

Appraisal of Concrete Bridges: Some Local Examples

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INTRODUCTION

Concrete bridges are structures, which enable a vehicle or a pedestrian to get across a river, a road or some other obstacles. Serviceability of a bridge depends on its maintenance records. A bridge needs to be inspected regularly and frequently to ensure that it is always in a safe condition for use. Serviceability of a bridge could deteriorate and become serious if proper maintenance, repair and refurbishment steps are not taken immediately. By the same token a concrete bridge could maintain its serviceability for more than a hundred years if it is properly maintained.

Failure of a bridge structure could be costly in terms of property and life. Although catastrophic failure seldom occurs, it is necessary to take steps to ensure integrity and safety at all times. Inspection surveys must be done at required intervals and corrective actions taken immediately if it is found to be experiencing deterioration. A Bridge Management System could be developed and used as a strategy for efficient and cost-effective bridge management [1].

BRIDGES IN MALAYSIA

There are more than ten thousand bridges in Malaysia. They are made up of concrete bridges, steel bridges, masonry bridges and wooden bridges. In Malaysia there are four parties or corporations who are responsible for the design, operations and maintenance of bridges namely: Jabatan Kerja Raya (JKR) (Public Works Department), Keretapi Tanah Melayu (KTMB) (Malayan Railways), Dewan Bandaraya Kuala Lumpur (DBKL) (Kuala Lumpur City Council) and Lembaga Lebuhraya Malaysia (LLM) (Malaysian Highway Authority). Table 1 shows the breakdown of these bridges according to the owners.

INSPECTION STANDARDS

Inspection

Bridges form parts of a structure of a network of roads, which are essential in

Table 1: Bridge owners in Malaysia

Routes	Authority/Owner	No. of Bridges	Notes
Federal-Peninsular	JKR Federal	> 7000	Include culverts
KTMB	KTMB	> 920	Exclude culverts
Federal-Sarawak	JKR Sarawak	> 890	Include culverts
Federal-Sabah	JKR Sabah	> 780	Include culverts
Toll Highway	LLM/JKR/DBKL	> 560	Exclude culverts
DBKL	DBKL	> 225	Include culverts

the support of the growth of economic activities of a nation. A systematic programme of inspection and maintenance of bridges therefore becomes critical. Inspection operations are important in order to determine the type of damage and the extent of the damage. The damage could be a result of poor design, over-loading, chemical attacks, environmental wear and tear and others. Among the main aims of bridge inspection are to examine the level of structural safety, identify the main cause of structural deterioration, record damage details and source of the problem in a systematic manner, provide information and to decide on matters related to maintenance, repair and replacements, provide feedback data to designers and contractors for future improvements and to determine and provide a true picture of the effect of loading on the bridge.

Classification of Inspection

The frequency of bridge inspection depends on the age of the particular bridge, the type of construction, volume of traffic and others. The type of inspection could either be visual inspection, which could be undertaken by a person with knowledge of road structure; principal inspection, which has to be carried out by a trained person; or special inspection, for which an expert is required to solve a complex problem. Inspection could also be categorised as Inventory Inspection which is the first examination after a bridge is built and is carried-out visually where dimensions are measured, bridge sections obtained,

and photographs taken and recorded in the inventory card; Routine Condition Inspection to ensure that the bridge is safe for use and is carried out by technical personnel visually against a standard check-list at least once a year, or after incidents such as flash floods, earthquakes and the like; and Confirmation Inspection to confirm routine reports received and to check that the routine inspection has been done consistently and according to standard procedures. Confirmation Inspection is usually done on bridges that have shown critical and serious damage. It is also required to assist in determining the proper maintenance steps to be taken or to justify a more detailed examination to be proposed. Detailed Inspection is done as a result of Routine and Confirmation Inspections. The objective is to evaluate the safety level of the bridge as a whole, conduct non-destructive testing, take samples from the structure, determine the extent of damage and provide information necessary to determine the approach towards repair and refurbishment [2].

STRUCTURAL DETERIORATION

Deterioration to concrete affects the strength and durability of structures. Concrete performance changes with time; the older the concrete structure the lesser the performance. The following are some of the more common mechanisms of concrete deterioration:-

(a) Carbonate or Chloride Reaction

Uninsulated steel reacts with water and oxygen electrochemically resulting in the

corrosion of the steel. Corroded steel will produce patches of corrosion products at the surface of the concrete. Spread of the corrosion will cause cracks in the structure, which will eventually make it fail. It is a slow process and acts as a warning when they first appear as hairline cracks.

(b) Chemical Attack

Reaction process alkali-aggregate is divided into two types: alkali reaction with silica and alkali reaction with chlorides. The latter rarely happens in Malaysia. Alkali-silica reaction is due to the types of aggregate with high silica content like granite, reacting with trapped air, which contains alkali from the cement mixture. This reaction produces gel, which can cause cracking of the concrete. In the presence of moisture, carbon dioxide and silica oxides become acidic and dissolve and remove parts of the hydrated cement mixture producing a soft and weak mass. Sulphate ions also attack calcium hydroxide and alumina [1,4].

TYPES OF DAMAGE

Poorly maintained concrete bridges will have poor serviceability from various kinds of damage. The damage can be a result of the materials used eg. cement, water and aggregate; external forces like excess loading and base movements; and joint and bearing failures. Maintenance actions need to be done immediately to avoid deterioration and consequent unsafe conditions. One of the more common types of damage is due to cracks. Cracking is caused by excessive loading, foundation movements, poor design, or excessive tension forces, which are applied to a structure. Cracking is differentiated according to the depth, width, form, location and source of the crack. Cracking can also be defined as the complete or incomplete separation of two or more sections as a result of a split or breakage. External forces can be a result of temperature, creep and shrinkage. Differential movements and compaction can also cause cracking. Spalling is the loss of material or concrete at the surface due to over-loading. Spalling can also cause concrete cover to break causing

corrosion of the reinforcement steel. The more voluminous corrosion products create forces on the concrete resulting in popping out from the surface. Spalling can also be caused by temperature and pressure. Another type of damage is reinforcement corrosion due to an electrochemical reaction as a result of chemical attacks such as alkali-aggregate, chlorides and others. Reinforcement strength will be reduced and the concrete will crack and spalling as well as staining will occur. Reinforcement corrosion and moisture dissolving the concrete materials can cause leaching and causing white staining at the surface. Honeycombing or voids is a condition where air spaces are present in concrete usually caused by improper or unequal compaction of concrete. It can also be caused by a poor method or technique of pouring and forming of the concrete. Mould and marine growth can also occur on concrete columns located in water. The growth is not only unsightly but can also react with the concrete.

METHODS TO DETERMINE DAMAGE

There are generally three methods of determining the type and the extent of damage of concrete bridges.

(a) In-situ Test

In-situ tests are tests conducted at the bridge site to gather important information to determine bridge damage. In-situ tests could be non-destructive (NDT) or destructive (DT). Easily available NDT usually involves only the surface layers, while DT could provide a more detailed picture. The rebound hammer is used to obtain the value of concrete strength at the surface where the impact is applied. This test needs to be conducted on a level surface. Core drilling is used to obtain information on concrete strength, compaction, cracking and others.

The cover meter is used to determine the location of the steel reinforcement and the depth of cover available for protection of the reinforcement from chemical and other attacks. The Ultrasonic Pulse Velocity Technique is used as a quick and simple method to determine the density

of the medium and other parameters related to density. It can be used to measure homogeneity of concrete in a structure, and it can also detect the presence of cracks and honeycombs. The Half-Cell Potential is used to determine the probability of the presence of corrosion with the use of copper-copper sulphate half-cell on the concrete surface and comparing the difference in potential between the half-cell and the reinforcement. The results will indicate potential areas where corrosion could occur thus giving an early warning as to the onset of serious corrosion. Endoscopy is used to obtain images of concrete structures, which are not normally visible; and it is also used to gather information on joints and bearings. Permeability Test can be carried out by boring a small hole in the concrete, covered with liquid rubber and water is introduced into the concrete at a certain pressure. Carbon dioxide and calcium hydroxide in concrete react to form carbonates, which at high concentrations will cause corrosion of the reinforcement. Spraying phenolphthalein on the concrete surface can indicate the presence of carbonates. A change of colour to violet indicates the presence of carbonates. Radiography is a method of taking pictures using radiation particularly gamma rays. It can give images of the reinforcement and also the presence of damage in the matrix.

(b) Visual Examination

Visual examination is an external method of examination. It is done in order to ascertain and to evaluate the extent of damage due to major, medium or fine cracks; spalling and pop-outs; rust stains, water and grease on concrete; leaching; corrosion of reinforcement; voids, poor aggregate and sand mixing, and honeycombs; and mould and marine growth.

(c) Laboratory Tests

Laboratory tests are carried out for more accurate results. The following tests can be carried out on the concrete bridge samples:

Determination of Carbonate Depth

To determine the presence of carbonates on bridge structures, phenolphthalein indicator is sprayed. A colour change to violet indicates the presence of carbonates.

Compressive Strength

Compressive strength is determined by carrying out the test according to BS 1881: Part 120: 1992 on the test specimen.

Porosity

Porosity test is based on BS 1881: Part 122. This test is conducted to determine the rate of absorption of water by capillary forces of the concrete. It is done on unsaturated sample away from water or moisture.

Chloride and Sulphate Content

Sample powder obtained from coring can be tested for chloride and sulphate content using the nitration method according to BS 1881: Part 6 or by using the capillary tube indicator. Chloride content of more than 0.4% can activate corrosion, while sulphate content of more than 4% can cause concrete expansion and disturbs concrete structure.

Petrography

The petrography tests are based on ASTM C856-95 where the type and properties of the materials used such as the cement and the aggregate, homogeneity of the mixture, micro structure and durability potential of the concrete are determined [1, 3, 4].

CASE EXAMPLES

Three case examples on concrete bridges owned and operated by different organisations follow, giving examples of damage and corrective actions taken on each case.

(a) Endau-Mersing (JKR)

This bridge was built in 1974 with a length of 397.32 metres. The type of construction is pre-stressed concrete beam. The Endau-Mersing bridge spans across the Endau River in the district of Rompin, Pahang. This bridge was detected to experience corrosion and honeycombing on the columns. Laboratory tests were carried out on concrete, soil and water samples from the surrounding area to determine the level of chlorides. The test on the concrete sample indicated that the chloride levels were beyond the threshold limit for corrosion. It was categorised as serious as the depth of the affected zone had gone beyond the concrete cover.

Repair on the bridge was done by the Bridge Division of JKR. Pore lining treatment was done together with cover by silane/siloxine to reduce the absorption of water, chlorides and carbon dioxide.

(b) Seberang Perai (Malayan Railways)

The Seberang-Perai bridge was built in 1967 as a swing bridge to allow boats to pass under it. It is 220 metres long and it is the pre-stressed concrete beam type. Examination of the concrete bridge was undertaken in July 2003 by IKRAM C&S Sdn. Bhd. as the bridge construction advisor appointed by KTMB. The job scope involved structural tests, sources of concrete deterioration, maintenance and repair methods. This case example focused on Pier 1 only. The following are the types of damage experienced by the bridge on this pier:

Cracks

Major, medium as well as fine cracks were found on this pier. They could be seen with the naked eye. The cracks were measured using a crack gauge. For major ($CE > 1\text{mm}$) and medium ($0.5\text{mm} < CW < 1\text{mm}$) cracks, the damage was repaired using the formwork grouting method. For fine cracks epoxy resin was injected into the cracks.

Spalling

Spalling is classified into two types: one that exposes the reinforcement bar and one that does not. Since the former type usually is caused by corrosion, the method of identifying the source of the damage is by the use of the half-cell potential method, and core samples are taken for carbonate and chloride depth tests. The method of repair for this class of spalling was by replacing badly corroded reinforcement; sandpapering minor corroded parts and followed by patching using a modified shrinkage polymer to replace the mortar. For spalling that does not expose the reinforcement bars, laboratory tests are carried out to determine chloride depth and in-situ half cell potential test was carried out to detect any early onset of corrosion of the reinforcement in the concrete. For spalling of this type the repair method was by patching using modified shrinkage polymer.

Rust Staining

Rust staining caused by corrosion of the reinforcement could be seen naked eye. This kind of damage was repaired by replacing and cleaning the corroded reinforcement, and patching with modified shrinkage polymer.

Corrosion

Corrosion is caused by chloride attack or by electrolytic reactions. Laboratory tests were carried out to determine carbonate content in concrete. Method of repair was to replace or clean the corroded parts followed by epoxy resin injection of patching using modified shrinkage polymer.

Mould and Marine Growth

Mould and marine growth usually occur when the concrete surface is submerged in the river or seawater. In this case study the pier is in the river. Mould and marine growth was present. The growth was cleaned using suitable cleaning agents.

Oil and Grease

Staining as a result of oil and grease makes the concrete surface look dirty. This staining originates from steel members resting on the concrete. This stain was cleaned using proper detergents or removers.

(c) Jalan Mahameru (DBKL)

This is a bridge located on a highway, built in the seventies. The damage on this bridge is the presence of gaps at the joints which could be caused by traffic or non-homogeneous materials mixture. The gaps spoil the looks of the bridge surface and also slow down traffic. The repair method was the use of asphaltic plug joint, which involved a modified bonding polymer mixed with good grade aggregate. Old joints and bolts were replaced with new ones. The joints with gaps were caulked with heat resistant polyurethane foam before a bonding agent was applied. Metal bridging plates were placed at the joints to cover the gaps. More bonding agent materials were poured to fill up any gaps between plates. This was followed by compaction of the road and finally bitumen was placed at the joints and allowed to dry and harden.

OBSERVATIONS AND DISCUSSION

From the three case examples seen, the common types of damage to concrete bridges could be observed. The most persistent damage experienced by concrete bridges in Malaysia is chloride attack. Methods of repair for the various types of damage were also indicated. Various types of examination were done to ascertain the cause of damage and to choose the most appropriate method of maintenance and repair. Serviceability of concrete bridges in Malaysia could be classified as moderate since there have not been any major failures involving

lives. However, concrete bridges in Malaysia experience many kinds of deterioration and damage that cost a lot of money to repair and refurbish.

CONCLUSION AND RECOMMENDATIONS

Serviceability of concrete bridges in Malaysia could be considered moderate since most of the deterioration and damage originate from natural causes although there are also some, which are due to human factors such as accidents and impacts by vehicles and boats, block drainage systems and sub-standard designs.

Some steps which can be done to reduce the overall costs of maintenance and operations are application of standard designs, more frequent inspections to detect onsets of damage at an early stage and research and development for better materials and techniques in concrete bridge design, construction and maintenance and operations.

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REFERENCES

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| <p>[1] Radomski W. <i>Bridge Rehabilitation</i>. Imperial College Press, (2003)</p> | <p>[2] JKR, <i>Bridge Appraisal, Rehabilitation and Maintenance</i>, Bridge Division, JKR Headquarters (1996)</p> <p>[3] JKR, <i>Annual Bridge Inspection Manual</i>, Bridge Division, JKR Headquarters (2003)</p> | <p>[4] Kumpulan Ikram Sdn Bhd, "Kajian dan Penilaian Ke Atas Jambatan Keretapi No1, Km 1.00 Perai, Seberang Perai, Pulau Pinang". KTMB Report.</p> |
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