Considerations in Preparing Preservation Strategy Options for Deteriorating and ageing Bridges

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Summary: A diverse range of infrastructure currently exists in Australia, covering sectors such as transport, energy, water and communications, with bridges providing a key role in this network. There is increasing pressure to operate and maintain these structures in an optimal fashion to ensure its long-term functionality and accessibility without compromising on public safety for the duration of its serviceable life. However, asset owners and managers face the challenges of an increasing asset age profile and a backlog of existing maintenance and rehabilitation works in an environment of budget restrictions. Additional issues relating to condition deterioration and load deficiencies require further consideration. This paper presents a recent study carried out by the Queensland Department of Transport and Main Roads, which explored these issues in the management of a key bridge in the state's north. The composite steel girder and RC slab bridge was noted to be in poor condition, and TMR sought advice on various preservation strategies that were available, taking into account technical, economic and social influences. The paper shares insights on the history of the bridge, the preservation options required, how the various strategies were approached and developed, and what considerations were explored, including external and life-cycle management issues, the influence of condition and capacity, and deterioration over time. The paper concludes with observations and key messages that could be used to assist in the development of similar strategies for ageing bridges affected by condition issues.

Keywords: Asset management, strategic planning, preservation, maintenance, bridge inspection, case studies

1 INTRODUCTION

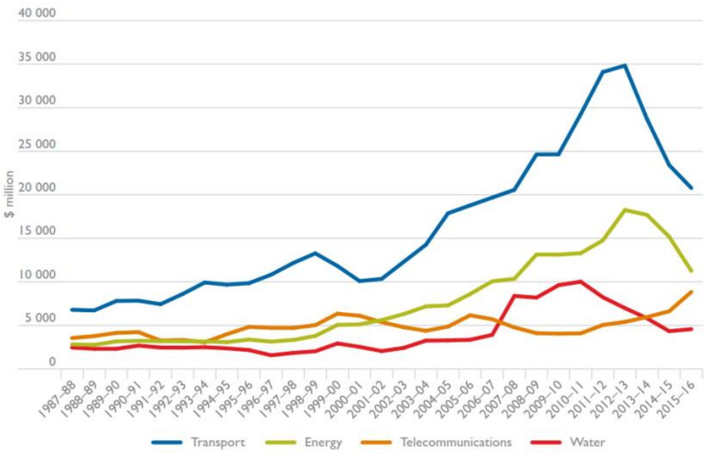

Figure 1 Infrastructure Construction Activity

Within Australia, there is a diverse range of infrastructure assets covering many sectors, such as transport, energy, water and communications. In recent history, there has been an increasing level of new infrastructure development, most notably in the transport sector (Error! Reference source not found.)[1]. This activity ultimately adds to the pool of existing ageing assets that require funding for maintenance and management to ensure long term functionality and safety over their serviceable life. In the 2015/16 budget, the Australian Federal government allocated over $6.8 billion to the States and Territories for infrastructure expenditure, which included both capital and operational costs [3]. Of this amount, approximately $550m was attributed to bridge maintenance and rehabilitation [4]. This covers a variety of issues such as aging, condition deterioration, fatigue, redundancy of the asset, unplanned damage, and functionality obsolescence. This does not fully address the backlog in maintenance which has been recently documented [2], where cyclical funding and inefficiencies in allocations means that there is insufficient investment in maintaining our current transport infrastructure, resulting in a “hidden deficit” of maintenance liabilities and declining service standards [3].

Balancing required service levels and access with maintenance requirements within a constrained budget environment and conflicting priorities puts increasing pressure on asset owners and managers. Therefore careful consideration is required to develop and implement appropriate management strategies that help achieve this balance in an optimised fashion.

There is an increased focus required to prioritise maintenance works, not just on the choice of asset, but on addressing particular deficiencies within a structure. This strategic approach moves away from what could be classed as a condition based maintenance programme to that of a functionality based programme, addressing only the areas that have the potential of affecting and reducing the functionality and level of service of the asset.

Preservation strategies are becoming increasingly significant for transportation agencies. The FHWA defines bridge preservation as [5]:

“*actions or strategies that prevent, delay or reduce deterioration of bridges or bridge elements, restore the function of existing bridges, keep bridges in good condition and extend their life.*”

The objective of a good bridge preservation strategy is to employ cost effective preservation treatments and activities at the appropriate time to maximise the useful life of bridges, which ultimately lead to lower lifetime costs. Such activities are considered preferable as the cost of major reconstruction or replacement activities are significantly greater than timely maintenance treatments or interventions. Timely and effective bridge preservation of sound bridges to assure their structural integrity and extend their useful life before they require replacement is considered a more palatable option [6,7].

The Queensland Department of Transport and Main Roads is aware of these challenges, managing approximately 3000 bridges on its road network of which the majority were constructed in the post-WW2 construction boom of the 1960s and 70s. In recent times, there are a number of bridges in sub-optimal condition that are under review and may require the possibility of life extension depending on the outcomes of future network functionality requirements. One such bridge is Rooneys Bridge in North Queensland. AECOM, in conjunction with TMR, carried out a preservation strategy review to explore management options for the bridge based on various service requirements. This has provided TMR with an informed position regarding the management of this bridge, which leads to optimal and cost-effective solutions.

The outcomes of this project provide useful learnings for other projects, and form the basis of this paper which is now discussed. The paper initially shares insights on the history of this bridge, the preservation options required, how the various strategies were approached and developed, and what considerations were explored, including external and life-cycle management issues, the influence of condition and capacity, and deterioration over time. The concept of preservation strategies is then explored in light of this project, incorporating the project learnings noted and outlining observations and key messages that could be used to assist in the development of similar strategies for ageing bridges affected by condition issues.

2 ROONEY BRIDGE CASE STUDY

To illustrate the application of sound management principles to reduce the effects and consequences of deterioration in ageing assets, an example is presented. This case study concerns an ageing asset where issues of corrosion were identified and found to be diminishing the functionality of the asset and the larger network that it supports. The case study deals with the factors affecting the deterioration and the measures that were put forward to reduce the consequence of the reported defects: the key aspect being to provide cost effective solutions to the ongoing management of the asset.

2.1 Background

Figure 2 Rooney Bridge

Rooney Bridge is located in Townsville and is a vital link within the city's transport network. Constructed in 1950, the bridge provides local access from the CBD to the southern residential and commercial areas and leads onto the Bruce Highway. It is a steel/concrete composite bridge of a total length of 198 metres, with 16 spans of 12.2 metres length. The deck has an overall width of 8 metres, with two traffic lanes and 7.4 metres width between kerbs. The superstructure comprises five simply supported steel I-girders with steel cross-girders at quarter points and a continuous composite RC deck. The piers and abutments comprise steel headstocks supported by four square RC driven piles. The bridge underwent major refurbishment in the early 2000s, with concrete repairs, pile encasements, re-painting of steelwork, replacement of corroded bearings and altering of some of the existing expansion joints to fixed joints to improve load distribution across the bridge for braking loads.

Recent inspections (March 2016) have highlighted that the structure is in a deteriorated state: Condition Rating 3 (poor), with severe cracking, spalling and reinforcement corrosion reported in the piles; and protective coating failure and significant corrosion in most steel components. To inform future management strategies, the following factors needed to be understood:

- current condition of the bridge and potential future traffic requirements
- implications that the condition will have on its short and long term functionality
- load capacity

TMR sought to understand the implications of its condition to explore the risks and strategies to manage the structure in the short and long term, with the intention to ensure no reduction in structural capacity over its remaining required life. Two separate preservation strategies were investigated and developed to facilitate this understanding to appropriately manage Rooney Bridge over its intended remaining life. These were:

- **short-term strategy**: five year plan to maintain the bridge at a safe level of service until its replaced as part of proposed route upgrade works
- **long-term strategy**: 20 year plan to restore and maintain the bridge at a safe level of service and integrate it into the proposed upgrade works, with the intent that it be replaced after 20 years.

2.2 Development of Strategies

A desk top review of existing inspection data was completed. This included a review of all reports dating back to 2002. From this an understanding of the historical deterioration rates was developed, as were the current maintenance requirements. This desk top review was also supplemented by a general overview condition inspection by the project team and TMR.

A streamlined structural assessment of the bridge was undertaken to determine the critical elements and inform the strategic management of the structure. From the assessment it was concluded that the girders had sufficient capacity in bending and shear for a T44-76 design vehicle, which included some cross-sectional area losses due to corrosion in critical locations (i.e. mid-span). Piles were found to be sufficient for vertical loads, however pile bending results were more sensitive to corrosion losses depending on assumptions (such as pile lengths, load distribution and corrosion location).

For the short-term five year plan, considerations were more on minimising capital expenditure and seeking to maintain its serviceability until the end of the five years. Based on the rate of deterioration on key structural components, such as piles, headstocks and girders, it was noted that a minimal approach of monitoring and access management would likely be sufficient. The monitoring regime included an increased frequency of inspection, with particular focus on critical components and measurement of defects to identify areas of structural distress. The development of a Structure Management Plan was also recommended to capture key issues and risks identified, such as structure critical components, key defects and permit/heavy vehicle access management. Recommended intervention levels were provided in relation to corrosion section losses to enable TMR to assess where a failure in the level of service was imminent.

For the long-term 20 year strategy, different considerations were required; such as projected deterioration, future use of the bridge and the maintenance/intervention requirements. Based on the estimated projected deterioration, it was evident that significant maintenance would be required at some stage during its remaining life. It was assumed that the first five years would follow the same intensive monitoring programme recommended for the short-term strategy, which would enable any permits and approvals to be developed prior to designing and repair or maintenance works to ensure its prolonged service. Several maintenance interventions were considered. For the piles, this involved cathodic protection, full encasements, targeted concrete patch repairs and crack injection. For the steelwork, it involved complete blast/re-paint all components, a component-specific programme of blast/re-paint or targeting deteriorated areas only. A multi-criteria analysis (MCA) identified the optimal maintenance solution, based on aspects such as cost, reliability of repair and anticipated life of repair. From this, the optimum solution put forward was targeted re-paint of steelwork on the bearings, girders and headstocks. Estimated life-cycle costs were determined for each strategy, taking account of operational costs, such as the frequency of inspections and routine replacement of items such as joints.

Relatively low costs of approximately $126,000 were estimated over the intended period of the short term strategy: the greater proportion of costs being in early in the period (Error! Reference source not found.). These are based on minimal maintenance and operational costs, such as increased frequency of inspections. Estimated costs for the longer term strategy were

Figure 3 Estimated Costs for Short Term Preservation Strategy

developed based on the preferred maintenance solutions identified from the MCA, with overall costs in the order of $2.5 m (Error! Reference source not found.). The minimalistic approach of the of the short term strategy was proposed for the first five years of the programme, followed by the first of two significant interventions to reinstate critical condition-poor components to a serviceable state. Based on deterioration modelling, a second intervention was recommended to allow for repairs on components not previously repaired.

2.3 Other Observations

During the review, a number of key pieces of information were identified and influenced the provision of the advice given. These are mostly related to corrosion of steelwork and reinforcement. Other observations had been made in the inspection reports, with either a CS3 or CS4 (Poor or very poor respectively) rating, but after review these were considered to be condition based only and not affecting overall functionality. These aspects are discussed below.

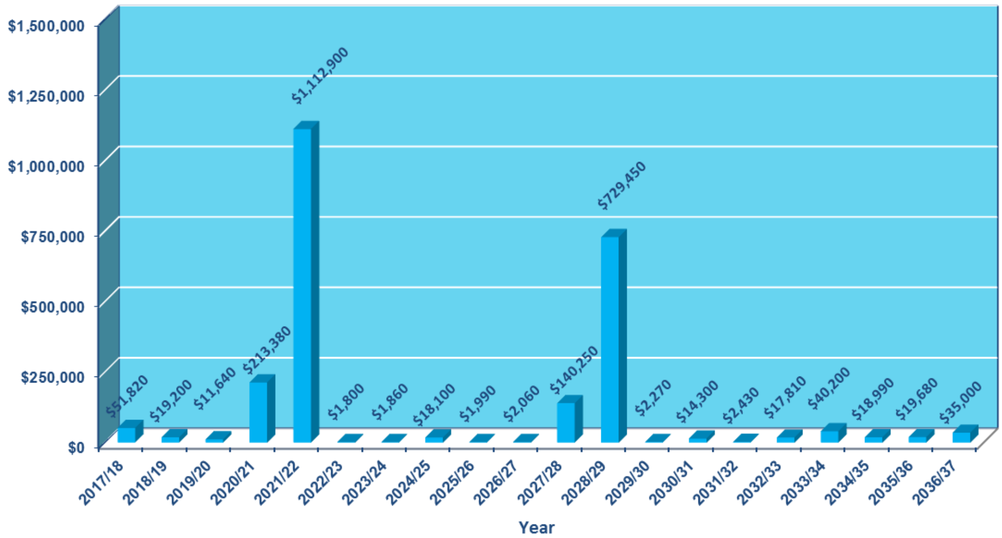

Figure 4 Estimated Costs for Long Term Strategy

2.3.1 Corrosion Related Defects

Several areas across the new and refurbished bearings; the RC piles and the steel headstocks were identified with significant corrosion section losses. Notably, the girders were generally in a relatively good condition with minimal losses despite the onset of corrosion being evident. The corrosion in the sliding bearings was significant and had appeared to cause some of the bearings to seize. After reviewing the corrosion impact on the overall performance of the bridge, the fixity of the bearings was noted to be more beneficial in catering for braking loads. For longer term management of the bridge, a monitoring regime was recommended for the bearings to review the impacts of the corrosion on the bridge’s ability to accommodate thermal movements.

For the headstocks, the location of the corrosion had occurred towards the ends of the member and was not part of the direct load path from the superstructure. Whilst additional section losses were noted in the headstock stiffeners, these are elements that are only critical for jacking up the bridge during bearing replacement activities – something that is not likely to occur now the majority of the bearings have been fixed retrospectively.

In contrast, significant corrosion of the reinforcing bars in a number of piles at the welded interface connecting to the headstock support required review due to the amount and location of the corrosion. This connection point represents a key mechanism in the transfer of loads from the deck to the piles, particularly for bending, which the piles were assessed to be sensitive. However, it was observed that not all piles in the same pier were in this condition. Due to the degree of redundancy at this location, i.e. the alternative load paths offered by the number of piles, the structural significance of the observed defects was more accurately considered in the assessment of the bridge and in the recommendation for future inspection and maintenance requirements.

Finally, most severe cases of corrosion were found to coincide with water leakages either from the water main service attached to the bridge or via failed bridge joints, allowing water to pass through from the deck to the substructure below.

(i) Existing piles

(ii) Bearings and Adjacent Steelwork

Figure 5 Examples of Deterioration in Rooney Bridge

Repairing such components can reduce the risk of ongoing corrosion in these locations due to the elimination of water. Such remedial measures are an effective and relatively inexpensive strategy to implement in a preservation plan to ensuring ongoing service of the bridge. As such, these options were recommended for the long-term strategy provided.

To explore the impact of corrosion on the bridge, a structural review was conducted on the piles and the girders. A number of section loss scenarios were trialled in structure-critical areas, with each trial showing progressively more severe corrosion losses. It was found that for the girders almost 50% section loss would be required in the bottom flange to trigger an unsatisfactory assessment ratio for both shear and bending. For the piles, concrete section losses at each corner was considered, however in compression it made minimal difference to the overall compression capacity of the pile, which is not unexpected [8]. Corrosion of the reinforcement also was found to be non-critical, however as previously discussed the location of corrosion at the welded headstock interface was found to compromise the integrity of the pile.

The impact of corrosion was also considered from a failure mechanisms perspective. The amount of corrosion can alter the ductility of steel, therefore promoting a brittle, sudden failure [9]. However due to the number of piles and steel girders in the structural system, the presence of cross-girders (facilitating the even distribution of load), the distribution of corrosion across the various components, and the composite concrete-steel superstructure, a reasonable degree of redundancy is noted.

2.3.2 Condition Based Defects

The most recent inspection report noted a 10 mm sag in the girders of all spans, which were subsequently marked to be in a severe condition. It was originally thought that these girders had been damaged by the previous heavy vehicle regime permitted to access the bridge. However upon closer inspection of the drawings, it was noted that this sag in the girders was identified in refurbishment drawings, flagging an intentional detail.

Other defects recorded in the most recent Level 2 inspection report included spalling in the soffit of the deck slab and severe cracking in the RC kerbs. Each of these was rated as CS3, poor, with recommendations that they be repaired. In developing the strategy plans, the focus was to take account of each the defects' potential impact on functionality and structural integrity. Taking account of the reported condition and potential worst-case deterioration, it was concluded that these defects would not have an impact on the functionality or structural integrity of the bridge and, consequently, no recommendations for their remediation were made as part of the short and long term strategy plans.

3 DEVELOPMENT OF ASSET MANAGEMENT AND PRESERVATION STRATEGIES

In alignment with ISO 55000: 2014 "Asset Management" [10] and the International Infrastructure Management Manual (IIMM) [11], assets only exist to deliver a required service for an acceptable level of risk and lifecycle costs. In new structures this process would commence at the earliest stage of the asset creation process: typically planning/Business Case. At this stage, the assets are only conceptually designed; with their base form and functionality defined to support the preparation of cost estimates for the Business Case. This ultimately drives the decision to proceed to asset creation. Furthermore, at this early stage, it is a sound asset management approach to develop lifecycle cost analysis to aid the selection of the optimum asset option. An understanding of the factors affecting potential component failures and deterioration can be taken into consideration by the engineering team and reflected in the early cost estimates for both the asset creation and operation over its intended lifecycle. The focus at this stage is to effectively balance the two potential asset management risks, namely:

- Underspending/reducing the CAPEX to the point that it significantly impacts the OPEX over the asset's life
- Overspending on the CAPEX to minimise risks of asset failure below what could be an acceptable manageable level. This could be achieved through over-engineering solutions where the worse consequences of asset failure drives the design and material selection process, for instance, as opposed to a risk based approach.

Within Australia, there is a large stock of ageing assets that have not gone through the above "ideal" asset management process from the conceptual phase. In many instances a more informal approach to the asset management has been adopted, whereby defect rectification is undertaken on an “as required” approach. In order to fully understand and manage asset maintenance costs in an effective manner, it is necessary to develop such management strategy plans that extend over the intended remaining life of the asset. For the outcomes to be effective, a number of factors need to be considered, namely:

- current asset condition
- historical records: as constructed drawings, maintenance records, historical inspection records, etc.
- intended remaining asset life
- required level of service: both current and future requirements
- environmental and locational factors, i.e. effects on durability
- assumptions for material deterioration rates
- current material properties

Given the age of many assets, a full suite of such records may not be available to asset owners and development of future strategy plans may be based on a series of assumptions taking account of knowledge of similar assets and/or conditions. Again, a risk based approach to strategy development is required, taking account of likelihood and risk to functionality.

4 DISCUSSION

As stated previously, there is an increasing level of ageing transportation assets within Australia placing higher demands on maintenance funding and budgets. In order to best channel this funding effectively, a greater understanding of the condition and deterioration effects is needed, with a focus being on how overall functionality is, or is likely, to be affected.

Councils and road authorities implement a programme of Level 1 and Level 2 bridge inspections, adopting set policies and procedures. One example of this is TMR’s Structure Inspection Manual [12]. This details the requirements for setting up an inspection regime and frequency. Details of inspector experience requirements are also provided. Also within the manual, there is guidance on the condition state requirements for each type of component. Generally, the inspection reports serve as providing a sound and detailed view of the structure condition along with that of individual condition. Following on from these inspections, structure maintenance schedules are generally developed for action based on those structures and components rated as being in CS3 (poor) or CS4 (very poor).

It is apparent, when developing these maintenance schedules that the focus is more on general condition. The resultant is that essential funding may not be apportioned to the more needy structures. As part of the process of developing maintenance schedules a series of factors should be considered, namely: does the reported defect adversely affect any of the following:

- structural functionality and integrity
- general safety of the public
- durability of key components
- route significance

The follow up to these should also consider what the consequence would be if the defect was not addressed. Essentially, this is taking a risk based approach to developing maintenance strategies. The key outcome from this is addressing functionality rather than purely condition. In the Rooney Bridge case study, recommendations were made in the 2016 inspection report that all steelwork should be fully re-painted along with encasement of the RC piles. This is clearly a high cost approach, especially when taking into account the potential future road upgrades at that location that could result in the bridge being replaced after 20 years. With this in mind focus can then move away from a full rehabilitation and take a targeted, more cost-effective, approach to preservation.

To develop effective preservation strategies, a sound understanding of the impacts of the defects and their effect on the factors listed above is required. This coupled with historical records can help with establishing potential deterioration rates, from which a more reasoned judgement can be made as to potential residual life and intervention actions. This, though, is most effective, in situations where clear and consistent inspection and maintenance records are maintained.

5 CONCLUSIONS

A wide variety of management strategies can be utilised for the design and operation of assets. In developing strategies for new assets, the balance of CAPEX and OPEX costs need to be considered in relation to the availability of the asset for maintenance, its intended functionality, the potential risks and impacts throughout the assets' life, and its intended lifecycle. Developing of such an overarching understanding at the planning stage is key to the lifecycle strategic planning of new assets.

In developing asset management strategies for existing ageing assets, the maintenance needs to be optimised between short and long term strategies in order to minimise disruption to operations while providing a safe and reliable asset appropriate for future requirements. Understanding the relevance of the impact of deterioration in components, and the effect on structural performance, is critical for the development of appropriate asset management and preservation strategies for existing infrastructure. Being able to assess what defects can lead to a decrease in the levels of service provided by the assets allows optimising the extent of future intervention and the associated costs.

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Brian Finegan is a Principal, Structural Engineer with AECOM and has over 25 years' experience in the area of structural asset management and condition appraisal in both the UK and Australia. He has worked in public and private sectors and understands the importance of sound asset management strategies and aligning condition with structural significance. Brian has and undertaken and overseen the inspection of a large number of highway structures for various clients including the Highways Agency and Transurban. Through previous roles with TMR, Brian also has a sound understanding of the financial impacts of bridge maintenance works and the importance of effective strategic planning.

Dr Torill Pape has over 17 years' experience as a structural engineer across a number of sectors, including consulting, construction, public service and academia. She holds a PhD on the validity of inspection techniques when assessing corrosion-affected concrete structures, providing a sound understanding the relationship between condition and structural performance. Throughout her career she has built up extensive experience in asset management of road and rail structures, with technical and managerial experience in structural and condition inspections, durability assessments, the development of life-cycle management strategies, and linking component condition with the overall performance of a structure. In her previous role in ARRB Group providing specialist technical advice and applied research solutions for various road authorities, she has acquired a unique perspective of the challenges facing infrastructure owners.

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