BRIDGE PROBLEMS IN MALAYSIA

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1.0 BACKGROUND

Problems in existing bridges are often variously identified by terms such as "distress", "defects", "damage", "deterioration" and even "bridge failure". The purpose of this paper is to discuss some of the bridge problems (in whatever names one wants to call them) that the authors have encountered in their career of inspecting bridges in the Federal routes in Peninsular Malaysia, Sabah and Sarawak; bridges in Kuala Lumpur as well as bridges in privatised highways. Many of these problems had been rectified; some were rectified and recurred. Still others are not "acted on" - a classic case of "tragedy waiting to happen" [1]. It is hoped that description and discussion of the problems would give bridge designers, researchers and owners some ideas of what could go wrong with bridges.

The paper first enlists and discusses common problems that had been encountered. The more interesting cases are deliberated on. Indeed, some of these problems had also happened elsewhere in the world and been reported in the literatures. By referring to these literatures and extracting some of the explanations reported would allow the reader to have a better understanding of the nature of the problems.

2.0 BRIDGE COMPONENTS AND THEIR PROBLEMS

A bridge is fundamentally a structural system comprising many components serving different structural and functional roles. Deck slab, girders, abutments and piers are *primary members* transmitting and bringing the loads from the bridge deck down through the foundation to the soil stratum, in a complete load path. Secondary members are also important. Expansion joints and bearings, provide the articulation needed by the system to accommodate movements due to loads and temperature changes. Parapets serve to contain the vehicles within the carriageway while gullies and downpipes bring the water from the deck down to the ground clear of and away from the bridge components.

Primary or secondary, when any of these components fails to function as designed or intended, problems arise. The Road Engineering Association Malaysia (REAM) bridge inspection guide [2,3], which identifies all these problems as "damage", itemizes and describes each of them as a basis for condition rating. This paper does not intend to duplicate it but simply to discuss some of the more common ones that the authors have dealt with. They are:

i. Problems in concrete members
ii. Problems in steel members
iii. Bearing problems
iv. Joint problems
v. Hydraulic problems
vi. Excessive vibrations
vii. Impact of vehicles
viii. Vegetation growth

The remaining part of the paper will discuss items i, ii, iii and v. The other topics will be briefly explained here. The authors' experience in bridge joint had already been reported in [4]. Some updates are provided by Leaw [5]. On excessive vibration, it suffices for the purpose of this paper, to say that it is normal for a bridge to vibrate under the passage of the vehicular traffic. There is no accepted standard to say when the vibration becomes excessive. The authors had inspected a number of bridges reported to have excessive vibration: Sg. Muar Bridge, Sg. Golok Bridge, Bridge at Jalan Kinabalu, Bridge over Sg. Tuaran in Sabah (static and dynamic load tests were also carried out for this bridge) but found them to be structurally sound. The Muar Bridge, Golok Bridge and Tuaran Bridge did exhibit some scouring problems.

Damage of bridge components by impact of vehicles is common for urban bridges. Fig. 1 and Fig. 2 show some recent examples. Vegetations growing in bearing shelves of abutments and piers is also very common in Malaysian bridges (Fig. 3). Their presence does not actually cause any physical damage to the bridge component. However, the roots tend to collect dirt and retain water which can cause long term durability problem.

Fig. 1: Damage at underside of a beam in K.L. due to vehicular impact

Fig. 2: Damage at underside of beams of a bridge in Shah Alam due to vehicular impact

Fig. 3: Vegetation growth at bridge abutment

3.0 PROBLEMS IN CONCRETE MEMBERS

The majority of bridges in Malaysia are of concrete construction. Contrary to the belief of the general public, concrete does have durability and maintenance problems. Concrete may be susceptible to direct chemical or acid attack as seen in Fig. 4 , but by and large, cracking and spalling of concrete are most common in Malaysia.

Fig. 4: Acid attack of lime stone aggregates

Cracking is defined in the REAM Bridge inspection guide [2] as “a linear fracture in concrete which extends partly or completely through the member...” while spalling is “a fragment, which has been detached from a larger concrete mass...”. When the cracks widen causing discontinuity of concrete surface (but not completely detached) the term “delamination” is used.

Problems in concrete members often manifest themselves in the form of cracks. This has made diagnosis of the problems rather difficult. Cracking in concrete can broadly be categorized in terms of the nature and root source of the problem:

- load induced,
- corrosion induced, and
- intrinsic.

This way of categorisation allows the bridge inspector to assess the severity of the crack (whether it is critical or not?) and facilitate finding the right solution.

3.1 LOAD INDUCED CRACK

In structural design the endeavour of the designer is to ensure that the structural member has a resistance R that is at least equal to the load effect S. Conceptually when R<S cracks would form, the nature and pattern of which depend on whether the load effect of concern is bending moment, shear or torsion etc. We thus have cracks that can be identified as flexural (bending), shear and torsional. Pictures in Figs. 5 to 10 show examples of load induced cracks.

Fig. 5: Flexural and shear problem in beams

Fig. 6: Flexural problem in RC culvert (note tension crack at the crown)

Fig. 7: Flexural problem in RC culvert (note compression crack at mid way of the wall)

Fig. 8: Pot hole in the deck slab initiated by cracks similar to Fig. 21

Fig. 9: Cracks in the reinforced concrete bent caps

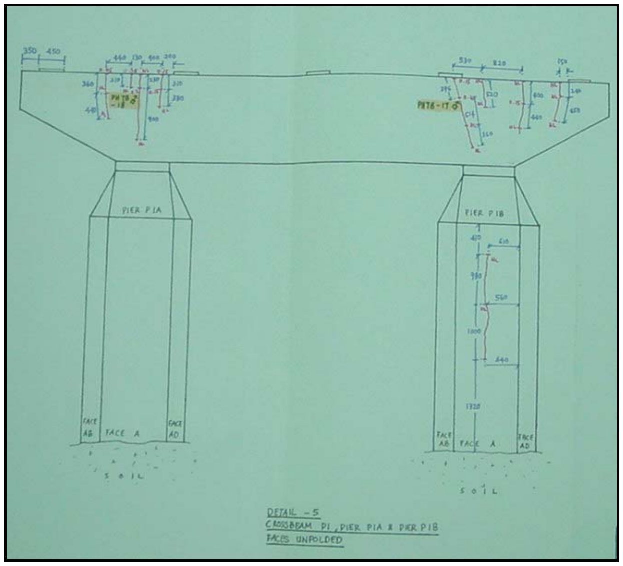

Fig. 10: Cracks as mapped out

Cracking in the reinforced concrete bent caps of a bridge in J.B. and at MRR2 had led to the interest in *deep beam* among local engineers. ACI Structural Journal had also reported on a similar type of cracking that occur in Texas highway bridges [6]. A deep beam is defined as "a beam in which significant amount of the load is carried to the supports by a compression thrust joining the load and the reaction" [7]. The transition from ordinary beam behaviour to deep beam behaviour is imprecise, and ACI Sec. 10.7.1 specifies that for design purposes an effective span/depth ratio of 1.25 (for simple spans) and 2.5 (for continuous spans) be used [7]. According to the literature, the "plane section remains plane after bending" assumption (the Bernoulli hypothesis) no longer holds for a deep beam. The conventional design practice is thus not suitable for a deep beam. In a deep beam design a strut and tie model is recommended. The reader is referred to a presentation by Fu entitled "The Strut-and-tie model of concrete structures" [8].

The anchorage zone in the box girder is also within the so-called "D-region" that is descriptive of the deep beam. Fig. 11 shows the crack patterns resembling the stress trajectories under a concentric load. The repair by epoxy indicated that the cracks were likely to have occurred during construction.

Fig. 11: Cracks at the anchorage zone (sealed with epoxy) of a box girder

Load-induced cracks are very often identified as structural cracks. The term carries the connotation of "structural failure" that require immediate attention; and rightly so considering the aim of structural design.

3.2 CORROSION INDUCED

The literatures on concrete durability discuss the "passivation" (and thus protection) of the steel reinforcement within the alkaline environment of the concrete mass. When the passivating barrier is disrupted by the ingress of atmospheric carbon dioxide in the presence of water, the environment becomes "depassivated" as evidenced by the drop of pH value from around 12 to below 11. The steel reinforcement corrodes and expands causing the concrete to crack, delaminate and spall (Fig. 12). This is known as *carbonation*.

Fig. 12: Cracks and spalling of concrete due to carbonation

In another instance the aggravating agent is the chloride ion. Regardless of whether the alkalinity is available the presence of chloride ion exceeding the threshold value would start the electrolysis process and cause the steel reinforcements to corrode. Again, cracking is the result (Fig. 13).

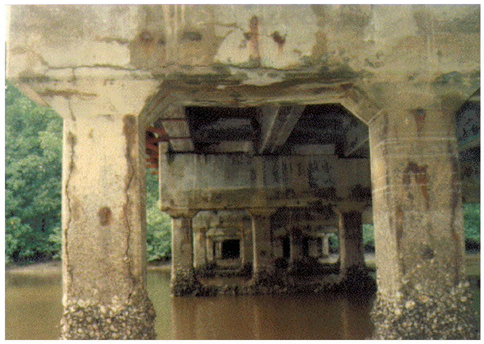

Fig. 13: Cracks at pier columns due to corrosion of reinforcement as a result of chloride attack

The concrete element cracks not under the load but due solely to the corrosion and expansion of the embedded steel reinforcement. We term this type of crack as corrosion induced.

3.3 INTRINSIC PROBLEM

While cracking problems mentioned above have their source from external actions (loading or movement) or the environments, there are cracking due to the intrinsic properties of the concrete. The UK Concrete Society has published a comprehensive report on the types of intrinsic cracks in concrete [9]. In Malaysia three types of intrinsic cracks are common: plastic settlement/shrinkage (Fig. 14 / Fig. 15), early thermal contraction (Fig. 16) and long-term drying shrinkage.

Fig. 14: Plastic settlement cracks on a bridge deck
typically follows the line reinforcement

Fig. 15: Plastic shrinkage cracks on top of the deck slab

Fig. 16: Early thermal contraction cracks at underside of cantilever slab

The first term in the description refers to the time of appearance. Plastic shrinkage appears within 10 minutes to three hours, early thermal contraction one day to two or three weeks and long-term drying shrinkage several weeks or months. The second term(s) describes the primary cause of cracking.

Random map-like crack from alkali silica reaction (ASR) is also a type of intrinsic cracks, although it is not so common. The first case of ASR was reported to occur at the pile head of Sg. Pontian in Rompin in the Axle Load Study (1986-87) as a suspect case [10]. A full analysis was later carried out by Dr. Hashim of Universiti Malaya and later JICA [11] which confirmed the presence of ASR. A few suspect cases in Sabah, such as Tamparuli Bridge (Fig. 17) and Datuk Salleh Sulong Bridge were detected during the Bridge Management Study for Sabah and Sarawak in 2004-2006.

Fig. 17: Random map cracking (chack line drawn alongside)
at the abutment of Tamparuli Bridge resembling that of AAR

Although not included in [9], another type of non-structural cracks could be grouped under intrinsic cracks: delayed ettringite formation (DEF). The term DEF was first mentioned in the report by the British consultant investigating the cracks in MRR2 in 2005. The literature [12] has a good account of how DEF happens:

Ettringite is commonly formed at early ages in concrete cured under ambient condition. This is not damaging to the concrete. But if the concrete was subject to high temperature (over 70° C) during curing ettringite formation may be delayed. Its gradual formation in the cooled set concrete (when sufficient water is available) can lead to expansion and cracking in a process known as delayed ettringite formation (DEF). It can take up to 20 years for cracking to become apparent.

MRR2 is certainly not the only bridge in Malaysia that experiences this type of problem. The authors had encountered a bridge with similar cracking pattern (see Fig. 18), and had DEF confirmed in the laboratory.

Fig. 18: Multiple cracks of a bridge pier in K.L. that was caused by DEF

4.0 PROBLEMS IN STEEL MEMBERS

Corrosion and loss of section is the most common type of problem associated with steel members (Fig. 19). In Peninsular Malaysia, most of the steel bridges particularly the *steel buckled plate* bridges had been replaced after the Axle Load Study in 1988. Today, the states of Sabah and Sarawak still have a great number of steel bridges and corrugated multi-plate culverts (CMP). The majority of the steel truss and girder bridges are in good condition except for some corrosion at the connection and damage from vehicular impact in the case of steel truss bridges (Fig. 20). However, the steel truss bridges appear to be under-strength as indicated by cracking in the concrete deck slab (Fig. 21) and excessive vibration.

Fig. 19: Total loss of section of a steel girder bridge in Ipoh

Fig. 20: Deformation of member of a steel truss
bridge in Sarawak due to vehicular impact

Fig. 21: Cracking at the underside of concrete
deck slab of a steel truss bridge

In the case of CMPs, the main problem is corrosion (Fig. 22). The loss in capacity due to the corrosion might have been the cause of the structural failure (Fig. 23). No matter, the CMPs are progressively being replaced with concrete culverts.

Fig. 22: Widespread corrosion at bottom half and joints of a CMP

Fig. 23: Failure of CMP due to loading

5.0 BRIDGE BEARING PROBLEMS

Problem of walking bearings is rather common in Malaysian bridges (Fig. 24). Each case may be unique but all happened in the situation when the bearing is not uniformly loaded. Many methods had been used to overcome the problem but they largely involve provision of restraint to the existing bearings. Leow et al. presented a case of walking bearing involving diamond shaped rubber bearings [13].

Fig. 24: Walking of the diamond shape bearing

The problem of walking bearing mainly involves elastomeric (rubber) bearings. There were, however, some bearing problems related to mechanical bearings. In Jambatan Ahmad Shah at Termeloh, the roller pins of two of the *HiLoad* type (a trade name) bearings were displaced (Fig. 25). A bold decision was made by JKR to replace all the four mechanical bearings by laminated elastomeric bearings (Fig. 26). Details of the problem and its solution were reported in Lee et. al. [14]. It is interesting to report that the replaced rubber bearings slowly walked out of their positions about a year after the celebration of the apparent successful installation of the new bearings. The problem was finally nailed down by jacking up the bridge deck to reinstate the rubber bearings, somewhat deformed – and addition of two sheets of sand paper, on the top and bottom faces of each bearing. Chang [15] has a report on the works involved.

Fig. 25: Roller pin of the mechanical bearing for Ahmad Shah Bridge

Fig. 26: Newly replaced laminated elastomeric bearing at Ahmad Shah Bridge

In another case involving an *autopont* bridge in Batu Gajah, the bolts holding the restraining frame of some mechanical bearings at the fixed abutment gave way causing the bridge to spring up and settle with each passage of a heavy vehicle (Fig. 27). The problem was causing much nuisance to the bridge user but the solution was relatively straight forward involving reinstatement of the restraining frame [16] (see Fig. 28).

Fig. 27: Damaged mechanical bearing of the *autopont*

Fig. 28: Bolts and restraining frame of the
bearing in the *autopont* bridge reinstated and painted

As the bridges in Malaysia are designed for longer spans, more pot bearings are being specified by the designers. Not many cases of problems with pot bearings had been reported. Three bridges in the same locality having a high fill at each abutment had their pot bearings damaged, caused by movement of soil behind the abutment wall (Fig. 29). In one of the bridges the concrete parapet walls were crushed (Fig. 30), testifying to the great force from the soil movement. Pot bearings over the piers were not spared because the deck movement was transferred from the end spans to the intermediate spans in a domino effect.

Fig. 29: Anchor bolts and plinth damaged

Fig. 30: Crushed parapet at the expansion
joint due to movement of the deck

Sarawak and Sabah still have a number of bridges with traditional types of steel bearings. The majority of them are still in good condition. Nevertheless, regular maintenance and greasing must continue.

From the authors' observation, the bearing shelf is the most forgotten part of a bridge in Malaysia. The dirt and debris collected at the bearing shelf tend to retain water causing steel bearings to corrode. Fig. 31 shows a picture of a "frozen" bearing.

Fig. 31: Frozen bearing

6.0 HYDRAULIC PROBLEMS

Scouring of river bed, either general scour or local scour around the piers causes instability of the bridge (Fig. 32). Bridges that the authors had been required to investigate include:

- Sg. Jeniang, Kedah
- Sg. Pukin, Pahang
- Sg. Tempias, Sabah
- Sg. Golok, Kelantan
- Sg. Trolak, Perak
- Sg. Keratong, Pahang
- Sg. Gombak, Selangor
- Sg. Plentong, Pahang
- Sg. Kerayong, W.P. KL
- Sg. Salor, Kelantan

Fig. 32: General scouring of river bed at Sg. Jeniang

Chiew et. al. [17] had presented the JKR experience in facing hydraulic problems in Malaysia. Revetment of Pukin River Bridge, Keratong River Bridge and Plentong River Bridge are cited as case history. It is later learned that the Pukin River Bridge was badly scoured at both abutments during heavy flooding in December 2006 [18]. As a solution two spans were added in February 2008. For update, Jeniang Bridge (Fig. 32) had also been replaced.

Hydraulic problems are the main, if not the only cause of bridge collapse in Malaysia. Bridges that had collapsed include:

- Sg. Buloh, Selangor (1988)
- Tanjong Laboh, Muar (1993)
- Gurun, Kedah (1995)
- Muar, Johor (1996)
- Sg. Batang Busu, Gombak (1998)

9.0 CONCLUSIONS

Inspection of bridges in the country had permitted the authors to gain much idea of how bridge components can fail to function causing problems to the users. "Big problems" involving a collapse is rare and when it does happen it is almost certain to be related to hydraulic problem. "Small problems", for example, under-strength parapet or broken downpipes though trivial may sometimes lead to major safety problems and bridge owners have thus to take caution.

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