Geometry Control of Precast Segmental Concrete Bridges

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Geometry control needs to be accounted for from conceptual design through production and final erection of segmental concrete bridges. If this control is not adequately provided, the project will be unsatisfactory. Conversely, if suitable geometry control is established in the beginning and maintained throughout the project, excellent results will be achieved.

Geometry control is required whether the segmental bridge is precast or cast in place and erected in cantilever. It is required whether the bridge is on tangent or curved, flat or on vertical curve. Control is also required in other types of erection, but each varies in some way. This discussion will concern precast segmental bridges erected in cantilever since many bridges have been and are being built in this manner.

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Time of Control

Contrary to some thinking, geometry control should not wait until construction starts. Waiting until production or erection begins is a serious oversight and will cause problems and delays. Rather than starting control in the construction phase, the process should begin in the conceptual design phase and be carried through design, detailing, the casting curve, production plan, shop drawings, form and manufacturing plant design, production of segments, curing, storage, erection of segments, and post-tensioning.

Of course, the actual geometry control as described later is accomplished in the production and erection phases. Nonetheless, the designer should keep geometry control in mind when developing the structural concept, se-

Very close and constant control is necessary to obtain a completely satisfactory segmental concrete bridge. This control must be established and maintained in production and during erection of segments. Methods and amount of control are discussed.

lecting the most likely erection method, developing details to facilitate the control, and preparing the casting curve. Then the contractor must keep the control aspect in mind while preparing the production plan and the shop drawings.

The contractor must certainly discuss the amount of control and methods to achieve it with the form designer. Control during production and erection are usually understood, but one must not overlook the curing and storage of segments.

Changes in geometric measurements can occur if just the newly cast segment is steam cured, so it is recommended that both the new and the old segment be so cured. This amounts to two time periods of curing for each segment and while usually not needed for strength, maintaining the higher moist temperature does aid in geometry control. Likewise, if segments are not set level on a firm storage pad with bearings under the webs, warping can occur.

The designer must maintain a concern for geometry control throughout the design and detailing phases. Also, the designer must select a likely method of erection, especially in cases where erection loads will occur on the cantilevers, and compute accurate casting curves which will become part of the plans.

Some might say that this is not necessary because the contractor might want to change the erection scheme, the size of segments, post-tensioning or some other item which would alter these casting curves. However, it is highly desirable to include this information in the plans because it will inform possible bidders and will direct attention to the importance and need of geometry control. Moreover, most bidders do not have the staff, capability or desire to revise the plans.

It has been noted that with complete, detailed plans, the contractor usually uses most of the design and sometimes all of it. Also, it must be remembered that these complete plans include tendon layouts for all permanent post-tensioning, adequate temporary post-tensioning used during erection, and the sequence of tensioning, as this could alter the geometry in certain cases.

With these well conceived and detailed plans, all contractors can prepare accurate bids. They will be forewarned of the need for geometry control in the construction phase, and if they should choose to change some item, they will know what is required in their submittal. In preparing bids, the em-

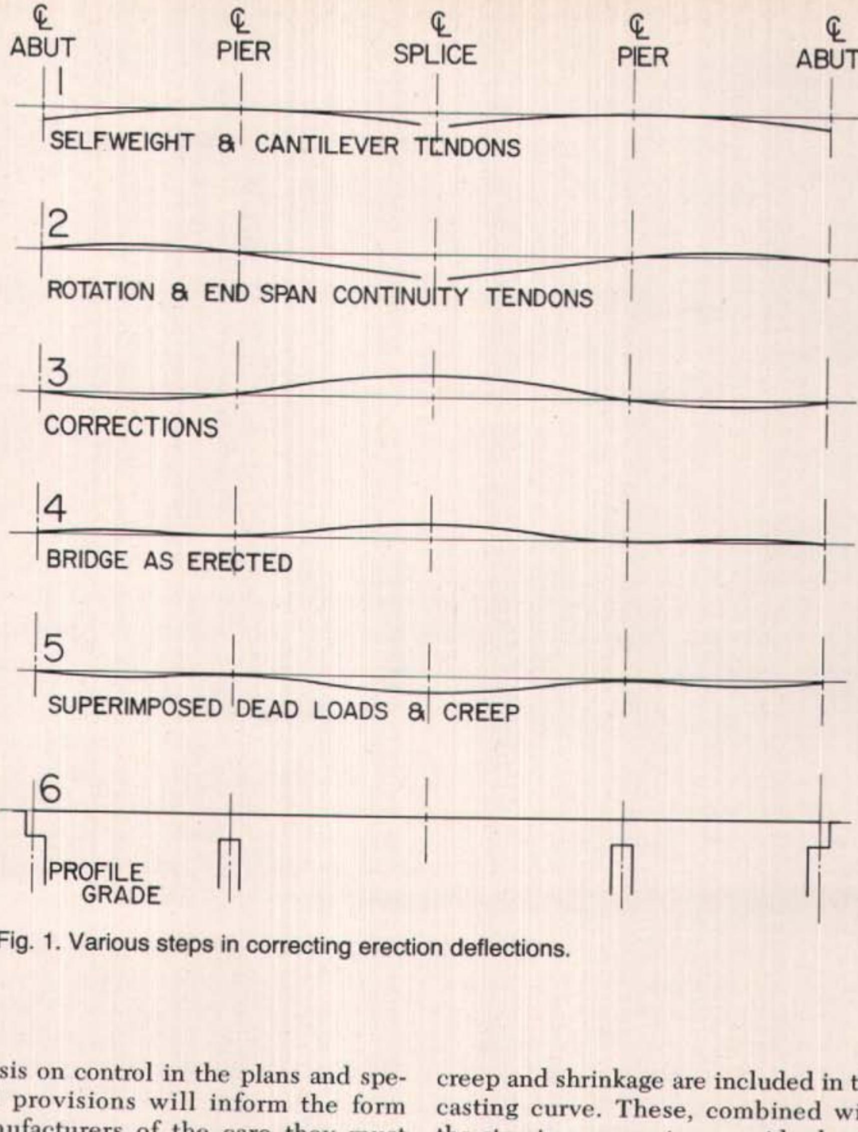

Fig. 1. Various steps in correcting erection deflections.

phasis on control in the plans and special provisions will inform the form manufacturers of the care they must take to provide an adequate casting machine.

The successful contractor can immediately begin the work by ordering the form, preparing the production schedule, and preparing shop drawings. With the casting curve and other items on the plans, shop drawings can be started with no other computations if the design plans are used. The geometry control functions of dead load deflection, post-tensioning camber, creep and shrinkage are included in the casting curve. These, combined with the structure geometry, provide the information for each segment shop drawing.

With adequate forms installed in a complete manufacturing area, and with approved shop drawings in hand, the production of segments can begin. Anyone who is familiar with segmental precast concrete bridges knows that the segments must be match cast. This is elementary, but most important. Likewise, all prudent engineers will realize that a box girder constructed on

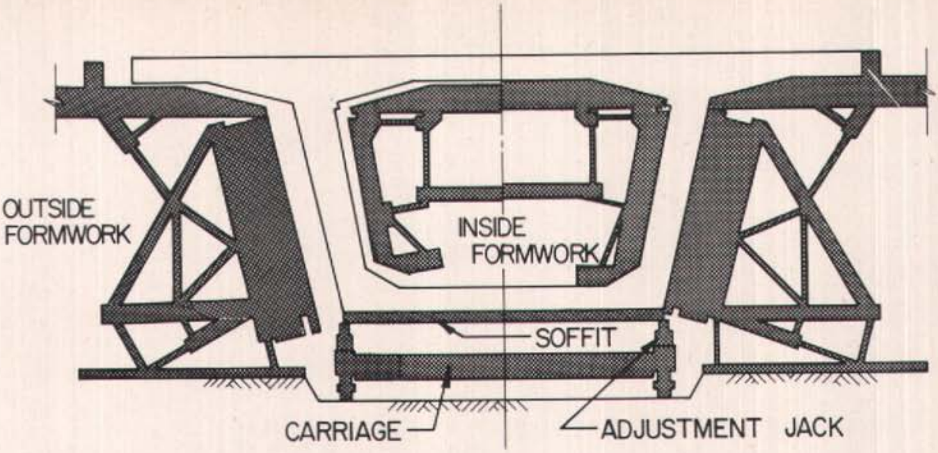

Fig. 2. Formwork (Short-line method).

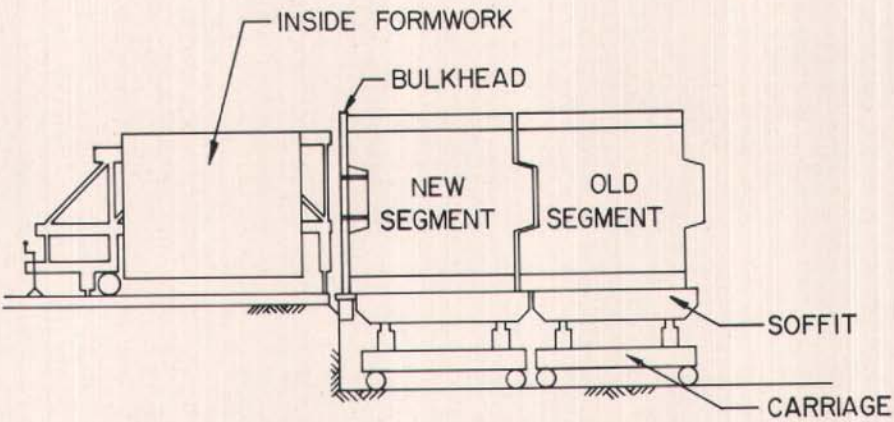

Fig. 3. Step 1 (Short-line method).

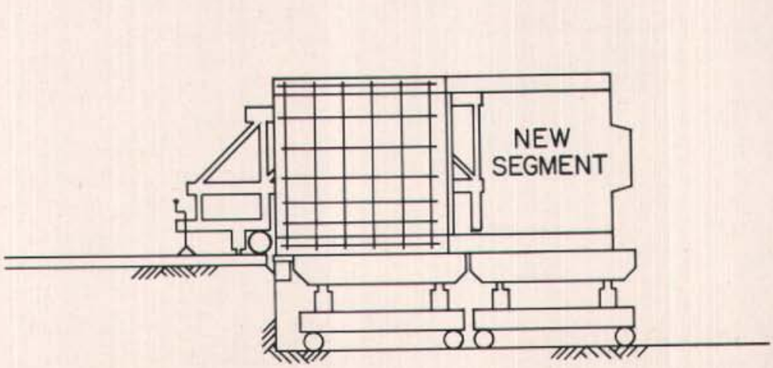

Fig. 4. Step 2 (Short-line method).

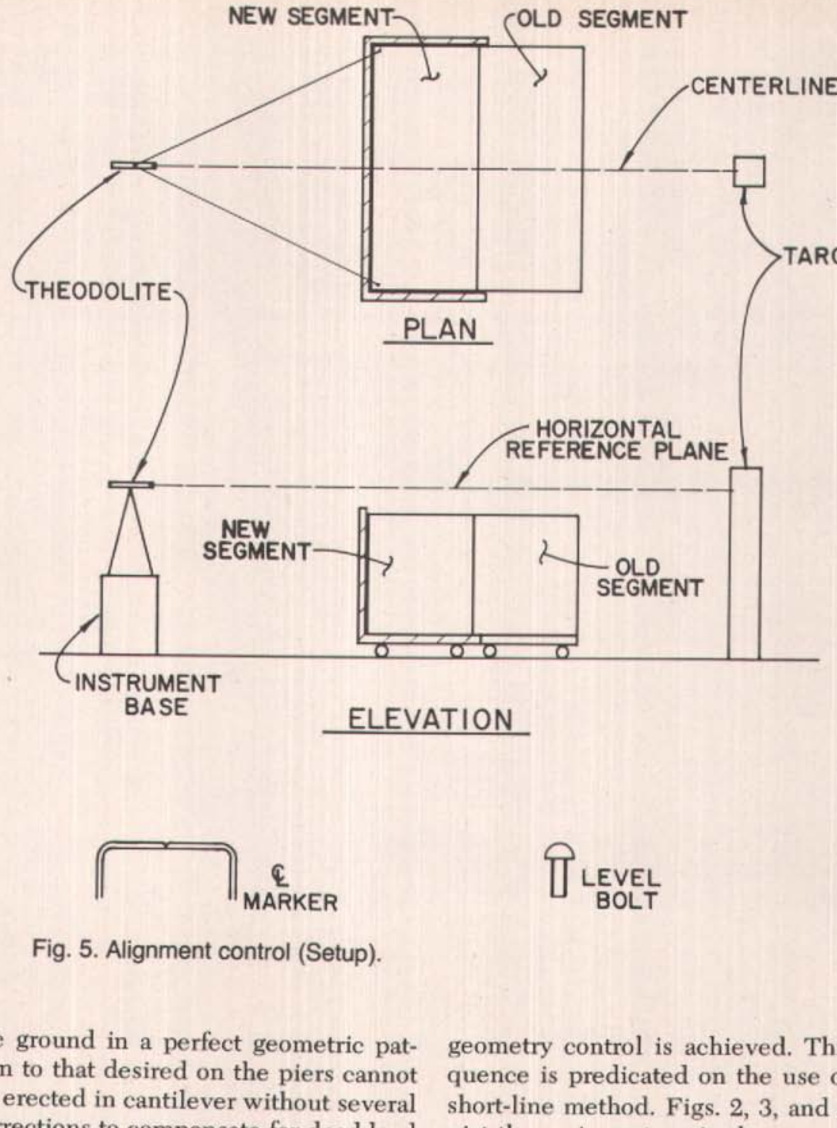

Fig. 5. Alignment control (Setup).

the ground in a perfect geometric pattern to that desired on the piers cannot be erected in cantilever without several corrections to compensate for dead load deflection, prestressing cambers, creep, and shrinkage. Fig. 1 indicates the need for these corrections. Each segment is intentionally deformed during production to achieve the desired results. From this follows the importance of geometry control in production.

Production Control

Let us now follow through the casting procedure to indicate how the required geometry control is achieved. This sequence is predicated on the use of the short-line method. Figs. 2, 3, and 4 depict the various steps in the case of the short-line method of production.

Fig. 5 shows the setup required in the casting area. Especially note the instrument on a permanent base and a permanent target (Fig. 6). It is very important that neither instrument nor target be disturbed throughout the production. In case of a disturbance, control must be reestablished so adequate bench marks must be provided. Note that in Fig. 5 a new segment has been match cast against an old segment.

The form is always plumb, level and square so the geometry control is established by properly setting the old segment.

But to begin, the first segment must be cast. This might be a pier segment, but it could be any other element that the contractor's scheduling indicates should be first. Since there is no old segment, a second bulkhead is required and the segment is cast plumb, level, and square. As the top slab is being finished, the four elevation bolts, A, B, C and D, as well as the centerline marker are inserted. The following morning the levels on the bolts are recorded and the centerline is scribed onto the centerline markers. Now the temporary second bulkhead can be removed and the segment rolled forward for match casting (see Figs. 7, 8, and 9a, 9b).

Here it is desirable to interject the idea of permanent record keeping. The instrument person should be on the job daily, have the complete confidence of

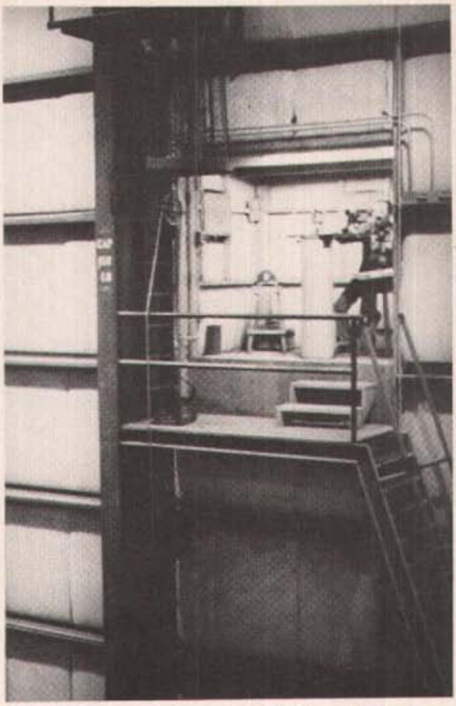

Fig. 6. Instrument set up (Zilwaukee Bridge, Michigan).

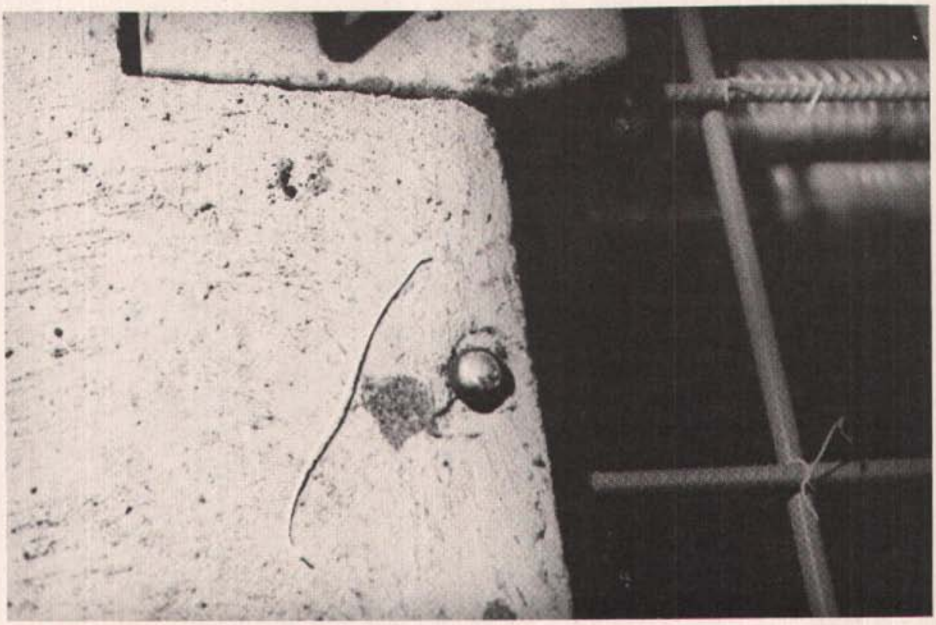

Fig. 7. Match-cast segment showing elevation bolt.

Fig. 8. Match-cast segment showing centerline marker.

the superintendent, and keep accurate, daily records.

When the first segment is rolled forward, it is reset to the information on the shop drawings. The centerline will be identical as to what it was the previous day, unless the bridge is curved and then an offset angle is used as shown in Fig. 9a. Likewise, vertical curvature is handled as shown in Fig. 9b. But in addition to the vertical curvature adjustment, if any, it is necessary to adjust for the segment deformations as mentioned before and illustrated in Fig. 1.

These deformations will be on the

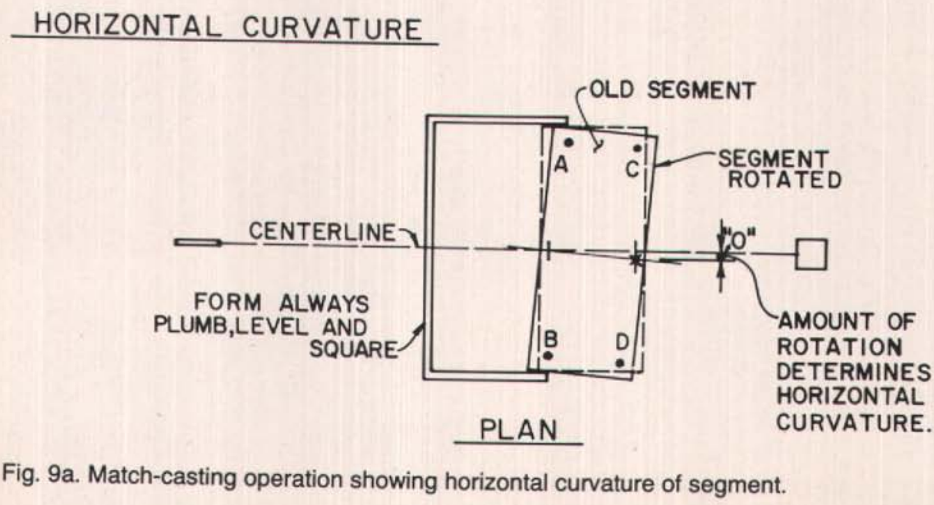

Fig. 9a. Match-casting operation showing horizontal curvature of segment.

shop drawings, and can be taken directly from the plans unless changes were made to these. In that case, the contractor, or his designer, must recompute them. After this first (the old) segment is properly reset and the setup for the second segment is complete, including reinforcing bar cage, tendons, anchors, embedded items and the position of the inner mandrel, the second segment can be cast. This second segment is called the new segment in Figs. 5 and 10.

The following morning it is necessary to mark the centerline and record the bolt elevations of segment number two. Also, before segment number one (the old segment) is moved, it is imperative to recheck the elevations of its bolts and its centerline position to determine if its position has changed since it was set so carefully the previous day. It is often noted that position changes occur due to settlement of the soffit rails by the segment weight, or due to vibrating of fresh concrete against it, or due to temperature changes.

There is no need to be concerned about these small changes as long as these are known and recorded every day. From these, daily compensations can be made. It is only from neglected or accumulated errors that the geometry becomes jeopardized. As compensation is made daily, the bridge superstructure

Fig. 10. Positioning the old segment (Zilwaukee Bridge, Michigan).

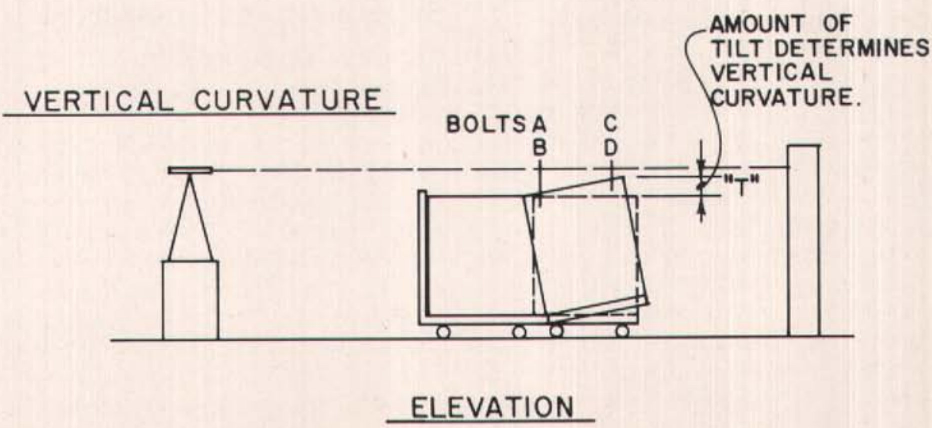

Fig. 9b. Match-casting operation showing vertical curvature of segment.

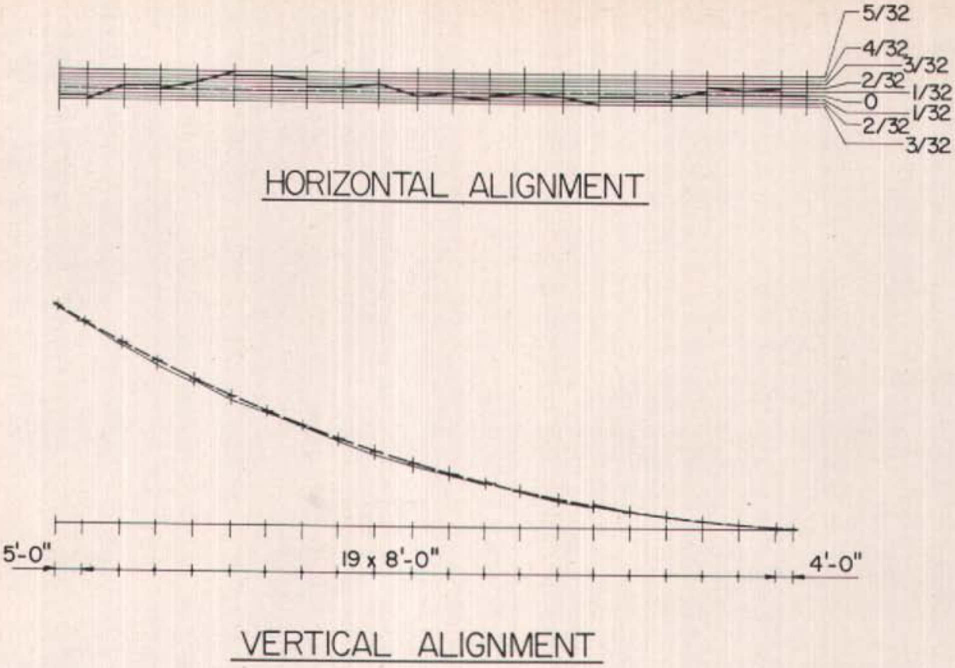

Fig. 11. Graphical production chart showing horizontal and vertical alignment.

deviates both vertically and horizontally from the theoretical alignment by very small amounts. However, if these small deviations are left uncorrected, they will soon magnify and create an unsatisfactory condition.

The instrument person should maintain a graph of these corrections from the records as shown in Fig. 11.

After the alignment of the "old segment" is recorded, it can be removed from the soffit and moved to proper storage. Many times segments are kept one more day in the manufacturing area to complete transverse post-tensioning and clean-up.

The setup to cast segment three, and all other segments, is similar to that of casting segment two with one exception. When segment two is rolled forward, it is set to the proper position as per the drawings, but this time it must also have a small compensation for a position change of segment one that occured during casting. If segment one had moved ⅛ in. (3.2 mm) to the left, segment two will now be adjusted ⅛ in. to the right. The same procedure holds for any vertical adjustment. This shows the importance of constant surveillance.

Superelevation Control

Another geometric problem is handling superelevation for horizontal curvature. If the superelevation is constant within a span, no transverse tilting of the old segment is required in setting it for match casting. Rather, the superelevation is achieved by setting the pier segment on the proper tilt as shown in Fig. 12. However, as indicated in the bottom portion of Fig. 12, the tilting of the pier segment does create an undesirable deflection which must be corrected by introducing counteracting vertical curvature. Likewise, if the structure is on a strong vertical curve,

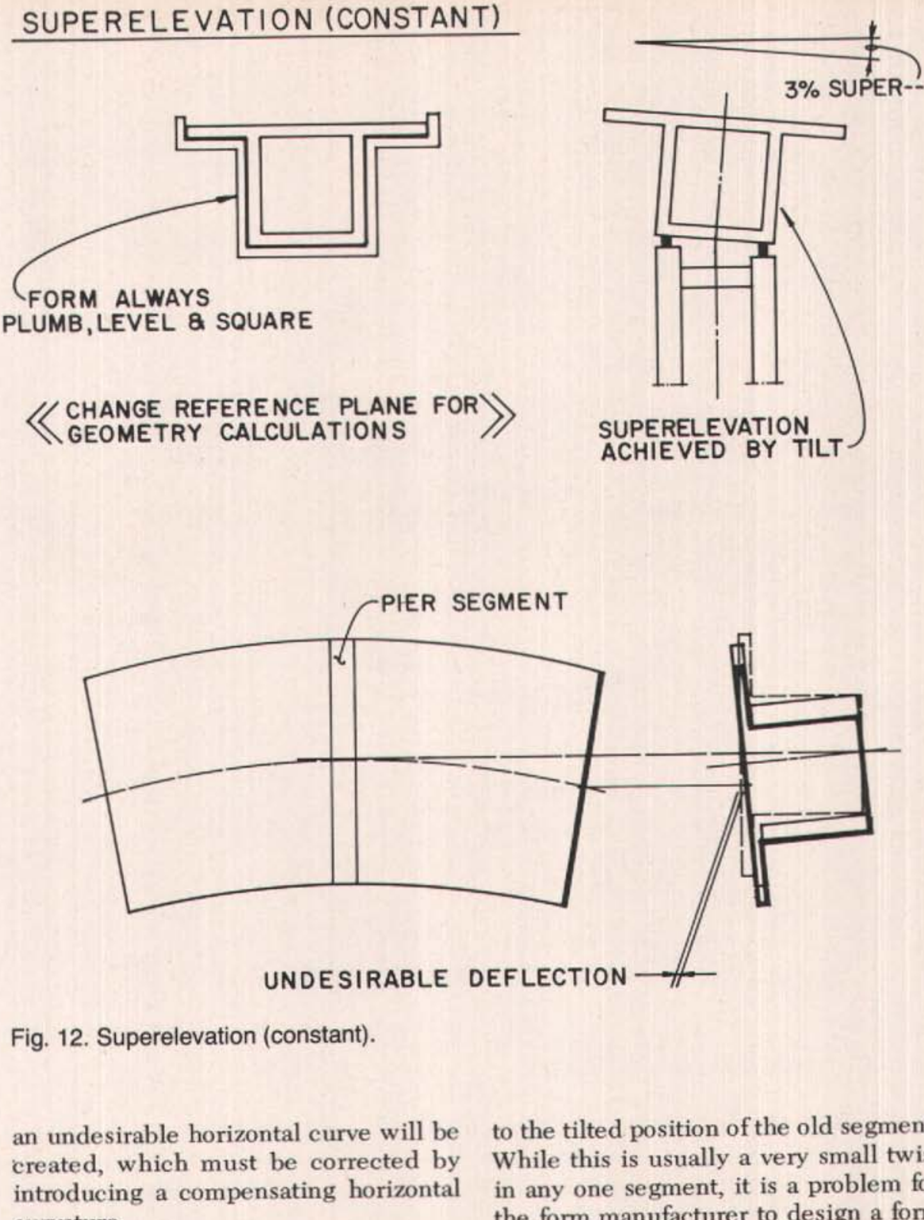

Fig. 12. Superelevation (constant).

an undesirable horizontal curve will be created, which must be corrected by introducing a compensating horizontal curvature.

More complicated is handling a superelevation transition that occurs when the superelevation is increasing or decreasing in a span. Now the old segment needs to be tilted with respect to the new segment as shown in Fig. 13. While the permanent bulkhead remains plumb, level and square, the rest of the form must assume the transition to the tilted position of the old segment. While this is usually a very small twist in any one segment, it is a problem for the form manufacturer to design a form which can accomplish the twist and remain structurally rigid for the concrete casting and still maintain a mortar tight seal at the point of joining the old segment. The practical point of rotation is the centerline of the bottom slab.

A consequence of transverse tilting of the old segment with respect to the new segment is that the centerline of

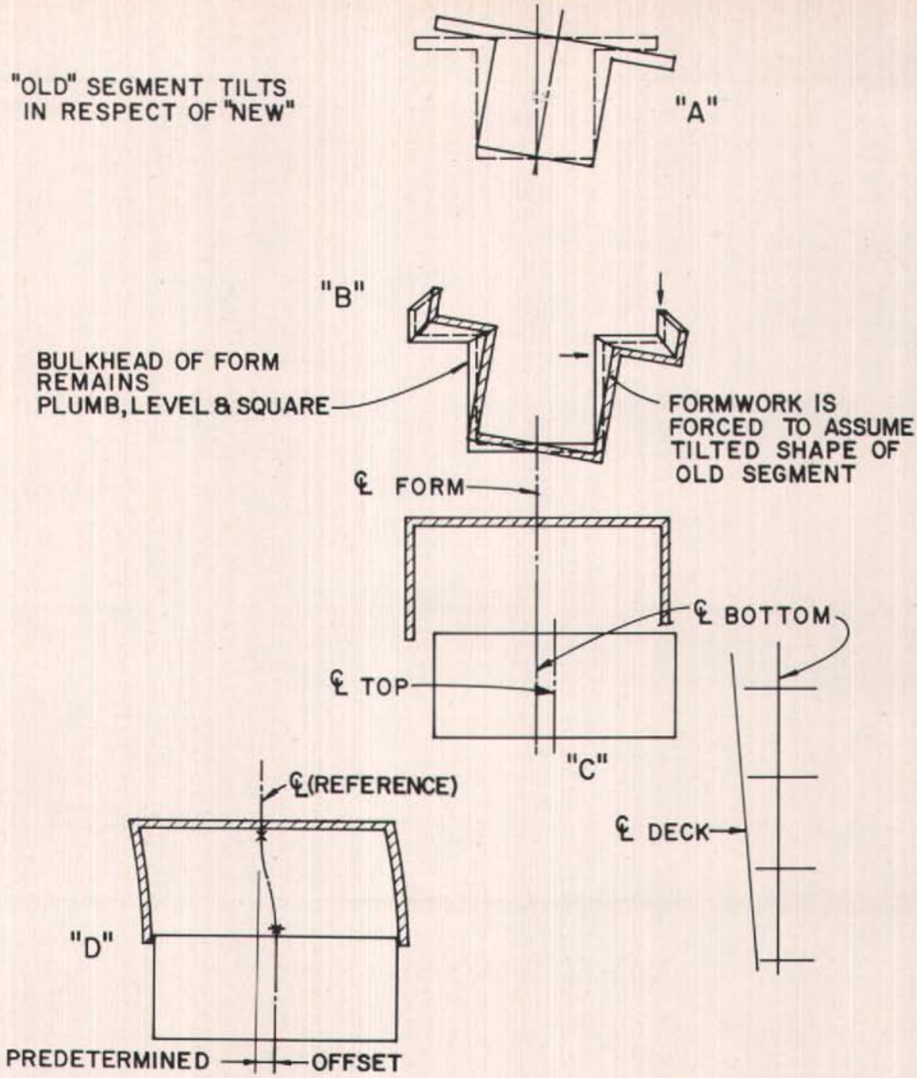

Fig. 13. Superelevation Transition I during casting.

the top and bottom slabs are no longer in a vertical plane. It is ideal if the instrument is in a position to establish both the bottom slab centerline and the top slab centerline. Since the centerline of the top slab is offset a predetermined amount, it is essential that this be measured in the setup.

Fig. 13 shows that the bottom slab centerline remains constant during production. Fig. 14 indicates the rotation from no superelevation to full superelevation. According to the picture in the middle of Fig. 14, the segments in the transition area will have some small irregularities which are caused by warping of the form.

In order to line up top slab center-

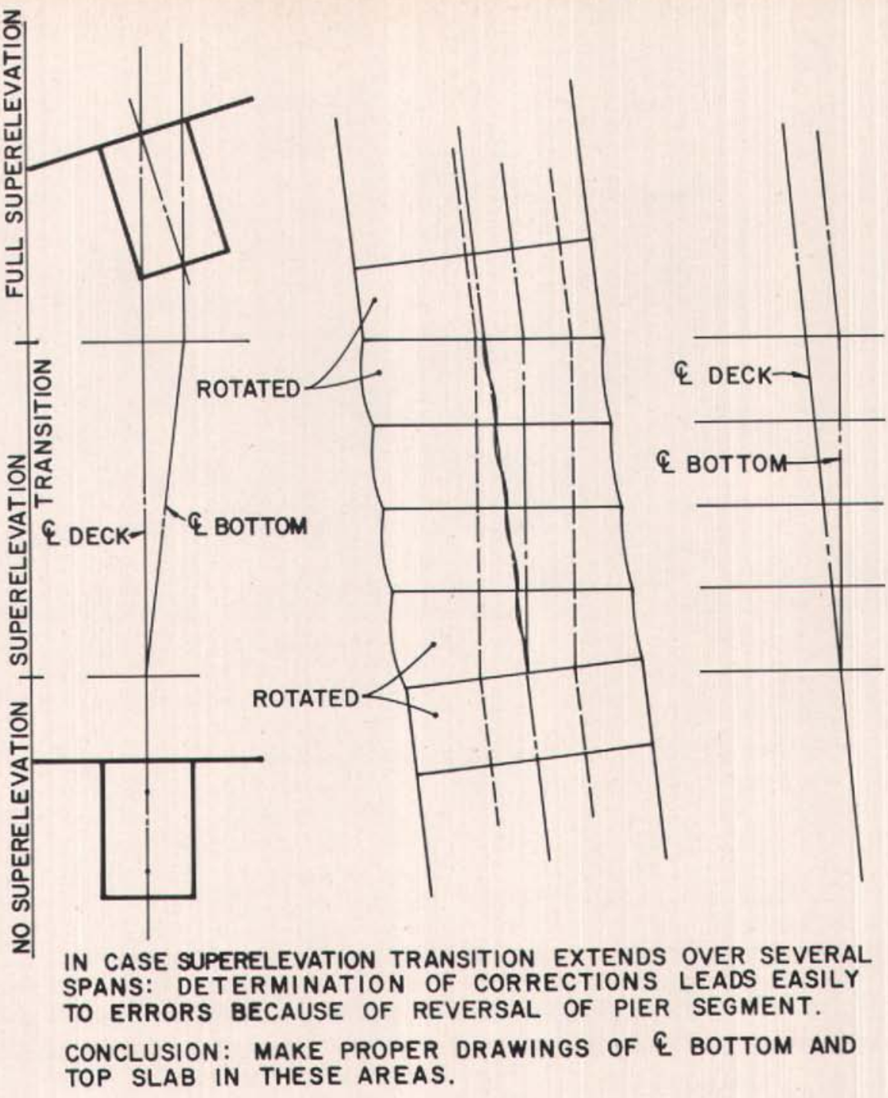

Fig. 14. Superelevation Transition II during erection.

lines instead of bottom slab centerlines, segments at the beginning and end of the superelevation transitions need to be rotated.

This subject can be more complicated than shown in Figs. 13 and 14 because usually the transition will start within a span and continue over several piers. This is complicating in itself, but the complexity increases because the production often calls for a reversal of the pier segment after completion of half a cantilever. In order to avoid errors, therefore, it is mandatory that proper shop drawings be made clearly showing bottom and top slab centerlines.

It follows from the above that alignment control is a matter of combining

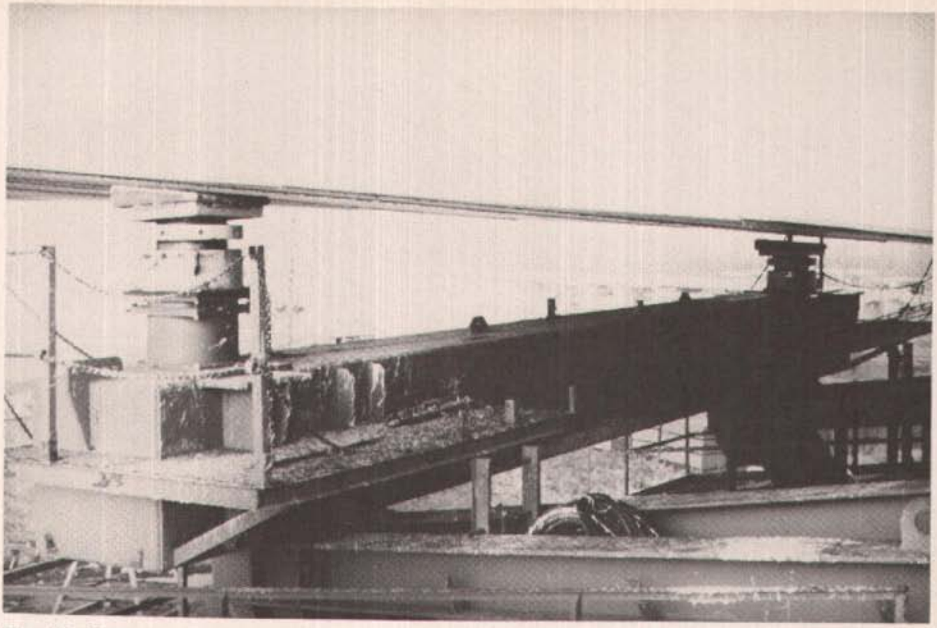

Fig. 15. Temporary support of pier segment group (Zilwaukee Bridge, Michigan).

the calculated deformations with the structure geometry on the shop drawings and:

1. Implementing these at the casting site.
2. Recording each morning the corrections achieved.
3. Comparing the corrections with the requirements.
4. Correcting the corrections.

Erection Control

It is necessary to consider alignment control during erection of segments. First, an erection table, chart, or graph must be prepared after the segments are produced. This provides the theoretical position of each segment based on actual production measurements. The same leveling bolts are used and offsets from an established centerline provide horizontal control. Transverse or horizontal tilt or rotation is also on the theoretical chart.

The designer of the structure should provide information regarding the elevation of each segment after erection of that segment. If this information is provided, the actual position of the segment can be checked against the theoretical. Readings should be taken as the segments are erected in order to notice discrepancies, if any. However, the only true readings that can be obtained are those taken early in the morning before the sun's heat has had time to affect the girder.

This effect is very pronounced, and is caused by the fact that the top slab of the box girder heats rapidly while the bottom remains cool. This condition will cause substantial deflection of the girder. Each morning after accurate readings are taken, a determination must be made whether any corrections are necessary in erecting the next segment.

Usually only two segments are placed at each end of the cantilevers in a work day. Hence, there is an accurate reading after every two segments. From this

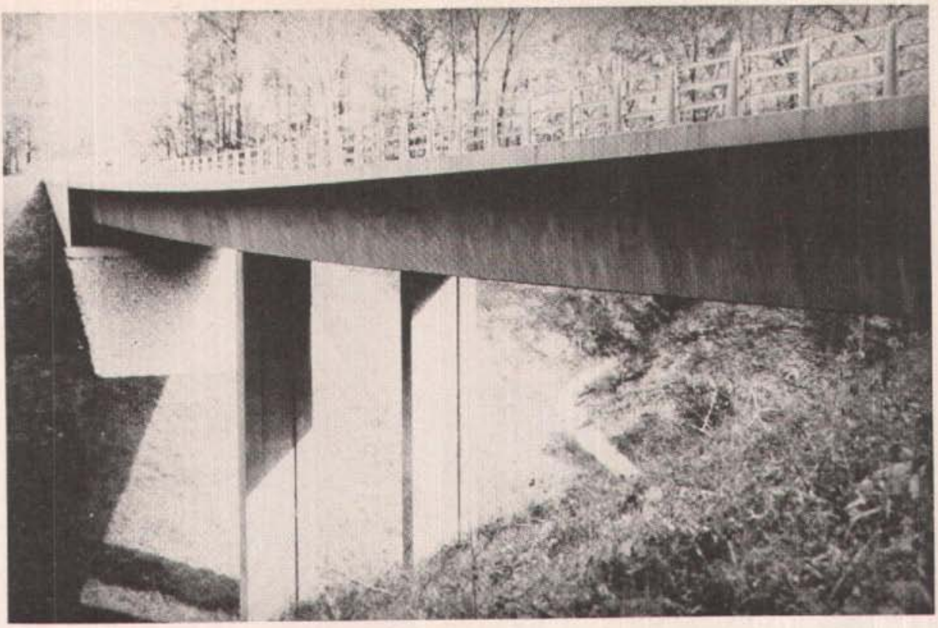

Fig. 16. Vertical sag (Turkey Run Bridge, Indiana).

it can be decided whether any field corrections are required.

If small erection corrections are desirable, shimming is recommended with stainless steel screen wire mesh about $\frac{1}{16}$ in. (1.6 mm) thick. This allows the epoxy to flow through and prevents stress concentration points, yet it will effectively turn the next segment up, down or laterally. It is recommended that shimming not be started too soon. Only after a number of segments have been erected in a cantilever, and after the temporary bearing assemblies are checked for any discrepancy, can a judgment of the alignment be made. And if measurements indicate that the erected structure will be out of tolerance, careful use of shims will regulate the problem.

It is advisable to start erection of the pier segment or group of segments on temporary bearings. These temporary bearings are designed to allow the cantilevers to be adjusted after the segments are erected and then let down onto permanent bearings. It is very important that the pier group of segments be precisely set because an error made in this will be multiplied upon completion of the cantilever (Fig. 15).

Other items affecting geometry during erection are provisional post-tensioning, post-tensioning of permanent tendons, and midspan splices. Both provisional and permanent tendons are a design function, and the use of correct number and correct placing are a production responsibility. However, the sequence of tensioning can be important and should be established in the work check list for the erecting crew. Before the splices are cast, the cantilevers must be aligned. Structural hardware should be provided to hold the cantilevers in line during midspan splice casting and continuity post-tensioning (Figs. 16 and 17).

Further information on the subject of geometry control in segmental construction can be obtained from References 1 through 6.

Fig. 17. Horizontal curve (Zilwaukee Bridge, Michigan).

CONCLUSIONS

From the preceding discussion the following conclusions can be stated:

1. Geometry control is most definitely needed for a satisfactory segmental bridge.

2. Control is essential in all stages of the work from design through casting the final midspan splice.

3. Control functions are relatively simple, but it is more important that control be started as each phase starts and does not cease until that phase ends.

4. Cooperation must exist between groups responsible for various tasks. No one group has more or less responsibility than another. Teamwork is essential.

5. Careful, complete control will insure that the bridge will meet the segment criteria.

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