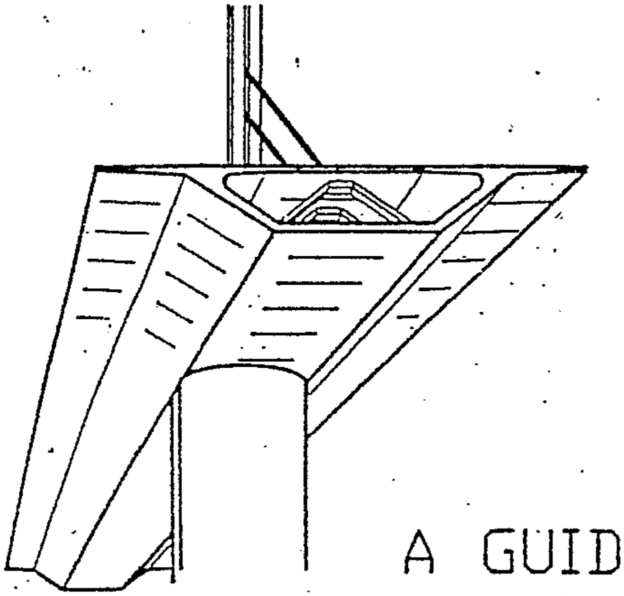
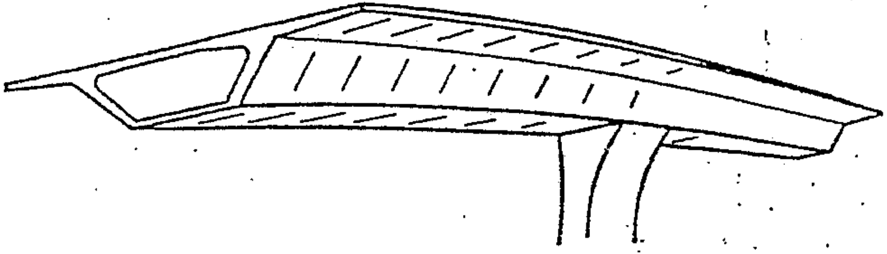
SEGMENTAL MANUAL



A GUIDE TO THE CONSTRUCTION OF SEGMENTAL BRIDGES



FLORIDA DEPARTMENT OF TRANSPORTATION
BUREAU OF CONSTRUCTION
OCTOBER 1989

Acknowledgements

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Disclaimer

The Construction Bureau of the Florida Department of Transportation has prepared this guide to the construction and inspection of segmental bridges for information only. The intent is to promote understanding, improve quality and avoid problems previously encountered on various segmental projects. It is not a supplement to, nor an interpretation of, any contract documents or specifications. In cases of conflict between this guide and particular project specifications or plans, then the specifications and plans shall be followed. Although this guide covers various construction practices related to segmental bridges, it is not intended to imply that other practices not described herein are less suitable. Contractors can, within the limits of the applicable contract documents, plans and specifications, always elect a method that better suits their own operations.

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POST-TENSIONING MANUAL

Post-tensioning is an important part of segmental construction, but this technique applies to many other bridge construction methods as well. The reader is referred to The Florida Department of Transportation Post-Tensioning Manual for an extensive description of post-tensioning techniques.

Listing of Drawings

1.0 INTRODUCTION

1.1 Purpose

The purpose of this guide is to provide a basic outline of segmental bridge construction emphasizing matters needing particular attention on the job site. It is hoped that this will be a positive contribution and will help to avoid some problems previously encountered and lead to fewer problems and greater quality assurance for all concerned. By improving basic understanding of segmental construction techniques, delays and costs caused by concern over non-critical areas of construction and from lack of understanding of critical items will hopefully be reduced.

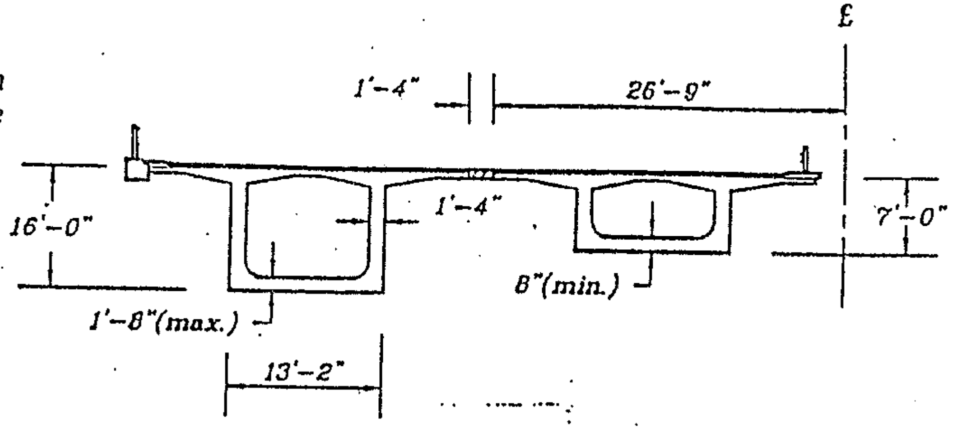
1.2 Benefits

Segmental bridges were introduced into the USA in the early Seventies after an initial period of development in Europe and elsewhere. They help fulfill a need with certain types of bridge design and construction, particularly where other forms of construction might not be possible or too costly for some reason due to access, time, material limitations and so on.

Segmental construction can be particularly useful and competitive over water, for very long spans, for highly curved structures of variable span lengths dictated by pier locations and clearances and where access restrictions or the need to maintain traffic, etc. have a significant impact upon the construction.

Trent Viaduct, U.K.

Precast segmental construction was selected for this structure against a steel plate girder design with a reinforced concrete deck slab.
Each box girder is made up of 91 precast segments 10ft. long, varying in weight between 38 tons to 82 tons.
All segments were placed in balanced cantilever with a launching gantry, with precast units being delivered across the finished deck.



@ Pier @ Midspan

Typical Cross Section Of Superstructure

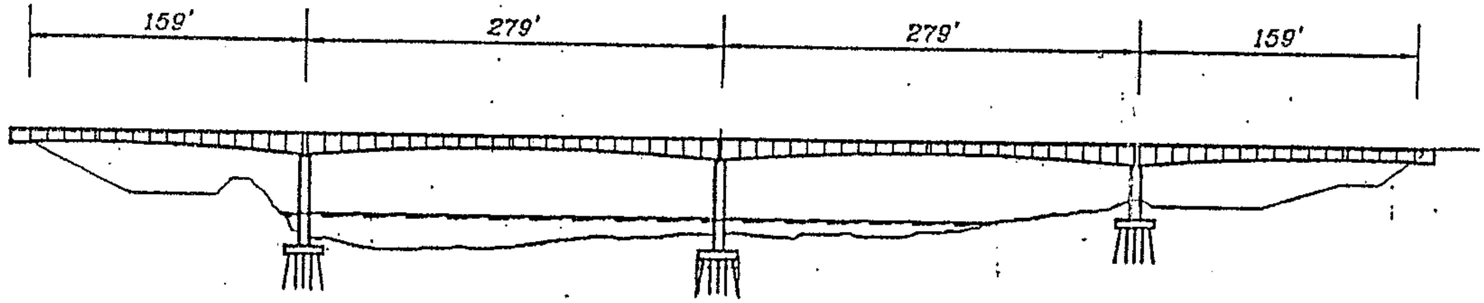
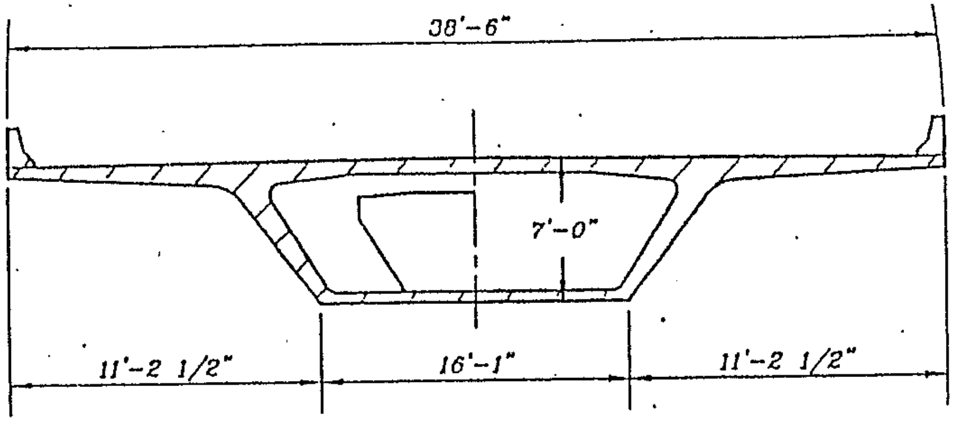


Fig. 1.2(a) Trent Bridge (U.K.)
Balanced Cantilever Construction—Variable Depth Boxgirder

Long Key Bridge

The 113 spans of this 12,144 ft. long structure were constructed, span-by-span, by placing the precast segments with a barge crane on an erection truss supported at the V-piers.



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Typical Cross Section Of Superstructure

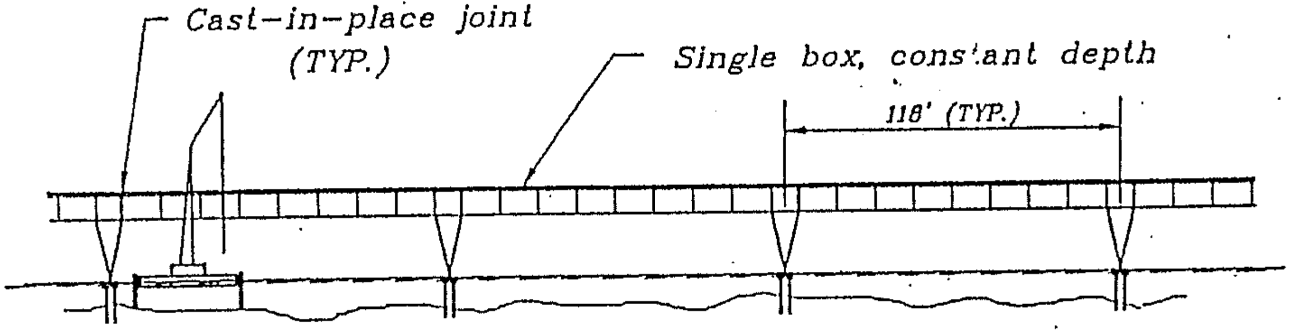
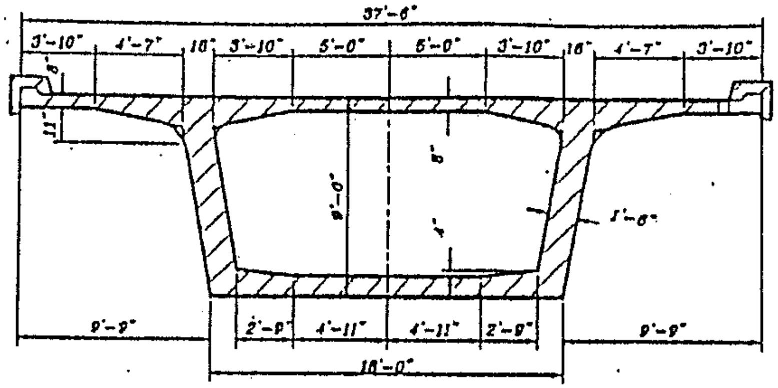


Fig. 1.2(b) Long Key Bridge
Span-By-Span Construction

Linn Cove Viaduct (N.C.)
Because of environmental sensitivity this 1243 ft. long, 8 span structure was built without requiring access to the terrain below the bridge. Foundations and piers were constructed by lowering equipment from the cantilever tips.



Typical Segment Cross Section

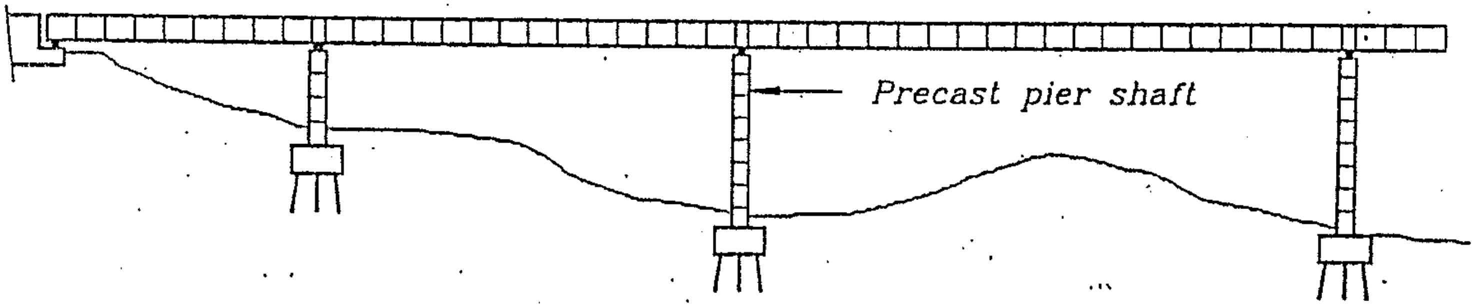


Fig. 1.2(c) Linn Cove Viaduct (N.C.)
Progressive Cantilever Construction

The manufacture of precast segments remote from the bridge site means that the site need be no larger than the bridge itself and the segments can be made on a production basis under factory controlled conditions. This also helps with construction programming by removing many operations, materials delivery, weather susceptibility, etc., from the critical path. Some examples of constructed precast segmental bridges are shown in Figures 1.2(a) through (c).

2.0 TERMINOLOGY

For the following list of terms and definitions, reference is made to Figures 1.2(a) through (c), 2.2 and 2.3.

2.1 Precast Segmental Bridge.

A bridge constructed with precast segments. Common types are shown in Figures 1.2(a) through (c).

2.2 Box Girder or Box Pier.

Box shaped structural member used for bridge superstructures and piers as shown in Figure 2.2.

2.3 Precast Segments.

Box shaped precast concrete elements which can be assembled to form a bridge superstructure or pier (see Figures 2.2 and 2.3).

2.4 Match Cast.

Method of casting segments whereby a segment is cast against an existing segment to produce a matching joint. When the segments are separated and re-assembled in the structure, the mating surfaces fit together perfectly and reproduce the "as cast geometry." Match casting is described in detail in Section 3.3.

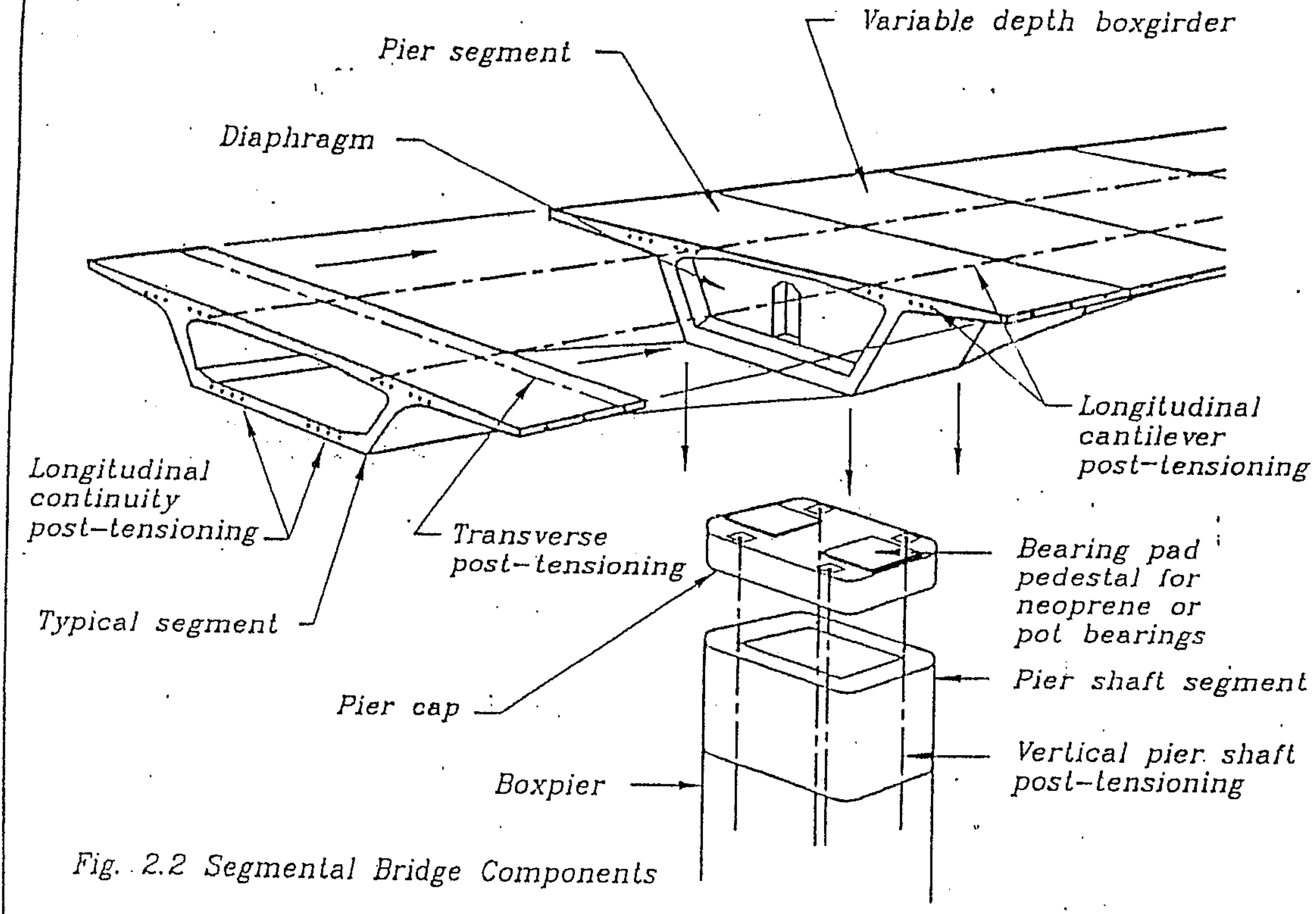


Fig. 2.2 Segmental Bridge Components

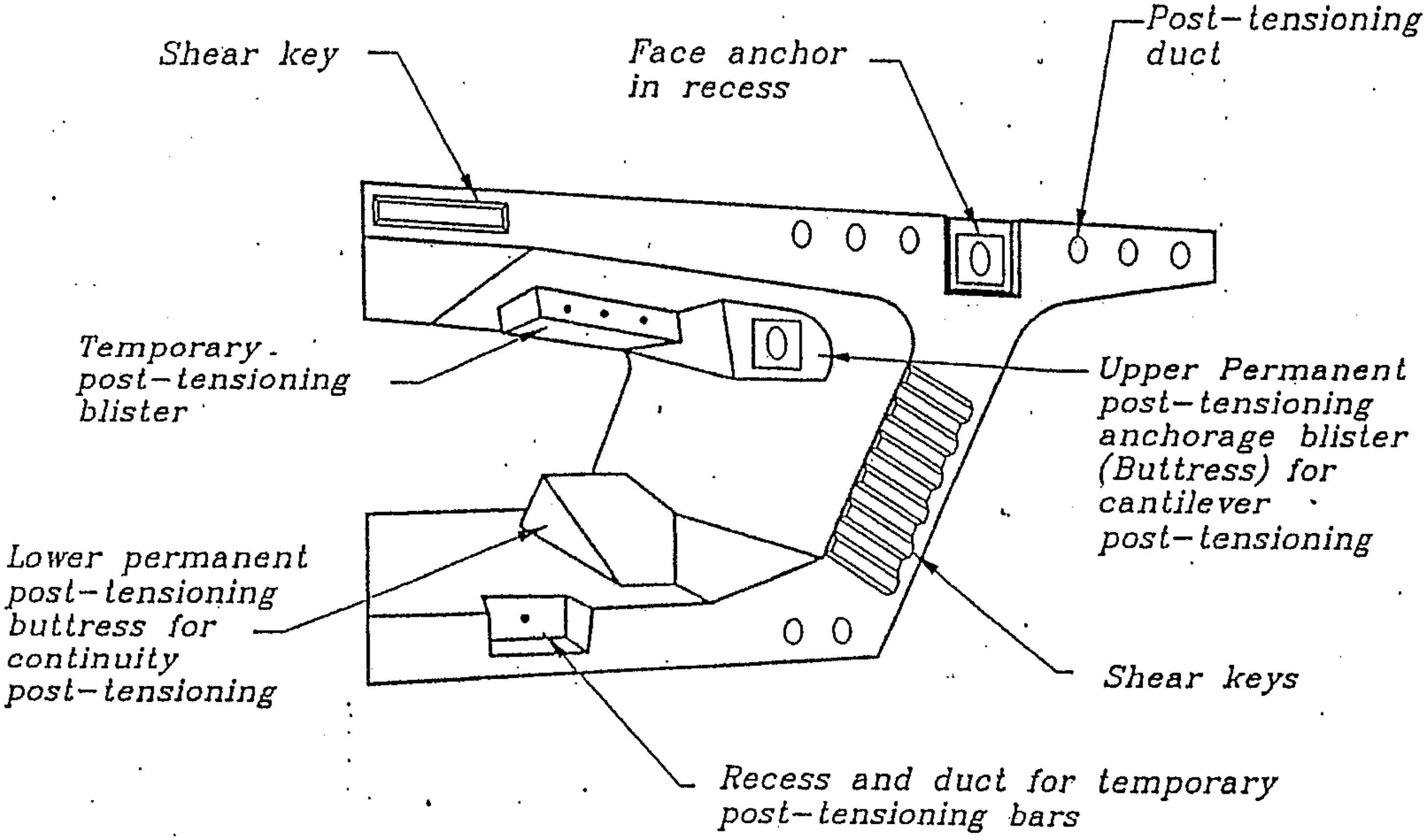


Fig. 2.3 Segment Features

2.5 Short Line Casting.

Method of casting each segment in a special form called a casting cell using a fixed bulkhead at one end and a previously cast segment at the other as shown in Figure 3.2.2 (a and b). The form is only one segment long, hence the term "short line." Short line forms are described in Section 3.2.

2.6 Long Line Casting.

Method of casting segments on a long casting bed which makes up the soffit of a complete cantilever or span between field closures as shown in Figure 3.2.1. The long line casting method is described in Section 3.2.

2.7 Wet Cast Joint System.

Method whereby segments are cast in a single form between two bulkheads, so they are not matchcast. Segments must be supported on falsework until wet joints are cast and the girder is post-tensioned, see Section 5.7.

2.8 Span-by-Span Erection.

This is an erection method where all the segments for one span are placed on a temporary support truss, aligned, jointed, and longitudinally post-tensioned together in one operation to make a complete span. See Section 5.2.

2.9 Balanced Cantilever Erection.

This is an erection method where segments are erected alternatively on either side of the pier in cantilever up to the point where a cast-in-place closure is made with the previous cantilever or existing side span structure. See Section 5.3.

2.10 Progressive Erection in Cantilever.

Segments are erected in cantilever and in one direction only from one pier to the next using temporary intermediate piers or temporary cable stays or both to support the advancing cantilever. See Section 5.6.

2.11 Casting Curve.

This is the geometric profile to which the segments must be made in the casting yard in order to achieve the required theoretical bridge profile after all final structural and time-dependent (creep and shrinkage) deformations have taken place. See Section 8.0.

2.12 Launching Gantry

Custom built erection equipment which is used to take delivery of the segments, lift, move and place them in their final erected locations in the superstructure. After completion of a cantilever or span, the gantry is capable of launching itself forward into a position ready to construct the next cantilever, or span and so on. See Section 5.4.

2.13 Beam and Winch.

Custom made erection equipment consisting of a longitudinal beam fitted with lifting pulleys, tackle and winches which is attached to the end of a cantilever and lifts up the segments. After erecting a segment, the equipment is advanced for erection of the next segment. This equipment is used with balanced cantilever or progressive cantilever erection. See Section 5.5.

2.14 Erection Truss Span-by-Span.

This is a custom built truss which rests underneath a span on supports connected to the pier and/or previously erected superstructure onto which a complete span of segments is placed by crane or other device. Such trusses may be self launching to the next span or may be moved by cranes. They are typically used for span-by-span erection. See Section 5.2.

3.0 REVIEW OF TECHNIQUES FOR SEGMENT PRODUCTION

3.1 Casting Yards

The major advantages of making segments in a precasting yard lie in bringing factory controlled production techniques, efficiency, quality control and time savings to bridge construction, removing casting operations from the critical path for construction and reducing the overall construction period.

The essential features of a casting yard as shown in Figure 3.1 include:

- Delivery and storage points for all materials, aggregates, sand, cement, reinforcement, post-tensioning hardware, etc.
- Concrete batch plant and delivery system.
- Rebar cage assembly areas, jigs and templates.
- One or more casting cells for superstructure segments.
- One or more casting cells for substructure segments.
- An area for the production of any special segments such as pier segments, abutment segments or expansion joint segments.
- Steamcuring facilities.
- Control stations and survey towers for geometry control.
- Segment lifting and handling equipment.
- Segment storage areas.
- Segment loading and delivery facilities.
- Offices and concrete testing facilities.

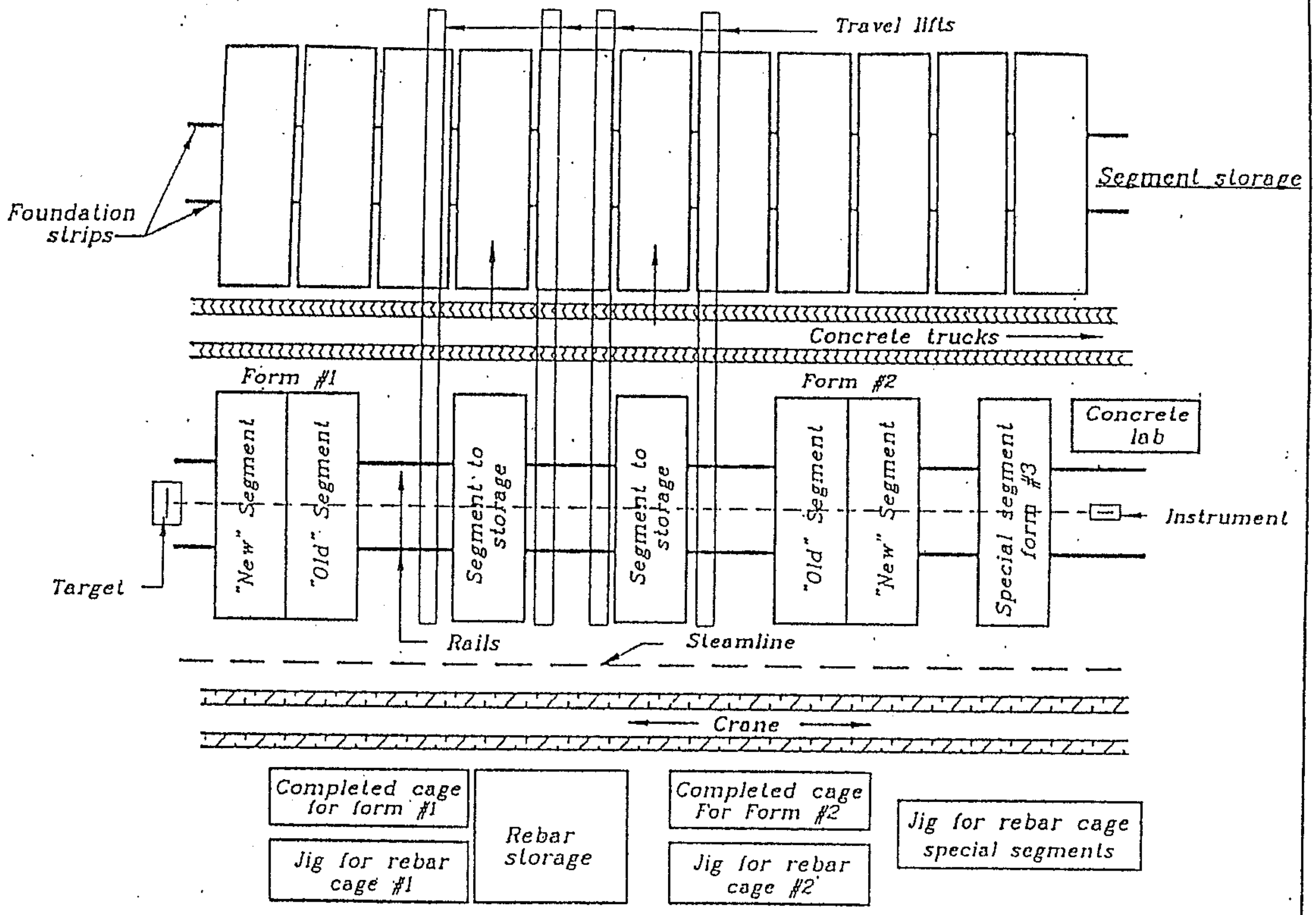


Fig. 3.1 Casting Yard

The size of the yard depends on the size of the job and rate of segment production required. It usually takes 3-5 months to establish a yard and achieve the routine production of one segment per day from each casting cell. Allowing for typical production problems, a realistic production rate is about four to five segments per 5 day week per casting cell.

3.2 Long Line and Short Line Forms.

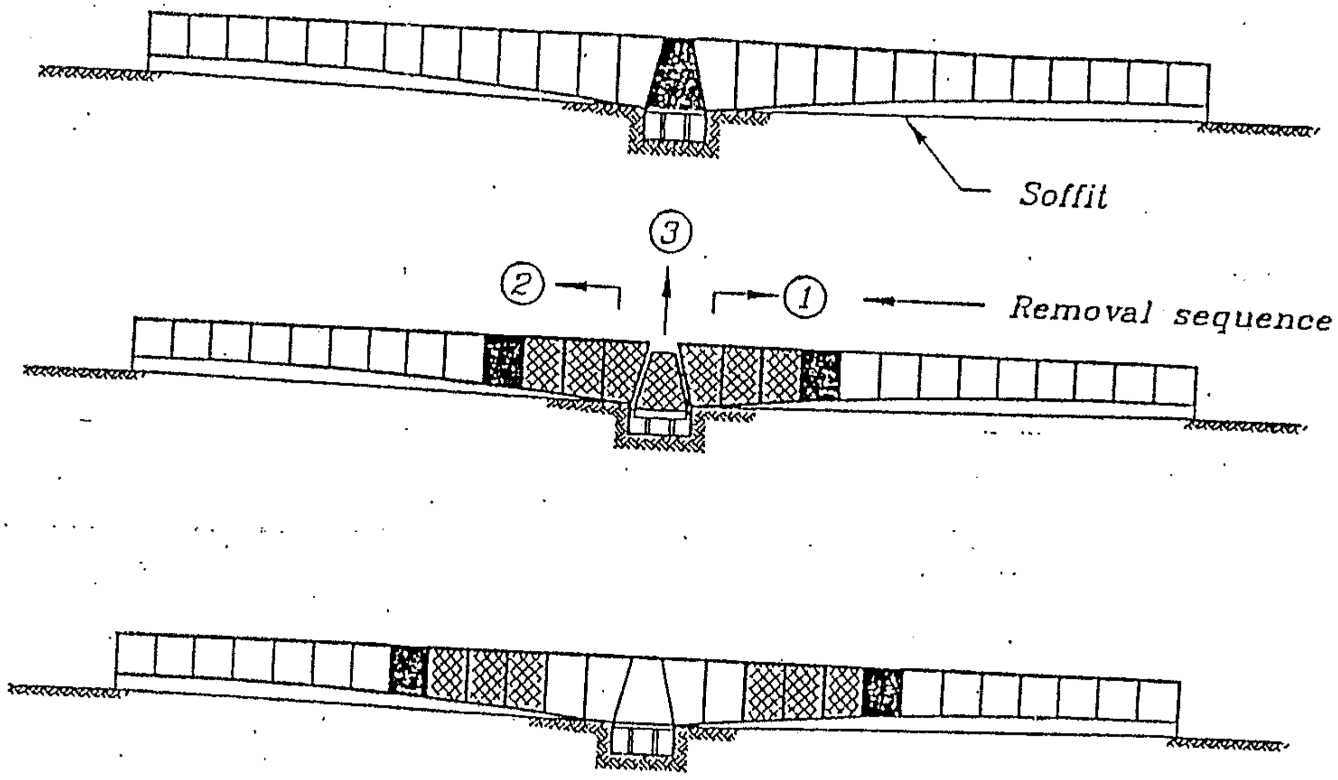
3.2.1 Long Line Casting Bed.

The long line casting bed is shown in Figure 3.2.1. All segments are cast on a soffit which is as long as a full cantilever (or half a cantilever if the cantilever is symmetrical). The soffit must be made in the profile of the structure with corrections for short and long term deflections. One or more forms and the bulkhead travel along this long line.

The obvious advantage is that all the geometry control is done when constructing the soffit thus simplifying this process during segment production.

Disadvantages of this method are that:

- it requires a large area
- it must be built on a firm, non-settling foundation
- it does not allow either horizontal or vertical geometry variations
- the soffit cannot be reused for a new project
- the soffit can be made only for one casting curve which must be used for all cantilevers of the structure.



■ Segments being cast

▨ Segments completed

Fig. 3.2.1 Typical Long Line Production

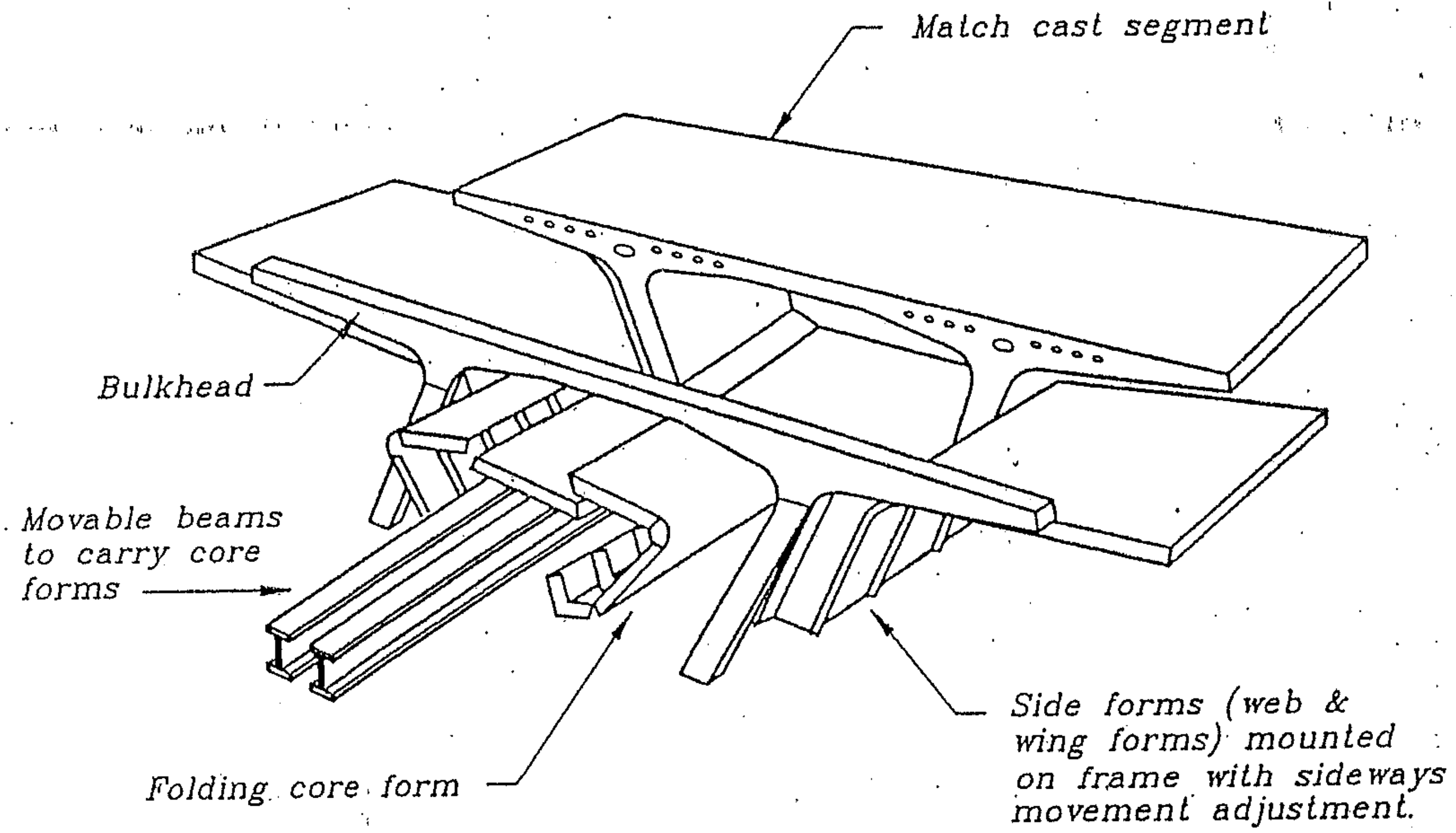


Fig. 3.2.2(a) Casting Cell (Short Line Method)

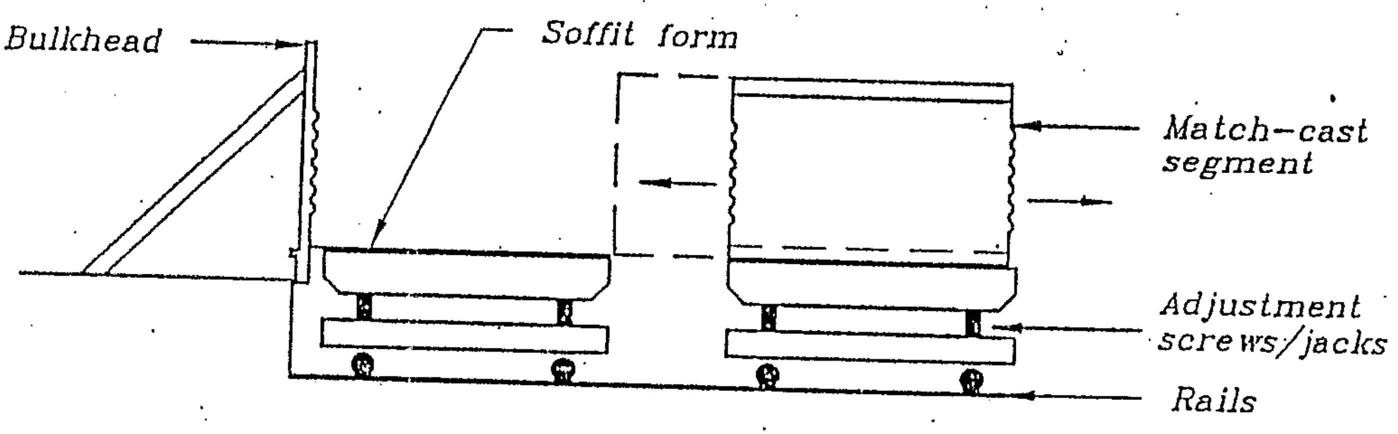


Fig. 3.2.2(b) Casting Cell (Short Line Method)

3.2.2 Short Line Casting Bed.

The short line casting bed is shown in Figures 3.2.2(a) and 3.2.2(b). With this method the form is stationary while the segments move from the casting position to the match casting position and then to storage.

Advantages of this method are:

- o space requirements are much less compared to the long line method.
- o The entire manufacturing process is centralized.
- o The system is extremely adaptable to geometry variations such as horizontal and vertical curvature and superelevation transitions which are obtained without increase in costs.
- o The forms are reusable for other projects.

The disadvantage of the system is that the match casting segment must be very accurately placed. This requires high skills in surveying and equipment capable of measuring elevations with a 1/1000 foot tolerance.

3.3 Match Casting.

This is a method where fresh concrete of the new segment is cast against the already hardened concrete of the old segment. A bond breaker (usually a mixture of wax, soap, and talcum powder, but there are also chemical compounds) is applied to the hardened concrete surface in order to ensure that the segments will come apart. The match casting technique as applied now on thousands of segments is based on the fact that, provided proper precautions are taken, the segments will come apart cleanly and, upon erection, will join together perfectly with the joint being almost invisible.

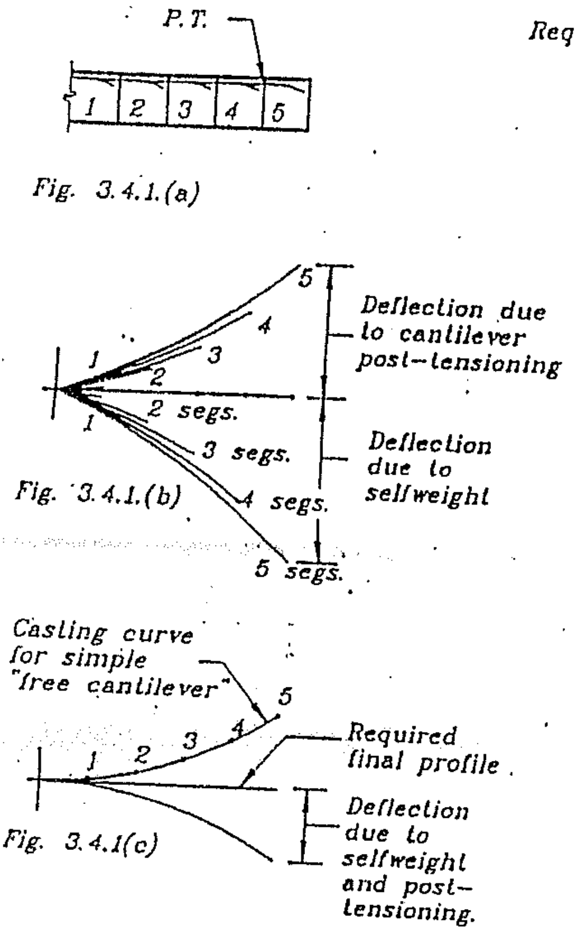


Fig. 3.4.1.(a)

Fig. 3.4.1.(b)

Fig. 3.4.1(c)

Simple Cantilever
Casting Curve

Fig. 3.4.1

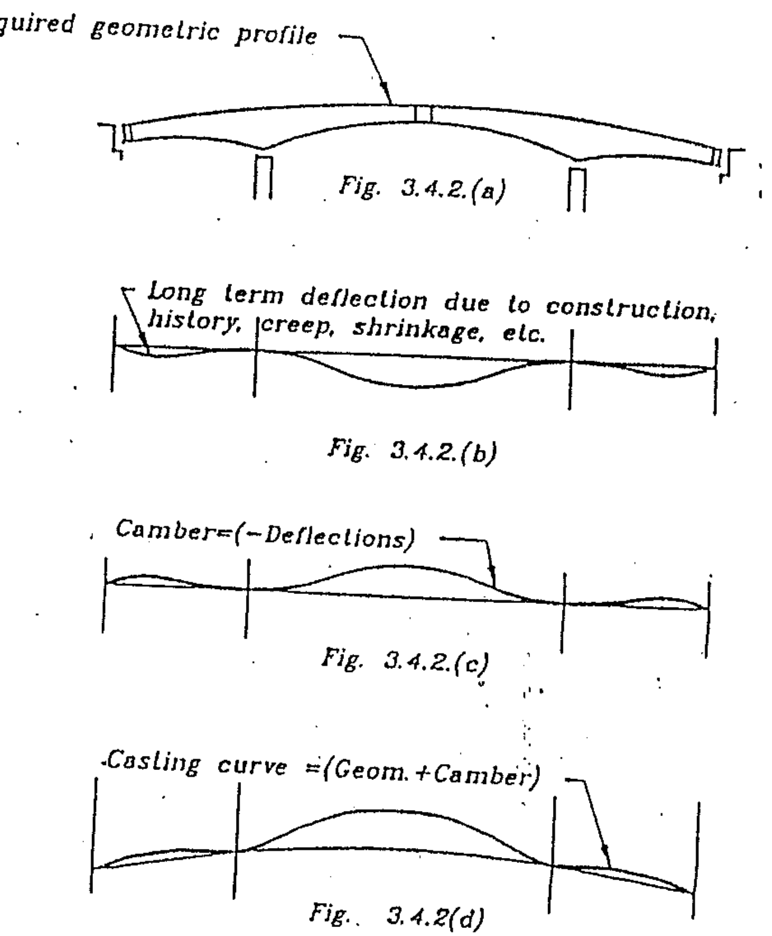


Fig. 3.4.2.(a)

Fig. 3.4.2.(b)

Fig. 3.4.2.(c)

Fig. 3.4.2(d)

Casting Curve For Typical Cantilever Bridge

Fig. 3.4.2.

The precautions are merely the careful application of the bondbreaker and the avoidance of jamming protrusions which make it physically impossible to break the bond (see section 3.14).

For correct fit at the time of erection the joint faces must not have been altered, except for a light sandblasting. This generally means that no work can be done on the joint faces and that segments must be stressed in such way that differential deformation cannot occur.

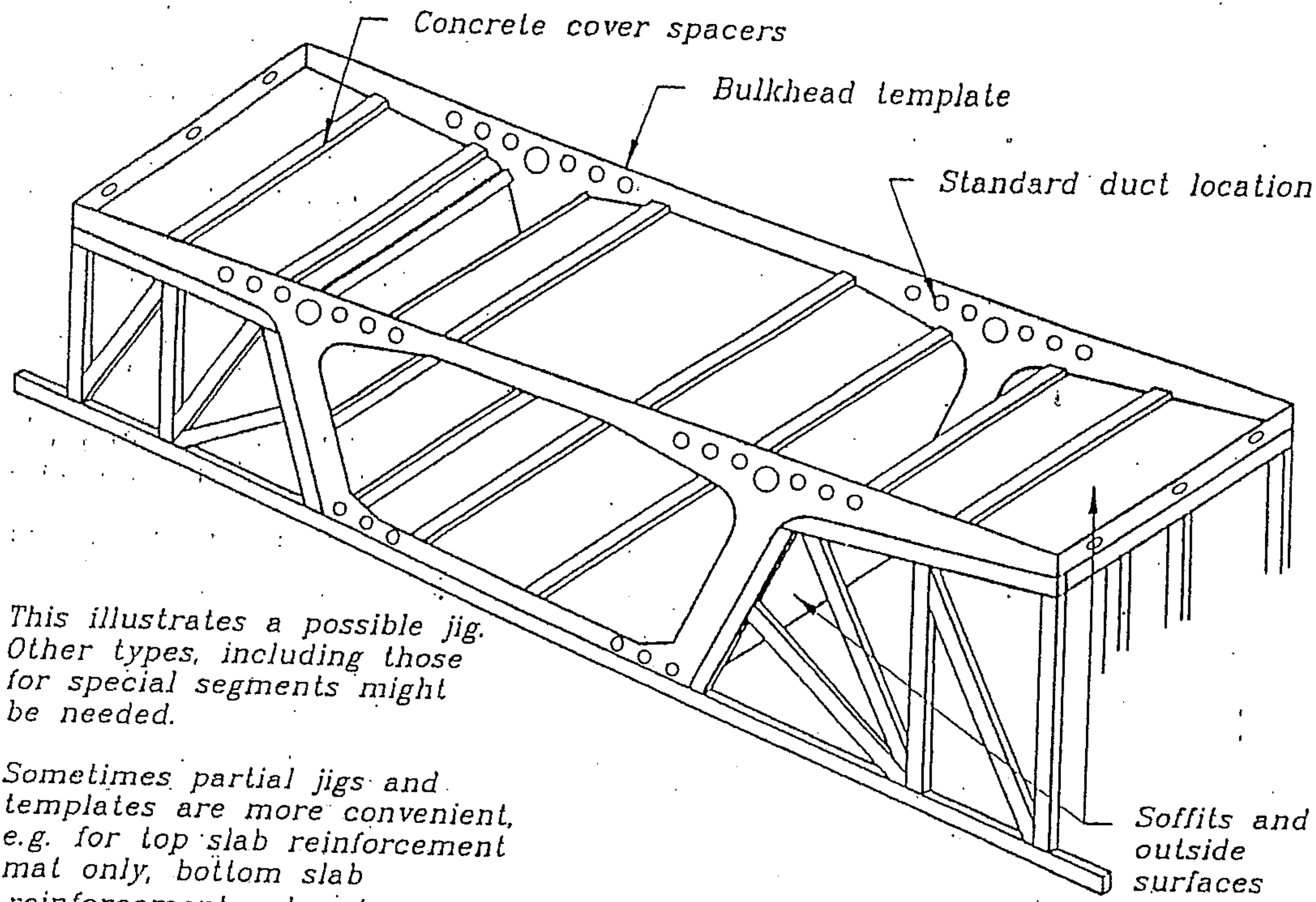
3.4 Casting Curve.

The casting curve, as defined in 2.11, is made up of two important components:

(1) The required geometric profile, which is actually the horizontal and vertical curvature and superelevation shown on the plans, and

(2) The compensation of deflections. Both the deflections which occur during construction and the long term deflections.

The deflections which occur during construction are shown in Figure 3.4.1. While erecting the sample 5-segment cantilever shown in (a) in the five steps required, both selfweight and post-tensioning deflections increase as the cantilever increases. Figure (b) shows the deflections after each step. The situation at the end of erection is shown in (c). The combined effect of selfweight and post-tensioning results in some deflection. Now, if our goal would be to have a horizontal profile after this erection took place, we would have to provide a casting curve which is precisely opposite the calculated deflection line.



This illustrates a possible jig. Other types, including those for special segments might be needed.

Sometimes partial jigs and templates are more convenient, e.g. for top slab reinforcement mat only, bottom slab reinforcement only, etc.

Fig. 3.5 Jig For Fabrication Of Rebar Cage

In Figure 3.4.2, structural deflections are shown combined with the geometric profile. The required geometry of the structure is shown in (a). The deflections occuring during construction are shown in (b). The structural deflections are compensated in Figure (c) and finally added to the geometric profile of (a) to form the casting curve in (d).

3.5 Fabrication of Rebar Cage with Post-Tensioning Ducts and Hardware

Prefabrication of the rebar cage preferably with post-tensioning ducts and as much as possible of the hardware installed as needed in order to achieve a production of one segment per day. This is readily accomplished by means of custom built jigs and templates. A possible jig for a complete typical segment is illustrated in Figure 3.5. Sometimes it is more convenient to use partial jigs, for example, one for the bottom slab and webs and another one for the top slab. By having several jigs it is possible to fabricate rebar cages well in advance for segment production.

The essential features for a jig are:

- Walls and floors, of plywood or other suitable material, held rigidly by a frame to accurately define the main concrete surfaces (outside webs and slab soffits).
- Bulkhead templates cut and/or marked to the proper section size with standard post-tensioning duct locations accurately defined.
- Wing cantilever and templates marked and fitted with locators as needed for transverse post-tensioning ducts, etc.
- Spacer bars laced to the walls and floors to provide correct concrete cover to rebar.

Using a jig of this type also permits rebar, post tensioning duct positions and any other hardware locations to be accurately fixed and marked up for repeated use. Duct profiles can be traced onto the walls to ease assembly, and so on. String lines are used to check rebar, cover and duct positions from open surfaces.

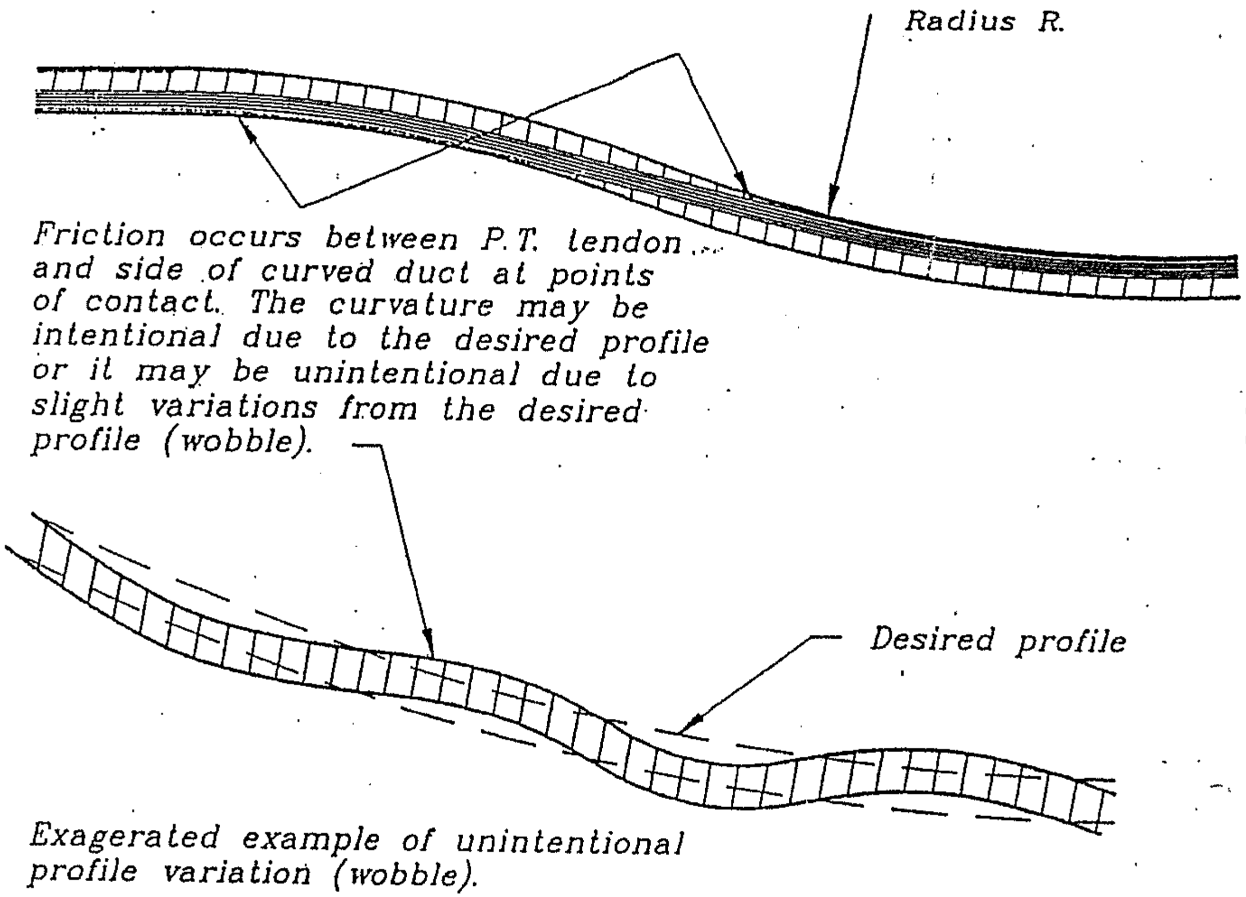
Because segments can vary a little in shape from each other, contain different post-tensioning duct and anchorage arrangements, and because the rebar cage will deform in transportation from the jig to the casting cells, final adjustments must be made after placing the cage in the casting cell.

For pier segments, abutment segments, and expansion joint segments, the typical segment jig could be modified or a separate jig made. Sometimes the pier and expansion joint segments are cast in separate casting cells. In such cases it might be convenient to fabricate the cage directly in the casting cell itself.

It is advisable to periodically check the accuracy of jigs and templates as they can deteriorate with repeated use and adjustments.

Special care is needed when using epoxy coated rebar in order to avoid damage to the coating during fabrication. The use of padding materials in the jigs and templates and padded slings will help. Damaged epoxy coating must be repaired using a "paint on" epoxy.

/ Radius ?



Friction occurs between P.T. tendon and side of curved duct at points of contact. The curvature may be intentional due to the desired profile or it may be unintentional due to slight variations from the desired profile (wobble).

Exagerated example of unintentional profile variation (wobble).

Friction between tendons and ducts due to curvature and wobble causes a loss of prestressing force in the tendon.

Fig. 3.6.1 Friction Effects in Post-Tensioning Ducts

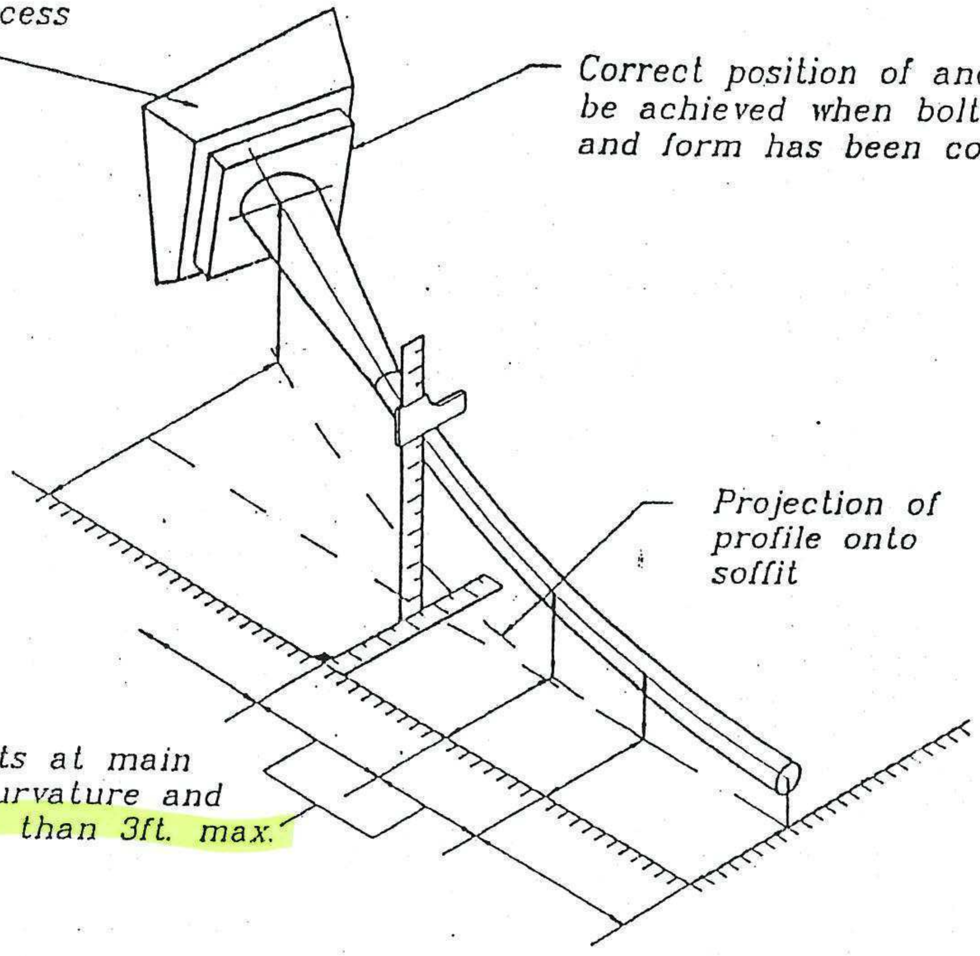
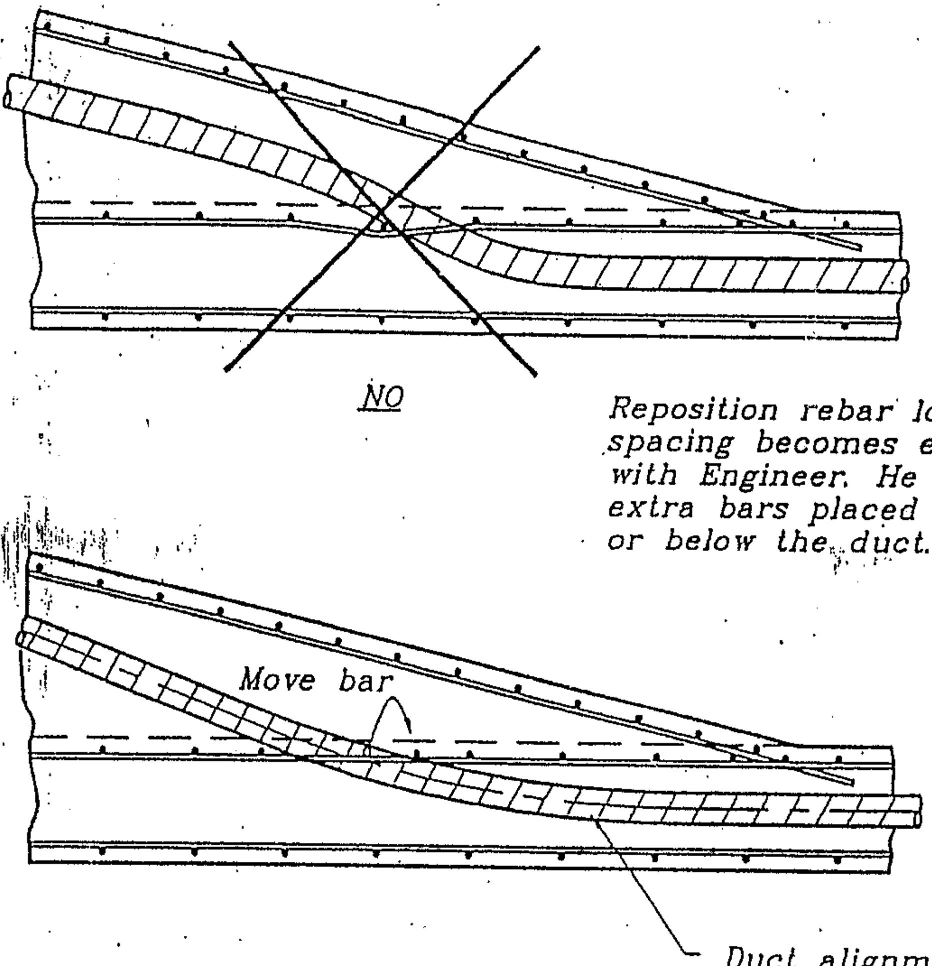


Fig. 3.6.2 Checking a Three Dimensional Duct Alignment



Reposition rebar locally — if spacing becomes excessive check with Engineer. He might require extra bars placed either above or below the duct.

Duct alignment is more important than rebar location

Fig. 3.6.3 Rebar and Duct Conflict Problems

3.6 Installation of Post-Tensioning Ducts

As mentioned in 3.5 above, most of the post-tensioning hardware and ducts are installed in the rebar cage. An exception to this are the anchorages themselves which, because of their weight, are usually installed in the form.

An accurate and smooth alignment is essential for all post-tensioning ducts. This will ensure that the required concrete compressive stress level is obtained. Variations from the required alignment will cause undesirable variations in stress level and will also increase friction. This will reduce the post-tensioning tendon force (Figure 3.6.1). Kinks in ducts can trap wires and strands and may lead to wire failures. Such kinks are therefore not acceptable.

Post-tensioning ducts should be securely connected to their respective anchorages. Duct locations and alignments must be checked (Figure 3.6.2). Curved post-tensioning ducts should be checked at intervals of 2 - 3 feet and there should be no kinks or misalignments at connections with anchorages and between ducts. The position of post-tensioning ducts should be set correctly in preference to the position of reinforcing bars which should be locally adjusted in case of conflict (Figure 3.6.3). If it is necessary to move the reinforcing bars, the Engineer should be consulted.

Efforts should be made to avoid conflicts between the reinforcing bars and post-tensioning ducts. Integrated shop drawings showing the particular post-tensioning hardware system, ducts, reinforcing bars, and any special construction details are very helpful. These should be prepared by the contractor.

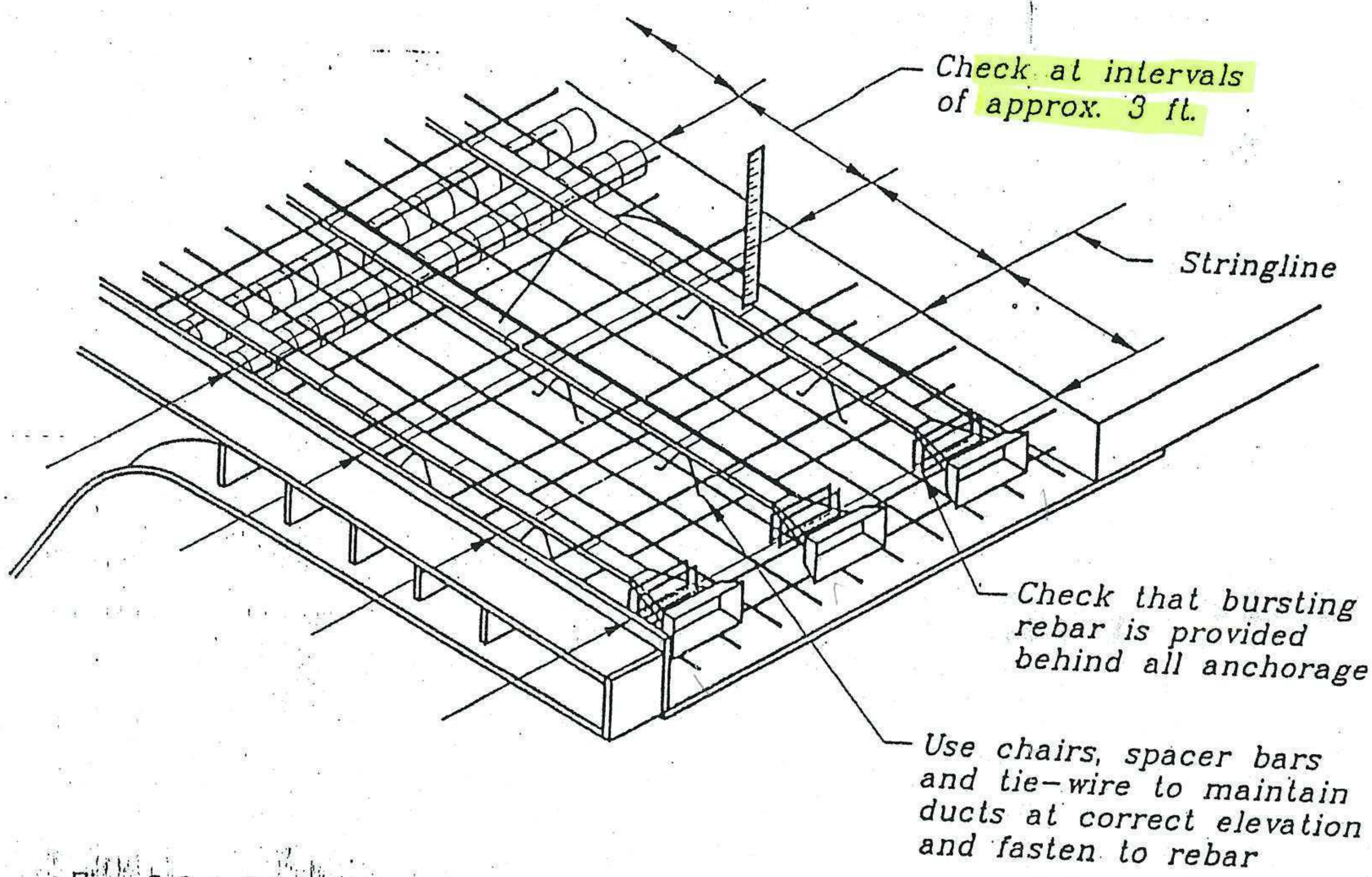
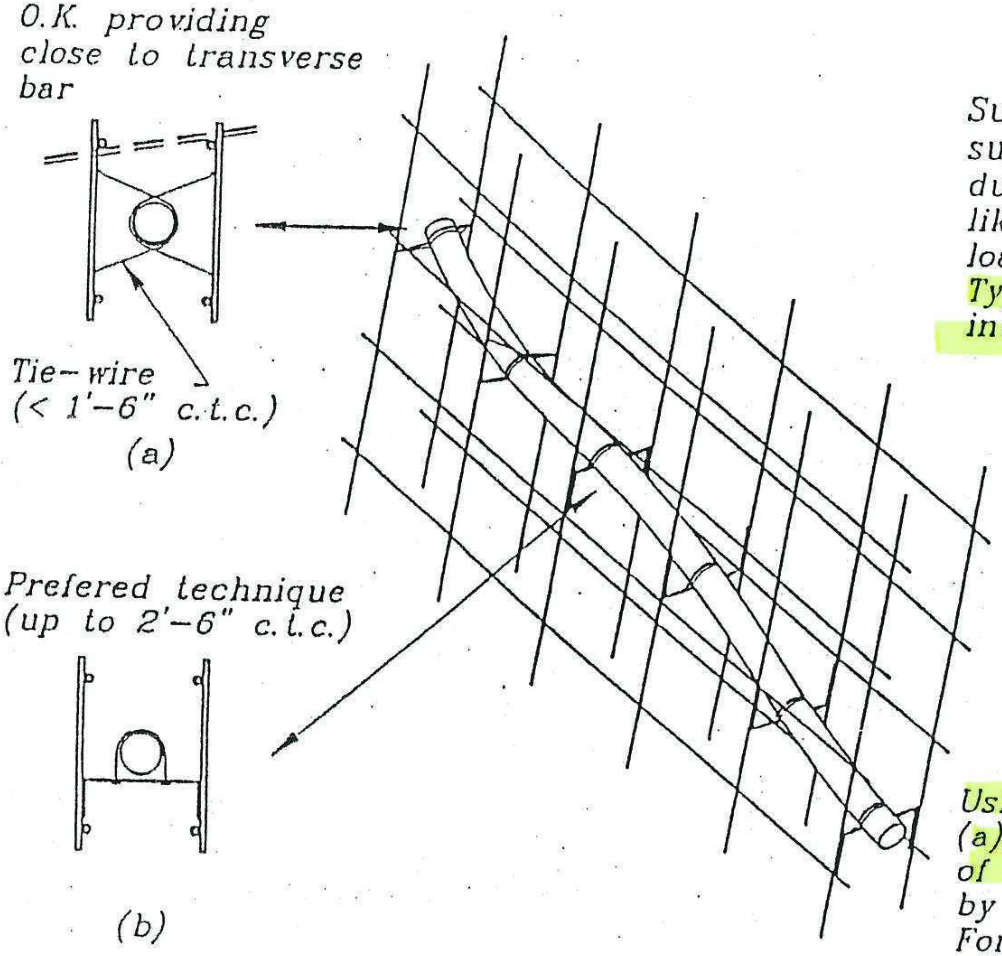


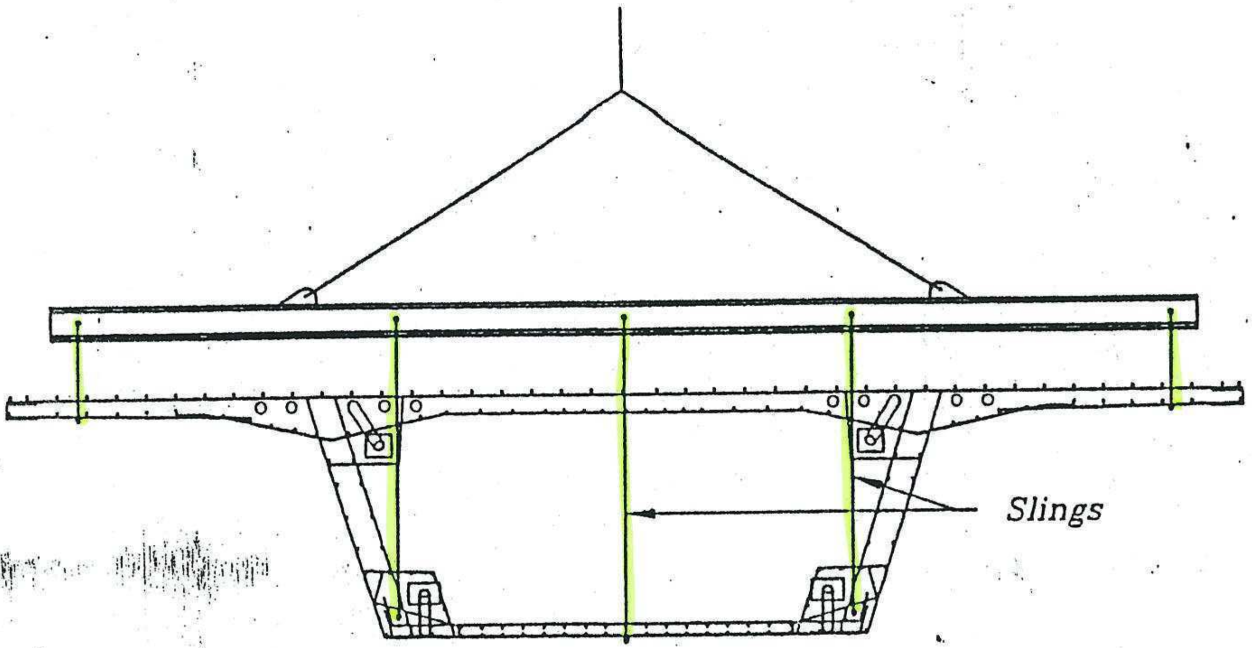
Fig. 3.6.4 Transverse Post-Tensioning Duct Supports and Checking



Suitable interval between supports depends upon duct curvature, location, likely concrete placement loads, stiffness of ducts. Typically 1'-6" to 2'-6" intervals are needed.

Using tie wire only, as in (a), can cause deformation of rebar cage unless braced by local transverse rebar. For this reason, tie-wire <u>alone</u> is not a recommended technique.

Fig. 3.6.5 Supporting Post-Tensioning Ducts in Webs



Deformation and damage to rebar cage during transportation and handling can be minimized by using a special lifting frame and/or slings or similar.

Fig. 3.7 Handling of Prefabricated Rebar Cage

Final adjustments of ducts and reinforcing bars should be made and inspected before the form is closed.

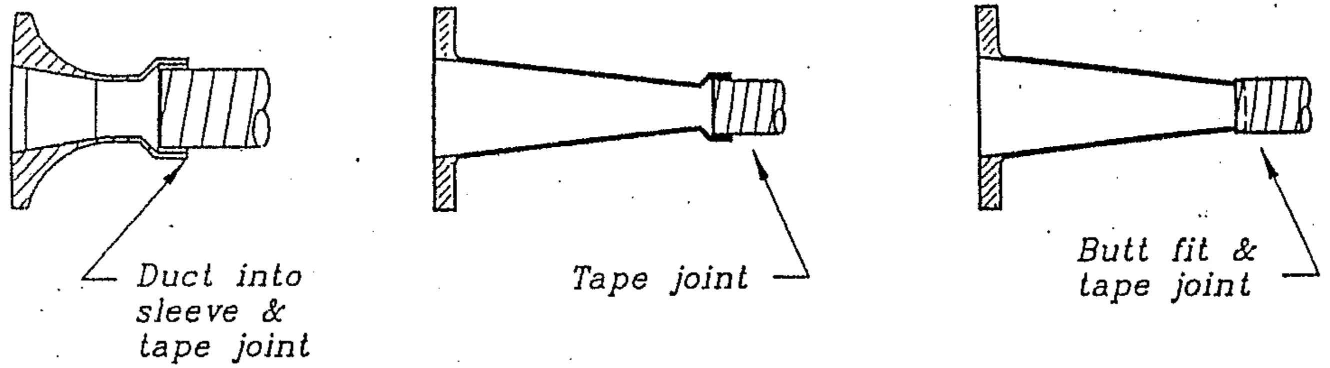
Final adjustments and inspection of ducts and rebar in slabs can be made any time before casting of the concrete (Figure 3.6.4).

Post-tensioning ducts should be securely fastened to the rebar cage which in turn must be firmly supported against the forms by chairs and spacers in order to avoid displacement during concrete placement and compaction. Flexible post-tensioning ducts especially are likely to move when subjected to the pressure of moving concrete, vibration and buoyance. For this reason, flexible ducts are fastened at closer spacings of about 1 ft. or so. Ducts in slabs, such as transverse deck prestressing, are less susceptible to movement but should be fastened at no more than 2 ft. intervals. Post-tensioning ducts can be secured with several layers of tying wire and/or auxiliary reinforcing support bars laced firmly to the rebar cage. The latter is preferable as it avoids distortion of the rebar cage (Figure 3.6.5).

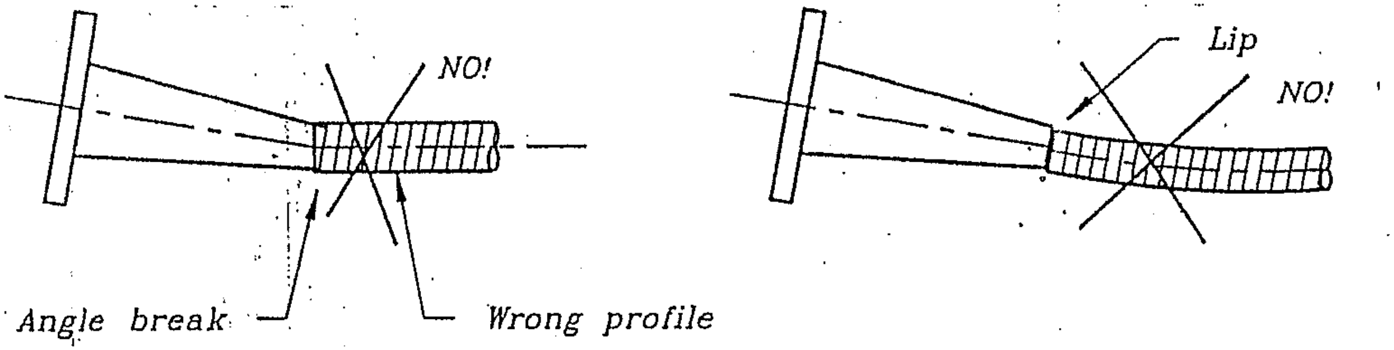
3.7 Handling the Prefabricated Rebar Cage

Transportation of the rebar cage from jig to casting cell should be done carefully to avoid excessive distortion. It is customary to use a special frame (strong back) with hangers which can support the cage at many points (Figure 3.7).

The rebar cage should be securely fabricated with adequate tie wire to maintain as much rigidity as possible.



Different types of commercial anchors



Examples of unacceptably connected anchors & ducts

Fig. 3.8 Connections of Ducts to Anchorages

3.8 Rebar Cage in Casting Cell.

After the form has been thoroughly cleaned out and oiled, the post-tensioning anchors are installed. The important items to watch for in case of anchor installation are orientation of the distribution plate, connection of plate to trumpet and of trumpet to duct and also the position of bursting reinforcing. Ensure that the congested anchor zone can be concreted properly without fear of honeycombing.

The orientation of the distribution plate is provided on the shop drawings, usually by providing angle offsets to the plane of the form. Based on this information, recess pockets are to be made. In case of many repetitive uses of the form, these recess pockets will be made of steel plates. Once a steel recess pocket has been checked for dimensional accuracy, it will consistently provide the correct orientation. Wooden recess pockets are for one time use only and these need to always be checked. Figure 3.6.2 shows installation of an anchor and the proper alignment of the anchor with the duct.

The trumpet is sometimes an integral part of the distribution plate, in which case there is no installation problem. If plate and trumpet consist of 2 pieces, the joint must be made watertight by means of a seal. The connection of trumpet and duct must be watertight, usually achieved with duct tape. The alignment of trumpet and duct should be within a 2 - 3 degree tolerance (Figure 3.8).

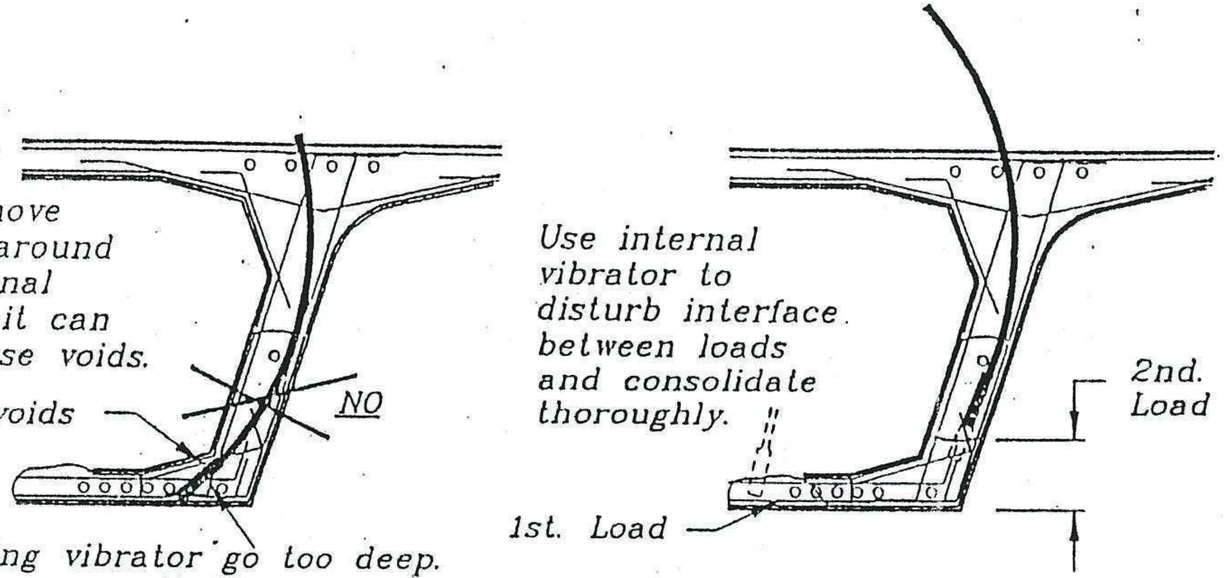
The required bursting reinforcement is shown on the plans (for example Figure 10.7.1). The location of the bars should be strictly adhered to. Spirals should be centered properly in respect of the ducts and begin right at the distribution plate of the anchor. Dimensions for placement of hairpins are important and these should be within 1 inch. Particularly at the anchors, drawings should be integrated and show all reinforcing, tendons and hardware present in the area. All conflicts between tendons and reinforcing should be resolved on the drawing board. Spirals are supplied closely wound. These should be stretched out to the proper pitch as shown on the drawings.

Since anchor zones are densely reinforced, judgment should be made beforehand whether or not concreting will cause problems. If problems are anticipated, the Engineer should be consulted.

After placing the anchors, the rebar cage is placed in the cell. All post-tensioning ducts are securely connected to their respective anchorages and standard duct locations and alignments are checked. Final inspection of the tendons should be performed after the connection with anchors and match cast segments are made.

3.9 Setting the Match Cast Segment.

This segment is usually set as close as possible to its desired position prior to placement of the rebar cage, then the rebar cage and ducts are properly adjusted, all inserts fixed, all post-tensioning anchorages bolted up to the forms, and the ducts taped. In order to ensure that there will be no mortar leakage, the match cast segment is checked and its position fine tuned after closing the form securely around the match cast segment. Refer to Section 8.0 on Geometry Control.



- *DO NOT* move concrete around with internal vibrators–it can easily cause voids.

Use internal vibrator to disturb interface between loads and consolidate thoroughly.

- Avoid letting vibrator go too deep. (It can cause aeration or voiding of earlier placed concrete which has perhaps already started the setting process.)
- Also, vibrator can easily get stuck.
- Avoid too much contact with ducts and rebar.

To consolidate concrete: push vibrator vertically into concrete to depth of no more than 2FT. (±) and withdraw slowly, in steps, at the same point.
Withdraw vibrator from concrete to move to another point–*DO NOT* drag vibrator through concrete.
Vibrate at intervals of about 1Ft. to 1'-6".

Fig. 3.10 Use of Internal Vibrators for Compaction

3.10 Placing Concrete

Good concrete placing practice will ensure a good product. Some of the important points to watch for are:

(1) First, make sure that the forms are thoroughly clean, that all joints are tight and sealed, that all ducts are aligned and secure and that everything is in its proper place, the form should be lightly oiled for stripping and the face of the match cast segment given a coating of a suitable bond breaking agent.

(2) Place the concrete in the specified sequence (see section 3.11).

(3) Use skips, chutes, or pumps to deliver concrete and do not let it fall from a great height, as this causes segregation and the impact can damage ducts and displace rebar, concrete placement should be in accordance with approved procedures and specifications.

(4) Keep as continuous a delivery as possible; avoid holdups which can allow the concrete already placed to take on an initial set. Sometimes deliberate short waits are necessary especially after placing the bottom slab and web corner concrete so that it can stiffen just enough to take the weight of the rest of the web concrete - but be careful that this waiting is not overdone, and avoid cold joints. Often, use is made of retarders in the concrete mix to simplify the casting operation.

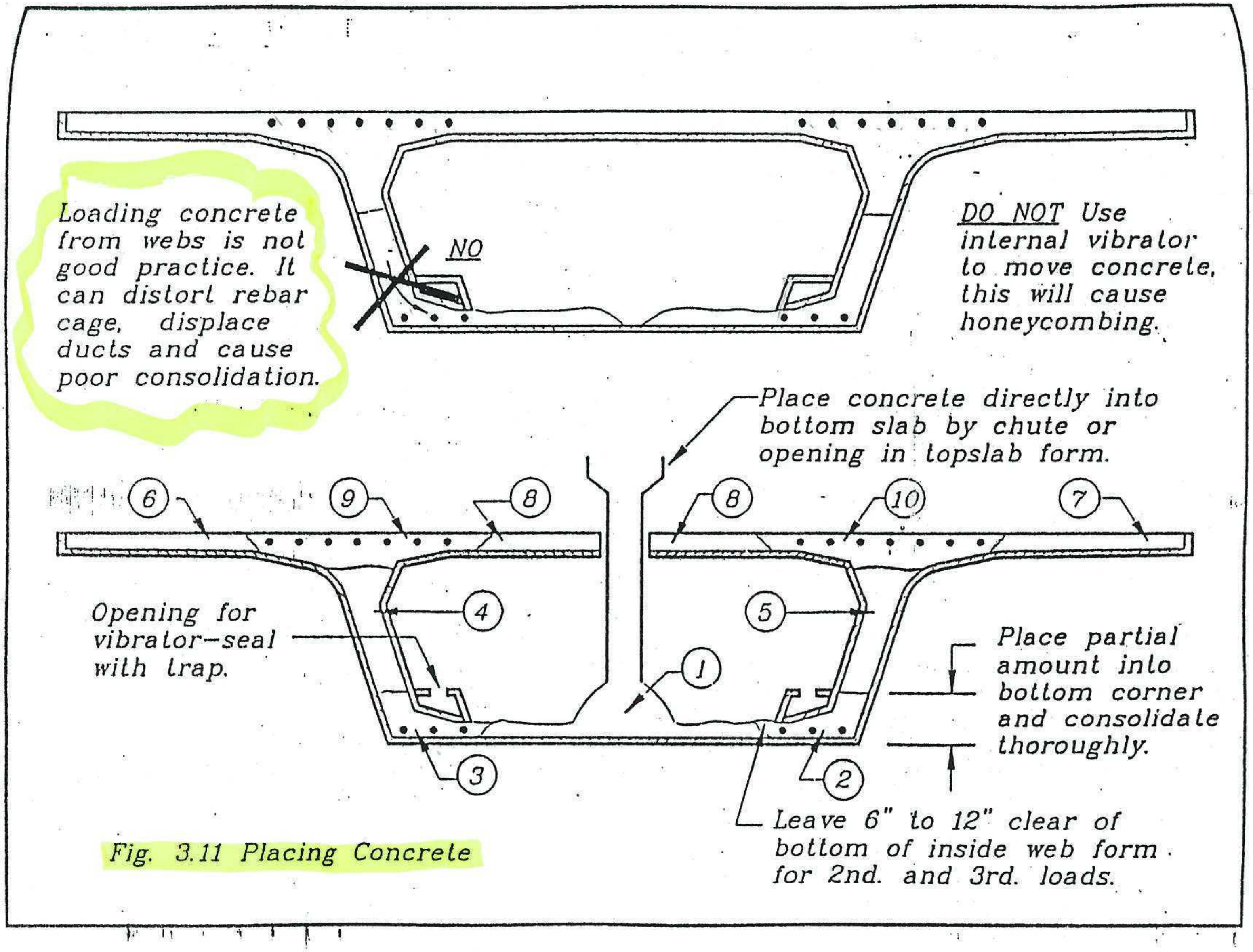
(5) Make proper use of internal "poker" vibrators to thoroughly consolidate the concrete. These types of vibrators should be pushed into the concrete for no more than 2 ft. or so and should slowly be withdrawn from the same location. Do <u>not</u> move the vibrator sideways while still in the concrete. Do <u>not</u> use the internal "poker" vibrators to move concrete around or to drag it from the webs into the bottom slab, for example, as this will cause poor compaction and honey combing. Avoid contact of the vibrator with rebar and post-tensioning ducts as this can cause damage or displacement (Figure 3.10).

(6) Make sure concrete is thoroughly compacted, especially in awkward areas such as the corners around heavily reinforced anchorage zones and within spirals. Sound compaction is essential as for every 1% air void content, the concrete strength reduces by approximately 5%.

(7) The finish on the top surface should be good. As this is usually the riding surface, great care is needed in finishing. In spite of this being the last job for the day, it should not be hurried.

3.11 <u>Concrete Placing Sequence.</u>

A good placing procedure should prevent the concrete placed in the bottom of the web spilling into the bottom slab. This movement of the web concrete can easily displace rebar and ducts and can pull concrete away from heavily reinforced bottom anchorages or the web itself causing honeycombing. Some such flow of the concrete is unavoidable, but it can be minimized by using the following procedure, which is considered good practice (Figure 3.11).



Loading concrete from webs is not good practice. It can distort rebar cage, displace ducts and cause poor consolidation.

DO NOT Use internal vibrator to move concrete, this will cause honeycombing.

Place concrete directly into bottom slab by chute or opening in topslab form.

Opening for vibrator–seal with trap.

Place partial amount into bottom corner and consolidate thoroughly.

Leave 6" to 12" clear of bottom of inside web form for 2nd. and 3rd. loads.

Fig. 3.11 Placing Concrete

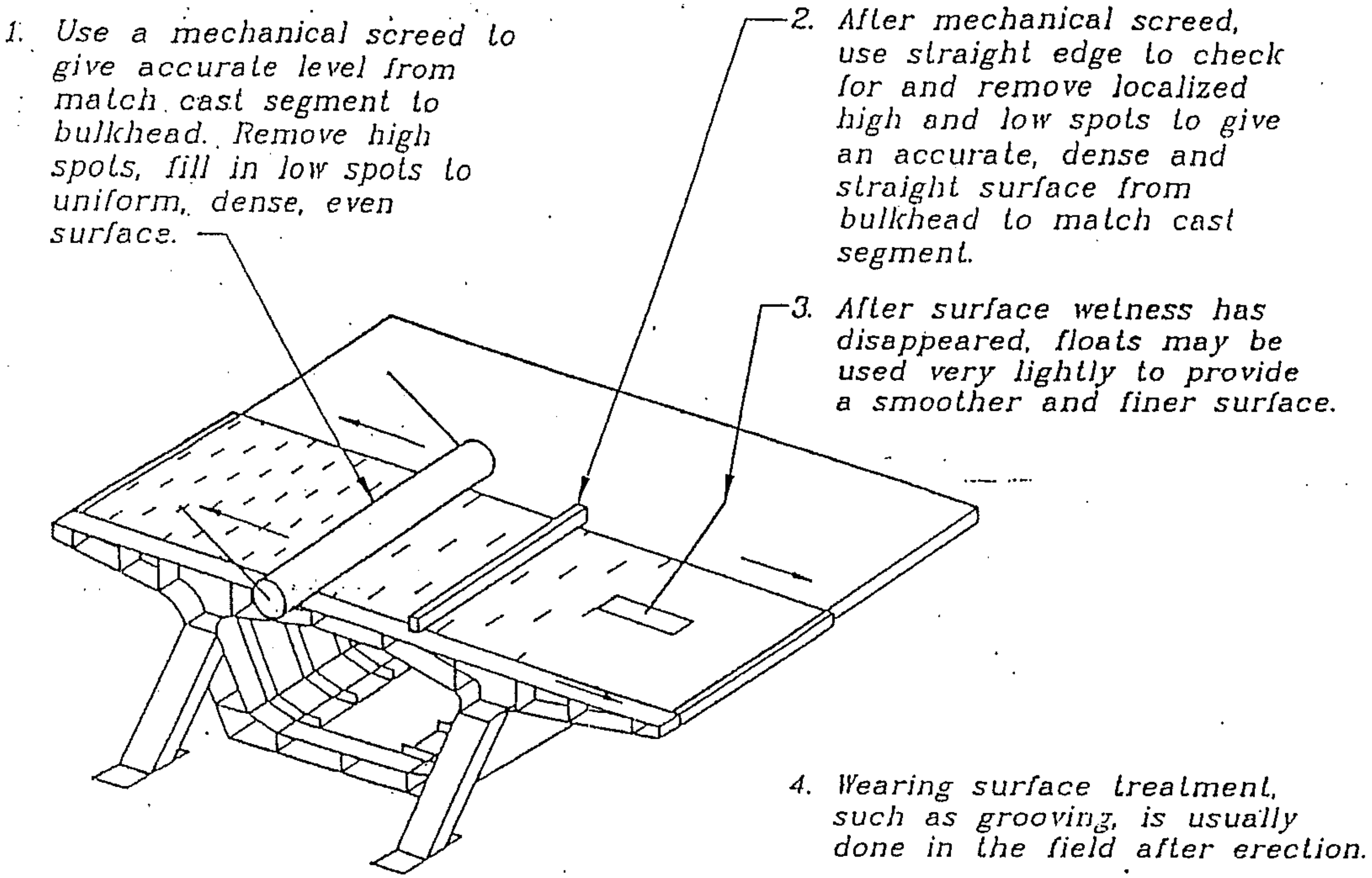


Fig. 3.12 Finishing Concrete Surface

Place the first concrete in the middle portion of the bottom slab, leaving about 6 to 12 inches clear of the side forms at the bottom of the webs. It is possible to do this by a delivery chute through a trap in the top slab soffit or by a chute through the bulkhead end. Place the second concrete in the webs and compact it around the bottom corners to complete the bottom slab. Compact the concrete in any bottom anchorage blister through windows in their top forms. Place the next concrete in the webs working up to the top slab. Finally place the concrete in the top slab working from the center and outside edges towards the web. Strike off the top surface and finish as described below.

3.12 Finishing the Top Surface.

A good quality finish of the top surface is essential, as this, in case of superstructure segments, is also the riding surface. The only one opportunity to achieve this properly is in the casting operation (Figure 3.12). Grinding unevenness out of the top surface after construction is never very satisfactory for anyone as it reduces the concrete cover, takes time and costs money. In addition, it is then usually necessary to improve the skid resistance by grooving.

It is possible to achieve a good finish by mechanical means providing that the equipment is used properly by trained and experienced operators. Care is needed to make sure that all depressions are filled and all high areas removed to give a very uniform, dense and even surface. The surface must be accurate and should be as smooth as possible prior to applying the riding surface treatment. After such treatment, the surface must still be even and accurate. Undulation should not be permitted. Hand finishing has been used successfully on many segmental structures in the past. Hand finishing requires that a good strong, straight screeding board be used extending from the top of the bulkhead to the top of the match cast segment to strike off the surface to an accurate level. Mechanical screeds also work very well. Good results have been achieved with both rolling and vibratory screeds. The former are a little more efficient.

Mechanical screeding should be followed by a straight edge - usually a substantial, stiff aluminum beam - worked by hand and used to check and correct any low and high spots to give an accurate and straight surface from the bulkhead to the match cast segment.

After surface wetness has disappeared, the surface may be very lightly "touched up" with floats to produce a finer and smoother surface. Floats should not be used in such a way as to move concrete or disturb the accuracy of the straight surface.

When finishing a concrete surface it is important to keep the concrete live for working by proper vibration, tamping and floating and <u>not to add</u> water to wet any stiff areas. This will create patches of weaker surface material which will dust and wear badly in use. In order to take advantage of workable concrete, the initial leveling and finishing should follow immediately after placement. This is the best time to get the surface level. The best quality can be achieved by finishing the segments to a smooth finish and then providing a transversely grooved riding surface cut after erection of the structure. A small amount of extra cover is specified to allow for the depth removed by the grooving process.

Be careful not to spoil the top surface when and if the concrete is to be covered for curing. (Use means to support tarps and prevent contact with top surfaces, etc.)

The top surface of the bottom slab should be finished in a similar manner although the appearance of the surface finish is not so critical, it should, nevertheless, be accurate. Mechanical screeds need not be used on the bottom slab.

3.13 Curing.

In order to achieve a production rate of one segment per day from one casting cell, it is essential to ensure that curing is proper and sufficient to provide the necessary strength and control of shrinkage, etc. Project Specifications or Special Provisions prescribe the curing procedures to be followed.

Curing procedures depend upon the type of concrete, its chemical hardening processes, temperature and exposure conditions. It is common practice to cover the segment with tarpaulins and apply steam to maintain a controlled temperature and humidity. Other methods have been used, including burlap, blankets, water and so on.

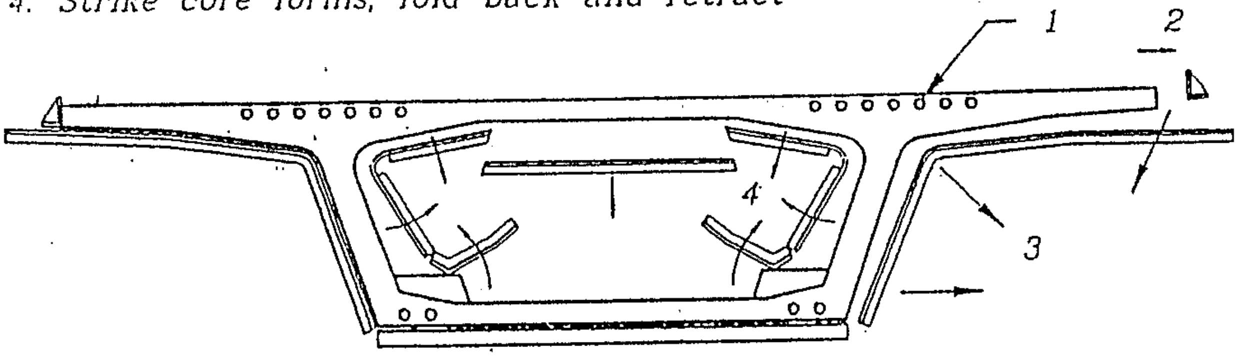
As a general rule, the slower the concrete's heat of hydration and loss of moisture is dispersed, the better. With a production rate of one segment per day, clearly the curing process in the casting cell cannot be more than a few hours from the completion of the casting in the evening to the start of survey and stripping the next morning. This is why a controlled environment is essential. The segment must remain covered with moist burlap even after stripping the form. Precise procedures will differ from job to job.

3.14 Striking Forms.

Striking of forms should not start until the concrete has reached the required strength. This is usually

When concrete reaches required strength, commence striking forms

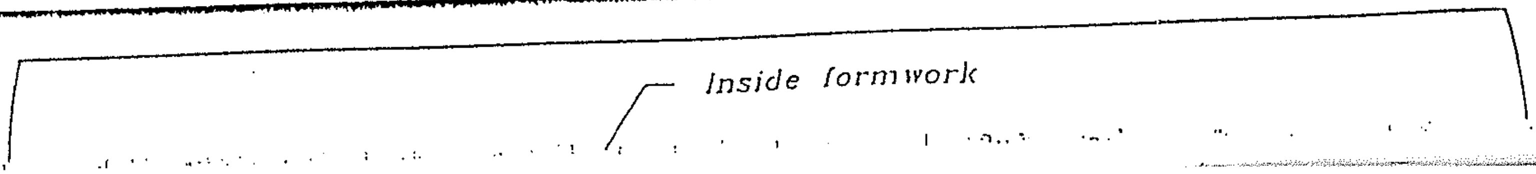
1. *Disconnect inflated duct liners or dollies*
2. *Remove wing stop end pieces*
3. *Drop wing soffit and pull back web outside forms*
4. *Strike core forms, fold back and retract*

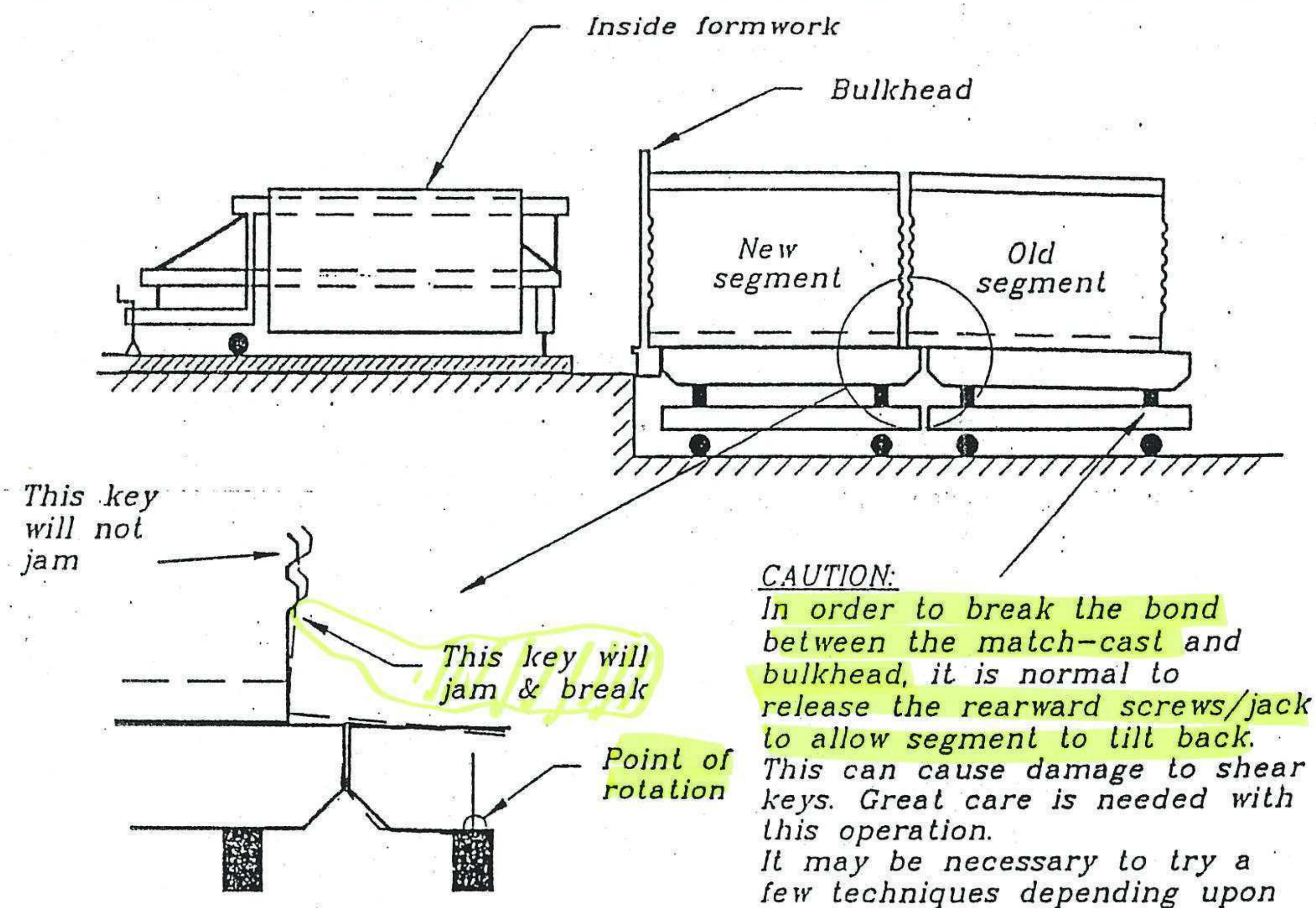


5. *Strike and pull back match cast segment (Use caution to avoid damage to shear keys, etc.–see Fig. 3.13.2)*

6. *Pull segment back from bulkhead (Use caution to avoid damage to shear keys, etc.)*

Fig. 3.14.1 Striking Forms





CAUTION:
In order to break the bond between the match-cast and bulkhead, it is normal to release the rearward screws/jack to allow segment to tilt back. This can cause damage to shear keys. Great care is needed with this operation.
It may be necessary to try a few techniques depending upon the form mechanisms. There is no simple solution.

Fig. 3.14.2 Striking Match Cast Segment

17.5 kN/m^2 kN/mm^2

specified at 2500 psi. At this strength it is normally possible to ease off the side forms, remove the core form, and pull back the match cast segment provided that the top slab is self-supporting. At this strength the segment could also be moved on its pallet but not lifted. In case the reinforcing provided is incapable of carrying the weight of the unsupported top slab at ~~27.6 N/mm^2~~ 2500 psi, then transverse post-tensioning must be stressed in full or in part. This would require a higher strength usually specified at 27.6 N/mm^2 4000 psi. It is customary to break cylinders in order to verify that these strengths are in fact obtained.

Striking the forms should be done with care as it is very easy to cause spalling and other damage when the concrete is young.

Most casting cell forms are removable in whole pieces (Figure 3.14.1) but it is advisable to leave removal of any special blockout forms for as long as possible as it is very easy to break the edges of blockouts.

Striking and pulling back the match cast segment should be done with particular care. If the bond breaker has not been properly applied, portions can be broken off either segment. The shear keys are especially vulnerable. Also, the movement mechanism on the pallets must be examined and understood by the stripping crew. Sometimes, the loosening of jacks and tilting of the pallet can be done in such a way as to "lift" the newly cast segment (see Figure 3.14.2). This motion can easily damage the shear keys and should be avoided or minimized as much as possible. The same applies when pulling the new segment away form the bulkhead.

Although the above refers specifically to the "short line" system, the same applies to the "long line" and "wet cast joint" systems of segment production.

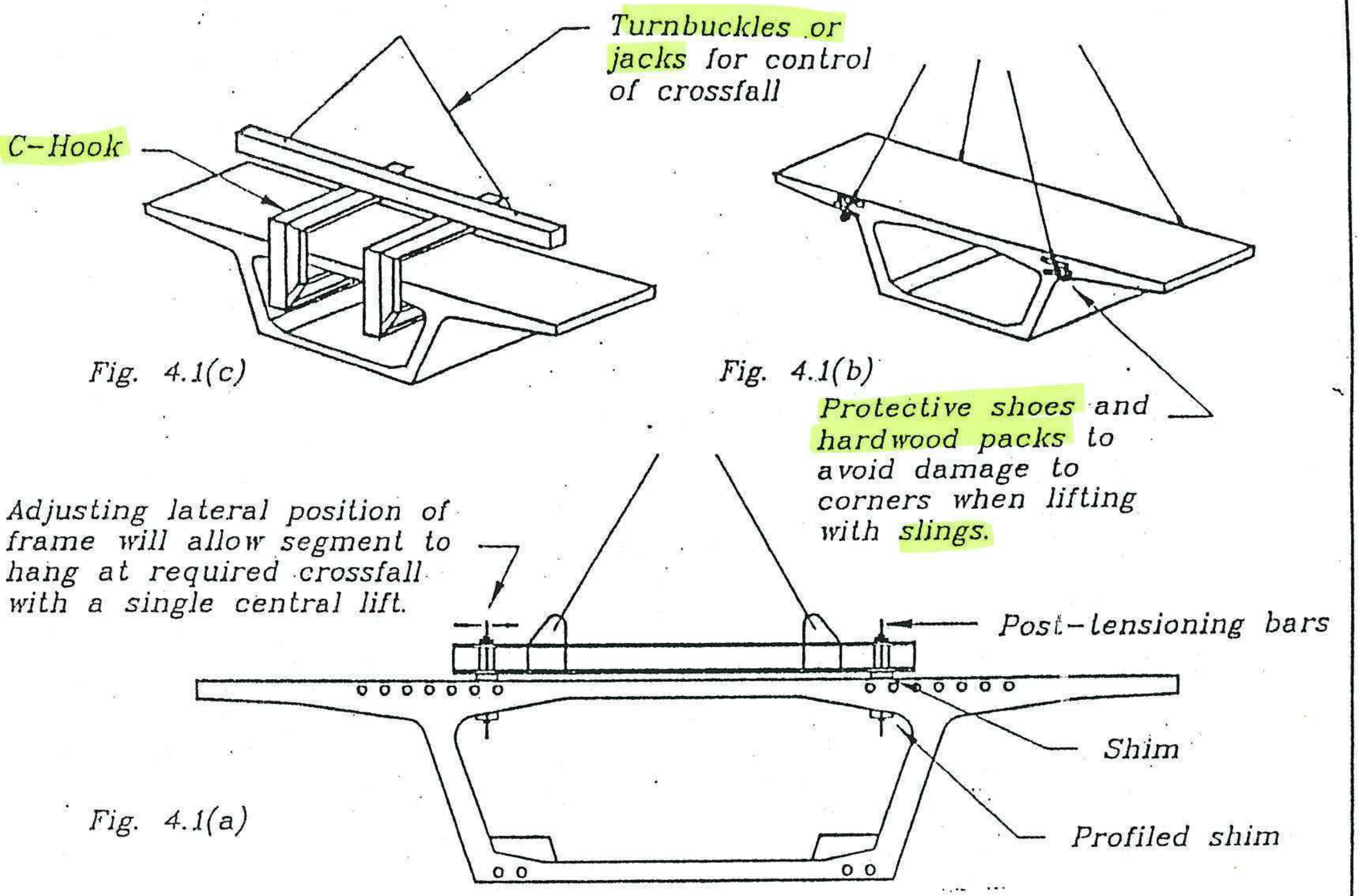
4.0 REVIEW OF TECHNIQUES FOR HANDLING SEGMENTS.

4.1 Handling Segments.

Lifting of the segments should only be done when the concrete is at a suitable strength. Normally this means at least 27.6 kN/mm^2 4000 psi concrete and after any transverse stressing has been carried out (if this is specified to take place prior to handling).

Most methods of segmental erection use lifting holes through the top slab near the inside or outside of the webs. Special inserts or lifting loops cast into the concrete are also possible, but these require approval of the Engineer. A lifting frame secured with post-tensioning bars through holes in the top slab close to the webs is a good technique (Figure 4.1(a)). By adjusting the lateral position of the location where the bars are attached to the frame, the segment can be made to hang at the crossfall required for erection.

It is not always necessary to use a lifting frame for moving the segment in the casting yard. Slings may sometimes be used (Figure 4.1(b)). However, great care must be taken to avoid damage to the corner of the concrete by using protective hardwood shoes, etc. With span by span construction where segments are placed on a truss before jointing, it is possible to use slings for erection also.



Turnbuckles or jacks for control of crossfall

C–Hook

Fig. 4.1(c)

Fig. 4.1(b)

Protective shoes and hardwood packs to avoid damage to corners when lifting with slings.

Adjusting lateral position of frame will allow segment to hang at required crossfall with a single central lift.

Post–lensioning bars

Shim

Profiled shim

Fig. 4.1(a)

Fig. 4.1 Handling Segments

Lifting with a frame is prefered and is often the only solution for erection.

4.2 Storing and Stacking of Segments.

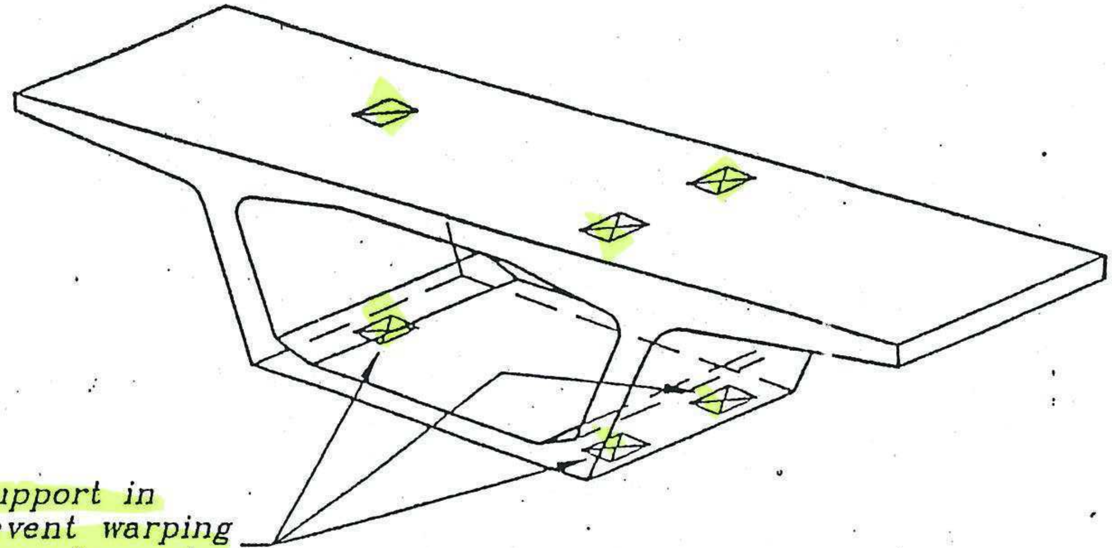
Segments should be stored using three point support (Figure 4.2(a)) in order to avoid warping with time in storage.

distorting/twisting.

Double stacking is usually possible (Figure 4.2(b)) providing three point support is used. However, segments should be periodically checked for any evidence of detrimental effects resulting from double stacking.

It is essential that the designer check the effects of localized loadings so that cracking will be avoided. Double stacking, therefore, requires the approval of the designer.

After placing the segments in storage, other routine tasks are performed, such as transverse post-tensioning and grouting, sandblasting of the joint faces, and repair of small defects.



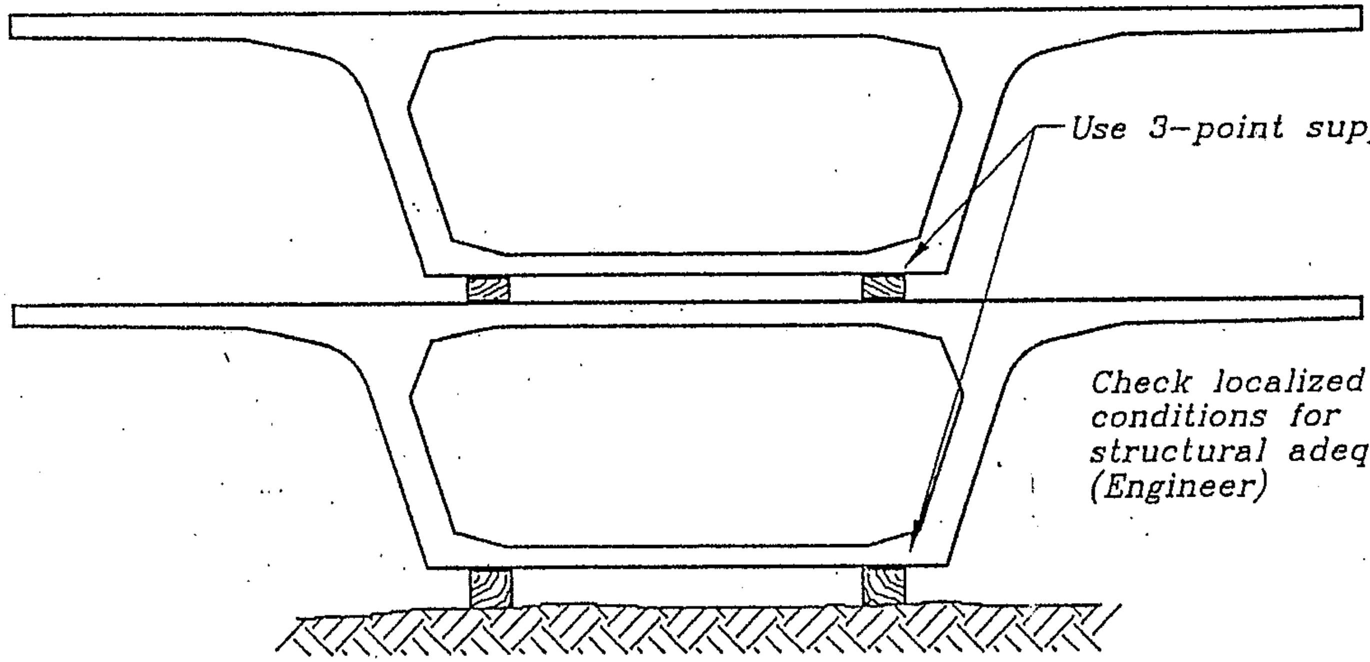
Three point support in storage to prevent warping
<u>NOTE:</u> Supports under webs

Stacking of segments is usually acceptable with no more than two high
Check with Engineer.
(See 4.2)

Fig. 4.2(a) Storing & Stacking Of Segments

Double stacking is only possible if allowed by specifications and has

Double stacking is only possible if allowed by specifications and has been approved by Engineer



Use 3-point support

Check localized conditions for structural adequacy (Engineer)

Periodically monitor stacked segments for any evidence of undesirable effects such as cracking and take appropriate action if necessary.

Fig. 4.2(b) Double Stacking

5.0 REVIEW OF ERECTION METHODS

5.1 General.

The different types of superstructure erection systems fall into the following categories:

5.2 Span-by-Span Erection.

This method, pioneered in Florida, utilizes a custom made truss to temporarily support all the segments for a complete span. The truss, which is normally slightly longer than a span is usually supported on the pier footings or, in case of a higher pier, on brackets attached to the piers themselves.

Because of the size, weight and limited load bearing capacity of these trusses, the method is only suitable for shorter spans (up to 150 feet).

The method has been extensively used in a variety of conditions, on water, but also in urban and environmentally sensitive areas. The method has also been applied to construction in difficult terrain. The truss can move from pier to pier and segments can be transported over the completed bridge. Alternatively, if there are no restrictions posed by the terrain, trucks can deliver segments adjacent to the truss and a crane can place them.

Within the limitations posed by the straight truss, the method can also be used for curved bridges. However, strong curvature is not possible.

Post-tensioning is normally accomplished with external tendons. Such tendons are placed in polyethelene pipes and are attached to the structure at the pier diaphragms and at so called deviation blocks or saddles. A typical deviation block is shown in Figure 5.2.2.

There is usually a narrow cast-in-place wet joint in each span close to the piers. This wet joint is used to correct alignment errors made during production or erection of the segments.

The sequence of erection is usually as shown in Figure 5.2.1.

- After erection of all the segments in a span, the cast-in-place wet joint is made. This is the situation shown in Figure 5.2.1(a). During this time the ducts for the post-tensioning are placed and tendons are inserted.
- After curing of the wet joint, the post-tensioning tendons are stressed and the truss is moved to the next span.
- After securing and aligning the truss, the pier segments are placed.
- The next segment is placed leaving a small gap, enough to apply epoxy.
- After applying epoxy, the segments are stressed together using post-tensioning bars in order to squeeze out any excess epoxy. Since this process requires that the segments can move freely in all directions, they are supported by rollers provided with teflon sliding pads and small jacks for height adjustments. Figure 5.2.1(b) shows the situation after erection of a few segments.

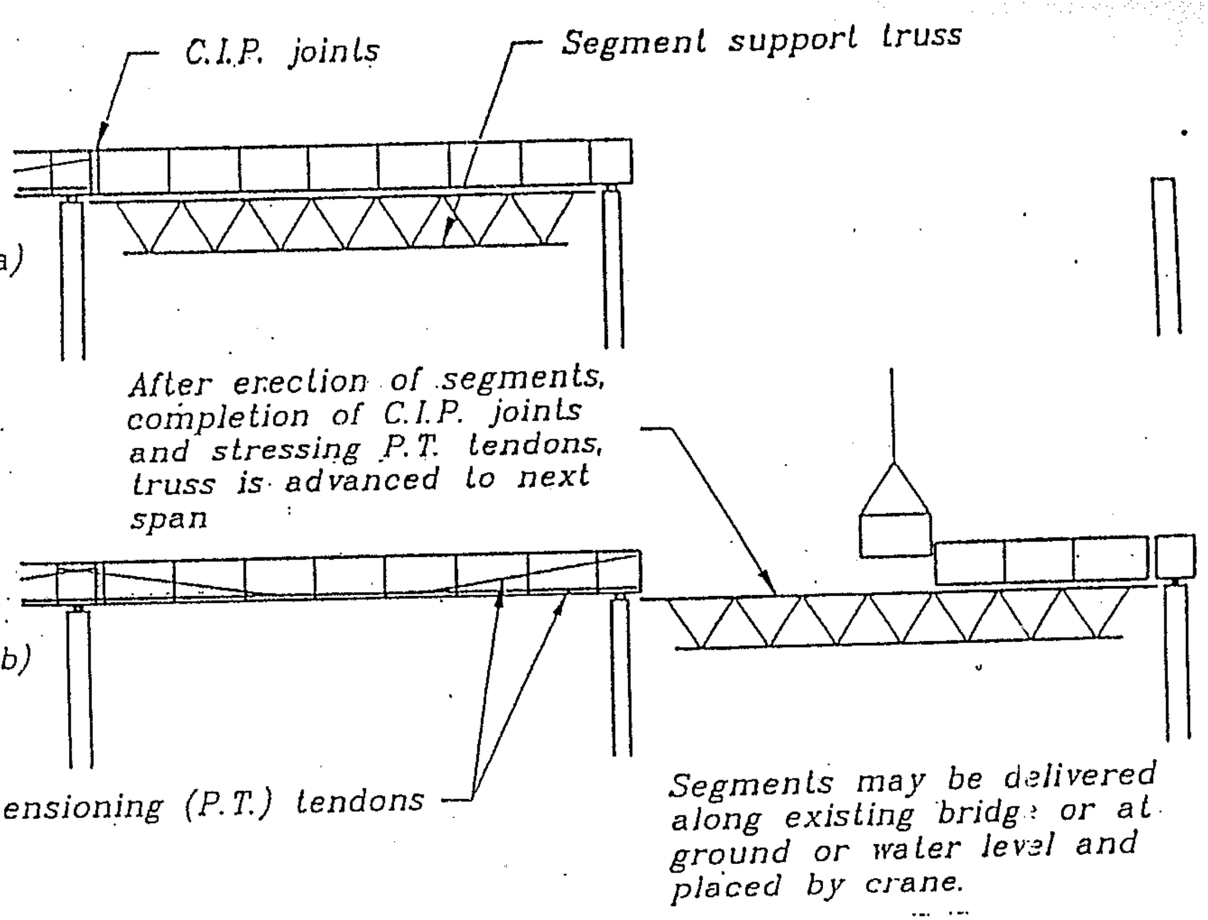


Fig. 5.2.1(a)

Fig. 5.2.1(b)

After erection of segments, completion of C.I.P. joints and stressing P.T. tendons, truss is advanced to next span

Segments may be delivered along existing bridge or at ground or water level and placed by crane.

Fig. 5.2.1 Span-By-Span Construction

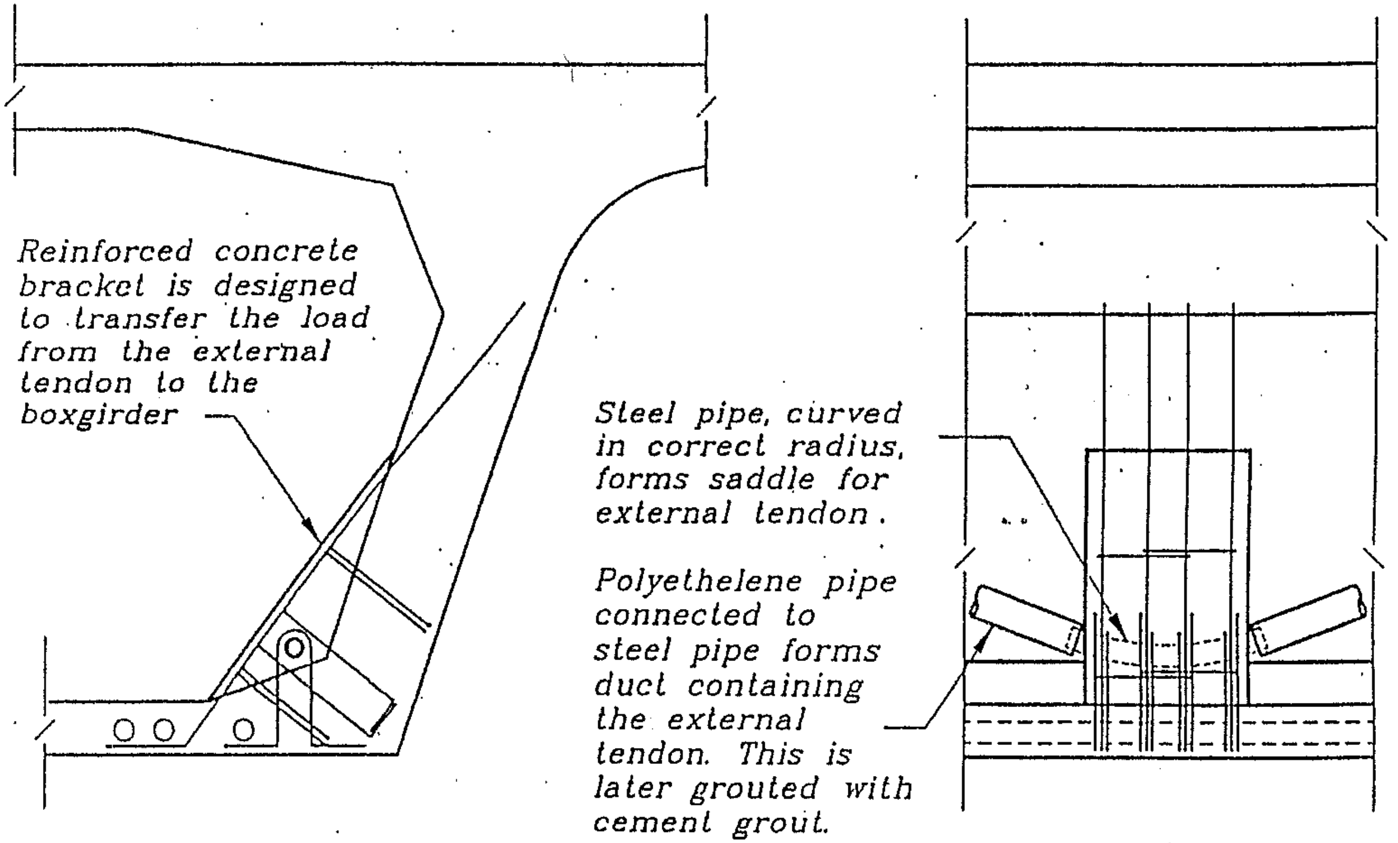


Fig. 5.2.2 Typical Deviation Block

- The process is repeated until all segments in the span are erected. As soon as the alignment is checked and satisfactory, the bearings are grouted and the cycle is repeated. A typical rate of erection would be 2 - 3 spans per week.

5.3 Balanced Cantilever Erection.

This method is by far the most versatile erection method. The reason for this is that it is suitable both for long spans and for strong curvatures. Spans of up to 400 120m feet and curved bridges with a 150m 500 foot radius have been successfully constructed by this method. Added to this versatility regarding bridge layout is the fact that, over the years methods have been developed which enables construction of the superstructure independent of terrain.

The method derives its name, "balanced cantilever", from the construction sequence. As indicated in Figure 5.3(a) construction starts by placing a pier segment on top of the pier. This is followed by erection of the two next segments, one on either side of the pier segment. As the structure grows by placing one segment on each side of the pier segment at the time it forms a cantilever which, because of the fact that an equal number of segments is added on each side is "balanced" after each completed cycle.

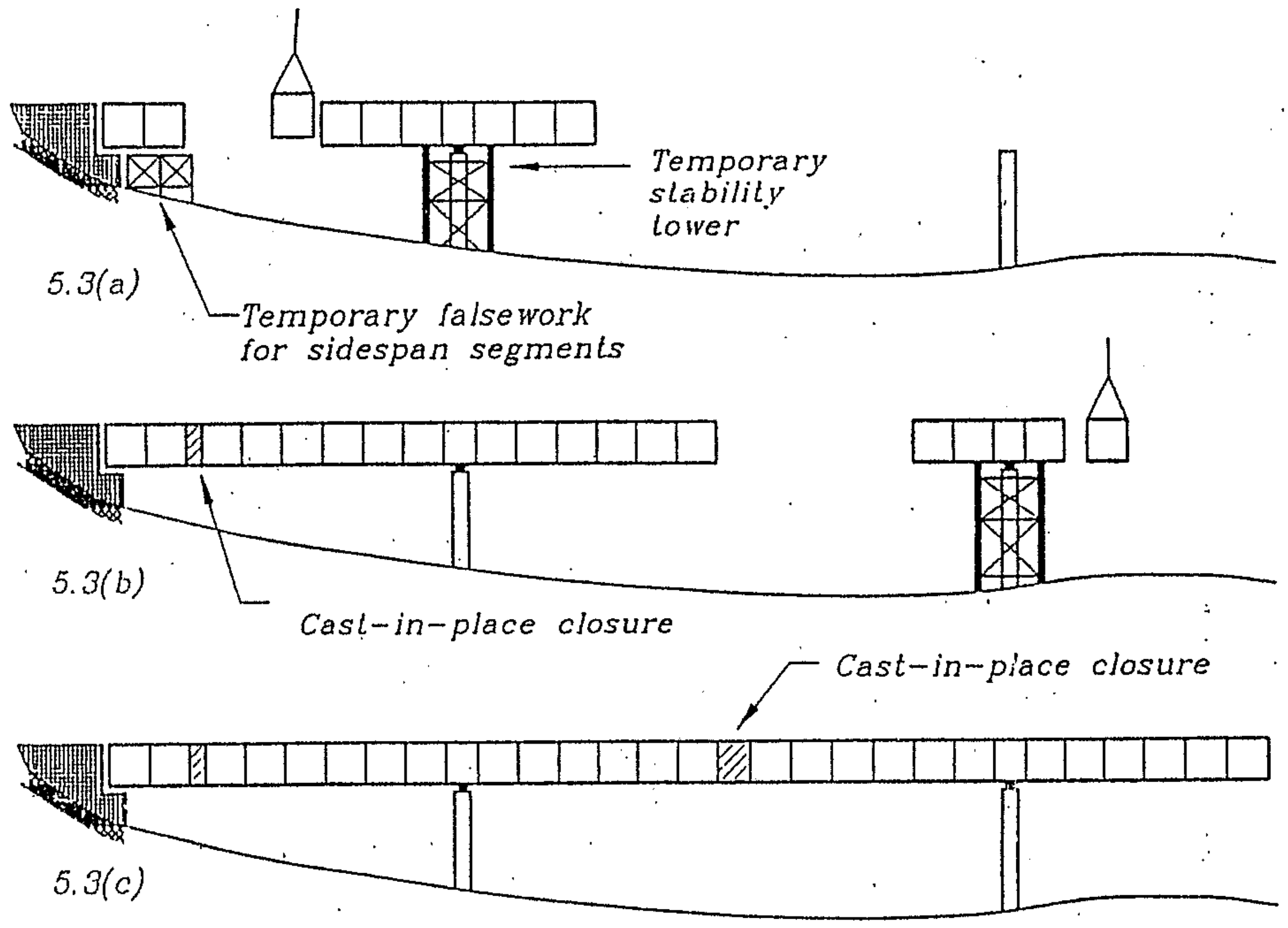


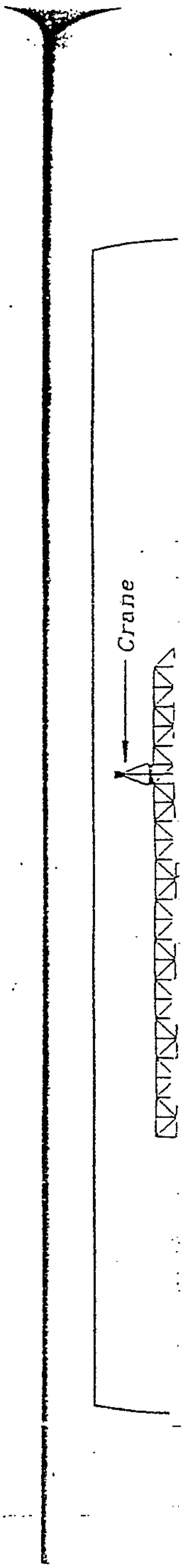
Fig. 5.3 Balanced Cantilever Erection

Although possible, it seldom happens that two segments, one on each side of the pier, are erected simultaneously. Usually there is only one crane available which will first place the segment on the one side and then the segment on the other. Because of this there usually is a temporary unbalance. This unbalance requires steel strutting, placed on the footing, to stabilize the cantilever (Figures 5.3(a) and (b)). While most segments are erected in cantilever, some segments, usually the ones in the end spans, require support by falsework (Figure 5.3(a)).

As segments are erected, post-tensioning tendons are stressed, usually two or four tendons per segment. So, as the cantilever grows, more tendons are stressed, which is needed to provide the structural strength of the cantilever. The tendons stressed during this cantilevering process are called "cantilever tendons."

Cast in place closure splices occur in the endspans and in the middle of the interior spans. Here, the cantilevers are connected to each other. After casting and curing of the splice a second stage post-tensioning is applied called "continuity post-tensioning."

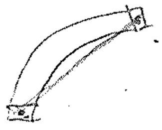
Erection of the segments is usually done by crane. Because of their availability and familiarity most contractors will opt for crane erection if this is a choice.



5.4 Launching Girder Erection.

– large curvature is not prefered.

Launching girders may be used on large projects or projects in areas where the terrain is not accessible for cranes. Launching girders are large, expensive, custom built pieces of equipment which make it possible to handle and erect segments very fast and efficiently independent of the terrain below. Figure 5.4 shows a launching gantry in



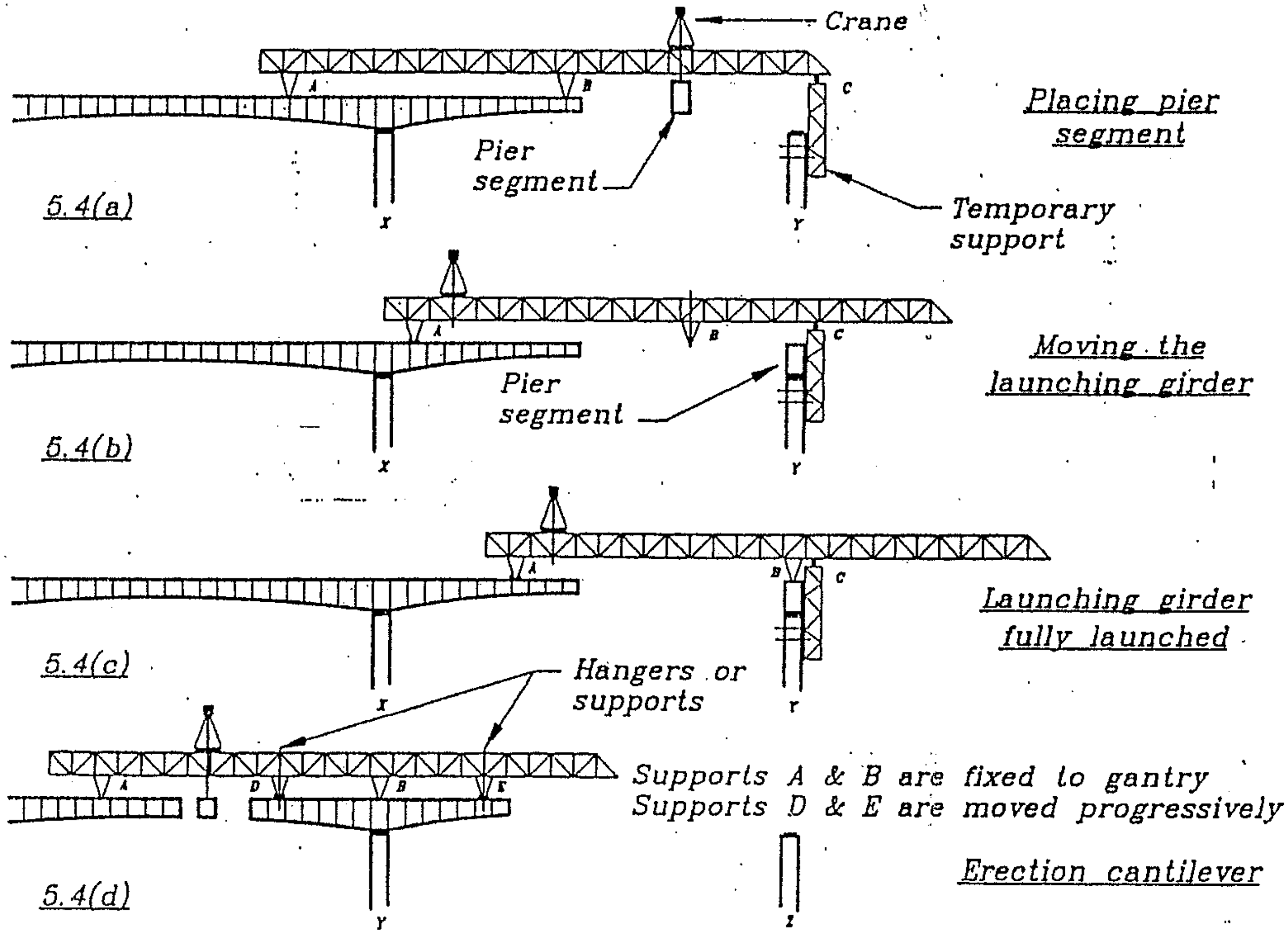


Fig. 5.4 Launching Gantry For Overhead Construction

various stages of operation. The girder, which is slightly longer than the largest span, is supported on legs A and B which are part of the girder (Figure 5.4(a)). In addition it is shown to be supported at C. This temporary support C is attached to the piers and supports the end of the launching girder while the pier segment is being transported and placed. Figure (b) shows the gantry being rolled over while resting on supports A and C until suport B is located above the pier segment. Figure (c) shows the girder supported on legs A and B in the position required for erection. Figure (d) shows erection in progress. Note that the launching girder is supported on the cantilever by supports "D" and "E". These supports also ensure that the weight of an unbalanced segment is carried by the launching girder and not by the substructure. Similar results can be achieved if supports "D" and "E" are replaced by hangers. Figure 5.4 shows one of many ways launching girders can be used.

5.5 Beam and Winch Erection.

Another method sometimes used is the Beam and Winch method shown in Figure 5.5. This is a very simple method using a straight forward piece of equipment. Since the device can make only vertical lifts, segments need to be brought directly under the end of the cantilever. The terrain below must therefore be accessible everywhere. This makes the method very suitable for erection over water. For one pier, two pieces of equipment are needed, one for each cantilever end and special arrangements are needed for erection of the pier segment, which is often cast-in-place.

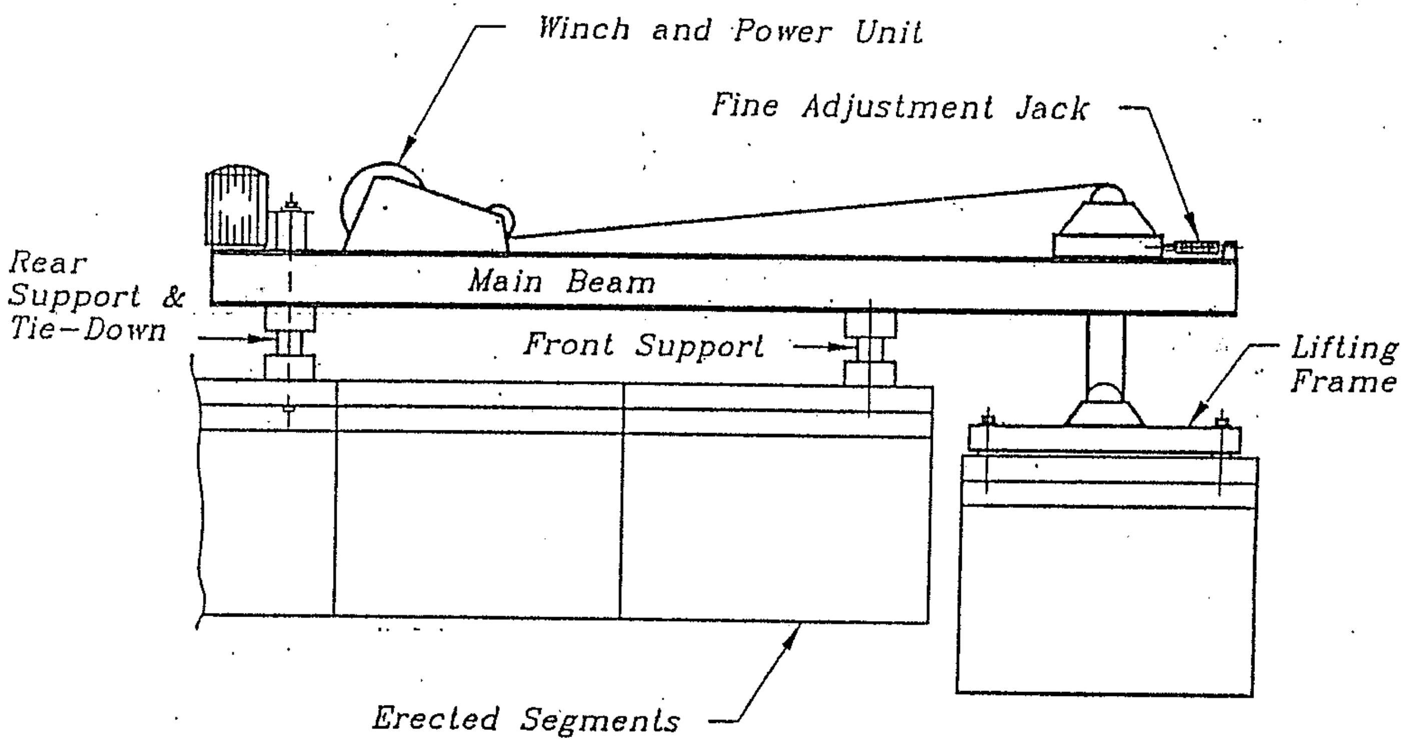


Fig. 5.5 Beam And Winch Equipment

5.6 Progressive Erection in Cantilever.

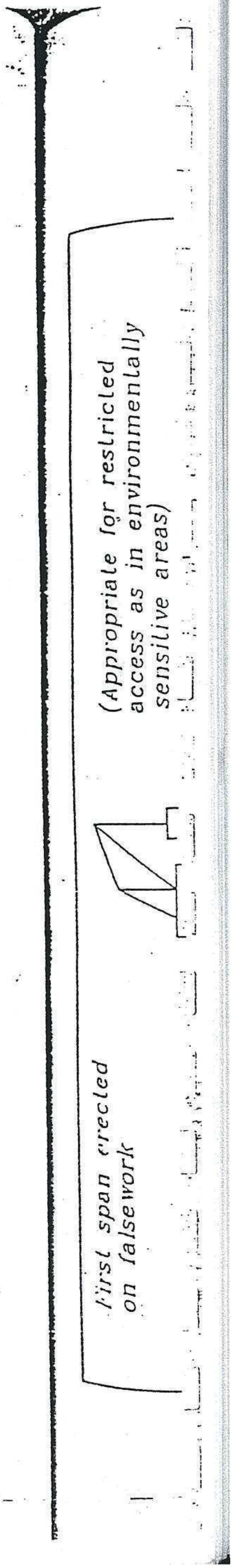
With this method the bridge is constructed starting on one end, erecting one segment at the time, until complete. Figure 5.6.1(a) shows the endspan being erected on falsework after which a crane rides to the tip where it can pick up a segment as it is brought on a truck and place it at the so far completed cantilever end. In the only example constructed in this Country this was a stiff leg derrick, but a normal crane could be used.

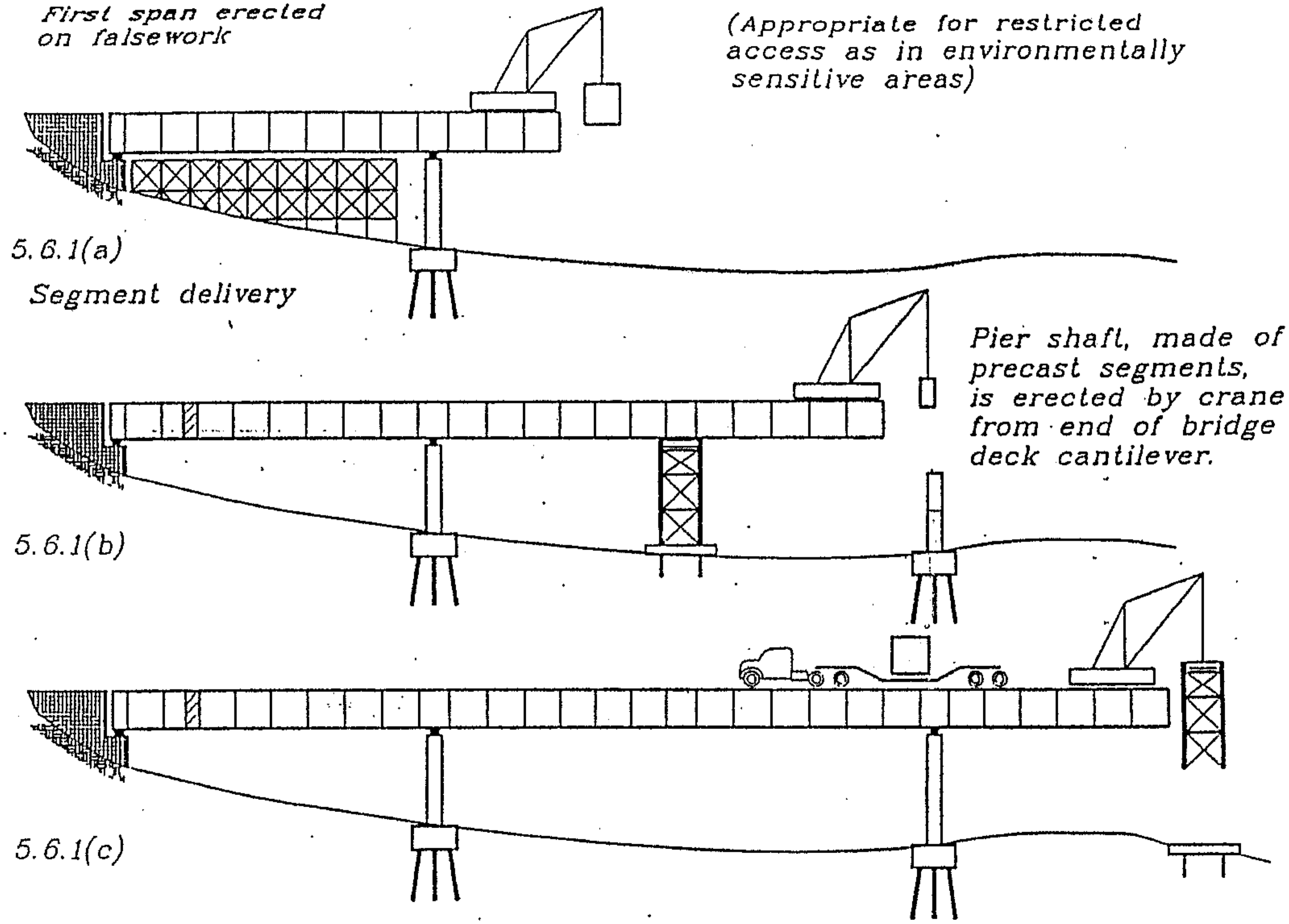
Once a cantilever exceeds half a span, it must be supported on a temporary tower in order to reduce the cantilever moments.

Interestingly, the technique lends itself to construct the bridge entirely, that is piling, footings, piers and superstructure, from above, without disturbance to the terrain. Thus specified by the "U.S. Park Service", the bridge at Grandfather Mountain in the Blue Ridge Parkway was constructed this way.

"Microshaft" piling, so called because of the small size, was drilled into the ground with equipment suspended from the erection crane. The remainder of the pier was precast and was also erected from the cantilever end (see Figure 5.6.1(b)). Because of the way the piers were constructed, the method was slow and expensive. However, if piers are constructed normally, but access over the length of the project is difficult for cranes, the method need not necessarily be uneconomical specially if launching girder erection would be the alternative. Other limitations are that spans should be limited to about 180 feet.

55m





5.6.1(a)

5.6.1(b)

5.6.1(c)

Fig. 5.6.1 Progressive Cantilever Erection

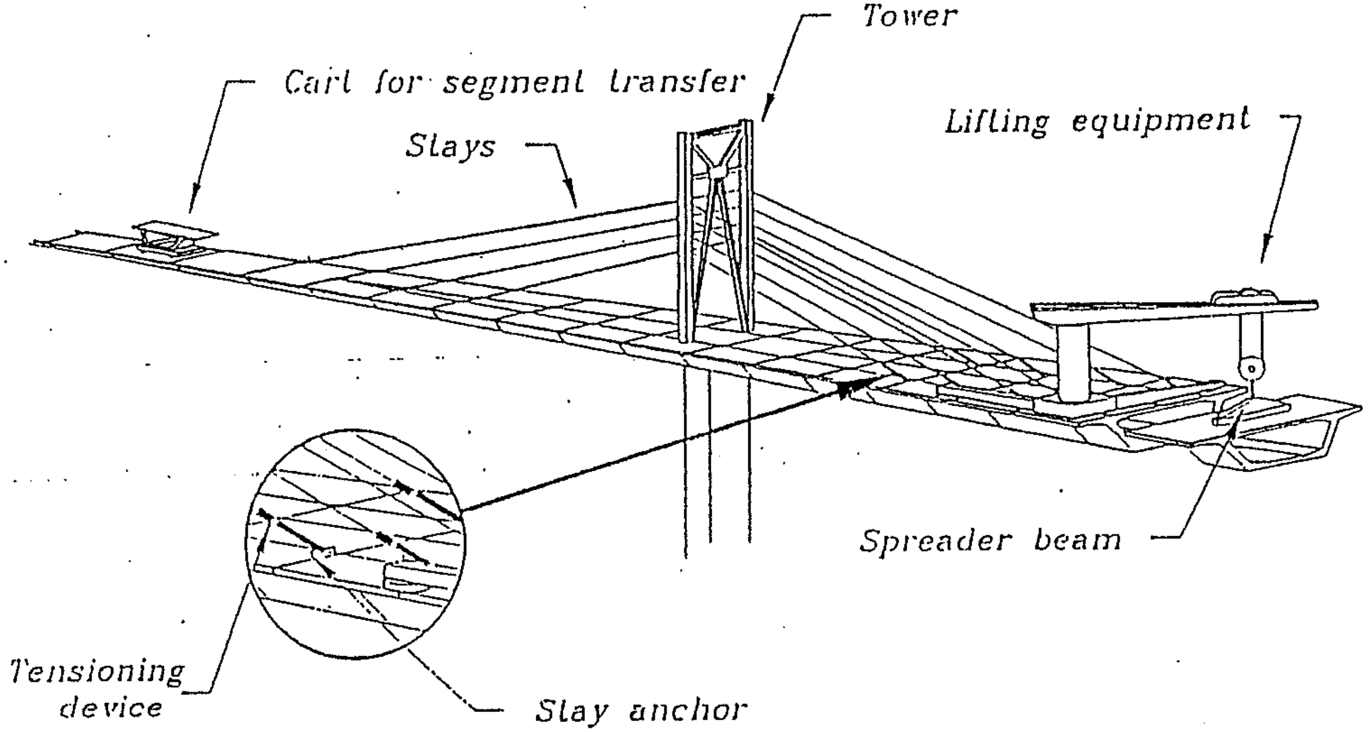


Fig. 5.6.2 Construction Sequence Using Progressive Segment Placing

Figure 5.6.1(c) shows erection of temporary towers placed at midspan for support of the cantilever. Figure 5.6.2 shows a bridge constructed by this method using a system of stays instead of towers to reduce the cantilever length.

5.7 Wet Cast Joint Erection.

With this method segments are not match cast, but made in a form with two bulkheads. All other aspects of segment production are similar to the match casting system.

The advantage is that the geometry control of the structure is removed entirely from the production process, Instead the segments are placed on falsework in the geometric shape desired, the joints are cast and the structure is post tensioned. Figure 5.7.1 shows the segment arrangement and how erection could proceed in an economical manner using falsework only in one span at the time. Naturally it would also be possible to erect all the segments in one operation using falsework or a temporary embankment over the entire length of the project.

This method was used for two viaducts at the M180/M18 Langham Interchange in the U.K.

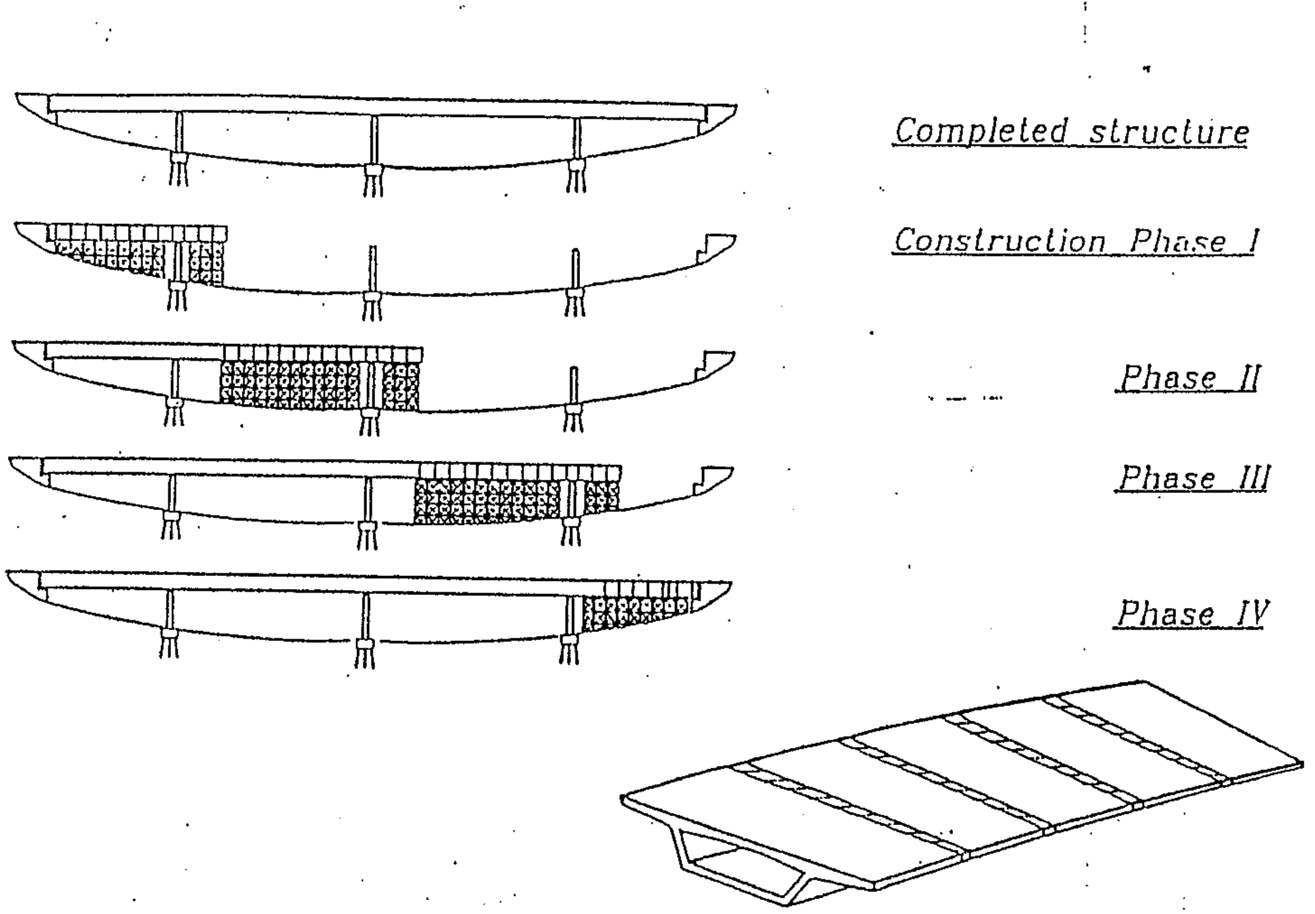


Fig. 5.7.1 Construction Using Wet Cast Joint System

6.0 ERECTION DETAILS

6.1 Post-Tensioning.

6.1.1 Temporary Post-Tensioning

With most forms of segmental construction, it is common practice to use temporary post-tensioning to secure the erected segment or segments before the main longitudinal post-tensioning is installed (Figure 6.1.1). The purpose is:

(1) To provide a rapid means of transferring the weight of the segment from the lifting equipment to the structure within the allowable setting time called "open time" of the epoxy jointing material.

(2) To allow a fairly even stress to be applied over the whole joint face in order to bed down the epoxy and let it set under uniform conditions. It is normal to provide 30 - 50 psi 200kPa 345kPa average compression for this purpose. If the compression is significantly non-uniform from top to bottom, especially in cantilever construction, then the epoxy joint thickness tends to vary which, after several segments, can affect the desired alignment.

* WATCH OUT — Release segment too early will affect the alignment.

(3) In some cases, temporary post-tensioning bars are used to control a temporary stress condition in the structure. For this case the bars can only be removed after construction has reached a stage at which the stress condition no longer exists. If this is necessary because of some design feature of the bridge, the amount of temporary post-tensioning and its sequence of installation and removal is shown on the contract plans. If, on the other hand, the temporary post-tensioning is required to

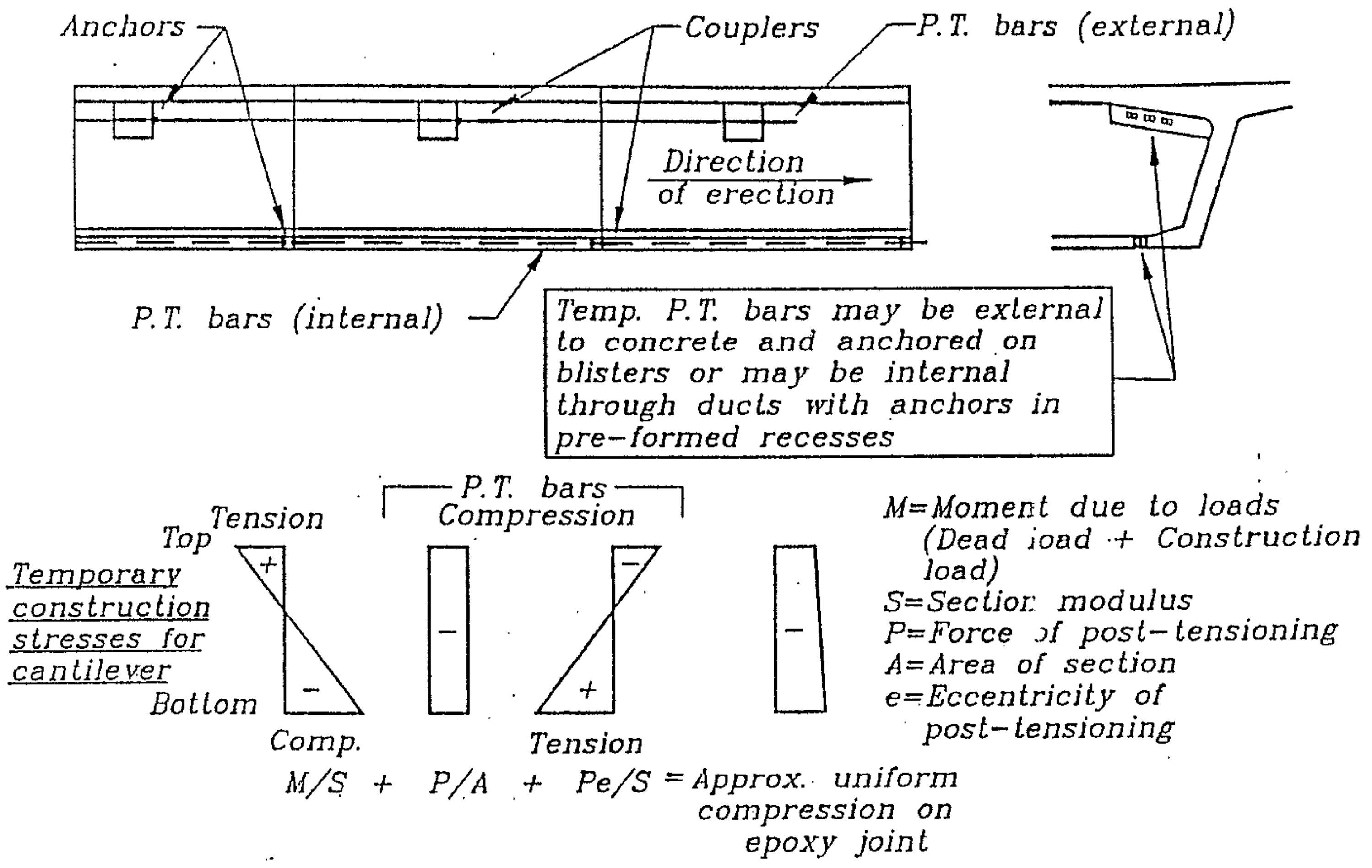


Fig. 6.1.1 Use Of Temporary Post-tensioning (P.T.) For Erection

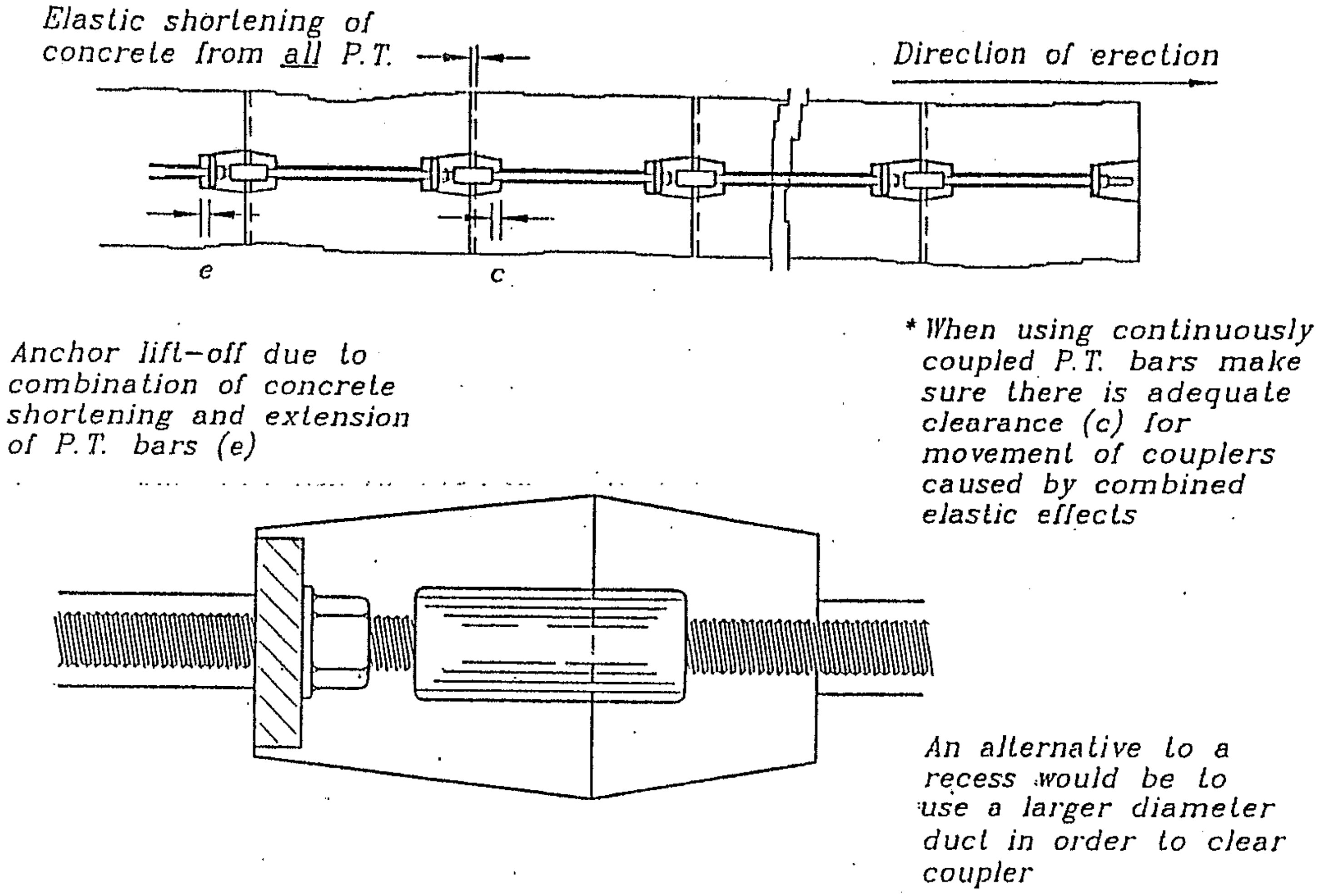
control a stress arising specifically from the contractor's elected method of operation, equipment, construction loads or his own sequence of erection, then clearly the temporary post-tensioning should be designed by the contractor and approved by the Engineer within the shop drawing process. In any event, the sequence of installation, stressing and removal of the temporary post-tensioning should be clearly shown on the shop drawings and/or erection manual.

Temporary post-tensioning bars may be overlapped so that individual bars or coupled bars extend only a few segments or they might be continuously coupled throughout a cantilever or span. With continuous coupling it is advisable to evaluate in advance the likely cumulative effect of bar extension and concrete shortening, as the point of coupling can "drift" significantly and eat into tolerances of the space within the blockouts (Figures 6.1.2 and 6.1.3).

It is normal practice to limit the stress in temporary post-tensioning bars to 50% of the breaking strength of the bars. This will allow many reuses of the bars and the anchors. Sometimes, however, it is necessary to exceed this figure and if so, then these bars should not be reused without the express permission of the post-tensioning bar manufacturer. If there is any doubt, it is safer not to reuse the bars. In case bars are permanent or cannot be removed for reuse, it is acceptable to stress the bars up to 70% of the ultimate tensile strength.

} for reuse purpose.

In cantilever construction the temporary bars are needed normally only for the last two or three segments of the cantilever. Occasionally, when using continuously coupled bars, it may not be possible to retrieve them after the closure has been made at the midspan. In such case it is advantageous to plan the temporary post-tensioning so that



Elastic shortening of concrete from all P.T.

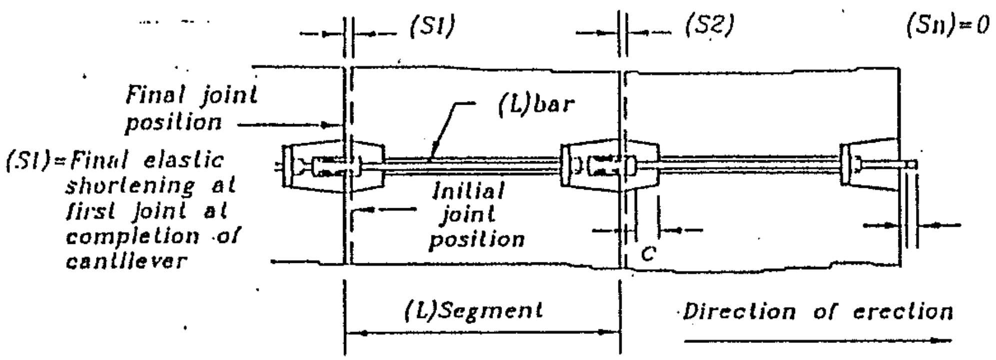
Direction of erection

Anchor lift-off due to combination of concrete shortening and extension of P.T. bars (e)

* When using continuously coupled P.T. bars make sure there is adequate clearance (c) for movement of couplers caused by combined elastic effects

An alternative to a recess would be to use a larger diameter duct in order to clear coupler

Fig. 6.1.2 Use Of Continuously Coupled Post-tensioning (P.T.) Bars



Points to beware of when using continuously coupled P.T. bars:

1. Each bar will extend a small amount–(typically 3/8"–1/2" per 10ft. segment). so if the position of the couplers is critical, bars should be ordered short of a segment length by this amount, (0) also:–

2. Particularly in a cantilever, the cumulative effect of adding more segments and P.T. tendons causes an increasing shortening of the earlier segments. (S) This can be significant and will effectively make the point of coupling of bars in later segments drift in the direction of erection–eating into any tolerance (C). To avoid or minimize loss of tolerance by these effects the bars should be ordered to a length shorter than segment length by=(S=S1/2).

3. But–always allow for variation in segment lengths, also. i.e. provide ample tolerance!

Fig. 6.1.3 Coupled Post–tensioning (P.T.) Bars (contd.)

most of the bars can be recovered prior to adding the last cantilever segment. Temporary bars and particularly their anchors and couplers are expensive pieces of hardware. Hence maximum reuse is essential.

6.1.2 Permanent Post-Tensioning

Permanent post-tensioning tendons are installed and stressed as erection of segments proceeds. Both internal and external tendons are used. Internal tendons are located in ducts inside the concrete slabs and webs. They are commonly used in case of balanced cantilever erection. External tendons are located in polyethylene pipes which are placed in the interior space of the box girder. They are attached to the structure at the pier diaphragm and at deviation blocks (see Figure 5.2.2).

Since placing, stressing and grouting of post-tensioning tendons for segmental bridges is no different from tendons used in other applications, the reader is referred to the Florida Department of Transportation Post-Tensioning Manual for an extensive description of these techniques.

6.2 Lifting Segments for Erection.

Lifting and handling of segments was also discussed in Section 4. Clearly the method is the contractor's choice, subject to the approval of the Engineer.

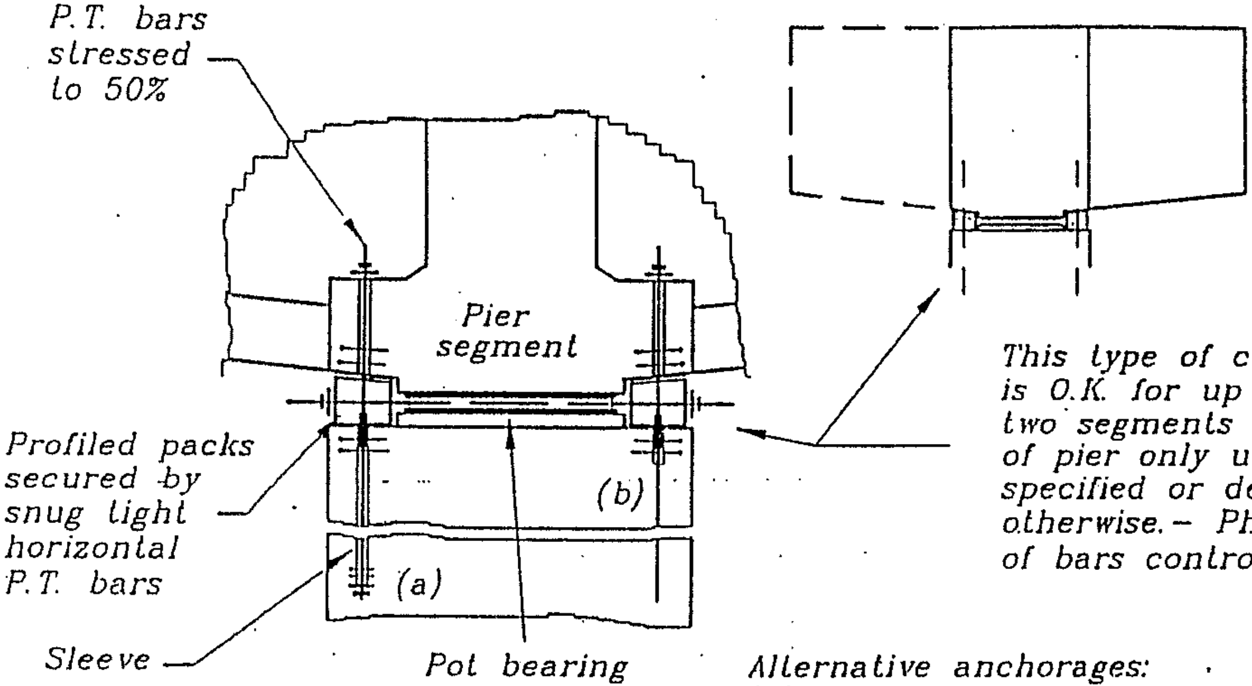
When erecting in cantilever it is necessary to lift the segments in such a way that they hang precisely in the position of the previously erected segment in order to align the shear keys and temporary post-tensioning bars during the epoxy jointing process. If the position of the two segments does not match, the segment will bear temporarily only on a few keys which might lead to cracks when jointing. It is quite easy to align the segments if two lifting points (such as with a beam and winch) are used, one over each web. With a single central lift, it is necessary to lift slightly off center so that the segment hangs at the required crossfall. This can be done by using a lifting frame with laterally slotted holes for the attachment of the slings (Figure 4.1(a)). In any case the lifting device used for erection must have the means to adjust the position of the segments.

Lifting segments at a preset crossfall is not necessary when they are to be placed on an erection truss as with span-by-span construction.

6.3 Temporary Supports.

Construction in balanced cantilever begins by placing the pier segment on the pier. Setting this segment at the correct vertical and horizontal alignment is critical as any errors are magnified in the cantilever (see Section 8 - Geometry Control). It is furthermore essential to support the pier segment in such a way that successive segments can be added. One method of doing this is shown in Figure 6.3.1. Vertical post-tensioning bars and shim packs are used to stress the segment down to the piers and provide temporary support. (Note the provision of local reinforcement above and beneath the packs to control any possible "bursting" effects). A support system as shown is only suitable for the first few segments, at most two on each side of the piers. Beyond this, the out of balance effects are likely to exceed the capacity of the concrete and of the available bars which can be fitted into the restricted space.

After the first few segments, stability should be provided by some other means. Temporary towers as shown in Figure 6.3.2(a) can be used either "wrapped around" the pier



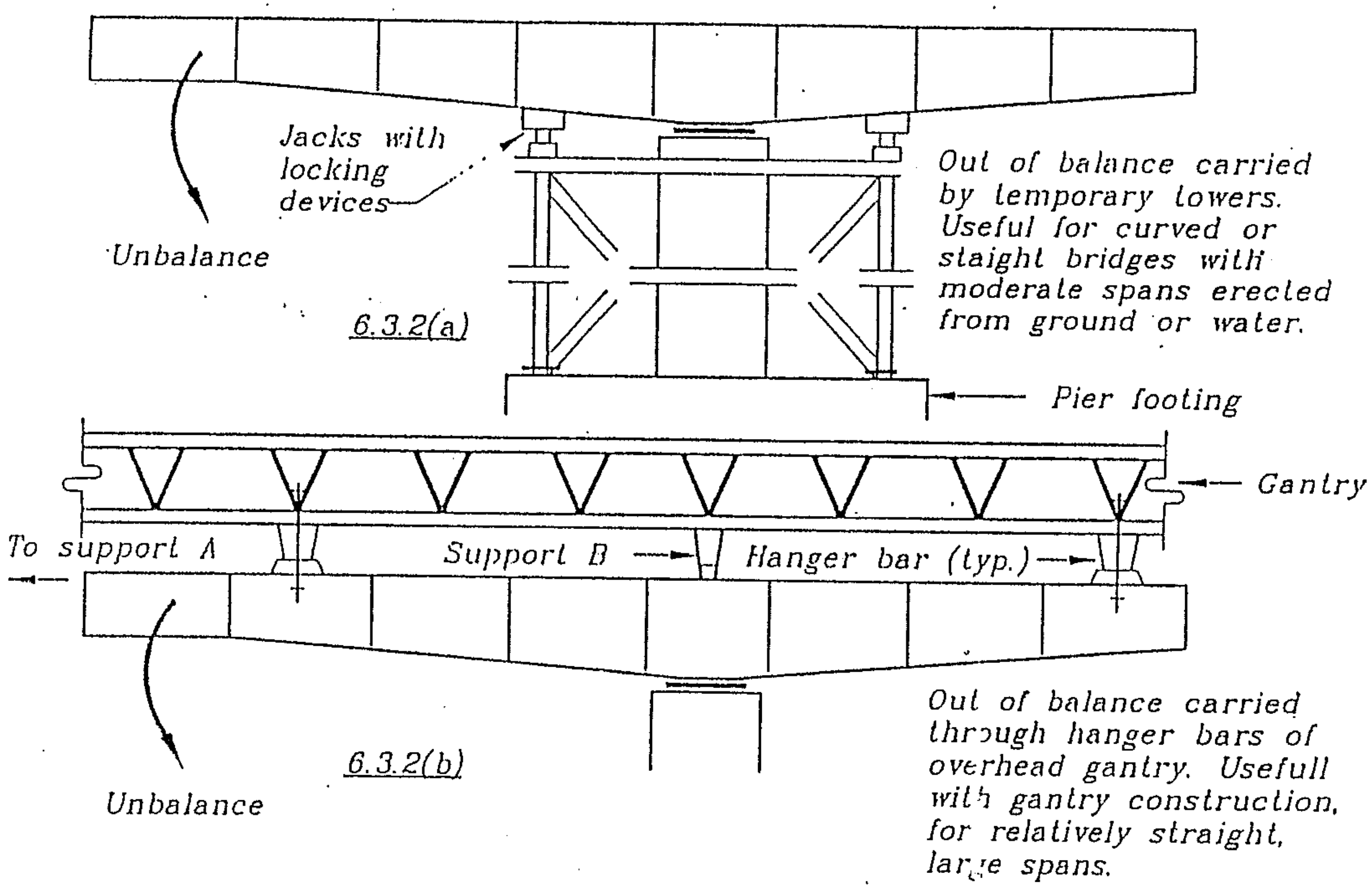
This type of connection is O.K. for up to one or two segments each side of pier only unless specified or designed otherwise.– Physical limits of bars control.

Alternative anchorages:
(a) Dead end plate & nut; wrap with tape to allow bar to be screwed out afterwards.
(b) Embedded P.T. bar with coupler.

P.T.=Post-tensioning

Fig. 6.3.1 Erection Systems: Setting Of A Pier Segment & Start Of Cantilever

Fig. 6.3.1 Erection Systems: Setting Of A Pier Segment & Start Of Cantilever



Out of balance carried by temporary towers. Useful for curved or staight bridges with moderate spans erected from ground or water.

Out of balance carried through hanger bars of overhead gantry. Usefull with gantry construction, for relatively straight, large spans.

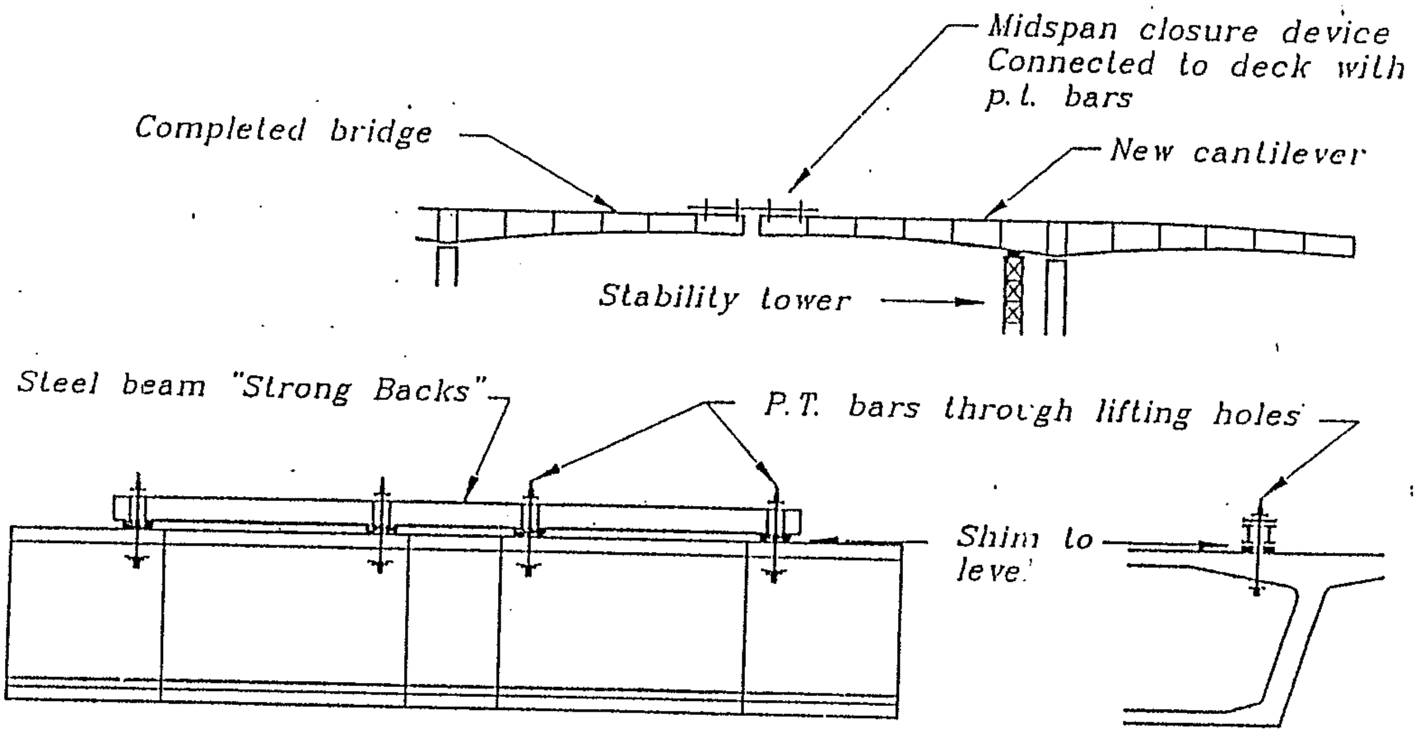
Fig. 6.3.2 Erection Systems: Means Of Stabilizing Cantilever with support provided to both sides of the cantilever through a system of hydraulic jacks or by a tower on one side of the pier only. With the latter system the cantilever should always be kept out of balance in the same direction so that the tower is always loaded. Another method of providing stability is through an overhead launching gantry. Figure 6.3.2(b) shows how the cantilever is suspended from the gantry. The hanger bars are repositioned to be always next to the last erected segment.

With these systems, namely the towers and gantries, control can be exercised over the amount of rotation of the cantilever. This is advantageous when it comes to aligning cantilevers for mid span closures.

6.4 Midspan Closures.

In order to make a midspan closure, it is necessary to secure the new cantilever to the rest of the bridge. This is readily accomplished through "strong backs" stressed by post-tensioning bars to the segments (see Figure 6.4). Strong backs should be carefully checked for the loads likely to be carried. Apart from the weight of the closure joint concrete, this can be some of the remaining out of balance forces and any force needed to pull the cantilever tip up to level. In addition the strong backs should be capable of overcoming the bearing friction on the adjacent pier(s) so that the cantilever can follow daily temperature movements after connection to the structure.

Usually the midspan closure is a nominal two to five feet gap. Sometimes, however, it can be larger and might be as long as a segment. In such cases the added weight of concrete can cause a deflection and rotation at the closure. For the precast segments this effect is compensated for in the casting curve. The cast-in-place joint itself requires careful placement of the concrete working from one



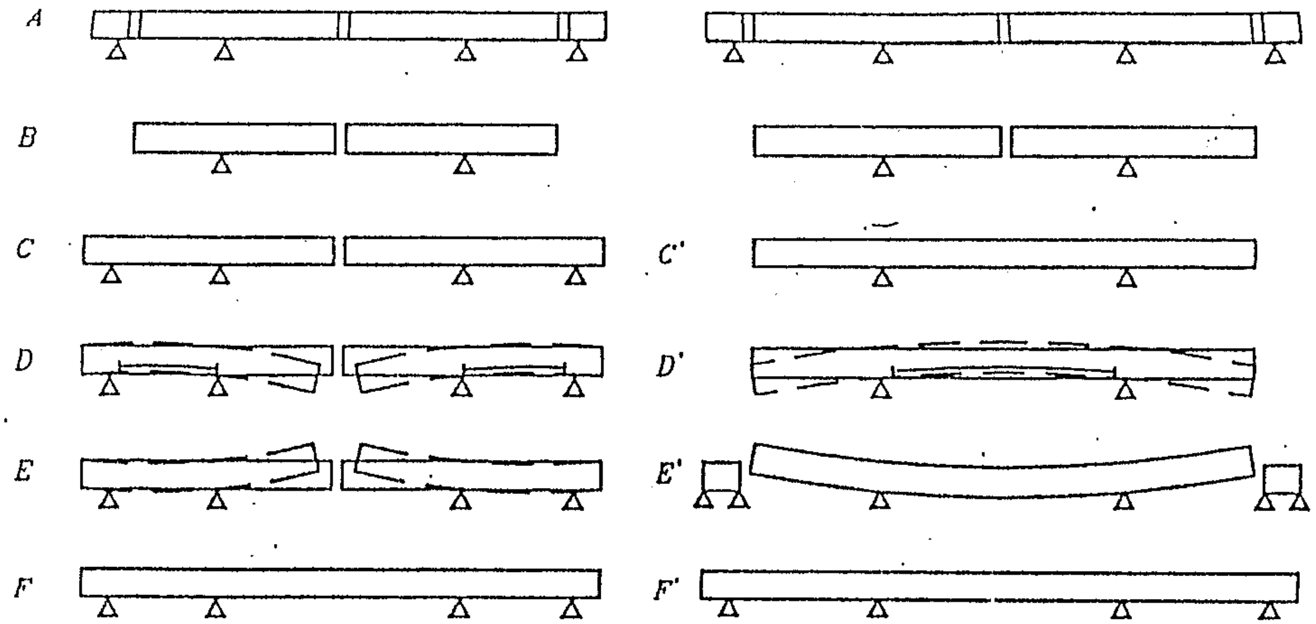
P.T.=Post-tensioning

Fig. 6.4 Aligning Cantilevers For Midspan Closure end of the segment to the other, to avoid any tendency to "crack" or open up at the bottom of the joints between the segments and the cast-in-place concrete. If the anticipated deflection or rotation is likely to be very large such as with a very large closure, then consideration should be given to casting the bottom slab first and applying a nominal post-tensioning force (say, 100 kips) through it prior to completing the rest of the pour. This will help to avoid cracks in the joints.

The weight of the first cast-in-place joint connecting two cantilevers causes an unbalance which is usually controlled by the stability tower (Figure 6.4). This tower will deflect under the effects of the additional load. This deflection will lower the elevation at the cantilever end where the cast-in-place splice is poured. The amount of this should be carefully predetermined and compensated for. Cantilever tips also move because of the effect of sun radiation on the deck. The effect of this on the casting of midspan splices is described in 8.9.2.

6.5 <u>Construction Schedule and Sequence</u>.

The casting curve will reflect the various deformations the bridge will get if constructed in accordance with the schedule and sequence the contractor proposes. The construction schedule and sequence are important. In fact, so important that once sequence and schedule are selected as a basis for the casting curve, a change of sequence or schedule or both may require a change of the casting curve and possibly even a design change. The schedule is important because once cast and under stress, concrete has the tendency to deform. One sees this, for example, with I-beams which camber up as soon as the prestressing is applied. If the camber is checked again after say a month it has often increased and as time goes by, it will increase even more.



A. Three-span structure showing mid-span and tailspan splices
B. Erect cantilevers
C. Close tailspan splice and post-tensioning
D. Deflection caused by "C" above
E. Compensation of deflections by "C" above
F. Completed structure

C'. Close mid-span splice and posttension mid-span
D'. Deflection caused by "C'" above
E'. Compensation of deflections by "C'" above
F'. Completed structure

6.5.1(a)

6.5.1(b)

Fig. 6.5.1 Effect of Construction Sequence

This increase in camber is caused by concrete creep. In segmental bridges where spans can be longer, this creep effect may amount to several inches. In order to compensate for these creep effects, they are calculated based on the contractor's contruction schedule.

The construction sequence is also very important. First of all, because the sequence tells us when certain spans will be built and therefore provides an indication of the timing; but, in addition, the sequence indicates when continuity post-tensioning is applied. This is the post-tensioning provided in the span to connect two adjacent cantilevers. The continuity post-tensioning has the tendency to camber the span in which it is stressed but will deflect the adjacent cantilever end (see lines "D" in Figures 6.5.1(a) and (b)). These deflections are carefully compensated for in the casting curve. If the sequence were changed so that the continuity post-tensioning in the span with the deflecting cantilever were stressed first, the span would go up instead of down and the compensation made would be wrong. An example of this is given in Figures 6.5.1(a) and (b) where different sequences are used to construct the same bridge requiring completely different compensation of deflections caused by continuity post-tensioning.

The bridge deflections are generally calculated by the contractor and reviewed by the DOT or a consultant. The reason is clear. Only the contractor, after making out his schedule can know for sure when and how the structure will be constructed. Exceptions to this rule occur, for example, when the designer decides to prescribe the sequence and has determined from his calculations that the effect of the schedule is minor (in case of short spans).

8.0

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8.0 GEOMETRY CONTROL

8.1 General

The Geometry Control of segmental bridges is achieved in the casting yard. The "short-line" casting system is based on making very fine adjustments to each match cast segment in the casting cell and therefore requires precision; more so than the "long-line" system where the Geometry Control is mainly achieved when building the soffit. The following discussion concentrates on the "short-line" system since it is more commonly used although the principles apply to both systems.

Precision geometry control has nothing to do with the sizes, thickness variations or tolerances of the component pieces of the segments, important though as these are to the overall quality of the finished product. The precision is required for measuring the relative as-cast position of the new segment in relation to its match cast neighbor. These measurements are critical.

The setup required for this in the casting yard is shown in Figure 8.1.1. The alignment is controlled by an instrument on a permanent base and a permanent target. Neither instrument nor target should be disturbed throughout the production, otherwise control must be reestablished. For this, adequate bench marks should be maintained. The casting cell is always plumb, level and usually square so the geometry control is established mainly by positioning the old segment as prescribed by the casting curve and as shown in Figures 8.1.2(a) and (b).

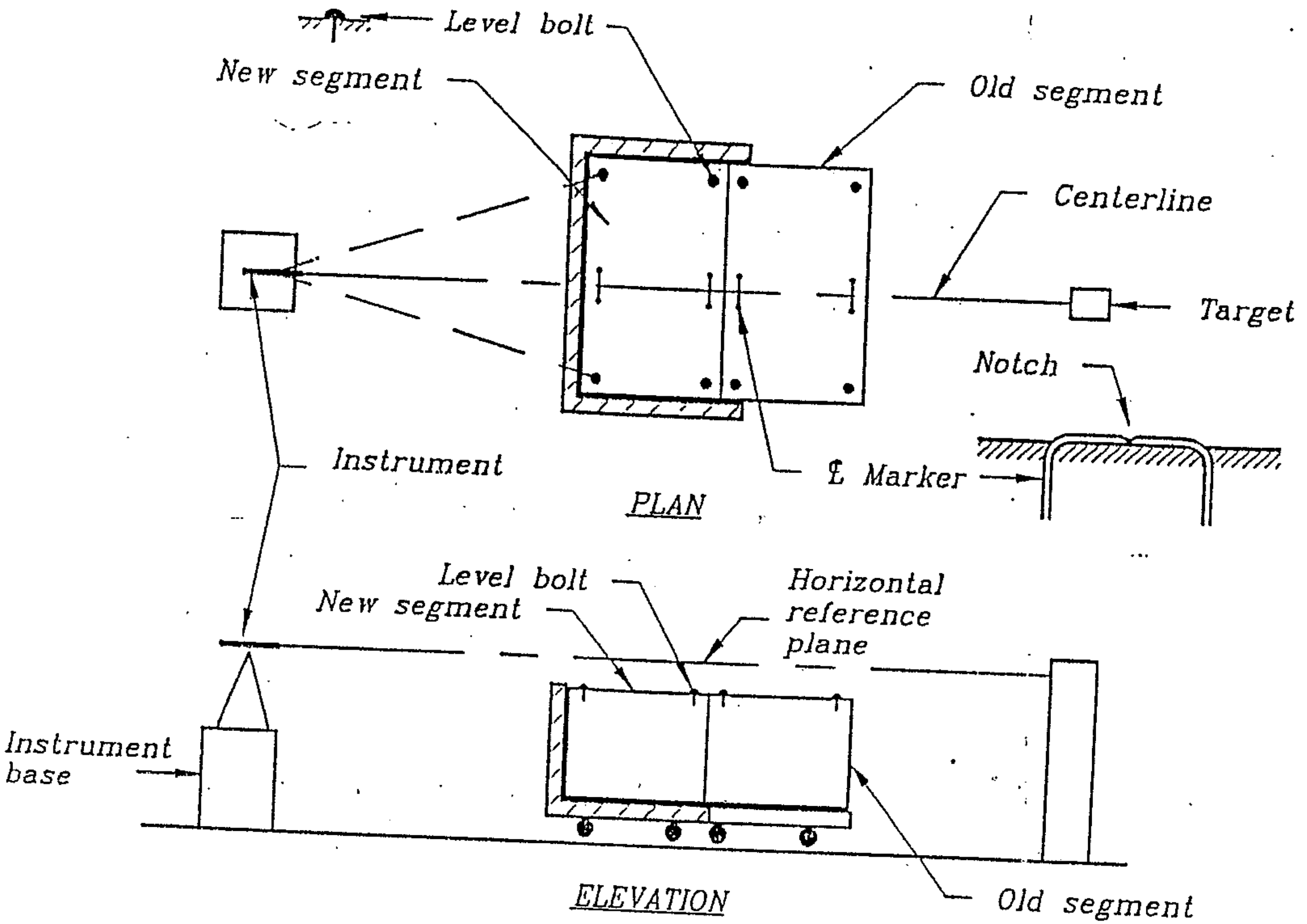
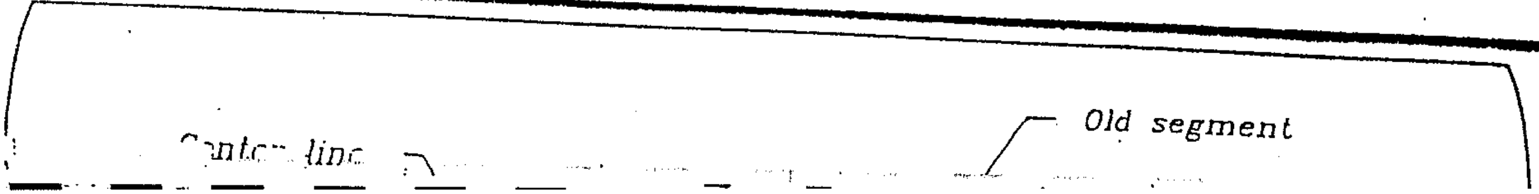


Fig. 8.1.1 Alignment Control: Set Up



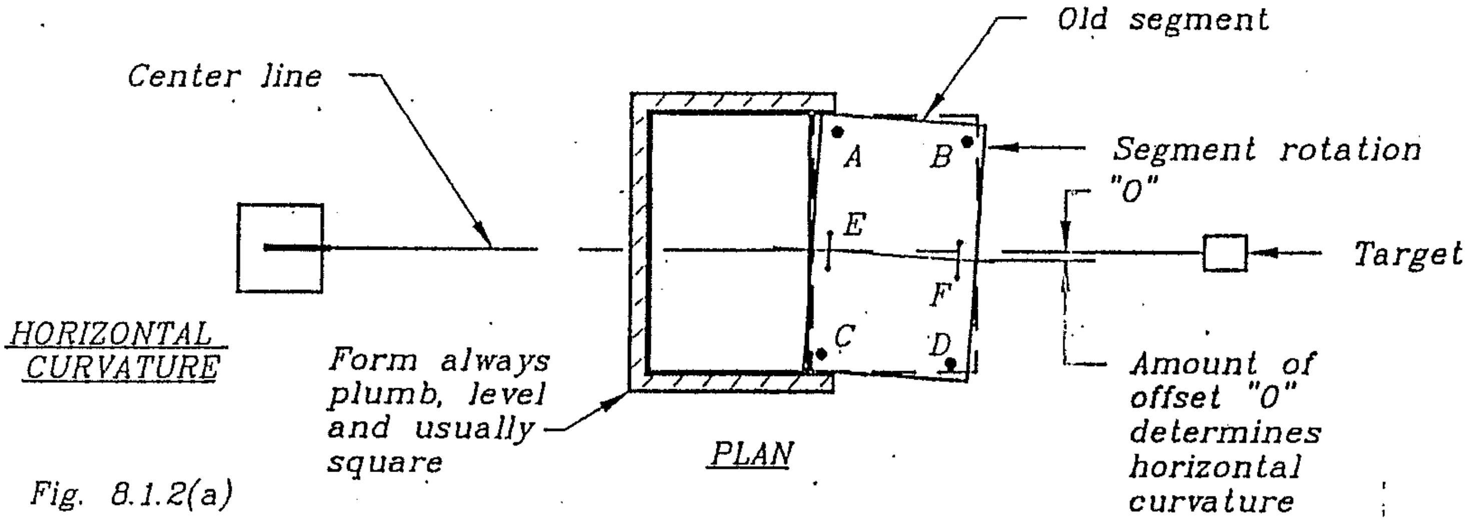


Fig. 8.1.2(a)

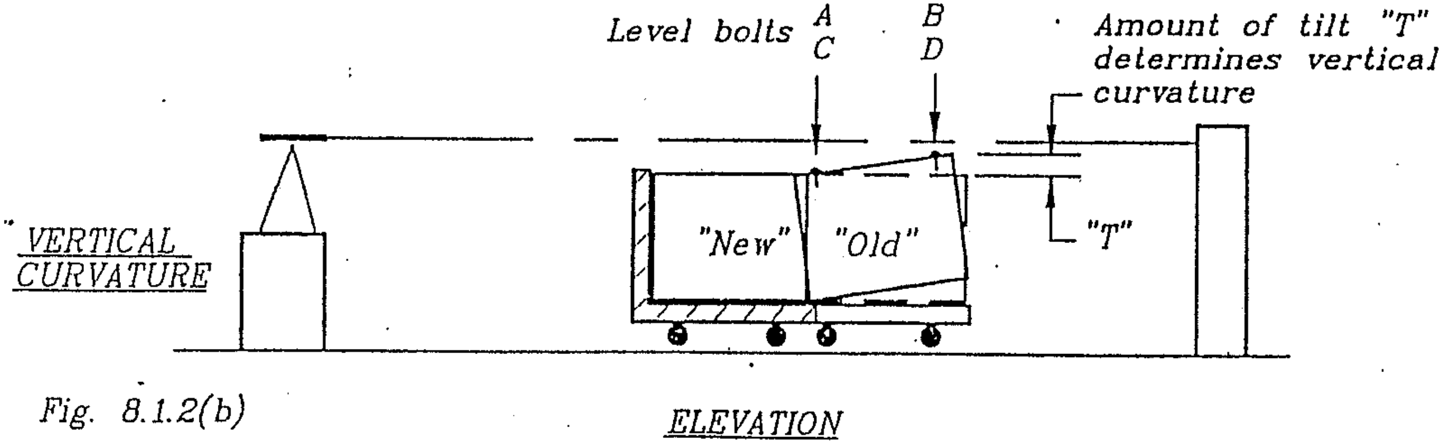


Fig. 8.1.2(b)

Fig. 8.1.2 Alignment Control: Set Up (contd.)

As the first segment is cast and the top slab has been finished, four elevation bolts, A, B, C, and D, as well as two centerline markers, E and F are installed. The following morning the elevations of the tops of the bolts are recorded and the centerline is scribed onto the centerline markers. Now the segment can be rolled forward for match casting.

After the first segment is moved to the match casting position, it is reset to the instructions provided by the casting curve. The centerline will be as it was before, unless the bridge is curved. In case of a curved bridge, an offset "O" is used as shown in Figure 8.1.2(a). The vertical curvature is handled similarly. But even if the bridge is flat, it is necessary to adjust for the deflections, which occur during construction. As mentioned, the amount of adjustment to be made is determined by the casting curve which is part of the shopdrawings. Note that if the segment would be positioned in such a way that both centerline markers are in line with instrument and target and the bolt elevations are the same as those measured before the segment was moved, the segment would line up exactly with the next segment to be poured.

Geometry control for segmental bridges requires an excellent surveyor. He should be on the job daily and keep accurate records. In spite of his competence, his work should be meticulously checked by the inspector since errors are expensive and time consuming to correct.

After the old segment is properly reset and the setup for the new segment is complete, the new segment can be cast. The following morning the surveyor marks the centerline and records the bolt elevations of the new segment. In addition, before the old segment is moved, the elevations of its bolts and its centerline position are checked to deter-

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mine if the old segment has moved during casting the new segment. It is often noted that position changes of the "old segment" occur due to settlement of the soffit rails by the segment weight, due to vibrating of fresh concrete against it, or due to forces applied to it while closing the forms.

When constructing a bridge using girders or whole spans cast in place, it is normal practice to set forms to within 1/100 feet (1/8 inch) of the desired position duly corrected for anticipated deflections and so on. Since, in a segmental bridge, there are a number of short segments within a span, it follows that in order to obtain the required erection tolerance (i.e. 1/100 feet), the precision within any pair of segments must be proportionately greater. For example, if there are 10 segments in a cantilever, then the precision in the casting cell should be to 1/10 of 1/100 feet or 1/1000 feet. Direct reading to 1/1000 feet on elevations and offsets in the casting cell is at the limit of normal surveying equipment and measuring devices. Certain equipment enhancements, however, allow even accuracies of 1/10000 feet. Trained surveyors can consistently obtain readings with an accuracy of this order. As accuracy depends upon consistency, it is important that the same individuals make the critical "as cast" observations at the same time each day prior to stripping the forms of both the new and the old match cast segments. Usually, this is the first thing each morning before the daily crews arrive and when weather conditions are most stable from day to day.

Note that all the critical readings are those after casting. While it is important to have an accurate set up before casting, this is unlikely to remain so during the casting operation. Some movement, however slight, will occur, so the true achieved geometry is recorded _after_ casting. It is possible to compensate for casting errors by adjusting the position of the next set up and so on. In fact, the major trick in geometry control lies in keeping track of casting errors and correcting for them.

Erection of the first segment, usually a pier segment, is critical and should be done as accurately as possible.

It is very important that all the information from the casting operations and the calculated "as cast" actual relative positions of the segments be carried through the field erection process as well.

This poses some practical difficulties because it is by no means as easy to obtain the same accuracy in the field as in the casting yard. However, the field setting is only required at each pier segment or start of a succesive run and it is worthwhile doing this correctly. Placing a large chunk of concrete with a crane to an accuracy of a few thousandths of a foot is asking a lot! In practice it is possible to use shims, packs and wedges to maneuver the segments to within an acceptable accuracy (e.g. Figure 6.3.1). Also, by installing supplementary transverse alignment markers while in the casting cell, the horizontal adjustment of the piersegment can be set in the field using the base line of the full segment width, thereby not relying solely upon the shorter, front to back, longitudinal centerline marks (Figure 8.1.3).

During erection, elevations and horizontal alignment should be checked to see if they are in agreement with the calculated, as-cast positions. If not, then adjustments may be necessary. Such compensations include: reorienting or rotating the cantilever after erection, calculating a compensatory setting for the next cantilever or shimming the joints. The latter should only be used as a last resort as

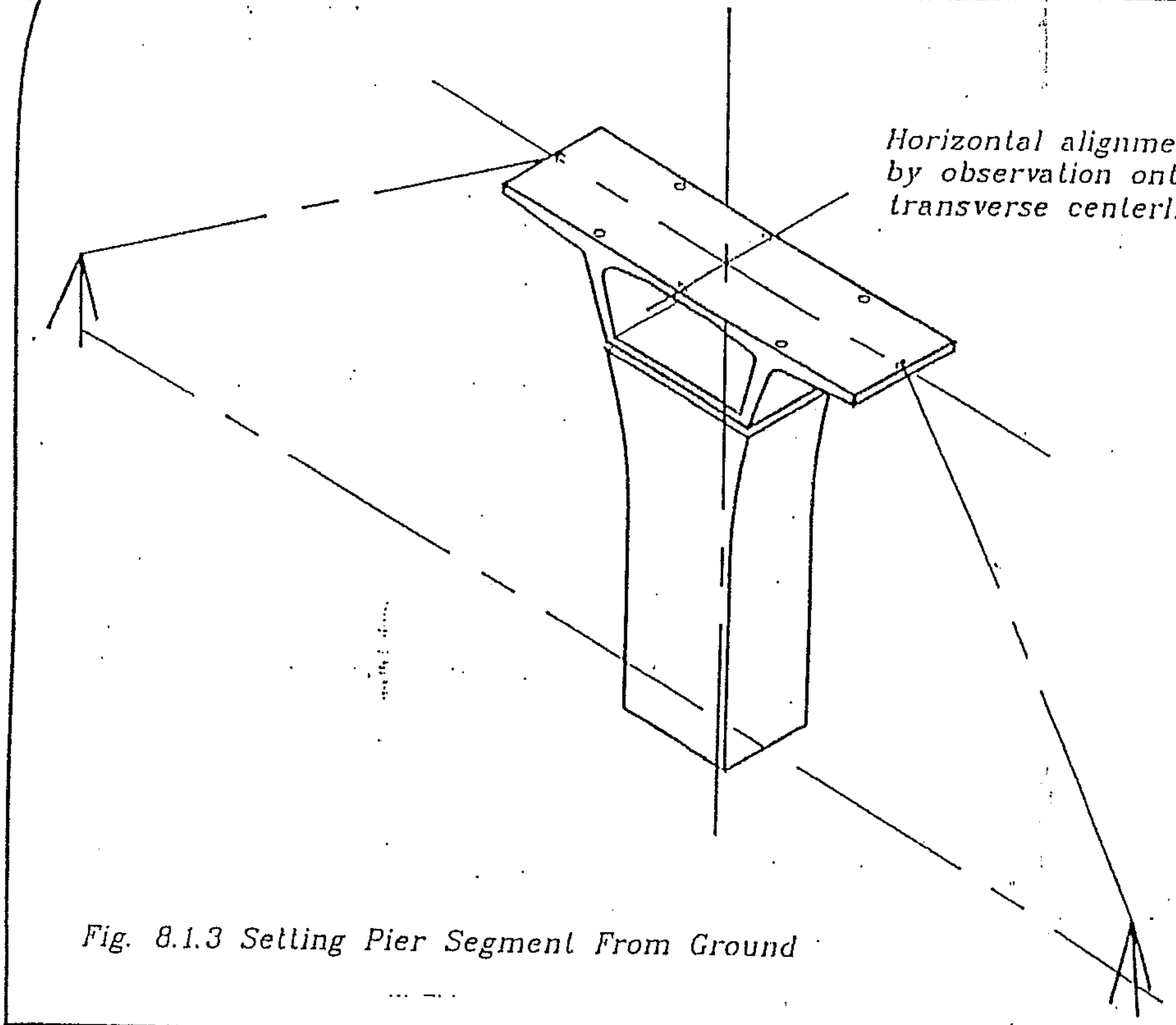


Fig. 8.1.3 Setting Pier Segment From Ground

it can unpredictably lead to "correction of corrections" and so on. Moreover it is not effective for short cantilevers or deep girders.

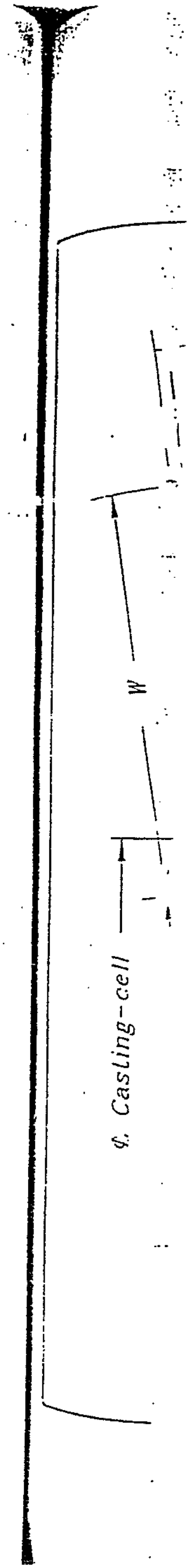
Precision within the geometry control system is essential in order to avoid errors in the geometry of the structure. A source of error in alignment may arise from the deformation characteristics of the concrete being different from those assumed. Deformations of concrete are difficult to predict with any degree of confidence and most attempts are at best sophisticated judgements. In segmental construction the actual deflection can differ from the theoretical just as in precast girder production where identical girders can differ in camber by a few inches. However, with precast segmental construction most of the shrinkage has usually occurred during storage and the concrete has matured substantially by the time of erection. This helps to eliminate the significant variations likely with young concrete.

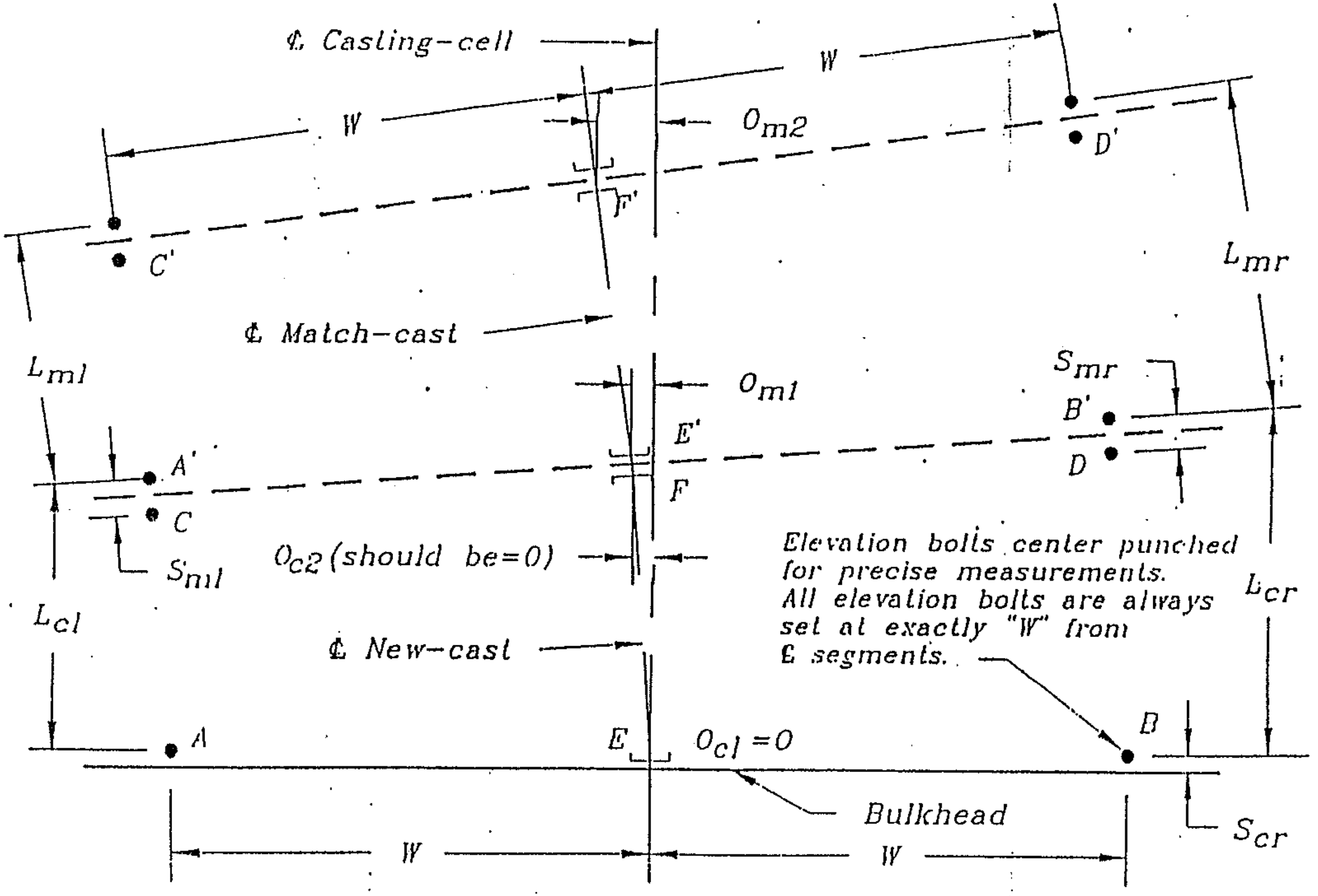
.2 Casting Cell Geometry Control System.

Geometry control is achieved in the casting cell by eans of a system as illustrated in Figure 8.1.1 and 8.1.2.

The bolts A, B, C, and D are set over the webs as these are the points where no vertical deflection will occur ue to transverse bending or post-tensioning effects. For example, the wing tips can deflect or camber by as much as 3/4 inch under the effect of deadload and transverse prestress. This location would therefore not be suitable for vertical alignment control bolts.

The horizontal alignment is established by setting he match cast segments at the necessary skew and offset, as asured on its centerline hairpins E and F, from the casting





Elevation bolts center punched for precise measurements. All elevation bolts are always set at exactly "W" from ℄ segments.

Fig. 8.2 Observations Required For Geometry Control cell centerline. Likewise, vertical alignment is set by adjusting the jacks on the match cast segments carriage until its elevation bolts are at the calculated levels above or below the plane defined by the top of the bulkhead.

After casting, the exact position of the newly cast segments and match cast segments is carefully measured by taking elevation readings on all eight bolts and offset readings on all four centerline hairpins. Auxiliary length measurements are made along the lines of the elevation bolts (Figure 8.2).

The observations are made to an accuracy of .001 feet. It is advisable that parallel but separate readings be made by the contractor and resident staff in order to avoid any major misreading. It is likely that two sets of observations will not agree exactly but parallel readings and subsequent computations will track the geometry better and avoid gross errors.

Periodically the alignment of the cell centerline and elevations of the bulkhead should be checked back to remote bench marks to guard against inadvertent errors due to drift of the equipment through usage.

Processing of the observations is made either by numerical analysis or by graphical plotting. The former is quite conveniently handled by desk top computer or calculator for, once the procedure has been established, it becomes very repetitious and automatic.

Desk top computer programs are available through the industry to handle such computations, but this does not guard against mistakes, and it is good practice to check by making parallel graphical plots.

The above description provides the basic introduction to the techniques with emphasis on good practice. It is not the intent here to present the full thesis on geometry control computations as these can be extremely involved and would add nothing significant to the object of this guide.

8.3 Tools Used for Geometry Control.

(1) Offsets: Centerline offsets are measured from the casting cell centerline using a metal scale fitted with a center point which sits in a punch mark on the hairpins. A spirit level should be attached to this scale so that it is set horizontal. Also, it should be held at right angles to the centerline of sight in the cell (Figure 8.3.1).

(2) Elevations: Elevation readings on the bolts are made with a precision level placed on top of the fixed mounting, reading onto a leveling rod fitted with a scale divided down to at least .005 feet. In order to make sure the readings are taken at exactly the same point each time, the leveling rod should be fitted with a center point which sets into a punch mark in the top of the bolt.

(3) Lengths: A steel tape is used for length measurement. It is advantageous to measure lengths between the center point marks on the hairpins, the distance between adjacent hairpins and similarly along the bolt lines between the leveling punch marks. Readings should be estimated to at least .002 feet for length (Figure 8.2).

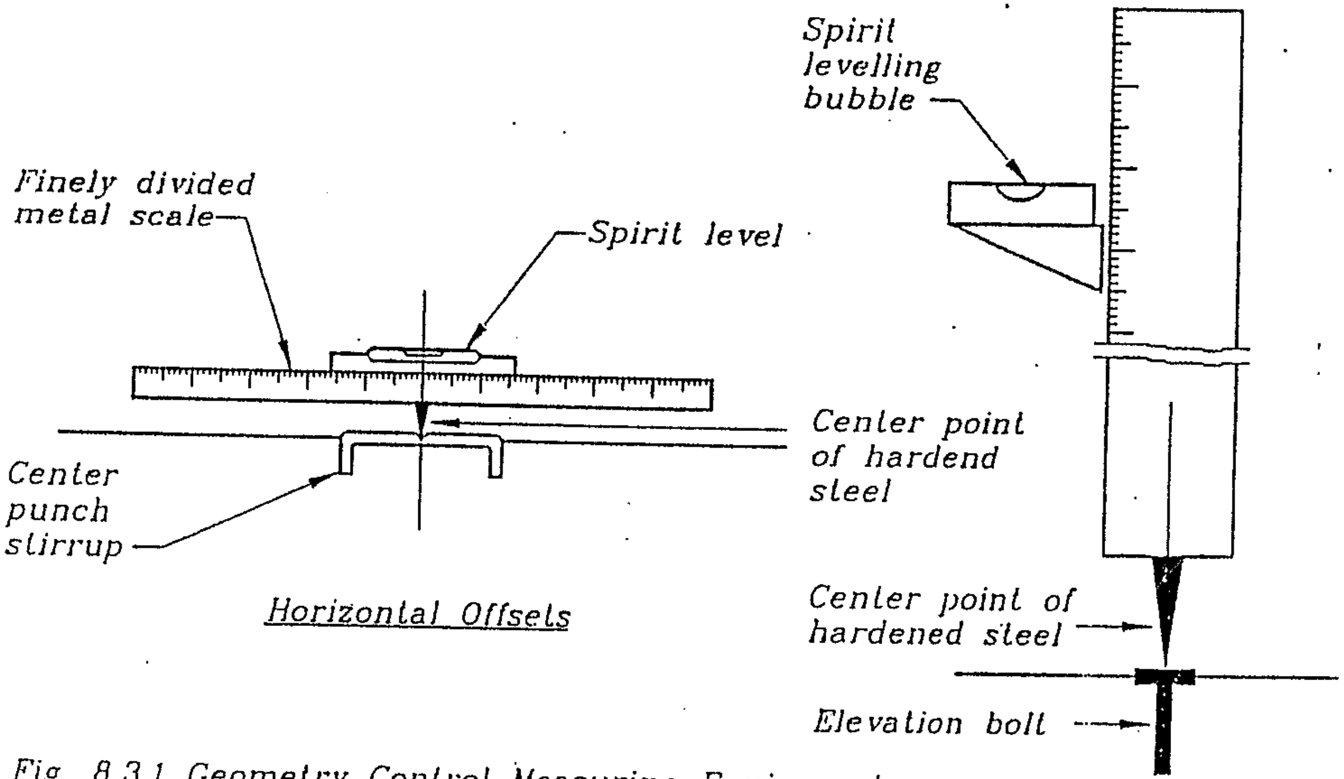


Fig. 8.3.1 Geometry Control Measuring Equipment

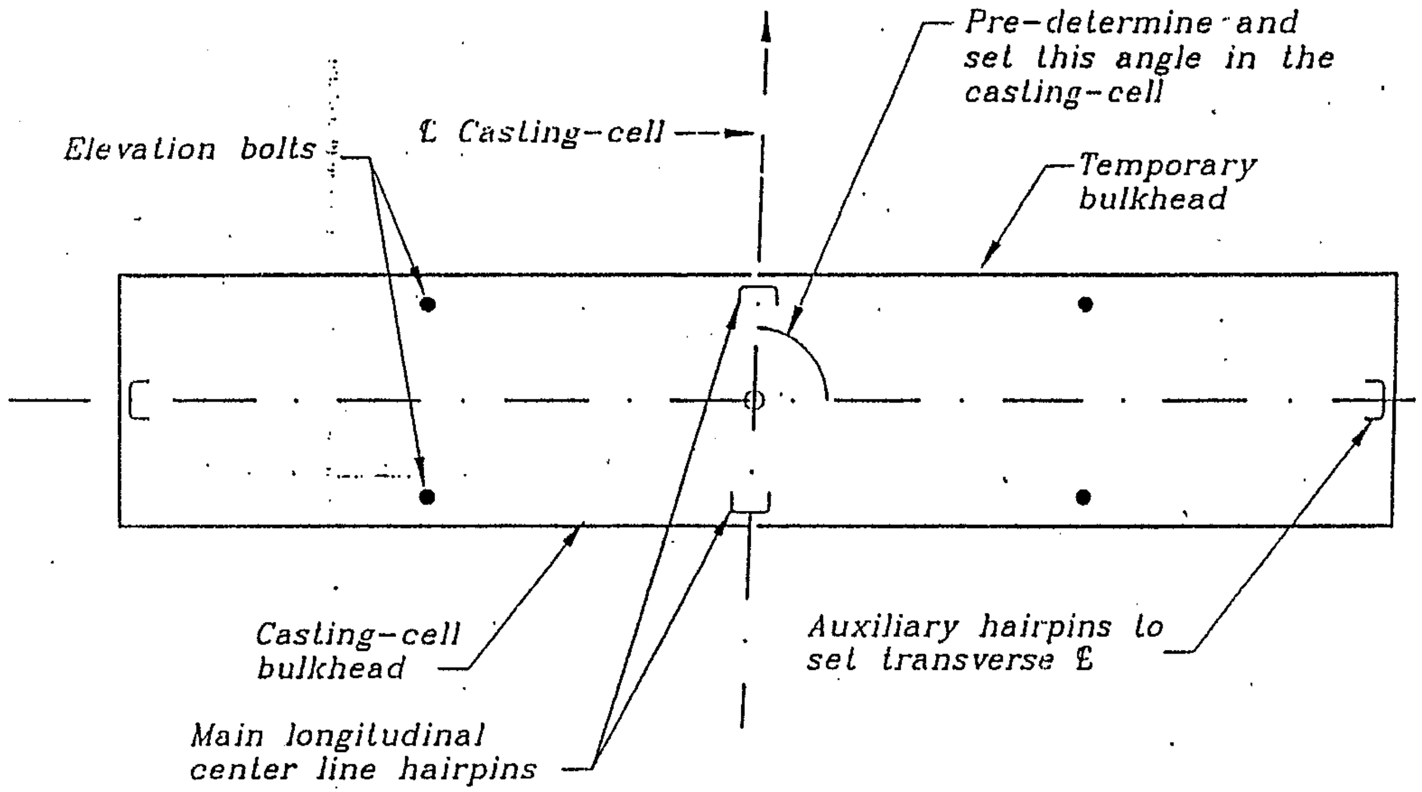


Fig. 8.4 Geometry Control For Starting (Pier) Segment

(4) Lateral offsets to the level bolts should be measured from the centerline hairpins. It is preferable to have the bolt positions accurately marked on the bulkhead so that they are always at the exact required offset from the centerline (Figure 8.2).

With care and precision, the readings obtained will allow precise processing using three-dimensional coordinate geometry computations which are the most accurate when it comes to defining curved surfaces in space. Good record keeping is essential as well.

There have been occasions when accidentally one or more of the geometry control hairpins or bolts were lost. This is not irretrievable. It is usually possible to continue construction by using known relative positions of adjacent undamaged markers. What it means is merely a little less predictable control over the erection alignment.

8.4 Geometry Control of the First Pier Segment.

The first segment of a run or a cantilever is cast between the bulkhead and a temporary bulkhead. Consequently, it has no match cast segment to which its geometric position to be referenced. When moving this segment from temporary storage into the matchcasting position, it is simply set to the same position it had after casting by reading the same elevation on the bolts and the same offsets on the markers. This gives a starting point from which all other segments can be subsequently referenced, assuming that there is no casting curve adjustment to be made. If there is a casting curve adjustment needed, it can be made at this time. The bolt and centerline marker readings are also used for setting the first segment in its required attitude in the erected structure. The technique is again part of regular geometry control procedures and will not be elaborated further here.

The main feature of the first segment which, if it is a pier or abutment segment, is usually shorter than the typical segments, is to establish a transverse horizontal control line on the surface of the segment in the casting cell (Figure 8.4). This provides a greater base line length to align the segments in the field. The normal procedure is to determine either a radial line or a line parallel to the bulkhead and establish this on the center of the segment with horizontal alignment hairpins set as far out on the segment wings as possible. This requires that this line be observable on the bridge, either from above or from the ground below. In the latter case, the line has to be scribed onto the end faces of the wings and two observation stations must be established on the ground on either side of the pier (Figure 8.1.3).

Precise setting and checking of the first erected segment is essential since any error in its position is magnified proportional to the ratio of the length of the cantilever or continuous run of segments, and the transverse base line width.

8.5 Field Survey Checking During Erection.

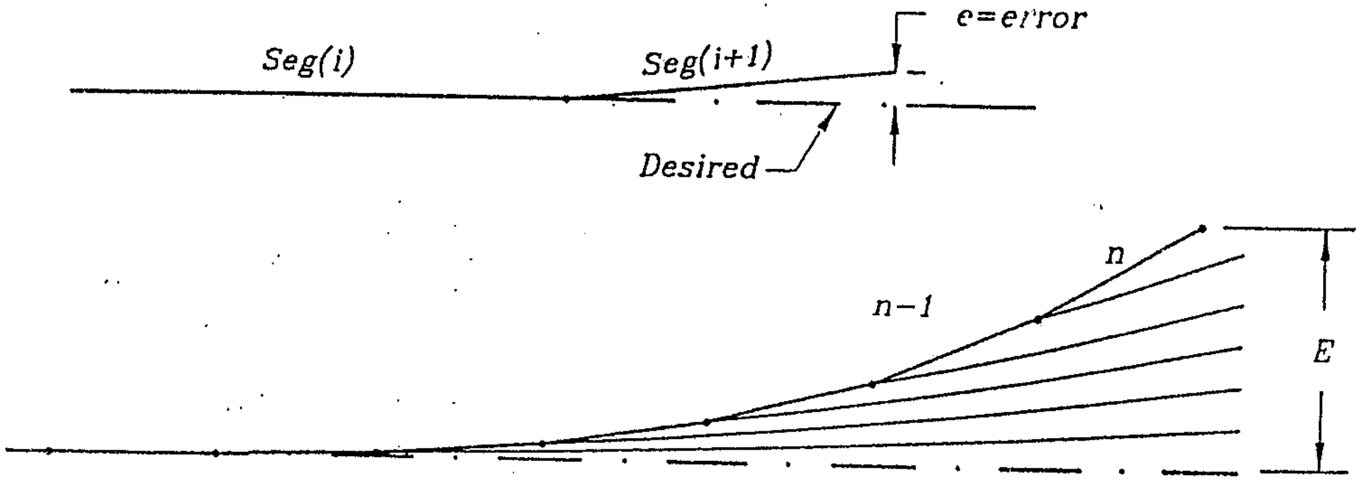
After the pier segment has been set and checked the horizontal and vertical alignment of successive segments must be checked as well. It is normal practice to calculate and measure elevations each time after four or six segments have been erected. The horizontal alignment is also checked and should match the theoretical horizontal geometry. The only errors occuring should be slight deviations due to casting errors and corrections. The overall line should closely track the desired line.

A generous tolerance should be allowed for the vertical alignment since this is subject to all kinds of variations due to construction loads, creep, shrinkage, temperature, post-tensioning variations and so on. However, the alignment should closely agree with the required alignment at the time of erection when duly corrected for these effects. It is difficult to put a precise figure on this tolerance as it depends upon the type of construction. For cantilever construction, the vertical alignment should generally be within one to two inch per cantilever length of 100 feet and similar cantilevers should behave comparably. (This latter point is a guide to the accuracy of the inital material assumptions and calculations).

Any substantial variations from line and level or any trends noticed early in the construction should be subject to close study and corrective action should be taken. The latter would include checking procedures for errors, especially systematic errors, amending casting curves for future segments and perhaps shimming the joints with glass fiber matting to adjust the alignments. The latter is a "last resort", since it causes stress concentration on the shims and prevents the joints from closing properly which will cause problems during grouting.

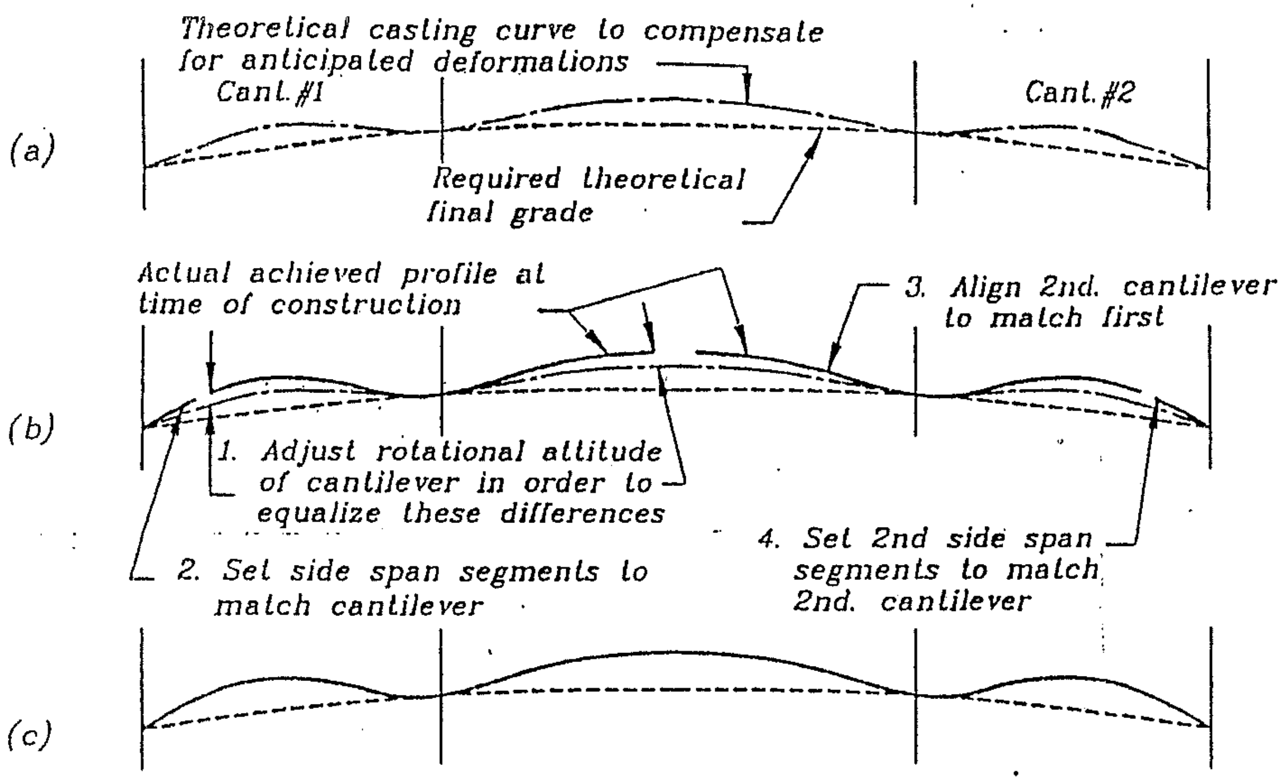
8.6 Systematic Error.

It is worthwhile giving some consideration to the implications of making a systematic error in each casting operation either as a result of a computational method error or as a physical defect of the equipment which is systematically repeated in each segment of a run. Figure 8.6 shows the effect which creates a total off line error many times the small systematic error (e). The final error after "n" segments amounts to n(n-1)e/2. In other words, a systematic error of .002 feet in each segment would amount to an off line



It can be shown that the effect of a small consistent error E, if continuously repeated, will accumulate to a total error of $E = \frac{n(n-1)e}{2} \approx \frac{n^2 e}{2}$ after "n" segments.

Fig. 8.6 Effect Of Accumulation Of Systematic Errors



Final profile at end of construction should match required theoretical casting curve (a). If it does not, then the difference at each cantilever should follow a uniform pattern and represent the difference between assumed conditions and actual conditions, especially material properties and constrution loadings. Any other differences are due to casting errors.

Fig. 8.7.1 Alignment Of Cantilever Structure (3 Spans) error of .1 feet after 10 segments and .4 feet after 20 segments. Clearly systematic errors must be avoided and the use of proven techniques should be encouraged.

8.7 Achieved Profiles.

Figures 8.7.1 and 8.7.2 illustrate the kinds of variations in cantilever and span-by-span profiles. Figures 8.7-3 and 8.7.4 show the means of correcting a profile by shimming a joint. It is emphasized that this should only be done if absolutely necessary as a last resort. It can lead to complications and is not entirely predictable.

8.8 Pier Shaft Segments.

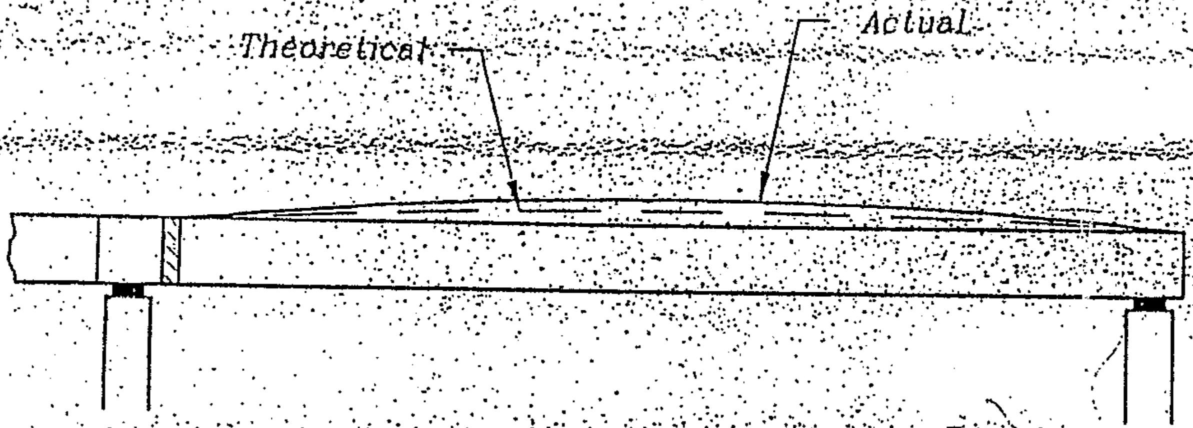
Figure 8.8 shows one technique of observations for the alignment control while casting precast pier shaft segments. Other methods are possible by using inserts, plumb lines, leveling bolts, etc.

8.9 Temperature Effects.

8.9.1 Temperature expansion and contraction.

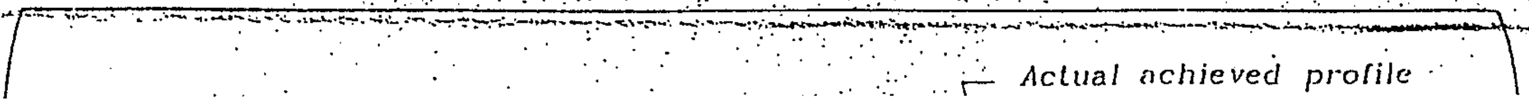
A rise or fall in temperature will cause a structure to become longer or shorter. Bearings and road joints are designed to accomodate this movement.

In some cases this temperature effect may cause problems during construction. Figure 8.9.1(a) for example shows a structure with a fixed pier in the center. After the cantilever on this fixed pier is erected a connection is made to the remainder of the structure. The connection should be able to pull the erected part of the structure over its bearings in order to take care of the temperature movement. If

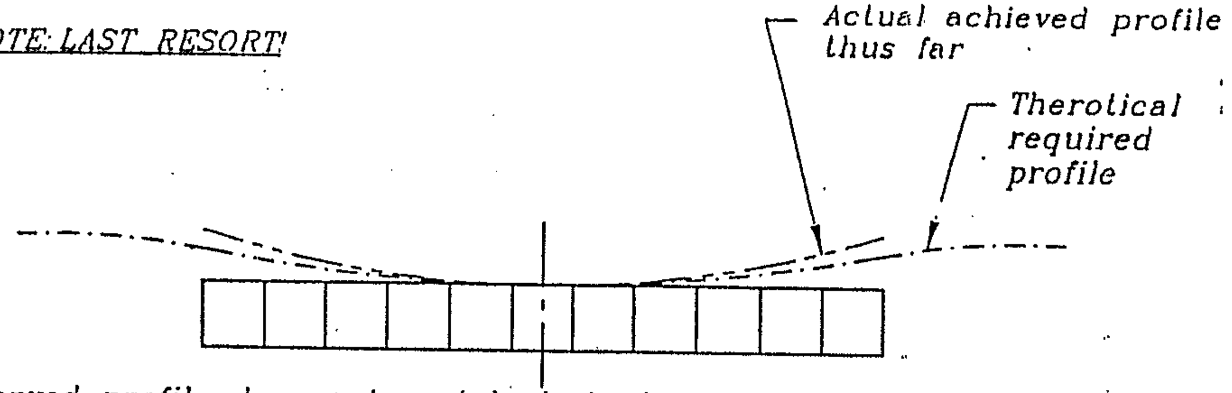


Span-by-span construction is less susceptible to casting curve and casting geometry discrepancies than cantilever construction because there are typically fewer segments per span (the spans are usually shorter and segments longer) and there is usually a closure joint in each span which permits some adjustment. Also, the structure is generally stiffer.

Fig. 8.7.2 Alignment of a Span-By-Span Structure



NOTE: LAST RESORT!



If observed profile does not match desired and if it is clear that they will continue to diverge, then some corrective action is possible by shimming the joints with woven glass fiber matting embedded in the epoxy. Usually the remaining cantilever segments have already been cast by this time making corrections by casting compensations impossible.

Shimming should be done only if absolutely necessary, and then it should be kept to a minimum because its effect is not predictable and the thicker joints can lead more easily to intrusions of epoxy into ducts, etc.

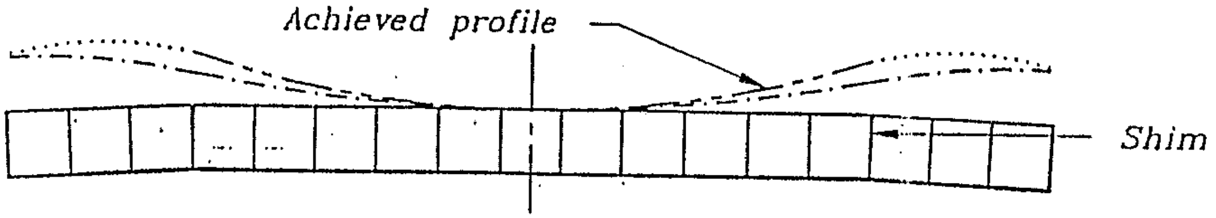
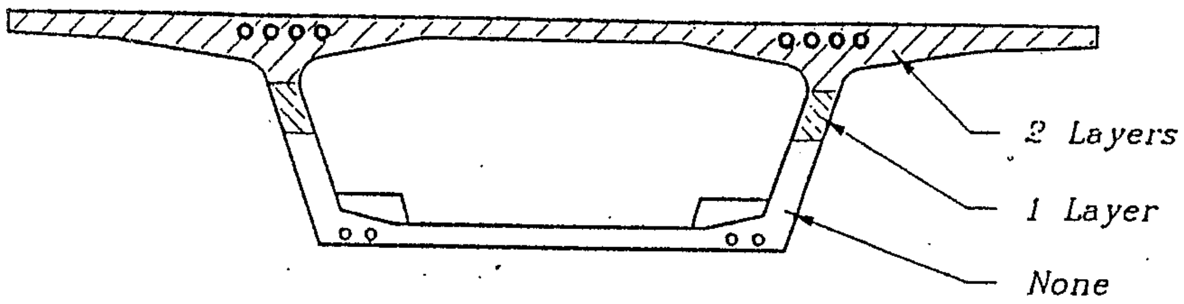


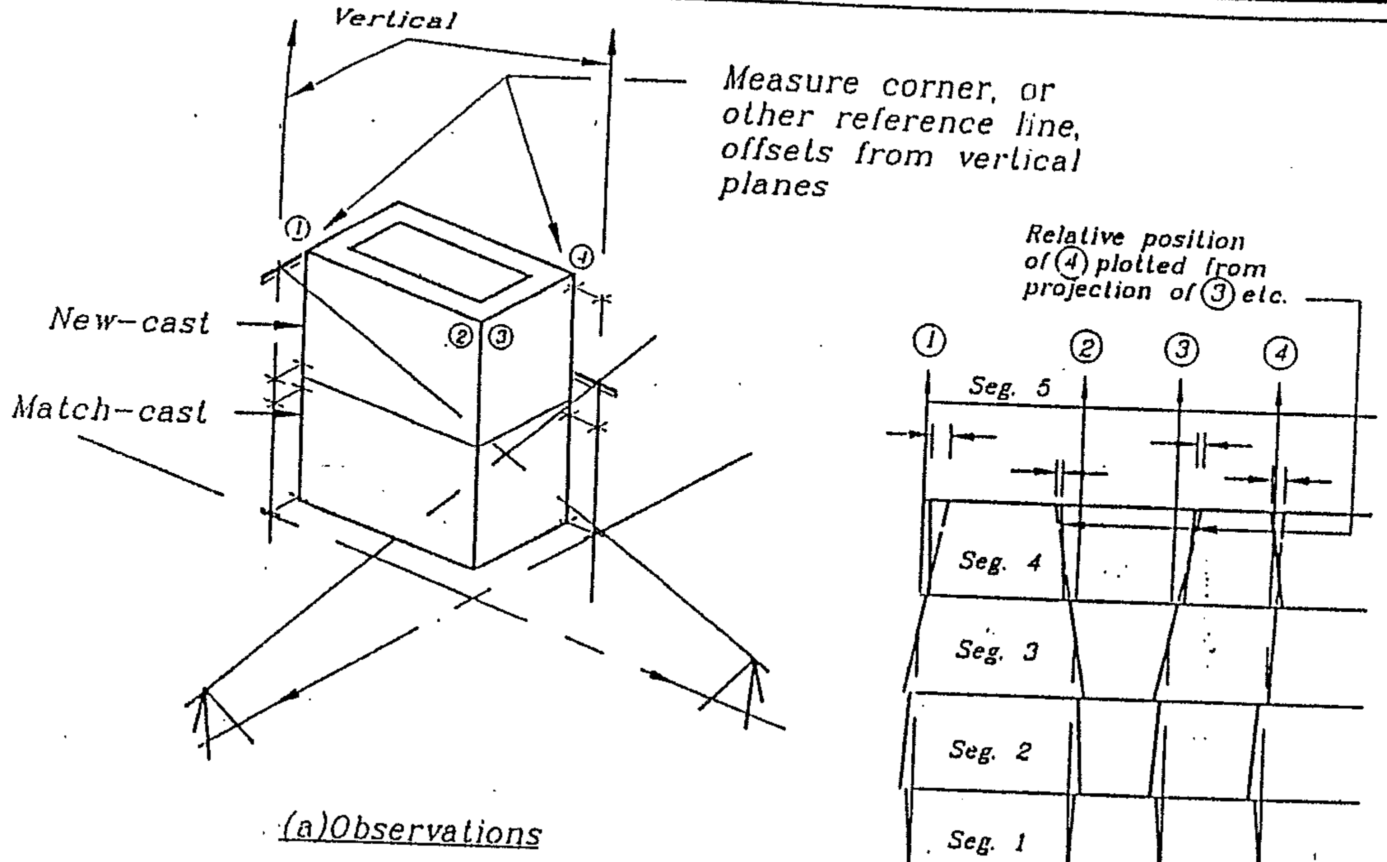
Fig. 8.7.3. Shimming Joints To Correct Profile



Shimming joint with woven glass fibre matting to provide wedge shaped joint to correct alignment.
It is recommended that no more than 2 layers maximum be used in any joint.
Layering as shown would tip next segments downwards.
To tip next segments upwards, shim from bottom.

Shimming joints may occasionally be necessary in cantilever construction.
It is never likely to be used in other segmental construction i.e. span-by-span.

Fig. 8.7.4 Shimming Joints to Correct Profile (contd.)



(a) Observations

(b) Graphical plot

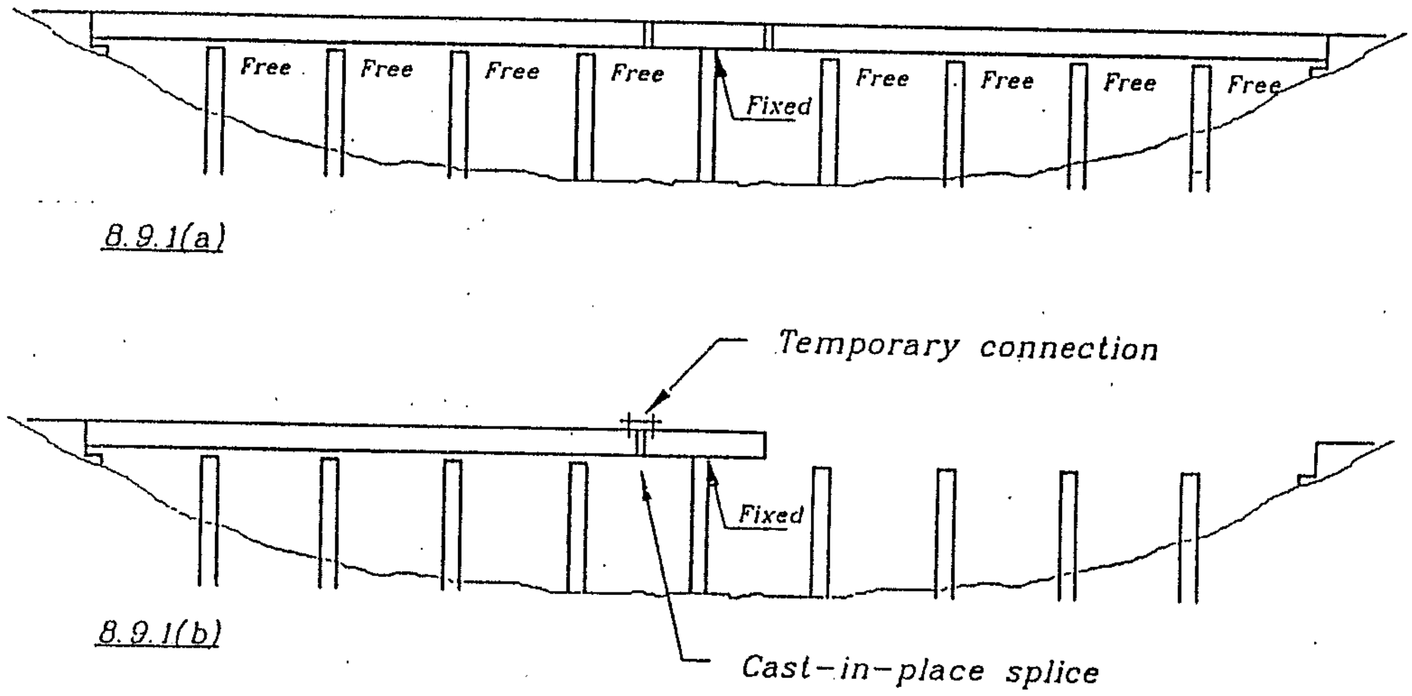
Fig. 8.8 Geometry Control For Precast Pier Shaft Segments the connection is not strong enough, the cast-in-place splice will crack (Figure 8.9.1(b)).

8.9.2 Temperature Gradient.

A temperature gradient or temperature differential exists when a part of the structure has a different temperature than another part. This commonly occurs when the top slab of the box girder, which is exposed to the sun, heats up faster then the webs and the bottom, which are not directly exposed. Temperature differences of 30-40 degrees Fahrenheit can easily occur. As a consequence of this temperature differential, the top slab wants to expand, but the bottom slab does not. As shown in Figure 8.9.2(b) a girder will camber due to this temperature effect if supported at the ends. In case of a free cantilever as shown in Figure 8.9.2(c) it can be seen that the tips of the cantilever deflect. The amount of movement noted in the field increases of course with the length of the cantilever. A 1 inch deflection, however, is common. Because of this effect it does not make sense to measure elevations any time after the structure has been exposed for some length of time to sun radiation. The only suitable time for measuring elevations during erection is at sunrise. The fact that the cantilever tips move as they are exposed to the daily temperature cycle also affects the timing of casting midspan splices. The best way to do this is:

(1) connect the cantilevers at the tip by means of a strong back, as shown in Figure 6.4.

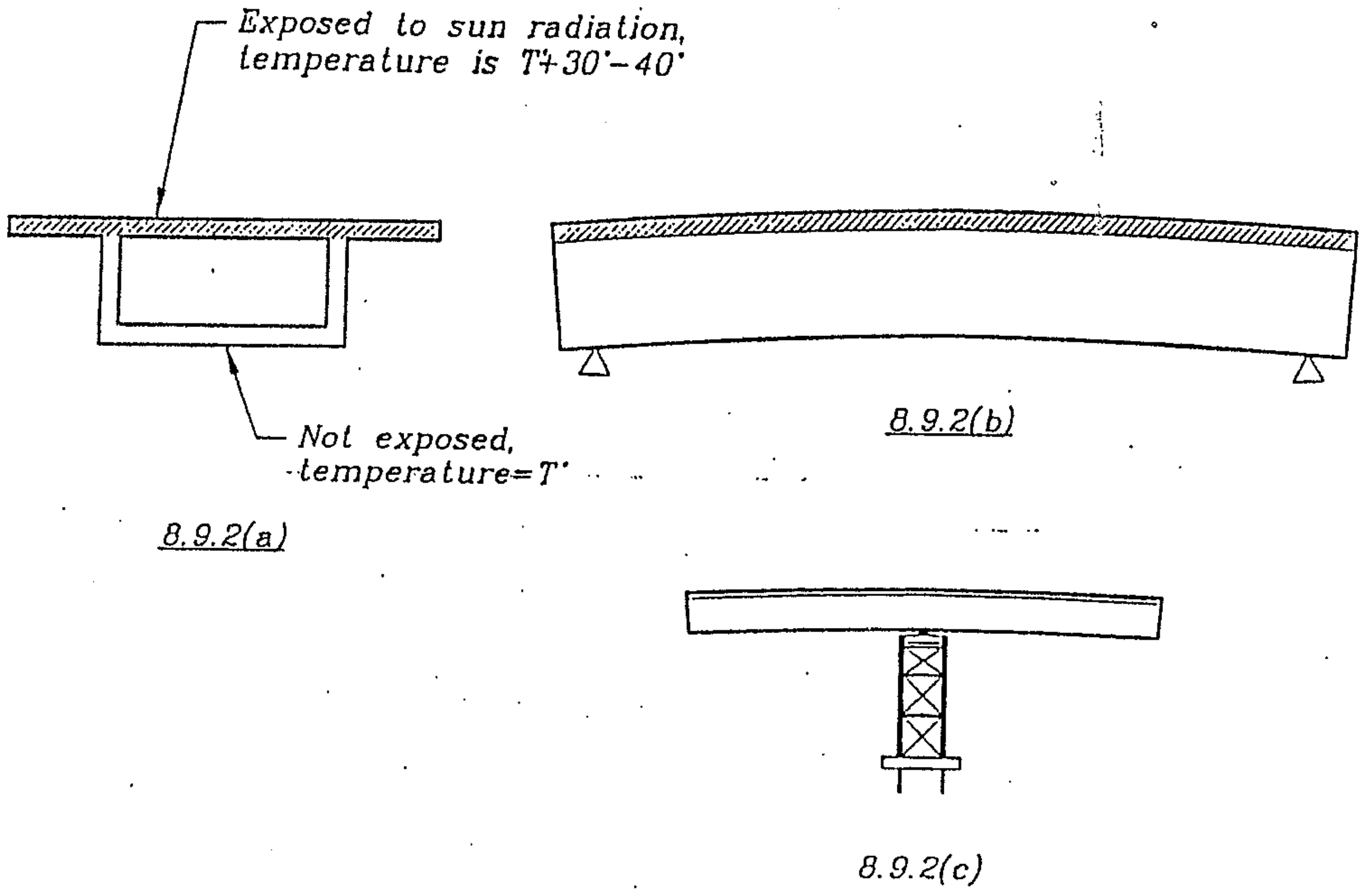
(2) cast the splice when the deflection at the cantilever ends is the greatest (say 3 p.m.).



8.9.1(a)

8.9.1(b)

Fig. 8.9.1 Temperature Expansion and Contraction

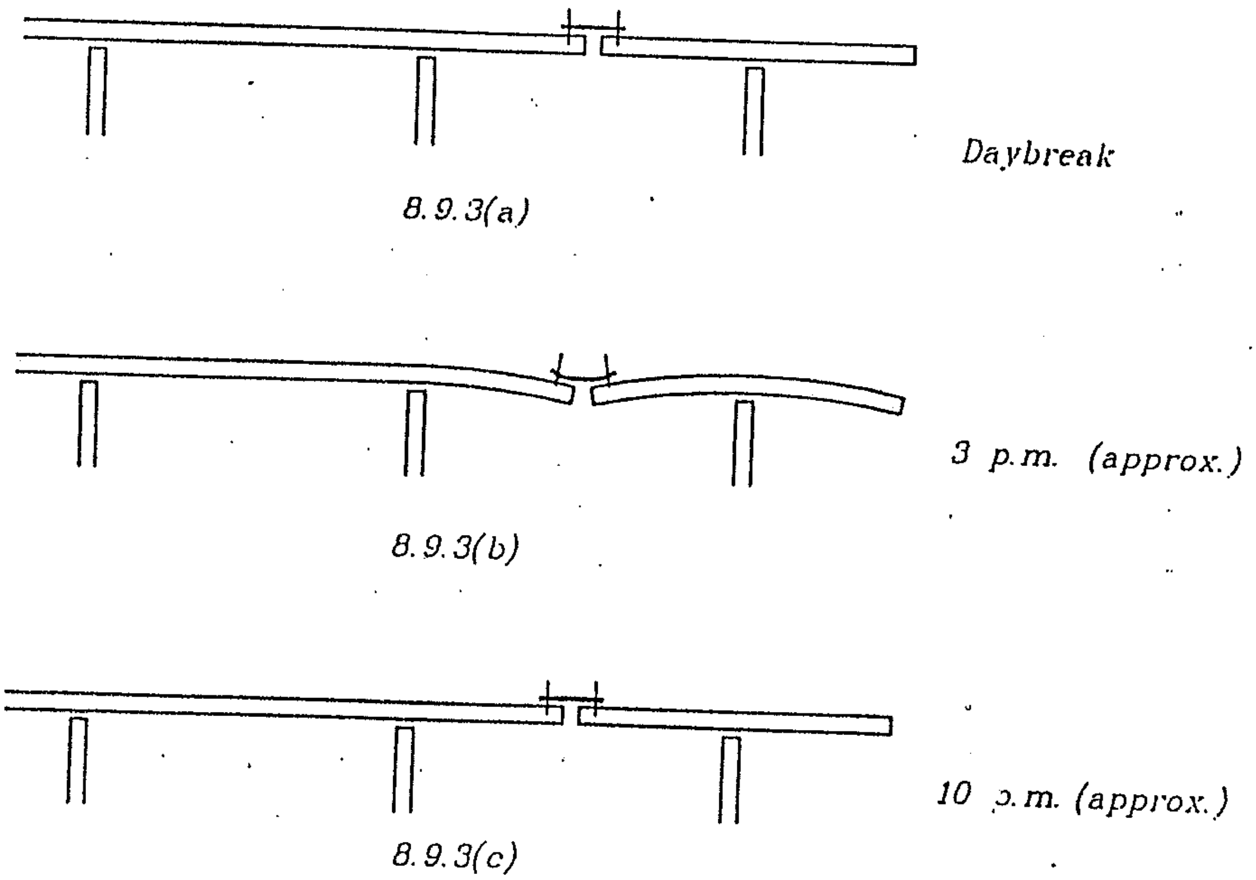


8.9.2(a)

8.9.2(b)

8.9.2(c)

Fig. 8.9.2 Temperature Gradient



8.9.3(a) Daybreak

8.9.3(b) 3 p.m. (approx.)

8.9.3(c) 10 p.m. (approx.)

Fig. 8.9.3 Deflection Caused by Temperature Gradient

(3) At sunrise the next day stress as many tendons as allowed by the strength of the "still green" concrete. Usually this is two or four tendons, which is enough to compress the splice so that the subsequent temperature deflection will not crack the concrete at the splice at the bottom.

If the splice were cast in the morning, it is obvious that the temperature effect will crack the bottom before the day is over.

9.0 BEARINGS AND ROAD JOINTS

Bearings and road joints are provided to allow the structure to expand and contract. In addition, bearings transfer the loads from the superstructure to the substructure. In general, bearings and road joints are the most vulnerable parts of a structure. Road joints are subject to much wear and tear by traffic and cause many maintenance problems.

Bearings and road joints are specified on the plans. Usually a drawing of the type of bearing or road joint required is included with the note that an "approved equal" may be substituted. In addition, special provisions should provide a detailed description regarding material quality and tolerances.

Since the product supplied is seldom equal to that shown on the plans, the contractor will submit shop drawings which will be provided to the inspector for his use in the field after they have been approved.

Upon delivery to the site the inspector needs to verify that the product is in agreement with the shop drawing and is properly installed.

9.1 Bearings.

There are two types of bearings commonly used on segmental bridge projects, namely, neoprene bearings with or without sliding pad and pot bearings.

Neoprene bearings are the more desirable bearings for their simplicity of installation and maintenance free performance, However, both load bearing and movement capacity limit the application to short spans and short distances between expansion joints. Neoprene bearings with sliding pads have more movement capability and therefore allow longer distances between expansion joints (see Figure 9.1(a) and (b)).

Pot bearings are available for large loads and movements and this is therefore the type of bearing most used. Pot bearings consist of a base plate containing a rubber cushion inside a low cylinder or ring which allows a small rotation in the base plate. This is the reason for the name "pot" bearing. The top plate rests on a piston which rests on the rubber cushion inside the cylinder. Since this rubber disc is under high pressure, a seal is required to prevent the rubber from squeezing out of the "pot". The top plate can have one of three arrangements either allowing or preventing movement; namely, fixed, free, and guided. A typical fixed bearing which does not allow movement, a free bearing, and a guided bearing are shown schematically in Figure 9.1(c).

Bearings are usually bolted down to the pier and have dowels at the top to provide horizontal fixity to the structure.

9.1.1 Bearing installation.

Important items for bearing installation are:

- Mortar pads below and above the bearings
- Horizontal position of bearings
- Temperature adjustment
- Direction of the movement of the bearing

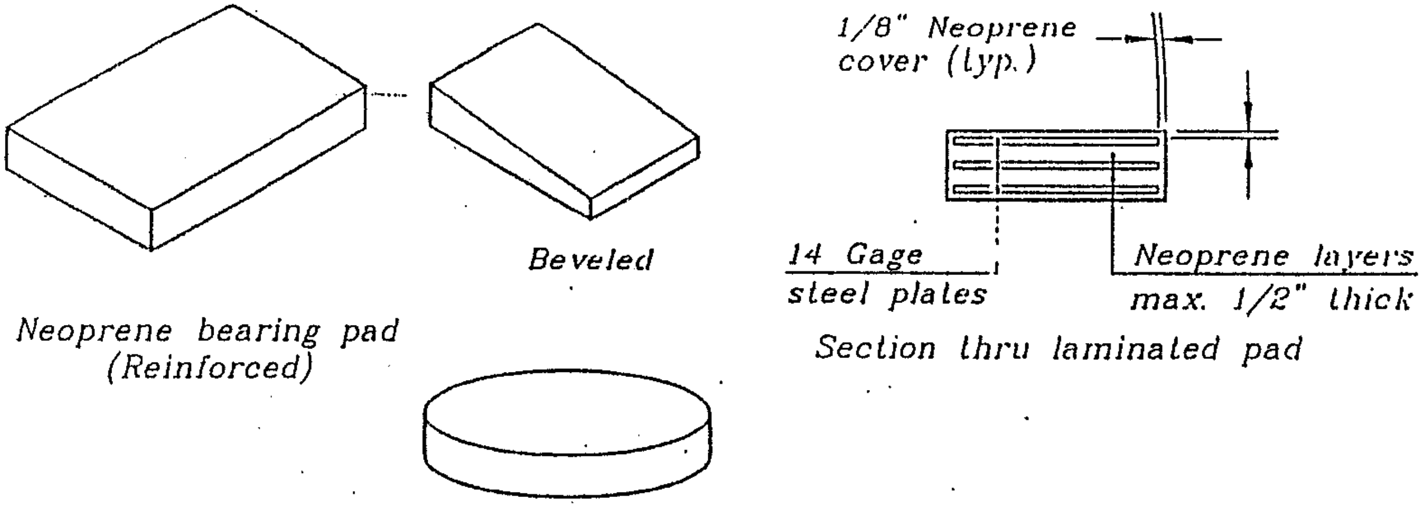


Fig. 9.1(a)

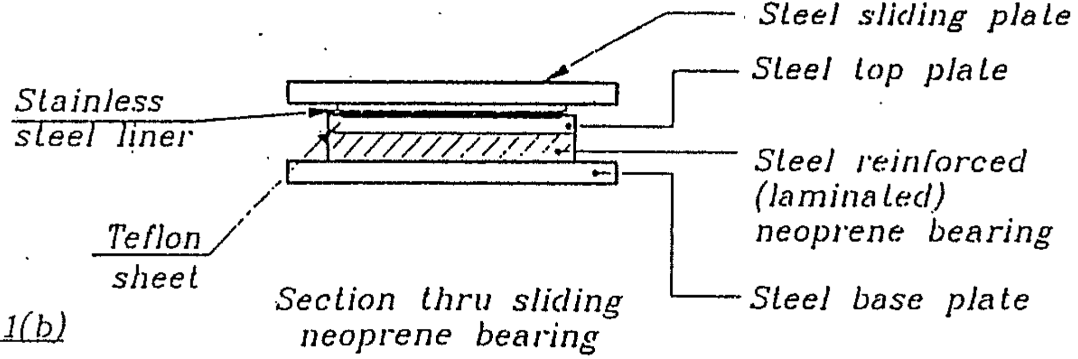


Fig. 9.1(b)

Fig. 9.1 Neoprene Bearings

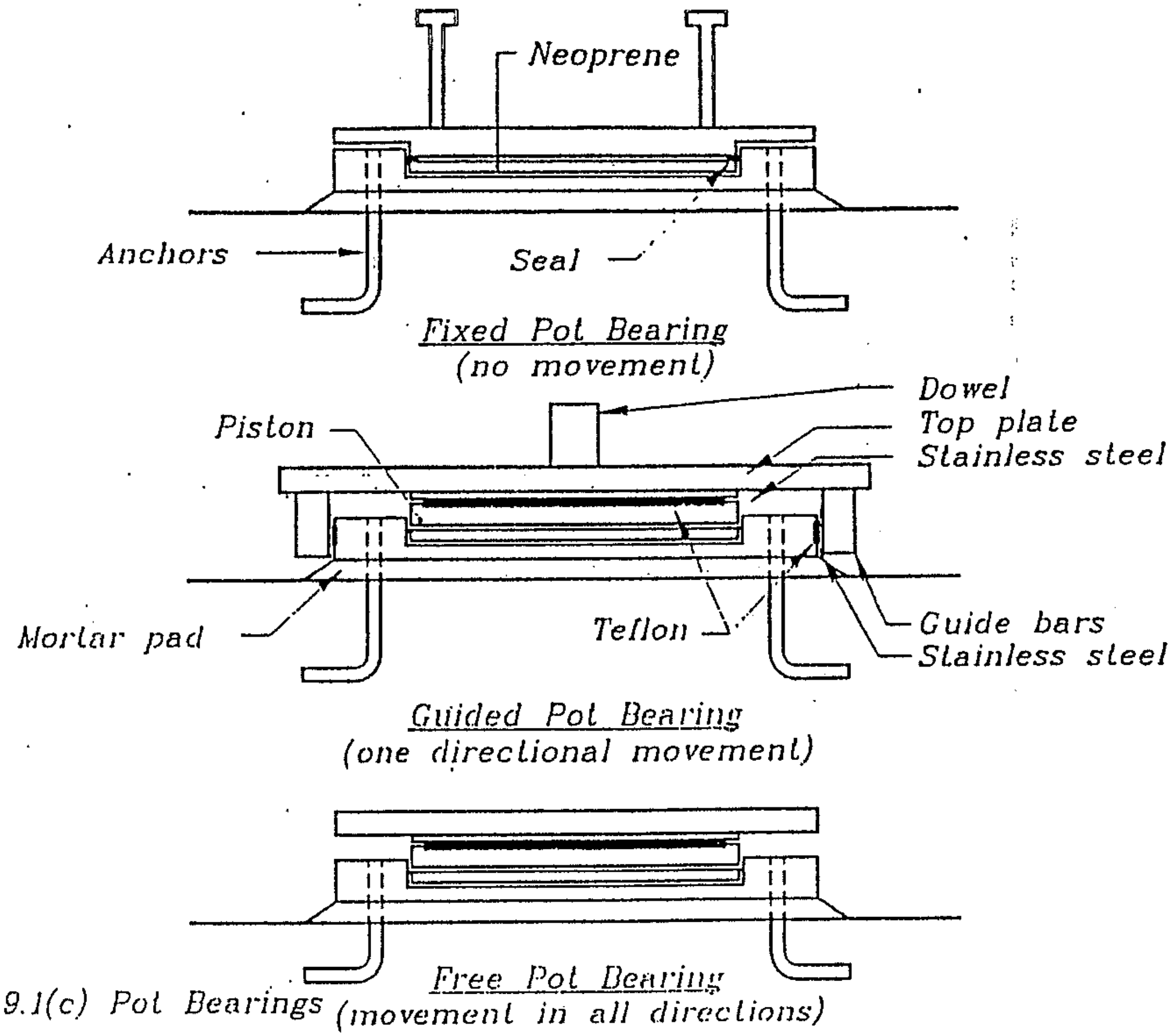


Fig. 9.1(c) Pot Bearings

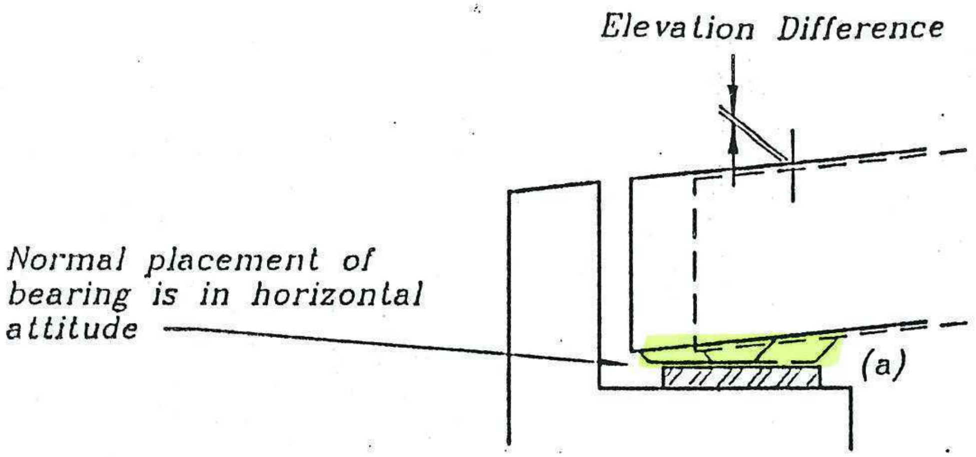
9.1.2 Mortar Pads

Bearings transmit heavy loads from the superstructure to the substructure. This means that the substructure and superstructure concrete on both sides of the bearings is highly stressed.

Both neoprene and pot bearings are usually installed with mortar pads both below and above the bearing. The reason for this is that neither the top of the pier nor the bottom of the structure can be built with a small enough tolerance to allow installation without these. The materials used for these mortar pads are usually specialty mixes which have high early strength and low shrinkage properties. The material is subject to approval. The mortar strength required when used with Neoprene pads is 3000-4000 psi while 41.5 N/mm² 6000 psi is common when used with pot bearings. Most importantly, the mortar pad should provide uniform bearing under and above the bearing and should therefore be without voids. This requires both good workmanship and inspection. Specifically in case of poured or grouted joints a full scale test of the grout placing procedures is recommended.

9.1.3 Horizontal Position of Bearings.

Bearings are usually installed horizontally. The reason is, that a structure placed on bearings which are installed on a slope has the tendency to move (see Figure 9.1.3(a)). An exception to this would be bearings at end bents of long sloped bridges which have a lot of movement. In such a case the movement should be in the direction of the slope in order to prevent an elevation difference at the joint which would cause high impact forces on the road joint. However, this is a special case, the details of which should be carefully noted on the plans (Figure 9.1.3(b)).



However, in cases of very large movements and longitudinal slope of deck a horizontal bearing (a) leads to elevation differences at the road joint. Consideration should be given to place the bearing on the same slope as the roadway surface (b).

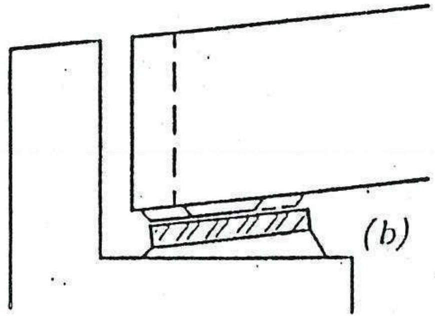


Fig. 9.1.3 Horizontal Bearing Position.

9.1.4 Temperature Adjustment.

At the time of installation, pot bearings should also be adjusted for the temperature of installation. The designer of the bridge assumes installation at the average ambient temperature and calculates how much the bridge will expand or contract and, therefore, how much the bearing will need to be able to move either way. If, contrary to the assumption the bearing is installed in for example the coldest possible time of year, it can be expected that the bridge will just expand when the temperature rises. In this case, the bearing top plate will need to be shifted so that the full temperature movement becomes available for expansion. This explains why there usually is a need for a temperature adjustment.

9.1.5 Direction of Movement.

Guided pot bearings, which allow movement in one direction only, need to be installed in such a way that the direction of the movement of the bearing is the same as the direction of the movement of the bridge. In case of straight bridges, this is the bridge axis. In case of curved bridges, however, this is not necessarily so and an instruction should be provided on the plans regarding the direction of movement. There usually is some tolerance on the movement direction because of the fact that the space between guide bars is usually about 1/8 inch larger than the top plate of the bearing sliding between it. This amount can also be specified.

This 1/8 inch space should be carefully divided into two equal amounts on each side of the top plate and preferably kept constant with wooden inserts until the bearing is placed. The guides now have some movement capabilities both ways and some tolerance to turn.

9.2 Expansion Joints.

Adjustments as discussed for bearings must also be made for expansion joints. The types of expansion joints used on segmental bridges are:

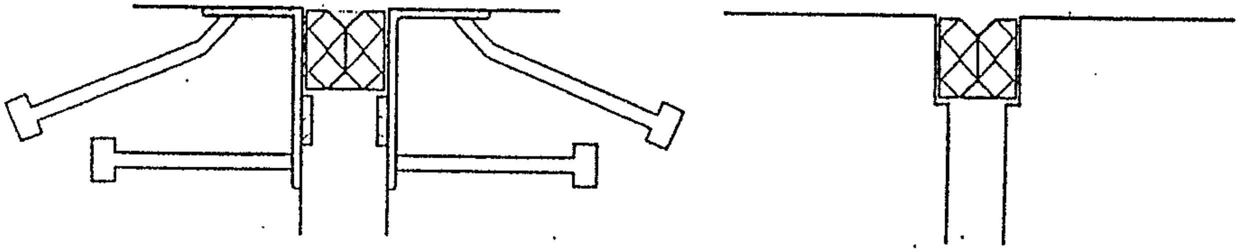
- Compression seals, for movements up to 3 inches
- Transflex joints, for movements up to 13 inches
- Modular joints, for movements up to 15 inches
- Finger joints, for movements up to 12 inches

9.2.1 Compression Seals.

A compression seal is shown in Figure 9.2.1.

This type of seal is economical and effective for small movements. It consists of a durable neoprene extraction that will be installed under compression. The amount of compression at installation is determined in such a way that at a maximum opening, the seal is still compressed. In addition, the seal is glued to the joint faces. In order to facilitate placement under compression, the glue also acts as a lubricant. From this it follows that the compression seal is also "adjusted" for ambient temperature by varying the amount of precompression at the time of installation. Since there is a limit to the amount the seals can be precompressed by the installation tools, there is also a maximum installation temperature beyond which the joint cannot be installed. In this case, the installation needs to wait until temperatures are lower.

The advantages of this joint are that there are no movable parts, the joint is cost effective and has low maintenance. The only disadvantage is that the application is limited to short distances between expansion joints.



Armored Block Out

Non Armored Block Out

Fig. 9.2.1 Compression Seal

9.2.2 Transflex Joints.

The transflex joint is shown in Figure 9.2.2.

This is a popular joint, the advantage of which is that it is suitable for fairly large movements (13 inches total capacity) and does not have movable parts. Another advantage of the joint is that it does not require a large recess for installation. Disadvantages are that the joint cannot be adjusted for installation at other than median temperatures and therefore requires oversizing of the joint. Also, the force required for opening and closing the joint is substantial. It takes for example about 2000 pounds per foot to provide maximum opening of the larger joints. For the normal bridge width of 42 feet, this means a horizontal force of about 40 tons at the top of the abutment back wall. This requires special design of the end bent, and consequently the transflex joint cannot be substituted for other joints without end bent redesign.

9.2.3 Modular Joints.

A typical modular joint is shown in Figure 9.2.3.

The term modular joint is used for mechanical joints which allow large movements (approximately 15 inches). The structural and sealing function of the joints are separated by attaching neoprene profiles, which make the joint watertight, to structural steel or aluminum extrusions which carry the traffic loads. These extrusions in turn are supported by support beams which transfer the traffic loads to the concrete and also provide the expansion capability. Efforts by the industry to provide a joint which performs under the continuous impacts by wheel loads have resulted in very sophisticated products incorporating a great number of different parts such as neoprene and steel sections, sliding

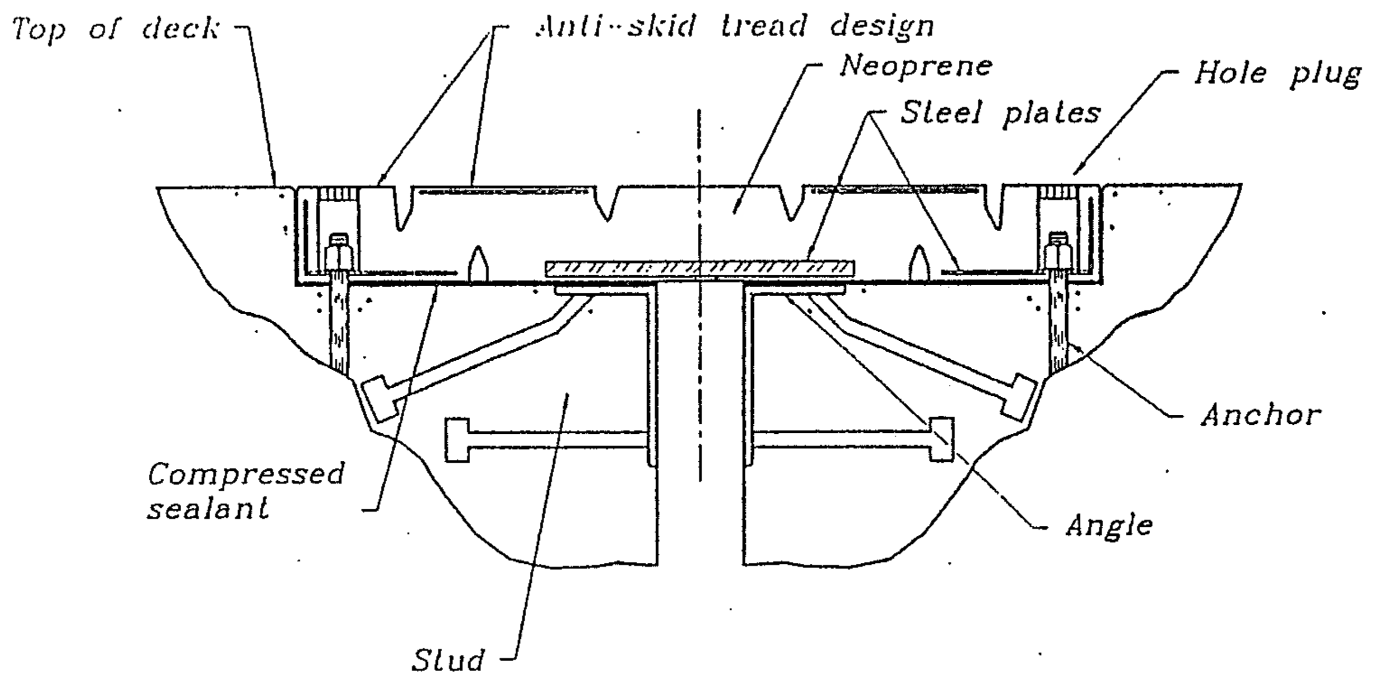


Fig. 9.2.2 Transflex Joint

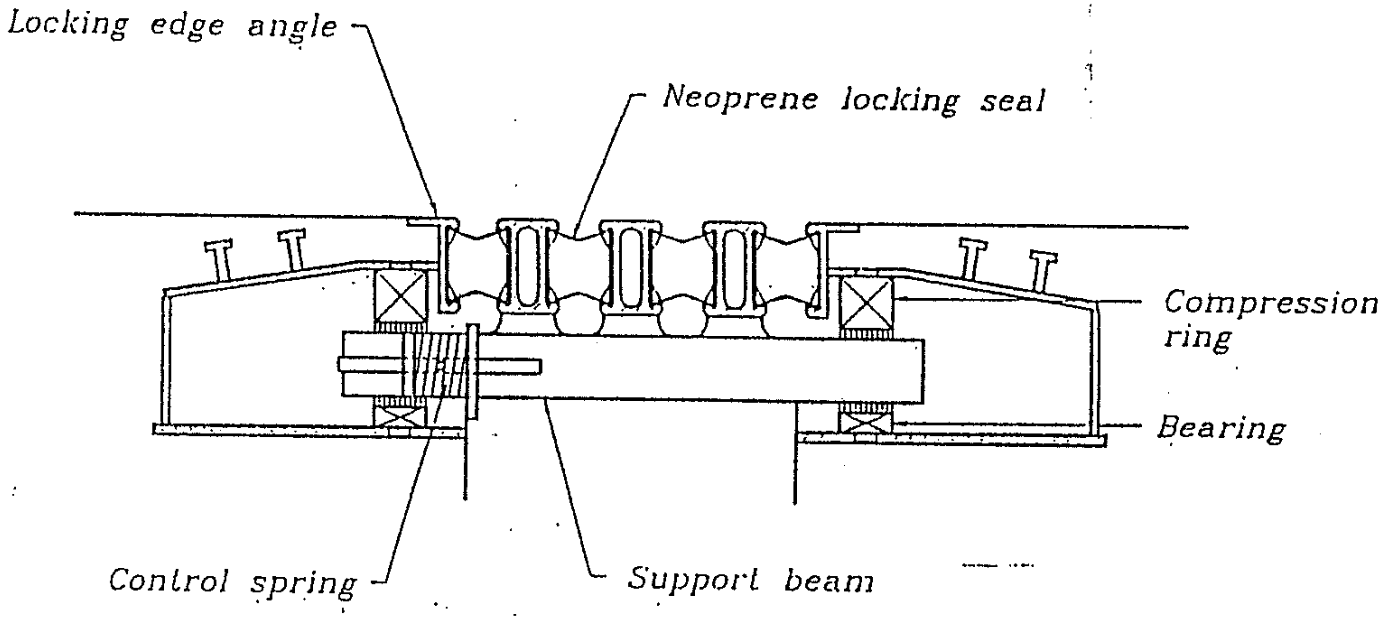


Fig. 9.2.3 Modular Joint

pads, springs, dampers, fasteners, etc. This makes the joints rather expensive, both to buy and to install, and they are not maintenance free.

Installation should occur preferably by, but certainly under supervision of, the manufacturer. The joints are suitable for large movements allowing up to 2500 foot sections of bridge to be built without expansion joints. They are fully adjustable for installation temperatures other than the median temperature used for sizing the joints.

9.2.4 Finger Joints.

A typical finger joint is shown in Figure 9.2.4.

A finger joint is a type of joint which consists of two steel plates, one attached to the bridge, and the other to the end bent. The fingers of the steel plates allow the joint to open and close freely while the traffic continues to be carried. Finger joints have a separate arrangement to seal the joint. Usually this is a neoprene sheet firmly attached to the end bent and bridge.

Finger joints of special design are marketed in the United States or are custom designed for certain projects. Careful installation is usually required emphasizing the load-bearing material under the joint and the direction of the movement. The direction of movement is particularly important since the design of the fingers usually leaves little tolerance or room for error. The advantage of this type of joint is that there are no movable parts. The principal disadvantage is that the water tight seal or trough is difficult to keep clean.

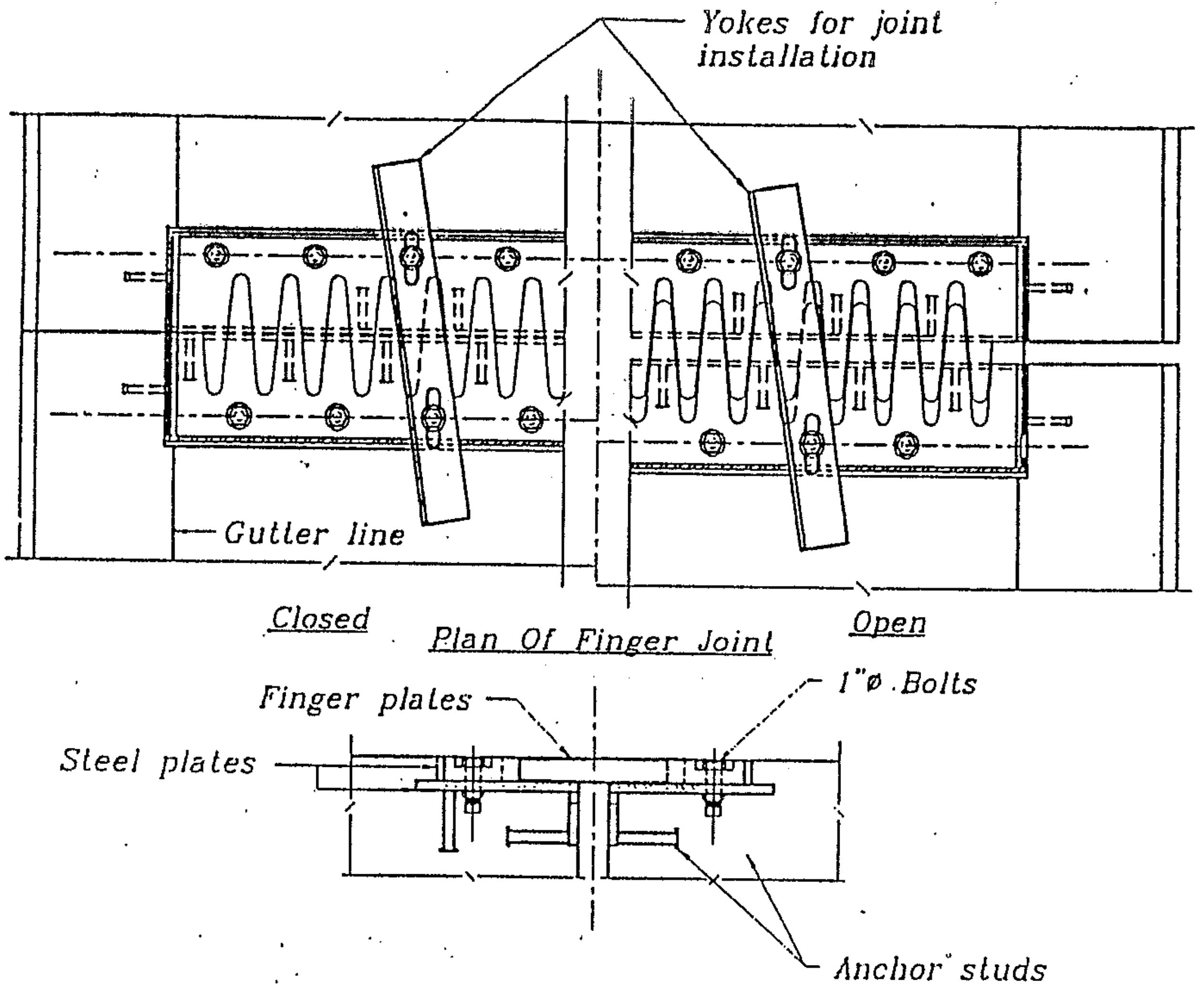


Fig. 9.2.4 Finger Joint

10.0 FREQUENTLY OCCURRING TECHNICAL PROBLEMS.

10.1 <u>Epoxy Not Setting.</u>

This has occurred on a number of projects. The cause has usually been traced back to careless mixing of the two components. Other causes, however, are possible.

The consequence of soft epoxy is that the shear keys will have to transfer all the design shear from one segment to the next. Normally the shear keys are not designed for this and, in the event soft epoxy is noted, an engineering check must be carried out. In the top slab there are normally only a few keys which should prevent vertical displacement of the joint faces in respect of each other; but, on the other hand, there may be a lot of tendons which act as dowels. Each case will have different circumstances.

Remedies are:

(1) Good quality control on the mixing. It helps to color the hardener differently from the resin so that proper mixing can be checked visually.

(2) After soft epoxy has been noted, the cause established, and an engineering review indicates that keys across the joint are adequate (which they may well be), no further structural repair is required.

(3) The material in the joint should be tested in order to find out if there may be a problem with the durability.

10.2 Construction Overloads.

Several failures have occurred during construction which were caused by construction overloads. In normal balanced cantilever erection where segments are placed by crane, such events have not occurred for the simple reason that heavy loads are usually not placed on the cantilever.

This is different, however, when heavy equipment is used for erection. For example, launching girders have been used just a few times in the Country; but on two occasions, serious accidents have occurred which, by sheer luck, did not take lives.

In both cases the structural analysis of the equipment, though made very thoroughly, did not address sufficiently the interaction of the equipment and the structure. It also appeared that personnel operating the equipment did not thoroughly understand it because of complicated operating procedures.

When dealing with situations where heavy equipment operates on structures it is important that:

- An engineering analysis is prepared showing that the operations are safe.
- Operating instructions should be prepared which can be understood by all (paint the spot for the crane on the bridge! physically limit the boom!).
- Pay attention to the shop drawings for all load carrying temporary work such as strutting, falsework, etc. and enforce them as if they were a final product.

10.3 Poor Reinforcing Details.

Poor reinforcing details are a common cause for problems, especially during construction of the first few segments.

- There is a 1 inch tolerance on most bar dimensions. Bars which should fit a certain dimension exactly should therefore not be used. Instead, use a bar with a lap splice which can always be made to fit.
- Bars with small variations should not be used. If the iron worker cannot see the difference between 2 types of bars, he'll mix them.
- Crossing bars take up the space of 2 diameters. It is not uncommon to find that the number of bars provided by design can't be made to fit because this fact was overlooked.
- Reinforcing bars and tendons should be integrated to avoid conflicts.
- Standard curves and bends in bars take up space. The thicker the bar, the larger the space. Typical bars should be detailed on a large scale to verify that the standard bends will fit.

10.4 Alignment Problems.

Alignment problems have occurred on several projects with sometimes a very poor alignment of the completed bridge as a result. The only way to prevent this is quality control both during production as well as erection.

- The contractor's casting curves and geometry control procedure must be meticulously reviewed.
- The contractor must implement the geometry control, however, his readings and set up calculations should be independently checked.

- The position of the instrument; target and form bulkhead, which are all supposed to be at fixed positions, should be checked frequently using independent bench marks.
- The contractor should provide erection elevations and horizontal alignment controls which are to be used during erection in order to check whether or not the correct alignment will be obtained.

10.5 Freezing of Water in Ducts and Recess Pockets.

In spite of the common knowledge in the industry of the expansion effect of water when it freezes, many projects show the signs of neglect to take neccessary precautions.

(1) Grout tendons and recess pockets, if possible, before the onset of frost. Note that grout can itself freeze and that it does not help to grout when it freezes or at low temperatures.

(2) If recess pockets are to be filled with grout during the grouting of tendons, ensure that the pocket is indeed filled.

(3) If certain tendons and/or anchor pockets cannot be grouted, they must be emptied of water

- By providing drains. If drains were provided, check that they function.
- By displacing the water with compressed air. Note that high air pressure can itself be a cause for fracture.
- Fill ducts with antifreeze.

(4) If ducts are to be left ungrouted for a long period of time, corrosion of the tendon must be addressed as well.

10.6 Fit of Match Cast Segments.

In general match cast surfaces will always fit perfectly upon assembly, but there are a few logical exceptions.

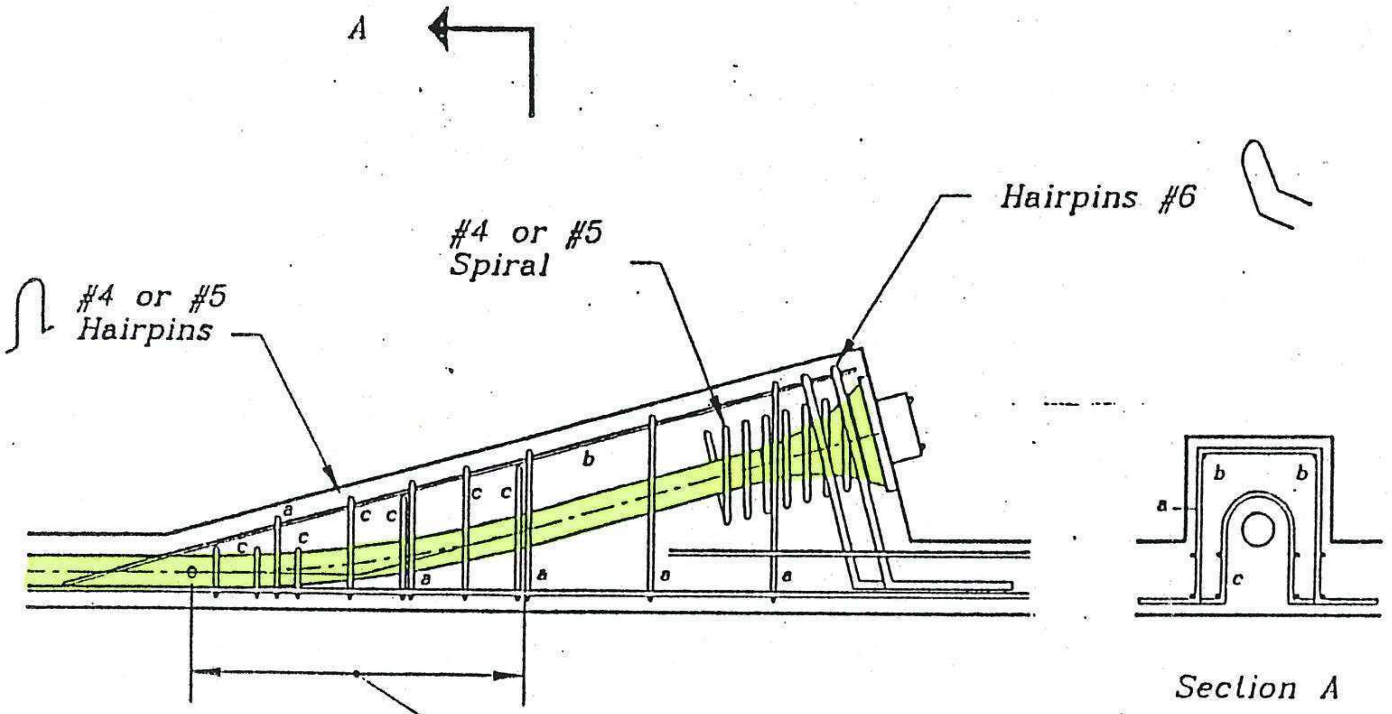
(1) If the surfaces were changed after they were taken apart, they will not match. Such changes can be:

- Excessive sandblasting.
- Repair of surface defects (for example a broken key).
- Epoxy grouted cracks.

(2) If the section were deformed, transverse prestress will, for example, camber the top slab. Normally this camber is quite consistent but there are situations where the camber is different due to differences in the slab or in the post-tensioning (for example the segment adjacent to a pier segment). Normally the shear keys in the slabs will even out the differences in camber.

10.7 Blister Failure.

A blister is a protrusion from the concrete used for placing a post-tensioning anchor. Figure 10.7.1 shows a type of blister often used. The tendon, located in the slab, curves into the blister. In the curved area the tendon exerts an upward pressure which is resisted by reinforcing. If the blister is constructed correctly, it will not fail. An often made mistake, however, is to kink rather than curve the duct thus concentrating the upward force on one point rather than distributing it. Care should also be taken that the curve is started in the blister and not in the slab.



Curved part of tendon must be located in blister. Hairpin reinforcing concentrated in curve of tendon length.

Fig. 10.7.1 Blister for Tendon Anchorage

10.8 Tendon Pop-Out.

As mentioned in 10.7 prestressing tendons exert outward pressures in areas where they are curved or kinked. In case the curvature is by design, the designer will provide reinforcing to contain the tendon. As is the case with the blister of 10.7, however, mistakes can be made during construction which can cause tendon pop-out. Figure 10.8.1 shows a slab which contains a tendon which is supposed to be straight. Due to insufficient support, however, the tendon sagged in between the joints thus creating a possiblity for tendon pop-out, delaminations or bending cracks.

Figure 10.8.2 shows two curved tendons, side by side. In case of small tendons, adequate distance between the tendons, a large radius of curvature, and properly compacted concrete in-between the ducts, no problems need arise. However, during construction both the distance as well as the concrete quality between the ducts can be made to be less then intended. As a consequence of this, duct "b" can be pressed into duct "a", spalling the concrete and causing a problem with the stressing of the tendon in duct "a".

10.9 Deck Delamination.

Deck delamination may occur in areas of the deck or bottom slab where a great many ducts are placed close together, thus leaving only a relatively small area of concrete in the line AB of Figure 10.9.1. This concrete can crack for a variety of reasons, namely:

- High compression exerted by the tendons.
- Ducts which are not straight and exert pressure square on the slab.
- Pressure exerted by the grout pumps while grouting the ducts.

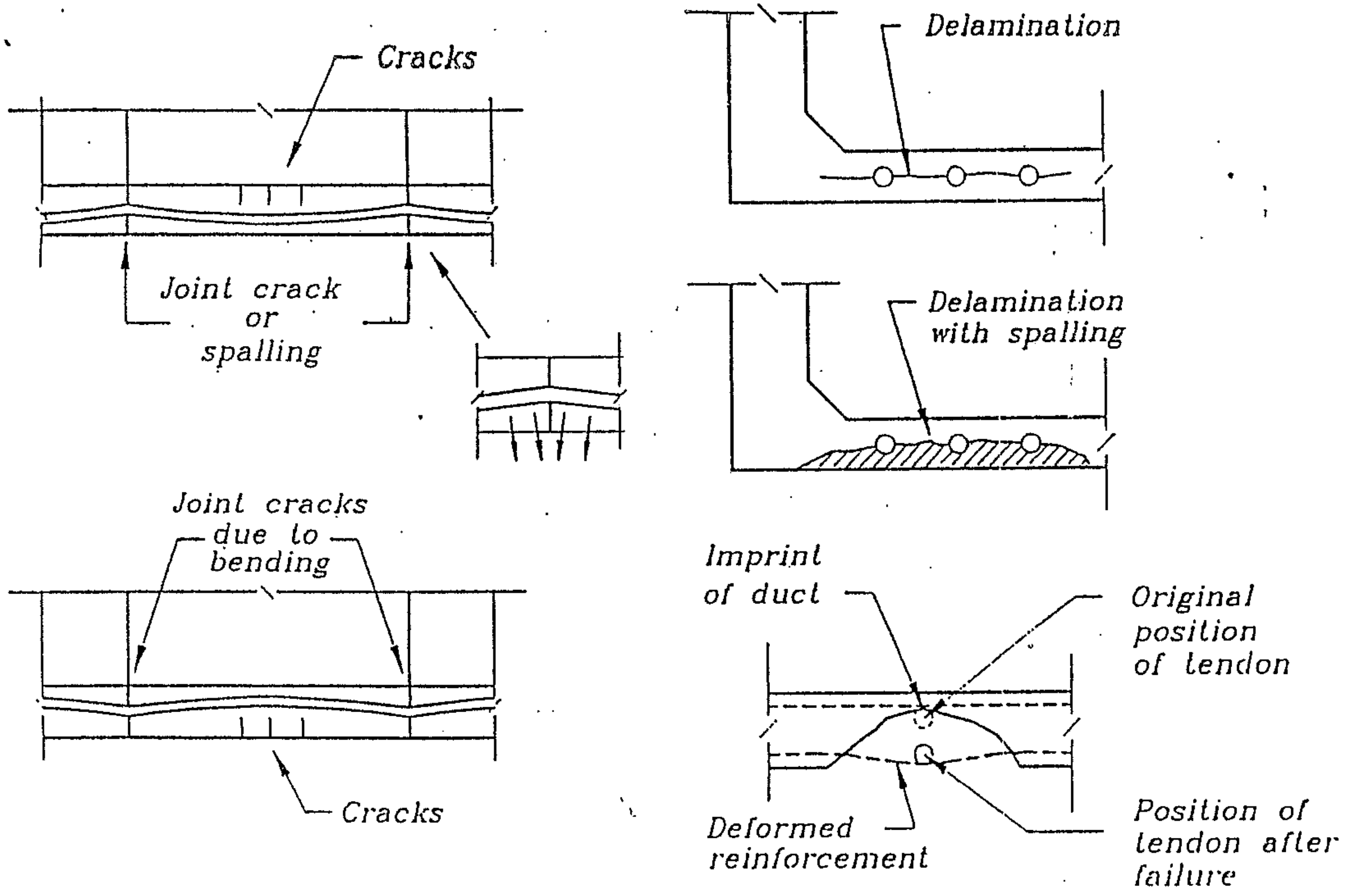
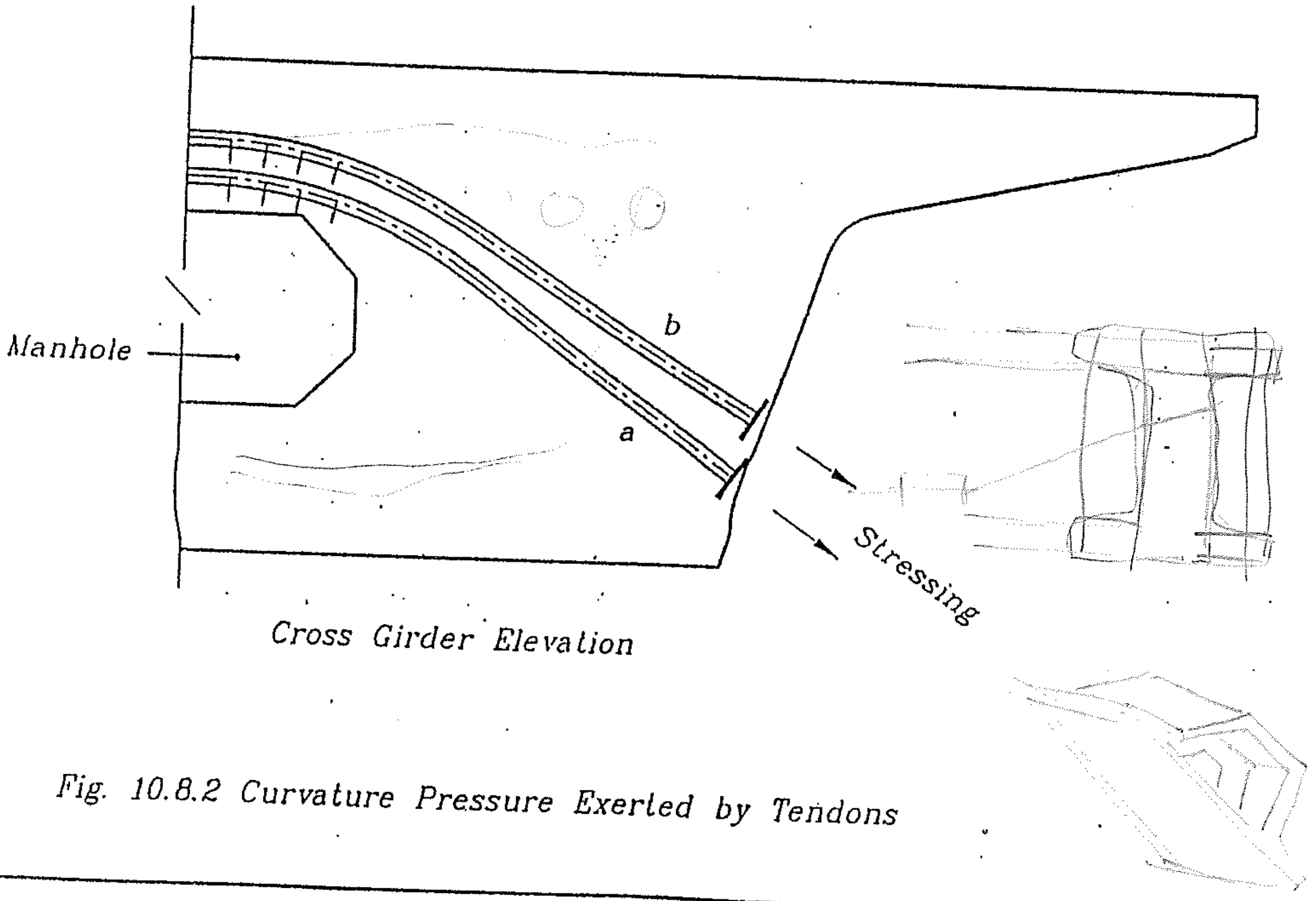


Fig 10.8.1 Effects of Misalignment of Tendon Ducts



Cross Girder Elevation

Fig. 10.8.2 Curvature Pressure Exerted by Tendons

The type of delamination along the line A–B is generally caused by spacing the ducts too closely. A min. space of 2 inches should be kept in between the ducts.

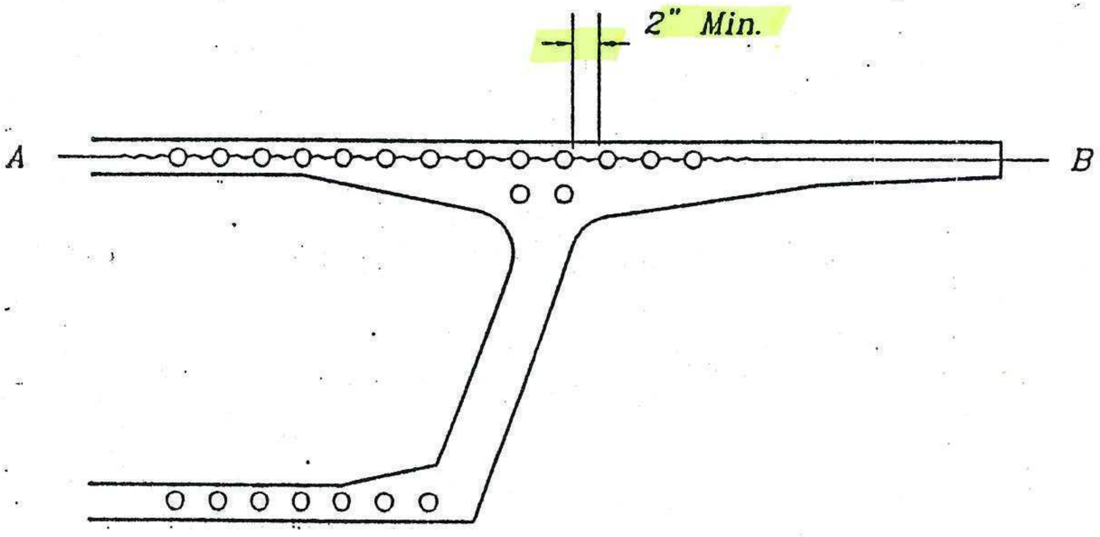


Fig. 10.9.1 Deck Delamination

Deck delamination can be noticed by, for example, pulling an iron chain over the deck and listening for changes in the sound. Deck delamination should be repaired.

10.10 Cracking.

Cracking occurs often in concrete structures for a variety of reasons. This may not be important but when noticed, should always be reported to the engineer so that the cause may be determined. Some common causes of cracking are:

- Cracks due to pouring new concrete against old concrete.
- Cracks due to the introduction of high forces for example at post-tensioning blisters.
- Cracks near post-tensioning anchors.
- Cracks caused by structural defects.

Figure 10.10.1 shows the situation where new concrete is cast against old concrete. This, of course, occurs at every cast-in-place joint. Cracks as shown may appear. These are shrinkage cracks which are difficult to avoid. In order to control the cracking, the designer may provide some additional reinforcing steel or transverse post-tensioning.

Figure 10.10.2 shows a crack pattern, which is sometimes noticed at points where high forces are introduced into the concrete. In this case this is a post-tensioning anchor acting on a blister. Note that the designer can, by selecting the type of prestressing tendon correctly and also by selecting the location of the blister properly entirely eliminate this type of cracking.

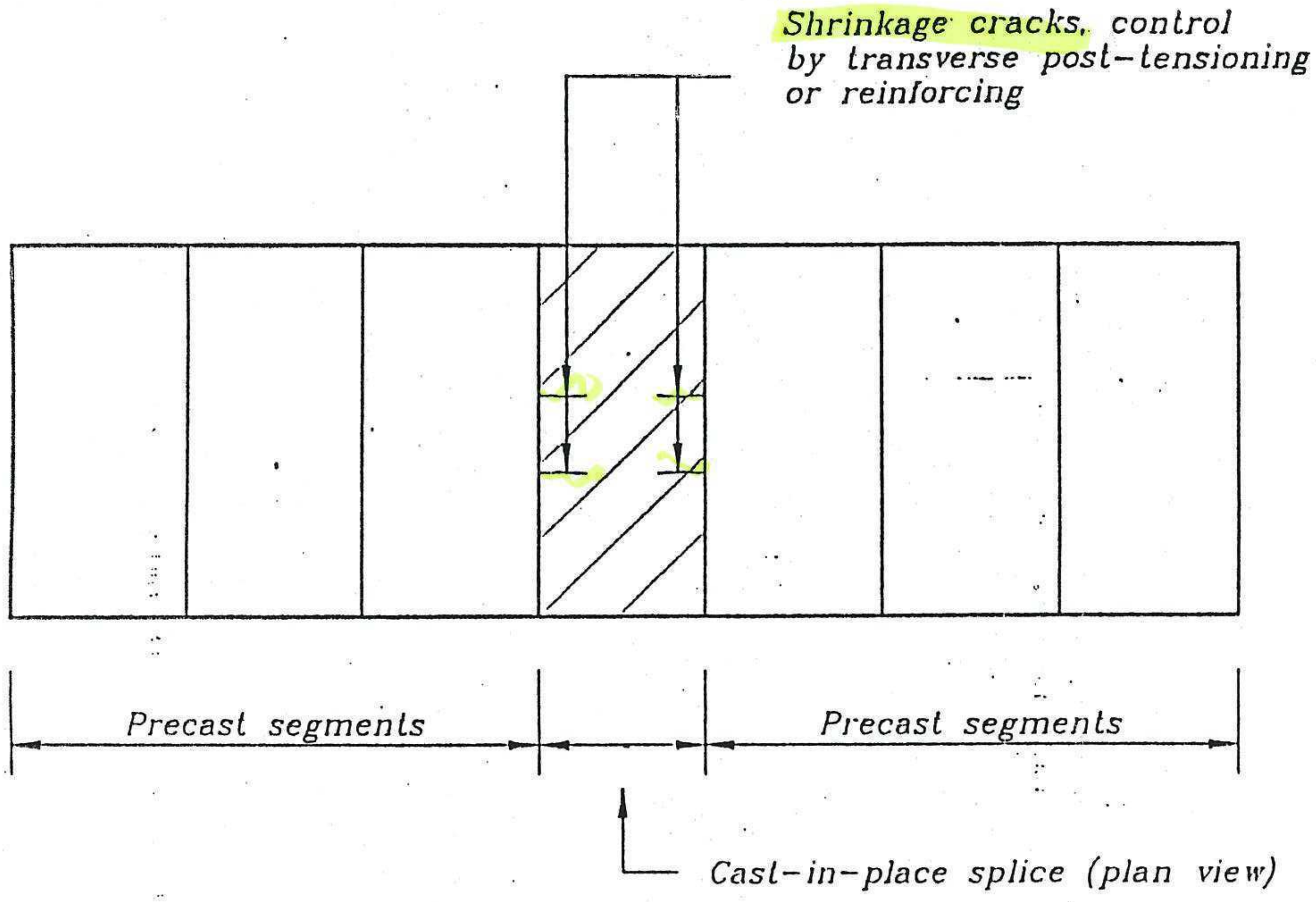
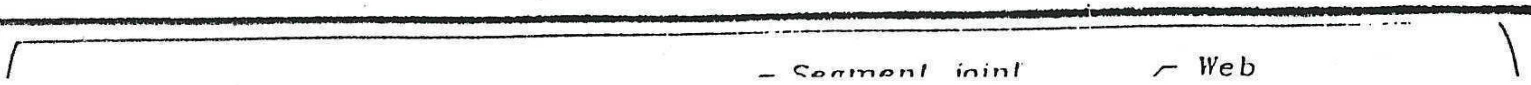
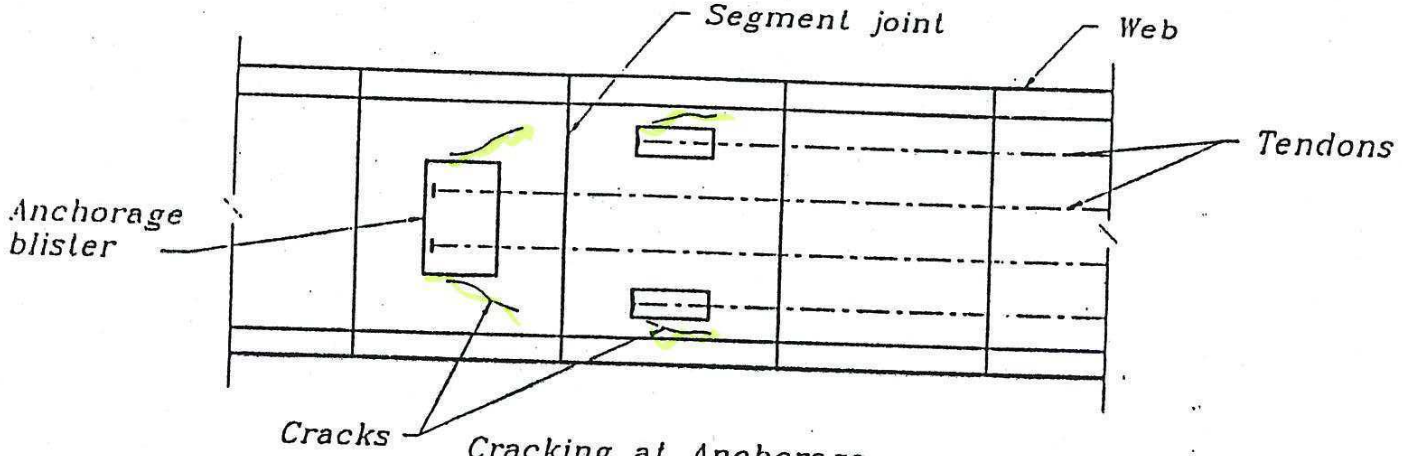
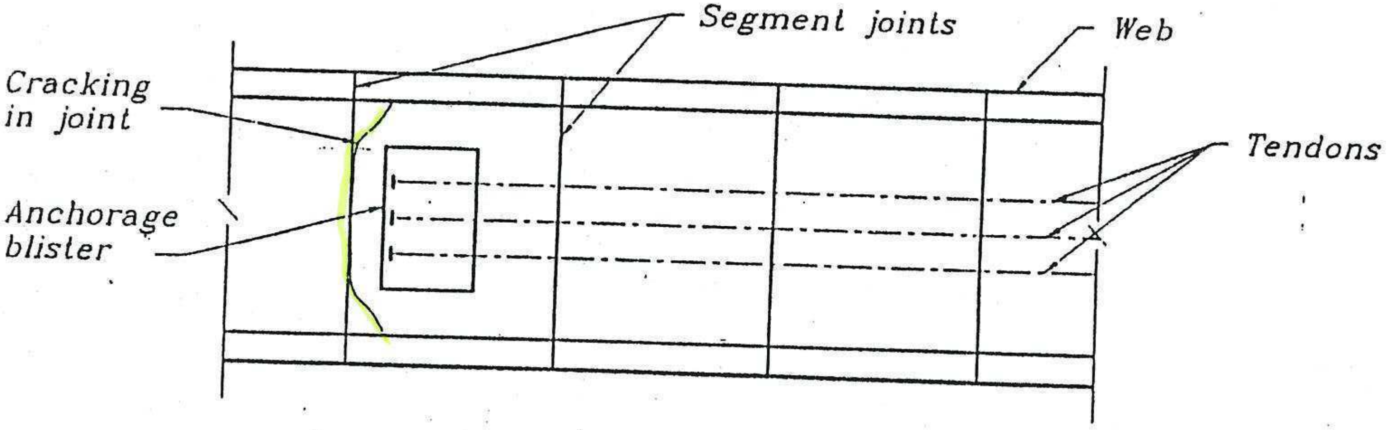


Fig. 10.10.1 Cracking due to Shrinkage





Cracking at Anchorage



Cracking behind Anchorage

Fig. 10.10.2 Cracking near Anchorage

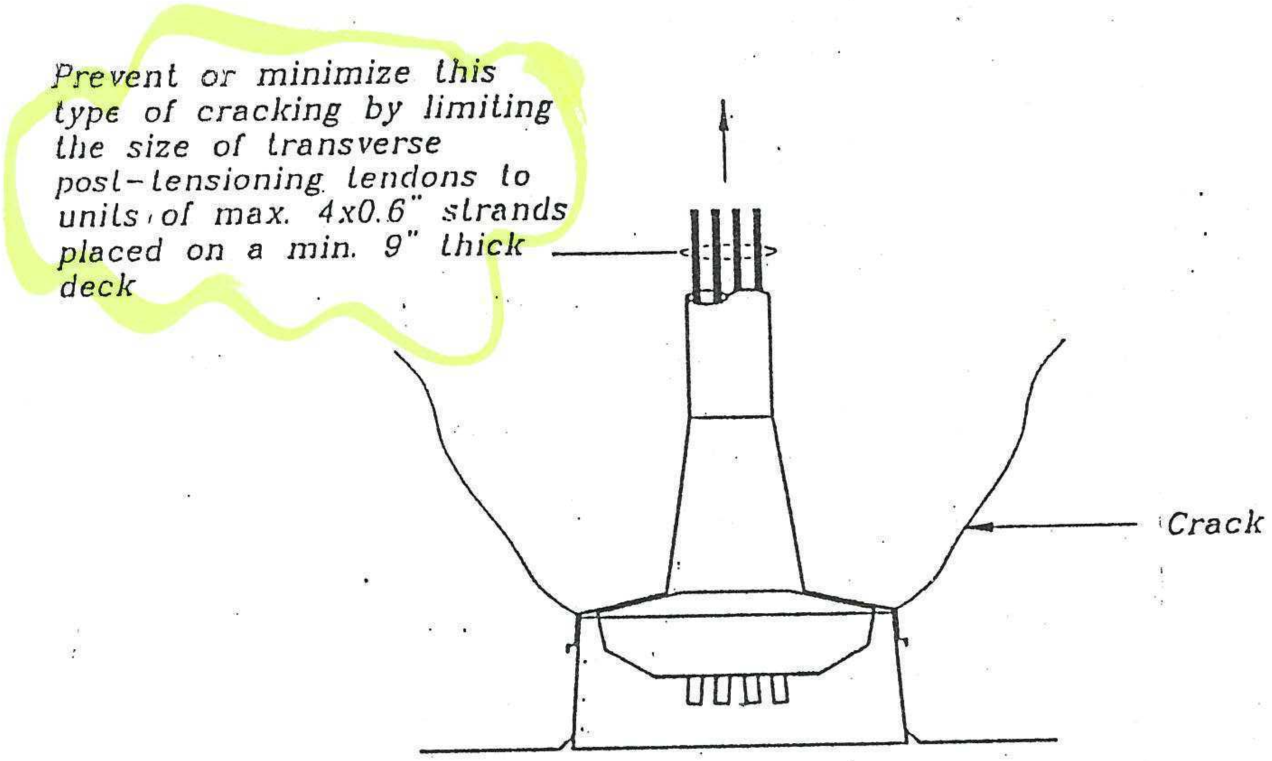


Fig. 10.10.3 Cracking at Transverse Post-Tensioning Anchorage

Figure 10.10.3 shows cracking at a post-tensioning anchor. Particularly anchors placed on the edges of thin slabs are very susceptible to cracking. This occurs often at the anchors of transverse post-tensioning tendons. Tendon sizes should not be larger than 4x.6 inch diameter strands on a 9 inch thick edge.

10.11 Honeycombing.

Flaws in the casting and vibrating of concrete will cause unintended voids in the concrete which become apparent after removal of the forms. Voids such as these are usually referred to as honeycombing.

Most honeycombing is repairable. Repairs should, however, not be undertaken without approval of the Engineer.

All projects having substantial quantities of concrete structure to be made will, at one time or another, have to deal with the repair of honeycombing. It is prudent, therefore, to have an approved procedure for such repairs.

The approved repair procedure should address the following:

(1) Repair of Voids (honeycombing)

- o The appearance of the repair. This concerns color and surface finishing. Since most repairs are darker than the surrounding concrete, it is best to make trial mixes of the mortars proposed for repairs at the time of approval so that color differences can be judged. These trial mixes should be made <u>before</u> they are needed.

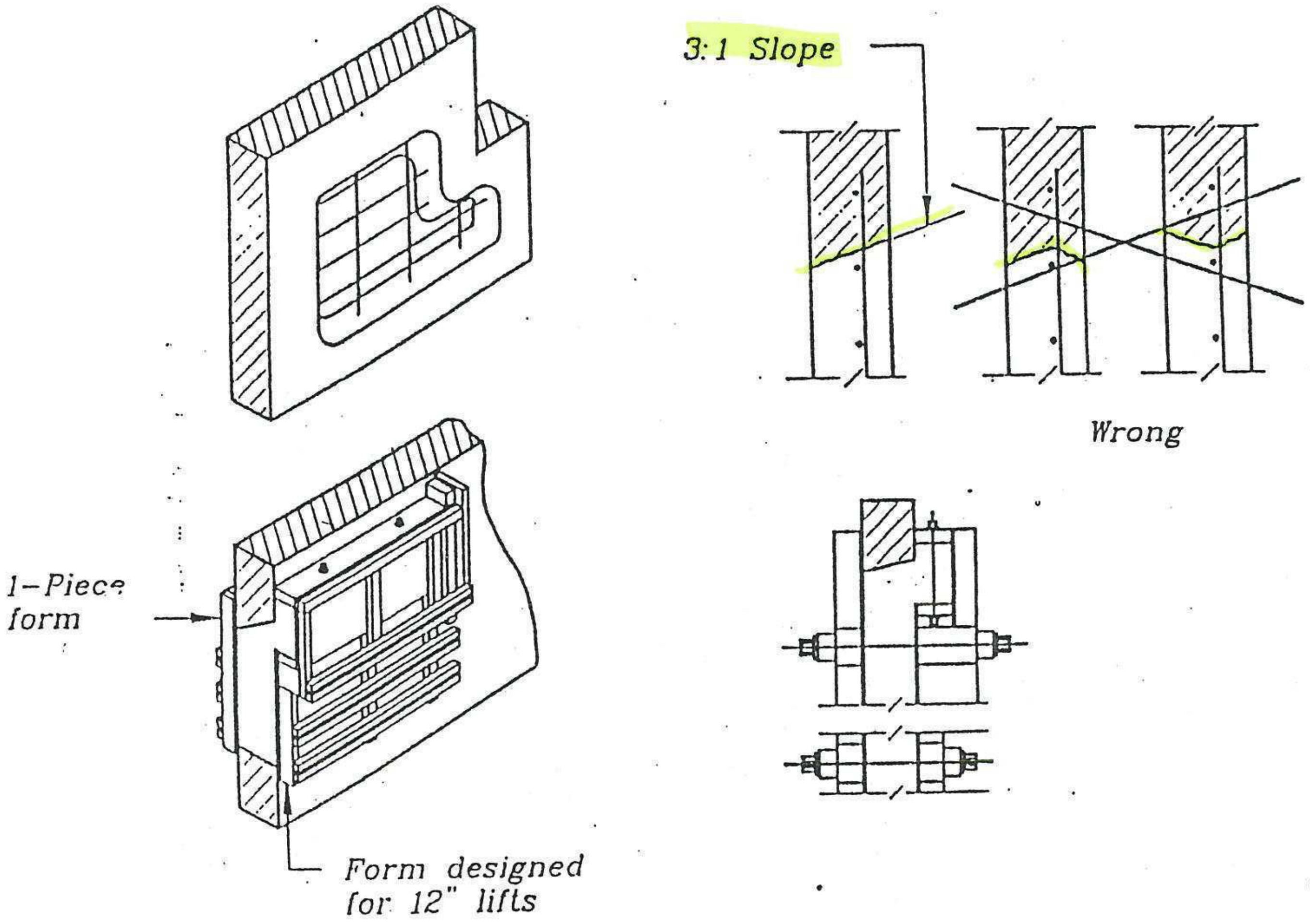


Fig. 10.11 Repair of Honeycombed Area

- Required skills. Much skill is required for making good looking repairs. Part of the procedure submitted by the contractor should be names and qualifications of the person(s) making the repairs.
- Durability of the repairs. The durability is determined by the quality of the repair material and the bond of the repair material to the old concrete. Bond is determined by surface preparation, type of bonding agent and method of filling the void. The different types of voids require different treatment. Figure 10.11 shows, for example, a hole in the web. This can be effectively repaired, more so than, for example, surface damage.

Other issues to be addressed are curing and shrinkage of the repair.

- Structural adequacy. Segmental box girders are often over-designed. $40 N/mm^2$ The high concrete strength of 5500 $38 N/mm^2$ - 6000 psi is only needed in the support area (bottom slab and webs) and in post-tensioning anchor zones. In other areas it ensures a high quality and durable product. Therefore, more often than not, repairs should be judged by their durability rather than by structural adequacy. Structural adequacy however is generally assured by the composition of the repair mix. This mix should have adequate strength, and it should be a concrete mix. This means that it should depend on cement and not on an epoxy resin or similar material for strength. Epoxy materials are strong but also more elastic than concrete and therefore do not always perform the intended structural function.

(2) Epoxy Injection.

Most smaller voids and cracks over a certain size are repaired by epoxy injection. This is specialty work and an approved repair procedure should address:

- Qualifications of the subcontractor. There are a number of specialized firms who all have their own products. The proposal for the injection procedure should include the range of products offered and their chemical and physical properties so that an engineering judgment can be made about their suitability.
- Size of openings to be injected. Particularly in aggressive environments, it is common practice to epoxy inject cracks over .008 inch wide. These cracks can be measured easily with optical crack meters.

Defects of segments will be cause for delays, costs, meetings, etc. All are reasons for a well-meaning superintendent to cover up the defect before it is discovered. This is unacceptable practice. Repairs thus made should be removed and redone in the presence of an inspector. The inspector should also be present when forms are removed from a segment so that he has first hand information about defects when these occur.

Unless repairs are obviously cosmetic, all judgments regarding feasibility of repairs should be with the design/bridge office engineers.

Repairs in joint faces should not be made. If defects occur in the joint faces, the repair should preferably be postponed until after erection of the segment. The reason is that the joints will not match after such repairs and any lack of fit will cause damage when stress concentration occurs on a high point of the joint during post-tensioning.

11.0 CAST-IN-PLACE SEGMENTAL CONSTRUCTION

11.1 General

Cast-in-place segmental construction has been commonly used in Europe since the early 1950's. As part of post war reconstruction, the technique effectively substituted concrete construction for the more traditional steel construction for bridges in the 500 foot span range. The technique has been used extensively in the United States since the late 1960's.

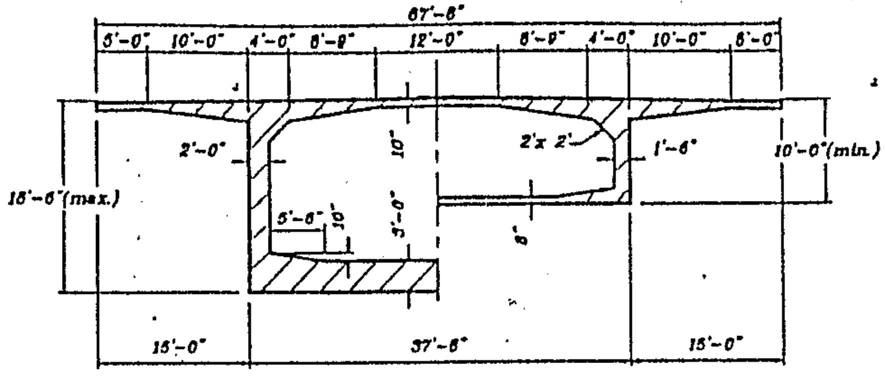
Nowadays, cast-in-place segmental is common on bridges with spans between 350 feet and 750 feet. In fact the technique competes extremely well with steel plate girders in this span range.

The reason for the lower boundary of 350 feet is that spans in this range require variable depth construction with a depth at the piers of approximately 18 feet. The bottom slab would already be approximately 2 feet thick. Precast segments with dimensions such as this are difficult and therefore costly to construct, handle and erect; and it becomes more logical therefore to cast such segments in place.

The 750 foot upper boundary follows from the fact that at this span length, the material quantities required to construct a box girder become very high. The construction depth at the piers may be 38 to 40 feet reducing to 15 to 20 feet at midspan. Cable stayed construction, which is a more refined and expensive technique becomes cost effective in comparison and has, in addition, better aesthetics and efficiency.

Nebraska City Bridge

This structure across the Missouri River was cast-in-place with form travelers. Segment length was 13'-10" and the maximum segment weight 550k. The pier table was constructed asymmetrical about the centerline by a half segment length in order to reduce the unbalanced moment. Piers 2 and 3 are fixed to the superstructure. The unbalanced moments at these locations are resisted by the piers. At pier 4 there is an expansion bearing. A steel strut was built here to resist the unbalance.
Stressing of longitudinal tendons was moved off the critical path by allowing advancement of traveler to precede stressing of longitudinal tendons. The design was verified for this condition.



Section @ Pier @ Midspan

Typical Cross Section Of Superstructure

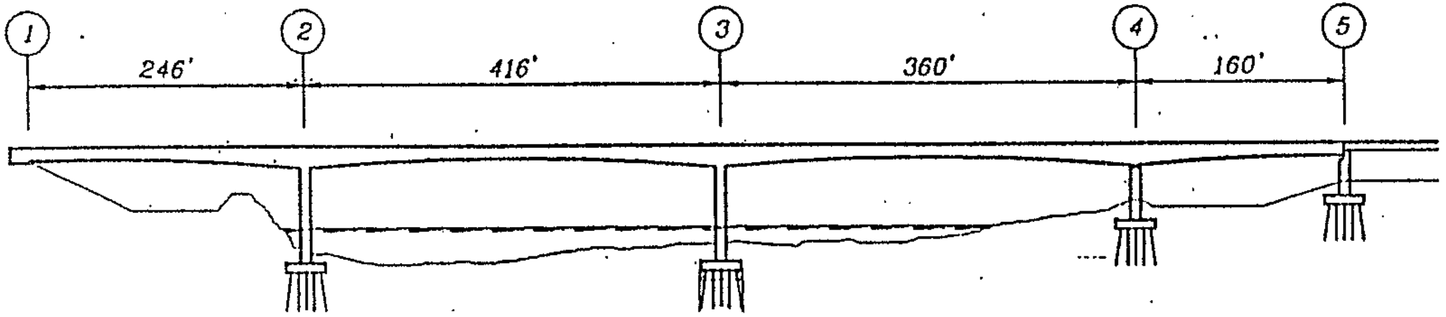


Fig. 11.1 Nebraska City Bridge
Cast-in-Place Segmental, Balanced Cantilever Construction
Variable Depth Boxgirder

Cast-in-place segmental construction has not yet been used in Florida. It may be used on the Acosta bridge and other projects presently being designed. For an example of a recently completed cast-in-place segmental bridge, see Figure 11.1.

Many of the operations in the construction of a cast-in-place segmental bridge are similar to those in precast construction - consequently, most of the foregoing sections of this manual apply. Also, all post-tensioning operations are essentially the same and these are covered in the "Post-Tensioning Manual". This chapter is intended to provide an overview of the various techniques which are relevant to cast-in-place segmental construction and different from precast segmental.

11.2 Review of the Cast-in-Place Segmental Technique.

Most all cast-in-place segmental bridges are constructed in balanced cantilever. As with precast segmental, this type of construction starts by building the "pier table" on top of the pier. The typical sequence is shown in Figure 11.2.

The pier table is generally about 40 feet long. This length is needed for assembly of the form travelers (see Figure 11.4). Form travelers are large steel trusses designed to carry the weight of forms and wet concrete without too much deflection. Form travelers are placed at the ends of the last completed segment in a cantilever and are tied down securely.

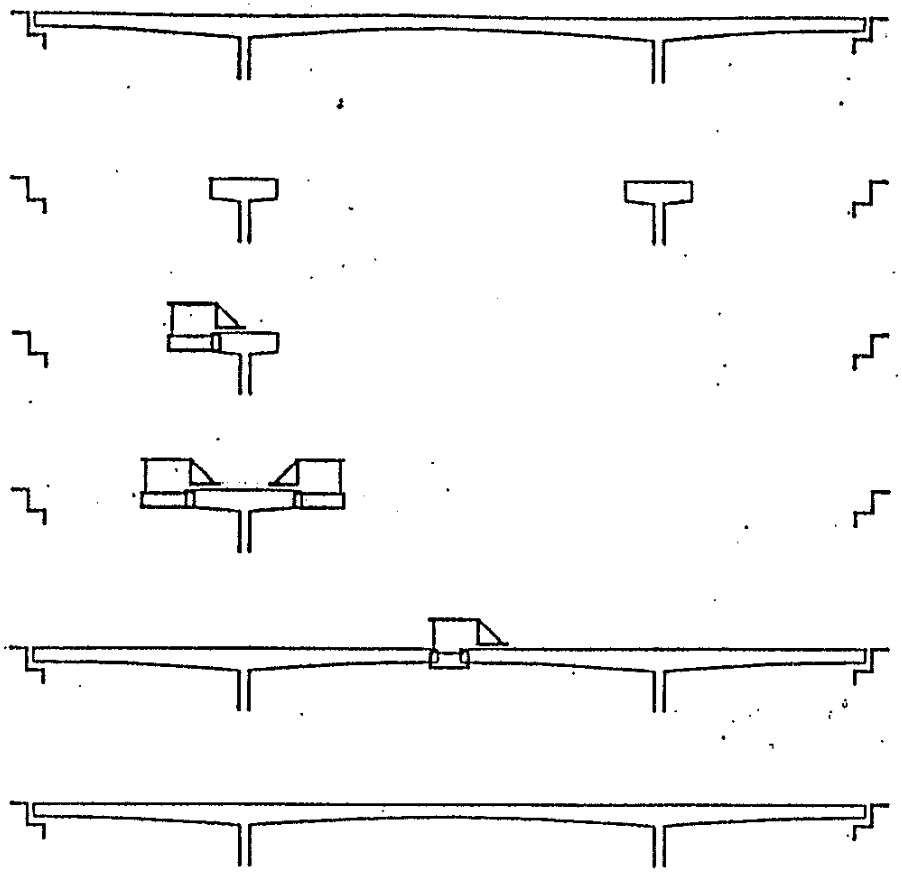


Fig. 11.2 Cast-in-Place Segmental
Typical Construction Sequence

After casting the first segments adjacent to the pier table, the concrete is cured and post-tensioned after which the travelers are advanced for casting the next segments. This cycle is repeated until the cantilever is completed, usually at midspan. After two adjacent cantilevers are constructed, a midspan splice is cast in the same way as is done for precast segmental construction except for the fact that the form for the closure is carried by the traveler and the closure pour can therefore be much larger.

11.3 Casting Cycle

A typical cycle for casting segments is shown in Figure 11.3. The cycle is based on a normal progress of one segment per week per traveler. Note that segments 1 and 2 are cast on separate days. By staggering this operation, the contractor improves his utilization of personnel. Concrete curing is on the critical path with this type of construction. Concrete strength required for stripping is usually no less than 2500 psi and a minimum strength of 3500 psi is normally required for stressing. In order to post-tension at this low strength, special, larger than normal, anchor plates are recommended. In the schedule shown in Figure 11.3, the weekend is utilized for curing.

In order to minimize curing requirements and to gain the flexibility to speed up construction, contractors often utilize high early strength concrete which allows stressing after only 2 days.

In the cycle shown, which was used on the Nebraska City Bridge, the traveler is advanced prior to stressing of the longitudinal prestressing. This caused minimal tensile stresses in the unprestressed joint at the last segment which did not lead to cracking even of 2500 psi concrete.

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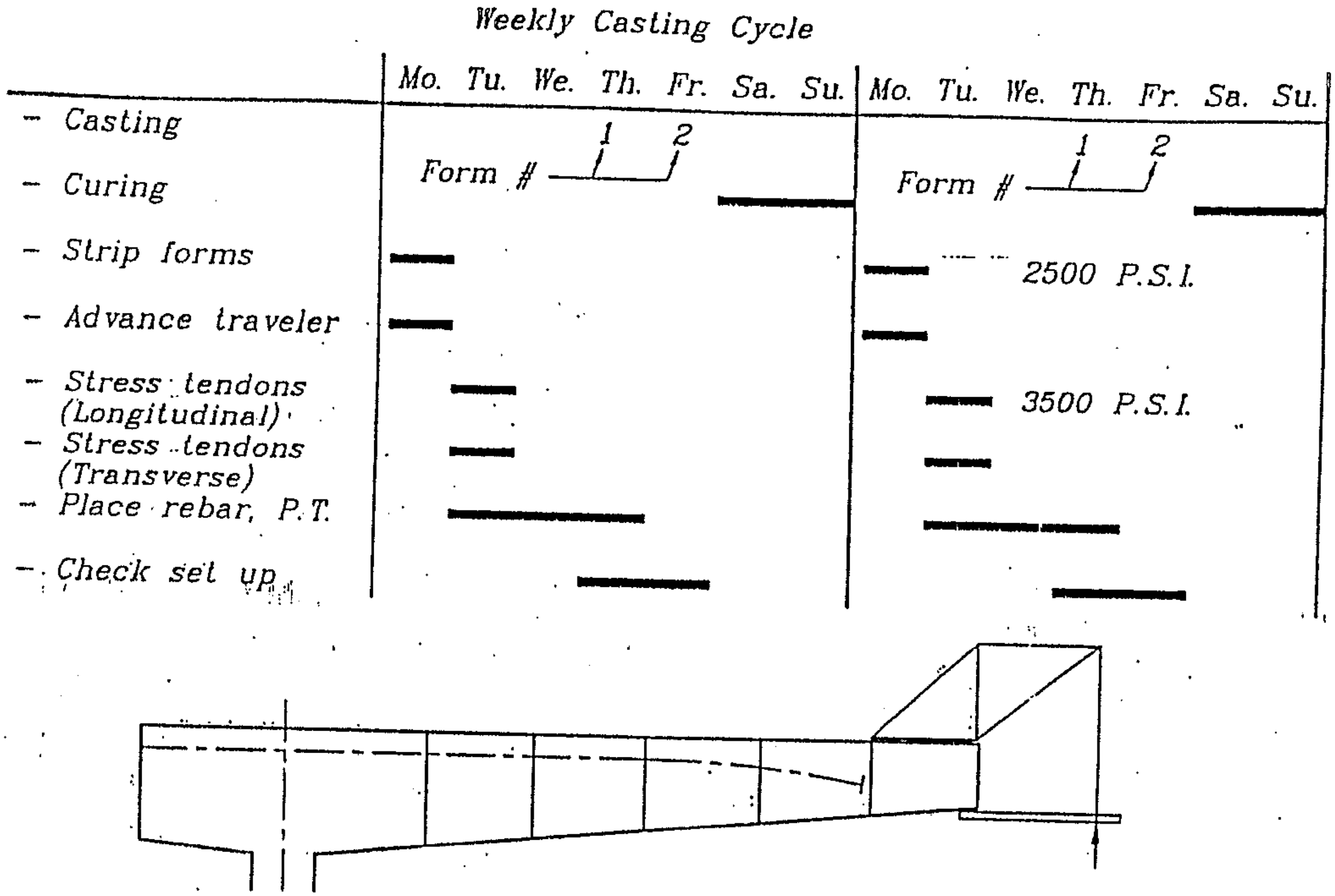

Fig. 11.3 Nebraska City Bridge Casting Cycle

The reinforcing steel through the joint assured ample structural safety for this operation. Reversal of the sequence of traveler advancement and post-tensioning would have eliminated the tension at the expense of speed and efficiency of construction.

As a consequence of subsequent casting of segments in a cantilever on either side of the pier, there are unbalanced moments. These are similar to those occurring in precast segmental construction but generally much larger in magnitude. The reason for this is that the segments used for cast-in-place segmental are much larger and the cantilevers, i.e. lever arms, are getting longer. The large unbalanced moments would require very heavy steel strutting. Very often, therefore, the main spans of a cast-in-place cantilever are designed integral with the piers and the piers are in turn designed to resist the unbalanced moment.

If not resisted by the piers, the out of balance erection moments must be taken by specially designed and built equipment such as temporary towers, temporary ties to anchors, special brackets and/or similar devices. It is a requirement in Florida that this equipment be designed by the Contractor's Specialty Engineer. Use of the equipment should be clearly outlined in manuals or on shop drawings which must be reviewed and approved by the Engineer prior to use.

11.4 The Form Traveler

The most important equipment used for cast-in-place segmental construction is the form traveler. A schematic drawing of a traveler is shown in Figure 11.4. The traveler consists of a steel truss which can be moved easily from segment to segment. This steel truss protrudes beyond the end of the cantilevers and is designed to carry the weight of forms, the concrete of the new segment and working loads.

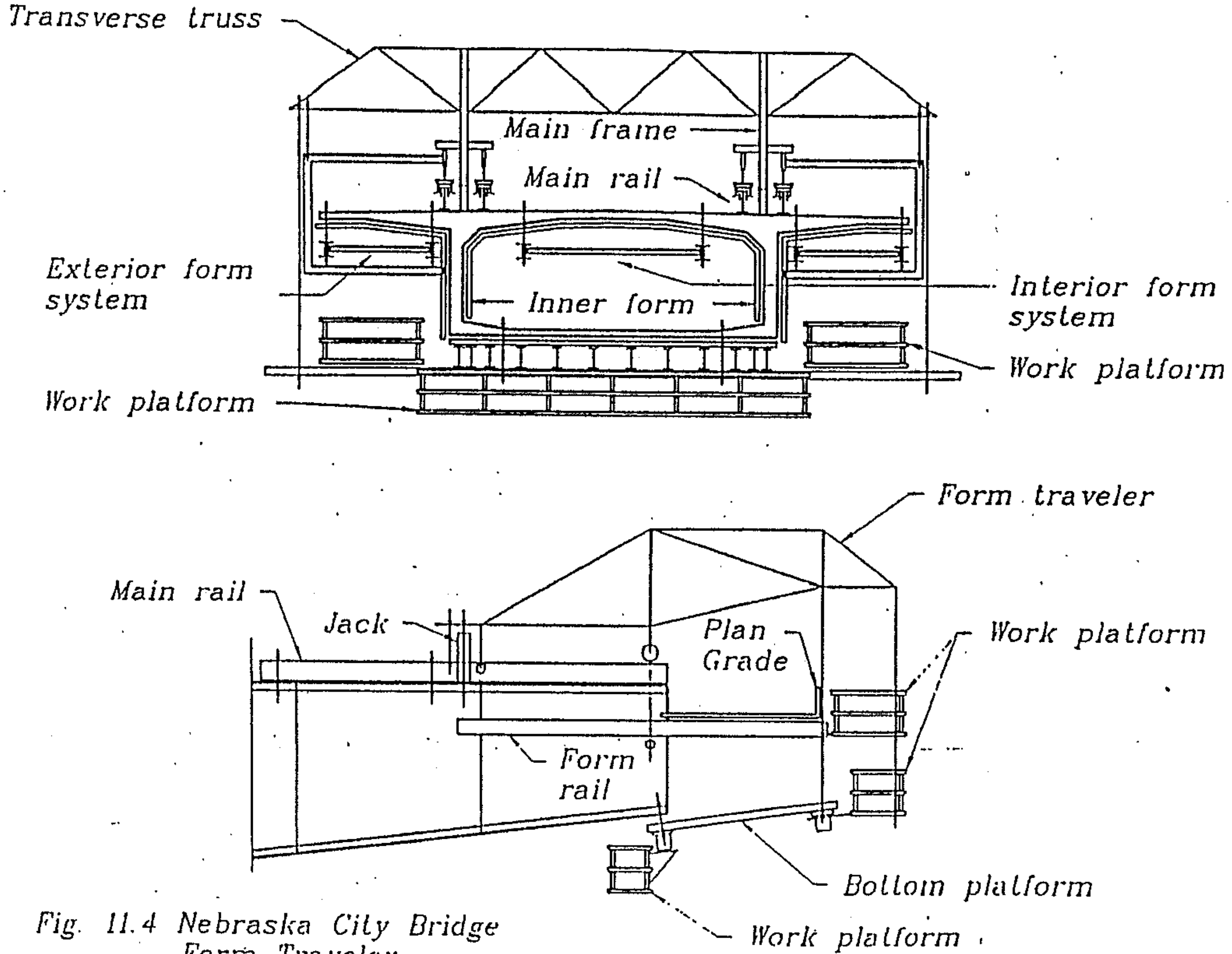

Fig. 11.4 Nebraska City Bridge Form Traveler

The frames are securely held down to the existing deck by means of prestressed anchor bars. It is most important that such hold-down devices be correctly installed and removed in their correct sequences as the travelers are moved. This operation should be clearly described in a manual or on shop drawings prepared by the Contractor and reviewed and approved by the Engineer.

The formwork normally consists of outer web, wing soffit and bottom slab soffit forms suspended by hangers from the form traveler support frame. These outer forms may be made of either steel or timber and are usually of variable configuration in order to accommodate the structure shape which may change from one segment to the next. The inner core form is often built of timber as required to suit the inside shape of the segments. Sometimes steel core forms will be used, especially if there is a repetition of shape from segment to segment. Core forms are supported on longitudinal supporting girders which attach to the already constructed concrete at one end and are held on hangers from the traveler at the other. The cross section at the end of the segment is usually formed with a bulkhead of timber or expanded metal reinforced with steel. Since cast-in-place segments are designed with rebar protruding through the joint, the bulkhead forms are usually made for one use only.

Although much of the formwork is made as standard and as reusable as possible, there is a lot of dismantling, readjustment and reconstruction involved between the completion of one segment and the casting of the next.

11.5 Placing, Consolidation and Curing of Concrete

The description provided in chapter 3 regarding the concreting is equally valid for cast-in-place segmental.

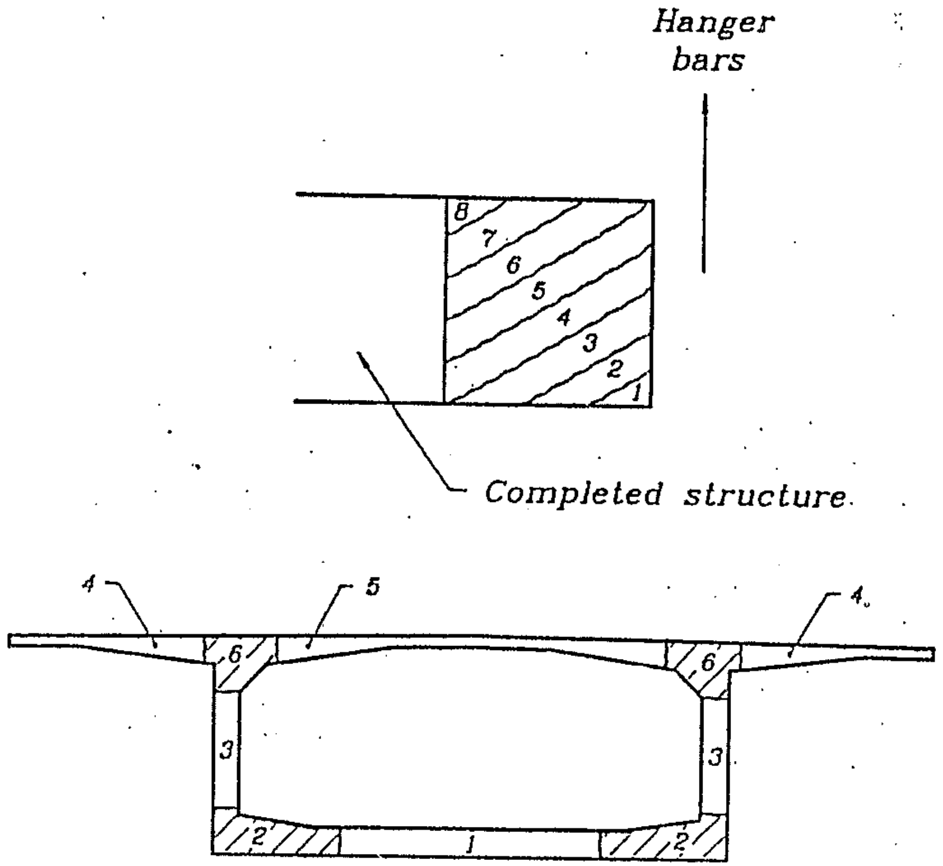

Fig. 11.5 Nebraska City Bridge
Concrete Pour Sequence

The casting sequence, as shown in Figure 11.5, is however more complicated than is the case with precast segmental because of the fact that the form is suspended from a somewhat flexible traveler. The most flexible parts of the traveler are the hangers. These hangers will elongate as their load increases and this elongation tends to open the joint between old and new segments. The pouring sequence as shown, which preloads the hanger bars as much as possible, alleviates this problem. This sequence is to be used in combination with frequent revibration of the concrete near the joint.

Good control of the curing of cast-in-place concrete is also essential. Generally the degree of exposure to the weather is greater with cast-in-place than with precast construction, the latter being done under factory controlled conditions. Also, the material properties, such as creep and shrinkage, of the very young concrete have a much greater influence on the final structure than with precast where the concrete is much more mature before it is erected. As mentioned, construction progress with cast-in-place work depends upon the early strength gain of the concrete. It is therefore in everyone's best interests to ensure that the concrete is protected from the weather, cast, consolidated and cured properly. Methods used for curing concrete until sufficient strength is obtained depend largely on the project specifications. A possible method consists of wet burlap curing of the deck starting immediately after casting. This would be followed by wet curing (hosing) of the sides after form removal. Curing would cease when the concrete strength requirements of the specifications have been met. Curing compounds might be permitted in some cases, but these have the disadvantage of unsightly staining which may persist for some time.

11.6 Traveler Settings

The geometry control of cast-in-place segmental bridges is similar to what is required for precast segmental construction. Anticipated deflections, both long term and short term, must be determined as accurately as possible. These deflections and the vertical profile are combined into the casting curve.

The actual geometry control occurs in the field by setting the elevations of the bulkhead form using an instrument. These elevations are called traveler settings. Traveler settings are determined based on casting curve, anticipated deformations of the form traveler caused by the weight of the wet segment concrete and the difference between short term deflections assumed in the casting curve and those which occur at completion of casting the segment.

11.7 Safety

Travelers can be ordered new or used from a number of companies in the United States. The equipment has an excellent safety record. Often the question is raised what happens if a traveler, which can easily weigh 150 tons falls off the end of a cantilever. Particularly in case of a long cantilever, the effect would be devastating and would surely lead to a catastrophic failure. It is for this reason that the traveler operation must be designed so that this cannot happen.

12.0 INSPECTION PROCESS

12.1 Inspection Team.

It is Florida D.O.T.'s policy to encourage good construction practices by providing adequate construction inspection for three reasons:

(1) Protection of investment. A structure that is well built can be easily maintained at low cost and will have a long useful life. Good quality control ensures good construction.

(2) Protection of public safety. Good construction practices increase safety during construction. Also, a poorly constructed bridge can become a safety hazard after a number of years of service.

Good construction inspection means:

- enforcement of plans, special provisions and standard specifications.
- enforcement of shop drawings for items that will be part of the structure.
- ensuring quality of materials by testing and observation.
- ensuring installation of materials within reasonable tolerances.

(3) Improve construction administration. A good inspection team can prevent delays, cost increases and/or construction claims by efficiently addressing problems which were not foreseen. Both design and contractor errors become evident or occur during construction. When this is the case, costs and delays can be greatly minimized by

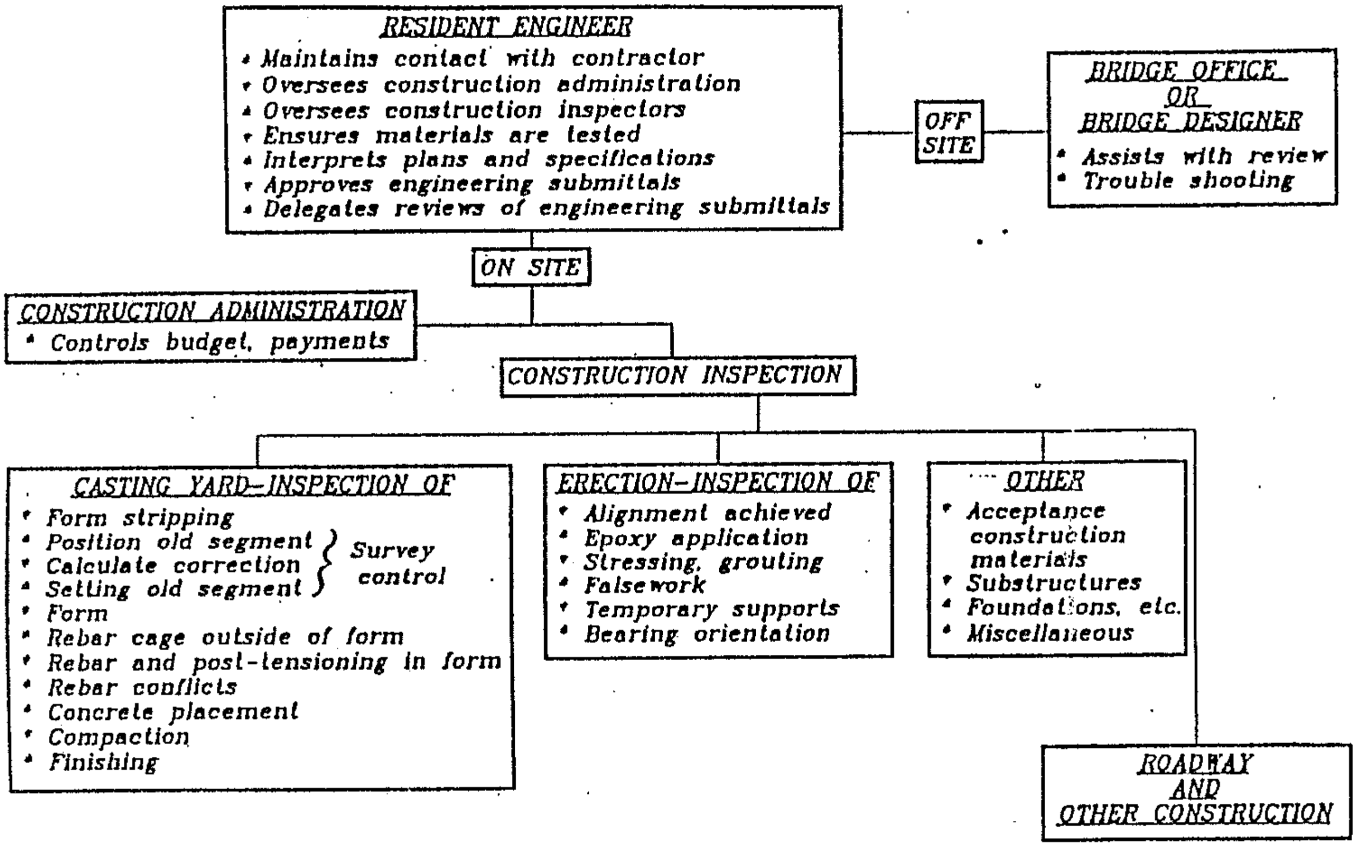

Fig. 12.1 Inspection Team

contractor and the inspection team working together on a solution. The inspection team should be able to meet this challenge when the need arises.

In order to achieve these goals, an inspection team is usually put together and organized as shown in Figure 12.1.

The task of the field inspectors is to inspect everything. In the casting yard several errors can be made which are detrimental!

- Alignment: Errors are difficult and expensive to correct. Devise a way to daily check the contractor's alignment control.

- Layout of Tendon Ducts: If ducts are omitted or connected to the wrong ducts in other segments, the post-tensioning cannot be installed and the structure cannot be built as designed.

Also in the field the consequences of some errors can be disastrous.

- Location of erection equipment: If erection calls for placement of heavy loads on the structure these should be placed as noted on the plans. Catastrophic failures have occurred due to this type of error.

- Order of erection: The specified order of erection should be carefully followed in order to prevent alignment problems and/or structural failures.

Errors are made frequently and their occurrence is embarrassing for all parties involved. The solution lies in quality inspection.

12.2 Submittals

Segmental bridges are technically rather complicated to construct and it has proven necessary to allow the contractor a certain input in the way he wants to make and erect segments.

The contractor makes his intentions known regarding the means and methods to be used for contruction of the project by preparing a set of shop drawings. These shop drawings and other types of submittals, once approved, represent the understanding between contractor and FDOT as to how the structure will be built.

In addition to shop drawings, the contractor often generates requests for design revisions which also need to be reviewed and approved. The preparation, review and approval of shop drawings is a tedious process.

The intent of this chapter is to give an indication what the shop drawings and submittals should cover. The diagrams in Figures 12.2(a) and (b) indicate which parties are involved in the approval process.

Submittals generally will consist of drawings, calculations, computer printouts and text (description, procedures), and test results.

The items to be submitted by the contractor pertain to materials, procedures and equipment, broken down as follows:

- Segment fabrication and handling (materials, procedures and equipment).
- Segment storage (materials, procedures and equipment).
- Segment transportation (procedures and equipment).

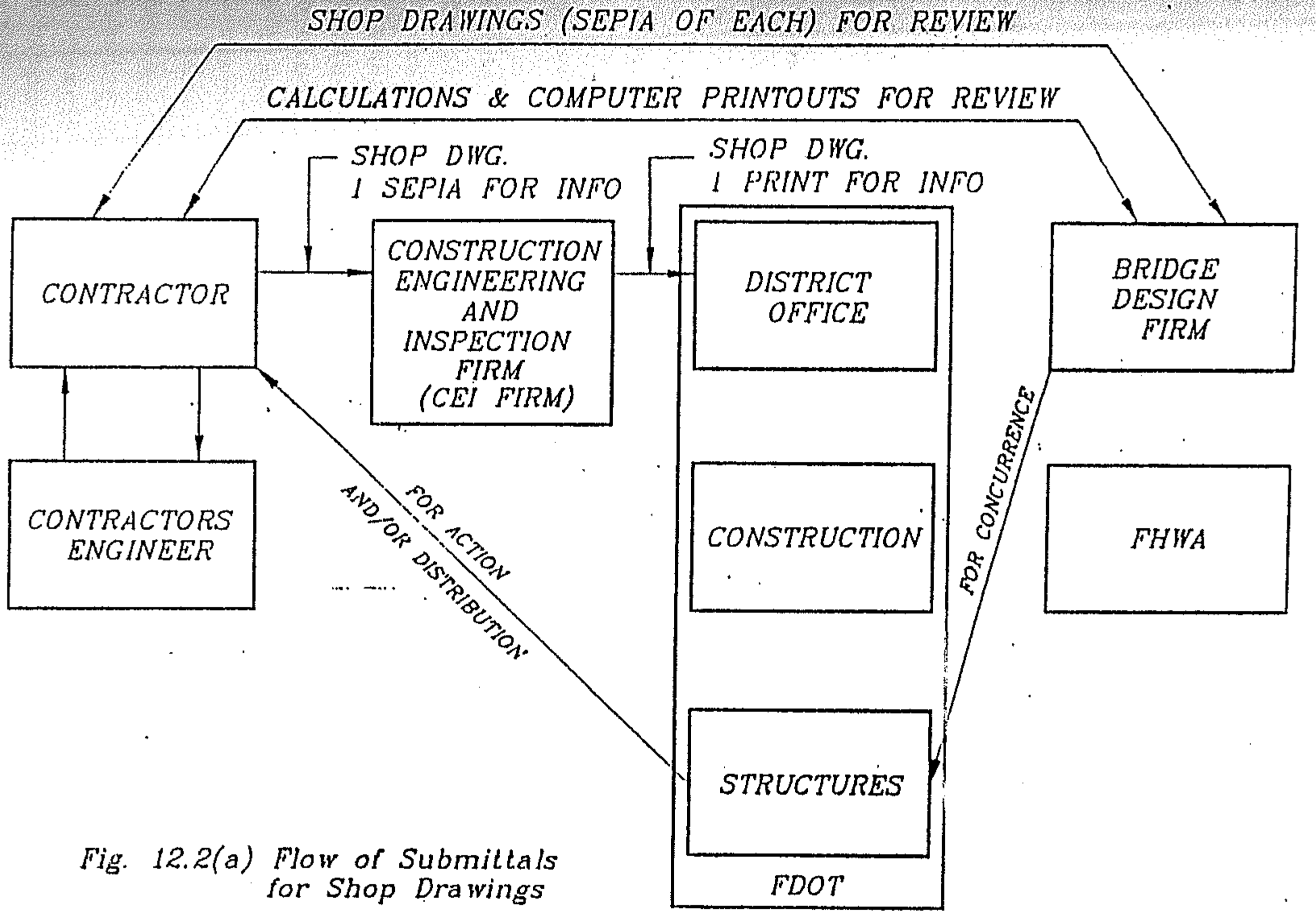

Fig. 12.2(a) Flow of Submittals for Shop Drawings

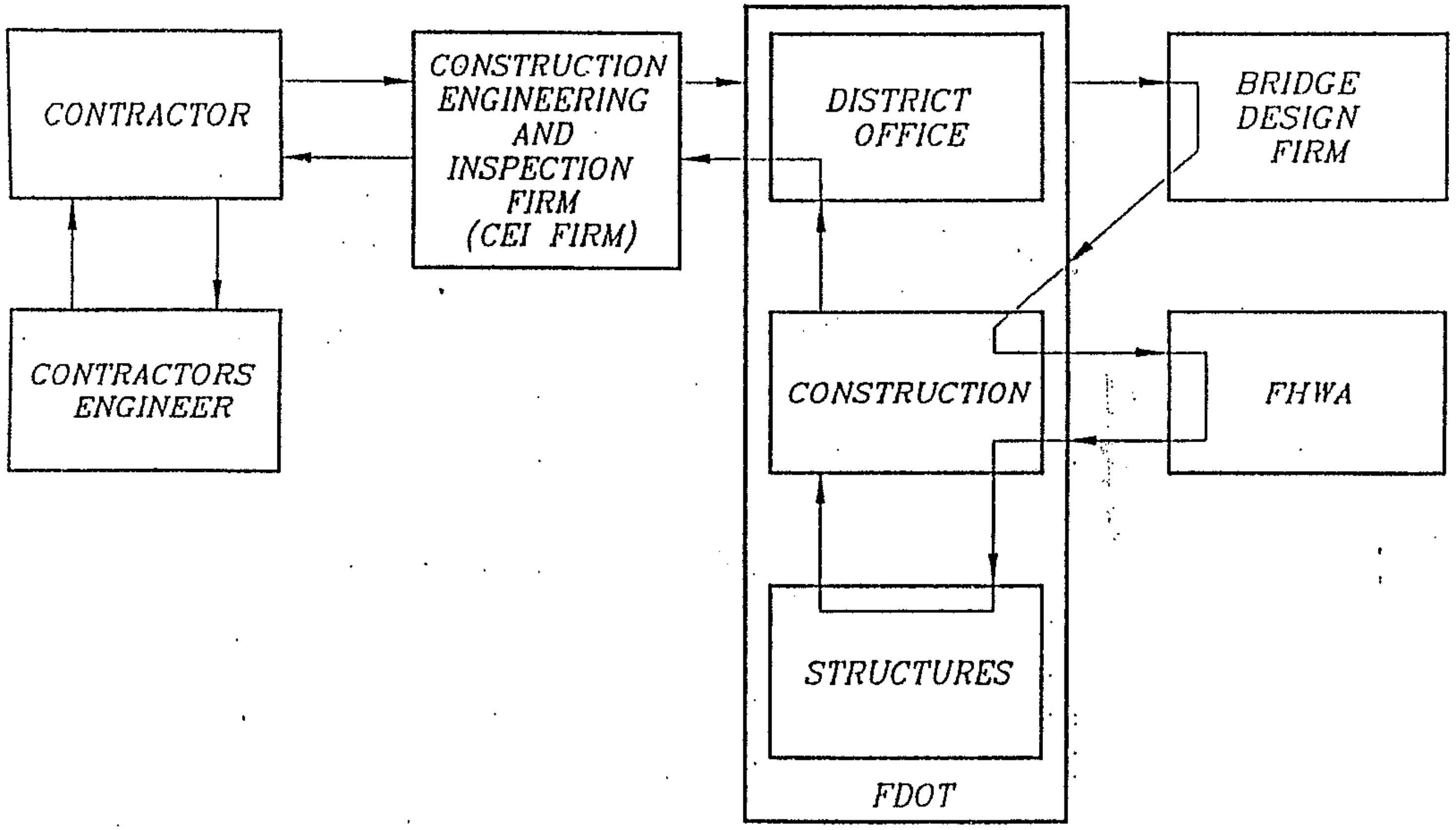

Fig. 12.2(b) Flow of Submittals for Design Revisions

Segment erection (materials, procedures and equipment).

Following is a listing of the items which require a tal. The inspector should note that:

All the standard quality control requirements apply to this type of project.

The listing is not all inclusive and submittals on individual jobs will vary.

egment Fabrication.

Materials for segment fabrication
Submittals are required for:

- concrete
- reinforcing steel
- prestressing steel
- grout
- post-tensioning hardware

Embedded items (permanent)
Submittals are required for:

- drain inlets and pipes
- manholes
- blockouts for bearings
- blockouts for road joints
- light fixtures
- overhead signs

Embedded Items (for construction only)
Submittals are required for:

- inserts
- temporary openings
- holes

- extra reinforcing

D. Procedures for Segment Fabrication

Submittals are required for:

- layout of casting yard
- segment designation
- set up and operate casting cells (forms)
- preparing , handling and placing rebar cages
- setting the old segment
- control geometry
- prepare "as built" geometry data
- geometric error correction
- pouring sequence
- placing, compacting and finishing concrete
- curing of concrete
- form stripping, bond breaking
- handling of partly cured segment

E. Equipment for Segment Fabrication

Submittals are required for:

- forms
- concreting of segment
- vibrating
- curing
- surveying
- lifting
- transporting

F. Segment Shop Drawings

Submittals are required for:

- dimensions
- shape and location of rebar
- size and location of post-tensioning tendons
- nature and location of embedded items

II. Segment Transportation.

A. Submittals are required for:
- vehicle for segment transportation
- timing and duration of transport
- permits
- maintenance of traffic
- support of segments during transportation

III. Segment Storage

A. Materials used in the Stockyard

Submittals are required for:
- specialty mortars for filling of transverse post-tensioning recesses
- specialty mortars for small repairs

B. Procedures

Submittals are required for:
- layout of stock yard
- method and location of supports
- single or double stacking
- curing
- transverse post-tensioning
- grouting transverse tendons
- placing erection marks and segment identification
- making small repairs
- surface finishing (if applicable)
- type and movement of handling equipment
- order of placing and removing of segments

IV. Segment Erection.

A. Materials for segment erection

Submittals are required for:
- epoxy resin

- specialty mortars
- grout, grout additives
- corrosion protection of tendons
- lubrication of tendons
- temporary post-tensioning

B. Procedures for segment erection

Submittals are required for:

- setting of pier segments
- handling of segments
- placing of segments
- mixing of epoxy
- placing of epoxy
- placing of temporary post-tensioning
- stressing of permanent tendons
- alignment control
- compensation of errors
- casting of midspan splices
- operation of special equipment

C. Equipment for Segment Erection

Submittals are required for:

- pier frame
- falsework
- lifting equipment
- interaction of equipment and structure

D. Miscellaneous Materials

Submittals are required for:

- bond breaker
- concrete mix for filling voids
- bonding agents
- high strength grouts and mortars
- bolts for elevation measurement