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A Study on the Connector of Floating Platform based on Concrete Structures

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콘크리트 구조물 기반 플로팅 플랫폼 연결에 관한 연구

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Abstract : *This study is about the connector of the floating platform in order to ensure safety due to various climate changes. The purpose of this study is to recommend the connector model of floating platform based on concrete structures after reviewing the literatures related in establishing floating structure in case of various climate changes in domestic coast. This study introduces the concept generation, existing model, detailed design and evaluation including current and future development of the technologies of marina floating platform connector based on concrete structures. The results from the research show that the analysed connector design (Rigid Pontoon Connector) provides a highly efficient and practical solution to facilitate connection of stable floating platform.*

Key Words : *Various case, Rigid connector, Pontoon, Concrete, Floating platform*

요 약 : 본 연구는 다양한 기상변화에 따른 안전을 확보하기 위한 해상에서의 플로팅 플랫폼의 연결에 대하여 연구하였다. 본 연구의 목적은 다양한 해상변화가 일어나는 연안역에 설치되는 플로팅 구조물에 관한 문헌 조사를 실시한 후, 콘크리트 구조물 연결하는 모델을 제시하는 것이다. 본 연구에서는 플로팅 구조의 개념, 기존의 모델, 설계적 평가를 포함한 콘크리트 구조물 기반 플로팅 플랫폼을 기술하였고, Rigid Pontoon Connector를 국내 연안역에 적합한 모델로 제안하였다. 연구의 결과로서, 리기드 폰툰 커넥터 디자인은 (Rigid Pontoon Connector) 안정적으로 플로팅 플랫폼의 연결을 구축할 수 있는 매우 효율적이고 실용적인 솔루션으로 분석되었다.

핵심용어 : 다양한 사례, 리기드 커넥터, 폰툰, 콘크리트, 플로팅 구조물

1. Introduction

Floating structures depend on the buoyancy force in order to reduce the reaction force. It may be categorized as either pontoon-type or the semi-submersible type. structures can be joined together to make a larger overall working surface such as floating bridges, floating platforms and several floating platforms. Floating platforms are used to create ship-to-ship, ship-to-shore as well as shore-to-shore links. However, the major technical problems for constructing the floating platforms lie in the connector design having difficulties of relative motion between the floating platforms in case of rough seas. Floating structures divided into pontoon type and semi-submersible type. A concrete pontoon system is the most cost-effective solution. In this study, we reviewed the several patented floating platform designs which provide the solutions of connecting two pontoons in water. Also, this study suggested applicable floating concrete platforms in water. Current and future development of the floating concrete technologies are discussed and potential applications are illustrated.

2. Fundamental Requirements

Basically, an ideal securing systems have the capabilities such as self alignment, impact attenuation, rigid engagement, self fastening, and adequate strength. It should facilitate the joining of two

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floating platforms in rough water with minimum effort in the shortest time. Safety and cost saving are the other two main considerations. The system once interlocked should provide a stable working surface and survive in rough seas without any structural damage. The characteristics of concrete in preference to steel. Of all types of concrete, reinforced concrete and pre-stressed concrete types are analyzed as follows.

2.1 Reinforced concrete

Reinforced concrete is found inside steel armour, properly calculated and placed. This concrete is able to withstand compressive forces and traction. The tensile stress of steel reinforcement is resisted by reinforced steel. Reinforced concrete has far fewer maintenance requirements than steel, if properly executed. However, if the tension is increased, the concrete develops cracks over time, which may cause the rebar to rust. In addition, tension limits restrict its range of applicability in shipbuilding, especially in the structures. Floating structures are constantly subjected to tensile stresses. Given the yield strength of steel on top of concrete, withstanding a given load requires much more concrete than steel in terms of volume. Even if the concrete has a lower density, this translates into heavier components, roughly a factor of two or three times more weight than that of standard concrete (Hoogendoorn, 2011). Even so, the cost per weight of concrete is much cheaper than steel, so the concrete structure would have a lower cost.

2.2 Pre−stressed concrete

Pre-stressed concrete has special steel reinforcement under tension inside, which yields much higher tensile stress than normal concrete. Although it superficially resembles, but it should be considered as a different material. It may be categorized as follows. Pre-stressed if the armour has been tightened before placing fresh concrete. Post-stressed if the armour is stressed after the concrete has gained strength. In pre-stressed concrete steel tensioning supports all loads, and the concrete role simply completes protection against corrosion and as a non-thermal link (non-thermal bond) for steel.

The concrete connections are typically based on the principle of embedding steel within the concrete behind the reinforcing steel layers, so that the elements are part of the structure. To achieve enhanced subsequent layers, dowels, steel rods or the like can be used. Examples of concrete connections are the connections between the hull and the topsides, guides and mooring and towing consoles, support pipes, supports for roofing elements (Sandvik et al., 2004).

There are several specific industry regulations for the design of concrete platforms. These include (Holand et al., 2003).

- Government Rules: in the US, UK and Norway who apply them in their territorial waters.
- Regulatory standards: Canadian standard, ISO, Norkse standard (with NS 3473 concrete structures).

Main standards for the design, construction and in service inspection of structures.

A floating concrete structure shall be planned in such a manner that it can meet all requirements related to its functions and use as well as its structural safety and durability requirements. (Fernandez and Pardo, 2012) In order to have sufficient safe basis for the engineering, adequate planning shall be done prior to the actual design is started. Also, workable and economical structure can fulfil the required functions. The initial planning shall include determination and description of all the functions the structure shall fulfil, and all the criteria upon which the design of the structure are based. Site-specific data such as water depth, environmental conditions and soil properties shall be sufficiently known and documented to serve as basis for the design. All functional and operational requirements in temporary and service phases as well as robustness against accidental conditions that can influence the layout and the structural design shall be considered.

All functional requirements to the structure affecting the layout and the structural design shall be established in a clear format such that it can form the basis for the engineering process and the structural design.

Investigation of site-specific data such as seabed topography, soil conditions and environmental conditions shall be carried out in accordance with requirements of classification societies.

Since concrete is very resistant to salt water and keeps maintenance costs low, floating concrete structures have become quite attractive for oil and gas industry in recent decades.

Temporarily floating platforms such as Condeep float during construction and towing, but are finally placed on the ocean floor. Permanently floating concrete structures were used in the discovery of oil and gas deposits for production, storage, offloading units and in some cases as a system of heavy lifting.

3. Review of Patented Designs

There are several patented designs providing solutions for connecting two pontoons in water. The following patents are of detachable pontoon connecting devices. They are reviewed based on the aforementioned fundamental requirements.

1) Aurele(1931) introduced a pontoon connection design (Fig. 1), which consists of two top-down protruding bars and two coupling recesses between the adjacent pontoons as well as two steel strips running across the joined platform to connect the pontoons.

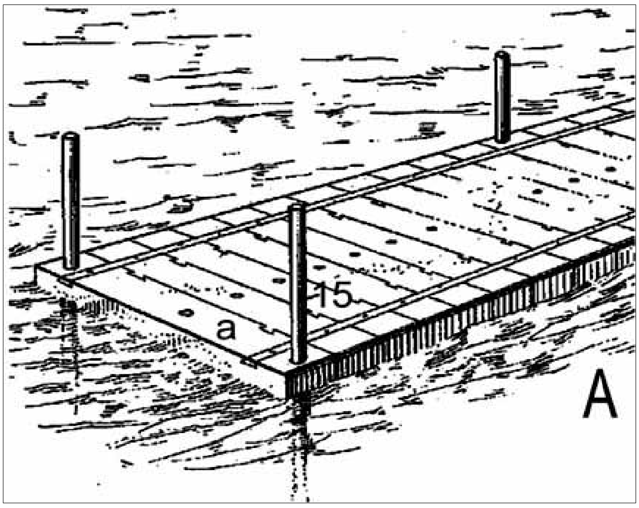

Fig. 1. Aurele's design.

The shear strength of the platform is provided but also limited by the relatively thin steel strips. As the steel strips are only applied on the deck, the design potentially has poor strength against sagging of the platform in wave. Depending on the size and weight of the pontoon module, a floating crane may be required to lower the module from top to bottom over the pontoon height. Although the connection is designed to be rigid, the result often depends on the tolerance control of the pontoon connectors. It is suitable for calm water only. There is no impact damping or self fastening capability in the design.

2) Gardner(1965)'s pontoon connector design consists of a male and a female coupling members on the side adjacent to another pontoon in order to align the two pontoons, as well as an elongated connecting member fitting into a recess on the adjacent pontoon and locking them in place (Fig. 2). The connection is meant to be a rigid type. The shapes of the coupling members do not provide much self-alignment capability and therefore they can be easily damaged due to hitting in wave motion. As a result, the joining process would take longer time. The elongated connecting member can be designed to bear high tension and bending moment between adjacent pontoons using I-shape.

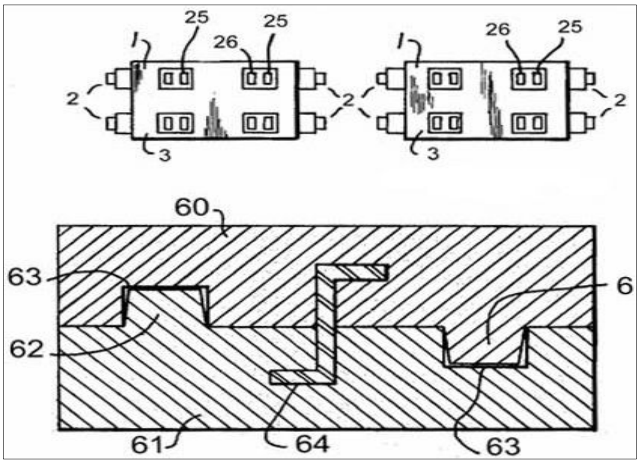

Fig. 2. Gardner's design.

Theoretically it can lock both the top and bottom of the connector together to form a rigid connection. Practically, however it is hard to achieve because of tolerances of components and assembly as well as relative tolerance between connectors. Even if the joining of the pontoons can be done by loosening the tolerances, the tension/compression forces of the connecting members would be uneven and therefore unpredictable. Noise would be generated due to the poor tolerance. There is no impact damping or self fastening function. Relative movement between pontoons would be practically unavoidable.

3) Armin(1970)'s pontoon connector design consists of two male and two female coupling members (placed diagonally) on the side adjacent to another pontoon in order to align the two pontoons, as well as a detachable locking pin as a vertically-oriented latch to lock the upper male and female coupling members after engagement (Fig. 3). As the locking pins are placed only on the deck level for manual operation, the lower edges of the joined pontoons tend to open up in sagging condition. Tolerance control for the locking pin"s holes position and the overall platform assembly is very crucial. There is no impact damping or self-fastening or self-alignment function in the design. The male coupling members would likely be damaged during connection operation in choppy sea.

4) Bargeco(1985) introduced a pontoon system which has the outer dimension corresponding to those of a standard freight container. The pontoons are interconnected by male and female coupling members.

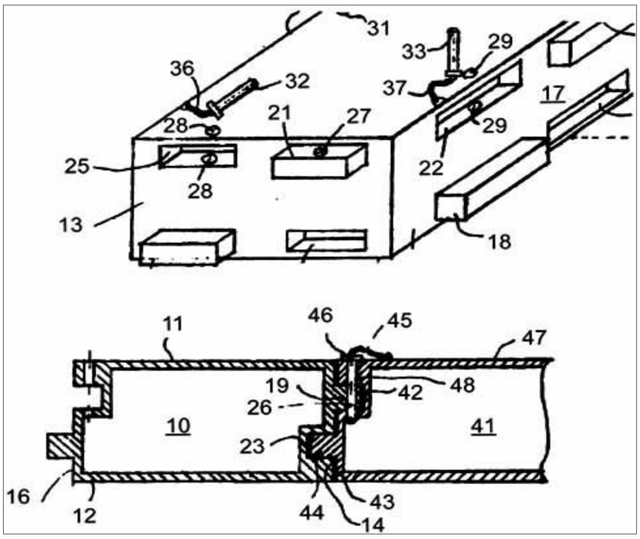

Fig. 3. Armin's design.

The coupling members can contact with a wedge engagement, with one or both couplings provided with locks (Fig. 4).

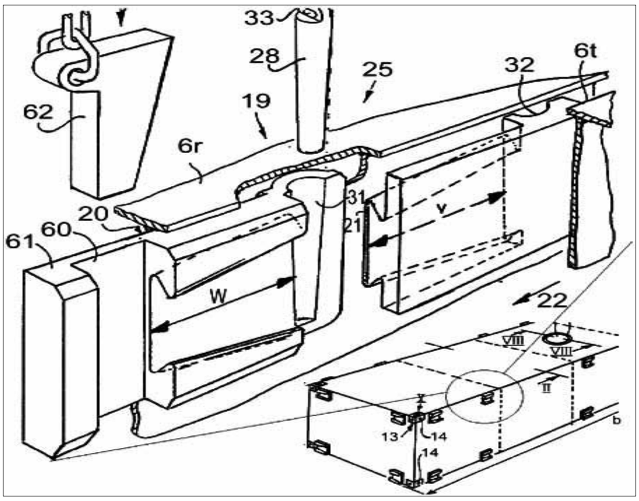

Fig. 4. Bargeco's design.

A series of the floating pontoons positioned at the same level can be interconnected with their upper and lower edges by the couplings. There is no impact damping or self-fastening in the design. Due to limited self-alignment capability, this design is only suitable for calm water operation. Apparently, it has limited tensile strength and demands high tolerance control for the assembly.

5) Willy(1986) designed a joining system for pontoons, which can be joined to form a pleasure craft. The joint consisting of a male and a female coupling column, extends over the height of the pontoons (Fig. 5). When the craft is floating, the pontoon can be inserted or taken out by sliding the parts parallel to each other from top to bottom or bottom to top over all their height. Due to the way of assembly, a floating crane is required for offshore operation.

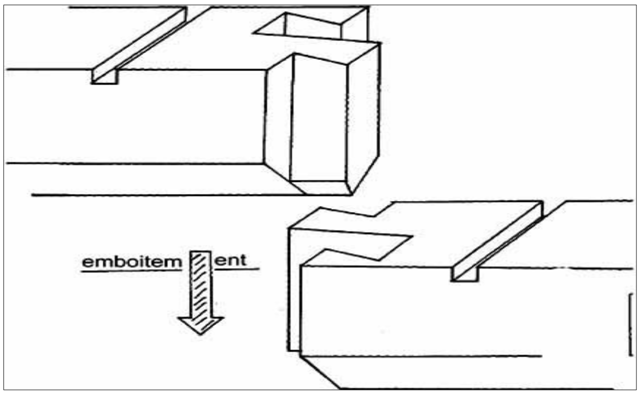

Fig. 5. Willy's design.

This method is only in applicable for small, light weight pontoons and operation in calm water. The male and female coupling does not provide shear constraint/strength. To prevent the pontoons from movement in vertical direction, plate-like transverse links are required to fit on the deck of the pontoons. As a result, the shear strength is limited by the thickness of the links. There is no impact damping or self-fastening in the design.

6) Zwagerman(1988) introduced a constructive assembly comprising separate assembly parts with side-projections and corresponding side-recesses. Moreover, the assembly parts comprise cooperating recesses at their top for accommodating coupling elements for holding together assembly parts (Fig. 6). Although I-shape or "dog bone" like locking bar is meant to be strong, because it is only placed at top lever, it does not contribute to the securing strength in case of platform sagging in wave. Moreover, the connection needs one of two mating pontoons to be listed outwards so that the lower protruding surface can be raised high enough to slot down into the recess of the adjacent pontoon. Practically, it would be difficult to pull 2 pontoons together when one must be listed outwards. Due to the lack of end-to-end connection, the longitudinal bending and tension can not be transmitted smoothly over the pontoons. The load path is not continuous. Therefore the longitudinal strength is limited. Ballasting to list a pontoon is a must. It consumes time and resources like water pumps or floating crane to shift deadweights.

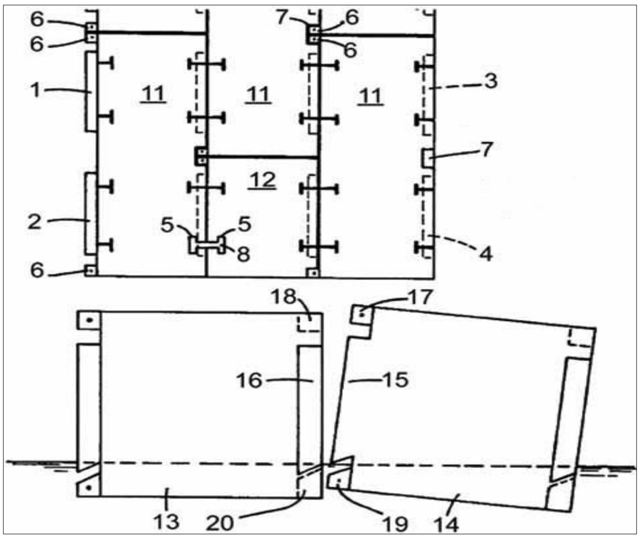

Fig. 6. Zwagerman's design.

No self-tensioning is provided. The design also demands high tolerance control over large area of protrusion/recess which would increase the manufacturing cost. To disconnect the pontoons, tug boats or winches may be required during which the ballasting control would be more difficult. No impact damping or self-alignment is catered in the design.

7) Au-Yeong and Tan(2005) invented connector assemblies for floating sections/pontoons. It consists of two housings respectively mounted on the mating sides of 2 adjacent pontoons and one movable connector element (i.e. rectangular rigid frame). By shifting the connector element from one housing to the other so as to be captive in both and securing the element by horizontal latches at top and vertical pins at bottom (Fig. 7), the connection between the two sections/pontoons is established. This design lacks self-alignment, impact attenuation and self-fastening. It is meant to be rigid connector. However, due to relative motion of pontoons and installation tolerances of the connectors, in order to latch all the connector elements with their housings, the tolerance between the latch pin and latch hole has to be large enough (e.g. 24 mm) for higher chance of success of the engagement. Such an unavoidable large tolerance results in loose connection in which the latch pin and holes could hit each other periodically causing fatigue issues. Moreover, this loose connection generates metal hitting noise and creates gap movements and changing levels between pontoons (e.g. 24 mm).

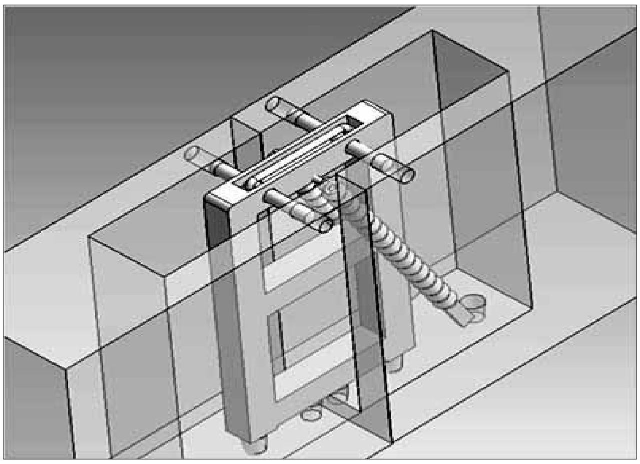

Fig. 7. Au-Yeong's design.

8) Han's design : A new innovation Frictional Locking Connector has been developed by Hann-Ocean to eliminate the bottom-opening scenarios so as to provide complete secured connection between pontoons (Han, 2006). The Frictional Locking Connector is a rigid pontoon connector (Fig. 8). It has two coupling parts namely Coupling Part I and Coupling Part II, one each on one of the two adjacent pontoons. The Coupling Part I include a downwardly directed receiving recess that has at least one bearing surface facing away from a plane of abutment of the two pontoons. The bearing surface increases in distance away from the plane of the abutment from top to bottom. The Coupling Part I also have two Locking Bars to be retained by the Coupling Part II in a manner to allow it to move vertically and to project from Coupling Part II for engagement with the Coupling Part I. Each Locking Bar includes a receiving surface to abut with the bearing surface. The relative movement of the two pontoons together causes the locking bars to drop down the receiving recess.

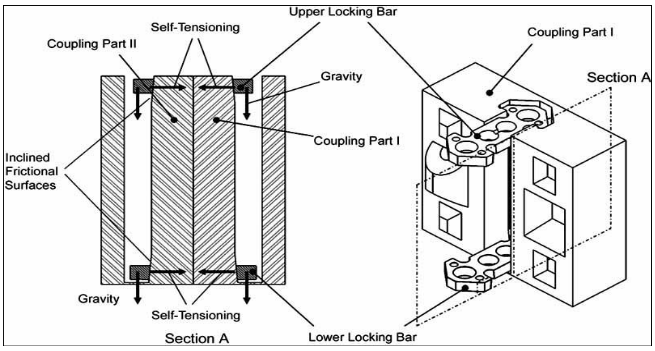

Fig. 8. Frictional Locking Mechanism for Connector.

3.1 Characteristics of Floating Structures

Systematic calculations of the effects of cross-sectional shape of each module and its arrangement on wavebreaking efficiency are needed to design the optimum floating structure. (Park and Park, 2001) Floater by a wave incident from the x-axis forward sway when considering ω harmonic motion at a frequency, floating around this time of the flow field of the velocity potential can be expressed

$$\phi(x,y,z,t) = Re[\phi(x,y,z)e^{iwt}]) \quad (1)$$

ϕ satisfies the Laplace equation in the fluid inside, free surface boundary conditions, radiation condition, meet the conditions and the boundary conditions of the object's surface and spoon condition.

Velocity potential can be expressed as follows.

$$\phi = \phi_0 + \phi_7 + i\omega \sum_{j=1}^{6} \xi j \psi j \quad (2)$$

from here,

$$\phi_0 = \frac{g\zeta_a}{\omega} \frac{\cosh\kappa(z+h)}{\cosh(\kappa h)} e^{kz + ik(xcosa + ysina)} \quad (3)$$

$g\zeta_a$: frequency

κ : wave number

g : acceleration gravity

ξ_j : floating motion amplitude (j=1,...,6)

ϕ_0 : incident wave speed

ϕ_Υ : diffraction speed

ψ_j : floating unit of j direction through amplitude motion radiation potential (j=1,...,6)

In addition, ϕ each of speed potential which satisfies the boundary conditions if release Green function G (x, y, z, x', y', z') for the solution of the Laplace equation, following is indicated.

$$\phi(P) = \iint_s \sigma(Q)\, G(P,Q) dS(Q) \quad (4)$$

from here, P (x, y, z) random points of fluid, Q (x', y', z') is object surface (S) on the distribution location of Source, $\sigma(Q)$is from the point of Q location strength of source, G (P, Q) is expressed by Green function.

$$\frac{G(P,Q) = \frac{1}{R} + \frac{1}{R'} + 2\int_0^\infty (\mu+K)e^{-\mu h}\cosh\mu(z+h)\cosh\mu(z'+h)\Upsilon_0(\mu\Upsilon_1)}{\mu\sinh\mu h - K cosh\mu h} d\mu \quad (5)$$

from here,

$$K = \kappa\tanh(\kappa h)$$
$$R_1 = \sqrt{(x-x')^2 + (y-y')^2} + (z-z')^2$$
$$R_1' = \sqrt{(x-x')^2 + (y-y')^2} + (z+2h+z')^2$$
$$\Upsilon_1 = \sqrt{(x-x')^2 + (y-y')^2}$$
$$J_0 = 0 \; zero\ order\ of\ type\ 1\ Bessel\ function$$

In order to find the $\sigma(Q)$ of source strength using object surface, differential expression both sides in the direction of the normal of the object surface S when approach a point P on the object's surface (S) to the point Q on the integral of the unknown, the following equation is derived.

$$\frac{\delta\phi(P)}{\delta n} = -2\pi\sigma(P) + \iint_s \sigma(Q) \frac{\delta}{\delta_n} G(P,Q) ds(Q) \quad (6)$$

Expression point P (x', y', z '), Q (x', y ', z') is the on the point object's surface (S). Integral is applied for the object surface S. If substitute $\sigma(Q)$ which obtained from expression, can find the $\phi(P)$ of potential.

3.2 Application of Floating Concrete Structure

RPC works on gravity-induced static friction. Each pair of RPC comprises 2 Locking Keys (Upper and Lower), 8 Diamond Cups, 4 Diamond Stoppers and 8 Locking Pads. Among them, the Locking Keys are designed to bear tension forces (up to 100 ton each) and Locking Pads take compression loads (up to 85 ton each).

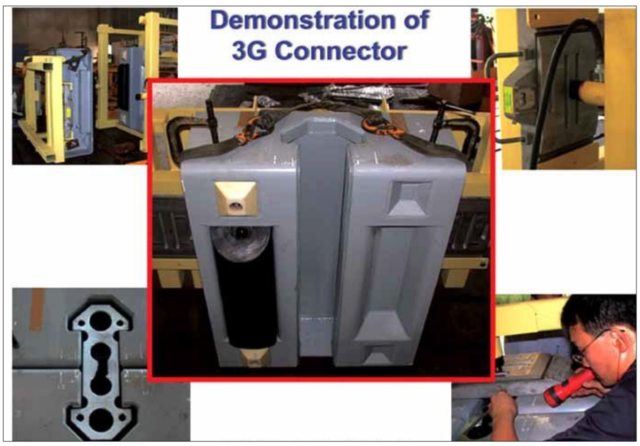

Fig. 9. 3G Connector based on prototype.

The design concept can be used for many application in water space utilization as well as offshore engineering (Fig. 9).
The following applications of Rigid Pontoon Connector which is suitable for permanent structures with expected lifespan of 30-50 years with minimal maintenance and superior stability (Fig.10).

Related applications include (Hann-Ocean, 2013) :
- Transformable Floating Entertainment Hub (TFEH)
- Floating Oil & Gas Production and Storage
- Floating Breakwater
- Floating Homes
- Marina Jetty
- Offshore Renewable Energy Production platform
- Mega Cruise Terminal
- Floating Stadium
- Port Facility

Fig. 10. Transformable Floating Entertainment Hub (TFEH).

4. Recommendation and Suggestion

Analysis of advantages of connectors which can be suggestion for using connector. Rigid connector is a new generation of pontoon connector with outstanding performance in both dynamic and static conditions. The combined advantages can be summarized as follows:

Higher Safety. The design offers superior strength by eliminating bending stress in the components. It also provides rapid self-alignment to speed up the operation and reduces impact-induced vibration for structural and operator safety.

Better performance. The design minimizes the relative movements between pontoons using static frictional locking. The structure configuration of the RPC provides excellent rigidity for the connector. It has self-fastening feature utilizing the pontoon movement in wave and gravity effect on the locking keys. It is a silent device as there are no moving parts in the connector once the engagement is stabilized. It is robust because there are only 2 movable parts locking keys, which are made of solid metal.

Easier Installation/Operation. The design caters for 5-10mm allowable tolerance for the assembly and installation without affecting the performance. The design employs a "Drop-n-Work" operational concept using light weight locking keys (20-25kg each). The connection and disconnection can be performed manually and easily without tools.

Low Life Cycle Cost. The simple mechanical configuration of the connector reduces the initial investment. Minimum maintenance is required as the frequently contact/bearing surfaces are made of non-metal material or stainless steel. The connector platform and locking keys are designed to survive in sea water for 20 years in Sea State 4 without any replacement.

5. Conclusion

This study introduced about the concept generation, model, detailed design and evaluation including current and future development of the technologies of marina floating platform connector based on concrete structures. There are several designs on floating platform securing device are applied after reviewing in terms of Aurele, Gardners, armin, Bargeco, Willy, Zwagerman and Au-Yeong. These patented devices utilize male and female coupling pairs, fitting and locking members to secure floating bodies or pontoons to each other. However, the coupling pairs are rigid by design and they can cause significant impact loading on each other particularly while the engagement process is not completed. None of them has the constant self-fastening capability to always secure the pontoons tightly. Some of them have no or limited self alignment capability for pre-connection. The relative motion of the joint pontoons depends largely on the tolerance of individual parts as well as installations of connectors. But rigid connector (RPC) design provides a highly efficient and practical solution to facilitate the construction of stable floating platform in rough water. The design concept can be used for many applications in water space utilization as well as offshore engineering. For economical reason, concrete floating platforms in many applications are even more attractive to the end users.

Rigid connection (RPC) has key advantages. First, it has firm engagement with self-tension. Second, it is simple yet robust that only one pair of movable solid keys for superior strength. Third, it is a ‘Drop-n-Lock’ feature which means 20 seconds to join with self-alignment feature. The RPC applies a 'Drop-n-Lock' working concept. To engage the connectors, the lower locking key and upper locking key can be lowered by hands respectively into the U Channel. As the lower locking key is slightly longer than the upper locking key, it can go all the way down and engage with the lower locking pads when the upper locking key can only stay on top and engage with upper locking pads with friction on a sloped surface.

As results from research, rigid connector (RPC) design provides a highly efficient and practical solution to facilitate the construction of stable floating platform in rough water. RPC is a mechanical connector designed to join floating modules or modular pontoons together rigidly in the water even in rough seas. As different components of the RPC bear different loads respectively and independently, the RPC is capable to withstand large loads using little material. This connector clearly shown that the suggested connector can be used for many applications in water space utilization.

Acknowledgment

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