e-mosty

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SEGMENTAL BRIDGES

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Photo on the Front Cover: L57 Gantry Erecting the Dulles Corridor Metrorail in Reston, Virginia
Credit: Matthew Williams, McNary Bergeron & Associates

Photo on the Back Cover: Final Segment Erection of the Cantilever Al Bustan South Project, Qatar
Credit: VSL International

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Contact: info@professional-english.cz

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Dear Readers

This issue focuses on segmental bridges.

The topic of the first article of this issue, which was prepared by **Jeremy Johannesen from McNary Bergeron & Associates**, is Constructability: Segmental Bridge Details. The material presented here has been mined from a wide range of designers and builders on bridges going back many years. The article attempts to highlight and share some examples of the best practices that have been found in use around the industry.

For the first time, we publish a 3D model which can be read as pdf. We trust that it is useful and we are going to bring more content of this type in the future.

The next article was prepared by **Matthew Williams and Jeremy Johannesen from McNary Bergeron & Associates.** It deals with Design Considerations for Gantry Erected Bridges and brings a breakdown of the typical construction loads a bridge has to accommodate during gantry operation.

Joakim Dupleix from Case International (formerly VSL), and Martin Pircher from ABES in their article Geometry Control for Precast Segmental Construction describe using a specially developed software suite dedicated to managing the geometry control of segmental construction at every stage of the construction process.

The last article of this issue, Precast Segmental Bridge Construction Using Lifting Frame in Qatar is presented by **Joakim Dupleix from Case International (formerly VSL), and German A. Pardo R. from VSL International.** In Qatar, VSL designed and operated two very different types of lifting frames as part of the Al Bustan corridor upgrade project.

I would like to **thank all authors and companies involved for their cooperation**; and also **Juan C. Gray** (T. Y. Lin) and **Richard Cooke** for reviewing this issue, and **Guillermo Muñoz-Cobo Cique** (Arup) for his final check. I would like to thank **Jason Hatcher from Hatcher Technical** for his assistance with the 3D model.

I would also like to thank our **partners for their continuous support**. And many thanks to **José Calisto da Silva from Biggs Cardosa Associates** who has decided to financially support our magazine.

September 2021 Edition of e-mosty will be about BIM for Infrastructure Projects and Ports. We still welcome your articles, especially with a focus on BIM for port operations and maritime projects. Please contact us here. And also for this Issue, **Edinson Guanchez**, Associate Professor at Universidad Politécnica de Cataluña (UPC) and CEO at Sísmica Institute S.L, Barcelona, Spain has prepared an article about Caissons for Bridges over Water.

December 2021 Edition will be about American Bridges. And we are already working on a special edition of e-mosty **June 2022 which we would like to dedicate to the 1915 Çanakkale Bridge Project.** This suspension bridge with a total length of 4,608m and 2,023m of a middle span is currently under construction in Turkey.

With our other magazine, e-maritime, we go on focussing on maritime construction projects, design and construction of ports and docks. **e-maritime June 2021 will be about Shipyards and Maritime industry and construction in Malta** and will be released on 30 June at www.e-maritime.cz with open access.

Magdaléna Sobotková

Chief Editor

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It is published quarterly: 20 March, 20 June,
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The magazine **brings original articles about bridges and bridge engineers** from around the world.
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of the structures.

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The readers are mainly bridge engineers, designers,
constructors and managers of construction
companies, university lecturers and students,
or people who just love bridges.

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INTERNATIONAL ONLINE PEER-REVIEWED MAGAZINE
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e-maritime

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It is published at **www.e-maritime.cz** three times a year:

30 March, 30 June and 30 November.

September Issue is shared with the magazine e-mosty ("e-bridges"): "BIM / Vessels and Equipment for Bridge Construction" which is published on 20 September at www.e-mosty.cz.

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e-mosty

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The magazine e-mosty was established in April 2015 and its first issue was released on 20 June 2015 as a bilingual English – Czech magazine aimed mainly for Czech and Slovak bridge engineers.

Very quickly it reached an international readership.

In 2016 we extended the already existing Czech and Slovak Editorial Board by two bridge experts from the UK, and since then four more colleagues – from the USA, Australia and The Netherlands – have joined us.

Since December 2016 the magazine has been published solely in English.

Each issue now has thousands of readers worldwide.

Many of our readers share the magazine in their companies and among their colleagues so the final number of readers is much higher.

Most importantly the readership covers our target segment – managers in construction companies, bridge designers and engineers, universities and other bridge related experts.

The magazine e-maritime was established in 2018 and its first issue was released on 30 March 2019.

The magazine is published in English. It is going to cover a vast range of topics related to vessels, maritime equipment, ports, docks, piers and jetties - their design, construction, operation and maintenance, and various maritime and construction related projects.

The Editorial Board already has two members – from the UK and the Netherlands.

Both magazines are with Open Access with possibility to subscribe (free of charge).

In January 2019 we established their own pages on LinkedIn with constantly increasing number of their followers. Number of subscribers of both magazines is also increasing.

We also know that the readers usually go back to older issues of both magazines.

CONSTRUCTABILITY: SEGMENTAL BRIDGE DETAILS

Jeremy Johannesen, McNary Bergeron & Associates

I. INTRODUCTION

If any of these topics sound familiar, you are in good company. The material presented here has been mined from a wide range of designers and builders on bridges going back many years.

From the vantage point of a construction engineer, there are a number of common, avoidable problems that we encounter. Sometimes the problems are obvious. Other times, rooting out these problems requires getting immersed in complexities that no one else would care to understand.

Detailing is tedious and for that reason, good-detailing is rarely recognized and clever ideas get lost.

This paper attempts to highlight and share some examples of the best practices that we have found in use around the industry.

II. SEGMENT GEOMETRY AND CONVENTIONS

The key principles for segment geometry are commonly accepted and understood within the industry. Geometry in curved alignments is achieved by chording the individual segments.

In plan, segment joints are perpendicular to the chord of the segment being cast. In profile, joints are vertical at the time of casting.

While it is understood that these rules provide a basis for survey control, it is more important to know that these are based on the practical limitations of the formwork system.

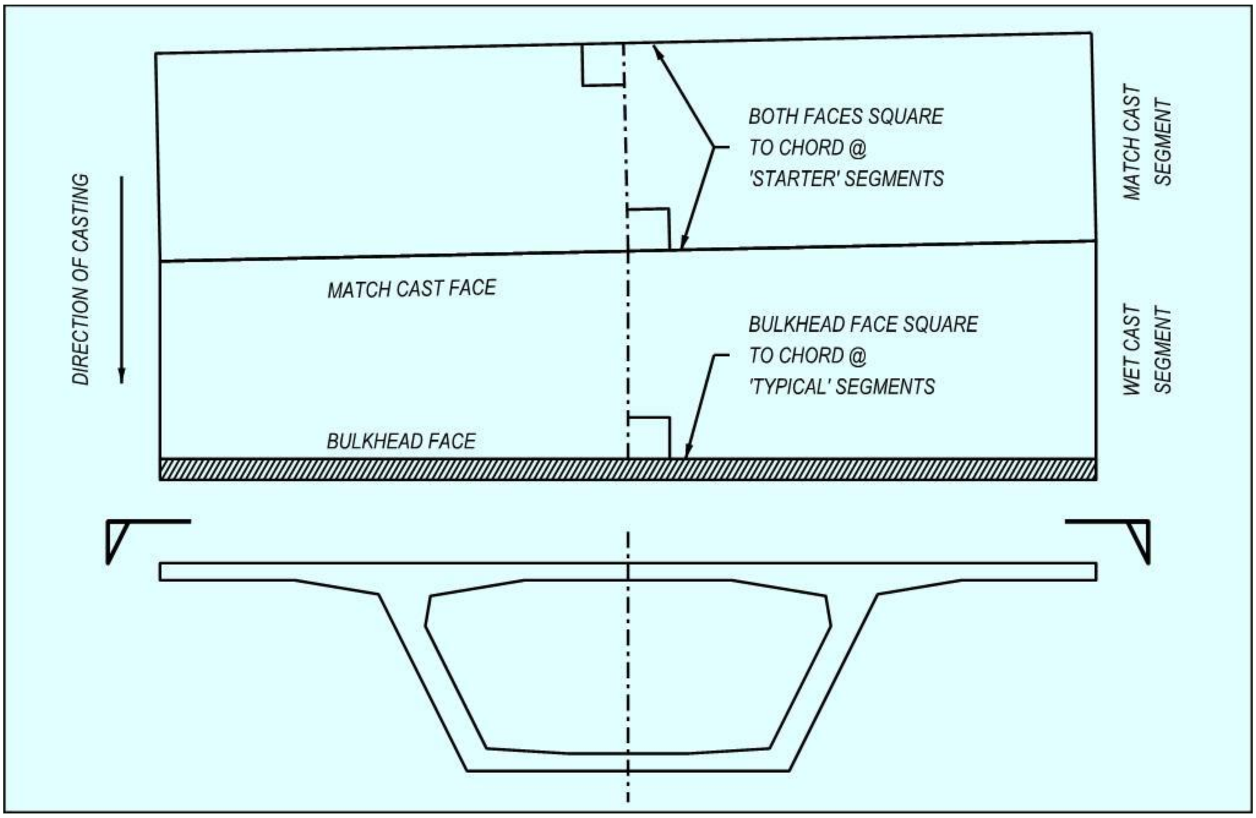


Figure 1: Segment Geometry

III. CROSS-SECTION

As a starting point for any design, the AASHTO-PCI-ASBI standards provide solid examples of cross sections and basic segment details. When adapting those details to specific project requirements, consider the following:

DECK SLAB. In a structure where the construction method or loads require dual cantilever anchors at each web, the anchors should straddle the web reinforcement. This is a simple solution and avoids many reinforcing conflicts. However, large anchors (larger than 12 strands) often do not fit in the deck haunch.

The top of the web is an appealing spot for a single, large anchor. Be aware however that placing the anchor in the web creates some reinforcing challenges and may require adding concrete to provide flexibility in bar placement. Refer to Section X. on the following pages for details to help evaluate the most practical anchor arrangement.

BOTTOM SLAB. There are two schools of thought on how best to detail the bottom slab transverse profile. One is to use a constant thickness from web to web and the other is to use a haunched profile.

Each has its advantages (see Section X. for reinforcement examples).

For either the case, verify that the ducts near the web pass cleanly over the horizontal legs of the web rebar. In some cases, it is worth raising the ducts near the web slightly.

When using a haunched slab, extend the fillet far enough to prevent conflicts between the top mat rebar and the ducts.

CORE FORM. A successful design is based on a realistic understanding of the formwork system. Standardization and simplicity should be the goal. To be specific:

- Use consistent anchor block geometry to eliminate formwork modifications from the casting cycle.
- Proportion anchor blocks to allow the formwork to collapse and retract.
- Avoid using continuity tendons in the top slab because the anchor blocks make the operation of the core form complicated. History shows that balanced cantilever bridges will work without top slab continuity tendons.

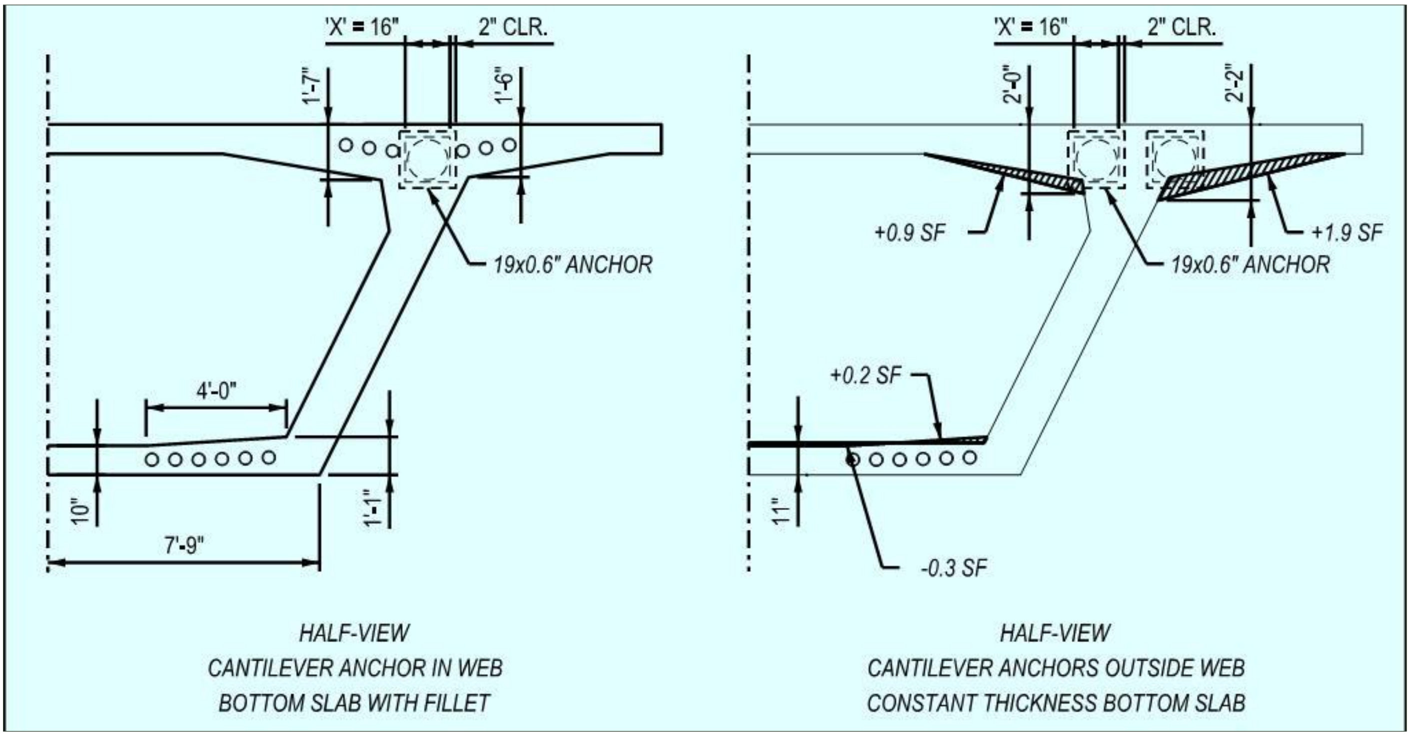


Figure 2: Cross Section Comparison. All the dimensions on this figure are in imperial feet and inches

IV. REBAR LAYOUT & SPACING

Often, designs are prepared in a divide-and-conquer approach, where the PT and reinforcing designs are done without close coordination.

One simple method to better integrate details, is to adopt an assumed reinforcement layout early in the design. This establishes dedicated lanes for the reinforcement to integrate everything else around.

Once that is established, it is preferable to maintain the reinforcing layout and vary bar sizes as demands require. The benefits of this approach become evident when integrating the girder reinforcing with anchor blocks, etc.

LAYOUT. Commonly used rebar spacings are 15 or 20cm (6" or 8"). Note that a 15cm spacing is adequate to fit transverse tendons between bars and also allows the use of 30cm spacings when demands are less.

CURVATURE. In "straight" bridges, where segments are effectively rectangular, the layout is simple (offset the first bar-set half of the nominal spacing from the bulkhead face and then repeat at the nominal spacing). For segments in curves, space the bars parallel to the bulkhead until beyond the anchor block reinforcement (or other details requiring integration).

Then, vary the spacing in an accordion fashion near the match cast face.

This approach is similar to timber framing in house construction, where rather than spacing the studs uniformly along each wall, the studs are spaced at 40cm (16") as much as is practical and any remainder is left as a single, short spacing.

This is a well understood technique and it is based on a practical approach to integrating different building components. For example, a 1.2 x 2.4m sheet of plywood in multiples of 40cm, thus the sheeting aligns with the framing studs.

MINIMUM SPACINGS. Knowing that the web on the outside of the curve will be longer than the centerline length of the segment, the designer should decide if it is acceptable for the bar spacings in the 'accordion zone' to exceed the nominal spacing.

Where spacings are already relatively tight, it is preferable to increase the spacings locally, since the 'average spacing is effectively unchanged. Where the bar spacing is larger (30cm for example) it may be reasonable to add an 'extra' bar-set to take up this variation.

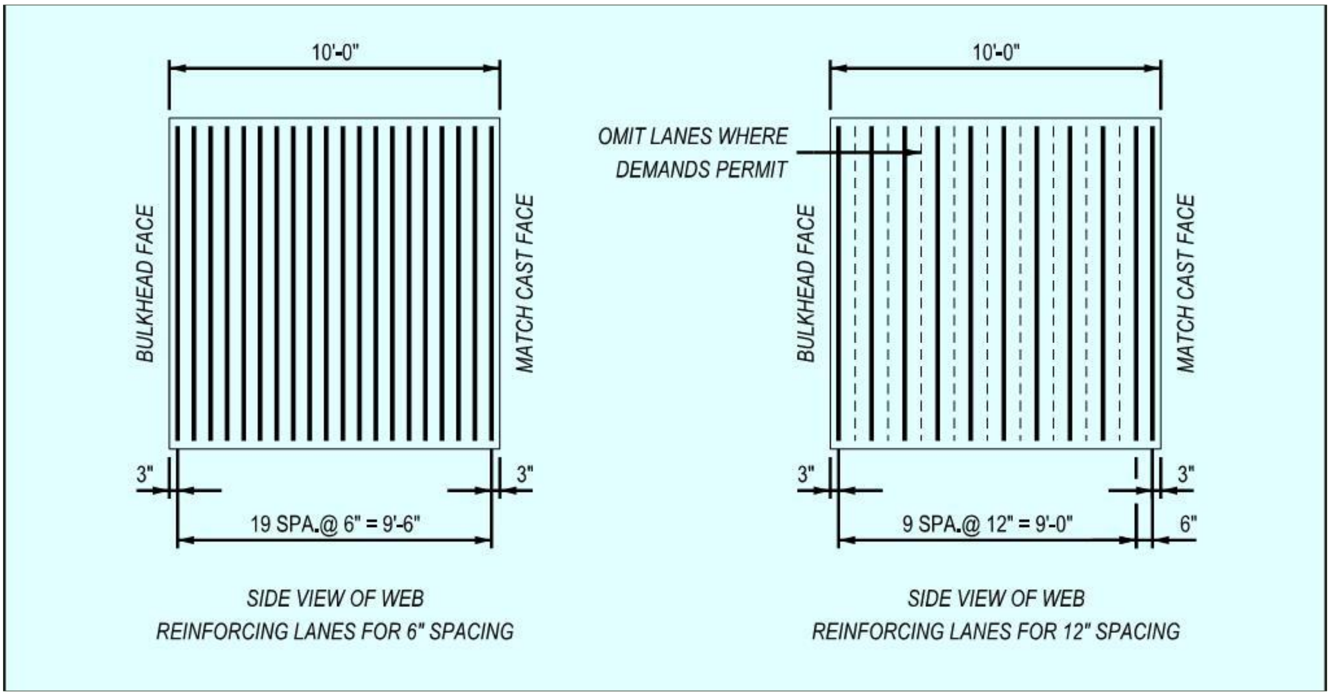


Figure 3: Rebar Layout Methodology. All the dimensions on this figure are in imperial feet and inches

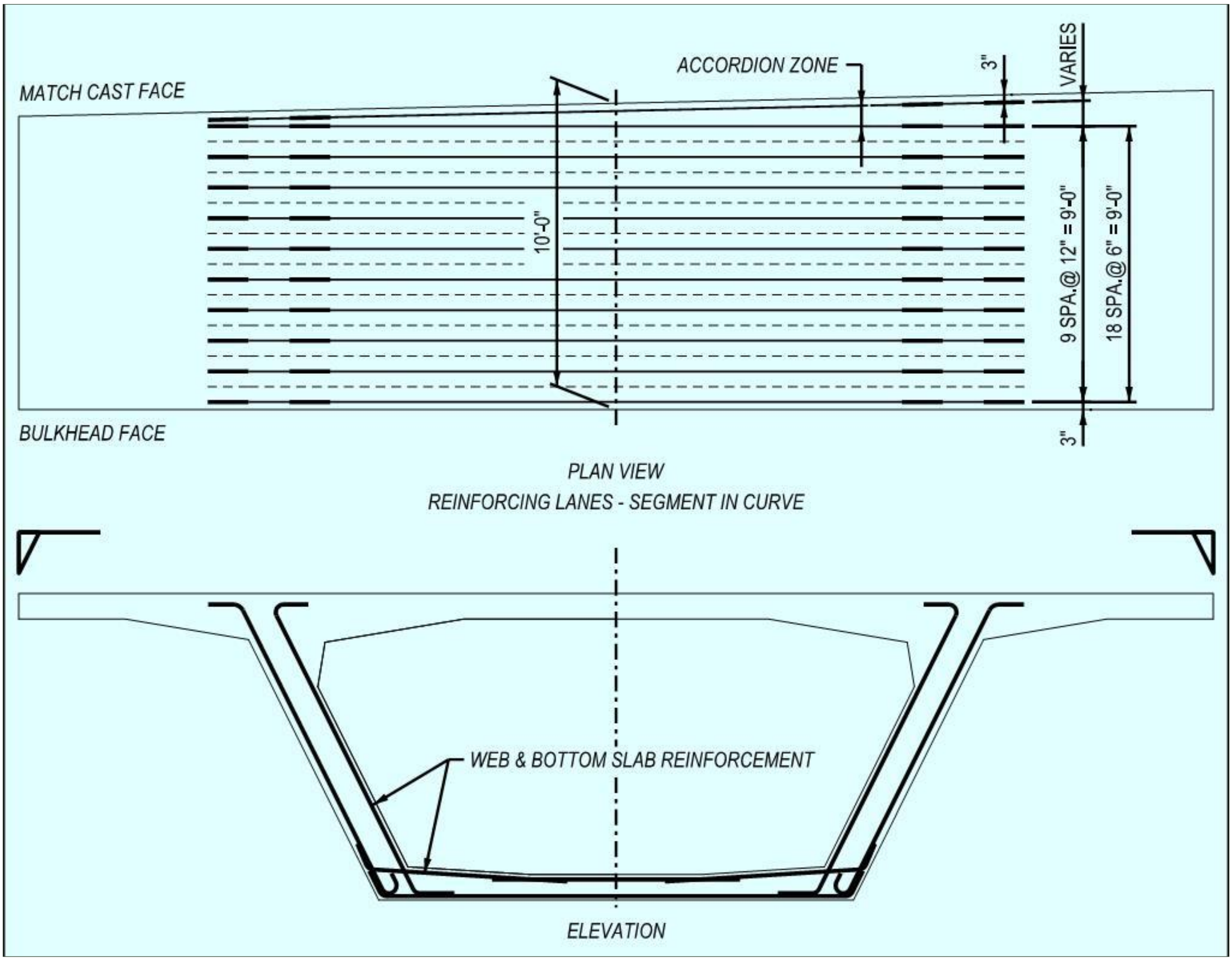


Figure 4: Rebar Layouts in Curved Segments

DECK REINFORCEMENT. Deck reinforcement should either be spaced with or spaced between the lanes established by the web reinforcement.

On several projects the deck reinforcement has been pre-tied and then mated to the webs in the forms. This has been a successful approach and is most effective when the deck bars can be arranged to fall between the web rebar.

V. TRANSVERSE PT

LAYOUT. Space the transverse tendons around the nominal reinforcing lanes. Locating transverse tendons without regard for the reinforcement results in non-uniform rebar spacings and sometimes additional reinforcing to cover those gaps created by the tendons.

For best results, establish a reinforcing layout and then put the tendons in the gaps.

POURBACKS. There are numerous opinions as to the best way to detail the pourbacks at the anchorages.

On some projects, a variety of different details have been tried, with no clear consensus on which was best.

Anchor pourbacks located under a travel lane are by default closed-top or better yet, dead-end anchors with no blockouts.

The trickier question becomes what to do with anchors under barriers and how best to patch them. "ASBI/PTI M50" contains relevant examples and guidance.

As long as the details provide adequate protection to the anchor, it is worth being flexible to the contractor's preferences.

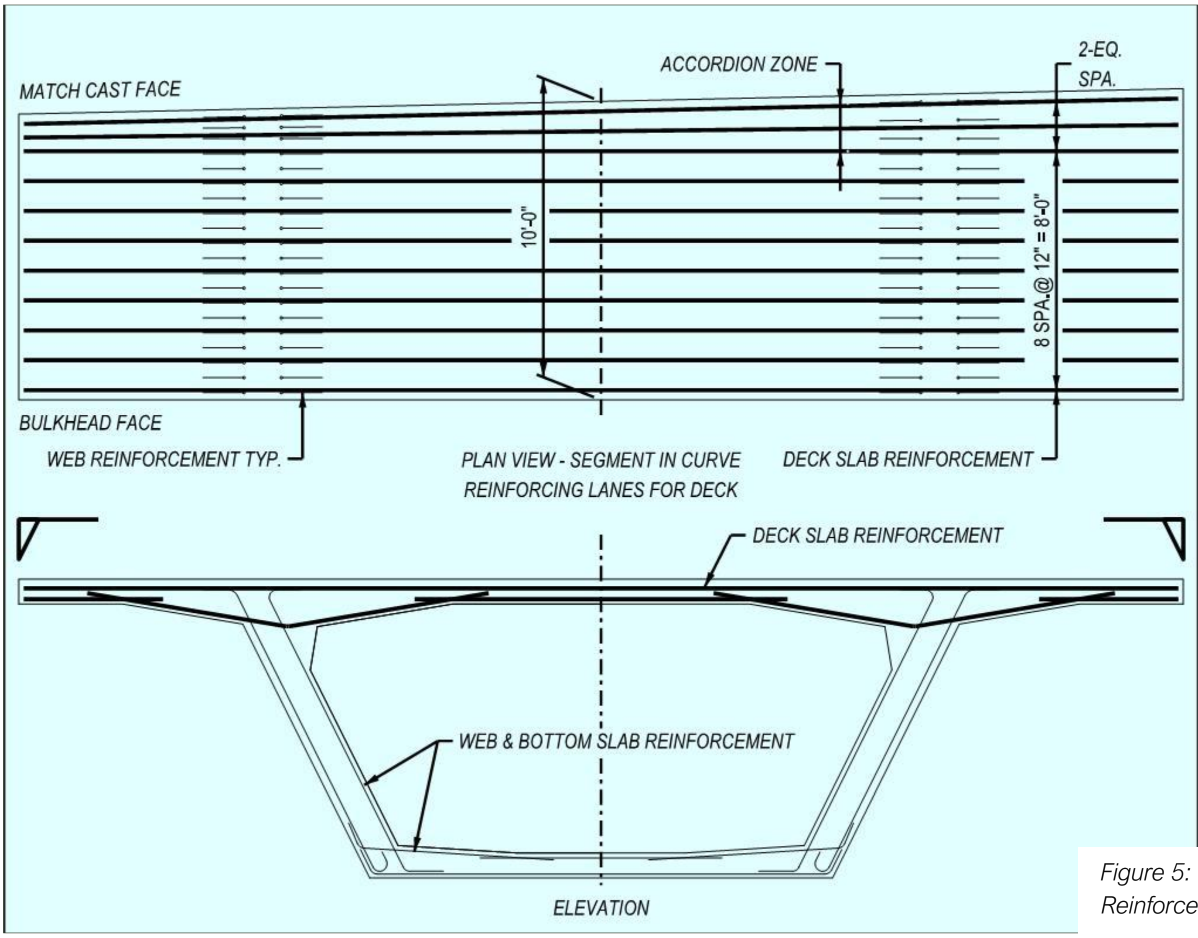


Figure 5: Deck Reinforcement

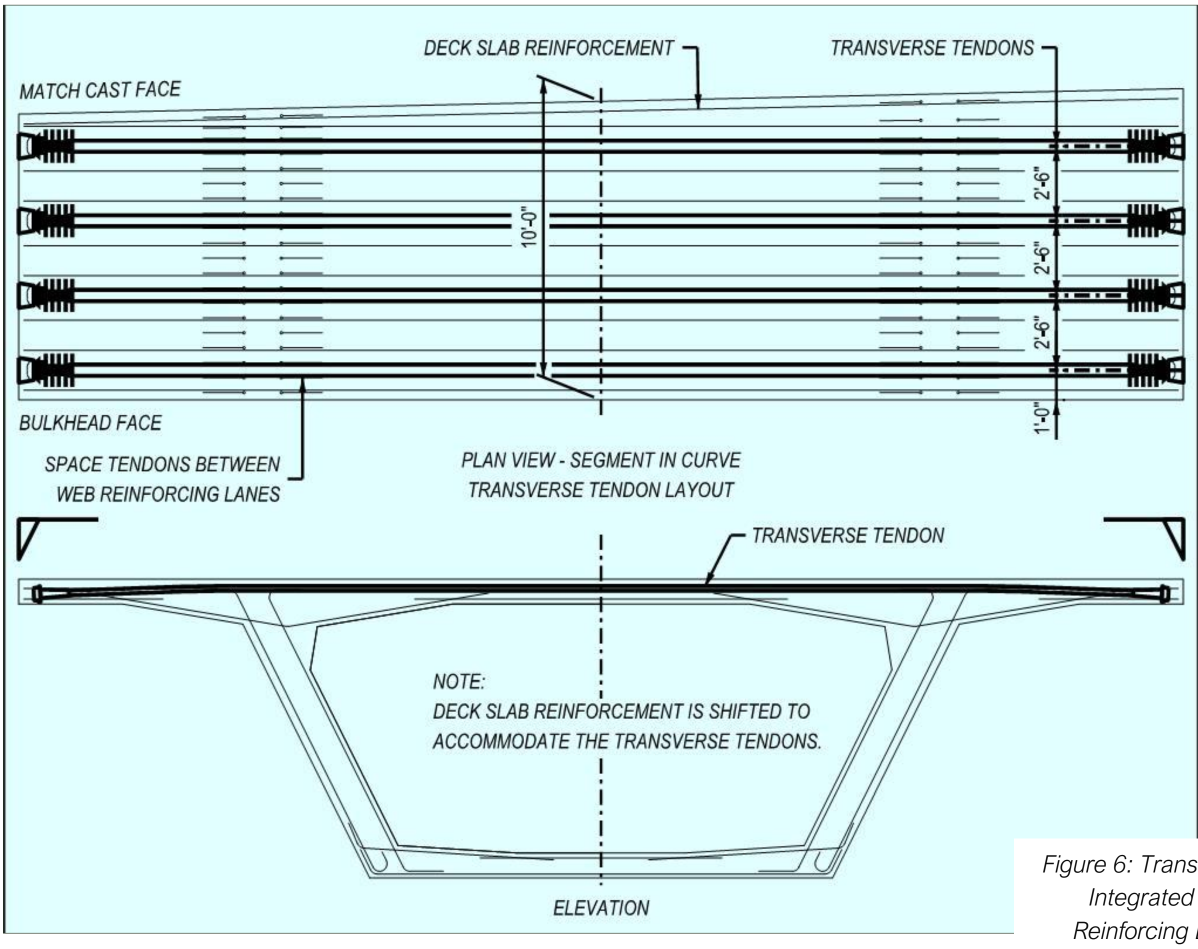


Figure 6: Transverse PT Integrated with Reinforcing Lanes

STRAND INSTALLATION. In dual box girders, transverse tendons are sometimes used across the in-situ closure. This detail has complications and should be discouraged. Strands cannot be reliably fed through a flat duct after is has been cast in concrete because the duct is often flattened (even flatter) during concreting.

Secondly, accumulated tolerances between the segments create significant misalignments across the closure. If a bridge deck really requires post-tensioning between two barrels, consider round duct to address both of these challenges with what is ultimately, a modest difference in duct size.

Figure 7: Dual Box Structure with in-situ Closure. Veterans Memorial Causeway. Courtesy of Reed & Reed Construction

VI. LONGITUDINAL PT: TOP SLAB TENDONS

Avoiding or minimizing the number of tendons in the deck slab can improve a bridge's lifespan. Similarly, the details related to the top slab PT are equally important in the structure's durability.

BLOCKOUTS. The most common example of longitudinal tendons in the top / deck slab are cantilever tendons. These tendons are typically anchored at the joint face. In order to orient the tendon to the bulkhead, anchorages are mounted to a recessed blockout.

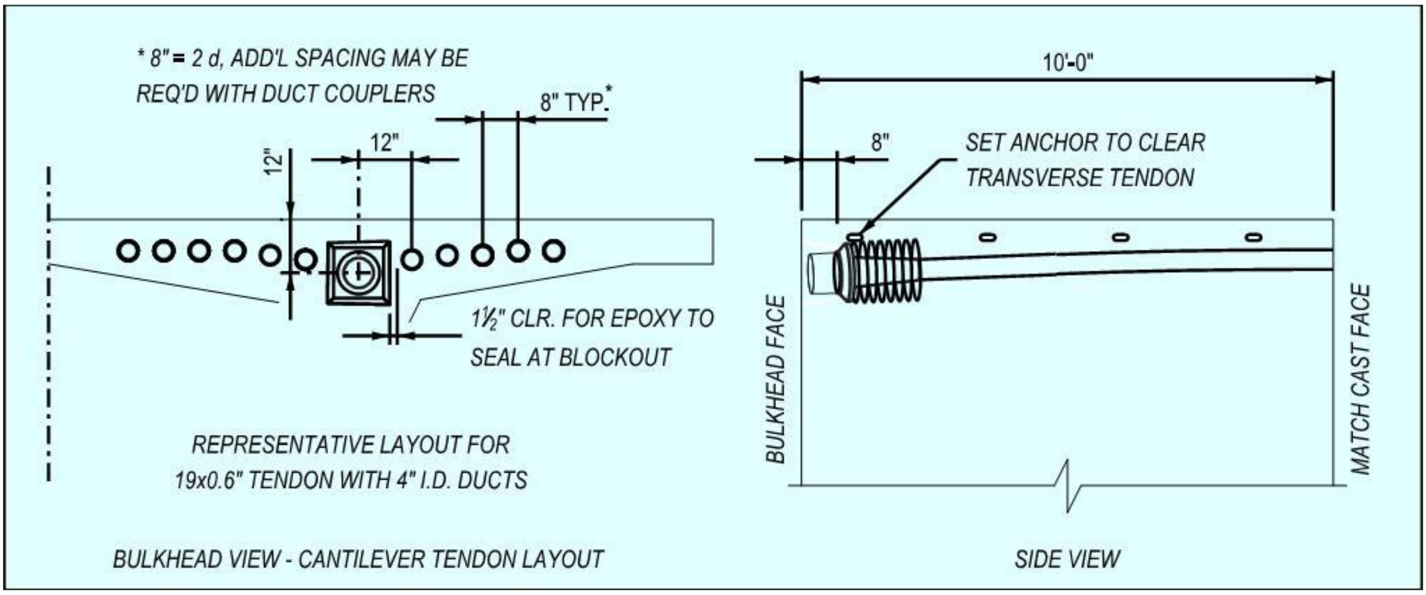


Figure 8: Cantilever Anchor Layout

This recess should be deep enough to contain the entire grout cap, consequently it consumes a significant amount of space on the bulkhead.

Just as with a duct located along any other face, it is important to provide adequate clear cover to the blockout to prevent water or grout leakage to and from the ducts.

LAYOUT. Set the cantilever anchorage low enough to clear the transverse tendon. In some cases, anchor spirals have been found to conflict with the first transverse tendon.

This is a problem for a number of reasons including the reduction in anchor confinement, the potential to crush the transverse tendon, and the sheer nuisance to the builder.

TOP CONTINUITY. Avoid the use of top slab continuity tendons and associated anchor blocks.

This is particularly relevant in form traveller construction, where the core-form beams are typically larger, longer, and may extend into the previous segments at a skew.

REINFORCEMENT. The duct layout should consider the reinforcement and related fabrication tolerances. As outlined in Section X. below, lowering the ducts in and around the web reinforcing addresses a number of problems with a minimal effect on the tendon eccentricity.

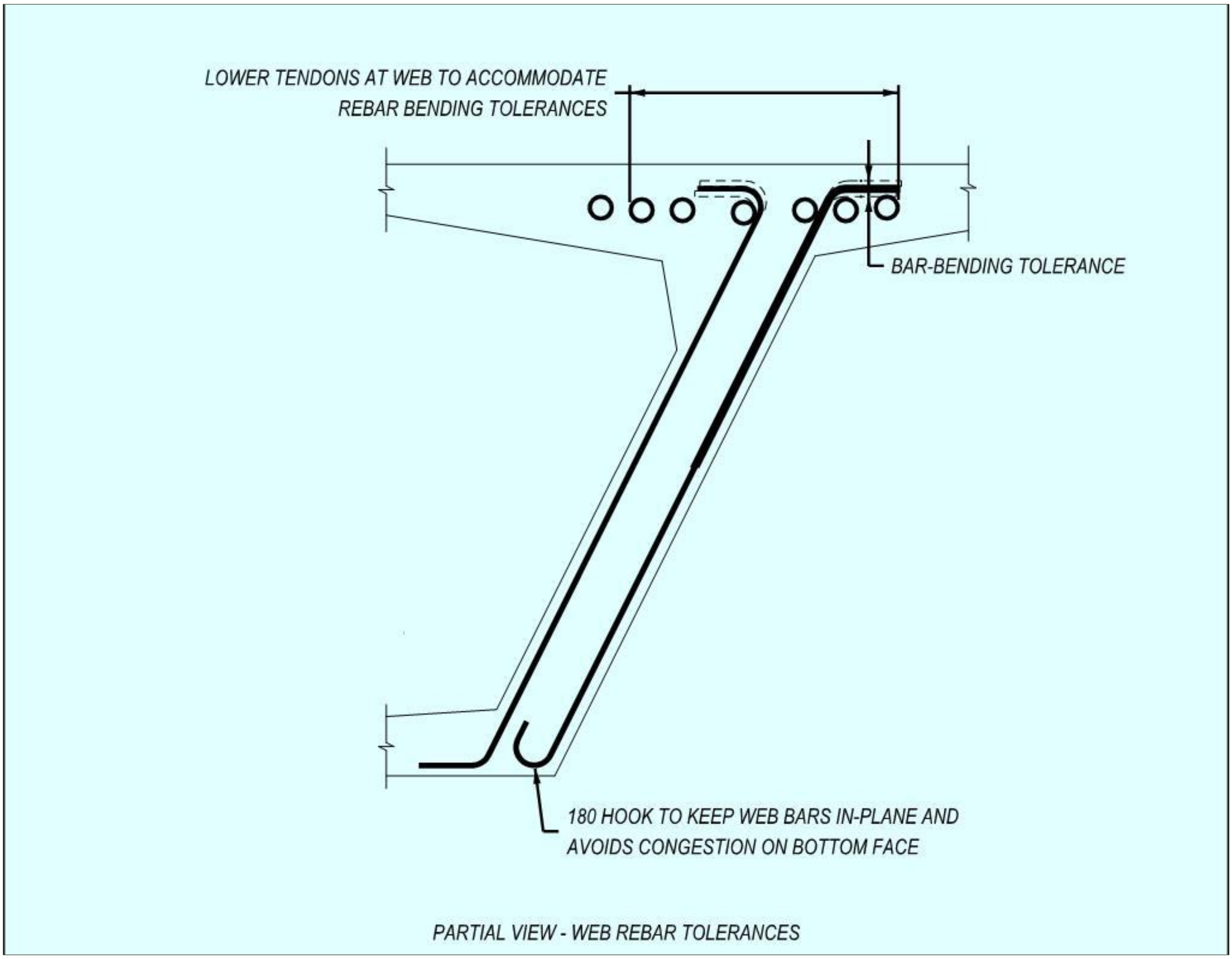


Figure 9: Web Rebar Tolerances

Figure 10: Web Rebar Tolerances. Upper Ducts lowered (slightly) at full Height Stirrups for rebar tolerances. Hong Kong Mtr South Island Line. Courtesy of Leighton Construction

VII. LONGITUDINAL PT: BOTTOM SLAB TENDONS

LAYOUT. While there are exceptions to every rule, fixing the bottom slab tendon layout and anchor block geometry from the inside corner of the box girder can standardize many details.

With this approach, the relative geometry between the anchor block and the duct-runs remains consistent while the depth of the girder varies.

SLAB THICKNESS. Consider making the bottom slab thickness constant through the anchor block segments. In variable depth box girders, specifically balanced cantilever with form travellers, there is a natural instinct to vary the bottom slab thickness in parallel with the girder depth.

However, tapering the bottom slab down to its minimum thickness prior to the anchor blocks is an effective approach in simplifying the design.

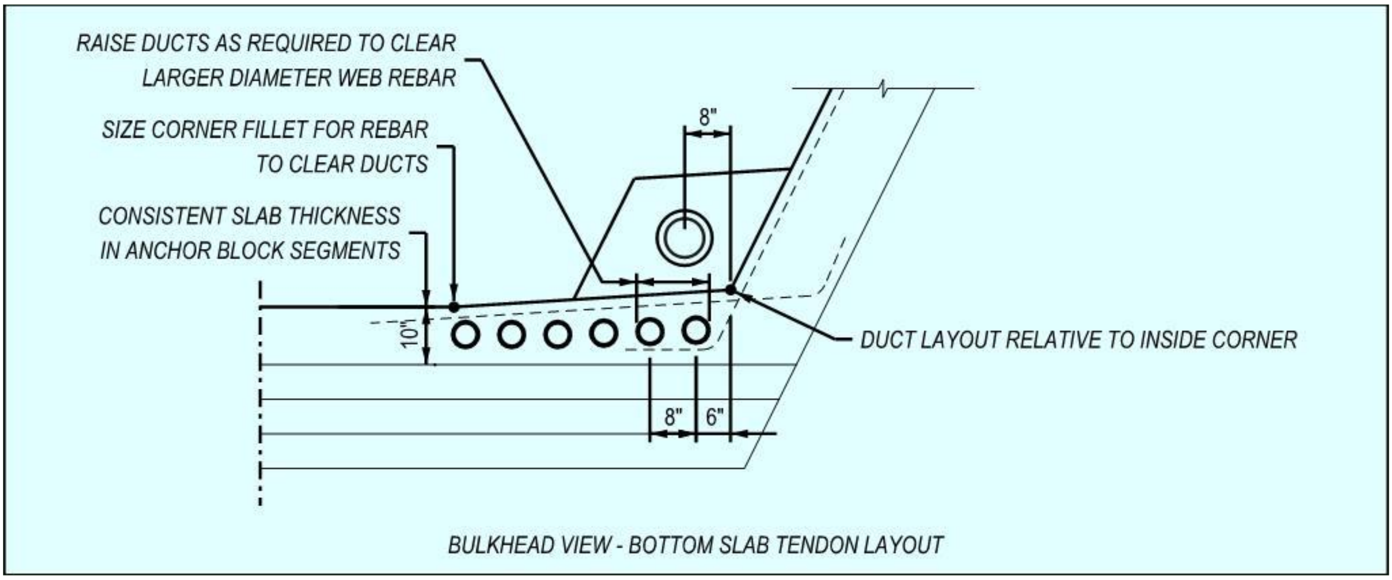


Figure 11: Bottom Duct Setout

REINFORCEMENT. Check for conflicts between the web reinforcement and the duct layout. The webs typically require larger diameter rebar than the bottom slab. For that reason, it may be necessary to raise the ducts located over the web bar legs.

Finally, verify that the first duct is set far enough from the web to allow for any plan curvature at the anchor.

DUCT GEOMETRY. Aim the anchorage slightly inboard for jack access. This is important in curved bridges where the web in the next segment may encroach on the jack envelope.

The tendon profile at the anchor block should allow for PT system radius and tangent requirements. The bend radius should be measured in the plane of the curve.

Fitting the requisite tangent and radius for a 19 strand tendon into a 3m long segment can be challenging. Specify 'tight radius' duct where needed.

This duct has corrugations that permit smaller bending radii without buckling and caving.

Some ducts can also be heat-bent to achieve small radii.

The last resort is using pre-bent steel pipes. Being aware of and designing within the radii that can be achieved with corrugated plastic duct should be the goal for cost-effective design.

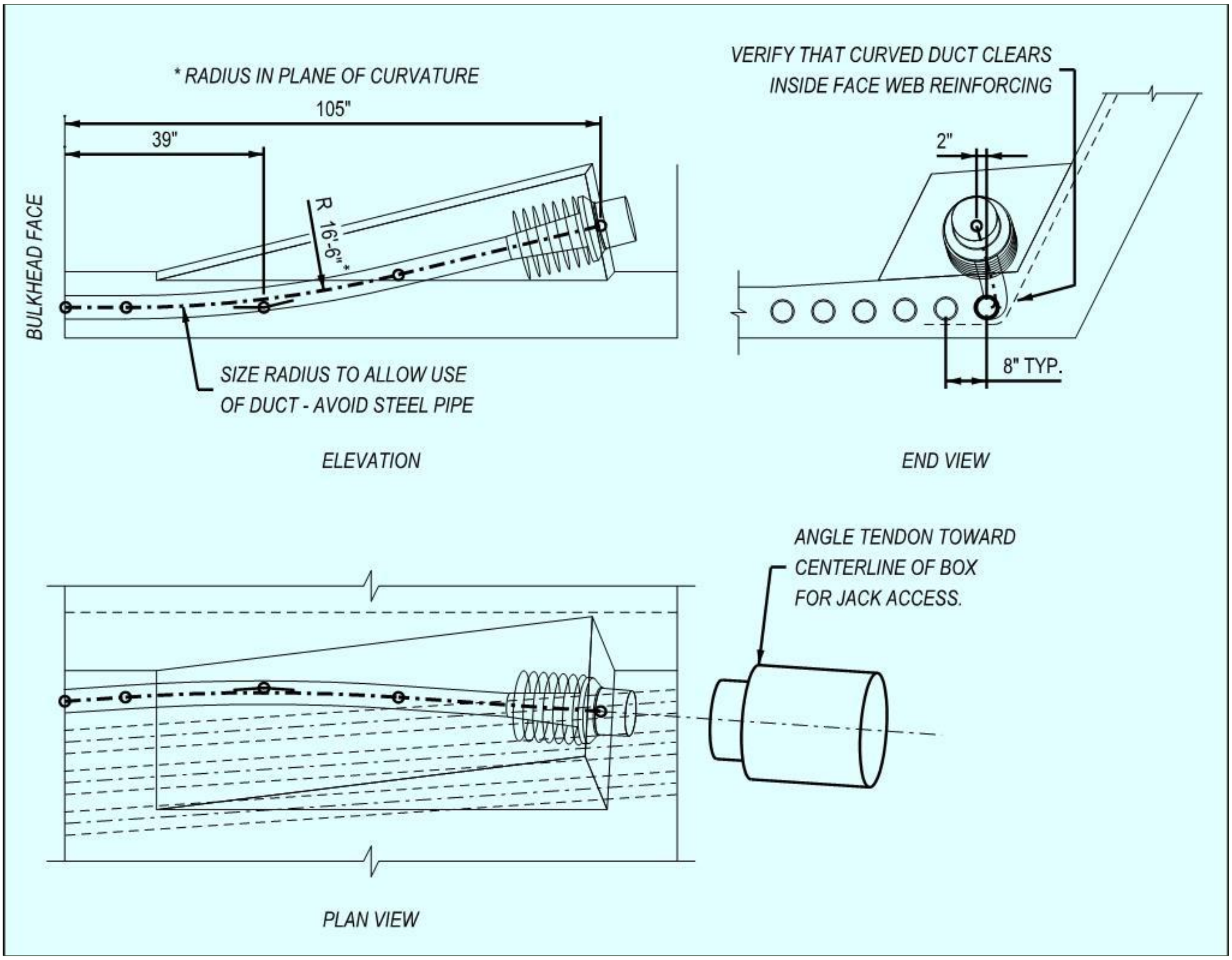


Figure 12: Bottom Duct Profile

VIII. LONGITUDINAL PT: WEB TENDONS

While very common in traditional post-tensioned construction, web tendons are not often used in precast segmental bridges. However, there are two situations where web tendons are sometimes used.

First is to supplement or eliminate bottom slab continuity tendons. Second, is to provide some form of bonded continuity steel across the entire span – seismic requirements for example.

In these cases, the most practical approach is to anchor the web tendons in pier or expansion segments and run them pier-to-pier, thereby avoiding unique anchor blocks.

In order to have a rational duct arrangement on the bulkhead, the tendons should use an angular or 'deviated' profile – not draped profiles. Furthermore, use a profile that is coordinated with the shear key arrangement, or coordinate the shear keys with the duct holes to avoid altering the bulkhead during casting.

In the situation where web tendons are used in conjunction with anchor blocks, avoid locating anchor blocks in-plane with the web tendons. The web and bottom slab tendon will inevitably slope at different angles, which prevents the anchor block reinforcement development into the web.

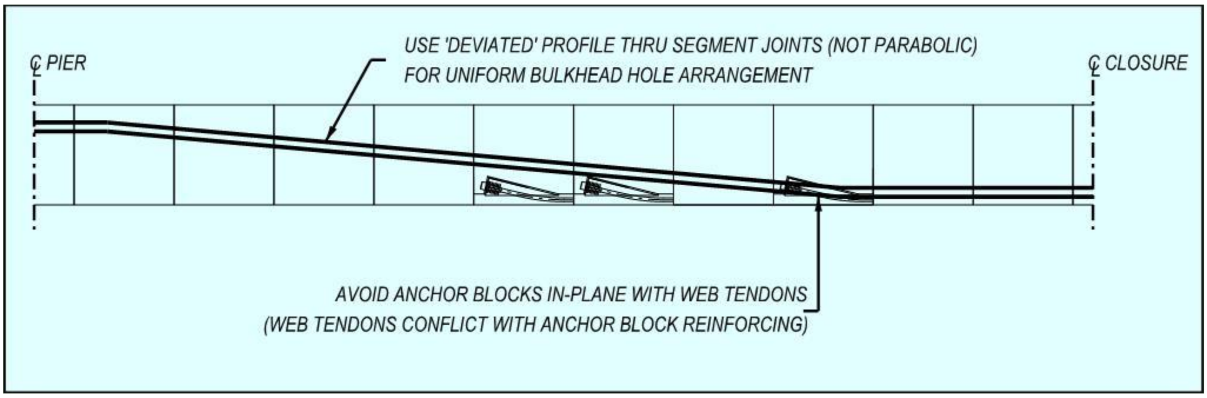


Figure 13: Web Tendon Profile and Bottom Blocks

IX. LONGITUDINAL PT: EXTERNAL TENDONS

For those wanting potentially replaceable post-tensioning, external tendons are the answer. The Florida DOT Bridge Design Manual provides some of the best advice for these details.

DEVIATOR. A point of debate between experts is diabolos vs. pipes. For smaller quantities, pipes may be more economical. Pipes are also smaller. On the other hand, pipes can and do get placed incorrectly, which requires expensive re-work to correct.

When laying out the tendon paths, be aware that diabolos require more space since they flare out in 360 degrees.

Furthermore, diabolos without stay-in-place plastic formers require more stringent clear cover requirements between rebar and the diabolos. That said, a well thought out design with diabolos is relatively fool-proof with only the up-front cost of the formers.

CONFLICTS. One consideration for any design with external tendons is to verify that the external tendons have a clear line-of-sight between deviation points. Confirm that the tendons do not hit other anchor blocks.

In curved structures, check that the tendons do not hit the web walls. Where structures are on tight radii, it may be necessary to add an additional deviator to guide the tendons around the curved span.

X. BOX GIRDER REINFORCEMENT

To paraphrase the theme of Section IV. above: "Use Common Denominators." Simply spacing the reinforcement together at regular intervals goes a long way to simplifying construction.

The answer to "why not mix spacings if it saves a few bars" is that it becomes necessary to shift some bars out of their nominal spacings to mesh with the other set, leading to localized congestion and conflicts.

Space rebar at common denominators; i.e. 15 and 30cm work together, but not 15 and 20cm.

Once the reinforcing lanes are established, the key to constructability is the web reinforcement. PT anchors, anchor blocks, transverse tendons, and construction embeds all gravitate to the webs.

Furthermore, the web reinforcement is a full-height shear stirrup which is sensitive to bending and placing tolerances.

TOLERANCES. Rebar fabrication tolerances should be a primary consideration in detailing. The fabricated bending tolerance on most bars is +/-25mm per leg. Tighter tolerances can be specified but keep in mind that there is no magic, tolerance setting on the bending machine. If the design requires tighter tolerances, this translates to more rejected bar and associated cost.

If a bar is constrained by clear cover at each end, the logical approach is to detail the bar 25mm short of the nominal length and verify that the details can accommodate the tolerance.

Sometimes the clear cover tolerances help. And sometimes the bar tolerances can be absorbed at two faces and the effects are minor. With web reinforcing however, the bars are typically supported on chairs on the soffit slab, which requires all of the tolerance to be taken up at the top face, where the bar legs are constrained between the clear cover and the cantilever ducts.

A simple solution is to lower the ducts within this area to clear the bar tolerance envelope. While this lowers the eccentricity of some tendons, consider that it is likely a small number of the tendons, moving a small percentage of the overall depth so the effect is minor.

NESTING BARS. Give consideration to the bends and orientation of the web bar tails. In order to minimize congestion and make room for other reinforcement, it preferable to keep the web bars in-plane with each other. Use 180 degree hooks where appropriate to avoid bundled legs.

RE-ENTRANT CORNERS. Be thoughtful when detailing reinforcement at re-entrant corners. For example, the inside web face often has a fillet. Reinforcing this face with a single bar is not advisable.

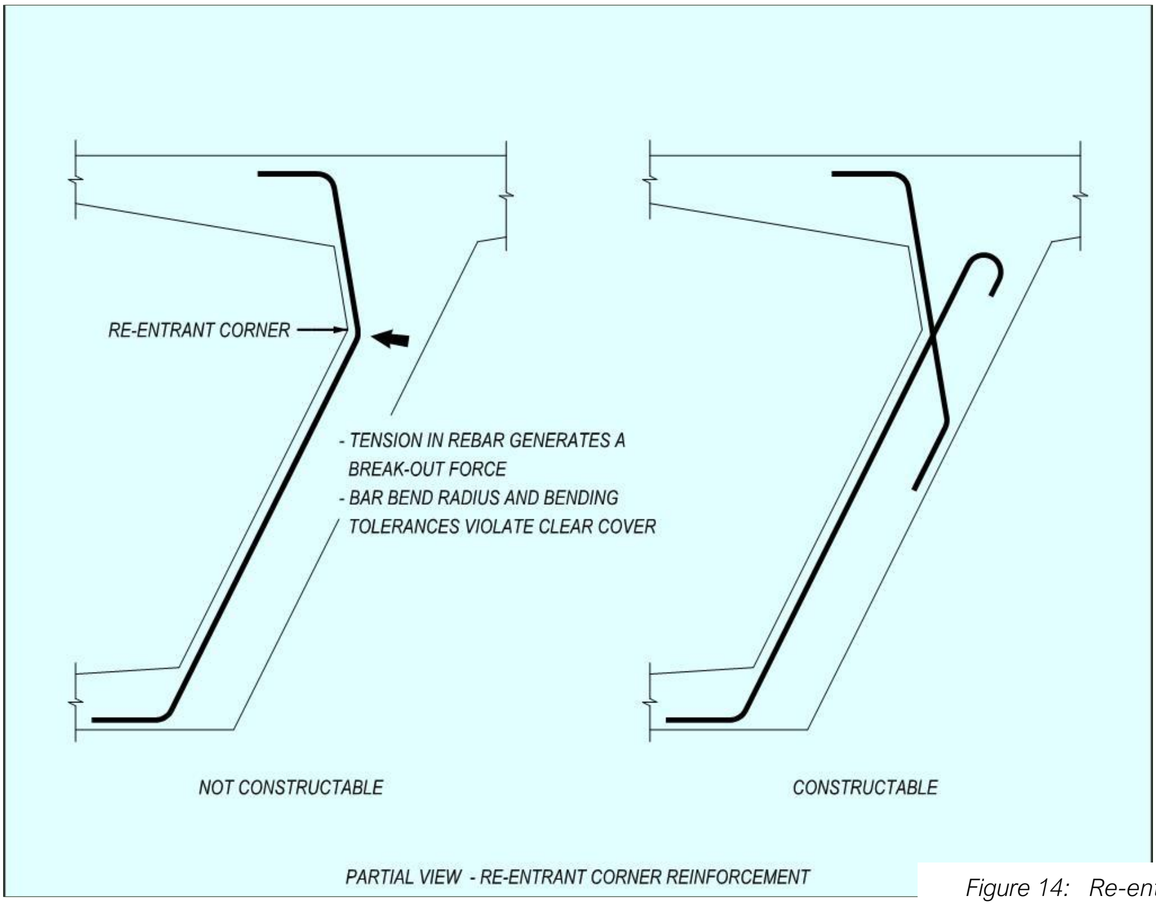


Figure 14: Re-entrant Corners

Consider that when this bar is in tension, it will want to straighten and pop-out the cover concrete at the corner. It is preferable to use crossing-bars which develop beyond the corner.

TENDON PASS-THRU. Where tendons pass thru reinforcing mats, the design should specify how. Note that the tendons in anchor blocks typically slope at 12-15 degrees. At this angle, the duct can conflict with rebar over a length of 60-90cm.

Simply shifting bars longitudinally to clear the conflict is not practical because it displaces too many bars and leaves a large gap.

In most cases, it is preferable that the cross-thru details are modifications (by moving, bending, or cutting) to the typical reinforcing as opposed to introducing unique bars at specific locations.

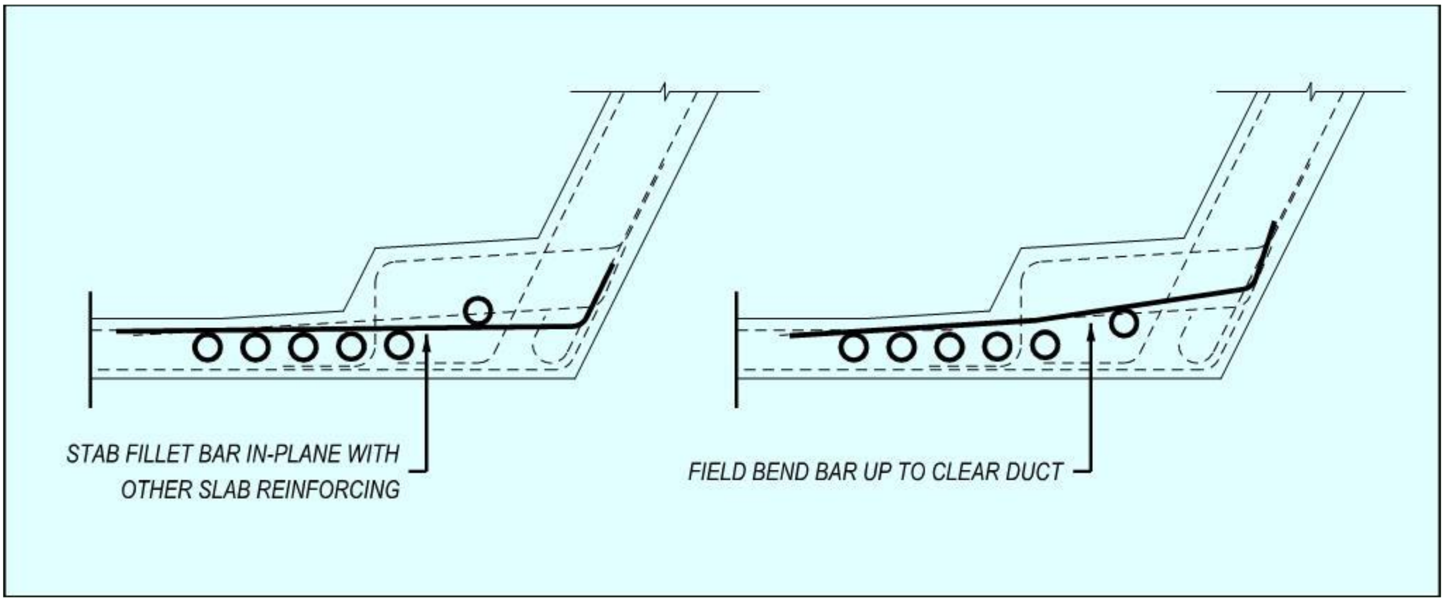


Figure 15: Top Mat Bars at Cross-Thru (with fillet)

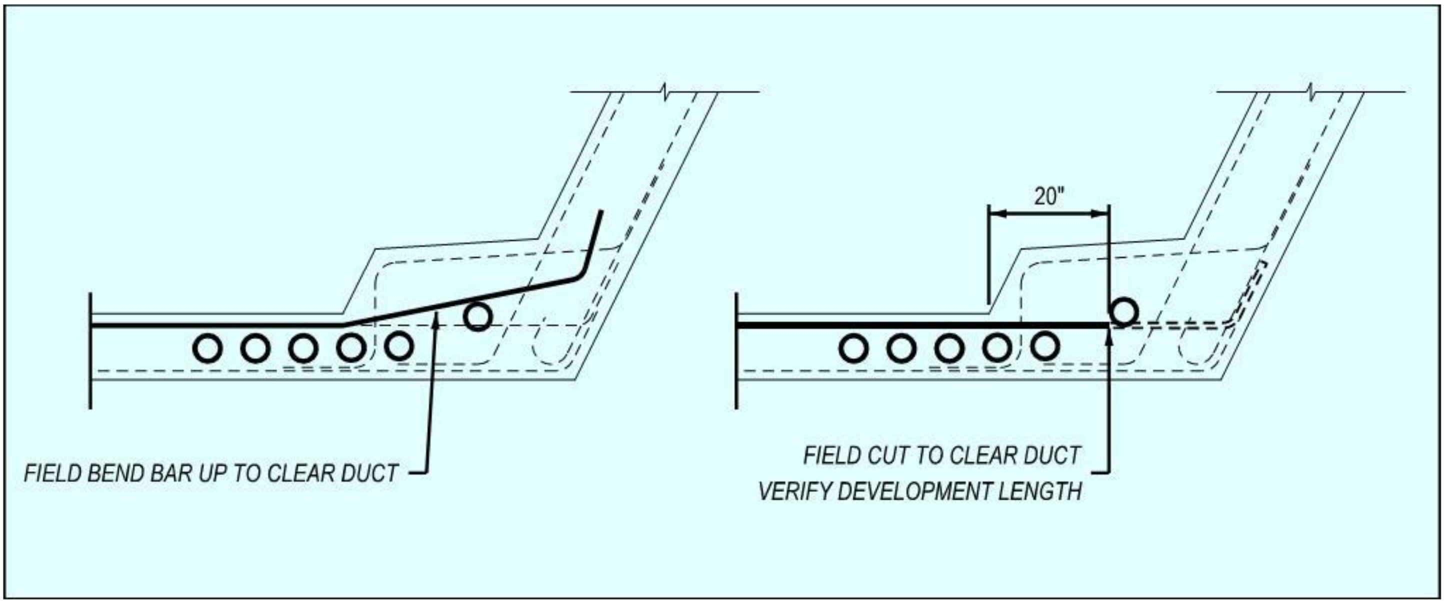


Figure 16: Top Mat Bars at Cross-Thru (flat slab)

LONGITUDINAL REINFORCING. An additional topic to highlight is the treatment of longitudinal reinforcing in curved segments. In cast-in-place construction, the bars are detailed long enough to satisfy the lap splice requirements on the outside of the curve and the extra length on the short side is taken up in the lap splice.

In precast segments, the detailing of longitudinal reinforcement becomes complicated. Longitudinal bars are broken into sub-sets in order to graduate the lengths across the width of the segment.

Otherwise identical reinforcing cages but with slightly different plan-view geometry, become different reinforcing types, requiring additional drawings and submittals, not to mention more time spent sorting bars on-site.

Given that segment cages are pre-tied in jigs, it would be reasonable to detail all the bars long, tie them in the cage, and then cut them to match the pie-shape of the specific segment. This would streamline shop drawing process and potentially simplify fabrication.

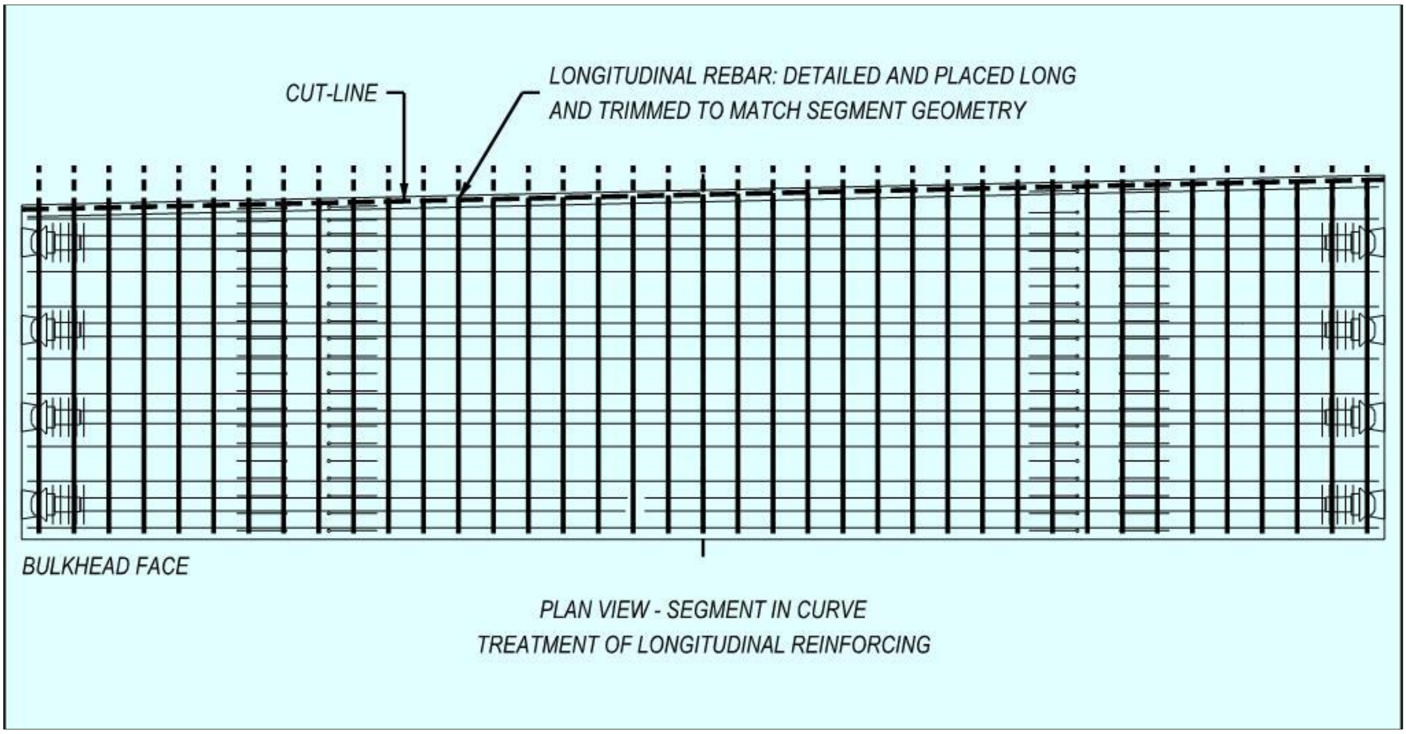


Figure 17: Treatment of Longitudinal Bars

XI. ANCHOR BLOCK REINFORCEMENT

Before reading any further, prepare to go 'deep in the weeds'. In order to lessen the headache, refer directly to the appendix for an example of an anchor block that addresses the challenges.

CONGESTION. Anchor blocks typically have two sets of bars (outer confinement + inner tie for curvature), which mesh together with the web reinforcement (2 faces) and slab reinforcement (2 faces).

Altogether, this can translate to six bars which must pass each other. Many of these bars may have legs on the same face, creating 'walls' of bundled rebar.

These zones of bars are problematic for placing concrete, prone to spalling, and do nothing to develop the reinforcement. There are several techniques to address this.

- Place the web reinforcement in the same plane. Turn the leg on the inside-face web bar toward centerline of segment. If the leg on the outside-face web bar contacts the inside-face reinforcement, consider using a 180° hook.
- Place bottom slab reinforcement in the same plane. If the legs happen to conflict, shorten or place the top-mat bar to nest inside the bottom-mat bar.

- Turn the legs of the outer anchor block reinforcement away from the web. Full 360° or even 270° confinement of the anchor block is not necessary as the bottom slab and web reinforcement already exist on these faces and are waiting to be put to work.
- Consider the direction of the legs on the inner anchor block bars (i.e. the in-plane pullout reinforcement). Turning both legs the same direction and/or using 180 degree hooks may be helpful.

TENDON GEOMETRY. Anchor block reinforcement should be organized with thought to the actual tendon geometry. In most cases, the other tendons in and around the anchor block are not running parallel to the web.

Tendon paths should not be altered to snake thru the reinforcement. Instead, configure the reinforcement to the lanes between the ducts. There are several techniques to address this.

- Begin by designing the reinforcement around the typical (probably deviating) tendon arrangement.
- Slope the inside face of the anchor block. By varying the clear cover, the outer block reinforcement may be detailed to follow either straight or deviating tendon paths.
- Adjust the width of the in-plane pullout reinforcement as needed. Where these bars are tall, use a wide bar in order to straddle ducts running below. Where these bars are short, a narrow, top-hat bar is appropriate to avoid clashing with other ducts.

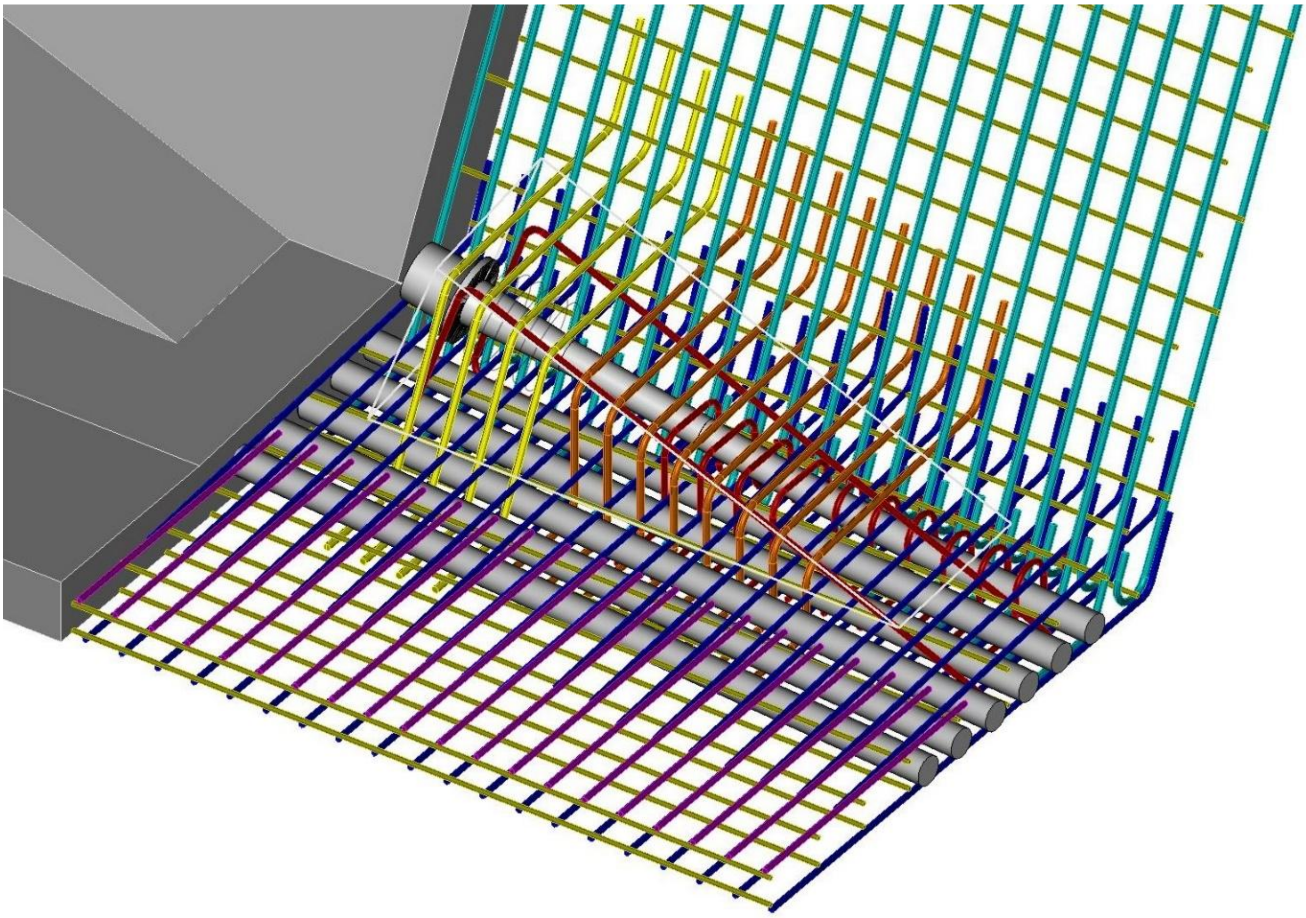


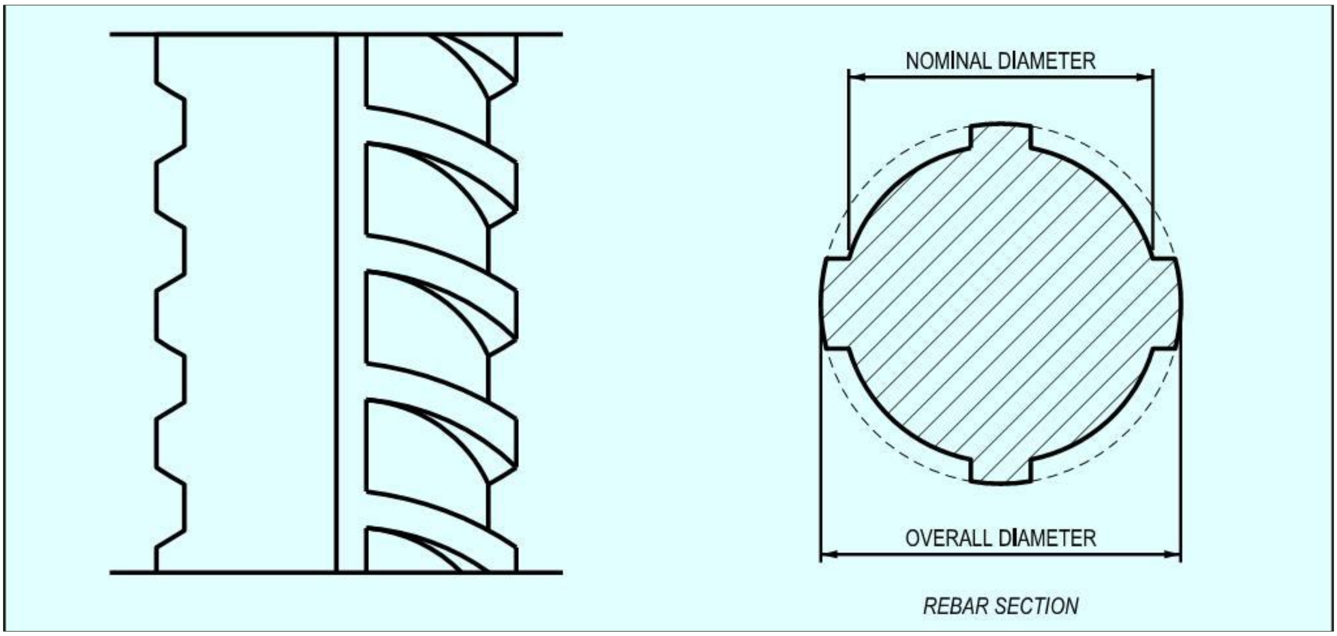
Figure 18: Anchor Block Reinforcement (see Appendix)

XII. DIAPHRAGM REINFORCEMENT

There are a number of different approaches to diaphragm design and this paper will not go into depth on the possibilities. However, the challenges found in diaphragm reinforcement are variations on others already identified. When presented a problem, engineers are good at finding fixes. For that reason, simply being aware of these issues goes a long way.

- Rebar Fabrication Tolerances
- Rebar Placing Tolerances
- Actual Size of Rebar and PT
- Actual Size of Bar Bend Radii
- Congestion (see Figure 19)
- Uniformity / Standardization

Finally, just to give the contractor a sporting chance, identify all of the intersecting bars, ducts, and other elements (with their overall sizes), and verify that they do indeed fit inside of the concrete. An allowance for placing tolerances is recommended too. Incorporating this analysis into the design process should be standard practice.



↖ *Figure 19: 'Real' Rebar Diameter*

← *Figure 20: Example of Congestion. Too Many Bars in Same Plane*

XIII. SUBSTRUCTURE CONNECTIONS

The details associated with the superstructure connection to the substructure have a significant impact on the constructability. This interface is typically at the bearings and in some cases the superstructure may frame into other types of construction.

Short closures are used to connect segments which are not match cast. However, when a segment is taken from one form and mated up with one from a different form, you can expect some degree of misalignment in the cross section and ducts.

BEARINGS. In precast segmental, where the structure requires fixity through the bearings, it is preferable to use a limited number of large pintles to transfer horizontal load to the bearings.

In these situations, the void for the pintle should be oversized to allow for grade and superelevation, as well as reasonable fabrication and placing tolerances.

These voids may be formed using 'cans' or it may be practical to void out a rectangular volume in and around the reinforcement using foam block. In either case, the pintles must be integrated with the reinforcement.

In cast-in-place construction, headed anchor studs may be a good option, provided again, that the stud layout is integrated with the reinforcement.

INTEGRAL STRADDLE BEAMS. Precast segments are sometimes cantilevered from straddle beams or similar CIP elements. In this configuration, set the first precast segment just off the straddle beam with a short closure, avoiding a complicated cast-in-place starter. Minor skews can be absorbed in the closure.

Larger skews can be cast into the starter segment. In the case of cantilever construction, most if not all, of the post-tensioning ducts are in the top slab. Rather than trying to cast ducts in precise locations in the straddle beam, set the segment slightly higher than the top of beam and cast the deck slab after the segments have been placed.

This avoids complications with tolerances as well as conflicts between the straddle beam stirrups and PT ducts.

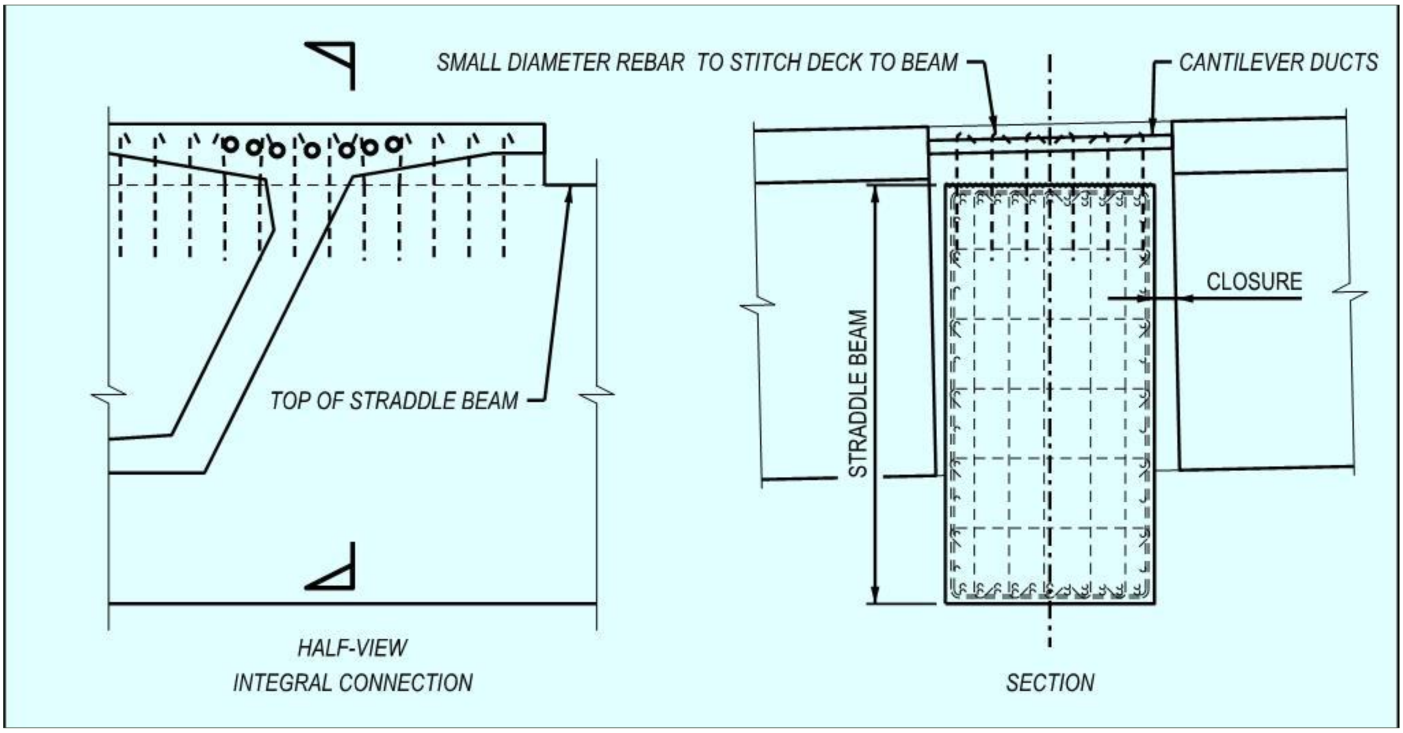


Figure 21: Straddle Beam Connection

Figure 22: Straddle Beam Connection. Top of Beam held low to allow Cantilever Tendons to pass over without conflict. Hong Kong Mtr South Island Line. Courtesy of Leighton Construction

Figure 23: Straddle Beam Connection. Top of Beam held low to allow Cantilever Tendons to pass over without conflict. Hong Kong Mtr South Island Line. Courtesy of Leighton Construction

INTEGRAL PIER COLUMNS. Making precast segments integral with pier columns presents challenges but there are a number of benefits. Integral connections can eliminate bearings and associated maintenance, provide robust connection for lateral loads (i.e. seismic), and can eliminate the need for temporary stability shoring.

Integral connections can be achieved several ways. Similar to the previous straddle beam example, the conventional approach is to construct cast-in-place pier segments and erect precast segments on either side with short closures.

This requires realistic expectations for the construction tolerances involved. For example, it may be prudent to thicken the in-situ cross section to minimize misalignments in the cross section in addition to incorporating means to accommodate duct misalignments.

XIV. PLAN PRESENTATION

Efficient construction requires good drawings. BRIM and 3D CAD tools allow us to create some amazing work, but as this is being written, there are still a lot of us humans involved in the process.

Modern drafting tools allow us to make drawing easier, and to balance that, it is important to be disciplined in minimizing drawings and details.

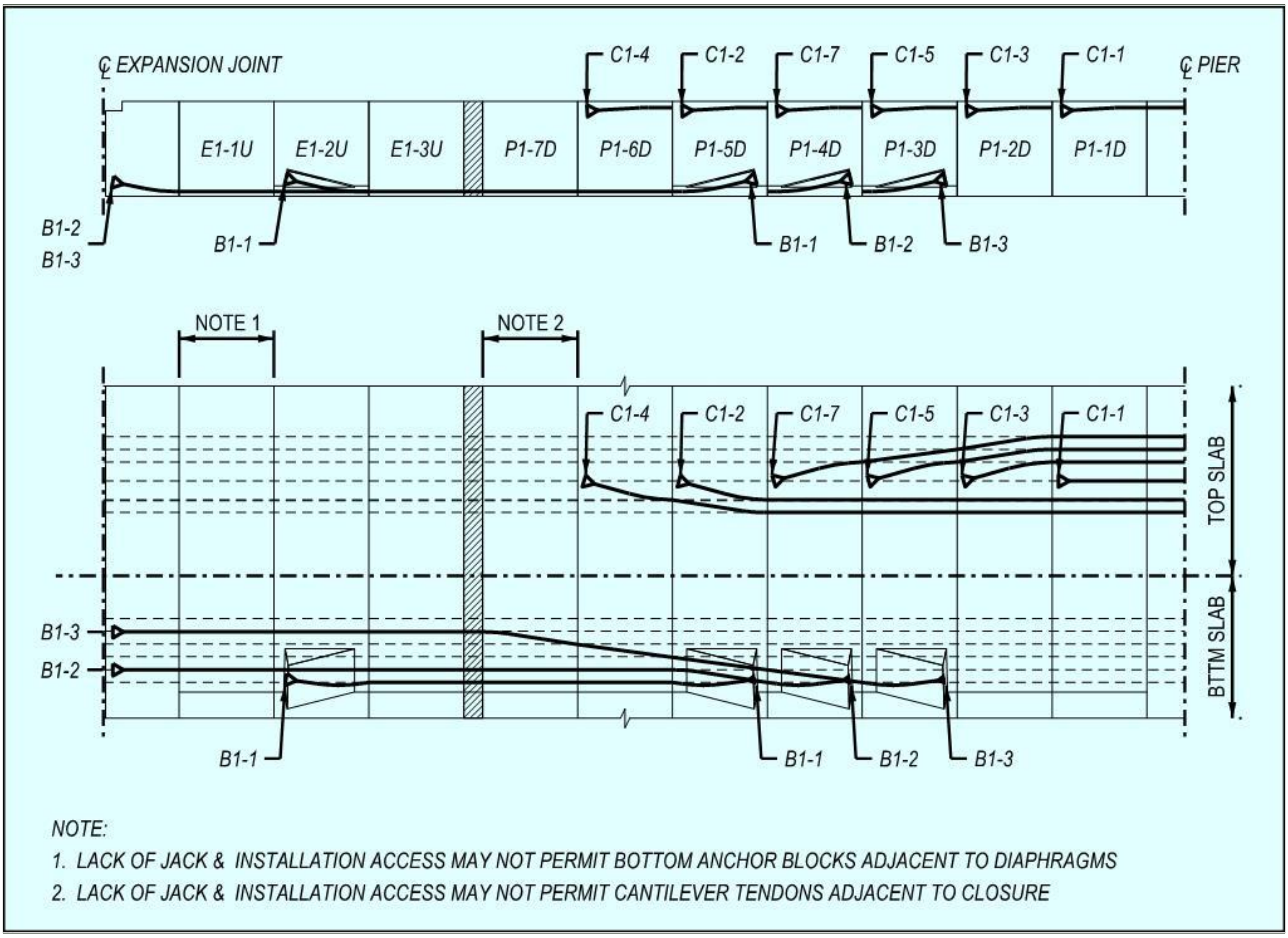


Figure 24: PT Layout Example

SYMMETRY. If something is symmetric, or even close to it, use half views. Showing redundant information invites confusion and errors. This also allows views to be larger and show details more clearly.

PT LAYOUTS. All longitudinal PT for a given segment should be shown on the same drawing sheet. Scale plan views in the transverse direction to better illustrate tendon geometry and neglect horizontal curvature. Last – call out each end of each tendon.

APPENDIX: 3D MODEL

The following page is a 3D pdf to illustrate some of the points discussed in this document.

The source DGN file is attached here:

3D SEGM.dgn 3D SEGM.dxf

I hope you find this document useful and Good Bridgebuilding!

DESIGN CONSIDERATIONS FOR GANTRY ERECTED BRIDGES

Matthew Williams, Jeremy Johannesen

McNary Bergeron & Associates

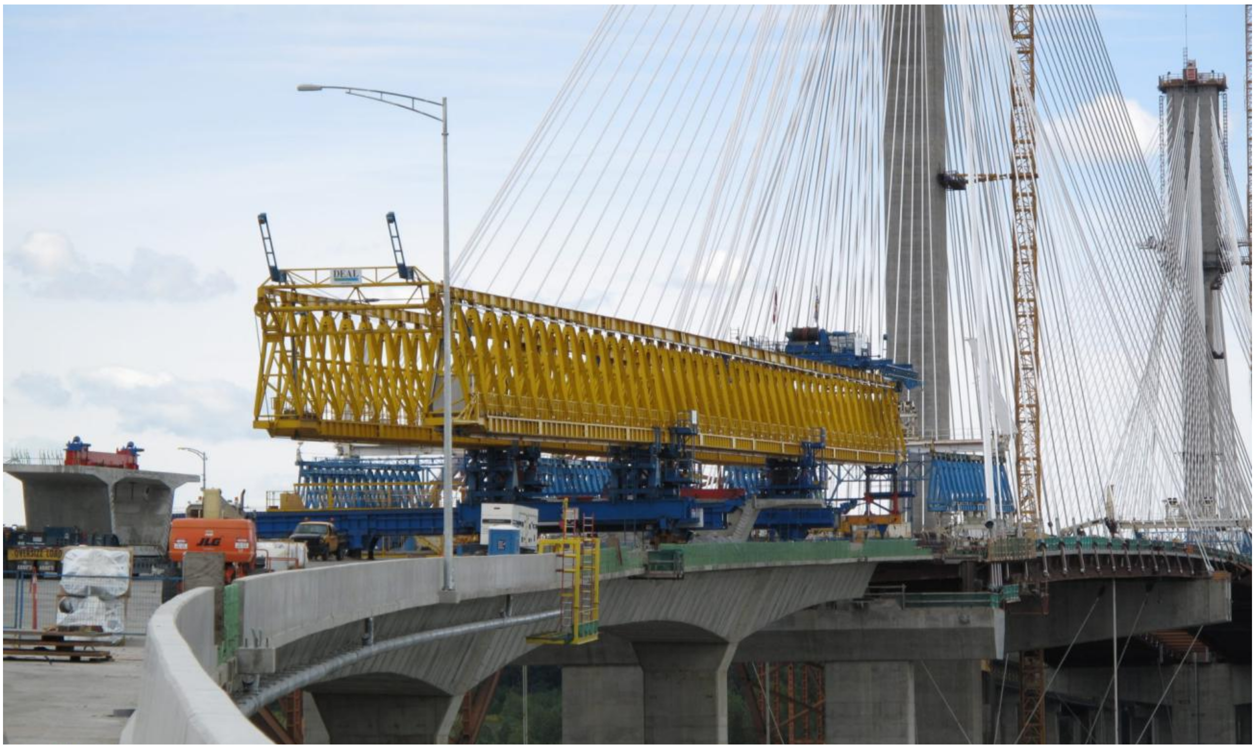


Figure 1: The L53 launching gantry erecting pre-cast segments up to the cable stayed portion of the Port Mann bridge in Vancouver, Canada

INTRODUCTION

Bridge gantries provide many benefits to pre-cast concrete bridge construction such as top down construction where everything is fed to the gantry from behind so that it never has to touch the ground as well as span erection cycles that are as short as a few days.

At the same time, launching gantries can also pose interesting challenges and unique loads for bridge designers.

Gantry loads are unique in two ways. First, the loads are unlike any other in-service loads given the size of the construction loads and their placement.

Second, gantry loads are being applied to an incomplete structure.

Both of these conditions can lead to novel loads and load paths that may govern the design of some bridge components.

The better these loads are understood during the design phase of a project, the less redesign will be required during construction.

What follows here is a breakdown of the typical construction loads a bridge will have to accommodate, organized by gantry operation.

Figure 2: Underslung gantry erecting the Susquehana River Bridge in Pennsylvania

GANTRY TYPES

The two most common types of launching gantries are overhead and underslung gantries. Overhead gantries stand on top of the superstructure and the leading pier.

All launching takes place on top of the bridge and pre-cast segments or girders are suspended beneath the gantry.

Underslung gantries are supported by brackets mounted to the piers and support segments by the wings on top of the gantry.

Overhead gantries may be broken down further into conventional and articulating gantries.

Conventional gantries are generally comprised of two "main girders" that are parallel to one another.

Articulating gantries have a main girder used to hang segments from and a support beam that is used for launching the gantry.

The benefit of articulating gantries is their ability to launch through tight radius curves.

The L122 articulating gantry (designed by DEAL) is shown in Figure 4 on the following page navigating a 124m (407ft) radius horizontal curve on the HART Light Rail project in Honolulu, Hawaii.

Figure 3: Conventional Gantry Erecting Red Line North in Doha, Qatar. DEAL L107 Gantry

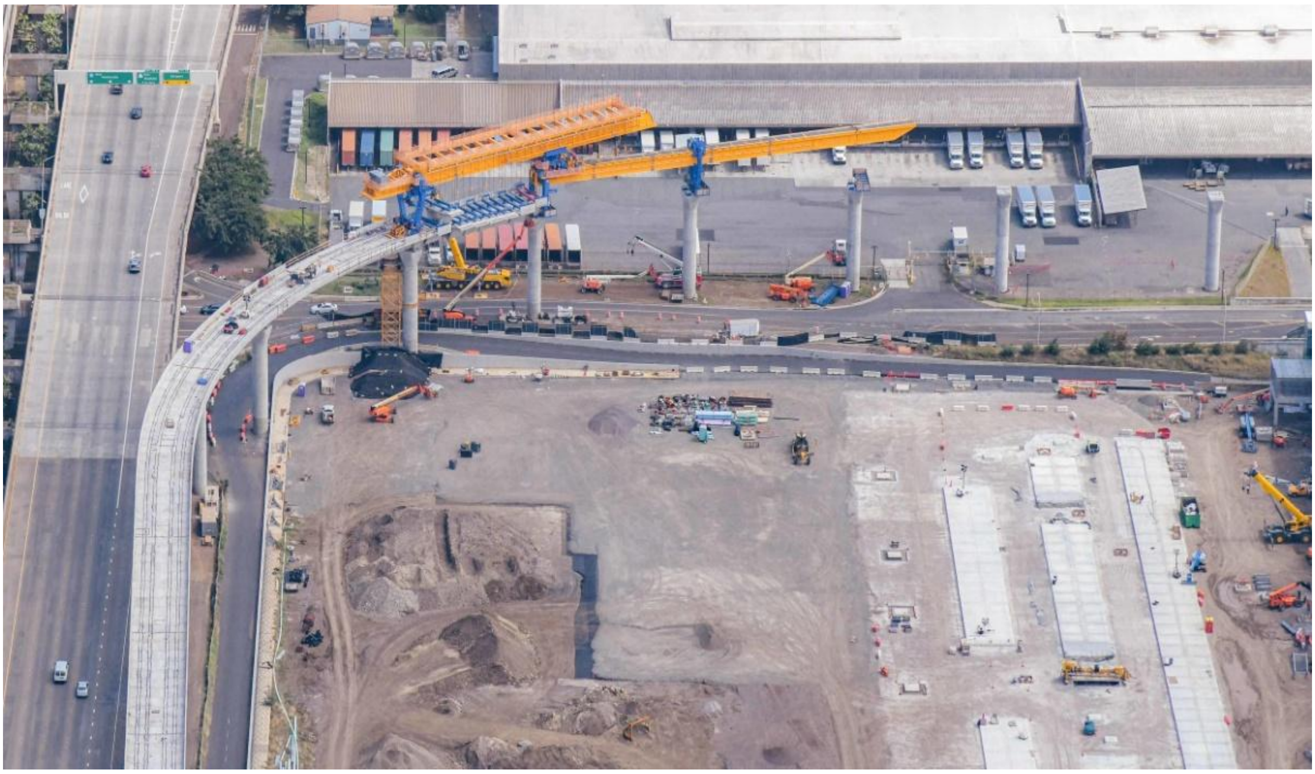


Figure 4: Articulating Gantry erecting the HART Light Rail in Honolulu, Hawaii. DEAL L122 Gantry

GANTRY ERECTION

The first loads imparted by a launching gantry occur during the assembly of the equipment.

Launching gantries are typically erected with the front support on the leading pier and the rear support on either a previously erected span or on falsework.

The falsework tower shown here on the Seattle Sound Transit project is tied to the rear pier to ensure longitudinal stability of the tower and gantry.

SEGMENTAL CONSTRUCTION: SEGMENT ERECTION

Once the gantry is assembled and ready to use the construction can begin with the hanging of the segments. Segments are lifted via lifting holes in the top slab.

These can be either between the webs of a segment or outside the webs in the wings.

Lifting between the webs can induce top slab tension at the center of the segment which can be exacerbated by transverse post-tensioning in the deck.

Figure 5: A conventional lattice gantry with the rear support on falsework for the erection of the first span. DEAL L81 Gantry, Seattle Sound Transit, Seattle Washington

Figure 6: Segment lifting during the static winch load test where the winch is loaded to the weight of the heaviest segment plus 25%.
The segment shown here has several spools of post-tensioning strand to increase the weight of the pick.
DEAL L107 launching gantry, Doha, Qatar

Another troublesome spot can be the tops of the webs.

The secondary PT demand due to transverse post-tensioning adds to the moment from lifting the segment and can lead to cracking in the webs.

Usually, the cracks form on the inside face of the web, protected from the elements and can be self-healing once under service loading.

COMPLETING THE SPAN

After hanging all the segments in the first span a load test will be performed.

A typical load test involves overloading the gantry to 10% above the weight of the heaviest span to be erected by the gantry.

Once the load test is complete the segments are epoxied together and stressed with temporary post-tensioning.

Stressing the permanent post-tensioning presents a challenge for controlling stresses in the suspended span due to the continuous support of the launching gantry.

As the tendons are stressed, the span immediately begins to pick up in the middle. This upward movement allows the gantry to recover from the deflection it underwent while hanging segments.

A span/gantry analysis is necessary to understand how the stresses in the span change throughout the stressing sequence.

In this analysis, a model is developed that includes the span being erected, the launching gantry, and the hanging bars used to suspend the segments.

To control stresses during this process the gantry can be incrementally lowered in order to shed the span self-weight from the gantry into the bearings.

Figure 7: The L121 conventional launching gantry from DEAL completing a span on the HART Light Rail in Honolulu, Hawaii

This increases compression in the top slab as the span becomes self supporting.

Another approach is to change the tendon stressing order to better control top fiber tension. Some spans require both methods to be used together.

While it is not possible to avoid top fiber tension completely given the continuous support provided by the gantry during stressing it is possible to keep them within a reasonable limit.

LAUNCHING

With span construction complete, the gantry is now ready to launch itself to the next span.

Different gantries launch in different ways.

Conventional gantries typically have three supports, a front support, rear support, and an auxiliary support, that are maneuvered beneath the girder for launching.

Every effort is made to keep support placement over the webs in segments adjacent to the pier segments.

However, on tight radius horizontal curves, it may be necessary to place supports along the span to allow the gantry to navigate the curve.

Placing supports at midspan on a small radius curved span can lead to span stability concerns as the center of the loading could potentially be outside the footprint of the bearings.

This risk can be mitigated by providing optional tie-downs to hold the span down at the piers.

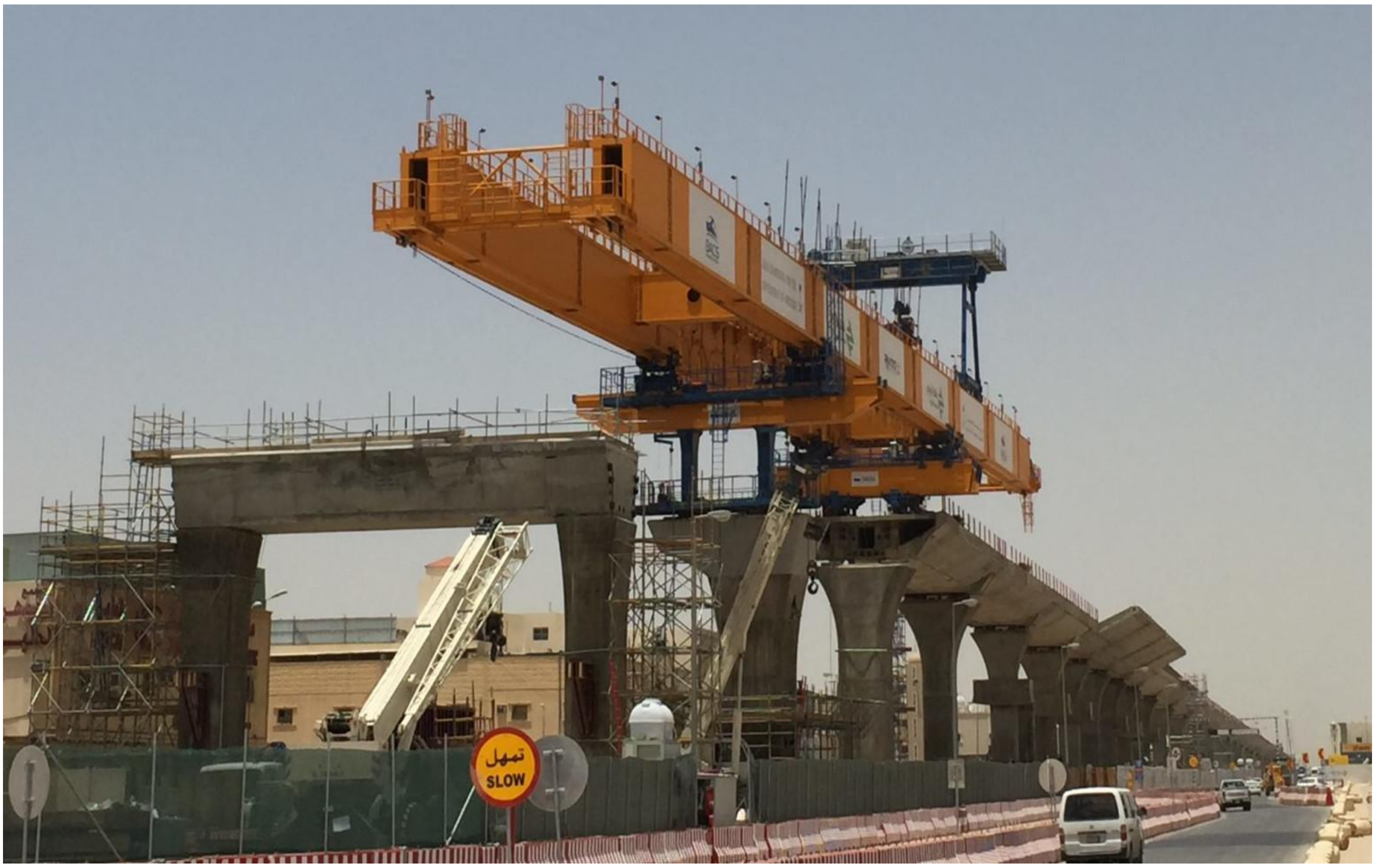


Figure 8: The L100 conventional launching gantry completing a launch in Riyadh, Saudi Arabia

Articulating gantries have a different method of launching. A front leg suspended from the support beam is placed onto the leading pier, and then the rear support rolls along the superstructure.

When the rear support has reached the end of the span, the front support and support girders are launched forward.

The wheels of the rear support are meant to ride directly over the webs, however, it is possible to get off-course and start loading the wings or haunch of a pre-cast segment.

Any offset from the center of the web induces a moment in the top of the web as well and may be compounded by the presence of transverse post-tensioning.

A steering tolerance should be checked with a transverse analysis of the segments.

Much of the loading from a launching gantry goes into the previously erected superstructure.

However, the front support of a launching gantry typically sits on the up-station side of the leading pier during span erection.

Large moments can develop in the pier as a result of the following factors:

1. Front supports are placed ahead of the pier centerline to ensure that there's room to set the span being erected.
2. The slope of gantry as it follows the bridge slope imparts a longitudinal load on the leading pier at the top of the front support, several meters above the top of the pier.
3. The slope load is increased by the gantry deflection under the weight of suspended segments. This can be as much as 2%.
4. Friction in the front support roller group can add another 1% of the vertical load acting longitudinally.

Figure 9: Gantry front support showing forward offset from pier centerline and the roller group supporting the main girders. DEAL L57 Gantry, Tyson's Corner, Virginia

Thus, if the gantry is erecting "up-hill" the slope of the bridge, deflection of the gantry, and friction in the roller group are all additive.

Conventional gantries have rollers on the front support to avoid being statically indeterminate. Longitudinal fixity is at the rear support.

As such, all of the moment inducing forces listed above must be resisted by the flexural capacity of the leading pier alone.

These loads can be significant and can potentially govern the design of taller piers.

Another concern with the longitudinal loads is the deflection of the pier itself. This can lead to locked-in deflection if the span is set directly on permanent bearings that aren't free to slide longitudinally (elastomeric bearings for example).

NON-TYPICAL SPANS

Erecting typical length spans with gentle horizontal curves produces predictable construction loads. Where launching gets tricky, and therefore applies loads on the permanent structure, is where span lengths vary widely from one span to the next.

Often gantries will have to set their supports at several locations along the length of the span to get set up for either a short or long launch.

Another launching concern is walkovers. This is where a gantry erects up to another span that has been erected with another method or at another time and launches over the completed span to arrive at the next span to begin erecting again.

Typically, this occurs where bridges have spans that exceed the design length for the gantry and have been previously erected by other means.

During walkovers supports will often be placed on typical segments away from the pier segments in order to make the launch.

Any time supports are placed on typical segments and not pier segments, the span should be designed to take the flexural, shear, and principal tension demands of the launch.

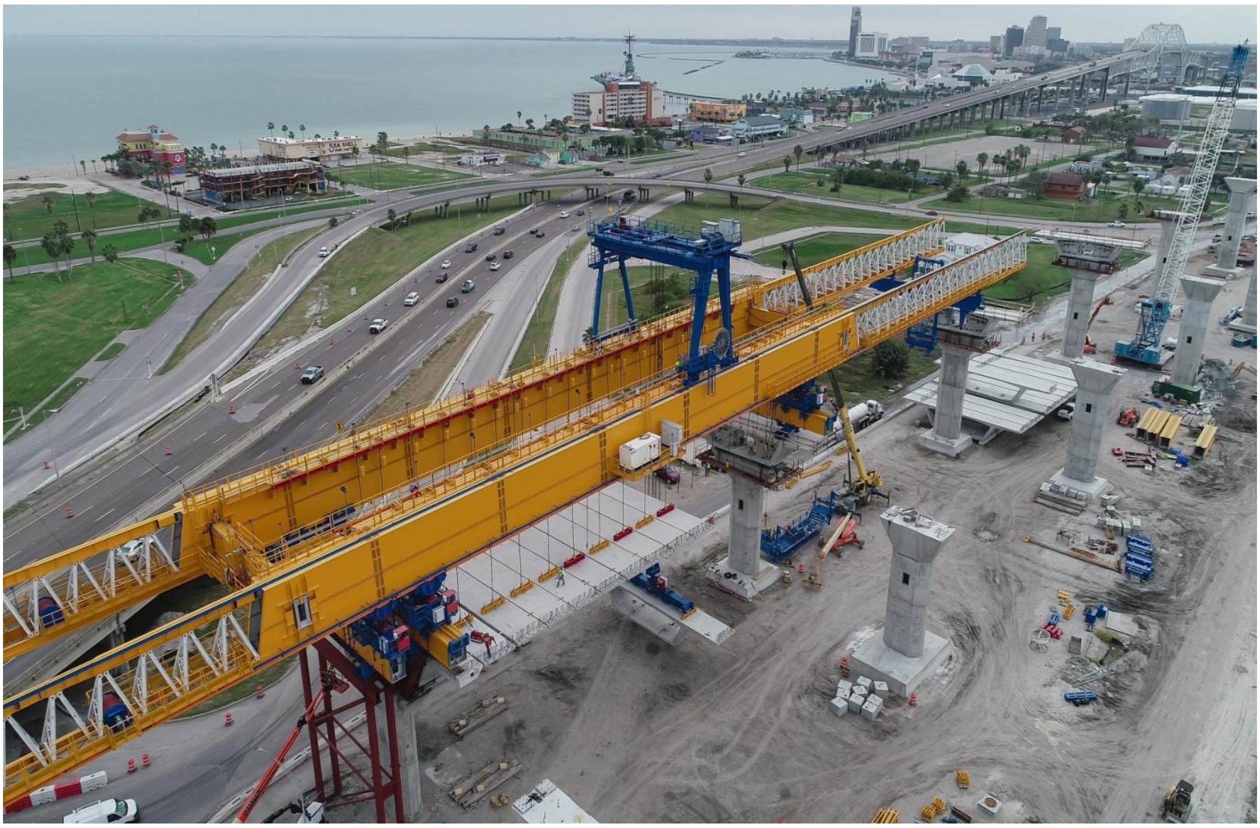


Figure 10: The L120 launching gantry (by DEAL) lifts the pre-cast concrete segments of the first span

WIND LOADS

A common concern among bridge owners and designers is with regards to the applicable wind loads that a gantry and bridge should be designed for. Bridge design codes require specific wind speeds and pressures to be considered while launching gantries are typically designed to overhead crane design codes that have a different set of requirements.

The launching gantry should be designed for the wind loads specified by the applicable crane codes while the bridge should consider the gantry as an appurtenance affixed to the permanent structure and use the applicable bridge wind loads in the design of the bridge.

On the Harbor Bridge project in Corpus Christi, Texas there is the potential for large wind loads given that the bridge is located on the Gulf of Mexico and the piers are upwards 45m tall.

The L120 launching gantry (designed by DEAL) is 160m long and 3m tall, giving it a large projected wind area.

The two major concerns that arise are the lateral loads on the pier columns and the stability of the span when the gantry is tied down for wind events.

To accommodate the large out of service (hurricane) wind loading, the designers opted to design specific locations along the bridge for hurricane winds on the structure and gantry together.

The piers and superstructure have increased capacity to accommodate the gantry should it need to be tied down a wind event.

This was a more economical solution than designing every pier for the out of service winds.

In the event of an approaching hurricane, the gantry does not have far to back launch to get to a safe place to tie-down.

CONCLUSION

In conclusion, launching gantries apply unique loads on both the super and substructures of bridges.

Wind and longitudinal loads on the piers can sometimes govern the design and stability checks of the bridge. Considering these loads during the design phase of a bridge project can eliminate costly redesigns later.

GEOMETRY CONTROL FOR PRECAST SEGMENTAL CONSTRUCTION

Joakim Dupleix, CaSE International (formerly VSL)
Martin Pircher, ABES

Figure 1: Closing of Mesaimeer Bridge main stay cable span, Qatar

PRECAST SEGMENTAL CONSTRUCTION

Precast segmental construction is a great method to limit the impact of the works on a bridge construction site.

By fabricating the concrete elements in a controlled environment, many of the unpleasant by-products of the construction site are also exported.

However, a key challenge of constructing elements remotely is to ensure they will achieve the required bridge geometry once erected on site.

Furthermore, the fact that the bridge is built “piece-by-piece” in segments, means that the geometry needs to be controlled and forecasted at every stage during construction, anticipating and forecasting movements and deflections during the temporary stages of the construction process.

Often bridges have varying curvature and superelevation which require tools to capture the geometry in all dimensions.

These tools must allow efficient and accurate ways to correct geometry imperfections: such as correction in setting out in the precast yard or shimming of segment joints during balanced cantilever erection on site.

Figure 2: Balanced cantilever construction

ABES SOFTWARE SOLUTION

ABES Pircher & Partner GmbH is an independent software house providing solutions for bridge engineering topics.

Together with VSL, they have developed a software suite dedicated to managing the geometry control of segmental construction at every stage of the construction process.

The software is split in 3 components which are all interrelated:

- geoDes, to be used in the design office to model the intended theoretical geometry of the bridge.
- geoCon, to be used in the casting yard, providing setting out and casting error compensation for any yard setup.
- assemCon, to be used on site to forecast the as-built geometry during balanced cantilever construction, based on real time survey results.

The software works fully in 3D, with a visual interface, which means it can control geometry in all directions, not only vertically.

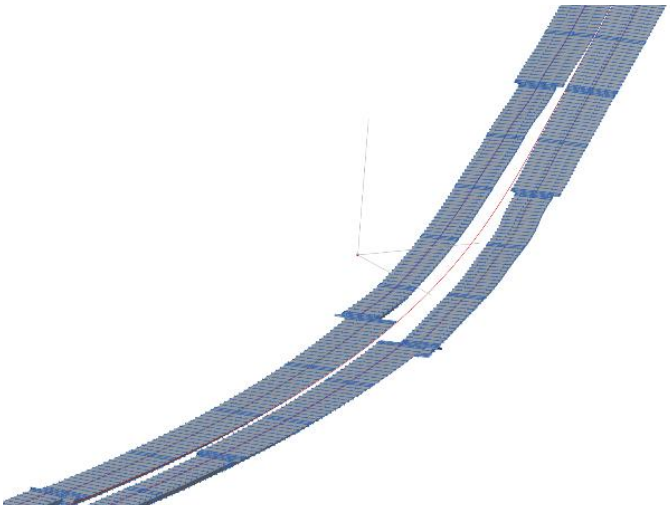


Figure 3: Snapshot of 3D model within ABES geoDes

The Figure below illustrates an example of a cross-section modeled in geoDes.

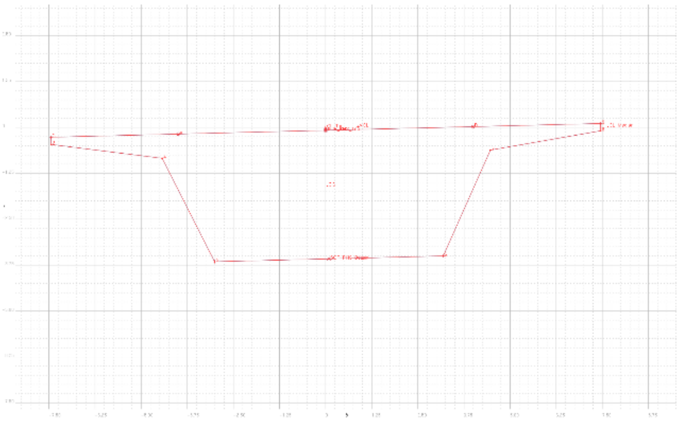


Figure 4: Cross section (inner void omitted)

KEY PRINCIPLES

The geometry control principles used by ABES are as follows:

- The theoretical modelling of the bridge defines a casting curve, in 3D, which is the "perfect" geometry of the bridge. This includes the camber of the bridge if defined by the designer.
- Each segment is recorded in its entire three-dimensional shape and identified by a minimum of 4 control points, which are physical survey items to be cast anywhere on the segment.
- Segment shapes are prepared considering the specific requirements of the casting machines used in the yard.
- The position of control points in the wet concrete, which may vary due to placing error, defines the setting out curve.
- When segments are cast, movement of the formwork, the bulkhead, or the conjugate segment may induce deviations from the theoretical shape, this defines the "as cast" curve.
- Segment imperfections are compensated for during casting of sub-sequent segments. This is true for both short-line and long-line casting, or the combination thereof.
- During balanced cantilever erection, each construction stage must be monitored and compared to the deflected position of the entire bridge as defined by the designer. Again, geometric deviations need to be corrected for during sub-sequent construction stages.

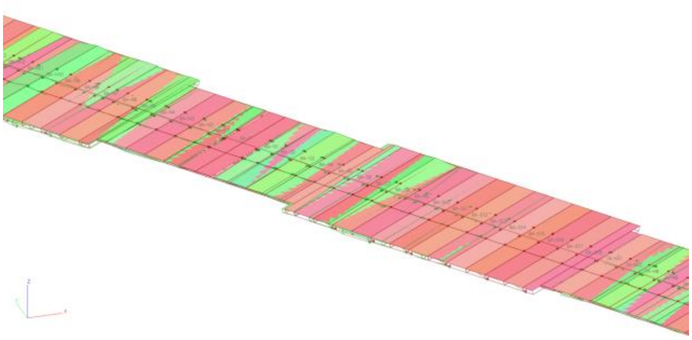


Figure 5: 3D interface showing theoretical (red) and as cast segments (green)

MAIN ADVANTAGES

Modelling

By modelling the bridge from base alignments, and with geometric rules derived from the specific capabilities of the casting cells, the software achieves the best constructable theoretical fit.

Multiple alignments can be accommodated, including deviation from the main alignment such as for ramps or train stations as required. Refer to Figure 3 above.

In the precast yard

When using geoCon, the software automatically compensates for the user the required setting out, according to the survey data of the previous segment.

This is key to ensure seamless casting operation and minimize operator error. Besides, benefitting from the 3D modelling, it always works in all three dimensions.

There is no limit to the number of control points per segment, ensuring high accuracy.

Another key feature for a stay cable bridge, pipes must be cast in advance into the segment in the yard to achieve the final geometry after all deformations have occurred.

The software can transform the theoretical pipe coordinates, adjust them for cambers and segment imperfections, and display them in the local coordinate system which can be processed by the surveyor in the yard.

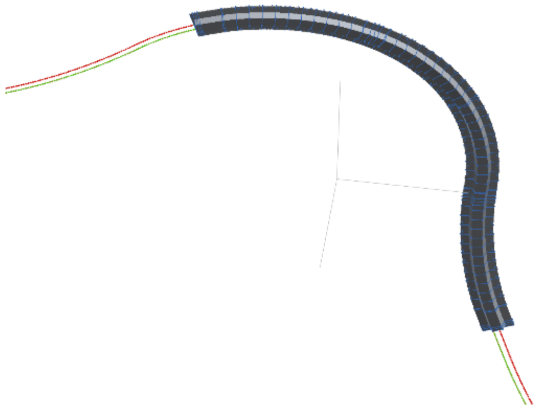


Figure 6: Gewan Island bridge 3D modelling, with plan radius of less than 125m

On site, for balanced cantilever erection

On site, assemCon gives two key insights to the user:

- Forecast the position of the bridge at any construction stage in 3D, considering the as-built data, the as-cast curve, and the calculated deflections for each construction stage.
- Assist in finding an optimal shimming strategy to correct the forecasted position, and to target a final as-built structure as close as possible to the theoretical geometry.

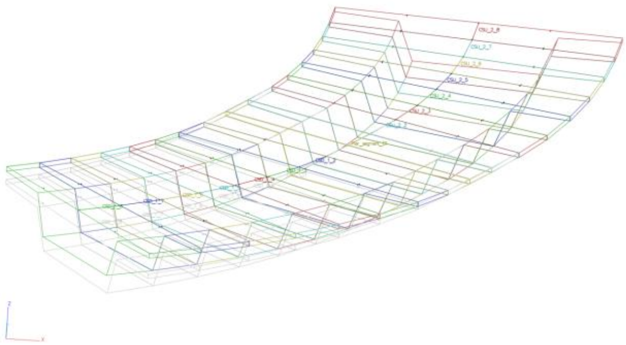


Figure 7: 3D view of a cantilever being built

Figure 8: Precasting of segments with cable stay pipes

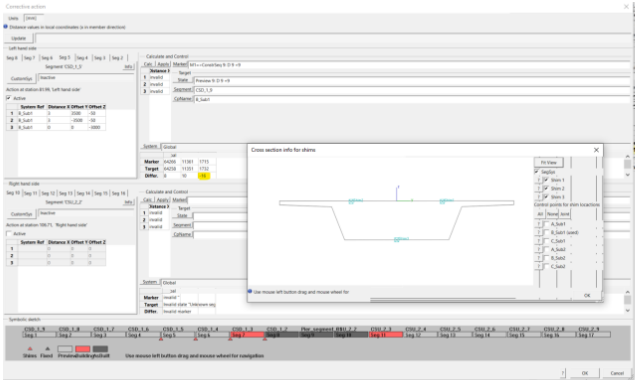


Figure 9: Definition of shimming strategy, to reduce differences

Figure 10: Karimnagar cable stay bridge, India

CONCLUSIONS

Pre-cast segmental bridge construction is applied to increasingly complex and geometrically challenging structures.

Efficient geometry control is essential for the success of such projects.

Geometry control already starts during the planning process where individual segments need to be laid out to suit the available equipment in the casting yard.

Segment casting needs to be tightly controlled and monitored, and geometric imperfections need to be identified and compensated for.

And finally, bridge construction at the construction site requires monitoring of individual construction stages and optimised strategies for correcting for possible geometry deviations of the bridge structure during construction.

VSL in cooperation with ABES have developed a suite of software tools to assist in all these tasks.

The software is heavily influenced by practical experience during numerous pre-cast segmental projects of all sizes and shapes, across Asia and principally Qatar and India, and feedback from ongoing projects continues to inform the development work.

Figure 12: Al Bustan North bridge during construction above traffic, Qatar

Figure 11: Gewan Island Bridge being built, Qatar

Photos Credit: VSL

PRECAST SEGMENTAL BRIDGE CONSTRUCTION USING LIFTING FRAME IN QATAR

Joakim Dupleix, CaSE International (formerly VSL)
German A. Pardo R., VSL International Ltd.

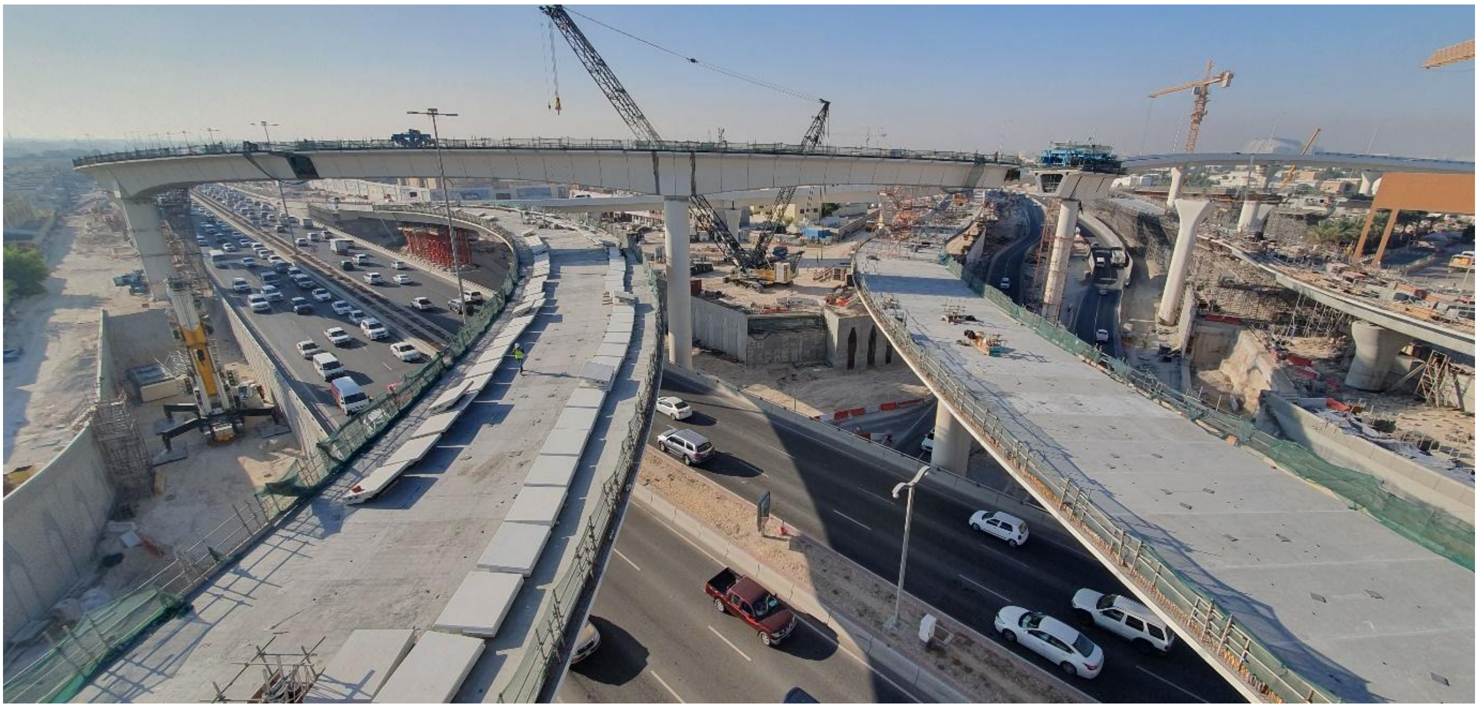


Figure 1: Overview of Al Bustan North construction site

PRECAST SEGMENTAL CONSTRUCTION

One of the most advantageous construction methods enabled by segmental construction is the balanced cantilever method.

In a busy brownfield environment, pre-casting the segments off-site is the best solution to minimize disrupting the existing traffic flow.

In these environments, access is often limited and restricted, and cranage may not be able to reach the whole site.

In these conditions, lifting frame equipment are often the solution to enable the erection of segments on the bridge.

In Qatar, VSL designed and operated two very different types of lifting frames, as part of the Al Bustan corridor upgrade project.

The lifting frames responded to different needs and segment delivery methods, carefully studied during the construction planning phase of the project.

SABAH AL AHMAD CORRIDOR (previously called Al Bustan)

Sabah al Ahmad or Al Bustan Corridor is part of the Qatar Expressway Programme and aims to provide an alternative to the existing expressway with free flow traffic on a length of 14 km from the North of Central Doha to the South, to improve connectivity to the FIFA World Cup stadiums.

Figure 2: Key map of the corridor in Doha

The project involved upgrading the existing main road by constructing various overhead bridges over existing crossroads, as well as connecting ramps to remove traffic lights.

The construction of this corridor was split into three main packages:

- Al Bustan North project, now known as Umm Lekhba Interchange
- Al Bustan South project
- Mesaimeer Road project

Al Bustan North consists of the major upgrade of a major interchange with Qatar main highway Al Shamal Road, to become a 4 level interchange.

Al Bustan South required the construction of large overhead bridges up to 2.6 km long, with overhead ramps connecting to crossroads.

Mesaimeer Road upgraded the existing road with 2 large bridges, up to 1.2 km long, with a cable stay section.

PRECAST SEGMENTAL BALANCED CANTILEVER METHOD

Because of the existing brownfield environment in which the bridges are being built, and to minimize the impact on the existing traffic, the precast segment balanced cantilever method was chosen for design and construction.

It avoids installing large falsework structures on site, where space is limited, and enables quick fabrication of the bridge but requires relatively large lifting equipment.

As a matter of fact, as the heavy concrete bridge segments are to be transported and erected into position with limited space, the key is to understand which areas are available, where possible if lifting equipment such as cranes can be positioned, and how to deliver the segments to their final position.

For very heavy segments, or if cranes cannot be used due to site constraints, it may be required to design custom made lifting frame machines, placed on top of the bridge already built, and fitted with their own lifting device to erect the segments in their final position.

These machines typically have a limited range, and segments must be first transported precisely near their final position.

On the Al Bustan Corridor, two different delivery situations were identified:

- For Al Bustan South and Mesaimeer, the large weight of the segments made it prohibitively costly to use a crane.

  However, assisted by a temporary diversion of the existing road during construction and the flat terrain, every segment could always be delivered directly below their final position.

- For Al Bustan North, the multi-level interchange, the existing highway Al Shamal Road could only be closed to traffic for a very limited time, and the existing road environment did not allow for flexible segment delivery below each new bridge ramp.

  A crane could be positioned near the piers, which allowed for segments to be lifted onto the already erected deck.

  To position the segment into its final position, a special lifting frame was designed to pick up the segment "from behind" and bring them forward into their final position.

LIFTING FRAME WITH DELIVERY FROM BEHIND

As mentioned previously, a lifting frame (LF) able to pick up a segment from behind was required for this project.

A few options for the trajectory of the segment were considered:

- Symmetrical Lifting Frame: segment crossing the lifting frame is rotated at 90 degrees in plan, lifted, and moved through the middle of the machine longitudinally.

  Once at the front, it can be rotated 90 degrees and lowered in position.

- Asymmetrical Lifting Frame: segment is delivered 180 degrees from its final orientation.

  The segment is picked up, rotated 90 degrees, moved through the LF longitudinally, rotated again, and then lowered in position.

Figure 3: Al Bustan North lifting frame

For this project, the bridges are quite narrow with a web spacing of 6 and 4 m, and therefore passing a 3.2 m long segment between two legs of the LF was not possible.

As shown in Figure 4 on the next page, a C shape was adopted to allow the segment to be rotated on the free side and moved forward.

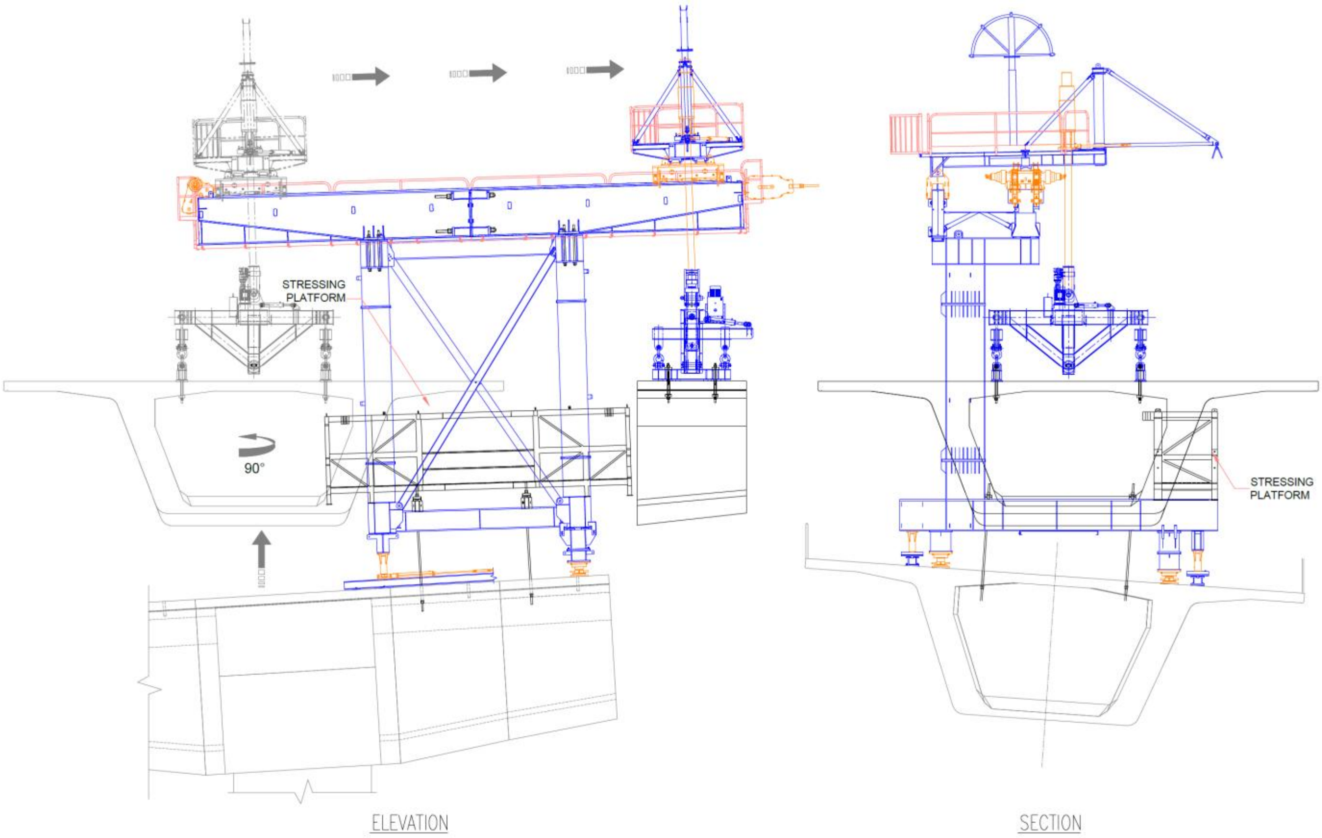


Figure 4: Segment delivery methodology. Click on the image to open it in full size

Description of Lifting Frame

The lifting Frame had the following key specifications:

1. Self-weight of 70 tonnes
2. Lifting capacity of 80 tonnes
3. Lifting speed of 12 m/h [0.2 m/min]
4. Longitudinal launching speed of 3 m/h [0.05 m/min]

The lifting frame is made of a few key components:

- *Upper Cross Beam (UCB)*: transverse beam carrying the strand lifting unit, as well as the stressing platform lifting mast. Adjustment capability of +/- 200 mm.
- *Main Beams (MB):* Longitudinal beams supporting the UCB. The UCB is moved on wheels with a bogie connected to 2 chain pulling units.

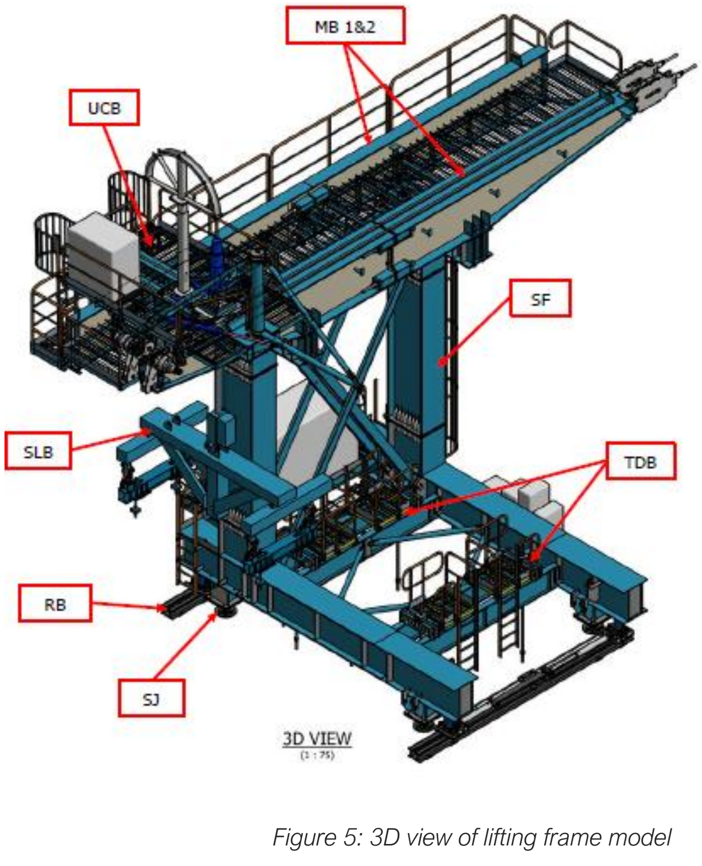


Figure 5: 3D view of lifting frame model

- *Support Frame (SF):* asymmetric frame in a C shape, supporting the MB. The frame is supported on the deck by adjustable screw jacks located over the webs.
- *Tie down beams (TDB):* during erection, the SF is tie down to the deck with 4 no 40 mm diameter stressbars, anchored in TDB. The TDB allows for longitudinal adjustment in the position of the bars, as the segment length varies.
- *Rail beams (RB):* two rail beams on each side of the SF are fitted with a hydraulic launching system able to move the entire frame forward in steps of 700 mm.
- *Segment lifting beam (SLB):* the SLB is stressed to the segment being lifted and is fitted with hydraulic jacks able to adjust the segment to the required crossfall and gradient, as well as rotated the segment in plan to pass through the SF.
- *Stressing platform (SP):* to complete the balance cantilever construction, a SP is required to be positioned each newly erected segment to provide access for personnel to complete the permanent post-tensioning operation.

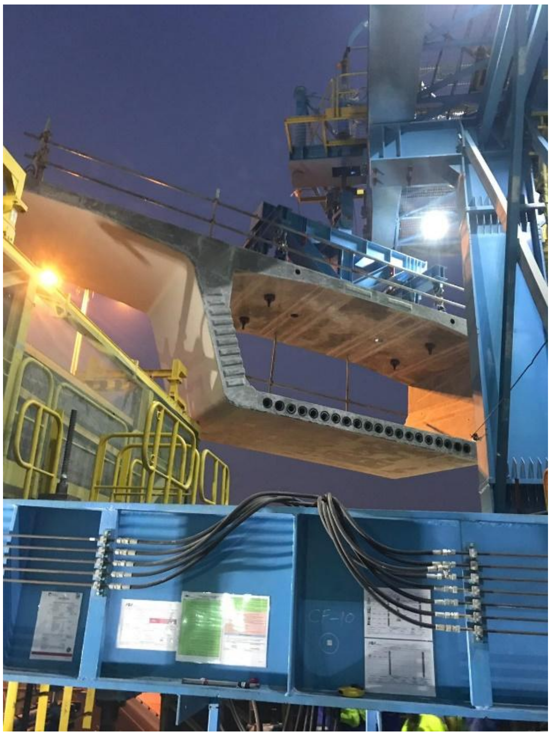


Figure 8: Segment rotated to its final orientation

SEGMENT ERECTION PHOTOS

The photo sequence below shows the segment delivery process:

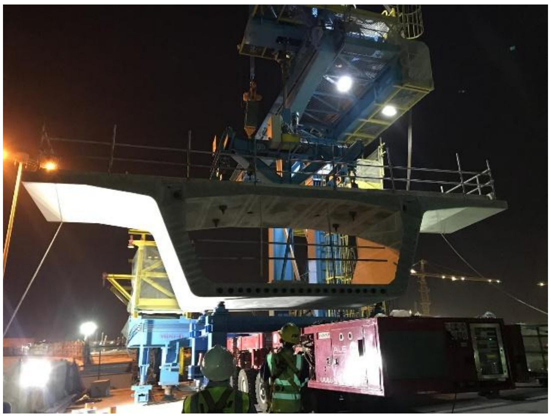
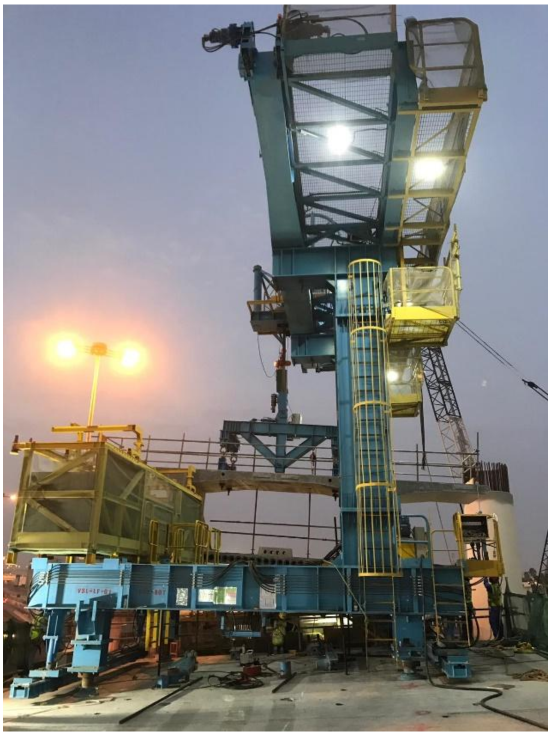


Figure 6: Segment delivered at the rear of the LF

Figure 7: Segment rotated and moved longitudinally



→ *Figure 9: Segment lowered into position and load transferred*

Challenges

Because of the limited width of the deck, and the congested site area with existing roads, one of the key challenges was to find a suitable storage position for the SP when not in use, which would not block the segment passage.

A rotation mast or davit arm was designed to lift and position the 6 tonnes platform. The mast was rotated up to 120 degrees with a small horizontal hydraulic jack.

The concept and design itself of the Lifting Frame required a solution which provided the minimum required space for manipulating the segment and the stressing platform in a very tight area while having enough stiffness and capacity to cover the demands.

LIFTING FRAME WITH DELIVERY FROM BELOW

Typical configuration for a Lifting Frame is such that segment can be lifted directly from below.

This was the case of Al Bustan South and Mesaimeer projects.

MESAIMEER LIFTING FRAME

Segments to be lifted by this lifting frame were the heaviest and widest on the project, for this reason a stiffer structure composed of rigid frames at the supporting areas was chosen, taking advantage of the fact that there was no restriction in height and section of the bridge.

The delivery of the segments in this project could be conducted almost at is final position in plan, which facilitated the configuration of the lifting equipment at the cantilever of the lifting frame.

For this purpose, the lifting frame was provided with a couple of Winches that could pick up the segment from the ground with minimum rotation in plan, lifted to required level and conduct final adjustment in the longitudinal and transverse directions.

Description of Lifting Frame

The Lifting Frame had the following key specifications:

1. Self-weight of 92 tonnes
2. Lifting capacity of 185 tonnes
3. Lifting speed of 60 m/h [1 m/min]
4. Longitudinal launching speed of 3m/h [0.05 m/min)

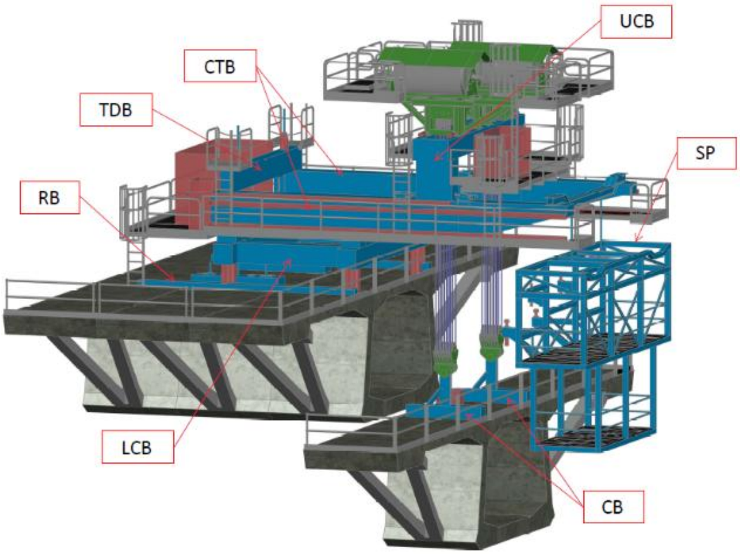


Figure 10: segment delivered at the rear of the LF

The lifting frame is made of a few key components:

- *Upper Cross Beam (UCB):* transverse beam carrying the main lifting equipment (Winch), as well as the stressing platform. Adjustment capability +/- 1325.
- *Cantilever Beam (CTB):* the 2 main longitudinal beams supporting the UCB and Stressing Platform at front, and the Tie Down Beam at the rear.
- *Lower Cross Beam (LCB):* main Frames underneath the CTB transferring all load to the bridge.
- *Rail Beams (RB):* two rail beams on each side of the LCB are fitted with a hydraulic launching system able to move the entire frame forward in steps of 850 mm.

- *Connection Beams (CB):* beams connecting the hook blocks of the Winches directly to the segment. They are provided with jacks for segment gradient adjustment. Crossfall is adjusted directly by the Winches.
- *Stressing Platform (SP):* it is positioned at the tip of the CTB and move backward for conducting stressing of bridge post-tensioning tendons. It is provided with 2 levels customized for this project.
- *Tie Down Beam (TDB):* the Support frame is provided with a set of tie down beams at the rear, which are the main stability system.

  TDB can be adjusted in the longitudinal direction to suit the different segment lengths and their respective tie down holes position.

  Tie down bars are of 75mm and 47mm in diameter and pre-stressed against the segment.

Challenges

- To accommodate the supporting area in a very limited length since there was insufficient space near the pylons.

  This created big reactions to be taken by the tie down elements due the big cantilever at front and heavy segments to be lifted.
- To be able to move all the way back the lifting equipment (Winch) and UCB, to provide enough stability during the launching procedure. Space at rear of the lifting frame was very limited.
- Provide a Stressing Platform with 2 different configurations (1 or 2 levels) that could be adapted for specific configurations.

SEGMENT ERECTION PHOTOS

Figure 11: Mesaimeer Lifting Frame

Figure 12: Segment lifting

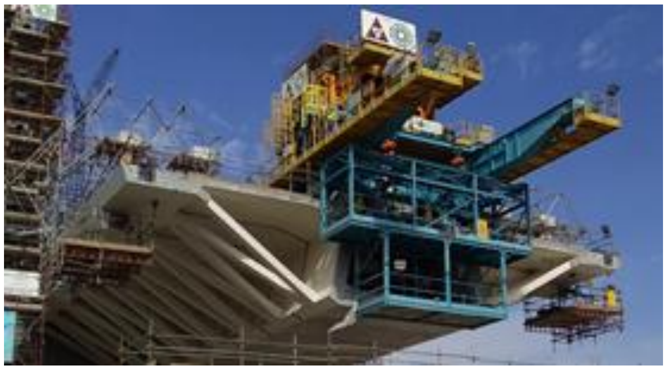


Figure 13: Segment permanent post-tensioning in progress

AL BUSTAN SOUTH LIFTING FRAME

For this project the lifting frame had to accommodate few main requirements, to suit the space constraints of the project and the bridge capacity:

- Height. A limit of 6m for total height the lifting frame was to be assured since the bridge had to pass under an existing viaduct.
- Load introduction. The bridge section is provided with 3 webs, and middle web capacity was to be respected by limiting the reactions at this point. Additionally, the total weight of the Lifting Frame was also limited.
- Segment delivered below, could not be positioned in its final orientation due to space constraints. It had to be rotated up to 90° once hanging from the lifting frame.

To overcome the limitations described, the lifting frame concept developed considered the following aspects:

- Main lifting equipment (Winch) was positioned at the bottom rear area of the lifting frame to reduce the total height.
- The three webs of the segment were loaded, and the Lifting Frame elements were studied in such a way that the total weight of the Lifting Frame and loading of central web were not exceeded.
- A single Winch and the hook block with rotation device were provided to allow rotation of the segment while hanging from the Lifting Frame.

Description of Lifting Frame

The Lifting Frame had the following key specifications:

1. Self-weight of 81 tonnes
2. Lifting capacity of 170 tonnes
3. Lifting speed of 36 m/h [0.6 m/min]
4. Longitudinal launching speed of 3m/h [0.05 m/min

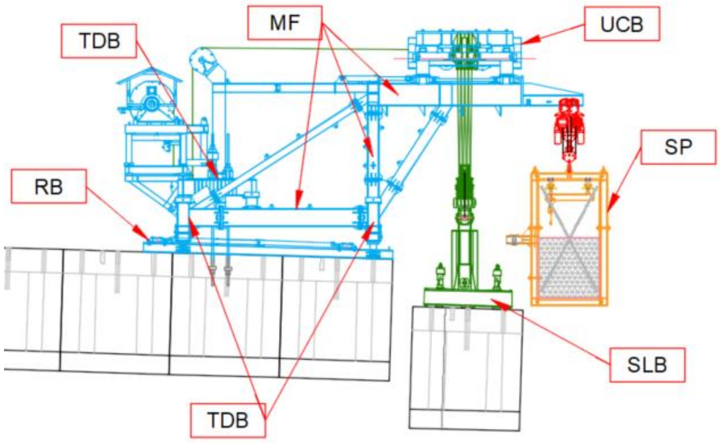


Figure 14: Segment delivered at the rear of the LF

The lifting frame is made of the following key components:

- *Upper Cross Beam (UCB):* uppermost element carrying the Winch Trolley. It can slide longitudinally to accommodate the segment in length. Transverse adjustment is done by sliding of the Winch Trolley over the UCB.
- *Main Frame (MF):* the Lifting Frame is provided with 2 Main Frames in section that support the UCB and Stressing Platform on top and transfers the vertical load to the lower elements of the Lifting Frame At bottom level it also receives the Tie Down Beam.
- *Lower Cross Beam (LCB):* spreader beam in the transverse direction located at front and rear that transfer all loads to the segment webs through 6 screw jacks (3 at the front and 3 at the rear).
- *Tie Down Beam (TDB):* located at rear part of the Lifting Frame and contain the tie down bars stressed down against the segment in order to assure the stability of the Lifting Frame. It contains a couple of back-up bars that provide redundancy to the system.
- *Segment Lifting Beam (SLB):* connecting element between the hook block of the winch and the segment. It is provided with a rotational device that allows full rotation of the segment in plan.

- *Stressing Platform (SP):* it hangs from the tip of the Main Frame cantilever beam. It is moved backwards after segment installation to conduct the stressing of the permanent post-tensioning system.
- *Rail Beam (RB):* two rail beams on each side of the LCB are fitted with a hydraulic launching system able it to move the entire frame forward in steps of 850 mm.

Figure 14 Lifting Frame installation on deck

Figure 15: Lifting of segment

SEGMENT ERECTION PHOTOS

Figure 16: Stressing of post-tensioning tendons

Figure 17: Lifting Frame crossing under existing viaduct

Challenges

- To develop a concept and design that did not exceed the limitations given regarding total weight and height.
- Allow full rotation of the segment while hanging.
- Provide redundancy to the Lifting Frame Tie Down system and to the Stressing Platform while under operation.

CONCLUSIONS

Precast segmental construction in a congested environment often requires the use of custom designed lifting frames.

These machines must always consider the segment delivery methods, as well as the bridge characteristics, in order to achieve the most cost-efficient methods of erection.

The more requirements a project has, the more customized the Lifting Frame will be.

For this reason, it is of key importance to integrate the development of the Temporary Structures (like Lifting Frames) as early as possible in the design process.

By doing this, some of the constraints can be solved in earlier stages which will improve the efficiency of the full process and the interfaces between the different parts involved: Permanent Works Designer, Temporary Works Designer and Main Contractor.

Figure 18: Al Bustan North

Figure 19: Al Bustan North

Figure 20: Al Bustan South

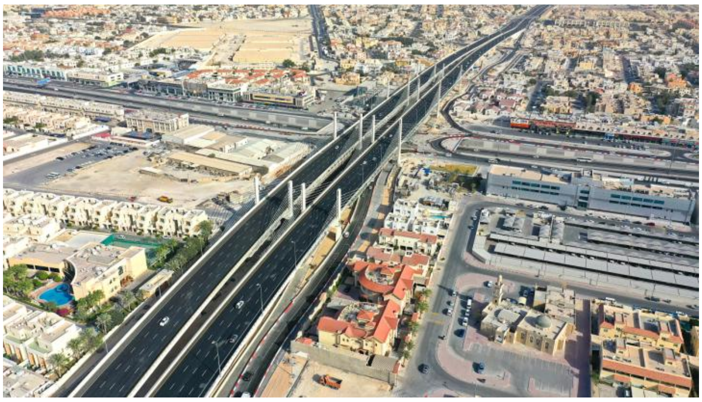


Figure 21: Mesaimeer

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Naeem Hussain
naeem.hussain@arup.com

Global

Richard Hornby
richard.hornby@arup.com

UK, Middle East & Africa

Steve Kite
steve.kite@arup.com

East Asia

Deepak Jayaram
deepak.jayaram@arup.com

UK, Middle East, India and Africa

Peter Burnton
peter.burnton@arup.com

Australasia

Marcos Sanchez
marcos.sanchez@arup.com

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Matt Carter
matt.carter@arup.com

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*Wyatt Brooks and Kevin Donovan - "Eliminating Uncertainty in Market Access: The Impact of New Bridges in Rural Nicaragua," 2017.

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