

Design of an Electrified Double Track Railway Swing Bridge in Malaysia

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Summary

A new swing bridge for an electrified double track railway has been proposed in Malaysia to replace an existing 40 years old single track swing bridge. The proposed swing bridge would have two equal cantilevers of 45m in length and features a steel sail at both sides as the main longitudinal structural elements. The 9.1m wide bridge deck is steel made composite with a concrete slab. The swing span will be powered by means of an electro-hydraulic drive situated in the center pier and would slew over the center bearing located below the center pivot shaft.

Keywords: railway, swing bridge, steel composite, steel sail structure, centre pivot bearing, end locks, hydraulic slewing cylinders, deep foundation, protection system

1 Introduction

MMC-Gamuda JV presently is constructing a new 328km electrified double track from Padang Besar to Ipoh in Malaysia. The electrified railway line has been designed to accommodate the meter-gauge double track. A 282m long crossing over the river Prai near Butterworth which includes a movable bridge would be part of the double tracking works. The Prai Swing bridge will be completed on a design & build basis, and as such, MMC – Gamuda JV have appointed Leonhardt, Andrä und Partner (LAP) as their consultant to perform the tender design for the new movable bridge. LAP has broad experience in movable bridges such as the Shatt-al-Arab [1] designed & constructed more than 35 years ago.

The movable bridge would be designed as a swing bridge with two equal spans of 45m and for vessel navigation purposes would be opened to an angle of approximately 72°. The complete swinging operation will be powered by an electro-hydraulic drive supported by a centre bearing located below the centre pivot shaft at the central pier.

The new bridge would be built parallel to an existing 40 year old river bridge with a single track which includes a movable bridge of the swing type as well (Refer to Fig. 1)



Fig.1: Existing river bridge

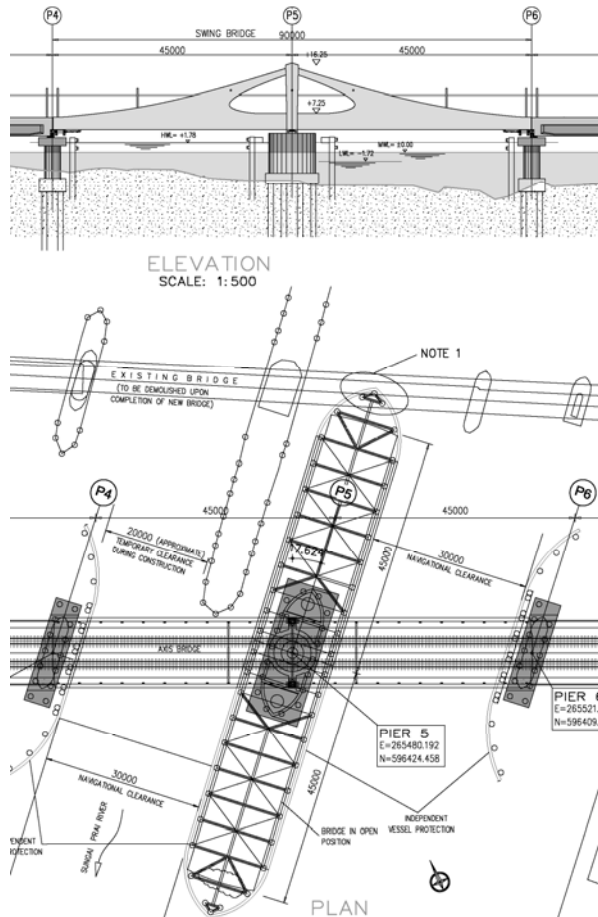


Fig. 2: General Layout of new swing bridge

2 Guidelines and Design Criteria

For the tender design LAP has been advised to give special attention to aesthetics, economy, constructability and to keep the bridge's deck width as small as possible. In addition, other aspects such as structural stability, durability, maintenance, serviceability and the navigation safety of vessels have been considered as well. Other features considered during the design stage were:

- The alignment in plan is straight and the bridge width is constant.
- The bridge is designed to accommodate two (2) new tracks spaced at 4.2m.
- The design speed of the train is 60km/h at the bridge.
- Provision for overhead electrification (contact wire 4.6m above top of rail) with structurally integrated masts/gantries at intervals of approximately 15m.
- Ballast-less track is used with composite sleepers fixed directly to the concrete deck.
- To prevent damage to structural members during possible train derailment a closed deck is used and guard rails are provided.
- The railway loadings are based on KTMB Loading Diagram A3 (locomotive with 12 axles of each 200kN followed by a trailing load of 58.3kN/m). Dynamic effects are considered in accordance with the requirements of BD37/01.
- Design wind speed of 35m/s is considered.

- Two (2) navigational channels with a minimum clear width of approximately 30m each shall be provided upon completion of the bridge. During construction a single channel with a clear width of 20m shall be provided. The existing bridge shall be demolished upon completion of the new bridge.
- The impact force of 5MN of aberrant vessels with a speed of 2 knots shall be considered at piers adjacent to the navigational channels.
- The piers are aligned in a skew angle (parallel to the current) to provide the least resistance against water flow.

3 Structure

3.1 Superstructure

The 45m equally balanced cantilever spans are composed of a steel composite deck slab supported by a grillage of steel girders, two outer steel sails with a central opening and a central column. The deck has a width of 9.1m. The steel sail is composed of an upper and lower chord and a deep web which is provided with stiffeners in longitudinal and transverse direction. The web is horizontally stiffened by a series of L-shaped sections. Vertically orientated T-shaped stiffeners, spaced at 4m, and fixed to the regular crossbeams provide stiffness transversely and provide a lateral fixation to the top chord. For aesthetical reasons an opening is provided at the sail centre. This feature provides a special design appearance and uniqueness to this bridge. At the bridge centre, a 1.0 x 2.0m column (pylon) is provided which is slightly tapered up to 2.4m at the top in longitudinal direction. The approximately 11m high column is composed of a steel box section which is welded airtight.

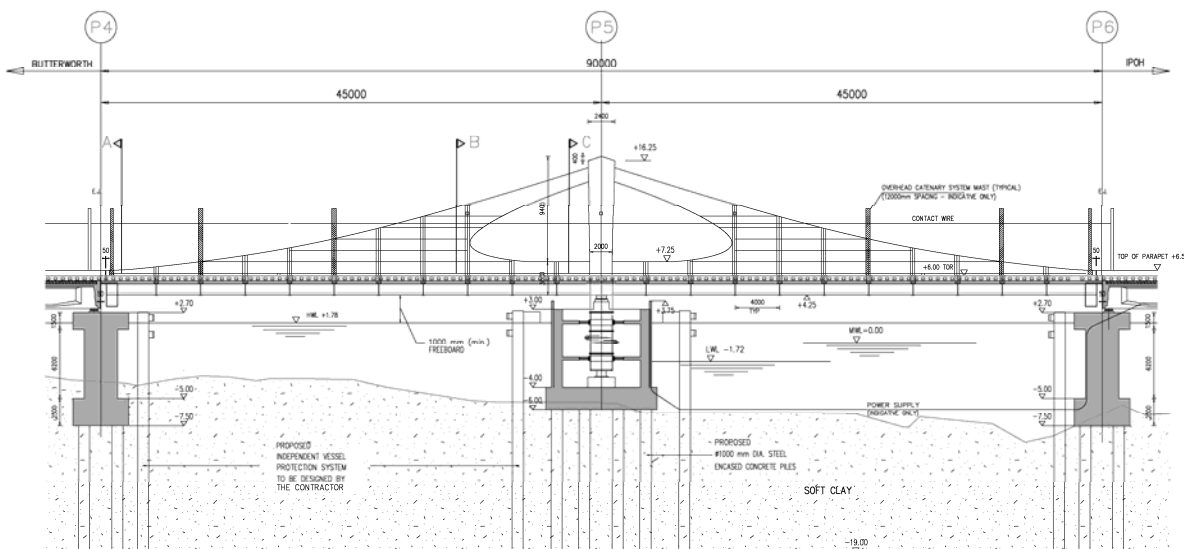


Fig.3: Longitudinal Section

The deck consists of the concrete slab, crossbeams at 4.0m intervals and 2 longitudinal stringers supporting the tracks. The regular crossbeams are of I-girder type and have a depth of approximately 1.40m to provide sufficient stiffness in transverse direction. At the top chord, shear stud connectors are provided for composite action with the concrete slab. A 2m wide central crossbeam of box type is provided at the bridge centre (axis P5). This beam is haunched transversely varying from approximately 1.4m to 2.75m at bridge axis.

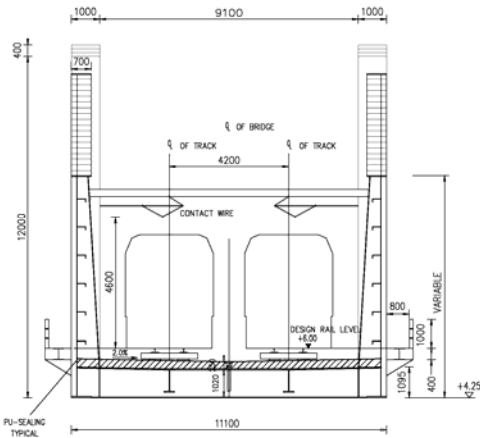


Fig. 4: Typical cross-section

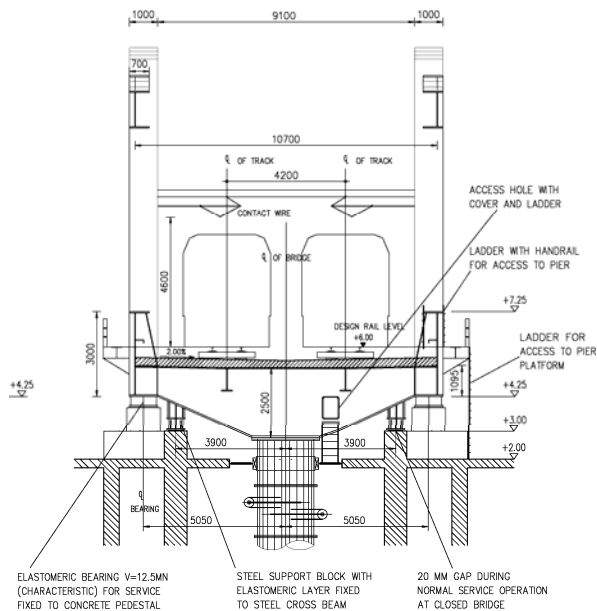


Fig. 5: Cross-section at central pier

An end crossbeam, consisting of a steel box, is provided at each cantilever end. The approximately 1.0m wide end-cross-beams are haunched transversely. The structural depth varies from approximately 1.4m to 2.25m at bridge axis providing sufficient stiffness in transverse direction which is required by the rail locking system. The steel structure shall be mainly composed of steel plates and built-up sections of steel Grade 50B. The steel structure shall be provided with a protection coating in accordance with EN ISO 12944. The concrete slab in general is 300mm thick, except at the inner 5m where the depth decreases to 250mm at bridge axis. The concrete is of Grade C 40/20. The slab is supported by a grid of steel beams and connected to them with shear stud connectors.

During bridge slewing this central crossbeam transfers the support forces from the main trusses to the centre pivot shaft. Two steel support blocks are attached at a spacing of 3.9m to the bridge axis at the bottom surface of the cross beam, which provide firm support of the bridge at its open situation. The bottom of the steel support block is provided with a 30mm thick elastomeric layer which shall equalize any unevenness on top of the concrete ring wall. For maintenance and emergency operation in case the 'lift and turn cylinder' should fail, the bridge can be placed onto the steel support blocks at any intermediate turning position and can be slewed back into the closed position. Herefore auxiliary jacks, each having a capacity of 2 x 200t, at each side of the steel support block are needed. The longitudinal stringers below the tracks consist of a steel composite section. The steel I-girders have a depth of 825mm. The bridge is supported during normal service on a single line bearing configuration situated on top of the central pier. The elastomeric bearings are located directly below the sail plane enabling a direct load path from the railway traffic. The elastomeric bearings, each have a characteristic loading of 12.5MN, are fixed on top of a concrete pedestal.

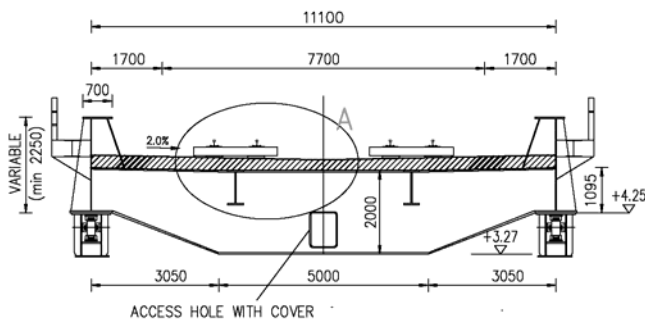


Fig. 6: Cross-section with end crossbeam

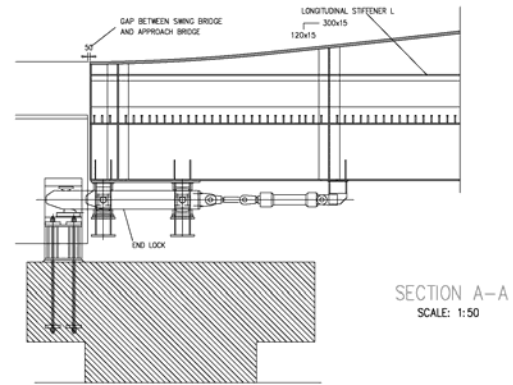


Fig. 7: Endlock

The top of the concrete is with a 2% transverse slope, free fall drainage outlets are provided at spacings of 4.0m at the bridge axis. Anchor bolts are embedded at the concrete slab for fixation of the sleepers. At the bottom of the cantilever ends of the sail, end locks are provided. For fixation of the endlocks, locally wider bottom flanges as well as stiffeners are provided. These endlocks shall achieve levelling and centering of both bridge ends. Furthermore, the endlocks serve also as support of the bridge during normal service and hence are designed herefore, e.g. for passing of trains or transverse wind.

3.2 Substructure

The 8m wide central pier shaft fulfils structural demands and M&E related space requirements e.g. housing of required machinery and equipment. For aesthetical and hydraulic reasons the pier shaft is triangular shaped at its front. With an overall pier shaft length of 25m sufficient space next to the bridge deck is provided for the installation or exchange of equipment or machinery inside the pier.

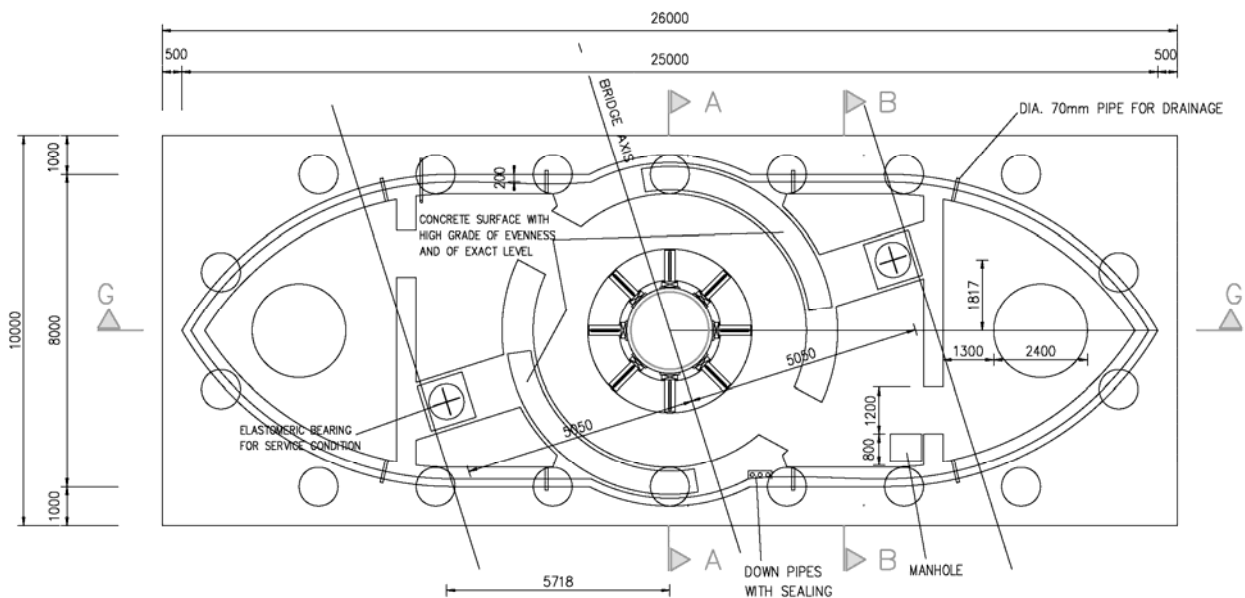


Fig. 8: Plan View Central Pier P5

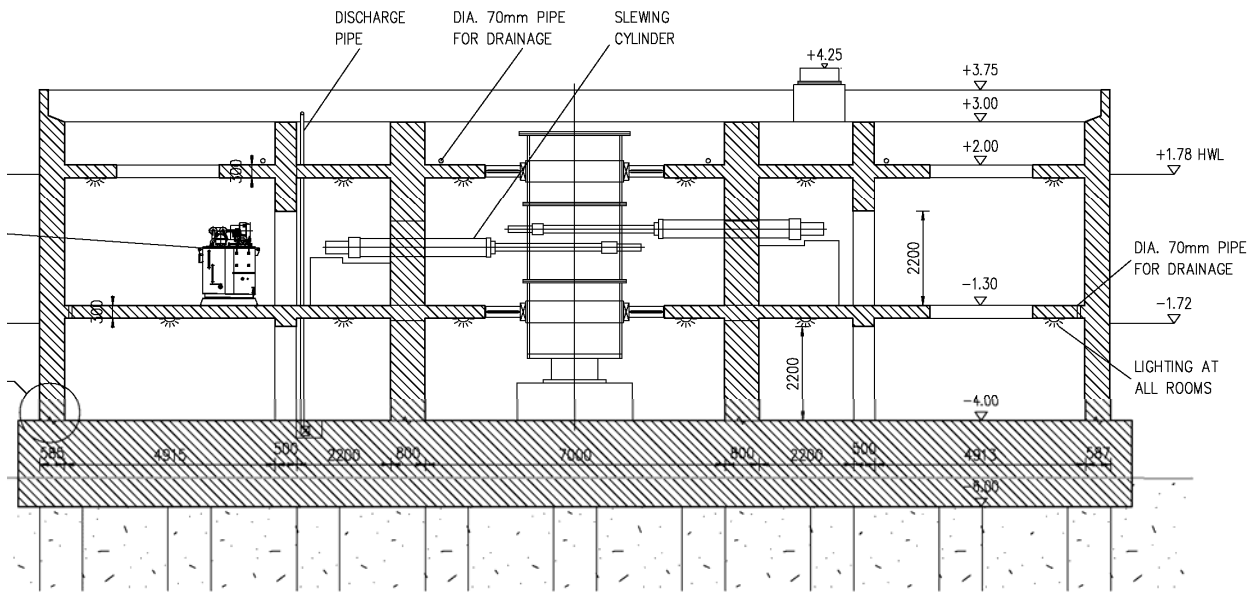


Fig. 9: Longitudinal Section Central Pier P5

The central pier shaft has a height of approximately 7.75m and provides a freeboard of about 2m in relation to the high water level. At the pier centre, an inner ring wall is provided with a mean wall thickness of 80cm. The top of the ring wall serves as firm support of the bridge deck at its open position as well as sliding path at emergency situations. The concrete surface is provided with a high degree of evenness and of exact level in order to allow slewing of the bridge deck's steel support shoes on Teflon pads which are placed on top of the ring wall. Besides the ring wall, two 50cm thick vertical walls are provided inside the shaft to support the upper crossbeams, the slabs and to stiffen the shaft. All inner walls and slabs are provided with manholes and ladders for access, inspection and maintenance and are provided with large openings for exchange of mechanical parts, equipment and material. The concrete bottom slab (pile cap) has dimensions of 25 x 10m and is 2.0m thick. Inside the ring wall, the lift and turn cylinder is supported by means of a large concrete pedestal on top of the bottom slab. The piers P4 and P6 consist of a 20 x 5m pile cap, a solid 3.0m thick shaft and the heading beam. These piers give support to the approach bridge viaducts as well as to the swing bridge. The shaft has a length of 14m and is triangular shaped at its front ends similar as the central pier. On top of the 5.2m wide skewed heading beam steel anchor blocks are provided to give support for the endlocks. All piers are supported by deep foundation using bored piles diameter 1.0m made of reinforced concrete. All piles are vertical and have a length of approximately 61.5m.

4 Drive System of the Swing Bridge

4.1 Design Features

At the Swing Bridge an electric-hydraulic drive will be provided at the centre pier in order to open and close the bridge for navigation or for railway traffic services. The slewing drive is powered by two electric motors and two hydraulic pumps acting on four hydraulic cylinders. The time for turning the swing span from 0° through 72° is about 2 minutes. The total time for opening (closing) including lifting (lowering) and unlocking (locking) is about 5 minutes; hereby the time for traffic regulation is not included.

4.2 Centre Bearing

The centre pivot shaft provides the vertical and horizontal support of the swing bridge during slewing operation only and transmits all vertical and horizontal forces due to wind load and out-of-balance to the foundation. The centre pivot shaft is of structural steel. The hydraulic cylinders for the turning drive act onto the centre pivot shaft during turning and transmit the torque due to friction, wind and inertia to the foundation structure at pier P5. For railway service the swing bridge is supported by two standard elastomeric bearings situated left and right of the centre pivot directly below the steel sail. This support system ensures that during railway service the centre pivot shaft will not receive loadings to minimize wear and tear of the turning mechanism (low operational cost). For normal turning/slewing purposes the complete swing bridge is – prior to unlocking the bridge ends – lifted by approximately 50mm by the lift and turn cylinder situated beneath the pivot shaft. This ensures that the friction forces at the end-locks are minimized during locking and centering operation. During the turning operation the dead weight of the complete swing bridge is supported by the hydraulic fluid within the lift and turn cylinder. In order to achieve stability of the bridge during turning the centre pivot shaft is supported in horizontal direction by means of guide bearings at two levels. During normal service operation, the upper guide bearings serve as horizontal support of the bridge deck, e.g. from wind loads or loads from braking & acceleration. After the bridge is turned into the opened position, it is lowered onto 2 steel support blocks which are fixed to the main crossbeam. These 2 steel support blocks take the total vertical bridge loads, whereby the pivot shaft resists any out-of-balance loading by its two horizontal guide bearing supports. No special locking device for the bridge is provided at this stage because any eccentric horizontal loadings (e.g. from wind) is resisted by the friction forces acting at the steel support blocks.

4.3 Hydraulic Central

The hydraulic central is located within the centre pier P5 and facilitates the operation of the turning drive and the locking systems. Two motor pump units are provided for opening and closing of the bridge and for operation of the locking system. In case of emergency (should the power supply or the electronic control fail) the swing bridge may be operated with reduced speed by means of separate Diesel powered emergency pump units.

4.4 Turning Machinery

Turning of the bridge is carried out with four double-acting hydraulic slewing cylinders which act with sufficient torque onto the centre pivot shaft. The hydraulic slewing cylinders are connected to the pier by means of concrete pedestals. It is not envisaged to carry out lifting and turning simultaneously although it is possible. Spherical bearings are attached to the ends of the turning cylinder (eye-bar) which allow for an oblique angle of the cylinder axis. After completion of each turning cycle no special stopping or buffer device is required. The slewing motion is precisely controlled and stopped by means of the large slewing cylinders. The capacity of the centering lock is adequate to centre the swing span precisely at the closed bridge position.

4.5 Locking System

In order to achieve proper leveling and horizontal adjustment of the bridge deck for railway service a locking system is provided which consists of 4 nos. of end locks each one per deck corner, and of 4 nos. of rail locks each one per rail track end.

The end lock achieves leveling and centering of both bridge ends. The lock capacity is adequate to lift the bridge cantilevers up to 80mm. This is necessary to level the bridge deck precisely with the approach bridges after a slewing cycle is completed. The lock will be wedge-shaped (both vertically and horizontally) for bridge lifting and be supported by sliding bearings situated within the steel anchor block. The locks will be operated by means of hydraulic cylinders.

To allow slewing of the bridge a small gap between the UIC rails needs to be provided at the bridge ends. Therefore, rail locks are provided at both bridge ends to allow for rail continuity. The rail locks are designed to allow for expansion of the rails and minor misalignment of the bridge ends due to temperature effects. The rail locks are operated by means of hydraulic cylinders.

5 Protective system against vessel impact

The purpose of protective works is to protect the bridge superstructure in its open position and its supporting piers from damage which may be caused by accidental vessel collision. Such protective works are designed to eliminate or reduce the impact forces to non-destructive levels by either redirection of the vessel, or by dissipation and absorption of the vessel energy. In accordance with the AASHTO Guidelines for vessel collision design, the piers, which house mechanical equipment or support movable machinery, should be fully protected from vessel contact by aberrant vessels. There should be no contact of the vessel with the pier or the bridge deck when the protection system is in the fully deformed position. Special consideration must be given to the overhang of the raked bows which are common for ships and barges.

At the tender design, a pile supported fender system is indicated only in principle, the final solution will be developed by the design – build contractor. The fender system is independent from the piers and in addition is acting for vessel guidance purposes. This system is a common mean of protection for shipping channels with non excessive water depth and effective in low energy vessel collision events where severe impacts are not anticipated. The indicated pile supported fender system is composed of steel piles with horizontal walers and bracings to ensure that the fender system acts as one unit with increased stiffness. The horizontal walers will be equipped with an anti-sparking rubbing surface.

6 References

- [1] SEIFRIED G., WITTFOHT H., “Swing bridge crossing over the Shatt-al-Arab in Iraq”, Beton- und Stahlbetonbau 4/1979, pp.77ff
- [2] CLARK J.H., “West Seattle Swing Bridge in Seattle”, Structural Engineering International 1/95, pp.23ff