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Guidelines for Camber and Profile Management in Adjacent Beams

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Abstract:

The camber variation in decked and topped beam elements is a complex issue, as opposed to beams with haunches that are used to account for these variations in girder type bridges. This document focuses on beam systems that do not have haunches. However, much of the information contained in this guideline can be applied to beams with haunched cast-in-place or precast concrete decks.
This report can be utilized by Designers, Plant Production Managers, Plant Quality Control Inspectors and Plant Engineers and State Inspectors.

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PCI NORTHEAST

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FORWARD

This guideline has been developed for the purposes of promoting a greater degree of uniformity among owners, engineers, and industry of the Northeast, with respect to planning, designing, fabricating, and constructing bridges using precast concrete beams.

The PCI Northeast would like to acknowledge the members of the Technical Committee that contributed to the development of this guideline.

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1 Scope

These guidelines cover the design, detailing, and construction of precast beam elements that do not include a haunch over the top of the beam to accommodate camber and profile. This includes beams such as NEXT D, F, and E beams, Deck Bulb Tee Beams, Adjacent Box Beams, Deck Beams, and Slabs.

The designer needs to account for camber variation and the roadway profile in the design and detailing of any prestressed concrete beam.

The effects of camber variation, roadway profile, and roadway cross slope can affect the thickness of the top flange for decked beams, and/or the thickness of the overlay or topping. These can affect the design of the beams due to the variation of the dead loads and can also affect the detailing. Also affected may be the bearing size, beam seat elevations, and even the roadway profile.

These guidelines contains recommended approaches to camber and profile management in the design and construction process. Designers are cautioned that these are guidelines, not specifications, and are encouraged to discuss these issues with bridge owners during the development of plans, to come to an agreement on the camber and profile management during construction.

C1

The camber variation in decked and topped beams is a complex issue, as opposed to beams with haunches that are used to account for these variations in bridges with girders supporting the bridge deck. This document focuses on beam systems that do not have haunches. However, much of the information contained in these guidelines can be applied to beams with haunched cast-in-place or precast concrete decks.

In decked beams and topped beams, the thickness of the top flange, the topping, or the overlay will vary over the length of the bridge.

1.1 Definitions

Adjacent Beams	Beams that are separated by a small grouted joint, or a small closure pour. (also referred to as butted beams)
Box Beam/Deck Beam/Slab	Rectangular adjacent beams that typically support a topping or receive an Overlay; however the bare top of the beam surface may be used as a riding surface
Camber	The variation of the beam profile caused by prestress forces and dead loads (note: camber cannot be prescribed as in steel beams)
Camber Management	The process of accounting for camber in the design, detailing and construction of the bridge
Camber Tolerance	The specified allowable camber variation
Camber Variation	The actual deviation between the measured camber and the design camber
Deck Bulb Tee Beam	A type of bulb tee beam where the top flange is used to form the bridge deck
Deck Haunch	The area between the bottom of the deck and top of the girder
Decked Beams	Adjacent beams that have a top flange that is used to form the bridge deck

	without a topping
Design Camber	Estimated camber that is calculated by the Designer
Differential Camber	The difference in measured camber between adjacent beams after erection
Measured Camber	Actual camber that is measured in the shop or field
NEXT D Beams	Decked Northeast Extreme Tee (NEXT) Beams
NEXT E Beams	Topped NEXT Beam, where the top flange is part of the structural deck
NEXT F Beams	Topped NEXT Beam, where the top flange is not part of the structural deck
Overlay	Wearing surface over membrane or a layer of non-structural cast-in-place concrete placed on top of beams
Profile Management	The process of accounting for roadway profile in the design, detailing and construction of the bridge
Topped Beams	Adjacent beams that have a cast-in-place concrete topping that supplements the top flange to form the structural bridge deck
Topping	Structural reinforced cast-in-place concrete added to the top of non-decked beams to form the bridge deck

1.2 Assumption

This document is based on the assumption that the beams are fabricated within the specified camber tolerance.

C1.2

The recommended guide for camber tolerances is the PCI Tolerance Manual for Precast and Prestressed Concrete Construction (MNL-135). Designing and detailing beams for camber tolerances in excess of specified tolerances is not recommended. Beams that are out of tolerance will require a special review to determine which recommendations within these guidelines may be used to mitigate the camber variation.

1.3 Potential Causes of Camber Variation

The following are the major causes of beam camber variation:

- Concrete weight variation due to mix design
- Concrete modulus of elasticity variation based on the mix design
- Prestress losses variation
- Curing and storage variation
- Concrete release strength variation

These variables, which are part of the normal beam fabrication process, are not known to the designer during design stage. Camber tolerances are used to account for these variables.

C1.3

The issue of camber variation and the tolerances employed to account for this have been under study for several years by the PCI National Bridge Committee. The causes listed are thought to be some of the most significant variables.

The unit weight of the concrete can vary from mix to mix. The designer usually assumes a value based on the recommendations in the *AASHTO LRFD Bridge Design Specifications*. However, in production, the unit weight of the concrete can be somewhat different than the design assumption depending on the mix proportions, concrete strength, and air content.

The equation for the modulus of elasticity in the *AASHTO LRFD Bridge Design Specifications* considers only the concrete strength and weight. However, the modulus of elasticity of the concrete can vary greatly depending on the mix used. The aggregate type and gradation can have a significant impact on the modulus of elasticity. Variation in this value can have a significant effect on the measured camber.

The ACI document entitled "*State of the Art Report on High Strength Concrete (ACI 363R-92)"* contains alternate equations for concrete modulus, which may provide a more accurate estimate.

The methods used for storing beams can also affect measured camber due to variation in dead load moments brought on by differing support locations. Sunshine and temperature have also been known to cause camber and sweep variations.

The use of longer span beams has led to larger measured camber variations. PCI National is considering changing the camber tolerance specifications. Certain states have already changed their camber tolerance specifications. Increasing the camber tolerance leads to the need for larger deck haunches and thicker toppings and overlays. This will lead to thicker superstructures, which is not always desirable.

2 Recommended Approach to Camber Management

This section contains a recommended approach to the management of camber and camber tolerances in the design and construction process.

C2

The goal of this section is to reduce the number of construction issues.

2.1 Camber Calculations During Design

The designer should calculate the estimated beam design camber at various stages of fabrication based on the best information available at the time of the design. At a minimum, the designer should calculate the beam design camber at the following stages:

1. At release: This will be used for quality control of the beam as it is removed from the

C2.1

The designer will typically calculate camber based on the specified design strength and estimated concrete weight. The designer is not privy to the properties of the concrete mixes that are used by the various producers during the fabrication of beams. If camber is a critical factor in the design and detailing of the bridge, the designer may elect to contact fabricators during design to determine a more accurate modulus of elasticity.

Care should be taken with beams left in the forms for longer periods (weekends) prior to release, form.

resulting in a potentially different release strength than beams released within one day. The fabricator can make adjustments in curing to minimize strength gain over the period to produce a beam of similar camber.

The use of 30 days may be adjusted by the owner based on historic data of beam delivery ages.

2. At 30 days (often referred to as "at erection"): This represents an average age of beam just prior to delivery. This value will be used to establish the deck, topping, or overlay thickness and beam seat elevations that will be used for the design and detailing.
3. Long-Term Camber: Designers may choose to evaluate the effect of long-term camber growth on the bridge profile and detail the bridge accordingly.

There are several methods for calculating long-term camber. PCI has developed a method that involves the use of multipliers applied to short-term deflections and cambers to determine long-term camber prediction. These multipliers were developed for non-composite vertical construction members and may not produce a true representation of the long-term camber of a composite bridge beam. Based on this, owners, designers and contractors should exercise caution in relying on the use of long-term multipliers for calculating future camber in composite bridge beams.

The age at erection may vary with owners. Designers should verify the required age for design camber calculations with the owner.

For staged construction projects, the casting of all beams at one time can lead to differential camber between adjacent beams at stage construction lines. The beams used in the early stage may have less measured camber than beams cast in subsequent stages leading to undesirable camber variations (see Section 2.4). It may be desirable to cast the beams for each stage separately and commensurate with the anticipated project schedule. This will provide beams that will be erected with equivalent camber. If this is desired, the plans and specifications should clearly indicate this requirement. In some cases, it may be possible to manage the camber growth in the fabrication facility through the use of weights. Provisions can be added to allow the fabricator the option of producing all of the beams at one time provided that camber management can be achieved.

Design camber calculations should follow common industry practice and the *AASHTO LRFD Bridge Design Specifications*. The designer may elect to use a final concrete strength that is higher than the specified final concrete strength in the camber calculations to better reflect the actual condition during fabrication.

Typically, the actual final concrete strength of fabricated beams is higher than the one specified on the plans. To provide a better estimate of the measured camber a value of 1.2f'c is recommended. This recommendation should not be used for the camber calculations at release.

The design camber values should be provided on the plans along with the age for which the design camber is estimated.

2.2 Camber Tolerance

The recommended camber tolerance should be based on the latest edition of the *PCI Tolerance Manual for Precast and Prestressed Concrete Construction (MNL-135)*, or the criteria established by the bridge owner.

C2.2

Some owners have developed their own camber tolerance criteria that differ from the PCI recommended criteria.

2.3 Camber Impacts to Plan Details and the Design

Design camber needs to be accounted for in the design of the beams and the detailing of the bridge. Roadway profile and cross slope can also have an impact on the detailing of the bridge. The plane of the beam top will inevitably not be parallel to the plane of the finished roadway (after accounting for deflections due to dead loads).

Designers should account for the variable geometry between the top of beam and the final profile in the detailing of the bridge. Camber variation should be part of this effort.

The variation of the bridge geometry should be accounted for in the design of the beams.

C2.3

In order to develop a design that can match the required roadway profile certain dimensions in the design need to be adjusted including the deck thickness, overlay thickness, barrier height, and/or beam seat elevations. This is not an inclusive list. There may be other potential variables in the detailing that should be accounted for. The measured camber of the beam affects these adjustments. For instance, a cambered beam on a tangent profile will need to have certain variable dimensions (overlay thickness, parapet height, etc.) in order to provide a bridge with a tangent profile.

The variable dimensions will inevitably lead to variation in the dead loads imposed on the beams and/or different beam section properties. The effect of camber tolerances needs to be included in the design.

2.4 Differential Camber in Adjacent Beams

Adjacent beam designs should be developed with an allowable differential camber tolerance, which is separate from the beam camber tolerance.

In lieu of owner specified values, a differential camber between adjacent beams of ± 1/8” per 10 feet of beam (3/4” maximum) is recommended. The PCI Northeast Bridge Technical Committee has recommended a maximum differential camber of ½” for NEXT D Beams due to the complexity of the beam flange connection. A larger specified differential camber can be used, provided that the flange connection details can accommodate the differential.

For beams with overlays, the designers should account for the potential weight of the over-thickness in overlay due to differential camber.

For beams with reinforced closure pours, differential camber may lead to inadequate cover on the

C2.4

The typical camber tolerance for a beam is the difference between design camber and measured camber. Adjacent beam designs often require control over the differential camber. This can affect the detailing of the joints between the beams.

This value is taken from the *PCI Tolerance Manual for Precast and Prestressed Concrete Construction (MNL-135)*. Special care should be exercised for adjacent beams of different design (i.e. 3 foot wide beams combined with 4 foot wide beams). This situation may require larger specified differential camber.

Differential camber of adjacent beams with overlays will result in a potential for over-thickness in the overlay on the lower beam. This will affect the dead load on the beam.

closure pour reinforcing. This may require special detailing of the closure pour.

It is recommended that the skew for adjacent beams with reinforced closure pours be kept to a maximum of 20 degrees.

The skew of beams combined with camber can lead to differential grades between adjacent beams, primarily near the ends of the beams. This is caused by the difference in distance of the flange edge from the support combined with the profile of the cambered beam. This issue is exacerbated by wider beams. Larger skews can be used; however special care should be exercised with the detailing of the reinforcing and the concrete cover around the reinforcing.

2.5 Fabricator's Role in Camber Management

In certain situations, the fabricator may determine during development of shop drawings that the design cambers (at release and at erection) shown on the plans may not be consistent with the fabricator's estimated camber (based on the fabricator's experience and proposed materials). In this case, the fabricator should contact the owner (designer) in order to adjust the design camber used for acceptance criteria.

The fabricator should monitor camber during curing. The recommended minimum time interval is within 24 hours of release, once monthly during storage, and once approximately 2 weeks prior to delivery.

For adjacent beams, the fabricator should monitor the differential camber in addition to the measured camber of each individual beam. Special mitigation may be required in the fabrication facility to control the differential camber.

C2.5

Fabricators should be aware that if they do not verify the design cambers shown on the plans, and the measured camber is out of tolerance then a fabrication error may be concluded by the owner. Actual camber may be significantly different than the designer's estimates due to different material properties of the actual concrete used in the plant. Fabricators should provide justification for revising the design camber. Acceptable justification would be the actual modulus of elasticity values for the proposed mix design at the anticipated release strength, or a calculated modulus of elasticity based on the measured camber of similar beams previously cast.

Owners may specify different camber measuring intervals, which should be followed, such as a certain time prior to overlay or deck placement.

It may be possible to adjust camber growth through the application of additional dead load or adjusting the support points in storage. It may not be practical for the fabricator to provide the space and weight for large quantities of beams. Alternate methods to account for differential camber variation should be considered.

2.6 Designer's Role in Camber Management During Construction

If the fabricator's estimated cambers, which are different from the ones specified on the plans, are accepted by the designer and owner, the designer should review the impact of the revised design camber on the design and make appropriate adjustments.

The impact of the variation on the design and

C2.6

The camber variation may have an impact on the design of the beam and the details on the plans. At the time that a camber variation is noted by the fabricator, there should be ample time to make minor adjustments to the design to accommodate the variations. The following are some of the potential changes that could be considered:

detailing should be addressed prior to shipment of the beams. This may result in a revisions to the plans.

- Adjust beam seat elevations
- Adjust the top of deck elevations (this change can have significant ramifications to the overall design)
- Adjust bearing heights (use of shims or a re-design of the bearing heights)

Knowing that some of these changes may be necessary, designers may choose to consider adjustability criteria in the design (see Section 3 of this document).

The owner should be aware that these changes are not considered design errors. They are a result of variations in materials and the fabrication process (see Article 1.2 above).

Clearly specify camber measuring intervals that are different than that specified in the PCI MNL-116-99

2.7 Recommended Camber Acceptance Criteria

Accepted revised design cambers should be used as the basis for camber measurements. The tolerances specified in the project should be applied to the revised design camber.

3 Potential Approaches for Managing Roadway Profiles and Camber Variation in the Design

There is not one recommended method for management of variations in roadway profiles, camber variation and differential camber. The following articles describe several methods that can be used. The designer should apply one or more of these methods in the design and detailing of the bridge.

3.1 Deck Thickness, Overlay Thickness, and Barrier Height

The thickness of the deck or overlay and the height of the barrier can be varied across the bridge to accommodate roadway profiles.

The designer should detail the potential variation in deck or overlay thickness on the plans based on the profile and the design camber. The design of the beams should also account for this.

Several potential solutions include:

C3.1

The nature of precast/prestressed bridge beams is such that the profile of the top of beam will not be parallel to the profile of the finished roadway (after accounting for dead load deflections and camber). For example, the PCI Northeast recommended guide details for NEXT Beams indicate “minimum”, not “constant” deck, topping, or overlay thicknesses.

There are benefits and drawbacks to each of these methods. The magnitude of the variation may lead the designer toward one solution or another. The PCI

- Varying the thickness of the top flange (NEXT D Beams and Deck Bulb Tee beams).
- Varying the concrete topping (NEXT F and E Beams and adjacent beams)
- Varying the overlay thickness (this will require the variation of the height of the barriers or curbs).

Guideline drawings for NEXT Beams and Deck Bulb Tees include suggested details depicting these approaches.

It should be noted that adjustments to the height of crash tested barriers may not be acceptable to the bridge owner. Height variations should be kept to a minimum. Designers should get approval for this approach from the bridge owner.

3.2 Dead Loads and Beam Design

Each of the solutions noted in Section 3.1 will have an effect on the design of the bridge. The designer should choose a solution and design the bridge accordingly.

The designer should also account for the camber tolerances in the calculations.

C3.2

The dead loads applied to the beams will vary. If the thicknesses of the top flanges are varied, the section properties for the beams will also vary.

The maximum dead loads created by the beam being at the maximum or minimum camber tolerance should be used in the beam design.

3.3 Beam Seats

The height of the beam seats should always be set to accommodate the roadway profile and the camber variation. In general, the beam seats should be set low enough to accommodate the maximum anticipated camber (design camber plus camber tolerance).

The variation between the roadway profile and the top of beam should also be accounted for in the development of beam seat elevations (see Section 3.1).

3.4 Bearing Design and Detailing

The bearings can be detailed to accommodate camber variation and differential camber, by including provisions for thickness adjustments during construction.

The designer may also choose to re-design the bearing during construction (if the schedule permits), to accommodate camber variation or differential camber noted by the fabricator.

C3.4

The PCI Northeast Bridge Technical Committee has developed suggested details for variable height bearings including the incorporation of shims into the details (www.pcine.org). Certain bearing details can include the use of shims within the bearing assemblies. The designer could detail shims that could be removed or supplemented depending on the nature of the camber variation (plus or minus).

There may be a certain amount of leeway in the design of the bearings. In some cases, the bearings can be increased in height within the limits of the design specifications. This option would most likely occur if the fabricator’s design camber is significantly different than the specified design camber. In this situation, there may be sufficient time to re-design the bearings prior to fabrication of the beams or bearings.

3.4.1 **Bearings at Skewed Beam Ends**

C3.4.1

The combination of skew and camber can lead to gaps at bearings on beams with skewed ends. Designers should consider using bearing details that include allowances for shimming bearings on beams with skewed ends. The maximum height of shims should be reviewed on a case-by-case basis.

High durometer neoprene shims such as random fiber sheet has proven to be effective in shimming under an elastomeric bearing. The shim has the same coefficient of friction as the bearing. Therefore slipping of the shims has not been problematic.

This issue is especially true for beams with wide bottom flanges such as box beams, deck beams, and slabs or for NEXT D beams. The preference for box beams, deck beams, and slabs should be to use two bearings at each end as opposed to one wide bearing. In most cases, the beam will seat on the two acute corners and rock toward the obtuse corners. Allowing shims on the loose bearings will provide proper seating of all bearings.