Segmental Inspection for Improved Condition Reporting in BMS

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ABSTRACT

Methods for segmental inspection of bridges have been developed for efficient execution of element-level inspections and for collection of data on patterns of deterioration in elements. Segmental inspection determines element conditions and element quantities required by bridge management systems, and also captures the locations of conditions within bridges. Segmental inspection offers rapid field inspection, reproducible determination of quantities, and simple, direct check of accuracy and completeness of inspections. Segmental inspection supports new automated evaluations in staging of repair activities, coordination of repairs for nearby elements, and selection of repair actions. Related and possibly causative deterioration among groups of elements can be recognized. Segmental inspection supports direct recognition of rates of change in condition. New evaluations in load capacity estimation and durability in maintenance actions are possible. New and better communication of between bridge inspectors and maintenance forces is achieved.

SEGMENTS AND SEGMENTAL INSPECTION

Segments are specific portions of bridge elements. Each segment has a fixed location and quantity. During inspection, condition ratings are assigned to all segments. Element-level condition reports are formed as sums of segment quantities in each condition state. This task of summing is done in software after the inspection. The limited size of segments, relative to the total quantity of an element, assures precision in element-level reports. For medium span bridges, quantities are determined within ±4% for deck elements, ±1% for superstructure elements, and ±3% for substructure elements (*1*).

Examples of segments are shown in Figure 1. Deck segments are bounded by lane stripes, by deck joints, and by railing joints or other features. Segments for joints in decks are bounded by lane stripes. Segments for curbs and railings share boundaries with deck segments. Approach slabs are one segment per approach. Beam segments are defined along beam lines and bounded at bearing points and diaphragm locations. Segments for pier caps are bounded by beam lines. Pier columns are each a single segment. Bearings are each single segments. Abutment segments (not shown) are bounded by beam lines. Truss segments (not shown) are defined as one per truss member. Features such as beam lines, bearing points and diaphragms are selected as boundaries of segments because these are obvious physical landmarks. Each segment is easily recognized in the field.

Each segment has the attributes *Element, Quantity, Location*, and *Condition.*

Segment (Element, Quantity, Location, Condition)

where

Element = The element reported by the segment.
Quantity = The quantity of element included in the segment.

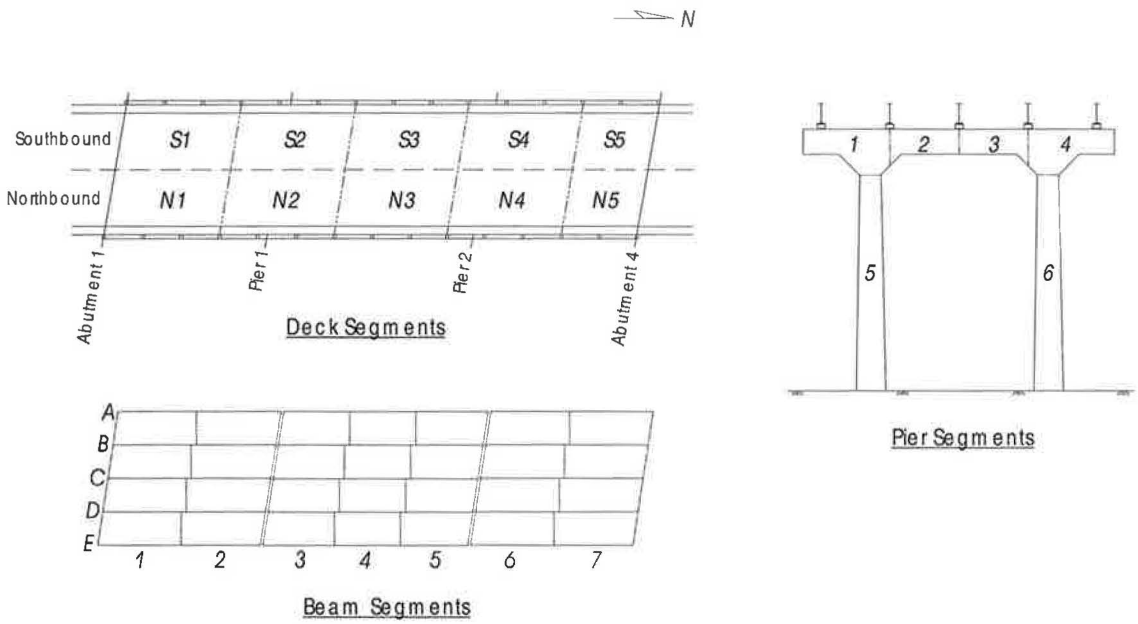


Figure 1: Examples of segments for bridge elements.

Location = The location of the segment within a bridge.
Condition = The condition rating for the segment.

Segments collectively are models of bridges. Segmental models are templates for all subsequent inspections, condition reports, deterioration modeling and maintenance planning. A database of segments for a bridge lists segment IDs, elements, quantities, locations, and current and past condition ratings. Segments are permanent. The segmental model of a bridge changes only if the bridge is modified.

The total number of segments is determined by the size of the bridge. In a demonstration of segmental inspection of eight medium-span bridges in Colorado (*1*), there were 10 to 80 deck segments per bridge, 28 to 107 superstructure segments, and 8 to 54 substructure segments. The size of segments, that is the element quantity per segment, is similar among bridges. Deck segments average 20 m^2 area, beam segments average 6 m length, and substructures average 7 segments per substructure assembly (per pier or per abutment).

During field inspection, each segment is assigned a condition rating. The field practice is simple and requires only the inspectors' observation and assessments. Condition ratings are recorded directly on inspection forms that include schematic plans of bridges. These forms show standard views of bridges (deck top plan, deck bottom plan, and separate elevations of each substructure assembly). Segment boundaries are shown, along with a specified location to record a condition rating for each segment. The completed segmental report shows the locations of each condition rating.

There are no measurements of quantities during inspection. Segments have known quantities. Assigning a condition rating to a segment adds the segment's quantity to the condition state. The total quantities for each element in its various condition states are determined after inspection by summing the quantities of segments.

Field books have between 4 and 16 graphical reporting forms. The number of forms is determined by the size of the bridge. Forms are developed from design documents. The forms are permanent. Once created as electronic files, forms are printed out for each new inspection.

ADVANTAGES OF SEGMENTAL INSPECTION

Segmental inspection offers a simple, quick field practice, consistent determination of quantities, and direct verification completeness and accuracy of inspections. Segmental data support definite, clear communication of information among branches of transportation agencies. Segmental inspection provides new data on location of deterioration that is useful to selecting repair programs, estimating costs, and staging repair activities. Segmental inspection allows a focus of deterioration models on changes in condition rather than on changes in quantities.

Automatic Determination of Quantities

Each segment has a known quantity, and this quantity is implicitly added to a condition state when a condition rating is assigned. During field work, inspectors can focus on the observation of conditions and the assignment of condition states.

Reproducible Quantities

Segmental inspection operates on fixed portions of elements. This eliminates measurements and errors in measurement, and provides good resolution in quantities. Quantities are reproducible specifically because it is only the assignment of condition rating that is in question. There are also no differences or disagreements among inspectors about boundaries of conditions. Boundaries of segments are explicit. There is no difference in method of measurement among bridges. There is no mixing of estimated quantities and measured quantities.

SELF-CHECKING FOR CONDITION RATINGS

Differences in condition ratings between inspectors or between inspection cycles can be identified, evaluated and reviewed, if necessary. Inspectors on the same team can compare condition ratings and resolve differences. Changes in condition ratings between inspection cycles can be examined, and unexpected changes can be reviewed. Change are unexpected if the change is too large, if the pattern of changes is odd, if there are improvements in condition rating without repair to segments, etc. Inspectors can use segmental reports to examine the affected elements and locations, and to resolve errors.

The processing here is simple. Condition ratings from two inspectors or from different inspections are subtracted, segment by segment. Nonzero differences identify the points of disagreement or of change. The process is illustrated in Figure 2. The figure shows beam segments for two spans of a multibeam bridge. Beam lines A through E are labeled.

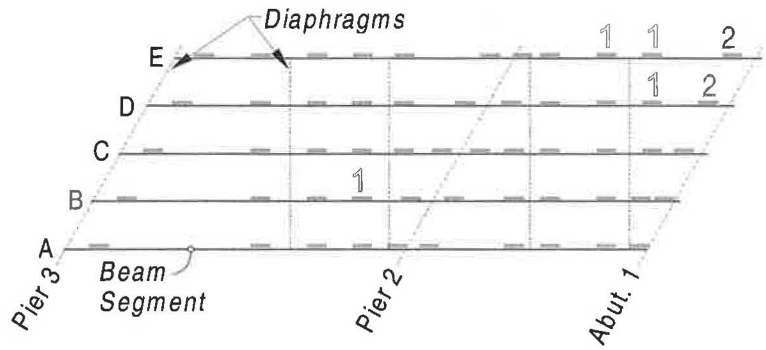


Figure 2: Differences in condition ratings.

Locations of diaphragms, piers and an abutment are shown. The double blue lines indicate locations for condition rating of segments. Not that most beam segments receive two ratings, one for each half. Reports from two inspections of the bridge have been collected and differences in condition rating have been computed at each location of rating. Five locations have differences in a cluster near the abutment at beam lines D and E. For comparison of two inspection intervals, a loss of 1 condition rating is possible, differences of 2 rating values are less likely, and should be verified. The isolated difference of one condition rating at beam line B is suspicious, and may be due to an error in field coding, or an error in transmission of the segmental report to the database of condition ratings.

SELF-CHECKING FOR COMPLETENESS OF INSPECTIONS

Forms for segmental inspections are organized as topside/bottom side regions, and arranged in the order of spans. Deck topside forms include deck, curb, railing, joint and approach segments. Forms for the underside include deck, and beam segments. Forms for substructures include substructure elements, and bearings. The forms are composed to contain all of the segments that an inspector would perceive in a single view. As such, field inspections follow forms. Inspected regions of the bridge are marked off, and areas that remain are apparent. For teams of inspectors, it is easy to compare forms and assure that all regions of bridges have been inspected.

Minimal Effort for Subsequent Inspections

Among the ~200 condition ratings recorded on average for a structure, most will not change in the two-year inspection cycle. Subsequent inspections may be performed on forms that show all previous ratings. Inspectors then affirm or update condition ratings.

Automation of Inspections

Segmental inspection is readily adapted to field computers. The transfer of graphical forms to computers is straightforward. The link to previous inspections, segment by segment, is useful to each new inspection. Moreover, inspectors' notes can be linked to segment numbers, offering a coordination of graphic, ratings, and electronic files.

COORDINATION OF ALL INPUTS ON BRIDGE CONDITION

Condition ratings are one input to bridge condition. Inspectors also make notes on conditions, provide sketches of conditions, and take photographs. All of these inputs can be coordinated through segment numbers. Notes can be linked to specific parts of bridges. Sketches can be made directly on segmental inspection forms. Photographs can be keyed to segment numbers. Field test data and material samples can be tagged with the segment numbers. Segment numbers support simple storage, indexing, and retrieval of any data, report or observation concerning bridges.

Related Deterioration in Several Elements

Related problems in several elements may have a common cause. The needed action is repair of all elements, *and* correction of the underlying cause. This is a necessary aggregation of elements in the selection of repair actions. It is not adequate to make repairs to some elements without addressing the cause. Using segmental data, proximity of conditions is an indicator of a possible single cause.

Coordination of Repairs

Even where causes of deterioration are not related, there can be cost savings in coordinated repair of nearby segments of other elements. Many repairs completed in a single contract share the costs of traffic control.

Causal Relations in Exposure or Deterioration

Deterioration of one element may affect the exposure of other elements, and can contribute to their deterioration. In the demonstration of segmental reporting in Colorado (*1*), correlation was observed between poor conditions of deck joints, and poor conditions of beam segments at joints. Correlation was also observed between poor deck segments, and deterioration of beams immediately below. In both cases, it is likely that early deterioration of joint segments and deck segments contributed to deterioration of beams. Such relations exist among many bridge elements with some elements sheltering others. In bridge management, these causal relations can be recognized two ways. The designation of service environment and rate of deterioration of elements can be changed to reflect deterioration in elements that provide shelter. Second, the benefit of repair of elements can be computed as the improvement in the element itself, and in the mitigation of exposure of other elements.

COMMUNICATION OF WORK ORDERS AND ACTIVITIES

Segmental inspections report the particular locations that need repair. The segmental report can be transmitted directly to maintenance forces for execution. There is clear communication of the amount and locations of work. There is, as well, an opportunity for maintenance forces to report the segments that have been repaired, to identify segments that were not repaired or required other, additional operations.

PROJECT STAGING

Segmental reports can be used to evaluate the access and traffic control demands of repair projects. An example is shown in Figure 3. Five segments of beams are in poor condition (state 5) and need repair. If the five segments are along one beam, then the operation might be completed with a single lane closure. If the five segments are instead along the abutment, then both lanes of the two-lane bridge must be closed. Either the bridge is closed for the duration of the repair, or the project is staged to repair one lane, and then shift operations to the second lane. The impact of these projects and their costs can be quite different. These differences can be anticipated from segmental data, but not from element-level data. The element-level reports for these two bridges could be identical.

INSTITUTIONAL MEMORY

Maintenance and repair operations can be recorded and indexed using segment numbers. This is an extension of the concept of comprehensive electronic recording keeping and indexing for bridges. The repair operations and the history of inspection, deterioration, and mitigation can be tracked for all segments. Such direct knowledge of performance of bridges, elements and segments is new. It allows the study of relative performance of segments, of relative performance of sheltered and exposed elements, and the relative performance of repaired and unrepaired segments.

BETTER MODELS

Changes in condition ratings at segments reveal rates of deterioration that may be obscured in reports of element quantities. An example is shown in Figure 4. Part (a) of the figure shows condition ratings recorded for segments of an element in one bridge. The deterioration process at work on this element begins slowly but worsens at an accelerating pace. This is evident in the increased steepness of curves of condition ratings. Some segments begin deterioration early in service life, others remain at condition rating 1 for a time and begin to deteriorate in middle life, and some persist in rating 1 for a long time before deterioration begins. The quantities in condition states are collected for this same element. The plot of average condition ratings is shown in part (b) of the figure. Notice that the information on different initiation times among segments is lost, and that the model based on quantities shows a slowing rate of deterioration. This disagrees with the actual rates of deterioration at segments. Deterioration models based on element quantities

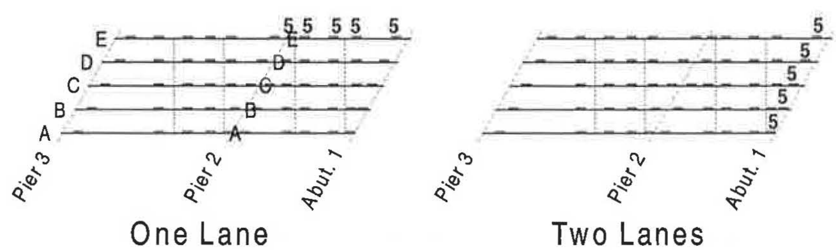
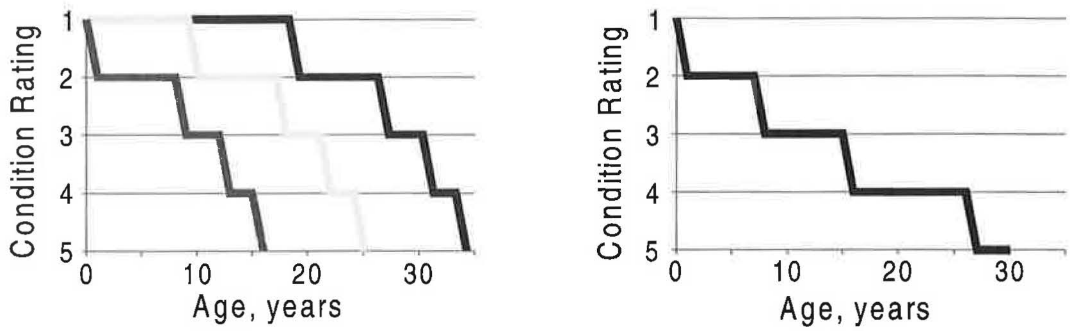


Figure 3: Staging repair projects.



(a) – Condition Ratings for Segments (b) – Condition Ratings for Elements

Figure 4: Segment deterioration and quantity deterioration.

are in fact models that combine rate and extent of deterioration. As such, deterioration rates are obscured. Segment data yield the right model of deterioration.

NEW AUTOMATED ASSESSMENTS

Segmental inspection data support new automated assessments in bridge management systems. The lifetime of repair actions can be evaluated. Condition ratings at repaired segments can be tracked. The rate of deterioration of repairs and the time needed for the return of elements to poor condition can be captured. The lifetime of the repair is needed for an evaluation of its benefit.

Consistency among bridge inspectors can be investigated. Some inspectors may differ, repeatedly, from the average of their peers. These differences are readily seen in segmental data, but are harder to detect in element quantities. It is possible even that quantities in element-level reports will not have large differences, even when inspectors have disagreed about condition ratings at most locations.

Losses in load capacity of bridges can be estimated using segmental data. Approximate relations between condition ratings and loss in member strength have been proposed (2). If deteriorated and possibly weakened segments are in regions of high load demand, bridge load ratings may be affected. Approximate evaluation of this sort is not appropriate to actual bridge rating, but it is useful in the optimization of maintenance programs. The possibility of loss in load capacity in the future is a factor for maintenance management to recognize.

Segmental inspection is readily adapted to field computers. The transfer of graphical forms to computers is straightforward. The link to previous inspections, segment by segment, is useful to each new inspection. Moreover, inspectors' notes can be linked to segment numbers easily, offering a coordinate of graphic, ratings, and electronic files.

SUMMARY

Segmental inspection captures locations of condition ratings and provides the spatial distribution of conditions. This is useful data, and has not been available in NBI records nor the element-level reports for CoRe elements. With segmental inspections, quantities are reproducible, condition ratings can be checked, communication with maintenance forces and planning of repair projects are improved, and deterioration models accurately indicate rates of deterioration.

ACKNOWLEDGMENTS

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