Shaping the Integrated Floating Stage at Marina Bay

ABSTRACT

This paper presents the challenges faced and the systems engineering solutions implemented in developing a large floating steel platform at the Marina Bay of Singapore. The floating platform is designed to be a multi-purpose facility on the bay for mass spectator events, sporting activities and cultural performances, as well as be a re-configurable "pier" for water sports and boat shows. This floating stage, the world's largest floating performance stage on water, hosted the National Day Parade 2007, its first big show. Since then, the stage and its seating gallery have been used as the venue for lifestyle events, extreme sports, the Singapore Fireworks Festival, the WaterFest as well as the finishing point for the Singapore Bay Run, the biggest mass run organised in Singapore. Building the floating platform for all these events involved complex engineering and many considerations had to be taken into account in the systems development.

Dr Koh Hock Seng
Lim Yoke Beng

Shaping the Integrated Floating Stage at Marina Bay

INTRODUCTION

Pontoon-type, very large floating structures are rare in the world (Suzuki, 2005). This very large floating structure (VLFS) technology provides an alternative solution to the traditional land reclamation method for creating large usable space on water. Singapore's first application of the floating structure technology is the construction of the floating performance stage at the Marina Bay (Koh et al., 2007a and 2007b).

The Marina floating stage measures 120m x 83m x 1.2m and was constructed by assembling multiple steel pontoons on water at the site. The floating stage hosted Singapore's National Day 2007 Parade in August 2007 (see Figure 1). It is the largest floating stage in the world for performances on water. An artificial turf, when laid on its large surface, turns the floating stage into a temporary sports field. As the floating platform is a multi-purpose facility for mass spectator events including concerts, mega festivities and water activities like boat shows, the connecting system that interlocks the multiple steel pontoons is designed such that the floating platform can be dismantled and reassembled.

A 27,000 seating capacity gallery, which faces the floating platform allows the spectators on shore to view various events on the stage as well as on the water against the backdrop of the Singapore city skyline. The floating platform on the edge of the water of the Marina Bay is located in the new downtown area, opposite the location of the Marina Bay Sands Integrated Resort as shown in Figure 2.

ENGINEERING CHALLENGES

DSTA was approached to study the technical feasibility of staging the National Day Parade on a floating structure and to work out the design specifications. The main challenge was

Figure 1. National Day Parade held on the floating performance stage on 9 August 2007

Figure 2. Location of the floating platform at Marina Bay *(courtesy of URA)*

to design a large-scale floating platform to carry a high load comprising 9,000 people, 200 tons of stage props and three 30-ton vehicles. The solution needed to incorporate floodlight masts and an artificial turf to create a floating sports field.

The Marina floating stage is one of the most technically challenging floating platforms of her size, in view of the many unique considerations and the innovative design. As far as we know, VLFS applications reported by Watanabe et al. (2004a) have been designed as a "single piece". The Marina floating platform had to be versatile, movable and of modular design for re-configuration into various shapes and sizes to meet different event requirements.

With a modular design, one of the greatest challenges was connecting all these multiple floating modules into one single platform to create the large working surface. It was also important to keep the motions of this connected platform within the allowable limits for its intended purposes. The platform had to be stable and unaffected by waves, winds and tidal currents and at the same time be safe for holding mass performances on it. The major challenge was the design of the connecting system for the functionality and robustness of the integral platform. To hold the floating platform in position against currents and waves, dolphins were used for the mooring system. However, these dolphins are detachable at the bottom of the seabed to allow an unobstructed water surface for sea-sporting activities at the bay.

To allow large numbers of performers and vehicles weighing up to 30 tons to go onto the platform, access bridges were constructed to connect the floating platform to the land and the seating gallery.

The other key challenges faced in the design of such a large floating platform included having to contend with the environmental conditions and developments in the downtown Marina Bay. The shallow water at the site limits the platform depth while the changing tides put constraints on both the positioning of the platform with respect to the shore and the gradient of the access bridges that link the platform structure to the land. As the floating performance stage is relatively flexible due to its low profile in relation to the length dimensions, it exhibits elastic behaviour similar to a thin plate when subjected to wave actions. Hence there was a need to perform hydroelastic analyses (Watanabe et al., 2004b) of the stage under the action of waves found in the Marina Bay. The design also had to address the non-existence of established design rules and standards for connecting multiple floating pontoons rigidly as an integral platform.

As safety is of paramount importance in the engineering aspects of the integrated floating stage, stringent safety requirements have been adopted in the design.

SYSTEMS ENGINEERING SOLUTIONS

The floating stage design was conceived as a pontoon-type VLFS to support various requirements such as hosting the National Day Parade, and to serve as a re-configurable "pier" for water sports and boat shows.

Various concepts were assessed technically and also in terms of schedule risk as such requirements had not been implemented and tested on floating structures before. Market research and engineering feasibility studies of the static and dynamic behaviour of a thin flexible floating structural system had to be performed. These included the parametric study of the platform freeboard and draft, the forces at the connection of the floating pontoons and study of suitable mooring system and access bridges. Environmental conditions such as tidal variation, waves, water currents and wind speeds were also considered in the design of the floating platform.

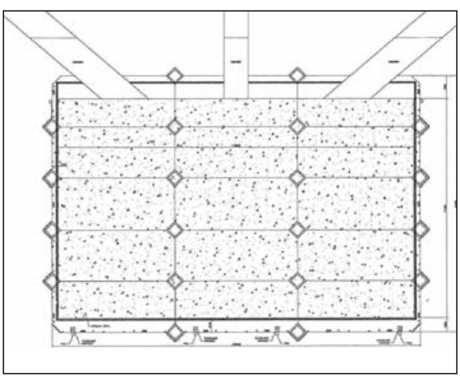


Figure 3. Plan View of floating platform consisting of 15 pontoons (each measuring 40m x 16.6m x 1.2m) and three access bridges

The final solution was to create 15 identical pontoons of dimensions 40m x 16.6m x 1.2m each, to form the 120m x 83m floating platform (see Figure 3). Figure 4 shows the completed floating stage including the access bridges. Each pontoon is a box-type structure based on longitudinal and transverse bulkheads or girders. In view of the shallow water depth and the need to carry heavy live loads, the floating structure is made of steel as the material is strong and lighter than concrete of similar strength. These pontoons are connected by mechanical connectors, but the structural design provides flexibility for the pontoons to be customised into smaller platforms, to be re-located and re-configured for different purposes. The design of the rigid connector is the key component for the functionality and robustness of the integral system. The rigid connector was thoroughly evaluated to ensure that the whole platform was safe and the downtime that might result during production and testing was minimised.

Model tank tests were performed to study the behaviour of the floating platform in water. Several combinations of parameters were investigated, including loading conditions, tidal variations, wave heights and water speeds. Measurement data concerning the motions and mooring loads in both operational and extreme environmental conditions were

Figure 4. Floating performance stage at Marina Bay

collected for the engineering analysis. Figure 5 shows the hydrodynamic model test to examine the performance of the floating platform.

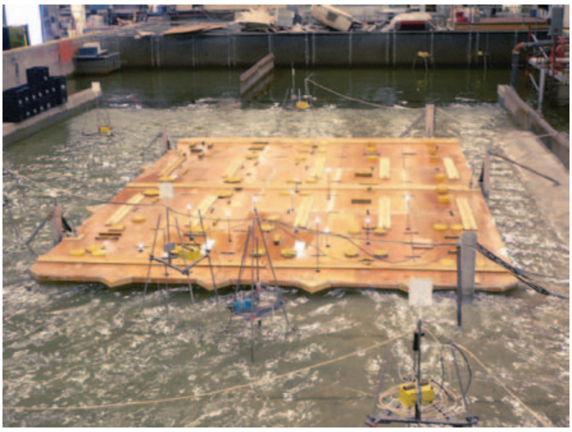


Figure 5. Hydrodynamic model testing

Three access bridges (of eight metres to 10 metres wide) connect the floating platform to shore for vehicle access and the mass movement of people. In order for the access bridges to have gentle gradients, a two-segment bridge was developed. The first segment is a fixed bridge supported by piles. The second segment is a gangway, articulated at one end while the other end moves horizontally on the platform. The change in the gradient of the gangway allows unaffected access at all times despite the tidal variations. Besides ensuring that the bridge system was designed with adequate strength, deflection and vibration (resulting from human movement) analyses were performed to study the structural stiffness.

The method of mooring the floating platform in the Marina Bay also required a specially customised solution. The water depth in the middle of the Bay varies between one metre and seven metres while the water channel between the floating platform and the opposite embankment is about 100 metres. Hence the depth and space constraints do not permit the conventional anchoring system to be deployed properly and effectively. An innovative piling method was devised where the dolphins are designed to be detachable just above the seabed as this solution allows the freeing of the sea space area for sea sports.

Another important area of focus is to turn the seating gallery (for the spectators on shore to view performances on the floating stage) into an integrated facility by taking into consideration the viewing angle, distance, lighting effect and mass movement of performers. While maximising the seating capacity, the architectural design had to take into consideration the orientation of the spectator seats and the steepness of the seating gallery, and to ensure that the comfort of the spectators was not compromised. Many factors such as the tidal variation of some three metres to four metres on site were taken into account in the facility design. This tidal variation affects the distance of the floating platform from the seating gallery as the floating platform has to be located further away in the bay because of the shallow seabed near shore.

The need to comply with environmental specifications for a reservoir also complicated the design as typical corrosion prevention measures are prohibited.

With the floating platform sited in downtown Marina Bay, the integrated floating stage has been designed to be aesthetically pleasing. The aesthetic requirements were achieved through the treatment of the platform structures and careful selection of fittings such as railings and lighting so that the architectural design blends well with the surrounding development in the Marina area.

STRUCTURAL DESIGN

The floating platform has been designed according to the American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels for Service on Rivers and Intra-coastal Waterways, as well as applicable industry standards and codes.

In the case of conventional ships, the global response is dominated by rigid body motions whereas in VLFS, the global response is determined by elastic response, either

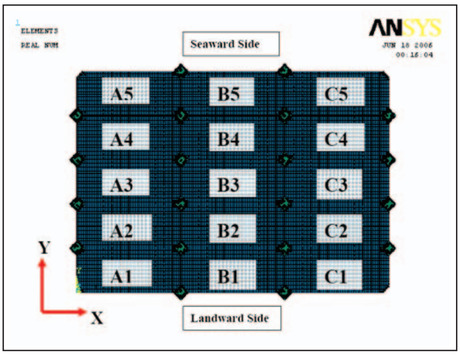


Figure 6. Finite element model of floating platform

dynamically or statically (Fujikubo, 2005). As there were no established rules for the design of such thin flexible plated structures, a first-principles approach was adopted for the structural design and this requires extensive finite element analysis and hydroelastic computations to predict structural responses.

The response of the global platform to a given loading scenario was analysed using a 3D finite element model of the complete platform consisting of 15 pontoons, connectors and the three access bridges. Figure 6 shows the computer model used for the engineering analysis. Supporting the platform model are linear springs that simulate the buoyancy force.

For the static analysis, the floating platform under static dead weight and different live loads scenarios including eccentric loads was studied to determine the stress distributions and deflection of the platform as well as the maximum loads at the connecting system.

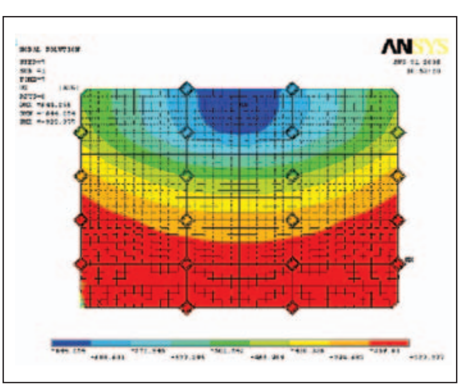


Figure 7. Plots of Vertical Deflections

For the dynamic analysis, hydroelastic analysis was performed to estimate the structure and connector loads when the floating platform was exposed to wave loading. The wave loading applied to the global finite element was calibrated based on experimental results obtained from the hydrodynamic model tank test.

The stresses were checked against strength requirements while the vertical deflections were checked against serviceability requirements. Figure 7 shows the vertical deflection contours of a load case.

CONNECTING SYSTEM

The connecting system ensures adequate strength and rigid connection to the floating platform when the pontoons are inter-locked. These pontoons are joined at the corners using a floating corner connector and along the mating edges with side connectors (five along the long edge and two along the short edge). These are designed to withstand dynamic forces resulting from personnel movement and wave motion. The corner connecting system consists of a male member at the corner of each pontoon and a female member at each of the four sides of the corner connector (see Figure 8). The coupling members come into engagement via detachable locking pins. The pontoons are connected adjacently using blade-

Figure 8. Joining the pontoons using the corner connector

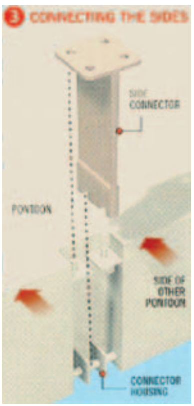


Figure 9. Joining the pontoons using the side connector

type engagement to bear the tensions and bending moment between adjacent pontoons (see Figure 9). These side connectors lock the top and bottom of the adjacent pontoons together to form a rigid connection.

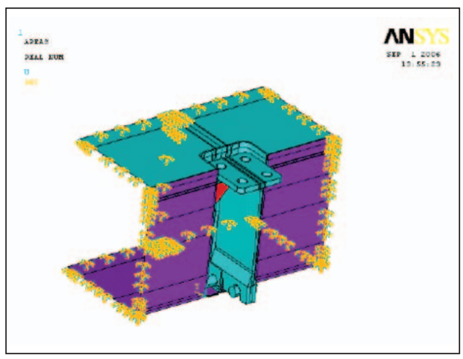
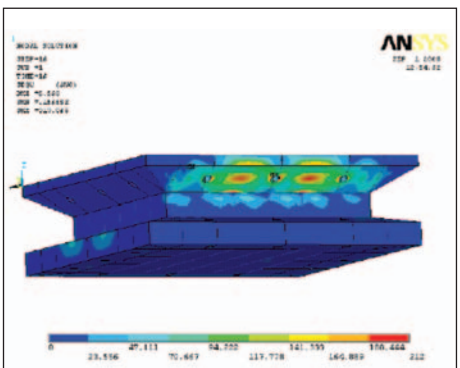
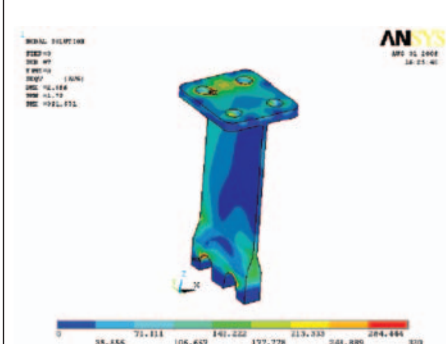


Figure 10. Boundary conditions for localised finite element model of side connector and its housing

From the results of the global response analysis, the local stress response at the connectors under combined loading was evaluated using detailed structural modelling and static analysis. Figure 10 shows the local structural model for the analysis of the stress response of the side connector with its housing. Figure 11 shows the results of the finite element analysis of the corner and side connector in terms of Von-Mises stresses.



Corner Connector



Side Connector

Figure 11. Plots of Von-Mises Stress

In addition to numerical computer simulations, verification using prototype testing of the corner and side connectors was sought (see Figure 12). The stresses and elastic deformation were measured and the results were compared with the finite element analysis of the localised model.

MOORING SYSTEM

In the development of the mooring system, various environmental constraints such as shallow water and tides were key factors for consideration. Conventional mooring systems involving cables and chains were not suitable for the floating platform because the tidal range was relatively large when compared to the shallow depth of the platform. The heavy frame guide dolphin mooring system and caisson-type mooring system were also not suitable because the floating platform has to

Figure 12. Full-scale prototype load testing

be moved to another site from time to time. Therefore, a detachable dolphin mooring system with the aim of easing the process of installation, keeping the floating platform in position and preventing the structure from drifting away was devised and implemented. The detachable dolphin mooring system also has the advantage of having its components detachable and reusable.

The detachable mooring system comprises four components, namely the dolphin column, the platform anchor, the casing pile and the fender rollers (see Figure 13). The casing pile is rammed deep into the seabed and protrudes slightly above the seabed to provide a secure footing where the dolphin column is bolted, and the top of the dolphin is locked using the platform anchor attached to the sides of the floating platform. The dolphin mooring system moors the floating platform from lateral movement and prevents it from drifting away with the current.

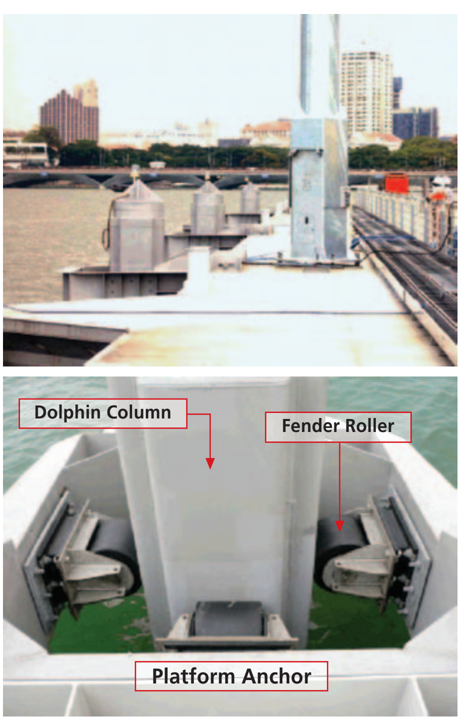


Figure 13. Detachable dolphin mooring system

For the design of the mooring dolphin columns, an extreme scenario where conditions such as waves, currents and wind acting simultaneously on the floating structure was simulated. The layout of the dolphin columns is such that the horizontal displacement is adequately controlled and the mooring forces are appropriately distributed.

SAFETY CONSIDERATIONS

Safety is a primary consideration in the engineering aspects of the floating stage design, specifically safety against structural damage and personnel safety. This is supported by conducting system safety assessment where potential hazards are identified and mitigated through technical solutions or procedures.

The design of the pontoons and the floating platform meets the International Maritime Organisation standards for intact and damaged stability, with each pontoon having at least two-compartment subdivision status. The floating platform has been designed as a rigid

Figure 14. Pontoons being towed to Marina Bay by tugboats

platform in which the connectors hold the pontoons securely. Due to the large horizontal dimensions of the floating platform, stability of the structure is not a problem, even in the event of few compartments suffering damage.

The types of marine craft in the vicinity consist mainly of small cruise boats or sports craft. The probability of these marine craft coming into close proximity with the floating platform is very low and highly unlikely. For accidental contact, it is expected that most of the damage will be borne by the striking craft and not the floating platform or mooring piles.

The connecting system is designed to hold the pontoons together with the expected loading on the platform and has been certified by ABS Consulting. The designed loading capacity distribution is documented and allowable operating parameters are established.

In contrast to the mooring lines system, the dolphin mooring system prevents free drifting of the floating platform and averts damage to the surrounding facilities. The design is in compliance with the technical conditions imposed by the Building and Construction Authority of Singapore.

The heaving effect of the floating platform on the performers was investigated to determine the translational accelerations of the structure as a large number of personnel are expected to remain on the stage for prolonged durations. The computed frequency-weighted accelerations were analysed to be within the established human tolerance limits for motion sickness and endurance or proficiency level for an eight-hour duration.

In addition, the response of the floating platform to participants' simultaneous jumping was studied. This human response analysis provided the assurance that the floating stage is suitable for mass performance and sporting activities.

For better protection against lightning, two 40m-high masts on each side of the seating gallery and six 30m-high masts on the floating platform have been erected to serve as lightning masts with an overhead wire spanning between two pairs of masts.

ASSEMBLY AND VERIFICATION TESTING

The 15 pontoons were transported individually by tugboats from the shipyard in Jurong where they were fabricated, to the Marina Bay (see Figure 14). The journey included a passage through the Marina Barrage at the mouth of the Singapore River (see Figure 15). Once at the site, the pontoons were fully assembled using the connecting system to form the

Figure 15. Passage through the Marina Barrage

Figure 16. Assembly of floating pontoons on-site

Figure 17. Load Testing of floating platform

floating platform, which was then secured to the mooring piles (see Figure 16).

Extensive full-scale load tests were conducted on the platform at the site to validate the floating platform design and to ensure that the stage could withstand the large loads of performers, vehicles and stage displays (see Figure 17).

CONCLUSION

Besides hosting the National Day Parade, the floating platform also provides a wonderful opportunity for all kinds of activities such as concerts, sports events and activities on and around the water. The integrated floating stage is now a landmark in the Singapore cityscape and adds to the vibrancy of the Marina Bay.

It also opens up new possibilities in space creation - the offshore space - and in the process generates economic value in land-scarce Singapore. It serves to complement other space creation initiatives such as land reclamation, construction of high-rise buildings or the development of underground caverns.

The Marina floating platform has created much awareness of the technical viability of large-scale floating platforms and will inspire the building of more floating structures such as floating storage facilities for processed petrochemicals, mobile offshore bases, floating airports, floating houses / community and floating industrial facilities in the future.

REFERENCES

Fujikubo, M. (2005). Structural Analysis for the Design of VLFS. Marine Structures, 18, pp. 201-226.

Koh, H.S. and Lim, Y.B. (2007a). Integrated Floating Platform. Proceedings of the 11th Naval Platform Technology Seminar, Singapore.

Koh, H.S. and Lim, Y.B. (2007b). The Floating Platform at Marina Bay: The Challenges, Proceedings of IStructE Asia-Pacific Forum on Structural Engineering: Innovations in Structural Engineering, Singapore.

Suzuki, H. (2005). Overview of Megafloat: Concept, design criteria, analysis and design, Marine Structures, 18, pp. 111-132.

Watanabe, E., Utsunomiya, T., Wang, C.M. and Moan, T (2004a). Very Large Floating Structures: Applications, Analysis and Design, Core Report No. 2004-2, National University of Singapore, Singapore.

Watanabe, E., Utsunomiya, T. and Wang, C.M. (2004b). Hydroelastic analysis of pontoon-type VLFS: A literature survey, Engineering Structures, 26, pp. 245-256.

BIOGRAPHY

Dr Koh Hock Seng is Senior Principal Engineer and Senior Programme Manager (Naval Systems). He has extensive experience in the conception, planning, systems engineering and project management of large-scale systems such as the Landing Ship Tanks and the Stealth Frigates. Hock Seng led the DSTA team in the effort to develop the mega floating platform at the Marina Bay. He graduated from the University of Hamburg (Germany) with a degree in Naval Architecture and obtained his PhD in 1991. Currently, he serves in the Germanischer Lloyd's Technical Committee for Naval Ships. His awards include the Defence Technology Prize (in 1996, 2001 and 2007), the SAF Good Service Medal (in 2003) and the National Day Award (in 2001).

Lim Yoke Beng is Senior Principal Engineer and Programme Manager (Land Systems). He has extensive experience in military vehicles and bridges-related projects and was involved in the mega floating platform at the Marina Bay. He obtained his Bachelor of Mechanical Engineering from the University of Newcastle (Australia) in 1988. In 1995, he obtained a Master of Science in Military Vehicle Technology from the Royal Military College of Science, UK.