Bridge Design - Concrete Design Theory

Course Number: CE-02-403

PDH: 3

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CONCRETE DESIGN THEORY

1.1 INTRODUCTION

Concrete is the most commonly used material in California highway structures, especially after the wide acceptance of prestressing technology in the 1950s. Nowadays, concrete bridges, prestressed or non-prestressed, account for about 90% of all bridges in the California highway system. Such dominancy is attributable to the many advantages that concrete offers:

- Ability to be cast in almost any shape
- Low cost
- Durability
- Fire resistance
- Energy efficiency
- On-site fabrication
- Aesthetic properties

Concrete design has evolved from Allowable Stress Design (ASD), also Working Stress Design (WSD), to Ultimate Strength Design (USD) or Load Factor Design (LFD), to today's Limit State Design (LSD) or Load and Resistance Factor Design (LRFD). Concrete design takes on a whole new look and feel in the *AASHTO LRFD Bridge Design Specifications* (AASHTO, 2012). New concepts that had been ruminating amongst concrete experts for decades reached a level of maturity appropriate for implementation. While not perfect, the new methods are more rational than those in the *AASHTO Standard Specifications for Highway Bridges* (AASHTO, 2002) and entail an amount of effort appropriate given today's technology compared to that available when the LFD was developed. Changes include:

- Unified design provisions for reinforced and prestressed concrete
- Modified compression field theory for shear and torsion
- Alternative Strut and Tie modeling techniques for shear and flexure
- End zone analysis for tendon anchorages
- New provisions for segmental construction
- Revised techniques for estimating prestress losses

This course will summarize the general aspects of concrete component design using the *AASHTO LRFD Bridge Design Specifications* (AASHTO, 2012) with the *California Amendments* (Caltrans, 2014a).

1.2 STRUCTURAL MATERIALS

1.2.1 Concrete

The most important property of concrete is the compressive strength. Concrete with 28-day compressive strength f_c' = 3.6 ksi is commonly used in conventionally reinforced concrete structures while concrete with higher strength is used in prestressed concrete structures. The California Amendments (Caltrans, 2014a) specify minimum design strength of 3.6 ksi for concrete, and AASHTO Article 5.4.2.1 (AASHTO, 2012) requires minimum design strength of 4.0 ksi for prestressed concrete. When a higher strength is specified for a project, designers should consider various factors including cost and local availability.

1.2.2 Reinforcing Steel

Steel reinforcing bars are manufactured as plain or deformed bars. In California, the main reinforcing bars are always deformed. Plain bars are usually used for spirals or hoops.

Reinforcing bars must be low-alloy steel deformed bars conforming to requirements in ASTM A 706/A 706M with a 60 ksi yield strength, except that deformed or plain billet-steel bars conforming to the requirements on ASTM A 615/A 615M, Grade 40 or 60, may be used as reinforcement in some minor structures as specified in *Caltrans Standard Specifications* (Caltrans, 2015).

1.2.3 Prestressing Steel

Two types of high-tensile strength steel used for prestressing steel are:

1. Strands: ASTM A 416 Grade 270, low relaxation.
2. Bars: ASTM A 722 Type II

All Caltrans designs are based on low relaxation strands using either 0.5 in. or 0.6 in. diameter strands.

1.3 DESIGN LIMIT STATES

Concrete bridge components are designed to satisfy the requirements of service, strength, and extreme-event limit states for load combinations specified in AASHTO Table 3.4.1-1 (AASHTO, 2012) with Caltrans revisions (Caltrans, 2014). The following are the four limit states into which the load combinations are grouped:

I. *Service Limit States*
Concrete stresses, deformations, cracking, distribution of reinforcement, deflection, and camber are investigated at service limit states.

Service I: Crack control and limiting compression in prestressed concrete
Service III: Crack control/tension in prestressed concrete
Service IV: Post-tensioned precast column sections

II. *Strength Limit States*
Axial, flexural, shear strength, and stability of concrete components are investigated at strength limit states. Resistance factors are based on AASHTO Article 5.5.4.2 (AASHTO, 2012).

Strength I: Basic load (HL-93)
Strength II: Owner specified load (Permit)
Strength III: Wind on structure
Strength IV: Structure with high DL/LL (>7)
Strength V: Wind on structure and live load

III. *Extreme Event Limit States*
Concrete bridge components and connections must resist extreme event loads due to earthquake and appropriate collision forces, but not simultaneously.

IV. *Fatigue Limit States*
Fatigue of the reinforcement need not be checked for fully prestressed concrete members satisfying requirements of service limit state. Fatigue need not be investigated for concrete deck slab on multi-girder bridges. For fatigue requirements, refer to AASHTO Article 5.5.3 (AASHTO, 2012).

1.4 FLEXURE DESIGN

1.4.1 Strength Limit States

1.4.1.1 Design Requirement

In flexure design, the basic strength design requirement can be expressed as follows:

$$M_u \le \phi M_n = M_r$$

where M_u is the factored moment at the section (kip-in.); M_n is the nominal flexural resistance (kip-in.); and M_r is the factored flexural resistance of a section in bending (kip-in.).