



Bridge Deck Design

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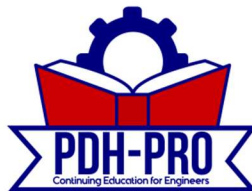
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1.0 INTRODUCTION

This course provides practical information regarding the decking options and design considerations for steel bridges, presenting deck types such as concrete deck slabs, metal grid decks, orthotropic steel decks, wood decks, and several others. The choice of the particular deck type to use can depend on several factors, which may include the specific application, initial cost, life cycle cost, durability, weight, or owner requirements. For the deck types discussed herein, a brief description of the particular deck type is given, in addition to general design and detail considerations. Reference should be made to the *AASHTO LRFD Bridge Design Specifications (5th Edition, 2010)*, Section 9: Decks and Deck Systems (1), for specific design requirements associated with the various deck types.

The primary function of a bridge deck is to support the vehicular vertical loads and distribute these loads to the steel superstructure. The deck is typically continuous along the span of the bridge and continuous across the width of the span. In most applications, the bridge deck is made composite with the steel superstructure through positive attachment to the girders, such as using shear connectors to attach the concrete deck slabs to steel girders. In such cases, the deck serves as part of the top flange in the composite section and can be utilized for strength and stiffness. The deck is subjected to local flexural bending of the slab spanning over the girders in the transverse direction caused by the vehicle wheel loads. When the deck is made composite, it is also subjected to longitudinal stresses caused by flexure along the span. The deck, when positively attached to the girders, provides continuous bracing of the top flange in the finished structure, and provides stability to the overall bridge system. The deck will also act as a horizontal diaphragm that is capable of transferring lateral loads, such as wind or seismic loads, to the supports.

2.0 CONCRETE DECK SLABS

Generally, reinforced concrete deck slabs are the most often used type of deck for steel bridges. Concrete deck slabs can be constructed with cast-in-place or precast methods, and typically include mild steel reinforcement in the longitudinal and transverse directions. Although not common to typical steel bridges, concrete decks can utilize post-tensioning steel in addition to the mild steel reinforcement in an effort to provide additional strength and durability.

2.1 General

Reinforced concrete deck slabs must not only be designed for dead and live loads at the service and strength limit states, the *AASHTO LRFD (5th Edition, 2010)* requires that the deck also be designed for a vehicular collision with the railing system at the extreme event limit state (Article 9.5.5). The fatigue limit state does not need to be investigated for concrete deck slabs used in multi-girder bridges.

The *AASHTO LRFD (5th Edition, 2010)* provides two methods for deck design: The Traditional Design Method and the Empirical Design Method. The traditional design method can typically be employed in any situation, while the empirical design method has limitations based on deck geometry and bridge behavior. Additionally, a bridge owner may explicitly specify which design method shall be used by the designer.

The *AASHTO LRFD (5th Edition, 2010)* requires that the minimum thickness of concrete deck, excluding any provisions for grinding, grooving, or sacrificial wearing surface, should not be less than 7 inches. Thinner decks may be acceptable, only if approved by the bridge owner. For concrete deck slabs with a thickness less than 1/20 of the design span, consideration should be given to the use of prestressing steel in the direction of that span in order to control cracking (see Article C9.7.1.1).

2.2 Traditional Design Method (Equivalent Strip Method)

The Traditional Design Method, typically referred to as the Equivalent Strip Method, is based on flexure of the deck in the transverse direction. The equivalent strip method applies to concrete deck slabs that are at least 7 inches thick, have sufficient concrete cover, and have four layers of steel reinforcement, with longitudinal and transverse layers at both the top and bottom of the deck slab. In a typical girder bridge the longitudinal direction of the deck is parallel to the main supporting girder, and the transverse direction is perpendicular to the main supporting girder. If the deck is only supported by the main supporting girders, then the deck is typically designed for primary reinforcement in the transverse direction, and that primary reinforcement is perpendicular to the direction of traffic.

The equivalent strip method assumes a transverse strip of deck supports the truck axle loads. The transverse strip is to be treated as a continuous beam, or simply supported beam as appropriate, assuming pinned supports at the centerline of each girder web. The deflection of the beam is assumed to be zero for this design procedure. The width of the strip is determined in accordance with *AASHTO LRFD (5th Edition, 2010)* Article 4.6.2.1. As shown in Table

4.6.2.1.3-1, a different equivalent width is used for the overhang, and for positive and negative moment regions of the deck.

To determine live load effects, the strip can be analyzed with classical beam theory, moving truck axle wheel loads laterally, along the transverse strip, to produce moment envelopes. Multiple presence factors and the dynamic load allowance (impact) should also be included. Article 4.6.2.1.6 of the *AASHTO LRFD (5th Edition, 2010)* allows the axle wheel loads to be considered as concentrated loads, or as patch loads whose length along the span is taken as the length of the tire contact area plus the depth of the deck. The tire contact area should be computed in accordance with *AASHTO LRFD (5th Edition, 2010)* Article 3.6.1.2.5.

The primary reinforcement, along the transverse strip is designed using conventional principles of reinforced concrete design, similar to a one-way slab. The design location for maximum positive moment is at the location of the maximum positive moment. However for negative moment design, the design location for a typical steel girder bridge can be taken at a point that is located at one-quarter of the flange width, measured from the centerline of the support, in accordance with Article 4.6.2.1.6. In bridges where the flange width varies, to be conservative, designers will typically use the smallest flange width to determine the negative moment design location.

In lieu of more precise calculations, unfactored design live load moments for many practical concrete deck slabs spans can be found in Table A4-1 of the *AASHTO LRFD (5th Edition, 2010)*. In this table, the design live load moments are provided as a function of girder spacing (S). Multiple presence factors and the dynamic load allowance (impact) are included in the tabulated values shown in Table A4-1. Interpolation is permitted between the girder spacings and design sections provided in the table. The tabulated values are not to be used for the design of the deck overhang.

The use of the equivalent strip method also requires that distribution reinforcement be placed in the secondary direction in the bottom of the slab, per Article 9.7.3.2. The amount of distribution reinforcement is based on a percentage of the primary reinforcement required to resist the positive moment in the primary direction, along the transverse strip. For primary reinforcement placed perpendicular to traffic, this secondary reinforcement in the bottom of the slab shall be taken as a percentage of the primary reinforcement equal to $220/S^{0.5}$, but does not need to be greater than 67%, where S is the effective span length and is equal to the effective length specified in Article 9.7.2.3.

The amount of reinforcement in the secondary direction in the top of the deck slab depends on whether the deck slab is in an area in which the main supporting girders are subjected to negative or positive flexure. If the deck slab is in an area of positive flexure, nominal reinforcement such as #4 bars spaced at 12 inches may be required. However, if the deck slab is in an area of negative flexure, additional steel reinforcement is required per Article 6.10.1.7, as discussed later within this section. This additional steel reinforcement may affect both the top and bottom reinforcement in the secondary direction.

2.3 Empirical Design Method

The Empirical Design Method is based on experimental research of reinforced concrete deck slabs, and employs the notion that the deck behaves more like a membrane as opposed to a series of continuous beams (transverse strips). Experimental research indicates that the primary structural action by which concrete slabs resist concentrated wheel loads is not flexure, but a complex internal membrane stress state referred to as internal arching that distributes the live loads from the deck to the supporting girders. This internal arching occurs due to the cracking of the concrete in the bottom of the slab, in the positive moment region of the design slab, and the resulting upward shift of the neutral axis in that section of the slab. Membrane compressive stresses develop which transmit the vertical live load from the deck to the girders, relying on the lateral confinement at the girder that occurs with the use of a composite design and ties between girders, such as those provided by cross frames with top struts or top flange lateral bracing.

The internal arching can be thought of as an internal compressive dome. Failure usually only will occur when there is overstraining around the perimeter of the wheel footprint, and will be in the form of a punching shear. The internal arching action of the concrete alone cannot resist the full wheel load, but a small amount of isotropic reinforcement is more than adequate to resist this small flexural component. The isotropic reinforcement also creates a global confinement, which is required to produce the internal arching effects.

Per Article 9.7.2.4 of the *AASHTO LRFD (5th Edition, 2010)*, the empirical design method can only be used if several limitations related to the geometric configuration of the concrete deck slab are satisfied. The empirical design method does not necessarily employ any design procedures, as the minimum reinforcement required is specified. The minimum amount of reinforcement is 0.27 in.²/ft of steel for the bottom layer in each direction and 0.18 in.²/ft of steel for the top layer in each direction. The steel reinforcement ratios correspond to a 7.5 in. thick deck slab, and may need to be adjusted if a thicker deck slab is used. Also, spacing of the steel reinforcement can not exceed 18 inches, and the steel reinforcement must have a yield strength of 60 ksi or greater. The empirical method can not be applied to cantilever portions of the deck slab.

2.4 Other Methods of Analysis and Design

Article 9.6.1 of the *AASHTO LRFD (5th Edition, 2010)* allows for the use of refined methods of analysis for deck slabs as specified in Article 4.6.3.2. Refined methods can include finite element analysis, grillage analyses, or orthotropic plate theory. A finite element analysis may consist of a mesh of shell or brick-type elements representing the concrete deck alone, and can be used to determine the local transverse bending moments in the concrete slab. A grillage analysis using beam elements to represent the deck can also be used to determine the transverse bending moments in the concrete slab.

Local moments in the deck slab due to wheel loads can also be calculated through the use of Pucher Influence Charts, a practice somewhat common in Europe. The Pucher charts are a series of contour plots of influence surfaces for various plate and loading geometries, which can be used for deck design.

2.5 Bridge Deck Overhang (Cantilever Slab) and Barriers (Railings)

The cantilever portion of the deck slab (deck overhang) must be designed for dead and live load moments for the strength and service limit states, where the moments are based on traditional beam theory. However, the deck overhang design must also consider a vehicular collision load with the railing system at the extreme event limit state. Article A13.4 of the *AASHTO LRFD (5th Edition, 2010)* provides the design procedures associated with the vehicular collision load. In accordance with Article A13.4.1, bridge deck overhangs should be designed for the following three design cases:

- Design Case 1: Transverse and longitudinal forces specified in Article A13.2 for the Extreme Event Load Combination II limit state;
- Design Case 2: Vertical forces specified in Article A13.2 for the Extreme Event Load Combination II limit state;
- Design Case 3: The loads specified in Article 3.6.1 that occupy the overhang for the Load Combination Strength I limit state.

Although not explicitly stated in the above three design cases, the design of the bridge deck overhang should also consider serviceability requirements with regard to crack control and minimum steel reinforcement required for shrinkage and temperature effects.

Additionally, the bridge barriers (or railings) must be designed to withstand a predetermined level of crashworthiness, typically specified by the bridge owner or governing agency. The combination of the deck overhang and the bridge barrier must be capable of resisting a horizontal vehicular collision force. Bridge barriers (or railings) used on the National Highway System must be crash tested, and the crash test specimen should include the barrier and deck overhang. In accordance with Article 13.7.3.1 of the *AASHTO LRFD (5th Edition, 2010)*, “a railing system and its connection to the deck shall be approved only after they have been shown through crash testing to be satisfactory for the desired test level.” Most States have typical barrier designs that have been tested and meet the specified levels of crashworthiness.

To develop a preliminary design of a barrier and overhang the Engineer should reference Section 13 of the *AASHTO LRFD (5th Edition, 2010)*, which provides design guidelines and specifications. Most often, concrete barriers (railings) are employed, and Article A13.3.1 provides a methodology for the design of the barrier based on an application of the yield line theory. For further information, design examples demonstrating the application of the yield line theory, in accordance with Article A13.3.1 have been previously published by the Federal Highway Administration (FHWA), see references (2) and (3).

2.6 Precast Deck Slabs

Precast concrete deck panels can be used as an alternative to cast-in-place concrete decks, as they may reduce construction times associated with placing the deck in new bridge construction and deck reconstruction. Precast concrete deck panels are typically fabricated offsite, at a precasting plant that can provide optimal casting and curing conditions. As such, precast concrete deck panels are often more durable and more uniformly constructed than their cast-in-place



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