New FHWA Post-Tensioned Box Girder Design Manual

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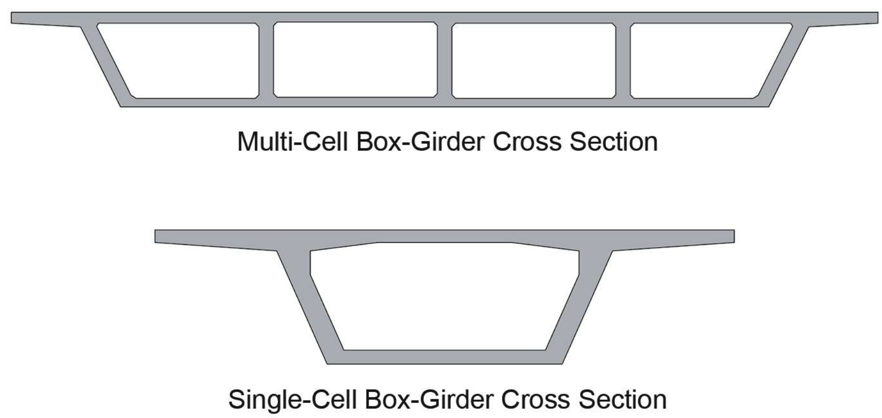

Figure 1. Typical concrete box-girder cross section. All Figures: Developed by Corven Engineering for the Federal Highway Administration.

The Federal Highway Administration (FHWA) is pleased to announce the release of a new manual for the analysis and design of concrete box-girder bridges. The *Post-Tensioned Box Girder Design Manual* was developed as a part of the FHWA project Advancing Steel and Concrete Bridge Technology to Improve Infrastructure Performance. Brian Kozy and Reggie Holt of FHWA are providing direction to the project team led by Lehigh University and that includes Corven Engineering. The author of the manual is John Corven of Corven Engineering.

The *Post-Tensioned Box Girder Design Manual* focuses on cast-in-place, post-tensioned concrete box-girder bridges with superstructure cross sections similar to those shown in Fig. 1. The manual serves as a resource to state departments of transportation and consulting firms that are exploring the benefits of, or are looking for guidance on, using this method of bridge construction.

Introductory Chapters

The FHWA *Post-Tensioned Box Girder Design Manual* was developed for engineers who have limited exposure to the design and construction of prestressed concrete bridges. Chapter 1 presents a brief history of the use of the bridge type and describes the basic components of a box-girder superstructure. Typical geometries of post-tensioning tendons for cast-in-place concrete bridges are also presented in Chapter 1, along with descriptions and photographs of the components that comprise a post-tensioning tendon. This chapter concludes with an overview of the construction of cast-in-place concrete box-girder superstructures.

Material characteristics of the concrete and prestressing steel are presented in Chapter 2 of the manual. Pertinent time-dependent characteristics in accordance with the *CEB-FIP Model Code* (1990) of the concrete (creep and shrinkage) and the prestressing steel (relaxation) are presented. Design provisions of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications* that address prestress losses related to time-dependent material characteristics are presented in a later chapter.

Prestressing with Post-Tensioning

Two chapters of the manual deal with the mechanics of prestressing a girder with post-tensioning. Chapter 3 presents typical stress summaries that are the result of girder self-weight, superimposed loads, and post-tensioning. Equations for the summation of total stress are then rearranged in two useful ways, so that the prestressing force required at a cross section can be found directly for a given tendon eccentricity and the permissible limits of eccentricity can be found for a given prestressing force. Figure 2, taken from Chapter 3, graphically depicts the first of these two, where the internal moment resulting from the prestressing, taken about the upper kern, is equated to the externally applied bending moment. Chapter 3 also presents the geometric features of post-tensioning tendons comprised of a series of parabolic profiles, the tendon geometry most commonly used in cast-in-place concrete box-girder construction. These geometric features are then used to evaluate secondary moments due to the prestressing of continuous-span girders.

Losses in prestress resulting from tendon friction, wobble, anchor set, and elastic shortening are developed and presented in Chapter 4. The calculation of tendon elongations is presented in this chapter, as well as lump-sum time-dependent losses in prestressing force as predicted by applicable AASHTO LRFD guidelines. Considerations for single-end and two-end stressing are discussed. Figure 3, taken from Chapter 4, shows a typical tendon force diagram along the length of a three-span, post-tensioning tendon after two-end stressing and anchor set.

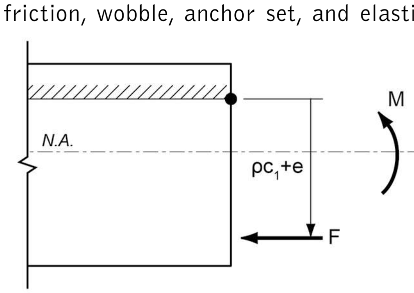

Figure 2. Equilibrium of internal and external moments.

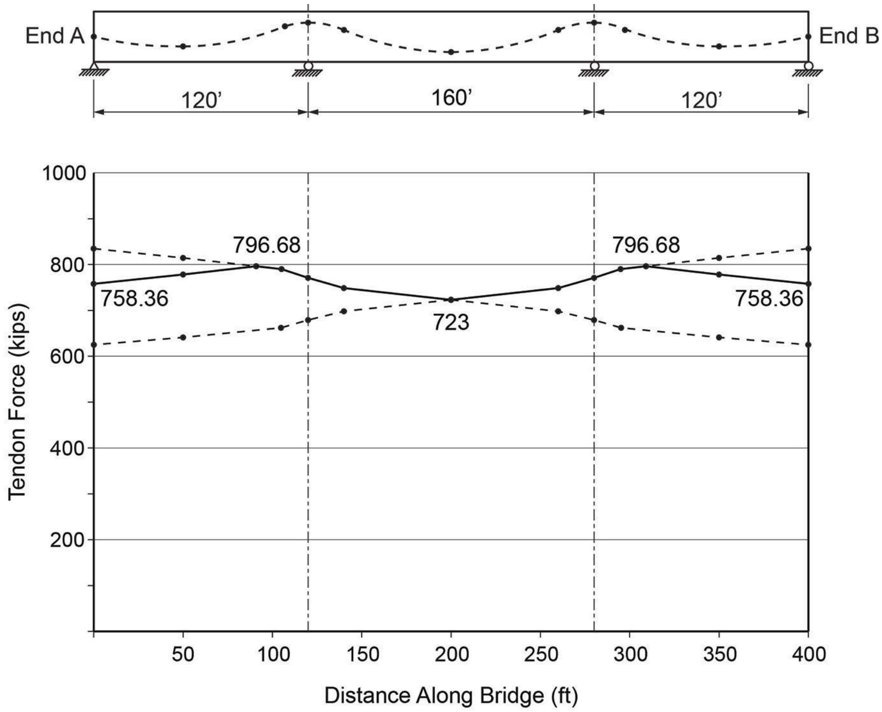

Figure 3. Tendon force diagram after stressing from both ends.

Preliminary Design

Chapter 5 walks through the preliminary design process for a cast-in-place, post-tensioned box-girder bridge using a three-span continuous bridge as an example. Guidelines for the dimensions of the box-girder superstructure, both of the overall girder and the members of the cross section, are presented. This is followed by the longitudinal analysis of the bridge to determine bending moments at critical sections. Post-tensioning tendon profiles and the number of strands in the tendons are selected based on the required prestressing force at each critical section. The jacking force of the tendons (P_{jack}) is established based on understanding the force in the tendon along its length. Finally, service limit states are verified, substantiating the preliminary design.

Cast-in-place box-girder bridges are often constructed monolithically with supporting columns. Chapter 6 presents additional design considerations when the substructure is integral with the superstructure. Superstructure bending moments caused by the restraint of the integral substructures are evaluated. The load cases discussed include temperature rise and fall, temperature gradient, concrete creep, and concrete shrinkage.

Final Design

Chapters 7, 8, and 9 of the *Post-Tensioned Box Girder Design Manual* focus on final design. Longitudinal superstructure analysis and design are addressed in Chapter 7. Guidelines for computer modeling of post-tensioned box girders are presented in this chapter. Modeling concepts for straight and curved bridges, with or without integral substructures, are discussed. Final design is presented by continuing the design of the bridge for which preliminary design was developed in Chapter 5. The mechanics of cross-section ultimate capacities with regard to flexure and shear are developed. The chapter concludes with the verification of strength limit states in accordance with the AASHTO LRFD specifications.

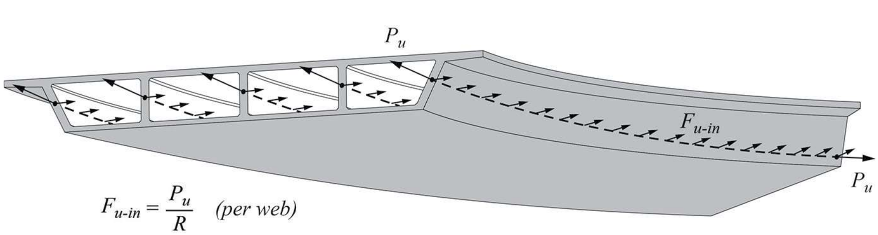

Figure 4. Effects of tendons in curved concrete members.

Box-girder superstructures require analysis and design in the transverse direction. Chapter 8 presents both the approximate design method from the AASHTO LRFD specifications and a generalized approach to transverse analysis and design for single-cell box-girder superstructures.

Chapter 9 presents three important design considerations for post-tensioned box-girder bridges, beginning with a detailed look into the local behavior of tendons in curved concrete members, depicted in Fig. 4. Both in-plane and out-of-plane force effects and resistances are presented. This information is followed by a discussion of end anchorage zones and the transfer of superstructure loads to the substructure through diaphragms for both nonintegral and integral superstructures.

Useful Appendices

The *Post-Tensioned Box Girder Design Manual* includes four useful Appendices. Appendix A presents a hand method of structural analysis of indeterminate structures—the Method of Joint Flexibilities. This flexibility-based method, which relates simple-span girder rotations to continuity moments in continuous structures, is an excellent tool for analyzing post-tensioned structures where tendon paths are quickly integrated as curvature diagrams to produce simple span end rotations. Appendix B presents fundamental torsional characteristics of single- and multi-cell box-girder structures. Equations for shear flow and the torsional constant for cross sections are presented in this Appendix. Appendices C and D contain design examples for three-span continuous bridges.

No Cost Download

The *Post-Tensioned Box Girder Design Manual* can be downloaded from the FHWA at no cost at https://www.fhwa.dot.gov/bridge/concrete/. This website contains many excellent bridge analysis and design resources.

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