DECISION SUPPORT IN USING FIBRE REINFORCED POLYMER (FRP) COMPOSITES IN REHABILITATION OF CONCRETE BRIDGE STRUCTURES

The research is being undertaken by the Australian CRC for Construction Innovation

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ABSTRACT: In management of civil infrastructure facilities made of concrete, lack of decision support tools, which identify the whole of life benefit/cost of using smart materials and technologies such as fibre reinforced polymer composites, hinders adoption of such smart technologies. A newly commenced research project the Australian CRC for Construction Innovation is primarily being undertaken at RMIT University in Australia is aimed at addressing this gap in knowledge by developing an integrated framework for the use of fibre reinforced polymer composites in rehabilitation of concrete structures. This paper presents a guideline and recommended procedures for Decision Support Tool that relies on the life-cycle cost analysis. It is anticipated that the results from this research will help officials in making sound decisions regarding FRP strengthening of bridges based on a life cycle cost analysis (LCCA). The LCCA will be transparent such that it can be utilized by users with little or no background on the complicated formulation behind it.

Introduction

Fenwick & Rotolone (2003) reports that, Queensland Department of Main Roads (QDMR) manages a state controlled road network of some 33,000 km which contains some 2850 bridges. This primary network carries over 80% of the freight task. Table 1 shows the major construction materials used in the existing network of bridges in three periods (Fenwick & Rotolone 2003) [1].

Table 1 Age and Material Distributions of Bridges[1]

Bridge Material	Oldest still in service	Number Built			Subtotal
		Pre 1950	1950-1976	Post 1976	
Timber	1886	322	177	1	500
Reinforced Concrete	1896	49	60	17	126
Steel	1886	32	187	12	231
PSC	1954	0	679	1319	1998
Total		403	1103	1349	2855

In the first and second periods (pre 1950 and 1950-1976) the design loads were relatively lower than the current loading criteria of Austroad bridge standard (e.g. A Class – a 15 ton truck, 5 t + 10t axles) [1]. However, some of the older bridges were designed for higher load capacities due to higher design loads (often crowd load on larger spans) and conservative design methods. This resulted in a very low “working stress” compared with ultimate capacity of the bridge, which made some of old bridges safe to be in operation[1].

QDMR has an asset management system to maintain the bridges in an acceptable condition and to keep the network in full operation. This system uses regular inspections, condition report data, analysis and prioritisation tools, maintenance manuals, and heavy load routing systems to allow heavy vehicles free access to all parts of the network and to avoid placing load restrictions on any bridge in the primary (state-controlled roads) network.[1] A number of bridges have been observed to require immediate strengthening to avoid such restriction. The management is seeking a sound decisions methodology for assessment of the capacity of the structures and efficient strengthening methods. A new research project at RMIT University is aimed at developing a decision support methodology for use of FRP composites in rehabilitation of concrete bridge structures.

Background

Keeping bridges in a good operation condition is a continuous challenge faced by Transportation agencies. Fast rate of deterioration and the high cost of repair, rehabilitation and replacement of bridge structures have become major issues in road asset management. Even when the resources have been allocated, completing rehabilitation tasks with minimal interruptions to traffic flow and inconvenience to the public has been a major issue in identifying a given method of rehabilitation.

Deficient bridges include two basic types. Structurally deficient bridges are those with deteriorated structural components, which require restrictions to be placed on usage by traffic since they have inadequate load carrying capacity. Functionally obsolete bridges are the ones that cannot meet the new strategic function and level of use of the route including traffic, width, alignment, height clearance and flood frequency. These bridges may have older design features that prevent them from accommodating current traffic volumes with modern vehicle sizes and weights.

The strengthening or retrofitting of existing concrete structures to resist higher design loads, correct deterioration-related damage, or increased ductility has traditionally been accomplished using conventional materials and construction techniques. Externally bonded steel plates, steel or concrete jackets and external post tensioning are just some of the many traditional techniques available. In the context of the strengthening of the reinforced concrete bridges, advanced composite materials have the potential for leading to innovative solutions.

These advanced composites used in bridge rehabilitation are being developed from fibres, polymers, metals and composites of these materials. While the concept of composites have been used in building industry for several millennia, the application of fibre reinforced polymer (FRP) for rehabilitation and strengthening of reinforced concrete structures is new. The FRP composites combine the strength of the fibres with the stability of the polymer resins. They are defined as polymer matrix, that are reinforced with fibres or other reinforcing material with a sufficient aspect ratio (length to thickness) to provide a desirable reinforcing function in one or more directions. The FRP composite materials are different from traditional construction materials such as steel, aluminium and concrete because they are anisotropic; i.e., the properties differ depending on the direction of the fibres. Due to the resulting benefits, FRP composite applications have affected entire industries including aerospace, marine, electrical, and transportation (Nystrom at el. 2003)[2].

FRP composites gain their strength largely from the fibres, which are usually glass, carbon, or Aramid fibre. FRP materials are lightweight, non-corrosive, non-magnetic and exhibit high tensile strength. Additionally, these materials are readily available in several forms ranging from factory made laminates to dry fibre sheets that can be wrapped to conform to the geometry of a structure before adding the polymer resin. The relatively thin profile of cured FRP systems is often desirable in applications where aesthetics or access is a concern. The growing interest in FRP systems for strengthening and retrofitting can be attributed to many factors. Although the fibres and resins used in an FRP system are relatively expensive compared with traditional strengthening materials like concrete and steel, labour and equipment costs to install FRP systems are often lower. FRP systems can also be used in areas with limited access where traditional techniques would be difficult to implement.

FRP systems with their high versatility can be used to rehabilitate a deteriorated structural member, strengthen a functionally obsolete structural member to resist increased loads due to changes in use of the structure, or address design or construction errors. To assess suitability of a FRP system for a particular application, the condition assessment of the existing structure should be performed and the best treatment option should be then determined based on the assessment (ACI, 440, 2002)[4].

The decision maker requires information on lifecycle performance of the structure and durability as well as underpinning social and economic factors to make an informed decision. This paper presents a decision support framework, which will enable asset owners and managers to select the best option available to them in dealing with ageing bridge structures.

Decision support framework

Almost every organization faces the need to evaluate several program proposals or projects competing for scarce resources. Most of the time, the decision maker is trying to satisfy conflicting objectives or cater for opposing group interests. The challenges faced in developing an integrated decision making framework are both procedural and conceptual. In operational terms, the framework should be easy to be understood and employed. In philosophical terms, the framework should be able to deal with challenging issues, such as uncertainty, time frame, network effects, model changes, while integrating cost and non-cost values into the evaluation. The choice of evaluation techniques depends on the feature of the problem at hand, on the aims of the analysis, and on the underlying information base [5].

With the advancement of technology, more sophisticated analytical tools are available to cover technical consequences and hidden costs of investment decisions. However, decision makers are often faced with the daunting task of optimising other more dominating objectives such as construction costs, material quantities, discount rates, method of rehabilitation and their expected lives and maintenance treatments. These multi rather than single-goal planning requires a framework for decision making.

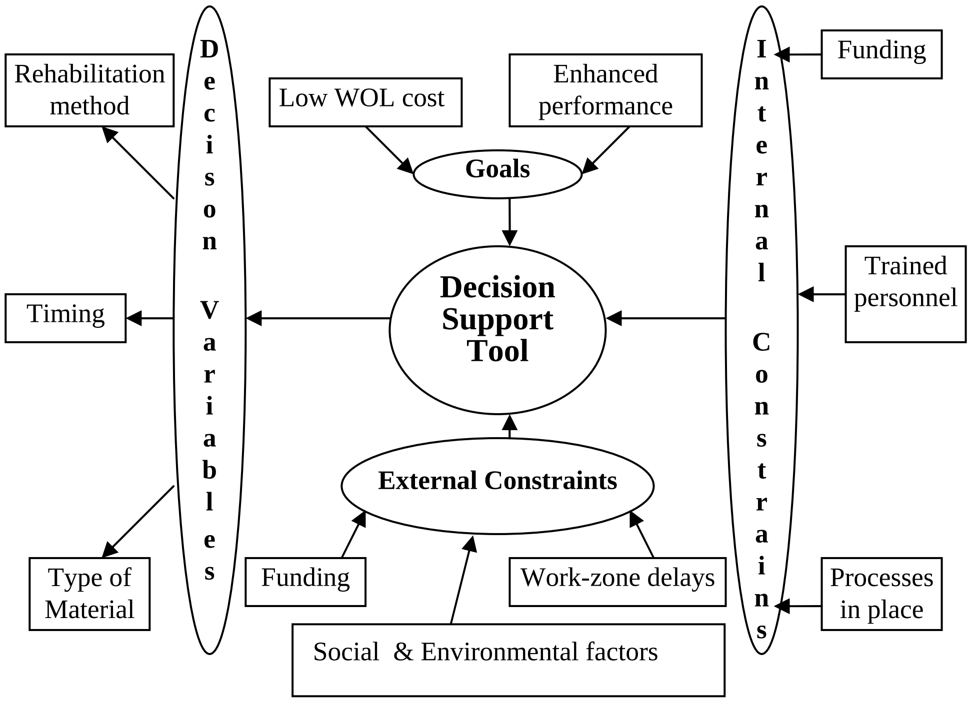

Figure 1: A draft decision making framework for rehabilitation of the bridges.

A multi-criteria decision making model (Figure 1) was developed based on a comprehensive literature review covering goals, input data, constraints and decision variables[5],[12,13]. The model was presented to the industry partners and was customised considering the industry input and expected outcomes.

The revised decision support framework shown in Figure 2 was developed after identifying the most important factors to be covered from those depicted in the MCDM model (Figure 1). The framework was developed around three key tasks: Identification of deficiencies, establishing available treatment options and then conducting a life cycle cost analysis for each of the options. Thse tasks were identified through industry consultation.

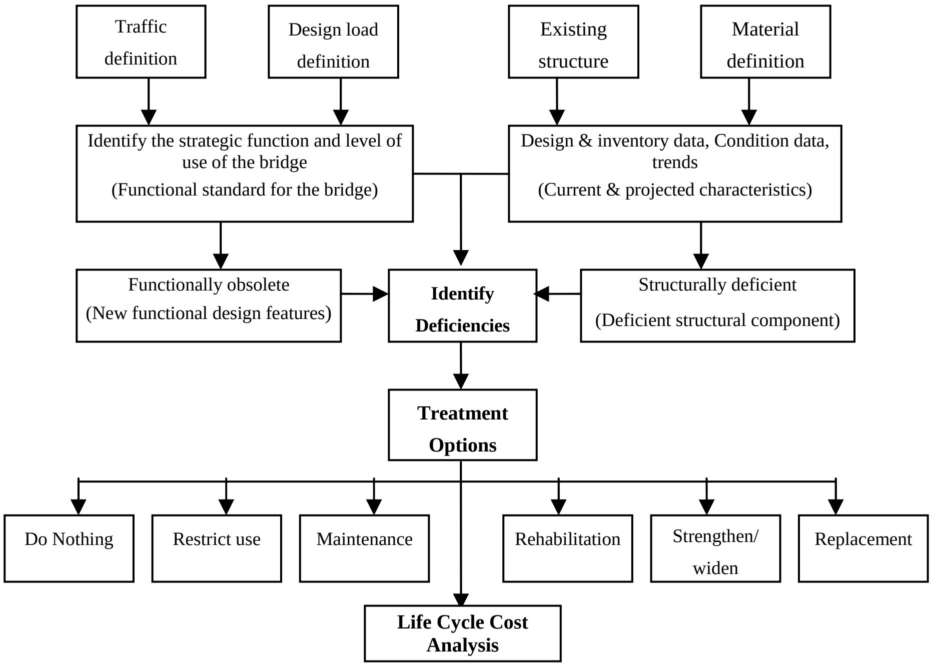

Figure 2: Proposed decision making framework for rehabilitation of bridges

Identification of deficiencies

Identification of the deficiencies of the bridge structure is the first step in addressing the issue of rehabilitation. This requires clear identification of performance requirements of the bridge structure and then evaluating the performance based on existing information of the bridge.

As reported by Li et al (2003) most transport authorities are well progressed with their bridge assessment programs. However, dealing with structures identified as “failed” the initial assessment now has to be dealt with in a systematic manner.

Condition assessment of the structure is the first step in determining the rehabilitation methodology. Clear identification of the performance level needed and deficiencies requires design load definition, definition of traffic, material properties and design documentation of the existing structure. Project specifications and identified strategic function and level of use of the route can be used to establish some of the above information. Evaluation of the structure should commence by conducting a systematic field assessment and recording details of previous repair or rehabilitation task undertaken and accident and traffic overloading data if available. This would be followed by a structural analysis and design calculations complying with the recommendations of the relevant codes and standards.

At the end of this phase, the bridge structure can be categorised as “Structurally Deficient” or “Functionally Obsolete”, with a clear understanding of the deficiency.

Treatment options

This is an extremely important component of the framework. Options available to the authorities have been expanded over the years with new developments in materials and structural technology. However, a lack of availability of complete information, which facilitates a fair comparison, makes it difficult for the decision maker to make an informed decision. Broad range of higher level options identified by the authorities are given below.

- Do nothing
- Restrict use
- Maintain and monitor
- Rehabilitate
- Strengthen/widen
- Replace super-structure
- Replace entire bridge

Recent developments related to materials, methods and techniques for structural strengthening and rehabilitation of the deteriorated bridges have been enormous. One of today’s state-of-the-art is the use of fibre reinforced polymer (FRP) composites, which are currently viewed by engineer as a “new” and highly promising material in the construction industry. The reasons why FRP composites are increasingly used as strengthening materials of reinforced concrete elements may be summarised as follows:

- Immunity in corrosion
- Low weight
- Resulting in easier application in confined space
- Elimination of the need for scaffolding and reduction in labour costs or stopping the traffic and bridge operation
- Very high tensile strength (both static and long term, for certain types of FRP material)
- Large deformation capacity
- Unlimited availability in FRP sizes, geometry and dimensions

In regards to these advantages, uses of FRP strengthening systems make the rehabilitation and strengthening of bridges more achievable. However, final decision regarding the FRP technical use should be based on consideration of several factors, including not only mechanical performance aspects, but also constructability and long-term durability.

Evaluation of Options

Presenting clear and concise information to the decision maker regarding the available options will enable him/her to make a higher level decision from the list identified above. Detailed discussions with the industry revealed that the "cost" is the prime deciding factor in making a decision in selecting a particular strengthening scheme. Although it is clear that the decision maker will balance social, environmental and political goals as well in making the decision, this is expected to be left at the discretion of the decision maker in the first stage of the tool development. Authorities prefer to be presented with the whole of life cost of a selected treatment option and incorporate other factors through their own judgement.

Whole Life cycle cost analysis (WLCCA) is an evaluation method which uses an economic analysis technique that allows comparison of investment alternatives having different cost streams. WLCCA evaluates each alternative by estimating the costs and timing of the cost over a selected analysis period and converting these costs to economically comparable values considering time-value of money over predicted whole of life cycle. The analysis results can be presented in several different ways, but the most common used indicator in road asset management is present value of the investment option. The present value of an investment alternative is equal to the sum of all cost associated with the alternatives discounted to today's values [3].

Following factors associated with the calculation of WLCCA will need to be considered in evaluation of treatment options.

- Material costs
- Service life associated with each treatment option including do nothing solution (existing structure)
- Maintenance, monitoring and repair associated with each treatment option
- User costs
- Sensitivity analysis – evaluate the sensitivity of life cycle cost analysis to predicted whole life of structure

Finally, it is understood that presenting a deterministic value of cost to the decision maker is unrealistic, considering the huge uncertainty of the input parameters. The reliability of each treatment option needs to be evaluated and the methodology has to be calibrated over a period of time. This requires records maintained over a period of time.

Conclusion

Availability of innovative materials and new technologies of structural rehabilitation has opened up opportunities for more efficient structural rehabilitation. However, lack of decision support tools which facilitate comparison of these options has stalled ready application of these technologies in the field. Due to the desirable properties and easy installation of fibre-reinforced polymer composites (FRP), uses of these materials for strengthening of ageing concrete structures have increased significantly. Bridge strengthening using FRP composites is generally less expensive than replacement and it is preferable to restricting loads on bridges. Use of FRP materials also shortens downtimes for rehabilitation, which reduces inconvenience to the travelling public and economic loss to areas served. Capturing of the advantages of using these materials require a framework for comparison of different options available for rehabilitation.

The work reported herein presents a decision making framework for rehabilitation of reinforced concrete bridge structures. The major components of the framework have been identified as, capacity analysis, identification of treatment options and whole of life cost analysis of each of the options using a reliability-based methodology. The framework is currently being calibrated using a case study of a bridge structure in Queensland, Australia.

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