

USER'S MANUAL

Post-tensioned Concrete Haunched Slab Bridges

Design and Construction

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Bridge Section - Bureau of Design

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I. INTRODUCTION

I.1 Description

Post-tensioned concrete haunched slab (XCSH) design and details included in this manual are intended for the use of bridge details that can be obtained from KDOT Bridge Section for the preparation of bridge plans. The format is similar to the existing standards available for reinforced concrete haunched slab bridges (RCSH). This manual consists of eight (8) major sections: Introduction, Design, Plan Preparation, Specifications, Cost Estimate, Construction Inspection Requirements, Lessons Learned, and Appendix.

I.2 Scope

The project scope consists of design and plan preparation for a 3-span, post-tensioned concrete haunched slab bridge, referred to by the KDOT bridge superstructure log code as XCSH in this manual. There are four (4) span arrangements and five (5) roadways plus one 2' offset crown roadway for each span arrangement included in the manual. No skews are included in the preparation of the standard plans at the present time. However, a sample set of a skewed bridge is made available.

The four span arrangements are:

- A. 50 ft – 65 ft – 50 ft
- B. 55 ft – 72 ft – 55 ft
- C. 62 ft – 82 ft – 62 ft
- D. 71 ft – 92 ft – 71 ft

The five roadway widths are:

- 1. 28 ft
- 2. 32 ft
- 3. 36 ft
- 4. 40 ft (plus a 40 ft roadway width with 2' offset crown)
- 5. 44 ft

I.3 XCSH Application – Where to use XCSH?

The following criteria may be used to evaluate the choice of the XCSH bridge solution for a given location of a bridge crossing:

- 1. The need for a shallow superstructure depth for the main span in the 65 ft to 92 ft range due to constraints such as approach road profile (right-of-way and/or other constraints), shallow stream depth, or vertical clearance conditions. The approximate span to superstructure depth ratio for XCSH is about 40:1, compared to 25:1 for girder options in that span range.

2. The need for improved safety under overpass structures by minimizing the number of piers and maximizing horizontal clearance (in comparison to RCSH).
3. The need to minimize the number of piers in the stream channel in relation to scour, drift accumulation, minimizing obstruction to flow, etc. (in comparison to RCSH).
4. The need for a "high-performance" type bridge superstructure. The bi-directional, pre-compression in the slab reduces the cracking of the concrete slab, rendering the slab more impervious to moisture penetration and thus, chlorides. The entire superstructure is in a state of pre-compression.
5. The need for competitive cost alternatives to shorter span prestressed girder bridges.
6. The need for a low-maintenance type bridge with least life-cycle cost potential.

Limitations

Constructability: XCSH application should be considered carefully where very deep channels are encountered which may preclude the use of a cast-in-place type structure requiring formwork. However, many contractors have innovative ways of forming the concrete superstructure using steel beams or trusses, so the designer should check the availability of such construction technology before ruling out the post-tension (P/T) option for bridges over deep channels. The same concern should be checked for overpasses over railroads or existing highways to allow traffic through construction.

Skews: Even though skewed XCSH bridges are entirely possible and have been built in the past up to 30 degrees, the current standards do not include standard XCSH details for skews. However, an example set of plans is available for reference. See Section II.7 for additional information.

Horizontally Curved Bridges: The current standards do not include horizontally curved XCSH applications. See section II.8 for additional details.

Multi-Span Applications: The current standards are limited to a three (3) span configuration of XCSH. The concepts and details needed to add additional interior spans require further investigation regarding prestress losses, movement at the abutments, etc. More than three-span XCSH applications are beyond the scope of these standards at this time.

I.4 Cost Considerations

There are a number of factors associated with XCSH that should help to produce a very economical bridge solution over the life of the bridge crossing.

- Minimizing the number of piers for a given bridge length, compared to RCSH
- Substantial savings in mild steel reinforcement placement in the slab
- Savings in cost due to eliminating the need to raise the approach grade profile, compared to girder type superstructures

- Excellent life-cycle cost performance due to the anticipated high-performance bridge slab

This user's manual is not intended to endorse the choice of XCSH as the most effective bridge solution for a given project location. The designer of the project is solely responsible for the choice of the XCSH application as well as all structural design and calculations required by the codes of professional practice. The standard design and details presented in this manual and the available developed standard sheets require checking by the designer for the required and applicable loading conditions specific to each project location.

II. DESIGN

II.1 Designer's Responsibility

The integral pile bent type abutment and the superstructure slab have been pre-designed in the preparation of the plan standards, available as a part of this project. A wall type pier has been included in the plans as an example. The designer is solely responsible for the complete design of all foundation elements (both piers and abutments), the piers and any non-standard abutments in accordance with the requirements of this manual and applicable AASHTO and other design specifications. The designer is also responsible to check the standard abutment and superstructure design for all loading and functional conditions specific to each project site.

II.2 Design Loads

The superstructure slab has been designed for the following loads:

1. Dead Loads

Concrete (Reinforced):	150 lb / ft ³
Traffic Barrier Load:	376 plf per rail (2'-8" Kansas Corral rail with curb)
Future Wearing Surface:	25 psf

2. Live Loads

The XCSH Bridge standards have been designed to meet KDOT requirements for three live loads:

HL-93	(LRFD Design & LRFR Rating)
HS-20	(LFD Rating)
HET	(LFD Rating) (Heavy Equipment Transporter – Operating only)

The designer is responsible for checking the design of the superstructure and the standard abutment for the specific loads applicable to each project location.

3. Design Methodologies

The superstructure and substructure was designed using the AASHTO 2004 edition of the LRFD Specifications, and then rated using the AASHTO 17th Edition of the LFD Specifications. The Designer is responsible to use Engineering judgment to verify no code changes since 2004 will affect the superstructure design. Allowable concrete stresses used for the service conditions are:

Tension in concrete (psi):

$$3\sqrt{f'c} \text{ for HL - 93 Design \& Inventory Rating ; } 6\sqrt{f'c} \text{ for HL - 93 for Operating Rating}$$

0 Tension for 110% * HS – 20 Inventory Rating ; $6\sqrt{f'c}$ for HS – 20 Operating Rating

$6\sqrt{f'c}$ for HET Operating Rating

Compression in concrete:

$0.60f'c$ – All live loads

$0.45f'c - P_{effective} + DL$

The goal of the load rating is to achieve a minimum rating of 1.1 (10% margin) for the governing rating truck. The governing LFD rating truck for all span groups is found to be the HS-20 loading. The allowable concrete stresses used under 'service conditions', in determining the flexural resistance capacity of the slab, is based on the values shown above.

II.3 Superstructure Design

The longitudinal P/T, in conjunction with the concrete in the slab, is the primary structural element for the bridge superstructure. The longitudinal P/T is vertically "draped" or profiled to provide compression in the highest tension demand regions. The spacer frames in the XCSH standards have an additional horizontal bar, in comparison to the conventional spacer frames of the RCSH standards. This additional bar varies in height to support the longitudinal P/T in its correct location. The transverse P/T is provided for secondary effects, such as biaxial tension, etc. The mild (conventional) reinforcing is provided as a construction framework and for shrinkage and temperature effects. Unlike the 4.0 ksi concrete in conventional RCSH bridges, XCSH bridges utilize 5.0 ksi concrete. The aggregate selection for the concrete, however, should follow the same process prescribed by KDOT for RCSH bridges.

The P/T supplier is responsible for "local" zone design. The engineer of record, however, is responsible for the "general" zone design of both the longitudinal and transverse post-tensioning. The abutment and post-tensioning detail plan sheets provide reinforcing details for these general zone requirements.

Conceptually, two aspects may be mentioned here regarding the unique results of the design of XCSH bridges. First, by design, the service HS-20 truck will not introduce any tension into the bridge slab. The benefits of having a slab without flexural cracking at service level conditions for maintenance and durability are obvious. Second, because the controlling aspect of design is the tensile stresses in the slab due to service live loads, the structural system provides ample reserve flexural strength capacity compared to other superstructure systems (RCSH, prestressed girder, steel girder, etc.).

II.4 Substructure Design

Design considerations for the substructure in the XCSH application are the same as those for the conventional KDOT RCSH application, with the exception of additional deformations occurring due to post-tensioning and creep forces which must be accounted for and allowed to occur in the design. Post-tensioning will induce displacements and rotations of the

substructure due to elastic deformations, as well as time dependent deformations. The basic structural model of the superstructure used in the post-tensioning design and analysis procedure assumes a 'pinned' connection between the superstructure and the substructure. Therefore, the abutment and piers must be designed to replicate the assumed design condition. The additional displacements and rotations of the top of abutment piles, in particular, can be significant and must be accounted for in the design. The longer span configurations of XCSH, and more importantly, the foundation geology of a specific bridge site, impact this pile design.

The abutment vertical pile reactions for dead and live loadings are shown on the standard plans. The total superstructure vertical dead and live loads at the top of the piers are shown on the sample pier detail sheet to assist the designer in the design of the pier.

1. Abutment Design

The plan standards include a fully designed pile bent type abutment with pre-selected pile spacing and pile size. Due to slab deformations at the abutment as a result of the P/T forces, the pile needs to be checked for flexural and axial capacity as a structural member. A sample calculation is included in the Appendix for reference. The pile spacing and size shown on the standard plans are to be used as 'minimum' due to this condition.

The shortening of the slab at the abutments due to the combined effect of dead load, live load, post-tensioning, ambient temperature variations, and concrete creep and shrinkage is shown in Table A.1 (Appendix) for design purposes. The 'overall' design of the abutment must be such as to allow this movement to occur freely without restraining the superstructure. If the abutment foundation is too rigid to allow movement of slab at the abutment, the superstructure may not develop the assumed precompression, or the abutment foundations may behave undesirably. One way of achieving this movement and meeting the overall structural stability is to design a shallow depth (berm type), integral abutment on a 'single' row of piles as shown on the standard plans. This concept will work for bridge sites where the geology is such that the piles have ample depth of fixity. Additional measures may be needed based upon an analysis of the project site geology, especially where hard geology such as shale or rock strata is encountered close to the bottom of the abutment beam.

Pre-drilled pile holes may be required in cases where hard subsurface soil conditions are encountered very close (within 15 ft) below the bottom of the abutment beam. The provision of the pre-drilled pile holes will allow the piles to accommodate the shortening of the slab at the abutment without exceeding pile capacity. Pre-drilled holes for XCSH abutment piles typically extend a minimum of 10 ft below the bottom of the abutment beam. The diameter of the pre-drilled hole shall be such that a minimum 3 in clearance is provided all around the pile (Fig. A.1 - Appendix) to allow placement of backfill material in the pre-drilled holes after the pile is driven. The backfill material shall meet current KDOT plans and specifications. Consideration could also be given to using the "empty" pre-drill hole currently recommended by KDOT for piles behind an MSE wall at the abutment. Pre-drilled pile holes for XCSH are somewhat different than the conventional bid item of that name, in that they do not necessarily take place in rock, and they typically do not take place at the bottom of the pile, but at the top. (As an aside, these two factors should cause these pre-drilled pile holes to be more economical than conventional pre-drilled pile holes in rock). The design intent of these

XCSH pre-drilled pile holes with backfill material is to move the “equivalent point of fixity” of the pile down, so that the moments generated at the point of fixity in the pile from the displacement happening above at the abutment, are reduced. Example A.1, provided in the Appendix at the back of this report, provides a detailed analysis of such a check. For the example (a “D” span configuration with a 44’ roadway), in effect, a 16’ depth to fixity is needed below the abutment beam. If the project site geology will not allow the pile that depth of fixity, then pre-drilled pile holes should be employed as appropriate.

Drilled shafts can be used at the abutments; however they must be designed to allow shortening of the slab to occur without significant restraint. In cases where the subsurface rock/shale is very near the bottom of the abutment beam, integral abutment design on pile foundations, even with pre-drilled holes, is not a practical solution. The superstructure slab, in such instances, must be independently supported on the abutment beam using ‘expansion bearing devices’ and a backwall at the abutment (Fig. A.1 - Appendix). Alternatively, a semi-integral abutment could be employed. Either design is beyond the scope of this manual and should be performed entirely by the designer.

2. Pier Design

The design of the pier is similar to the substructure design of the abutment. However, the requirement of shortening of the superstructure at the pier is much lower than that at the abutment (about 60 percent less), due to the pier’s close proximity to the point of no movement.

The connection between the superstructure slab and the top of the pier must be designed to not transfer any moment between the superstructure and the pier in the longitudinal direction, providing essentially a ‘pinned’ connection, in order to allow the free movement of the superstructure. The standards provide a plan detail for a sample wall type pier showing a typical connection detail between the slab and the pier beam. This consists of the single row of piling stopping short of the top of wall, and an “X” bar reinforcing connection from the top of wall to bottom of superstructure. Such a connection succeeds in providing a ‘pinned’ connection between the superstructure and substructure.

However, when a single row of columns are used, the primary column reinforcement can be extended into the slab for the minimum embedment length required as per the code. Stop the web walls between the columns, 1 ft below the bottom of the slab. For moderate to large column spacing, many XCSH bridges have been constructed with a separate pier cap, sitting immediately below the superstructure. This separate pier cap is conservatively designed to accommodate all the flexural and shear loadings (neglecting the superstructure above). More importantly, the connection between the separate pier cap and the superstructure again consists of “X” bar reinforcing, to achieve a ‘pinned’ connection.

Pre-drilled pile holes may be required when hard subsurface soil conditions are encountered very close to the bottom of the pier wall or the footing (within 7 ft) as per the discussion above in the case of the abutment design.

Drilled shafts can be used at the piers; however, they must be designed to take into consideration the forces due to deformations of the slab.

In summary, the procedure for the design of the substructure in the XCSH is not greatly different than that for RCSH, except for considering the 'magnitude' of deformations that occur in the slab as a result of post-tensioning. This is usually more of a concern at the abutment than at the pier.

II.5 Bridge Rail

The standard plan details have taken into consideration the use of a Kansas corral rail system. It is imperative to use the spacing of the rail posts and the special reinforcing as shown on the XCSH standard plans in order to avoid conflicts of the post reinforcing steel with the post-tensioning. Any changes to the post spacing must result in a re-evaluation of conflicts, both between the post reinforcing and the longitudinal P/T, and the new locations of the transverse P/T with the longitudinal P/T.

The use of Type F4 concrete barrier will require further investigation to check potential conflicts with both transverse and longitudinal post-tensioning hardware. XCSH bridges have been successfully constructed with Type F4 concrete barriers. In any event, the profile of the longitudinal PT tendons should not change from the values shown in the plans.

II.6 Bridge Approach Slabs

The standard abutment details include provision for the support of a concrete approach slab. KDOT recommends the use of the approach pavement rest detail even if approach pavement is not used (as in the case of rural dirt roads) for sake of uniformity in construction as well as for a future paving option. When required, use the KDOT standard approach slab details.

II.7 Bridge Skews

The current scope of the XCSH standards does not include standard details for skews; however an example is given for reference. XCSH bridges with skews are possible; up to 30 degrees have been built in the past. The structural design of the slab itself is not expected to change for the skew. However, the layout of the transverse post-tensioning and the corral rail post spacing will require modifications to the standard details to accommodate skews.

This manual may be upgraded to include provisions for skews, depending on future needs.

II.8 Curved Bridges

The plan standards do not include consideration for bridges on curves. Curves with very large radius should be feasible with required modifications of the standard plan details (e.g., the bridge could be designed slightly wider, still as a "rectangle", and the post-tensioning would remain on a tangent). Horizontally curved tendons exert lateral forces on the

surrounding concrete, which must be accounted for in the design. Extreme caution is required in the design of horizontally curved tendons.

II.9 Multi-Span XCSH

The scope of these standards is limited to a three (3) span configuration of XCSH. In general, a single unit P/T slab bridge could conceivably have a thermal unit length in excess of what is given in these standards. However, concepts and details to add additional interior spans need further investigation. At this point in time, it appears the limiting thermal unit length is dictated by the amount of allowable pile displacement taking place at the integral abutments.

II.10 Future Widening of XCSH

It may be possible to widen "existing" XCSH bridges, but this is a complex procedure requiring detailed thought and inspection. Removal of concrete and/or P/T in a bridge can damage the entire superstructure if not done properly. In some cases, it may be simpler to build an adjacent structure with a longitudinal joint, in order to avoid removing any of the existing XCSH.

III. PLAN PREPARATION

III.1 General

All standards are prepared in English units. All drawings are prepared in Microstation (.dgn) format using the KDOT CADD graphics standards for bridge plans and standard sheets.

It is imperative that the designers of XCSH are thoroughly familiar with the design theory and procedures as outlined in Section II prior to preparing construction plans, specifications and cost estimates. The designers are urged to read this entire manual prior to the design and plan preparation of XCSH.

III.2 Standard Format

The standard drawings are categorized in three (3) groups.

Group I contains standards that are basically fully complete requiring only information regarding elevations, concrete type, designer notes, project number, title, sheet numbers, date, etc.

Group II are standards that are mostly complete except for requiring additional design information to be filled in such as quantities, project specific notes, substructure bar list and bending diagrams, etc., primarily due to specific site conditions and pier design.

Group III consists of 'sample plans' that can be used as examples by the designer to develop the required sheets, specific to the site conditions.

The designer is responsible to check all sheets, regardless of category, for accuracy and requirements as per applicable specifications, standards and site conditions for loads, geometry and function.

Group	Sheet Title
I	Abutment Details I
	Abutment Details II
	Slab Details I
	Slab Details II
	Post-tensioning Details I
	Post-tensioning Details II
	Grouting Sequence & Post-tensioning Notes
	Post-tensioning Data & Construction Sequence
	Spacer Frame Details
II	General Notes & Quantities
	Bill of Reinforcing Steel & Bending Diagrams
III	Pier Details

All sheets from Groups I, II & III are required in the plans for XCSH application without any exception. In addition, the following sheets are required in the plans for any XCSH bridge design:

- Slab Elevations
- Contour Map
- Construction Layout
- Engineering Geology
- Abutment Strip Drain
- Corral Rail Details
- Bridge Excavation
- Supports & Spacers for Reinforcing Steel
- Standard Pile Details

The rail detail sheet, which is an existing KDOT base sheet, will require a special detail inclusion as shown on the Post-tensioning Details II sheet. The designer should reference both the Post-tensioning Details sheets and the Post-tensioning Data & Construction Sequence sheet for proper post spacing and reinforcing.

The designer must thoroughly familiarize oneself regarding the details on the standards in Group I so all other sheets will have information and details consistent with and as required by the sheets in Group I.

III.3 Sheet Indexing System

The sheets are indexed by span arrangement and roadway width. The following system is used to designate the span arrangement:

Spans	Designation
50 ft – 65 ft – 50 ft	A
55 ft – 72 ft – 55 ft	B
62 ft – 82 ft – 62 ft	C
71 ft – 92 ft – 71 ft	D

The sheets are indexed with span designation followed by the roadway width and an abbreviated title of the sheet. Thus,

D44SS2.dgn refers to Slab Details II for 44 ft roadway in a 71 ft – 92 ft – 71 ft span (D) arrangement. A list of abbreviated titles for the standards is shown below:

Sheet Title	Sheet Designation
General Notes & Quantities	*GNOT.dgn
Abutment Details I	*ABT1.dgn
Abutment Details II	*ABT2.dgn
Pier Details	*PIER.dgn
Slab Details I	*SS1.dgn

Slab Details II	*SS2.dgn
Post-tensioning Details I	*PTD1.dgn
Post-tensioning Details II	*PTD2.dgn
Grouting Sequence & Post-tensioning Notes	*PTN1.dgn
Post-tensioning Data & Const. Sequence	*PTN2.dgn
Bill of Reinf. Steel & Bending Diagram	*BAR1.dgn
Spacer Frame Details	*BAR2.dgn

Note: KDOT may have revised the sheet designations to match their latest CADD standards and naming conventions. Use KDOT latest naming conventions for sheet labeling.

III.4 Step-by-step Plan Preparation Procedure

Step 1: Determination of Sheet Designation

Determine the span arrangement (A through D) and roadway width (28 ft through 44 ft). For example, the designation for 62 ft – 82 ft – 62 ft spans with 40 ft roadway would be 'C40'.

Step 2: Obtain Standards for Groups I, II and III.

Obtain all CADD plan standards for the designation determined in step 1 (ex. 'C40') for Groups I, II and III as outlined in Section III.3.

Step 3: Abutment Design and Details (Group I)

Based on subsurface soil conditions as noted in Sections II.4, check if the standard pile bent type abutment design and plan standards can be used. If not, perform the abutment design as per the procedure outlined in Section II.4 for the loads specified on the standard abutment sheets as well as AASHTO specifications. Use the example in the Appendix as a guide, if necessary. If non-standard abutment design is performed, use the format of the standard abutment plans to prepare the plans for the non-standard abutment design. In most circumstances, the standard abutment design should be satisfactory. However, note the standard abutment design and details are for Steel "H Piles" only. The designer should use appropriate pile type, size and number as needed by the site geology and check the design as required.

- Check to see if pre-drilled pile holes are necessary as per Section II.4.

Step 4: Pier Design and Details (Group III)

Based on subsurface soil conditions as noted in Section II.4, design the piers following the procedure outlined in Section II.4 for the vertical loads specified on the Sample Pier sheet as well as all other loads specified in AASHTO. The following pier types are most common:

Wall type pier – only the height of the wall, as per site conditions, needs to be adjusted. Modify the example details and loads for the changed wall height.

Single row of columns on drilled shafts or spread footings (founded either on rock/shale or pile group) need to be designed following the procedures outlined in Section II.4.

Use the format of the sample plan detail sheet to prepare the actual pier detail sheet.

- Check to see if pre-drilled pile holes are necessary as per Section II.4.
- Make sure the connection between the superstructure slab and the pier beam is a pinned type connection as shown on the sample pier detail sheet for a wall type pier.

Step 5: Traffic Rail Details (KDOT Standard)

Download the appropriate Kansas corral rail base sheets from the existing KDOT standards library. Use the post spacing shown on Post-tensioning Details I sheet. Include the special post bar detail from the Post-tensioning Details II sheet, if applicable. Reference the Post-Tensioning Data & Construction Sequence sheet for special rebar locations.

Step 6: Bill of Reinforcing and Bending Diagrams (Group II)

Modify the standard sheet to revise/include rebars from re-designed abutment detail sheet(s) if applicable, pier detail sheet(s), and the rail detail sheet.

Step 7: General Notes and Quantities (Group II)

Compute the quantities for items left blank on the bridge quantity tabulation. Complete the sheet listing on the bridge index of sheet table. Review and modify the general notes as per site conditions and other related design items. Complete design pile / footing load information.

Step 8: Construction Layout (Group III)

Prepare Construction Layout sheet similar to any other bridge.

Step 9: Slab Elevation Sheet

Calculate elevations required of the Engineer, similar to that which is required for RCSH bridges. **Note: camber for XCSH bridges is “negative”, and care must be exercised to correctly calculate the slab elevations.** Negative camber indicates that the slab form needs to set lower than the finished bottom soffit taking into considerations deflections and camber due to the uplift that will take place from the P/T forces. It is recommended that an engineer review and approve the slab elevation sheet prior to concrete placement. This standard sheet should provide an important reference for the Contractor's Surveyor on the project.

Step 10: Typical Plan Sheets

Include other typical plan and standard sheets. This includes, but is not limited to the: Approach Pavement Details, Contour Map, Engineering Geology, Abutment Strip Drain, Bridge Excavation, Bar Supports, and Standard Pile Details.

Step 11: QA/QC

Check all plan details, quantities and notes on Group I and II plan standard sheets as well as all other sheets modified or added to the plans for the given project.

Please note that it is the responsibility of the designer to check the design of all pre-designed components of the plan standards used in the given project, as to its suitability for site conditions in terms of structural and functional design criteria. Such procedures shall be done in accordance with all applicable specifications of AASHTO and KDOT.

IV. SPECIFICATIONS

IV.1 General

The Contract Documents for the post-tensioning work shall be as stated on the plans and any Project Specifications. There should be consistency between the information shown on the plans and any Project Specifications that may be used by the designer.

See KDOT Specifications, "Post-tensioning (Haunched Slab Bridges)", Section 716, and subsequent Special Provisions. Note that the Sika Grout 300PT will not be allowed due to recent discovery of chloride presence.

V. COST ESTIMATE

V.1 Unit Price

The Contract Unit Price for all post-tensioning work is set as Lbs of strand weight, including longitudinal and transverse strands. Limits and method for calculating strand weights, as well as a breakdown of the transverse and longitudinal weights, is shown for information only on the General Notes sheet. The Unit Prices for other work in the bridge project shall be as per the Specifications, and is similar to what is done for RCSH.

V.2 Estimating Unit Prices

The plan shows approximate quantity of the TOTAL prestressing strand weight. Based on XCSH bridges built in Kansas since 1989, the following information is presented for certain items that are affected by post-tensioning:

Item	Unit
Concrete, Grade 5.0 (AE) (*)	Cu. Yds.
Post-Tensioning	Lbs.

* See Bridge Manual for aggregate type. Note: "PB" aggregate is intended for prestressed girder bridges and not for XCSH.

Unit prices for bridge items should be estimated using similar assumptions as for any other similar type of bridge and location.

VI. CONSTRUCTION INSPECTION REQUIREMENTS

VI.1 General

The construction of XCSH is similar to RCSH construction in many ways. The significant differences are as follows:

- Pre-drilled pile holes may be required more often at the abutments for XCSH than for conventional RCSH.
- The top of wall type pier is not monolithic with the superstructure slab in a XCSH. The reinforcement, projecting above the top of the pier beam, is “crossed” into the superstructure slab to provide a pinned connection. Additionally, a Type B expansion joint material is placed on top of the pier beam along the edges to allow rotation of the superstructure slab.
- The superstructure formwork design and construction may require special considerations due to the longer span applications, not typically encountered for conventional RCSH. Also, the camber on a XCSH bridge is “negative” (opposite of a RCSH bridge).
- The placement of P/T tendons and the varying slab depth will require significant control, precision, and care. The longitudinal duct profile and the slab depth are critical. The ducts must be sealed properly to prevent the entrance of concrete.
- The conflict between P/T tendons and mild steel reinforcement in the slab, even though checked carefully in the plan preparation, may require some ‘trouble shooting’ in the field. Post-tensioning ducts always have precedence over mild steel reinforcement, and longitudinal P/T has precedence over transverse P/T. As per the plans, adjust the location of the transverse P/T up or down to avoid conflicts with the longitudinal P/T, but this adjustment should be minimized to make sure eccentricity from the transverse P/T does not introduce tension into the slab.
- The slab concrete requires higher concrete strength than conventional RCSH. Additives such as a superplasticizer may be required to increase workability. Note, it is desirable to minimize shrinkage, and superplasticizers sometimes increase the rate of shrinkage.
- Extra care is required to make sure the ducts are not dislocated during concrete placement. Concrete consolidation is critical, especially in congested areas, such as at the abutments near the end anchorage.
- The timeliness and the manner required for concrete testing are critical due to the requirements of stressing operations.
- Extreme caution and complete compliance with safety procedures are required during stressing operations.

- The grouting process is a unique component of post-tensioning and has received the most attention in recent times due to issues related to grouting of other P/T structure types. The grout material used is critical and must meet KDOT Specifications. As per the Contract documents, an ASBI Certified Grouting Technician is required to supervise all grouting operations on the bridge. It is important for the Contractor and Inspector to realize that the intent of the grouting operation is to fully encapsulate the P/T tendons, both for the protection of the tendons from chloride attack, and for the continuous bonding of the tendons to the slab. The grouting process should result in zero non-grout voids (i.e., no pockets of air or water should remain in the ducts after the grouting operation).
- Slab forms must be left in place as stated on the plans, at least until after all stressing and grouting operations are complete.
- Protecting all exposed end anchorages and filling the anchor recesses, after grouting, are important finish items.

In general, the construction of XCSH, though not more complex than any other type of bridge, does require more care than most conventional concrete bridges in terms of sequence, precision and safety.

The information presented in this section is intended to assist the Owners' representative to conduct a proper inspection of XCSH construction. It is not intended to release the Contractor or the Inspectors from the responsibilities of carrying out the project as per Plans and Specifications, nor does this information represent all procedures required in the construction of the project.

VI.2 Checklist for Construction Inspection

The check list for XCSH must include all items common to any bridge construction. The following is a list of items of particular importance to XCSH.

1. Pre-Construction Submittals

- A. Check shop drawings and other submittals by P/T Manufacturer, especially the following:
 - a. Duct profile to conform to the plan specified center of gravity (cg) of the tendons
 - b. Spacer frame dimensions to conform to the duct profile submitted by the P/T Manufacturer
 - c. P/T End Anchorage assembly "local zone" design calculations, testing certifications, and dimensions to fit within the concrete slab
 - d. Duct size conforms to plan specifications
 - e. Elongations and stressing procedures
 - f. Review Manufacturer's instruction to Contractor regarding the protection of the strands
 - g. Review slab form work drawings and design calculations
 - h. Review all testing certificates furnished by the P/T Manufacturer

- B. Check shop drawing for Spacer Frames; the plan dimensions are based on the design profile and the assumed duct size. If duct sizes are different from plan dimensions and if approved by the Engineer, have the Contractor revise and re-submit Spacer Frame dimensions to match the approved duct size and profile.
- C. Review the slab concrete mix and placement procedure submitted by the Contractor.
- D. Review the slab curing procedure submitted by the Contractor.
- E. Review all concrete testing procedures submitted by the Contractor.
- F. Review grout mix and placement procedure submitted by the Contractor.

2. Piles

- A. Check the requirements for pre-drilled pile holes.
- B. Check the orientation of the piles.

3. Piers

- A. For wall type pier, check the rebar connecting the pier beam to the slab; it must cross at the top of pier beam and the exposed portion must be protected until the slab concrete is placed.
- B. For wall type pier, Type B expansion joint material must be placed on the top of the pier beam as shown on the plans.

4. Slab Form

- A. Check the slab depths at spacer frame locations and at the faces of abutments and piers along the center line and the edges of the roadway. Check the tolerance for slab depth as per the plans.
- B. Check the form soffit for camber, especially for negative camber as per the plans. Adjust plan camber if long span beams are used to support the forms.
- C. Check the dimensions of the recesses in the forms for the P/T anchors.
- D. Record elevations on the "Slab Elevations" sheet.

5. P/T Ducts

- A. Check longitudinal duct size, spacing, duct profiles at spacer frame locations and at the center line of abutments and piers. Check the tolerance for duct placement in the horizontal and vertical directions. Make sure that the longitudinal ducts are laid out in a straight line and follow a smooth parabolic profile. Snaking of the profile should not be allowed.

- B. Check transverse duct size, spacing and profile at the edges of the slab and at the center line of the roadway. The transverse duct spacing is critical to avoid interference with rail posts.
- C. Check the splices and connections in the ducts to make certain they are sealed to prevent the entrance of concrete during placement.
- D. Check to make sure that the minimum clearances to concrete surfaces from the ducts are provided near mid-spans and piers as shown on the plans.
- E. Check to make sure that the P/T Ducts and mild steel reinforcement are tied securely to prevent displacement during concrete placement. It is critical that the longitudinal ducts do not shift during concrete placement.
- F. Check to make sure that all parts of the ducts are corrosion protected as per the plans.

6. P/T End Anchorage

- A. Check the type of anchor device installed and special reinforcing such as spirals and grids in the 'local zone' of the end zone. Make sure that spiral and local zone reinforcement is securely tied in place prior to concrete placement.
- B. Check to make sure parts of anchor devices are corrosion protected, as per the plans.

7. General End Zone Reinforcing

- A. Check the proper installation of the general end-zone reinforcing in the abutment consisting of closely spaced stirrups, "O" bars and "L" bars as per the plans.

8. Inspection by P/T Manufacturer

- A. Prior to the placement of concrete in the slab, check to verify for the inspection and the approval of all P/T hardware and end-zone reinforcing installation by a qualified representative of the P/T Manufacturer. Such inspection must be done in the company of the KDOT inspector and the Contractor.

9. Slab Concrete Placement

- A. Verify appropriate strength (5 ksi) concrete (with superplasticizer, as applicable) is delivered for the slab, capable of attaining specified release strengths.
- B. Verify the slab concrete is thoroughly vibrated around the ducts.
- C. Verify the test samples are taken and kept on site to accurately represent the strength of concrete at site conditions.
- D. Alert the Contractor to place concrete in a manner to avoid direct impact to the ducts or displacement of the ducts during all concrete placement, vibration, and screeding operations.

10. Slab Concrete Curing

- A. Check that the curing process is followed by the Contractor as per Standard Specifications.
- B. Check the testing of the concrete cylinders at days noted on plans for the purposes of stressing the slab.

11. Installation of Strands

- A. Check the condition of strands prior to installation. Check for rust and damage.
- B. Make certain that the strands are installed as soon as possible after the concrete is placed since stressing can commence within days after concrete placement. It is desirable to begin transverse stressing operations as soon as the notes on the Plans and the Project Specifications allow.
- C. Check the number of strands in each tendon.
- D. Check to make sure adequate strand length is provided beyond the anchor plates for the stressing operation.

12. Stressing Operation

- A. Check the calibration of the jacks used for stressing.
- B. Check to make sure a qualified representative of the P/T Manufacturer is present throughout the stressing operation to assist the Contractor.
- C. Check to verify the attainment of the required concrete strengths prior to stressing.
- D. Check that the proper stressing sequence is followed.
- E. Check to verify proper record keeping procedures are followed during stressing by the Contractor.
- F. Check to verify the approval of the stressing completion by the P/T Manufacturer's Engineer and KDOT Engineer prior to cutting off excess strands.

13. Grouting Operation

- A. Check the readiness of the proper grouting equipment and materials prior to grouting.
- B. Check to make certain that the ducts are grouted in full by observing the flows through the vent pipes and gage pressure.
- C. Check the grout type and material specifications prior to grouting operation.

- D. Check the grout material and type that will be used for the recess pockets. It is critical to use an approved material as specified on the plans.

14. Form Work Removal

- A. Removal of slab forms shall be in accordance with the plans. In any event, check to make sure the slab forms are not removed until after all stressing and grouting operations are complete.

15. Finishing

- A. Check to make sure exposed anchor devices and recess pockets are cleaned of all debris, grout and other material.
- B. Check the corrosion protection applied to all exposed anchor devices after grouting is complete.
- C. Check to ensure that the exposed surfaces of the recess pockets are appropriately prepared for filling with material as per the plans and specifications.
- D. Check to ensure all recess pockets (transverse and longitudinal) are filled with an approved material per the post-tensioning specifications, and the appropriate surface treatment waterproofing membrane is applied on required surfaces (see plans and specifications). Recess pockets should be filled thoroughly and finished smooth and flush with the adjacent concrete surface.
- E. Check to verify all stressing record documents are properly completed and signed by the P/T Manufacturer's Engineer.

VII. LESSONS LEARNED

Post-tensioned Concrete Haunched Slab Bridges have been in use in Kansas since 1989. Based on monitoring and inspecting many bridges that were built for the past two decades throughout the state, Issues have been identified to improve the durability and performance of these kinds of bridges. Some of these issues are discussed in detail below.

VII.1 Transverse Pockets

On many bridges, the grout fill material of the transverse tendons is breaking apart and cracking as shown in the photos below. This issue has been observed on bridges that are located on routes that are treated for salt during inclement weather. The breaking of the fill material appears to be a localized material issue and does not affect the structural performance of the bridge; however the defect is highly visible and often unsightly.



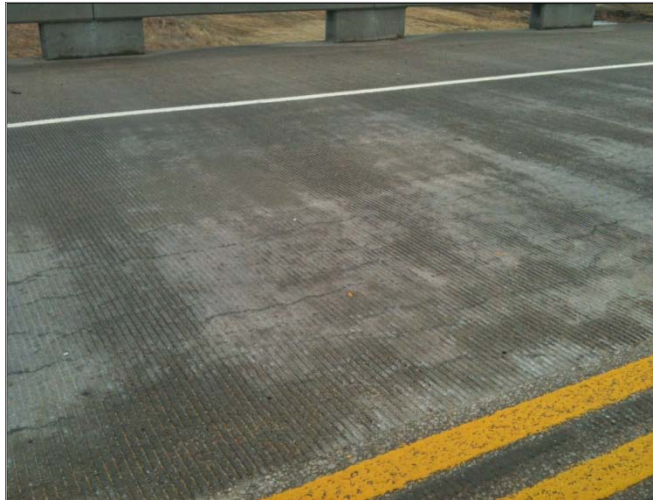
The pockets on the edge of the slab for transverse post-tensioning are exposed and visible elements. The primary importance for these pockets is that they must be filled with a material that is capable of providing protection for the end anchorage of the post-tensioning assembly. Such a material serves as a “line of defense” in preventing chloride access to the assembly and reducing corrosion potential. Of secondary importance, these pockets should blend in with the adjacent concrete for aesthetic purposes. Although perhaps not an issue in rural environments, and at many stream crossings, these pockets should not be unsightly in urban environments. Currently KDOT’s Specifications for Recess Pocket Filling read: “Fill all longitudinal and transverse end anchorage recess pockets as shown in the Contract Documents. Apply an approved epoxy resin bonding agent according to the manufacturer’ prior to placing an approved non-shrink, non-metallic grout. Apply grout according to the grout manufacturer’s instructions. Finish the outside exposed surfaces of the recess pockets smooth and flush with the surrounding concrete surface. Select grout to match the color of the surrounding concrete slab.”

It is believed that the current specifications succeed in achieving their primary objective: protecting the transverse anchorage assemblies. Potential ways to improve the secondary, aesthetic issue include:

1. The use of an approved epoxy system that will not break or deteriorate when in contact with salt and water.
2. The use of an approved material such as Magnesium Ammonium Phosphate Concrete. This material is widely used in Florida.
3. Applying a waterproofing membrane to serve as another layer of protection to the sides of the slab.
4. Avoid drainage through the corral opening by applying a continuous curb with scuppers to prevent drainage over the side. Drainage over the side is probably the primary “attack mechanism” on the transverse anchorage. If needed, scuppers would have to be placed carefully to avoid post-tensioning hardware.

VII.2 Longitudinal Shrinkage Cracks

Many post-tensioned haunched slabs bridges have shown hairline longitudinal cracks that start over the pier and propagate longitudinally along the bridge. These hairline cracks develop at the top of the slab only. It is believed that these cracks occur due to shrinkage (specifically, “drying shrinkage”) of the concrete in the transverse direction.



Conventionally reinforced concrete slab bridges have shrinkage cracks in transverse and longitudinal directions. It is believed that in the XCSH bridges the magnitude of the longitudinal post-tensioning forces eliminates the shrinkage cracks in the transverse direction. But not enough transverse post-tensioning is being applied to eliminate shrinkage cracks in the longitudinal direction.

Another suspected reason for these hairline longitudinal cracks is the lack of a mild steel reinforcement mat over the longitudinal duct over the pier. It is believed that the hairline crack starts over the pier before it grows through the slab. The longitudinal duct is located very close to the top of the slab with the 3" minimum cover. This in turns prevents adding mild steel over the duct near the pier.

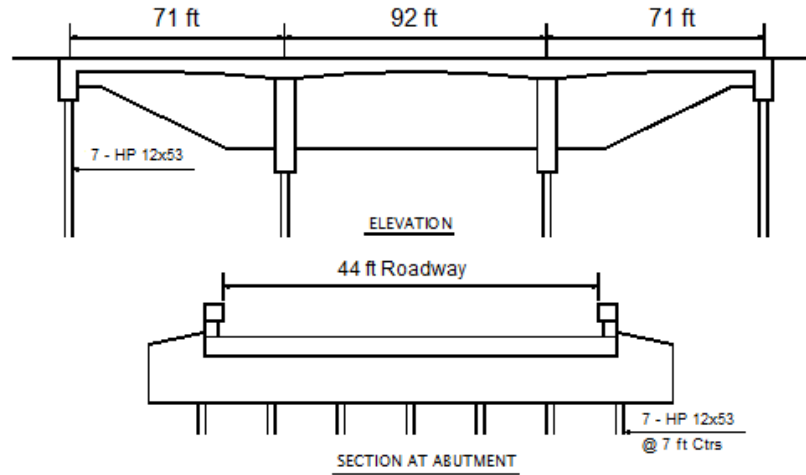
Although the top slab shrinkage cracks in the longitudinal direction should be taken seriously, it is not believed they are a critical danger to the structural integrity of the XCSH Bridge. That being established, following are possible approaches to this problem:

1. Provide wire mesh reinforcement over the duct near the pier so that the longitudinal duct is completely confined. Adding the wire mesh will not encroach much on the 3" minimum cover. The use of #3 bars in the mesh should be adequate.
2. Increase amount of top mat transverse mild steel in order to minimize shrinkage cracks in the longitudinal direction. Increasing the amount of mild steel may aid in reducing the amount of shrinkage. Currently the standards call for #4 at 12" centers, except at the piers, where #4 @ 6" centers is called for. #5 at 6" centers could be used everywhere, also aiding as a work platform prior to concrete pour. It should be noted that ACI SP-227-1 may indicate a stiffer mild steel top mat compared to the bottom mat may actually be counter-effective.
3. Increase amount of transverse post-tensioning. Increasing the transverse post-tensioning would not reduce shrinkage, but could eliminate shrinkage cracks. Currently, the compressive stress due to the transverse tendons is about 100 psi. Doubling up on this stress value will be beneficial and will control any potential cracks that may develop.
4. Apply an overlay to seal the cracks after they develop. Because the shrinkage cracks do not pose a critical threat to the structural performance of a XCSH bridges and because shrinkage cracks are tolerated on a RCSH bridge where they are more extensive in nature, a viable alternative is to live with the problem. Additionally, the cracks in the slab could be sealed after they develop. This would involve waiting many years for full crack development and then sealing them with KDOT's multi-layer polymer overlay, or something similar.

APPENDIX

Example A.1

Check capacity of the steel H-piles in the abutment for a 71 ft – 92 ft – 71 ft Post-tensioned Concrete Haunched Slab span bridge, 44 ft roadway subject to HL-93 Live Loading and 25 psf future wearing surface load. Pile orientation is such that the weak axis resists longitudinal forces.



1. Permanent Vertical Loads:

Permanent Vertical Loads	
Vertical Loading	Abutment Rxn (kip)
DC: Slab, Barriers, Abutment	466
DW: FWS	27
PS: Secondary	40
CR+SH: Creep and Shrinkage	-6
Summation (Service I):	528

2. Live Loads: (HL-93, No Impact)

One Lane Reaction at Abutment = 80 kip

Maximum live load on a single pile results from two lanes shifted to one side of the bridge

Therefore, Number of Design Lanes = 2 ; Multiple Lane factor = 100 %

Vertical Live Load Reaction = 80 kip * 2 lanes * 100% MLRF = 160 kip

$$Transverse\ Live\ Load\ Moment = 160\ kip * \left(\frac{44ft}{2} - 2ft - \frac{6ft}{2} - \frac{12ft}{2} \right) = 1,760kip - ft$$

$$\text{Single Pile Reaction} = \frac{P}{\# \text{ piles}} + \frac{M * y_{\text{pile}}}{\Sigma (y_{\text{pile}}^2)} = \frac{160 \text{ kip}}{7 \text{ piles}} + \frac{(1760 \text{ kip-ft}) * (21 \text{ ft})}{1372 \text{ ft}^2} = 50 \text{ kip}$$

3. Lateral Loads:

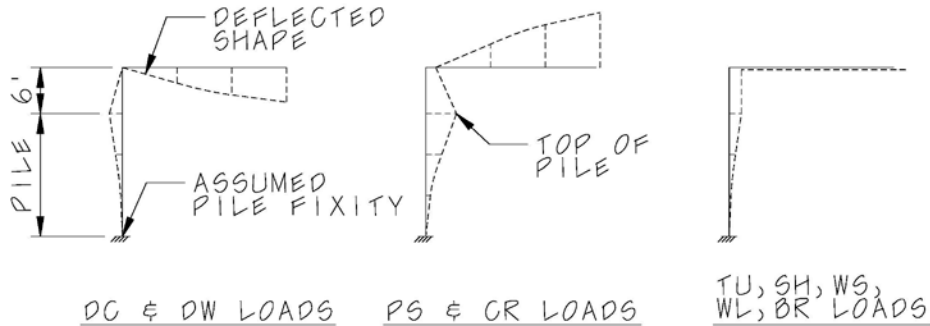
During the analysis, a relative stiffness comparison was conducted. It was found that the longitudinal and lateral stiffness of the abutments versus piers equaled 1:9, therefore the following ratio will be used to determine lateral load sharing between abutments and piers:

$$\text{Abutment Force} = \text{Lateral Force} * \frac{\text{Abut Stiffness}}{\Sigma \text{Pier Stiff} + \Sigma \text{Abut Stiff}} = F * \frac{1}{9 * 2 + 1 * 2} = 5\% * F$$

External longitudinal loads such as Braking, Longitudinal Wind on Structure, and Longitudinal Wind on Vehicles have conservatively been assumed to produce pile forces. This is a conservative approach, as any significant displacement caused by these forces is resisted by soil pressure at the integral abutments.

It should also be noted that for transverse external forces, such as Transverse Wind on Structure, and Transverse Wind on Vehicles, the point of load application occurs at a certain height above the piles. Due to this, a couple is resisted vertically among the piles. This force is negligible for these calculations, and has been omitted for clarity.

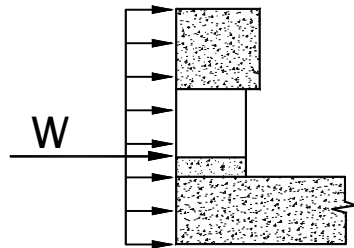
Displaced shapes of the structure will differ for certain loads. Magnitudes of this displacement will also differ at the top of slab versus top of pile. The following shapes are witnessed for the following loads:



Longitudinal Displacement Shapes

For this investigation, all piles are assumed to behave as cantilevers, with a pinned connection at the base of the integral abutment stem wall. This is assumed for longitudinal and transverse forces.

3a. Wind Pressure on Structure (WS):



Height (H) = 5ft (average)

$\sigma_{\text{wind_long}} = 12 \text{ psf}$

$\sigma_{\text{wind_trans}} = 50 \text{ psf}$

$WS_{\text{long}} = 5\% * (71 \text{ ft} * 2 + 92 \text{ ft}) * 5 \text{ ft} * 0.012 \text{ ksf} = 0.7 \text{ kip}$

$$WS_{trans} = W_{long} * \frac{50psf}{12psf} = 2.9 \text{ kip}$$

$$WS_{long_mom} = WS_{long} * 16ft = 11k - ft ; WS_{trans_mom} = WS_{trans} * 16ft = 47k - ft$$

3b. Wind Pressure on Vehicles (WL):

$$\omega_{wind_live_long} = 40plf$$

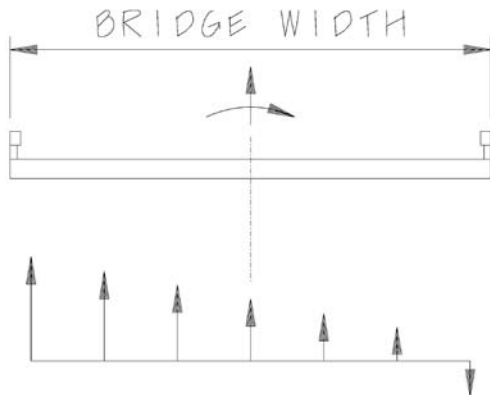
$$\omega_{wind_live_trans} = 100plf$$

$$WL_{long} = 5\% * (71ft * 2 + 92ft) * 0.04klf = 0.5 \text{ kip}$$

$$WL_{trans} = WL_{long} * \frac{100plf}{40plf} = 1.2 \text{ kip}$$

$$WL_{long_mom} = WL_{long} * 16ft = 8k - ft ; WL_{trans_mom} = WL_{trans} * 16ft = 19k - ft$$

3c. Vertical Wind Pressure (WS for Strength III Load Combination):



$$P_{uplift} = 0.02ksf * (71ft * 35\%) * 46ft = 23kip$$

$$M_{overturn} = P_{uplift} * \frac{46ft}{4} = 263 \text{ kip} - ft$$

$$P_{pile} = \frac{P_{uplift}}{\#piles} \pm \frac{M_{overturn} * y_{pile}}{\Sigma (y_{pile}^2)}$$

$$= \frac{23kip}{7 \text{ piles}} \pm \frac{(263k - ft) * 21ft}{1372ft^2}$$

$$= 7.3kip \text{ (tension)} / 0.8kip \text{ (compression)}$$

3d. Braking Force (BR):

$$Bridge_{length} = 71ft + 92ft + 71ft = 234ft ; P_{truck} = 72kip ; \omega_{lane} = 0.640klf$$

$$BR_{long_force} = 5\% * 3lanes * 0.85 * \max\{25\% * P_{truck}, 5\% * (P_{truck} + Bridge_{length} * \omega_{lane})\}$$

$$= 2.3kips$$

$$BR_{long_mom} = BR_{long_force} * 16ft = 37k - ft$$

3e. Longitudinal Forces due to Imposed Displacements:

As indicated at the beginning of this section, longitudinal pile displacements also occur due to the following loads: DC, DW, PS, CR, SH, & TU. These are a result of imposed displacements at the top of the pile, and are presented in the following section. For the shallow depth abutment on single row of piles, the steel pile is assumed to be pinned at the top of the abutment and fixed at 16 ft below the bottom of the bridge seat. Therefore moments in the pile can be calculated assuming the stiffness of a cantilever:

$$k_{cantilever} = \frac{3EI}{L^3} = \frac{3 * 29,000ksi * 127in^3 * 7piles}{(16ft * 12in)^3} = 10.9 \frac{k}{in}$$

$$M_{cantilever_base} = k_{cantilever} * \Delta_{pile} * L_{cantilever}$$

Rotations are also given in the proceeding section at the top of slab. If displacements are desired at the top of slab, this rotation should be multiplied by the integral stem wall height and subtracted from the displacement at the top of pile. Examples are as follows:

$$\Delta_{CRSH_at_top_of_slab} = 1.29in - 0.0045rad * \left(6ft * \frac{12in}{1ft}\right) = 0.97in$$

$$\Delta_{PS_at_top_of_slab} = 0.96in - 0.009rad * \left(6ft * \frac{12in}{1ft}\right) = 0.31in$$

$$\Delta_{TU_at_top_of_slab} = 0.38in - 0.00rad * \left(6ft * \frac{12in}{1ft}\right) = 0.38in$$

4. Pile Capacity Check:

AASHTO LRFD is used to combine load effects and check strength capacity of the piles. The assumed pile is an HP12x53, with minimum yield strength of 50ksi. The following steps will be followed to check capacity:

- Use factored load combinations to determine pile demand (Article 3.4.1-Load Factors and Load Combinations). Magnify moments as appropriate due to lateral displacements.
- Calculate pile capacities for axial, weak axis bending, and strong axis bending (Articles 6.9.4.2, 6.12.2.2, and 6.10.8.2, respectively). Also see Article 10.7.3.13 for fully embedded piles.
- Check capacity interaction values per Article 6.9.2.2-Combined Axial Compression and Flexure.

The table below provides a summary of pile capacities:

Pile Capacity Table	Nominal Capacity	Resistance Factor	Factored Resistance
Axial (k)	767	0.7	537
Weak Axis Bending (kip-ft)	114	1.0	114
Strong Axis Bending (kip-ft)	222	1.0	222

Interaction values for the piles use the following formula:

$$if \frac{P_u}{P_r} < 0.2, then \frac{P_u}{2P_r} + \frac{M_{u_long}}{M_{r_weak}} + \frac{M_{u_trans}}{M_{r_strong}} \leq 1.0, else \frac{P_u}{P_r} + \frac{8}{9} \left(\frac{M_{u_long}}{M_{r_weak}} + \frac{M_{u_trans}}{M_{r_strong}} \right) \leq 1.0$$

where P_r and M_r = Factored Resistance

The table below summarizes demands on a single pile and corresponding interaction values for the AASHTO LRFD Strength Load Combinations. Longitudinal moments have been presented both unmagnified and magnified. Due to the confining nature of the integral

abutment, magnified moments have simply been taken as the longitudinal displacement multiplied by the factored axial force.

Pile Demand and Interaction Table	Str I (min)	Str I (max)	Str III (min)	Str III (max)	Str V (min)	Str V (max)
P_u (k)	-152	-181	-66	-96	-132	-161
Δx_u (top of pile) (inch)	2.50	2.33	2.34	2.16	2.51	2.33
$M_{u\text{ long}}$ (unmagnified) (k-ft)	-52	-47	-59	-55	-55	-50
$M_{u\text{ trans}}$ (k-ft)	0	0	9	9	5	5
Mom. Mag. ($P_u * \Delta x_u$) (k-ft)	-32	-35	-13	-17	-28	-31
$M_{u\text{ long}}$ (magnified) (k-ft)	-83	-82	-72	-72	-82	-81
Interaction Value	0.93	0.98	0.73	0.76	0.91	0.96

The axial capacity of the pile, without bending is also checked per AASHTO LRFD Article 6.15.2, for pile damage and other unknowns occurring due to driving.

$$P_{r\text{ max}} = \phi_{c\text{ damaged}} * P_n = 0.50 * 767\text{kip} = 383\text{kip}$$

The maximum factored axial load on the pile is 181kips, therefore this is satisfied. Pile drivability shall also be checked according to Article 10.7.8 - Drivability Analysis.

Summary

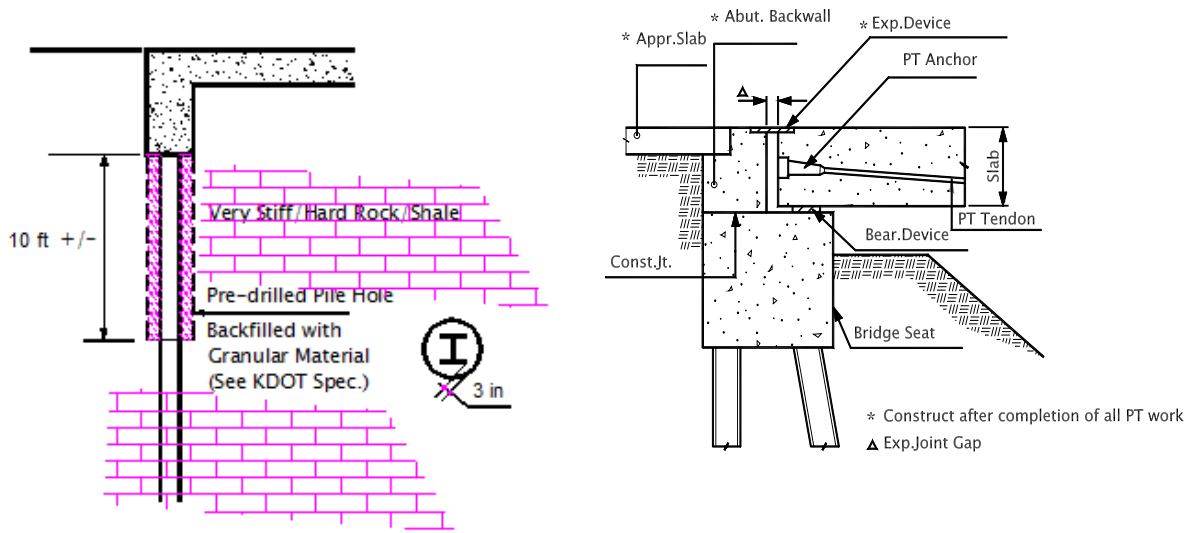
The procedure presented in this example is an approximate, simplified and practical approach for most commonly encountered soil conditions consisting of well drained and predominantly granular type soil. In the event complex soil conditions are encountered, such as highly plastic clay, etc., a detailed geotechnical investigation and analysis of piles for lateral loads by an experienced geotechnical professional might be warranted. The choice of the approximate method or a detailed geotechnical analysis using more advanced methods of analysis should be made by the professional engineer in charge of the design of the bridge based on site conditions and choice of substructure design. The above example is presented to illustrate the concept for checking substructure capacity when post-tensioning of the superstructure is involved.

Table A.1

Movement of the Slab at Abutments

Span	XCSH Information			Top of Slab Displacements			
	Depth (min) (in)	Depth (max) (in)	Total Length (ft)	CR+SH (in)	PS (in)	TU (in)	Total (in)
A	17	29	165	0.66	0.18	0.27	1.11
B	18	31	182	0.71	0.19	0.29	1.19
C	20	35	206	0.91	0.26	0.33	1.51
D	22	38	234	0.97	0.31	0.38	1.66

Figure A.1



Integral Abutment in Hard Strata

Standard Abutment with Expansion Joint

4a. Presentation of Abutment Forces, Displacements, and Load Combinations:

Table of Results from Analysis and Load Combinations for Abutment Piles (Results are summation of all piles in abutment)											
LRFD Loads \ Force, Disp.	Loads at Fixity, Displacements at Top of Pile					Load Combinations and Corresponding Load Factors					
	Axial (k)	Long Mom (k-ft)	Trans Mom (k-ft)	Δx (inch)	Phi (slab) (rads)	Str I (min)	Str I (max)	Str III (min)	Str III (max)	Str V (min)	Str V (max)
DC	-466	70	0	-0.40	-0.0056	0.9	1.25	0.9	1.25	0.9	1.25
DW	-27	4	0	-0.03	-0.0004	0.0	1.5	0.0	1.5	0.0	1.5
PS	-40	-168	0	0.96	0.0090	1.0	1.0	1.0	1.0	1.0	1.0
CR+SH	6	-226	0	1.29	0.0045	1.0	1.0	1.0	1.0	1.0	1.0
TU	0	-66	0	0.38	0.0000	1.0	1.0	1.0	1.0	1.0	1.0
*HL-93	-50	8	0	-0.04	-0.0005	1.75	1.75	0.0	0.0	1.35	1.35
BR	0	-37	0	0.17	0	1.75	1.75	0.0	0.0	1.35	1.35
WS Long	0	-11	0	0.05	0	0.0	0.0	1.4	1.4	0.4	0.4
WS Trans	0	0	47	0	0	0.0	0.0	1.4	1.4	0.4	0.4
WL Long	0	-8	0	0.04	0	0.0	0.0	0.0	0.0	1.0	1.0
WL Trans	0	0	19	0	0	0.0	0.0	0.0	0.0	1.0	1.0
*WS Overturn	-1	0	0	0	0	0.0	0.0	1.4	1.4	0.0	0.0

* This loading is per pile, see prior calculations.