Classification of Railway Bridges Based on Criticality and Vulnerability Factors

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ABSTRACT
Bridges are currently rated individually for maintenance and repair actions according to the structural conditions of their elements. Dealing with thousands of bridges and the many factors that cause deterioration, make the rating process extremely complicated. The current simplified but practical methods are not accurate enough. On the other hand, the sophisticated but more accurate methods are only used for a single or particular type of bridge. Therefore it is required to develop a practical and accurate rating system for a network of bridges. To achieve this aim, classifying bridges will be the first and most important step. This classification will be accomplished based on the differences in nature and unique characteristics of the critical factors and the relationship between them for a network of bridges. To build this classification for railway bridges, the critical factors and vulnerable elements will be identified and placed in different categories. This classification method will be used to develop a new practical rating method for a network of railway bridges based on criticality and vulnerability analysis. This rating system will be more accurate and economical and improves the safety and serviceability of railway bridges.

KEYWORDS
Bridge Classification; Criticality; Vulnerability; Bride Management; Rating Bridges

INTRODUCTION

Structural conditions of bridges change with time due to environmental effects, changes in quality and quantity of loads, etc. (Shih et al., 2009). Prioritising bridges according to their structural conditions for maintenance, repair or replacement actions is one of the most important parts in every Bridge Management System (BMS). To evaluate the condition of railway bridges with acceptable accuracy, many factors such as adequate information on the severity and extent of damage, environmental condition, geometry of the structure, material, loading, are involved.

Considering more factors increases the complexities of the structural models and consequently decreases the practicality of the rating system. Sasmal and Ramanjaneyulu (2008) consider that, to make sure the existing bridges are still able to carry loads, developing a rational algorithm for evaluating their condition is an immediate need. In fact an economical plan for providing adequate safety and functionality for bridges is highly dependent on the accuracy of current condition assessment and future condition prediction of bridges. The efficiency of this condition assessment and rating system for a group of bridges is dependent on how critical factors and the correlation between them are identified and classified.

Currently in practical inspection manuals the condition of each structural element of a structure will be assessed during an inspection process. The condition of a bridge derived from the condition of each individual element (Austroads, 2004). After the components and elements of the bridge have been classified, based on the importance of each element for the integrity of the structure a weighting factor will be assigned to them (Ryall, 2010), and finally the condition of the whole structure will be evaluated accordingly. In current practical rating systems the methods are too simplistic and may not be appropriate, as for determining these weighting factors they do not take into account many factors such as the geometry of different structures or the types of loading at network level.

In current inspection manuals such as Pennsylvania Report about Railway Bridges (Laman et al., 2010), attempts were made to incorporate the contribution of other critical factors, such as scour and fatigue, in evaluating the risk of failure as well. Also it has been tried to determine the criticality of elements subjected to particular crucial factors. For instance AASHTO (2011) shows that spread footings are more critical than piles where they are subjected to scour and erosion. Although the efficiency of these rating methods by considering critical factors increased, the responses of bridges with different geometry, material, etc, to these factors through an appropriate classification for a network of bridges have not been taken into account.

In Recent researches, scholars have made significant attempt to incorporate more critical factors, in order to be able to devise a more accurate method for condition assessment and rating bridges. Wong (2006) adopted a criticality and vulnerability analysis and Analytic Hierarchy Process (AHP) system to evaluate more accurately the structural condition of Tsing Ma Bridge in Hong Kong. Xu et al. (2009) by conducting criticality and vulnerability analyses and utilizing Fuzzy logic with AHP developed a rating system for Tsing Ma Bridge to deal with uncertainties comes from inspection process. AHP builds a hierarchy structure to solve a complex problem. In bridge rating system it is used for the classification and prioritization of factors such as environmental impacts, fatigue, etc. Saaty (1980) developed AHP method (Sasmal & Ramanjaneyulu, 2008), and Zahedi (1986) conducted a comprehensive investigation on the methodology of AHP and its applications. The mathematical concept and definition about the fuzzy logic operations is comprehensively explained in (Tee, 1988).

The results of these methods were reliable because the effect of different factors on the structure were calculated more accurately by identifying and classifying the criticality and vulnerability factors and conducting analyses associated with them. However they were all designed for one bridge only and therefore were not applicable for a network of bridges. Furthermore their methods need a large amount of accurate data about the bridge and a complicated analytical process and consequently make these rating systems impractical for a network of thousands of bridges. To be able to compare and rate a network of bridges, they should be classified first and the rating method should be simplified for different classifications.

AHP was used by other scholars for classifying and categorizing factors in different levels. Sasmal and Ramanjaneyulu (2008) developed a multicriteria process for condition evaluation of reinforced concrete bridges, and Zayed et al. (2007) applied AHP and utility function for risk assessment of bridges with unknown foundation. Tarighat et al. (2009) utilized fuzzy logic for rating bridges with concrete deck. They all proved that rating one type of bridges such as reinforced concrete bridges or a part of a bridge such as foundation or concrete deck based on identified and classified criticality factors is practical; however their classification has not been designed for a network of bridges with different geometry, material, loading, and environmental condition.

By appropriately classifying bridges, crucial factors will be taken into account efficiently and consequently the railway bridge rating system in a network level will be more practical, economical and accurate. Utilizing the resources including time, expertise and equipments efficiently for improving the safety and serviceability of railway bridges will be dependent on a rating system, founded on an appropriate classification.

CLASSIFICATION METHOD FOR A NETWORK OF RAILWAY BRIDGES

To be capable to classify railway bridges, primarily the important factors including, age, geometry of the structure, material, loading, and environmental effects, etc should be identified. To this purpose, data for a group of about 1000 railway bridges in Australia were collected from inventory data and inspection reports. Then some preliminary analyses were conducted on them to identify the most important factors that affect the current and future condition of railway bridges.

Survey and Results

As can be observed in figure 1 more than 70% of these railway bridges are older than 40 years old. It means that taking action for their maintenance or repair may be required. Consequently providing accurate inspection reports about their condition is essential. These reports should be able to provide sufficient and precise information about the critical elements of these railway bridges according to their classification.

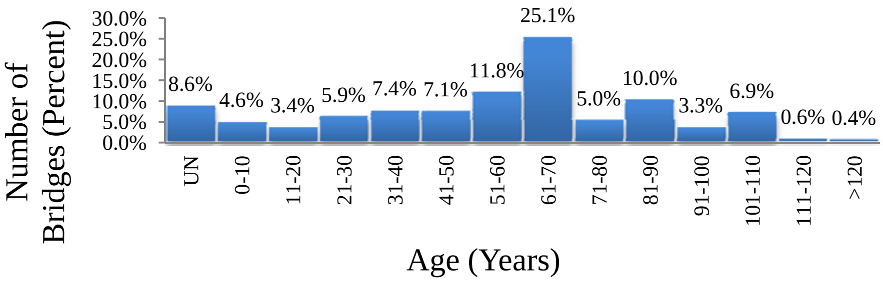

Figure 1 Age of railway bridges in a sample of 1122 in Australia

It has been observed that, steel was the main material that was used in superstructures' components of railway bridges. Therefore the effect of corrosion will be one of the most critical factors for the durability of the bridge. Besides, the fatigue impact was identified as a crucial factor for deteriorating railway bridges with steel structures. The fact that timber will not be used as a structural material any longer performing rigorous structural analysis on them may not be necessary.

Furthermore, the analysis of the collected data depicts that reinforced concrete that currently is greatly utilized, has not been used widely in past, therefore evaluating the current condition of railway bridges constructed with reinforced concrete seems to be a rational strategy. Mass concrete and masonry have been widely used as substructure materials. Therefore their condition and their vulnerability should be assessed in the inspection process. However structural analysis on them considering the ambiguity in their structural behaviour (Orbán et al., 2009) may not be valuable.

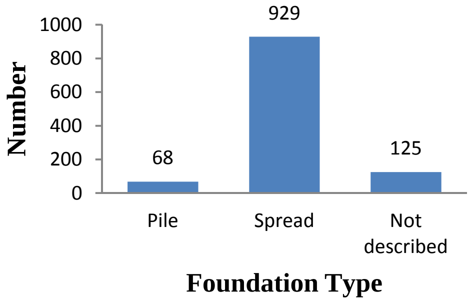

Figure 3 Foundation Type

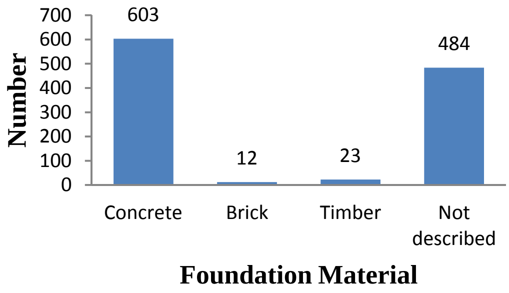

Figure 4 Foundation Material

The analyses of these data also show that the inspection process should be focused on spread footings as that are used much more frequently than piles (Figure 3). However for new railway bridges, pile is one of the common type foundations. Hence its behaviour is required to be evaluated through structural analysis. In addition, the materials of about 45% of the foundations of railway bridges were not identified through inspection process (see Figure 4). Therefore it can be concluded that the accessibility to these structural elements are very limited and consequently the type of questions that is required to be answered by inspectors should be designed considering these restrictions. Furthermore it was identified that, the changes in temperature, and scour, are two other important factors for deteriorating railway bridges and decreasing their remaining service life in Australia. Based on identified factors the following classification method for a network of bridges will be developed.

Classification Method

Many efforts have been made by researchers to identify crucial factors and critical elements of the structure and classifying them for developing a more reliable condition assessment method for bridges. However these attempts were focused on a single bridge or a group of one part or one type of bridges, and the structural condition of a network of bridges have not been assessed yet. Although modern technologies are improving and at the same time, power of the data analysis as well as engineering knowledge are being rapidly enhanced, these methods are still too complex to be used for a network of thousands of bridges. The reason is for each individual bridge, a massive amount of information, very rigorous structural analyses, profound engineering knowledge, and almost unlimited time is required. Therefore they should be modified and simplified to be utilized for rating a network of bridges. To this purpose railway bridges in network level should be classified first.

In this classification, to avoid conducting unnecessary detailed inspection on each single structural element and performing structural analyses on every individual railway bridge which is not practical, a network of bridges will be divided into several groups. For each group of bridges a typical analytical model that can represent the whole bridges in that group will be created based on the similarities between the geometries of their structures. Then factors such as loadings, and environmental effects that have impact on the current and future condition of that typical bridge will be classified based on their unique characteristics. In order to be able to take into account the correlation between these factors, it is essential to classify them appropriately. Ultimately this classification will be used for criticality and vulnerability analyses for determining weighting factors related to different critical factors for each structural element. The results will be used for developing a new rating system. Evaluating the structural condition of typical bridges by considering different critical factors will increase the accuracy of the condition assessment and rating system that uses this classification method. Furthermore by performing structural analyses on typical bridges instead of each individual bridge in a network of thousands of bridges the practicality of the method will improve. Different components of this classification, including the structure geometry, elements' materials, loading types and characteristics, environmental conditions are explained as follows.

Structure Geometry. The behaviour and response of a structure according to its geometry will be changed. To incorporate the geometry of the railway bridges into the rating process, the structure will be separated into two main components. These components are superstructure, and substructure. Each of these components consisted of several elements according to the bridge structural configuration. It is important to identify the fracture critical elements of the structure according to its geometry. Fracture critical elements/members (FCM) are those structural elements that any failure in them may cause the failure of a portion or the whole structure (Necati Catbas et al., 2008; Bridge Inspection Committee, 2010). Foundations are not easily accessible in inspection process and as a result, it is difficult to evaluate their condition. Therefore the number of questions that can be answered by inspector will be less and consequently the classification system should be design accordingly. After damages being identified through inspection process, the geometry of the model will be updated. Therefore current condition can be compared with previous or as built condition. The next step for creating the mathematical models of these typical bridges is to identify the material and assigning them to the geometry.

Elements Materials. Different types of materials including steel, concrete, timber and masonry are considered and will be assigned to the structure. Also for each of them for example for concrete, subcategories such as mass, reinforced, pre-stressed, and post-tensioned are defined.

Loading Types and Characteristics. According to the differences between loads, they can be put in different categories. The type of the load and its position may cause critical condition for the structure (Boothby, 2001). Some of these loads are unique for each individual railway bridge, but some of them can be the same for a network of bridges. For instance, for each single bridge the dead and live load is different and their effects are on the current capacity of the bridges. If the live load exceeds its limit a part or the whole structure may collapse instantly. But loads such as wind or flood in an area are almost the same, although the responses of the structures to them are different. The quantity of these types of lateral loadings can be calculated from available standard's maps such as AS 1170.2 (2002), and the response of the structure based on its geometry and material can be estimated for each typical railway bridges.

In order to compare the effects of each type of loadings, the coefficients that are applied to them according to load combination factors, will be utilized. These load combination factors can be obtained from current standards. It improves the accuracy of this rating system by utilizing available knowledge. Also the effect of fatigue as one of the most important factors in deteriorating the railway bridges will be analysed and incorporated to the classification. Live loads that are applied to railway bridges may change significantly during time (Nielsen et al., 2011). Therefore live load and its dynamic effect that will be used for load rating of bridges and estimating the live load capacity of the structure is the most important element of this classification. Structural health monitoring (SHM) can be used later to evaluate the effect of live load on the damaged structure with high confidence for validation of criticality analyses (Catbas et al., 2007). In Australia recent development in SHM are summarized in the booked edited by (Chan et al., 2011).

Environmental Conditions. Environmental factors such as corrosion and changes in temperature that affect the condition of the structure will be estimated and considered in different category. For the types of agents that maps are available such as the hazard of Termite, Decay for timber bridges (NAFI, 2003; Leicester et al., 2009) their information will be used to determine and incorporate the contribution of each of them in deteriorating railway bridges in an area.

RESULTS AND DISCUSSION

Figure 2 shows the classification proposed in this paper. Each of the elements of this classification will be broken down to subcategories. It is necessary to consider loading as one of the element of this classification. The reason is, even if the structural condition of a bridge does not change after many years, however the loading may change and therefore the structure may not be safe and/or serviceable.

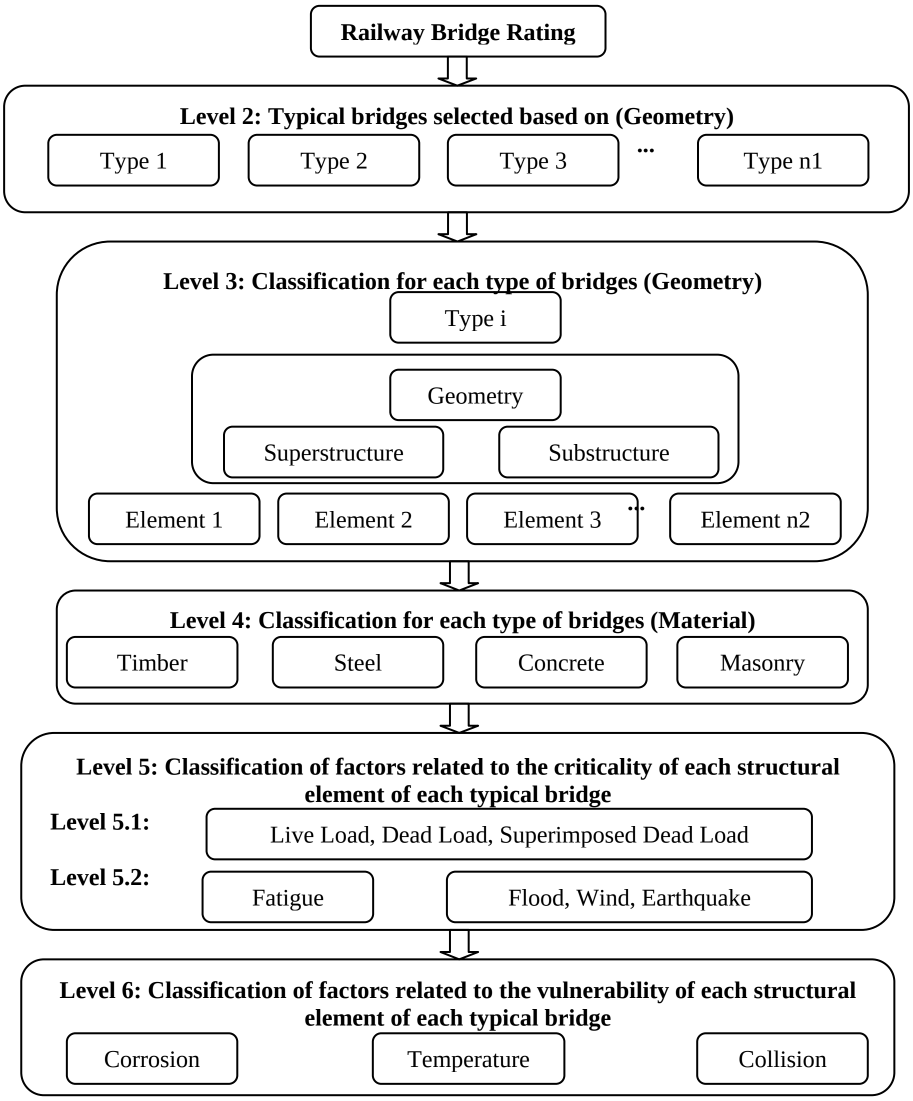

Figure 2 Railway Bridge Classification

According to this classification each individual critical structural elements can be assigned a weighting factor based on the type of factor that applied to the structure. Therefore instead of one set of weighting factors for the critical elements of a structure, for each typical railway bridge different sets of weighting factors will be identified. Also by identifying typical bridges different sets of weighting factors will be calculated for them separately, so the criticality of each element will be determined based on the geometry of the whole structure.

CONCLUSIONS

Current rating systems rate bridges according to the conditions of their structural elements. Weighting factors are assigned to each element to consider the criticality of the element. However in practice the criticality has not been taken into account based on different critical factors. Recently in particular cases it has been tried to identify critical factors and calculate the criticality of the structural elements associated with each of the critical factors. Also further attempts were made to estimate the vulnerability of the structure to predict the future condition of the bridge, but in their particular cases the focus were only on one bridge or one specific part or type of bridge and rating a network of bridges have not been conducted yet. In order to be able to take into account different factors for a variety of structures aiming at developing a rating system for a network of bridges, creating an appropriate classification is essential.

In this paper by utilizing previous efforts and trying to improve them, attempts were made to develop a new classification system which can be used for rating a network of railway bridges. The classification proposed here takes into account the effects of different factors on railway bridges with different geometry, material, loading, and under different environmental condition, in a systematic way to improve the accuracy of condition assessment. Categories were defined in order to be able to incorporate the correlation between factors.

To improve the practicality of the rating systems, a limited number of typical bridges that can represent the whole bridges in a network will be selected by this classification. Being able to improve the accuracy of rating system during time by conducting more structural analyses on more typical bridges is one of the advantages of this classification method. The other advantage of this classification is that, the structural analysis will be preformed one time only for determining the weighting factors, and the bridge rating process will take place based on the outcome of these analyses, therefore the logic of the rating system for users that will be developed based on this classification will be simple and understandable.

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