I-205 Over Columbia River Bridge: Geometric Control for Cast-in-Place and Precast Segmental Box-Girder Construction

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Precast or cast-in-place segmental cantilevered construction forms a relatively new generation in U.S. bridge construction. One of the largest-scale projects of this kind is the I-205 Columbia River Bridge in Portland, Oregon, which was started in 1979 and is due for completion in 1982. The project consists of two parallel bridges, each 75 ft wide. Its final contract for the main superstructure (length of 5770 ft) was awarded to a joint venture of S. J. Groves and Guy F. Atkinson. Responding to the Oregon Department of Transportation's policy of value engineering, the longer 480-, 600-, and 480-ft spans were changed from precast to in-place construction by using traveling wagons; the shorter 240-, 300-, and 360-ft spans remained precast. This unique setup afforded a special opportunity for comparing the two construction methods and for coordinating design and geometric control with construction. Included in this paper is an outline of geometric control for both cast-in-place and match-cast segments; methods for predicting deflections, which consider shrinkage and creep; and a brief description of computer programs for cantilevered construction. Also included are a description of the coordination between designer and field personnel in order to achieve quality and accuracy in construction, a comparison of actual constructed elevations with predicted elevations, and, finally, a discussion regarding implications for future segmental construction.

In cantilever construction, the structure usually undergoes two phases. During construction, cantilever arms progress outward, and segments are gradually added until the ends of the designed cantilevers are reached. For the final bridge, a continuous structure is achieved when the cantilever ends are either hinged or integrated into the cantilever construction from the adjacent pier (Figure 1).

Figure 1. Segmental construction.

During construction, the cantilevers are usually free from restraint at their cantilever ends and are fixed, or partly restrained, at their pier supports. Because this type of construction involves stage loading, which in turn involves time-dependent deflections and strain changes, camber control during the erecting or casting of the segments is absolutely essential for the successful completion of the structure.

Basically, determination of forces, stresses, and deflections of the cantilevers follows beam theory. Although the calculations themselves are fairly simple, their accuracy depends on the recognition of all influences that are responsible for the deflection of the structure. Especially important are inelastic strains, which must not be neglected.

This paper describes the methods used in simplified analyses of cantilever deflections. Correlation between calculated values and actual field measurements is also given.

ELASTIC AND PLASTIC DEFORMATION CHARACTERISTICS OF BRIDGES

Cantilever construction of segmental bridges progresses along a predetermined pattern, which recognizes the stages of the contruction or erection of the segments comprising the cantilever. Typically, the construction cycle will vary from three to seven days per segment, depending on field conditions. After all the segments are in place, the ends of opposing cantilevers are joined and the bridge structure becomes continuous.

The deflections of the cantilever during the various stages of construction and the deflections of the final structure are affected by the following conditions:

1. Cantilevered structure: dead load of segments, weight of traveler or hoist, weight of form and construction equipment, prestressing forces, and pier deflections due to unbalanced loading; and
2. Final structure: dead load of the connecting segment; removal of traveler or hoist; closure pour form; prestressing forces; topping, railing, curbs, and utilities; and removal of shoring, temporary supports, etc.

Cantilevered Structure

Cantilevered structures should take into account the following conditions:

1. Dead load: The dead weight on the bridge is the most significant item that produces deflection. If the bridge was left to deflect without compensating prestressing forces, it would be difficult to control its deflection and associated stresses during and after construction. Hence, posttensioning is essential and must be fully used.

2. Traveler: In cast-in-place segmental cantilever construction, a new segment is cantilevered from the previously constructed segment; hence, special travelers with movable forms that cantilever out to support the new segment are required. The effect of their weight must be considered. For precast segmental construction, hoisting equipment for lifting new segments is required, and its weight must be considered in the deflection of the precast cantilever structure. A common traveler weighs 90-135 tons (including forms) and a hoist weighs approximately 35 tons.

3. Form and construction load: Weights of steel or wood forms and a working platform must be included for cast-in-place construction. In precast segmental construction, a working platform attached to the hoisting equipment will be required because it will affect the deflection.

4. Posttensioning: In the longitudinal direction (along the top flange), posttensioning will counteract the dead-load deflection to a great extent. It is not economically feasible to supply enough posttensioning to totally offset the dead-load deflection for a long span cantilever. Generally, about 70-80 percent of the dead-load deflection will be counteracted by incremental posttensioning forces in the first half of the cantilever and about 50 percent in the last half. This leaves the dead load not assumed by posttensioning to deflect the cantilever downward. Because the posttensioning forces will gradually relax, the loss of prestress must also be taken into account, as it will produce a further deflection of the cantilever. Such losses are well known for both normal weight or lightweight construction and can be predicted successfully in the computation of deflections.

5. Pier deflection: Because the bridge is connected to its vertical supporting member or pier, the deflection due to pier deformation (both axial and rotation) may affect the cantilever end appreciably. An appropriate adjustment is required in cast-in-place construction, especially for long, slender piers.

6. Foundation rotation: Sometimes, cantilever construction is built with unbalanced segments at the two sides. This produces a certain degree of rotation at the pier and its foundation, and the ensuing angle change at the foundation and pier head may induce an appreciable amount of deflection at the cantilever ends. This effect is significant, particularly in cast-in-place construction and in elevations where the setting of forms must be adjusted.

Continuous Framed Structure

Continuous framed structures should take into account the following conditions:

1. Dead load: The dead weight of the connecting segment is shared by the two adjacent cantilevers before its hardening. The deflection due to this closure pour and the related forms must be determined and included in the camber design.

2. Travelers: Travelers are usually removed prior to the closure pour. The upward deflection that results from the removal of the weight has to be considered.

3. Forms and bracing: The deflection due to the weight of forms and the action of the bracing system that distributes the weight toward each end of the cantilever must be a part of the deflection computation.

4. Topping, railing, curb, and utilities: Topping, railing, curb, and utilities must be accounted for in the deflection calculations. The construction schedule for the above must be predetermined for purposes of camber calculations, since it will make a substantial difference whether or not these loads are applied after the bridge becomes a continuous frame.

5. Removal of shoring and supports: The deflections due to removal of the shoring, temporary supports, etc., will affect the bridge deflections and stresses. Staged removal or removal at the final stage is to be decided before the camber design and precast work can be planned.

MAGNITUDE OF DEFLECTIONS

The magnitude of the deflection will be influenced by the following conditions:

1. Cantilevered structure: free cantilever system, sectional properties, modulus of elasticity, prestressing losses, concrete creep and shrinkage, and loading cycle and loading age; and
2. Final continuous framed structure: continuous framed system, closure sectional property, modulus of elasticity, prestressing losses, creep and shrinkage, and ratio of dead load to prestressing balancing forces.

Cantilevered Structure

Cantilevered structure deflections are influenced by the following properties:

1. System: The cantilever is built in the earlier stage of bridge construction by using segmental cantilever techniques before the adjacent cantilevers are linked with either a hinge or an integrated closure, which will then form a continuous framed structure. As the result of the change in continuity, the deflection characteristics in the system prior to the connection are different from those in the connected system. Time dependency of load application is important. For example, the railing or curb loading may be added onto the bridge before or after the continuity pour in some precast segmental construction. Their deflections will be influenced by the system and the curing age of the concrete. The correspondent magnitude of the deflection will differ on the order of two to three times.

2. Sectional properties: The cross-sectional properties of the bridge superstructure--namely the moment of inertia of the section, its shear area, and torsional properties--will directly relate to its deflection. Proper span-depth ratios and dimensions for the bottom slab, which resist compression forces, are also essential to the performance and deflection characteristics of the structure. Sectional properties at the closure, either a hinge or integrated pour, will have an influence on the deflection behavior as well.

3. Modulus of elasticity: Because the modulus of elasticity for concrete varies with age, aggregate, and mix, its prediction must be verified with actual field conditions in order to make control of the camber possible. The approximate time-dependent function can be defined in accordance with recent research and committee recommendations. The 28-day concrete modulus of elasticity can be expressed by the American Concrete Institute (ACI) formula (in 8.5.1) for both lightweight and normal weight concrete:

$$E_c = W^{1.5} \cdot 33 \cdot \sqrt{f_c'} \qquad (1)$$

4. Prestress losses: Tendon forces are subject

to losses due to creep and shrinkage of concrete, elastic shortening of successive stressing, and relaxation of steel. For a cantilever system, the prestressing losses will not only influence stresses but also the cantilever deflection. All of these are time-dependent variables and can be expressed as time-dependent logarithmic functions.

5. Creep: The proper ultimate creep factor must be assessed before initial prediction for construction camber design. The effect of creep (1,2) must be checked with measured deflections in actual creep testing in order to obtain correct camber elevations for construction. In the camber design of the I-205 Columbia River Bridge in Portland, Oregon, ultimate creep values of 2.0 and 1.5 were assumed for cast-in-place and precast construction, respectively.

6. Loading cycle and age of concrete: Because the creep patterns are affected by the age of the concrete at loading and the duration of the load, the segment cycle, which dominates the prestressing operation cycle, will influence the long-term deflection of the bridge. This will also affect the stress and strain redistribution after the system changes. In the I-205 Columbia River Bridge, a working cycle of seven days was considered for cast-in-place construction and a two-day cycle was considered for precast construction.

Continuous Framed Structure

For continuous framed structures, the following items are additional considerations to the items mentioned for cantilevered structures:

1. Modulus of elasticity: The change in the modulus of elasticity will not influence deflections in the final structure significantly; however, it will produce changes in strains and stresses in association with time change.

2. Prestressing losses: At this stage, losses of the prestress forces will not influence deflections significantly, since the sensitive point--the tip of the cantilever--has been changed from a free end to the point of a continuous frame.

3. Creep and shrinkage: As the structural system changes from a simple determinate structure to an indeterminate structure, the strains and stresses associated with concrete creep and shrinkage will cause some change and redistribution of the stresses in the continuous systems after the connection of the cantilevers. Although the resulting deflection change is relatively small, the stress change should not be neglected.

4. Ratio of dead load to prestress balancing forces: As the ratio of the dead-load force and prestress balancing force increases, the stress redistribution after the continuity pour will also be increased. Although stress redistribution is significant, the associated deflections are not due to structural continuity.

BASIC THEORY FOR DEFLECTION COMPUTATION

For cantilever construction, the deflection on the bridge is basically the problem of a determinate structure. Deflections can be determined by the use of the moment-area method:

$$\text{Delta} = \Sigma\,(M \cdot X)/(Ec \cdot I) \qquad (2)$$

where

Delta = deflection of the cantilever;
M = moment due to dead load, construction load, and prestressing balancing load;
X = distances at each referenced point;
Ec = time-dependent concrete modulus of elasticity; and
I = cantilever segmental section properties (moment of inertia).

For analyzing the deflections and stresses of continuous bridges, various computer programs that use finite-element or stiffness-matrix methods can be used. The equivalent method for determining the long-term effects in the final continuous structure can be found in several papers (1-5). In this paper, only the deflection due to the cantilever will be discussed, and a simplified camber design will be described.

Design Parameters

The following are design parameters for evaluating segmental deflections.

Variable Modulus of Elasticity

The modulus of elasticity of concrete is defined by formulas in ACI 318-77 as follows:

$$Ec = W^{1.5} \times 33 \times \sqrt{f_c'} \text{ at 28 days} \qquad (3)$$

Time-dependent Ec can be described by an expression that is linear in the log scale and represents time-dependent characteristics. The Ec value in old concrete can be on the order of 20-30 percent higher (6) than in its initial 28 days. Proper assumptions can be made to define a curve that represents time-dependent Ec values for use in the computer program.

Loss of Prestress Force

The moment-area method is dependent on bending moments of dead load, construction load, and prestress balancing forces. The dead and construction loads are not time-dependent quantities, but the prestress balancing force and its effects are a time-dependent quantity, as these forces are added in conjunction with additional segments. The prestressing forces also vary due to relaxation of steel, creep, and shrinkage in concrete. For simplicity in predicting prestressing losses in a structure with a 50-year lifespan, it may be assumed that 15 percent (on average) of the initial force will be lost. The expression can be described as follows:

$$Fs = Fsi\,[1 - 0.0352 \text{ Log } (t - 1)] \qquad (4)$$

where Fs is the steel stress at t days after initially being stressed to Fsi, Fsi is the initial prestressing steel stresses, and there is a log base of 10.

Creep of Concrete

Concrete creep characteristics can be determined through laboratory testing procedures and estimated from values recommended by the Prestressed Concrete Institute (2) and Post Tensioning Institute (1). The ratio of the ultimate creep strain to initial elastic strain is defined as the ultimate concrete creep factor Cu. Its value is influenced by environment, percentage of steel, concrete age, duration of loading, concrete mix and aggregate, method of curing used (7), etc. Laboratory test values (in accordance with ASTM C512) will vary from 1.5 to 3.5. However, taking into consideration all external effects, the Cu value may reduce to 1.25 or 2.5 in most bridge construction.

For example, let Cu = 2.5 in a 50-year structure. Assuming that it is loaded at seven days, the

following formula can be used for analysis:

$$Ct = 0.235 \times Cu \times Log\,(t + 1) \times [1 - 0.224 \times Log\,(T/7)] \quad (5)$$

where

- Ct = creep coefficient at different time stages,
- Cu = ultimate creep coefficient,
- t = time after loading applied (days), and
- T = days when load is applied (7 days < T < 1 year).

The above formula should be modified to best fit actual concrete properties for individual projects. The ultimate creep value Cu must be verified with actual test data.

Shrinkage of Concrete

Due to its axial deformation characteristic, shrinkage of the concrete will not significantly affect the deflections and stresses of the structure during the cantilever construction. It will, however, cause strain and stress changes in the later stages of the continuous structure. The axial deformations are restrained by supporting piers; thus, stress redistribution will be induced into the system.

The following formula (6) can be assumed for axial deformation of the concrete:

$$Esh = 12.5 \times 10^{-6} \times (90 - H) \quad (6)$$

where H is the relative humidity (in percent) and Esh is the shrinkage strain (use 0.0005 for H = 50). Furthermore, shrinkage will vary with time and will reach 100 percent at 50 years, as shown in the following formula:

$$(Esh)\,t = 12.5 \times 10^{-6} \times (90 - H) \times 0.235 \times Log\,(t + 1) \quad (7)$$

where t is time at the point of concern (in days).

Basic Deflection Formulas

For basic deflection formulas, let us assume the following:

1. At each segmental stage between each increment of loads and prestressing forces, the superposition method is applied (4). Concrete modulus of elasticity (Ec) changes with time.
2. For each increment, the section will have a curvature change due to the dead load and prestressing force. The expression can be written as follows:

$$\theta_t = \theta_{mt} + \theta_{pt} \quad (8)$$

where

- θ_t = total curvature,
- θ_{mt} = curvature that is induced by dead load and construction load, and
- θ_{pt} = curvature that is induced by prestressing forces.

Thus,

$$\theta_{mt} = (1 + C_t) \times [M/(E_t \times I)] \quad (9)$$

where C_t is the creep coefficient at different time stages. For θ_{pt}, the rate-of-creep method is used, i.e.,

$$\theta_{pt} = [(-P_i \times e)/(E_t \times I)] + (P_i - P_t) \times [e/(E_t \times I)] - [(P_i + P_t)/2] \times C_t \times [e/(E_t \times I)] \quad (10)$$

where P_i is the initial prestressing forces and P_t is the prestressing forces after losses at the time of t. Therefore,

$$\theta_t = (M - P_t \times e) \times [1/(E_t \times I)] + \{M - [(P_i + P_t)/2] \times e\} \times [C_t/(E_t \times I)] \quad (11)$$

3. For axial deformation only, the following is used:

$$E = \{P_t + [(P_i + P_t)/2] \times C_t\} \times [1/(E_t \times A)] + Esh \quad (12)$$

where A is the cross-sectional area and Esh is the strain change due to shrinkage.

4. Shear deformation in cantilever girder was neglected.

Based on the above assumptions, the elastic deformations will be calculated by use of the beam theory. The moment-area method or stiffness-matrix method can accurately predict elastic deformations. However, in the above formulas, the moment is a time-dependent quantity and subject to variation of stage prestressing. This is also coupled with variable sectional properties. An electronic calculator or computer program that traces all the variable and relative displacements will ultimately give the deflections for each section at each construction stage. The program flowchart is illustrated in Figure 2.

Tabulation

The deflection for each stage can be tabulated and

Figure 2. Program flowchart.

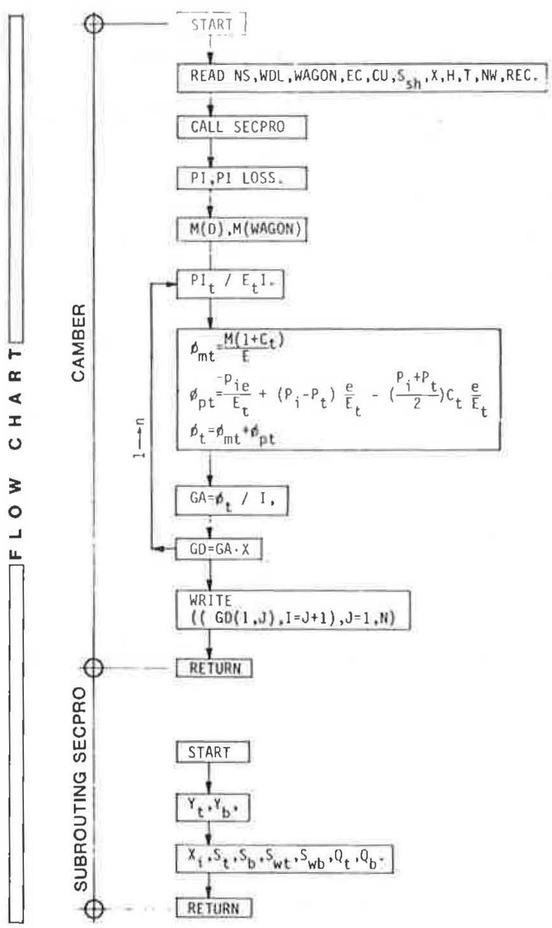


Figure 3. Tabulation of bridge deflection and camber.

ESTIMATE OF VERTICAL DEFLECTIONS IN INCH

RIGHT SPAN

INCREMENTAL DEFLECTIONS AT CONSTRUCTION STAGE

2	3	4	5	6	7	8	9	10
-.00								
-.01	-.02							
-.01	-.03	-.06						
-.00	-.02	-.04	-.08					
-.00	-.02	-.04	-.08	-.13				
.00	.01	.02	.03	.03	.04			
.00	.02	.03	.05	.08	.10	.12		
.01	.02	.05	.08	.12	.16	.20	.23	
.00	.01	.02	.04	.06	.07	.08	.08	.07

DEFLECTION AS THE RESULT OF SEGMENT 7 AND PRESTRESS

COMPLETE OF BRIDGE

.00	.00	.01	.01	.01	.01	.01	.01	.01

AFTER 50 YEARS (DUE TO CREEP)

.01	.02	.04	.06	.09	.12	.14	.15	.15

CAMBER TO COMPENSATE DEFLECTION DURING CONSTRUCTION
IF TOTAL CAMBER EQUALS

2	3	4	5	6	7	8	9	10
-.01	-.02	-.02	.05	.16	.37	.41	.33	.08

THEN CAMBER ELEVATIONS DURING CONSTRUCTION WILL BECOME

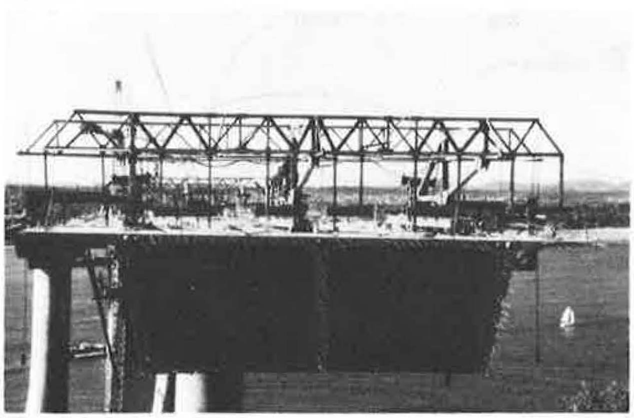
-.00								
.00	-.00							
.01	.03	.04						
.01	.04	.09	.13					
.02	.06	.13	.21	.29				
.02	.05	.11	.18	.26	.34			
.01	.04	.08	.13	.19	.24	.29		
.01	.02	.03	.05	.07	.08	.09	.09	
.00	.00	.01	.01	.01	.01	.01	.01	.01

CAMBER VALUE AFTER SEGMENT 7 CONSTRUCTION

COMPLETE OF BRIDGE

.00	.00	.00	-.00	-.00	-.00	-.00	-.00	-.00

Figure 4. Traveler for cast-in-place construction.



summarized. For compensating deflections, the camber can be obtained at a particular joint by adding all of the deflections found in one column. Figure 3 shows tabulated deflections for each construction stage at different segment joints. Camber calculation and camber design were based on the assumption that the deflection would be compensated 100 percent. For example, at the construction stage of segment 10, the camber value will be the summation of the deflections found under column 10, which is the total algebraic summation of 0.07 and 0.01 (total 0.08).

CAMBER CONTROL IN CAST-IN-PLACE CONSTRUCTION

The camber values for a cantilever can be determined by providing an opposite amount of deformations at each segment joint, such as the following:

1. Cantilever construction deflection due to dead load, construction load, and prestressing force;
2. Closure weight and forms and continuity prestressing force;
3. Topping, railing, curb, and utility;
4. Removal of traveler; and
5. Long-term deflection adjustment, if any.

Note that the deflection due to unbalanced moments at the pier and foundation must be considered in the field before the new form elevation is set. It must be recognized that, at the final balanced condition, this effect must also be compensated.

Cantilever traveling forms, as shown in Figure 4, have been used in most bridge construction of this type. In the I-205 Columbia River Bridge (north channel), the traveler was designed to have a total weight of 135 tons, including formwork. The maximum weight for a segment is 350 tons and the maximum length is 16 ft 3 in.

The camber for construction is tabulated and illustrated in the diagrams shown in Figures 5 and 6. On the upper table of Figure 5, the values shown in heavy diagonal boxes are the design camber readings for new segments. The new form at joint N is set at elevation EL. N (Figure 6). After concreting and prestressing, the elevation will drop to EL. Nn. The contractor must modify the forwarding form elevation if consecutive elevations are not consistent with those predicted.

Constructed elevations on a completed 300-ft cantilever have been examined and compared with the proposed cambers. The elevations at the cantilever segment joints were within 0.5 in from the designed elevations.

During the construction of segments, elevations at each segment can be surveyed and compared with the predicted elevation. If the deflection change between each segmental cycle was not compatible with the predicted change, either the design assumption or the material properties needs to be examined and adjusted.

CAMBER CONTROL IN PRECAST SEGMENTAL CONSTRUCTION

For precast segmental construction, the casting techniques can be put into two categories.

Long-Line Casting

For long-line casting, the bridge is cast in a bed with the entire bridge length as if it were built on shoring. The camber design is the same as the camber diagram for cast-in-place construction.

Short-Line Match Casting

For short-line match casting, the segment will be cast one segment at a time and cast against a previously finished segment. Figure 7 illustrates casting techniques in the I-205 project (note that the previous segment is used as the match-cast form and is seated on an adjustable table). The correct relative angle change between each adjacent segment becomes the governing factor in the successful control of deflections. Unlike in long-lined casting, only two segments are being adjusted at a time, and any error in one segment will affect the profile of the rest of the cast work and the qualities of its assembly. The procedure for deflection control when match casting is as follows.

Figure 5. Camber design values and diagram.

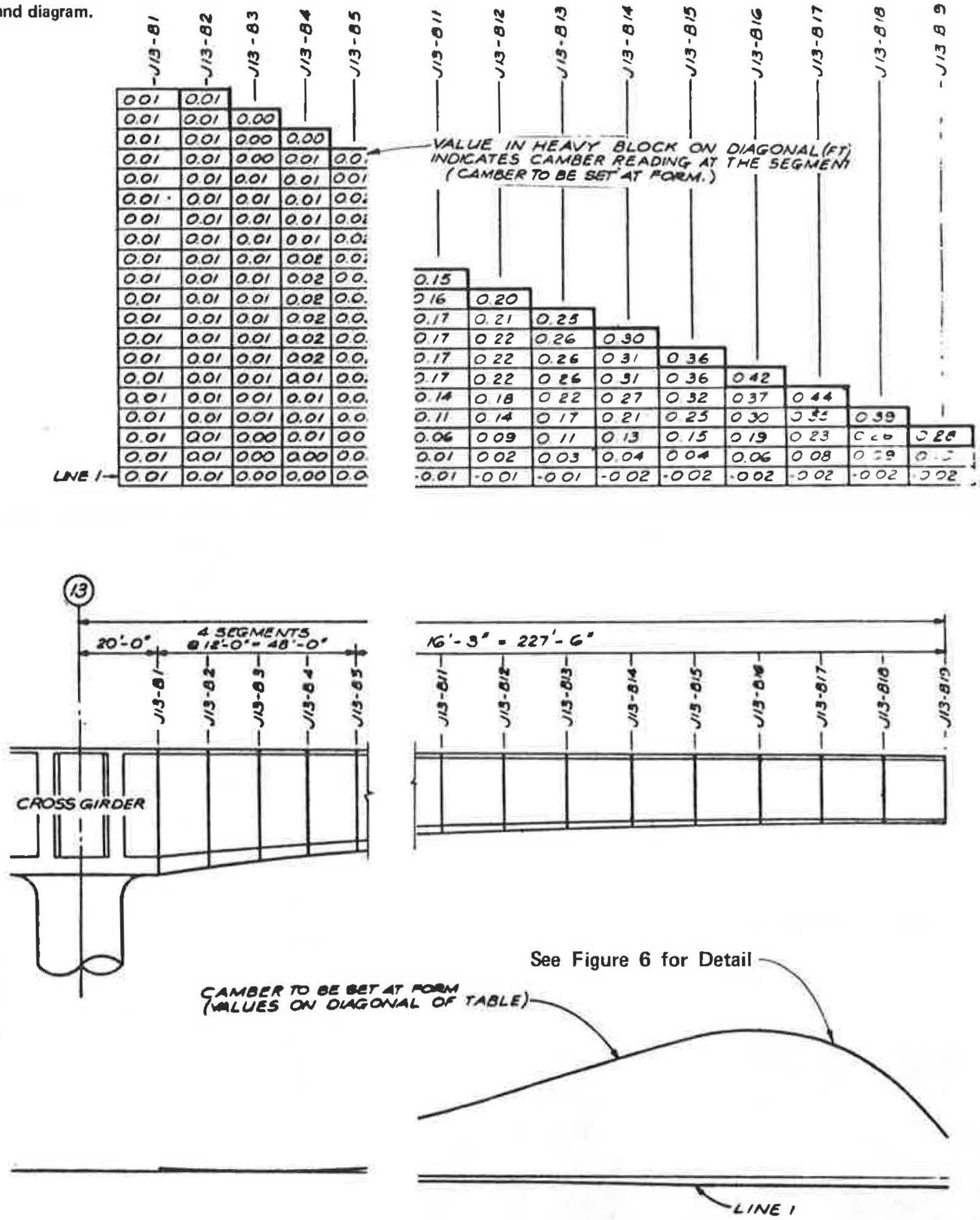
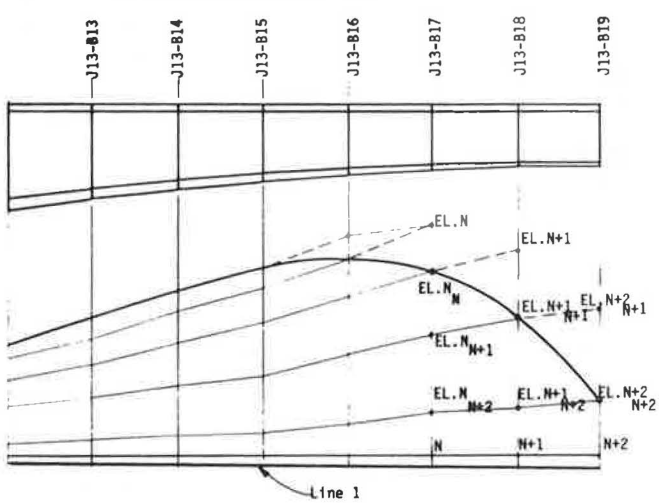


Figure 6. Bridge camber construction history.



For precast segmental construction, the camber shall be built accurately into the precast segment without the convenience of field adjustment found in cast-in-place construction. To avoid shimming in the field, adjustments are usually made in the precasting yard to correct relative angles. In order to compensate for deflection, the segments are cast with their camber, which requires a relative angle change. The angle between two chords that represent the two top surfaces of the segment indicates the angle change. Because it is a problem of space geometry, the relative angle may not necessarily lie in a vertical plane. It is also true that the angle change related to the bridge may not lie in a horizontal plane. A dihedral angle between two random surfaces can be derived through known formulas, and their angle can be obtained through vector computations.

The following is an example of angle change calculations. Assume two surfaces in a space, where one surface passes through three known points. A

Figure 7. Match-cast operation.

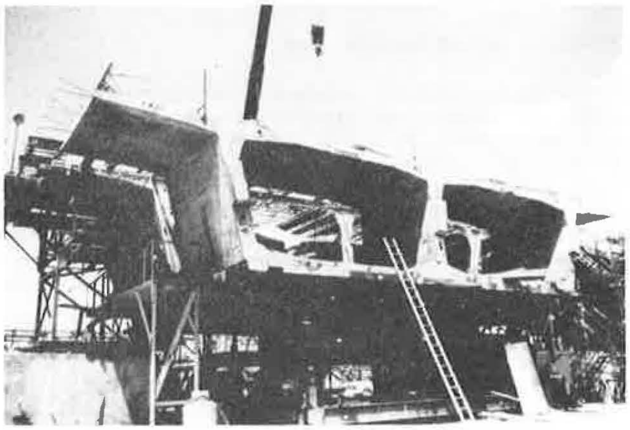
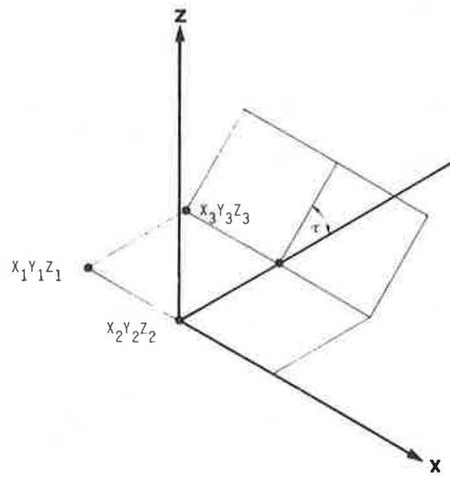


Figure 8. Two random surfaces and their dihedral angle.



plane shown in Figure 8 can be defined as follows:

$$\begin{vmatrix} X & Y & Z & 1 \\ X_1 & Y_1 & Z_1 & 1 \\ X_2 & Y_2 & Z_2 & 1 \\ X_3 & Y_3 & Z_3 & 1 \end{vmatrix} = 0 \qquad (13)$$

$$\begin{vmatrix} Y_1 & Z_1 & 1 \\ Y_2 & Z_2 & 1 \\ Y_3 & Z_3 & 1 \end{vmatrix} X + \begin{vmatrix} Z_1 & X_1 & 1 \\ Z_2 & X_2 & 1 \\ Z_3 & X_3 & 1 \end{vmatrix} Y + \begin{vmatrix} X_1 & Y_1 & 1 \\ X_2 & Y_2 & 1 \\ X_3 & Y_3 & 1 \end{vmatrix} Z = \begin{vmatrix} X_1 & Y_1 & Z_1 \\ X_2 & Y_2 & Z_2 \\ X_3 & Y_3 & Z_3 \end{vmatrix} \qquad (14)$$

$$A_1 \cdot X + B_1 \cdot Y + C_1 \cdot Z = D_1 \qquad (15)$$

Thus, solve determinant of A_1, B_1, C_1, D_1.

We can find the fourth point elevation Z if we knew X_4 and Y_4, or we can verify the calculated Z_4 with actual elevation. Two planes can be used to establish two equations that consist of A, B, C, and D. Their angle change of τ can be solved for a dihedral angle between two planes as follows:

$$\text{Cos}\tau = [(A_1 \cdot A_2) + (B_1 \cdot B_2) + (C_1 \cdot C_2)]/(\sqrt{A_1^2 + B_1^2 + C_1^2} \cdot \sqrt{A_2^2 + B_2^2 + C_2^2}) \qquad (16)$$

Figure 9. Cast procedure of precast segments.

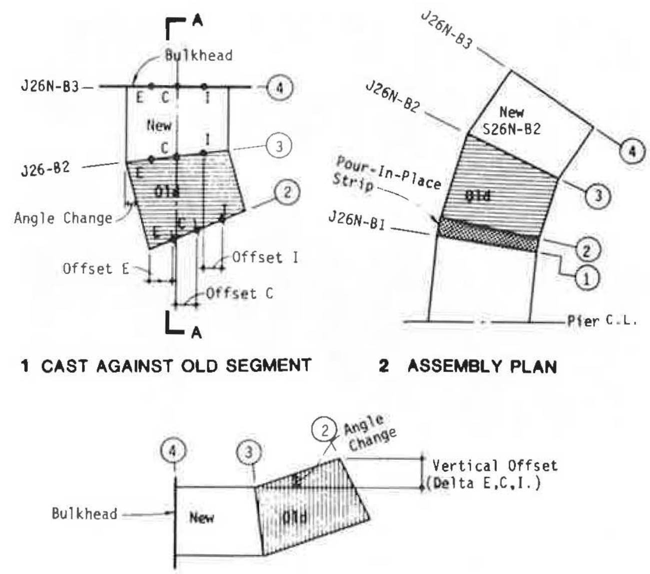
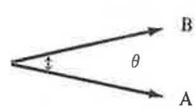


Figure 10. Precast segment is hoisted up to its key-in position

Scaler:



A • B = /A/ • /B/ • Cos θ

Thus, the relative angle change for each adjacent segment is established. Based on bridge grade profile and curve data, segment geometry can be established by superimposing the above data with design cambers. Then the angle change between segments can be determined in accordance with the above-outlined procedures. After the relative angle between two segments has been determined, the horizontal and vertical offset can be calculated based on the chord lengths. The diagram in Figure 9 illustrates the casting procedure. Then, segments shipped from the casting yard are hoisted into position, as shown in Figures 10 and 11.

By examining the structural record of a 180-ft precast segmental construction, it is found that the variations between the predicted and actual surveyed elevations are on the order of 0.25 in for most joints and 0.75 in at two particular joints (Figure 12). It is also noted that the above-mentioned cantilever construction was done without the use of shimming.

Figure 11. Hoisting equipment moves new segment into correct position.

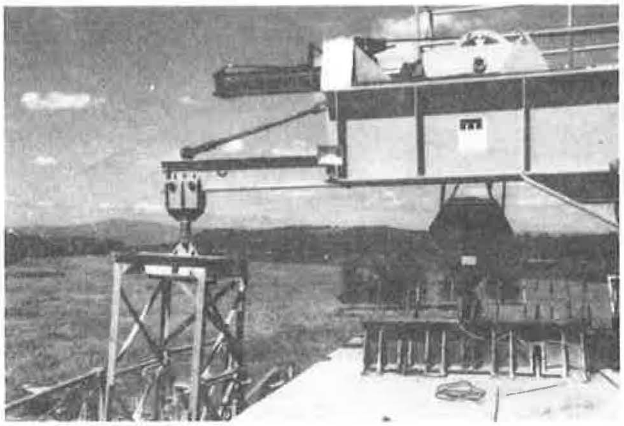
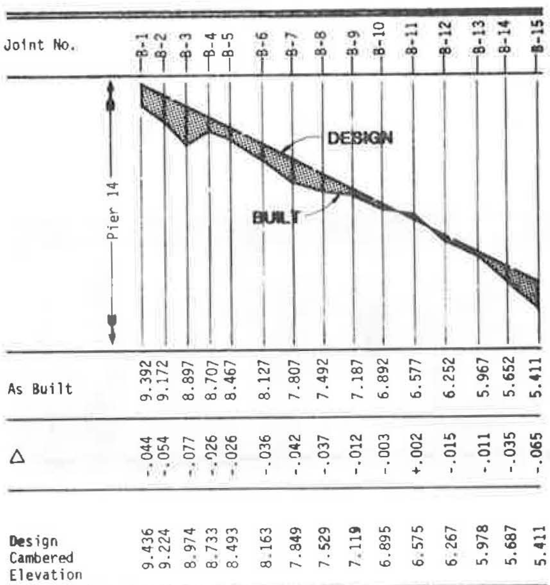


Figure 12. Design camber versus as-built elevation.



In precast segmental construction, it is difficult to construct a twisting angle between two adjacent segments, which is necessary to accommodate a superelevation change. It involves twisting of the web or bottom slab from the plane of the previous segment. It also causes a gap at the segment joint, which complicates the concreting. In the I-205 project, a slight tilting of one of the supports of the old segment at the casting bed was used to achieve the necessary superelevation angle change.

CONCLUSION AND RECOMMENDATIONS

With proper control, segmental cantilevered construction, either cast-in-place or precast, can be built accurately in elevation and plane geometry. Camber or deflection prediction involves many parameters, which are either time dependent or independent. In construction, a simplified analysis of deflection prediction is desirable. The methods outlined in this paper have demonstrated the practicality of a simple approach to deflection control, and the results have proved to be satisfactory.

From the experience of several projects, and the I-205 project in particular, the simplified method of deflection prediction can be used for both cast-in-place and precast cantilever segmental constructions. The correct elevation in cast-in-place construction relies on the correct setting of forms, while in precast segmental construction the correct elevation depends on accurate casting techniques. Success in both types of construction will depend on good camber prediction.

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REFERENCES

1. Post-Tensioned Box Girder Bridge Manual. Post Tensioning Institute, Phoenix, 1978.
2. Precast Segmental Box Girder Bridge Manual. Prestressed Concrete Institute, Chicago, 1978.
3. T.Y. Lin and N. Burnes. Design of Prestressed Concrete Structures, 3rd ed. Wiley, New York, 1978.
4. Deflections of Prestressed Concrete Members. Journal of the American Concrete Institute, Dec. 1963.
5. CEB-FIP Model Code for Concrete Structures. Comite Euro-International du Beton-Federation Internationale de la Precontrainte, Paris, 1978.
6. Deflections of Concrete Structures. American Concrete Institute, Detroit, Special Publ. 43, April 1974.
7. M. Polivka. Lightweight Concrete for the Ruck-A-Chucky Bridge. T.Y. Lin International, San Francisco, July 7, 1977.

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