Securing of

Marine Platforms in Rough Seas

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 introduces a novel design concept. The key technical challenges for constructing such large floating platforms in rough seas are discussed. The design concept amalgamates multiple functional requirements, such as rapid self-alignment, impact attenuation and rigid engagement, into an integrated design. The engineering process from concept generation, model testing, detailed design and evaluation, material selection, prototyping and sea trials are presented. Potential applications for offshore operation are illustrated.

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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, one of the key technical challenges in constructing such joined floating platforms lies 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 both during the connecting process as well as after the connection has been established.

The relative vertical motion of two platforms in choppy sea can be more than 0.5m (as has been observed during sea trials). In such conditions, 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 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.

There are several patented designs which have addressed the various problems with connecting two platforms in rough seas. They include the patent specifications of US 4290382, US 3386117, US 4695184, JP 20203488 and US 5606929. These patented devices utilise guided coupling pairs which allow for two platforms to become increasingly aligned as they are brought together. However, the coupling pairs are rigid by design and can cause significant impact loading on each other, particularly when the engagement process is not completed.

This paper presents a securing system (granted Patent No. 109504) – fender connector module. It is able to provide an alignment function and also absorb the severe impact loading between two platforms.

CONCEPT DESIGN

Fundamentally, an ideal securing system should have the following functions:

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

The system should facilitate the securing of two floating platforms in rough water with minimum effort in the shortest time. The system, once interlocked, should provide a stable working surface and survive in rough seas without any structural damage.

Design Principles

The dynamic motion of the floating platforms is the primary concern. When a specific operational sea state and the main parameters of the platform have been defined, the dynamic motion of the platform at sea can be predicted, from which the operational tolerance of the connecter modules can also be defined.

The following principles were used for guiding the conceptual design 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 modules 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 required functions without compromising 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 Figure 1.

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 Figure 2, the D and V coupling members on two different platforms have a complementary relationship 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 (for example, 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.

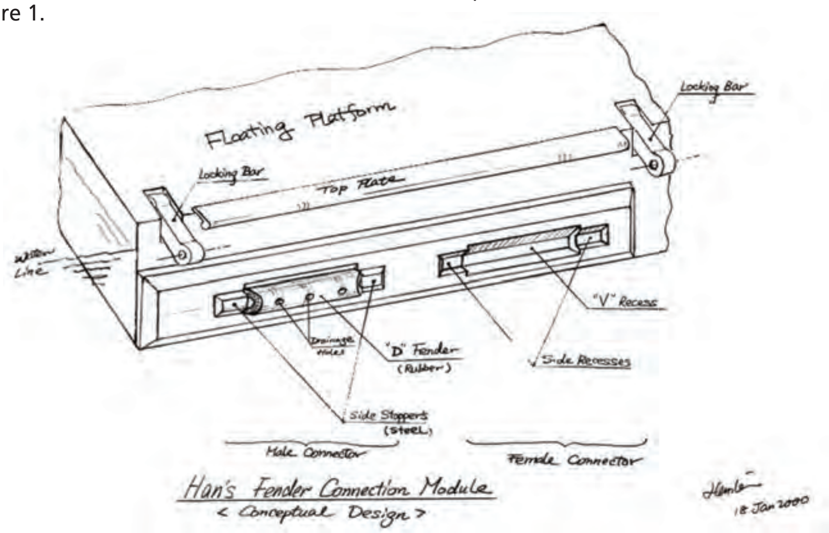

Figure 1. Fender connection module

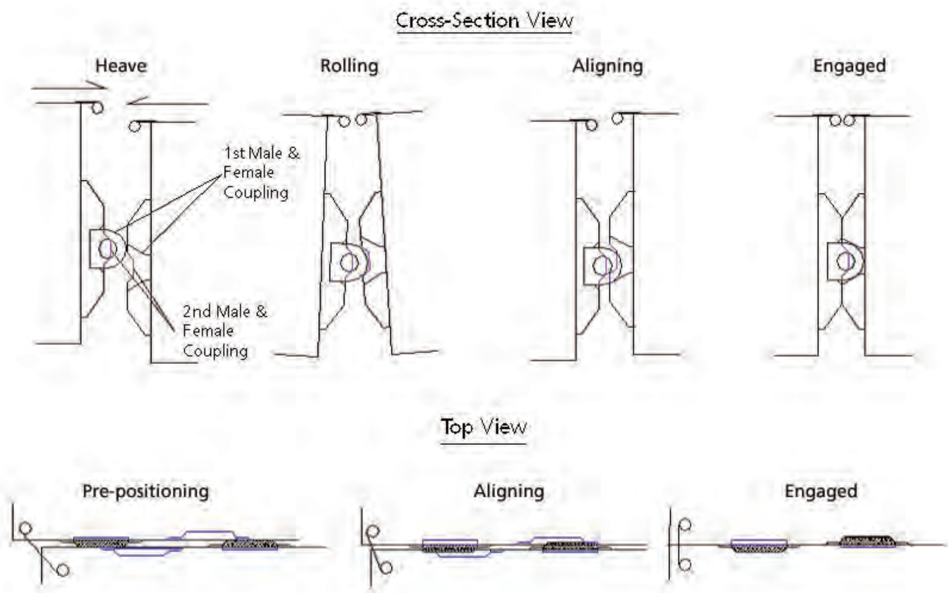

Figure 2. Fender connectors engagement in progress

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 modules become aligned, the stoppers and holders provide constraints in both horizontal and vertical directions so as to reduce the motions between the modules. Consequently, the operators can carry out final securing promptly and safely. As such, the stoppers work as rigid connectors for the two modules.

After the modules 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 modules provide highly rigid and strong links between adjacent pontoons for greater safety and higher stability in rough seas. They are also capable of withstanding high deck loading such as the loading of heavy vehicles or 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 potential 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 potential is minimised.

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 modules. 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 Figure 3.

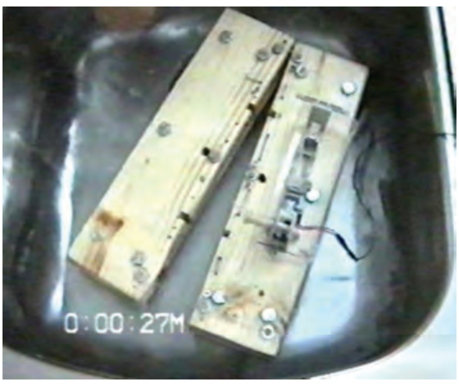

Figure 3. α model testing

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 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 Figures 4 and 5). The testing of the β models proved that the refined design concept was reliable.

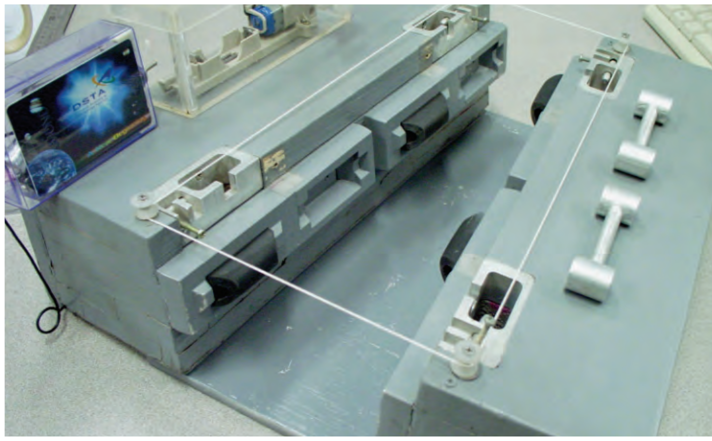

Figure 4. β model rigging layout

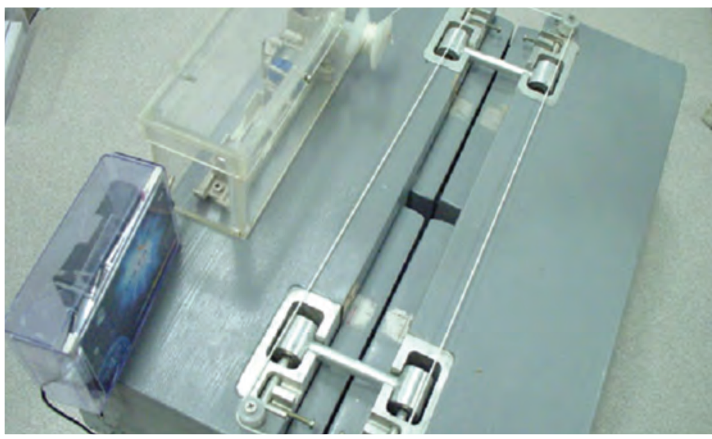

Figure 5. β model being secured

Design Consideration for Prototypes

After the concept design was confirmed, the detailed design of full-scale prototypes was carried out. During the design phase, various load cases were considered, including out-off-phase roll, pitch and heave of two connecting platforms in the specific sea state. 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 Figure 6). The dimensions of the 'D' fender and the stoppers were defined thereafter to avoid the mutual interference of their functions during operations.

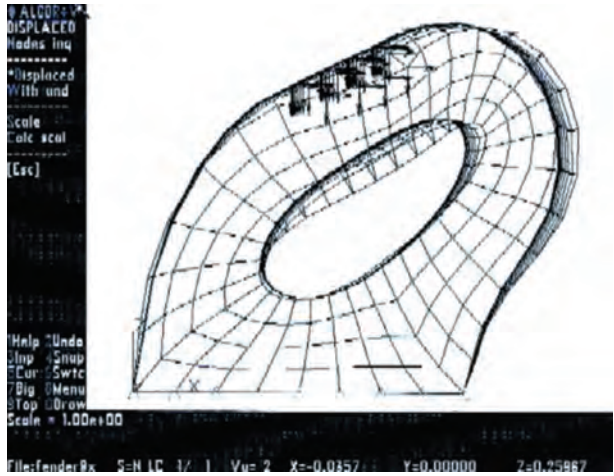

Figure 6. Finite Element Analysis of fender

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 modules. 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 a 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 Figure 7).

Figure 7. Full-scale load test of fender

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

Figure 8. Full-scale prototypes in sea trial

Two full-scale prototype platforms were built and each has three connector modules fitted on the longer edge. The sea trials were conducted in Sea State 2-3 where the vertical motion of platforms was about 0.5m (see Figure 8). 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

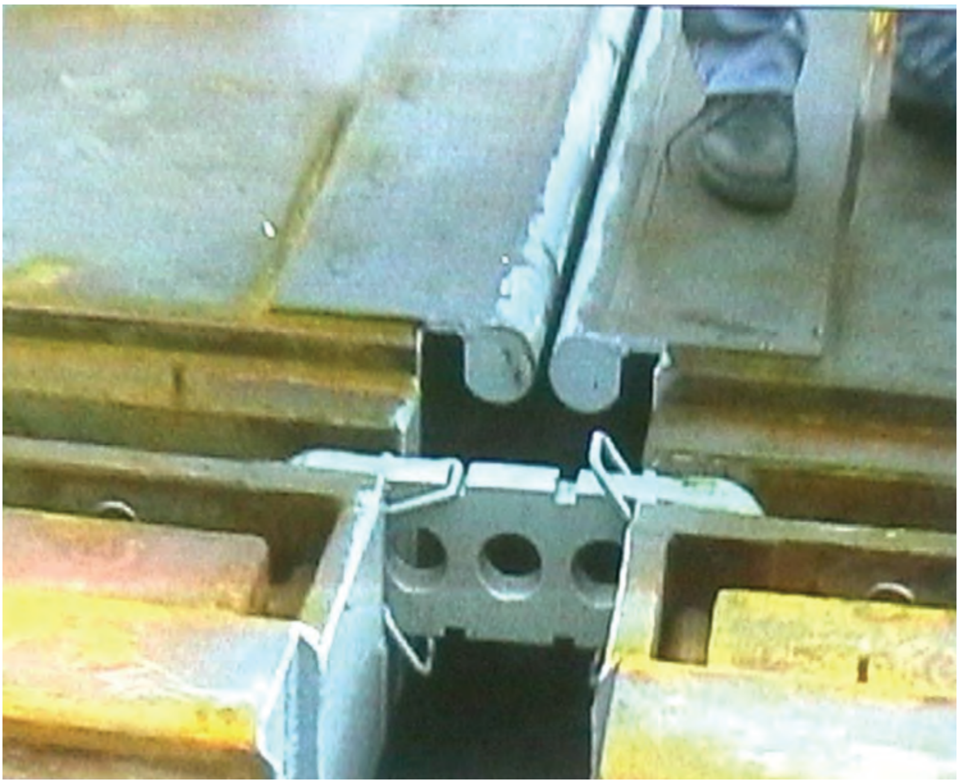

Figure 9. Negligible movement of two platforms observed

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 Figure 9). As a result, the operators can easily and safely engage the securing bars.

BENEFITS/ADVANTAGES

The benefits and advantages of using the securing system for the construction of large-scale marine platforms have been proven by repeated sea trials of the prototype platforms and are summarised 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 waters.

- **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 minimises the risk of injury to the operators during the connection.

- **High survivability in rough sea** - The securing strength is improved due to the elimination of bending stress. The secured prototype platforms in sea trials experienced Sea State 3-4 and there was no sign of structural failure.

- **Low life cycle cost** - The saving on manufacturing cost for the platforms is estimated to be significant compared to known design proposals. As the connector design does not have flimsy components or too many moving parts, it is robust and reliable. Regular maintenance is also minimised.

The optimal integration of multiple function features into a simple modular design is the key success of this concept development.

POTENTIAL APPLICATIONS

The fender connector system can be the essential part of extendable marine platform designs.

Potential applications include roll-on/roll-off discharge facilities, modular dredges in choppy seas, extendable floating restaurants, floating performance stages, floating car parks and shops, floating container stores, emergency rescue platforms, floating crane and offshore refinery plants at sea.

CONCLUSION

This fender connector design is innovative, efficient and cost-effective. It provides an alternative solution to facilitate the construction of large-scale marine platforms in rough seas. The design concept is applicable for all offshore operations.

ACKNOWLEDGEMENTS

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BIOGRAPHY

Han Lei was a Project Manager in DSTA, providing technical advice for marine platform designs when he invented the connector design. Han Lei has been granted a licence for the patent of the modular securing system by DSTA and has set up Hann-Ocean Technology Pte Ltd, commercialising the technology in marine and offshore industries. His work in the connector design has won him the DSTA Innovation Excellence Award 2003, the International Exposition of Innovation and Quality Circles – Eureka Award 2003 and the National IQC Carnival 2003 - Gold Award. Han Lei attained his Master of Science in Smart Product Design from the Nanyang Technological University in 2005.