Naaman, A. E. A New Methodology for the Analysis of Beams Prestressed with Unbonded Tendons. In *External Prestressing in Bridges*. ACI SP-120. Edited by A.E. Naaman and J. Breen. American Concrete Institute, Farmington Hills, MI, 1990, pp. 339–354.

Naaman, A. E. Unified Design Recommendations for Reinforced Prestressed and Partially Prestressed Concrete Bending and Compression Members. *ACI Structural Journal*, Vol. 89, No. 2. American Concrete Institute, Farmington Hills, MI, March–April 1992, pp. 200–210.

Naaman, A. E. Rectangular Stress Block and T-Section Behavior. Open Forum: Problems and Solutions, *PCI Journal*, Vol. 47, No. 5. Prestressed Concrete Institute, Chicago, IL, September–October 2002, pp. 106–112.

Naaman, A. E., and F. M. Alkhairi. Stress at Ultimate in Unbonded Prestressing Tendons—Part I: Evaluation of the State-of-the-Art; Part II: Proposed Methodology. *ACI Structural Journal*, Vol. 88, No. 5; No. 6. American Concrete Institute, Farmington Hills, MI, September–October 1991; November–December 1991.

NCHRP. *National Cooperative Highway Research Report 472: Comprehensive Specification for the Seismic Design of Bridges*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2002.

NCHRP. Recommended LRFD Guidelines for the Seismic Design of Highway Bridges. Draft Report, NCHRP Project 20-07, Task 193. TRC Imbsen & Associates, Sacramento, CA, 2006.

NCHRP. *Transportation Research Circular E-C171: Durability of Concrete,* 2nd ed. National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, DC, 2013.

Noppakunwijai, P., N. Jongpitakseel, Z. Ma, S. A. Yehia, and M. K. Tadros. Pullout Capacity of Non-Prestressed Bent Strands for Prestressed Concrete Girders. *PCI Journal*, Vol. 47, No. 4. Prestressed Concrete Institute, Chicago, IL, July–August 2002, pp. 90–103.

Nowak, A.S., and A. M. Rakoczy. Statistical Parameters for Compressive Strength of Lightweight Concrete. *Proc., Concrete Bridge Conference*, Paper 68, Phoenix, AZ, February 24–25, 2010.

Nowak, A. S., M. M. Szerszen, E. K. Szeliga, A. Szwed, and P. J. Podhorecki. Reliability-Based Calibration for Structural Concrete, Phase 3. SN2849. Portland Cement Association, Skokie, Illinois, USA, 2008, 115 pp.

Nutt, R., C. Redfield, and R. Valentine. *National Cooperative Highway Research Report 620: Design Specifications and Commentary for Horizontally Curved Concrete Box-Girder Highway Bridges*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2008.

O'Connor, C. *Design of Bridge Superstructures*. Wiley-Interscience, New York, NY, 1971, p. 533.

Ozden, S. Behavior of High-Strength Concrete under Strain Gradient. University of Toronto, M.A. Thesis, Ontario, Canada, 1992, pp. 112–113.

Paczkowski, P., and A. S. Nowak. Reliability Models for Shear in Lightweight Reinforced Concrete Bridges. *Proc., Concrete Bridge Conference*, Paper 69, Phoenix, AZ, February 24–25, 2010.

Pauley, T., and M. J. N. Priestley. *Seismic Design of Reinforced Concrete and Masonry Buildings*. John Wiley and Sons, Inc., New York, NY, 1992.

PCA. *Design and Control of Concrete Mixtures*, 15th ed. Portland Cement Association, Skokie, IL, 2011.

PCA. *PCA Notes on ACI 318-11 Building Code Requirements for Structural Concrete with Design Applications*. Portland Cement Association, Skokie, IL, 2013.

PCI. Recommendations for Estimating Prestress Losses. *PCI Journal*, Vol. 20, No. 4. Prestressed Concrete Institute, Chicago, IL, July–August 1975.

PCI. *PCI Design Handbook*, 7th ed. Precast/Prestressed Concrete Institute, Chicago, IL, 2010.

PCI. CB-02-16-E, Recommended Practice for Lateral Stability of Precast, Prestressed Concrete Bridge Girders. Precast/Prestressed Concrete Institute, Chicago, IL.

Podolny, Jr., Walter. Evaluation of Transverse Flange Forces Induced by Laterally Inclined Longitudinal Post-Tensioning in Box Girder Bridges. *PCI Journal*, Vol. 31, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 1986.

Podolny, J. W. and J. M. Muller. *Construction and Design of Prestressed Concrete Segmental Bridges*. Wiley, New York, NY, 1982.

Poston, R. W., R. L. Carrasquillo, and J. E. Breen. Durability of Post-Tensioned Bridge Decks. *ACI Materials Journal*, Vol. 84, No. 4. American Concrete Institute, Farmington Hills, MI, July–August 1987.

Priestley, M. J. N. *Assessment and Design of Joints for Single-Level Bridges with Circular Columns*. Department of Applied Mechanics and Engineering Sciences, University of California, San Diego, CA, 1991.

Priestley, M. J. N., and R. Park. Seismic Resistance of Reinforced Concrete Bridge Columns. *Proc., Workshop on the Earthquake Resistance of Highway Bridges*, Applied Technology Council, Berkeley, CA, January 1979.

Priestley, M. J. N., R. Park, and R. T. Potangaroa. Ductility of Spirally Confined Concrete Columns. *Transactions of the ASCE Structural Division*, Vol. 107, No. ST4. American Society of Civil Engineers, Washington, DC, January 1981, pp. 181–202.

Priestley, M. J. N., and J. R. Tao. Seismic Response of Precast Prestressed Concrete Frames with Partially Debonded Tendons. *PCI Journal*, Vol. 38, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 1993, pp. 58–69.

Rabbat, B. G., and M. P. Collins. The Computer-Aided Design of Structural Concrete Sections Subjected to Combined Loading. Presented at the Second National Symposium on Computerized Structural Analysis and Design, Washington, DC, March 1976.

Rabbat, B. G., and M. P. Collins. A Variable Angle Space Truss Model for Structural Concrete Members Subjected to Complex Loading." In *Douglas McHenry International Symposium on Concrete and Concrete Structures*, SP55. American Concrete Institute, Farmington Hills, MI, 1978, pp. 547–587.

Ramirez, G. Behavior of Unbonded Post-Tensioning Segmental Beams with Multiple Shear Keys. University of Texas, M.S. Thesis, Austin, TX, January 1989.

Ramirez, J. A. and J. E. Breen. *Experimental Verification of Design Procedures for Shear and Torsion in Reinforced and Prestressed Concrete.* 248-3; FHWA/TX-84/37+248-3. The Texas Center for Transportation Research, Texas Department of Transportation; Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 1983.

Ramirez, J. A. and J. E. Breen. Evaluation of a Modified Truss-Model Approach for Shear in Beams. *ACI Structural Journal* Vol. 88, No. 5. American Concrete Institute, Farmington Hills, MI, September–October 1991, pp. 562–572.

Ramirez, J. A. and B. W. Russell. *National Cooperative Highway Research Report 603: Transfer, Development, and Splice Length for Strand/Reinforcement in High-Strength Concrete.* National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, DC, 2008.

Rangan, V. Web Crushing Strength of Reinforced and Prestressed Concrete Beams. *ACI Structural Journal*, Vol. 88. No. 1. American Concrete Institute, Farmington Hills, MI, January–February 1991, pp. 12–16.

Rizkalla, S., A. Mirmiran, P. Zia, H. Russell, and R. Mast. *National Cooperative Highway Research Report 595: Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Flexure and Compression Provisions*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2007.

Roberts, C. L. Behavior and Design of the Local Anchorage Zone in Post-Tensioned Concrete. University of Texas, M.S. Thesis, Austin, TX, May 1990.

Roberts, C. L. 1993. Measurement-Based Revisions for Segmental Bridge Design and Construction Criteria. University of Texas, Ph.D. Dissertation, Austin, TX, December 1993.

Hamilton, H. R., G. R. Consolazio, and B. E. Ross. End Region Detailing of Pretensioned Concrete Bridge Girders. FDOT Contract No. BDK75 977-05. Florida Department of Transportation, Tallahassee, FL, 2013.

Rusch, H., D. Jungwirth, and H. K. Hilsdort. *Creep and Shrinkage*. Springer Verlag, New York, NY, 1983.

Russell, B. W., and N. H. Burns. *Design Guidelines for Transfer, Development and Debonding for Large Diameter Seven Wire Strands in Pretensioned Concrete Girders*. FHWA/TX-93+1210-5F. The Texas Center for Transportation Research, Texas Department of Transportation; Federal Highway Administration, 1993.

Russell, B. W., and N. H. Burns. Fatigue Tests on Prestressed Concrete Beams Made with Debonded Strands. *PCI Journal*, Vol. 39, No. 6. Precast/Prestressed Concrete Institute, Chicago, IL, November–December 1994, pp. 70–88.

Russell, H., C. Ozyildirim, M. K. Tadros, and R. Miller. *Compilation and Evaluation of Results from High Performance Concrete Bridge Projects*. Project DTFH61-00-C-00009 Compact Disc. Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2003.

Russell, B. W., N. H. Burns, and L. G. ZumBrunnen. Predicting the Bond Behavior of Prestressed Concrete Beams Containing Debonded Strands. *PCI Journal*, Vol. 39, No. 5. Precast/Prestressed Concrete Institute, Chicago, IL, September–October 1994, pp. 60–77.

Saleh, M. and M. K. Tadros. Maximum Reinforcement in Prestressed Concrete Members. *PCI Journal*, Vol. 42, No. 2. Precast/Prestressed Concrete Institute, Chicago, IL, March–April 1997, pp. 143–144.

Salmons, J. R. Behavior of Untensioned-Bonded Prestressing Strand. Final Report 77-1. Missouri Cooperative Highway Research Program, Missouri State Highway Department, Jefferson City, MO, June 1980.

Salomon, A., and C. Moen. Structural Design Guidelines for Concrete Bridge Decks Reinforced with Corrosion-Resistant Reinforcing Bars*.* Final Report VCTIR 15-R10. Virginia Polytechnic and State University, Blacksburg, VA, October 2014.

Sanders, D. H. Design and Behavior of Post-Tensioned Concrete Anchorage Zones. University of Texas, Ph.D. Dissertation, Austin, TX, August 1990.

Schlaich, J., K. Schäfer, M. Jennewein. Towards a Consistent Design of Structural Concrete. *PCI Journal*, Vol. 32, No. 3. Prestressed Concrete Institute, Chicago, IL, May–June 1987, pp. 74–151.

Schlaich, J., and H. Scheef. *Concrete Box Girder Bridges*. International Association for Bridge and Structural Engineering, Zurich, Switzerland, 1982.

Schnittker, B., and O. Bayrak. Allowable Compressive Stress at Prestress Transfer. Technical Report 0-5197-4. Center for Transportation Research, Bureau of Engineering Research, University of Texas at Austin, December 2008.

Seguirant, S. J. Effective Compression Depth of T-Sections at Nominal Flexural Strength. Open Forum: Problems and Solutions. *PCI Journal*, Vol. 47, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 2002, pp. 100–105. See also discussion by A. E. Naaman and closure to discussion in Vol. 47, No. 3, May–June 2002, pp. 107–113.

Seguirant, S. J., R. Brice, and B. Khaleghi. Flexural Strength of Reinforced and Prestressed Concrete T-Beams. *PCI Journal*, Vol. 50, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 2005, pp. 44–73.

Shahawy, M., and B. de V Batchelor. Bond and Shear Behavior of Prestressed AASHTO Type II Beams. Progress Report. Structural Research Center, Florida Department of Transportation, February 1991.

Seguirant, S. J., R. Brice, and B. Khaleghi, Design Optimization for Fabrication of Pretensioned Concrete Bridge Girders: An Example Problem. *PCI Journal*, Vol. 54, No. 4. Prestressed Concrete Institute, Chicago, IL, Fall 2009, pp. 73-111.

Shahawy, M., B. Robinson, and de V Batchelor, B. 1993. *An Investigation of Shear Strength of Prestressed Concrete AASHTO Type II Girders*, Research Report. Structures Research Center, Florida Department of Transportation, January 1993.

Shahrooz, B. M., R. A. Miller, K. A. Harries, and H. G. Russell. *National Cooperative Highway Research Report 679: Design of Concrete Structures Using High-Strength Steel Reinforcement*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2011.

Shahrooz, B. M., R. A. Miller, K. A. Harries, Q. Yu, and H. G. Russell. *National Cooperative Highway Research Report 849: Strand Debonding for Pretensioned Girders*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2017.

Shioya, T., M. Iguro, Y. Nojiri, H. Akiyama, and T. Okada. Shear Strength of Large Reinforced Concrete Beams. In *Fracture Mechanics: Applications to Concrete*. SP-118. American Concrete Institute, Detroit, MI, 1989.

Shrivani, M., R. E. Klingner, H. L. Graves, III. Breakout Capacity of Anchors in Concrete—Part 1: Tension. *ACI Structural Journal*, Vol. 101, No. 6. American Concrete Institute, Farmington Hills, MI, November–December 2004, pp. 812-820.

Skogman, B. C., M. K. Tadros, and R. Grasmick. Ductility of Reinforced and Prestressed Concrete Flexural Members. *PCI Journal*, Vol. 33, No. 6. Prestressed Concrete Institute, Chicago, IL, November–December 1988, pp. 94–107.

Stone, W. C., and J. E. Breen. Behavior of Post-Tensioned Girder Anchorage Zones. *PCI Journal*, Vol. 29, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 1984, pp. 64–109.

Stone, W. C., and J. E. Breen. Design of Post-Tensioned Girder Anchorage Zones. *PCI Journal*, Vol. 29, No. 2. Prestressed Concrete Institute, Chicago, IL, March–April 1984, pp. 28–61.

Sullivan, S. R., C. L. R. Wollman, and M. K. Swenty. Composite Behavior of Precast Concrete Bridge Deck-Panel Systems. *PCI Journal*, Vol. 56, No. 3. Prestressed Concrete Institute, Chicago, IL, Summer 2011, pp. 43–59.

Tabatabai, H., A. Ghorbanpoor, and A. Turnquist-Nass. Rehabilitation Techniques for Concrete Bridges. Project No. 0092-01-06. Department of Civil Engineering and Mechanics at University of Wisconsin-Milwaukee, Wisconsin Department of Transportation, Madison, WI, 2004.

Tadros, M. K., N. Al-Omaishi, S. P. Seguirant, and J. G. Gallt. *National Cooperative Highway Research Report 496: Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders*. National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, 2003.

Tadros, M. K. and A. F. Girgis. Concrete Filled Steel Tube Arch. SPR-P1 (04) P571. Nebraska Department of Roads, Lincoln, NE, 2006.

Tadros, M. K., N. Jongpitaksseel, J. Bowers, and W. Amornrattanepong. Development of Fatigue Limit Formula for Deformed Welded Wire Reinforcement (WWR). Paper #79. *Proc., 2004 Concrete Bridge Conference*. National Concrete Bridge Council, Charlotte, NC, 2004.

Tantipidok, P., C. Kobayashi, K. Matsumoto, K. Watanabe, and J. Niwa. Proposed Predictive Equation for Diagonal Compressive Capacity of Reinforced Concrete Beams. *Journal of Japan Society of Civil Engineers*, Vol. 67. No. 2, 2011, pp. 535–548.

Tassin, D., B. Dodson, T. Takobayashi, K. Deaprasertwong, and Y. W. Leung. *Computer Analysis and Full-Scale Test of the Ultimate Capacity of a Precast Segmental Box Girder Bridge with Dry Joints and External Tendons*. American Segmental Bridge Institute, Phoenix, AZ, 1995.

Taylor, A. W., R. B. Rowell, and J. E. Breen. Design Behavior of Thin Walls in Hollow Concrete Bridge Piers and Pylons. Research Report 1180-1F. Center for Transportation Research, University of Texas, Austin, TX, 1990.

U.S. Government Printing Office. *Concrete Manual*, 8th ed. Bureau of Reclamation, U.S. Government Printing Office, Washington, DC, 1981 p. 627.

Van Dam, T. J., G. Dewey, L. Sutter, K. Smith, M. Wade, D. Peshkin, M. Snyder, and A. Patel. *Detection, Analysis, and Treatment of Materials-Related Distress in Concrete Pavements.* Interim Report, FHWA Contract No. DTFH61-96-C-00073. Turner-Fairbank Highway Research Center, Federal Highway Administration, U.S. Department of Transportation, McLean, VA, May 1998.

Van Landuyt, D. W. The Effect of Duct Arrangement on Breakout of Internal Post-Tensioning Tendons in Horizontally Curved Concrete Box-Girder Webs. University of Texas, M.S. Thesis, Austin, TX, 1991.

Vecchio, F. J., and M. P. Collins. The Modified Compression-Field Theory for Reinforced Concrete Elements Subjected to Shear. *ACI Structural Journal*. American Concrete Institute, Farmington Hills, MI, 1986, pp. 219-231.

Walker, S., and D. L. Bloem. Effect of Aggregate Size on Properties of Concrete. *Journal of the American Concrete Institute*, Vol. 57, No. 3. American Concrete Institute, Farmington Hills, MI, September 1960, pp. 283–298.

Walraven, J., J. Fronay, and A. Pruijssers. Influence of Concrete Strength and Load History on the Shear Friction Capacity of Concrete Members. *PCI Journal*, Vol. 32, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 1987, pp. 66–84. See also "Reader Comments," *PCI Journal*, Vol. 33, No. 1. Prestressed Concrete Institute, Chicago, IL, January–February 1988, pp. 166–168.

Weigel, J. A., Seguirant, S. J., Brice, R., and Khaleghi, B. High Performance Precast, Prestressed Concrete Girder Bridges in Washington State. *PCI Journal*, Vol. 48, No. 2. Prestressed Concrete Institute, Chicago, IL, March–April 2003, pp. 28–52.

Wight, J. K., and G. Parra-Montesinos. Use of Strut-and-Tie Model for Deep Beam Design as per ACI 318 Code. *Journal of the American Concrete Institute*, Vol. 25, No. 5. American Concrete Institute, Farmington Hills, MI, May 2003, pp. 63–70.

Williams, C., D. Deschenes, and O. Bayrak. *Strut-and-Tie Model Design Examples for Bridges: Final Report*. FHWA/TX-12/5-5253-01-1. Texas Department of Transportation, Austin, TX, 2012.

Williams, C., A. Moore, D. Al-Tarafany, J. Massey, O. Bayrak, J. O. Jirsa, and W. Ghannoum. Behavior of the Splice Regions of Spliced I-Girder Bridges. FHWA/TX-14/0-6652-2. Texas Department of Transportation, Austin, TX; Federal Highway Administration, U.S. Department of Transportation, Washington, DC, 2015.
Available at http://library.ctr.utexas.edu/ctr-publications/0-6652-2.pdf

Wollmann, G. P. *Anchorage Zones in Post-Tensioned Concrete*. University of Texas, Austin, TX, May 1992.

Zhang, J., S. Qian, and B. Baldock. Laboratory Study of Corrosion Performance of Reinforced Steels for Use in Concrete Structures. Report IRC-RR, 284. National Research Council of Canada, Ontario, Canada, 2009.

Zia, P., H. K. Preston, N. L. Scott, and E. B. Workman. Estimating Prestress Losses. *Concrete International: Design and Construction*, Vol. 1. American Concrete Institute, Farmington Hills, MI, June 1979, pp. 32–38.

APPENDIX A5—BASIC STEPS FOR CONCRETE BRIDGES

A5.1—GENERAL

This outline is intended to be a generic overview of the design process using the simplified methods for illustration. It should not be regarded as complete, nor should it be used as a substitute for a working knowledge of the provisions of this section.

A5.2—GENERAL CONSIDERATIONS

A. Design Philosophy (1.3.1)
B. Limit States (1.3.2)
C. Design Objectives and Location Features (2.3) (2.5)

A5.3—BEAM AND GIRDER SUPERSTRUCTURE DESIGN

A. Develop General Section
    1. Roadway Width (Highway-Specified)
    2. Span Arrangements (2.3.2) (2.5.4) (2.5.5) (2.6)
    3. Select Bridge Type
B. Develop Typical Section
    1. Precast P/S Beams
        a. Top Flange (5.12.3.2.2)
        b. Bottom Flange (5.12.3.2.2)
        c. Webs (5.12.3.2.2)
        d. Structure Depth (2.5.2.6.3)
        e. Minimum Reinforcement (5.6.7) (5.6.3.3)
        f. Lifting Devices (5.12.3.2.3)
        g. Joints (5.12.3.4.2)
    2. CIP T-Beams and Multiweb Box Girders (5.12.3.5)
        a. Top Flange (5.12.3.5.1a)
        b. Bottom Flange (5.12.3.5.1b)
        c. Webs (5.12.3.5.1c)
        d. Structure Depth (2.5.2.6.3)
        e. Reinforcement (5.12.3.5.2)
            (1) Minimum Reinforcement (5.6.3.3) (5.6.7)
            (2) Temperature and Shrinkage Reinforcement (5.10.6)
        f. Effective Flange Widths (4.6.2.6)
        g. Strut-and-Tie Areas, if Any (5.8.2)
C. Design Conventionally Reinforced Concrete Deck
    1. Deck Slabs (4.6.2.1)
    2. Minimum Depth (9.7.1.1)
    3. Empirical Design (9.7.2)
    4. Traditional Design (9.7.3)
    5. Strip Method (4.6.2.1)
    6. Live Load Application (3.6.1.3.3) (4.6.2.1.5)
    7. Distribution Reinforcement (9.7.3.2)
    8. Overhang Design (A13.4) (3.6.1.3.4)
D. Select Resistance Factors
    Strength Limit State (Conventional) (5.5.4.2)
E. Select Load Modifiers
    1. Ductility (1.3.3)
    2. Redundancy (1.3.4)
    3. Operational Importance (1.3.5)
F. Select Applicable Load Combinations and Load Factors (3.4.1, Table 3.4.1-1)
G. Calculate Live Load Force Effects
    1. Live Loads (3.6.1) and Number of Lanes (3.6.1.1.1)
    2. Multiple Presence (3.6.1.1.2)
    3. Dynamic Load Allowance (3.6.2)
    4. Distribution Factor for Moment (4.6.2.2.2)

a. Interior Beams with Concrete Decks (4.6.2.2.2b)
b. Exterior Beams (4.6.2.2.2d)
c. Skewed Bridges (4.6.2.2.2e)
5. Distribution Factor for Shear (4.6.2.2.3)
a. Interior Beams (4.6.2.2.3a)
b. Exterior Beams (4.6.2.2.3b)
c. Skewed Bridges (4.6.2.2.3c, Table 4.6.2.2.3c-1)
6. Reactions to Substructure (3.6)
H. Calculate Force Effects from Other Loads as Required
I. Investigate Service Limit State
1. P/S Losses (5.9.3)
2. Stress Limitations for P/S Tendons (5.9.2.2)
3. Stress Limitations for P/S Concrete (5.9.2.3)
a. Before Losses (5.9.2.3.1)
b. After Losses (5.9.2.3.2)
4. Durability (5.14)
5. Crack Control (5.6.7)
6. Fatigue, if Applicable (5.5.3)
7. Deflection and Camber (2.5.2.6.2) (3.6.1.3.2) (5.6.3.5.2)
J. Investigate Strength Limit State
1. Flexure
a. Stress in P/S Steel—Bonded Tendons (5.6.3.1.1)
b. Stress in P/S Steel—Unbonded Tendons (5.6.3.1.2)
c. Flexural Resistance (5.6.3.2)
d. Limits for Reinforcement (5.6.3.3)
2. Shear (Assuming No Torsional Moment)
a. General Requirements (5.7.2)
b. Sectional Design Model (5.7.3)
(1) Nominal Shear Resistance (5.7.3.3)
(2) Determination of β and θ (5.7.3.4)
(3) Longitudinal Reinforcement (5.7.3.5)
(4) Transverse Reinforcement (5.7.2.3) (5.7.2.5) (5.7.2.4) (5.7.2.6)
(5) Horizontal Shear (5.7.4)
K. Check Details
1. Cover Requirements (5.10.1)
2. Development Length—Reinforcement (5.10.8.1) (5.10.8.2)
3. Development Length—Prestressing (5.9.4.3)
4. Splices (5.10.8.4) (5.10.8.5)
5. Anchorage Zones
a. Post-Tensioned (5.9.5.6)
b. Pretensioned (5.9.4.4)
6. Ducts (5.4.6)
7. Tendon Profile Limitation
a. Tendon Confinement (5.9.5.4)
b. Curved Tendons (5.9.5.4)
c. Spacing Limits (5.9.5.1)
8. Reinforcement Spacing Limits (5.10.3)
9. Transverse Reinforcement (5.7.2.4) (5.7.2.6) (5.7.2.7)
10. Beam Ledges (5.8.4.3)

A5.4—SLAB BRIDGES

Generally, the design approach for slab bridges is similar to beam and girder bridges with some exceptions, as noted below.

A. Check Minimum Recommended Depth (2.5.2.6.3)
B. Determine Live Load Strip Width (4.6.2.3)
C. Determine Applicability of Live Load for Decks and Deck Systems (3.6.1.3.3)
D. Design Edge Beam (9.7.1.4)
E. Investigate Shear (5.12.2.1)
F. Investigate Distribution Reinforcement (5.12.2.1)

G. If Not Solid
   1. Check if Voided Slab or Cellular Construction (5.12.2.2.1)
   2. Check Minimum and Maximum Dimensions (5.12.2.2.1)
   3. Design Diaphragms (5.12.2.2.3)
   4. Check Design Requirements (5.12.2.2.4)

A5.5—SUBSTRUCTURE DESIGN

A. Establish Minimum Seat Width (4.7.4.4)
B. Compile Force Effects Not Compiled for Superstructure
   1. Wind (3.8)
   2. Water (3.7)
   3. Effect of Scour (2.6.4.4.2)
   4. Ice (3.9)
   5. Earthquake (3.10) (4.7.4)
   6. Temperature (3.12.2) (3.12.3) (4.6.6)
   7. Superimposed Deformation (3.12)
   8. Ship Collision (3.14) (4.7.5)
   9. Vehicular Collision (3.6.5)
   10. Braking Force (3.6.4)
   11. Centrifugal Force (3.6.3)
   12. Earth Pressure (3.11)
C. Analyze Structure and Compile Load Combinations
   1. Table 3.4.1-1
   2. Special Earthquake Load Combinations (3.10.8)
D. Design Compression Members (5.6.4)
   1. Factored Axial Resistance (5.6.4.4)
   2. Biaxial Flexure (5.6.4.5)
   3. Slenderness Effects (4.5.3.2.2) (5.6.4.3)
   4. Transverse Reinforcement (5.6.4.6)
   5. Shear (Usually EQ and Ship Collision Induced) (3.10.9.4.3)
   6. Reinforcement Limits (5.6.4.2)
   7. Bearing (5.6.5)
   8. Durability (5.14)
   9. Detailing (as in Step A5.3K) and Seismic (5.11)
E. Design Foundations (Structural Considerations)
   1. Scour
   2. Footings (5.12.8)
   3. Abutments (Section 11) (5.12.9)
   4. Pile Detailing (5.12.9)

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APPENDIX B5—GENERAL PROCEDURE FOR SHEAR DESIGN WITH TABLES

B5.1—BACKGROUND

The general procedure herein is an acceptable alternative to the procedure specified in Article 5.7.3.4.2. The procedure in this Appendix utilizes tabularized values of β and θ instead of Eqs. 5.7.3.4.2-1, 5.7.3.4.2-2, and 5.7.3.4.2-3. Appendix B5 is a complete presentation of the general procedures in LRFD Design (AASHTO 2007) without any interim changes.

B5.2—SECTIONAL DESIGN MODEL—GENERAL PROCEDURE

For sections containing at least the minimum amount of transverse reinforcement specified in Article 5.7.2.5, the values of β and θ shall be as specified in Table B5.2-1. In using this table, ε_x shall be taken as the calculated longitudinal strain at the mid-depth of the member when the section is subjected to M_u, N_u, and V_u as shown in Figure B5.2-1.

For sections containing less transverse reinforcement than specified in Article 5.7.2.5, the values of β and θ shall be as specified in Table B5.2-2. In using this table, ε_x shall be taken as the largest calculated longitudinal strain which occurs within the web of the member when the section is subjected to N_u, M_u, and V_u as shown in Figure B5.2-2.

Where consideration of torsion is required by the provisions of Article 5.7.2, V_u in Eqs. B5.2-3 through B5.2-5 shall be replaced by V_{eff}.

For solid sections:

$$V_{eff} = \sqrt{V_u^2 + \left(\frac{0.9 p_h T_u}{2A_o}\right)^2} \qquad \text{(B5.2-1)}$$

For hollow sections:

$$V_{eff} = V_u + \frac{T_u d_s}{2A_o} \qquad \text{(B5.2-2)}$$

Unless more accurate calculations are made, ε_x shall be determined as:

- If the section contains at least the minimum transverse reinforcement as specified in Article 5.7.2.5:

$$\varepsilon_x = \frac{\left(\frac{|M_u|}{d_v} + 0.5N_u + 0.5|V_u - V_p|\cot\theta - A_{ps} f_{po}\right)}{2(E_s A_s + E_p A_{ps})} \qquad \text{(B5.2-3)}$$

CB5.2

The shear resistance of a member may be determined by performing a detailed sectional analysis that satisfies the requirements of Article 5.7.3.1. Such an analysis (see Figure CB5.2-1) would show that the shear stresses are not uniform over the depth of the web and that the direction of the principal compressive stresses changes over the depth of the beam. The more direct procedure given herein assumes that the concrete shear stresses are uniformly distributed over an area b_v wide and d_v deep, that the direction of principal compressive stresses (defined by angle θ) remains constant over d_v, and that the shear strength of the section can be determined by considering the biaxial stress conditions at just one location in the web. See Figure CB5.2-2.

For solid cross-section shapes, such as a rectangle or an "I," there is the possibility of considerable redistribution of shear stresses. To make some allowance for this favorable redistribution it is safe to use a root-mean-square approach in calculating the nominal shear stress for these cross sections, as indicated in Eq. B5.2-1. The 0.9 p_h comes from 90 percent of the perimeter of the spalled concrete section. This is similar to multiplying 0.9 times the lever arm in flexural calculations.

For a hollow girder, the shear flow due to torsion is added to the shear flow due to flexure in one exterior web, and subtracted from the opposite exterior web. In the controlling web, the second term in Eq. B5.2-2 comes from integrating the distance from the centroid of the section, to the center of the shear flow path around the circumference of the section. The stress is converted to a force by multiplying by the web height measured between the shear flow paths in the top and bottom slabs, which has a value approximately equal that of d_s. If the exterior web is sloped, this distance should be divided by the sine of the web angle from horizontal.

Members containing at least the minimum amount of transverse reinforcement have a considerable capacity to redistribute shear stresses from the most highly strained portion of the cross section to the less highly strained portions. Because