CENTER FOR TRANSPORTATION RESEARCH
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Project Summary Report 0-2135-S
Guidelines for Inspection of Fracture-Critical Steel Trapezoidal Girders
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PROJECT SUMMARY REPORT

Optimal Inspection of Fracture-Critical Steel Trapezoidal Girders: A Summary

To maintain acceptable levels of safety, one usually needs to perform frequent periodic bridge inspections and employ detailed inspection methods. This is especially true for fracture-critical members or details. Carrying out these inspections is often time-consuming and costly; further, inspections often result in traffic disruptions due to bridge and lane closures. A systematic reliability-based method for inspection scheduling is proposed to yield the most economical inspection strategy for steel bridges that, at the same time, guarantees an acceptable safety level through the planned service life. The inspection scheduling problem is modeled as an optimization problem with a well-defined objective function that includes the total expected cost of inspection, repair, and failure formulated on the basis of an event tree framework, and constraints on realistic intervals between inspections and on minimum acceptable safety levels. An optimal inspection-scheduling plan can thus be obtained for any specified fatigue details (fracture-critical details) in steel bridges. Examples presented demonstrate the advantage of the reliability-based optimal inspection scheduling in cost saving and structural reliability control over alternative periodic inspection plans.

What We Did...

A reliability-based inspection scheduling procedure was developed that can yield an optimal inspection schedule and can maintain a specified safety level for fracture-critical members in steel bridges through their planned service lives. The flow chart in Figure 1 outlines the key steps in the inspection scheduling procedure that was developed. This procedure is based, in sequence, on a stress range analysis, a fatigue reliability analysis, and an optimization analysis. In the stress range analysis, the "effective" stress range for the identified member or detail can be obtained from a stress spectrum analysis, an assumed stress probability distribution (e.g., Rayleigh) based on data, or a fatigue truck analysis. Once this effective stress range distribution representative of the actual traffic on a bridge is obtained, a fatigue reliability analysis of the member or detail of interest may be performed. For all details classified in specific AASHTO fatigue categories, a limit state function related to the number of stress cycles to failure based on Miner's Rule can be used; for all other details (i.e., those not classified in specific AASHTO fatigue categories), a limit state function based on crack growth rates can be used. An optimization problem for inspection scheduling that incorporates fatigue reliability calculations (for details of interest) along with an event tree approach, was formulated with an objective function that included costs and appropriate constraints on the inspection intervals and on acceptable minimum levels of structural safety. Solution of this optimization problem yields the optimal inspection schedule.

What We Found...

With two examples, we describe below how the procedure we developed can be used to schedule inspections for bridges subject to fatigue damage over time.

Example 1: Plate Girder Bridge

A category E detail in the Brazos River Bridge in Texas (see Fig. 2) was studied. Based on the AASHTO approach, the reliability index, *b*, related to fatigue failure of the detail over

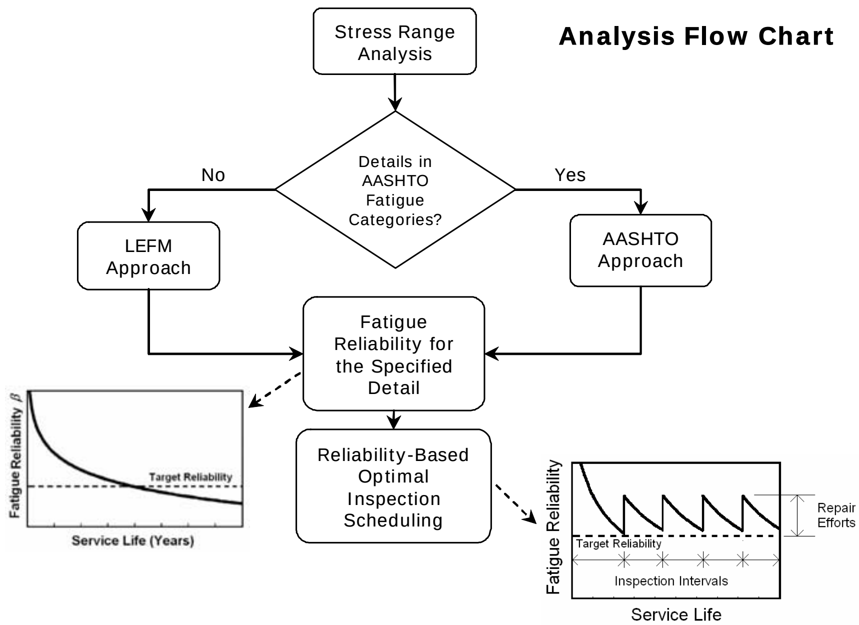

Figure 1. Flowchart summarizing reliability-based optimal inspection procedure

50 years, is shown in Fig. 3. It can be seen that, without intervention or repair of some sort, this reliability index would fall below an assumed safe level of 3.7 (corresponding to a failure probability of 1 in 10,000) by the thirteenth year. With a repair policy that returns a deficient detail to an "as good as new" condition, and when inspection costs (C_I), repair costs (C_R), and failure costs (C_F) are such that $C_I : C_R : C_F = 1 : 1.3´10^2 : 4´10^5$, it is found in Fig. 4 that the optimal number of inspections over the next twenty years is eleven and the associated optimal inspection schedule is as shown in Fig. 5 where, for comparison, an *ad hoc* periodic two-year inspection interval as required by FHWA is also shown. The optimal inspection schedule yields a lower total cost (C_T) of 162.7 versus a total cost of 168.9 for the periodic inspection plan.

Example 2: Box Girder Bridge

A center-notched crack in the bottom flange of a box girder bridge as shown in Fig. 6 was studied. Since the detail is not specifically defined in the AASHTO Specifications, a Linear Elastic Fracture Mechanics (LEFM) approach was needed to obtain the fatigue reliability curve shown in Fig. 7. It can be seen that, without intervention or repair of some sort, the fatigue reliability index for the chosen detail would fall below an assumed safe level of 3.7 by the

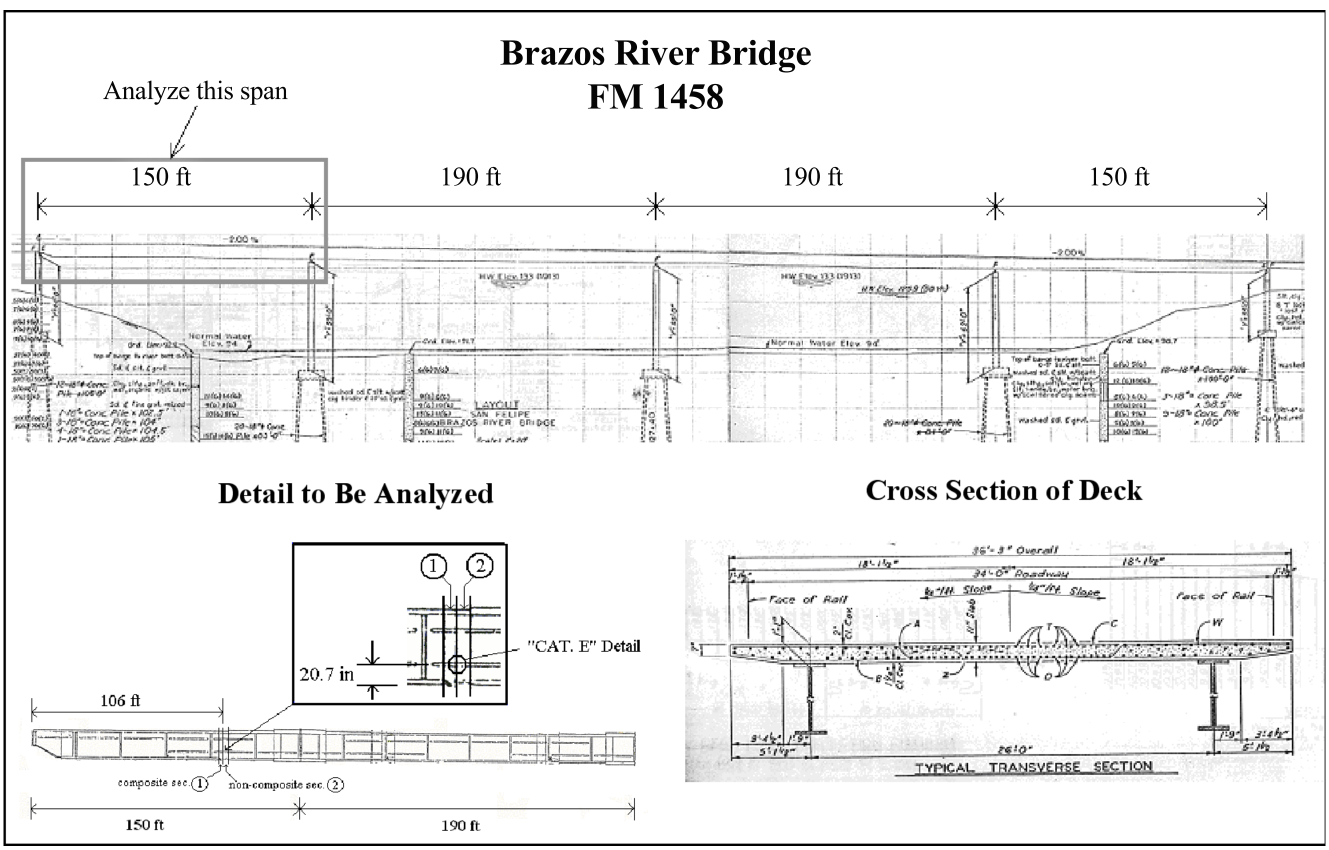

Figure 2. Brazos River Bridge in Texas

fifteenth year. The relative costs of inspection, repair, and failure were such that $C_I : C_R : C_F = 1 : 3\times10^2 : 3.6\times10^6$. Figure 8 shows that removing the constraint on maximum permissible time (T_{max}) between inspections can lead to even lower costs over the benefits already derived (compared to periodic inspections) by use of the optimal scheduling procedure with $T_{max} = 2$ yrs.

The Researchers Recommend...

Reliability-based inspection scheduling following a procedure such as that developed here offers a rational method to arrive at inspection and maintenance strategies for steel bridges. Applying the procedure described for various types of details, bridge authorities can optimally allocate their maintenance budgets in an efficient manner without compromising the safety of their bridges.

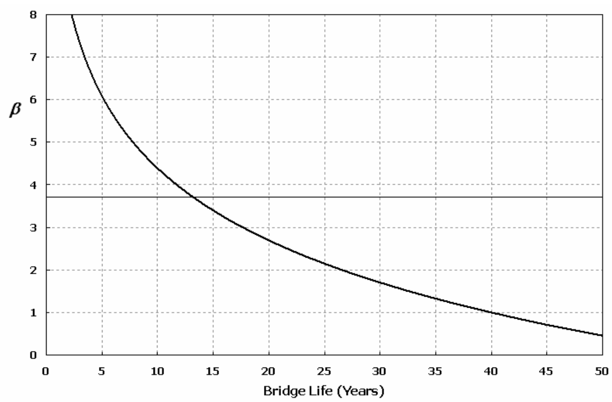

Figure 3: Fatigue reliability of the chosen detail over 50 years.

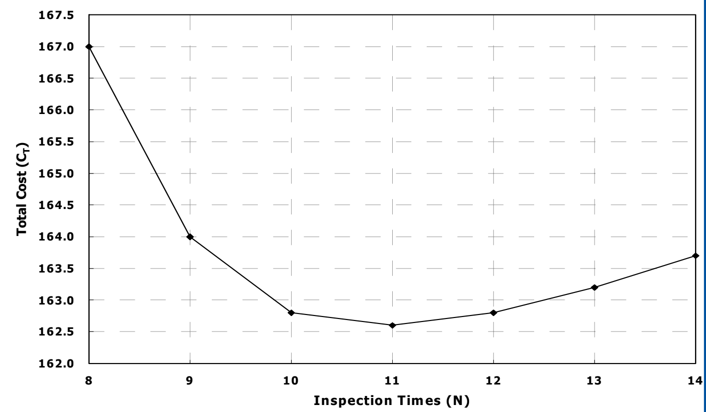

Figure 4: Optimal total cost as a function of the number of inspections for the chosen detail ($C_I : C_R : C_F = 1 : 1.3'10^2 : 4'10^5$).

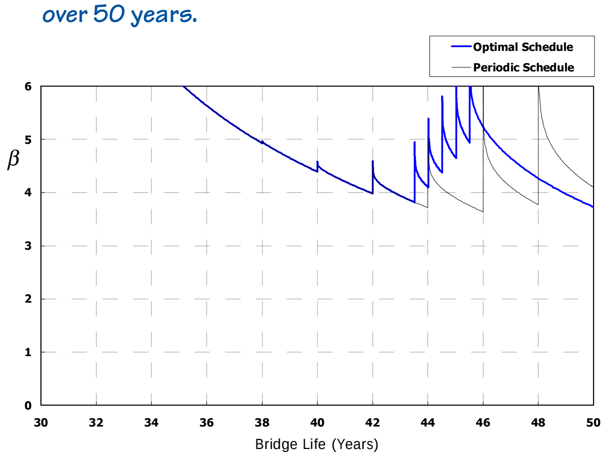

Figure 5: Optimal inspection schedule ($T_{min} = 0.5$ yrs, $T_{max} = 2$ yrs) for the case of $C_I : C_R : C_F = 1 : 1.3'10^2 : 4'10^5$, $C_T = 162.7$.

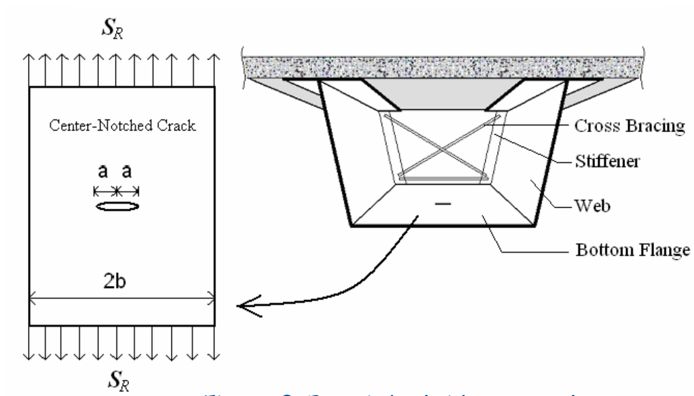

Figure 6: Box girder bridge example.

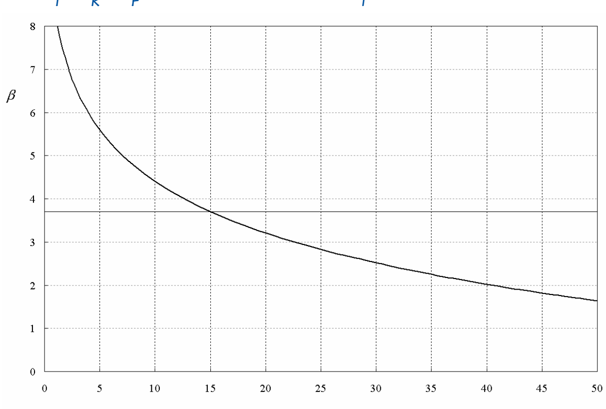

Figure 7: Fatigue reliability of the box girder detail over 50 years.

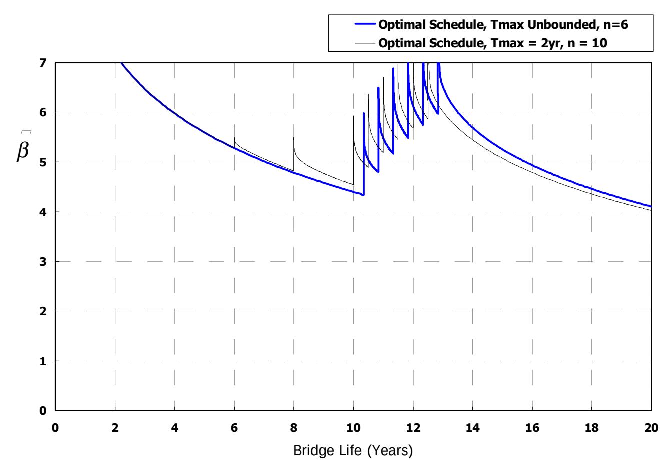

Figure 8: Optimal inspection schedules with $T_{max} = 2$ yrs and T_{max} unbounded

For More Details...

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The research is documented in the following report:
0-2135-1, "*Optimal Inspection of Fracture-Critical Steel Trapezoidal Girders*," August 2004.

To obtain copies of the above reports, contact the Center for Transportation Research, The University of Texas at Austin, (512) 232-3126, ctrlib@uts.cc.utexas.edu.

TxDOT Implementation Status
November 2004

At the present, the FHWA does not allow reliability, including consideration of age, details, materials, ADT, and actual traffic loads, in establishment of inspection frequencies. However, there is movement to allow such consideration. Depending on final rule changes which may be established by FHWA in establishing inspection frequencies for fracture-critical steel bridges, results from this research may be used by TxDOT in the future for establishing inspection schedules.

For information, contact Tom Yarbrough, P.E., Research and Technology Implementation Office, at (512) 465-7403 or tyarbro@dot.state.tx.us.

Your Involvement Is Welcome!

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