Bridge and Structures Office
Washington State
Department of Transportation

Memorandum

TO: All Design Staff
FROM: Bijan Khaleghi
DATE: April 13, 2012
SUBJECT: ASTM A706 Grade 80 Reinforcement

This design memorandum defines WSDOT policy for the use of ASTM A706 Grade 80 reinforcement. ASTM A706 Grade 60 reinforcement remains the preferred reinforcing steel type for WSDOT bridges and structures.

Reinforcement conforming to ASTM A706 Grade 80 may be used in Seismic Design Category (SDC) A for all components. For SDCs B, C and D, ASTM A706 Grade 80 reinforcing steel shall not be used for elements and connections that are proportioned and detailed to ensure the development of significant inelastic deformations for which moment curvature analysis is required to determine the plastic moment capacity of ductile concrete members and expected nominal moment capacity of capacity protected members.

ASTM A706 Grade 80 reinforcing steel may be used for capacity-protected members such as footings, bent caps, oversized shafts, joints, and integral superstructure elements that are adjacent to the plastic hinge locations if the expected nominal moment capacity is determined by strength design based on the expected concrete compressive strength with a maximum usable strain of 0.003 and a reinforcing steel yield strength of 80 ksi with a maximum usable strain of 0.090 for #10 bars and smaller, 0.060 for #11 bars and larger. The resistance factors for seismic related calculations shall be taken as 0.90 for shear and 1.0 for bending.

ASTM A706 Grade 80 reinforcing steel shall not be used for oversized shafts where in-ground plastic hinging is considered as a part of the Earthquake-Resisting System (ERS).

ASTM A706 Grade 80 reinforcing steel shall not be used for transverse reinforcement in members resisting torsion.

For seismic hooks, f_y shall not be taken greater than 75 ksi.

Modifications to Resistance Factors for Conventional Construction (AASHTO LRFD Bridge Design Specifications 5.5.4.2.1):

For sections in which the net tensile strain in the extreme tension steel at nominal resistance is between the limits for compression-controlled and tension-controlled sections, ϕ may be linearly increased from 0.75 to that for tension-controlled sections as the net tensile strain in the extreme tension steel increases from the compression controlled strain limit, ε_{cl}, to the tension-controlled strain limit, ε_{tl}.

This variation ϕ may be computed for prestressed members such that:

$$0.75 \le \phi = 0.75 + \frac{0.25(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 1.0$$

and for nonprestressed members such that:

$$0.75 \le \phi = 0.75 + \frac{0.15(\varepsilon_t - \varepsilon_{cl})}{(\varepsilon_{tl} - \varepsilon_{cl})} \le 0.9$$

where:

ε_t = net tensile strain in the extreme tension steel at nominal resistance

ε_{cl} = compression-controlled strain limit in the extreme tension steel (in./in.)

ε_{tl} = tension-controlled strain limit in the extreme tension steel (in./in.)

For sections subjected to axial load with flexure, factored resistances are determined by multiplying both P_n and M_n by the appropriate single value of ϕ. Compression-controlled and tension-controlled sections are defined as those that have net tensile strain in the extreme tension steel at nominal strength less than or equal to the compression-controlled strain limit, and equal to or greater than the tension-controlled strain limit, respectively. For sections with net tensile strain ε_t in the extreme tension steel at nominal strength between the above limits, the value of ϕ may be determined by linear interpolation, as shown in Figure 1.

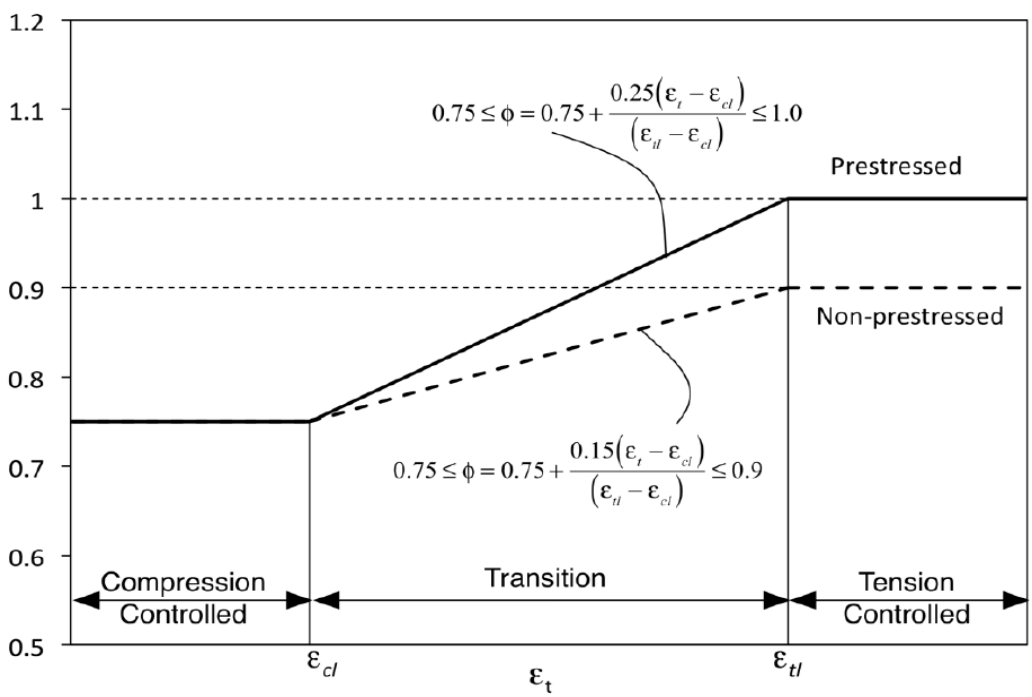

Figure 1—Variation of ϕ with Net Tensile Strain ε_t

Modifications to General Assumptions for Strength and Extreme Event Limit States (AASHTO LRFD Bridge Design Specifications 5.7.2.1):

Sections are compression-controlled when the net tensile strain in the extreme tension steel is equal to or less than the compression-controlled strain limit, ε_{cl}, at the time the concrete in compression reaches its assumed strain limit of 0.003. The compression-controlled strain limit is the net tensile strain in the reinforcement at balanced strain conditions. For Grade 60 reinforcement, and for all prestressed reinforcement, the compression-controlled strain limit may be set equal to $\varepsilon_{cl} = 0.002$. For nonprestressed reinforcing steel with a specified minimum yield strength of 80.0 ksi, the compression-controlled strain limit may be taken as $\varepsilon_{cl} = 0.003$. For nonprestressed reinforcing steel with a specified minimum yield strength between 60.0 and 80.0 ksi, the compression controlled strain limit may be determined by linear interpolation based on specified minimum yield strength.

Sections are tension-controlled when the net tensile strain in the extreme tension steel is equal to or greater than the tension-controlled strain limit, ε_{tl}, just as the concrete in compression reaches its assumed strain limit of 0.003. Sections with net tensile strain in the extreme tension steel between the compression-controlled strain limit and the tension-controlled strain limit constitute a transition region between compression-controlled and tension-controlled sections. The tension-controlled strain limit, ε_{tl}, shall be taken as 0.0056 for nonprestressed reinforcing steel with a specified minimum yield strength, $f_y = 80.0$ ksi.

In the approximate flexural resistance equations f_y and f'_y may replace f_s and f'_s, respectively, subject to the following conditions:

- f_y may replace f_s when, using f_y in the calculation, the resulting ratio c/d_s does not exceed:

$$\frac{c}{d_s} \leq \frac{0.003}{0.003 + \varepsilon_{cl}}$$

where:

c = distance from the extreme compression fiber to the neutral axis (in.)

d_s = distance from extreme compression fiber to the centroid of the nonprestressed tensile reinforcement (in.)

ε_{cl} = compression-controlled strain limit as defined above.

If c/d exceeds this limit, strain compatibility shall be used to determine the stress in the mild steel tension reinforcement.

- f'_y may replace f'_s when, using f'_y in the calculation, if $c \geq 3d'_s$, and $f_y \leq 60.0$ ksi. If $c < 3d'_s$, or $f_y > 60.0$ ksi, strain compatibility shall be used to determine

the stress in the mild steel compression reinforcement. Alternatively, the compression reinforcement may be conservatively ignored, i.e., $A'_s = 0$.

When using strain compatibility, the calculated stress in the nonprestressed reinforcing steel may not be taken as greater than the specified minimum yield strength.

When using the approximate flexural resistance equations it is important to assure that both the tension and compression mild steel reinforcement are yielding to obtain accurate results. The current limit on c/d_s assures that the mild tension steel will be at or near yield. The ratio $c \geq 3d'_s$ assures that mild compression steel with $f_y \leq 60.0$ ksi will yield. For yield strengths above 60.0 ksi, the yield strain is close to or exceeds 0.003, so the compression steel may not yield. It is conservative to ignore the compression steel when calculating flexural resistance. In cases where either the tension or compression steel does not yield, it is more accurate to use a method based on the conditions of equilibrium and strain compatibility to determine the flexural resistance. For Grade 40 reinforcement the compression-controlled strain limit may be set equal to $\varepsilon_{cl} = 0.0014$.

Values of the compression- and tension-controlled strain limits are given in Table 1 for common values of specified minimum yield strengths.

Specified Minimum Yield Strength, ksi	**Compression Control, ε_{cl}**	**Tension Control, ε_{tl}**
40	0.0014	0.005
60	0.002	0.005
75	0.0026	0.0054
80	0.0028	0.0056

Modifications to Development of Reinforcement (AASHTO LRFD Bridge Design Specifications 5.11.2):

Development lengths shall be calculated using the specified minimum yield strength of the reinforcing steel. Reinforcing steel with a specified minimum yield strength up to 80 ksi is permitted.

For straight bars having a specified minimum yield strength greater than 75 ksi, transverse reinforcement satisfying the requirements of AASHTO LRFD Bridge Design Specifications 5.8.2.5 for beams and 5.10.6.3 for columns shall be provided over the required development length. Confining reinforcement is not required for slabs or decks.

For hooks in reinforcing bars having a specified minimum yield strength greater than 60 ksi, ties satisfying the requirements of AASHTO LRFD Bridge Design Specifications 5.11.2.4.3 shall be provided. For hooks not located at the discontinuous end of a member, the modification factors of AASHTO LRFD Bridge Design Specifications 5.11.2.4.2 may be applied.

Modifications to Splices of Bar Reinforcement (AASHTO LRFD Bridge Design Specifications 5.11.5):

For lap spliced bars having a specified minimum yield strength greater than 75 ksi, transverse reinforcement satisfying the requirements of AASHTO LRFD Bridge Design Specifications 5.8.2.5 for beams and 5.10.6.3 for columns shall be provided over the required splice length. Confining reinforcement is not required for slabs or decks.

Background:

ASTM A706 Grade 80 reinforcing steel is commercially available in the United States. The use of steel with this higher capacity could provide benefits to concrete bridge construction by reducing member cross sections and reinforcement quantities, leading to savings in material, shipping, and placement costs. Reducing reinforcement quantities will also reduce congestion problems leading to better quality of construction. The use of high-strength steel reinforcement with high-strength concrete should result in more efficient use of both materials.

ASTM A706 Grade 60 reinforcement remains the preferred reinforcement type for all WSDOT bridges and structures.

Further research is required to establish the shape and model of the stress-strain curve, expected reinforcing strengths and strain limits for concrete components made with ASTM A706 Grade 80 reinforcing steel.

If you have any questions regarding these issues, please contact Bijan Khaleghi at 705-7181.

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