Slab and Screed Guidance

The purpose of this guidance is to further define the determination of slab and screed elevations and haunch thicknesses for bridge decks, and to establish standard interaction between design and field offices during construction. Example calculations done during the design phase will be presented in the appendix, along with emphasis on the specified material properties, and their impact on beam camber and various stages of deflection.

This guidance also serves to present a new process for verification of camber and deflection values to ensure comprehensive determination of slab and screed grades on bridge decks for optimal ride quality.

Screed Elevations:

Screed elevations are shown at the toe of barrier, or toe of sidewalk, as the contractor will typically place the screed rail for the self-propelled transverse finishing machine on the fascia beams, or as close as possible to limit the extent of hand finishing of the bridge deck. Elevations will also be shown at bulkheads and at the crown point to facilitate setting up the finishing machine properly prior to dry runs. Screed elevations are calculated by taking the beam self-weight and forms and rebar deflection values, and adding that value to the top deck surface elevation based on the theoretical roadway alignment. Screed elevations are based on the condition that no deck concrete has been cast, and beams have already deflected under self-weight, and forms and rebar weight (See Stages of Deflection section).

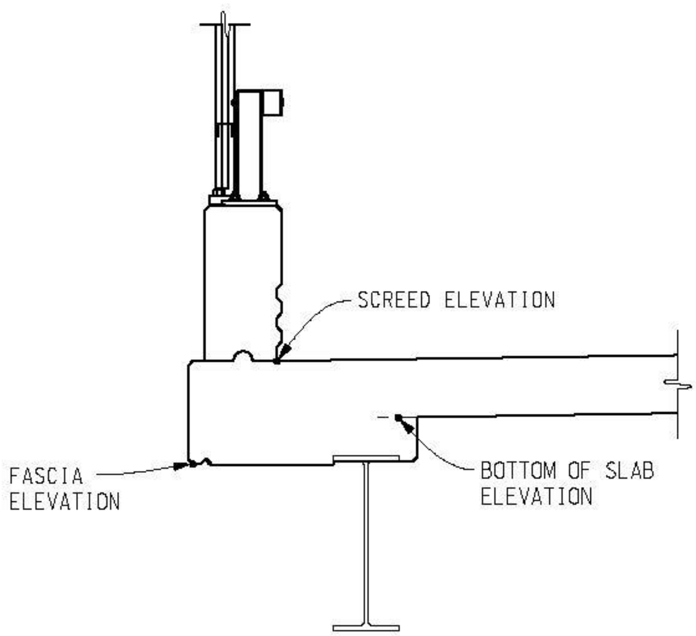

Figure 1. Screed elevation location at toe of barrier

Screed elevations are set higher than the finished deck surface elevations in an amount equal to the calculated deflections due to the deck concrete, and any sidewalk or barrier to ensure once the deck, sidewalk and barrier are cast; the deck surface matches the final roadway geometry. On rare occasions such as long spans, or horizontally curved girders, the self-weight of the transverse finishing machine resting on the screed rails may induce beam deflections. The deflections from the machine are insignificant when compared to the deflections caused by the plastic concrete; however, deflection of the screed rail and finishing machine itself may need to be accounted for.

Standard specifications subsection 706.03.A.2 requires the actual screed rail grades to be within 1/16 inch of the screed grades shown on the plans. The contractor is responsible to adjust the rail grades at their supports or to install tighter support spacing to ensure deflection of the rails (between supports) due to the weight of the self-propelled transverse screed machine does not exceed 1/16 inch.

Bottom of Slab Elevations:

Bottom of slab elevations are typically provided on the slab and screed sheet, and are calculated based on the proposed roadway vertical alignment (and horizontal alignment if on a curve or transition) and cross section. Elevations are provided at the right and left edge of each beam line, and represent the final elevation of the deck surface, plus deflections due to dead load, then minus the 9 inch deck thickness.

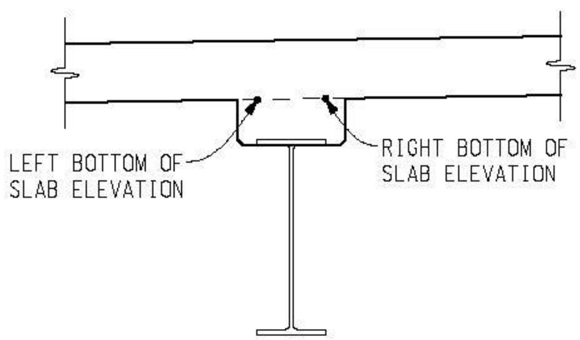

Figure 2. Bottom of Slab elevation points

The bottom of slab elevations take into account the fact that the beams and diaphragms are erected, and allowances are made for vertical alignment, and deflections due to forms and rebar weight, and bridge deck concrete weight. Bottom of slab elevations shown on the plans are set higher than the actual finished bottom of slab elevations in an amount equal to all the calculated dead load deflections to ensure once the deck, sidewalk and barrier are cast; the bottom of slab elevations equal the deck surface elevations minus 9 inches.

As a check, on the slab and screed details sheet, the screed elevation minus the bottom of slab elevation at the same point will result in approximately the 9 inch deck thickness. Due to the A-crown of the deck and the fact that bottom of slab elevations take into account weight of forms and rebar and the top of slab elevation do not, small variations of 9" will exist. Also, most fascia beams are poured with a negative haunch, therefore top and bottom elevation difference will exceed 9".

Bottom of slab elevations are important, as the contractors typically tack welds the stay-in-place metal deck form angles to the appropriate haunch height based on these elevations, except in tension zones, where straps are used. If the actual beam camber, or deflections deviate from the calculated values too much, this impacts the bottom of slab elevation, and could result in excessive or negative haunches.

Bulkhead Elevations:

Bulkhead elevations are deck surface elevations transverse to beam lines at each abutment, and when crossing expansion or construction joints. The intent is to provide the contractor with an elevation to place expansion joint rails, or metal bulkheads for construction joints when following the deck pour sequence as shown on the plans. Similar to bottom of slab elevations, bulkhead elevations take into account vertical alignment, and deflections (there is no deflection at the abutments or piers) due to beam self-weight, forms and rebar, and bridge deck concrete weight. Bulkheads may be eliminated when combining deck pours. Changes to the pour sequence or the combining of deck pours must be approved by the design engineer.

Haunches:

Haunches are determined based on the fact that the final deflected shape of the beam will not exactly match the proposed roadway vertical alignment. Designers calculate haunch thicknesses based on the difference between the bottom of slab elevation, and the top of beam elevations. On new structures or superstructure replacements, designers will assume a minimum haunch thickness to afford flexibility in the field if bottom of slab elevations require adjustment. On deck replacements, designers are at the mercy of existing beam conditions and must calculate haunches on known conditions and calculated deflections. The beam elevations are determined based on the elevations of points of support, and the in-span deflections. Haunch thicknesses are variable along the length of the beam to accommodate the difference between roadway geometry, and structural deflections of the beams. The goal being satisfactory ride quality transitioning from road to bridge.

For structures on sag vertical curves with ideal beam camber, the haunch will typically be maximum at the ends the span, and minimum at midspan. For structures on crest vertical curves, the haunch may be minimum at the ends of the span, and maximum at midspan. Designers try to coordinate the beam camber to match the crested roadway when possible to offer consistent haunch grades. The Michigan Bridge Design Manual, section 7.02.19C directs designers to use a uniform 1" thick haunch for steel beams, and a minimum 2" thick haunch for prestressed concrete beams.

Haunch thicknesses are also variable across the cross section, given the crown, or superelevation of the roadway surface, or the skew of the bridge.

Beam Camber:

Beams are positively or negatively cambered to compensate for dead load and live load deflections to match the proposed roadway vertical alignment. There are several stages of dead load deflection that are taken into account as described in the Stages of Deflection section, and the camber ordinates are determined based on the magnitude of these deflections.

There are differences in control of camber and deflections between steel beams and prestressed concrete beams as described below.

Steel Beams:

Camber ordinates on steel beams are developed based on the vertical alignment going across the bridge, and the calculated dead load and live load deflections. It is undesirable to induce negative camber at service loads, as this could impact the vertical underclearance, so live load has to be taken into account. All of the stages of dead load deflection, plus the live load deflection are summated to determine the maximum required midspan camber ordinate value. Additional camber may also be required for geometry.

MDOT Bridge Design Manual section 7.02.06 requires a compensating camber to be designed into the beams where dead load deflection or vertical curve offset are greater than ¼”. This may include a negative camber for portions of beams on continuous spans to ensure uniform haunch depths, and bottom of slab elevations such that the sum of all dead load deflections results in the deck top surface matching the proposed roadway vertical alignment as close as practicable.

During fabrication, camber is easier to control for steel beams than for prestressed concrete beams. For built up steel plate girder, fabricators have two options to fabricate beams to the specified camber:

- The web plate can be cut in a parabolic shape to match the camber ordinates shown on the contract plans, and the top and bottom flange plates are then welded to the shaped web plate.

- The web plate can be cut straight, the top and bottom flanges welded on, and the entire beam heated as to allow manipulation to the desired camber. The beam is then allowed to cool while being restrained to the required position as to lock in the cambered shape.

For rolled wide flange shapes, fabricators heat the beams is the same fashion as the second option for built up plate girders to achieve the required camber.

As a result, the maximum camber for steel beams is a function of fabricated geometry and greater control of camber can be achieved.

For deck replacement projects on steel beam superstructures, the slab and screed elevations in the plans will be based on the beams rebounding to their original elevation prior to weight of the concrete deck. This does not always occur, and permanent camber loss can result due to years of dead and live load deflection during service. It is always important to survey the tops of the beams at the same intervals as shown on the slab and screed sheets, and provide this information to the designer for review, and to make adjustments to grades if necessary.

Prestressed Concrete Beams:

Similar to steel beams, camber is also required for prestressed concrete beams; however, the amount of upward deflection is a function of the prestress force, the eccentricity of the prestressing strands to the neutral axis of the beam, the beam shape, and properties of the concrete mix. To understand prestressed beam camber, and how changes to the specified design compressive strength of the concrete impact camber, please see Appendix A for detailed calculations.

Designers specify a minimum compressive strength required at prestress strand release based on acceptable levels of stress in the beams, and this value is used in the deflection calculations. Fabricators often add accelerators and water reducers to increase the short-term strength gain in the concrete mix, to ensure the prestressing beds can be turned around in a specified time needed for production. Although fabricators are required to meet camber tolerances per Table 708-1 of the standard specifications, the result is the actual prestress beam deflections diverging from the theoretical deflection calculated during design due to the higher compressive strength.

Stages of Deflection:

The slab and screed, and bulkhead elevations on the project plans are calculated to ensure the final deck position closely matches the design roadway alignment taking into account camber, and all stages of superstructure deflection. To accomplish this, the calculations assume that a beam lying on its side is fully cambered, as shown in Figure 3.

The camber ordinates shown in Figure 3 will be shown on the project plans for steel girders to direct the fabricator what camber is required.

Maximum midspan camber taking into account beam dead load deflection will be shown on the plans for prestressed concrete beams.

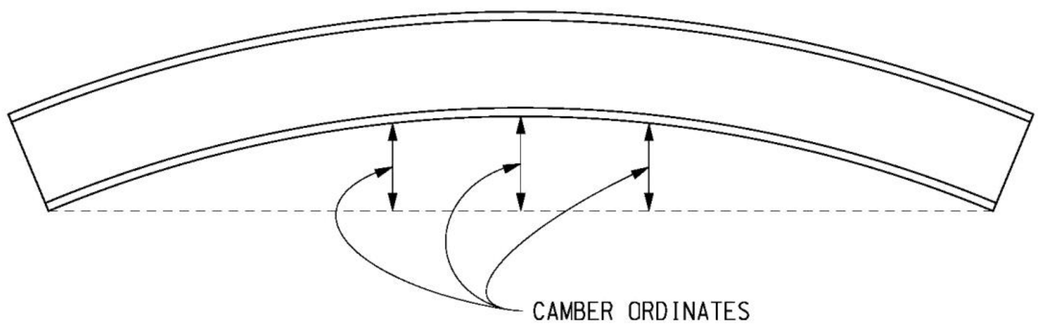

Figure 3. Beam lying on its side

The first step in determining the slab and screed grades is calculating the reduction in camber due to the girder self-weight. When a girder is supported at points of bearing, either on a pier or abutment, the girder will deflect under its own self-weight. At support points there will be no deflection. For simply supported spans, maximum deflection will occur at midspan, and for continuous girders, maximum downward deflection will occur at some point prior to midspan, and upward deflection in adjacent spans is considered in the bridge deck pour sequence. Figure 4 shows a span supported at bearing points deflecting under the girder self-weight load, which is designated as Δ_1.

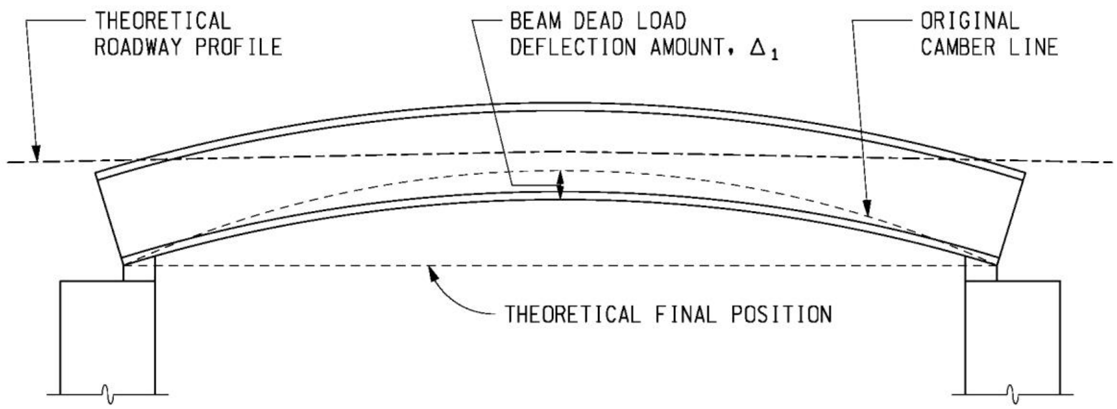

Figure 4. Deflection of the beam due to self-weight

Note that the theoretical roadway profile is actually below the top flange line during this stage, as the beam has not fully deflected into its final position. The theoretical final position of the bottom flange of the girder is the position required to ensure the top surface of the bridge deck matches the roadway vertical alignment as closely as practicable.

Another stage of deflection to consider is that produced by the weight of the forms and rebar. The MDOT Bridge Design Manual section 7.02.22.B instructs designers to assume 10 lbs/sft each for the weight of forms and rebar in computing the screed elevations. Figure 5 shows the additional deflection, Δ_2, due to the weight of forms and rebar that is taken into account by designers in computing slab and screed grades. This results in a relatively small deflection when compared to self-weight, or deck dead load deflection, however, it needs to be taken into account, and field offices should communicate with the designers if the actual deflections significantly vary from the design assumptions.

At this stage during construction, if Contractor Staking is included in the contract, the Contractor may take shots along the top flange of the girder, at the same interval as shown on the slab and screed detail sheet in the project plans, and provide this survey information to the engineer and designer. If Contractor Staking is not included in the contract, the project office may have their surveyor perform this function. If there is cause for concern, or significant anomalies in deflection are identified, this information should be submitted to the designer to compare these elevations to the theoretical elevations based on the camber and self-weight deflection calculations. This allows the designer to make any necessary grade adjustments to the haunch or deck thicknesses to ensure proper corroboration of the deck surface with the final roadway vertical alignment, and provide the new grade information to the field. Because the deflections due to forms and rebar is relatively small, most deflection issues may be identified after beam erection and evaluation of beam self-weight effects.

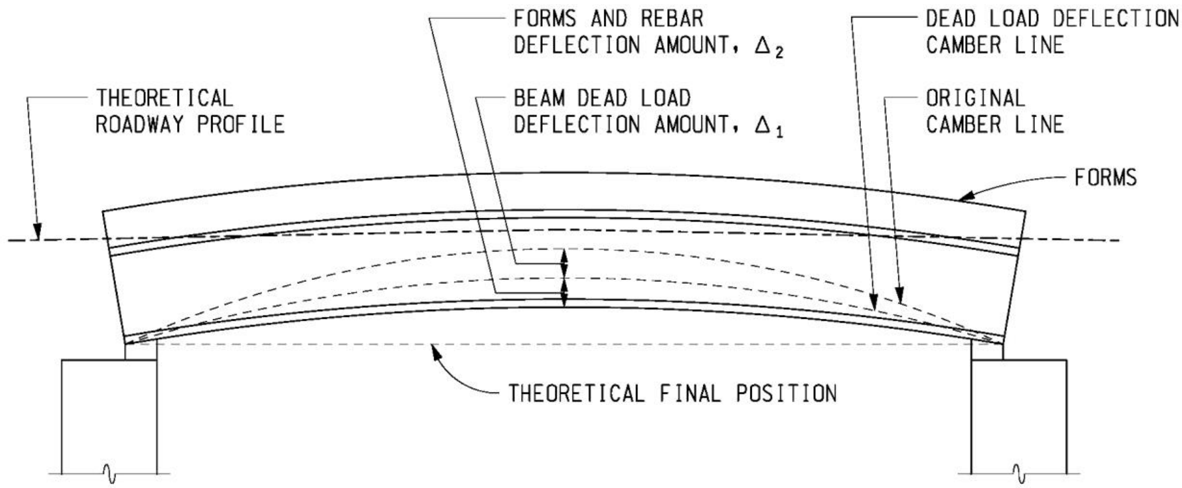

Figure 5. Deflection of the beam due to the weight of forms and rebar

Once the forms and rebar are set, the screed rails for the self-propelled transverse finishing machine should be set on the fascia beams to either the elevations shown on the plans, or adjusted elevations based on changes between the theoretical and actual camber and beam self-weight deflections. At this stage, a dry run is to be conducted by the contractor to ensure proper deck thickness measurements from the bottom of finishing machine to the top of the deck forms.

The most significant deflections of the beams occur under the wet load of concrete, prior to concrete cure, and attainment of composite action. Figure 6 shows the deflection, Δ_3 due to the weight of the deck concrete. At this stage the beams should be very near their theoretical final position.

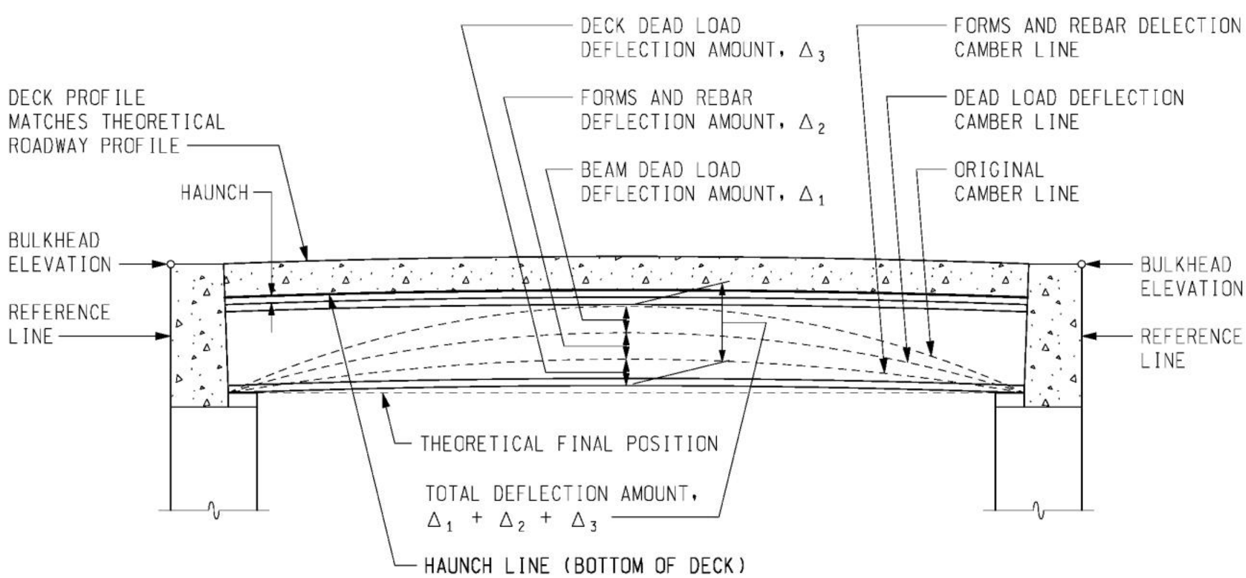

Figure 6. Deflection of the beam due to the weight of deck concrete

Once the bridge deck has been continuously wet cured for seven days per Standard Specifications subsection 706.03.N, succeeding portions of the structure, such as sidewalk and bridge barrier railing may be cast on the deck. Figure 7 shows the deflection, Δ_4 due to the weight of sidewalk and barrier.

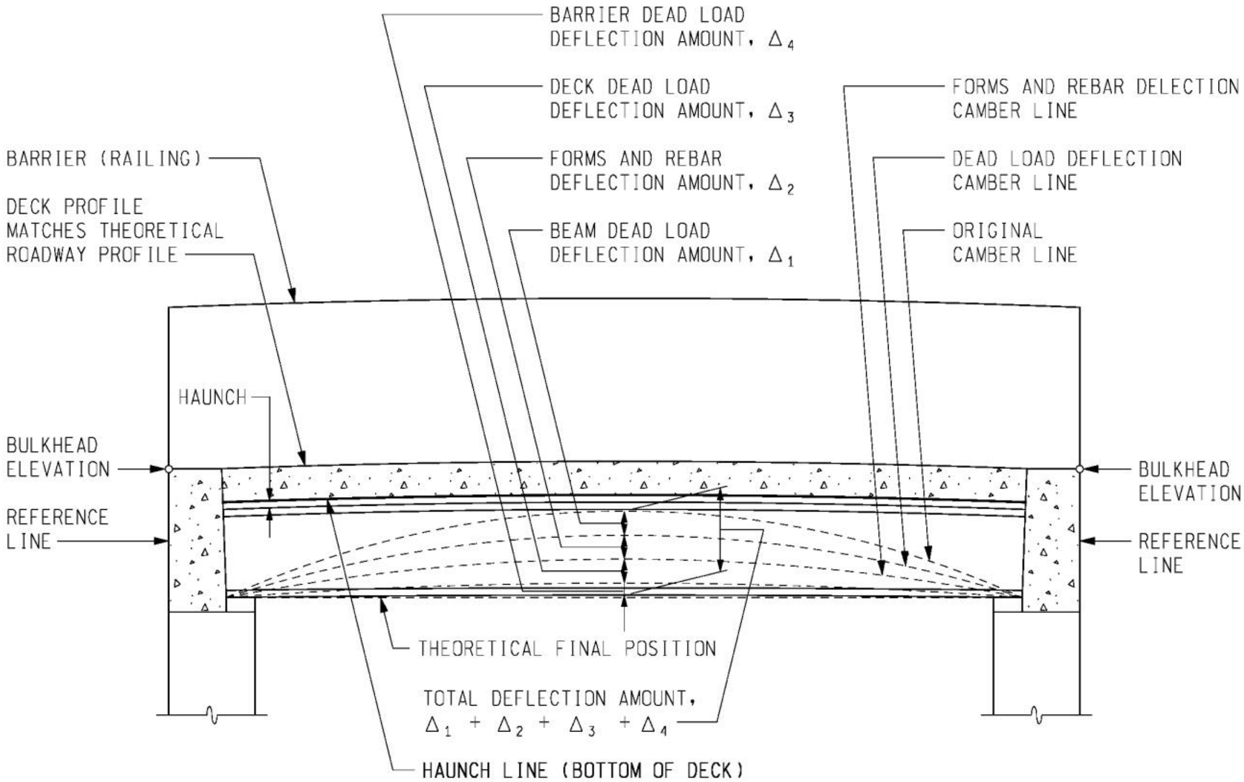

Figure 7. Deflection of the beam due to the weight of sidewalk or barrier

The value of Δ_4 will be relatively small, as the moment of inertia used in the deflection calculation is now that of the composite section of beam and concrete deck.

The slab and screed grades shown on the plans take into account the beam camber minus the sum of all stages of construction deflection ($\Delta_1 + \Delta_2 + \Delta_3 + \Delta_4$) to obtain grades that result in the bridge deck surface closely matching the theoretical roadway alignment upon completion of the sidewalk and barrier concrete pours.

At this stage, any bumps in the bridge deck, or surface tolerances exceeding 1/8 inch over 10 feet must be removed via grinding. This results in the removal of the densified floated finish portion of the bridge deck, and can introduce micro-cracks into the deck structure, both of which are undesirable. Ensuring the finished deck surface matches the final vertical roadway geometry as close as possible will help prevent grinding on the finished bridge deck. This requires careful attention to detail on the actual beam camber and deflections compared to what is shown on the plans and communication with the designer when values do not correspond.

Staged Construction:

Staged construction on bridge projects presents a challenge for geometry control on the finished deck surface.

On curved steel girder bridges constructed part width, there is a potential for the bridge deck not matching at the stage line due to differential deflections from the difference in beam stiffness (due to length and curvature) from beam to beam. This can be compensated by taking survey measurements on the tops of the Stage 2 beams, and the Stage 1 bridge deck, and providing these elevations to the designer for review.

On prestressed side-by-side box beam bridges constructed part width, all the box beams may be fabricated at the same time. The Stage 1 beams will be erected and experience full dead load deflection, while the Stage 2 beams may experience camber growth due to the prestressing force eccentricity. This causes issues during Stage 2 construction such as transverse post tensioning ducts not lining up, or potential change in deck thickness at the stage line. If all the beams for a staged construction project are cast together, the Stage 2 beams should be monitored for camber growth. The most significant camber growth is a result of curing concrete and strength gain and occurs within the first 28 days after beam casting. Any growth in camber should be communicated to the designer and adjustments made to the haunch grades if necessary. Preloading the beams after erection may be necessary to align post tensioning ducts. Contact the designer for assistance with prestressed side-by-side box beam bridge projects that are done part width.

Recommended changes to current requirements:

MDOT Bridge Design Manual:

Section 7.01.09: Restricting the use of the 0.3% allowable lower limit for longitudinal grade to require approval from the Bridge Design Supervisor. 0.5% should be the absolute minimum, and 1% should be preferred.

Add the following paragraphs to section 7.02.22B:

In computing camber ordinates for prestressed concrete beams, the number and length of debonded strands shall be taken into account.

Deflections due to sidewalk, barrier, brushblocks, utilities, and other non-structural attachments shall be computed using the composite moment of inertia.

The following notes should be added to Chapter 8, and the Slab and Screed sheet:

- Create note 8.07.06:

  ONCE BEAMS ARE ERECTED ON SUPPORTS, THE CONTRACTOR IS TO TAKE SURVEY ELEVATIONS OF THE TOP OF BEAMS AT A MINIMUM, AT THE ENDS AND MIDSPAN (OR POINT OF MAXIMUM DEFLECTION FOR CONTINUOUS GIRDERS)OF EACH BEAM.. THE CONTRACTOR IS TO SUBMIT THE TOP OF BEAM ELEVATIONS TO THE ENGINEER FOR REVIEW AND APPROVAL FIVE (5) BUSINESS DAYS PRIOR TO FORMING THE BOTTOM OF SLAB, OR PAN DECKING INSTALLATION.

- Create note 8.07.07:

  THE CALCULATED STAGES OF DEFLECTION ARE AS FOLLOWS:

  BEAM DEAD LOAD = XX INCHES
  FORMS AND REBAR = XX INCHES
  DECK DEAD LOAD = XX INCHES
  BARRIER AND SIDEWALK = XX INCHES

Appendix 1 – Sample camber and deflection calculations

Net beam camber upon release of the prestressing strands is given by the following expression:

$$\Delta_i = \Delta_{\uparrow} - \Delta_{\downarrow}$$

Where:

Δ_i = Net camber at transfer

$\Delta_{\uparrow}$ = Upward deflection due to prestressing

$\Delta_{\downarrow}$ = Downward deflection due to girder self-weight

$$\Delta_{\uparrow} = \frac{P_i e L^2}{8 E_c I_g} + \frac{P_i e}{E_c I_g}\left(\frac{L^2}{8} - \frac{\alpha^2}{6}\right)$$

Where:

P_i = Prestressing force immediately after transfer

E_c = Elastic modulus of girder concrete at transfer

I_g = Girder gross section moment of inertia

e = Prestressing strand eccentricity at midspan relative to the centroid of the girder gross section

e_e = Prestressing strand eccentricity at the end of the girder to the centroid of the girder gross cross section. Debonding is neglected.

L = Girder length

α = Distance from draping point to end of span

The above equation can be used for two point draped strands, and for straight strands, where the second term is zero, since α is zero.

Camber is also dependent on the number and length of strands debonded, and as such, the reduction in camber due to strand debonding is also taken into account.

The self-weight downward deflection equation is not unique to prestressed concrete beams. The following equation can be used to calculate deflections for all standard beam types:

$$\Delta_{\downarrow} = \frac{5 w_g L^4}{384 E_c I_g} + \Delta_{diaphragm}$$

Where:

w_g = Linearly distributed girder self-weight

$\Delta_{diaphram}$ = deflection due to midspan diaphragms

The theoretical elastic modulus of a concrete girder is a function of the compressive strength of the concrete mix used, given by the following equation:

$$E_c = 33{,}000 w_c^{1.5} \sqrt{f_c^{'}}$$

Where:

w_c = Unit weight of concrete

$f_c^{'}$ = Specified compressive strength of the concrete

To illustrate this further, consider a 120 foot long MI 1800 prestressed girder, with an initial prestress force of 1170 kips, with an eccentricity of 31 inches, and a required compressive strength at release of 5500 psi. Based on the required compressive strength at release:

$$E_c = 33{,}000(150\,lb/ft^3)^{1.5}\sqrt{5500\,psi} = 4496\,ksi$$

The camber of the beam taking into account the beam self-weight deflection is as follows:

$$\Delta_i = \frac{1170\,kips*31in*(120\,ft)^2*(12in/ft)^2}{8*4496\,ksi*624{,}700\,in^4} - \frac{5(0.910\,kip/ft)(120\,ft)^4(12in/ft)^2}{384*4496\,ksi*624{,}700\,in^4} = 3.22in$$

That camber value is used by the designer to develop the slab and screed grades. If the compressive strength of the concrete at release is 9000 psi, the difference is as follows:

$$E_c = 33{,}000(150\,lb/ft^3)^{1.5}\sqrt{9000\,psi} = 5751\,ksi$$

The revised camber of the beam taking into account the beam self-weight deflection is as follows:

$$\Delta_i = \frac{1170\,kips*31in*(120\,ft)^2*(12in/ft)^2}{8*5751\,ksi*624{,}700\,in^4} - \frac{5(0.910\,kip/ft)(120\,ft)^4(12in/ft)^2}{384*5751\,ksi*624{,}700\,in^4} = 2.52in$$

This results in a 0.70 inch change in camber, which is significant in terms of changes to haunches or deck thickness values to compensate. This demonstrates the importance of the field office taking shots on the beams when they are on their supports, with only dead load deflection taken into account. At this time, the designer may adjust the final bottom of slab grades, or screed elevations to accommodate changes from the theoretical grades.