Engineering analysis and design software

Bridge design and engineering

Case Study

Designing Michigan's I-94 Gateway Arch Bridges

National Steel Bridge Alliance 2007 PRIZE BRIDGE WINNER Medium Span Category

- **Optimization of arch profiles**
- **Vehicle load optimization for worst case loading patterns**
- **Examination of hanger forces and stressing requirements**

Michigan's Gateway Arch Bridges are part of a $55-million project by Michigan Department of Transport to improve Interstate 94 between Detroit airport and downtown Detroit in the United States. The bridges replace a previous 4-span structure and carry westbound and southbound traffic of I-94 over a re-designed Single Point Urban Interchange. LUSAS *Bridge* analysis software was used by Alfred Benesch & Company to optimize the arch profiles, to examine hanger forces under dead and live loading, and to determine the necessary hanger stressing forces to be applied in order to maintain the bridge at its proposed profile grade. In recognition of its innovative, aesthetic and cost-effective design the National Steel Bridge Alliance made it the winning bridge design in its medium span category.

Overview

The bridges are part of a $55-million project to improve Interstate 94 between Detroit airport and downtown Detroit. They replace a previous 4-span structure and carry westbound and southbound traffic of I-94 over a re-designed Single Point Urban Interchange. A key requirement in providing a new bridge was to maintain the existing 14'-9" clearance to prevent having to raise the road profile of I-94. To comply with this and to also maintain clear sight distances and improve aesthetics at the interchange, a single span arch bridge replacement was chosen. With the superstructure of the new arches having a depth of only 5' compared to the 8' depth of the previous structure the vertical clearance under the bridge is actually increased.

Bridge construction

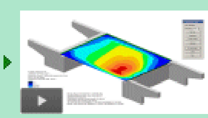
The bridges consists of single span, inclined, through arches of box-section construction. All arch ribs are of 3' x 4' box-section with ¾" thick webs. Flanges differ with exterior arch ribs being 2 ½" thick, and interior ribs 2 ¼" thick. The inclination of the arch ribs is limited to 25 degrees to maintain a desirable vertical clearance. Ribs are connected laterally using five American football-shaped braces . Arches are founded at differing levels; the bases of the exterior arch ribs are located at the lower Telegraph Road, whilst the interior arch ribs supports sit at the higher

Software Information

Bridge / Bridge plus
- Software overview
- Modelling in general
- Advanced elements, materials and solvers
- Load types and combinations
- Staged construction modelling
- Geotechnical / Soil-structure modelling
- Analysis and design
- Design code facilities
- Viewing results
- Software customisation

Bridge LT
- Software overview

Videos



Choosing Software
- Software products
- LUSAS Bridge LT
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- Software selection

Software Options
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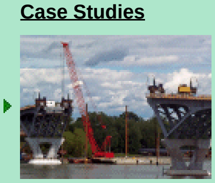
Case Studies



Additional Information

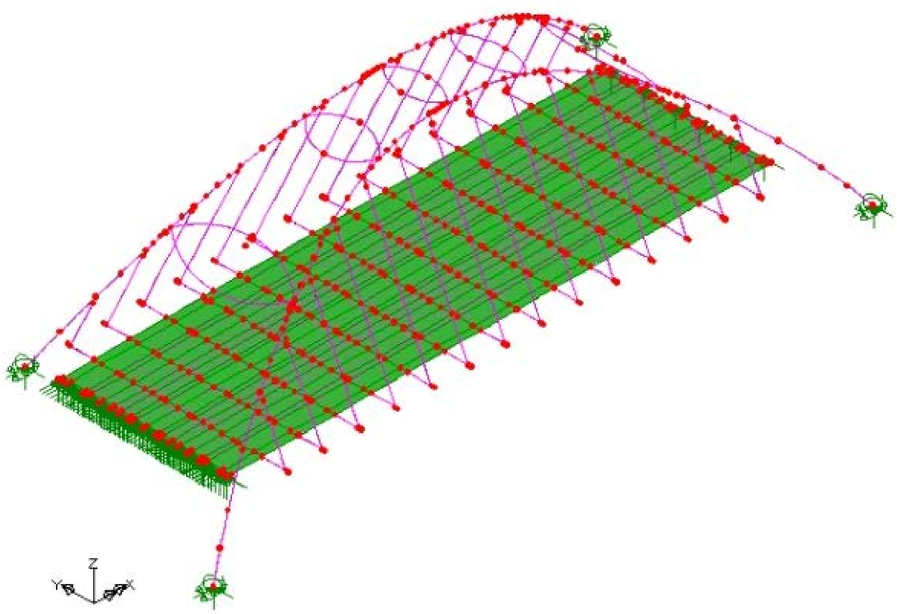
I-94 level. This results in exterior and interior arch rib lengths of 296’ and 257’, respectively. Overall clear span between east and west abutments is 246’.

In order to restrain the bases of the arch ribs at their relative locations, a number of design options were investigated. This eventually resulted in the selection of a true arch design having fixed bases. Because the soil profile at the site consists of medium to soft clay that will creep under the arch longitudinal thrust force, it was decided to provide a foundation tie system that was independent of the soil. Exterior arch ribs are restrained longitudinally by 289’ long, 7'-4" wide by 3'-2' deep concrete ties located 4 feet below the Telegraph Road roadway. Interior arch ribs both share the same 232 feet long, 14’-10 by 3'-2" longitudinal central concrete tie. Transverse ties, 11'-6" long, connect the exterior arch rib foundations to the abutment foundations. Ties are designed to resist the total arch thrust forces, but for redundancy reasons, several piles under the arch rib foundations are battered to help resist some of the arch thrust. Steel reinforcement in the ties is designed to resist the total arch thrust force, while maintaining maximum tensile stresses in the reinforcement of 24 ksi. Frictional resistance to the arch thrust between the foundation tie and the soil is also ignored in the design - increasing the redundancy of the foundation system.

The bridge deck comprises a series of floor beams, stringers and stiffening girders. Transverse floor beams, supported by hangers, carry a 9" thick concrete deck. Longitudinal stringers and stiffening girders help reduce the deck deflection due to live load. The stiffening girders also distribute the live load between the adjacent hangers and this results in lighter hangers. Each hanger assembly consists of two strands of 2 1/8" diameter, ASTM 586 structural strand. Each strand within the assembly is designed to carry the total load of any adjacent failed strand with an impact factor of 2.

Modelling with LUSAS

The geometry of the two bridges required detailed structural analyses to investigate their behavior under different loading conditions. LUSAS *Bridge* was selected for this task and proved vital in determining the final profile of the arch ribs. Thick beam elements were used for meshing the ribs, top bracing, hangers, and floor framing system, while thin shell elements were used for discretizing the concrete deck slab. This 3D model enabled the global behavior of the bridge to be examined as well investigating the behavior of its separate structural components. The ability to name and group together structural features in LUSAS was particularly useful for this.



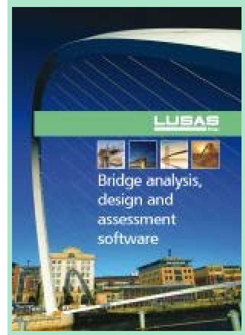
Dr Hiba Abdalla, Senior Designer at Alfred Benesch explains: "Using LUSAS, the arch ribs were optimized for minimum bending stresses under dead loads. Starting from a basic circular profile with constant radius, the profile radius was varied and the model re-analyzed until bending stresses were observed to attain a practical minimum. The resulting profile is an arch with a higher rise and two different radii, one for the crown segment and the other for the two outer landing segments. The arch optimization phase was greatly enhanced by the result processing facilities in LUSAS and the ease with which the geometrical outline of the structure could be manipulated."

Results obtained

- Linear and nonlinear buckling analysis
- Curved girder analysis
- Integral or jointless bridges
- Post-tensioning
- Concrete modelling
- Interactive Modal Dynamics
- LUSAS Programmable Interface (LPI)

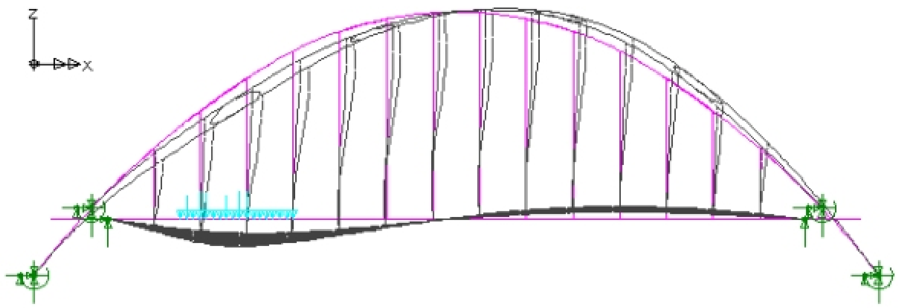
General information

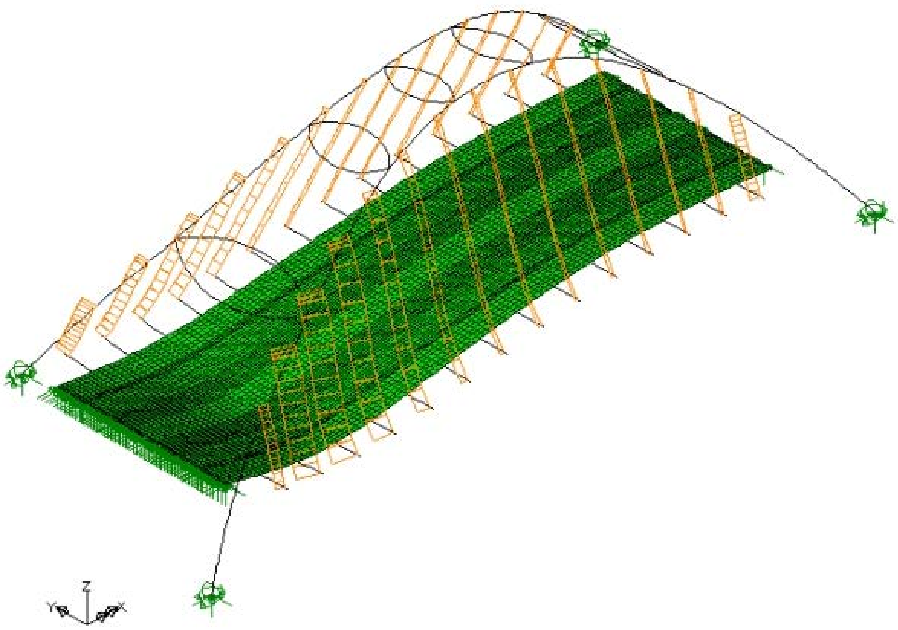
- Hardware specification
- Licencing and Networking options
- Software prices
- Documentation
- Links page



Request Information

Once the final geometry was decided, extensive LUSAS analyses examined the bridge performance under live, wind, and temperature loads, and all combinations thereof. Due to the unusual geometry of these bridges, live load effects at numerous locations along the arch ribs, transverse girders and longitudinal girders, had to be determined. The Autoloader vehicle load optimization facility, which identifies worst-case vehicle loading positions, coupled with influence analysis capabilities of LUSAS help speed up this repetitive task enormously. LUSAS animations of bridge displacements from moving live loads gave a better understanding of how the different components work together to carry traffic loading. Linear buckling analyses were also carried out to determine load factors. Since structural strands are used for hangers, it was crucial to accurately determine the force levels within each hanger during and after construction. LUSAS analyses examined hanger forces under dead loads, and helped determine the necessary stressing forces to be applied in order to maintain the bridge at its proposed profile grade. This technique proved to be very useful in predicting and accounting for displacements that occurred during construction.





"The arch optimization phase was greatly enhanced by the result processing facilities in LUSAS and the ease with which the geometrical outline of the structure could be manipulated."

Dr Hiba Abdalla, Senior Designer, Alfred Benesch

Other LUSAS Bridge case studies: