Tentative Design and Construction Specifications for Precast Segmental Box Girder Bridges

Prepared by

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Precast segmental box girder bridge construction has gained wide acceptance throughout the world and is now being used increasingly in the United States.

Therefore, the PCI Bridge Committee, which is composed of engineers and managers in the prestressed concrete industry and the Subcommittee on Prestressed Concrete of the AASHTO Committee on Bridges and Structures, believes the need exists for specifications covering this type of bridge construction.

These tentative design and construction specifications and commentary are preliminary recommendations made available to bridge designers as advance information. They are not to be taken as approved specifications and should be used with proper discretion. Comments on the tentative specifications are invited.

The PCI Bridge Committee will evaluate all comments and new information prior to developing and submitting the final specifications to the AASHTO Committee on Bridges and Structures for approval.

CONTENTS

1.6.25—PRECAST SEGMENTAL BOX GIRDERS*

(A) General

Except as otherwise noted in this section, the provisions of Section 6—Prestressed Concrete shall apply to the analysis and design of precast segmental box girder bridges. Deck slabs without transverse post-tensioning shall be designed under the applicable provisions of Section 5—Concrete Design.

Elastic analysis and beam theory may be used in the design of precast segmental box girder structures. For box girders of unusual proportions,† other methods of analysis which consider shear lag shall be used to determine the portion of the cross section to be used in resisting longitudinal bending.

(B) Design of Superstructure

(1) Flexure

The transverse design of precast segments for flexure shall consider the segment as a rigid box frame. Top slabs shall be analyzed as variable depth sections considering the fillets between the top slab and webs. Wheel loads shall be positioned to provide maximum moments, and elastic analysis shall be used to determine the effective longitudinal distribution of wheel loads for each load location (see Article 1.2.8). Transverse post-tensioning of top slabs is generally recommended.

In the analysis of precast segmental box girder bridges, no tension shall be permitted in the joints between segments during any stage of erection or service loading.

(2) Shear

(a) Shear keys shall be provided in segment webs to transfer erection shears. Possible reverse shearing stresses in the shear keys shall be investigated, particularly in segments near a pier. At time of erection, the shear stress carried by the concrete section engaged by the shear key shall not exceed $2\sqrt{f'_c}$ unless a more detailed analysis is made in accordance with Sections 11.5 or 11.15 of the ACI Building Code Requirements for Reinforced Concrete (ACI 318-71).

(b) Design of web reinforcement for precast segmental box girder bridges shall be in accordance with the provisions of Article 1.6.13. Vertical or diagonal prestressing in webs may also be used to resist shear.

(3) Torsion

Consideration shall be given to the increase in web shear resulting from eccentric loading or geometry of structure.

(4) Deflections

Deflection calculations shall consider dead load, prestressing, erection loads, concrete creep and shrinkage, and steel relaxation. Deflections shall be calculated prior to manufacture of segments, based

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*Proposed sections to be inserted in *Standard Specifications for Highway Bridges*, American Association of State Highway Officials, Washington, D.C. 1973.

†Normal proportions for precast segmental box girder bridges are described in the Commentary.

on the anticipated segment production and erection schedule, as a guide against which construction deflection measurements are checked.

(5) **Details**

(a) Epoxy bonding agents for the match cast joints shall be thermosetting, 100 percent reactive, non-solvent compositions. They shall be formulated to permit erection of match cast segments at site air temperatures from 40 F (5 C) to 105 F (40 C). Epoxy bonding agents shall be relatively insensitive to damp conditions during application and, after curing, shall exhibit high bonding strength to cured concrete, good water resistivity, low creep characteristics and tensile strength greater than concrete. In addition, the epoxy bonding agents shall function as a lubricant during the joining of the match cast segments, as a filler to perfectly match the surfaces of the segments being joined, and to provide a durable water tight bond at the joint. See Article 2.4.33 (M) for epoxy bonding agent specifications.

b) Articles 1.6.24 (C) and 1.6.24 (F) relating to flange thickness and diaphragms shall not apply to precast segmental box girders.

(C) Design of Substructure

In addition to the usual substructure design considerations, unbalanced cantilever moments due to segment weights and erection loads shall be accomodated in pier design, with auxiliary struts, or using erection equipment that can eliminate these unbalanced moments.

COMMENTARY

1.6.25—PRECAST SEGMENTAL BOX GIRDERS

(A) General

Material strengths and allowable stresses need be no different from other prestressed concrete bridges; therefore, current limits in *Standard Specifications for Highway Bridges* should apply. However, higher strength concrete may be advantageous. It is usually available and generally has more durability, not only because of the mix design but also because of the quality control required to produce it.

(B) Design of Superstructure

Precast segmental box girders may be designed by beam theory. Influence surfaces for design of constant and variable depth deck slabs have been published by Adolf Pucher, Springer-Verlag, Berlin, Heidelberg, New York, and by Helmut Homborg, Springer-Verlag, Vienna, New York, 1964.

The following limitations are recommended:

1. Single cell boxes should be no more than 40 ft (12 m) wide, including cantilevers. For bridges wider than 40 ft, multiple box cross sections or multiple cell boxes are usually used. Single cell boxes of width greater than 40 ft can be used if carefully analyzed to deter-

mine the portion of cross section capable of handling longitudinal moment.

2. For maximum economy, the span-to-depth ratio for constant depth strutures should be 18 to 20. However, span-to-depth ratios of 20 to 30 have been used when required for clearances or esthetics. The shallower depths require the use of more high strength post-tensioning steel. Variable depth structures usually have span-to-depth ratios of 18 to 20 at the supports and 40 to 50 at midspan.

3. Width-to-depth ratios should also be considered. A shallow box girder that is too wide begins to behave as a slab. No criteria have been established, but when the width-to-depth ratio is greater than six, considering the total width of the section including slab cantilevers, it is recommended that the designers use multiple cell boxes or carefully analyze the cross section.

4. Proper fillets should be used in the cross section to allow stress transfer around the box perimeter and to provide ample room for the large number of tendons.

5. Diaphragms should be considered. These are usually required only at piers, abutments, and expansion joints.

6. The thickened bottom slab in pier segments, when required for stresses, should taper down or step down to the minimum midspan segment bottom slab thickness in as short a distance as is practical.

7. Web thicknesses should be chosen for production ease. If post-tensioning anchorages are located in the webs, web thickness may be governed by the anchorage requirements.

8. Permanent access holes into the box section should be limited in size to the minimum functional dimension and should be located near points of minimum stress.

(C) Design of Substructure

Unbalanced cantilever moments occur during erection only and are usually greater in magnitude than service load moments. Wind loads in combination with erection loads could develop critical stresses and, thus, wind loads should be considered in accordance with Article 1.2.22.

Selected References

The following selected references provide some useful guidelines in the design and construction of precast prestressed segmental box girder bridges:

1. PCI Committee on Segmental Construction, "Recommended Practice for Segmental Construction in Prestressed Concrete," PCI JOURNAL, V. 20, No. 2, March-April 1975, pp. 22-41.
2. Muller, Jean, "Ten Years of Experience in Precast Segmental Construction," PCI JOURNAL, V. 20, No. 1, January-February 1975, pp. 28-61.
3. Swann, R. A., "A Feature Survey of Concrete Box Spine-Beam Bridges," Cement and Concrete Association, 52 Grosvenor Gardens, London SW1W OAQ, 1972.
4. Maisel, V. I., and Roll, F., "Methods of Analysis and Design of Concrete Boxbeams with Side Cantilevers," Technical Report No. 42.494, Cement and Concrete Association, 52 Grosvenor Gardens, London, SW1W OAQ, November, 1974.

2.4.33—PRESTRESSED CONCRETE

(L) Precast Segment Manufacture and Erection

(1) **Manufacture of segments**

Each segment shall be match-cast with its adjacent segments to ensure proper fit during erection. As the segments are match-cast they must be precisely aligned to achieve the final structure geometry. During the alignment, corrections to compensate for deflections are made.

All tendon ducts are placed during production. To maintain alignment and to prevent indentations, suitably hard and rigid material or inflatable rubber tubes shall be used to form the ducts.

(2) **Erection of segments**

The segments shall be erected by the cantilever method from each pier without falsework. Temporary supports may be used. With the approval of the Engineer, other systems of erection may be considered.

Match-cast segments shall be erected using epoxied joints. A minimum compression of 30 psi (0.21 MPa) shall be provided by means of temporary post-tensioning over the entire joint area until the permanent tendons are stressed.

Deflections of cantilevers shall be measured as erection progresses and compared with computed deflections. Any deviation from the required alignment shall be corrected by either modifying the segment geometry during the casting operation or by inserting stainless steel wire shims in the epoxy joints during erection. The maximum thickness of shims at any joint shall be 1/16 in. (1.6mm). Provision shall be made to permit alignment adjustments of a completed cantilevered portion of the box girder before the midspan splice connecting adjacent cantilevers is constructed.

(3) **Grouting**

Grouting of the ducts shall be done in accordance with Article 2.4.33 (I). Under normal conditions, grouting shall be accomplished within 20 calendar days following installation of tendons. For delays beyond 20 days, tendons shall be protected with a water soluble oil or approved equal protective agent.

(M) Epoxy Bonding Agents for Precast Segmental Box Girders

All epoxy bonding agents shall meet the requirements of Article 1.6.25 (B) (5) (a). Two-part epoxy bonding agents shall be supplied to the erection site in sealed containers, preweighed in the proper reacting ratio, ready for combining and mixing. All containers shall be properly labeled to designate the resin component and the hardener component as well as the temperature range for its application. The air temperature range of 40 F to 105 F (5 C to 40 C) may be divided into two but not more than three application ranges for bonding agents. Such ranges shall overlap each other by at least 6 F (3 C).

Surfaces of the match cast joints to be bonded shall be sound, dry and clean. All traces of mold release agents, curing compounds, laitance, oil, dirt and loose concrete shall be removed from surfaces to be bonded by sand blasting or needle scalers. All surface dust or water on cleaned surfaces shall be removed with an oil-free air blast immediately before applying epoxy bonding agent.

The level and alignment of the new segment shall be checked against the previous segment prior to application of the epoxy bonding agent.

Instructions for the safe storage, mixing and handling of the epoxy bonding agent shall be followed. Application of the mixed epoxy bonding agent shall be according to the supplier's instructions using trowel or brush to obtain a 1/16 to 3/32 in. (1.6 to 2.4 mm) thick coating on both surfaces to be joined. Erection operations shall be coordinated and conducted so as to complete the operations of applying the epoxy bonding agent to the segments, erection, assembling, and temporary post-tensioning the newly joined section during the open time period of the bonding agent.

As general instructions can not cover all situations, specific recommendations and instructions shall be obtained in each case from the engineer in charge.

Epoxy bonding agents shall be tested to determine their workability, pot life, open time, bond and compression strength, modulus of elasticity, and working temperature range (see Appendix for test methods and recommended specification limits). The frequency of these seven tests shall be stated in the Special Provisions of the Contract.

APPENDIX

EPOXY BONDING AGENT TESTS

Test 1—Sag Flow of Mixed Epoxy Bonding Agent

This test measures the application workability of the bonding agent.

Testing method: ASTM D 2730.

Specification: Mixed epoxy bonding agent must not sag flow at 1/16 in. (1.6 mm) minimum thickness throughout designated application temperature range.

Test 2—Pot Life of Mixed Epoxy Bonding Agent

This test is a measure of the application time range for the mixed bonding agent. Pot life is determined on samples of 11 lb (5 kg) mixed no longer than three minutes. It provides a guide for the period of time the mixed bonding agent remains workable in the mixing container and during which it must be applied to the match-cast joint surfaces.

Testing method: ASTM D 2471.

Specification: 15 minutes minimum at maximum temperature of designated application temperature range. (Note: Pot life is not to be confused with open time specified in Test 3).

Test 3—Open or Contact Time of Bonding Agent

This test measures workability of the epoxy bonding agent for the erection and post-tensioning operations. As tested here, open or *contact time is defined as the maximum period of time from the application of the mixed epoxy bonding agent to the precast segments* until the two segments have been assembled together and temporarily post-tensioned.

Testing method: Open time is determined using test specimens as detailed in the Tensile Bending Test (Test 4). The epoxy bonding agent, at the highest specified application temperature, is mixed together and applied as instructed in Test 4 to the concrete cubes also at the highest specified application temperature. The adhesive coated cubes are maintained for 60 minutes at the highest specified application temperature with the adhesive coated surfaces exposed and uncovered before joining together. The assembled cubes are then cured and tested as instructed in Test 4.

Specification: The epoxy bonding agent is acceptable for the specified application temperature only when 100 percent concrete rupture is obtained.

As construction situations sometimes require application of the epoxy bonding agent to the precast section prior to erecting, positioning and assembling, such operation may require epoxy bonding agents having prolonged open time. In general, where the erection conditions are such that the sections to be bonded are prepositioned ready for joining, the epoxy bonding agent shall have a minimum open time of 60 minutes within the temperature range specified for its application.

Test 4—Three Point Tensile Bending Test

This test, performed on a pair of concrete cubes bonded together with epoxy bonding agent, determines the bonding strength between the bonding agent and concrete.

Testing method: 4 in. (100 mm) concrete cubes of 6000 psi (41 MPa) compressive strength at 28 days are sandblasted on one side to remove mold release agent, laitance, etc., and submerged in clean water at the testing temperature for 72 hours. Immediately on removing the concrete cubes from the water, the sandblasted surfaces are dried with an oil-free air blast and are each coated with approximately a 1/16 in. (1.6 mm) layer of the mixed bonding agent. The adhesive coated faces of two cubes then are placed together and held together with a clamping force normal to the bonded interface of 20 psi (0.14 MPa). The assembly is then wrapped in a damp cloth which is kept wet during the curing period of 24 hours at the specified testing temperature.

After 24 hours curing at the lower temperature of the application temperature range specified for the epoxy bonding agent, the bonded specimen is unwrapped, removed from the clamping assembly and immediately tested. The test is conducted by placing the bonded cubes on 1 in. (25 mm) diameter steel dowel supports parallel to each other and 6 in. (150 mm) apart under the 4 x 8-in. (100 x 200 mm) area. Load is applied through a 1 in. (25 mm) diameter steel dowel, midpoint between and parallel to the support dowels and directly on top and in line with the bonded joint. The speed of testing shall be 0.05 ± 0.010 in. per min. (1.3 ± 0.3 mm per min.) with load applied until rupture.

Specification: The epoxy bonding agent is acceptable only when 100 percent concrete rupture is obtained.

Test 5—Compression Strength of Cured Epoxy Bonding Agent

This test measures the compressive strength of the epoxy bonding agent.

Testing method: ASTM D 695.

Specification: Compressive strength at 77 F (25 C) = 10,000 psi (69 MPa) minimum after 24 hours cure at upper temperature of specified application temperature range for epoxy bonding agent.

Test 6—Elastic Modulus in Compression of Cured Epoxy Bonding Agent

This test measures the modulus of elasticity of the bonding agent in compression.

Testing method: ASTM D 695.

Specification: Modulus of elasticity at 77 F (25 C) = 800,000 psi (5520 MPa) minimum after 24 hours cure at upper temperature of specified application temperature range for epoxy bonding agent.

Test 7—Temperature Deflection of Epoxy Bonding Agent

This test determines the temperature at which an arbitrary deflection occurs under arbitrary testing conditions in the cured epoxy bonding agent. It is a screening test to establish performance of the bonding agent throughout the erection temperature range.

Testing method: ASTM D 648.

Specification: A minimum deflection temperature of 122 F (50 C) at fiber stress loading of 264 psi (1.8 MPa) is required on test specimens cured 7 days at 77 F (25 C).

Discussion of this report is invited.
Please forward your discussion to
PCI Headquarters by December 1, 1975.