Floating Performance Stage at the Marina Bay, Singapore

H.S. Koh and Y.B. Lim

Abstract The Marina Bay was identified as the venue for the National Day Parade for 2007 and subsequent years. The concept was to create a large usable space on water for mass spectator events and to design it as a multi-purpose facility to be used for sporting activities, mega festivities, cultural performances and water activities. The pontoon-type floating platform technology was adopted to create the large-scale floating performance stage. The Marina Bay floating platform measured 120 m long, 83 m wide and had a depth of 1.2 m and was built by assembling fifteen modular steel pontoons. This floating stage, completed in April 2007, is believed to be the world's largest floating performance stage.

1 Introduction

The Marina Bay was identified as the venue for the National Day Parade (NDP) for 2007 and the subsequent years. The concept was to create a large usable space on water for mass spectator events and to design it as a multi-purpose facility to be used as an alternate site for sporting activities while the new Singapore Sports Hub[1] was being developed as well as for mega festivities, cultural performances and water activities.

[1] The old National Stadium at Kallang was demolished in 2006.

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C.M. Wang and B.T. Wang (eds.), *Large Floating Structures*,
Ocean Engineering & Oceanography 3,
DOI 10.1007/978-981-287-137-4_2

Fig. 1 National day parade held on the floating performance stage on 9 August 2007

The pontoon-type floating platform technology was adopted to create the large-scale floating performance stage. The Marina Bay floating platform measured 120 m long, 83 m wide and 1.2 m depth and was built by assembling modular pontoons made entirely of steel. This floating stage, completed in April 2007, is believed to be the world's largest floating performance stage. It hosted the National Day Parade (NDP) in August 2007 (see Fig. 1). A 27,000 seating capacity gallery was built facing the floating platform and functions as an integrated facility. It allowed the spectators on shore to view the various events on the stage as well as on the water against the backdrop of the Singapore city skyline (see Fig. 2). The integrated floating performance stage is now a landmark in the Singapore cityscape. Besides hosting the annual NDP, 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. An artificial turf was laid on its large surface and turned the floating platform into a temporary sport field.

This chapter discusses the pontoon-type floating structure technology and presents the engineering challenges and considerations involved in building the floating platform, design concepts, technical analysis as well as the construction, assembly and verification testing.

2 Engineering Challenges and Considerations

The Marina Bay floating platform, slightly larger than the size of a football field, is one of the most technically challenging floating platforms of her size, in view of the many unique considerations, constraints and innovative designs. The main challenge was to design and create a large usable space on water to carry a high load comprising 9,000 people, 200 tons of stage props and three 30-ton vehicles.

Fig. 2 Performing stage at Marina Bay, with backdrop of Singapore city skyline on 9 August 2013 (*Photo courtesy* of The Straits Times)

The way in addressing this challenge was to design a mega floating structure using pontoon-type floating technology. Pontoon-type, very large floating structures are rare in the world (Suzuki 2005).

Singapore's first application of the mega floating structure technology is the construction of the floating performance stage at the Marina Bay (Koh et al. 2007, 2008, 2009). The floating installations offered significant advantages, in particular the reduced development and construction period, ease of assembly as well as concurrent construction and installation. It only took 13 months to deliver the floating stage at the Marina Bay, meeting all the requirements.

2.1 Versatility and Mobility in Deployment

Most large floating structure applications reported by Watanabe et al. (2004) have been designed as a "single piece". The design of the floating platform at Marina Bay has to address the key requirements of versatility and mobility in deployment. To achieve this, the floating platform is uniquely designed to be modular and is constructed from assembling fifteen steel pontoons with a one-of-its-kind connecting system to allow for dismantling and re-assembling of the floating platform. Given the modular nature of the design, the floating pontoons can be easily relocated within the bay area or re-configured into various shapes and sizes to meet different event requirements.

2.2 Rigidity

With a modular design, one of the greatest challenges is connecting all the multiple floating modules into one strong single integral platform to create the large working surface in a manner that keeps the relative motions of the connected pontoons within the allowable limits for the intended purposes. These pontoon-type floating modules take advantage of the inherent free buoyancy to achieve floatation to take the gravity loads. The connecting system is the key component for the functionality and robustness of the integral platform and is specially designed to inter-lock the pontoons to ensure rigid connection and to withstand heavy loads.

2.3 Stability

One of the key design criteria is the stability requirement of the floating structure. The platform (and her pontoons) has to be stable in water and unaffected by waves, winds and tidal currents and at the same time safe for holding mass performances on it.

2.4 Relationship to Water Surface

The freeboard must not allow sea waves to get onto the surface and yet the depth cannot be increased, which is desirable to prevent tilt effect. The floating structure needs to be moored to permit vertical movement of the structure to follow the changing sea level. For given payloads, the surface of the floating structure thus remains a constant distance from the water surface despite the large tidal variations.

2.5 Consideration of Water Environment

The other key challenge faced in the design included having to contend with the water environment. The shallow water at the site limits the platform draft, and consequently the 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. There is a need to ensure that the presence of the floating structure would not create disruption to the water flow from the Singapore River and affect the marine ecology in the bay.

Fig. 3 Location of floating platform at Marina Bay (*courtesy* of URA)

2.6 Statutory Requirements

The design had to address the non-existence of established design rules and standards for connecting multiple floating pontoons rigidly as an integral platform. The design has to be compatible with the urban master-planning for the bay area (see Fig. 3), which was designated the new downtown and to be implemented within the environment and regulatory constraints imposed as the Marina Bay was designated as a fresh water reservoir. This requires the design to architecturally blend with the surrounding infra-structure developments and to address the environmental specifications for a reservoir.

2.7 Rapid Installation and Ease of Assembly

To achieve the desired (tight) construction deadlines, the modular pontoons are constructed at shore-based shipyards in multiple locations with concurrent on-site installation of supporting structures. When completed, each pontoon module is capable of floating so that they can be floated or towed to the bay site and assembled on water to the final built-form with minimal on-site work. On the other hand, filling the seabed and waiting for it to settle often requires time, anywhere around 2–5 years, before construction may occur.

3 Design Concepts

The design concepts are developed based on considerations in response to these challenges, as well as low acquisition and maintenance cost.

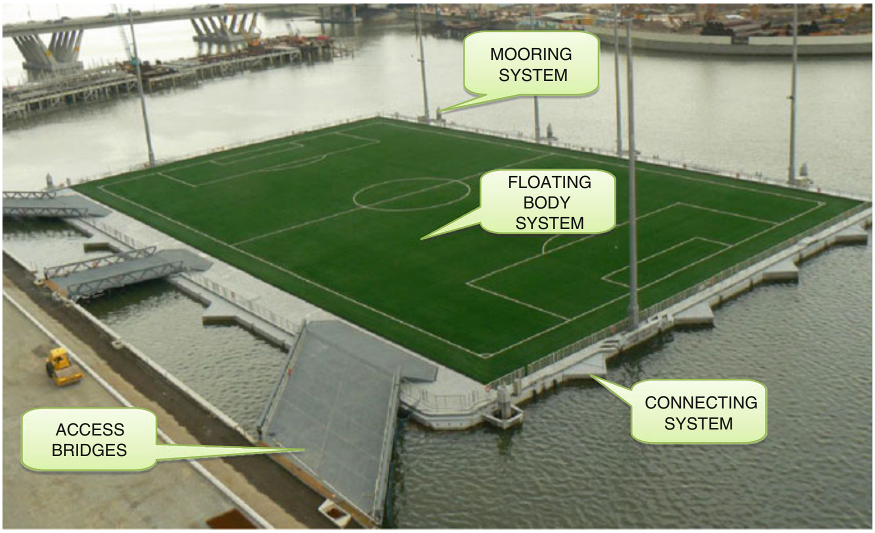

Fig. 4 System description of floating performance stage at Marina Bay

3.1 System Description

The floating platform at the Marina Bay is characterised by four main components,[2] as shown in Fig. 4, that need to be well integrated to achieve the desired outcome:

- Floating body
- Connecting system
- Mooring system
- Access bridges or linkways

3.2 Floating Body

The floating body or platform comprises the fifteen identical pontoons of dimensions 40 m × 16.6 m × 1.2 m each (see Fig. 5), which works on Archimedes' principle of buoyancy. The pontoon is of welded mild steel construction owing to the material's high tensile strength and elasticity to the heavy loads. They float on water, and as such, easier to move around.

Each pontoon is a box-type structure based on two longitudinal and two transverse watertight bulkheads to subdivide it into nine watertight compartments

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[2] The breakwater was eventually provided by the Marina Barrage erected to create a reservoir in the Marina Bay.

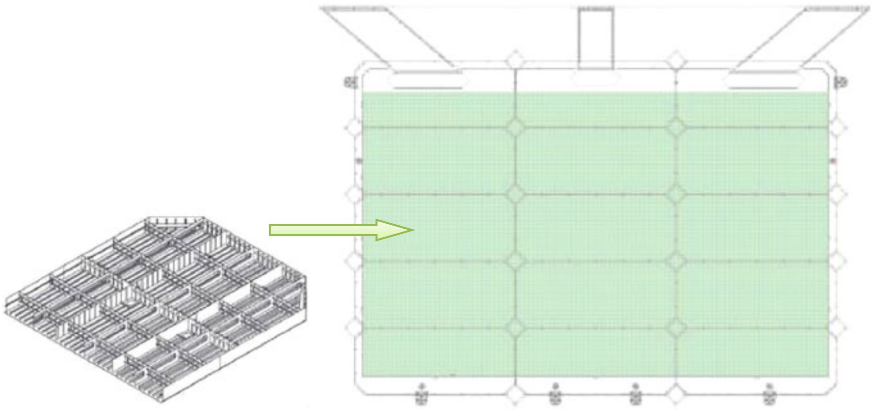

Fig. 5 Plan view of floating platform consisting of 15 pontoons (each measuring 40 m × 16.6 m × 1.2 m) connected together and three access bridges

to keep it stable in the event of flooding. Three non-watertight longitudinal full-depth web frames and several transverse frames were installed. The pontoons are characterised by their low depth-to-length ratios. The self-weight of the floating platform is about 2,800 ton.

The floating structure is subjected to heave (up/down) movement and rotational motions (about the horizontal axes) when load is applied. The buoyancy force acting from below the structure stabilises heaving movements and oscillations caused by gravity and dynamic loads. However, eccentric loads and/or moments can cause tilt movements or deflections in the floating structure, with one of its sides rotating deeper into the water.

3.3 Connecting System

The principal considerations for the connecting system include the need to satisfy the structural requirements that address the operating conditions, structural strength, serviceability, durability and safety standards.

The connecting system ensures adequate strength and rigid connection to the floating platform when the pontoons are inter-locked, and yet shall be easily dismantled and re-configured. These pontoons are joined at the corners using a floating corner connector and along the mating edges with side connectors (five along the longer edge and two along the shorter edge). These are made of high tensile steel and designed to withstand the heavy static loads and dynamic forces resulting from personnel movement and wave motion.

The corner connecting system utilizes the full depth of the platform and consists of a male member at the corner of each pontoon and a female member of a 4 m by 4 m diamond-shaped floating connector unit (see Fig. 6). The hollow edges of the

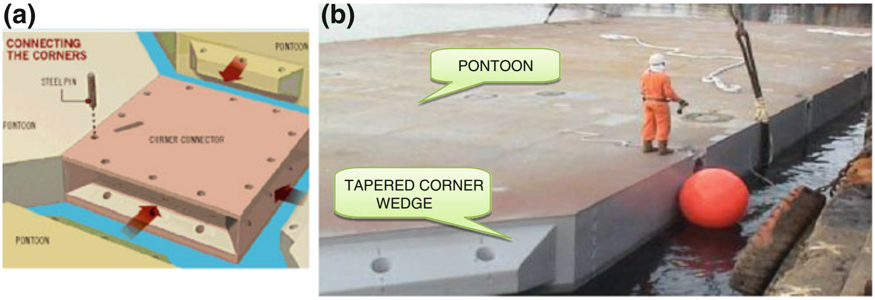

Fig. 6 Joining the pontoons using the corner connector

Fig. 7 Joining the pontoons using the side connector

corner connectors slip into the tapered wedges of the pontoons. The coupling members are kept in place by detachable steel locking pins. Twenty corner connectors are used to assemble the stage.

The pontoons are locked adjacently using blade-type engagement to bear the tensions and bending moment between adjacent pontoons (see Fig. 7). These side connectors lock the top involving steel stubs and bottom of the adjacent pontoons together to form a rigid connection so as to ensure that there is no differential displacement which may render the platform non-operational. Eighty side connectors are used to assemble the platform.

3.4 Mooring System

A mooring system is used to hold the floating platform in position considering key factors of the current and waves, and environmental constraints of shallow water

Fig. 8 Detachable mooring system

and tides as well as wind. Conventional mooring systems involving cables and chains were found not suitable for the floating platform because the tidal range was relatively large (of up to 4 m) when compared to the shallow depth of the platform. 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 m. The heavy frame-guide dolphin mooring method and caisson-type mooring system were also unsuitable because the floating platform has to be moved to another site from time to time. Therefore, a dolphin mooring system of six piles (4 on the long side and 1 each on the short side) with the aim of restraining the lateral and yaw movements, and easing the process of installation was devised. But these dolphins are designed to be detachable just above the seabed to allow a clear water surface for sea-sporting activities in the bay.

Each detachable mooring system comprises four components, namely the mooring pile, the platform anchor, the casing pile and the fender rollers (see Fig. 8). The casing pile is rammed 16–20 m into the sea bed and protrudes about 50 cm above the seabed to provide a footing where the upper removable mooring pile is secured by bolting at mating flanges. The top of the pile is linked to the sides of the floating platform via fender rollers using the platform anchor attached. The loads and moments exerted by the floating platform are transferred to each pile via the rubber fender rollers. The rollers guide the stage up and down as the current and tide change.

3.5 *Access Bridges/Linkways*

Three wide access bridges connect the floating platform to the land and seating gallery for the access by vehicles and mass movement of people onto the platform. Evacuation and rescue are also important design considerations.

The centre bridge is 8 m wide and 23 m long and can carry 30-ton vehicle. The two side bridges are 10 m wide and 40 m long for people and light vehicle. These bridges have to be designed in two segments. The first segment is a fixed bridge

Fig. 9 Access bridges

supported by foundation piles. The second segment is a gangway, articulated at one end with hinged connections that help it move with the tide so that the change in the gradient of the gangway allows unaffected access at all times despite the tidal variations in the bay of 4 m (see Fig. 9). The other end of the gangway moves horizontally on the deck resulting from the tidal change. The access bridges have the ability to match the tides for serviceability and comfort.

4 Design Analysis

The analysis and design of floating structures need to have special considerations when compared to land-based structures.

4.1 Structural Analysis

The floating platform is of welded mild steel construction and has been designed according to the American Bureau of Shipping (ABS) Rules for Building and Classing Steel Vessels for Service on Rivers and Intracoastal Waterways, as well as applicable industry standards and codes. This was complemented with building construction rules for the mooring system design and access bridges.

The primary hull structure of the pontoon has been designed with a uniform deck loading and 30-ton wheeled vehicle loads, which resulted in the top plate thickness of 12 mm. The bottom and side shells are of 8 mm thick plates. For the global response, as there were no established rules for the design of thin flexible plated structures and for connecting multiple pontoons as an integral platform, a first-principle approach was adopted for the structural design. This requires extensive finite element analysis to predict the static bending structural responses of the floating platform (including the connectors).

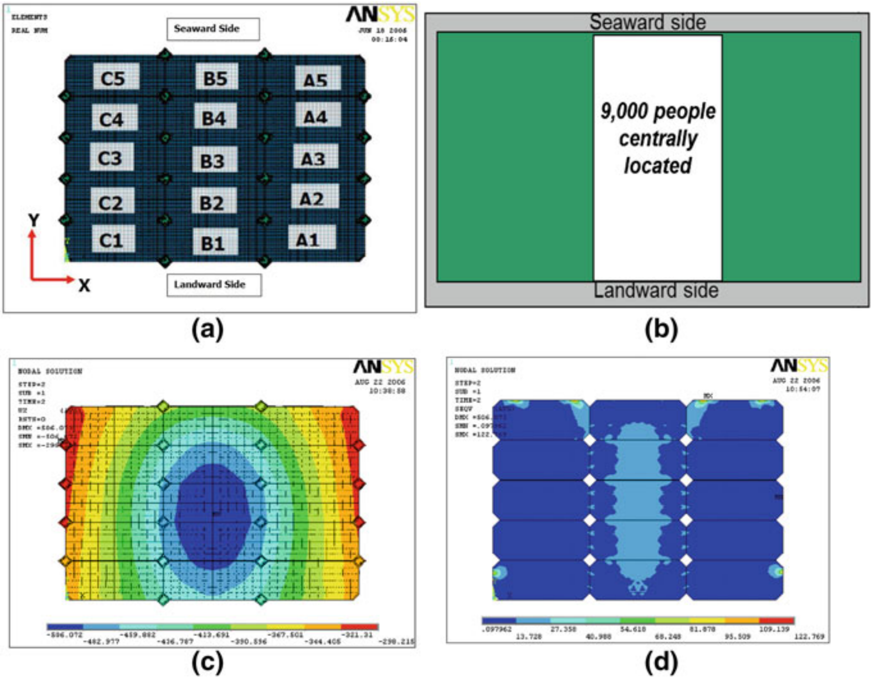

Fig. 10 **a** Finite element model of floating platform. **b** Load case: live load centrally located. **c** Plots of vertical deflections. **d** Plots of von-Mises stress on top deck

The response of the global platform to various loading scenarios was analysed using a three dimensional (3D) finite-element model of the complete platform, consisting of the fifteen pontoons, the connectors and the three access bridges. For the finite-element model of the pontoon, plate and beam element elements were used. Supporting the platform model are linear springs that simulate the buoyancy force. In-plane restraints were applied at the six mooring piles locations. Figure 10a shows the computer model used for the engineering analysis.

For the static analysis, the floating platform under static dead weight (including its own weight, stage props or towers) and different live load scenarios including eccentric patterns (due to personnel movement) (for example, Fig. 10b) were studied to determine the stress distributions and deflections (tilt movements) of the platform as well as the maximum loads at the connecting system. For structures (such as multi-media screens) that are subjected to wind loading, the loads transmitted to the top deck of the platform have to be considered.

The stresses are checked against material strength requirements while the vertical deflections were checked against serviceability requirements. Figure 10c shows the vertical deflection contours in the plan view of the floating platform under static dead weight and the live load scenario depicted in Fig. 10b. The platform is not flat and is in sagging condition. In this example, the platform displaces a maximum of about 500 mm towards middle of the platform to a

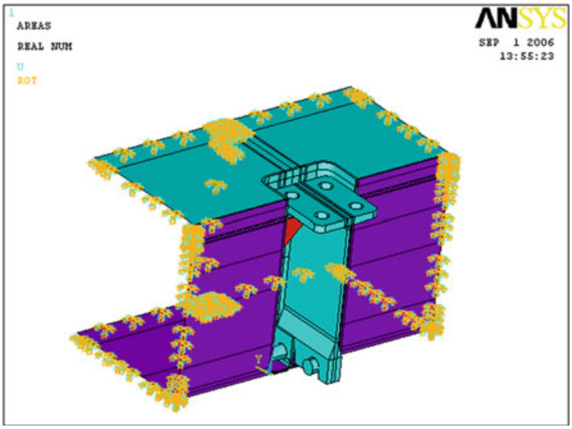

Fig. 11 Boundary conditions for localized finite element model of side connector and its housing

minimum of about 300 mm at the sea side of the platform. For the thin-plated floating platform, the maximum deflection is less than $L/400$, where L is the span of the platform. Stresses in all steel plates and stiffeners owing to the most unfavourable loading conditions, have to remain below the allowable factored material yield of 188 MPa (based on 0.8 × allowable material limits of 235 MPa). Figure 10d illustrates the von-Mises stress on the top deck plate.

From the results of the global response analysis, the local stress response at both the corner and side connectors under combined loading was evaluated using detailed structural modelling and static analysis. Figure 11 shows the local structural model for the analysis of the stress response of the side connector with its housing. Figure 12 shows the results of the finite element analysis of the corner and side connectors in terms of von-Mises stresses.

In areas of high stress concentration, such as pipe sleeve or connector pin, high tensile steel (355 MPa) is used for the corner connector. The side connector is constructed of the high tensile steel material to keep stresses within their allowable tensile stress limits.

(a) (b)

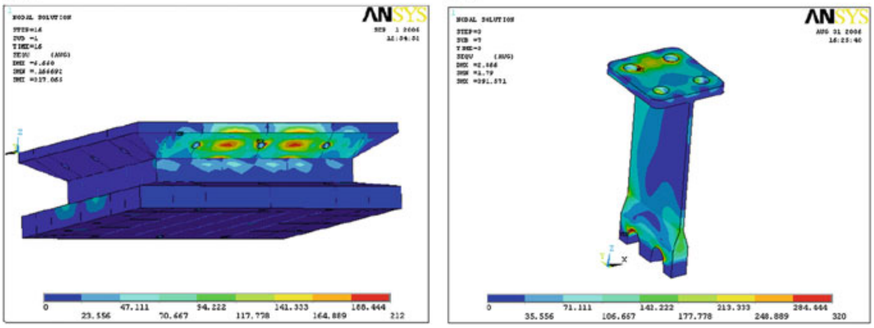

Fig. 12 Plots of von-Mises stress. **a** Corner connector and **b** side connector

For the mooring system, the design of the piles was performed considering the operational and survival environmental conditions: wind speed (20–30 knots), water current (2 knots) and significant wave height (0.5–1 m). For the sizing analysis, the floating platform was considered as a rigid body since it has large flexural rigidity in the horizontal direction. The extreme scenario where the forces are assumed to be co-linear and act simultaneously in the same direction both perpendicularly to the long side and parallel to the long side of the floating structure was simulated. These forces are calculated using the force pressure balance to derive the lateral loads, which are then distributed among the piles. The wave force (using Morison's formula) and current acting directly on each pile are added to its load carrying capacity. The horizontal displacement of the pile is adequately controlled. The upper and lower column of the piles has an outer diameter of 914 mm and is bolted together by 20 bolts, each of allowable tensile strength of 450 MPa.

For the access bridges, the two outer bridges were designed for performers or personnel and use by pedestrians. The centre bridge is assessed by both vehicle (one 30-ton vehicle) and people loading (400 kg/m^2). Based on the loading assumptions and the structural arrangement, the required minimum section modulus for the bridge structural members (truss girders, longitudinals and transverses) and the required minimum deck plate thickness have been assessed in accordance with the Canadian Institute of Steel Construction (CISC) beam formula and ABS "Rules for Building and Classing Steel Vessels for Services on Rivers and Intracoastal Waterways" (1997) respectively. The Lloyd's Register's "Rules and Regulations for the Classification of Linkspans" (1998) was used to define the load cases and to establish the maximum allowable stress and deflection criteria, which were used in defining and evaluating Finite Element (FE) model. The FE analysis was conducted to assess the distribution of stresses for the bridge truss girders in response to the maximum loading conditions as defined by the Lloyd's Register "Linkspans" rules. The Lloyd's Register rules define load conditions for vehicle loading, and for people loading.

4.2 Buoyancy and Stability Analysis

When the floating platform is fully loaded it sinks to a draft of 0.5–0.6 m, allowing adequate freeboard to prevent any water from getting onboard.

The robustness of the floating platform and each single pontoon is checked for its stability. The design of the pontoons and the floating platform meets the International Maritime Organisation's (IMO) guidelines for intact and damaged stability, with each pontoon having at least two-compartment subdivision status. The intact and damage stability computations of the single pontoon and platform are based on static and calm water conditions. The assessment of the stability was carried out in accordance with IMO's guidelines for stability criteria, Resolution A.469(XII) "Guidelines for the Design and Construction of Offshore Supply Vessels". Different loading conditions were considered and the "worst" deck loading generally corresponds with the maximum deck loads, resulting in the least freeboard.

For the intact stability, the metacentric heights (GM) for the different loading cases are way above the stated criteria of 0.15 m. Comparing with the computed limiting VCG curve, the stability of the pontoon and platform for all loading conditions are well within acceptable limits.

The floating platform is assessed according to "two-compartment" damaged stability. For each floating platform configuration, there are more than 10,000 unique two-compartment flooding combinations to be analysed. Given that the IMO damage criteria as applicable to the floating platform is defined in terms of submergence of the margin line (i.e. deck edge) and positive stability, several factors were considered to reduce the number of computational cases to a manageable number, for example:

- Symmetry in configuration and compartment sizes;
- Similarity in the righting arm curves for light and loaded conditions;
- Maximum draft condition is always the limiting load condition;
- Maximum reduction in freeboard occurs when the compartments that are damaged are those which create the largest heel and trim.

The critical damaged condition occurs when damaging the largest adjoining compartments whose joint centroid of buoyancy is furthest from that of the intact floating platform. The damaged stability was thus restricted to the largest draft condition in each configuration and the damaged compartments that gave the worst angles of heel or trim by virtue of the distance from the centre of buoyancy. For all cases, the damaged stability for the floating platform and pontoons meets the IMO criteria by wide margins. Owing to the large horizontal dimension of the floating platform, it remains stable, even in the event of flooding of a few compartments.

4.3 Frequency Analysis

An important parameter for hydrodynamic analysis of floating structure is the natural frequency of the structure. To avoid resonance and any response enhancement, the natural frequency of the floating platform should be significantly less than the frequency of exciting forces. The anticipated forces include effects of the marching contingency or performers during the NDP, jogging or running. Figure 13 shows the first two vibration modes of the floating platform and the natural frequencies are 0.99 and 1.02 Hz respectively. These were low frequency motion and less than the typical exciting frequencies of 2–3 Hz.

Besides ensuring that the access bridges were designed with adequate strength, deflection and vibration (resulting from human movement) analyses were performed to determine the required structural stiffness. The natural frequency of each of the two segments were computed and measured. These were found to be above 4 Hz.

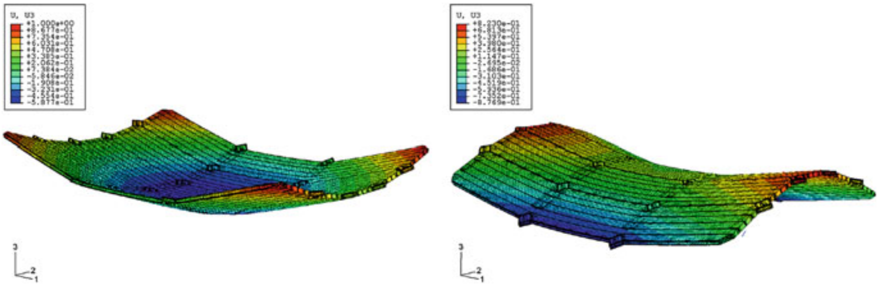

Fig. 13 Vibration frequencies and mode shapes. **a** First mode: 0.99 Hz and **b** second mode: 1.02 Hz

4.4 Hydroelastic Analysis

As the floating performance stage is relatively flexible due to its low profile in relation to the length dimensions, it exhibits elastic behavior similar to a thin plate when subject to wave actions (Fujikubo 2005). Waves caused heave oscillations, roll and pitch and variances in buoyancy along the length and width. Hence there was a need to perform hydroelastic analyses to estimate the structure and connector loads when the floating platform was exposed to the action of waves found in the Marina Bay (Wang et al. 2008a).

The challenge posed in the hydroelastic analysis was the modelling of an equivalent plate that captures the dynamic flexural behaviour of the floating stage. The floating platform was modelled as a thin plate and numerical technique was used to solve the fluid-structure interaction to determine the vibration frequencies and model stresses of the floating structure. This is done by determining an equivalent solid plate model (having the same length and overall depth dimensions as the actual structure), but its Young's modulus and Poisson's ratio were adjusted to furnish the same flexural stiffness and deflection behaviour as the floating platform. To do this, a free vibration of the floating platform modelled by the detailed finite-element model was performed. By adjusting the Young's modulus and Poisson's ratio so as to match the free vibration frequencies and mode shapes of the equivalent plate model with the results of the detailed finite-element model of the floating stage, the Young's modulus and Poisson's ration were determined for the hydroelastic analysis. To account for the flexibility at the connecting lines of the pontoons, plate strips (1.2 m in depth) along the boundaries were adopted to simulate the connecting system (see Fig. 14).

The analysis shows that the hydroelastic response of the floating structure is relatively mild due to the calm waters in the Marina Bay when compared to the static bending response from imposed loads (Fig. 15).

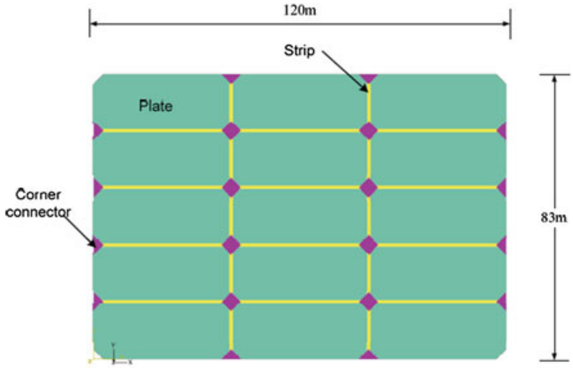

Fig. 14 Proposed equivalent plate model

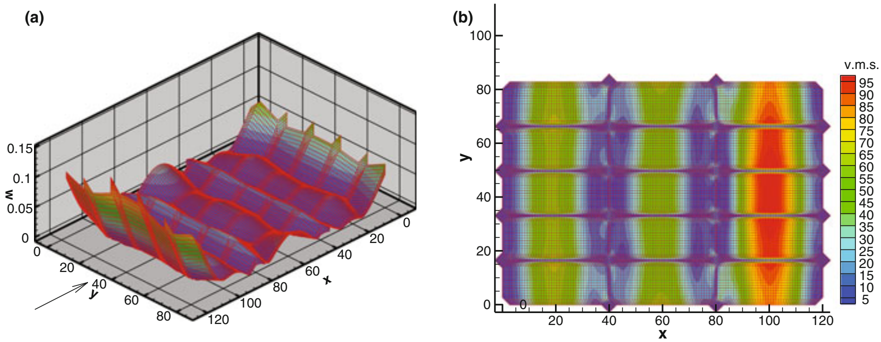

Fig. 15 Deflection and corresponding von-Mises stress in the bottom plate of floating platform under head sea of wave period = 2.4 s and water depth = 0.8 m

4.5 Heave Analysis

Another important area to study is the dynamic behaviour of the large floating platform in a heaving harmonic motion when some 9,000 performers or people simultaneously jumping in a mass event such as the National Day Parade. The objective is to estimate the heaving response of the floating structure so as to establish whether the participants will be comfortably at ease during their performances (Wang et al. 2008b).

By assuming the platform as a rigid body, the added mass and damping coefficient are first estimated. This requires the evaluation of a three-dimensional velocity potential governed by Laplace's equation. The Green's function method was used to solve the boundary value problem for frequencies ranging from 0.01 to 0.50 Hz to obtain the added mass and radiation damping coefficient. The added mass decreases with increasing frequency values, with rapid decrement at the lower frequency values. For high frequency values, the added mass becomes relatively small. The radiation damping coefficient first increases with respect to increasing frequency values and reaches a peak value at about 0.05 Hz, and then it decreases finally to a zero value for a very high frequency value.

Based on the estimated added mass and radiation damping, the finite element software NASTRAN was employed to solve the transient dynamic problem for the displacement and acceleration responses. The impulse force used for the transient problem is based on experimentally obtained ground reaction force (due to a human jumping) as measured by using a force plate.

Figures 16a, b show the heaving displacement with responses (positive sign indicates downward direction) for 2 and 50 s durations, and Fig. 16c, d present the acceleration response (positive sign indicates downward direction) for 2 and 50 s for the full-size platform when the performers jumped up and down once. These results are the same for more than one jump. As anticipated, owing to the relatively high natural period for heaving and critical damping factor, the transient displacements (maximum value of 0.30 mm) and accelerations (maximum of 0.0105 m/s^2) are relatively small. These transient responses will not be perceived by the performers. The large size floating platform provides a much greater inertia (due to greater added mass and radiation damping coefficient) in resisting motion. This advantage cannot be realized when the platform is supported at its edge and suspended in air. This human response analysis provided the assurance that the floating stage is suitable for mass performance and sporting activities.

4.6 Hydrodynamic Model Tank Tests

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 collected for engineering analysis. In particular, the experimental results obtained allowed the calibration of the wave loading applied to the global finite element analysis. Figure 17 shows the hydrodynamic model test to examine the performance of the floating platform.

5 Construction, Assembly and Verification Testing

To minimise on-site welding, the pontoons, connectors and access bridges were pre-fabricated off-site and transported to the Marina Bay.

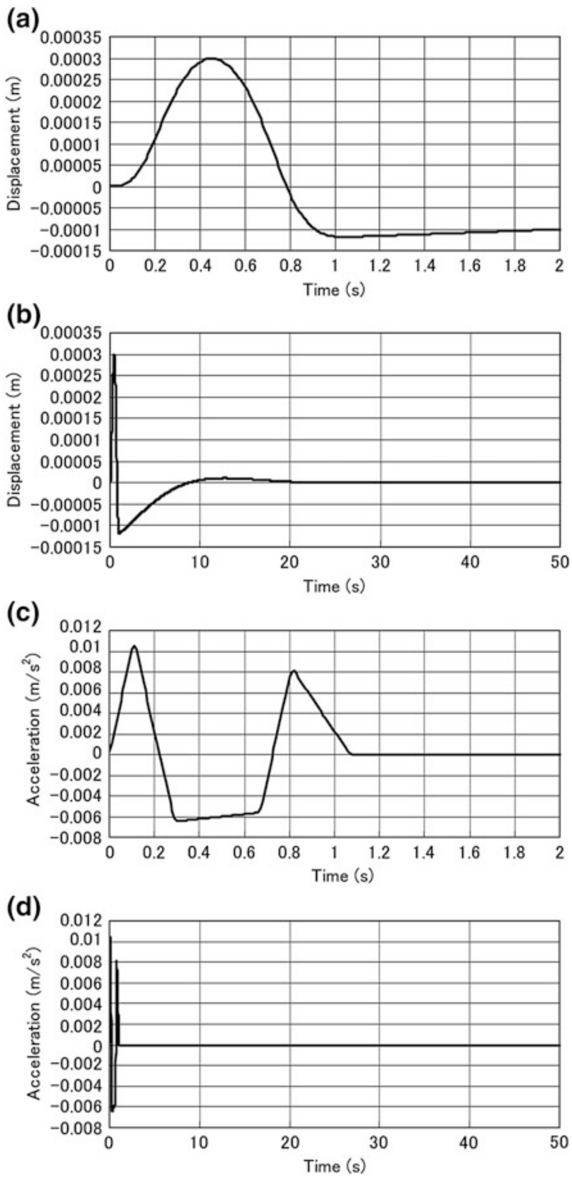

Fig. 16 Heaving displacement response for full-size platform **a** until 2 s and **b** until 50 s. Heaving acceleration response for full-size platform **c** until 2 s and **d** until 50 s

5.1 Installation of Fixtures at Site

Concurrent with the pre-fabrication off-site, the supporting piles for the three access bridges and the mooring piles were installed at the Marina Bay site (Fig. 18).

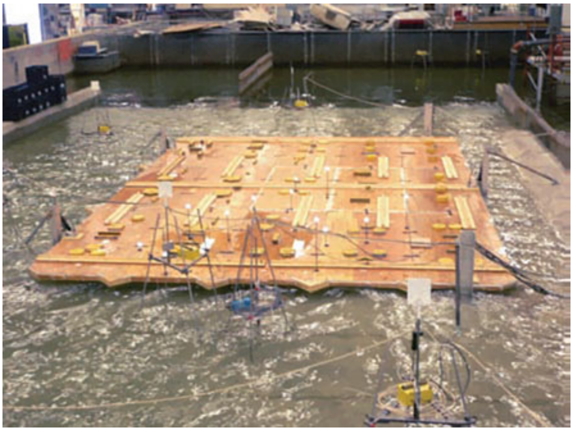

Fig. 17 Hydrodynamic model test

Fig. 18 **a** Installing supporting piles for access bridge. **b** Installing mooring piles. **c** Completed fixtures in Marina Bay

5.2 Component and Full-Load Testing

In addition to numerical computations, prototype model of the corner and side connectors were constructed and load-tested in the workshop to verify the stresses and elastic deformation (see Fig. 19). These were measured and the results were compared with the finite element analysis.

Before the final installation of the floating platform in the bay, the mooring piles were also subjected to pull load test to verify its holding strength and elastic deformations (see Fig. 20).

5.3 Transportation to Site and on-Site Assembly

The pontoons were transported or towed individually by tugboats from the shipyard where they were fabricated, to the Marina Bay. The journey included a passage through the open sea and a sailing through the Marina Barrage, which was

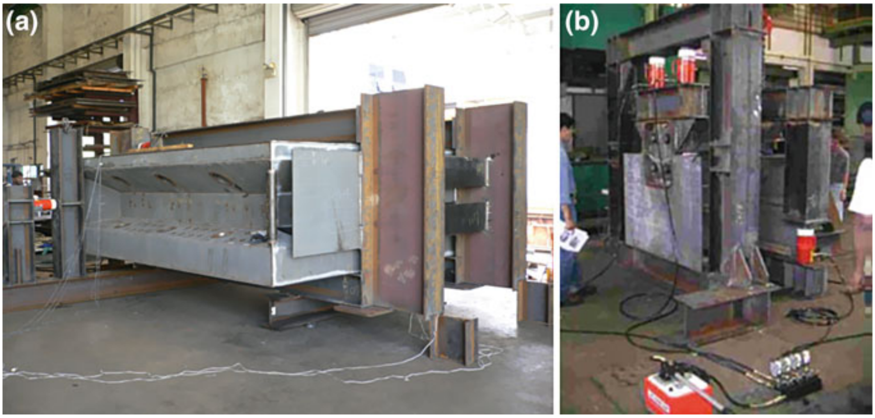

Fig. 19 Full-scale prototype load testing. **a** Corner connector and **b** side connector

Fig. 20 Load testing of mooring piles. **a** Pull cable attached to pile. **b** Pull cable attached to winch onboard barge and **c** pull load test set-up with barge

Fig. 21 **a** Pontoons being towed by tug boats. **b** Passing through the Marina Barrage. **c** Arriving and assembly of floating pontoons on-site

not fully closed, at the mouth of the Singapore River (Figs. 21a, b). This is possible owing to the modular design. Once at site, the pontoons were assembled using the connecting system to form the floating platform, which was then secured to the mooring piles (Fig. 21c).

5.4 Erecting the Access Bridges

The access bridges were then erected and assembled. Because the components were to be transported by truck, the access bridges components were limited to transportable size of approximately 2.5 m by 10 m. At site, the primary structure was bolted together by way of boltable flange connections and installed in place. Once the primary structure was in place, the deck panels were installed (Fig. 22).

5.5 On-Site Testing

Extensive full-scale load tests were conducted on the platform at the site to validate the floating platform design and to ensure that the platform could withstand the large loads of performers, vehicles and stage props (Fig. 23).

Fig. 22 **a** Erecting the truss girders and **b** installing the deck panels

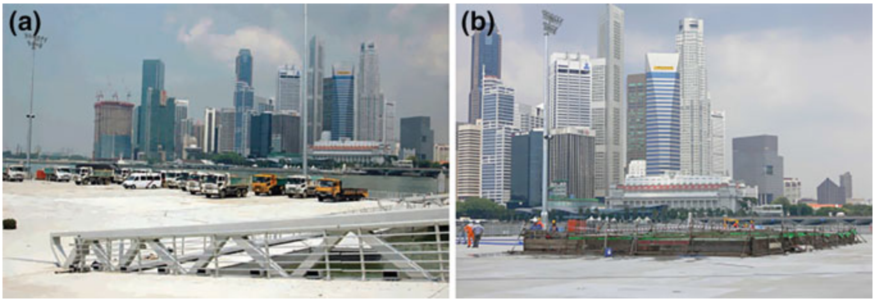

Fig. 23 Load testing of the floating platform **a** extreme vehicle load test **b** water containment load test

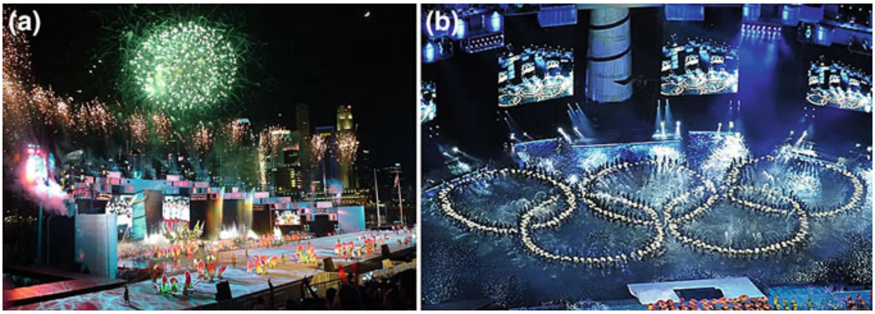

Fig. 24 Staging the opening and closing ceremonies of the inaugural Youth Olympic Games 2010 on the Marina Bay floating platform (*Photo courtesy* en.Wikipedia.org and flickr.com)

6 Conclusion

The Marina Bay floating platform is a large-scale pontoon structure and is unique and iconic from the structural engineering perspective. It has been staging the annual NDP celebrations and hosted the Opening and Closing ceremonies of the inaugural Youth Olympic Games in 2010 on water (see Fig. 24), and is now a landmark on the Singapore water. It serves to open up new frontier for space creation on water in land-scare countries and complement land reclamation, construction of high-rise buildings or development of underground caverns. It will certainly inspire many applications of the floating structure technology in floating storage facilities, mobile offshore platform, floating islands or cities and floating airports or industrial facilities in the future.

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Large Floating Structures
Technological Advances
Wang, C.M.; Wang, B.T. (Eds.)
2015, XII, 327 p. 331 illus., 282 illus. in color.,
Hardcover
ISBN: 978-981-287-136-7