U.S. Department of Transportation

Replaceable Grouted External Post-Tensioned Tendons

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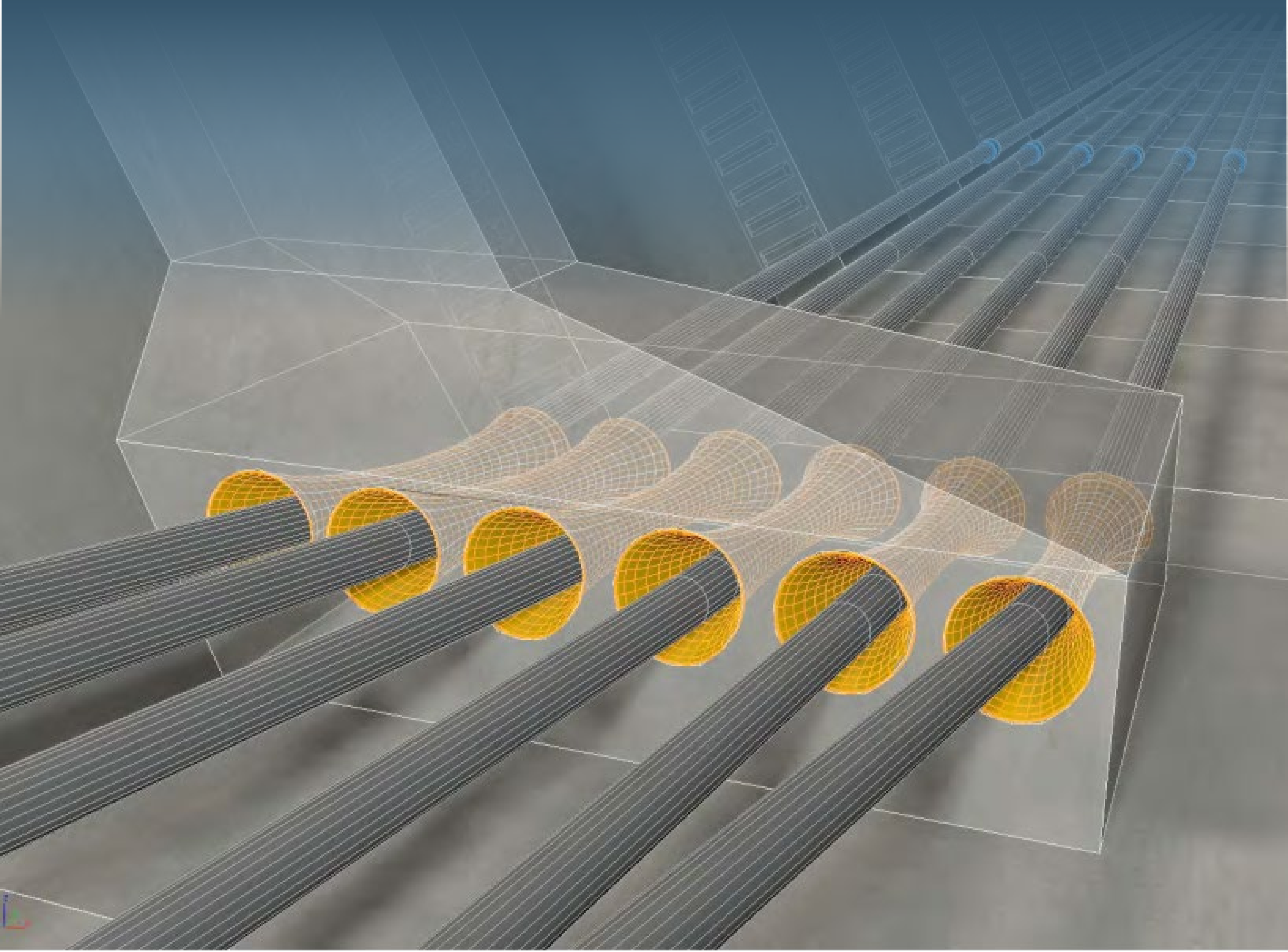

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TECHNICAL REPORT DOCUMENTATION PAGE

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16. Abstract

Corrosion of prestressing strands has required replacement of external post-tensioning tendons in several existing post-tensioned bridges. External tendons are commonly used in concrete box girder bridges constructed using the span-by-span or balanced cantilever methods. Currently in the US, external tendons are discretely bonded at anchorages and deviator locations. Replacement of these types of tendons is a complex and time-consuming operation with safety concerns for personnel. Under task order 5009, WSP conducted a state-of-the-art review, then developed and presented guidance for fully replaceable grouted external tendons. Specific details included post-tensioning system components, structural design and detailing aspects, and tendon installation and replacement procedures.

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DEFINITIONS AND ABBREVIATIONS

Definitions

Adjustable PT – Post-tensioned tendon in which the stressing force can be modified during the life of the structure if needed.

Balanced Cantilever – Segmental bridge erection method where segments are alternately erected outward starting from pier.

Blister – A concrete block with prismatic shape where a tendon is anchored outside of the main concrete section.

Deviator – A concrete block attached to the main concrete section to change the direction of an external post-tensioned tendon.

De-tensionable PT – Post-tensioned tendon detailed to allow the prestressing force in a tendon to be relieved without damaging the existing tendon or structure.

Diabolo – A formed void in a deviator or diaphragm with trumpet shaped ends to align and direct an external tendon through the concrete section.

Double envelope concept – Replaceable external tendon utilizing diabolo forms and guide pipes where the whole tendon, including anchorages is detailed so that no integral connection is made to the structure.

External tendon – A tendon located external to the concrete section and is thus an unbonded tendon.

Filler material – Material used to fill the space between post-tensioning strands and tendon duct. The most common filler material used is grout but grease or wax are also used.

Guide pipe – A structural assembly that aligns and directs the tendon at the anchorage location and provides separation between the anchor body/trumpet and duct to the surrounding concrete section.

Half-Shell Form System – A tendon deviation system comprised of curved cradle forms nested inside a circular tube.

Replaceable PT – Post-tensioned tendon designed and detailed to allow speedy removal and replacement without causing structural damage.

Span-by-Span – Segmental bridge erection method utilizing either underslung or overhead gantries to erect and assemble precast segments one span at a time in a linear fashion.

Abbreviations

ASBI – American Segmental Bridge Institute

EPDM – Ethylene Propylene Diene Monomer

EOTA – European Organization for Technical Assessment

ETAG –European Technical Approval Guideline

fib – International Federation for Structural Concrete

HDPE – High-density Polyethylene

GUTS – Guaranteed Ultimate Tensile Strength

PE – Polyethylene

PP – Polypropylene

PT – Post-tensioned or Post-tensioning

SETRA – French Technical Department for Transport, Roads and Bridges.

1.0 INTRODUCTION

1.1 Background

Due to corrosion of prestressing strands, several existing bridges in the United States (US) have required replacement of external tendons. External tendons are commonly used in concrete box girder bridges constructed using the span-by-span or balanced cantilever methods. Currently in the US, external tendons are discretely bonded at anchorage and deviator locations. Figure 1-1 shows typical external tendons in a span-by-span box girder. The replacement of these types of tendons is a complex and time-consuming operation with safety concerns for personnel.

Courtesy of Teddy Theryo

Figure 1-1
Typical External Tendons in a Box Girder

There is significant opportunity to further improve the state of practice for post-tensioned (PT) bridges. Replacement of external PT systems can be greatly advanced using currently available tools and technologies.

1.2 Objectives

The objective of this report is to develop and present guidance for fully replaceable grouted external tendons. Specific items of interest include post-tensioning system components, structural design and detailing aspects, and tendon installation and replacement procedures. Additionally, specification language is proposed for adoption into the PTI/ASBI M50.3 *Guide Specification for Grouted Post-Tensioning*.

Components required for tendon replaceability such as guide pipes or double trumpets at tendon anchorages and diabolo forms at diaphragms and deviators are existing technologies although their use is not widespread in the US. Part of the goal of this report is to compile these existing techniques and present background information.

1.3 Review of Other Replaceable Tendon Concepts

From 1994 to 2005, several bridges in France exhibited durability issues with their grouted external tendons and some bridges required removal and replacement of their external tendons [18]. After this experience, new projects were required to have replaceable external tendons.

There are several strategies for replaceable external tendons in Europe:

A. Implementation of flexible filler materials (grease or wax).

B. Implementation of mono-strand greased and sheathed tendons.

C. Implementation of diabolo form at deviators, and diaphragms (double envelope concept) in combination with A and B strategies.

The French Technical Department for Transport, Roads and Bridges (SETRA) later prohibited grease and replaced it with wax filler material.

Japan, on the other hand, implemented epoxy coated strands without any filler in their external tendons. The epoxy coated multi-strands are not bonded to the deviator or diaphragm but pass through plastic / steel pipes.

In early 2014, the Florida Department of Transportation (FDOT) issued Structures Design Bulletin 14-06 [12] requiring the use of flexible filler material in lieu of grout for certain tendon types. This is the first official replaceability requirement for external tendons by an owner in the US. In December of 2016, the Virginia Department of Transportation (VDOT) issued Instructional and Informational Memorandum IIM-S&B-91 requiring the use of flexible filler material for external tendons and stainless-steel strands with grout for internal tendons [28]. VDOT also required tendons with flexible filler to be replaceable.

A survey of several countries around the world found replaceable external tendons are required, while some countries also require tendons to be de-tensionable and adjustable as shown in Table 1-1 below.

Table 1-1
External Tendon Requirements in Various Countries

Country	De-tensionable	Replaceable	Adjustable (2)
France	Yes	Yes	No
Germany	Yes	Yes	Yes
Japan	No	Yes	No
USA	No	Yes (1)	No

(1) Florida [12] and Virginia [28]
(2) Ability to re-stress the tendon

The double envelope concept (see Section 2.1) can be used to provide replaceability for external tendons with any type of filler material. However, flexible filler materials are required for de-tensionable and adjustable tendons.

In France and Germany, both flexible filler materials and double envelope details are implemented at the same time.

2.0 REPLACEABLE EXTERNAL TENDON CONCEPT

2.1 Current Detailing of External Tendons

Typical construction details for external tendons consist of curved rigid steel pipes embedded in the deviators and diaphragms (see Figure 2-1). The free length between steel pipes consist of high density polyethylene (HDPE) duct which are then coupled to the steel pipes using neoprene sleeves and steel band clamps (see Figure 2-2 and Figure 2-3). Prestressing strands are installed, stressed and grouted in the tendon ducts.

This type of construction detailing does not easily allow the replacement of tendons since separating the strands from the embedded anchorages and pipes in the deviators and diaphragms requires chipping or water-blasting of grout inside the tendon duct. The replacement of these types of tendons quite often results in secondary damage to deviators and diaphragms where the tendons are embedded in the concrete section (see Figure 2-4 and Figure 2-5).

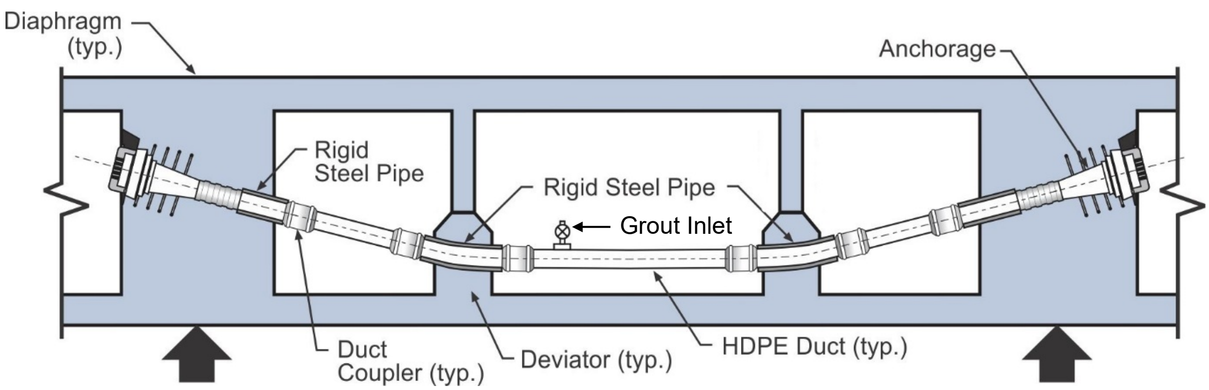


Figure 2-1
Typical External Tendon Details

Courtesy of Teddy Theryo

Figure 2-2
Bonded Rigid Steel Pipes in Deviator

Courtesy of Teddy Theryo

Figure 2-3
Bonded Rigid Steel Pipe in Diaphragm

Courtesy of Teddy Theryo

Figure 2-4
Cracked Concrete Anchor Block During De-tensioning

Courtesy of Teddy Theryo

Figure 2-5
Rigid Steel Pipe Pull-out Resulting in Spalled Concrete

2.2 Proposed Detailing of External Tendons

The focus of this study is to develop guidance and standard details for replaceable grouted external tendons using the double envelope concept, although the concepts presented herein can be applied to other filler materials.

Implementation of double envelope details for grouted external tendons results in post-tensioning that is not bonded to the concrete at any location along the length of the tendon. Force from the post-tensioned tendon is transferred to the superstructure by bearing plates at the anchorages and bearing of the tendon duct against the concrete at the diaphragms and deviators. Some of these anchorage types are very similar to stay cable anchorages. The use of guide pipes or double trumpets at anchorages and diabolo forms at diaphragms and deviators permit this force transfer (see Figure 2-6).

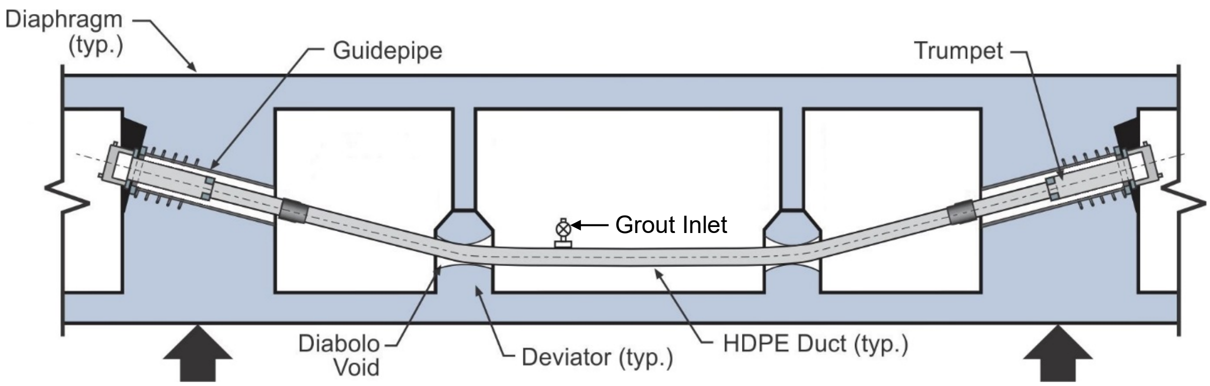


Figure 2-6
Replaceable External Tendons using the Double Envelope Concept

3.0 DIABOLOS

Diabolos typically refer to the shaped voids which allow external tendons to deviate through a concrete element while minimizing stress concentrations along the interface with the concrete element. Diabolos can be used at deviators, blisters, end diaphragms and intermediate diaphragms of box girder bridges. The voids may be constructed using removable and reusable form tools or may be constructed using permanent forms.

3.1 Cross Section Shape

Diabolo forms may be configured into many different shapes and orientations. Several diabolo shapes are shown in

Figure 3-1 including; (a) basic trumpet shape, (b) trumpet shapes at ends of a straight pipe, (c) trumpet shapes at ends of a curved pipe, and (d) race track form.

The trumpet shape allows tendon deviations in the vertical and horizontal directions (see Figure 3-2). To minimize the spacing required at entry and exit points, the use of straight or curved pipes between the trumpet ends may be considered. The race track shape may also be used (see Figure 3-3), however, the race track shape allows tendon deviation and provides tolerances for misalignment in one direction only. Figure 3-4 shows a bridge with trumpet shaped and race track shaped diabolos at a deviator.

There are many alternative diabolo geometries and orientations that can be achieved; however, the trumpet shaped form will mainly be discussed in this report. The primary reason diabolos are used is to simplify forming and construction detailing. Complicated forms and geometric requirements negate some of the main advantages for using the diabolo form. However, each project is unique, and the designer may modify the details as appropriate for the project.

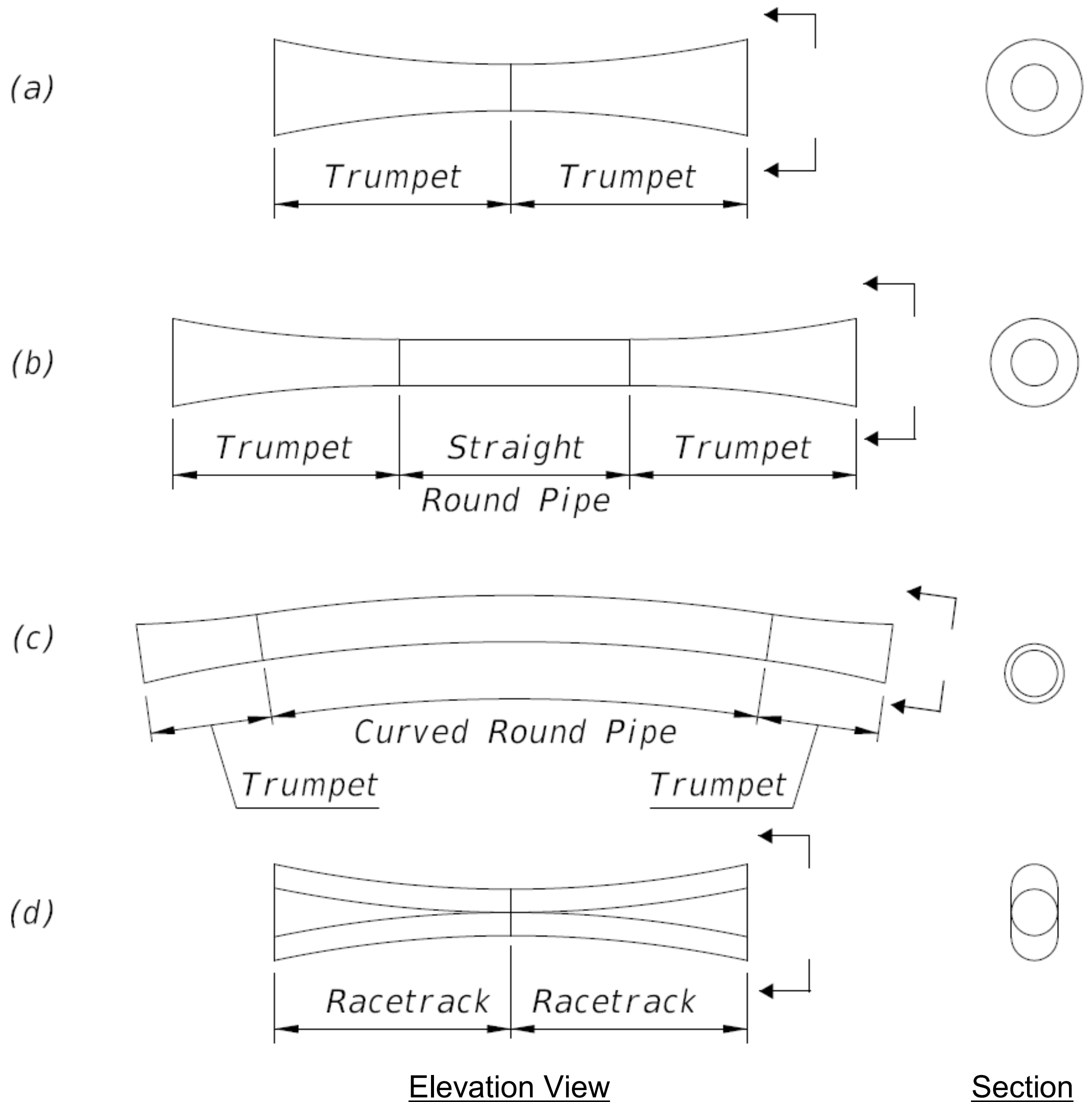


Figure 3-1
Alternative Diabolo Cross Section Shapes

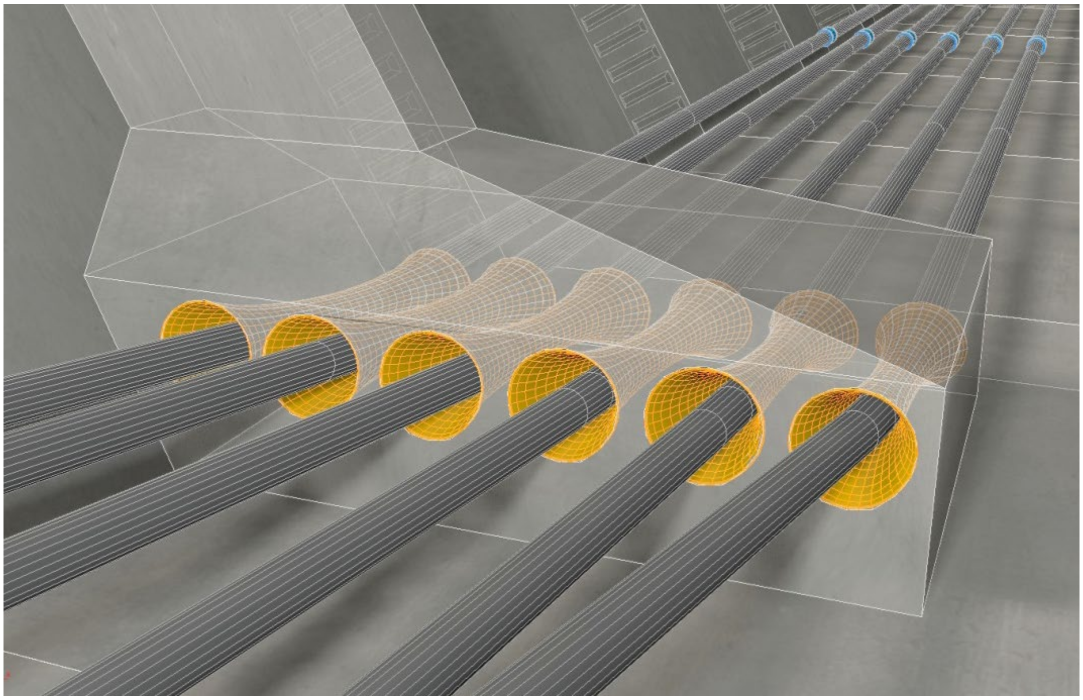


Figure 3-2
Rendering of Trumpet Shaped Diabolos at a Deviator

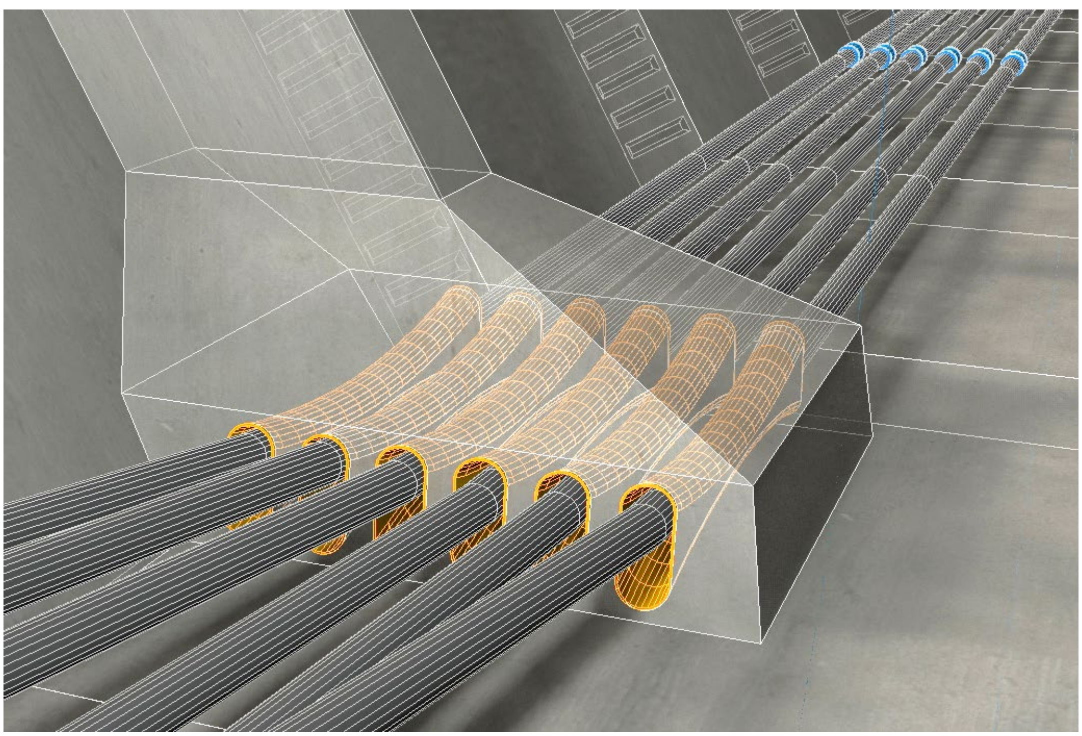


Figure 3-3
Rendering of Race Track Shaped Diabolos at a Deviator

Courtesy of Teddy Theryo

Figure 3-4
View of External Tendons at a Deviator
(Race track and circular shaped diabolo forms)

3.2 Basic Geometry

The basic diabolo form geometry is presented in Figure 3-5. The basic diabolo shape consists of a trumpet shaped curve with constant radius. The controlling parameter for the diabolo geometry is the tendon deviation angle, α, measured between the axis of the diabolo and the centerline of the tendon.

The force in the tendon is transferred to the concrete section by radial force between points of tangency (PT) and centered at the point of curvature (PC) along the diabolo form. To allow for construction tolerances and prevent concrete spalling due to kinks or hard points, points of tangency shall be set back from the concrete face of the deviator or diaphragm. To accomplish this, it is recommended that the exit angle of the diabolo form, β, is three degrees greater than the tendon deviation angle and tangent point is at least 6” from the face of concrete.

It is recommended that the minimum inside diameter of the diabolo form is at least one-half inch larger than the outside diameter of the tendon duct. This one-half inch gap allows the deformed duct to pass through the diabolo void in the event replacement of the tendon is required. Refer to Section 7.2 for further discussion and recommendations on diabolo geometry.

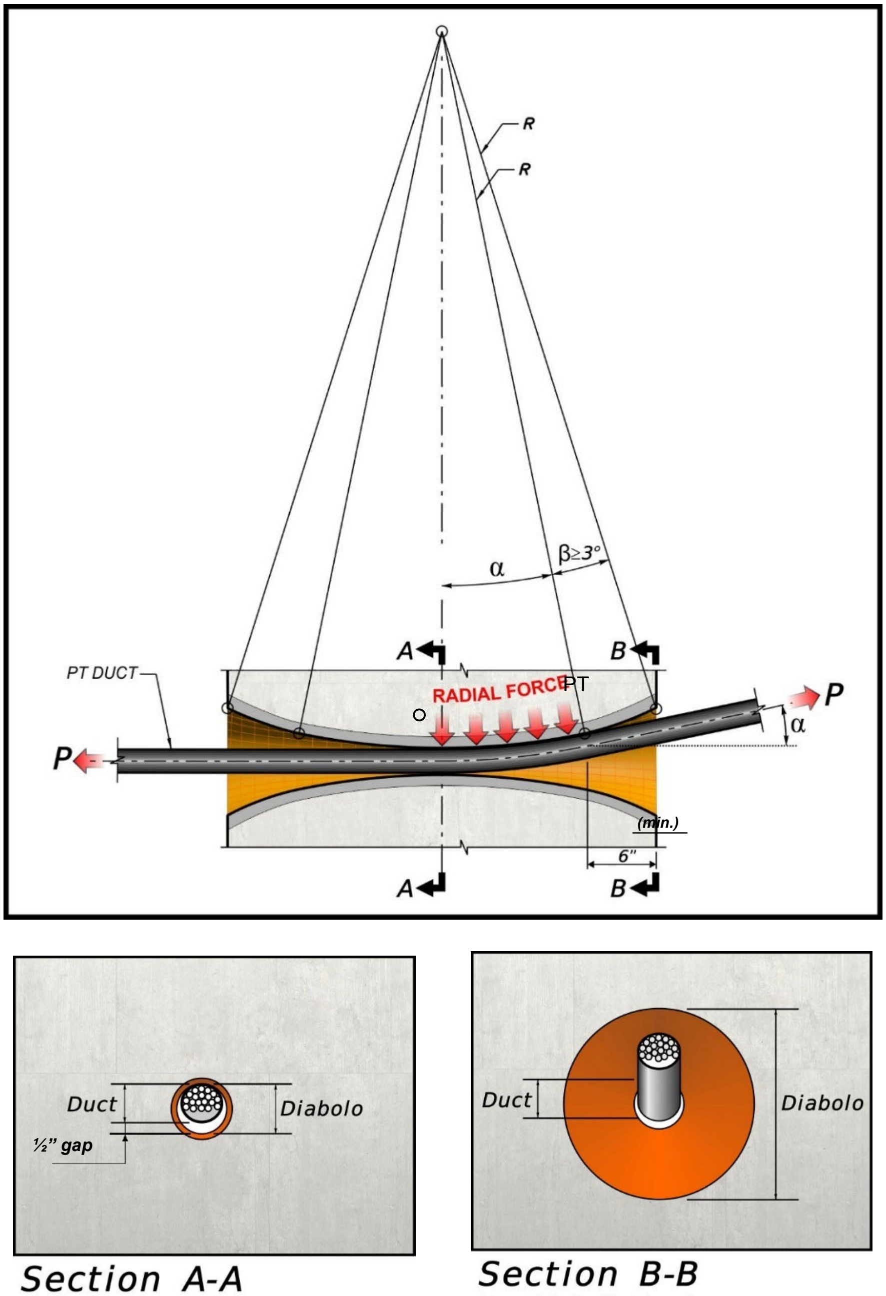
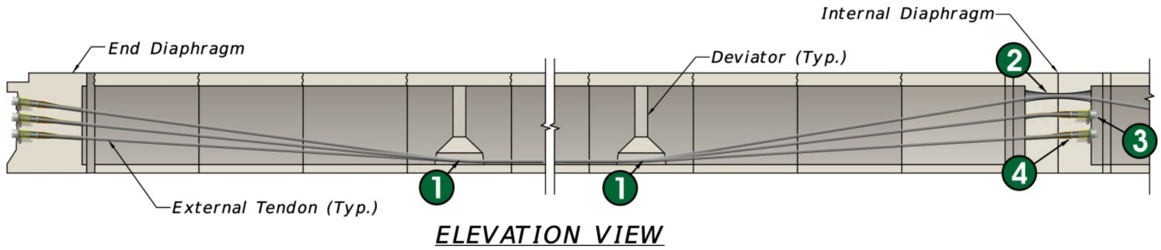


Figure 3-5
Diabolo Form Basic Geometry

3.3 Diabolo Uses

To accommodate complex external tendon layouts in post-tensioned bridges, the diabolo form can be differentiated into several types, depending on the location and particular geometry of the external tendons. Figure 3-6 shows a typical span-by-span segmental bridge. Various locations where diabolos may be used are identified in the figure and correspond to the form types shown in Figures 4-7 to 4-10.



1 - Form type

Figure 3-6
Elevation View of a Span-by-Span Bridge with External Tendons

The Type 1 form is typically used at deviator locations. The continuous curvature of the diabolo is simple to construct and is typically used where the deviation angle is moderate and the length of the concrete element in which the tendon is passing is through is relatively short.

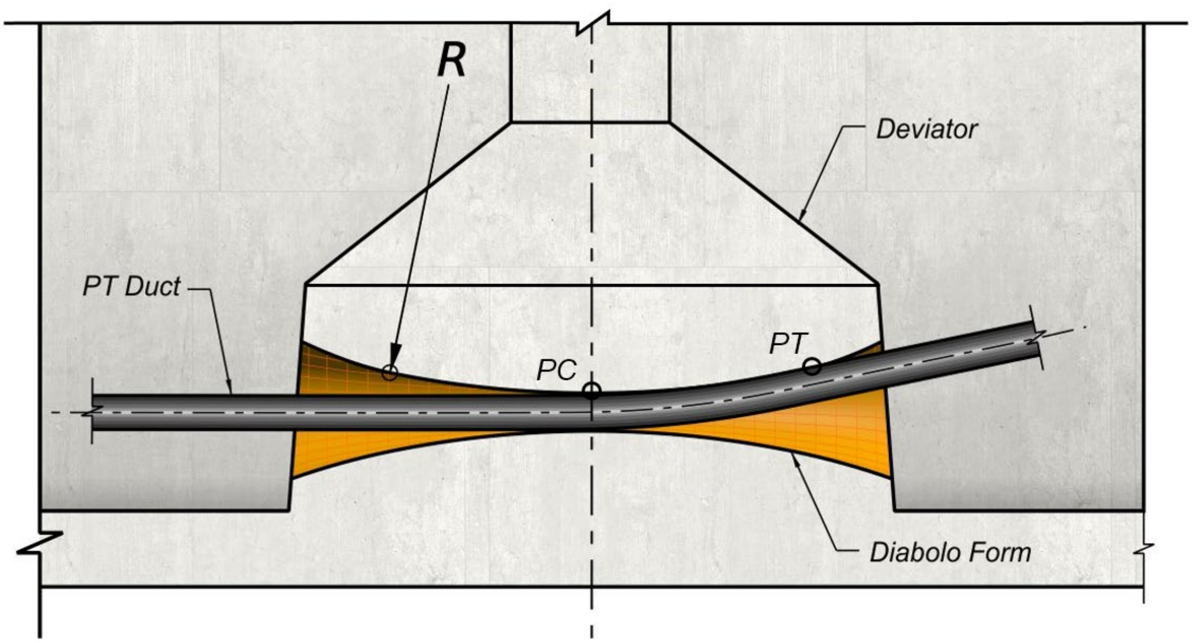


Figure 3-7
Type 1 Form at Deviator

The Type 2 diabolo form may be used at interior diaphragm locations when it is desirable for the tendon to pass through the diaphragm and anchor at a location away from the diaphragm. As the diaphragm thickness increases, it becomes more difficult to minimize the diabolo dimensions at the exit ends if using the Type 1 form. The addition of a straight or curved constant diameter section may be used between the diabolo ends in this instance. Note that this detail currently does not meeting current grouting practices where a grout outlet is required at the high point. Refer to Section 7.2 of this report for further discussion and details.

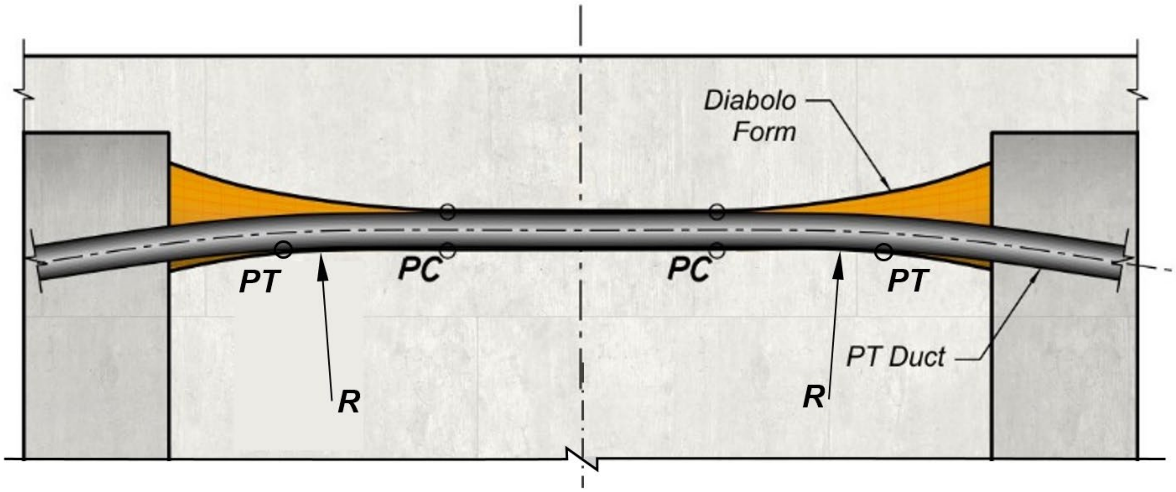


Figure 3-8
Type 2 Form at Pier Diaphragm for a Continuous Tendon

The Type 3 and Type 4 diabolo forms are used at anchor locations. The Type 3 form pictured in Figure 3-9 shows a tendon anchored horizontally with deviation at the exit end.

Figure 3-10 shows a tendon anchored at an angle and also angled at the exit end. Both forms consist of a guide pipe with a diabolo form at the exit end. The shape of the guide pipe at the anchorage end will depend on the type of anchorage supplied as discussed in Section 5.0 and may be constructed horizontal or angled.

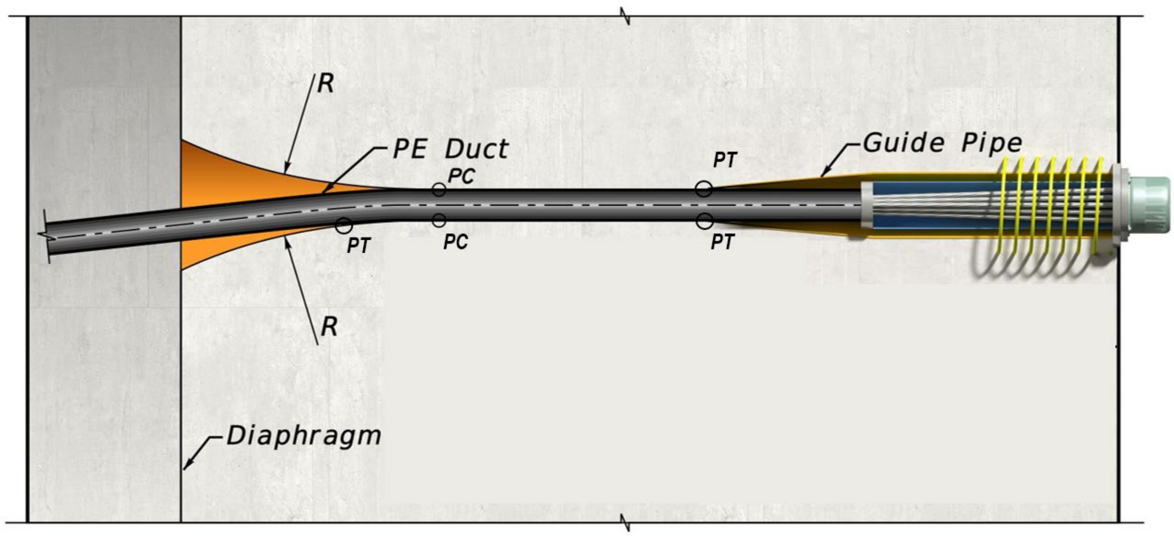


Figure 3-9
Type 3 Form near Anchorage

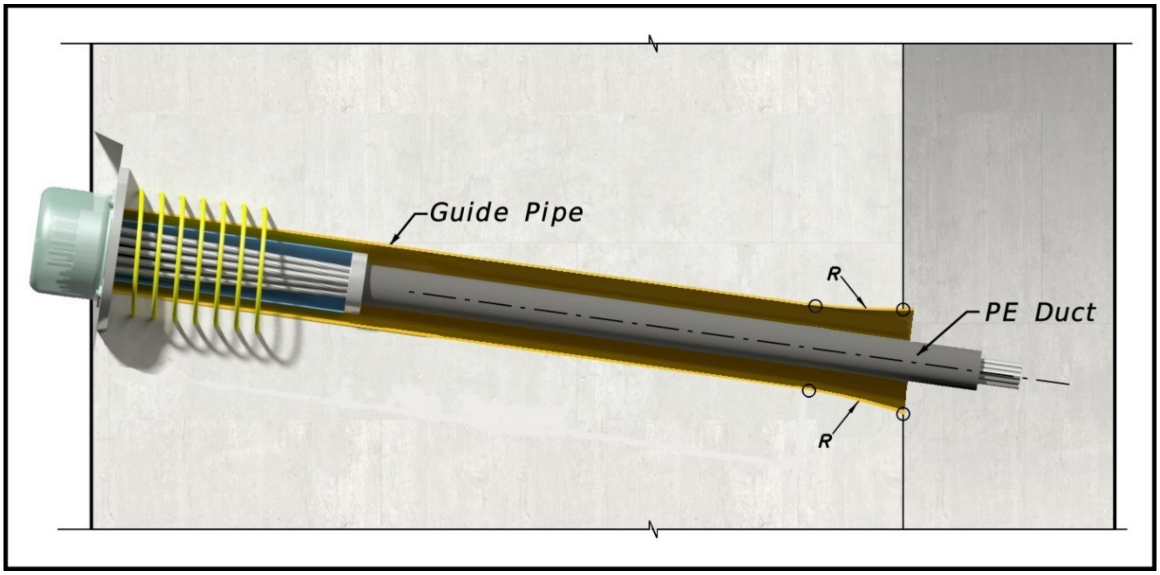


Figure 3-10
Type 4 Form near Anchorage

3.4 Half-Shell Cushion Form System

The diabolo forms shown in the previous sections are the most common method of deviating tendons while allowing replaceability. However, alternative systems may be used.

Half-shell Cushion Form System is an alternative detail to provide replaceability. In this system, a set of polyethylene (PE) cradles housed in straight tubes are utilized to provide support at deviation points as shown in Figure 3-11 to Figure 3-13.

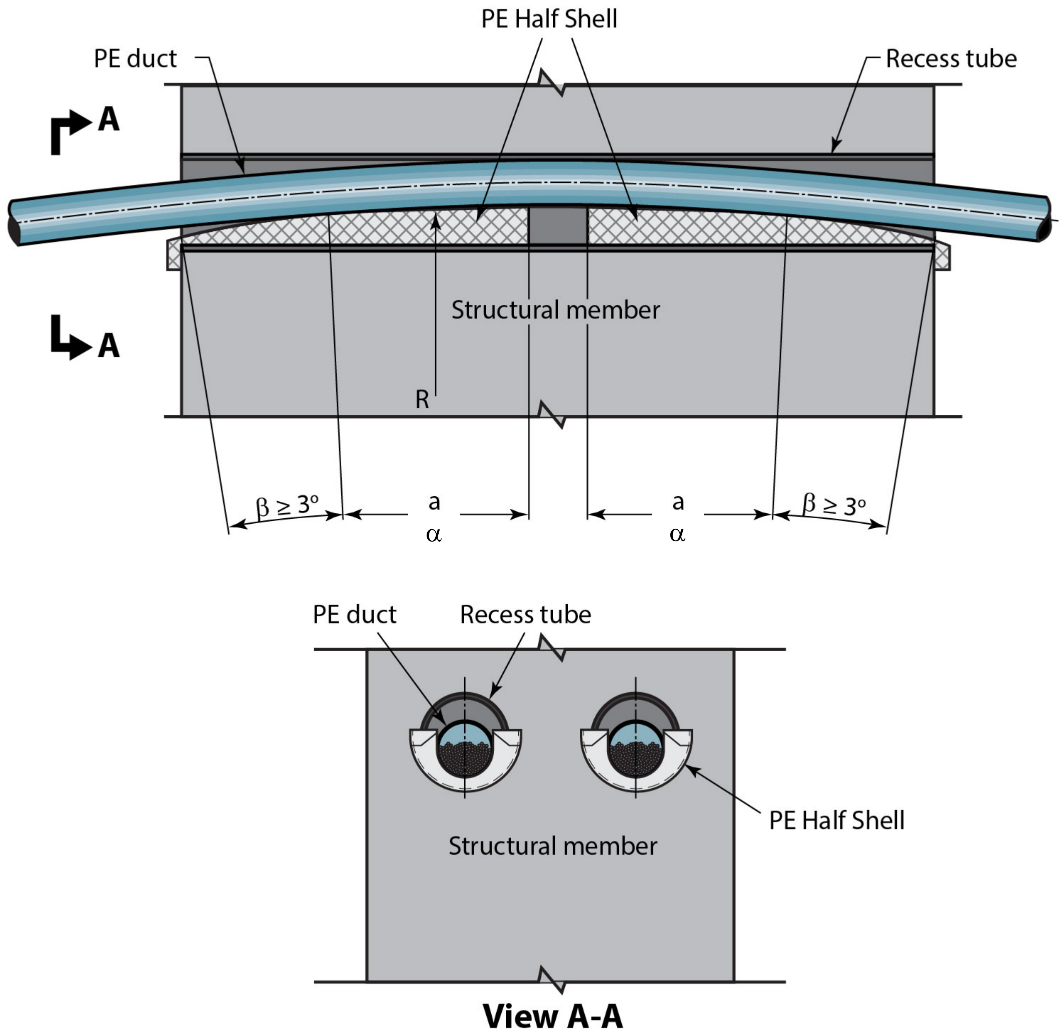


Figure 3-11
DSI PE Deflection Half Shell Systems

Courtesy of Teddy Theryo

Figure 3-12
DSI Half Shell Inserts in Diaphragm during Installation

Courtesy of Teddy Theryo

Figure 3-13
DSI PE Half Shell Inserts

4.0 POST-TENSIONING ANCHORAGES

Replaceability requires that the entire tendon including strands, grout and PE duct be removable and replaceable after tendon de-tensioning. To allow for this operation, the anchorage system is slightly different from the typical bonded system where the anchor body is cast into the concrete. There are several anchorage types currently available that allow replacement of the tendons. One system uses a guide pipe with bearing plate cast into the concrete. Strands are seated in the anchor head (wedge plate) which bears against the guide pipe bearing plate to transfer force to the concrete section as shown in Figure 4-1 and Figure 4-2. An alternative anchorage system uses a more conventional anchor body and trumpet system. In this system, a separate inner trumpet and duct system is inserted into the outer anchor body and duct which allows future replaceability as shown in Figure 4-3.

Anchorage systems are proprietary, and each supplier will have slightly different systems to accommodate replaceability. The designer should schematically show the anchorage system and guide pipe assembly and require the post-tensioning supplier to submit shop drawing details for the designer to review and approve.

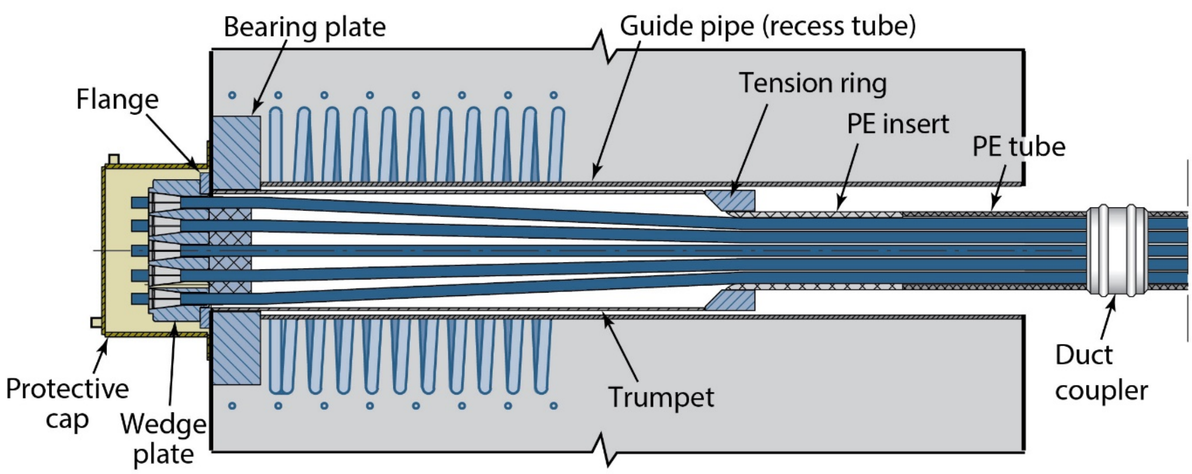


Figure 4-1
DSI External PT Plate Anchorage System

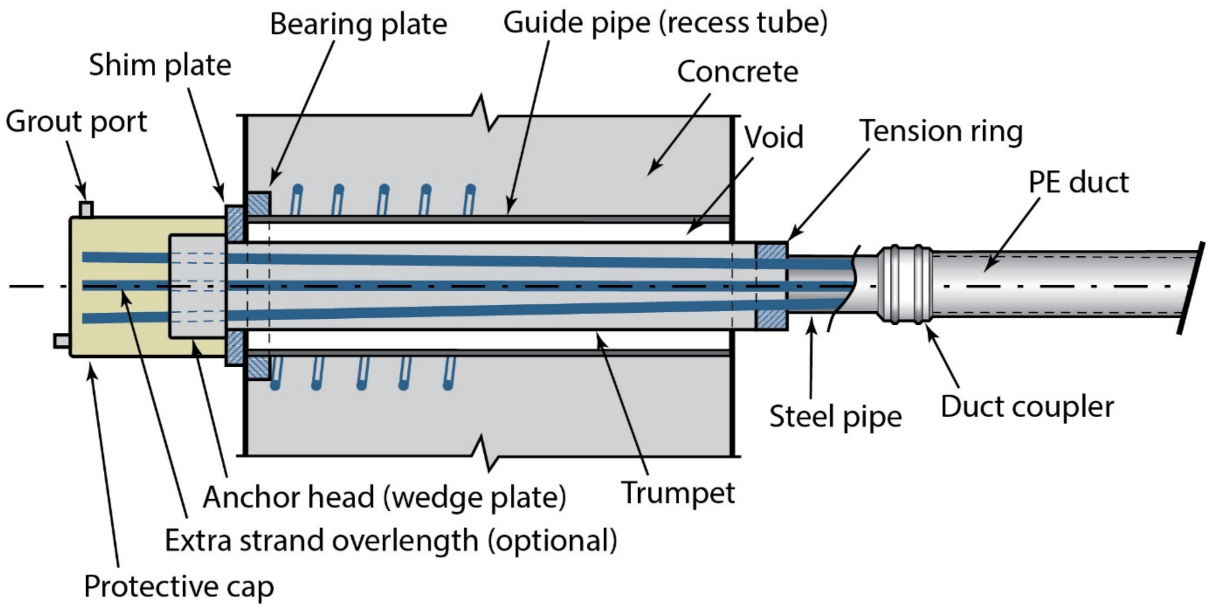


Figure 4-2
VSL Type A Plate Anchorage System

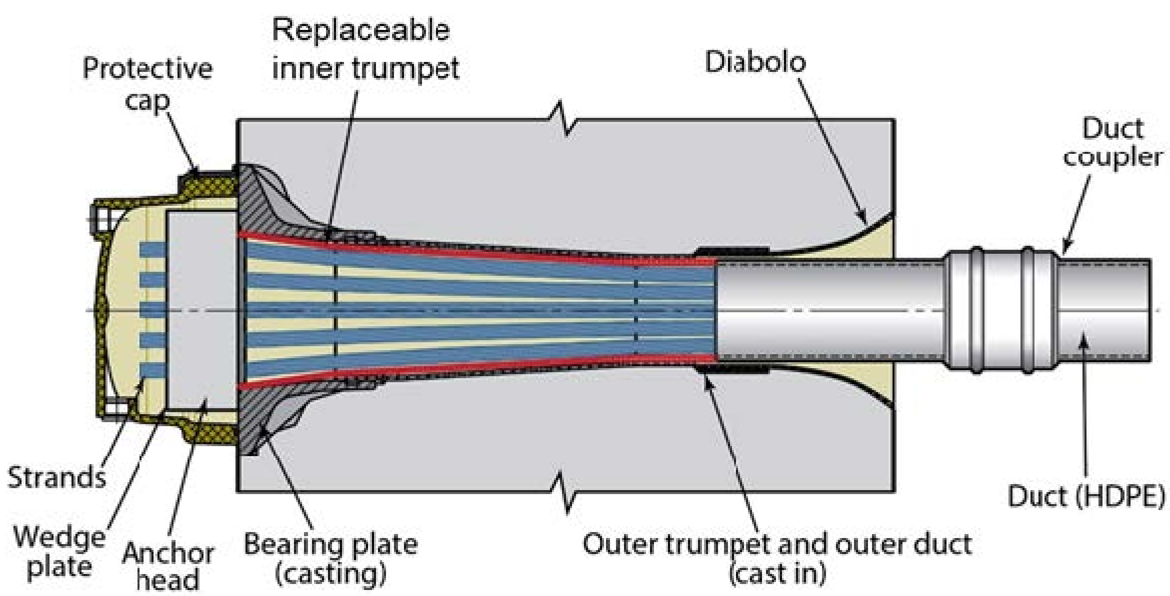


Figure 4-3
VSL Type GC Anchorage System for External Tendons

5.0 TESTING

In Europe, the European Organization for Technical Assessment (EOTA) issues guidelines for the requirements and testing of construction products not covered by a European Standard (EN). Post-tensioning systems must meet requirements specified in the European Technical Assessment Guidelines (ETAG) 013 – "Guideline for European Technical Approval of Post-Tensioning Kits for Prestressing of Structures." A European Technical Assessment (ETA) is a document that provides information about the performance of the product in relation to the ETAG.

In the United States, however, there is very little information regarding testing of diabolos and geometric requirements. One such case where testing was performed is discussed below. The tests specified in Section 6.1 are recommended for adoption into PTI/ASBI M50.3 *Guide Specification for Grouted Post-Tensioning*.

5.1 SR 826/ SR 836 Interchange Design-Build Project, Miami, FL

The application of diabolo forms at deviators of external tendons was proposed as a technical innovation in 2010 by the winning design–build (D/B) team of SR 826/SR 836 Interchange Project in Miami, Florida. The motivation for the diabolo proposal was to simplify and expedite the installation of external tendons. FDOT post-tensioning Specifications 462 prohibited the use of diabolo forms for external tendons at that time due to lack of experience with them (FDOT has revised its policy and diabolo forms are now allowed). However, FDOT would accept the proposal provided the D/B team perform two tests to meet the FDOT Modified Special Provision. The requirement was to test a deviated external tendon duct passing through a diabolo without causing excessive damage to the tendon sheathing. The two tests were conducted:

(a) Wear and Creep Test - The wear creep test is the modified test required by ETAG 013 – Post-Tensioning Kits for Prestressing of Structures, Section 6.1.5-I and test procedure specified in Annex B.5.1.

(b) Flexibility of Duct Test - The flexibility test is based on fib Bulletin 7 Section 4.1.3 requirement and test procedure specified in Annex A3.

The D/B team proposed to test four 19-0.6" diameter strand tendons with radius of curvature of 10' and angles of deviation ranging from 0.1 radians (5.7 degrees) to 0.4 radians (22.9 degrees). The specimens were tested between February 10, 2011 and March 4, 2011 [30]. Figure 5-1 shows the test set-up requirements from ETAG Annex B.5.1 [4].

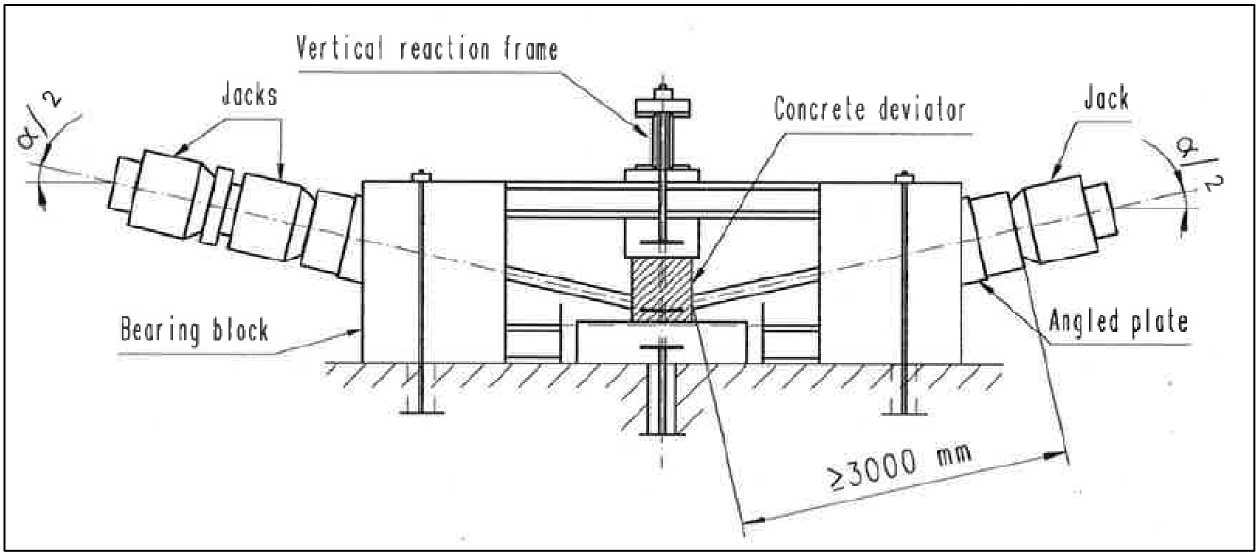


Figure 5-1
ETAG 013 Deviator Test Set-up for Static Load Test

Figure 5-2 to Figure 5-5 show the testing performed by VSL for FDOT. The test report concluded that the tests were successful and met the Modified Special Provision requirements.

Courtesy of Structural Technologies

Figure 5-2
Diabolo Test Specimen Prior to Concreting

Courtesy of Structural Technologies

Figure 5-3
Diabolo Testing in Progress

Courtesy of Structural Technologies

Figure 5-4
Stressing Jack Fully Retracted

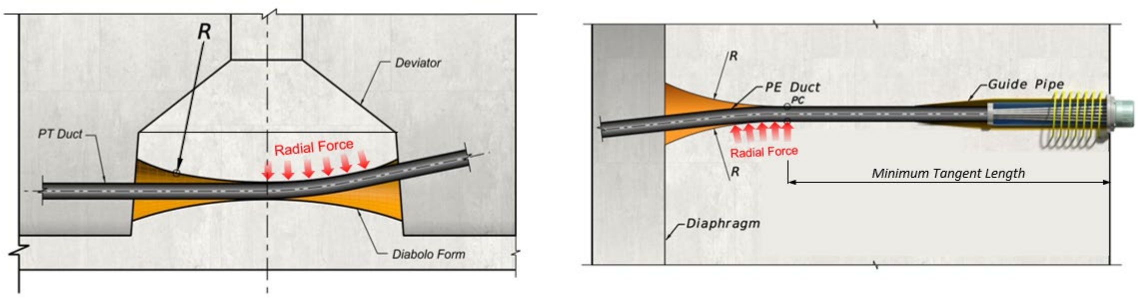
Courtesy of Structural Technologies

Figure 5-5
Duct Internal Area Wear after Testing

6.0 DESIGN PARAMETERS

6.1 Tendon Curvature Effects

Curved tendons transmit radial forces to the structure and need to be addressed in design and structural detailing. The radius requirements depend on their locations along the tendon as shown in Figure 6-1. The radius requirement adjacent to anchorages is typically larger than away from anchorages. The minimum tangent length is the straight length along the centerline of the tendon from the point of curvature to the anchor bearing plate. This minimum straight length of tendon is to ensure that strands enter the anchor head without excessive kinking, which can reduce fatigue life and anchorage efficiency.



At Deviator At Anchorage

Figure 6-1
Minimum Tendon Radii and Tangent Length

Based on European Technical Assessments (ETA) [5] [6] [7] [8] of various post-tensioning suppliers meeting ETAG 013 requirements and test results from the project in Florida [30], the recommended minimum radii and tangent lengths for different sizes of tendon are listed in Table 6-1 and Table 6-2. The designer should verify the dimensions based on the selected post-tensioning system as the requirements differ slightly. Refer to FDOT Structures Manual [14] for alternative minimum tendon radii and tangent lengths.

Table 6-1
Minimum Tendon Radii and Tangent Lengths at Anchorages

Tendon Size	Minimum Radius (feet)	Min. Tangent Length (feet)
7-0.6”	9.8	2.5
12-0.6”	11.5	3.3
15-0.6”	12.3	3.3
19-0.6”	13.1	3.9
22-0.6”	13.9	3.9
27-0.6”	14.8	4.3
31-0.6”	15.6	4.8

Table 6-2
Minimum Tendon Radii at Deviators

Tendon Size	Minimum Radius (feet)
7-0.6”	6.6
12-0.6”	8.2
15-0.6”	9.0
19-0.6”	9.8
22-0.6”	10.7
27-0.6”	11.5
31-0.6”	12.3

6.2 Diabolo Dimensions

The ratio of duct inside cross-sectional area to prestressing steel area remain unchanged from AASHTO LRFD Bridge Design Specifications Article 5.4.6.2 requirements. The inside duct area shall be 2.0 times the net area of the prestressing steel, except where tendons are installed by the pull-through method, in which case the inside area shall be 2.5 times the prestressing steel area.

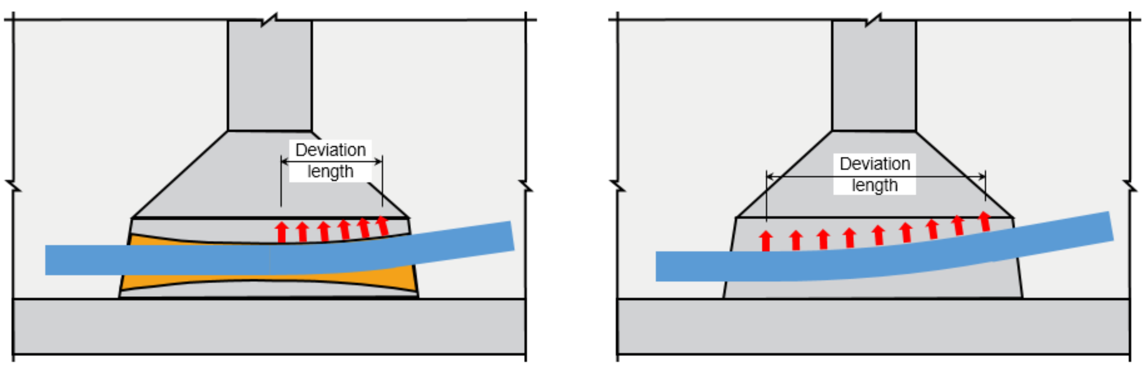
It is recommended that the minimum inside diameter of the diabolo form is at least one-half inch larger than the outside diameter of the tendon duct. This one-half inch gap allows the deformed duct to pass through the diabolo void in the event replacement of the tendon is required.

The main concern is the durability of the duct due to deformations during stressing of the tendon. The duct is not confined by the concrete section and is free to deform and expand. The diabolo inside diameter to tendon duct outside diameter varies along the length of the contact area as the diabolo form flares out. Durability associated with duct size to diabolo dimensions is addressed by testing in accordance with ETAG 013, Section 6.1.5-I. Note that this section allows that previous known successful behavior may be considered sufficient. Testing every diabolo to duct combination need not be required unless the minimum radius of the diabolo uses smaller radii than shown in Table 6-1 and Table 6-2.

6.3 Deviators with Diabolos

The design of deviators shall follow the requirements of AASHTO LRFD Bridge Design Specifications, Article 5.10.4.3 and include in-plane forces and regional bending effects (transverse bending effects within the cross-section).

Deviators design using diabolo forms differ from deviators using individually bent steel pipes. The contact length where the tendon bears against a diabolo form is typically shorter than when using pre-bent pipes which leads to more concentrated or larger tie-down reinforcement requirements.



Diabolo

Embedded Bent Steel Pipe

Figure 6-2
Deviator Design

7.0 CONSTRUCTION CONSIDERATIONS

7.1 Diabolo Construction

Diabolo forms may be constructed in one of two ways; use of removable form or stay-in-place forms. It is expected that the final formed surface is smooth with no irregularity in surface exceeding 1/8”.

Solid nylon and PE forms can be removable (Figure 7-1) or stay-in-place (Figure 7-2). The Type 2 through Type 4 forms discussed in Section 4.3 are typically stay-in-place due to the length and complexity of the shape. Figure 7-3 shows a diabolo at a future tendon deviator constructed using a removable wood form.

Courtesy of Jerry Pfuntner.

Figure 7-1
Diabolo Constructed using Removable Form – During Construction

Courtesy of Structural Technologies

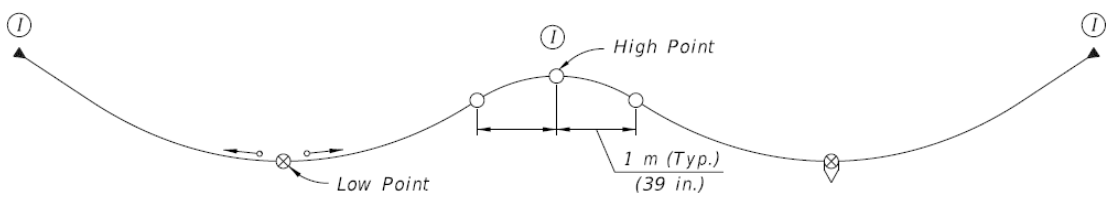
Figure 7-2
Diabolo Constructed using Stay-In-Place Form

Courtesy of Tony Ledesma

Figure 7-3
Diabolo Constructed using Removable Form – After Construction

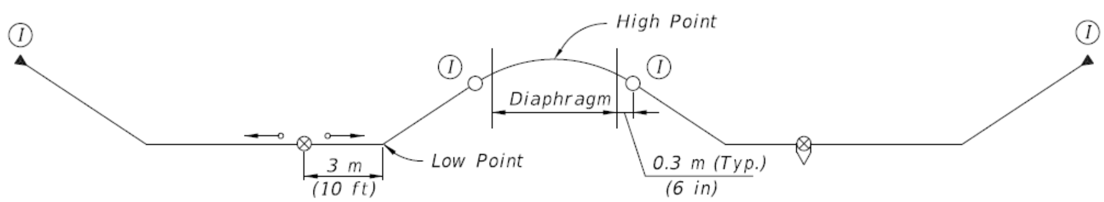
7.2 Grouting of External PT Tendon

Grouting of replaceable external PT tendons shall follow current PTI M55.1-12 Specification for Grouting of Post-Tensioned Structures. The location of grout inlets, outlets and inspection ports shall follow the details shown in Appendix C of that document. One difference that needs further investigation and discussion with PTI M-55 Grouting Committee is the Type 2 diabolo form used for a continuous tendon through a pier diaphragm as depicted in Figure 3-6, Figure 3-8 and Figure 3-13. Current requirements require a grout outlet at the high point of the tendon as shown in Figure 7-4. The proposed Type 2 diabolo form with an outer guide pipe would prevent placing the grout outlet at the high point. It is recommended that additional testing be performed to determine if proper grouting can be achieved using the proposed details shown in Figure 7-5 and Figure 7-6. Vacuum or vacuum assisted grouting may also be considered to minimize risk of voids at the high point.

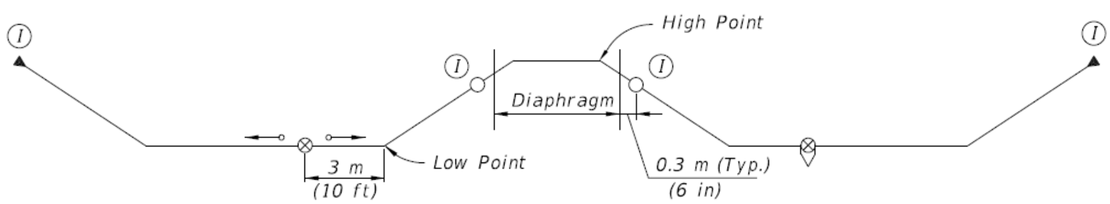


Refer to PTI M55.1-12, Appendix C, Profile 13

Figure 7-4
Current Grouting Detail for Tendon at Diaphragm



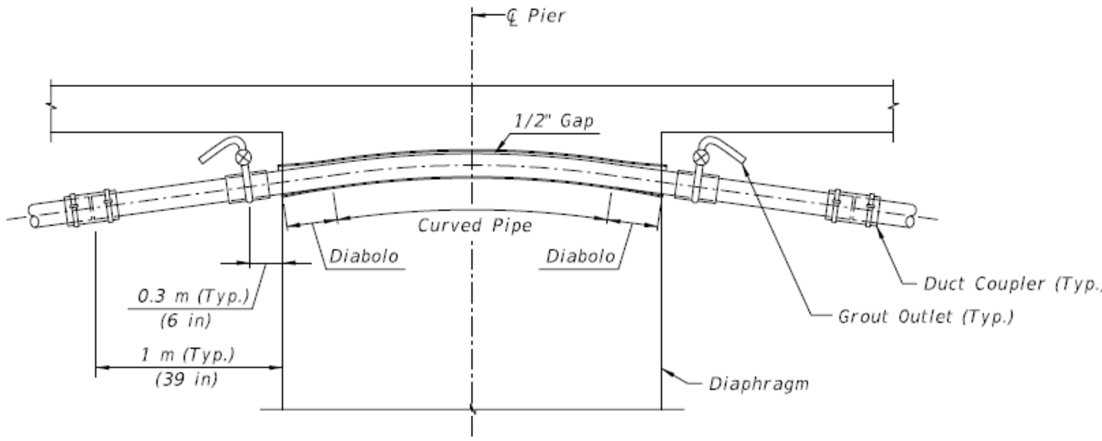
a) Saddle with Curved Profile



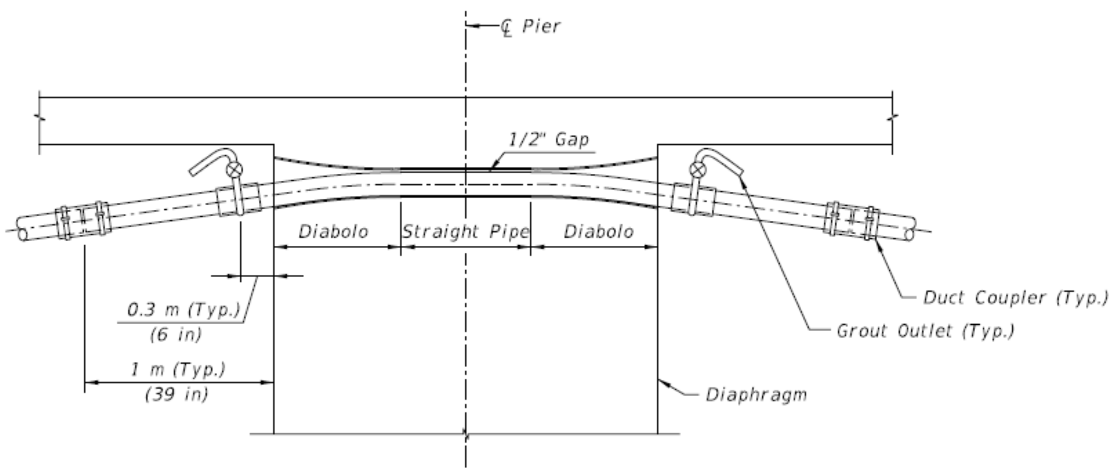
b) Saddle with Horizontal Profile

Figure 7-5
Proposed Grouting Detail for Tendon at Diaphragm

Figure 7-6 shows the details for the above grouting schematic. Grout outlets are placed as close as possible to the pier diaphragm. Duct couplers are placed 1 meter (39 in) from the diaphragm face to allow room for the grout outlet connections.



a) Saddle with Curved Profile



b) Saddle with Horizontal Profile

Figure 7-6
Proposed Grouting Detail for Tendon at Diaphragm

7.3 De-tensioning an External PT Tendon

Prior to de-tensioning a tendon, assess the structural capacity to determine what level of dead load and live load can safely be carried. Limit live load and construction loads on the structure as appropriate.

De-tensioning an external tendon is a dangerous operation. There is a substantial amount of potential energy stored in the strands. As the tendon is cut, the energy in the strands is released away from the cutting location. De-tensioning a tendon can be achieved by either cutting or burning the strands. Burning/heating the strands with an open flame is typically not performed for tendons located inside the box girder due to confined space requirements. The heat generation, ventilation requirements, and safety concerns typically rule out this option. Heating the strands at the end anchorages is feasible to release some of the energy in the strands. The typical method of detensioning the tendons is to incrementally cut the strands in an attempt to release the energy in the strands in as slow a manner as possible.

Additional personnel shall stay away from the tendon and from behind anchorages during de-tensioning operations. Installation of a steel containment plate behind the anchorages is encouraged. If the tendon is being replaced due to corrosion in areas of voids or soft grout, sections of strand may not be bonded to hard grout. Since grout is injected into the tendon duct after tendon stressing, compression in the grout is low. As the strands are cut, the force is transferred to the surrounding grout similar to a pretensioned girder. In the case of poorly grouted sections of tendon; the energy may be released more suddenly.

First, tie the tendon to be de-tensioned to adjacent tendons to control potential whiplash. Cut away the duct and chip out as much grout around the strands as possible at the cut locations. Cut the tendon near the center and move towards the anchorages as shown in Figure 7-7. At the cut location, use U-bolt clamps to restrain the strands during cutting as shown in Figure 7-8. Cut the tendon into large pieces as shown in Figure 7-7, and then into short pieces approximately 5 feet long to release remaining potential energy in the strands.

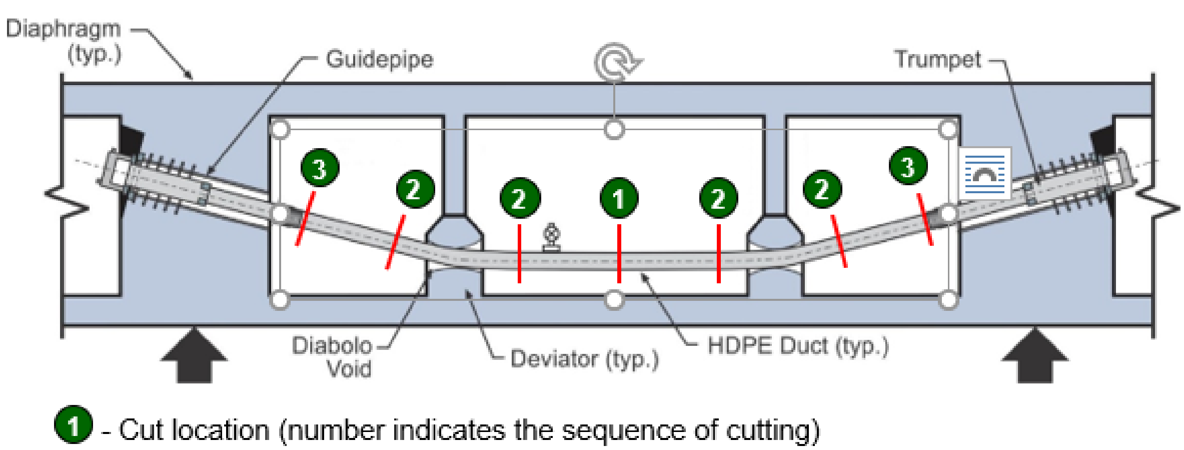


Figure 7-7
Tendon De-tensioning Schematic

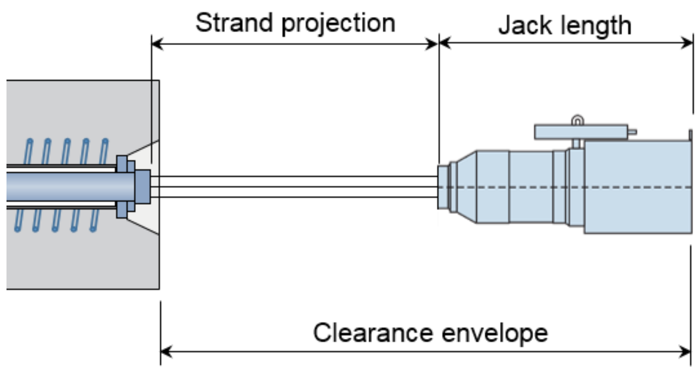
Courtesy of Teddy Theryo

Figure 7-8
U-bolt Clamps around Strands

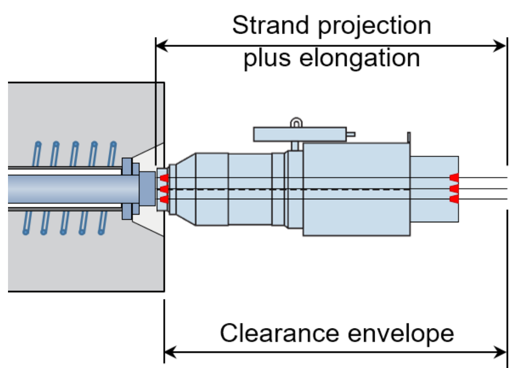
7.4 Stressing of New External PT Tendon

The sizes of external tendons in post-tensioned bridges typically range from 12-0.6” to 27-0.6” strands. Shorter single span tendons typically require single end stressing, while long multi-span continuous tendons may require double end stressing. Access to tendon anchorages is generally limited inside a box girder bridge. It is important to have sufficient clearance and space behind the anchorages for setting up the stressing jacks. All external tendons should be detailed to allow future jacking with a multi-strand jack.

Figure 7-9 shows the typical clearance requirements for stressing a multi-strand tendon. Figure 7-9a shows the clearance required for positioning the stressing jack. Adequate room for the strand projection plus the length of the stressing jack is required. Figure 7-9b shows the clearance required during stressing operations. The lengths and diameters of stressing jacks used by the various post-tensioning suppliers varies considerably. Therefore, the designer should refer to supplier data and conservatively evaluate the clearances required.



a) During Positioning



b) During Stressing

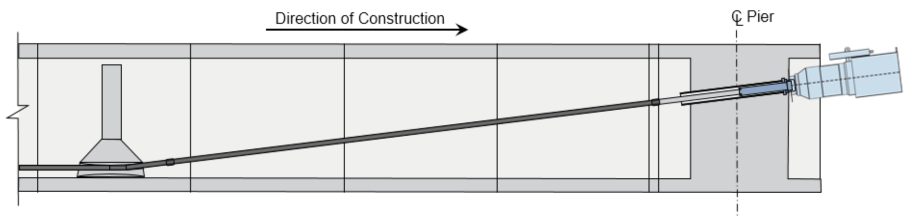
Figure 7-9
Stressing End Clearance Diagram

Recommended minimum end clearances associated with Figure 8-9a at the stressing end anchorage based on information from PT supplier brochures [17] [29] are shown in Table 7-1 along with minimum end and lateral clearances recommended by FDOT [14]. The designer should verify the dimensions based on the selected post-tensioning supplier's stressing jacks during design and shop drawing review.

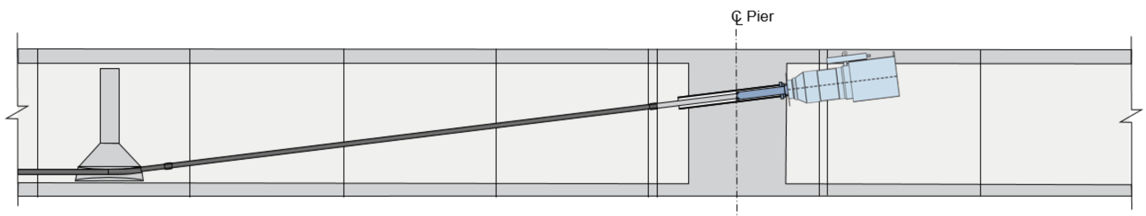
Table 7-1
Minimum Stressing Jack Envelope Dimensions

Tendon Size	End Clearance		Lateral Clearance
	PT Supplier Catalogues (feet)	From FDOT (feet)	From FDOT (feet)
7-0.6”	6’-0”	7’-8”	1’-3”
12-0.6”	6’-0”	7’-8”	1’-3”
15-0.6”	6’-0”	10’-0”	1’-3”
19-0.6”	6’-0”	10’-0”	1’-3”
22-0.6”	7’-0”	10’-0”	1’-3”
27-0.6”	7’-0”	10’-0”	1’-3”
31-0.6”	7’-0”	10’-0”	1’-6”

The designer should consider future replacement of the tendon and not only clearance during construction. Figure 7-10 shows typical stressing operations for span-by-span segmental bridge construction. During construction, tendons are typically stressed from the leading end of the span. During tendon stressing, the forward span has not been constructed and the stressing jack can easily be accommodated as shown in Figure 7-10a. After the forward span has been constructed, in the event of tendon replacement, conflicts between the stressing jack and the top slab arise as shown in Figure 7-10b. Reliance on curved stressing chairs or beveled plates should be avoided.



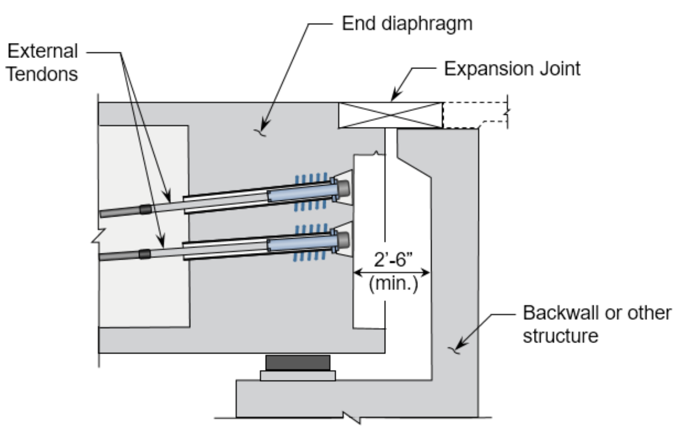
a) Stressing during construction – no conflicts



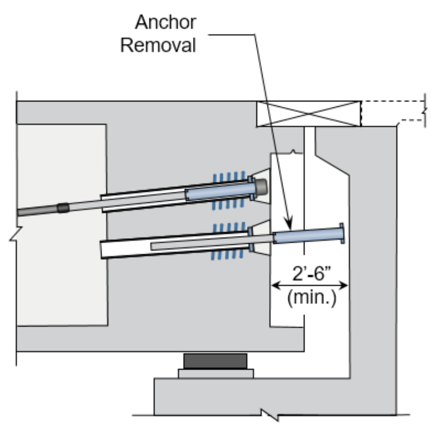
b) Stressing after tendon replacement – stressing jack conflicts with top slab

Figure 7-10
Anchorage Clearance at Interior Diaphragm for Span-by-Span Construction

Figure 7-11 shows the clearance diagram at the non-stressing end of the tendon. The non-stressing end clearance requirement is reduced but should still be sufficient to accommodate tendon replacement for the specific anchorage type used in the bridge. Specific anchorage replacement items include anchor body replacement, inner trumpet replacement, and adequate space for anchorage to duct connections, grouting operations, and strand tails. The recommended minimum clearance is 2'-6".



a) Tendons installed



b) Anchor replacement

Figure 7-11
Non-Stressing End Anchorage Clearance at End Diaphragm

Additional consideration should be given to the permanent access openings in the bridge. External access opening and internal openings at the diaphragms should be large enough to deliver and transport the equipment required for stressing. A clear pathway without transverse ribs or other obstructions along the box girder is also helpful for transporting equipment and materials. Temporary access openings may be constructed but their size may be limited based on the presence of internal longitudinal and transverse tendons in the top slab. Careful measures should be taken to ensure that internal post-tensioning is not damaged when creating temporary access openings. Temporary access openings also create additional joints that are susceptible to water intrusion.

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