Designing for Continuity

Precast Prestressed Bridge Girders Made Continuous For Live Load Offer Many Benefits:

- Lower Costs
- Improved Durability
- Longer Spans
- Improved Seismic Performance
- Improved Structural Integrity
- Improved Ride Quality

Sequence of Construction for Precast, Prestressed Girders Made Continuous

Precast, Prestressed Girders Erected as Simple Spans

Deck reinforcement for negative moment

Extended girder reinforcement for positive moment

Diaphragm Cast with Composite Deck, Making Bridge Continuous
Analysis of Precast, Prestressed Concrete Girders Made Continuous

Non-composite structure – simple span analysis for:

- Effect of Prestress
- Girder self-weight
- Deck and other non-composite loads

Composite structure – continuous span analysis for:

- Superimposed dead loads
- Future wearing surface
- Live load
- Time-dependent effects
  - Shrinkage
  - Creep
  - Temperature

Recommendation for Design

Design Method

- Non-composite dead loads (girder, deck and diaphragm) act on simple span structure
- Live load and superimposed dead loads act on continuous composite structure
- Neglect time-dependent effects in structural analysis
- Provide positive moment reinforcement at interior supports to develop a design strength $\geq 1.2M_{Cr}$, based on diaphragm concrete
- Provide mild reinforcement in deck at interior supports to resist live load moments
Embedment Considerations for Positive Moment Reinforcement

Adequate Development Length

Stagger Debonded Strands

Section for Computing Area of Reinforcement

Use Properties of Deck Concrete
DESIGN OF PRECAST PRESTRESSED GIRDERS MADE CONTINUOUS

Prepared by Basile G. Rabbat and Alex Aswad for PCI Committee on Bridges

NCHRP Report 322 titled “Design of Precast Prestressed Bridge Girders Made Continuous” was published in 1989. Since then, findings and recommendations of this document have been discussed at length at each of the PCI Bridge Committee meetings held twice yearly. One of the two annual meetings is held jointly with the AASHTO Technical Committee on Prestressed Concrete (T-10). Based on this dialog, the report findings, and the long-standing excellent experience of Tennessee and many other states with this type of construction, recommendations for consideration of AASHTO T-10 are presented below.

Background

Report 322 indicates that the U.S. practice for design and construction of this type of bridges has varied over the full gamut. In spite of all the differences in design and construction procedures, these bridges have performed well according to the survey results given in Report 322. This important observation confirms that concrete structures behave the way they are detailed.

The good performance, irrespective of design procedure and construction details, is probably due to the nature of the beast. Concrete behaves the way it is reinforced. For example, consider multi-span beams that are cast monolithically and have only bottom reinforcement from end to end. As long as the structure is uncracked, it will behave elastically and as if continuous. Under dead load and some live load, the magnitude of negative moments will eventually exceed the cracking negative moment capacity at the supports. At this point, concrete will crack over the supports. Subsequently, the structure will behave as if it were made up of simply supported beams.

Redistribution of moments due to creep and shrinkage occurs in indeterminate, reinforced concrete structures. This phenomenon has been observed in the laboratory and in the field. Consider segmental concrete bridges built using the balanced cantilever method of construction. During construction, the superstructure behaves as double cantilevers. After the concrete closure (where adjacent cantilevers meet) is completed, redistribution of stresses occurs due to creep and shrinkage. With time, the moments in the superstructure approach those of a monolithic continuous beam.

Section 8.4 of the ACI Building Code is titled “Redistribution of negative moments in continuous non-prestressed flexural members.” Section 18.10.4 of the Prestressed Concrete chapter concerns “Redistribution of negative moments in continuous prestressed flexural members.” Thus, the ACI Code recognizes that redistribution of moments will occur in a concrete structure, whether reinforced or prestressed. In Draft 3 of the LRFD Bridge Specifications, Article 5.7.3.5 addresses “MOMENT REDISTRIBUTION” for reinforced, prestressed and partially prestressed concrete members. Given that nature takes care of redistribution of moments in concrete structures, is there a need to perform complex computations to determine the restraint moments due to creep and shrinkage in precast prestressed concrete members made continuous? First, we do not have a good handle on the creep and shrinkage properties of concrete in each part of the country, or even within a given state. Second, and more importantly, Report 322 has shown that the restraint moments are a function of age of the precast girders when continuity is established. At the design stage, the designer has little control over the precast girders’ age at which the continuity connection will be established. Third, analysis usually assumes that the structure behaves within the linear elastic range. It is well known that bridge decks crack, with resulting changes in stiffness of members and redistribution of moments.
On page 1 of Report 322, under Summary, the authors state “Results indicate that the positive moment connection in the diaphragms does not provide any structural advantage and is not required.” This conclusion is based on extensive analytical work that is verified against experimental data. In spite of this conclusion, it is prudent to provide a positive moment connection if for nothing else than structural integrity. This is within the intent and spirit of AASHTO Article 1.1.2, titled “Structural Integrity.”

The state of Tennessee has the longest and most extensive experience with construction of precast prestressed girders made continuous for live load. Tennessee's practice is to design these structures as simple spans for dead load of girders, deck and diaphragms, and as continuous spans for live load and superimposed dead loads. Further, at continuity supports, a positive moment connection is provided as a standard detail. The designer ignores restraining moments due to creep and shrinkage.

Analysis

The attached table summarizes analysis of the standard positive moment connection details used in Tennessee and elsewhere. Assumptions made for this analysis are given at the top of the table. From left to right, the following information is included in the table columns:

1. Precast girder cross sections analyzed.
2. Reinforcement for the positive moment connection (standard details.)
3. Composite section modulus for bottom fibers for a cross-section consisting of the precast girder ($f_c = 6000$ psi) and portion of the deck 8 ft wide, with $f_c = 4000$ psi. The section of girder and deck is located immediately outside the diaphragm. The composite transformed section is based on the properties of the deck/diaphragm concrete (the weaker of the two.)
4. Cracking moment. It is equal to the product of composite section modulus for the bottom fibers and the modulus of rupture ($7.5 \sqrt{fc}$) of the diaphragm concrete (the lower at the girder/diaphragm interface.)
5. Nominal flexural strength (positive moment) for a section immediately next to the diaphragm. The cross-section consists of the deck and the girder including the positive moment connection reinforcement. The nominal flexural strength in all cases is higher than the cracking moment based on an unreinforced section.
6. The last column lists the ratio of nominal to the cracking moments. The lowest ratios are 1.20 for the AASHTO Type IV, and 1.19 for the AASHTO BIII-48. The highest ratio is for the PCI bulb-tee. Because the BT72 is as deep as the AASHTO Type VI, probably the same positive moment connection detail was used (8 #6 bars.) As the bulb-tee is an optimized section, a positive moment connection detail corresponding to Type VI yields a higher nominal strength, and thus a higher ratio of nominal to cracking moments.

All girders listed in the attached table have performed well when built with the corresponding positive moment connection. An evaluation of the ratios listed in Column 6 of the table indicates that a value of $1.2 \times$ cracking moment is adequate. Incidentally, this amount of reinforcement corresponds to the minimum specified in Article 8.17.1 of the AASHTO Bridge Specs.
Recommendations

Based on the results of extensive analyses reported in NCHRP Report 322, the performance of bridges in all states where precast girders are built continuous over piers, and lengthy discussions held during the PCI Committee on Bridges meetings during the last three years, the following is recommended for design of precast prestressed girders made continuous for live load:

1. Consider the dead load of the precast girder, deck and diaphragm concrete acting on a simple span.

2. Analyze the structure as continuous for live load and superimposed dead loads. Account for moments due to differential settlement if need be. Check serviceability and strength for all computed moments.

3. At continuity supports provide a positive moment connection, through reinforcing or prestressing steel, to develop a design strength equal to or greater than 1.2 times the positive cracking moment.

CROSS SECTION FOR $M_{cr}$

Note, the above cross section is taken at the interface of girder and diaphragm. For design purposes, the whole cross section is assumed to consist of diaphragm/deck concrete, i.e. the weakest of girder and diaphragm concrete.
Positive Moment Connection for Bridges Made of Precast Girders Made Continuous

Assumptions:

- $f'_c = 6000$ psi for bare precast girder
- $f'_c = 4000$ psi for cast-in-place diaphragm and deck
- Effective Deck Width = 8'-0"
- $f_r = 7.5 \sqrt{f'_c}$

<table>
<thead>
<tr>
<th>Precast Girder</th>
<th>Positive Moment Connection</th>
<th>Composite Section Modulus Sbc, (in.3)</th>
<th>Cracking Moment Mcr,(ft-kips)</th>
<th>Nominal Flexural Strength Mn,(ft-kips)</th>
<th>Ratio Mn/Mcr</th>
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<tr>
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Recommendations

1. Design for Girder and Deck DL based on:
   - Simple Span, Non-composite Properties
2. Design for Superimposed DL + LL + Impact based on:
   - Continuous Span, Composite Properties
3. Design Reinforcement for Positive Moment Connection (bottom of girder over pier) for:
   - 1.20 Mcr

If you have any questions, please contact sbhide@portcement.org