Study Title
Quantification of Field Performance and Nondestructive Testing of Timber Bridges in Colorado

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Study Objectives
The overarching goal is to develop practical evaluation methods for the condition rating of timber bridges using nondestructive testing:

- To understand the deterioration mechanisms of structural timber under aggressive environments.
- To quantify the level of damage using velocity, stress wave timing, and micro-drilling data, including AI-assisted investigations.
- To propose practice recommendations for decision-making alongside visual inspections.

Background
Wood has been instrumental as a means to build bridge structures before the era of contemporary construction materials. Given that timber is composed of organic substances, a number of factors degrade the performance of timber bridges, especially when random natural flaws combine with excessive vehicle loadings. Despite the popularity of nondestructive testing technologies, bridge evaluations still rely heavily on visual inspections, which depend significantly on the experience of field engineers and can lead to inconsistent condition ratings.

Methods
This report presents two major aspects related to evaluating timber bridges with nondestructive testing: i) laboratory experiments and ii) field applications. The first part of the report discusses the degradation processes and resulting outcomes of structural timber, Douglas Fir. In accordance with the standard protocol of ASTM D1037, specimens are conditioned and their physical and mechanical properties are measured using nondestructive test methods. The second part of the report deals with the condition evaluation of timber bridges with the aim of synthesizing ratings from visual inspections (qualitative) and nondestructive testing (quantitative). Ten benchmark bridges, visually rated as Poor and Fair according to the scale of the Federal Highway Administration, are selected and their responses are examined by moisture metering, stress wave analysis, and microdrilling techniques for determining deterioration levels.

Results
This report has discussed the condition evaluation of timber bridges based on laboratory testing, artificial intelligence (AI)-enabled computational modeling, and field application. A link is established for converting nondestructive metrics to deterioration ratios. Computational algorithms in line with machine learning predict the level of deterioration and are employed to formulate performance classifications. As far as deterioration levels are concerned, there are discrepancies between the results of the qualitative and quantitative methodologies for the Poor-rated bridges; however, consistent observations are made for the Fair-rated bridges. Comparative analysis demonstrates that the integration of the two inspection approaches is achievable to improve the rating

procedure for aged timber bridges. Practical equations are proposed alongside calibrated condition factors for the implementation of research findings.

Research Benefits

Although CDOT does not foresee the construction of new timber bridges, attention should still be paid to existing timber bridges for the safety of motorists until at least all these bridges are replaced by other types. Through the calibration and site implementation of nondestructive testing devices, the research outcomes will help CDOT in conducting accurate site inspections, which are a prerequisite to accomplishing sustainable built environments in Colorado. Specifically, findings will validate current inspection and evaluation approaches and will suggest changes to improve the Bridge Rating Manual (Sec. 13: Timber Structures).

Recommendations for Implementation (or Next Steps)

The research suggests new site inspection methodologies that integrate visual inspections with nondestructive testing for constructed timber bridges. Current rating approaches are largely empirical without measuring actual properties. By adopting the proposed methodologies, accurate rating outcomes are expected.