Zhengyu Liu

PhD, PE

Senior Staff Consultant

Dr. Zhengyu Liu, P.E. is a Senior Staff Consultant at Engineering Systems Inc. (ESi) with approximately 15 years of experience in structural engineering. He provides expertise in structural assessment, structural analysis, failure investigation, forensic engineering, and design support for a variety of infrastructure types, including bridges, culverts, retaining walls, and sign-truss structures, made of cast-in-place concrete, precast concrete, structural steel, timber, composites, and other innovative materials.

Dr. Liu is recognized for his expertise in advanced structural analysis, including linear analysis, material and geometric nonlinear finite element modeling, and analytical model calibration using laboratory and field-testing data. His areas of specialization include wind-structure interaction, soil-structure interaction, thermal-structure interaction, time-dependent material behavior, material volume-change effects, and structural contact mechanics. Using advanced analytical techniques, Dr. Liu helps clients gain a clear understanding of complex structural behavior by visualizing load paths, load redistribution, stress concentrations, deformation patterns, crack initiation and propagation, and potential failure mechanisms. His analyses support the evaluation of structural capacity, critical components, design alternatives, and the root causes of existing failures.

In addition to his consulting work, Dr. Liu is actively involved in the engineering profession. He serves as a judge for structural engineering competitions, including the Student Steel Bridge Competition sponsored by the American Institute of Steel Construction (AISC) and the Ready, Set, Build! Bridge-Building Competition in Des Moines. He is a voting member of the Transportation Research Board (TRB) Committee on Construction of Bridges and Structures (AKC40) and serves as a peer reviewer for more than ten leading structural and civil engineering journals.

Prior to joining ESi, Dr. Liu was a Senior Research Scientist and Adjunct Assistant Professor at Iowa State University. During more than 14 years at ISU, he provided analytical expertise for structural engineering research and worked on more than 30

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Areas of Specialization

- Structural analysis, failure analysis, and load behavior of complex systems
- Highly nonlinear finite element modeling
- Bridge Testing & Evaluation
- Structural Health Monitoring
- Bridge engineering
- Bridge materials: concrete, steel, timber
- Soil–structure interaction
- Wind–structure interaction
- Structure thermal behavior
- Repair of damaged infrastructure

bridge-related research projects sponsored by federal and state agencies. He is the author or co-author of more than 50 technical publications and is a licensed Professional Engineer (P.E.).

Education

Ph.D., Structural Engineering, Iowa State University 2018
M.S., Structural Engineering, Iowa State University 2014
B.S., Civil Engineering, Shenyang University of Technology, China 2012

Licenses & Certifications

- State of Iowa P.E. License No. 25328
- State of Missouri P.E. License No. 2026040326

Languages

- English
- Mandarin

Positions Held

Engineering Systems Inc.

- Senior Staff Consultant, June 2026 – Present

Iowa State University-Department of Civil, Construction, and Environmental Engineering

- Adjunct Assistant Professor, Apr. 2022 – Present

Iowa State University-Bridge Engineering Center

- Senior research engineer, May 2022 – June 2026
- Research Engineer, Jul. 2018 – May 2022
- Graduate Research Assistant, Sep. 2013 – May 2018

Tianbeihongji Construction, Inc, Shenyang, China

- Civil (Structural) Engineer Intern, July 2011 – June 2012

Project Experience

Selected Project Experience

Evaluation of an innovative joint design for the adjacent box beam bridges

Box beams were precast at the plant, and once delivered to the field, a cast-in-place longitudinal joint will be poured to form the transverse connection. Historically, cracks have been found in these joints for various reasons, such as thermal gradients and shrinkage. The goal of this project was to design a new box beam bridge joint for use between adjacent concrete box beams, with a particular interest in eliminating early-age cracking. A series of finite element (FE) models capable of simulating early-age concrete hardening was developed using Abaqus and MATLAB modeling software and validated against experimental data. The early-age, time-dependent stress development in the joint and at the joint-box beam interface was investigated using FE models to develop a crack-resistant design. The project outcome was implemented by the Iowa DOT and adopted as a State of Iowa design Standard.

Investigation of the Buckling Capacity of Concrete Encased Steel H-Piles on Highway Bridge Structures

The objective of this project is to determine the capacity of partially encased piles and to develop a capacity calculation tool to include monolithic encasement options. A series of theoretical equations was developed to predict the capacities of fully- and partially encased pile bents. The theoretical equations were then packaged into a design software package. For each model, a linear buckling analysis was performed to determine the theoretical buckling strength of an ideal column (and the bifurcation point) and to provide the initial deformed shape at buckling failure. Further, the pile steel and concrete encasement were assigned nonlinear material properties to estimate the actual pile strengths. Geometric imperfections and residual stress were incorporated into the FE models. Finite-element (FE) modeling was completed with the nonlinear ANSYS modeling software coupled with MATLAB modeling software to simulate the highly nonlinear buckling behavior and predict ultimate capacities.

Evaluation of the Performance of UHPC-and HCSC-Filled Noncontact Lap Splice Closure Joint Used for Lateral Slide-in Bridge Construction

With slide-in bridge construction, the bridge superstructure is constructed off the final alignment and then slides laterally from the temporary worksite onto the in-place substructure. Once the sliding is completed, a closure joint between the bridge super- and substructure is cast to establish continuity. The goal of this project is to investigate the performance of closure joints filled by ultrahigh-performance concrete (UHPC) and hybrid composite synthetic concrete (HCSC) connected by noncontact lap-spliced rebar, with a specific focus on determining when a noncontact lap splice has sufficient strength to either open a bridge or to expose it to additional construction loading. To achieve this objective, a series of laboratory tests was performed on 96 samples, including four noncontact lap-splice connection designs with different rebar development lengths and joint filling materials. A time-dependent pullout test was performed during the first 28 days to capture the time-dependent ultimate capacity of each design. Further, analytical simulations were conducted to evaluate the joint performance. Finite-element models were created based on the tested samples and calibrated against the lab test data. Finally, a parametric study was performed on the calibrated models to investigate the effects of design parameters on the ultimate capacity.

Numerical investigation on the early age performance of ultra-high-performance concrete shear keys between adjacent prestressed concrete box beams

Recently, ultra-high-performance concrete (UHPC) was employed in the shear keys with the anticipation of preventing joint cracking. Although the field-collected data at an early age from a bridge utilizing UHPC shear keys indicated promising performance, the results only reflected the early age joint behavior at locations that were instrumented during the field test. In the current study, a 3D finite element (FE) model was developed to calculate the early age stresses due to shrinkage and temperature. The results indicated that the UHPC material associated with a specific shear key configuration created a "self-locked" phenomenon that generated compression on the upper-level shear key. The early age tensile stress during the first couple of days near the end of the joint was relatively small compared to the tensile strength of the UHPC material. Although the interface had sufficient capacity to resist the early age stresses, it is still a critical component and needs to be designed with sufficient capacity.

Evaluation of the need for longitudinal median joints in bridge decks on dual structures

People have seen extensive cracking at the end that connected to an integral abutment. In this project, Dr. Liu investigated the need for using longitudinal expansion joints, a common practice in the construction of dual-direction bridges. Dr. Liu evaluated the bridge superstructure's long-term behavior and the relationship between bridge width and deck cracking through a live-load test and a field monitoring program lasting more than 2 years on an integral abutment bridge. Dr. Liu also developed a 3D full-scale finite element model to illustrate that longitudinal deck joints do not reduce deck-end cracks and that cracking in the vicinity region is a result of long-term temperature differences between the abutment and deck. This work is significant because it reveals that longitudinal joints do not actually reduce cracking in the deck and, in fact, often cause cracks and eventually lead to the deterioration of the bridge superstructures. The findings from this project resulted in an approach to build a wide bridge with no concerns of deck cracking. The results eventually reduced bridge maintenance costs by limiting the deterioration rate and increasing the service life of the integral abutment bridge. With these results and our help, the bridge owner was able to design and construct a very wide bridge, about 240 ft wide, near Cedar Rapids, Iowa.

Selected Structural Health Monitoring Projects

Estimation of the Moment Capacity during Bridge Service Life for Structural Health Monitoring System

The load rating factor is a measurement used to describe the load-carrying capacity of a bridge, issue permits to heavy trucks, and determine load postings on bridges. In the current load rating factor calculation approach, the nominal moment capacity (Mn) is usually calculated utilizing the nominal section dimensions and material properties of the bridge and might not represent the actual capacity of the bridge or its elements. In this work, the rating factor calculation process is further improved by estimating an improved flexural strength for concrete slab on steel girder composite sections. To achieve the objective, a hypothesis to estimate the moment capacity is proposed. To validate the hypothesis, an experimental program was conducted on four steel–concrete composite sections to obtain the moment of inertia of each section and the flexural strength. The experimental results show that the moment of inertia and the flexural strength of a steel–concrete composite section calculated based on nominal material properties are significantly different from the actual moment of inertia and the flexural strength of the section. In the absence of actual material properties, a Monte Carlo simulation along with Iexp from the calibrated load rating model may significantly improve the rating factor of a bridge.

Investigation of the Pier Response during the Lateral Slide of Multi-Span Bridges

The objective of this project was to develop durable design details to be used with the lateral slide concept, with a focus on pier connection details, and to evaluate the performance of the bridge pier during sliding. To achieve the goal, relevant information was collected and evaluated by conducting a literature review on various details and construction approaches for previously completed lateral slide projects. Further, a three-span, 300 ft long steel girder bridge on IA 1 southwest of Iowa City, Iowa, U.S., was.

Evaluation of the Earth Pressure Acting on Concrete Box Culverts

The objective of this project is to monitor and evaluate the real earth pressures acting on deep-buried culvert structures. To achieve this objective, two concrete box culverts–one in Ida County and the other in Crawford County–were monitored for more than 2.5 years and 1 year, respectively, to identify the realistic design soil pressure. The captured pressure, strain, and temperature data were analyzed to find the relation between the temperature and earth pressure experienced by the culverts. The measured vertical and lateral pressures were compared with the specified design pressure loading. The monitoring results from both culverts led to the consistent conclusion that the earth pressure experienced by the culverts was two to six times that of the design values with the LRFD and LFD/ASD methods. This paper revealed that the earth pressure acting on the deeply embedded culvert could be higher than the design-specified value.

Evaluation of Galvanized and Painted-Galvanized Steel Piling

This project aims to evaluate the efficiency of a galvanized and painted galvanized steel bridge pile for achieving a 100-year service life and to economically compare them for using piles without a coating. To meet this objective, 21 steel coupon samples and nine 30 cm pile samples with galvanized coating, painted-galvanized coating, and no coating were tested in a cyclic corrosion test chamber to investigate the efficiency of each coating. The test was conducted for 600 days, simulating a 100-year service life. Results from the experimental test revealed that galvanized and painted-galvanized coating methods show remarkable performance in protecting the piles against corrosion, and both methods can protect the piles from corrosion for 100 years. Further evaluation showed that, while the cost to increase the pile size was determined to be less than the premium for galvanizing or galvanizing and painting the piles for the bridge in this study, a cost–benefit evaluation for each protection measure is suggested, knowing that costs can vary widely depending on specific project requirements, location, market prices, etc.

Evaluation of the performance of expanded polystyrene block on the reduction of the deck cracking in a wide integral abutment bridge

The primary objective of this project is to investigate the effectiveness of an isolation foam block at the back of an integral abutment in reducing the stress-induced strain and the deck end longitudinal and diagonal cracking near the end of the deck with an integral abutment. To achieve this objective, a highway bridge designed with a width of 228 ft, was selected and equipped with thermal isolation pads behind the abutment. The newly constructed bridge was monitored for over two years, and this was followed by multiple bridge inspections. An analytical simulation was conducted to investigate the efficiency of the isolation foam on the bridge deck end structural behavior.

Concrete bridge deck overlay assessment using ultrasonic tomography

One Ultrasonic Tomography Device (UTD), called MIRA, which implements this technology was deployed on a bridge deck to explore its capabilities with respect to assessing the internal condition of a deck with an existing overlay present. To achieve this objective, a 65-year-old bridge deck was selected for the ultrasound evaluation. Five locations with various overlay and deck conditions were scanned. The results indicated that when the overlay and the concrete deck are in good condition, the UTD could effectively detect the location and size of the top layer rebar and the deck thickness.

Evaluation, Laboratory Testing, Construction Documentation, and Field Testing/Monitoring of the US 52 Overflow Bridge over the Mississippi River

The objectives of this project were to validate design assumptions and evaluate the performance of the structural components and construction approaches provided in the design documents for a pretensioned, prestressed concrete beam-supported partial-depth precast deck system with cantilever precast overhang panels. To achieve the objectives, laboratory tests were conducted on two small-scale specimens with horizontal loading on the barrier and vertical loading at various locations of the deck panels. The deck of each specimen generally consisted of two precast, cantilever overhangs, two precast, prestressed interior panels, and a portion of the cast-in-place (CIP) concrete deck. The load test results indicated that both types of interior panels have an ultimate load capacity of about 240 to 250 kips when subjected to a point load causing punching shear failure, exceeding the demands of the bridge service life. The composite action between the CIP and precast deck concrete is functional through the load application process, and no debonding or sliding was found at the horizontal interface between the CIP and precast concrete.

Selected General Bridge Engineering Projects

Investigation of the Causes of Transverse Bridge Deck Cracking

The goal of this project was to identify factors that consistently lead to the formation of early-age transverse cracks for mitigation in the future. The primary investigation was conducted in three stages with varying numbers of bridges and factors considered in each stage. The first stage was carried out on 2,675 bridges constructed in Iowa between 1900 and 2020. The goal of this stage was to identify the correlation between deck cracking and six parameters: deck concrete type, maximum span length, maximum structure length, year built, and main structure type. The second stage was conducted to include additional bridge parameters—but with a smaller number of bridges. A group of 20 bridges was selected after reviewing inspection reports for 116 bridges constructed between 2013 and 2018. Various bridge parameters in three main categories, structural, construction, and material, were investigated. The third stage was carried out based on data collected from six field visits while deck concrete was being placed. The parameters investigated in this stage included evaporation rate (lb/ft2/h), air temperature (°F), concrete temperature (°F), relative humidity (%), and wind speed (mph).

Qualitative relationship between increased legal loads and reduced bridge service life

State and federal legislators regularly request that axle or gross weight limits for commercial vehicles be increased. The objective of this project is to quantify the relationship between increasing legal loads and reduced bridge service life (and increased cost) for Iowa bridges and to provide a method to calculate expected bridge life reduction. To achieve the goal, Dr. Liu conducted more than 20 bridge tests with the goal of collecting the Iowa-specific in-service bridge performance data to understand the bridge structural response subject to cyclic truck loading and to gather bridge data that will be used in the subsequent tasks to estimate system-wide bridge behaviors. In addition, Dr. Liu collected Vehicle miles traveled (VMT) and Weigh-in-motion (WIM) data to predict changes in the Truck weight histogram (TWH) and Wheel weight histogram (WWH) when the load limits increase. Because this information is important to qualify the effect of the vehicle weight limit changes. Eventually, Dr. Liu ran a multiple-complex analysis related to bridge girder fatigue, load rating changes, and changes in bridge deck fatigue life to estimate bridge life reductions and bridge costs due to increased truck weight limitations.

NCHRP: Roadmap to Update Bridge Deck Design Requirements

Section 9 of the American Association of State Highway and Transportation Officials (AASHTO) *LRFD Bridge Design Specifications (BDS)* provides designers with requirements for the analysis and design of various bridge decks and deck systems for multiple types of bridges. The objective of this project is to develop a roadmap for the AASHTO Committee on Bridges and Structures Executive Committee to update the bridge deck and deck systems design and analysis requirements in Section 9 of the American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Design Specifications (BDS). To achieve this goal, this project identifies contents that are unclear, incorrect, outdated, or missing in Section 9 of the AASHTO LRFD BDS, conflicts with other AASHTO LRFD BDS requirements, other deck systems that have matured and should be added to the specifications, research that has been completed and should be considered for adoption, and additional research needs to address the issues identified above.

Advances in State Bridge Load Rating Processes and Practices: A Summary Report of 2024 Bridge Load Rating Peer Exchanges

In this project, Dr. Liu developed a framework for an improved bridge load rating process as part of a project sponsored by the Federal Highway Administration. Bridge load rating is a procedure in which structural engineers assess the structural pieces of a bridge to determine whether they are adequate for carrying a significant amount of weight from both car traffic and trucks. We developed a framework to standardize bridge load rating practices and to incorporate new technologies, such as digital asset maintenance and digital twins, into a fully integrated, centralized, continuously updated database. The framework also enables continuous monitoring of bridges, supporting bridge engineers in their decision-making and planning for rehabilitation and construction.

Evaluation of the Use of IRI Data to Estimate Bridge Dynamic Impact Factor (DIF)

The objectives of this project were to correlate international roughness index (IRI) data (which are widely collected and directly related to bridge deck roughness) to impact factors and develop a process for determining the impact factor to use for all bridges. To achieve the project objectives, a sample of 20 bridges was selected for bridge monitoring to collect dynamic strain data. To estimate the static strain data, the locally weighted scatterplot smoothing (LOWESS) function was used to smooth the dynamic strain time history. The dynamic impact factor (DIF) value was then calculated using maximum dynamic and static strain data. IRI data were extracted from PathWeb, a web-based application provided by the Iowa Department of Transportation (DOT) for all bridges considered in the field test program. Once the bridge was identified in PathWeb, the IRI data from four locations near each bridge deck approach were extracted and used to study the relationship between the IRI and DIF. According to the project findings, an equation was developed for the prediction of DIF on existing bridges with consideration of the bridge skew and the maximum IRI value near the bridge deck approach.

Selected Timber Engineering Projects

Evaluation of the load distribution of the timber slab bridge and the efficiency of the retrofit methods

The objective of this project is to evaluate the load distribution for timber slab bridges and the efficiency of the retrofit methods. To achieve this objective, ten timber slab bridges were identified for a program of bridge live load tests. Three of them were tested twice, once before and once after bridge strengthening measures were employed. The data collected from the field test program was utilized to calculate the equivalent strip width (ESW), and the results were compared with the codified values. In addition, a series of finite element (FE) models was created based on these ten field-tested bridges and validated against the field-collected data. The validated FE models were utilized for a parametric study to evaluate the wheel load distribution and the performance of various retrofit methods on the bridges with different truck loading, bridge geometry, and retrofit approaches. Based on the results from the field tests and analytical simulation, an equation to predict the equivalent strip width for the timber slab bridges was developed with consideration of numerous variables.

Investigation of cross-laminated (CLT) decks for bridge applications in the USA

Cross-Laminated Timber (CLT) panels have been primarily developed for the building industry. The use of CLT in bridge structures has been limited, and the adoption of CLT into governing bridge design codes has been slow-going in North America. The objective of this project was to investigate the feasibility of CLT as a primary structural material for highway bridge deck applications. To achieve the objective, two CLT interconnected deck panel configurations were investigated in the laboratory for their structural performance characteristics under simulated wheel loads. Configurations consisted of longitudinal deck panels that span the abutments and transverse deck panels supported by simply-supported longitudinal girders.

Selected Ancillary Transportation Structures Projects

Determination of U-bolt connection load capacities in overhead sign support structures

The load capacities of U-bolt connections used on highway steel overhead sign trusses (SOST) are not known because they are used in ways that do not match available manufacturer data. Although these U-bolt connections have appeared to perform satisfactorily in the past, in recent years, there has been a growing safety concern due to the need for overhead sign trusses to support larger signs over greater spans. In this project, Dr. Liu conducted a 1-year field monitoring program to investigate the structural behavior of the currently used SOST structures under ambient wind loading. The goal of this work is to determine the loading experienced by an on-site SOST structure, namely the wind pressure and wind direction. In addition, the data collected during the field monitoring will be used to validate the FE model. Then, Dr. Liu developed a full-scale FE model based on the design of the field-monitored SOST structures with highly geometric nonlinearity, utilizing mainly beam elements for the truss members and shell elements for the signs, and using beam/spring elements at the U-bolt connection to allow for load transfer in a certain direction and contact elements for plate-to-plate connections. The model will be loaded with wind pressure calculated from the wind speed/direction data, and then validated using field-collected strain data. Once the model is validated, the internal forces/moments in the beam/spring elements used to simulate the U-bolt connections will be output. We also conducted extensive static and fatigue laboratory tests to directly measure capacities in different loading directions and to compare the results with our analytical simulation results.

Re-Tightening the Large Anchor Bolts of Support Structures for Signs and Luminaires: Phase II

This project mitigates anchor bolt connection loosening and develops improved pre-tensioning steps for its sign, luminaire, and traffic signal (SLTS) structures. The Phase I study proposed new pre-tensioning procedures, completed laboratory testing, did an in-depth literature review, and set up instrumentation. The next part of the work started by implementing the proposed procedures in the field and suggesting revisions to be investigated further in Phase II. Through this work, the structural monitoring objective was to better understand field fatigue forces on the anchor rods and develop a testing procedure to replicate field stresses accurately in the laboratory. In the Phase II project, lessons learned from both the field results and additional literature review were tested in the laboratory to balance the efficiency and efficacy of the revised pre-tensioning procedures. Feedback from stakeholders and experience from in-field inspections were considered for the revised procedures. Testing methods and conclusions were validated with finite element models and structural health monitoring.

Publications

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"Evaluation of Galvanized and Painted-Galvanized Steel Piling,", Seyedamin Mousavi, Justin Dahlberg, Brent M. Phares, **Zhengyu Liu,** Journal of Materials in Civil Engineering 36, no. 3: 04023594, 2024.

"Evaluation of the Earth Pressure Acting on Concrete Box Culverts," Tristan Sanderson, Brent M. Phares, Katelyn S. Freeseman, **Zhengyu Liu**, Transportation Research Record 2678, no.6: 558-57, 2024.

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