Import and Export Terminals

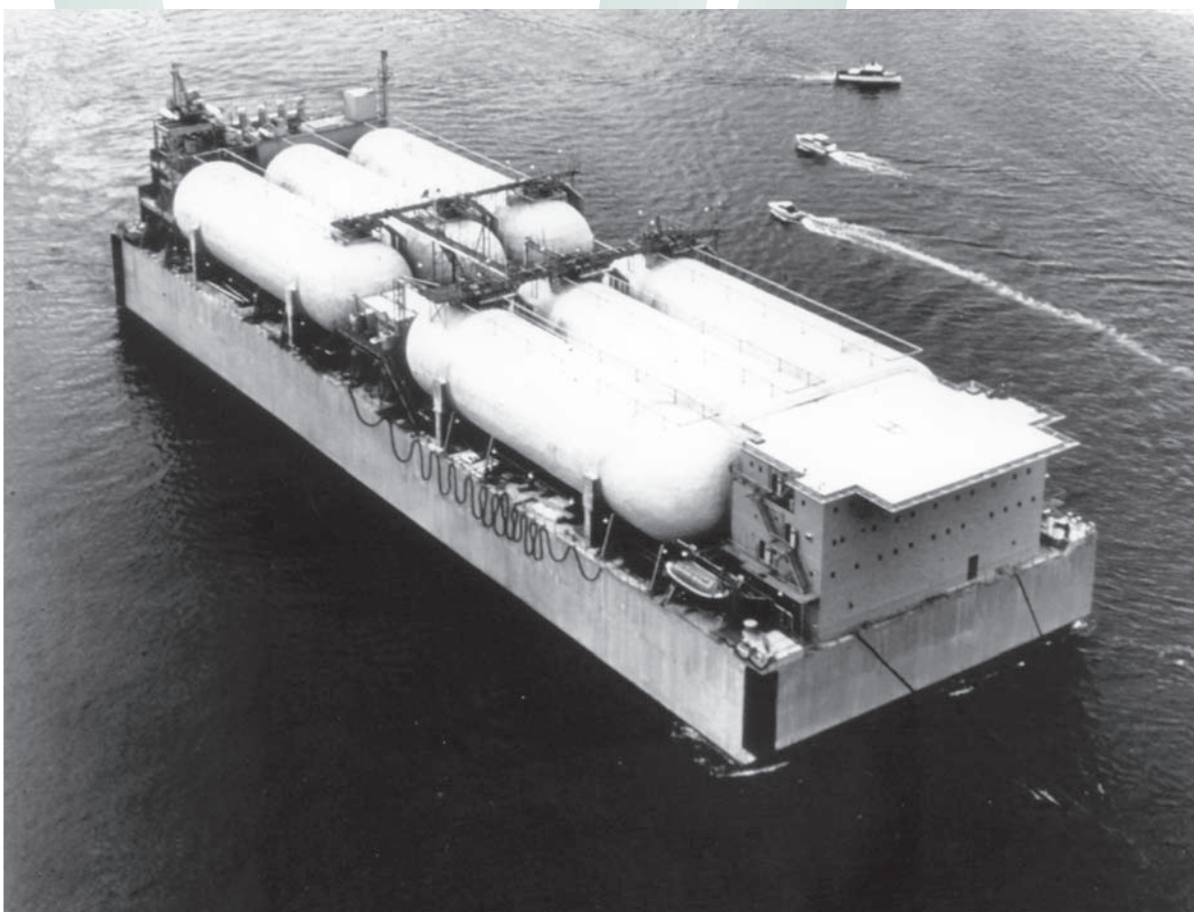
Fixed and Floating Concrete Offshore Terminals for LNG

By Ben Gerwick and Dale Berner

To meet the accelerating demand for natural gas, new import and export terminals for liquefied natural gas (LNG) are being constructed. Many of these will be large offshore concrete structures, some of which will be located in U.S. coastal waters. Both fixed gravity-base (GBS) structures and moored floating structures are being considered.

Export terminals are designed to liquefy natural gas, store it, and load it on specially-designed ships for transport. Import terminals are designed to re-gassify the LNG for transport to shore by pipeline.

Prestressed lightweight concrete is especially well-suited for these offshore applications because of its excellent performance at cryogenic temperatures (-163°C) as well as its durability and resistance to fatigue under repeated loads. Because of its favorable qualities, it has been extensively used worldwide for secondary LNG containment structures on shore.



Current widespread interest in importation of natural gas has sparked a new interest in offshore LNG terminals. They are inherently safer, eliminate the need for coastal land and deep water harbors and are more readily environmentally permittable. They reduce the overall time and cost. LNG ships can dock at the offshore import terminal and transfer their liquid gas for regassification transport by underwater pipeline. Several Gravity-Base (GBS) import terminals are currently being planned for the Gulf of Mexico.

LNG export terminals are usually floating structures, designed to receive and liquefy the natural gas at or near the production site, then store it until it can be loaded on a transport vessel. As floating terminals, they can be readily relocated to other offshore fields.

Figure 1

Prestressed Concrete Structures

Concrete structures and hulls constructed of prestressed structural lightweight concrete are durable, less costly, have the essential weight to offset light cargo and/or empty tanks and are cost competitive. Modified density concrete has similar favorable characteristics, as well as improved shear strength and higher modulus. It consists of a conventional mix for normal concrete in which a portion of the coarse aggregate has been replaced by lightweight coarse aggregate. For primary containment, the tanks usually incorporate membrane technology using 304 Stainless Steel or Invar to provide a gas tight primary membrane barrier on the face of the concrete. Independent primary containment tanks of 9% nickel steel 5083 aluminum are also utilized. Externally, the prestressed concrete structure then serves both as the secondary barrier and the hull or external shell. Unlike carbon steel, prestressed lightweight concrete and its prestressing tendons remain ductile at low temperatures. In the event of a rupture of the primary containment or a spill, the prestressed lightweight concrete is not embrittled; hence it can continue to contain the cryogenic liquid.

The American Bureau of Ships (ABS) has produced Rules for Classification of Offshore LNG Terminals, both fixed and floating, of both steel and prestressed concrete. Although this article primarily addresses offshore LNG terminals, prestressed lightweight and standard concrete has been used for many LNG tanks on shore, most frequently for secondary containment but, in a few cases, for primary containment as well.

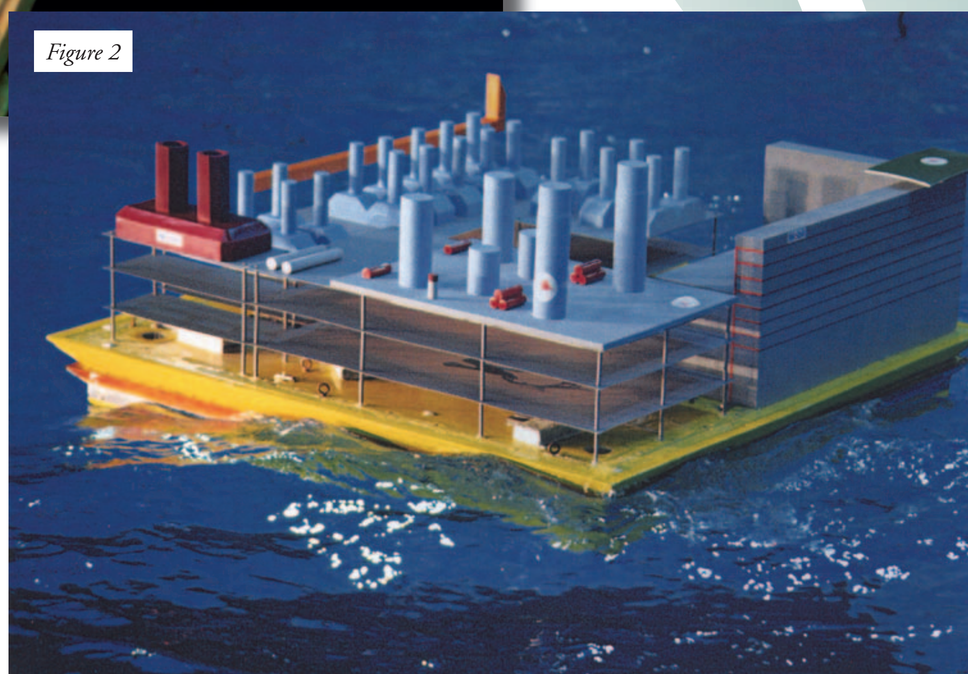


Figure 2

Structural Design

Basic designs of the concrete structure follow ACI-357, *Concrete Offshore Structures*. Alternatives are the Canadian S-474 and Norwegian NS-3473. These standards cover the environmental loading conditions in the offshore environment, the material requirements, the structural design rules (codes), construction, installation, maintenance and repair. Design considerations during the construction stages are addressed, as well as dynamic response during storm waves, wind and current loads, local impacts of waves and boat impact, and the dynamic loads of earthquake. Internal and external hydrostatic loads and sloshing of liquids in floating structures due to waves or earthquake are addressed. Provisions for inspection and safety are emphasized.

Geotechnical considerations are covered, whether the soils are serving as a base on which the terminal is seated, or for anchoring and mooring of floating structures. Among the potential anchoring systems are driven plate anchors and suction anchors. Driven-plate anchors are large steel plates driven into the seabed. They are hinged so that when a pulling force is exerted on the attached chain, they rotate to engage the full weight and shear strength of the column of soil above.

Suction anchors are large diameter steel tubes with a dome cap; in effect, large cookie-cutters. Embedded a short distance into the seabed, a suction is applied to the contained water, reducing its pressure. The resultant overpressure on the dome forces the cookie-cutter into the soil. Later, when a vertical pull is everted, it is resisted by the weight of the water column above plus the shear strength of the soil.

For floating structures designed to weather-vane, single point moorings are provided. In relatively benign seas, spread moorings are employed.

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Figure 4

Figure 3

Reference Standards and Guidelines

ABS "Guidelines for Building and Classing Offshore LNG Terminals", December 2003, American Bureau of Shipping.

NS3473 "Concrete Structures Design Rules", 4th ed., November 1992, Norges Standardiseringsforfund.

ACI 357R-84 "Guide for the Design and Construction of Fixed Offshore Concrete Structures", Reapproved 1997, American Concrete Institute.

CSA S474-94 "Concrete Structures Offshore Structures", June 1994, Canadian Standards Association.

Cryogenic Requirements

The special requirements for LNG service are given in the ABS *Guidelines for LNG Terminals*, and include the cryogenic primary barrier and the insulation, since the LNG is at -163°C (-263°F). Thermal strains in the structure have to be accounted for due to the extremely low temperatures, especially in corners where restraint may lead to cracking. Where a bulkhead divides two (2) tanks, its thermal shortening relative to the remainder of the vessel becomes critical, and may require double bulkheads and artificial heating. Artificial heating may also be utilized in order to prevent freezing of the pore water in the concrete.

Prestressing steels are made of cold-drawn wire and hence less subject to low temperature embrittlement than mild steel, while light-weight concrete gets stronger at cryogenic temperatures. Thus, these materials are well-suited for LNG service. The US Coast Guard has approved prestressed lightweight concrete to serve as the secondary barrier. Prestressed lightweight concrete has been rigorously tested under the impingement of liquid nitrogen at -190°C, while at the same time subject to cyclic loading simulating waves. Typical designs have been evaluated for resistance to penetration by a colliding vessel and approved on the basis of adequate energy absorption. One of the major advantages of prestressed concrete in LNG service is the reduced frequency of inspections requiring warm up and subsequent cool down. This in turn minimizes the consequent strains on the membrane and gives greater service availability for the terminal.

Relevant Experience

Today's floating terminal structures were pre-dated in the 1970s by the ARCO Sakti Ardjuna (*Figure 1*), a prestressed concrete barge-shaped vessel constructed and outfitted in Tacoma, Washington and towed 10,000 miles to Indonesia, where it has served continuously for almost 30 years as a floating LPG (Liquefied Petroleum Gas) terminal.

For LNG floating terminals, the hull must be designed to limit motion in order not to interfere with the gas processing and liquefaction. Semi-submersible vessels are specially configured so as to limit the motions to acceptable values.

Mobil (now Exxon-Mobil) Technology Co. has developed a very advanced but simple concept, a huge square "box", 164 meters square with a hole in the middle (*Figure 2*). It concluded that this shape is near optimum since the current and wave forces are primarily inertial, not drag forces. Ships can moor on the lee side for loading. Hydrodynamic tests showed that this facility could operate even during rough seas, since the platform is very stable. The hull would be constructed of four (4) barges in a drydock, then launched and joined by post-tensioning and grouting to form one large platform. It would be spread-moored on station. Mobil Technology has also developed an LNG Terminal for the Adriatic (*Figure 3*).

A recent concrete floating LPG Export Terminal, the N'Kossa oil facility is mounted on a 300 meter long prestressed concrete barge moored offshore the Congo. Chevron-Texaco is the first among several U.S. companies proposing to build an LNG import terminal on a concrete gravity-base structure (*Figure 4*). The GBS will be fabricated and equipped in a graving dock in a coastal harbor, then towed in the floating mode to an offshore location in the Gulf of Mexico, where it will be seated on the seafloor. Construction is planned for the summer of 2004. The extensive experience with concrete offshore platforms in the North Sea and elsewhere has produced a sound technical basis for these new structures.

Conclusion

Optimization of these structures requires use of the latest developments in concrete and prestressing technology. The principal considerations, in addition to performance in service and cost, are means to accelerate the construction schedule, reduced draft to permit maximum installation of equipment at the shore base, and long-term durability with minimum maintenance.▪

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