Material Redundancy for Enhancing the Resistance to Collapse of the Florida International University (FIU) Bridge

Xiao Tan [1], Weina Meng [1], Yi Bao [1,], Hani Nassif [2], Victor C. Li [3]*

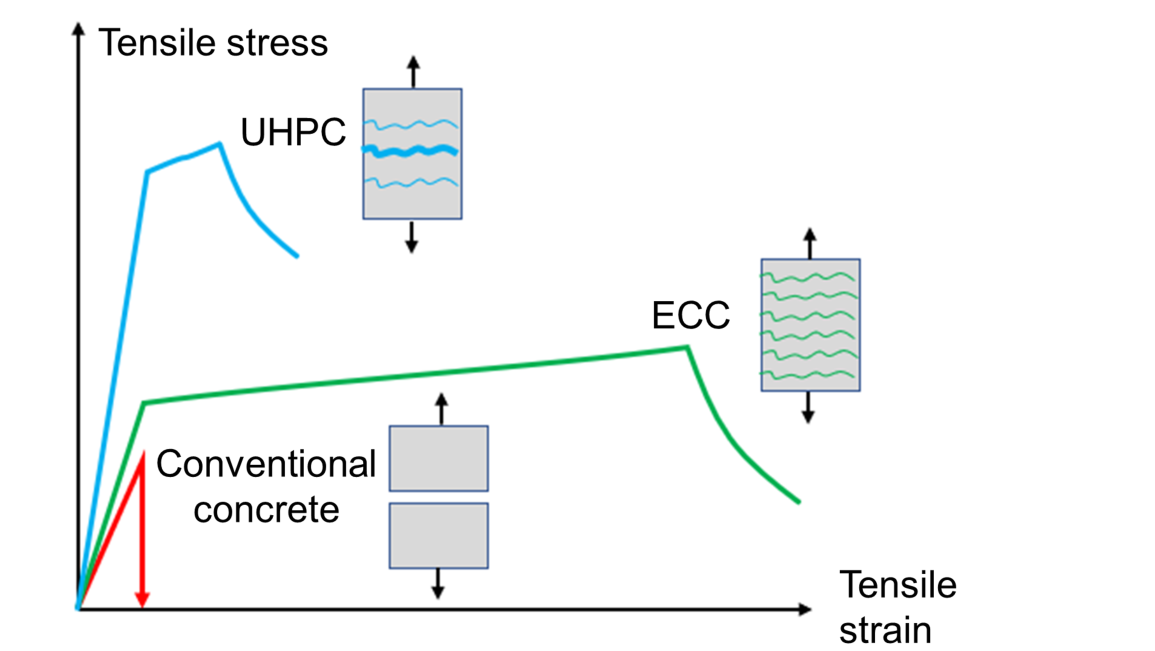
1. Department of Civil, Environmental & Ocean Engineering, Stevens Institute of Technology

2. Department of Civil and Environmental Engineering, Rutgers University

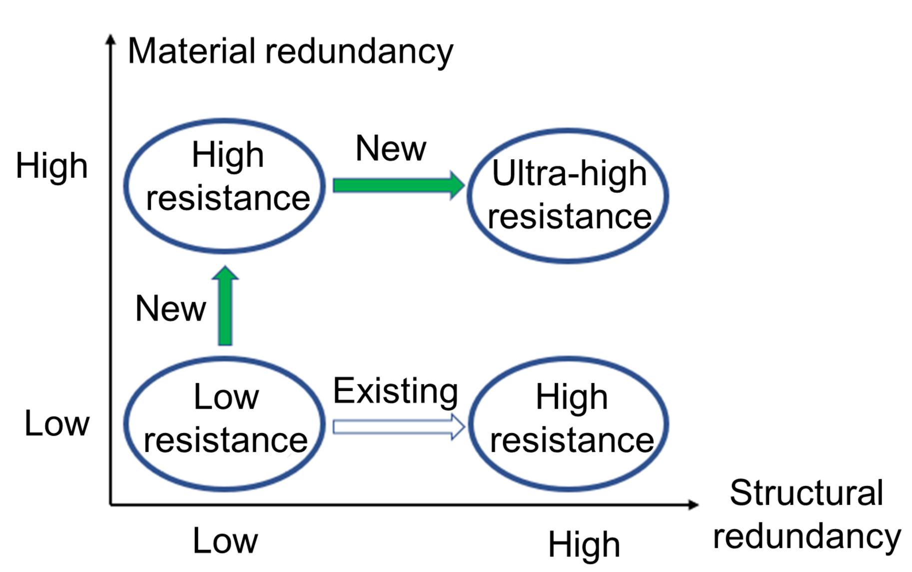
3. Department of Civil and Environmental Engineering, The University of Michigan - Ann Arbor

Goal and Objectives

- **The overall goal:**
  - Present a new concept – material redundancy, which provides a new pathway to improve resiliency of structures. The material redundancy pathway is expected to supplement the current structural redundancy pathway, and the combination of the material and structural pathways is expected to achieve multi-scale redundancy and significantly improve the resiliency. This study is expected to provide a new paradigm for improving the safety and resilience of bridges.



Comparison of UHPC and ECC against conventional concrete in tension

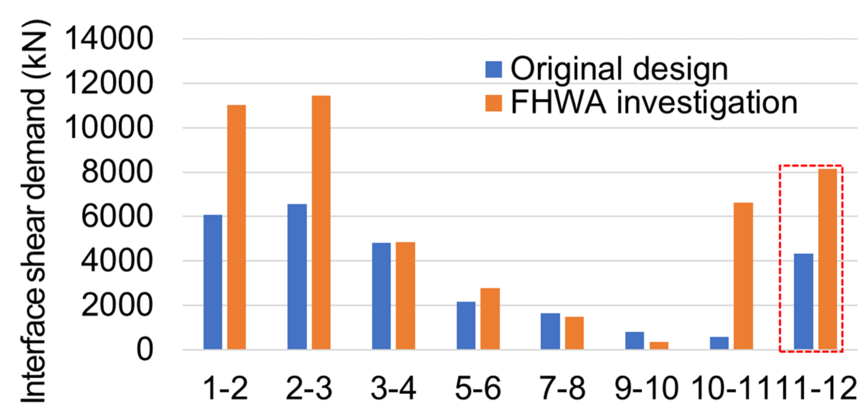


A new pathway to achieve redundancy

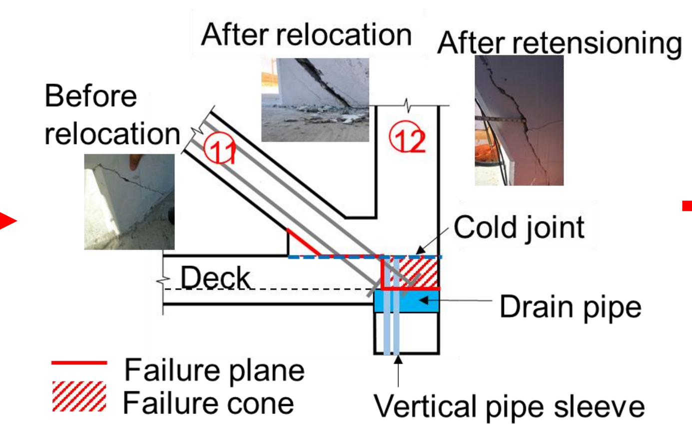
- **The main objectives:**
  - Demonstrate the presented pathway and evaluate the performance of the new pathway on the mechanical properties and safety of the bridge in Miami.
  - Investigates the effect of using UHPC and ECC in the bridge, respectively, through a finite element analysis.
  - A parametric study is conducted to understand the effect of tensile behaviors of ECC and UHPC on the redundancy and damage of the bridge.

Investigation of Bridge Collapse

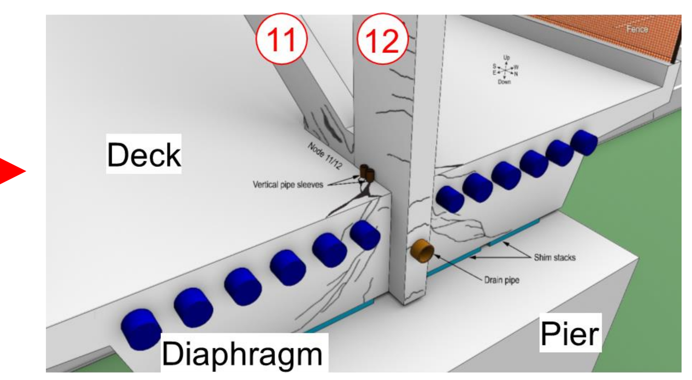
- **Failure of the bridge closely related to the tensile damage in member 11 and its nodal regions**



Shear force demands in the original design and Federal Highway Administration (FHWA)



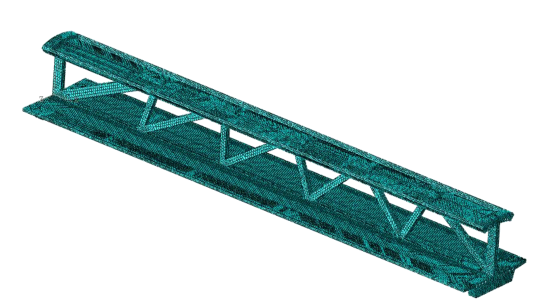
Failure mechanism of nodal region 11-12



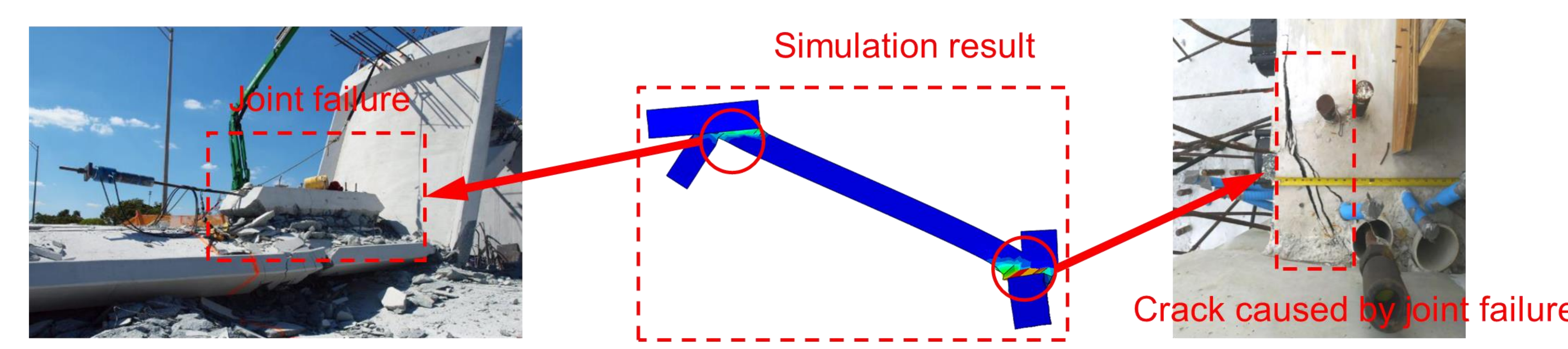
Cracking at nodal region 11-12

Finite element model

- **Validation of Finite element model**



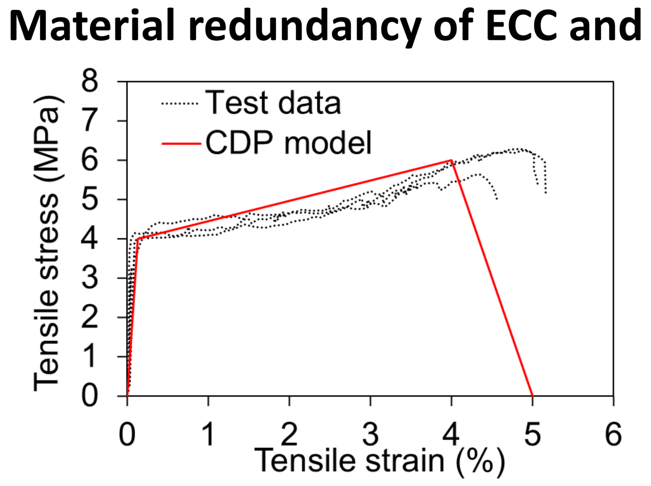
Finite element model of the bridge



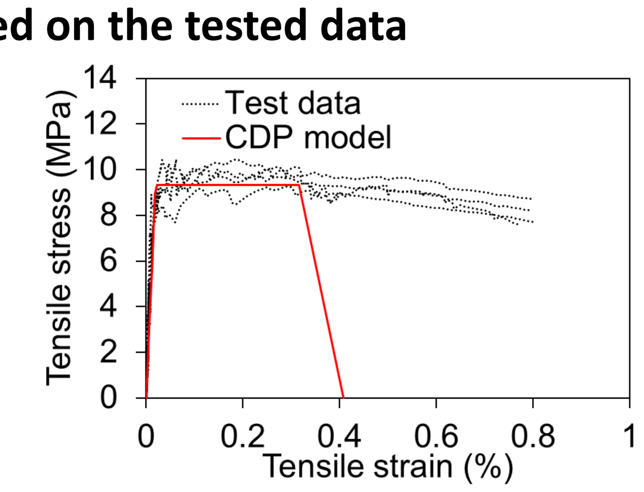
Failure mode of the bridge after the re-tensioning of member 11

Enhancing the Bridge Redundancy Using ECC or UHPC

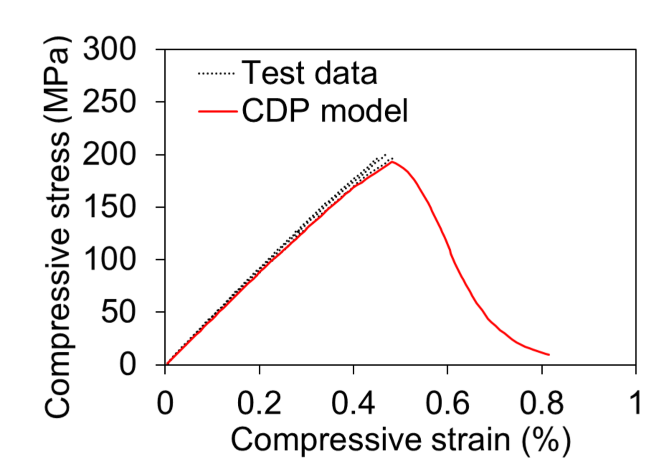
- **Material redundancy of ECC and UHPC based on the tested data**



Tensile properties of ECC

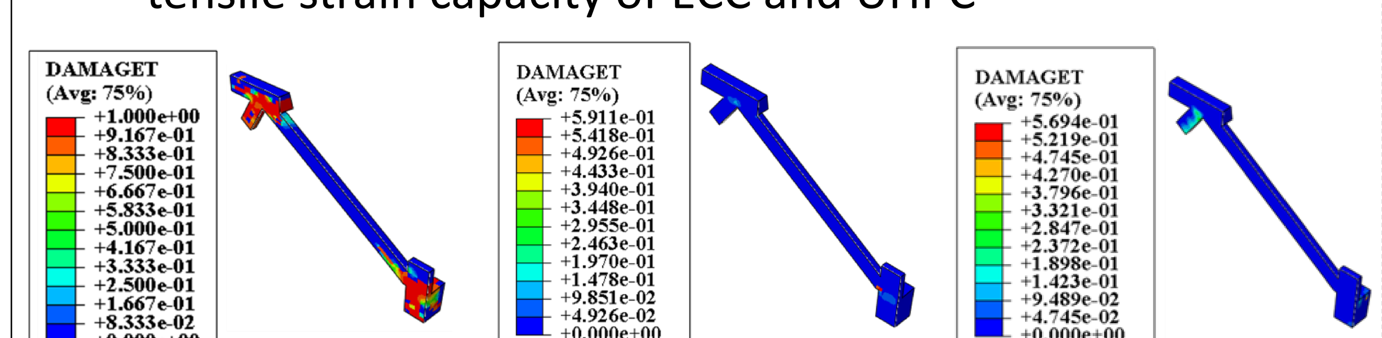


Tensile properties of UHPC



Compressive properties of UHPC

- **Material redundancy related to the tensile damage of the material, this research performs**
  - Damage initiation criterion (DAMAGET) are defined
  - Two investigated parameters: the tensile strength and tensile strain capacity of ECC and UHPC



(a) Conventional concrete (b) ECC (c) UHPC

Contour of tensile damage (DAMAGET) of member 11

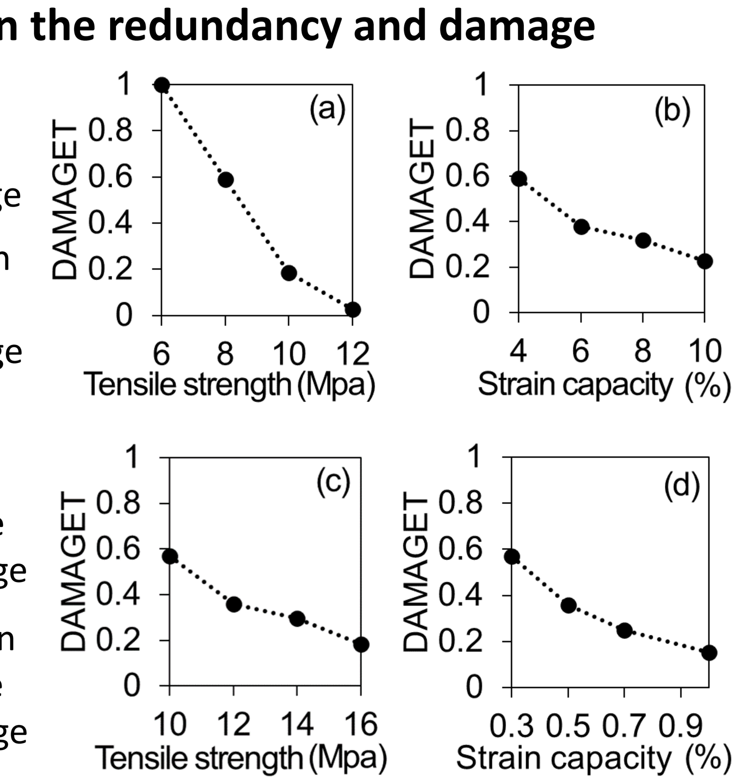
- **Parametric study of the effect of tensile behaviors of ECC and UHPC on the redundancy and damage**

(a) Effect of tensile strength of ECC on the maximum tensile damage

(b) Effect of tensile strain capacity of ECC on the maximum tensile damage

(c) Effect of tensile strength of UHPC on the maximum tensile damage

(d) Effect of tensile strain capacity of UHPC on the maximum tensile damage



Conclusions

- The presented material redundancy concept is promising to alleviate damage in structures and enhance the collapse resistance of structures under extreme conditions. With the use of the UHPC and ECC, the tensile damage level and area can be reduced from significant damage to minor damage states.
- The tensile properties of UHPC and ECC have significant effects on the damage condition of the bridge. The damage decreases with the increases of the tensile strength and strain capacity approximately until the damage index reaches about zero. The parametric study provides data to guide the design of the materials and the structures made using the ductile materials.
- The collapse of the FIU Bridge is associated with tensile damages in the concrete. For bridges controlled by tensile damage, the use of ductile materials can greatly improve the safety and resilience of the bridges. It is envisioned that the ductile materials allow the design of thinner structural elements with retained load-carrying capacity.

Further Research

- This study only considers the effects of the tensile strength and strain capacity on the tensile damage in the bridge. More parameters should be investigated in future studies, such as the first crack strengths of the UHPC and ECC mixtures, as well as the parameters that control the descending stages of the tensile stress-strain curves.
- This study only presents the feasibility of the concept in improving the collapse resistance, but it remains unclear how the use of ductile materials affects the lifecycle cost and long-term durability. It is envisioned that the use of ductile materials can reduce the lifecycle cost and improve the durability. Self-healing properties of UHPC and ECC should be considered in future studies.
- This study only considers the construction stages until the bridge collapsed. Although the use of UHPC or ECC is shown promising to avoid the collapse of the bridge, it is unclear whether collapse can occur at a latter stage of construction. The whole construction stages need to be considered in future research to gain a holistic understanding of the safety of the bridge construction.

Acknowledgments

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