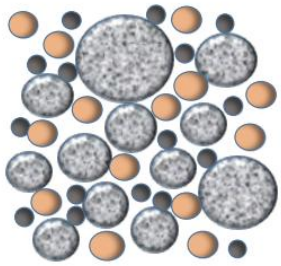
NDOT Research

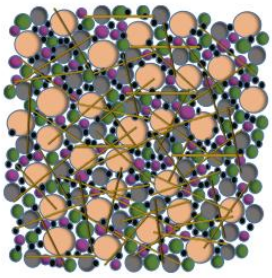
NEBRASKA
DEPARTMENT OF TRANSPORTATION

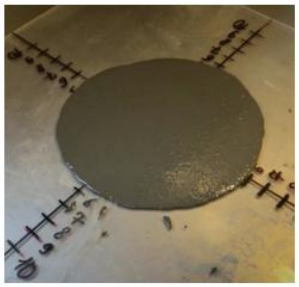
U.S. Department of Transportation
Federal Highway Administration

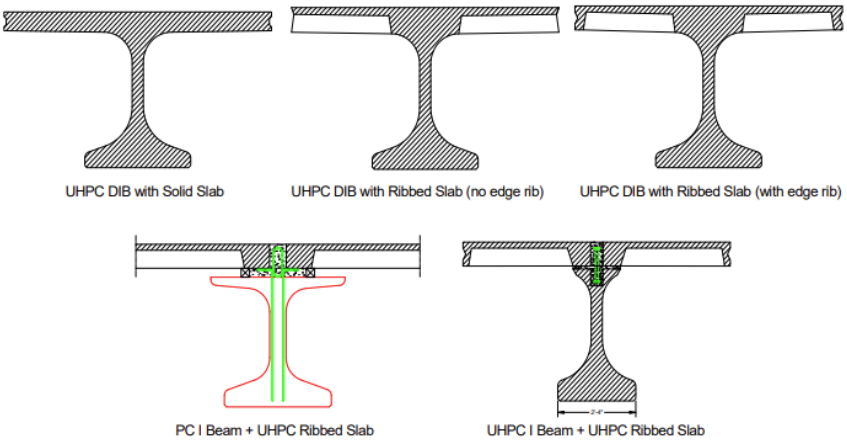
Development and Implementation of Ultra-High-Performance Concrete for Bridges in Nebraska

2017 – Present









Research Report

Technology Transfer

Research Readiness Level

The Research Readiness Level (RRL) Assessment provides a numerical assessment of the readiness of research to be implemented into standard practice. Through the RRL Assessment, the NDOT identifies the next steps for completed research, to best support the development and implementation of the results and practices discovered.

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Background

Ultra-High-Performance Concrete (UHPC) is a next-generation material known for its exceptional workability, mechanical performance, and durability. These advanced properties are achieved through a dense internal matrix, fiber reinforcement, and a low water-to-binder (w/b) ratio. As a result, UHPC provides significant improvements in structural capacity and lifespan, particularly in bridge construction, drawing growing attention from federal and state transportation agencies.

Federal Support and National Momentum

The Federal Highway Administration (FHWA) has been actively supporting UHPC development for over two decades, publishing research, technical notes, and design recommendations for use by state Departments of Transportation (DOTs). UHPC has gained increasing national attention due to its proven performance, particularly in critical structural applications.

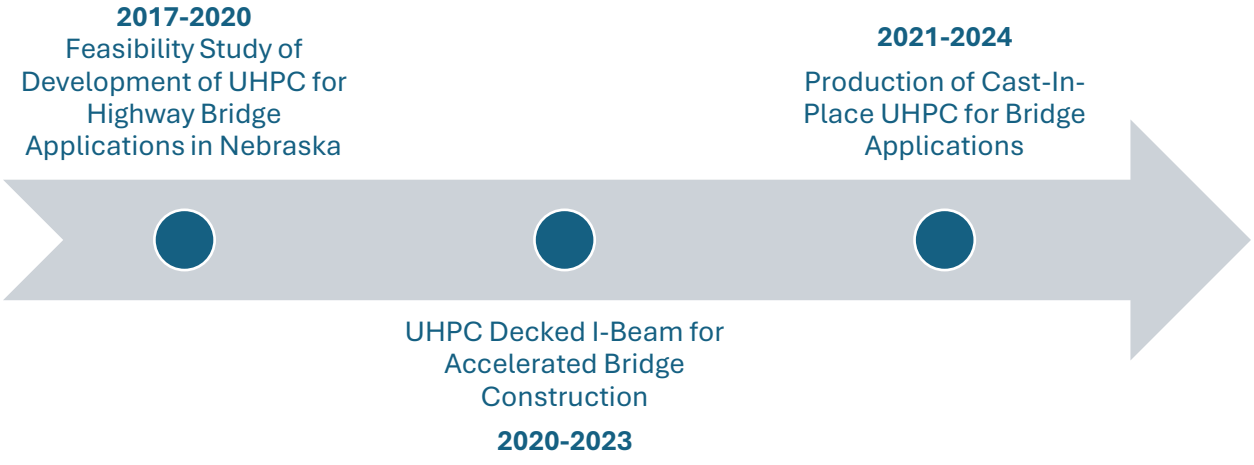
The Every Day Counts (EDC) initiative, spearheaded by FHWA to accelerate innovation in transportation infrastructure, has featured UHPC prominently: EDC-4 (2017–2018): Emphasized UHPC in joints and connections and EDC-6 (2021–2022): Focused on UHPC for repair and preservation.

Industry standards have also begun to formalize around UHPC:
In 2022, the Precast/Prestressed Concrete Institute (PCI) published guidelines for UHPC use in precast and prestressed concrete.
In 2024, the American Association of State Highway and Transportation Officials (AASHTO) released the first Guide Specifications for Structural Design with UHPC and is currently developing material conformance testing guidelines for UHPC qualification and acceptance.

Nebraska Department of Transportation (NDOT) and UHPC

Recognizing UHPC's potential, the Nebraska Department of Transportation (NDOT) has engaged in ongoing research to explore its application in local infrastructure. NDOT's work began with the development of a non-proprietary UHPC blend using locally available Nebraska materials. This approach not only reduces cost but supports material availability and local economies.

Timeline of NDOT Research in Ultra-High-Performance Concrete



Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Feasibility Study of Development of UHPC for Highway Bridge Applications in NE (2017-2020)

Research Objectives

Evaluate the feasibility of developing an economical non-proprietary UHPC mix with locally available materials for possible use in different bridge applications in Nebraska. The focus of this study was on UHPC developed for connecting precast superstructure components (e.g. deck panels and decked girders).

Research Benefits

1. Will develop non-proprietary UHPC mixes using local materials that will be significantly cheaper than proprietary mixes.
2. Gain improvements in structural capacity and durability of highway bridges.
3. Answer concerns about UHPC to ensure a successful use of materials in NDOT bridge development.

Principal Investigators

Jiong Hu (P.I.)
George Morcous (Co-P.I.)
University of Nebraska

NDOT Lead TAC Member

Fouad Jaber, PE, Assistant State Bridge Engineer
Wally Heyen, PE, PCC Engineer

Report Available Here

Background

Ultra-high-performance concrete (UHPC) is a new class of concrete that has mechanical and durability properties that far exceed those of conventional concrete. The use of UHPC will result in significant improvements in the structural capacity and durability of bridge components. However, because of the highly sophisticated mixture design and raw material availability, the current use of UHPC in the U.S. is limited to proprietary pre-packed products provided by international suppliers. The high material cost associated with these products, which can be as high as $2,000 per cubic yard in additional to batching, placing, and curing costs, has greatly prevented the wide use of UHPC in bridge applications. Therefore, there is an urgent need to develop economical non-proprietary UHPC mix(es) with materials readily available in Nebraska.

Conclusion

Multiple series of UHPC mixtures were investigated with different types and quantities of aggregate, fibers, cement, supplemental cementitious materials (SCMs), high range water reducer (HRWR), w/b, total binder content, and mixers. Mix design with type I/II cement, 8% of silica fume (by mass of binder), and 30% of slag (by mass of binder) is recommended. The developed mix exhibits sufficient flowability and stability to ensure the successful implementation in bridge components and connections. A comprehensive evaluation of mechanical properties demonstrated that the mix exhibits excellent mechanical properties, including compressive strength, modulus of elasticity, Poisson's ratio, flexural strength, splitting tensile strength, direct shear strength, slant shear strength, and bond strength. The developed mix also exhibits excellent durability properties, including mass loss of less than 1% based on freezing/thawing resistance test, very low chloride ion penetration based on surface resistivity test, and no cracking based on restrained shrinkage test. The unit cost of the developed mix is approximately $682 per cubic yard, which is approximately one-third of the current commercial products. The batching, handling, placing, and curing of the developed mix was demonstrated in a field-scale panel connection casting, which resulted in a satisfactory performance.

NDOT Recommendations Based Off Research Project – 2020 – RRL3

Having completed the research for Nebraska UHPC mix design, this is the first step in a series of steps to make UHPC available in Nebraska. Not just any Ready-Mix plant can mix UHPC— it takes special equipment and materials for the mix design. Because of this, contractors will need to practice mixing UHPC. The NDOT is working with the AGC to help contractors get the necessary experience to mix UHPC, after which the NDOT will specify projects using UHPC for precast bridge decks. NDOT is working towards is using UHPC for precast girders and bridge decks, such as the UHPC Decked I-Beam for Accelerated Bridge Construction research project, which began in July 2020.

- *As provided by Fouad Jaber, TAC Lead Member*

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

UHPC Decked I-Beam for Accelerated Bridge Construction (2020-2023)

Research Objectives

The project will develop a UHPC superstructure system for bridges optimized for structural efficiency, constructability, and economy. This project will review and evaluate previous highway bridges built using various UHPC superstructures to meet NDOT's needs. The research team will work with NDOT bridge engineers and local bridge producers and contractors to conduct materials testing, structural testing, and framework design.

Research Benefits

1. Implement a UHPC superstructure system, allowing for saving construction time of deck forming, reinforcing, cast, and curing.
2. Enhance construction safety and minimize traffic disruptions.
3. Supplement the research teams efforts on a PCI funded research project on the nationwide use of UHPC.

Principal Investigators

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NDOT Lead TAC Member

Fouad Jaber, PE, Assistant State Bridge Engineer

Report Available Here

Background

Several Departments of Transportations (DOTs), including NDOT, have limited the use of UHPC in bridge construction to joints and connections between bridge components due to the relatively high materials cost of commercially UHPC products. Recently, NDOT has sponsored a research project to develop a non-proprietary UHPC using local materials to reduce materials cost and ensure its availability to local contractors and precast producers. The project was completed successfully and an economical UHPC mix that satisfied all workability, durability, and strength requirements was developed and tested. The cost of the raw materials for this mix was about $700 per cubic yards which is about 30 percent of the cost of pre-bagged commercial UHPC materials. Therefore, it is economically feasible currently to expand the use of UHPC to bridge components, such as deck slabs and girders, to have a service life of over 150 years. Some researchers (Voo and Foster 2010) estimate the theoretical service life to be about 340 years. Its use will clearly minimize bridge maintenance costs and traffic disruptions.

Conclusion

Ultra-High-Performance Concrete (UHPC) is an excellent material for bridge construction due to its exceptional durability and superior mechanical properties. Several Departments of Transportations (DOTs), including NDOT, have limited the use of UHPC in bridge construction to joints and connections between bridge components due to the relatively high materials cost of commercially UHPC products. Recently, NDOT has sponsored a research project to develop a non-proprietary UHPC using local materials to reduce materials cost and ensure its availability to local contractors and precast producers. The project was completed successfully and an economical UHPC mix that satisfied all workability, durability, and strength requirements was developed and tested. Therefore, it is economically feasible to expand the use of UHPC to bridge superstructure components that can have a service life of over 150 years. The objective of this project is to develop a UHPC superstructure system for bridges in Nebraska that is optimized with respect to structural efficiency, constructability, and economy. Several UHPC superstructure systems used in France, Korea, Malaysia, USA, and Canada including pi-girders, bulb-tee girders, tub girders, box girders, decked I-beams, and waffle slabs, were reviewed and evaluated to determine the system(s) that meet NDOT needs. A decked I-beam (DIB) section was selected due to its ease of production, constructability, and structural efficiency. Formwork design, production trials, and material/structural testing were conducted for UHPC DIB specimens with ribbed and solid slabs using pre-tensioning and post-tensioning systems. Design examples of a typical bridge using DIBs were also presented to demonstrate the implementation of the latest UHPC design specifications/guidelines.

NDOT Recommendations Based Off Research Project – 2025 – RRL3

Bridge Division is looking for the next project to use the UHPC superstructure system for bridges in Nebraska, optimized with respect to structural efficiency, constructability, and economy. The project selected will include conducting necessary materials testing, structural testing, and formwork design, and addressing issues related to girder shipping and handling, longitudinal joints, differential camber and camber growth, railing connections, cross slope/skewed bridges, and multi span continuity.

- *As provided by Fouad Jaber, TAC Lead Member*

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

Production of Cast-In-Place UHPC for Bridge Deck Applications (2021-2024)

Research Objectives

1. Provide technical training for producers, contractors, and NDOT engineers required for batching, mixing, transporting, placing, and testing cast-in-place UHPC.
2. Develop guidelines for UHPC production and controlling and maintaining the workability of UHPC production in on-site conditions.
3. Develop special provisions for cast-in-place UHPC production and quality control.

Research Benefits

1. Address the challenges associated with UHPC production and on-site construction.
2. Provide the necessary knowledge and technical support for UHPC production and construction.

Principal Investigators

Jiong Hu (P.I.)
George Morcous (Co-P.I.)
University of Nebraska

NDOT Lead TAC Member

Fouad Jaber, PE, Assistant Bridge Engineer
Wally Heyen, PE, PCC Engineer

Report Available Here

Background

Recently, the research team has successfully completed a project on the development of a non-proprietary UHPC using local materials which is an economical alternative to commercial UHPC. However, the two challenges that still exist and prevent its use in cast-in-place applications are the lack of training and experience in batching and handling UHPC; and the lack of guidelines to control and maintain the workability during construction.

Conclusion

This project presents a comprehensive overview of the essential aspects associated with the cast-in-place application of UHPC, including formwork requirements, surface preparation, mixing procedures, placing methods, curing techniques, grinding specifications, and mockup construction. Each section provides in-depth insights into specific guidelines and practices outlined by various regulatory bodies. The research team has developed training materials designed for a full-day workshop tailored to benefit both contractors and NDOT engineers. This workshop comprises key topics such as proportioning, batching, testing, and the placement of both non-proprietary and proprietary UHPC mixes, as well as hands-on experience in batching, testing, and placing UHPC. The study investigating fresh and hardened UHPC tests to identify fiber segregation reveals that excessive water or the use of high-range water-reducing admixtures (HRWR) can lead to fiber segregation, which is observable in both fresh and hardened states. Techniques such as Visual Stability Index (VSI) and Hardened Visual Stability Index (HVSI) are somewhat subjective, while tests like the mini-V-funnel and falling ball tests provide more objective measures. Flow time shows promise as an indicator of fiber stability, but further research and data are required to establish Quality Assurance/Quality Control (QA/QC) ranges. The study also underscores the potential of surface resistivity testing and calls for more extensive research to refine these tests for practical application in construction. The experimental work explores the influence of shrinkage-reducing admixtures (SRA) and shrinkage-compensating admixtures (SCA) on UHPC. Optimal SRA dosage effectively mitigates both total and autogenous shrinkage of UHPC, with total shrinkage decreasing from 817με to 539με and autogenous shrinkage dropping from 691με to 437με. The effectiveness of SCA varies, and its impact on shrinkage is significant under specific hot batch curing conditions, although such methods may not be feasible for all concrete applications. The report also included a draft of the special provision for cast-in-place (CIP) UHPC.

NDOT Recommendations Based Off Research Project – 2025 – RRL3

Bridge Division is looking for the next project to use the UHPC decked I-beams for the construction in Nebraska. The selected project will include conducting necessary QA procedures during beam production to confirm that the material used and girder fabricated meet the specified design criteria. The project will provide detailed and comprehensive documentation of the production procedures and challenges as well as lessons learned for possible improvements in future NDOT projects.

- *As provided by Fouad Jaber, TAC Lead Member*

Executive Summary, Research Readiness Level Assessment, and Technology Transfer

NDOT Recommendations Based Off Research Project – 2025

Bridge Division let a bridge project using the UHPC decked I-beam and the non-proprietary mixture in May of 2024. The project was awarded, and a precast concrete producer had signed on to produce the girders. Due to unforeseen circumstances, this producer went out of business and could not produce the UHPC superstructure. To limit delays to the traveling public, the bridge project had to pivot to conventional construction. Therefore, Bridge Division is still evaluating where this system could be used in the State. Upcoming initiatives will represent the culmination and practical implementation of this multi-phase research series focused on UHPC applications for bridge construction in the state. Future research projects will be needed to oversee the construction of Nebraska's first bridge utilizing the non-proprietary UHPC mix design developed in the initial phase.

- *As provided by Emilie Hudon, TAC Lead Member*

Research Readiness Level (RRL) Assessment

Level 3: Development Field Level, Follow up in 4 years.

RRL 3

Technology Transfers

Transportation Research Board (TRB) papers and Publications

- F. Mendonca, J. Hu, G. Morcous, "Fresh and Hardened Behavior of Ultra High-Performance Concrete (UHPC) with Different Mixtures Design Parameters", Proceeding of the Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019. https://www.extension.iastate.edu/registration/events/2019UHPCPapers/UHPC_ID96.pdf
- Aitbayeva, A., Morcous, G., & Hu, J. (2023, June). Development of On-Site Test Methods to Evaluate Fiber Stability in UHPC. In International Interactive Symposium on Ultra-High-Performance Concrete (Vol. 3, No. 1).

Webinars/Presentations

- F. Mendonca, J. Hu, G. Morcous, "Fresh and Hardened Behavior of Ultra High-Performance Concrete (UHPC) with Different Mixtures Design Parameters", Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019.
- M.A. El-Khier, G. Morcous, J. Hu, "Interface Shear Resistance of Ultra-High-Performance Concrete (UHPC)", Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019.
- Mendonca, F., Hu, J., and Morcous, G. (2019) "Fresh And Hardened Behavior Of UHPC Prepared With Different Mix Design Parameters and Mixers", 2nd International Interactive Symposium on UHPC, Albany, NY, June 2-5.
- Morcous, Maguire, M., Tadros, M. K., "High performance materials in concrete bridge construction", Proceedings of the 2019 GeoMEast International Congress and Exhibition, "Recent Research in Sustainable Infrastructure", Springer.
- AboElkhier, M., Morcous, G., and Hu, J. (2019) "Interface Shear Resistance of Ultra High-Performance Concrete (UHPC)", 2nd International Interactive Symposium on UHPC, Albany, NY, June 2-5.
- Hu, J., Aitbayeva, A., & Morcous, G. (2024). UHPC Workability for Successful Construction. ACI 2024 Fall Convention, Philadelphia, PA, November 3-6, 2024.