An abstract:

State-of-the Art Report on Barge-Like Concrete Structures

Reported by Committee 357

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This report addresses the range of current engineering experience for the design and construction of floating, barge-like concrete structures. A brief discussion of past and present structures and design concepts is presented to establish both the versatility and technical viability of concrete barge-like marine structures.

Barge-like concrete structures are used at both sheltered and exposed sites. The marine environment can be both severe and highly unpredictable, necessitating unique design requirements for floating concrete structures. In addition, barge-like structures serve a wide variety of uses such as industrial plantships. floating bridges, floating docks, parking and hotel structures. and other applications, and as such, further attest to the wide range of possible design requirements.

Design loads and recommended design criteria are presented. Design procedures and methods of analysis are discussed to better acquaint the reader with the design considerations that are unique to barge-like marine structures.

Methods used to construct barge-like concrete structures play a major role in the success of each application. Construction methods and materials used for recent applications are presented to demonstrate the importance of the construction process during the planning and design of marine concrete structures. Important aspects of delivery from the construction site and installation at the deployment site are presented.

The durability and serviceability of barge-like structures at remote sites are important considerations to project planners and developers. Construction material selection and inspection. maintenance. and repair techniques are discussed.

Keywords: abrasion; accidents; admixtures; aggregates; barges; bridges (structures); concrete construction; concrete durability; construction materials; corrosion; deployment; detailing; docks; dynamic loads; fatigue (materials); finite element method; floating bridges; floating docks; freeze-thaw durability; inspection; lightweight concretes; limit state design; loads (forces); maintenance; marine atmospheres; moorings; permeability; plants; post-tensioning; precast concrete; prestressing steels; quality control; reinforcing steels; repairs; reviews; serviceability; stability; structural design; surveys; terminal facilities; towing; weight control.

CONTENTS OF FULL REPORT

The full report of ACI 357.2R-88 is available as a separate publication.

ABSTRACT OF REPORT

This state-of-the-art report highlights the current experience in design, construction, and installation of barge-like concrete structures used in both floating and fixed modes. The structures addressed in the report are primarily intended to be used in nonarctic locations. A generous amount of technical information is also available on concrete offshore structures intended for arctic applications, and the reader is referred to ACI 357.1R-85, "State-of-the Art Report — Offshore Concrete Structures for the Arctic," for a compilation of information on that subject.

Barge-like concrete structures assume many forms and are used in a wide variety of applications. Concrete offshore structures have a long history of efficient service to the marine industry. The technology to develop today's sophisticated barge-like structures began well over 100 years ago with the building of small reinforced concrete boats and has progressed to the development of prestressed concrete vessels that displace nearly 100,000 tonnes. These modern structures are constructed from durable, high-strength, normal density, and lightweight concretes.

Methods and criteria used in the design of concrete barge-like structures began as an extension of design methods used for steel vessels. Design methods specific to concrete applications are now available and place considerable emphasis on personnel safety and the in-service performance of the vessel. Construction methods were developed primarily by innovative marine concrete contractors who were willing to accept the challenge of building unique structures in accordance with rigid specifications and demanding delivery schedules. Progress in both the design and construction communities would not have been as rapid had it not been for the advancement of the state-of-the-art in concrete materials technology. These advancements were manifested by the development of today's high-strength, durable concretes. These combined developments have made it possible to construct economically a wide variety of marine concrete structures in many areas of the world.

This state-of-the-art report describes the wide range of applications assumed by barge-like structures and further presents an overview of current practice in design, analysis, materials technology, construction, deployment, and maintenance of these vessels.

APPLICATIONS

This report defines a barge-like structure as a floating vessel with near vertical sides and a near rectangular shape in plan. The bow and stern may, or may not, be raked. As defined, these structures are intended to be either temporarily or permanently operated while afloat. Some barge-like structures are towed to a deployment site, subsequently grounded, and refloated at a later time.

The report presents numerous examples of existing barge-like structures, and these examples illustrate a broad range of applications. Many of these applications have been selected and have proven successful because the required deployment site was located in deep water, in an adverse environment, and remote from developed construction facilities. For these applications, floating structures can be economically constructed off-site and towed to the required operation site.

Present applications include barges, bridge pier caissons, floating industrial plants, docks, bridges, breakwaters, heliports, parking garages, and airports. New applications are being identified at the present time. The current success of barge-like structure technology indicates that future applications will be even more widely diversified.

MATERIALS

Two characteristics common to barge-like concrete structures strongly influence the selection of concrete construction materials. The first is that these structures are often so large and located at remote locations that drydocking for inspection and maintenance is not possible. Hence, the structural materials must be inherently durable, even when exposed to harsh environments. Secondly, most of these structures are weight critical, and structural strength must be provided using minimal materials. These structures are often configured as a network of slender internal stiffening members (bulkheads) supporting the exterior watertight sidewalls and bottom. Many members are heavily rein-

forced, and the potential for reinforcing congestion is an important design consideration. Lightweight and high-strength normal weight concretes are currently used extensively.

To provide durability, the water-cement ratio is held to a practical minimum, and it is often necessary to use admixtures to enhance flowability and workability in areas where reinforcing concentration is high. Other important characteristics include resistance to sulfate attack and to freezing and thawing. Quality aggregates and materials are available to produce the specified concretes worldwide.

DESIGN

The design of barge-like structures consists of two distinct phases: determination of applied characteristic loads and definition of the structure necessary to safely and economically resist those loads. Floating structures are subject to a wide variety of loadings — some readily definable and others difficult to predict with confidence. Predictable loads include dead and live loads, construction loads, and deformation loads. Loads difficult to define accurately include environmental and accidental loads. For floating structures, the predominant environmental consideration is exposure to waves.

Dead and live loads are determined from the distribution of structure self-weight and operational loads on the hull, and these are balanced by the hydrostatic pressure distribution on the floating structure. Nonuniform distributions can give rise to conditions of trim and heel. Deformation loads are often caused by temperature effects, prestress, shrinkage, and creep. Accidental loads can occur due to vessel impact or dropped objects. Environmental loads can be calculated by dynamic (time or frequency domain) procedures or quasi-static procedures.

For floating structures, the designer is confronted not only with requirements for structure strength, but also with the overall stability of the floating body. Floating structures must be designed to provide adequate freeboard to prevent damaging wave overtopping; to provide adequate stability to enhance continued operations, and to maximize safety in the open sea. Stability must be considered from the onset of construction through deployment, and consideration must be afforded to both the intact and damaged conditions of the vessel.

CONSTRUCTION

The state of the art for construction of barge-like structures is well defined, and regulatory agencies have established comprehensive codes and guidelines for construction. Construction techniques are well established, and modern fabrication yards exist throughout the world. It is now possible to construct and completely outfit an industrial plant on to a concrete barge structure, then tow the completed unit thousands of miles over open ocean for hook-up and commissioning at a remote, undeveloped industrial site.

Some barge-like structures are small and can be easily constructed in temporary facilities having access to raw materials and open water. Smaller structures may be constructed either in dedicated drydocks, graving docks, or on landside slipways. However, many barge-like structures are quite large with lengths exceeding 500 ft (160 m). Very few construction yards exist that can accomodate the fabrication of these units in monolithic form. These larger units can be made as individual segments, each having dimensions compatible with facility dimensions and draft restrictions and then launched and joined with similar segments while afloat.

Both precast and cast-in-place construction methods are used. Extensive use is made of prestressing to control cracking in the relatively thin structural elements, and this is especially true at joints between individual segments. Economical methods for providing full global bending moments and shear capacity across segment joints have been developed and successfully implemented.

The construction process is often monitored by the design agent, and inspection can be provided by cognizant certifying agents.

TOWING AND INSTALLATION

Because barge-like concrete structures are often transported great distances from fabrication yards to deployment sites, special attention is given to design considerations for strength, maneuverability, and stability in the open seaway. For some applications, loads calculated for the delivery voyage are highly influential in sizing primary hull dimensions. For these reasons, towing considerations such as route selection, time of year, and towing and mooring attachments, require consideration early in the design process.

Once the tow route and schedule have been established, anticipated seastate conditions along the route can be formulated. These anticipated conditions are used to calculate expected loadings and vessel motions. Towing vessels are selected, and contingency plans for refueling and safe-harbor are established.

The configuration of the vessel is established by including not only deadweight, but also cargo distributions, and these are used to calculate the necessary vessel stability characteristics during the tow. Both intact and damaged conditions are assumed. Stability in the damaged condition is assessed by assuming that the vessel has sustained sufficient damage to cause flooding of certain compartments within the watertight hull.

Towing and maneuvering in restricted waters is also given special attention. Plans are made for transit through narrow channels and shallow water. Towing conditions are normally fitted to the structure to permit the towing vessels to be easily secured and released. For towing at sea, towing vessels are selected to provide sufficient power to hold the barge safely in gale force winds and associated waves concurrently with a 1-knot current.

MAINTENANCE, INSPECTION, AND REPAIR

Attention to detail during the design and preparation of construction specifications for barge-like concrete structures greatly reduces the maintenance requirements during the life of the vessel. Regular, well-planned, and executed surveys mitigate the need for costly maintenance and repairs. The effectiveness of the survey is enhanced by documented as-built drawings, past survey results, and repair records.

Should accidents or overloads occur, repairs may be necessary. The repair team should be trained to recognize causes for concrete deterioration, should understand the service requirements for the member to be repaired, and should be familiar with repair methods, materials,and techniques. Every repair should begin with an assessment of the cause for the distress or deterioration.

Since it is not often practical to move the barge to a well-equipped repair facility, repairs will need to be made on location. It may be necessary to transport special materials and trained personnel to remote locations to accomplish the repair. Environmental and operating conditions may influence the timing and success of the repair. Repairs may need to be made quickly during severe weather conditions and may even need to be made under water. Techniques are available **for** a wide variety of challenging applications.

SUMMARY

ACI 357R, "Guide for the Design and Construction of Fixed Offshore Concrete Structures," provides technical guidance for the design and construction **of** floating and fixed barge-like structures. ACI Committee **357** is currently in the process of revising this document, and this revision will further improve the state **of** the art of offshore concrete structures. **As** new applications for barge-like concrete structures arise, new design and construction challenges will be met.

This state-of-the-art report is intended to further the development of floating concrete structures. By presenting this report, the technology is demonstrated **as** available for a wide variety of applications. The existing applications have been presented as a means of demonstrating that the technology risks are at a known and acceptable level.

The lull **report** was submitted to letter ballot of the committee, which consists of **23** members; 21 members returned ballots, ***20 of*** whom voted affirmatively and 1 absrained.