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CALTRANS DIVISION OF RESEARCH, INNOVATION AND SYSTEM INFORMATION

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Geotechnical/ Structures

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Project Title: Second Order Effects on the Design of Slender Reinforced Concrete Bridge Columns

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DRISI provides solutions and knowledge that improves California's transportation system.

Second Order Effects on the Design of Slender Reinforced Concrete Bridge Columns

Bridge research to improve reinforced concrete slender bridge column design procedure and reduce construction and maintenance costs.

WHAT WAS THE NEED?

The current reinforced concrete slender bridge column design procedure is based on the American Association of State Highway and Transportation Officials Load and Resistance Factor Design (AASHTO LRFD) Bridge Design Specification approximate analysis method that was adopted from the building industry, i.e. American Concrete Institute (ACI), and has not been readily studied for applicability to bridge. Due to a lack of bridge focused guidance, designers often make very conservative assumptions when dealing with slender bridge columns. Refined analysis using finite element models have consistently resulted in lower second-order effects than would be predicted using the approximate method, yet the refined method is rarely used in design because it requires significantly more effort when compared to the approximate method. There is a clear need to evaluate the accuracy of the approximate method and the method formulation. Moreover, if the refined method is to become more widely used, better guidance and bridge modeling guidelines will need to be developed.

WHAT WAS OUR GOAL?

The primary goal of this project is to evaluate the performance of the AASHTO moment magnification method on slender bridge columns. Develop bridge modeling guidelines for using finite element models.

WHAT DID WE DO?

Through the PEER-Bridge Program, the California Department of Transportation (Caltrans) contracted with Oregon State University Principal Investigator (PI) and University of Tennessee, Knoxville (Co-PI) to evaluate AASHTO approximate moment magnification method using second-order analysis including P-Δ effects for deflection on axial loads and moments. Parametric studies were conducted on common Caltrans bridge types. Developed bridge modeling guidelines for the use of refined model analysis method. The study will also include recommendations on incorporation of slender column material effective stiffness and effective length factor for design practice based on a comprehensive literature survey and finite element modeling assessment.

WHAT WAS THE OUTCOME?

Numerical studies were done to improve the accuracy of the moment magnification approximate method. Advanced inelastic model for reinforced concrete columns was developed considering geometric nonlinearity, material nonlinearity, and long-term effects. The study is to investigate and quantify the accuracy of the current design method. The outcome of the study shown that simplified equations for flexural rigidity in the AASHTO LRFD are generally conservative but could result in unconservative error for more slender columns with relatively low axial load and high bending moments. As a result, new proposed equations for flexural rigidity were developed to minimize the unconservative error while controlling overall error. Column slenderness limits in the AASHTO LRFD were evaluated and to quantify unconservative error. The assessment shows that the new proposed equations could be safely used in the moment magnification method with slenderness greater than the current AASHTO limit of 100.

This project also developed a tool to better estimate the effective length factor for bridge columns. Using eigenvalue buckling analysis, new effective length factor for out-of-plane buckling of single-column bent was developed. The newly developed effective length factor was implemented in a spreadsheet-based design tool to be use by the design engineer.

Investigation on the requirements for the refined analysis method, long-term effects, restraint due to superstructure and foundation influence, and axial load with two axes bending on slender column is recommended for future work.

WHAT IS THE BENEFIT?

Bridges play a critical role in our transportation system in enhancing California mobility and economy. In the current slender bridge column design of approximate method of analysis, conservative estimates of slender column axial load carrying capacity can lead to unnecessary additional cost in the bridge support system. The current approximate method was adopted mainly from the building industry. Bridge frames are vastly different from building frames, so the assumptions and parameters that may be appropriate for use in buildings are not necessarily appropriate for bridges. By evaluating the approximate method against refined method, we can improve our current slender column design methodology, with better estimates of design parameters, a more efficient and cost-effective bridge column design can be achieved to meet the growing traffic demand of our users.

IMAGES

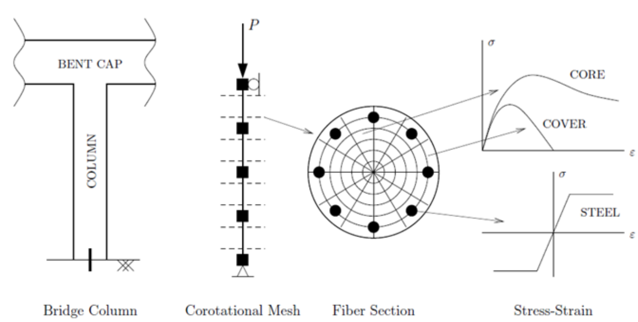

Image 1: Analytical model of a bridge column using corotational mesh and fiber sections with uniaxial stress-strain relationships for concrete and steel.

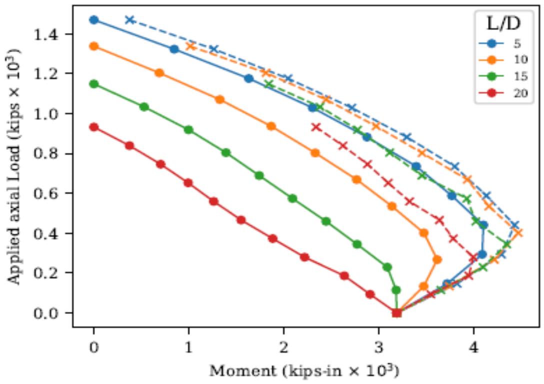

Image 2: P-M interaction diagram for different slenderness ratio values (diameter held constant).

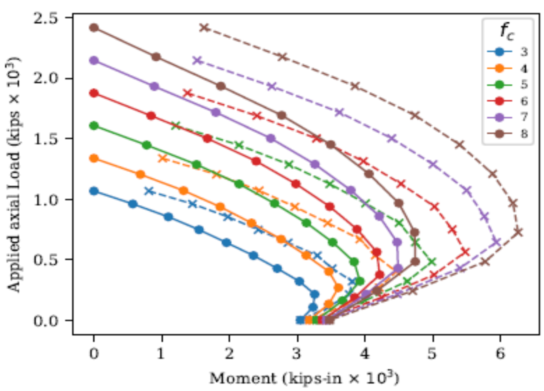

Image 3: P-M interaction diagram for different concrete compressive strength values.

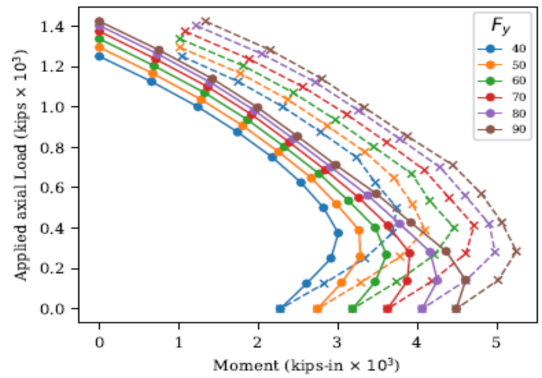

Image 4: P-M interaction diagram for different steel yield strength values.

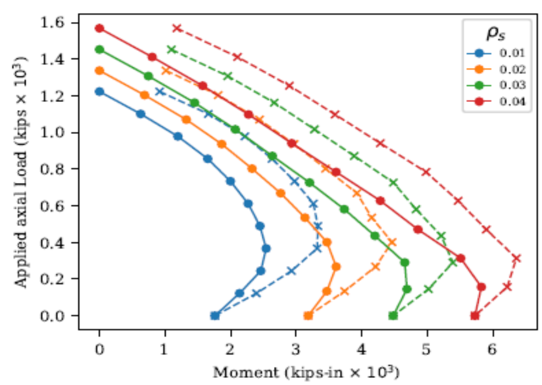

Image 5: P-M interaction diagram for different longitudinal steel ratio values (diameter and number of bars held constant).

Effective Length Factor for Transverse Buckling Mode of Single Column Bents

Version 1.4 (September 25, 2024)

Compute Normalized Superstructure Torsional Stiffness

Concrete Modulus of Elasticity, E_c	3605.00	psi
Concrete Poisson Ratio, ν	0.20	---
Concrete Shear Modulus, G_c	1,502.08	psi
Superstructure Torsional Constant, J	530.00	ft^4
Superstructure Span Length	200.00	ft
Superstructure Crack Factor	0.50	---
Column Moment of Inertia, I	12.50	ft^4
Column Height	40.00	ft
Column Crack Factor	0.70	---

Override Normalized Superstructure Torsional Stiffness

(leave blank to use computed torsional stiffness)		---

Effective Length Factor Calculation

Normalized Superstructure Torsional Stiffness	2.524	---
End Span Ratio	0.50	---

Number of Spans	Effective Length Factor, K	
	Idealized Fixed Base	Practical Fixed Base
2	1.18	1.23
3	1.18	1.23
4	1.32	1.37
5	1.45	1.51

Notes

1. Effective length factors are linearly interpolated from tabulated solutions to the governing differential equation.
2. Idealized fixed base assumes infinite rotational stiffness at the base.
3. Practical fixed base assumes rotational stiffness at the base equal to the value that results in $K = 2.1$ when the normalized superstructure torsional stiffness is zero.
4. For columns on pile caps or spread footings, it is recommended that the effective length of the column be taken as the length of the column down to the top of the foundation times the effective length factor, K, for a practical fixed base. For columns on shafts, it is recommended that the effective length of the column be taken as the length of the column down to the equivalent point of fixity times the effective length factor, K, for an idealized fixed base. See image below.
5. The equations are based on equal interior span lengths and equal end span lengths. For bridges with three or more spans, the span length should be the arithmetic mean of the interior span lengths and the end span ratio should be the arithmetic mean of the end span lengths divided by the span length. For bridges with two spans, the span length should be the arithmetic mean of the two span lengths. Variations in individual spans from the arithmetic mean of up to 20% will cause minimal error. See image below for example.
6. See Section 6.3 of [[REFERENCE TO PROJECT REPORT]] for background information.
7. The password to unlock the spreadsheet is "Caltrans".

Image 6: Screenshot of the interface for the Microsoft Excel based tool for determining the effective length factor for the transverse buckling mode of a single column bents.