MANAGING STRUCTURAL FAILURE: BRIDGES UNDER SURVEILLANCE

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ABSTRACT

News on bridges in trouble has caused much concern and anxiety to the public members over the safety of the bridges as well as the anticipated inconvenience that would be caused by the closure of the bridges for repair. This paper intends to stress the importance of managing structural failure before it happens, that is, by putting bridges under surveillance. The solution involves a systematic, proactive, and well coordinated approach of detecting any problems in a population of bridges, assessing the severity and extents of the problems, diagnosing their cause(s) and finding a remedy; followed by monitoring the effectiveness of the remedial action. Pertinent issues based on the authors' experience in implementing this solution are discussed.

1.0 INTRODUCTION

Failure in civil engineering structures is defined as "... an extreme form of damage which itself constitutes a material, nontrivial change in the safety, serviceability, appearance or repairability of the constructed facility." [1]. Structural failures, as the topic for this seminar, could be regarded as failures involving structural members that are load-induced, and may not necessarily involve a collapse. News on cracks observed in the flyovers at MRR2 and Puchong Jaya, and the recent collapse of the pedestrian suspension bridge in Kuala Dipang are becoming so sensational in the mass media causing much worry to the public members (Fig. 1). Besides being concerned over the safety of the bridges, the public is also unsettled over the anticipated inconvenience that would be caused by the closure of the bridges for repair. This paper intends to stress the importance of managing structural failure before it happens; that is, by putting bridges under surveillance.


Cracks may be due to overloading
Mending the gaps
BPR buat pemeriksaan projek pembinaan MRR2

a) Cracks at the pier heads of MRR2 flyover


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Kuala Dipang suspension bridge did not meet specifications

By PRIYA KULASAGARAN

b) Collapse of Kuala Dipang suspension bridge


Star Metro CENTRAL
TOMORROW: Modest target for tennis
MBPJ officers hit the streets to collect assessment arrears
Not cracking up
Litrak has announced that, despite appearances, the LDP is safe to use and repair works had started in March. >M4

c) Crack repairs in flyovers at Puchong Jaya

Fig. 1 Bridges that made the news

The phrase “bridges under surveillance” had been used by an article in a civil engineering magazine. The article reports interviews to a few bridge experts (including Prof. George G. Goble of the Pile Driving Analyzer fame) regarding the importance of bridge inspection and assessment. Surveillance, as the dictionary [2] explains, is “...close watch kept on persons suspected of wrongdoing, etc: under police surveillance...”. Does it make any sense for us to talk about bridges under surveillance as if bridges are but members of Homo sapiens to be watched over?

Indeed, a bridge inspection can be likened to other human activities. The senior author of this paper has referred to bridge inspection as similar to detective work. A bridge inspector needs to have an inquisitive mind to look for tell tales, as well as sufficient knowledge in bridge behaviours to interpret the “signals” that the bridge is giving. Bridge inspection has also been compared to a medical diagnosis. Cracking in concrete, for that matter, is a sign of some hidden problem, analogous to fever as a symptom of illness in people [3].

2.0 STATES OF AFFAIR

Without a doubt, people entrusted to take care of the bridges have a duty of care to ensure that the bridges are safe besides serving their intended functions. With the publicity now given to the reliability of constructed facilities thanks to collapse of the Terengganu stadium and Pedestrian Bridge in Kuala Dipang, etc., the role of people responsible for the surveillance of engineering assets like bridges is ever more challenging. It is important to note that we are not talking about surveillance of a single bridge, but rather a whole population of them. Consider, as an example: JKR has an estimated number of 6,000 Federal bridges in its custody. Each and every one of them needs to be checked regularly as failure to any one of the members of one of the spans of one of the bridges would spell trouble and cause havoc. The situation calls for a systematic, proactive and well coordinated approach to managing these bridges.

The requirements of a good management of existing bridge stock remain the same as that of the design:

- Safety
- Functionality
- Durability
- Aesthetics

... within the constraints of economy and sustainability. Yes, economy. Isn't it that engineering is " ... the art of ... [constructing] well with one dollar which any bungler can do with two after a fashion. – A. M. Wellington" [4]? When we discuss economy we are not merely talking about the expenses to be borne by the concessionaires (We may say, "well, serve them right, they deserve to pay,"). Rather, we aim at the national economy and talk in terms of the opportunity costs. If economy is an important consideration, we would not simply replace a bridge whenever a problem is found in the bridge. The money thus saved could be used in the construction of, say, a hospital. Likewise, we would not simply close down a bridge at the slightest hint of a structural problem. A bridge closure would cause traffic disruption that directly affects the economies.

How do we then make sure that the bridges under our care are safe – not so much from the technical aspect but more from the management approach? The logical procedures of surveillance of bridges would entail the detection of problems, assessment of their severity and extents, diagnosis of the root causes[1] and seeking of the remedies; followed by monitoring to check the effectiveness of the remedial action.

3.0 EXISTING PRACTICES IN BRIDGE INSPECTION

3.1 Guidelines for bridge inspection

Bridge maintenance is a world-wide problem and bridge authorities around the world have indeed come up with strategies on good bridge management as seen in a series of reports produced by the Organisation for Economic Co-operation and Development (OECD). The Highways Agency of the U. K. had also produced a set of documents on highway structures inspection and maintenance. BD 63/94 Part 4 [5], in particular, relates to inspection of highway structures. The document, consistent with the OECD report on bridge inspection [6] categorises bridge inspection into Superficial Inspection, General Inspection, Principal Inspection and Special Inspection.

Superficial inspection is a cursory check for obvious deficiencies which might lead to accidents or high maintenance costs. A *Superficial Inspection* would be carried out by highway maintenance personnel who have a good practical knowledge of road structure, but not necessarily trained in bridge inspection. *General* and *Principal Inspections* are carried out visually by a trained inspector under the general supervision of a bridge engineer. The two types of inspections are carried out periodically: General Inspection not more than two years after the last General or Principal inspection while Principal Inspection

[1] Plural is used here because most bridge problems could be traced to more than one root cause.

carried out at intervals which would normally not exceed six years, but exceptionally may be up to ten years. Also, a General Inspection is made on representative parts of a bridge and Principal Inspection a close examination of all inspectable parts of the structure. Lastly, *Special Inspection* is a detailed examination of the particular area of defect causing concern. It may be necessary to employ specialist inspection firms and equipment.

In Malaysia the REAM guide on bridge inspection [7], which is based on the JKR practice, has been adopted by all the bridge agencies in the country; and is by default, the national guide for bridge inspection. The guide does recognise that a complete surveillance of bridges would involve a series of bridge inspection: Routine Condition Inspection, Confirmatory Inspection and Detailed Inspection. *Routine Condition Inspection* is carried out by trained technicians (preferably under the supervision of a bridge engineer) using a checklist while *Confirmatory Inspection* by a senior bridge engineer. Both these inspections relate to General Inspection in the UK practice. On the other hand, a Detailed Inspection involves a close examination of an investigative nature on a specific problem with the aim of seeking remedies, much like Special Inspection in the UK practice.

Neither the British or Malaysian guide describes Specific or Detailed Inspections. Indeed, depending on the problem at hand, a Specific or Detailed Inspection may be supplemented by the following activities to help in the diagnosis and/or appraisal:

- Defect mapping
- Structural analysis
- Material testing
- Interviewing (to find out stages of concreting, when the cracks first formed?)
- Load test
- Monitoring

It cannot be overemphasised that both the British and Malaysian guides call for a series of inspections involving increasing levels of detail, first at “the network level” and then “the project level” - terms borrowed from Pavement Management System literature. Superficial, General and Principal inspections, all based on visual observations are the network-level inspections while Special Inspection is the project-level inspection. To go straight to the project level inspection is non-economical and, at times, not advisable. Considering the fact that a special inspection very often requires much time to plan and execute, care must be taken to make sure that necessary steps are taken whilst preparing for the special investigation. We must be mindful of the facts that the Pulau Banding tourism complex and Terengganu Stadium both collapsed in the midst of investigation.

Another important point to note is the position of the first line of defence: the inspector at the network level. Besides looking out for damage and reporting the conditions of the members, the inspector has also to shoulder an important responsibility: to appraise and judge if the bridge is safe, and whether or not a detailed inspection is necessary. To make a judgement on the safety of a bridge based merely on visual inspection is not easy, as evident from the overpass collapse at Laval, Canada in October, 2006 (see Fig. 2). After the tragedy that killed five, the Transport minister had said that "Somebody from the ministry was on site and picked up the fallen concrete pieces, evaluated the situation, but found nothing to warrant an immediate closure of this bridge…"[8].

Fig. 2 Overpass collapse at Laval, Canada [from the Internet]

3.2 When do we get concerned?

We discuss now the important decisions to be made by the first line inspector at the network level. In addition to basing on formal knowledge in bridge engineering, experienced bridge inspector often uses his engineering judgement, gut feeling, hunch, or whatever name you call it, to help make this type of decision. This gut feeling - the main subject of the #1 international best seller "blink" [9] - is derived from years of working in a particular field, in this case, inspecting bridges. Also known otherwise as "empirical knowledge", this is what researchers in Artificial Intelligence (AI) exploit to develop expert systems. However, decisions made based on gut feeling may not be acceptable by the engineering community.

What would appear to be more "scientific" and perhaps, more acceptable, is decision arrived at after considering the following questions:

i. Bridge components: structural member or non-structural member?

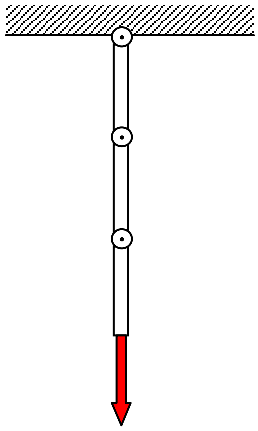
ii. Type of damage: Load induced or intrinsic damage?

iii. Mode of failure: Shear or flexural?

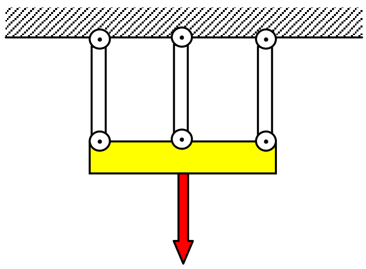
iv. Type of structural system: Series or parallel system?

Generally speaking, damage to a structural member is more worrying than one to a non-structural member. A load-induced damage tends to merit more concern than an intrinsic one. A shear failure is more objectionable than a flexural failure. A parallel system is more reliable than a series system. The first three statements are common knowledge to most and only the last statement needs further explanation.

The concept of redundancy is important in structural reliability theory. A structural system is considered series or parallel depending on whether failure of a component would lead to an overall failure of the whole system (see Fig. 4).



a) A series system

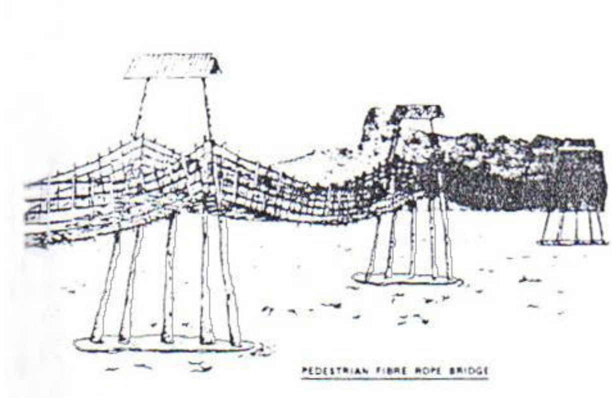


b) A parallel system

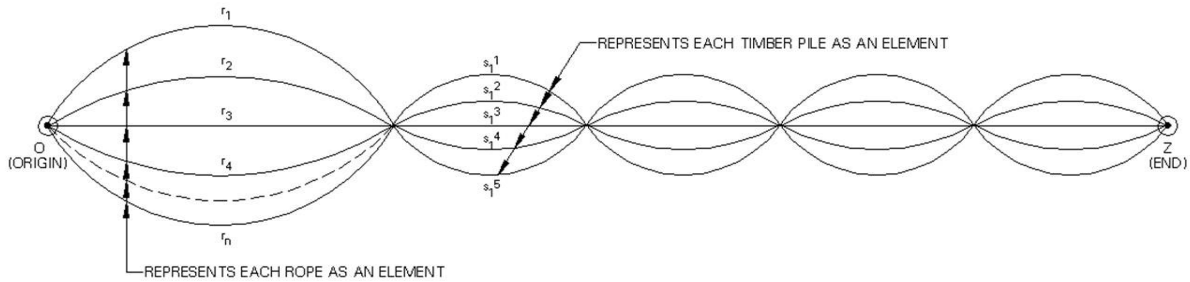
Fig. 4 Reliability models

In a *series system*, failure of a component would lead to the failure of the overall system. This is a classical notion among engineers: "a structure is as strong as its weakest component", which gives it another name "the weakest link" system. In a series system, the probability of system failure increases as the number of components increases. On the other hand, failure of all the components in a *parallel system* is necessary for a system failure. The reliability of the system thus increases as the number of components increases.

A real world system may indeed be a mixed system comprising a combination of series and parallel systems. Tharmabala & Nowak [10] has used this concept to demonstrate the reliability of a pedestrian suspension bridge as shown in Fig. 5a.



a) A pedestrian suspension bridge [10]



b) Structure diagram [10]

Fig. 5 Reliability model of a suspension bridge

The reliability of the bridge can be perceived by the structure diagram in Fig. 5b. The ropes and piles, etc., as sub-systems of ropes and piles respectively, are components of the overall system in series. If either the ropes sub-system or piles sub-system were to fail, it would lead to the overall failure of the structure. The ropes sub-system, on the other hand constitutes a parallel system of many ropes, requiring failure of each and every one of them to fail for the rope sub-system to fail.

To explore this concept further, if we have only two ropes as is the case of a simple pedestrian bridge as shown in Fig. 6, the reliability of the bridge may be tremendously reduced.

Fig. 6 A simple pedestrian suspension bridge

4.0 CONCLUSIONS

As a conclusion, it is obvious that a bridge failure is a nightmare of the bridge manager. With the publicity now given to the performance or rather, non-performance of constructed facilities the responsibility of bridge inspectors is becoming ever more challenging. This paper stresses the importance of managing structural failures before they happen – by a systematic, proactive system of surveillance of bridges.

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