Improved Bridge Capacity Assessment by Nonlinear Proxy Finite-Element Analysis

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Motivation

Many bridges built in the first half of the 20th century are still in service today, carrying modern service-level loads without undergoing obvious damage. Despite this, conventional engineering analysis often predicts that these structures lack the strength to carry modern traffic, leading to costly load restrictions, repairs and replacement. While field live-load testing can be used to assess bridge response to heavy truck loads, these assessments are extrapolations of linear, service-level behavior, ignoring structures' post-linear behavior. Here, a novel and computationally efficient numerical modeling technique – Nonlinear Proxy Finite Element Analysis (PFEA) – is developed to overcome limitations of physical testing and provide realistic capacity estimates by accounting for load redistribution and ductility.

Overview of Technique

1. Extract Moment-Curvature Behavior, Create a Proxy Section using Nonlinear Optimization, Verify in ABAQUS

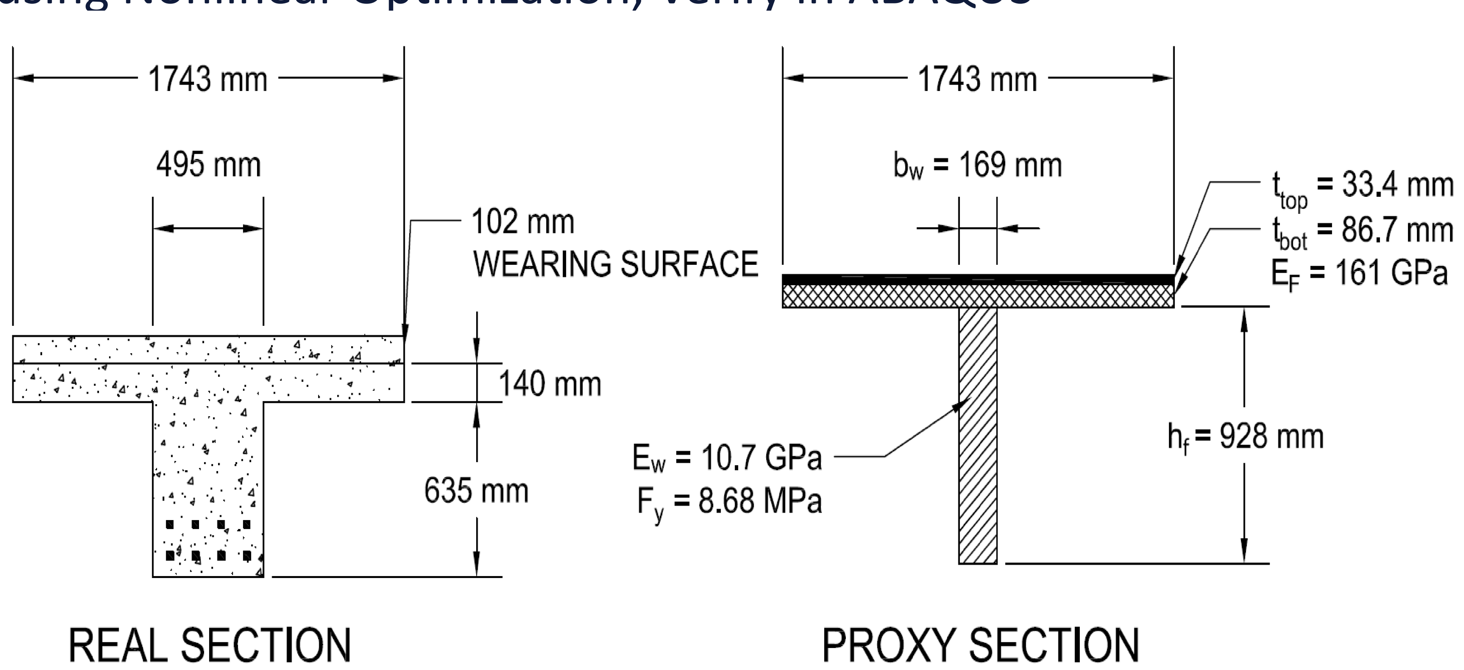

Figure 1: Comparison of Geometric and Constitutive Properties of Real and Proxy Sections

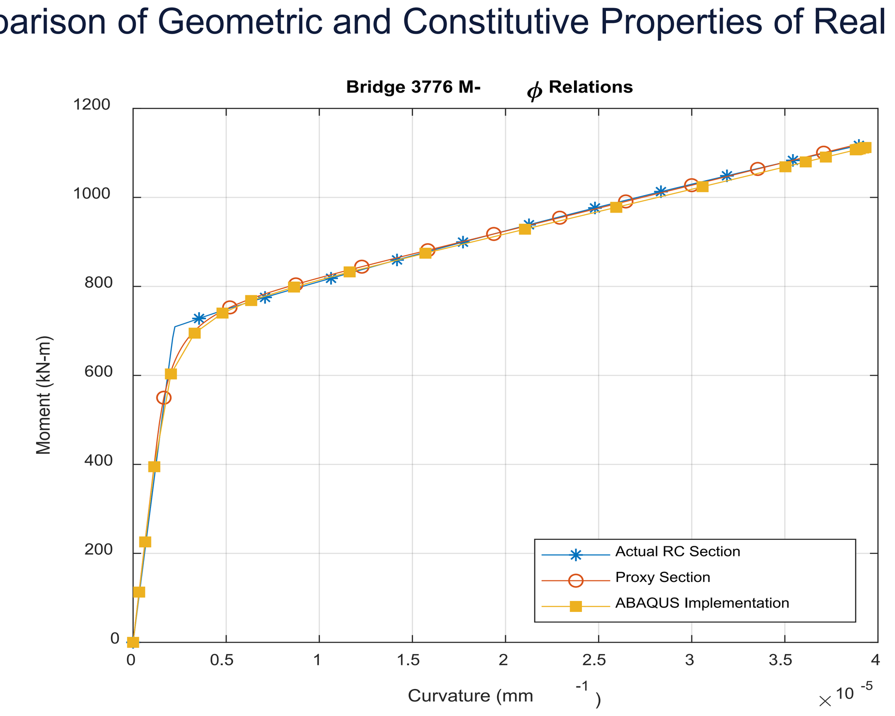

Figure 2: Actual, Proxy, and Implemented Moment-Curvature Relationships

3. Use PFEA Used to Determine Ultimate Capacity

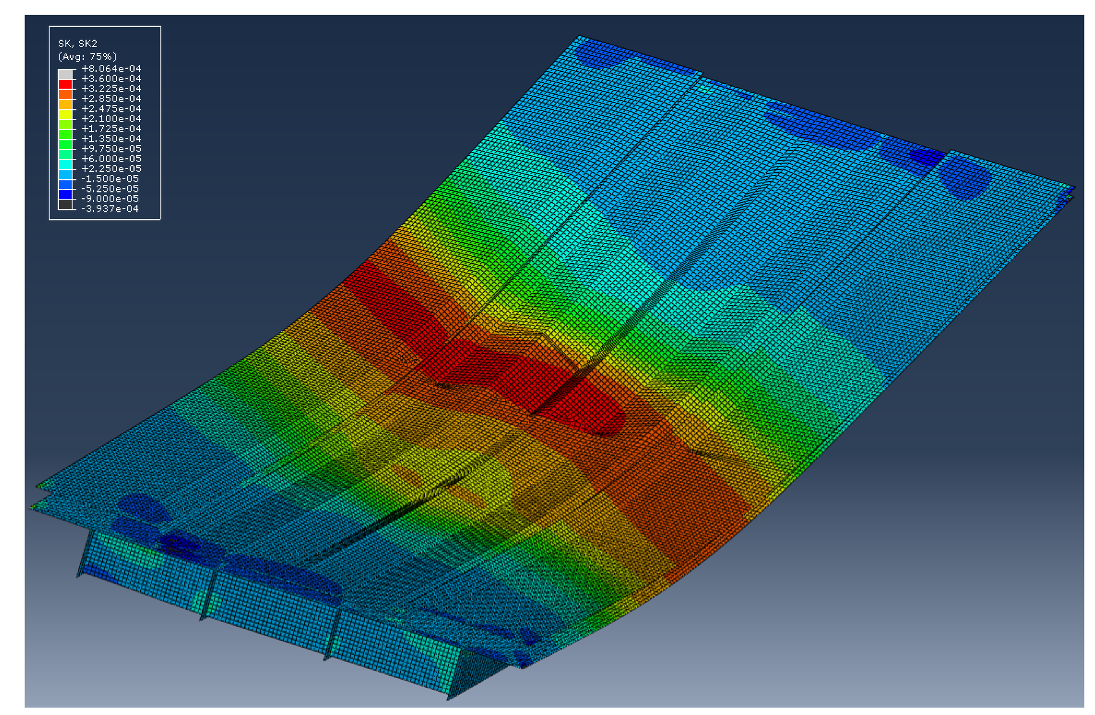

Figure 3: Deformed Shape of PFEA Model at Ultimate Capacity

Results

1. Constitutive models and moment-curvature extraction process verified against previous tests of reinforced concrete beams

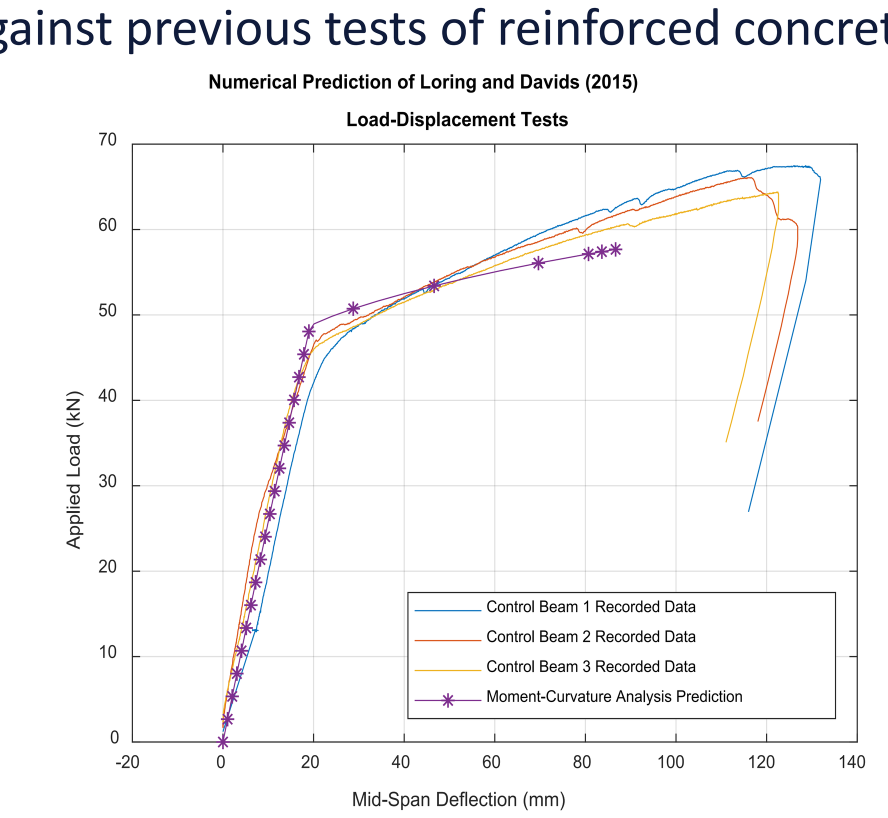

Figure 4: Validation of PFEA Prediction against Lab Beam Tests

2. PFEA accurately predicted redistribution of load after individual girder softening

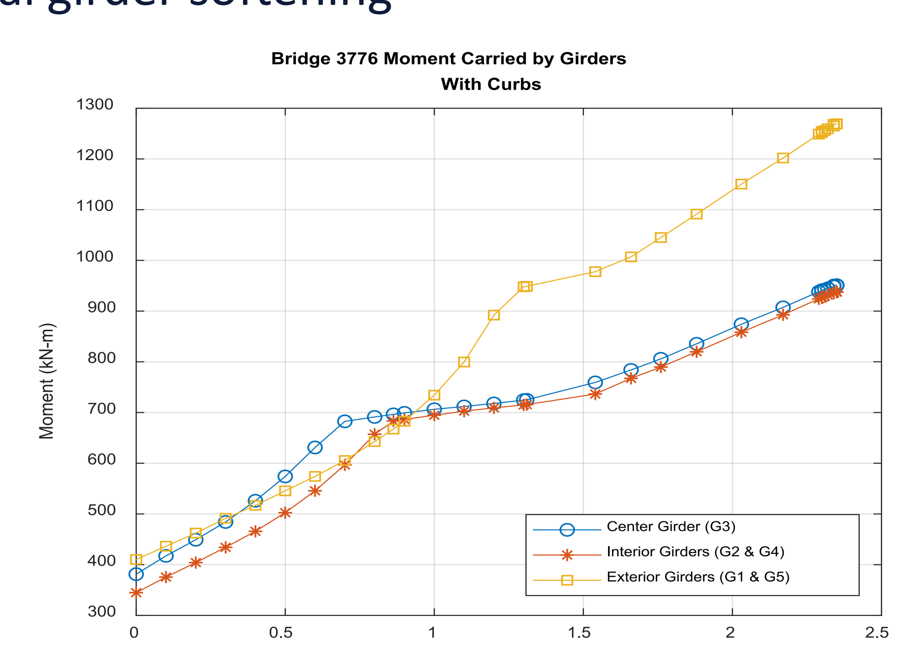

Figure 5: Demonstration of Load Redistribution at Higher Loads

3. PFEA led to significant increase in controlling rating factors

Table 1: Initial and Updated Rating Factors

Bridge	2130	3307	3356	3776	5432	2390	2879	3848	5109	5489
Initial RF	0.92	0.92	0.28	0.69	0.75	0.76	1.09	0.89	0.69	0.78
Field Test	1.28	1.61	0.30	1.20	1.10	0.84	1.35	1.15	0.94	1.10
PFEA	1.87	1.30	1.83	1.43	1.96	1.56	2.23	1.72	2.35	1.91

Extensions to and Uses of PFEA

- Effects of deck skewness explicitly incorporated
- Results of analyses used to rate bridges for shear capacity
- Effects of prestressing incorporated into the moment-curvature relationship extraction process – validated against results of a full-scale destructive bridge test available in the literature
- Results of PFEA analysis used to justify loosening of load restrictions on MaineDOT Bridge 5109

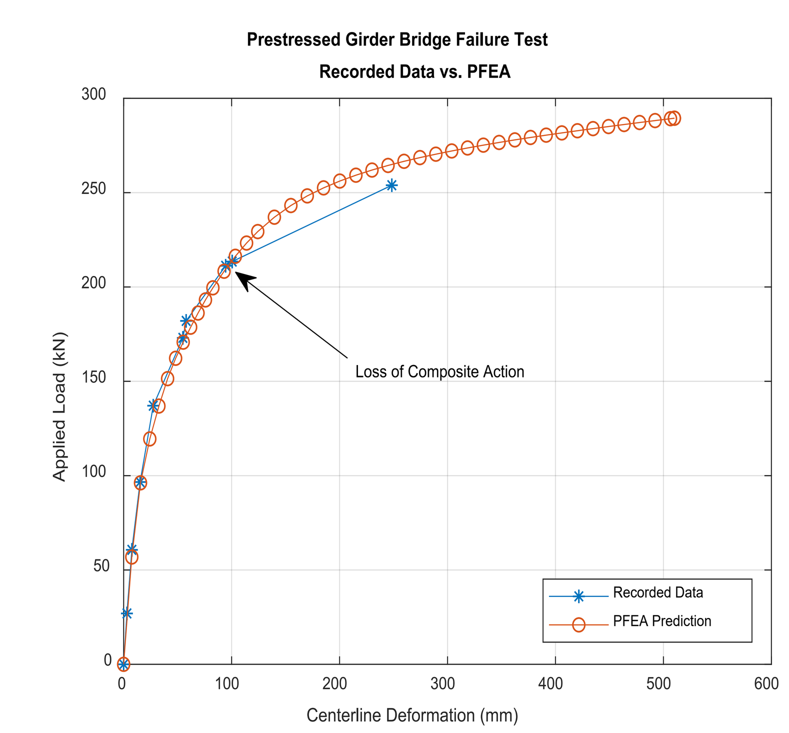

Figure 6: Prediction of Prestressed Bridge Load-Deflection Response to Failure

Conclusions

- PFEA can accurately predict a bridge's behavior at ultimate capacity including load redistribution, ductility, and nonlinear material behavior
- PFEA can be a useful tool in bridge capacity rating that can prevent costly remedial action and avoid field load tests
- With minimal, straightforward alteration of the moment-curvature extraction and modeling processes, PFEA's utility can be expanded to cover bridges for which it was not initially designed
- PFEA's mechanics basis and built-in conservatism justify its use for bridge analysis, and has been successfully used to update the rating of a real bridge

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