Determination of Hidden Shear Capacities of Overloaded Pier Caps Using the Deep Beam Theory

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Problem Statement

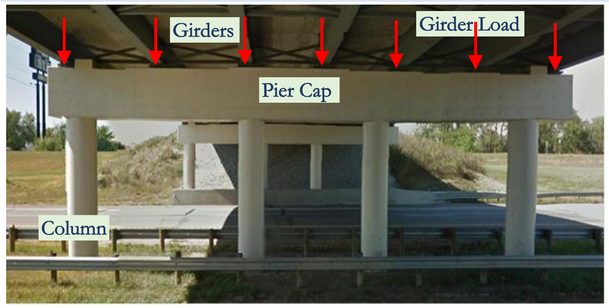


Fig. 1: A sample pier cap

'Pier caps' or 'bent caps' transfer the load from the girders to the columns, as shown in Fig. 1. In Ohio, there are approx. 28,000 bridges with multiple pier caps for every bridge. When analyzed using the slender beam theory, a considerable number of pier caps are found shear-overloaded despite the fact that they don't exhibit any noticeable cracking or signs of distress. This casts some doubt on the currently used analysis methods for pier caps.

Rehabilitating all shear-overloaded pier caps will result in prohibitive costs. An accurate analysis method is needed to obtain more realistic shear capacities to correctly identify the overloaded pier caps.

Kani's Shear Test[1]

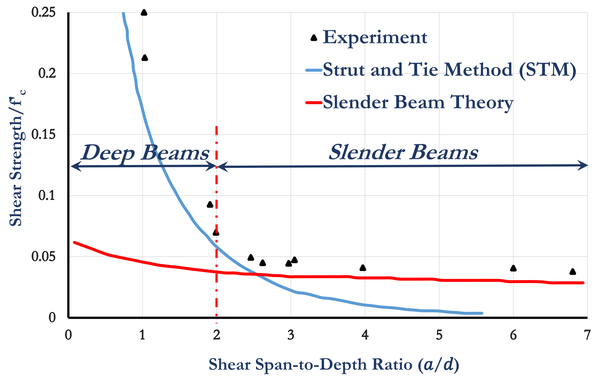


Fig. 2: Shear capacity of beams

The beams with shear span-to-depth ratios ($\frac{a}{d}$) less than 2.0 are classified as deep beams. Fig. 2 shows the result of experimental tests for deep beams for different ($\frac{a}{d}$) ratios. Note that when the $\frac{a}{d}$ ratio < 2.0, the slender beam theory becomes increasingly conservative at predicting the shear strength of the sections. Strut-and-Tie Method (STM), on the other hand, provides more accurate and less conservative results.

Research Objective

The main objective of this study is to develop a practical and accurate analysis methodology that can be used for evaluating the shear capacities of pier caps.

Deep Beams vs. Slender Beams

Fig. 3 shows the shear capacities obtained for a deep beam ($\frac{a}{d}$ = 1.6) using different analysis methods.

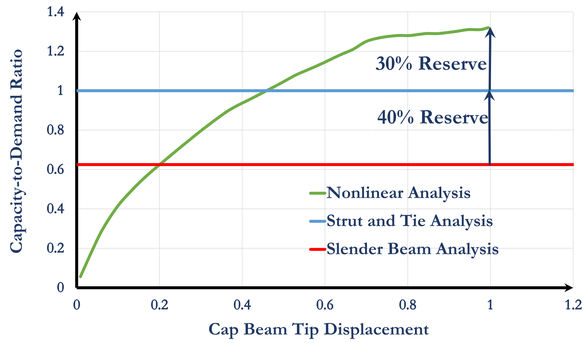


Fig. 3: Comparison of shear capacities from different methods

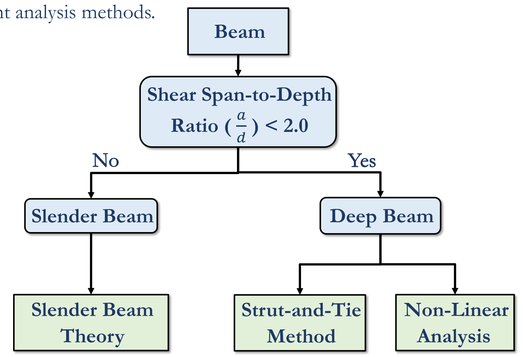


Fig. 4: Flowchart for selecting appropriate analysis method

As seen in Fig. 3, the STM provides higher shear capacities for deep beams. As most of the pier caps are deep, STM is the required method for the analysis and design of deep beams as shown in Fig. 4. The typical failure modes for deep and slender beams are shown in Figs. 5 and 6.

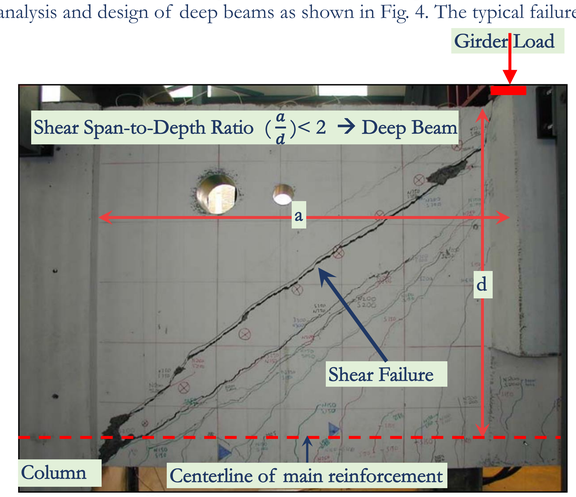


Fig. 5[2] : Typical shear failure of deep beam

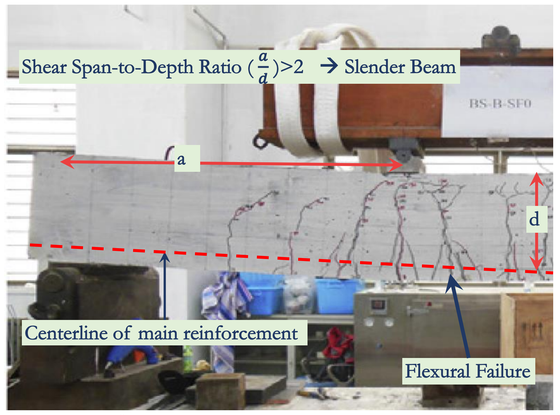


Fig. 6[3]: Typical flexural failure of slender beam

Strut-and-Tie Method (STM) for Deep Beams

STRUT-AND-TIE METHOD

This is an analysis and design method where the internal stress distribution in a structure is idealized by a truss mechanism (system of struts, ties, and nodes).

AASHTO LRFD 2014

Clause 5.6.3.1[4]: "The strut-and-tie model should be considered for the design of deep footings and pile caps or other situations in which the distance between the centers of applied load and the supporting reactions is less than about twice the member thickness."

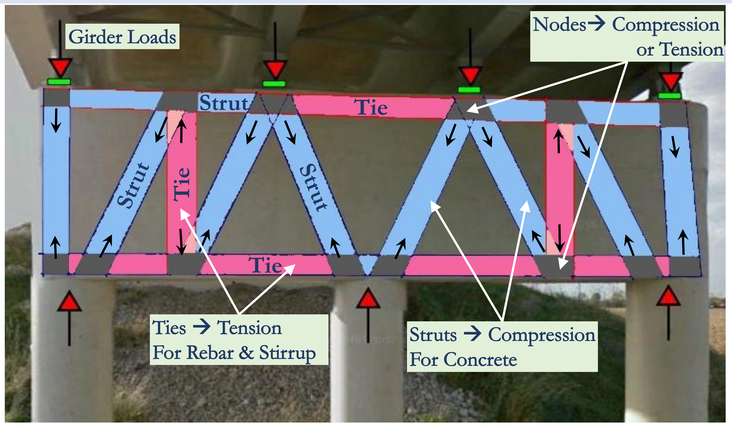
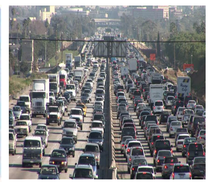


Fig. 7[5]: A sample strut-and-tie model

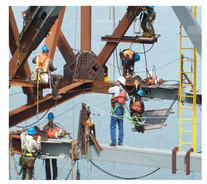
Benefits

1. Significant cost saving due to rehabilitating less number of bridges,
2. Reduced construction work and associated traffic congestion, and
3. Reduced hazard to construction crews and traveling public.

Cost Saving



Reduced Congestion



Reduced Safety Risk

Research Directions

AASHTO LRFD requires the use of either Strut-and-Tie Method or Finite Element Analysis for deep beams with shear span-to-depth ratios ($\frac{a}{d}$) < 2.0. This study will use the Strut-and-Tie method and develop a spreadsheet tool to expose the hidden shear capacities of deep pier caps that are found overloaded by the slender beam theory. The research results will provide ODOT with higher and more accurate shear capacities.

References

[1] Collins, M. P. and Mitchell, D. (1991) "Prestressed Concrete Structures" Prentice Hall: Englewood Cliffs, NJ.

[2] Senturk, A. E. & Higgins, C. (2008) "Evaluation of bent caps in reinforced concrete deck girder bridges, part 2" Final Report, Oregon Department of Transportation.

[3] Ning, X. & et al. (2015) "Experimental study and prediction model for flexural behavior of reinforced SCC beam containing steel fibers" Construction and Building Materials 93, 644-653

[4] AASHTO (2014) "LRFD Bridge Design Specifications." Customary US units, 7th Edition. American Association of State Highway and Transportation Officials, Washington, DC, 2016.

[5] Schlaich, J., Schäfer, K. and Jennewein, M. (2008) "Toward a Consistent Design of Structural Concrete." PCI Journal, 82(1), 74–50

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