Impactful Resilient Infrastructure Science and Engineering (IRISE)

-Project Scope of Work-

(FY 2023-24 (IRISE Year 6) Annual Work Program)

SUMMARY PAGE

Project Title: Bridge Load Ratings

Person Submitting Proposal: Piervincenzo Rizzo, Ph.D., Professor

Proposed Funding Period: February 1, 2024 – July 31, 2025

Project Duration: 18 months

Project Cost: $ 174,578.31

Project Title:
Bridge Load Ratings

Problem Statement:
According to District 1 representatives, load rating analysis is leading to a large increase in posted and closed bridges. This consequential outcome appears to be mostly due to the age of many bridges, which are deteriorating and reaching or exceeding their service lives. Another contributing factor is the progressive increase in load demand over the past decades. State Districts are aware that postings impose inconveniences and increase transportation costs for the public, including businesses. Some engineers believe the standard load rating analysis practices are often overly conservative; for example, the standard practices disregard superstructure redundancies that facilitate load distribution, thereby mitigating the effects of deterioration for some load-bearing members.

Project Objectives:
The objective of this research project is to create the digital twins of a few selected Pennsylvania bridges using a commercial finite element (FE) code (e.g., ANSYS) and perform a static analysis of these bridges to recognize glaringly over-conservative postings. The results will be then compared to the results of simplified bridge representations that simulate a more automated process in which the model does not need to be built "manually". The comparison will establish the accuracy and reliability of the semi-automatic approach for determining whether posting is over-conservative.

Project Scope:
We propose to work with District 1 to select up to three bridges of the same type, namely concrete tee beam bridges (preferably among those currently posted), and then use ANSYS to create:

(1) three accurate numerical models of these bridges based on original engineering drawings;
(2) three accurate numerical models of these bridges based on original engineering drawings but modified to account for the damages annotated in the latest inspection reports;
(3) three approximate models that that simulate images obtainable in the visible spectrum.

The FE models will be based on engineering drawings instead of aerial images, such as those obtainable with LIDAR scanning or drones. This is because LIDAR scanning (or drones) cannot "look inside" but FE models require information on reinforcement layouts, design details (e.g., shear keys), and other bridge parts that are "invisible" to a laser beam mounted on a fixed support or a drone. In addition, flying a drone requires authorizations and a certified pilot.
The results of the analysis will be: 1) compared to the results of the semi-automatic models; and 2) assessed vis-à-vis the load ratings methodology outlined in the Bridge Safety Inspection Manual Publication 238, 2022 Edition (Chapter 3 – Bridge Analyses and Load Ratings). The comparison will determine if current postings are overly conservative, and therefore unjustified. If so, a software tool will be develop to supplement current analytic methodologies. The main outcomes of the proposed IRISE project will be the generation of high-fidelity FE models based on engineering drawings of bridges of interests for District 1, the determination on the validity of postings based on current load ratings, and the (eventual) development of a software tool.

Task Statements:

This project consists of the following six tasks to be completed within eighteen (18) months from the Notice to Proceed (NTP) date.

Task A: Bridge Selection.

Bridge engineers from District 1 will work with the research team to identify up to three concrete tee beam bridges to be analyzed. Candidate bridges will be those currently posted with high average daily traffic counts or close to strategic buildings. District 1 will provide the shop drawings of the selected bridges and the latest bridge inspection reports.

Completion: 3 months from NTP date.

Task B: Model Creation.

For each selected bridge, three finite element (FE) models will be created using ANSYS. As such, nine finite element models are created in total.

First, a high-fidelity FE model will provides an accurate representation of the bridges based on the shop drawings. Details of the reinforcements and other significant structural details that are not visible will be accounted for. The concrete parapet system will be included in the model to quantify the added capacity that it may add by acting as an additional beam, adding stiffness to the span. For illustrative purposes, **Fig. 1** shows a detailed finite element model of the Smithfield Street Bridge developed by the principal investigator (PI).

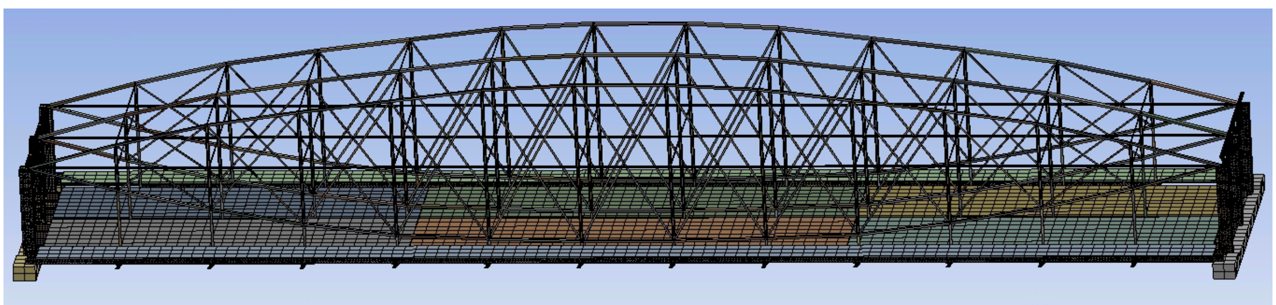

Fig. 1 – Finite element model of the Smithfield Street Bridge.

The above model will then be modified to include damages reported in the latest inspection reports. The damages will be considered individually to quantify individual effects on the static response of the structure.

The third model will ignore any items invisible to a laser or to digital images obtainable with a drone. This simplified representation of the bridges will determine whether drone/LIDAR technology offers sufficient information to predict the structural response of bridges.

Completion: 9 months from NTP date.

Task C: Static Analysis.

A static analysis will be performed with each model to estimate the change in stresses and strains induced by AASHTO-truck loads. A minimum of two types of truck will be considered, e.g., ML-80, H20, and HS20. Truck such as the PHL-93 may be considered in lieu of one of the trucks listed above. The vehicles will be analyzed at minimum six different positions on the bridge. For example, the truck may be simulated on the southbound or the northbound lane, at the midspan, or close to the north / south abutments. Thus, a minimum of 9 (models) x 3 (trucks) x 6 (positions) = 162 static analyses will be conducted for each bridge.

If allowed by the software without adding too much computational cost, the ability of simulating the continuous travel of the truck across the bridge will be considered in order to identify the exact location of the worst-case scenario, which may not be exactly at the midspan, especially if deterioration is at a different location.

The static analyses will yield a database of stress/strain at certain locations for each bridge model. The values will be compared against each other to assess any margin of error, and it will be determined whether this margin is acceptable. Stress and strain increases will be calculated, not the absolute stresses and strains, which would include any pre-stress/post-tension.

Fig. 2 shows a simulation of an ML-80 Truck traveling northbound on the Smithfield Street Bridge. The strain at the diagonal member labeled as L1U2 was calculated with the truck at several longitudinal positions in order to capture the largest strain induced by the truck at that diagonal member. **Table 1** summarizes the results of such analysis, which demonstrate the potential accuracy of finite element models. The table also demonstrates that one analysis (i.e., the truck located at a single individual point) is not sufficient to identify the maximum stress and strain experienced by the structural element of interest.

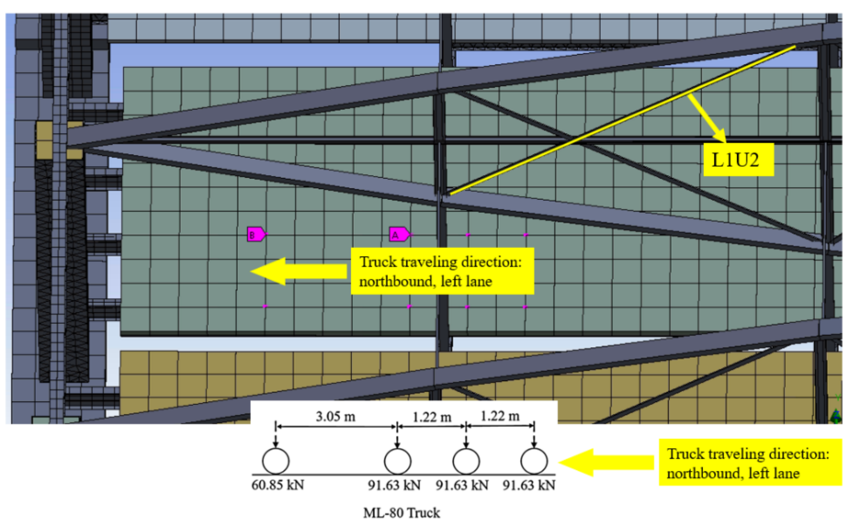

Fig. 2 – Example of the PI's analysis of the Smithfield Street Bridge. Numerical setup relative to the analysis of the ML-80 AASHTO truck. The pink dots locate the position of the truck wheels.

	Distance of rear axle from north portal	Axial Force at member L_1U_2	Axial Strain at member L_1U_2 ($\mu\varepsilon$)
Position 1	15.24 (600)	39.26 (8.83)	58.84
Position 2	13.97 (550)	53.93 (12.12)	80.83
Position 3	12.70 (500)	65.89 (14.81)	98.75
Position 4	11.43 (450)	73.69 (16.57)	110.40
Position 5	10.16 (400)	76.15 (17.12)	114.10
Position 6	8.89 (350)	72.67 (16.34)	108.90
Position 7	7.62 (300)	63.77 (14.34)	95.57

Table 1 – Example of the PI's analysis of the Smithfield Street Bridge. Position of the rear axle of the truck from Pier 3 and corresponding strain on the diagonal member. The distances are expressed in meters (in.). Forces are expressed in kN (kip).

As part of this project, three finite element models will contain damages that are representative of the issues that warranted the postings.

Figure 3 shows a recent simulation of the Smithfield Street Bridge. One of the diagonal members was removed from the central truss of the bridge close to the south side. Note that this was only a simulation; no members were missing from the real bridge. From this simulation, the adjacent members that would be under greater stress and strain could be identified, and the increase in stress and strain could be quantified.

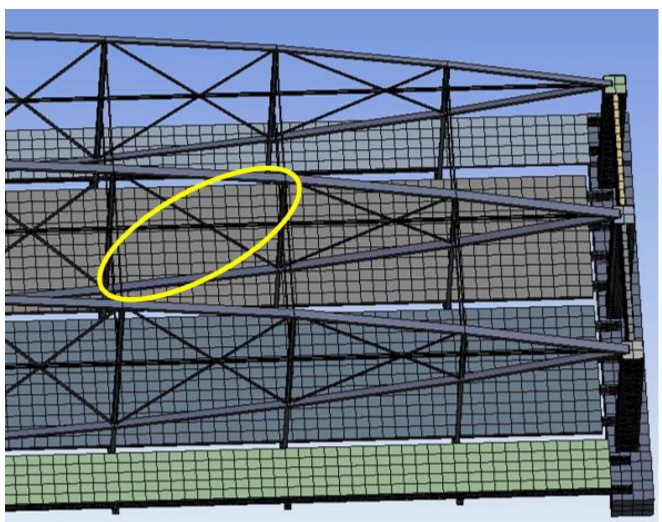

Fig. 3 – Example of the PI's analysis of the Smithfield Street Bridge. Simulated damage in the form of a missing diagonal member.

Completion: 12 months from NTP date.

Task D: Load Bridge Rating Analysis and Software Tool Development.

This task consists of three parts.

1. The results of the static analyses will be assessed vis-à-vis the load ratings determined with the methodology outlined in the Bridge Safety Inspection Manual Publication 238, 2022 Edition (Chapter 3 – Bridge Analyses and Load Ratings). The comparison will determine whether current postings are overly conservative and therefore unjustified. The comparison of the outcomes of

Tasks C and D would eventually allow District 1 to remove postings that may be overly conservative using Pub 238.

2. If the current postings are overly conservative, a software tool will be developed for T-beam bridges. The tool, likely in the form of a spreadsheet, will allow users to input some geometric properties of any T-beam concrete bridge such as span length, curb-to-curb width, number of beams, etc. to estimate variation of the stress, vertical displacement, and strains at certain critical locations on the bridge caused by standard AASHTO Trucks load. These estimations will be based on data extrapolated from the accurate FE models developed in Task 2 and applied in Task 3.
3. Finally, the comparison between the Pub 238 approach and the numerical results associated with the pristine, damaged, and approximated bridge models will determine whether a simplified approach based on LIDAR scanning or drone photogrammetry is adequate for bridge posting. If time allows, the results will be compared with the results obtained using PennDOT software, which are assumed to be already available and included in the documentation relative to the bridges to be studied in this project.

Table 2 summarizes the number of finite element models to be created, and the number of analyses to be conducted in this project.

Table 2 – Summary table of the models and the static analyses to be carried out in this project.

Number of Bridges	**3** (Tee bridges)
Number of models per bridges	**3** (pristine, damaged, and approximate)
Trucks types	**3** (e.g., ML-80, H20, and HS20)
Positions of the truck on the bridge	**6** (e.g. two trucks on the bridge simultaneously one on each lane; midspan and close to north and south abutments)
Summary:	**9 finite element models; 162 static analyses**

Completion: 15 months from NTP date.

Task E: Final Report.

Upon completion of Tasks A through D, a Draft Final Report that summarizes all project activities, findings and recommendations will be generated and provided to the technical monitors for review. The final report will provide a comparison between our ratings obtained using the FE models, and the PA state rating and the LFRF to be obtained with the documents on file with the bridges to be analyzed or calculated by using the current approach followed by District 1. A roadmap to guide the implementation that provides detail on the broader use of the results of this project will be included in the Draft Final Report. A Final Report will be provided, taking into consideration comments received on the Draft Final Report. Once the Draft Final Report has been reviewed, approved, and accepted the University will provide the electronic copy of the Final Report.

Deliverables:

A draft final report will be submitted within sixteen (16) months of the NTP date. The final report that takes into consideration comments on the draft report, will be submitted within eighteen (18) months from the NTP date. Upon completion, deliverables will be submitted to PennDOT.

Completion: 18 months from the NTP date.

Budget Notes

Key Personnel:

Principal Investigator: Piervincenzo Rizzo, Ph.D., Professor

Other Personnel:

Grad Students: TBD

Senior personnel: Fabio Matta, Ph.D. (subaward)

Proposed Person-Hours by Task:

Team Member	Task A	Task B	Task C	Task D	Task E	Total
Key Project Team Members, Estimated Hours Per Task						
P. Rizzo	10	60	40	50	50	210
GSR-TBD	260	390	310	320	280	1560
F. Matta	5	30	30	30	25	120
Total	275	480	380	400	355	1890

Schedule:

Calendar Year	Year 1				Year 2			
Quarters	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task A: Bridge Selection	X							
Task B: Model Creation		X	X					
Task C: Static Analysis			X	X				
Task D: Load Bridge Rating Analysis			X	X	X			
Task E: Final Report						X		

Budget: The total project cost is $174,578.31

		UPitt FY 24 (PennDOT FY 23)	UPitt FY 25 (PennDOT FY 24)	Total
Personnel				
Piervincenzo Rizzo	PI	4,195.20	18,237.60	22,432.80
	Faculty 2	-	-	-
	Faculty 3	-	-	-
	Post Doc	-	-	-
TBN	Grad Student 1	15,958.80	32,718.40	48,677.20
	Grad Student 2	-	-	-
	Hourly Student 1	-	-	-
	Hourly Student 2	-	-	-
Total Personnel		20,154.00	50,956.00	71,110.00
Fringe Benefits				
Piervincenzo Rizzo	PI	1,380.22	6,000.17	7,380.39
	Faculty 2	-	-	-
	Faculty 3	-	-	-
	Post Doc	-	-	-
TBN	Grad Student 1	7,979.40	16,359.20	24,338.60
	Grad Student 2	-	-	
	Hourly Student 1	-	-	-
	Hourly Student 2	-	-	-
Total Fringe Benefits		9,359.62	22,359.37	31,718.99
Total Salaries & Fringe		29,513.62	73,315.37	102,828.99
Travel:		-	-	-
Supplies:		-	-	-
Professional Services		-	-	-
Subaward		4,000.00	12,000.00	16,000.00
Total Direct Costs		33,513.62	85,315.37	118,828.99
Indirect Cost Base		25,534.22	68,956.17	94,490.39
Overhead		15,065.18	40,684.14	55,749.32
TOTAL Fund Request		**48,578.80**	**125,999.51**	**174,578.31**

Acknowledged By:

Piervincenzo Rizzo, Ph.D.
Principal Investigator