Numerical Modeling of Willow Valley Bridge Under Static Loading

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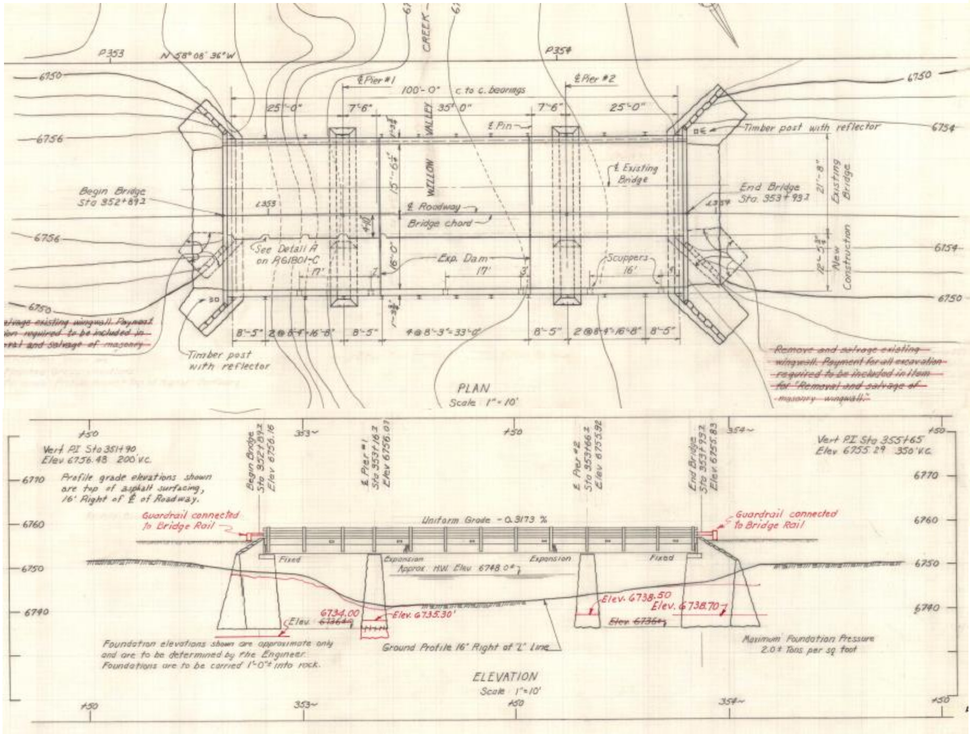
Marta Sitek, PhD
Cezary Bojanowski, PhD

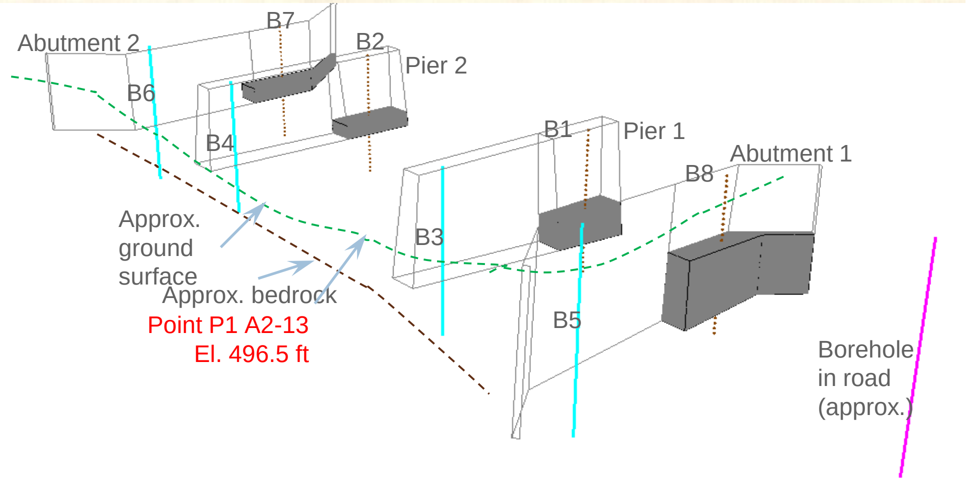
Motivation

- The main goal of the ongoing project is to find a set of tools to assess the integrity and capacity of foundations and reduce the risk of foundation reuse.
- This part of the research concentrates on developing a finite element modeling technique to assist engineers.
- A computational model of the Willow Valley bridge, including superstructure and foundations, was developed in a finite element software LS-Dyna.
- Extensive numerical modeling was done to determine the response of the superstructure, foundations and bedrock to existing static loads and evaluate structural and geotechnical capacity.
- Analysis was done to predict foundation and bedrock behavior under the weight of a new superstructure.

Input from design drawings and measurements

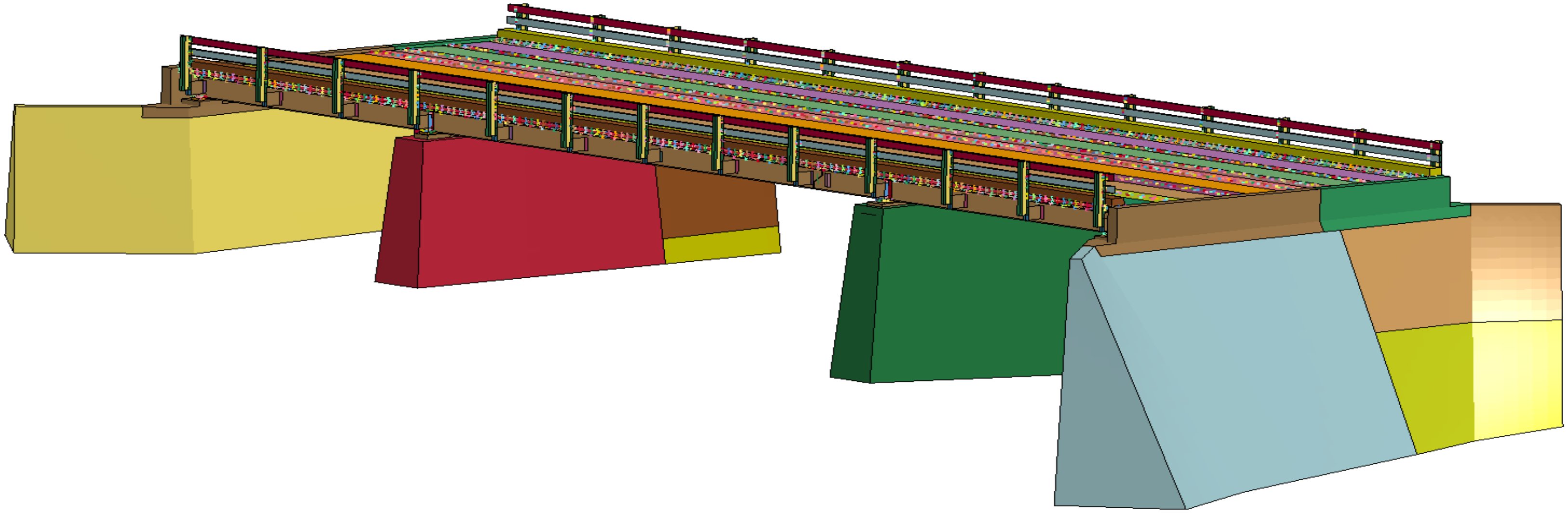
- Preparation of a good numerical representation of any structure requires a significant amount of data.
- Design drawings provide information on the geometry.
- Cooperation with surveyors and geological and geotechnical engineers is essential to obtain up-to-date knowledge on
  - structure dimensions, coordinates of characteristic points
  - types of soil layers present on-site and their properties





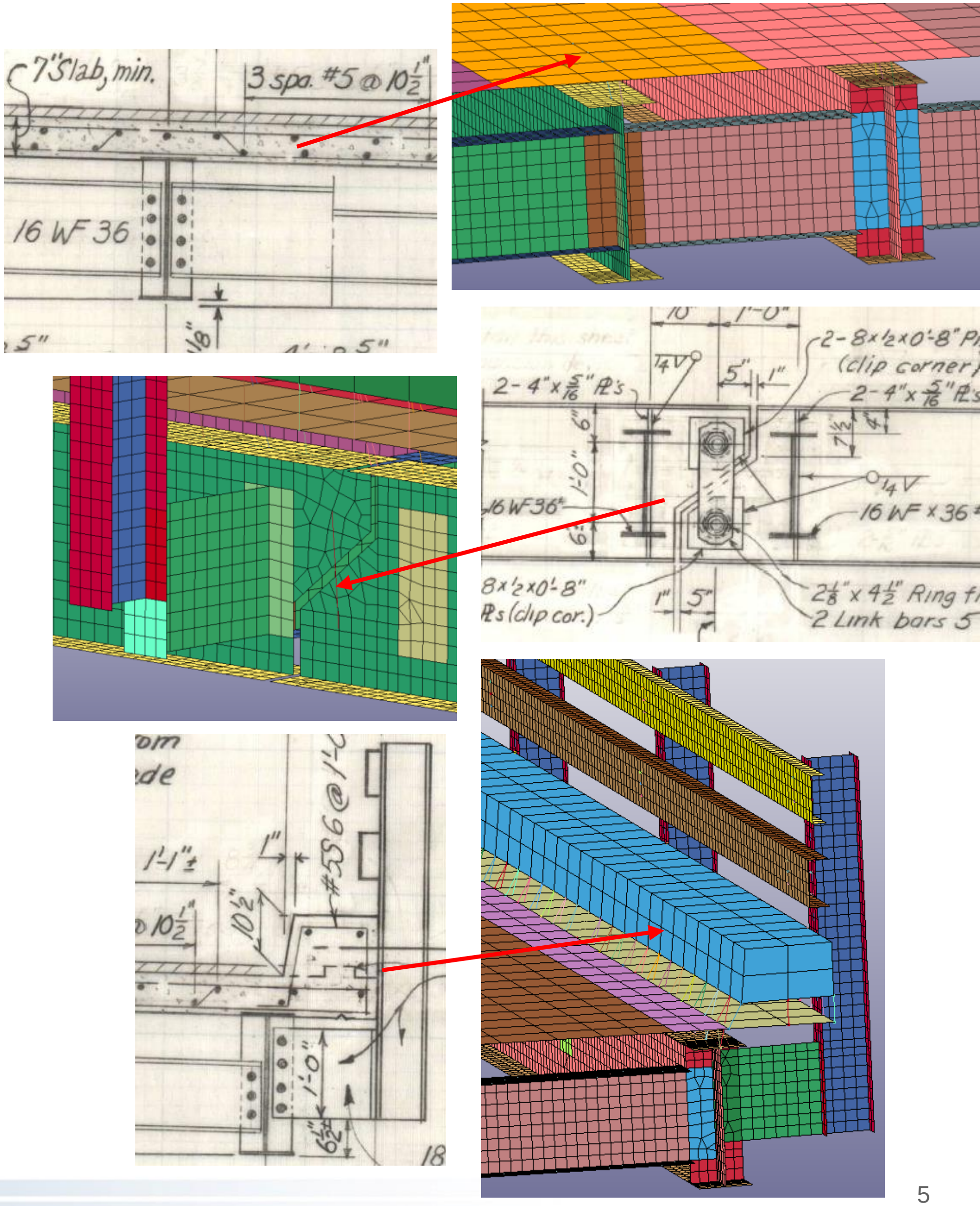
Numerical model

- Each color in the model represents a section – region of a particular thickness, material or finite element formulation.
- The superstructure was modeled with shell finite elements and the substructure with solid finite elements.
- The material properties were obtained mostly from the design drawings, field and lab tests. Some values were assumed according to literature.

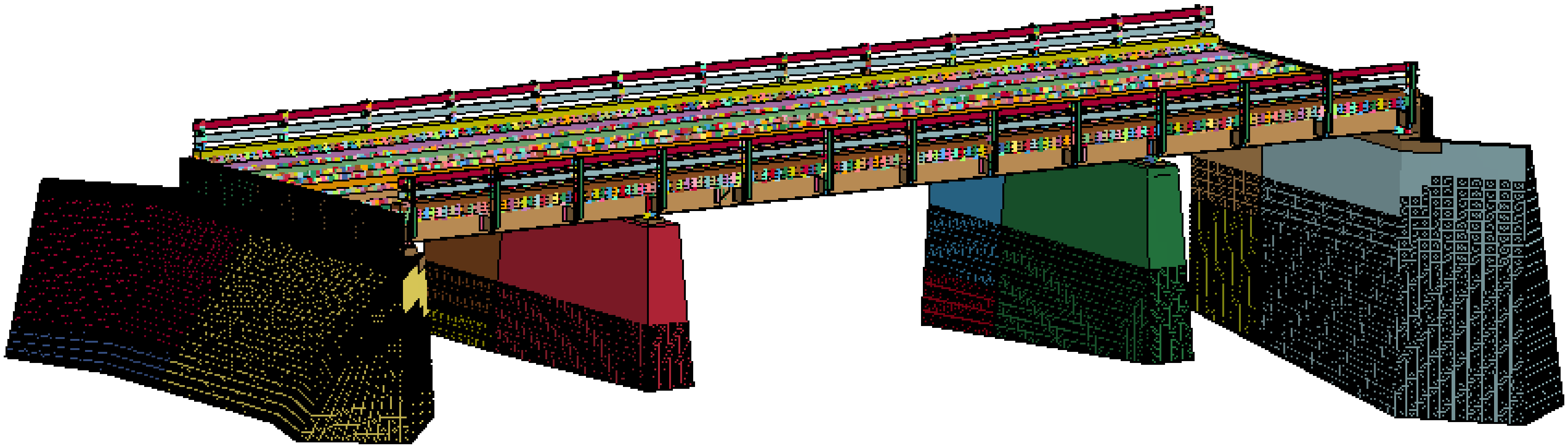


Numerical model. The superstructure

- The deck was modeled with composite shell elements that allow definition of various layers of materials along the shell thickness.
- The slab was tied to the girders with rigid links.
- The pins in the expansion joints are represented by truss finite elements with cross-sectional area of the link bar.
- The curbs, as they are more bulky than the rest of the slab, are modeled with solid elements and tied to the slab with rigid links (CNRB elements).



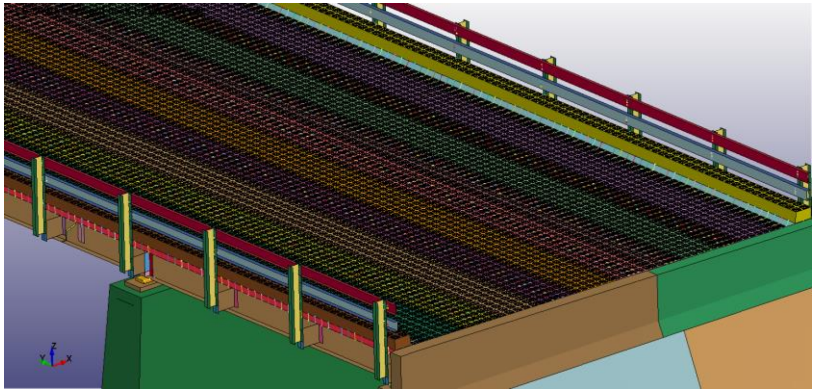
Numerical model. The substructure

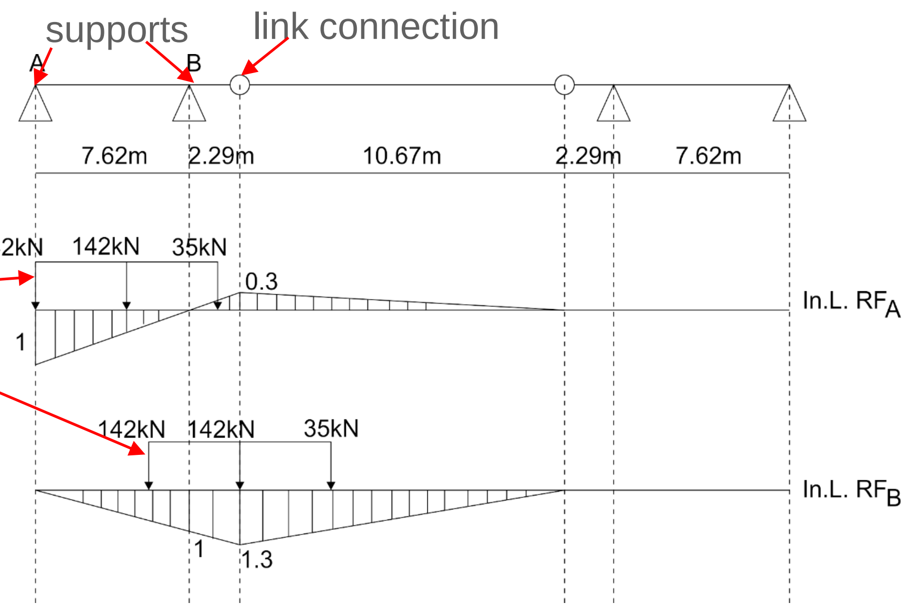


- The foundations are built on a limestone bedrock which is uniform and in good condition - fixed conditions on the bottom surfaces are justified.
- Fixed boundary conditions on the back of the abutments are considered.
- Granular overburden is represented as earth pressure acting on the walls of the supports.
- The foundation is built of masonry and concrete.
- Differences in properties between old and new parts – 20% decrease in stiffness and strength for both materials.

Loading conditions

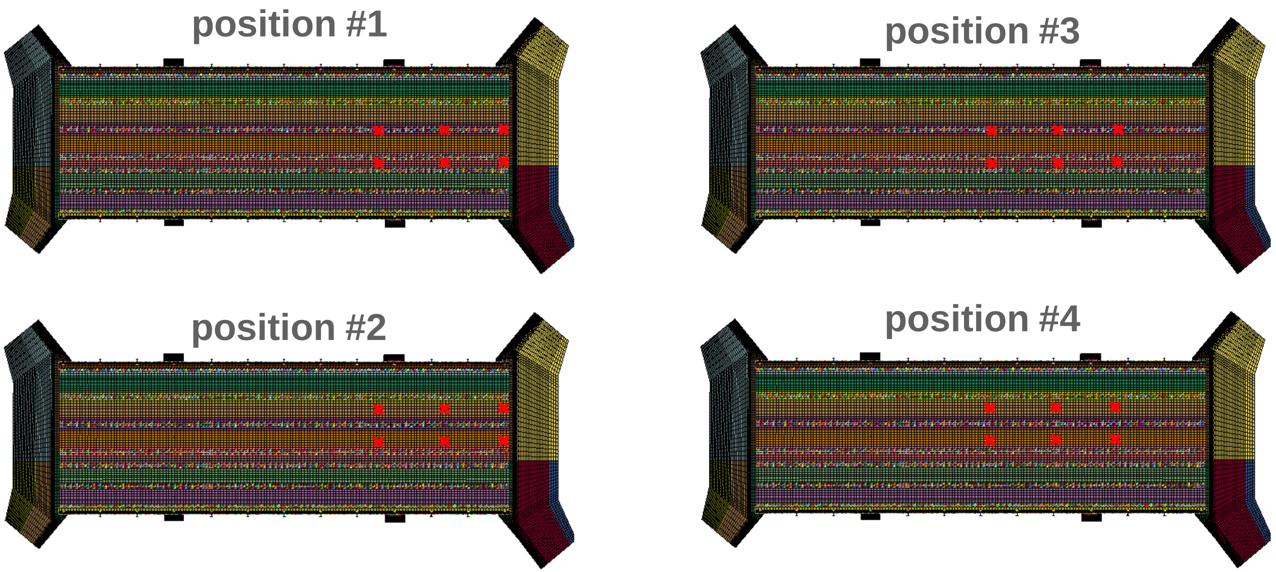
- Two static loading cases are considered:
  1. The planned replacement of the superstructure and resulting increase in weight is expressed by a uniform distributed load equal to 10%, 20% and 30% of the superstructure weight.
  2. To establish the highest load acting on the supports, the standard load from a HS20-44 truck was applied in critical positions.
     - Influence lines of forces in bearings on Abutment #1 (RF_A) and Pier #1 (RF_B) are used to find the critical position of the truck on the structure.
     - Influence lines of reactions in the other two supports were not drawn due to the symmetry of the system





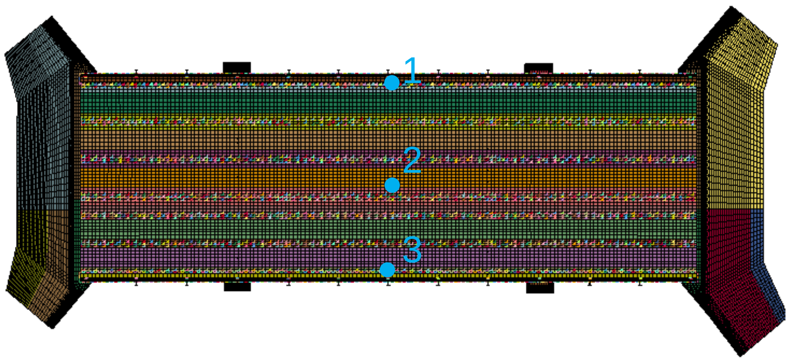
Loading conditions

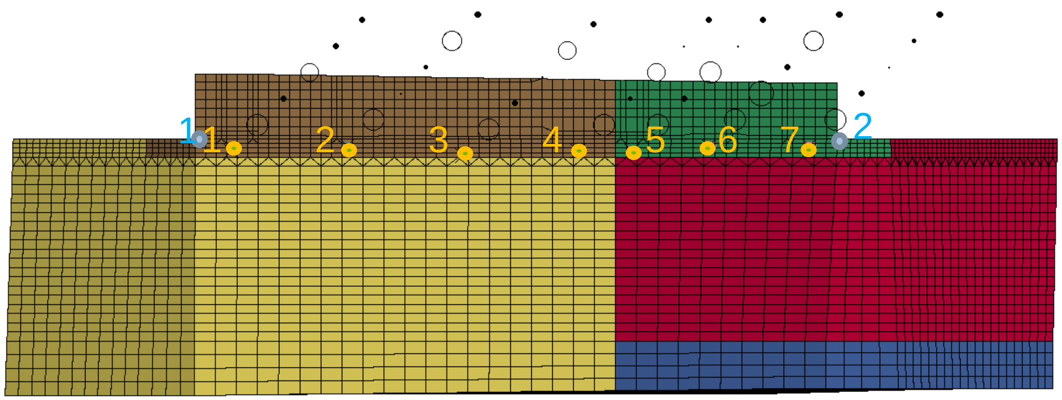
- In a 3D case the truck is represented as 6 concentrated loads, four of them equal to 142kN and two – 35kN.
- Four positions of the load were considered
  - Loads are applied over the girders and in-between them

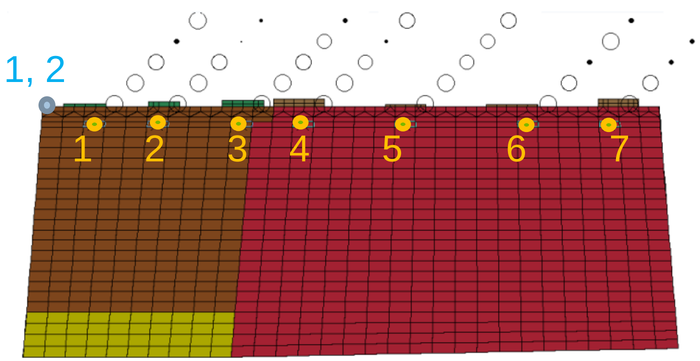


Discussion of results

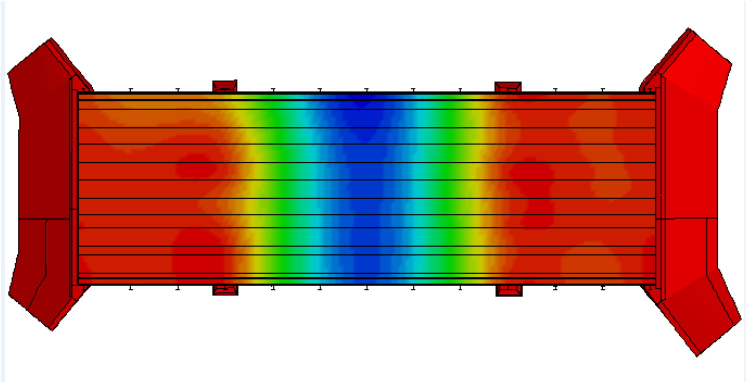
- Quantities chosen for comparison in different loading cases:
  - Vertical displacements
    - three points the middle of the deck
    - top parts of abutments and piers (blue dots)
  - Mises stress values
    - under the bearings (yellow dots)
    - on the bottom of the foundations

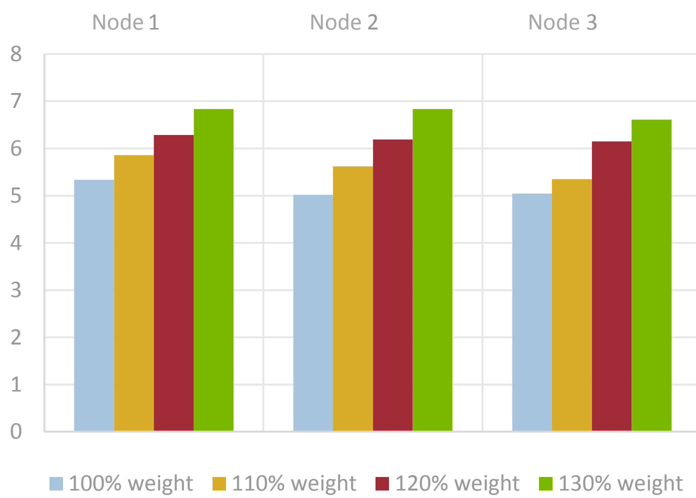






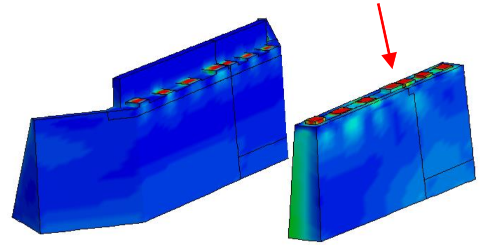
Discussion of results. Increase of superstructure weight

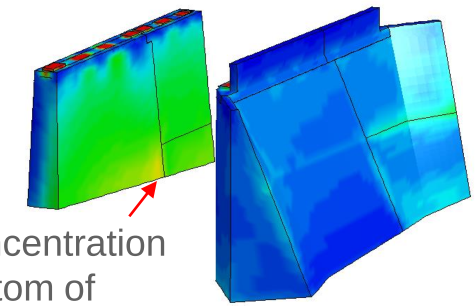




Vertical displacements [mm] in selected points on the deck

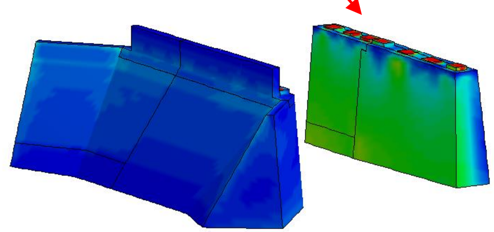
Stress concentration under bearings

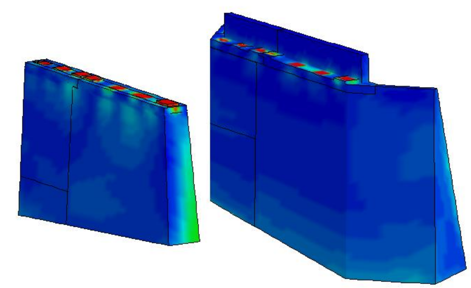




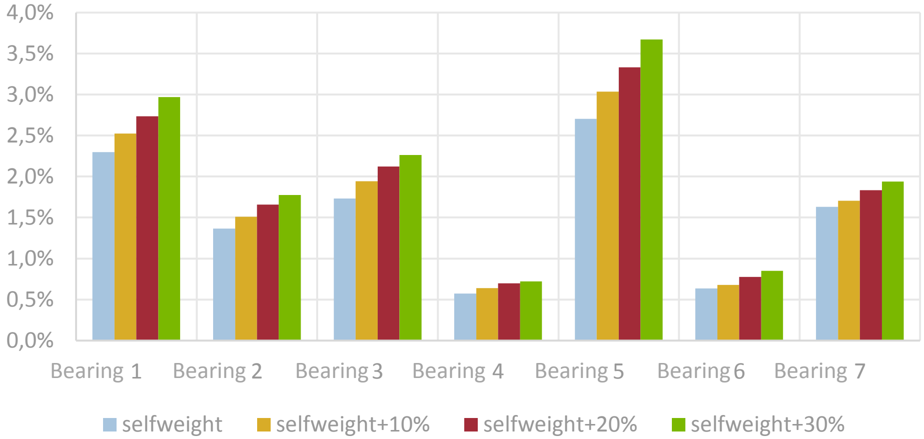
Stress concentration on the bottom of foundations

Highest values of Mises stress on the bearings

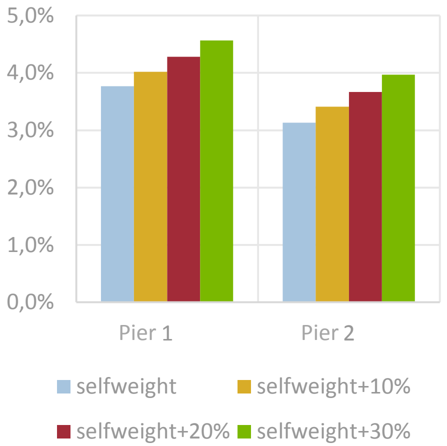




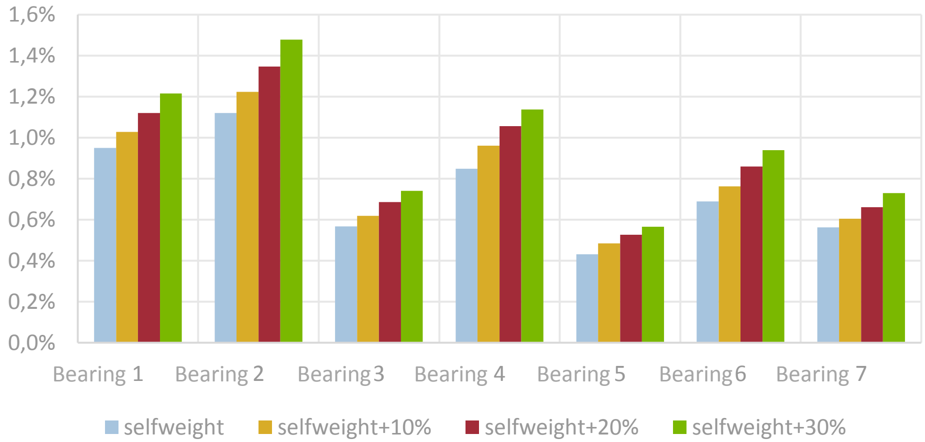
Discussion of results. Increase of superstructure weight



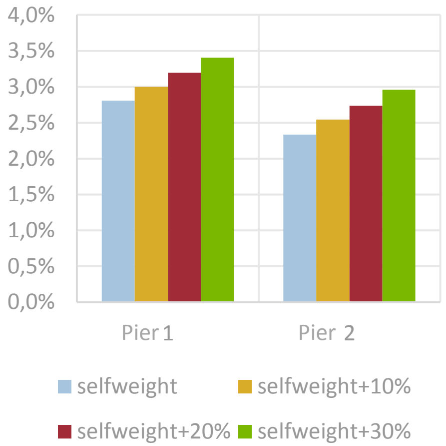
Used percent of structural capacity under bearings in Pier#2



Used percent of structural capacity in the bottom surface of Piers #1 and #2

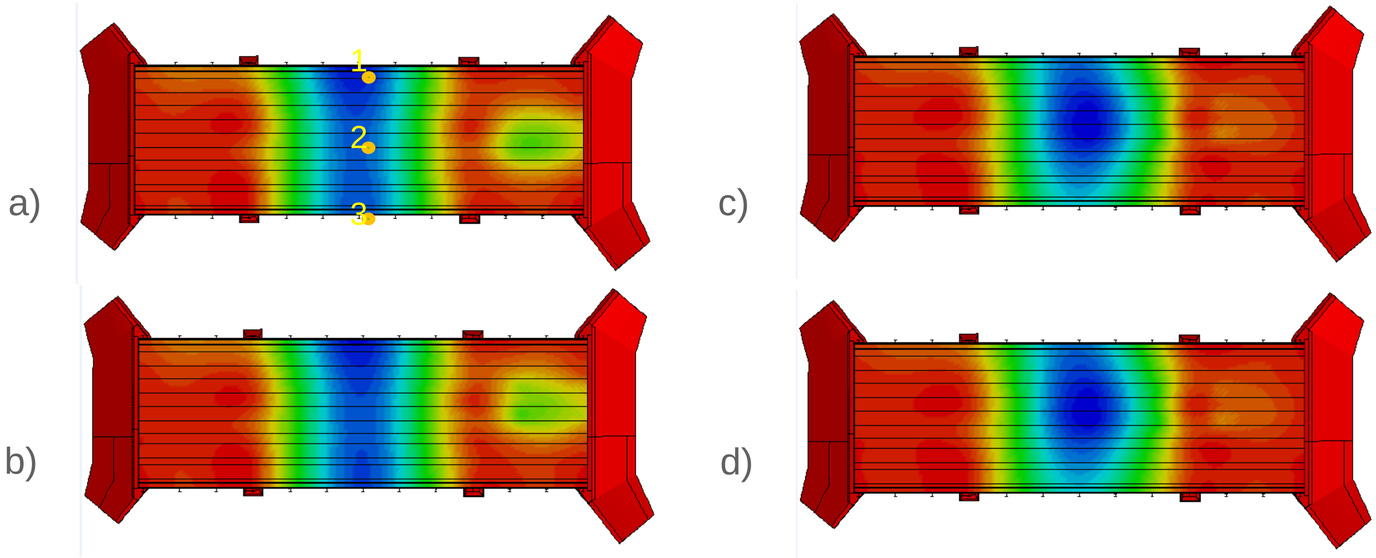


Used percent of structural capacity under bearings in Abutment#2

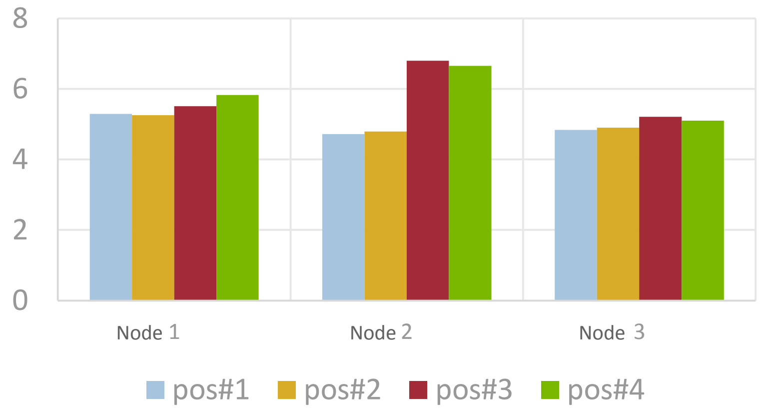


Used percent of geotechnical capacity

Discussion of results. HS20-44 truck load

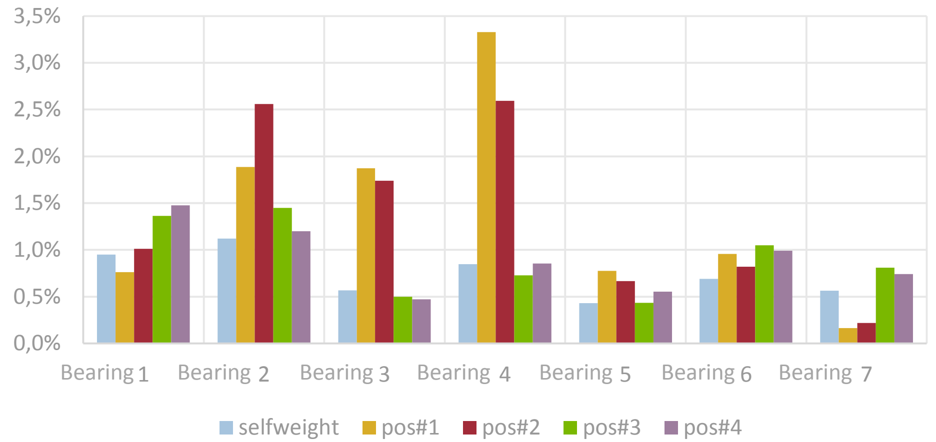


Contour maps of vertical displacements for HS20-44 load: a) position #1 , b) position #2 , c) position #3, d) position #4

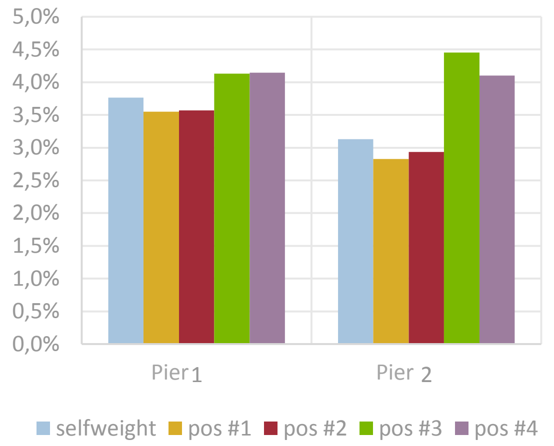


Vertical displacements in selected points on the deck [mm]

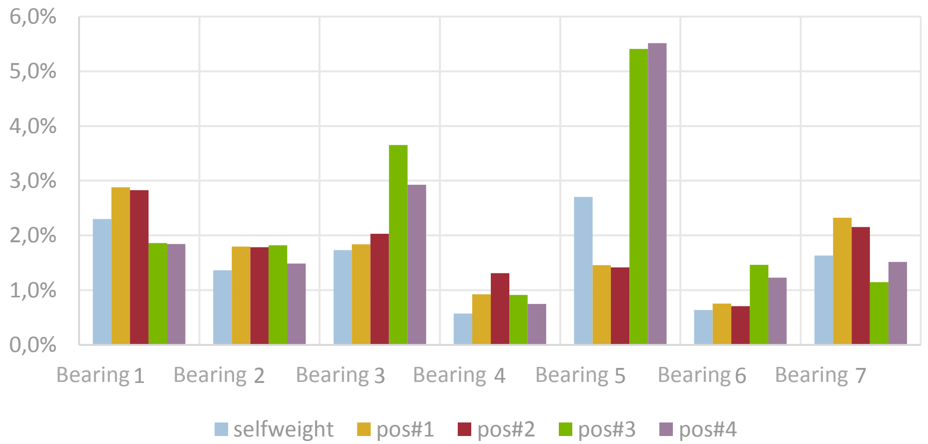
Discussion of results. HS20-44 truck load



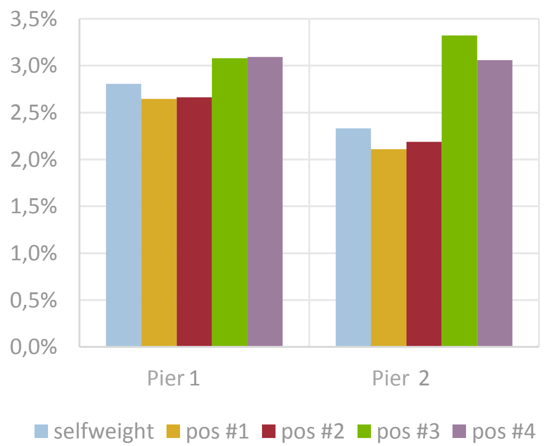
Used percent of structural capacity under bearings in Abutment#2



Used percent of structural capacity in the bottom surface of Piers #1 and #2



Used percent of structural capacity under bearings in Pier#2



Used percent of geotechnical capacity

Discussion of results

- Differences in deck and substructure deflection values are significant
  - Maximum deck deflections in existing conditions are ~5mm (0.2in) and increase to ~7mm when the case of 130% of the deck weight is considered.
  - The supports show very small deformations, of the order of 0.01mm (0.0004in) or lower.

→ With the use of appropriate sensors even such small displacements can be potentially measured.

- Concentrations of stresses are located underneath the bearings and on the bottom of the foundations

→ Load cells will be used in chosen areas as a part of structural monitoring

- Less than 5% of structural capacity of the foundations is used
- Margin of safety of geotechnical capacity is also high (percentage of capacity used: less than 3.5%)

→ There is enough capacity for the foundation reuse

Conclusions

- A numerical tool to assist engineers was developed.
- It allows the assessment and evaluation of
  - the interaction between superstructure, foundations and bedrock
  - the differences in behavior of the new and old parts under different loading conditions
  - structural and geotechnical load-carrying capacity
  - how to proceed with structural monitoring - what instrumentation to use and where to locate the sensors
- The model will be further improved to take into account
  - a more detailed analysis of interaction between the foundation and bedrock
  - impulse and other dynamic loading tests of the structure

Thank you!