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Incorporation of Quantitative Structural Assessments in Bridge Management Systems

Évaluation structurale quantitative prise en compte dans les systèmes de gestion des ponts

Einbezug quantitativer Tragwerksbeurteilungen in Brückenbewirtschaftungssysteme

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SUMMARY

Bridge management systems are assuming an increasingly important role in the planning of maintenance and repair operations. The expanding use of bridge management systems exerts an influence on many aspects of the operations of highway networks, and it is essential to integrate them with other operations. This paper outlines a broad effort in the integration of bridge management systems and structural engineering evaluations. The approach taken is one of a redefinition of condition data obtained in field inspections, an expansion of the content of field data, and the application of bridge management systems modelling capabilities to calibration of models of physical processes of deterioration.

RÉSUMÉ

Les systèmes de gestion des ponts jouent un rôle sans cesse croissant dans la planification des travaux d'entretien et de réparation. Cela influe sur d'innombrables aspects de l'exploitation des réseaux autoroutiers, d'où la nécessité de les intégrer dans d'autres applications. L'article esquisse les efforts d'intégration des systèmes de gestion des ponts avec l'évaluation des structures. Cette approche du problème consiste à redéfinir les données réelles à partir d'essais effectués sur le site et à prendre en compte l'aptitude de modélisation des systèmes de gestion des ponts pour étalonner des modèles de processus de dégradation physique.

ZUSAMMENFASSUNG

Brückenbewirtschaftungssysteme spielen bei der Unterhalts- und Reparaturplanung eine zunehmend bedeutendere Rolle. Dies wirkt sich auf viele Aspekte im Betrieb von Autobahnnetzen aus, und es ist wichtig, sie mit anderen Tätigkeiten zu integrieren. Der Beitrag skizziert eine umfassende Anstrengung zur Integration von Brückenbewirtschaftungssystemen mit der Tragwerksbeurteilung. Der Ansatz besteht aus einer Benutzung von Zustandsdaten aus Felduntersuchungen, einer inhaltlichen Erweiterung der Felddaten und der Kalibrierung der Modellierungsfähigkeit von Brückenbewirtschaftungssystemem am physikalischen Verfallsprozess.

1. STRUCTURAL ENGINEERING AND BRIDGE MANAGEMENT

Decisions about maintenance planning necessarily entail decisions about structural load capacity and structural safety. The preservation of the strength of bridges relies on the maintenance actions. Often, cost is the primary criteria applied by management systems in an automated optimization of maintenance programs. Other, quantitative measures of the condition of bridges, such as load capacity, often are not modeled explicitly in BMS. Safety constraints on maintenance programs are introduced separately and on a bridge by bridge basis.

A cost basis for optimization is compatible quantitative structural evaluations. Repair costs are a reasonable general indicator of structural health for a network of bridges [1], but are not reliable for assessment of individual bridges [2]. Costs can be small if only a small portion of a component needs repair. But if this small portion is in a critical location, it can correspond to a significant threat to structural safety. The recognition of safety constraints in BMS requires separate, specific computation and modeling of structural engineering evaluations.

1.1 Structural Engineering Evaluations

The structural engineering evaluations of interest in the planning of maintenance programs include present-day load capacity and structural reliability as well as an estimate of minimum likely load capacity and structural reliability within the planning horizon. Bridges that are today vulnerable or that may become vulnerable should be identified. The data needed for present-day evaluations of load capacity and reliability are strength of components (present-day remaining strength for members with deterioration) and load demand in components. Estimates of capacity at future times require, at a minimum, an estimate of the future strength of components, and may also recognize the potential for redistribution of loads under damage.

Load demand in components and the original strength of components are available from design computations. Data on present-day strength can be evaluated if there are adequate, quantitative descriptions of deterioration in components. Load capacity, then, is computed for known components strength and load demand. Since load demand depends on the location of a component within the bridge, it is necessary that data on deterioration in components identify the location of deteriorated portions of the component. Estimates of load capacity at future times is accomplished through the use of models of deterioration processes. Using models of processes, the growth in severity and extent of deterioration can be estimated, future (lessened) section properties are computed, remaining strength is computed, and evaluations of load rating and structural reliability can be performed.

1.2 Bridge Inspection

Inspection of bridges provides data on present-day condition of components. Bridge inspection is, in most instances, a visual inspection. Deterioration in components is reflected in qualitative condition rating values, and additionally as notes and sketches that the inspector prepares. Condition ratings are particularly important to automated procedures such as bridge management because the condition ratings form the electronic database that is employed directly for present-day evaluations, and that is modeled for estimates of expected condition ratings in the future.

There are two important aspects to condition ratings. First is the scope of the rating. The United States practice since 1970 has employed three ratings, one each for deck, superstructure and substructure, that are assigned during the inspection of a bridge. Each rating covers an assembly of large extent made up of many components. Second is the definition of rating values. US practice defines ratings by qualitative descriptions of the appearance of the assembly. The so-called 'condition state language' describes conditions as excellent, good, fair, poor, etc. But the language does not offer specific indication of the type of deterioration that may be present, and does not provide quantitative measures of the severity of deterioration. Newer, element-level bridge management systems being implemented in the United States employ an expanded set of condition ratings [3], but the condition state language remains a qualitative naming of good, fair and poor conditions.

1.3 Use of Condition Ratings in Bridge Management Systems

Bridge management systems interpret qualitative condition ratings in terms of repair needs. The condition rating values can be linked to the cost of repairs, and to the immediacy of the need. Trends in condition ratings over time can be modeled either as static models that respond to bridge age, traffic level and other variables [4], or as dynamic models that are regularly recalibrated against the record of condition ratings

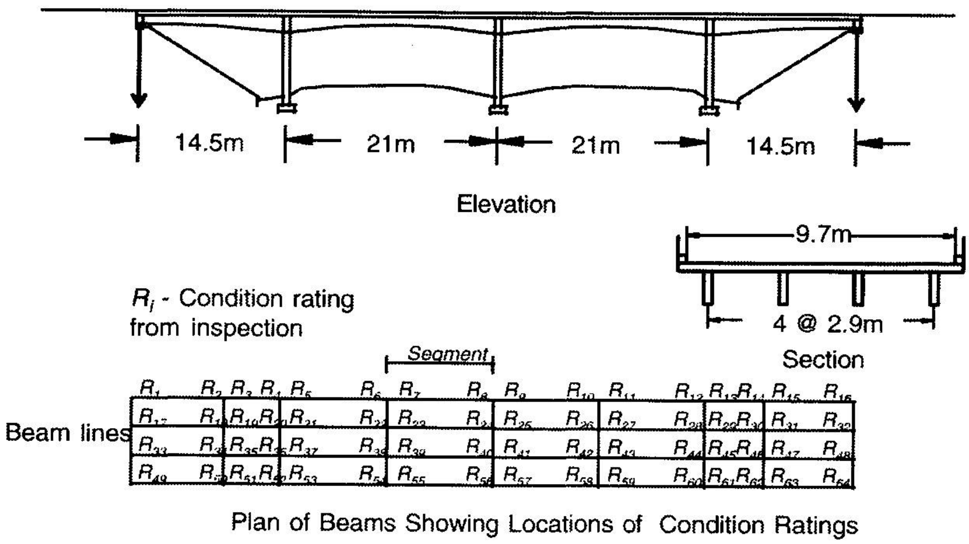

Figure 1 - Beam Segments for Reinforced Concrete Bridge

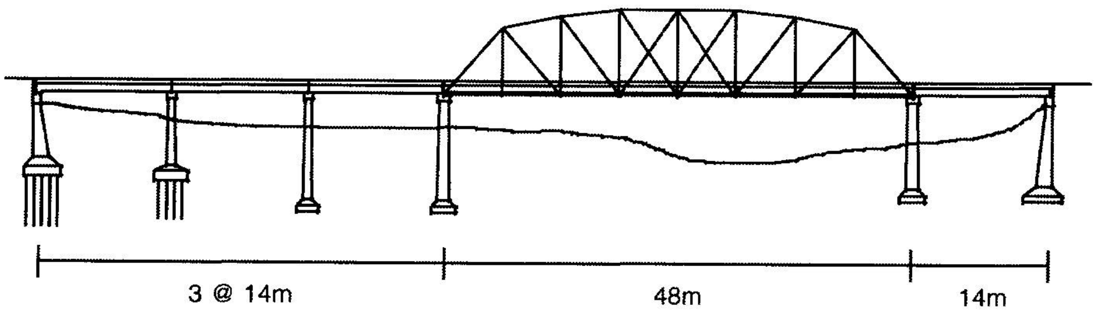

Figure 2 - Truss Bridge Elevation

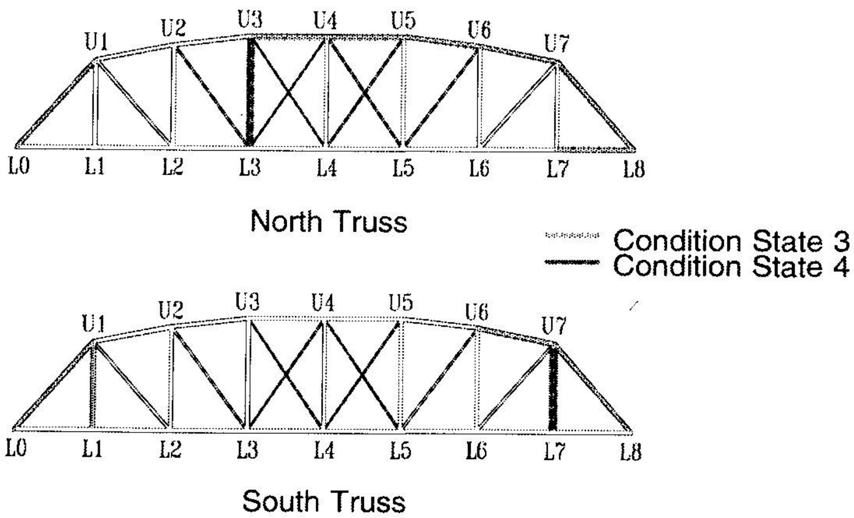

Figure 3 - Condition States from Field Inspection

for a network of bridges [5]. Dynamic models are particularly useful because they indicate the actual performance of a network of bridges. Models of condition ratings are identified, in BMS, as deterioration models. But since the condition ratings are qualitative, BMS models are not able to indicate the mechanisms of deterioration that are active in member, nor the location of deterioration, nor the severity of deterioration.

2. STRUCTURAL ENGINEERING EVALUATIONS IN BRIDGE MANAGEMENT SYSTEMS

Structural engineering evaluations such as load capacity require new quantitative forms of condition ratings, and require that condition ratings be linked to locations in a bridge. New quantitative condition rating scales are formed as discrete-value scales, a necessity for condition ratings used in routine inspection of bridges. Quantitative condition ratings are defined in terms of damage indices. Different damage indices are selected for different types of members. Condition ratings for steel members are linked to a damage index that expresses normalized thickness loss in parts. Reinforced concrete members employ damage indices linked to crack opening and spacing. Note that the use of a damage index for condition ratings is compatible with standardized reporting of precise data, such as thickness measurements by ultrasonic methods. These detailed data can be reported to the BMS database through the use of quantitative condition ratings.

Remaining strength of members is assessed as a reduction of original strength. The magnitude of the reduction is determined by the value of the damage index for the member [6]. Each condition rating value corresponds to a range of the damage index. This allows an unambiguous assignment of condition ratings during visual inspections. Of course, if a single rating value indicates a range of a damage index, then the remaining strength computed using the condition rating indicates a range of strengths. It is approximate. The pattern of deterioration is as important as the severity. For populations of similar components it is possible to identify standard patterns of deterioration [7]. The assumed patterns of deterioration can be augmented with other data if available [8].

The location of weakened members in the bridge is established in field inspections through a process of segment-based recording of condition ratings. Segments are portions or lengths of a member that can be readily identified by physical boundaries in the structure. For beams, segments are portions between diaphragm connections. For trusses, segments are individual truss members between panel points, etc. An example of beam segments for a four-span reinforced concrete bridge is shown in Figure 1. During inspection, each segment is assigned a quantitative condition rating. The completed inspection report indicates the distribution of condition ratings R_i throughout the structure. Load ratings can now be assessed for each segment in the structure. The lowest load capacity among all estimates controls and is taken as the load capacity of the bridge. Together, quantitative condition ratings and segment-based reporting provide adequate data to support automated estimation of present-day load capacity within management systems.

Load capacity at future times is computed using estimates of future values of damage indices. Here, a direct use of existing BMS models for condition ratings are employed. Models are formed for quantitative condition ratings. Condition ratings are future times are estimated, and these future condition ratings are again used to compute the remaining strength of segments. In turn, load capacity is determined.

BMS models for condition ratings can also be used to determine parameters of models of deterioration processes [9]. Though discrete-valued condition ratings offer little precision in damage indices, the transition times for rating values for a population of bridge components is an adequately detailed representation of the deterioration process to allow the formation of models of deterioration mechanisms. This allows engineers to recognize the rates of deterioration in the network, and to examine the correlations between deterioration rates and exposure or service environment.

3. FIELD DEMONSTRATION

In the summer of 1994, inspections of eight highway bridges in Colorado were conducted using new quantitative condition ratings and segment-based reporting. The bridges included two steel beam bridges, one steel plate girder bridge, two steel truss bridges, a timber beam bridge, one reinforced concrete continuous beam bridge (and two approach viaducts of reinforced concrete spans at two of the steel bridges), and a prestressed concrete beam bridge. For each bridge, segments were identified and inspection forms were prepared. Quantitative condition states were established separately for steel members, for reinforced concrete members, for prestressed concrete members, and for timber members. Quantitative condition ratings were chosen to correspond to R Codes (rust severity codes) for steel elements, and to S Codes (spall / ero-

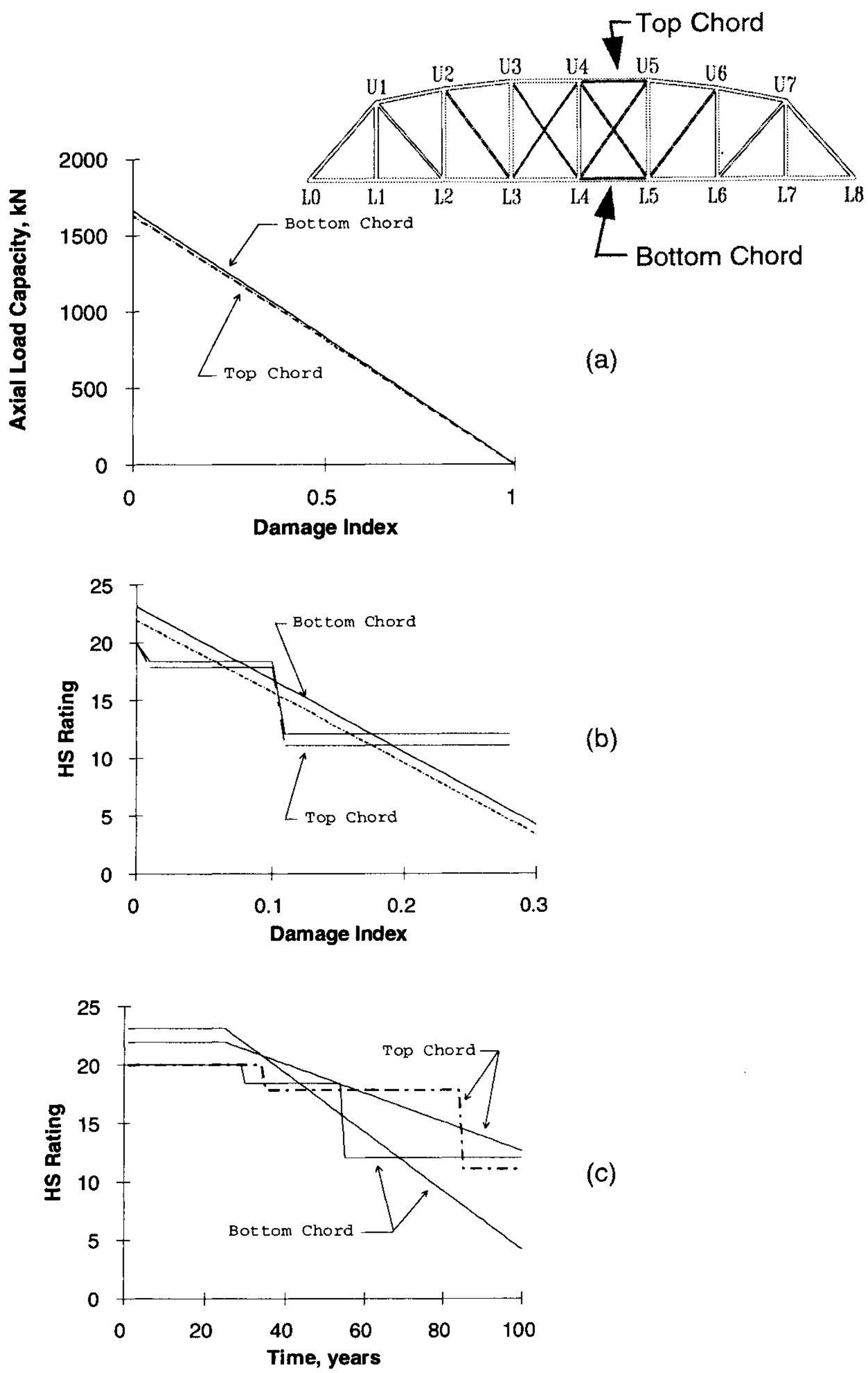

Figure 4 - Load Capacity Evaluation for Truss Bridge

sion severity codes) for concrete elements. R and S Codes are an established reporting basis for Colorado DOT inspectors.

3.1 Example: Load Rating of a Steel Truss Bridge

An example of load rating of a steel truss bridge is considered. Figure 2 shows an elevation of a simple thru truss with a span of 48 m. The bridge is more than sixty years old. Today, it carries a single lane of traffic, but could carry two lanes if required. Truss members are riveted, built-up members. Most are pairs of channels connected by flat lacing bars. The bridge has simple reinforced concrete approach spans.

The bridge is in good condition. There is minor surface rust and some pitting on truss members. Inspection of the bridge included all components of the deck, superstructure, and substructure in both the truss span and the approach spans. This example will consider the trusses only.

Quantitative condition ratings were assigned to all truss members. The rating scale used here is a 5-valued scale. Rating 1 is perfect condition. Higher rating values indicate poorer condition. Figure 3 shows the two trusses, with members in condition ratings 3 and 4 highlighted. These are the members with the poorest condition in the trusses. The relation of between condition rating and remaining strength is shown in Figure 4(a) for one top chord and one bottom chord member. Each chord in the truss can be given a unique damage / strength curve since the damage index is itself a normalized measure of deterioration. Only condition ratings 4 and 5 indicate a loss in member strength.

For these same two truss chords, the HS live load ratings are plotted as a function of damage index in Figure 4(b). The smooth curves are the exact results for load ratings computed for known (precise) damage indices. The stepped curves are the HS ratings that would be assigned on the basis of quantitative condition ratings. Load capacity computation using condition ratings is approximate, but vulnerable structures can be identified.

Plot (c) in Figure 4 shows the HS ratings as a function of time for an assumed set of deterioration rates. Bottom chord members typically corrode more quickly than top chords. Here for assumed corrosion rates, it is seen that the load rating of the truss is at first controlled by the capacity of the top chord, but is later controlled by the bottom chord as deterioration advances. The deterioration models used here would be obtained from the larger historical database of condition ratings observed in all members in similar exposure classes.

4. CONCLUSION

Structural engineering evaluations can be made a part of the automated evaluations in management systems through the introduction of quantitative condition ratings and an enhanced practice of recording for field inspections. Estimates of load capacity obtained from condition ratings are approximate, but vulnerable structures can be identified and an evolution in controlling members or in modes of failure over time can be recognized. Models of deterioration mechanisms can be formed using quantitative condition ratings. Segment-based reporting can support the classification of members by exposure for more accurate modeling of deterioration. The methods proposed here are being demonstrated in an ongoing project conducted with the Colorado Department of Transportation.

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