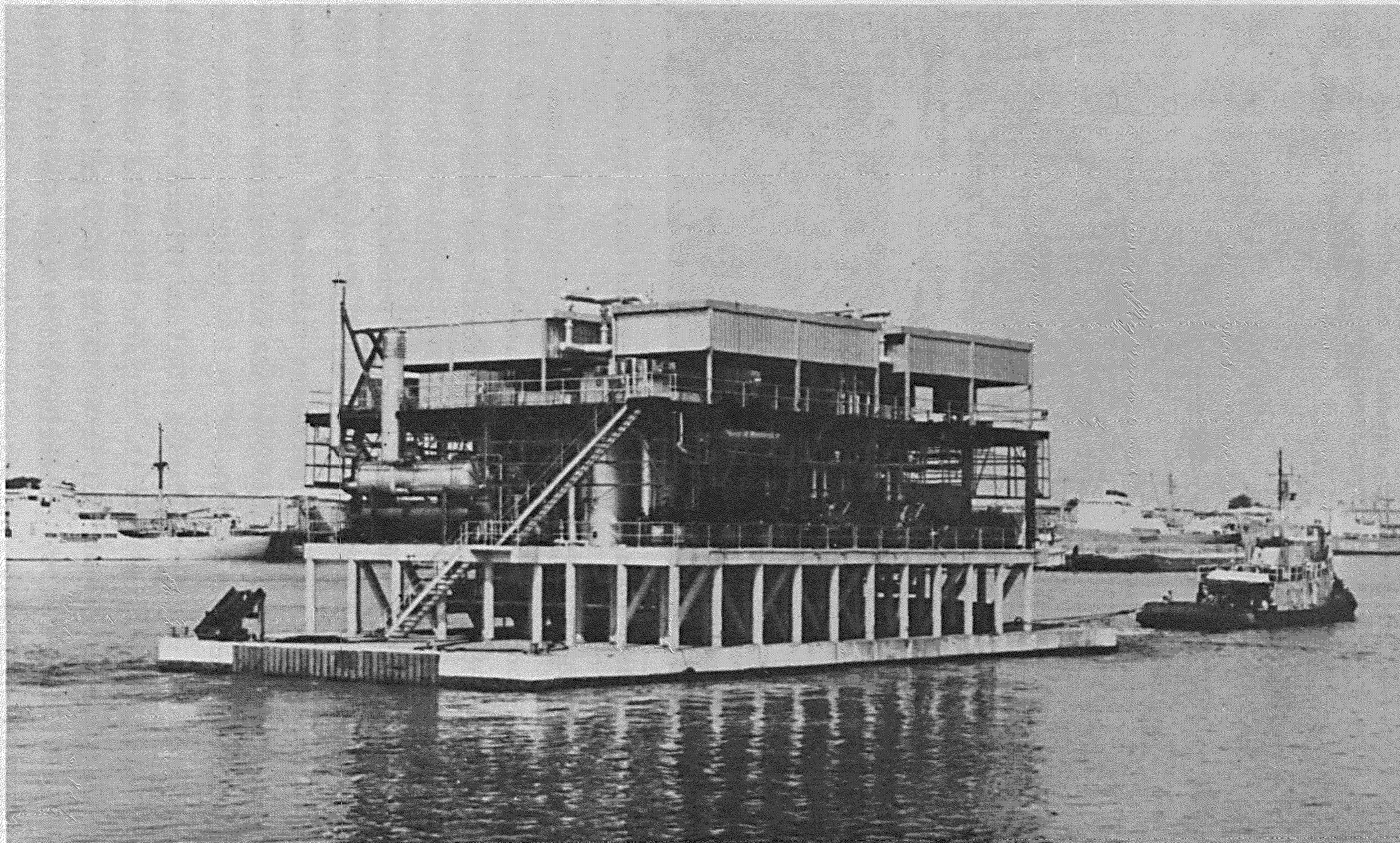

Figure 4. Concrete barge completely equipped in the United States for shipment to an overseas location via ocean tow.

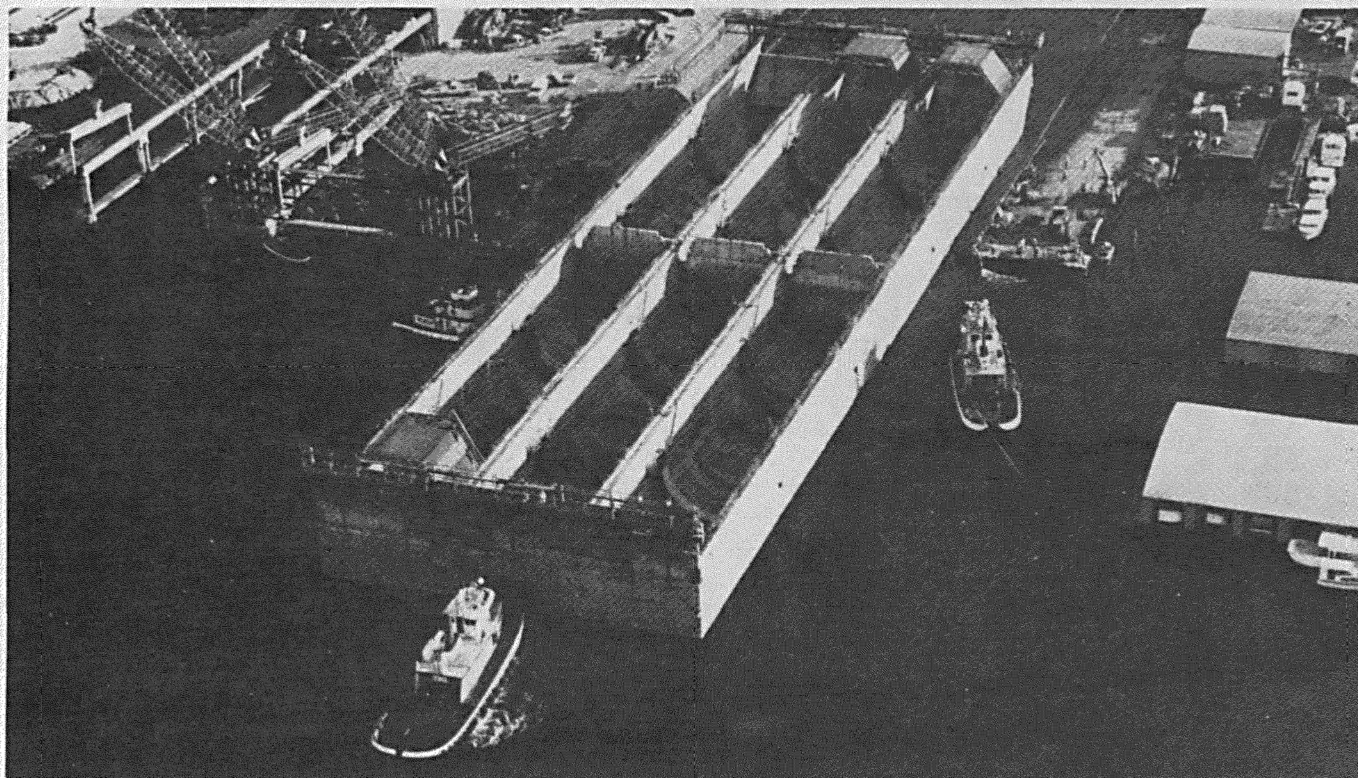

Figure 5. ARCO LPG prestressed concrete barge.

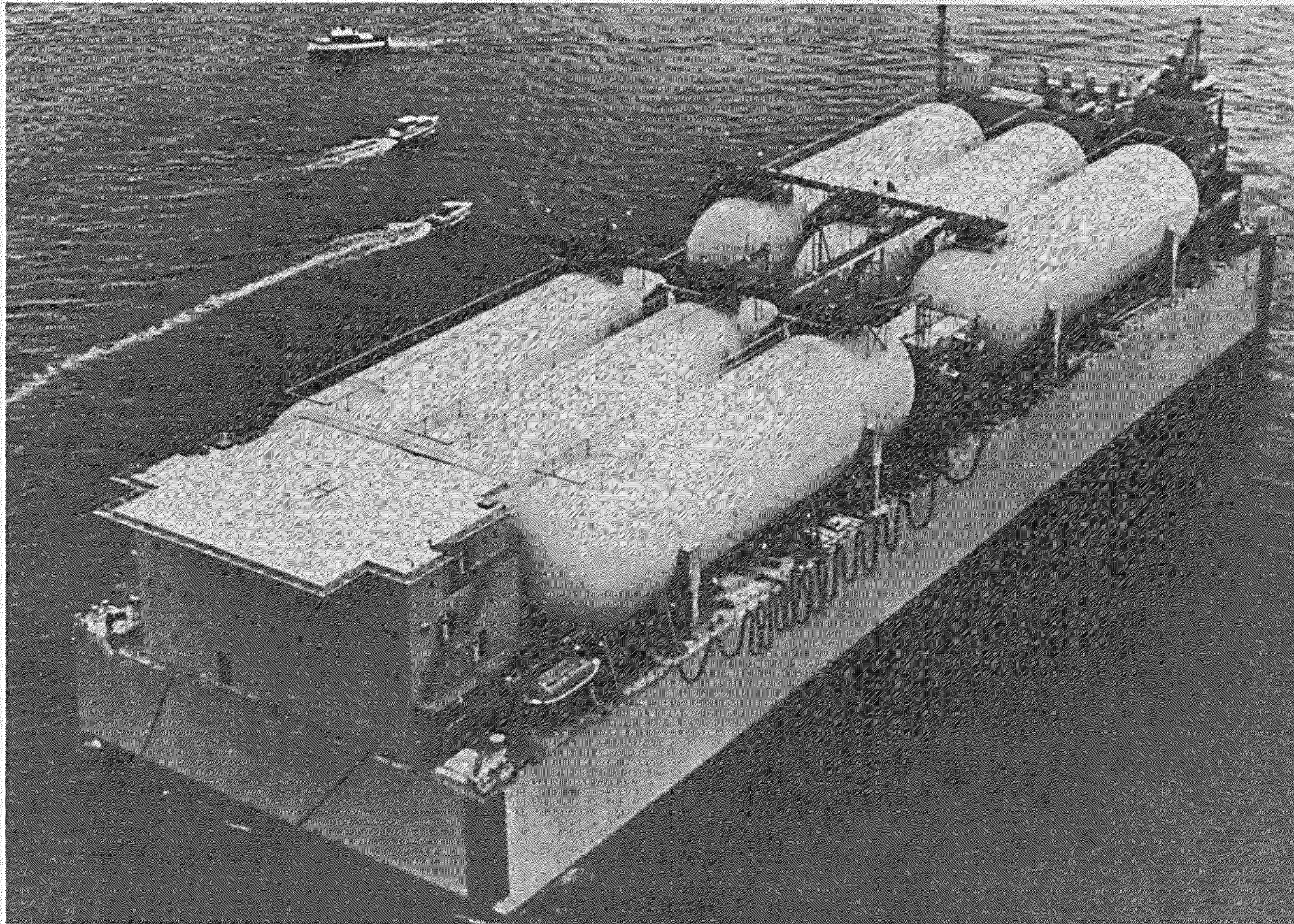

Figure 6. Prestressed concrete barge outfitted as LPG processing and storage terminal.

mooring in the Java Sea. The platform was segmentally constructed in a dewatered basin and then floated. The hull, including the precast curved bottom shell elements which weighed 35 tons each, was post-tensioned longitudinally and transversely.[21]

OPERATIONAL EXPERIENCE

Mr. N. K. Fongner, the Norwegian pioneer in concrete ship construction, claimed the following advantages for concrete ships when compared to steel ships:[12]

> "Concrete ships are cheaper to build and cost less in upkeep. They are less subject to vibration from engines, or due to 'panting' and, owing to the heavier hull, they require less ballast when running light and have easier movements in rough seas. Concrete ships are more quickly and more cheaply repaired. They are fireproof and not subject to corrosion. They have better insulating properties for cargoes, such as ice, fruit, etc., and are more easily kept clean."

The following paragraphs review the operational experience on concrete ships and vessels in order to examine the validity of Fongner's claims.

Initial Construction Costs

According to Tuthill,[13] the actual cost for the World War II vessels was approximately \$280 per ton DWT. The repetitive use of molds and accompanying experience did, however, produce significant reductions from approximately \$300 to \$135 per ton DWT during the production of 22 similar sized (6375 ton) oil tankers, while the most costly vessels, the 24 self-propelled tankers (5200 ton), built at Tampa fell from \$410 to \$314 per ton DWT.

Barges built in Brazil in 1911 cost \$719 per ton DWT as against quoted steel barges at \$1782. Barges in Panama in the same period were built at half the cost of steel ones and modern Soviet floating docks were 60 to 70 percent the cost of all steel construction.[1]

Yee's prestressed concrete barges showed a saving of 16 percent against steel, and a Soviet report[22] gives the cost of construction of a 600-ton barge 12 percent lower than steel in prestressed concrete and 3.5 percent lower in reinforced concrete. Considering the stress ratio, price ratio, and efficiency ratio, Lin and Chow[23] concluded that the cost of construction of a prestressed concrete hull is 75 percent of the cost for a similar steel hull.

Concrete ships do not require extensive construction facilities and installations. Therefore, they are usually built independently of shipyards. The equipment required is essentially the same as that commonly used in general engineering construction. Prestressed concrete vessels can generally be constructed utilizing normal construction contractors and labor more rapidly than their steel counterparts.[10] Costs are greatly dependent on local conditions and substantial savings can certainly be made in developing countries where there is a vast pool of unskilled labor, expansive dockyard equipment associated with steel shipbuilding is not necessary, and the basic materials for cement and aggregates are readily available locally.[1]

Utilizing the advantages of mass production, precasting and segmental construction methods for achieving high quality, economy, and speed would certainly contribute to reduced initial construction costs.

Operational Costs

Heavier concrete hulls and increased skin friction will make fuel costs higher although Yee and others reported that better steerage and seaworthiness in heavy weather compensate for this.[1]

Because of the low initial construction costs for concrete ships, potential savings in capital recovery costs and insurance costs can be realized.[24] Shorter concrete vessel construction time will also reduce final capital cost through lower interest during construction. The economic analysis of large prestressed concrete vessels for the transportation and storage of liquefied flammable gases shows that the operational cost of concrete vessels is about 13 percent lower than that of steel ships.[23]

The benefits of low maintenance and easy repairability will be discussed later.

Durability and Maintenance

When properly designed and built, concrete can be among the most durable and maintenance free of all structural materials.

The ferrocement vessel, "Zeemeeuw," built in 1887, was still afloat and in regular use until 1968.[1] Other ferrocement vessels have also exhibited higher durability and low maintenance and this would be expected with a rich mortar.[1]

The reinforced concrete ship "Selma," built in 1919 as part of the emergency program, is grounded on the beach in Galveston. Her 4-in.-thick hull of expanded shale aggregate concrete with minimum cover still displays good durability.[25]

Studies of the performance of concrete barges of World War II vintage indicated that they showed no sign of hull deterioration after almost two decades of service.[18] The vessels functioned continuously without drydocking and have evidenced no apparent need for maintenance or repair. Conventional steel barges, however, required drydocking, cleaning, and repainting at intervals of about 10 to 18 months.

After many years of service, the average annual maintenance cost of Yee's 2000-ton prestressed concrete barges was $2830 as against $8200 for 1750-ton steel barges.[26]

Floating docks show the most dramatic savings, something over 90 percent, in maintenance against all steel docks.[1]

Compared to steel, concrete in the sea experiences much reduced fouling from marine growth due to its alkalinity.[10] Also, marine growth is easier to remove from the concrete hulls because of the freedom from rivets and seams. Tuthill[13] and others have reported that barnacles are less likely to adhere to a concrete hull, certainly in its early life.

Damage and Repair

Concrete vessels cannot tolerate as much impact as steel hulls without suffering minor cracking. However, with adequate fendering, the concrete vessels perform satisfactorily under towing and docking conditions.

Under impact or explosion forces sufficient to cause overloading concrete hulls do not suffer extensive damage due to tearing and ripping similar to steel plate but crack and crush locally. Repairs to damaged sections are easily effected: in many cases repairs can be accomplished under water by the use of rapid-setting cement mortar and the vessel placed in service without the need for dewatering or drydocking.[20]

All types of concrete are far less affected by fire and heat than unprotected steel, and wartime brought the additional hazards of bombs and mines. Meyer[27] reports that in 1944 a 1000-ton German concrete barge hit a mine which exploded under the stern and the vessel was able to reach shore, being repaired while afloat with underwater concrete. A steel barge of the same size sailing alongside received an equal shock, sprung a leak, broke apart, and sank.

Watertightness

There is no evidence of leakage in any operational hull, and reports emphasize that concrete ships remained tight and dry even under the worst conditions.[28] Yee[18] also reported that the interior of the hulls of the World War II vintage concrete barges remained dry even after 20 years of service.

Seaworthiness

Owing to the heavier hull, the concrete barges behaved in a much more stable fashion with almost no yawing or vibration while under tow.[18]

Concrete is a good damping material and many sailors comment on the universal pleasures of sailing in concrete ships which are almost free from vibration.[1] It has been reported that concrete ships only pitched somewhat, but there was no rolling, parting, weaving, or pounding even under hurricane conditions.

Condensation

The concrete thermal conductivity is only one-sixth that of steel, and therefore, condensation in the cargo holds is held to a minimum.[18]

Tuthill[13] reported that weeping and condensation was virtually absent, and bulk wheat stored within bare concrete hulls remained in perfect condition.

FUTURE TRENDS

Long-range economists forecast a world fleet of 30,000 major vessels by 1990, several times that existing now. Many of these are desired by developing countries interested in special cargoes and maximum use of indigenous facilities, materials, and labor. Concrete ships will have a significant role to play.

Cryogenic cargoes pose a special problem for conventional steel ships because of low temperature behavior. The favorable behavior of prestressed concrete at very low temperatures possesses significant advantages. In fact, prestressed concrete barges for the transport of cryogenic materials have been studied and proposed in England.[29]

An international team that has spent $3 million during the past three years designing the world's first concrete, self-propelled liquid natural gas (LNG) tanker is now negotiating with shipyards in the United States, Europe, and Japan to build the vessel.[30] It is estimated that the 129,000-cu metre capacity carrier would cost less than $120 million to build, compared to $150 million for a steel ship of the same class. Meanwhile, negotiations are under way for construction of a $270-million, 860-ft-long prestressed concrete barge (not self propelled) that would process and store LNG.[30]

For service in the Arctic regions, ships must possess mass, low temperature, impact strength, rigidity, crack propagation resistance, and abrasion resistance. Concrete fulfills these requirements admirably, and the development of the Arctic may well require concrete ships for safe and economic exploitation.

Special cargoes of a highly abrasive or corrosive nature such as urea are another potential use of concrete ships.

The concrete hulls are sparkproof, fire resistant, and extremely advantageous for transporting explosive and flammable cargo.

The primary immediate concern, today, however, appears to be the large concrete floating and gravity platforms to support power plants, both fossil fuel and nuclear, and to support other offshore production and processing plants.

The recently-installed Hay Point Terminal, Australia, is believed to set an important landmark in concepts for deepwater ocean terminals.[31] Concrete caissons can be built in a harbor, completely outfitted with transfer equipment, towed to the site, and seated on the sea floor as a gravity structure.

Large precast concrete pier components capable of handling live load of 1000 psf, high concentrated wheel loads, and gantry-type container cranes are seen as a means of providing expedient military ports. This concept permits completion of construction ashore, launching or towing to the theater of operations and through the use of appropriate support and jacking systems the pier modules can be jacked to the required elevation. The advantages of this concept are many: reduced construction cost, reduced construction time, reliability, and mobility.

RESEARCH AND DEVELOPMENT NEEDS

The sound use of concrete in the sea requires that its most highly developed techniques be effectively employed. The following research and development is recommended:

a. Structural lightweight concrete was utilized with excellent results and durability in some of the ships from World War I and II; it appears that prestressed lightweight concrete may be an ideal material for concrete ships. The basic design information on the time-dependent behavior, permeability, and seawater absorption characteristics of the high-strength lightweight concrete should be developed.

b. There is a need to establish minimum levels of corrosion protection for design purposes. The existing knowledge on the influence of environmental conditions on corrosion, concrete cover, workmanship, type of reinforcement, and allowable crack width is fragmented; it needs to be integrated.

c. The fatigue strength of structural concrete under the randomly varying wave and wind loads is of concern, both from the viewpoint of fatigue life in the marine environment and the effects of repeated reversals of load could have on crack widths. Some work in this area should be carried out.

d. A comprehensive study should be conducted on construction methods for concrete ships and vessels. It appears that the large floating concrete structure can be constructed segmentally from smaller precast concrete components. The advantage of this technique is that the smaller components may be built with better quality and tolerance control.

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