Structural Design Using Stainless Steel Strands

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This article highlights some of the articles in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* that need special consideration when stainless steel strands are used in the design of pretensioned concrete members. The article numbers and titles referenced here are those of the 8th edition of the specifications.[1] The numbers in parentheses are article numbers (if different) from the 7th edition.[2]

Stainless steel strands being used in the production of prestressed concrete piles for Louisiana Department of Transportation and Development Bayou Thunder Overflow Project (LA 1 bridges near Grand Isle). All Photos: Krista Brown.

5.4.4 Prestressing Steel

Article 5.4.4.1 states that strand shall conform to AASHTO M 203. The AASHTO *Standard Specification for Steel Strand, Uncoated Seven-Wire for Concrete* (AASHTO M 203)[3] provides the required properties for Grades 250 and 270 carbon steel prestressing strands. No similar standard currently exists for stainless steel. A comparison of the properties of carbon steel strand and 2205 stainless steel strand is provided in the following table. Currently, the availability of 2205 stainless steel strand is limited to Grade 250, which has a slightly smaller nominal cross-sectional area than Grade 270. The lower strength of the stainless steel requires more strands compared to a design using Grade 270 strands.

5.4.4.2 Modulus of Elasticity

Article 5.4.4.2 states that the modulus of elasticity of prestressing steel may be taken as 28,500 ksi, if more precise data are not available. As shown in the table, 2205 stainless steel has a lower modulus of elasticity than conventional 1080 strand. Therefore, the lower modulus of elasticity shown in the table would be more appropriate to use when designing with 2205 stainless steel strand. However, it is most accurate to use the value recommended by the manufacturer.

	AASHTO M 203	Stainless Steel
Steel type	1080 carbon	2205 stainless
Grade	250 and 270	250
Total elongation	> 3.5%	1.2% to 2.0%
Relaxation: 1000 hours @ 80% GUTS	< 3.5%	< 3.5%
Modulus of elasticity	28,500 ksi*	24,500 ksi*

Note: Data from www.sumidenwire.com/products/stainless-steel-pc-strand.
GUTS = guaranteed ultimate tensile strength.
Nominal value—actual value may vary with manufacturer's production lot.

5.5.4.2 Resistance Factors

As shown in the table, 2205 stainless steel strand has considerably less elongation at rupture than conventional 1080 strand. Consequently, flexural members are likely to have less maximum ductility when stainless steel strand is used. To offset this lower maximum elongation, it may be appropriate to use a lower value for the strength resistance factor ϕ in tension-controlled sections when 2205 strand is used. However, specific values for ϕ have not been determined.

5.6 Design for Flexural and Axial Force Effects – B Regions

Equations in Article 5.6.3.1.1—Components with Bonded Tendons are based on the assumption that the distribution of steel is such that it is reasonable to consider that all of the prestressing force is located at the centroid of the prestressing steel. In addition, an average stress in the strands may be used for calculation of nominal flexural resistance. However, because of the lower ductility of the 2205 stainless steel strand, it may be more appropriate to use a method based on the condition of equilibrium and strain compatibility, with the stress in the extreme row of strands not exceeding 250 ksi for Grade 250.

5.7 (5.8) Design for Shear and Torsion – B Regions

Alvaro, Kahn, and Kurtis[4] reported that the use of 2205 stainless steel strands in combination with stainless steel 304 wire spiral reinforcement provided shear strength equivalent to that of conventional wire spiral reinforcement when used in prestressed concrete piles. Although the research focused on the spiral reinforcement, there does not seem to be any reason why shear design should be different when 2205 stainless steel strand is used, except to account for its lower tensile strength when calculating the longitudinal reinforcement requirement of Article 5.7.3.5.

5.9.2.2 (5.9.3) Stress Limitations for Prestressing Steel

Table 5.9.2.2-1 limits the stress in low-relaxation strand immediately prior to transfer to 75% of the specified tensile strength f_{pu}. Based on their research with piles, Alvaro, Kahn, and Kurtis[4] recommended that, until further studies are completed, the 2205 stainless steel strand be initially stressed to not greater than 70% of the specified tensile strength f_{pu}. This recommendation was implemented in the project described in the companion article, "Production of Prestressed Concrete Piles Using Stainless Steel Strand," beginning on page 30 of this issue of *ASPIRE*®. Stressing the 2205 stainless steel strand to a lower percentage of the specified tensile strength in combination with the lower tensile strength of the strand results in a larger required area of stainless steel prestressing strand compared to a design using conventional 1080 strand.

5.9.3.3 (5.9.5.3) Approximate Estimate of Time-Dependent Losses

Article 5.9.3.3 includes an equation for long-term prestress loss from creep of concrete, shrinkage of concrete, and relaxation of steel. The values of creep and shrinkage should not change with the use of stainless steel strand. The estimated relaxation loss is taken as 2.4 ksi for conventional low-relaxation strand. Tests have indicated that relaxation losses are similar for both 1080 and 2205 steel strands.[4] However, it is more accurate to use the value recommended by the manufacturer.

5.9.3.4 (5.9.5.4) Refined Estimates of Time-Dependent Losses

Article 5.9.3.4 includes a term for relaxation losses to be taken as 1.2 ksi before the deck is cast and 1.2 ksi after the deck is cast, for a total of 2.4 ksi. Again, it is recommended to use the manufacturer's recommended value.

5.9.4.3 (5.11.4) Development of Pretensioning Strand

Article 5.9.4.3.1 states that the transfer length of pretensioned strand shall be taken as 60 strand diameters. Test results from prestressed concrete piles have indicated that the transfer length of 2205 stainless steel strand was similar to that of 1080 strand and less than 60 strand diameters.[5] Therefore, it seems that 60 strand diameters can be used for stainless steel strands.

Article 5.9.4.3.2 provides an equation for the calculation of development length of pretensioned strand. Measured development lengths of 2205 stainless steel strand were 55% of the lengths calculated using the AASHTO equation.[5] Therefore, the development length with 2205 strand can be conservatively estimated using the equation in Article 5.9.4.3.2.

5.10.1 (5.12.3) Concrete Cover

Article 5.10.1 states that cover for pretensioned prestressing strand shall be the same as for reinforcing steel. Because the specifications do not currently include stainless steel strand, the required concrete cover for 2205 stainless steel strand is the same as that for conventional 1080 strand.

Summary

The availability of stainless steel prestressing strand provides another means to enhance the durability of prestressed concrete. The properties of the stainless steel strand, however, must be considered in the structural design.

References

1. AASHTO (American Association of State Highway and Transportation Officials). 2017. *AASHTO LRFD Bridge Design Specifications*. 8th ed. Washington, DC: AASHTO.
2. AASHTO. 2014. *AASHTO LRFD Bridge Design Specifications*. 7th ed. Washington, DC: AASHTO.
3. AASHTO. 2012. *Standard Specification for Steel Strand, Uncoated Seven-Wire for Concrete* (M 203-12). Washington, DC: AASHTO.
4. Alvaro P., L. F. Kahn, and K. E. Kurtis. 2015. *Corrosion-Free Precast Prestressed Concrete Piles Made with Stainless Steel Reinforcement: Construction, Test and Evaluation*. Report no. FHWA-GA-15-1134. Atlanta: Georgia Institute of Technology.
5. Alvaro, P., L. B. Gleich, and L. F. Kahn. 2017. "Transfer and Development Length of High-Strength Duplex Stainless Steel Strand in Prestressed Concrete Piles." *PCI Journal*, 62 (3): 59–71.

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Packs of stainless steel strand to be used in the production of prestressed concrete piles.