Management of Bridge Asset in an Environment of Increasing Live Loads

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SYNOPSIS

The Roads and Traffic Authority of NSW (RTA) has over 5000 bridges in the road network under its jurisdiction. These bridges were built from different materials, at different times to different standards and quality in various environments.

There has been a significant increase in the volume, size, mass, frequency and speed of heavy vehicles using the road network and consequently older existing bridges have been subjected to far greater loads than what they have been originally designed. This has resulted in rapid deterioration of these bridges and consequently greater maintenance requirements. This situation has necessitated for the RTA to develop an effective bridge management process to provide an efficient road network without compromising safety or performance of the bridge assets.

This paper describes the bridge asset management processes developed and used by the RTA to manage its complex bridge asset.

1. INTRODUCTION

Bridges are vital elements in any road network and they represent a major investment of the community. Any failure of a bridge may limit or severely restrict road traffic with consequent inconvenience and economic loss to the community.

Historically bridge design live loads have increased steadily at a rate of approximately 10% of current levels per decade. Bridges designed for less than half the current standards at the turn of the last century (T44) will be called upon to carry even heavier loadings in the future. Some bridges are over 100 years old, still in service and perform satisfactorily, with failure due to overloading being rare. In addition volume, size and speed of commercial vehicles have increased significantly on our aging bridge stock resulting in more rapid deterioration of these bridges.

To keep the serviceability of these bridges to a safe level there need to be a significant increase of maintenance funding. However to obtain increase funding in the current economic climate is very difficult.

Therefore the RTA has developed a strategy for management of the bridge asset to ensure that they are maintained cost effectively without compromising safety.
2. The RTA Bridge Infrastructure

The Roads and Traffic Authority of NSW (RTA) has over 5000 bridges in the road network under its jurisdiction. These bridges were built from different materials, at different times to different standards and quality in various environments. The replacement value of this bridge infrastructure is over $13 billion.

The age profile of RTA bridges constructed by Materials is shown in Figure 1.

2.1 Materials in Bridge Construction

The RTA bridge infrastructure consists of different materials of construction such as Masonry, Timber, Concrete – RC; PSC, Steel, Fibre Composite and Combinations thereof.

Bridges and their components of different designs and materials deteriorate with age at different rates. The rate of deterioration and the associated reduction in capacity of a bridge are dependent on:

- Age of the bridge
- Design load and load history
- Material of construction
- Environment
- Quality of design and construction
- Incident and extent of impact damage
- Quality of maintenance
- Type and volume of heavy loads
- Extent and quality of rehabilitation work.
2.2 Challenges Facing Asset Managers

The challenges facing the asset Managers are:
- Ageing Bridge asset
- Limited funding
- Limited resources (staffing)
- Lack of trained staff.

Real challenge is how the limiting funding can be used to manage the ageing bridge asset and keep the effective operation of the road network without compromising the safety and performance of the bridge stock.

This challenge can be overcome by developing and implementing a good bridge management process. The process developed by the RTA is shown in Figure 2.
Figure 2. RTA Bridge Management Process

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3. DEVELOPMENT OF BRIDGE INFORMATION SYSTEM (BIS)

In order to manage bridges and ensure their safety the RTA developed a Bridge Information Management System (BIS).

The aim of BIS is to provide the means to store, update and access the necessary information for the proper management of bridges and it covers information on:

- Design
- Construction
- Inspection
- Load rating
- Maintenance

4. INSPECTION

Inspection is the process by which information on the physical and structural conditions of a bridge is collected to enable the updating of its information. The inspection should commence after a new bridge is constructed and continue through its life at regular intervals depending on the type of the bridge.

The objective of bridge inspection is to ensure that a bridge continues to perform its function under acceptable conditions of safety and with a minimum of maintenance.

To undertake a bridge inspection, it is necessary to have:

- appropriately trained and experienced personnel
- good preparation including OH&S issues
- proper equipment and techniques
- effective inspection procedures

Bridge inspections achieve their objectives by collecting and reporting observations correctly.

The RTA has procedures and methods for undertaking bridge inspections in accordance with the RTA’s Bridge Inspection Procedures Manual.

Type of Inspections

Generally there are four different levels of bridge inspections.

4.1 Level 1 - Inspection

This inspection applies to all bridges.

This is a basic drive-by cursory inspection performed as part of general network asset assessment on a regular basis. This inspection is performed by a works supervisor and will collect information regarding the status and performance of ancillary elements such as:
• barriers
• deck suppers
• waterways
• deck wearing surface

This level of inspection may also be generated by reports arising from an incident or community complaints.

4.2 Level 2 - Inspection

This is a more detailed visual assessment of element condition in accordance with defined parameters in the Bridge Inspection Manual.

This inspection is undertaken by an experienced Bridge Inspector to assess the specific material type and element condition.

4.2.2 Concrete and Steel Bridges

Level 2 inspections for concrete and steel bridges are normally carried out at 2 yearly intervals. If all elements are in condition 1, interval of inspection for these bridges could be extended to 4 years.

Bridges in marine or aggressive environment should be inspected at a 2 year interval even if all elements are in condition 1. This level of inspection may recommend the need for a higher level of inspection depending on the condition state of the elements.

Level 2 inspection may also be initiated as a response to an incident or a community report.

4.2.3 Timber Bridges

Level 2 inspections of these bridges are carried out annually, with test bores taken every 4 years or shorter intervals as nominated by the Bridge Engineer responsible.

4.2.4 Complex Bridges

Level 2 inspections of bridges classified as “complex” in the BIS are carried out every 4 years or at an interval recommended in a prior Level 3 inspection including close up inspection of joints, bearings, cable anchorages, areas adjacent to joints and potential corrosion traps.

4.2.5 Underwater/ Underground/ Scour Inspection

This is done under level 2 inspection to determine the condition of footings, piles and piers buried in aggressive soil or in water.

These inspections are carried out every 4 years or shorter intervals depending on the environment as nominated by the Bridge Engineer responsible.
4.3 Level 3 - Inspection

This is a detailed structural inspection of a bridge based upon reported or suspected deterioration of critical elements which could make the strength of the bridge a concern. This could also be initiated by the performance of similar type of bridges or through Level 2 Inspection.

As a routine complex bridges are inspected once every ten years.

The inspection is undertaken by an experienced structural engineer.

The inspection should record sufficient data to enable a structural assessment of the bridge to be undertaken to determine:

- capacity of the bridge in its “as is” condition
- whether strengthening is necessary
- possible future maintenance actions

4.4 Level 4 - Inspection

This is a Level 3 inspection carried out for Load Capacity Assessment, required for carrying increased legal loads or new vehicles.

5. CONDITION ASSESSMENT

Condition Assessment of elements is required for the effective maintenance management of bridges and is carried out in accordance with the RTA Bridge Inspection Procedure Manual.

The structural elements are classified into four condition states and are detailed below.

<table>
<thead>
<tr>
<th>Element Condition State</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1 - Nearly 'As-built'</td>
<td>The element is in good condition with little or no deterioration. Superficial defects may be present, but without effect on strength and/or serviceability.</td>
</tr>
<tr>
<td>2 - Good</td>
<td>The element shows deterioration of a minor nature. Minor defects may be present but with no loss of section or insignificant effect on the serviceability of the element.</td>
</tr>
<tr>
<td>3 - Fair</td>
<td>The element shows advancing deterioration. Some minor loss of section may be present, but insufficient to significantly affect the strength and/or serviceability of the element.</td>
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6. STRUCTURAL ASSESSMENT

6.1 General

The Procedure for structural assessment of existing bridges requires knowledge of physical conditions of the bridge determined from Level 3 structural inspection and material testing, if necessary, and vehicle loading including configuration for which the bridge is to be assessed to determine its load carrying capacity or load rating.

The strength assessment procedures should recognise a balance between safety and economics.

Generally, structural assessment is carried out for legal vehicle loading and to recommend under capacity bridges for posting, testing or replacing with new structures.

Assessment for issuing of permits may require load factors different from those used for assessment for legal loads and should also consider the actual vehicle size, weight and configuration.

DLA - Dynamic load allowance
E_d - Dead load effect
E_ds - Superimposed dead load effect
E_L - Live load effect due to nominated rating vehicle
E_p - Parasitic effect due to prestress
E_s - Effect due to differential settlements
E_t - Effect due to differential temperature
R_u - Nominal strength or resistance
γ_d - Dead load
γ_ds - Superimposed dead load factor
γ_L - Live load factor
φ - Capacity reduction or resistance factor
RF - Rating Factor

6.2 Rating Equation

The concept of rating is based on the Limit States Design principle that the assessed minimum capacity of the bridge must be greater than the assessed maximum loading.

The assessment is carried out with a comparison of the factored live load effects and factored strength or resistance after discounting for factored dead and superimposed dead load effects.
The live load factors are used to account for uncertainties in load effects due to variation in maximum vehicle loading effect.

The dead load factor includes normal variations in material dimensions and densities.

The resistance factor accounts for:

- uncertainties in strength prediction theories
- material properties
- deterioration influences over time periods between inspections.

The ability of the bridge to carry repeated live loadings is assessed as a proportion of a nominated rating vehicle.

The rating procedure is carried out for all strength checks (moments, shear etc) at all potentially critical sections.

The lowest rating factor determined, from all strength checks, is the rating factor for the bridge. The rating equation is:

\[
\phi R_u = \gamma_d E_d + \gamma_{ds} E_{ds} + \gamma_p E_p + E_s + E_t + \gamma_L (RF) E_L (1 + DLA)
\]

\[
RF = \frac{\phi R_u - (\gamma_d E_d + \gamma_{ds} E_{ds} + \gamma_p E_p + E_s + E_t)}{\gamma_L (1 + DLA) E_L} \quad (1) \text{ (by theoretical analysis)}
\]

\[
RF = \frac{\text{Available Capacity for Live Load}}{\text{Live Load Effect}} \quad (2) \text{ (by theoretical analysis)}
\]

\[
RF = \frac{\text{Maximum Applied Load}}{\gamma_L (1 + DLA) E_L} \quad (3) \text{ (by load testing)}
\]

If \( RF \) (by theoretical analysis) \( \geq 1 \), no further action is required until the next Level 2 inspection.

If \( RF \) (by theoretical analysis) \( < 1 \) conduct bridge load testing.
7. NON-DESTRUCTIVE LOAD TESTING

Load testing is an effective means of evaluating the structural performance of a bridge as it determines the actual strength of a bridge to carry live loads. A typical proof load testing of a bridge is shown in Figure 3.

Load testing applies particularly to:

- bridges which cannot be accurately modelled by analysis.
- bridges whose structural response to live load is in question.
- bridges whose analytical rating is less than the legal loads.

The actual performance of most bridges to live load is better than what the theory predicts, i.e. the actual load capacities of most bridges are greater than their analytical load capacities.

When an analytically rated load of a bridge is less than the legal load limit prevailing at the time, it is generally beneficial to the bridge owner to take advantage of the bridge’s inherent extra capacity by carrying out a non-destructive load test.

The objectives of non-destructive load testing are to quantify in a scientific manner the enhanced capacity that can be reliably used to establish a more realistic load rating of the bridge.

The analytical load rating of the bridge can then be adjusted to reflect the results of the non-destructive test.
Non-destructive load testing is the monitoring and measurement of the response of a bridge subjected to controlled and pre-determined loadings within the linear-elastic range of the structure.

The principle of load testing is the comparison of the field response (load vs deflection or load vs strain), in real time, of critical members of a bridge with their theoretical performance characteristic as predicted by analysis in order to determine the actual capacity of the bridge to carry live loads.

There are two main types of non-destructive static load tests. They are:

- Performance load tests
- Proof Load tests.

Both types utilise pre-determined loads, instrumentation and analysis of test results.

But they differ in the manner in which the capacity of the bridge to carry live load is obtained from the test results by factoring the maximum applied load.

7.1 Selection of Load Test

The choice of a test load type is based upon:

- the condition of bridge
- the type of bridge
- the availability of design details and "As Constructed" drawings
- the results of analytical evaluation
- the availability of funds and equipment.

In general, performance tests are recommended if sufficient data and information such as “As Constructed” drawings, dimensions and materials and structural condition of the bridge is available.

It is also suitable for bridges where accurate analytical information is available or results from proof load tests of similar bridges are available.

7.2 Performance Load Test

Performance load test is a serviceability limit state test.

Under the Performance type test, the bridge is carefully and incrementally loaded in the field to a pre-determined live load level, marginally higher than the legal load limit current at the time.

Generally, this pre-determined load level is determined by multiplying the pre-determined live load by the DLA and the serviceability limit state live load factor given in the Australian Bridge Design Code AS 5100.

The effects of the applied loads on critical members of the bridge are measured by instruments attached to these members.
The resulting field measured effects, load-deflection or load-strain are measured and from these results the actual strength of the bridge to carry live loads is determined by making allowance for the live load factor and the DLA, using the rating equation.

7.3 Proof Load Test

In Proof Load Tests, the bridge is carefully and incrementally loaded in the field to a pre-determined target proof load or until the bridge approaches its elastic limit, which ever occurs first.

The effects of these loads on critical members of the bridge are measured by instrumenting these members and monitoring them in 'real' time to ensure that the structure behaves linear-elasticity at all stages of loading.

The target proof load is generally set at the lower of theoretical ultimate load determined by analysis and two to two and half times the current legal load. The test is terminated when this goal is reached or if non-linear behaviour is observed.

From the maximum applied load, the actual rated load can be determined by making allowance for the live load factor, dynamic load allowance and test factor, using the rating equation.

The RTA has carried out proof load testing of over 60 bridges and determined their actual load capacities.

7.4 Dynamic Load Test

Dynamic test can be conducted by running test vehicles of known axle configuration and gross vehicle mass over the bridge at varying known speeds. The dynamic strains and deflections and acceleration are measured for these speeds.

These measurements can be used to obtain information on dynamic characteristics and dynamic load allowance.

The dynamic load allowance, thus obtained, can be used in the load rating the bridge.

Therefore, it is important to carry out Dynamic Load Test when a Performance or Proof Load Test of a bridge is carried out.

7.5 Asset Management Options

If after conducting a suitable load testing of a bridge, the RF (by load testing) is found to be $\geq 1$, no further action is required until the next Level 2 inspection.

In case RF (by load testing) is less than 1 the following asset management options are available; provided RF (by load testing) $\geq 1$ for options below:

- Reduce traffic lanes on bridge
• Sign post bridge for speed
• Strengthen bridge

If none of the above options are satisfactory, the bridge needs either to be bypassed or replaced.

8. CONCLUSION

The Bridge asset can be cost effectively managed without compromising safety or performance by having a good understanding of the Bridge stock and implementing a suitable well developed bridge asset management process, as described in the paper.

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DISCLAIMER

The opinions expressed in this paper are those of the author and do not necessarily reflect the policies of the Roads and Traffic Authority of NSW.