Zeitschrift: IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht

Band: 10 (1976)

Artikel: New application including submerged and floating structures

Autor: Anderson, Arthur R.

DOI: https://doi.org/10.5169/seals-10398

New Applications including Submerged and Floating Structures

Utilisations nouvelles, comprenant les constructions sous-marines et flottantes

Neue Anwendungen einschliesslich Unterwasserbauten und schwimmende Konstruktionen

ARTHUR R. ANDERSON
Senior Vice President
ABAM Consulting Engineers
Tacoma, Wash., USA

1. INTRODUCTION

Precast concrete, as applied to structures, may be reinforced or it may be prestressed. The precast concrete elements may be produced on the construction site or they may be plant-manufactured and transported to the construction site.

The technique of precasting concrete structures has been known for more than 100 years. In fact, the first recorded example of reinforced concrete is a small boat built in France by Joseph Lambot in 1848. One may wonder why precast concrete has not been more extensively used since Lambot's time. Perhaps the comparative ease of building wooden forms on the site and the placement of wet concrete by relatively unskilled labor with simple tools resulted in the lowest construction cost. Many entrepreneurs with limited capital have competed successfully employing transient labor utilizing simple tools.

In contrast to dry-land construction, submerged and floating structures have not been adaptable to in-situ concrete methods. For technical as well as economic reasons, structures located under the sea as well as floating structures have been precast in special facilities equipped with graving docks or launching ways. Production equipment such as batching and mixing plants, large capacity cranes, stressing beds and permanent steel forms are used.

The permanent nature of a precast/prestressed concrete enterprise depends on management by technical specialists and steadily employed skilled production workers.

Factory-produced precast concrete can reach very high strengths (500 to 800 kg/cm^2) and, when prestressed with high tensile strength steel, impressive gains in economy and structural performance are attainable.

2. SUBMERGED STRUCTURES

Precast/prestressed concrete piles for bridges and harbor structures in sea water have demonstrated performance with minimum maintenance problems. To avoid cracking, concrete piles are prestressed in the range of 60 to 90 kg/cm². When exposed to sea water, dense, well-compacted concrete with a water-cement ratio of 0.38 to 0.42 is recommended for durability and corrosion protection for the reinforcing steel.

Submerged sewers constructed from precast/prestressed concrete, such as the Hyperion Outfall in Los Angeles and the Lake Washington Interceptor Sewer in Seattle[1] (Fig. 1) are outstanding examples.

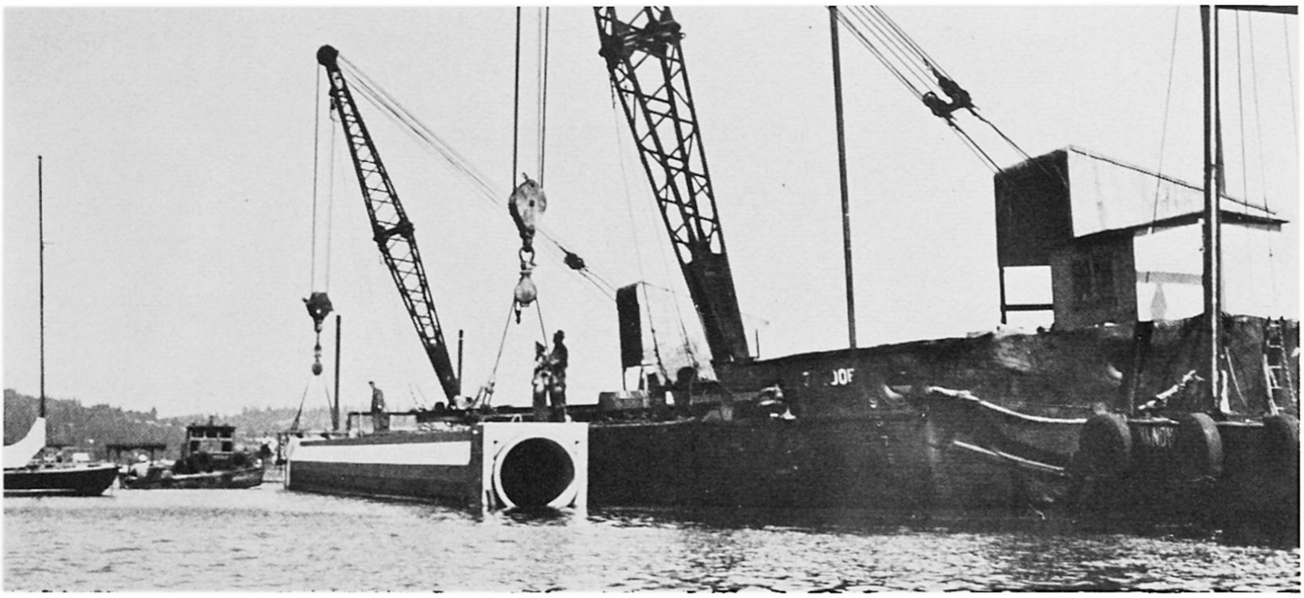

Fig. 1: Metro sewer - Lake Washington Interceptor Sewer in Seattle, Washington.

Large caissons for subaqueous tunnels have been precast in dry basins. The caissons are launched by flooding the basin. When afloat, they are towed to the site where they are submerged to their final location (Fig. 2). Good examples of highway and rail-

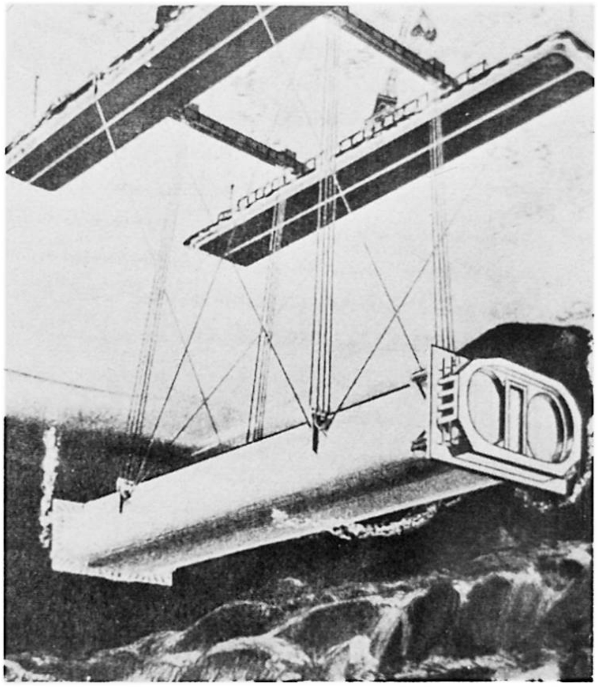

Fig. 2: San Francisco Rapid Transit Tube being submerged to its final location.

way tunnels include the La Fontaine Tunnel at Montreal, the San Francisco Rapid Transit Tube[2] (Fig. 2) and the new Tokyo Bay Loop Expressway Tunnel.

The latter is a submerged tunnel 1 km long, containing 9 precast caissons. Each caisson measures 115 x 37 x 9 m, and weighs 38,000 tons. The elements were precast in a dewatered basin 645 m long and 126 m wide. When all caissons were completed, the basin was flooded and the precast concrete elements were floated and towed to their final location and then sunk to the bottom.

Some recent and dramatic examples of submerged precast structures are to be found in the North Sea. The first of the giant oil drilling and production facilities is Norway's Ekofisk I,[3] which was completed in June 1973. Shown in Fig. 3, this structure contains 83,000 m^3 of concrete, 8,600 metric tons of reinforcing bars and 3,300 metric tons of half-inch diameter prestressing strand. Ekofisk I was constructed in Stavanger and towed 480 km to its designated location in the North Sea and then lowered to the bottom in 70 m of water.

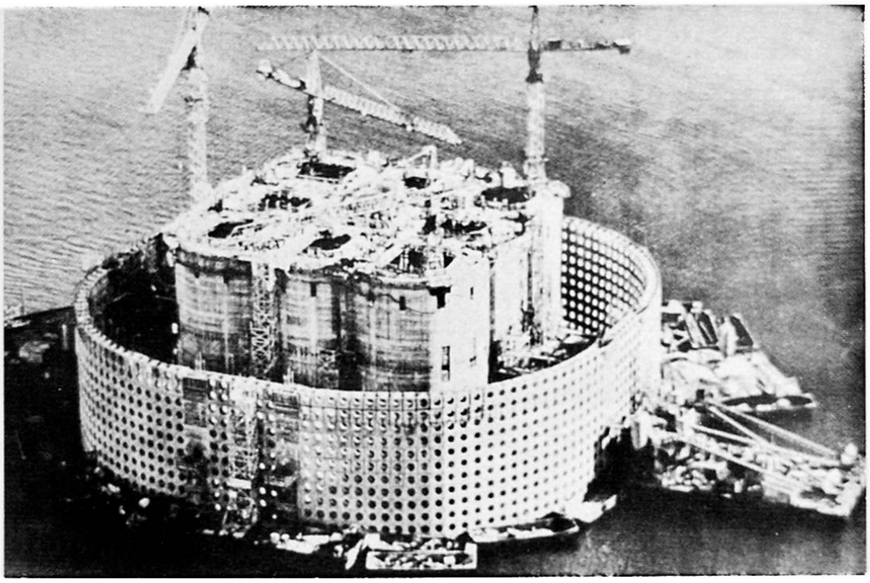

Fig. 3: Ekofisk I, oil drilling and production facility for use in the North Sea.

Immediately following Ekofisk I, the Stavanger facilities have started construction of a series of multicell precast concrete oil production facilities called Condeeps (Fig. 4). Like Ekofisk, the Condeeps (four under construction in 1974) are started in a dewatered basin 10 m below sea level. When constructed to floatable depth, the basin is flooded and the partly-complete elements are moved into the Stavangerfjord where construction continues while they remain at anchor in deep water. (Fig. 5) The nineteen cylindrical cells are concreted in slip forms to a height of 80 m. Each cylinder is closed with a dome roof. Rising above the 19 cells are three slip-formed concrete legs which support the operating platform.

Another precast concrete submerged oil facility, the Selmer Tripod (Fig. 6), is being developed in Norway. Designed for a water depth of 130 m, it has an oil storage capacity of 1 million barrels.

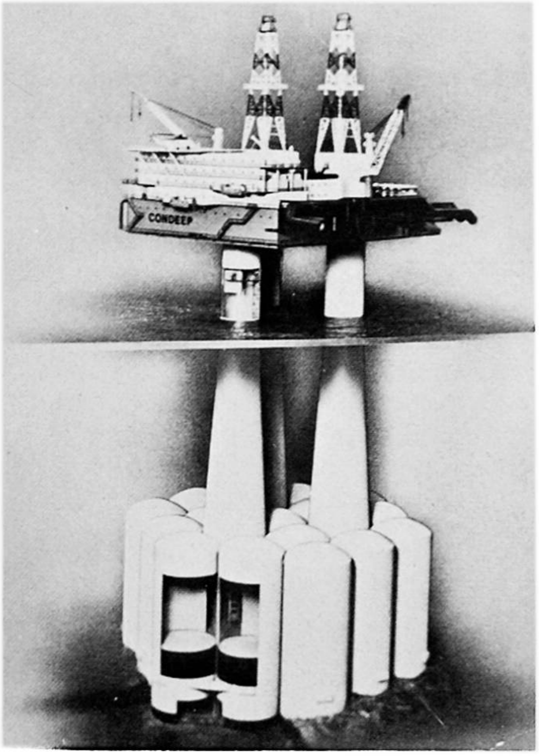

Fig.4: Condeep, Norway's multi-cell precast concrete oil production facility.

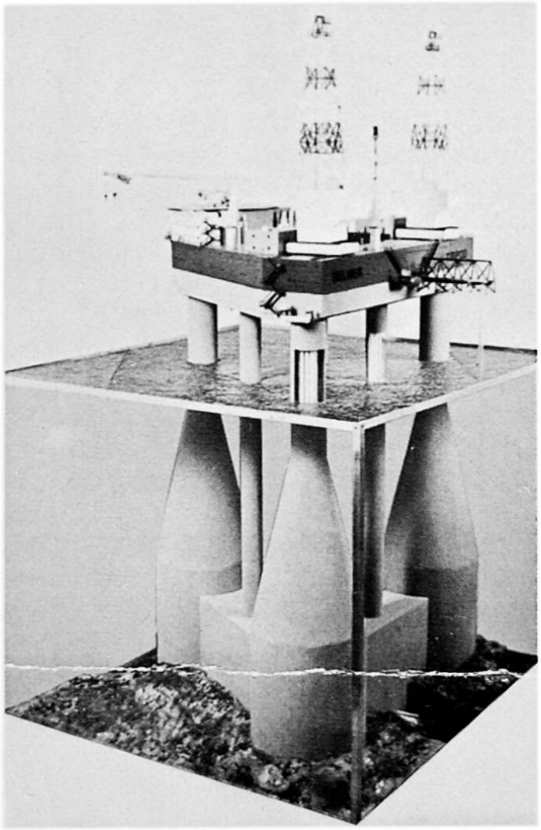

Fig.6: Selmer Tripod, million-barrel oil storage facility being developed in Norway.

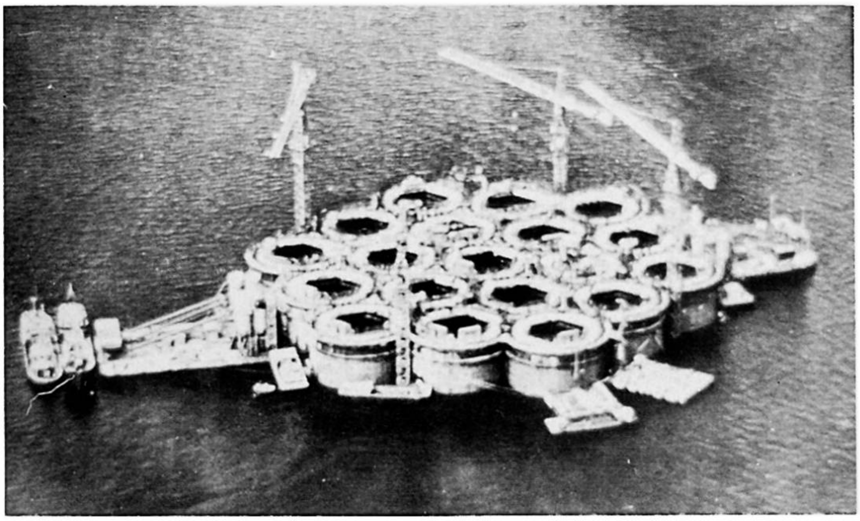

Fig.5: After flotation, construction on the Condeep continues in the Stavangerfjord.

Concrete platforms for North Sea oil production are under construction by McAlpine-Sea Tank in Scotland. Shown in Fig. 7, the structure is intended for installation in water depths ranging from 137 to 163 m. Each structure requires 257,000 tons of concrete and 13,000 tons of reinforcing steel.

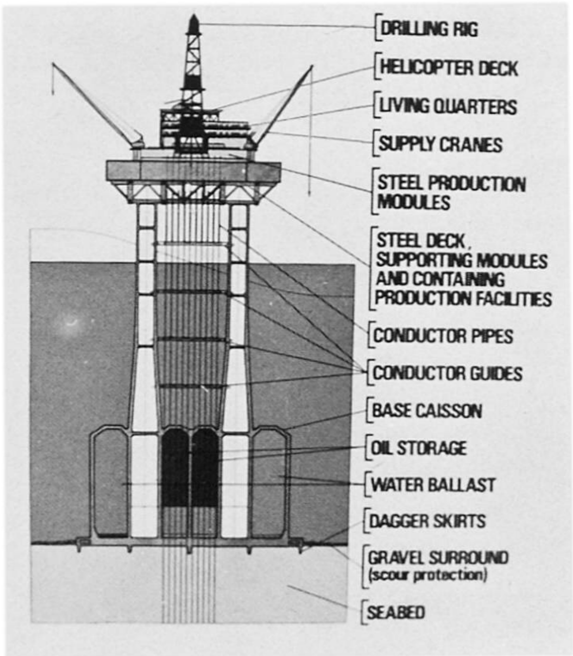

Fig. 7: McAlpine-Sea Tank gravity platform being constructed in Scotland.

Very deep submerged precast concrete structures have been tested by the U.S. Navy.[4] Figure 8 shows a cylindrical concrete shell structure that was tested at a depth of 180 m below sea level. After eleven months' submergence, the vessel was raised. The interior walls were dry, but approximately 3 liters of water had leaked around a hull fitting.

Fig. 8: SEACON, tested at 180 m below sea level by the U.S. Navy.

3. FLOATING STRUCTURES

The total number of concrete floating structures, including concrete ships that have been launched, probably exceeds one thousand.

In service as floating highways are three precast concrete multi-pontoon structures, two crossing Lake Washington (fresh water), at Seattle, and one crossing Hood Canal (salt water), in Washington State.

All three floating bridges feature precast concrete pontoons, whose dimensions are: length, 110 m; width, 20 m; and depth, 4-1/2m. The shell thickness is 23 cm (Fig. 9).

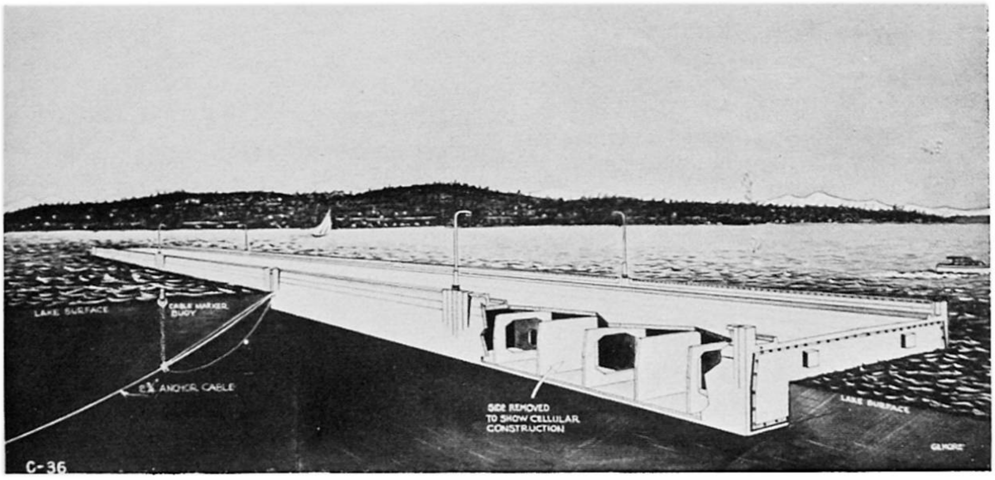

Fig. 9: Cutaway view of floating bridge pontoon.

The first of the floating bridges, built in 1939, was reinforced with standard deformed bars. The second bridge, built in 1955, and the third bridge, built in 1962, were post-tensioned with seven-wire strand tendons.

All precast pontoons were built in a graving dock and launched by flooding the dock (Fig. 10).

After the pontoons were afloat, the elevated superstructure was built and, when completed, the pontoons were towed to the construction site (Fig. 11).

A very large concrete floating harbor for super tanker cargo transfer on the high seas has been proposed by Ulrich Finsterwalder. Shown in Fig. 12, this huge concrete structure would accommodate the ultra large crude carrier having a cargo capacity of 1,000,000 tons.

A. J. Harris has proposed a floating airport, with two parallel runways 4,270 m long, and 4,000,000 square meters of taxiways and parking aprons[5].

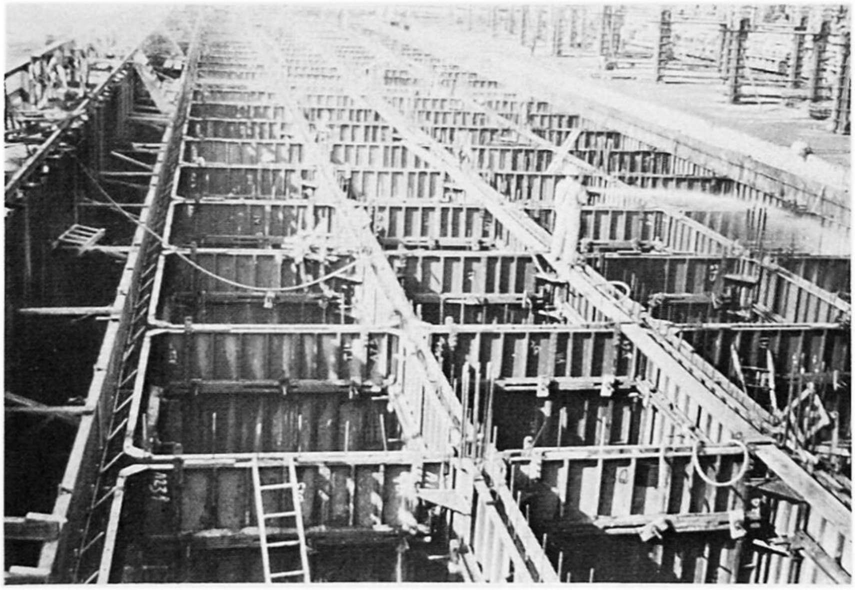

Fig. 10: Precast pontoon construction in graving dock.

Fig. 11: Precast pontoon under tow to elevated superstructure construction site.

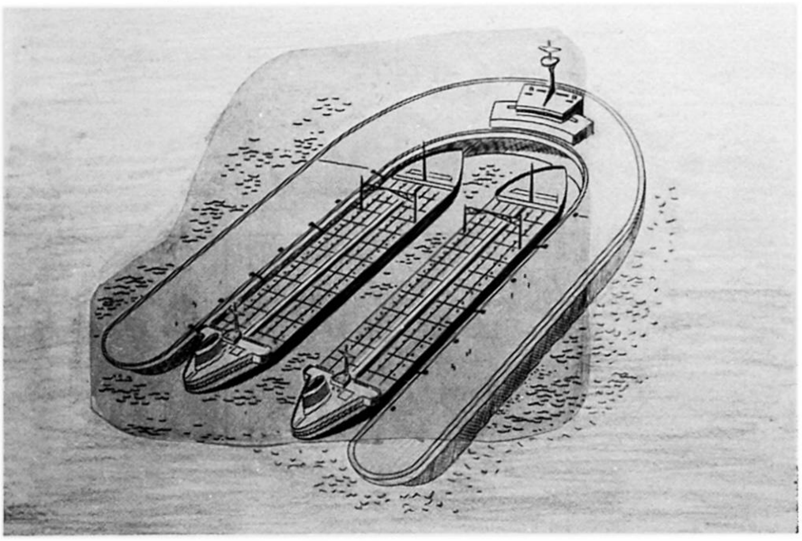

Fig. 12: Concrete floating harbor proposed by Ulrich Finsterwalder.

A very recent application of precast/prestressed concrete is a floating platform for processing and storage of liquid petroleum gas. The vessel, 140 x 41 x 17.4 m, contains 9,000 cubic meters of concrete. The full-load displacement of the vessel is 65,000 tons. (Fig. 13)

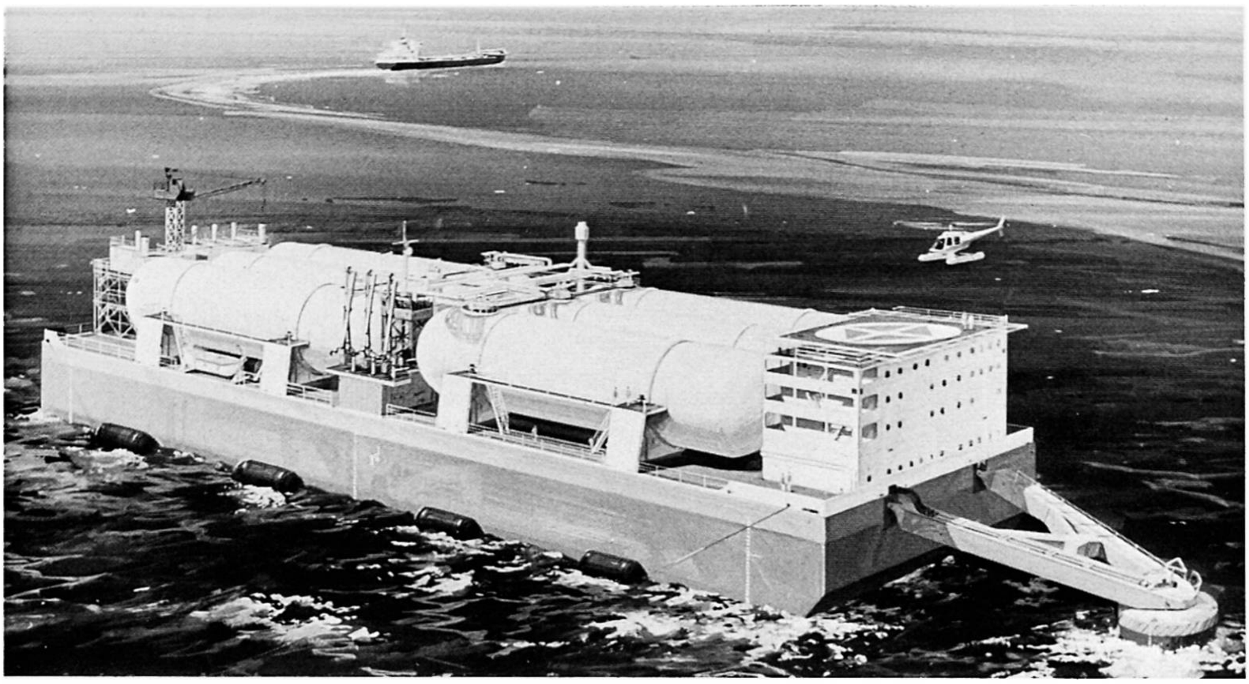

Fig. 13: Liquid petroleum gas production facility, prestressed concrete hull. Total displacement 65,000 tons. To be located in the Java Sea.

4. RULES AND RECOMMENDATIONS FROM OTHER GROUPS

Much valuable information on design, construction and inspection of fixed offshore structures has recently been published by Det Norske Veritas*, the Norwegian ship classification Society. Their rules for design and construction have, in the past, primarily related to steel ships and offshore structures.

The 1974 rules include considerable material applicable to reinforced and prestressed concrete offshore structures.

The rules require analyses for two loading conditions:

a. Functional loads.

b. Environmental loads and associated functional loads.

Functional loads are those loads incidental to the structures' existence, use and treatment under ideal conditions for each design condition (ideal conditions means no wind, waves, etc.), i.e., no "environmental" loads.

Environmental loads are all directly or indirectly due to environmental actions, such as wind, waves, currents and ice.

For design purposes, the maximum environmental load conditions are based on the most probable severity over a 100-year period.

*Det Norske Veritas, Grenseveien 92, Oslo, Norway.

The required material properties and principles for design and analysis are thoroughly explained. The rules are based on the limit state method.

In addition to the functional and environmental loads given above for all offshore structures, effects unique to prestressed and precast concrete structures must be considered. These include:

- Prestressing
- Creep
- Shrinkage and absorption
- Heat of hydration
- Temperature of stored fluids
- Load concentrations due to uneven sea floor
- Differential settlement

The limit states for design of concrete offshore structures are placed in two categories:

a. The ultimate limit states (ULS) which are those corresponding to maximum load carrying capacity:

- Loss of overall equilibrium
- Rupture of critical sections
- Instability by deformation
- Plastic or creep deformation necessitating replacement of the structure, etc.

b. The serviceability limit states (SLS) which are those related to the criteria governing normal use and durability of the structure:

- Premature or excessive cracking
- Unacceptable deformations
- Corrosion of reinforcement or deterioration of concrete
- Undesirable vibrations, etc.

Valuable recommendations for constructional arrangements and practices are given, as are provisions for quality assurance.

Recommendations for the design of concrete sea structures published in 1973 by the Fédération Internationale de la Precontrainté contains much valuable basic information on prestressed concrete sea structures, which parallels and augments information from other sources. Included in the FIP Recommendations is a comprehensive bibliography of reference material.

5. LOADS AND FORCES FROM THE SEA

Floating and submerged structures are exposed to systems, loads and forces not fully understood nor quantifiable. More experience and research is needed in order to construct safe, yet economical concrete offshore structures.

Recent work in this field has been presented at the Sixth Offshore Technology Conference, May 6-8, 1974, Houston, Texas.

Tørum, Larsen and Hafskjold, in Paper No. OTC 1947[6], discussed the safety of a concrete gravity structure resting on the bottom of the sea. Research on wave forces, hydraulic aspects related to bottom-mounted concrete structures, shock waves, wave damping devices and scour are discussed.

Investigations have been carried out on the effect of wave loads and wave damping under the sponsorship of Ingeniør F. Selmer A/S, Norway, and with financial support by the Royal Norwegian Council for Scientific and Industrial Research.

Tests were conducted at the River and Harbor Laboratory at the Norwegian Institute of Technology, where research work on shock waves and scour was also performed.

Conclusions reached from this work include:

- Sea bottoms on which gravity structures rest are often vulnerable to scour, small structures more so than large ones.

- Designs based on forces from regular waves may give conservative results when compared to irregular waves.

- For evaluation of stresses in the sea bottom soil, one should consider possible dynamic amplification. There is no doubt that, for certain types of soil, such amplification may occur for large structures in deep water.

- When large shafts protrude upward above the waterline, they become susceptible to shock pressures. Model studies indicated the presence of shock pressures during combined wind and irregular wave loading. For a curved surface, the irregular contact face between water, air and structure is difficult to model mathematically. Neither theoretical nor empirical relationships between shock intensities, duration or distribution and wave height, wave steepness or shaft diameters are available.

- The structural response to shock pressures may be separated into global and local effects. The global response to the shock pressure is in most cases negligible, as the resulting load is small compared with the loading from non-breaking waves. For example, a 12 m diameter shaft subjected to 20 t/m^2 shock pressure over a 10 x 10 m lateral area is approximately 100 tons. For comparison, the lateral load from a non-breaking wave with a height of 25 m and period of 15 sec at 80 m depth is 2,800 tons.

However, the repeated action of the wave shocks sets up small amplitude shock waves propagated down the shaft, and this effect must be included when evaluating the risk of failure at the base of the shafts.

- Wave damping devices have been studied to find methods to damp waves where vessels are moored next to gravity platforms. Much remains to be learned about scour at the base of large concrete gravity structures resting on the ocean floor.

- Scour protection may be provided by a stone blanket which is placed on a suitable filter.

6. CONCLUSIONS

The potential for precast concrete floating and submerged structures almost defies imagination, especially offshore construction for petroleum production facilities. Considerable work has already been accomplished or is in advanced stage of engineering and design.

The advantages for precast and prestressed concrete construction are manifold, and include the following:

a. Can be produced under factory conditions with labor-saving mechanization.

b. Precast concrete made with low water-cement ratio and vigorous mechanical compaction can reach very high strength and resistance to sea water attack.

c. Production proceeds independently of weather conditions at the site, assuring high quality and time saving on construction schedule.

d. Economy in total capital cost and maintenance cost favors precast construction.

To advance the state of the art, research and development is needed. More understanding of hydrodynamic loading and stability of foundations on the ocean floor is very necessary.

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SUMMARY

New applications for precast structures are becoming increasingly interesting for offshore construction, both floating and submerged. High quality prestressed concrete is especially attractive for environments where resistance to fatigue as well as corrosion are a major concern.

RESUME

L'emploi de structures préfabriquées devient toujours plus intéressant pour les constructions en mer, qu'elles soient flottantes ou submergées. Le béton précontraint de haute qualité est particulièrement favorable à l'environnement, partout où la résistance à la fatigue et à la corrosion est essentielle.

ZUSAMMENFASSUNG

Die Verwendung vorfabrizierter Tragwerke wird für Bauwerke im Meer immer interessanter, sei es für Unterwasserbauten oder schwimmende Konstruktionen. Der Spannbeton von hoher Qualität ist besonders umweltfreundlich was bezüglich Widerstand bei Ermüdung und Korrosion von grösster Bedeutung ist.