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Analysis and design of floating prestressed concrete structures in shallow waters

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ABSTRACT

Prestressed concrete floating structures have been used for over a century with notable success in various parts of the world. However, there still exist issues related to the analysis and design, and the service performance of concrete floating structures. This paper highlights the design concepts, material behavior, analysis approaches and structural systems for floating prestressed concrete structures deployed in shallow waters. Material and design requirements related to prestressed concrete floating structures in particular are reviewed and potential technical challenges are identified. Moreover, some recommendations and suggestions are summarized as a guide for future practice.

1. Background

The use of concrete in floating structures dates back to the early twentieth century. The first reinforced concrete sailing vessel, *Namsenfjord*, was built in Norway in 1917 [1]. Subsequently, hundreds of concrete ships were built in the first and second world wars due to the shortage of steel. In particular, two vessels were constructed of prestressed concrete (PC) precast cellular modules during World War II [2]. In the late 1950s, some ocean-going barges made of pre-tensioned concrete were designed and constructed in the Philippines. In 1975, the world's first large PC floating liquefied petroleum gas (LPG) storage vessel was constructed and deployed in Java Sea [3]. The vessel hull was designed and constructed as a post-tensioned concrete segmental structure to carry twelve independent steel tanks with a total capacity of 375,000 barrels. As the largest existing PC floating barge in the world, N'Kossa Oil Production Unit, was constructed in 1996 off the coast of Congo. It measures 220 m in length, 46 m in width and 16 m in depth. The N'Kossa barge has successfully operated on site without interruption for 20 years [4,5]. In 2002, the world's largest concrete floating dike, 352 m long and 28 m wide, was installed in Monaco harbor, which serves as a breakwater as well as a cruiser terminal. It was built in a 15 m deep dry dock and towed to Monaco for installation. It is expected to fulfill its functions for 120 years [6].

For the purpose of oil exploration and production, the first major base-supported concrete offshore structure, Ekofisk tank, was installed in 1973 in the North Sea. Since then, more than 40 concrete fixed offshore platforms have been built in the North Sea, the Gulf of Mexico and West Africa [7]. These offshore concrete platforms have performed extremely well in the seawater environment with little maintenance. In 1995, an innovative type of floating concrete platform structure, known as tension-leg platform (TLP), was first installed at the Heidrun field of the North Sea at a water depth of 345 m. In the same period, Troll Oje's floating platform, a semi-

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(a) Ujina Floating Ferry Piers (b) Incheon Floating Cruise Ship Piers

Fig. 1. Floating concrete piers located next to shoreline.

submerged concrete hull anchored by catenary moorings, was also built in the deep waters of the North Sea.

For some metropolis with coastal areas, such as Singapore, Shanghai and Tokyo, there is a need for usable space expansion to address the issue of land scarcity in an urban setting. Previous experience shows that land reclamation and the use of floating structures are two main options to increase usable space to accommodate industry facilities, habitation and infrastructure as the city grows and develops. Compared to land reclamation, floating structures are preferred because they are more environmental friendly and require less construction costs, especially when the water depth is large and the seabed is soft.

Most existing floating concrete structures have been located in deep seawater area, and may not be suitable or appropriate for shallower coastal areas. Fig. 1 presents two floating concrete piers located in shallow coastal areas. According to previous engineering experiences, one major difference between floating structures in deep and shallow seawater areas is in the mooring system, whose function is to keep the structure in position and prevent it from drifting under critical sea conditions [8]. As compared to conventional mooring systems, like chain/cable, tension leg and others, the dolphin - fender system (Fig. 2 (a)) is more suitable for floating structures in shallow waters because it can effectively restrict the lateral motions [9]. The dolphin - fender mooring system was first adopted in the two floating oil storage bases at Kamigoto and Shirashima islands in Japan, and has since been used for other facilities [10,11]. Fig. 2 (b) and (c) show practical lateral and roller fenders installed at the interfaces between the dolphin and floating structure, which are able to undergo large deformations and absorb kinetic energy of floating structures [9]. When the topside is to be installed on the substructure, the intersection should be carefully designed to take account of interface shear forces. Given that floating structures often undergo relatively larger displacement than fixed structures, it is preferable that the topside structure can be de-coupled from the floating substructure's deformation. Due to the lack of documented interface configurations from existing concrete floating structures, engineering solutions from FPSO can be referred herein and they include the use of: (1) multiple snipped column supports; and (2) supporting stools fitted with roller and sliding joints or elastomeric pads [12,13].

This paper provides a critical review of the design considerations and requirements pertaining to materials and analyses for general purpose floating concrete structures. Issues pertaining to PC floating structures deployed in shallow waters are highlighted, and some recommendations are made.

1.1. Characteristics of PC structures in seawater environment

Marine structures have been built of iron-and-steel for more than a century due to historical reasons. However, engineering experience shows that, when properly designed and constructed under strict quality control, prestressed concrete may be a preferred material over steel for floating structures because of its excellent durability and corrosion resistance [3]. The advantages of prestressed concrete over steel in the seawater environment have been recognized by many researchers [14–16], among which the main ones are:

(a) Dolphin-Fender System (b) Lateral Fender (c) Roller Fender

Fig. 2. Dolphin-fender mooring systems.