A STRUCTURAL ASSESSMENT STUDY ON THE SUSTAINABILITY OF SULTAN ISKANDAR BRIDGE KUALA KANGSAR PERAK MALAYSIA

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ABSTRACT

The Sultan Iskandar Bridge in Kuala Kangsar in State of Perak, Malaysia was built around 1932. It was built for seven (7) spans, 284.01m length, crossing Perak River and bridging in the towns of Kuala Kangsar and Sungai Siput. Over the years, the Bridge has been carrying as increasing traffic loads on Route 1 Federal Trunk Road. Extensive corrosion of the steel trough supporting the Reinforced Concrete (RC) deck slab, triggered an emergency structural rehabilitation in 1986. Four (4) additional numbers of 16" x 7" x 45 lb/ft steel Universal Beam longitudinal stringers were added to reduce the RC deck slab transverse span. In July 2003, the Medium-Term Axle Load (MTAL) Policy was implemented in Malaysia through Weight Restriction Order (WRO) 2003. It allows an increase in legal load limits from 10-tonnes to 12-tonnes single axle load and a corresponding increase in Gross Vehicle Weight from 38-tonnes to 44-tonnes on the Bridge. Thus, necessitating the PWD to commission a full Structural Assessment Study to provide an engineering basis for management decision on the continued sustainability of the over eighty (80) years old steel bridge. The study by a team of professional engineers was completed on 24 July 2015 over a period of eight (8) months. The Scope of Works comprised a reconnaissance survey, inspection and condition assessment of bridge superstructures, nominal material tests and bridge structural integrity and serviceability could be sustained instead of being merely replaced by another modern bridging system. The bridge was adequate for the present traffic loads in accordance with WRO 2003 for MTAL. Only very minor strengthening was required. The mild to moderate corrosion of steel members could be treated with protective coating system. Concrete carbonation was negligible. Rehabilitation works to fully restore and sustain the bridge's integrity was proposed.

Keywords: sustainability, structural assessment, bridge capacity, traffic load, rehabilitation

Introduction

The Sultan Iskandar Bridge in Kuala Kangsar in the State of Perak, Malaysia was built around 1932. The seven (7) spans steel arches superstructure bridge over River Perak (Sungai Perak) bridges the towns of Kuala Kangsar (North) and Sungai Siput (refer Figure 1 and Figure 2) :-

Figure 1: An Elevation Sketch of Sultan Iskandar Bridge

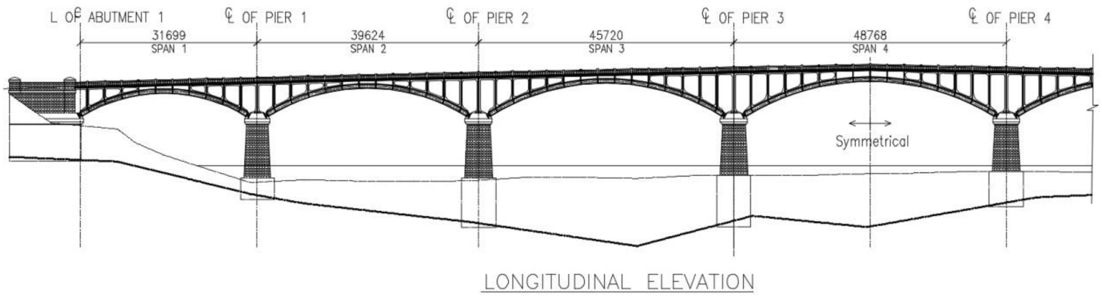


Figure 2: (a) Elevation View of Bridge; (b) View of Bridge Soffits.

(a)

(b)

Emergency Rehabilitation

The Bridge on the Route 1 Federal Trunk Road has seen increasing traffic load over the years. No significant structural maintenance works have been carried out on the very well-constructed Bridge. Nevertheless, extensive corrosion of the transverse steel troughs supporting the Reinforced Concrete (R.C) bridge deck slab triggered an emergency structural rehabilitation in 1986. Due to the urgent needs to ensure the continued structural integrity of the bridge deck structural system, four (4) numbers 16” x 7” x 45 lb/ft. steel universal beam longitudinal stringers were added to augment the R.C deck slab transverse structural capacity (refer Figure 3):-

Figure 3: (a) Elevation View of End Span; (b) Added Universal Beam Longitudinal Stringers to Bridge deck soffits.

(a)

(b)

Need For Structural Assessment Study

In July 2013, the Malaysian Medium Term Axle (MTAL) Policy was implemented through the implementation of Weight Restriction Order (WRO) 2003. It allows an increase in legal load limits from the present 10-tonne to 12-tonne single axle load and a corresponding increase in Gross Vehicle Weight from 38-tonne to 44-tonne on the Bridge. In the interest of ensuring absolute structural safety of the bridge, the Public Work Department (PWD) of Malaysia commissioned a full Structural Assessment Study to provide an engineering basis for management decision on the continued sustainability of the over 80-year old steel Bridge, which had been designed to a much lower traffic loading requirements than the present traffic intensity. The Study by a team of professional engineers was completed on 24 July 2015 over a period of eight (8) months.

Study In Brief

The basic Scope of Works included a reconnaissance survey, inspection and condition assessment of bridge superstructures, bridge piers and bridge abutments. Bridge capacity assessment involving structural analysis and design check of the bridge superstructural analysis and design check of the bridge superstructural components with respect to Medium Term Axle Load (MTAL) traffic load and nominal material tests were carried out.

Following a process of systematic engineering input, it was established that the Bridge actually could be sustained for many years to come instead of merely being replaced by another modern bridging system. In particular, the following findings were pertinent:-

- The Bridge was able to sustain the present traffic loads in accordance with WRO 2003 for Medium-Term Axle Loading (MTAL) which is of near equivalent to BD37/01 for the spans range encountered. The legal load limit for MTAL is 12-tonne single axle with Gross Vehicle Weight of 44 tonnes.
- Only very minor strengthening to some vertical steel components of the steel Arches would be needed.
- Concrete carbonation was almost negligible due to good concrete quality encountered and relatively high humid environment at the bridge site.
- The corrosion on the steel members (assessed as mild to moderate) were not wide spread and could be easily overcome with suitable application of protective coating system.

A comprehensive rehabilitation works to fully restore and sustain the Bridge integrity to sustain the present traffic loadings was proposed.

The Bridge Structure Configuration

Bridge Dimensions: -

- Bridge width between parapet = 32-0" (9.76m).
- Seven (7) Bridge spans of 2 x 104 feet + 2 x 130 feet + 2 x 150 feet + 160 feet (48.77m) centre span for total length of 928 feet (284.07m).

Bridge Superstructure: -

- R.C slab on steel Trough spanning transversely on four (4) numbers 13" x 5" x 35 lb/ft. RSJ steel longitudinal members supported on 9" x 7" 50 lb/ft. RSJ verticals rising from the riveted steel plate girders, Note that four (4) numbers universal beams were added in 1986 to enhance the RSJ members.
- The main superstructure consists of four (4) riveted steel plate girders arches.

Bridge Sub-Structure: -

- The bridge steel arches are supported on concrete piers and concrete abutments through steel bearings. The piers and abutments are on concrete caissons into riverbed.

Structural Assessment Study

The following Scope of Works were involved :-

- Review of all information and available drawings for planning of access and work methodology.
- Inspection and condition assessment of the bridge superstructure and substructure (defects mapping, verification of as-built details nominal material testing).
- Structural analysis of the bridge structural capacity, particularly the bridge Deck, bridge Deck RSJ supports, Vertical members and the arches.
- Structural assessment report and design for structural rehabilitation.
- Rehabilitation Documents: Bill of Quantities, drawings, specifications.

In the course of the execution of the study, the Team produced the Inspection Report, five (5) Progress Reports and one (1) Final Report.

Engineering Assessment

Complete visual inspection of all superstructure bridge components generally confirmed the followings: -

a) The Bridge Deck (Reinforced Concrete) and the Steel Bridges superstructure components were in good stable condition with no observed significant material deterioration or degradation as to affect the bridge structural integrity and safety.

b) There were some observations of minor (<1%) to moderate (up to 5%) corrosion on certain steel structural components particularly at: -
   - The top flange of the arch beam.
   - The end connections and bracing members near to bridge piers due to leaking water from damaged bridge deck joints.
   - Those steel members directly exposed to rainwater

c) In several locations, plant growth and debris had covered some of the surfaces of the steel members. It must be stated that the Bridge was built from 1928 to 1930. The only known significant rehabilitation was the strengthening of bridge deck in 1986 (some 29 years back). Back then, the whole steel superstructures were substantially repaired. The repainting system has lasted remarkably very well until now.

The bridge was assessed to be in good stable structural condition with no obvious signs of significant deformations, deflections or any other signs of structural instability. However, the followings are noted for subsequent repair works:-

- Missing rivets at some connections.
- Damaged expansion joints.

- Observation of crack line on the end plate of the vertical post of the steel truss at the bridge pier location. (It must be noted that the crack could not be caused by inadequate design provision. The crack was already there some twenty years back during the early inspection. However, the crack line had remained stable and did not propagate). Further assessment in the detailed structural analysis and design check confirmed that there was no structural integrity issue as the section would only be subjected to pure compression. However, structural enhancement via additional plate bonding has been recommended.
- The Bridge steel bearings were inspected and found to be generally in good operation conditions though there were some observation of debris accumulation and minor rusting. These bearings were generally termed 'rocker type' bearings though essentially for this Bridge the bearings function more like 'rotating hinge'. Some cleaning and greasing works would be in order.

A complete set of 'near-as-built' drawings (total 55 drawings) have been prepared so as to serve as future reference for the maintenance of Bridge Structure.

Structural material testing
Nominal structural material testing conducted generally revealed the following :-

a) Concrete compressive strength of: -
  - Bridge Deck > 40 N/mm^2
  - Bridge Piers > 30 N/mm^2 (Adoption of fcu = 25 N/mm^2 OK)

b) Steel Yield Strength > 226 N/mm^2 (Adoption of fy = 220 N/mm^2)
c) Concrete Carbonation Depth < 1 mm
d) Chloride content in cement < 0.07% by weight of concrete
e) Plate thickness loss about 4.2%

For the nominal material testing, it could be established that the bridge construction was carried out with good quality and durable concrete and steel material. Figure 4 shows the extraction of steel samples from the bridge.

Figure 4: (a) Extraction of steel sample at Span 7; (b) the extracted steel section was immediately made good.

(a)

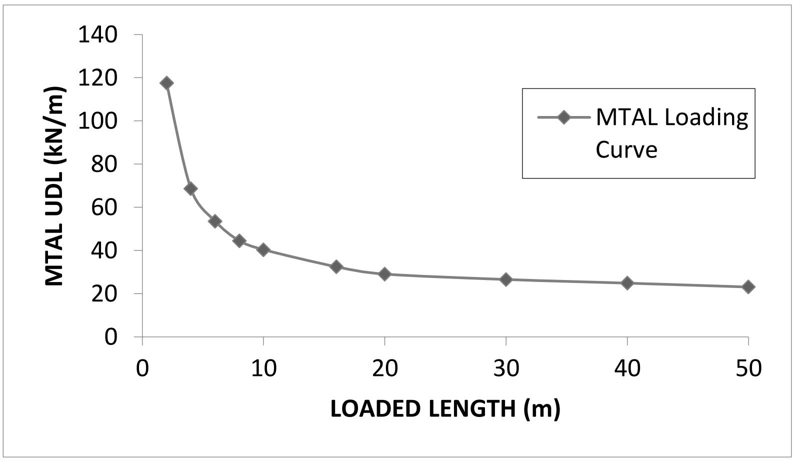
(b)

Bridge Capacity Assessment
For ease of reference, the regime of various live loadings for MTAL traffic loadings are presented on Table 1 and Figure 5.

Table 1: MTAL (HA-UDL)

LOADED LENGTH (M)	MTAL (HA–UDL) (kN/m)
2	117.5
4	68.8
6	53.6
8	44.5
10	40.4
16	32.5
20	29.1
30	26.6
40	24.9
50	23.1

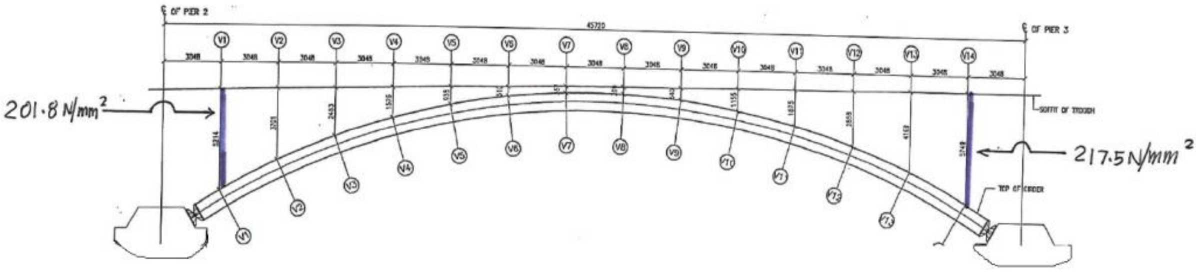
Figure 5: MTAL Uniformly Distributed Load



Structural Analysis Bridge (Superstructure): -

- Bridge Deck
  The Composite Grade 40 N/mm^2 225 mm thick Concrete Deck with BRC-A10 top reinforcement RSJs and the 1987 added universal beams was adequate.
- RSJS/UB Members
  Using adopted steel strength of 220 N/mm^2, the “permissible” steel strength use with 1.05 material partial factor was 190 N/mm^2. The steel sections were found to have maximum structural stresses of only 102.3 N/mm^2.
- Arch Vertical Members
  These were evaluated with 5% thickness reduction taking into account of the measured steel corrosion. In general, only the end member experienced steel stresses beyond the 190 N/mm^2 adopted (refer Figure 6 for typical Span 3 example): -

Figure 6: Span 3 steel arch vertical members.



The actual stresses in the steel arch members were found to be very much below the adopted steel stress as seen in Table 2.

Table 2: Maximum steel fibre stresses in the arches

Span	Outer Arches (Arch 1 & Arch 4) N/mm^2	Inner Arches (Arch 2 & Arch 3) N/mm^2
1 & 7	27.8 & 91	17.6 & 107.6
2 & 6	19.5 & 60.6	12.7 & &70.2
3 & 5	20.5 & 64.1	13.5 & 72.7
4	20.7 & 61.1	14.5 & 68.0

Structural Analysis (Bridge Substructure)

- The Bridge substructure was built of mass concrete piers on concrete pile caps sitting on caissons.
- Pier 1 (maximum height of 10.5m) was found to have a factor of Safety against overturning under the worst loading condition of only 1.08 when treated as a free body. The engineering assessment considered the stability to be acceptable as the pier did not behave as free body, but rather, the top of the pier has been deemed to be propped by the ends of the steel arches each side.
- Maximum concrete compressive stress was found to be only of the order of 1.5 N/mm^2 (very much below the threshold of 0.25 fcu = 6.25 N/mm^2).

Bridge Rehabilitation

The detailed Scope of Works, Bill of Quantities and Specification requirements for the Bridge Strengthening and Rehabilitation Works were prepared. The Works covered: -

- General Preliminaries
- Contractor’s engineering Input (optional)
- Bridge Deck Works – Replacement of Expansion Joints.
- Steel Strengthening Works for arches.

Conclusions

The study confirmed the followings on the Sultan Iskandar Bridge: -

- Overall, the Bridge structure was in satisfactory material condition with no significant deterioration to the concrete components. However, there were some minor to moderate steel corrosion on some steel components of steel Arch superstructure.
- The bridge was also observed to be in good structural condition with no observed structural defects.
- Generally, the steel Arches were able to sustain MTAL traffic Live Loading with some minor exceptions, hence the need for some localised strengthening works.
- The bridge piers have adequate capacity to safely sustain the present MTAL traffic Live Loading.

The paper illustrates a practical and systematic approach in ensuring the sustainability of an existing old bridge. The proposed Rehabilitation and Strengthening Works would ensure good satisfactory performance of the Bridge structure for years to come. Similar assessment approach may be adopted for the Bridge when a new Weight Restriction Order is implemented in the future.

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