THE ASSESSMENT AND REPLACEMENT OF SUNGAI PINANG BRIDGE

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ABSTRACT

The existence of a bridge involves a series of engineering activities from its inception till completion: planning and design, construction, control of use, maintenance and finally, replacement. The notion of these activities within the life cycle of a bridge is the basis of the "whole life" concept in bridge management.

An old steel truss bridge over Sungai Pinang in the Penang island was replaced in 2008 with two steel tied-arch structures, converting Jalan Jelutong from a one-way single carriageway into a two-way dual carriageway. The existing bridge was earlier inspected and assessed by Jabatan Kerja Raya (JKR) and a consulting firm before the decision to replace the bridge.

This paper documents the works involved, as well as the considerations made, in the assessment of the existing bridge as well as the planning, design and construction of the new one.

1.0 INTRODUCTION

The existence of a bridge involves a series of engineering activities from its inception till completion: planning and design, construction, control of use, maintenance and finally, replacement. The notion of these activities within the life cycle of a bridge is the basis of the "whole life" concept in bridge management.

An old steel truss bridge over Sungai Pinang in the Penang Island was found to be in a state of concern. The bridge was assessed of its condition; it's safe load-carrying capacity evaluated and finally a decision made to replace it. This project serves to showcase typical bridge management activities within the life cycle of a bridge. The purpose of this paper is to document the works involved, as well as the considerations made, in the assessment of the existing bridge as well as the planning, design and construction of the new one. This information and data may become useful in future maintenance and control of the new bridge.

1.1 History

The old Sungai Pinang Bridge was located on the busy Jelutong Road and carried a high volume of traffic daily. At the end of 2002, the bridge was found to have suffered from severe deterioration. The Majlis Perbandaran Pulau Pinang (MPPP) was concerned if the bridge was safe and solicited JKR's assistance. Personnel from JKR HQ, Kuala Lumpur inspected the bridge on 19 December 2002 and recommended that the bridge be replaced immediately.

In order to affirm the proposal to replace the bridge, MPPP decided that a structural assessment of the bridge should be carried out first. In this way, the decision to replace the bridge would be substantiated by a more rational and systematic approach. A consultant, Evenfit Consult (the Consultant) was then appointed by MPPP to conduct an inspection and assessment of the bridge in August 2003.

1.2 The Structure

The existing Bridge over Sg. Pinang was constructed in 1907. The bridge consisted of the main bridge structure carrying two lanes of traffic and a timber-decked footbridge at either side (Fig. 1). The main load-carrying members of the bridge comprised two steel lattice girders of build-up sections. The bridge deck of "steel buckled plate" construction was supported by cross-girders (Fig. 2), which transferred the deck load to the lattice girders. The skewed bridge deck (17° skewness) was supported at two ends by masonry abutments sitting on piles.

Fig. 1: The old Sungai Pinang Bridge

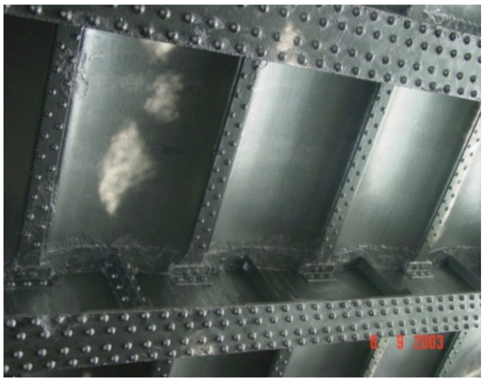


Fig. 2: Underside of the bridge deck showing steel buckled plate

2.0 ASSESSMENT OF THE OLD BRIDGE

Assessment of the old Sungai Pinang Bridge was carried out following JKR's 'Terms of Reference for Bridge Assessment Procedure'[1]. The procedure requires that the decision for bridge replacement must be based on assessment in three areas:-

i. Physical condition of the bridge.
ii. Hydraulic capacity of the bridge.
iii. Existing structural capacity.

The procedure specifies that only if there is inadequacy in any one of the above areas would the bridge be replaced. This rule reflects JKR's intention to keep a bridge whenever possible.

2.1 Detailed bridge inspection

The detailed inspection of the bridge was carried out by a team of bridge inspectors from the Consultant following the guidelines given in REAM's publication 'A Guide for Bridge Inspection' [2]. The procedures involve a systematic inspection of every major bridge components with a checklist. In addition, senior bridge inspectors also carried out an independent assessment and diagnosis of the structural problem(s) found and conceptualise its solution. Inspection was carried out mainly on foot, but for access to the underside of the bridge deck, a pontoon was used. Binoculars were also used to discern details that were too high to reach. Simple equipment like hammer and scraper were used to tap and check the severity of the corrosion.

Besides assessing the condition of the bridge members, the inspection team also carried out measurement of bridge dimensions and member sizes, defect mapping and extraction of steel samples for testing in the laboratory. This information was used in strength evaluation.

Inspection of the bridge revealed that it had varying degrees of corrosion. The main damage to the bridge was severe corrosion of the steel sections at the bottom chords and supports of the lattice girders, as well as connections between the cross girders and the lattice girders (Fig. 3 and 4). These were areas where water was easily collected but took longer time to dry up thus providing a good environment for promoting corrosion. This severe corrosion problem would have greatly undermined the integrity of the bridge and thus reducing its load carrying capacity.

Fig. 3: Corrosion at bottom chord of lattice girder at the support (newly painted)

Fig. 4: Corrosion at connection of cross girder and main lattice (newly painted)

2.2 Hydraulic Assessment

From the Consultant's inspection, the river and the drains were full of rubbish. The bridge span appeared to be too short for the width of the river thus forming a flow constriction at the bridge. However, there was no sign of scouring observed.

The river Sungai Pinang carries water from tributaries upstream and is subjected to tidal effect. The terrain within the catchment is rather flat. Nevertheless, in a study conducted by the Japan International Cooperation Agency (JICA) in 1991 [3], the flow capacity of the bridge was found to be inadequate. The current flow area at the bridge was 290m^2 whilst the JICA Study proposed a flow area of 445m^2 in order to mitigate flooding in the Penang Island. The proposed flood mitigation plan for the Sungai Pinang system involves the deepening and widening of the main stream and its tributaries. The Consultant thus designed the new bridge following JICA's recommended channel dimensions.

2.3 Strength Evaluation

For strength evaluation the JKR method was followed. This method adopts recommendations of a JKR study 'Determination of Structural Capacity of Existing Bridges in Peninsular Malaysia' [4]. The method involves comparing the sectional resistance of critical members with the effects of the live load LTAL (long-term axle load). Two scenarios were modelled: i) the structure with all its members in an intact condition and ii) the structure with resistance of deteriorated members discounted to account for section loss.

The results of strength evaluation are summarised in Table 1. From the results it is noted that the bridge, in its 'intact' condition was capable of carrying only 0.41LTAL as compared to the allowable load of 0.8LTAL, i.e., the permitted load under Weight Restriction Order 1989 (WRO'89). In the case where the loss in sections in the critical members was considered, the load-carrying capacity of the bridge was reduced to 0.33LTAL. The low evaluation load rating (ELR), even for the 'intact' scenario, was expected since the bridge was designed around 1906, using a much lower loading standard than BS 153.

Table 1: Results of strength evaluation

LOAD EFFECT	EVALUATION LOAD RATING (in terms of LTAL)	
	Scenarios	
	Intact Condition	As-is Condition
ELR Moment (Bottom chord)	0.41	0.38
ELR Shear Force (Bottom chord)	0.45	0.33
ELR Axial Force (Top chord)	0.88	0.83

** Bridges with rating ELR_{LTAL} higher than 0.8 deemed be considered adequate for carrying vehicles permitted under WRO'89.*

2.4 Assessment Results

Upon completion of the assessment, the Consultant recommended that the bridge be immediately posted with a weight restriction of 16 tonnes to reduce the chance of a collapse. The MPPP, with the advice of the JKR and the Consultant, agreed that the old bridge be replaced. Besides replacing the bridge, MPPP intended to also reconstruct the road approaches at Jalan Jelutong road to turn it into a two-lane dual carriageway.

3.0 DESIGN

For the design of the new bridge and road, the Consultant adhered to the following requirements from the authorities:-

- 2-lane dual carriageway to cater for future expansion of Jelutong Road.
- Minimal acquisition of existing land to reduce cost for land acquisition, avoid delay in construction and to reduce complaints from landowners.
- Existing free board to be maintained for the bridge to be navigable (requested by JPS).
- The bridge to be aesthetically attractive.

Three alternative design concepts were submitted and presented to MPPP. They are:

i. Alternative Design 1: 43m concrete cantilever bridge (estimated construction cost of RM 8.9 million);
ii. Alternative Design 2: 60 m Steel tied-arch bridge (estimated construction cost of RM 12.33 million);
iii. Alternative Design 3: 45 m Steel tied-arch bridge (estimated construction cost of RM 11 million)

A compromise between Alternative 2 and Alternative 3 was decided by MPPP with a revised total length of 50m (Fig. 5) as it provided more advantages than Alternative 1, i.e., meeting JPS navigable freeboard requirement, maintaining present road level to minimise inconvenience to the roadside buildings, aesthetically attractive, better quality control (off-site fabrication), shortest construction period. The beautiful arc it exhibited would make it as another landmark bridge for Penang, besides the Penang Bridge. The 50mm span length would be sufficient to clear the existing bridge foundation and skewed configuration.

The Consultant also recommended that the new bridge should comprise two independent structures (Fig. 6) to facilitate construction in two stages, so as to cause minimal disruption to existing traffic.

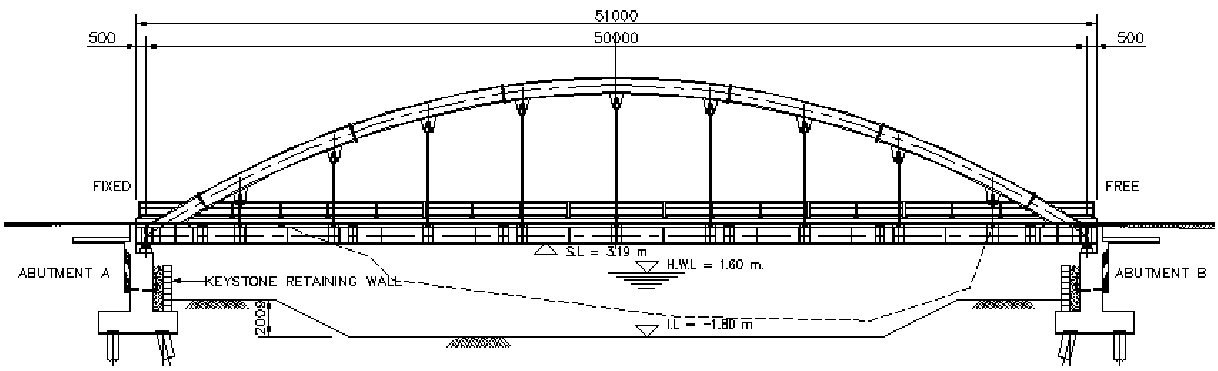


Fig. 5: Long section of new Sungai Pinang Bridge

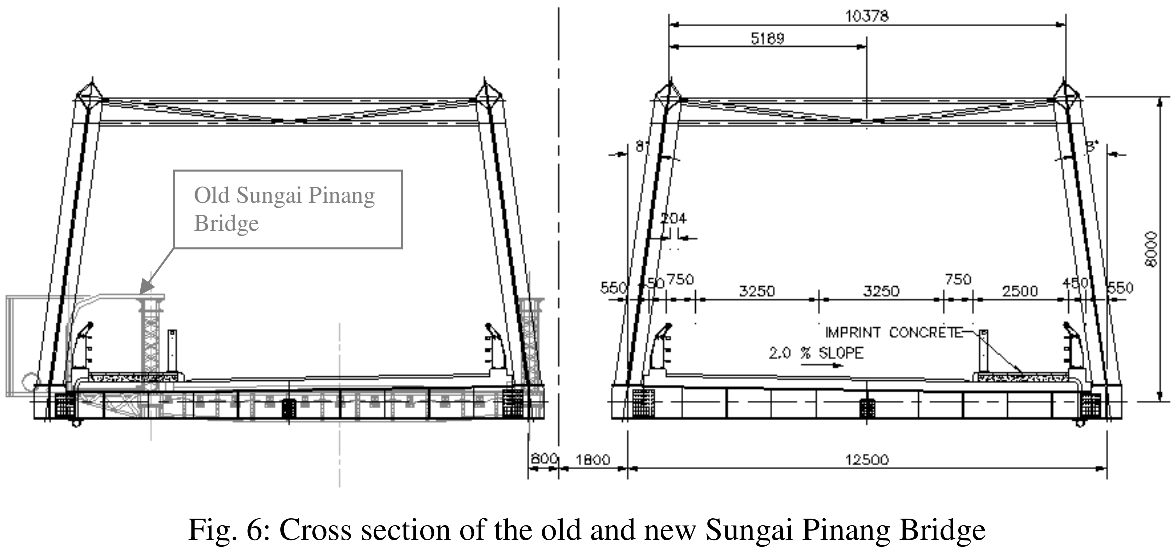


Fig. 6: Cross section of the old and new Sungai Pinang Bridge

An interesting feature of the bridge is that the arch rings are of a diamond shape which is the first of its kind in Malaysia. This detail follows a railway bridge in Manchester, United Kingdom. In addition, the arch rings were inclined at 8^o from the vertical to enhance its aesthetics. The RC deck slab was constructed using half-precast concrete slabs to do away with the formwork, thus speeding the construction and reducing the cost of construction.

Each arch structure was supported by four pot bearings seated on the retaining-wall typed abutments. The retaining-wall typed abutment was chosen to provide maximum water flow area, in accordance with JICA flood mitigation scheme. The abutments, in turn, were supported by 600mm diameter spun piles. In order to blend with the environment, keystone walls were placed in front of the abutments and the adjoining riverbanks to beautify the area thus complementing JPS efforts to spruce up the river for tourism.

The Consultant also incorporated durability features in the design by making the exposed structure curved or circular to reduce trapped water, which is the root cause of corrosion problems. All the structural steel members were also painted with anti-corrosion protective system in accordance with BS 5493. Steps were constructed to provide access to the abutments and underside of the bridge for ease of future inspection and maintenance.

4.0 CONSTRUCTION

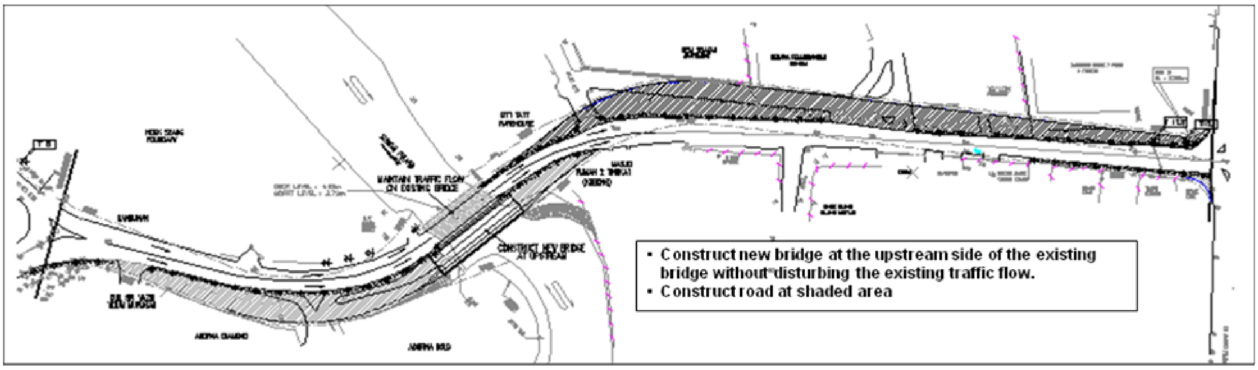
The contract to construct the bridge was awarded to a local Class A contractor Hayana Sdn. Bhd. with a tender price of RM 12,198,000.00. The details of the Contract are as given in Table 2 below.

Table 2: Details of Contract

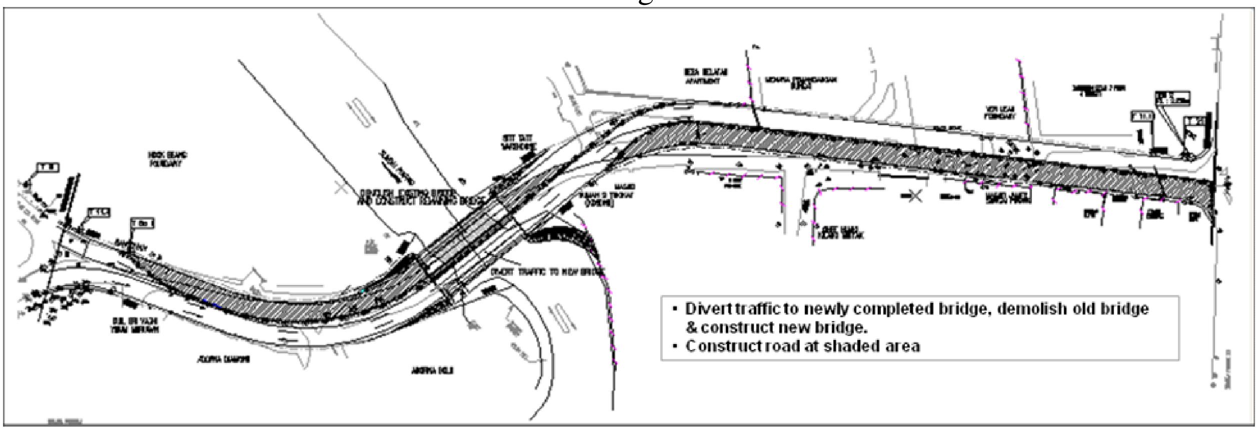
No.	Item	
1.	Contractor	Hayana Sdn. Bhd.
2.	Tender price	RM12,198,000.00
3.	Construction period	20 Nov. 2006 – 18 Feb. 2008 (64 wks)
4.	Scope	• Replace old Sg. Pinang Bridge • Upgrade Jelutong Road at both ends of the bridge – total length 600m
5.	Extension of time	19 Feb 2008 – 6 Dec. 2008
6.	Completion Date	6 Dec. 2008
7.	Quantity of concrete used	2542 tonne
8.	Quantity of structural steel used	420 tonne
9.	Quantity of steel reinforcement used	188 tonne

The construction work was carried out in two stages (Fig. 7). In Stage 1, the new bridge was constructed at the upstream of the existing bridge. Traffic was allowed to use the existing bridge and the existing Jelutong road as the road was also constructed in stages without disturbing the existing traffic.

In Stage 2, the traffic was diverted to the newly completed bridge and road. The old bridge was then demolished to make way for the construction of the second bridge. The remaining part of the new road was also constructed in this stage.



a: Stage 1



b: Stage 2

Fig. 7: Stages of construction

The bridge was fabricated off site in Seberang Perai (Fig. 8). NDTs such as magnetic particle inspection, dye penetrant inspection and ultrasonic scanning examination were conducted at the fabrication yard (Fig. 9). Besides the tests at the yard, cut-out samples were brought to the laboratory to conduct tensile, bend and charpy tests.

Fig. 8: Fabrication of the bridge

Fig. 9: Non-destructive testing witnessed by MPPP, JKR and the Consultant

When the fabrication of the bridge components was completed, the bridge was first assembled at the yard before being brought to site to ensure that all the connections fitted perfectly (Fig. 10). The assembly involved constructing the end supports and two equally spaced intermediate supports for the longitudinal girders. Then the longitudinal and the end transverse girders were assembled on the supports. The main arch was then erected starting from the end and finishing at the centre of the arch ring while being temporarily supported by a portal frame structure. This was followed with fixing of the arch lateral bracings and hangers to complete the temporary assembly of the bridge. The bridge was then dismantled and brought to site in transportable pieces for final assembly.

Fig. 10: Trial installation of the bridge at the fabrication yard

Fig. 11: The completed new Sungai Pinang Bridge

5.0 CONCLUSION

The completion of the new Sungai Pinang Bridge marked the end of a series of engineering activities within the life cycle, which started with general inspection; followed by detailed inspection and structural assessment; design of the new bridge; and finally its construction (Fig. 11). Future inspection and maintenance are expected within the next life cycle of the bridge, thus specific features, for example, sufficient headroom for inspection and jacking of the bridge deck, were incorporated in the design. The project also presented a good example on the engineering processes that were undertaken by MPPP before a decision was made to replace the old Sungai Pinang bridge. The whole process is documented in this paper and it is hoped that it can serve as a good guide for bridge owners before making decisions in bridge replacement.

REFERENCES

[1] Jabatan Kerja Raya. 2001. Terms of Reference for Bridge Assessment Procedure.

[2] Road Engineering Association of Malaysia. 2002. A Guide for Bridge Inspection (Final Draft).

[3] Government of Malaysia. 1991. Japan International Cooperation Agency (JICA). Final Report for Study on Flood Mitigation and Drainage in Penang Island.

[4] Jabatan Kerja Raya. 1995. Final Report for Determination of Structural Capacity of Existing Bridges in Peninsular Malaysia.