CONCRETE FLOATING STRUCTURE TECHNOLOGY

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Abstract

Concrete floating structures have been built for more than a century now. The first concrete ships and floating houses were built about a century ago in also Amsterdam. The choice was made for concrete, especially because of the high cost of steel in that period. In the beginning of floating construction, only Ferro-concrete was used because no pre-tensioning and post- tensioning of concrete was possible then. Currently the world population is expanding rapidly and living concentrates mostly in large cities located often next to the sea or rivers. Expansion of the cities towards the water is a viable option for urban planning. Floating construction offers a cheap solution for real estate development on water and needs political support for long term planning of our nations. FDN Group of companies has carried out much technical research in the last 20 years concerning the different possibilities for floating structures and building methods on the water. The research has involved design of floating breakwaters (Dutch Floating Breakwaters), large floating bridges, floating cruise terminals, floating storage tanks, very large floating platforms, floating islands for recreational use, floating buildings and high-rise and floating cities. In our research we conclude that the cheapest construction material for creating floating structures is concrete as this material is maintenance free. Especially using new UHPFRC concretes can increase the life period of the structure up to a few hundred years. The protective coating of steel structures subjected to seawater environment needs maintenance about every 15-20 years. For movable floating structures such as ships, construction in steel may be the best solution, but for permanent and semi-permanent structures, which may change location only once in 15-20 years, concrete is the best solution considering maintenance cost and stability criteria of the structure.

Keywords: Anchorage of floating structures, concrete Floating Structures, Floating islands, Certification, Design Rules, Floating Building Methods, Maintenance free, Forces on floating structures**.**

1 Introduction

This paper describes concrete floating structures from design up to practical application. It is a summary of the possibilities achieved from 20 years of experience from designing and building small and large floating structures all around the world. The aim is to provide general knowledge about building floating concrete structures on the water and describe the design criteria such as loadings, durability issues, structural materials, connections and anchorage to allow current concrete structural designers to explore also on the water. Furthermore the paper provides an overview of building methods, area of applications and examples of projects carried out by FDN.

2 Main Building methods

The choice for a building method is directly determined by the type of designed structure and related requirements. The majority of the floating structures are based on a concrete pontoon or

EPS-concrete system. The floating concrete elements with or without polystyrene filling can be constructed in several ways:

- In situ at the waterside, next to water and launched into the water on rails or lifted by cranes
- In situ on the water, with concrete poured on the EPS blocks
- In situ in a dry dock
- Prefabrication in a factory, assemblage/connecting elements on the water
- Precast elements connected together in a dry dock to form an element

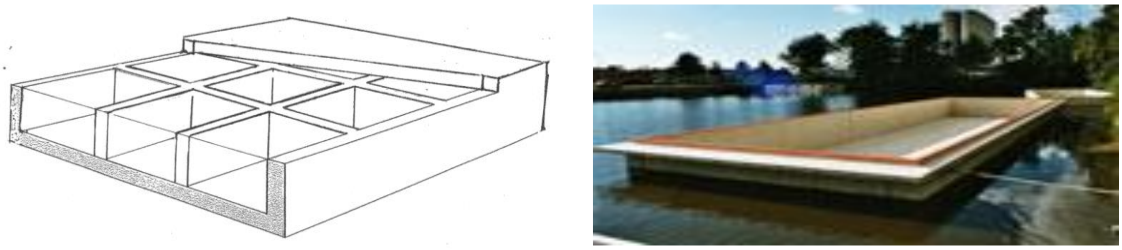


Fig. 1 Concrete closed (left figure) and opened (right figure) floating base. This is the most common and economical solution for floating concrete structures. The suitable building method is in situ casting in a dock, or at water side and connecting elements to form large floating platforms.

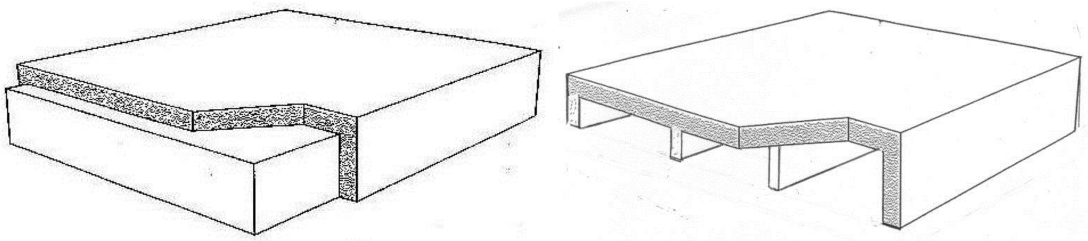


Fig. 2 The left figure represents a method where the polystyrene blocks are installed first and concrete can be poured afterwards. The right figure illustrates structure with additional ribs. The building process is predominantly executed near to the water in a dock or on rail construction after which the structure can be launched into the water.

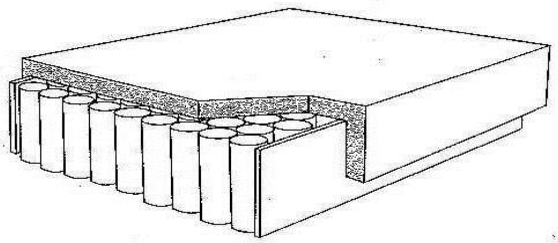


Fig. 3 A stable solution for the floating platforms is the use of vertical cylinders. This solution is convenient both for small-scale objects and large heavy loaded platforms for the off-shore industry. In the case of large structures, the system is pneumatically stabilized by controlling of air pressure in the cylinders.

3 Design criteria for floating structures

Unlike traditional structures built on land, design of floating structures comprises several aspects, which must be taken additionally into consideration. A special attention must be paid on buoyancy and stability issues. The structure must be designed in such a way that the buoyancy is preserved under any potential loading condition during the whole life period of the structure. In other words, the minimal freeboard and limited rotation angle must be always satisfied. Correct design must also consider problems regarding durability such as exceeding cracking and corrosion due to water leakage or damage of connections. The complexity of design is also enhanced by the fact that there are no direct building regulations, recommendations or codes, which would directly define design aspects such as recommended loading combinations, loading factors, maximal displacement or rotation. The floating civil structures fall into a special category of structures which are not fixed structures on land nor floating vessels on the sea. This category of the civil floating structures falls under a new category of constructions; which are also designed by a category of engineers needing design know-how in both fields; ship building and civil concrete construction.

Loadings

Every floating structure is subjected to the following loads:

- Hydrostatic pressure
- Waveload
- Flow (current) load
- Wind
- Collision (accidental) loads
- Traffic variable loads

Hydrostatic pressure is a permanent load, which creates an isotropic pressure on the submerged parts of the floating structure. Unlike dynamic loads, the hydrostatic pressure can be easily predicted and calculated. The resulting force (vertical or horizontal) can be obtained by integration of the pressure over an affected area. The pressure, depending on water density ρ, and draft height x, can be expressed as:

$$p_{(x)} = \int_{x0}^{x} \rho g d(x) \tag{1}$$

Summed vertical and horizontal force, depending on width B and length L of a rectangular floating body, can be derived as:

$$F_v = \rho g x B L \tag{2}$$

$$F_h = \frac{1}{2} \rho g x^2 L \tag{3}$$

Wave load can be a serious issue mainly for massive floating bodies, which reflects, diffracts and damps the waves in larger scale. Those structures are mainly heavy breakwaters, which are designed to attenuate waves in severe load conditions. The transversal wave pressure is directly determined by significant wave height H_s, water density ρ_w, water depth H and wave length L. The properties of the waves according to rheological conditions can be determined by SWAN analysis, method developed at Delft University of Technology or other more advanced 2D and 3D wave analysis calculations. Normally for secured locations an initial estimate of the wave load is 10kN/m2 that can be applied for the side wall of the structure along the whole depth of the structure (next to the hydrostatic loading).

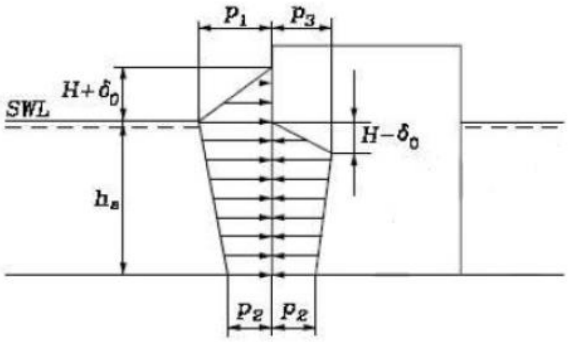


Fig. 4 Notation of wave loads acting on a concrete structure in transversal (orthogonal) direction – Sainflou method.

$$p_1 = (p_2 + \rho_w g h_s)\frac{H + \delta_0}{h_s + H + \delta_0} \tag{4}$$

$$p_2 = \frac{\rho_w g H}{\cosh(2\pi h_s/L)} \tag{5}$$

$$p_3 = \rho_w g(H - \delta_0) \tag{6}$$

$$\delta_0 = \frac{\pi H^2}{L}\coth\left(\frac{2\pi h_s}{L}\right) \tag{7}$$

Next to transversal waves, it is necessary to consider longitudinal waves, which cause mainly surge and pitch of the floating body. This load is not only relevant for the concrete structure but also for design of connections between the elements.

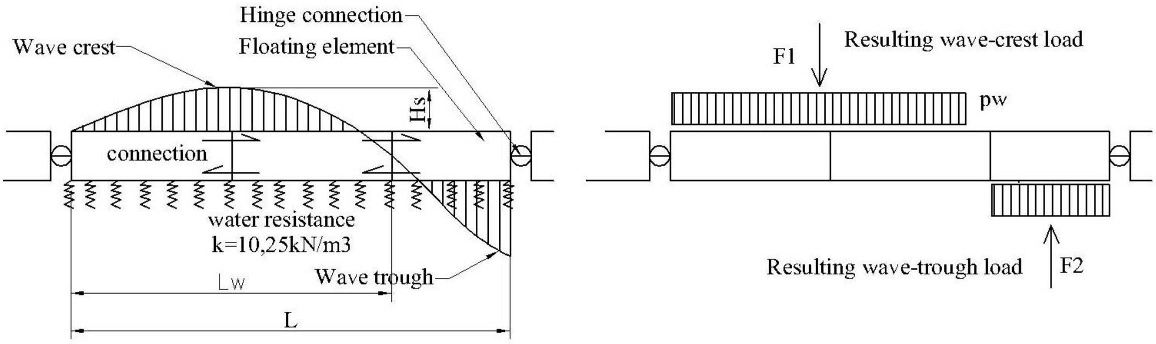


Fig. 5 Example of calculation of loads from longitudinal loads – sagging and hogging effect.

If the shape of the longitudinal wave is assumed as a simplified sinusoidal function, the resulting force F1 from fig.5 force can be expressed as:

$$F_1 = \int_0^{Lw} \rho H_s B \sin\left(2\pi \cdot \frac{x}{\lambda}\right) dx \tag{8}$$

, where ρ is water density, H_s is crest height of the maximum wave at location, B is the width of the floating element and λ the wave length.

The flow (current) load is important to consider in the area with large water velocity. The velocity depends on local conditions and location. Water velocity near to coast is often considered around

0.5-1.0m/s. In the inland waterways and rivers, the speed can be larger, especially if floods can occur. In general the speed of water can be according to BS6349 expressed as:

$$q_{current} = \frac{1}{2} \cdot \rho_w \cdot v^2 \cdot C_D \tag{9}$$

, where:

ρ_w	Density of water [kg/m3]
v	Water velocity [m/s]
C_D	drag coefficient, for rectangular objects 2 to 2.2.

Wind loads acting on high and large superstructures of floating platforms can cause significant mooring forces, which must be transferred by the anchoring system to the seabed. There are several building codes and recommendations, how to determine wind forces. The chosen code must correspond with the project location and jurisdiction.

Collision force is meant as an unintended load, which can negatively affect a floating structure. In the majority of design cases, the collision force is represented by a hit of a vessel during berthing or any other maneuvering process or accidental load. The impact force, as an accidental load case, is usually considered in design of floating pontoons or breakwaters. The value of the collision force is determined explicitly through the energy-absorption method. This method is based on the same principles as the method for design of fenders or dolphins. Every vessel with certain speed has a kinetic energy. At the moment of contact with the floating structure/fender, this kinetic energy is gradually transferred to deformation energy as the fender and adjacent structure deform. The total amount of energy must be preserved at every moment. Hence the equilibrium between deformation and kinetic energy must satisfy all the following relations:

$$E = \frac{G \cdot C_m \cdot C_s}{2 \cdot (k^2 + r^2)} \cdot [v^2 \cdot (k^2 + r^2 \cdot \cos^2 \gamma) + 2 \cdot v \cdot \omega \cdot r \cdot k^2 \cdot \sin \gamma + \omega^2 \cdot k^2 \cdot r^2] \tag{10}$$

$$k_{max} = k_{total} = \frac{{F_{impact}}^2}{2 \cdot E} \tag{11}$$

$$E = 0.5 \cdot F_{impact} \cdot u_{total} \tag{12}$$

The equation (10) describes energy of a moving vessel. This energy depends on dimensions of the ships, type of movement and boundary conditions. The equation (11) and (12) represent the energy, which is absorbed by deformation/horizontal displacement of the structure. These relations introduce impact force, which is necessary for static design of concrete structure. In addition, the energy-absorption method must be in agreement with structural (material) capacity.

Traffic load is variable load acting mainly on top slab of the floating element. Traffic load can be crowd of people (in the case of pontoons in marinas, pedestrian floating bridges etc.), vehicle loads (floating bridges, parking garages) or loads from cranes or any other relevant variable loading.

3.1 Design life period

Standard design life period for a concrete structure is 50-100 years, depending on importance of the structure. The lifespan is mainly determined by quality of material, detailing and correctness of design procedures. The concrete with larger compression and flexural strength gives a structure a longer life span. In the case of Ultra-High Performance Concrete (UHPC), durability is increased significantly. Unlike standard concretes (RC), the UHPC has very low permeability and porosity. The penetration depth under water pressure is just few millimeters. Diffusion of chloride ions is not dangerous for reinforcement if the cover is around 20mm. In the case of standard RC, the minimal concrete cover is around 60mm, which can result in a large weight of the structure.

Durability is also related to cracking. The minimal crack width is usually defined both for aesthetical appearance, water tightness and minimization of corrosion. The structure is considered water-tight, if maximal crack width does not exceed 0.1mm. In some cases a crack width of 0.2mm can be allowed, if the concrete body is filled with polystyrene and there is no risk of exceeding deterioration of the structure which can cause sinking.

3.2 Strength and stiffness

Generally speaking, external loading to floating structures is significant. A priority of design is to make sure, that no collapse will occur in the Ultimate Limit State (ULS). The concrete is a convenient material for floating structures, because it is heavy, robust and stiff. Experience from the existing structures has shown that the weakest points are the connections of floating elements, flexible connectors, anchor systems and all steel-to-concrete connections. Designers often underestimate forces in the anchor bolts or screws caused by waves during storms. Hence design must be based on relatively large safety factors including dynamic influence. In terms of general stiffness, the main concrete body must be stiffened by several transversal stiffening walls. In addition, sharp corners between two adjacent walls should be eliminated and substituted by rounded corners.

3.3 Stability

There are two types of stability, which have to be considered in the design of floating structures – static and dynamic. The static stability has to be considered in every case. The dynamic stability should be applied in design of those structures, where a risk of resonance is an issue. Static stability is a governing issue for mainly Service Limit State (SLS), where requirements of minimal rotation angle must be satisfied. The static stability of a floating structure is defined by the height between gravity center and its metacenter (the metacentric height GM). Generally speaking, a larger metacentric height means larger static stability.

Metacentric height for rectangular floating body can be simply expressed as [1]:

$$|GM| = \frac{b^2}{12d} + \frac{1}{2}d - |KG| \tag{13}$$

,where b is the width and d is draft of the concrete body and KG is distance between bottom plate and center of gravity. Rotation angle under unbalanced variable or permanent load should be limited. European codes for building recommends maximal angle 1:300. This requirement is difficult to satisfy in the case of floating structures. In practice, the temporary rotation angle can be considered 5-10° with the condition that minimal freeboard is preserved. The minimal temporary freeboard is usually around 100mm. However minimal freeboard for permanent loads is larger about 300-1000mm. The standard freeboard is usually determined in such a way, that wave overtopping will not occur.

The main aspect of dynamic analysis in terms of stability is natural frequency of structure related to frequency of incoming waves. The natural frequency of the rectangular floating breakwater can be simply expressed as [1]:

$$\omega_0^2 = \frac{\rho g A_w}{\rho L B d + \frac{1}{2} L \rho \pi \left(\frac{B}{2}\right)^2} \cong \frac{g}{d + \frac{1}{8}\pi B} \tag{14}$$

, where L,B,d are the dimensions of the floating body, Aw is the effective area of the structure, ρ is the water density and g is the gravity acceleration. The aim is to design a floating structure with significant larger or lower natural frequency than the incoming waves. This is mainly achieved by designing a heavy structure with low natural frequency and high own period T of the structure.

Dynamic analysis

Dynamic analysis is essential for the floating structures, which significantly attenuate incoming waves. Next to dynamic stability, described in previous chapter, damping analysis must be performed. There are several models and approaches for this damping analysis. Structural response is always described by equations of motions for six degrees of freedom: Surge, sway, heave, roll pitch and yaw. Each equation of motion has defined boundary conditions, which are determined by the surrounding environment or anchor system. The mathematical background of the damping analysis is relatively complex and will not be presented in this paper. Dynamic movements and wave attenuation are usually checked by computer programs such as Delfrac or Ansys Aqua.

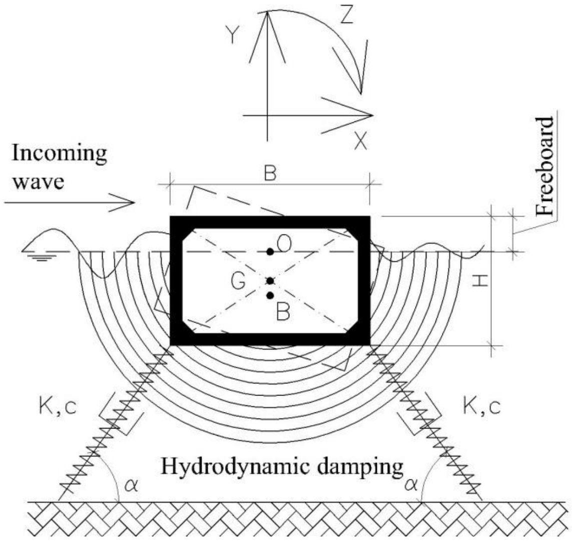


Fig. 6 A rough model for dynamic response of a floating structure.

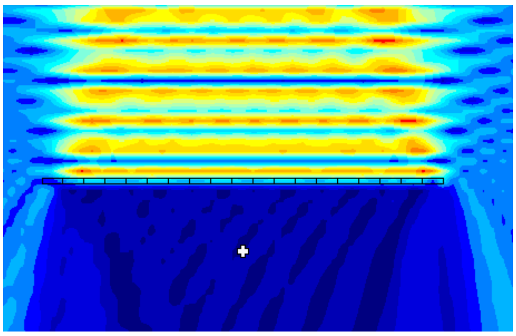


Fig. 7 Computer model in ANSYS Aqua simulating diffraction of the waves coming perpendicularly to the floating breakwater; the yellow contours represent wave height around 4m, the dark blue means damped wave height around 1m.

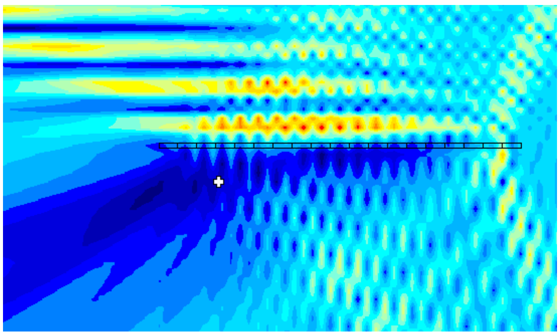


Fig. 8 Computer model in ANSYS Aqua simulating diffraction of the waves coming to the floating elements under angel 45°.

Fig. 9 Laboratory testing of jetty/breakwater structure – investigation of wave attenuation.

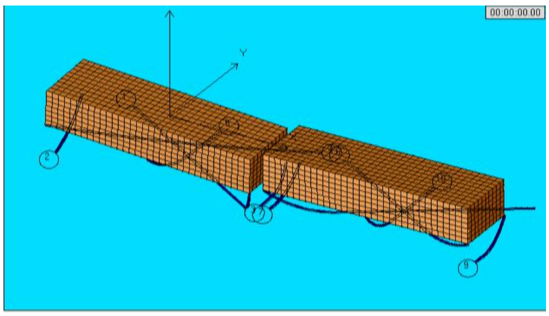


Fig. 10 Dynamic analysis in ANSYS Aqua of two floating bodies anchored to a mooring system.

3.4 Analysis of possible collapse modes

The collapse of the floating structure can be caused by either an insufficient resistance of the main concrete body or anchoring and connection systems. The collapse of a connection or anchor line should not cause progressive collapse. So, extra anchor chains and connections should be applied to prevent this. Also if collapse of a connection should occur the concrete elements should not hit against each other and cause damage. This can be prevented by applying a fender system.

3.5 Anchorage design

There are several types of anchor systems, which have been more or less successfully applied to anchoring floating structures. Floating structures can be anchored stiff using steel piles loaded horizontally (high own frequency of structure system) and high loading on the anchorage or slack anchorage by chains and anchor blocks (low own frequency of structure). The choice of anchorage is depending on the expected wave loading; if this is high a slack anchorage is advised so the total structure can reduce the mooring forces by allowing movement in the water and absorbing the energy instead of reflecting it. Choice of anchorage system thus depends also on the type of structure, local conditions and general requirements of client. The anchor system can be designed as a standard set of heavy-duty steel chains, which are attached to soil by a heavy concrete blocks, ship anchors in the soil or driven steel piles. For less-loaded structures such as floating family houses, a helix anchor can be an option. Several "sophisticated" systems have been introduced on the current market. However, the offered anchor system does not have to be always the best solution for the project and extra analysis is essential. For this reason, an experienced designer with a correct design approach is needed.

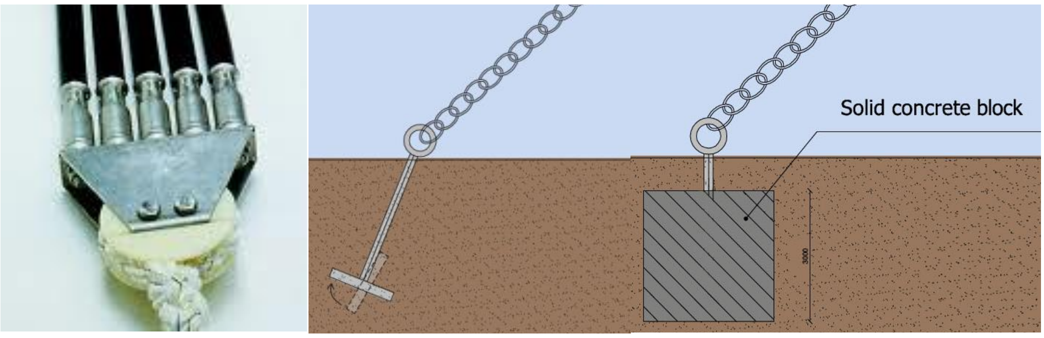


Fig. 11 Examples of mooring/anchor systems (Flexible system –left); folded anchor with chain (middle figure); Concrete heavy block with chain (right figure).

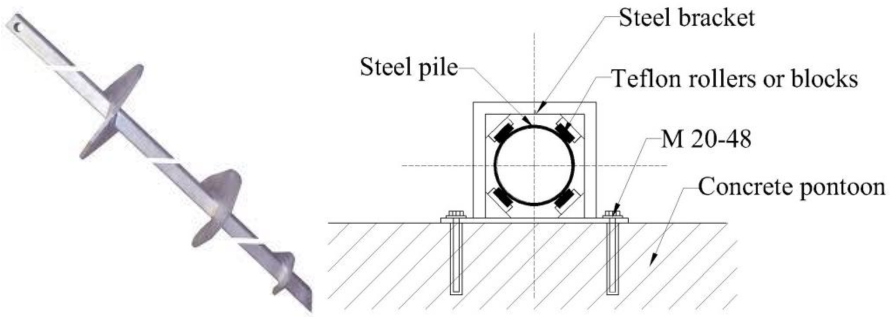


Fig. 12 Helix anchor for light-loaded floating structures (left figure), and direct connection to driven steel piles (right figure).

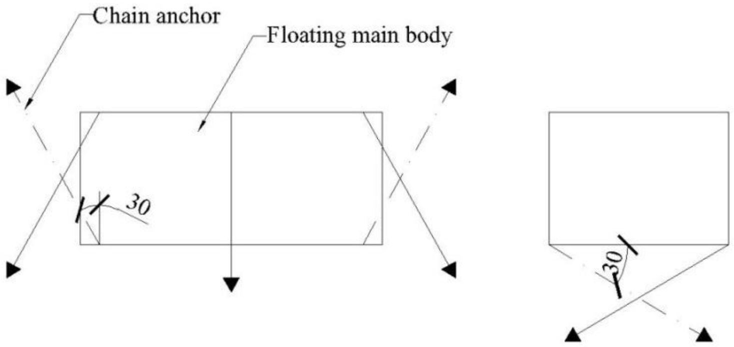


Fig. 13 The basic principle of disposition of anchor chains (right figure).

4 Materials

The most convenient building material for floating structures is concrete. Concrete elements are heavy and robust. These properties are essential for stability and potential damping of the waves in the case of breakwaters. Depending on given assignment and client`s requirements, concrete can be standard, high-strength or ultra-high strength. Standard reinforced concrete (RC-cubic strength up to 90MPa) is used for large floating structures, which need to be heavy and its transportation does not mean a significant problem. Because the environment is aggressive, the minimal cover, amount of cement or detailing must be carefully controlled in order to reach required durability. (see also chapter 3.2)

High-Strength Concrete (HSC – cubic strength 90-150MPa) or Ultra-High Strength Concrete (UHSC – cubic strength 150-250MPa) is convenient in such cases, where application of standard concrete would result in non-realistic dimensions of the structure, problems with transportation or insufficient resistance. Furthermore, UHSC tends to be more watertight and requires smaller concrete cover. In other words, the structure from UHSC is relatively light with large durability and minimal risk of leakage. On the other hand the price of UHSC is several times larger than standard RC. Hence it is necessary to consider all aspects of design.

The floating structures are usually designed as a hollow concrete box. The hollow part is very often filled with Polystyrene blocks EPS15-30, which increase safety against water leakage. If polystyrene is applied, safety is larger and dimensions of the concrete structure can be partly reduced or even some parts can be fully removed. However, the polystyrene should always have a protection layer or coating against deterioration if in an aggressive environment.

5 Structure

The main floating body is usually designed as a massive concrete structure. Depending on functionality and utilization, the structure can be designed in several levels of robustness and stiffness. Three fields of application can be distinguished regarding structural behaviour and level of robustness:

- Breakwater structures
- Floating pontoons and bridges
- Floating buildings

5.1 Breakwater structures

Breakwater structures are supposed to attenuate large waves coming from open sea in order to protect marinas and harbours. A floating breakwater is usually subjected to large waves, which directly hits the side walls and load anchor system and related connections. The whole body must be stiffened by additional internal walls. In order to damp waves properly (by 80% from initial significant wave height), the breakwater must have a large dynamic and static stability. This required behaviour is reached by design of a massive body with additional elements such as horizontal and vertical fins or catamaran arms. For wave heights up to 4.5 m and water depths from 6m onwards floating breakwaters can be economical. In the port of Monaco a floating breakwater has been built to damp 8m height waves with a period of up to 12 seconds.

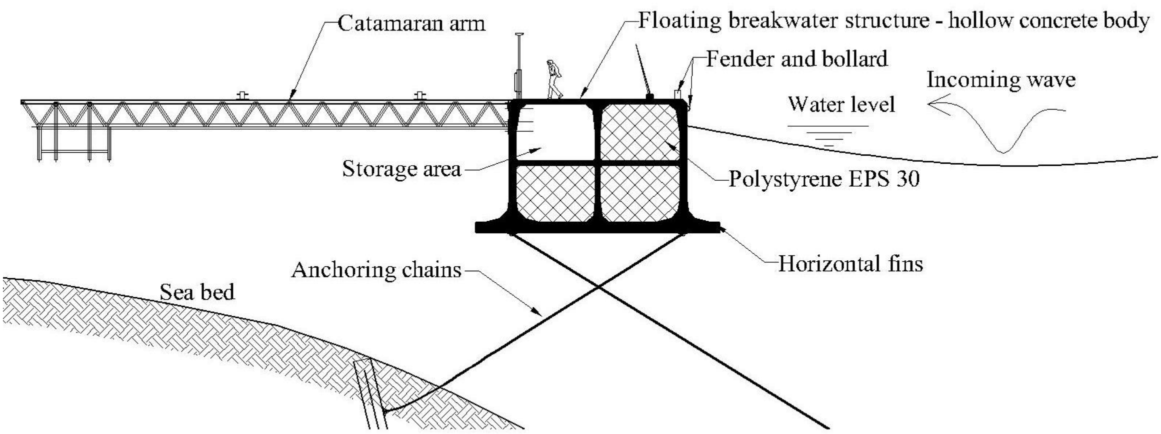


Fig. 14 Typical cross-section of a breakwater structure with a catamaran arm. The study has been carried out by FDN for Gokova Oren marina in Turkey in 2012.

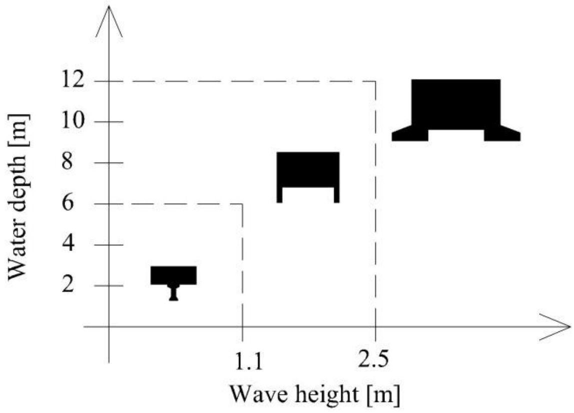


Fig. 15 Applicability of floating breakwater structures depending on wave height and water depth.

Fig. 166 FDN’s concrete U-block floating breakwater applied for wave heights up to 2m (90% damping can be achieved).

5.2 Floating pontoon and bridges

Floating pontoons are typically designed for berthing and mooring ships in marinas and harbours. Dimensions of pontoon are determined by several aspects such as size of berthing vessels, minimal freeboard or minimal surface area of top slab. The floating pontoon can be also equipped with static or movable crane for loading and unloading of the ships. Design is also directly determined by energy of the incoming vessel and related impact force which is transferred through the fender to concrete wall and supporting system.

The floating bridge is mainly loaded in vertical direction due to traffic on the top slab. However acceleration forces can cause horizontal loads as well. The floating bridge, both for pedestrians and cars, must preserve comfort ride or walk, without any sea-like behaviour. In addition, smooth transfer between individual floating elements must be assured by a sophisticated transition sliding plate.

The pontoon is usually not large as the massive breakwaters. Hence support in horizontal direction can be provided by steel piles and sliding steel brackets with Teflon blocks or rollers.

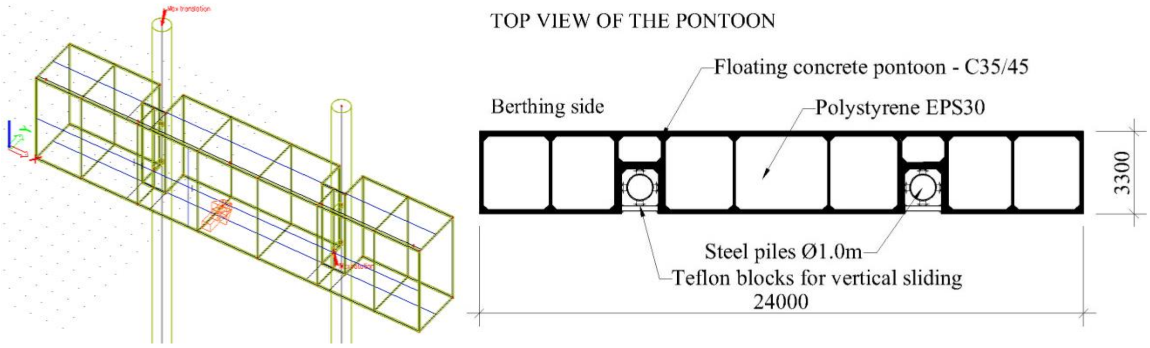


Fig. 17 Computer model of a floating pontoon attached to two driven steel piles (left figure). The vertical sliding is provided by Teflon blocks/rollers, directly fixed on the concrete. This pontoon has been designed as part of large project in Maasbracht, The Netherlands. It has been concluded that concrete pontoons are much cheaper than steel a variant in this case. With rubber fendering collision loads from boats can be absorbed.

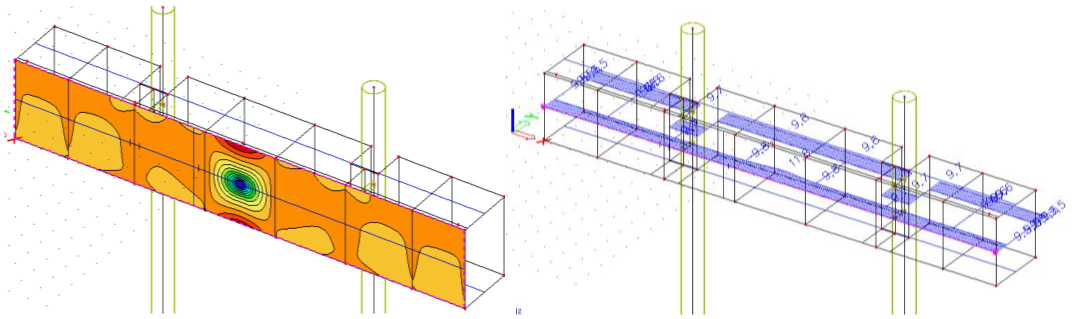


Fig. 18 Computer model of the floating pontoon attached to the steel piles. There are two boundary conditions applied to the model. The first is 2D elastic support defined at the bottom plate of the pontoon. This support simulates hydrostatic uplift pressure as a spring with vertical stiffness 10.25MN/m3. The second boundary condition is linear spring support of the piles. 1D springs simulate soil properties. Sliding connection between the piles and pontoon has been modelled as an interface with relevant degrees of freedom. The left figure illustrates moment distribution in front wall due to impact force form a ship and the right figure illustrates horizontal movement as the response. The obtained values are used for energy-absorption method.

5.3 Floating buildings

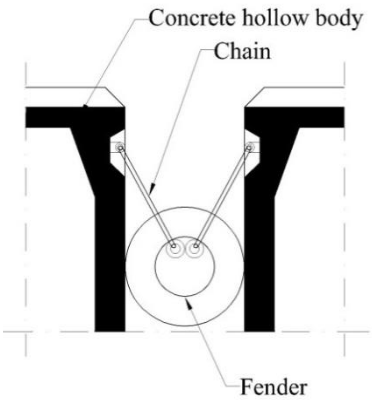
Unlike the breakwaters and sometimes pontoons, design of floating building does not require dynamic analysis. The base of a correct design is mainly buoyancy and static stability check with requirement of maximal rotation angle. The superstructure is rather to be light – steel or wooden structure to prevent a high floating base structure which is limited by the water depth. The floating body can be closed, with a top slab, or open, without a top slab. If the floating body is hollow, the inner part is used as the basement of the building. In the case of self-sufficient building, drainage or sewage system is usually located inside the floating body.

Fig.18 Floating building complex built in Amsterdam, 2001

Fig.19 Impression (left) from research of a building with a height of 60m on a floating base of 90m by 90m and (right) construction of a floating base of 45m by 245m from pre-fabricated elements in a floating dock.

6 Connections

The connections between elements are the weakest point of every designed floating structure. Unlike structures from other material, the concrete elements are heavy and the forces in connections are large. For this reason not all available connection types on current market are suitable. The fixed connection between concrete elements must be very stiff. Suitable solution is implementation of local pre-stressing such as bonded and un-bonded tendons or pre-stressed rods. In the case of hinged connections, stiff rubber or fenders are used.



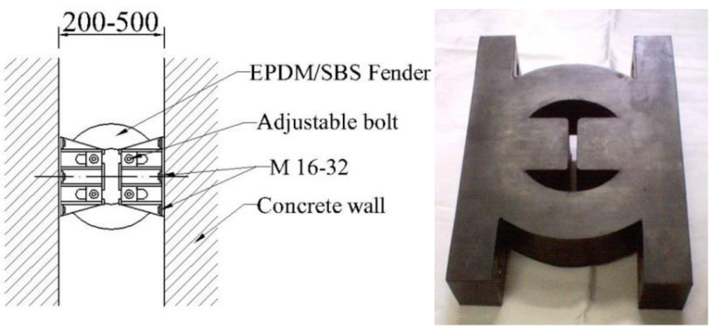


Fig. 20 A solution for flexible connections between the floating elements; the right figure illustrates a special FDN rubber connector.

7 Floating breakwater testing

At FDN we have done many tests in collaboration with several laboratories for floating structures and breakwaters. The main goal of each testing is to correctly evaluate transmission coefficients of wave attenuation, stresses in anchoring systems and connection forces between the elements. The testing of a small-scale physical model should be adequate to simulate real circumstances and results should support theoretical calculations. Laboratory testing with scale models with a minimum of 1:20 is advised.

Fig. 21 Testing of floating breakwaters and jetty in laboratory of hydrodynamics. The testing was conducted for Monaco harbour by Dorris Engineering.

8 Practical application

FDN engineering has around 20 years with design of the floating structures. During this period, FDN had to face several challenging problems in various situations. This experience has showed and proven that concrete floating structures can be applied in large scale in many areas and we would like to promote this for other engineers also to undertake. One of the unconventional applications is a floating protection against debris. The assignment was given by Shell chemicals BV, Rotterdam. The task was to provide a design for a protection of cooling intake system against debris coming from the watered area. FDN developed an effective system of floating concrete hollow blocks, which would prevent unintended accumulation of debris at the intake sieves. The concrete blocks are easy to build and install.

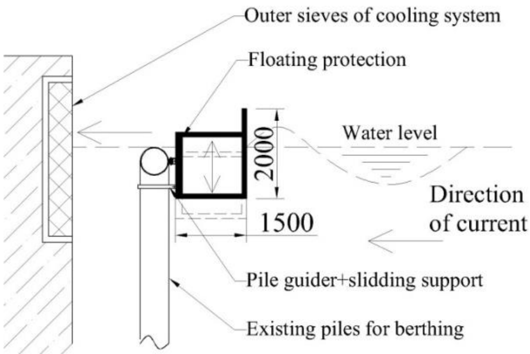


Fig. 22 Solution for protection of cooling system for refinery. Floating elements prevents accumulation of debris at the sieves.

Fig. 23 Current situation at the sieves of cooling system. In the period of floods, the whole area is full of debris and water circulation in cooling system is restricted.

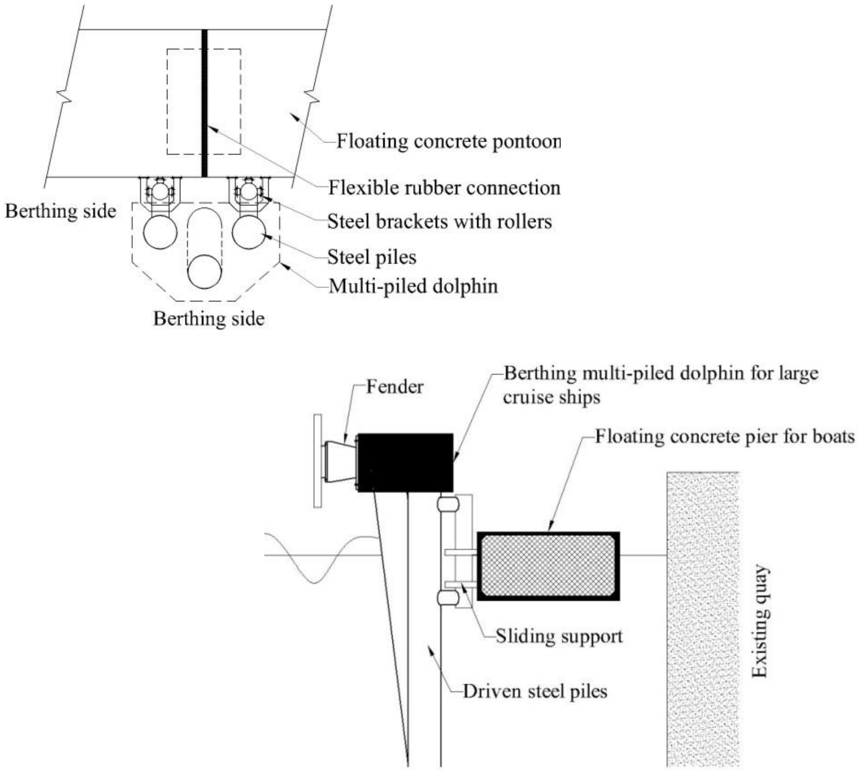


Fig. 24 Another application for floating structure is berthing system for a cruise terminal. This structural combination of floating pontoon attached to dolphins enables berthing both large cruise ships and small boats. This concept has been carried out for a cruise terminal Oslo, Norway.

9 Possibilities of floating structures

The floating structures have a wide range of application and its potential for even larger applicability brings a future importance of these structures. The floating structures can be divided into several areas of use:

- Floating houses and utility buildings, combined to floating cities

- Floating pontoons for marinas and harbours
- Floating infrastructure
  - Bridges
  - Roads
  - Tunnels
  - Airports
- Floating breakwaters
- Floating offshore industry
  - Oil&gas
  - Green energy production

Examples of applications:

Fig. 2519 Mega-float airfield, Tokyo, Japan [3].

Fig. 26 Floating road, Hedel, The Netherlands [5]; the floating element are made from aluminium, but concrete is an option.

Fig. 27 Floating tunnel, HogSWjord, Norway [4].

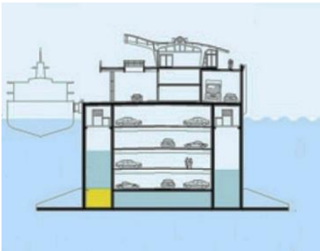


Fig. 28 Floating jetty with parking garage, Monaco, Head engineer Dorris.

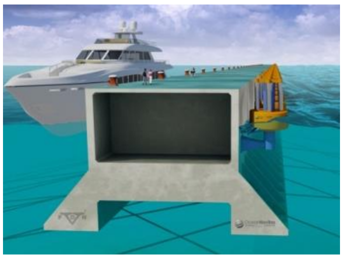


Fig. 29 Floating breakwater with wave energy converter, FDN design.

Fig. 30 Murrow Memorial Floating Bridge, USA [6].

9.1 Production of "green" energy

FDN has introduced a breakthrough idea related to "green" energy production. The idea is to create an offshore farm, which would effectively combine generation of electrical energy obtained both from the classical renewable sources (wind, sun) and the wave energy. In order to reach this goal, FDN developed a Wave Energy Converter, which is capable to effectively produce large amount of energy from the sea waves. The floating converter, attached to an appropriate floating structure, can be for example combined with existing wind mill off-shore farms, using the same grid connection, or it can be combined with floating solar plants. The purpose is to satisfy increasing demand for renewable energy, together with development of a new profitable market sector.

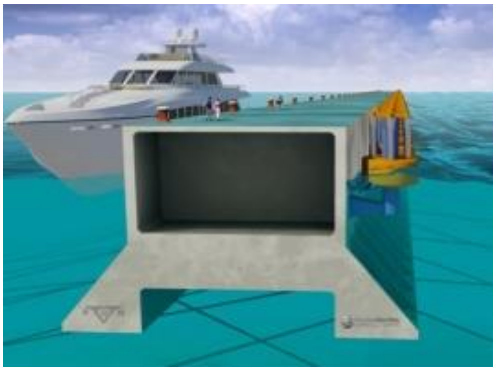


Fig. 3120 Illustration of breakwater structure combining production of energy from attached converters.

Fig. 32 Testing of a pilot device in a laboratory.

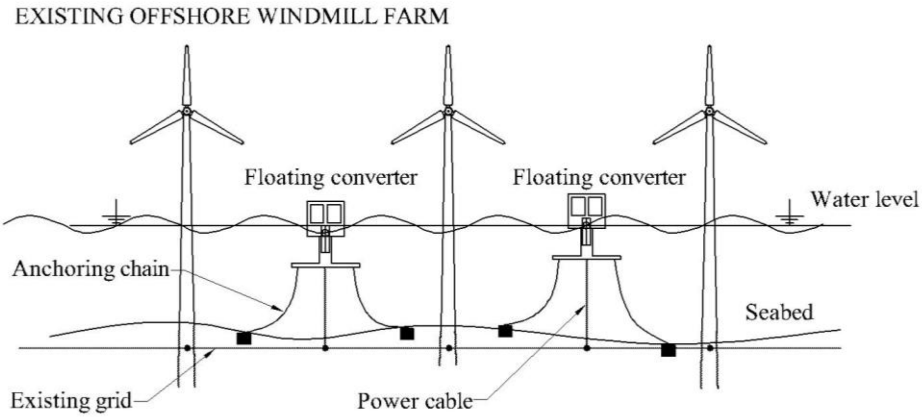


Fig. 213 Floating devices attached to a floating structures, connected to existing grid of a windmill farm.

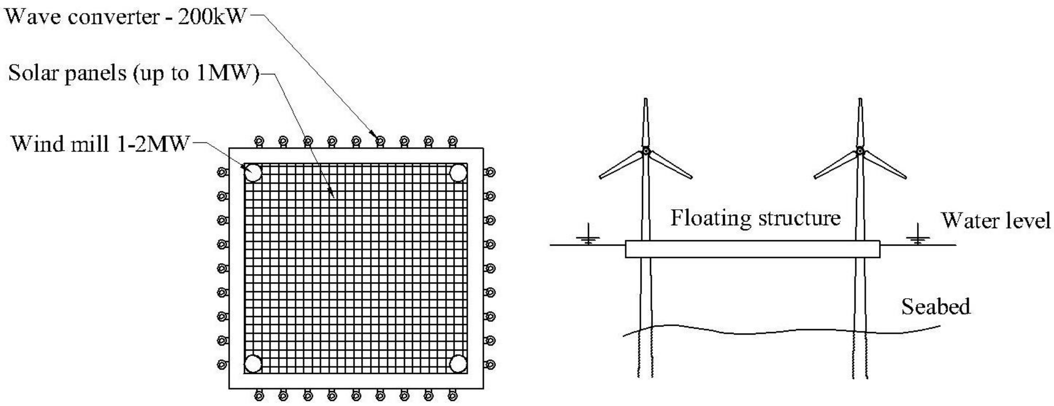


Fig.34 Floating device combining production of energy from waves, sun and wind.

10 Conclusions

The concrete floating structures are structures with its special design and construction specifics, but an area which is certainly a new frontier for traditional concrete designers willing to explore the sea. The concrete floating structures can reach a wide-scale application in many areas such as industry, living and urban planning if positively backed up by also politicians who have long term goals in view for their societies.

11 Information

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12 References

[1] **Maarten Koekoek**
Master Thesis –Appendices – Connecting Modular Floating Structures, Delft University of Technology, September 2010, The Netherlands

[2] **M.W.Fousert**
Final report of the master thesis - Floating Breakwater - Theoretical study of a dynamic wave attenuating system; Delft University of Technology; Faculty of Civil Engineering and Geosciences; Section of Hydraulic Engineering; Delft, 2006; The Netherlands

[3] **Ministry of Land, Infrastructure and Transport of Japan**
http://www.mlit.go.jp/english/maritime/mega_float.html;

[4] http://tunneltalk.com/Strait-Crossings-Jan10-Conference-report.php

[5] www.skyscrapercity.com

[6] http://en.wikipedia.org/wiki/Lacey_V._Murrow_Memorial_Bridge