AASHTO LRFD Bridge Design Specifications: Factored Axial Resistance

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In response to a question received by the *ASPIRE*® team, this article explains the technical background for the calculation of factored axial resistance. The factored axial resistance of concrete compressive components can be calculated using in Section 5.6.4.4 of the 8th edition of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1]

To begin, Eq. 5.6.4.4-1 indicates that the factored resistance P_r can be calculated by multiplying the nominal axial capacity P_n by the resistance factor ϕ:

$$P_r = \phi P_n$$

The resistance factor ϕ in this expression is based on the net tensile strain (see Fig. C5.5.4.2-1 in ref. 1). With that stated, the failure mode for the case of pure axial compression is compression-controlled; therefore, ϕ = 0.75.

Equation 5.6.4.4-2 applies to members with spiral reinforcement:

$$P_n = 0.85\begin{bmatrix} k_c f'_c\left(A_g - A_{st} - A_{ps}\right) + f_y A_{st} \\ -A_{ps}\left(f_{pe} - E_p \varepsilon_{cu}\right) \end{bmatrix}$$

Equation 5.6.4.4-3 applies to members with tie reinforcement:

$$P_n = 0.80\begin{bmatrix} k_c f'_c\left(A_g - A_{st} - A_{ps}\right) + f_y A_{st} \\ -A_{ps}\left(f_{pe} - E_p \varepsilon_{cu}\right) \end{bmatrix}$$

As explained in commentary C5.6.4.4, the values of 0.85 and 0.80 that appear outside the brackets in Equations 5.6.4.4-2 and 5.6.4.4-3, respectively, place upper limits on the usable resistance of compression members to account for unintended eccentricity. Historically, this was done by specifying a "minimum eccentricity" that was in the range of 5% to 10% of the column cross-sectional dimensions. However, the approach of specifying a minimum eccentricity has been abandoned in modern design codes including the AASHTO LRFD specifications. Placing a cap on the factored resistance diagram (P-M interaction curves) avoids the danger associated with producing designs in a region of the P-M interaction diagram where little bending resistance can be accommodated (**Figure 1**). In all other parts of the P-M interaction diagram, unintended eccentricities can be easily handled without creating a compliance problem with the specifications or a safety problem in the worst-case scenario.

Prior to the 8th edition of the AASHTO LRFD specifications, the constant 0.85 appeared before f'_c in the above equations where the variable k_c now appears. The origin of this k_c factor dates back to research conducted at the University of Illinois Urbana-Champaign and Lehigh University, in which 564 normal-strength concrete columns were tested. The researchers concluded that there was a difference between the concrete compressive strength of the columns and that of the corresponding concrete test cylinders. Most, if not all, failures observed in the reinforced concrete column specimens occurred in the top portions of the column specimens. As a result, the researchers attributed the 15% difference between the strength of the in-place concrete and the strength of concrete cylinders to potential segregation of concrete and migration of cement paste and air toward the top of the column, when concrete is consolidated by using internal vibrators.

To make design provisions in the 8th edition of the AASHTO LRFD specifications applicable to a broader range of concrete compressive strengths, the factor k_c replaces the constant 0.85 before f'_c as it appeared in the 7th edition. The k_c term accounted for design compressive strengths exceeding 10.0 ksi. Therefore, k_c = 0.85 for $f'_c \le 10$ ksi; for $f'_c > 10.0$ ksi, k_c is reduced at a rate of 0.02 for each 1.0 ksi of compressive strength in excess of 10.0 ksi to a minimum value of 0.75. Researchers found that reducing k_c from 0.85 to 0.75 accounts for the cover spalling observed in tests of high-strength concrete columns. This cover spalling behavior was found to be influenced by the following:

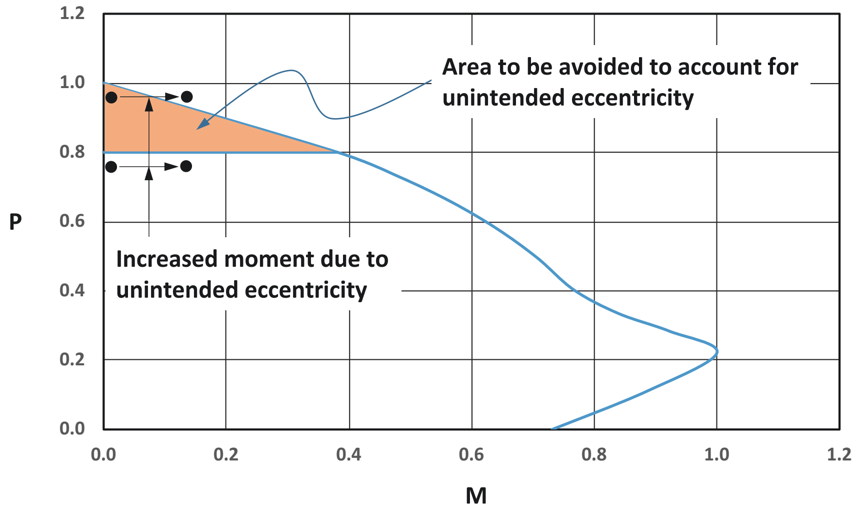

Figure 1. Upper limit on the usable resistance of compression members with tie reinforcement.

- Incompatibility of stresses in the unconfined cover concrete and confined concrete in the structural core;
- A plane of weakness created by the confining reinforcement (spirals or ties) that is used in relatively greater quantities in high-strength concrete columns, to comply with the AASHTO LRFD specifications; and
- Instability of cover concrete resulting from the interaction that takes place between the expanding structural core and the cover concrete at or near the axial compressive capacity.

Reference

1. American Association of State Highway and Transportation Officials (AASHTO). 2017. *AASHTO LRFD Bridge Design Specifications*, 8th ed. Washington, DC: AASHTO.

CONCRETE CONNECTIONS

Concrete Connections is an annotated list of websites where information is available about concrete bridges. Links and other information are provided at www.aspirebridge.org.

IN THIS ISSUE

https://cptechcenter.org/performance-engineered-mixtures-pem
This is a link to a website that gives details about the Performance Engineered Mixtures pooled fund project that is mentioned in the editor's note for the Focus article on p. 9.

https://www.pittsburghmagazine.com/Best-of-the-Burgh-Blogs/The-412/February-2018/Five-Fun-Facts-about-Pittsburgh-Bridges/
This is a link to a *Pittsburgh Magazine* feature with photos of several iconic bridges in Pittsburgh, Pa. The history of Pittsburgh's Roberto Clemente Bridge and other aesthetically notable bridges is the subject of a Perspective article on page 10.

http://www.aspirebridge.com/magazine/2012Fall/RichStreet.pdf
This is a link to an article in the Fall 2012 issue of *ASPIRE* about the Rich Street Bridge, which is discussed in the Perspective article on page 10.

http://ndotprojectneon.com
This is a link to a Nevada Department of Transportation website about Project Neon in Las Vegas, Nev. The Project Neon high-occupancy-vehicle connector flyover bridge is featured in a Project article on page 16 and a Concrete Bridge Technology article on page 30.

https://www.keepsandiegomoving.com/I-5-Corridor/gilman-drive-bridge-intro.aspx
This is a link to a website with videos and photos of the construction of the Gilman Drive Overcrossing at the University of California San Diego. The bridge is featured in a Project article on page 20.

https://ucsdnews.ucsd.edu/feature/building-connections-campus-celebrates-gilman-bridge-opening
This is a link to a news release about the opening of the Gilman Bridge that is featured in a Project article on page 20.

http://www.ltrc.lsu.edu/ltc_18/pdf/presentations/Session_37-I-49-I-220_Interchange__Segment_K-Phase_2__Shreveport,_LA.pdf
This is a link to an illustrated presentation on the construction of Segment K of Interstate 49 in Louisiana. The presentation provides details about the precast concrete segments and describes challenges of the project. The ramps of Segment K are featured in a Concrete Bridge Technology article on page 24.

http://www.i49shreveport.com/Site
This is a link to the official website for the Interstate 49 corridor project through Shreveport, La. Segment K of the project is featured in a Concrete Bridge Technology article on page 24.

https://www.dot.state.mn.us/bridge/lrfd.html
This is a link to access the Minnesota Department of Transportation's *LRFD Bridge Design Manual*, which contains details on the new MH-series shallow bridge beams. The development of the beams is the topic of a Concrete Bridge Technology article on page 34.

https://ftp.fdot.gov/file/d/FTP/FDOT%20LTS/CO/research/Completed_Proj/Summary_STR/FDOT_BC354_76_rpt.pdf
This is a link to the report on the vessel impact testing of the old St. George Island Causeway Bridge that is listed as a reference for the Concrete Bridge Technology article on page 36.

https://www.fhwa.dot.gov/publications/rtnow/17sep_oct_rtnow.pdf
This is a link to an FHWA news update that includes an article on a truck-platooning demonstration project in Virginia. The possible effects of truck platooning on bridge structures is the topic of the FHWA article on page 44.

https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16006.pdf
This is a link to Federal Highway Administration (FHWA) Tech Brief FHWA-HIF-16-006, which provides information on the concept and applications of internal curing concrete. The use of internal curing concrete for bridge decks in New York is the topic of a Safety and Serviceability article on page 48.

https://www.dot.ny.gov/main/business-center/engineering/specifications/english-spec-repository/2019_5_specs_usc_tc_vol2_0.pdf
This is a link to the NY State Department of Transportation's *Standard Specifications*, which contain the new requirements for high-performance internally-cured concrete for bridge decks in Section 557. These requirements are mentioned in the Safety and Serviceability article on p. 48.