Executive Summary, Research Readiness Level Assessment and Technology Transfer

Supporting Bridge Management with Advanced Analysis and Machine Learning

Research Objectives

The primary objective of this research was to investigate and demonstrate the validity and usefulness of ANNs as a supplementary tool for bridge load rating and bridge management decision-making, substantiated through validation with diagnostic bridge tests. This research calibrated and/or refined an existing, preliminary ANN model to better serve the needs of NDOT, by expanding the ANN training data with Nebraska bridges and integrating reliability into the ANN predictions consistently with AASHTO LRFD/R.

Research Benefits

Bridges are commonly designed and evaluated with an appreciable degree of conservativism, beyond that strictly required to satisfy safety according to codes. Unneeded conservativism can be reduced, allowing bridges to remain in service and/or to carry higher loads, when justified by rational analysis and/or load testing.

The primary functional deliverable for this project was an Excel workbook, allowing load rating engineers to quickly estimate the potential benefits of refined analysis and/or load testing. Bridge owners are able to rationally substantiate decisions to defer maintenance or replacement for bridges in the inventory.

Alternatively, bridge owners can potentially raise or remove load restrictions for bridges. The benefit to any particular bridge is difficult to assess without a significant amount of time and effort.

The primary benefits of the proposed research provided easy and rapid access to knowledge of the degree to which any individual bridge represented by the ANN training offers these benefits.

Background

This project provided easy access to an approximation of advanced structural analysis, allowing practicing engineers to more accurately calculate bridge load ratings without needing to perform rigorous analyses themselves. Advanced analysis provided insight into whether or not bridge management intervention is necessary. Rigorous modeling can sometimes reveal unacknowledged capacity overlooked in traditional simplified models. This existing but unacknowledged capacity can potentially be sufficient to justify removal of load posting and deferral of bridge maintenance or replacement. Effectively managing the bridge inventory serves several strategic goals identified by the Nebraska Department of Transportation, particularly by balancing safety and fiscal responsibility.

Conclusion

A supplemental Artificial Neural Network (ANN)-based tool was developed to support the Nebraska Department of Transportation (NDOT) in optimizing bridge management investments when choosing between refined modeling, field testing, retrofitting, or bridge replacement. Load ratings typically increase by approximately 15% to 20% when using detailed finite element analysis (FEA) instead of AASHTO approximate analysis methods. The ANN tool is implemented in an Excel spreadsheet to accept ten input parameters readily available to NDOT engineers performing typical load ratings, and predicts FEAequivalent critical girder distribution factors (GDFs), removing unnecessary conservativism from approximate AASHTO GDFs, potentially justifying load posting removal for existing bridges, and enabling more optimized design for new construction. The Excel tool outputs direct ANN-predicted GDFs and adjusted GDFs penalized to account for ANN error by reliability calibration philosophically consistent with AASHTO Load and Resistance Factor Rating. The study included detailed FEA for 174 simple span, steel girder bridges with concrete decks. Subsets of 163 and 161 bridges within these available cases comprised the ANN design and training datasets for critical moment and shear live load effects, respectively. The reliability calibration found that the ANN live load effect prediction error with mean absolute independent testing error of 3.65% could be conservatively accommodated by increasing the live load factor by less than 0.05. The study also demonstrates application of the neural network model validated with a diagnostic field test, including discussion of potential adjustments to account for noncomposite bridge capacity and Load Factor Rating instead of Load and Resistance Factor Rating.

Executive Summary, Research Readiness Level Assessment and Technology Transfer

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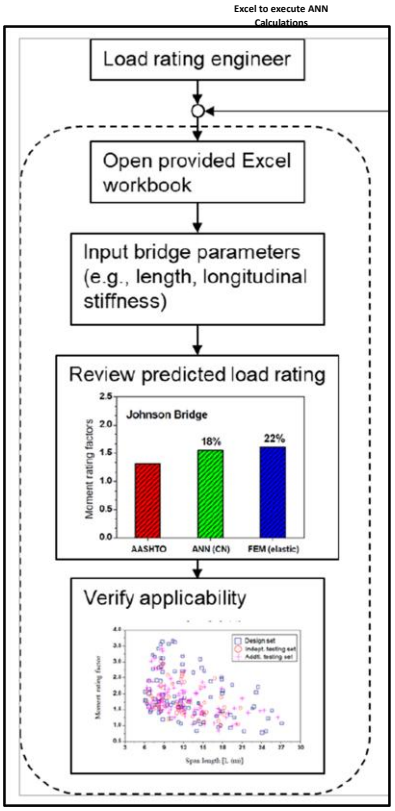
Interested in finding out more?

Final report is available:
HERE

NDOT Recommendations Based Off of Research Project – 2020 – RRL4

Bridge Division will use this research as screening method of potential load rating which required field measurements. Bridge Load Rating Section will validate the concept through production, using the spreadsheet developed as "Tool in the Box" to map the load rating which fits the research criteria.

The proposed validation of concept is summarized in the flowchart below under Load Rating Engineer.



The Load Rating Bridge Engineer will perform the following:

- The provided user interface in Excel, input bridge characteristics required for ANN predictions (e.g., length as a value from 20 to 89 ft, girder spacing, longitudinal stiffness, cross frames, number of girders, skew angle, barrier edge distance, Deck thickness, Compressive strength and steel yield stress.
- Review the output load rating prediction (load rating value predicted by the CN from background calculations).
- Verify that the predicted load rating versus the input parameters lies within the space of design set points in the scatterplots.

The primary functional deliverable (readily accessible to practitioners) for this project will be an Excel workbook, allowing load rating engineers to quickly estimate (and directly use, at their discretion) the potential benefits of refined analysis and/or load testing. Bridge owners will be able to rationally substantiate decisions to defer maintenance or replacement for bridges in the inventory. Alternatively, bridge owners can potentially raise or remove load restrictions for bridges.

- *As provided by Fouad Jaber, Lead TAC Member*

Executive Summary, Research Readiness Level Assessment and Technology Transfer

NDOT Recommendations Based Off Research Project – 2025 – Promise to Pause

This research provided a screening tool for load rating using machine learning. This is a tool in the Load Rating group's toolbox, meant to be used to 'remove unnecessary conservativism' from AASHTO girder distribution factors. The potential of the model lies in its ability to provide a result without investing resources into fully doing a Finite Element Analysis. It remains to be seen if it will see use for this case. The model provided is limited to select bridges that meet specific criteria, making the model limited in its potential uses. Furthermore, given the field information necessary to run the regression model, Bridge might consider running a Finite Element Analysis instead, providing a better load rating. As such, while the model was validated, it is unlikely to see future use.

- *As provided by Fouad Jaber and Emilie Hudon, Lead TAC Member*

Research Readiness Level (RRL) Assessment

From Promise to Pause

Research is completed but will not be implemented into NDOT practice. Moved from RRL4, assessed in 2020.

Technology Transfer

Transportation Research Board Annual Meeting Lectern Presentations/Sessions

- Garcia, F., Garfias, J. P. P., Sofi, F., and Steelman, J., "Integration of Artificial Neural Networks in Bridge Load Rating and Case Study Application," Lectern Session 1304: Bridge Load Rating Washington, D. C., January 13, 2020.
- Sofi, F., Lin, X., Steelman, J. S. and Garcia, F., "Supporting Bridge Management with Advanced Analysis and Machine Learning," Poster Session 1565: Application of Machine Learning Methods for Operation and Maintenance of Transportation Systems (Part 1), Washington, D. C., January 15, 2019.
- Sofi, F., Lin, X., Steelman, J. S. and Garcia, F., "Supporting Bridge Management with Advanced Analysis and Machine Learning," Panel Session 1652: Application of Machine Learning Methods for Operation and Maintenance of Transportation Systems (Part 2), Washington, D. C., January 15, 2019.
- Steelman, J. S., and Sofi, F., "Supporting Bridge Management With Refined Load Ratings Estimated Using Machine Learning" AHD30: Structures Maintenance Committee Meeting, Washington, D. C., January 9, 2018.

ASCE/SEI Structures Congress 2018, Fort Worth, Texas, April 19-21, 2018

- Sofi, F., and Steelman, J. S., "Structural Evaluation Augmented with Artificial Neural Networks with a Demonstration for Bridge Management,"

This brief summarizes Project SPR-P1(19) M088
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