Problem Statement
- Most bridge pier or bent caps qualify as deep beams.
- When analyzed using the sectional method, deep beams are found shear overloaded but shows little to no sign of cracking in field. AASTHO LRFD requires the use of either a strut-and-tie (STM) or a nonlinear finite element method (FEM) for the analysis and design of deep beams.

Research Objectives
- Determine the shear capacities of bridge piers from the nonlinear FEM.
- Rate the existing loading condition of the bridges from the nonlinear FEM.
- Capacities comparison of piers calculated from the nonlinear FEM with the strut-and-tie (STM) and sectional method.

Methodology
- The nonlinear finite element analysis of five pier caps of existing bridges in Ohio was performed using the program VecTor3.
- VecTor3 is based on Modified Compression Field Theory and incorporates advanced properties such as tension stiffening, compression softening, rebar dowel action, etc. to model realistic behavior of pier caps.
- The material models used in numerical modeling are shown below.

Comparison with Sectional Method & STM
- Shear capacity is calculated with the sectional method.
- Stresses distribution from the nonlinear FEM is compared with the strut-and-tie method (STM), based on the concept of utilization ratio.
- Nonlinear FEM shows less utilization ratio and hence higher capacities than strut-and-tie method for each member (Fig 7).
- Mode of failure and governing member matches from the nonlinear FEM & STM.

Numerical Modeling
- One-half of the cap beam is modeled.
- Beam is loaded to failure.

Numerical Response
- The cracking pattern and stress distributions were obtained from the nonlinear FEM.

Comparison of Capacities
- Load capacity from nonlinear FEM is 120% higher than sectional method (used for finding shear capacities).
- Nonlinear FEM calculates less reserve capacity in the bridge pier, whereas from sectional method it was found overloaded.

Practical Implications and Conclusions
- Nonlinear FEM models more realistic behavior of the bridge pier cap and eliminates the conservative assumptions made in the strut-and-tie method (STM) and sectional method.
- The shear capacities from the nonlinear FEM were found to be 2.5 times higher on average than sectional method and 4.5 times higher than the strut-and-tie method (STM).
- Using nonlinear FEM to evaluate existing bridge pier caps will result in higher capacity and may reduce or eliminate the need for rehabilitation, significantly saving the owner cost.

Acknowledgements
The research team thanks Ohio Department of Transportation (ODOT) for funding and supporting this research. We are grateful to Ms. Andrea Parks, P.E., Mr. Matthew Blythe, P.E., Mr. Pappu Baniya, and Ms. Michelle Lucas for their feedback and support in the research.