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From: John Lawson
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Subject: Geotechnical Design Policy SF-2
Load Resistance Factor Design (LRFD)
Limiting Eccentricity Criteria for Spread Footings based on Load and Resistance Factor
Design (LRFD) Methodology

The AASHTO (2010) LRFD Bridge Design Specifications are mandatory for all federally funded projects. The purpose of this policy memorandum is to address inconsistencies related to limiting eccentricity criteria between allowable stress design used to develop ADOT SD 7.01 Standard Walls (formerly referred to as B-Standard Walls) and current LRFD practice. Limiting eccentricity criteria used in LRFD with respect to eccentric loads and overturning have been modified to match successful past ASD practice. The recommended limiting eccentricity criteria for eccentric loads and overturning are presented in the attached policy.

Personnel, both within ADOT and design consultants working on projects that require LRFD for substructures, shall follow the attached policy. The designer should contact the ADOT Materials Group for an updated version of this policy in the event any interim revisions are made to AASHTO (2010) or a new edition of AASHTO is issued.

If you have any questions regarding this design policy please contact Jim Wilson at 602-712-8081 or John Lawson at 602-712-8130.



Arizona Department of Transportation

Materials Group - Geotechnical Design Section

MEMORANDUM

To:
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Date: December 1, 2010

From:
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Subject: Limiting Eccentricity
Criteria for Spread Footings based on
Load and Resistance Factor Design
(LRFD) Methodology¹

ADOT POLICY MEMORANDUM: ADOT SF-2

This memorandum presents guidance for the limiting eccentricity criteria in the following Articles of AASHTO (2010):

1. Section 10 (Foundations), Article 10.6.3.3 – Eccentric Load Limitations. This Article states the following:
“The eccentricity of loading at the strength limit state, evaluated based on factored loads shall not exceed:
 - One-fourth of the corresponding footing dimension, B or L, for footings on soils, or
 - Three-eighths of the corresponding footing dimensions B or L, for footings on rock.”
2. Section 11 (Abutments, Piers and Walls), Article 11.6.3.3 – Overturning. This Article states the following:
“For foundations on soil, the location of the resultant of the reaction forces shall be within the middle one-half of the base width.
For foundations on rock, the location of the resultant of the reaction forces shall be within the middle three-fourths of the base width.”

Note that even though the two articles are worded differently in terms of eccentricity and location of the resultant of the reaction forces, they are in effect identical because both quantities are measured with respect to the center of the base width². Therefore, a maximum eccentricity of

¹ This memorandum is based on AASHTO (2010) – 5th Edition. The designer should contact ADOT Materials Group for an updated version of this memorandum in the event any interim revisions to AASHTO (2010) are issued or a new edition of AASHTO is issued.

² The term “base width” applies to the total dimension of the footing in the direction that is being evaluated for limiting eccentricity compliance. The term “base dimension” is more appropriate, but “base width” is used herein for consistency with terminology in AASHTO (2010). Similarly, the words “spread footing” and “footing” should be considered synonymous with “shallow foundation,” and “foundation,” respectively.

one-fourth of the corresponding footing dimension, B or L , defines the kern corresponding to the middle one-half of the footing base dimension, B or L .

The commentary to Article 10.6.3.3 states the following (where ASD denotes Allowable Stress Design and B is the applicable footing dimension in the direction the limiting eccentricity is being evaluated):

“A comprehensive parametric study was conducted for cantilevered retaining walls of various heights and soil conditions. The base widths obtained using the LRFD load factors and eccentricity of $B/4$ were comparable to those of ASD with an eccentricity of $B/6$.”

I. Purpose and Scope for Re-evaluation of AASHTO Criteria

In contrast to the above statement in the commentary, the Bridge Group of the Arizona Department of Transportation (ADOT) determined that the base width of the footings for ADOT SD 7.01 standard walls³ that satisfy the requirements of ASD (AASHTO, 2002) do not satisfy the LRFD limiting eccentricity criteria in AASHTO (2010) and that 15-20% larger base widths are needed with consequent increase in costs. As indicated in the commentary to Article 10.6.3.3 of AASHTO (2010), the intent of AASHTO is to match successful past ASD practice based on the $B/6$ criterion for eccentricity. Therefore, a re-evaluation of the calibration of the past practice using current LRFD load factors in Section 3 of AASHTO (2010) was performed.

The scope of this re-evaluation was limited to the dimensions of ADOT SD 7.01 walls as well as typical dimensions of cast-in-place cantilever concrete walls in general (e.g., Figure 10-16a in FHWA, 2006). Backfill soils were assumed to be granular (i.e., no cohesion) with a unit weight of approximately 120 pcf and an effective angle of internal friction, ϕ'_f , ranging from 28 to 34 degrees. Concrete was assumed to have a unit weight of 150 pcf. Active earth pressure condition was assumed for evaluation. Note that the ADOT SD 7.01 walls provide guidance for walls up to 30-ft tall for 4 wall configurations (Case I, Case II, Case III, and Case IV) based on the slope of the wall backfill, traffic loads, and presence of traffic barriers⁴. The re-evaluation was limited to these configurations and the assumptions noted herein. In the re-evaluation, the live load surcharge was represented by an equivalent height of soil surcharge consistent with the recommendations in Article 3.11.6.4 of AASHTO (2010).

Sections II and III of this memorandum present the recommendations and commentary, respectively, based on this re-evaluation.

³ ADOT standard structure detail drawings, SD 7.01, address Reinforced Concrete Cantilever walls (ADOT, 2010).

⁴ Based on ADOT SD 7.01, Case I walls have a horizontal backfill, Case II walls have horizontal backfill with live load surcharge, Case III walls have a 2H:1V (H=Horizontal, V=Vertical) backfill slope, and Case IV walls are Case II walls with an ADOT standard (SD 1.02) 42-inch F-shape bridge concrete traffic barrier on top of the wall. In all cases, the wall is a cast-in-place concrete cantilever wall with no loads on the stem, either at the top (e.g., abutment wall) or through the stem (e.g., anchored wall).

II. Recommendations

Revise Article 10.6.3.3 of AASHTO (2010) to read as follows:

The eccentricity, e , of loading at the strength limit state, evaluated based on factored loads shall meet the following limits:

- For footings on soils: $e \leq B [(1/3) - (\beta/320)]$
- For footings on rocks: $e \leq B [(3/7) - (\beta/500)]$

where,

B = the footing dimension (width or length) in which the eccentricity is being evaluated,

β = the backslope inclination angle of the soil retained behind the wall in degrees with respect to the horizontal. The maximum limit on β is 26.56 degrees (i.e., 2H:1V slope; H=Horizontal, V=Vertical). In addition, the slope shall satisfy the minimum slope stability requirements for the project.

The eccentricity, e , computed by the above equations has the same units as B . For retaining walls, the effective angle of internal friction, ϕ'_f , of the wall backfill shall be greater than 28 degrees.

Revise Article 11.6.3.3 of AASHTO (2010) to read as follows:

The location of the resultant of the reaction forces shall be within the middle X of the footing width, where X is computed as follows:

- For footings on soils: $X = 2B [(1/3) - (\beta/320)]$
- For footings on rocks: $X = 2B [(3/7) - (\beta/500)]$

where,

B = the footing dimension (width or length) being evaluated,

β = the backslope inclination angle of the soil retained behind the wall in degrees with respect to horizontal. The maximum limit on β is 26.56 degrees (i.e., 2H:1V slope; H=Horizontal, V=Vertical). In addition, the slope shall satisfy the minimum slope stability requirements for the project.

The value of X computed by the above equations has the same units as B . For retaining walls, the effective angle of internal friction, ϕ'_f , of the wall backfill shall be greater than 28 degrees.

These revised criteria shall be applied taking into consideration the Commentary in Section III of this memorandum.

III. Commentary

1. The commonly used “middle-third” rule for the location of the resultant of unfactored reaction forces in ASD is used to assess the possibility of a part of a foundation losing contact with the supporting ground during loading and therefore the potential for overturning⁵. The limiting eccentricity criterion for soils in the LRFD approach is intended to replace the conventional overturning criterion of the “middle-third” rule in the ASD approach. In the LRFD approach, this criterion is evaluated at the Strength limit state, which uses factored loads. The limiting eccentricity criteria in Section II (Recommendations) are based on the Strength I limit state (AASHTO, 2010), which generally controls the design of spread footings for foundations of piers and retaining walls. The criteria are also applicable to MSE walls or other walls having shallow foundations, e.g., prefabricated modular walls.
2. The criteria in Section II are valid for wall applications under the following conditions:
 - a. Granular well-drained backfill.
 - b. Active earth pressures.
 - c. Level backfill (ADOT Case I walls).
 - d. Level backfill with traffic live load represented by equivalent soil surcharge height, h_{eq} , in accordance with Article 3.11.6.4 of AASHTO (2010) (ADOT Case II and IV walls).
 - e. Stable backfill slopes up to 2H:1V and having a minimum effective angle of internal friction, ϕ'_f , of 28 degrees (ADOT Case III walls).
3. The following considerations shall be implemented during computations of limiting eccentricity for wall footings:
 - a. The contact pressure surface behind the wall for the evaluation of lateral pressures shall be the vertical plane extending from the bottom of the heel of the wall base to the point of its intersection with the slope of the wall backfill.
 - b. The wall height for computation of lateral pressures shall be the height of the contact pressure surface as defined in Item 3a above.
 - c. The force and moment due to the soil on the top of the toe of the wall footing shall be neglected in the evaluation of limiting eccentricity.
 - d. Passive resistance in front of the wall and from the sliding key (if applicable) shall be neglected in the evaluation of limiting eccentricity.
 - e. The lateral earth pressure shall be computed using Rankine theory regardless of whether the wall is long-heeled or short-heeled as defined in Article 3.11.5.3 of AASHTO (2010). With respect to Equations 3.11.5.3-1 and 3.11.5.3-2 of AASHTO (2010), the Rankine theory is implemented by using $\delta = 0$ and $\theta = 90$ degrees, where δ is the friction angle between the fill and wall and θ is the angle of the backface of the wall as defined in

⁵ The term “middle-third” refers to the limits of the location of the resultant of the reaction forces with respect to the base width of the foundation. As noted earlier, this rule is an alternative representation of the criterion to limit the eccentricity of the resultant of the reaction forces within a dimension of one-sixth of the total base width on either side of the center of the base width.

Figure 3.11.5.3-1 of AASHTO (2010). The lateral earth pressure thus computed shall then be inclined parallel to the backslope inclination angle, β , of the retained soil as shown in Figure C3.11.5.3-1 of AASHTO (2010).

- f. Where the potential for water pressures exist, appropriate consideration should be given to water pressures and buoyancy (uplift) effects.
4. At abutments, the base width of the footing is a function of the superstructure loads at the top of the stem. The vertical load due to the superstructure provides a significant stabilizing force against overturning. Therefore, the base width of the footing is often smaller than for the case of non-abutment walls. Due consideration should be given to construction sequencing and load factors in terms of the application of loads from the superstructure with respect to the height of fill behind the abutments. For example, often the fill behind the abutment is raised to approximately the final grade before placement of the superstructure, which provides resistance to overturning. Similarly, large construction loads (e.g., crane loads) may be applied on the backfill during construction. Depending on the configuration of the abutment and because of the construction sequence including the application of permanent superstructure loads and temporary loads, the placement of the abutment backfill may have to be limited to a certain height to meet the limiting eccentricity criteria. As appropriate, an evaluation of overturning at the various stages of construction should also take into account the estimated settlement and rotation of the footing at those stages so that the final configuration of the abutment wall is in accordance with the tolerances for the superstructure. In general, an evaluation of construction sequencing is recommended for all walls, regardless of whether they are abutment walls or not.
5. When the computed eccentricity at any stage of construction approaches the limits noted in Section II of this memorandum, a careful review of the various forces is warranted because slight deviations may result in undesirable effects on safety and/or the configuration of the final structure, e.g., effect on joints and bearings at the abutments. In addition to a review of the forces, factors such as the structural integrity, second-order effects in supported structures and loss of serviceability should also be evaluated.
6. To avoid potential detrimental consequences on the limiting eccentricity criteria from poor workmanship, it is recommended that project plans include construction tolerances for foundation plan dimensions (length and width) to be +2-inches and -0.5-inches.
7. As a safeguard against design errors, it is recommended that the adequacy of the final footing size with respect to limiting eccentricity (i.e., overturning) be checked by using the “middle-third” rule based on ASD forces. In the LRFD context, loads for the Service I limit state and resistances with a resistance factor equal to 1.0 could also be used to check for conformance with the “middle-third” rule. This is true for any wall configuration that does not meet the assumptions noted in Item III.2 above.
8. The eccentricity computed for the evaluation of the limiting eccentricity criteria should not be confused with the eccentricity computed for the evaluation of the net equivalent uniform vertical bearing stress (ADOT SF-1, 2010) used to determine the relationship between bearing resistance, effective footing width, and settlement for the appropriate limit states. The load factors that are used in each of these limit states are different from those used for

the evaluation of limiting eccentricity. Therefore, the computed eccentricity values are different for each limit state.

9. Extreme event loads such as those caused by vehicular collisions on traffic barriers, seismic events, scour at check flood events, etc. should be evaluated by using the appropriate ADOT and AASHTO procedures for such events.

IV. Closing Comments

This memorandum contains guidance for the application of the limiting eccentricity criteria based on LRFD methodology in AASHTO (2010) for wall configurations similar to ADOT SD 7.01 walls (ADOT, 2010). The Bridge Group should be contacted for other appropriate modifications to ADOT SD 7.01 walls based on implementation of LRFD methodology. Examples of these modifications are structural design, concrete cover, reinforcement size and distribution, etc. It is recommended that the footing widths for ADOT SD 7.01 walls (ADOT, 2010) be used only as a preliminary guidance for initial sizing of the footing to start the LRFD design process and that all applicable loads and limit states be considered in the design, particularly for cases with finite surcharge loads.

The evaluation of limiting eccentricity is based on the total footing dimension in the direction of the eccentricity. The governing footing width may be a function of other limit states such as settlement and bearing resistance. As demonstrated in ADOT SF-1 (2010) close interaction between geotechnical and structural engineers is required for this purpose. Therefore, it is anticipated that close interaction between geotechnical and bridge engineers will also be necessary during the evaluation of limiting eccentricity.

V. References

- AASHTO (2002). *Standard Specifications for Highway Bridges, Seventeenth Edition*, American Association of State Highway and Transportation Officials, Washington, D.C.
- AASHTO (2010). *AASHTO LRFD Bridge Design Specifications, Fifth Edition*. American Association of State Highway and Transportation Officials, Washington, D.C.
- ADOT (2010). *Bridge Group Structure Detail*, Arizona Department of Transportation. Phoenix, AZ. (<http://www.azdot.gov/highways/bridge/detaildwg/Retaining.asp>)
- ADOT SF-1 (2010). *Development of Factored Bearing Resistance Chart by a Geotechnical Engineer for Use by a Bridge Engineer to Size Spread Footings on Soils Based on Service and Strength Limit States Based on Load and Resistance Factor Design (LRFD) Methodology*, Memorandum from N. H. Wetz and J. D. Wilson to J. Lawson, Dated December 1, 2010 (Revision 2), Arizona Department of Transportation. Phoenix, AZ. (http://www.azdot.gov/Highways/Materials/Geotech_Design/Policy.asp)
- FHWA (2006). *Soils and Foundations – Volumes I and II*. Authors: Samtani, N. C. and Nowatzki, E. A., Publications No. FHWA NHI-06-088 and FHWA NHI-06-089, Federal Highway Administration, Washington, D.C.