Strength Prediction of Deep Cap Beams Using The Finite Element Method

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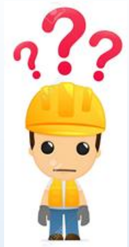
Problem Statement

- 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.

Fig.1 Existing bridge with deep cap beams.

No sign of cracking but sectional analysis found shear overloaded.

FEM ? **STM ?**



- In this study, the deep beams are analyzed using **the nonlinear FEM** and the results are compared with the **strut-and-tie method (STM)** and sectional method.

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.

Numerical Modeling

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

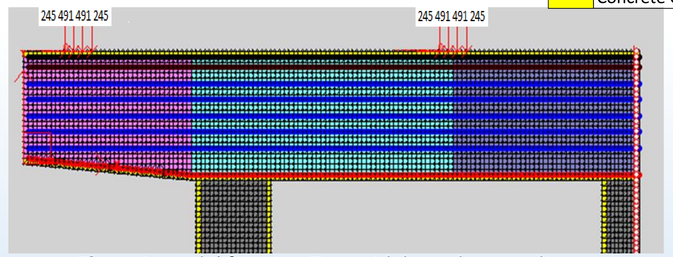


Fig.3 2D model from VecTor2 with boundary conditions and factored loading.

Numerical Response

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

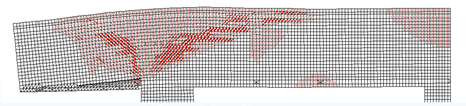


Fig.4 Cracking pattern

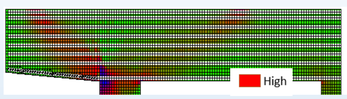


Fig.5 Concrete stress at failure load

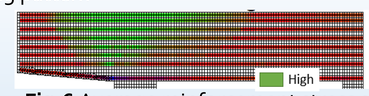


Fig.6 Average reinforcement stress at failure load

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.

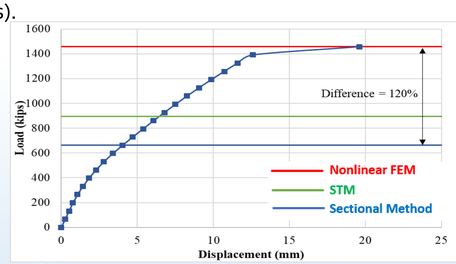


Fig.8 Load-displacement response (Capacity comparison)

Effect of Shear Span to Depth(a/d) Ratio

- **Deep region (a/d<2.0)** – Nonlinear FEM computes **2.5 times higher** shear capacities than sectional method and **1.5 times higher** than STM.

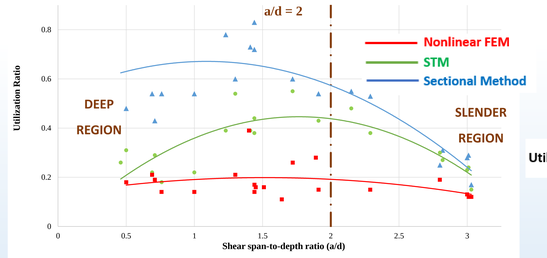


Fig.9 Comparison of utilization ratios with a/d ratio

Methodology

- The nonlinear finite element analysis of **five pier caps** of existing bridges in Ohio was performed using the program **VecTor2**.
- **VecTor2** 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.

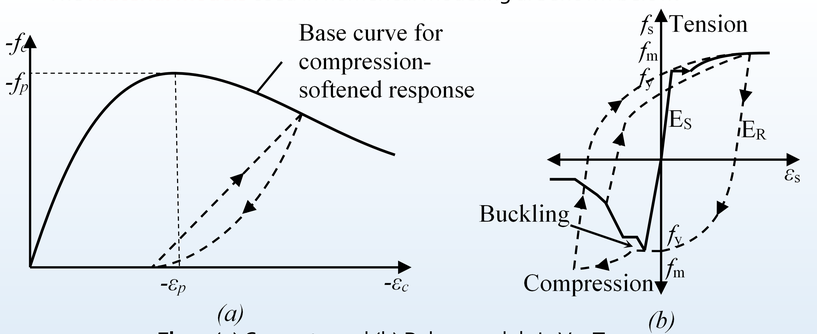


Fig.2 (a) Concrete and (b) Rebar models in VecTor2.

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.

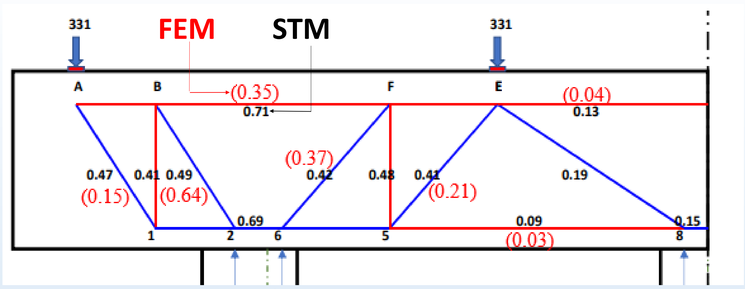


Fig.7 Utilization ratio from FEM and strut-and-tie method (STM).

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 1.5 times higher on average 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**.

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