Securing of Marine Platforms in Rough Sea

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Abstract: Marine platforms such as pontoons or barges often need to be joined together to create a larger overall working surface such as a bridge, a floating base or a floating causeway. This paper discussed the key technical challenges of joining such platforms for constructing large floating platforms in rough seas. Nine relevant patents on pontoon connector designs are reviewed. A novel design concept is introduced, which consists of Han's patented Fender Connector [1] and Frictional Locking Connector [2]. The design concept amalgamates the multiple functional requirements, such as rapid self-alignment, impact attenuation, self-tensioning, rigid engagement and superior strength into an integrated design. The engineering process from concept generation, model testing, detailed design and evaluation, material selection, prototyping and sea trials are presented. Current and future development of the technologies are discussed. Potential applications are illustrated.

Keywords: Pontoon, floating platform, securing device, connector, assembly of floating modules.

INTRODUCTION

Joined platforms at sea can be used as floating bridges or causeways to create ship-to-ship, ship-to-shore as well as shore-to-shore links. However, the key technical challenges for constructing such joined floating platforms lie in the connector design which must address the difficulties related to the relative motion between two floating platforms, particularly during the connection process in rough seas. The connector design must also be able to sustain the dynamic forces as a result of the wave motion during both the connecting process as well as after the connection has been established.

The relative vertical motion of two steel platforms with size of 40m x 7.8m x 1.6m in choppy sea (with wave height of 0.3~0.4m) can be more than 0.5m (as has been observed during sea trials. In such a condition, it is very difficult for an operator to judge exactly when the two platforms are aligned in order to secure the platforms together manually. It is also very dangerous for the operators working at the edges of the platforms as the platforms not only move up and down but this platform can also knock against each other. Such violent motion can potentially cause serious or fatal injuries to operators who may lose their balance and fall into the gap between the two platforms.

FUNDAMENTAL REQUIREMENTS

Fundamentally, an ideal pontoon securing system should have the following capabilities:

- Self-alignment
- Impact attenuation
- Rigid engagement
- Self-Fastening
- Adequate strength

It should facilitate the joining of two 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.

REVIEW OF RELEVANT PATENTS

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 [3] introduced a pontoon connection design (see 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. The

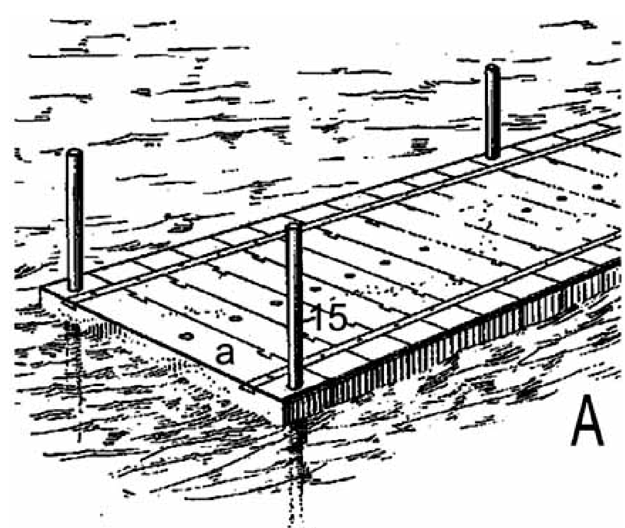

Fig. (1). Aurele's design.

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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's pontoon connector design [4] 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 (see 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. 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.

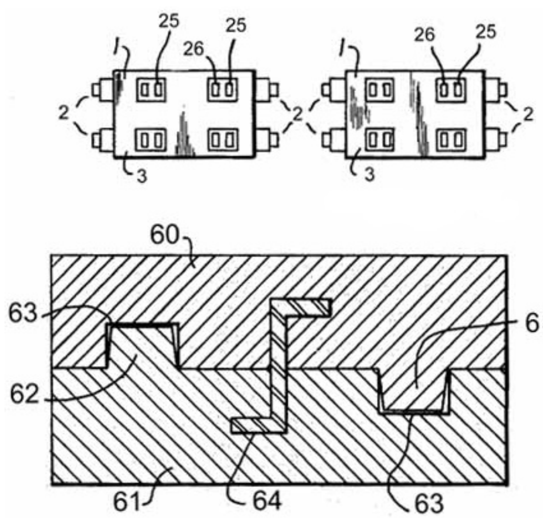

Fig. (2). Gardner's design.

3). Armin's pontoon connector design [5] 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 (see 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.

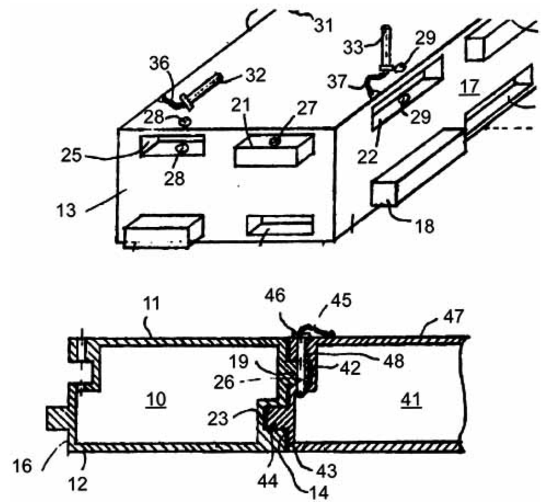

Fig. (3). Armin's design.

4). Bargeco introduced a pontoon system [6] which has the outer dimension corresponding to those of a standard freight container. The pontoons are interconnected by male and female coupling members. The coupling members can contact with a wedge engagement, with one or both couplings provided with locks (see Fig. (**4**)).

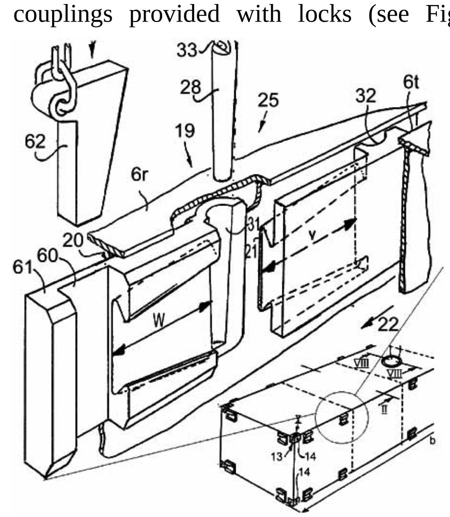

Fig. (4). Bargeco's design.

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 claim water operation. Apparently, it has limited tensile strength and demands high tolerance control for the assembly.

5). Willy designed a joining system for pontoons [7], 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 (see 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. This method is only 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.

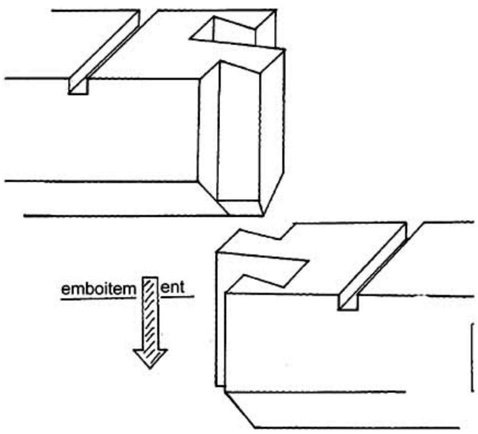

Fig. (5). Willy's design.

6). Zwagerman's introduced a constructive assembly [8] 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 (see 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. 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.

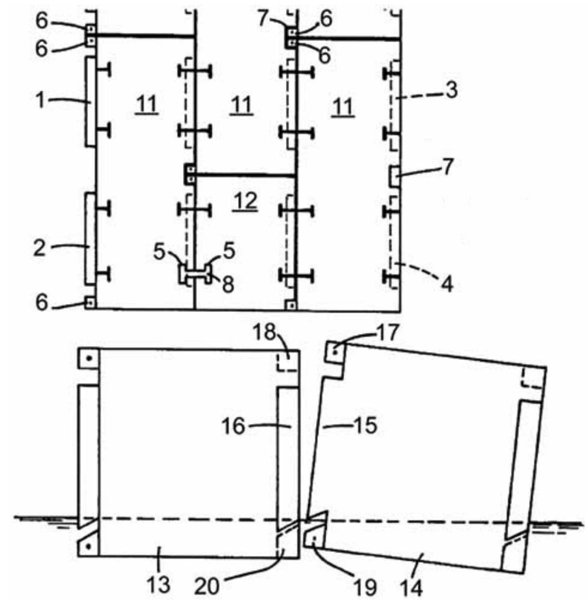

Fig. (6). Zwagerman's design.

7). Au-Yeong invented connector assemblies for floating sections/pontoons [9]. 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 (see 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. 24mm) 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. 24mm).

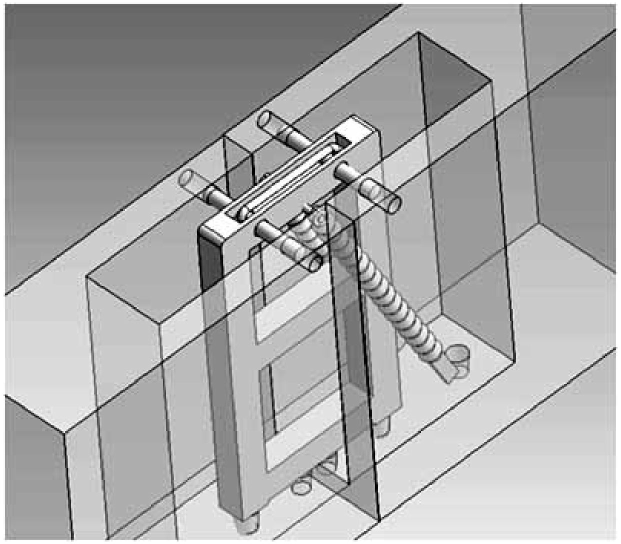

Fig. (7). Au-Yeong's design.

These patented devices utilize male and female coupling pairs, fitting and locking members to secure floating marine 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.

This paper presents a securing system which consists of Han's patented Fender Connector [1] and Frictional Locking Connector [2]. It amalgamates all the five fundamental requirements namely rapid self-alignment, impact attenuation, rigid engagement, self-fastening and superior strength into an integrated design.

HAN'S FENDER CONNECTOR

Design Principles

The following principles were used for guiding the concept development:

(1) To fulfill the self-alignment requirement, the shapes of the connector should be of simple male and female profiles.

(2) To increase the operational speed and enhance safety, damping material should be used to attenuate the knocking impact during the connecting process.

(3) To eliminate flexor-type weak points in the system, the connection between connectors should be as rigid as possible once the platforms have been joined.

(4) To survive in rough seas, the structural members of the connector design should minimise the effect of bending stress, as bending can easily cause solid material to yield. The design should thus be optimised for the material performance by utilising its axial/shear strength. Hence, the connectors would then be less elastic and be stiffer due to the reduction of bending.

Systematic Design Approach

Among the four principal design requirements, (2) and (3) are contradictory because characteristics of elasticity and rigidity are in opposition in a single material. While we can go for a "smart" composite material which could adjust its hardness on demand, its cost effectiveness would however be questionable. This was the key challenge that the design had to resolve. An integrated and optimal design is derived by achieving the four principles without compromising on individual performance. Staging the functional requirements and separating the features into different components were the main ideas leading to the design development.

Conceptual Design

The conceptual design was generated based on the principles discussed and is illustrated in Fig. (**8**). The connector comprises a 'D' fender and a 'V' recess fixed to one side of the marine platform, and two Rigid Stoppers and two Side Recesses fixed next to the 'D' fender and the 'V' recess respectively on the same side of the marine platform. As illustrated in Fig. (**9**), the 'D' and 'V' coupling members on two different platforms have a complementary relation-ship and can be moved from an unengaged position to a fully engaged position by the movement of the two platforms towards each other at the water level plane. The freedom of movement between the two coupling members decreases as they become engaged. The Rigid Stoppers and Side Recesses will create a rigid coupling to prevent relative vertical and longitudinal movement, as the freedom of movement between the 'D' and 'V' coupling members nears complete engagement.

The 'D' member is made of a resilient yet flexible material (e.g. rubber) and can withstand impact loading between the two platforms. Securing means - Locking Bars - are included to secure the floating marine platforms together in the transverse direction.

Functional Description

Following Principle 1, the 'D' fender and 'V' recess are of complementary male and female profiles, providing self-alignment means for platform securing in the initial stage of operation.

In accordance with Principle 2, the 'D' fender is made of high-density rubber, which is able to absorb the kinetic energy of the moving platforms and effectively dampen and gently decelerate the motion. It can hence facilitate a rapid and safe securing of floating platforms.

To apply Principle 3 in the design, steel was chosen for the stoppers. After the two opposing Connectors become aligned, the stoppers and holders provide constraints in both horizontal and vertical directions so as to reduce the motions between the Connectors. Consequently, the operators can carry out final securing promptly and safely. As such, the stoppers work as rigid connectors for the two Connectors.

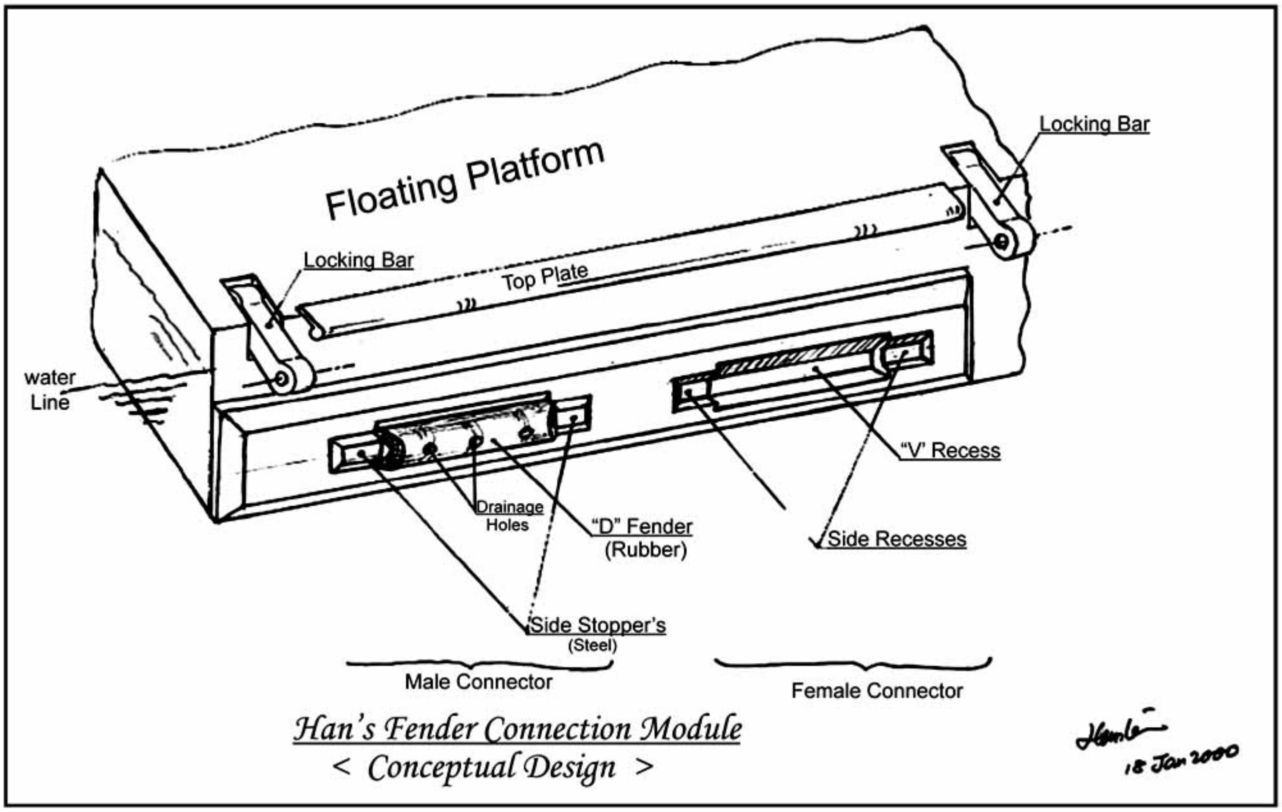

Fig. (8). Han's Fender Connector.

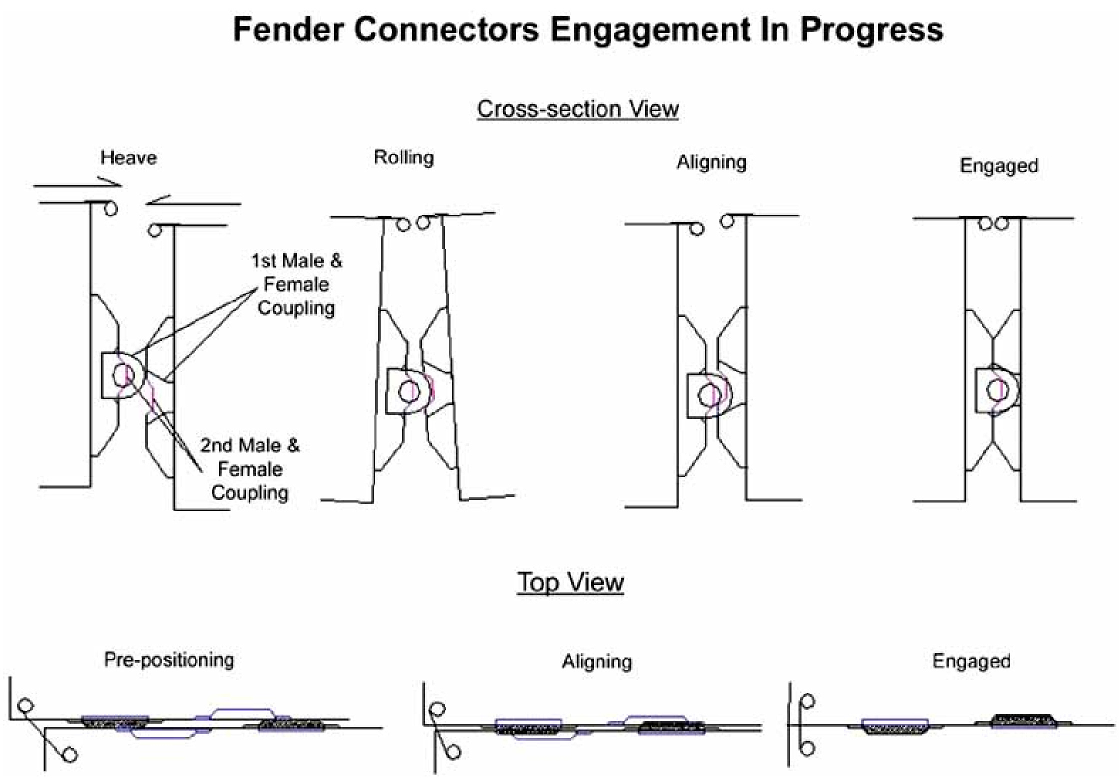

Fig. (9). Fender Connector engagement in progress.

After the Connectors have been secured, the stoppers sustain only the shear loadings in the vertical and longitudinal directions and leave the transverse constraint to the locking bars. Instead of bending stress which is absorbed by the stoppers, only transverse tension is experienced by the locking bars. Hence, the Connectors provide highly rigid and strong links between adjacent pontoons for greater safety and higher stability in rough seas. It is also capable of withstanding high deck loading such as the loading of heavy vehicles and acting as a ship's ramp. As the locking bars are located above the Fender Connector (at deck level), when the two platforms are in the downward motion at the connection side, the bottom portions of the two platforms have the possibility to open up and move in opposite direction. However, due to the weight of other adjacent platforms joined to the two platforms in question, such a possibility is minimized.

The stoppers were designed to be so small that they will not be in contact with the opposing module when 'D' fenders are compressed or distorted during the initial alignment stage in the specified sea state. Once the 'D' fender and the 'V' recess have been fully engaged, the stoppers replace the 'D' fender in securing the Connectors. The design arrangement and size difference of the 'D' fender and the stoppers decompose Principles (2) and (3) into two sequential stages - alignment (by the fender) and securing (by the stoppers). In this way, conventional material - steel (for the stoppers) and rubber (for the fender) can be used separately to fulfill the two contradicting requirements.

Model Testing

Two 1:40-scale working models - α version were built to examine the design concept. The configuration of the models is presented in Fig. (**10**).

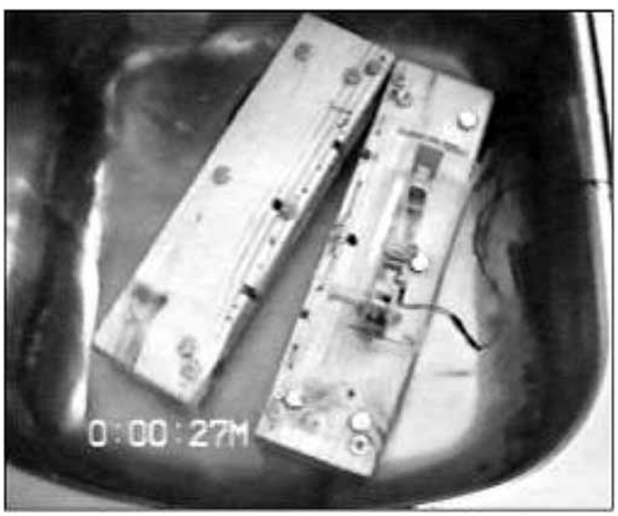

Fig. (10). α model testing.

One of the models is equipped with a miniaturised remote-controlled winch to bring the two models together. This simulates the movement of platforms at sea.

During the test, the shaping of the fender, recess, stopper and holder were experimented with and refined for smoother and faster engagement. Numerous arrangements of rope pulling to bring two pontoons initially together were also examined and improved. The horizontal securing means were tried out and optimised.

The model test achieved a 100% success rate in 20 repeated trials, in which the initial positions of the models and wave heights were varied specifically. Most of the trials were successfully completed at the first attempt without trial-and-error adjustments.

Taking into consideration the practical constraints and production feasibility, a refined configuration was designed. Accordingly, two 1:30-scale prototype models - β version - were built to verify and improve the detailed design (see Fig. (**11**) and Fig. **12**). The testing of models proved that the refined design concept was reliable.

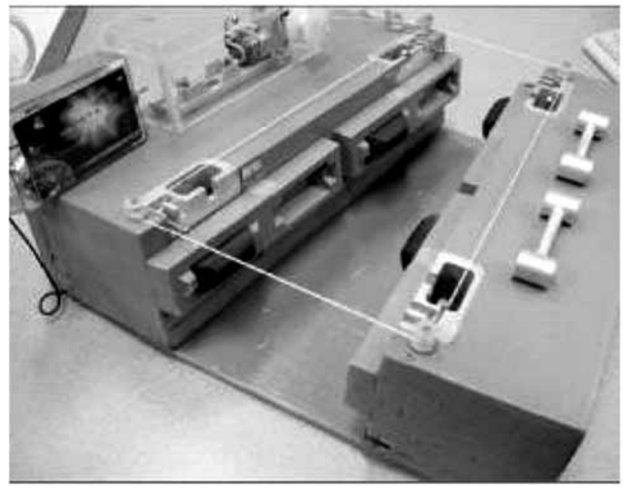

Fig. (11). β model rigging layout.

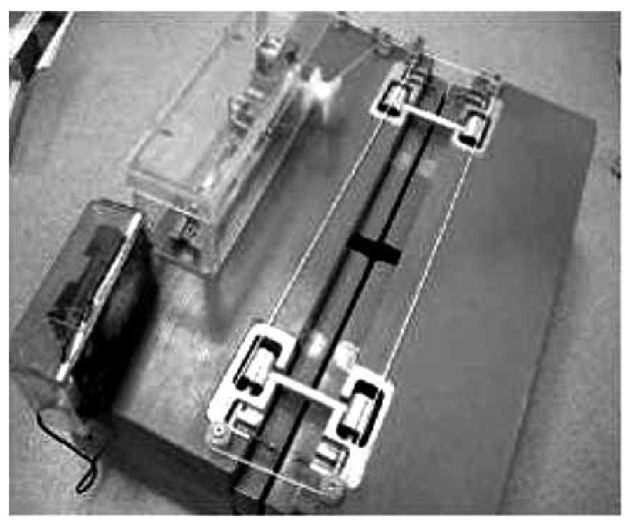

Fig. (12). β model being secured.

Design Consideration for Prototypes

After the concept design was confirmed, the detailed design of full scale prototypes was carried out. During the design, various load cases were considered, including out-off-phase roll, pitch and heave of two connecting platforms in Sea State 3. The maximum compression and shear forces borne by the 'D' fender, and the maximum shear forces to be withstood by the stopper during and after the securing were determined. The minimum number of in-contact fenders during the operation was examined.

The required breaking strength of the pulling ropes was computed for the maximum tension with an adequate safety margin. The capacity of pulling-winch (optional) was estimated. Furthermore, the brake holding strength of the winch was designed to cater for sudden surge. In order to ensure the proper functioning of the 'D' fender and the stoppers, a Finite Element model was built and analysed to predict the deformation of the 'D' fender under the maximum design loading (see Fig. **13**). The dimensions of the 'D' fender and the stoppers were defined thereafter to avoid the mutual interference of their functions during operations.

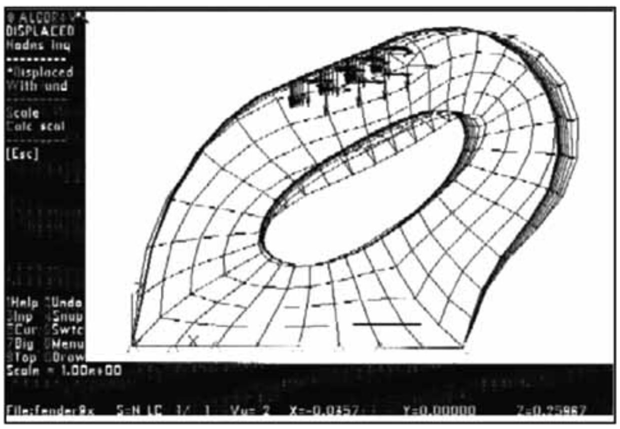

Fig. (13). Finite element analysis of fender.

Material Selection and Prototyping

A prototype platform of 40m x 7m x 3.5m (L x B x D) was designed. Mild steel was chosen for the platforms and the Connectors. An off-the-shelf marine type fender of 'D' shape was selected for the experiment. In addition to the Finite Element Analysis (FEA), the sizing of the fenders was examined by full-scale load test. During the test, the elastic deformation of the fender under progressive loading from vertical and/or horizontal directions was measured and photographed (see Fig. **14**).

The results were compared with that of the FEA to confirm the suitability of the fender and to refine the design of the Connectors.

Two full-scale prototype platforms were built and each has three Connectors fitted on the longer edge. The sea trials were conducted in Sea State 2-3 where the vertical motion of platforms was about 0.5 meter (see Fig. **15**). At the beginning of the operation, instead of pulling the winch, manual rigging was applied to bring the platform together. Prior to the connection, the rigging ropes were replaced by steel wires with tension crank to provide sufficient forces for securing the platforms. It was observed that the platforms approached and self-aligned rapidly. The deceleration when the platforms were knocking each other was effectively dampened. Vibration of the platform structure due to impact was reduced. Once the engagement had been completed even before securing, the relative movement of the two platforms was negligible (see Fig. (**16**)). As a result, the operators can easily and safely secure the locking bars.

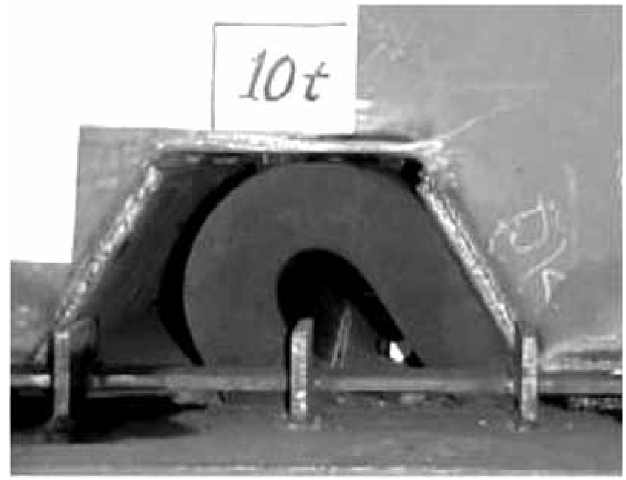

Fig. (14). Full-scale load test of fender.

Fig. (15). Full scale prototypes in sea trial.

ACHIEVEMENTS OF FENDER CONNECTOR

The advantages of using the Fender Connector for the assembly of large scale marine platforms have been proven by repeated sea trials of the Prototype Platforms and are summarized as follows:

Rapid engagement in high sea state - The operating time has been reduced from about 25 minutes to five minutes for the prototype platforms using the Fender Connectors in choppy seas (Sea State 2~3).

Safe operation and easy handling - The relative movement of the opposing platforms was reduced from 500mm to less than 10mm in the alignment stage, and further reduced from 150mm to less than 5mm when the locking bars are engaged. This minimizes the risk of injury to the operators during the connection.

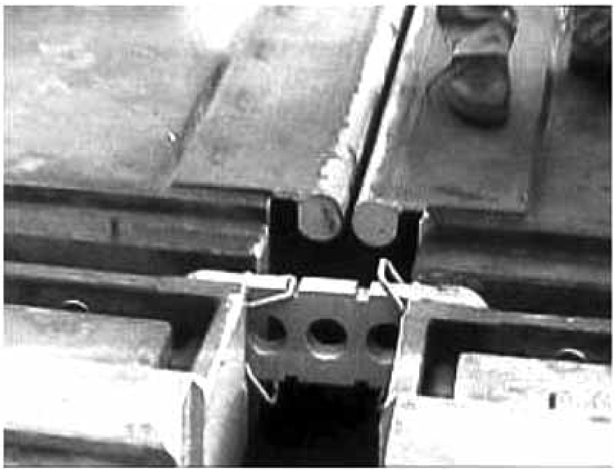

Fig. (16).

HAN'S FRICTIONAL LOCKING CONNECTOR

According to the Fender Connector design [1], the bottom portions of the two pontoons have the possibility to open up and move in opposite direction (see Page 9). A new innovation - Frictional Locking Connector [2] has been developed by Hann-Ocean to eliminate the bottom-opening scenarios so as to provide complete secured connection between pontoons.

Design Concept

The Frictional Locking Connector [2] is a rigid pontoon connector (see Fig (**17**)). 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.

Functional Description

As the Upper Locking Bar is designed to be shorter, it stops dropping by the upper inclined bearing surface while the longer Lower Locking Bar stops dropping by the lower inclined bearing surface, thereby holding the two pontoons together, in more restrained juxtaposition. Due to the gravity effect, the Locking Bars generate self-tension between the coupling parts and lock themselves on the bearing surfaces with static frictional forces. The locking bars and body are designed to work within elastic deflection range under the design loads. A locking bar removal kit has been designed and tested with mechanical force amplification factor of 100:1 to remove the upper bar in case of stuck. Once the upper locking bar is removed, the lower locking bar can be removed easily as the bending constraint formed by two locking bars has been released.

This coupling can accommodate larger tolerance of parts and installations by stopping the locking bars at different

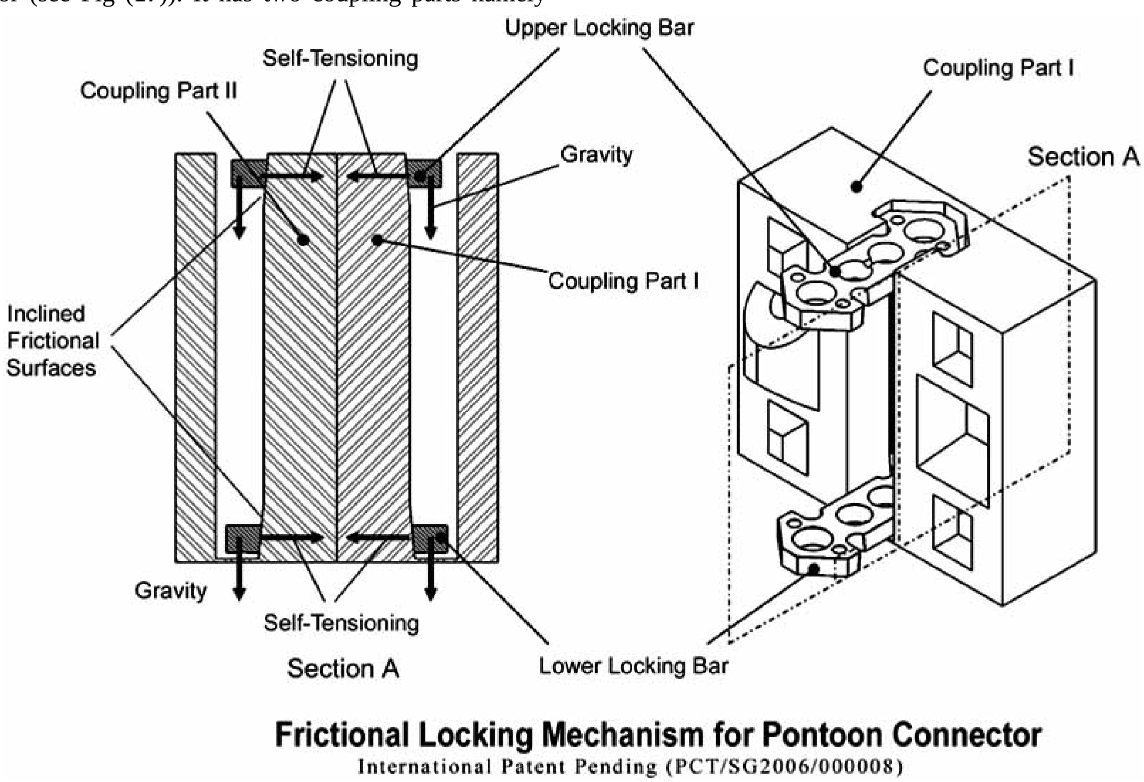

Fig. (17).

heights on the inclined frictional bearing surfaces. As there is no sliding or rotating parts (after completion of dropping), the connection is silent. There will be neither relative movement of connection nor noise (except material elongation). The fatigue problem caused by impact loading (low cycle and high peak) due to tolerances between movable components is eliminated. The fatigue issue caused by cyclic sea loading is minimized because no welding is located at the high stress areas in Han's connector and solid locking bars are used.

The International Search Authority has confirmed that the Frictional Locking Connector design [2] is novel, inventive and industrial applicable.

Model Testing & Prototyping

A 6DOF Rigid Pontoon Connector with size of 1200Hx850Bx700D was designed and proposed for Singapore National Day Parade (NDP) Floating Stage to be located in Marina Bay. The technical specification (model no. SFPC II) is shown in Table (**1**). A 1:10 scaled working model of the RPC has been made to validate the design concept. Subsequently, the full-size RPC prototype has been built to study its manufacturing process and achievable tolerances. For aesthetic and reliability, non-metal material is used for the stoppers and stainless steel is used for the bearing surfaces. The prototyping has been successfully completed. The extensive product tests (see Fig. (**18**)) are in progress to confirm the product performance such as breaking loads and load-deflection curves. A sea trial for the RPC to be integrated with pontoons is being planned.

Table 1. Technical Specification of SFPC II

Loading Description	Breaking Load (BL)	Maximum Working Load (MWL)	Relative Movement under MWL (RM)
Tension	1.84E+06N	1.24E+06N	< 1mm
Shear	1.12E+06N	7.57E+05N	< 1mm
Compression	1.64E+06N	1.11E+06N	< 1.5mm
Bending	7.41E+05NM	5.02E+05NM	< 1mm

Maximum Acceptable Tolerance for installation/assembly :+10mm

BENEFITS/ADVANTAGES OF 6DOF RIGID PONTOON CONNECTOR

The Hann-Ocean's 6DOF Rigid Pontoon Connector is a new generation of pontoon connector with outstanding performance in both dynamic and static conditions (proven by sea trials and workshop tests). The Fender Connector and Frictional Connector are integrated into one compact connector product fulfilling the 5 fundamental requirements of being ideal rigid pontoon connector. 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 (20~25 kg 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 base and locking keys are designed to survive in sea water for 20 years in Sea State 4 without any replacement.

CURRENT & FUTURE DEVELOPMENTS

For economical reason, concrete floating platforms in many applications are even more attractive to the end users. As there is no corrosion issue for concrete structures, the floating platform can last 50 years or more without any maintenance. Hann Ocean is currently designing a concrete pontoon connector using the 6DOF Rigid Pontoon concept. The preliminary design of the concrete pontoon connector has been generated and proposed for a mega floating oil storage facility to be built in Singapore. The computer simulations have been performed to verify and optimize the design. The prototyping of the connector to study its integration with concrete floating modules is being planned.

POTENTIAL APPLICATIONS

Hann-Ocean's pontoon connector is the ideal solution for creating large floating marine platforms on the seas. Potential applications include floating bridges, floating emergency bases, floating mass performance stages, floating industrial facilities like storage for oil, gas and other chemical products, container ports, cruise terminals, floating yacht club/marina, offshore reusable energy generation bases, entertainment/recreation spaces like restaurants, casinos, Karaoke clubs, mobile shopping gallery on water etc

CONCLUSION

Nine patents on floating platform securing device (or pontoon connector) are reviewed. Han's 6DOF Rigid Pontoon Connector (RPC) design consisting of patented Fender Connector [1] and Frictional Locking Connector [2] provides a highly efficient and practical solution to facilitate the construction of large-scale stable floating marine platforms in rough water. The design concept can be used for

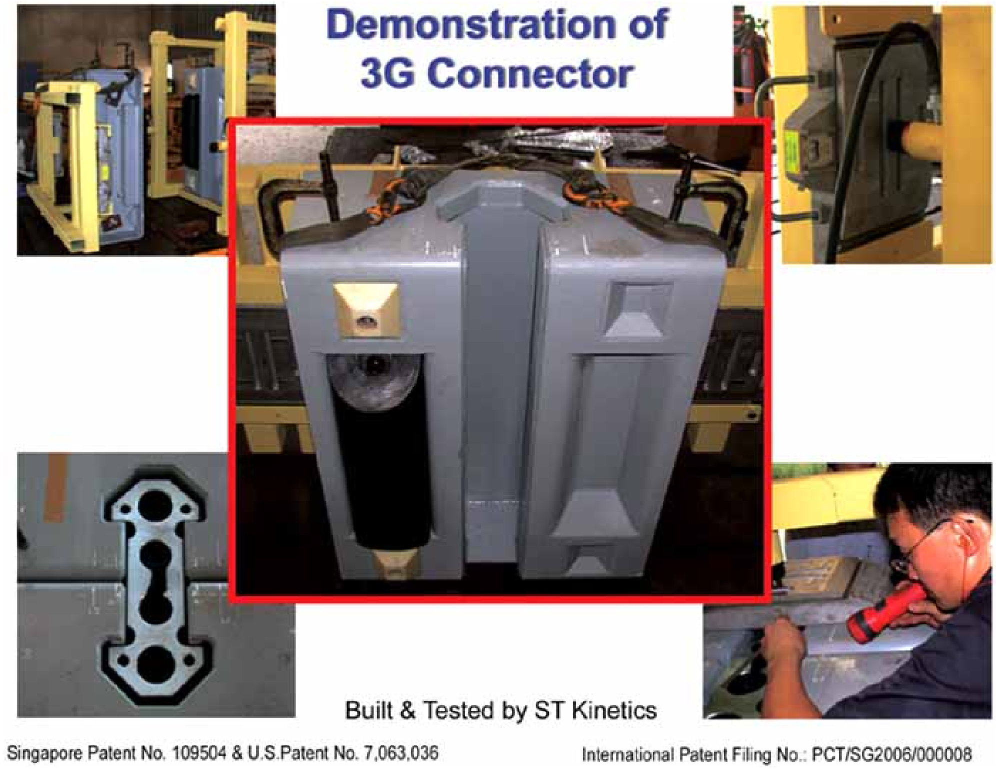

Fig. (18). SFPC II Prototype under Testing.

many applications in water space utilization as well as offshore engineering.

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