FDOT TRANSPORTATION SYMPOSIUM 2019

Anchorage Zone Design and Detailing from Practical Perspective

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Learning Objectives

- Background of Anchorage Zone Design
- Development of Proprietary Anchorages
- Case Study of Anchorage Zone Failure
- Local and General Zones
- Anchorage Zone Design Methods
- Good Detailing Practice
- Design Examples

Presentation Outline

- Introduction
- Case Study of Anchorage Zone Failure
- Development of PT Anchorages
- Design Methods for General Zone
- The Art of Proper Detailing
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Introduction

Timeline of Anchorage Zone Design Development

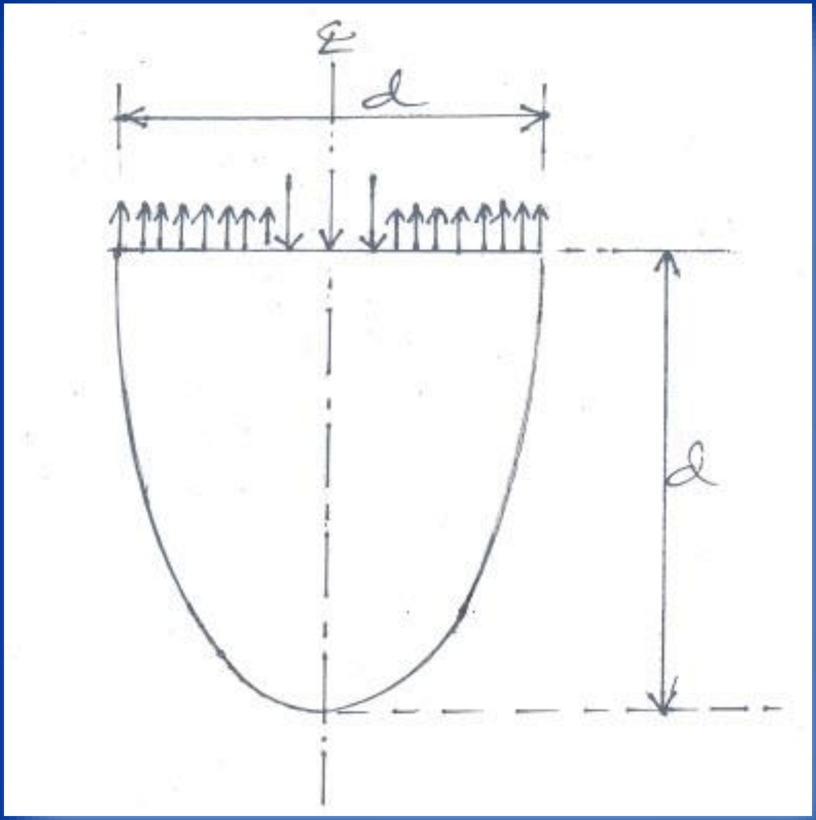
1855: St. Venant Principle
1924: Mörsch's Theory
1932: Tesar, M Theory
1935: Bortsch's Theory
1949: Magnel's Theory
1953: Guyon's Theory
1954: Leonhardt, Fritz Theory
1956: Bleich's and Sievers's Theory
1960: Iyengar, K.T. Sundara Raja Theory
1960: Sargious, M. Theory
1960: J. Zielinski and R.E. Rowe of Cement and Concrete Association, UK. Conducted Laboratory Test. Two Reports and recommendations were published from this research project.
1990: J. Breen et. al. of University of Texas, Austin conducted Anchorage Zone research and Laboratory Tests as part of NCHRP Project 10-29. The recommendations of the research were adopted by AASHTO LRFD.

Notes: St. Venant, Mörsch's, Tesar's, Guyon's, Magnel's, and Leonhardt's work laid out the most significant foundations of anchorage zone design practices we are using today.

Introduction

St. Venant Principle (1855)

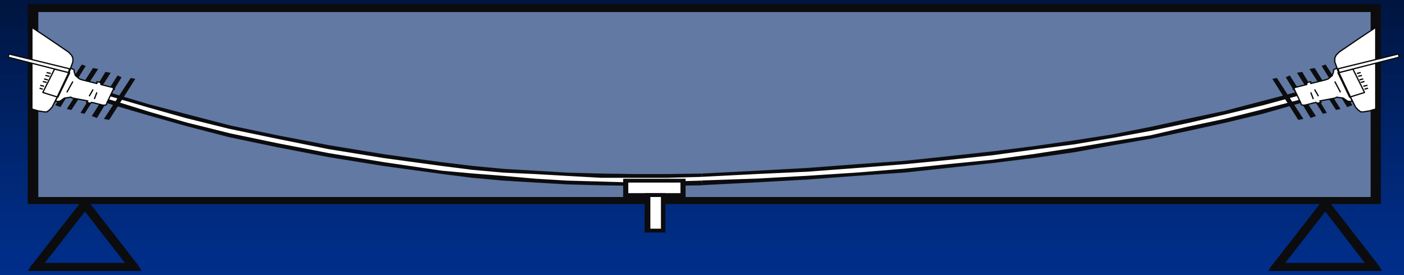
The influence of stresses resulted by a local disturbed load in an elastic system dissipates rapidly with a distance d, where d is the depth of the member [14].

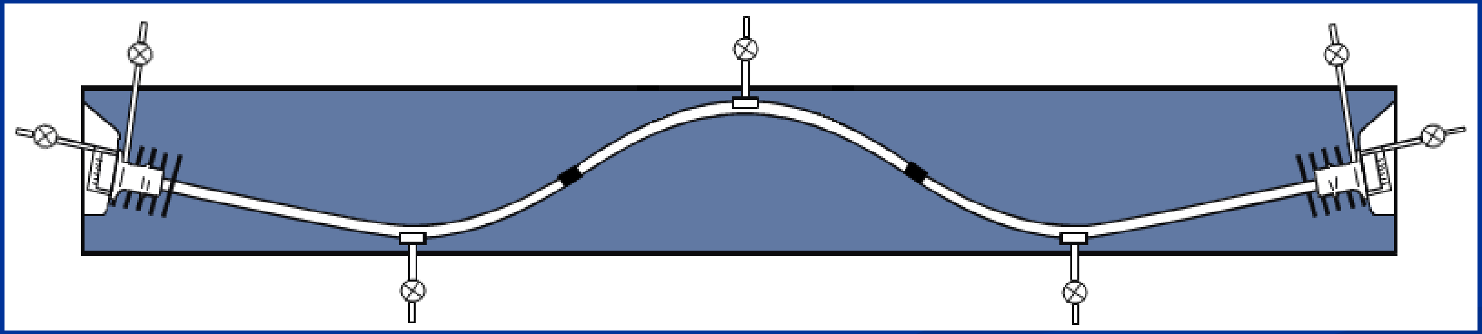


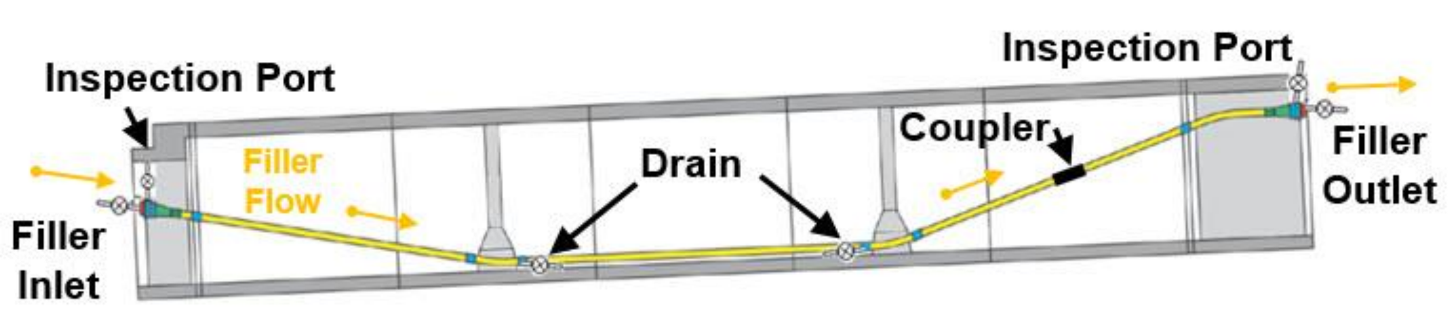
Introduction Overview of PT Anchorage Design

- In post-tensioned prestressed concrete members, the prestress forces are directly applied to the end of the members with relatively very small mechanical anchorages and large forces.
- The PT concentrated force induces a complex 3D stress pattern near the anchorage zone.
- For practical purposes the anchorage zone design is simplified from 3D to 2D.
- A single tendon jacking force could vary from 100 tons to about 1000 tons.
- Single PT anchorage has been studied both theoretically and experimentally. However, in reality multiple anchorages with different configurations and cross sections exist.
- Improperly design and detailing of anchorage zone can cause longitudinal and vertical cracks around anchorage zone.

Introduction

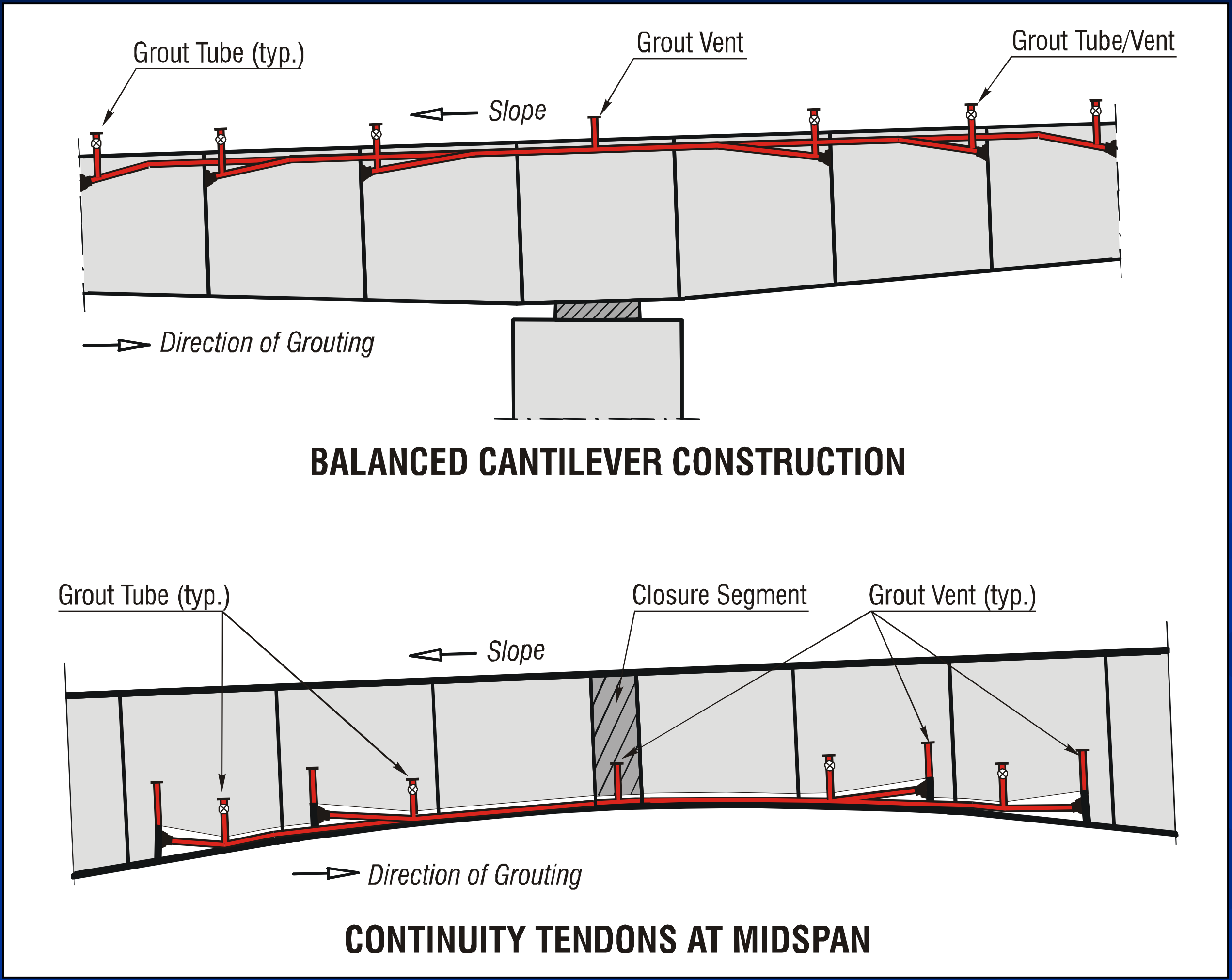






Examples where the PT tendons are anchored at the end of girders

Introduction



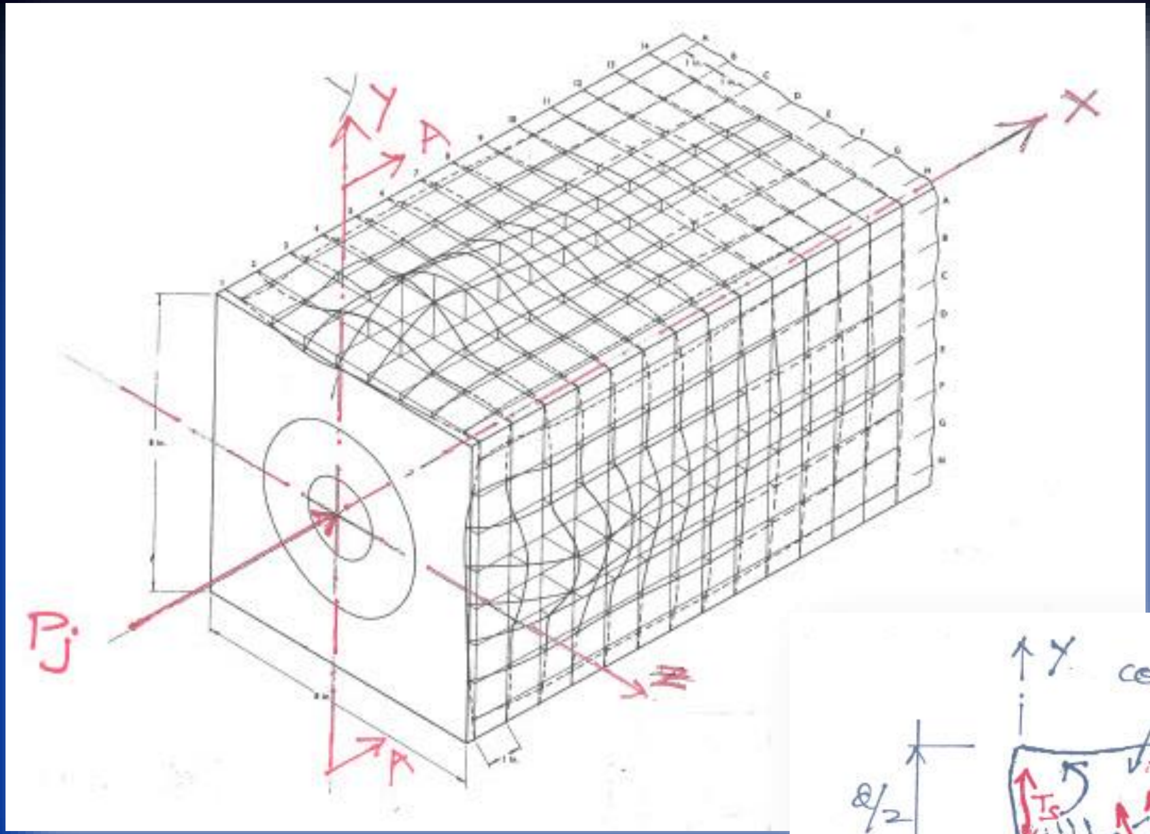
Example of PT tendons are anchored at intermediate span and blisters

Introduction

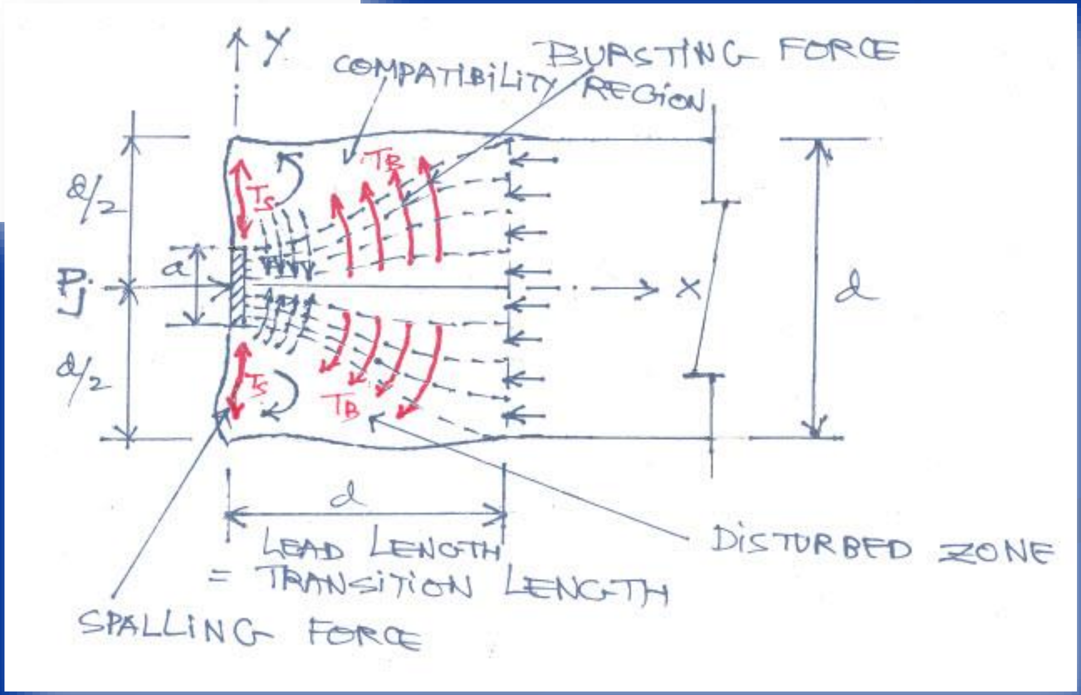
Definitions

Anchorage Zone / End Zone / Saint-Venant Region: The volume of concrete through which the concentrated PT force is transferred to a section more or less has linear stress distribution.
Local Zone: Rectangular prism of concrete surrounding and immediately ahead of bearing plate.
General Zone: Region within which concentrated force spread out to a more linear stress distribution over the cross section
Lead Length / Transition Length: the length of equivalent / symmetrical prism
Bursting Force: Tension force perpendicular to the concentrated force axis in the equivalent prism
Spalling Force: Tensile stresses along the loaded face of a beam induced by compatibility requirement
Splitting Force: Tension force between two or more anchorages which could result in splitting cracks
Longitudinal Edge Tension Force: The tension force in the beam edge longitudinal direction due to eccentric load.

Introduction

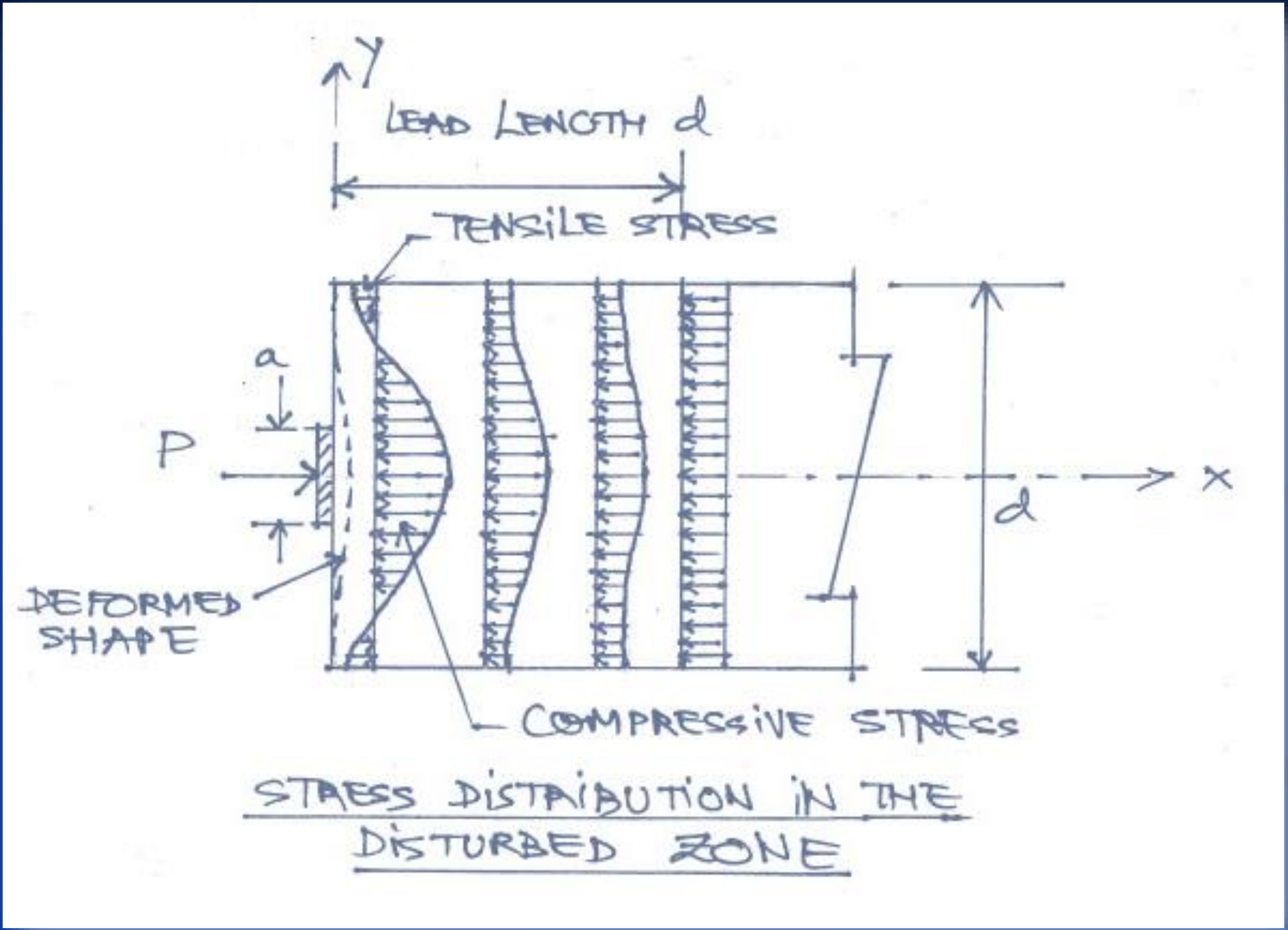


Isometric of anchorage zone deformed shape [17]



Section A - A

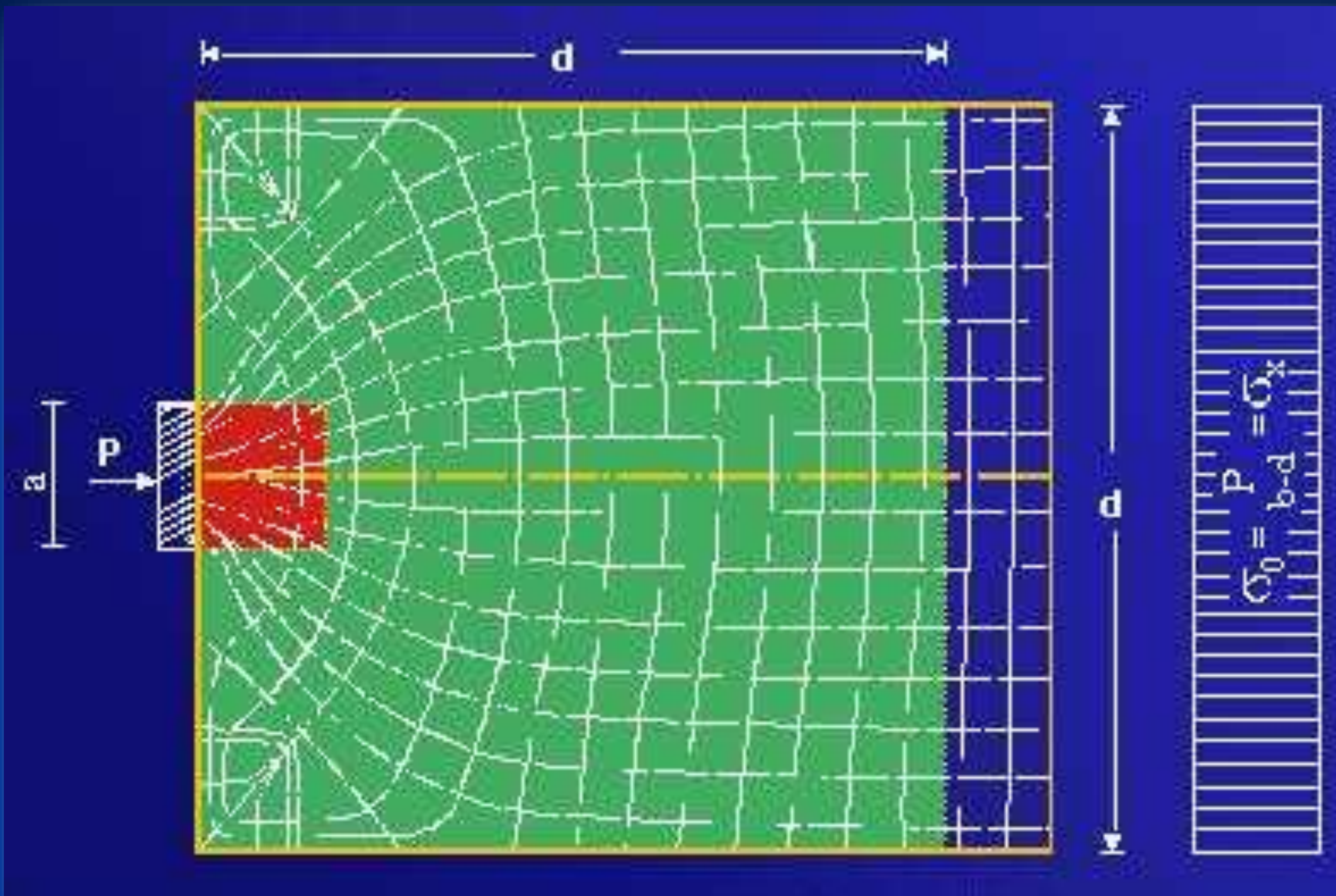
Introduction



Introduction

Local Zone

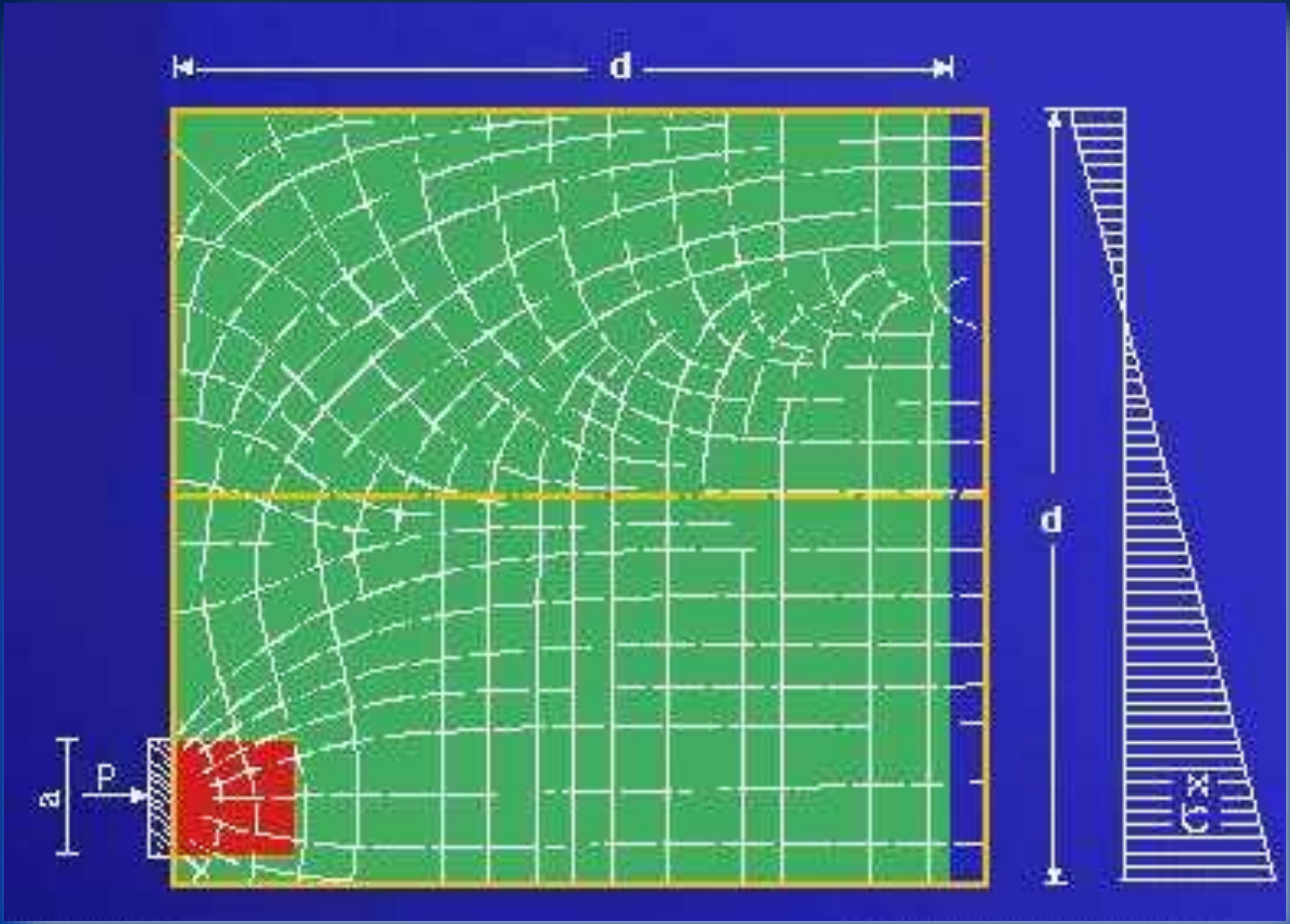
General Zone



Local and General Zone Limit

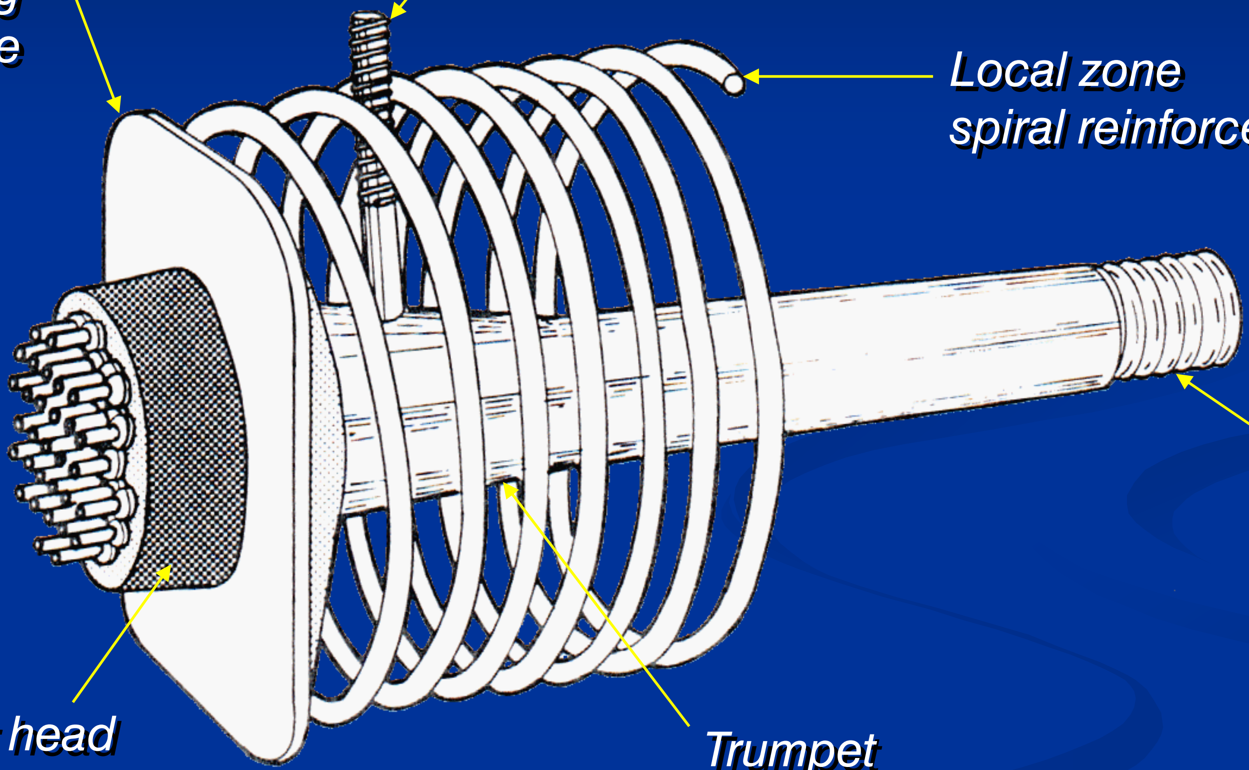
Introduction

Local Zone
General Zone



Local and General Zone Limit

Introduction



Local Zone Confinement Reinforcement

Introduction

Responsibilities (LRFD 5.8.4.4)

- The Engineer of Record
  - Overall design
  - General zone design
  - Approval of working drawings, e.g. general zone reinforcement, stressing sequence, tendon layout, anchorage device and its local zone confinement reinforcement

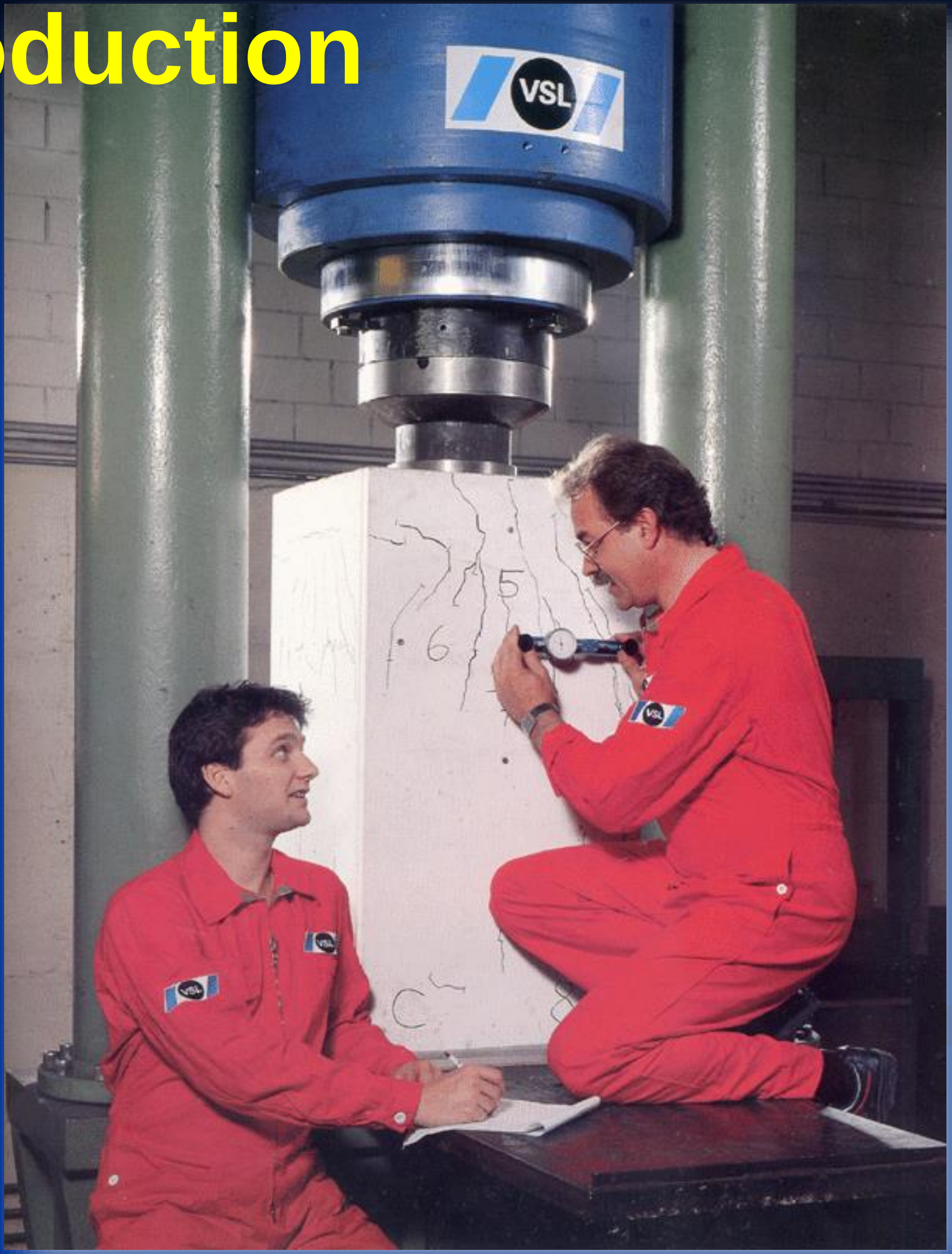
Introduction

Responsibilities (LRFD 5.8.4.4) (cont.)

- **The Anchorage Device Supplier (Proprietary / Special Anchorage Device)**
  - Supply the Anchorage Device and its local zone confinement reinforcement
  - Meet the efficiency test requirement (96% GUTS) as per LRFD Bridge Construction Spec.
  - Meet the special anchorage device acceptance test as per LRFD Bridge Construction Spec.

Introduction

Anchorage Device acceptance test and efficiency test requirement of AASHTO LRFD Bridge Construction Specifications



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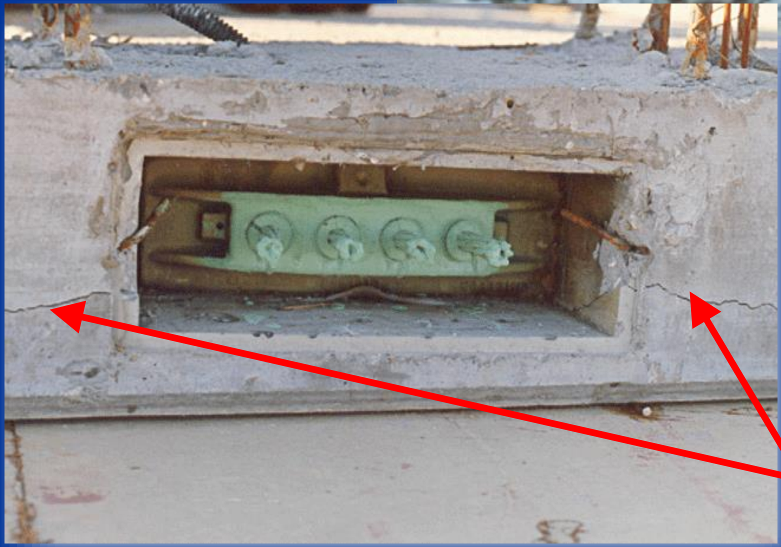
Case Study of Anchorage Zone Failure



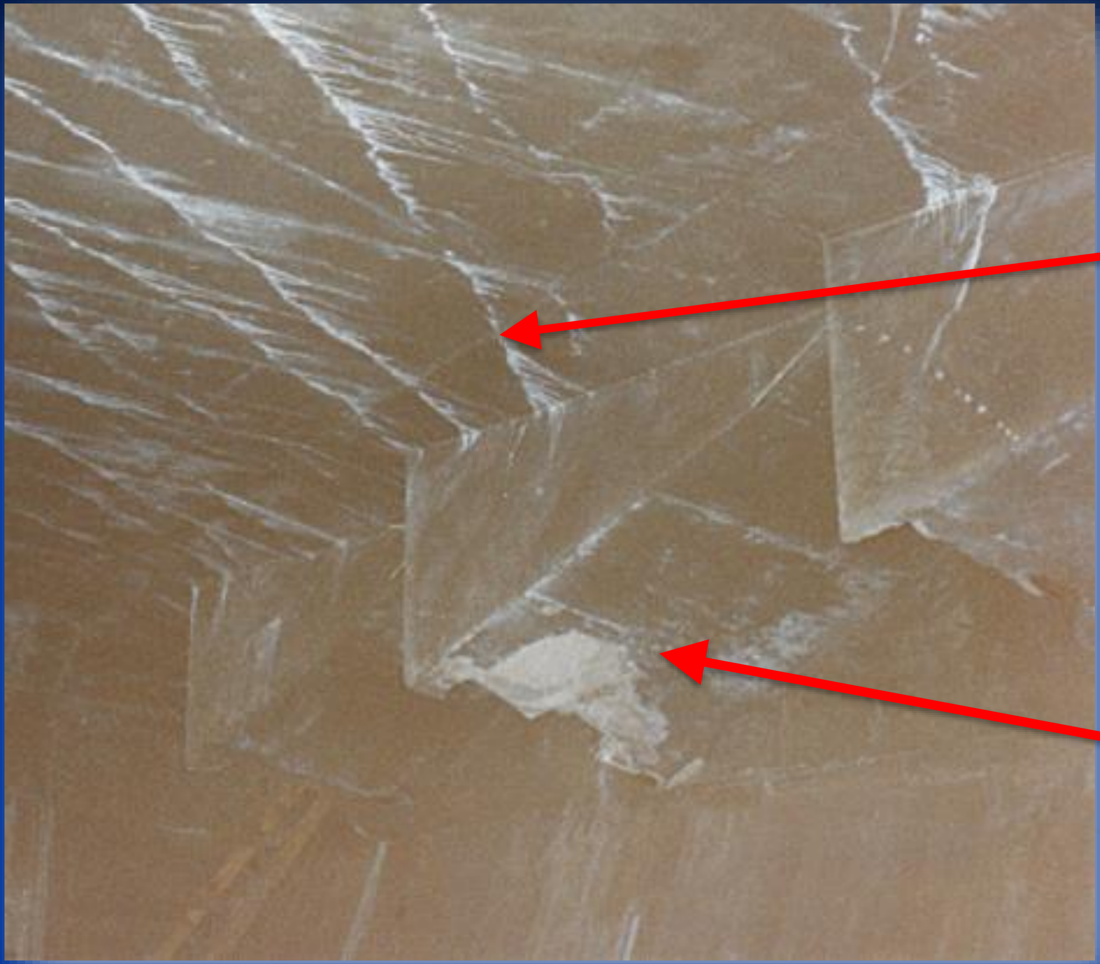
Transverse tendon anchorage zone failure due to poor anchorage zone design and detailing

Cracks

Case Study of Anchorage Zone Failure

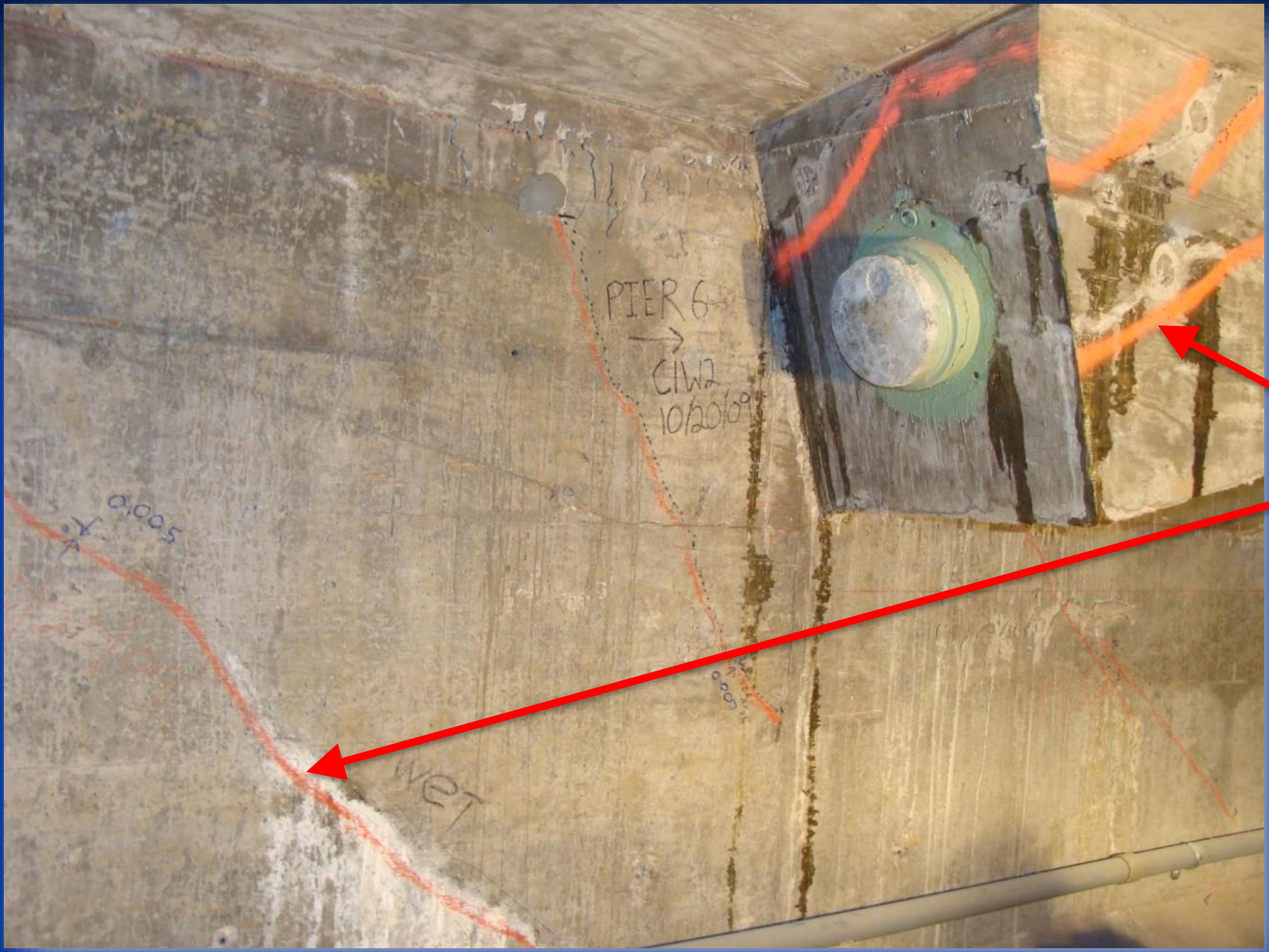
Spalled concrete as a result of incorrect tie down rebar details in the curved tendon zone. The curved tendon has a very thin concrete cover.

Case Study of Anchorage Zone Failure



Top slab cracks due to lack of longitudinal tie back reinforcement

Case Study of Anchorage Zone Failure



Top Blister and web cracks (1)

Case Study of Anchorage Zone Failure

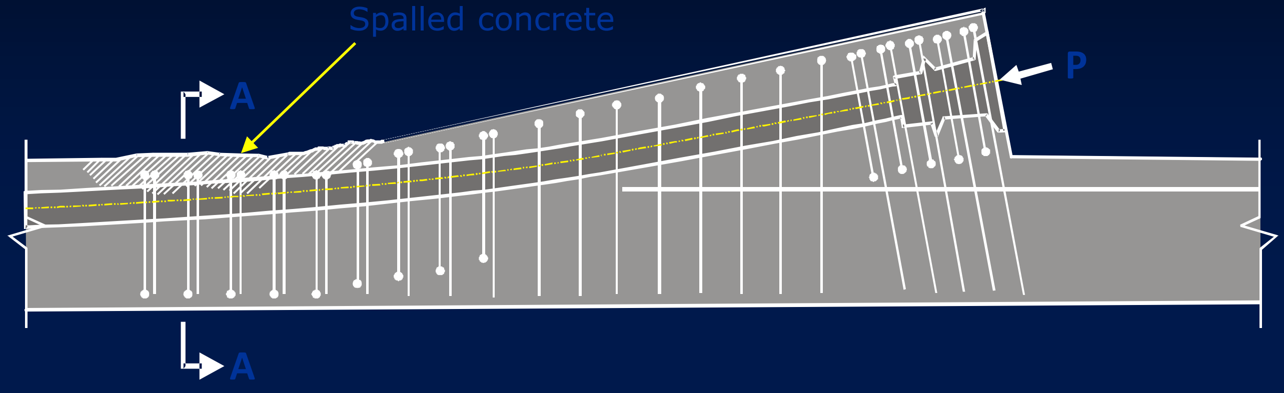
Top blister and web cracks (2)

Notes: PT blister impacted web and resulted in web cracking

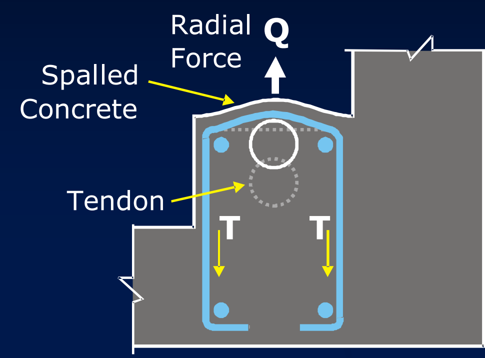
Case Study of Anchorage Zone Failure

Spalled concrete as a result of incorrect tie-down rebar details in the curve tendon zone of a blister with a thin concrete cover

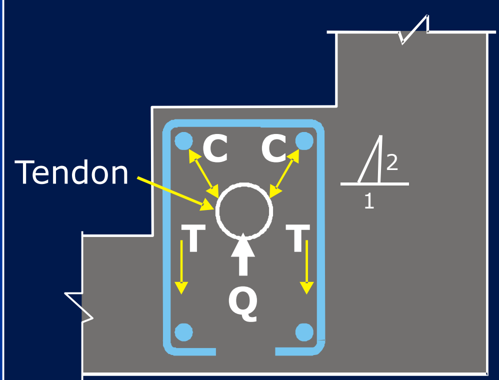
Case Study of Anchorage Failure



PROBLEM

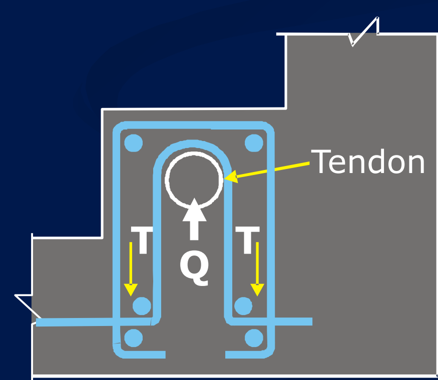


SECTION A-A



Provide sufficient concrete over the duct to effectively transfer the compression struts C to tie down reinforcement (lower PT duct)

SOLUTION 1



Radial force Q is directly transferred to tie down reinforcement

SOLUTION 2

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Development of PT Anchorages

The most common types of high strength prestressing steel use in Post-tensioned Structures

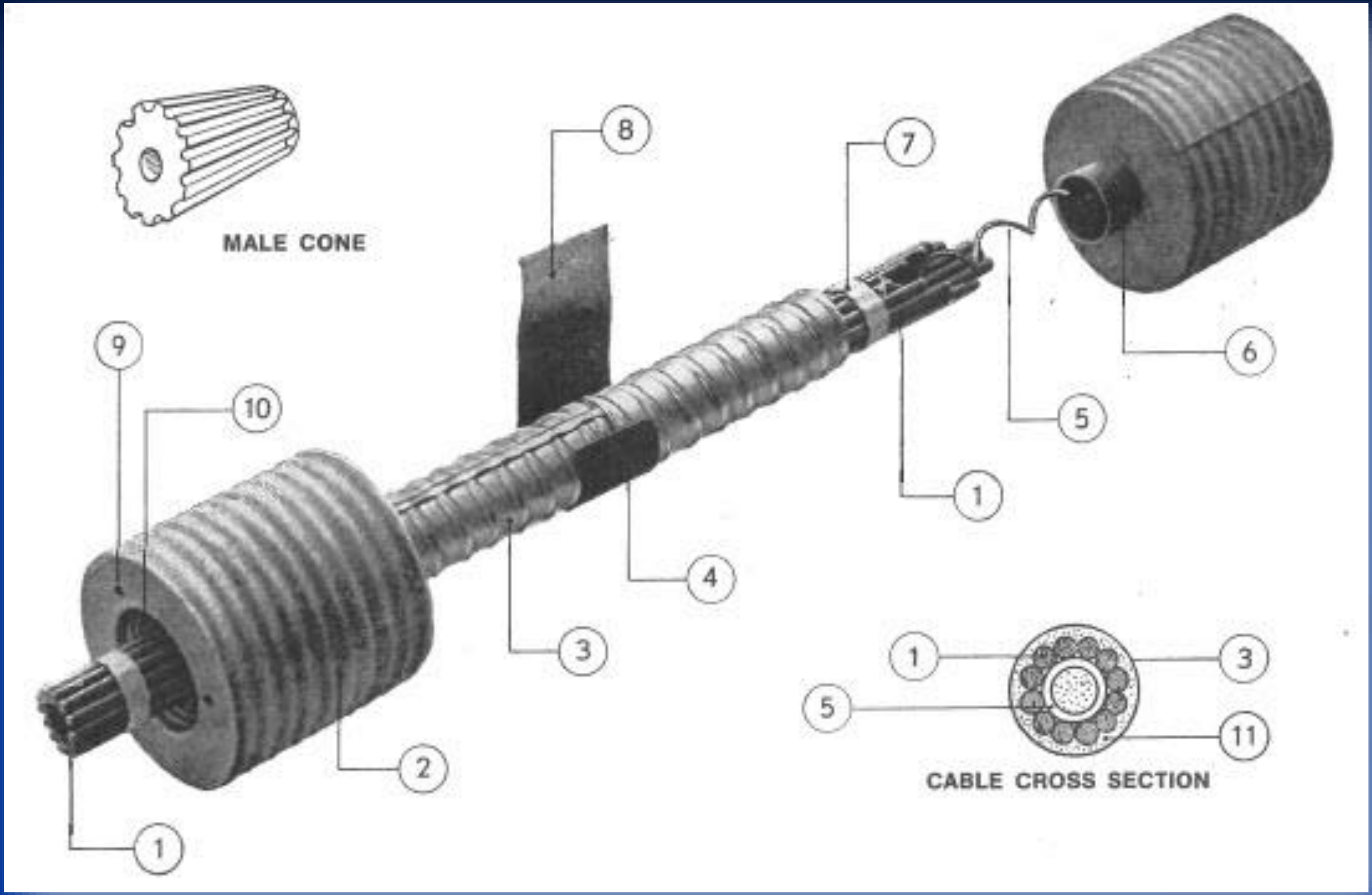
1. Seven wire strands (0.5”, 0.6”, and 0.62” diameter), Grade 270
2. High strength bars, Grade 150
3. Wires (not available in Florida)

FDOT Standard Tendon sizes for strand system (FDOT IDS Index 21800 Series)

- 0.6” Multi-strand system: 4, 7, 12, 15, 19, 27, and 31.
- PT bars diameter: 1”, 1 ¼”, 1 3/8”, 1 ¾”, 2 ½”, 3”.

Notes: 0.62” diameter strands are commonly used in stay cables

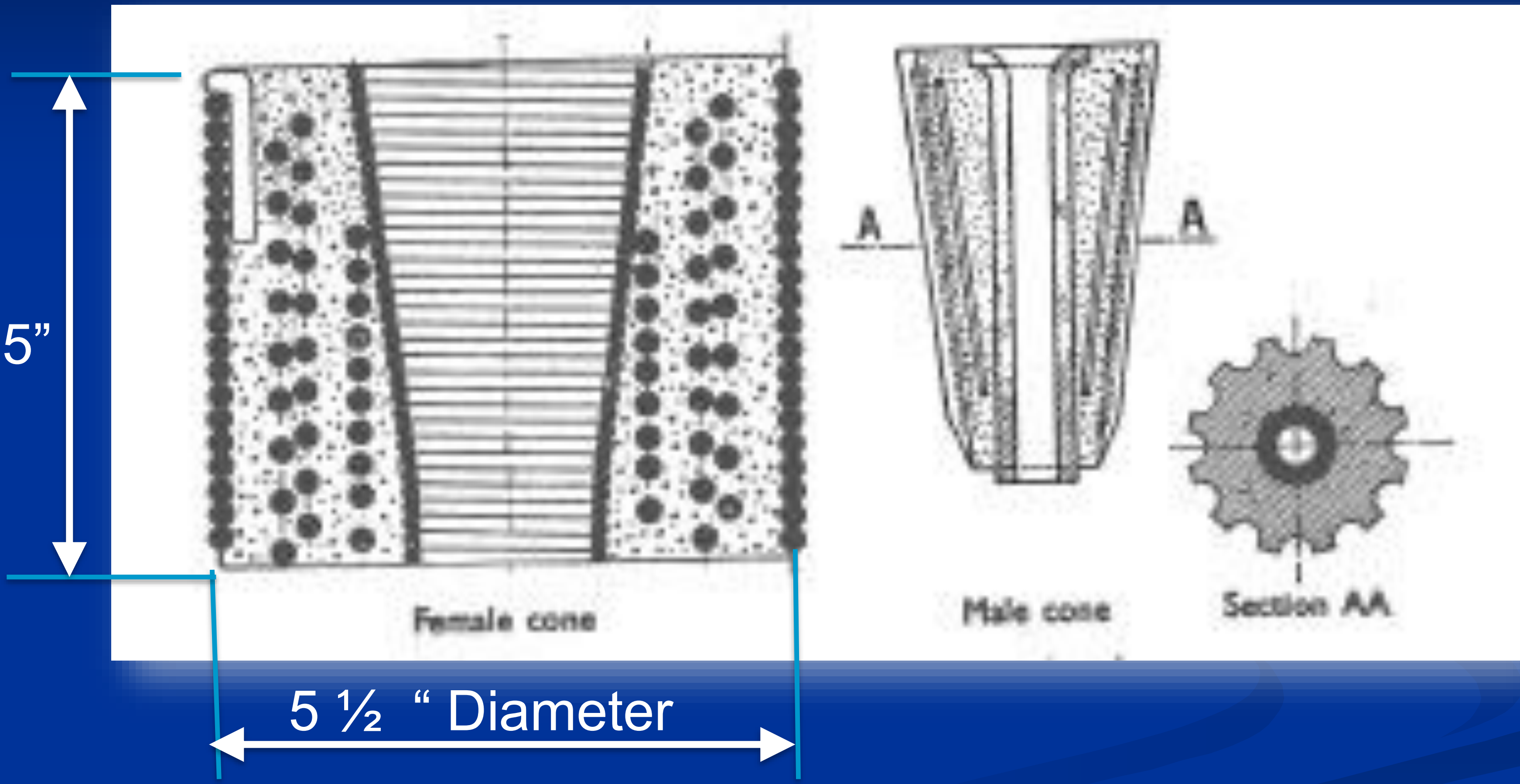
Development of PT Anchorages



Overall view of the Freyssinet PT wire tendon from anchorage to anchorage. Freyssinet System was one of the earliest PT systems in the world.

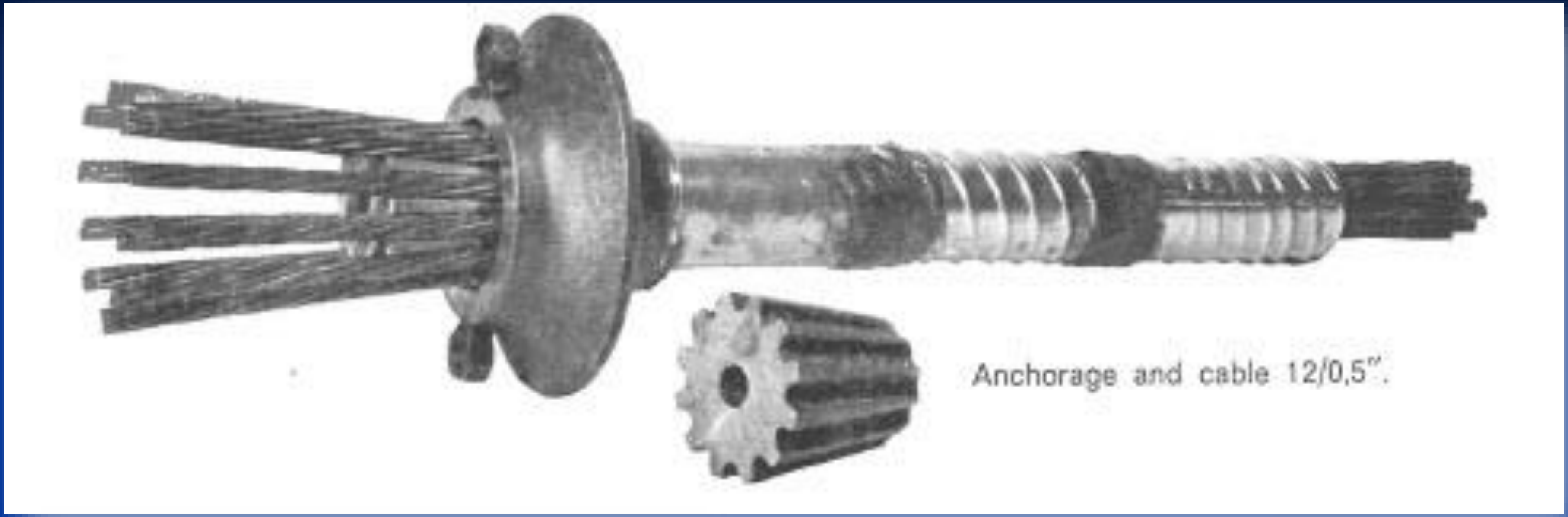
Development of PT Anchorages

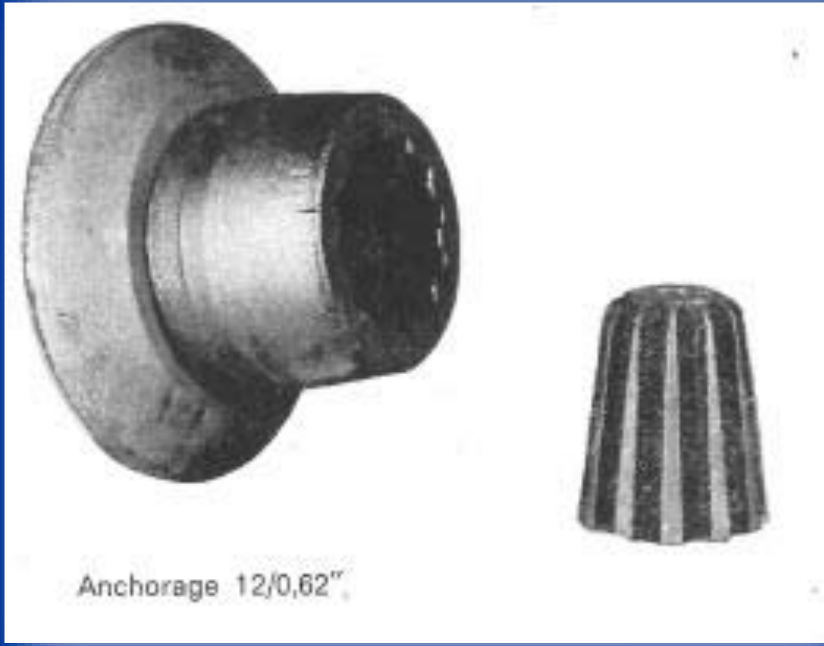
12/7 Freyssinet Wire system



Freyssinet Wire System was one of the earliest proprietary mechanical PT anchorage system (1930)

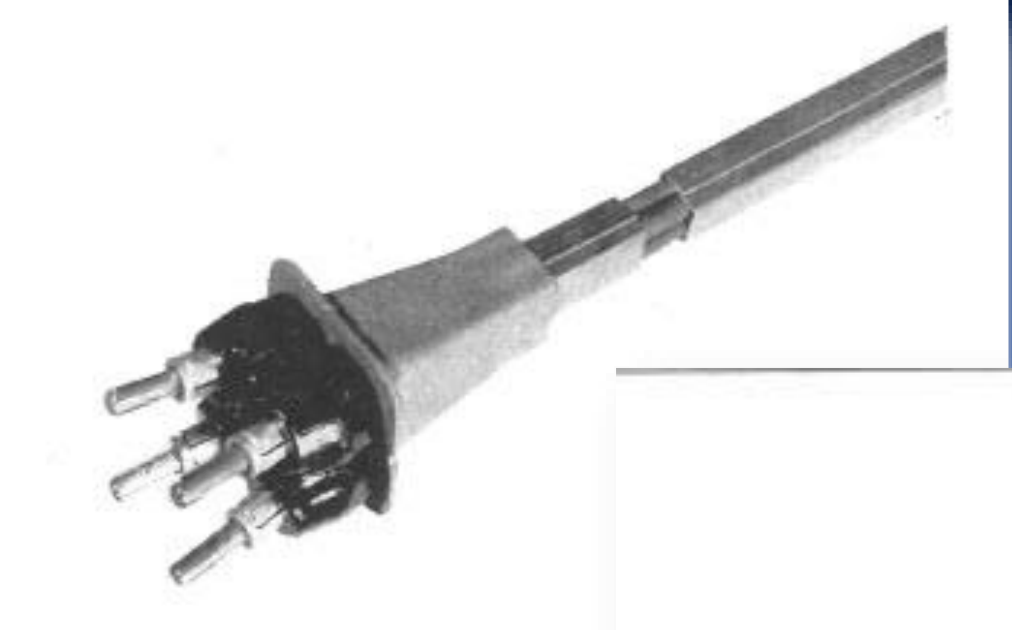
Development of PT Anchorages



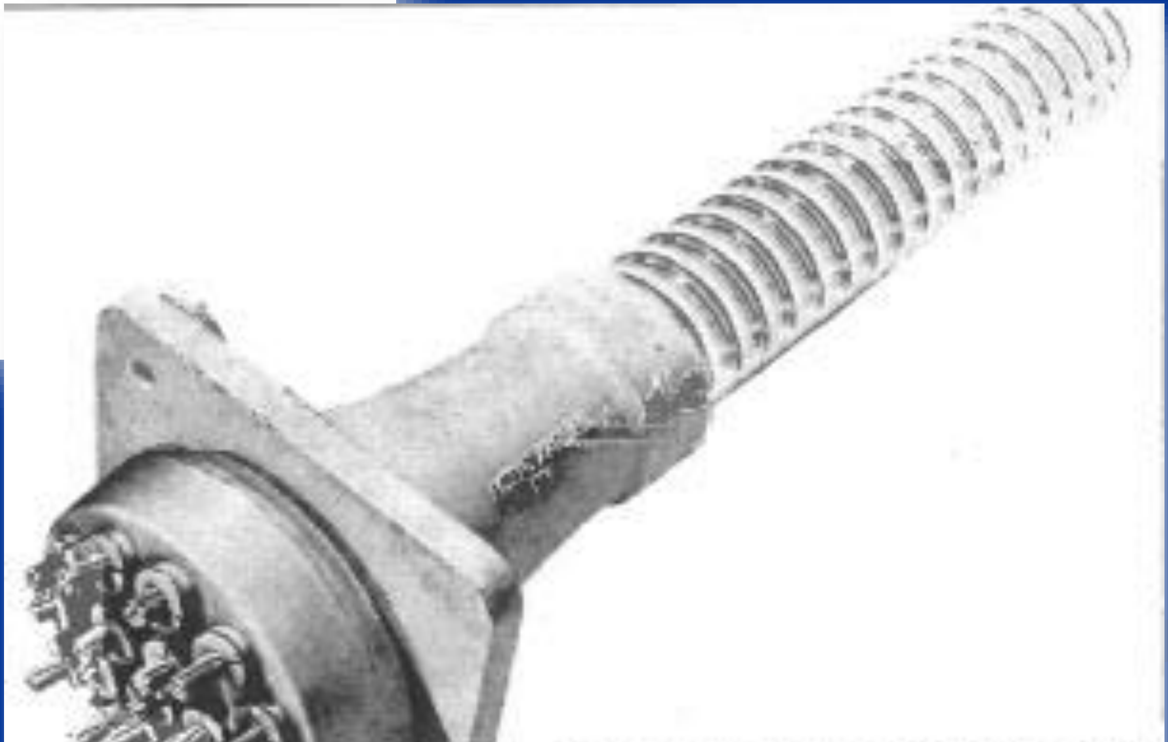


Freyssinet multi-strand system

Development of PT Anchorages

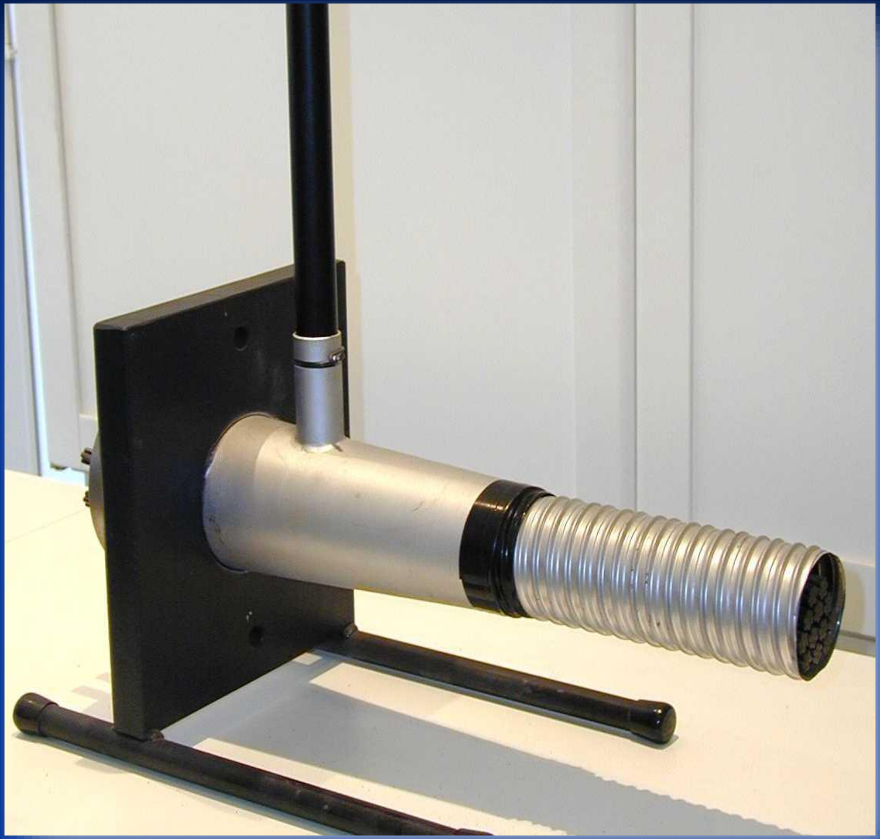


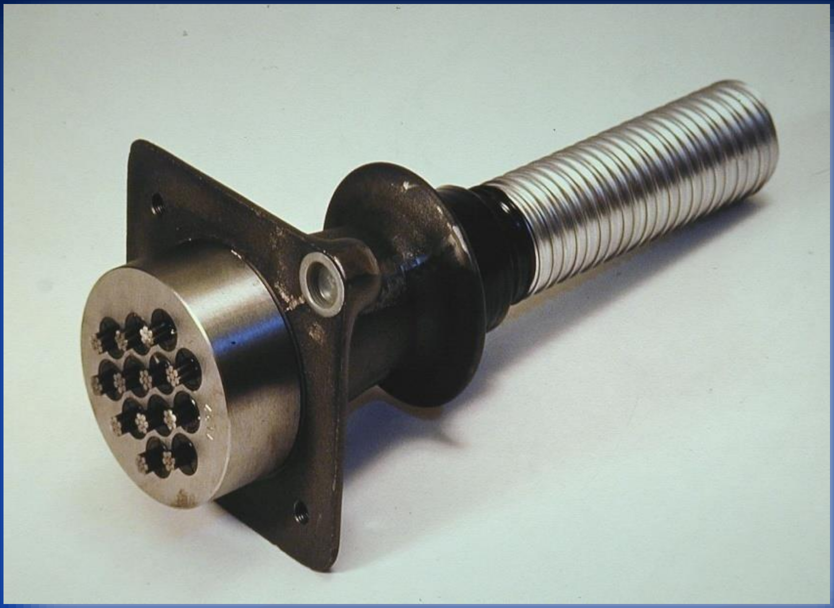
Monowire tendon 4/7 mm.

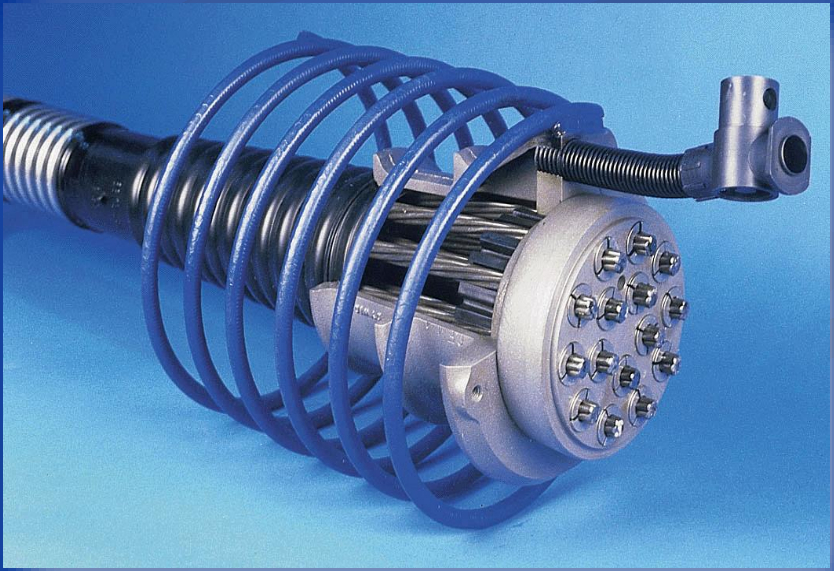


Monogroup tendon 19/0,6" Dyform.

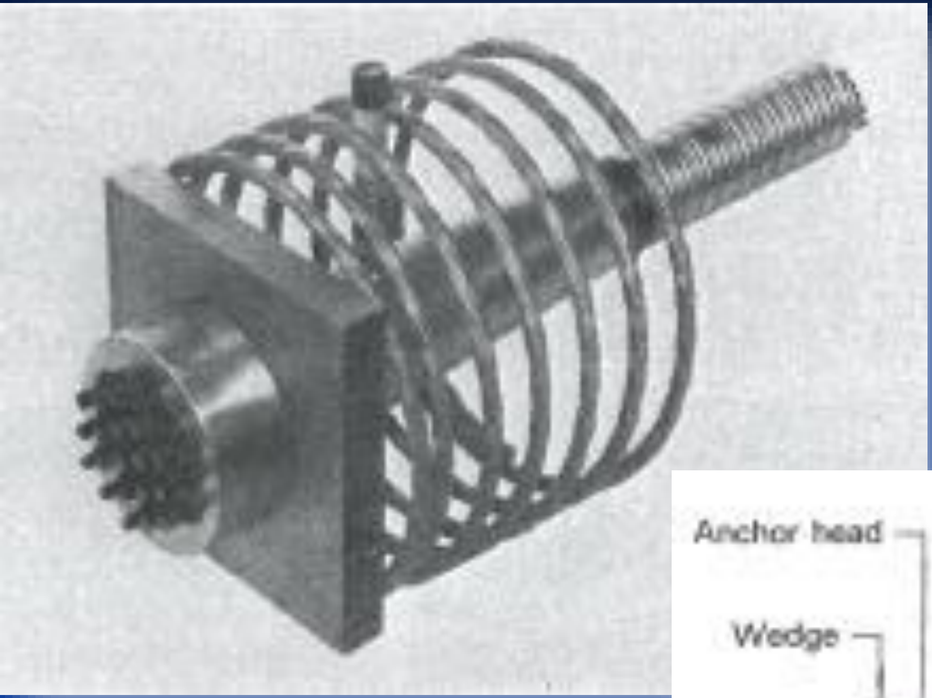
Development of PT Anchorages

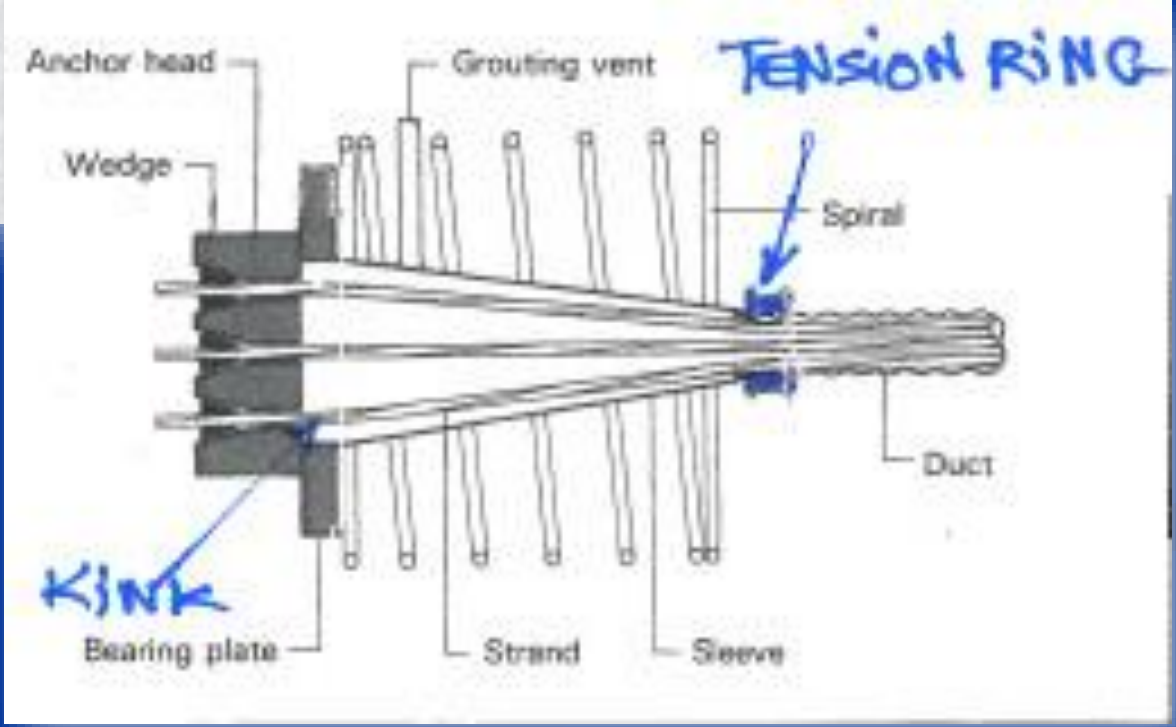




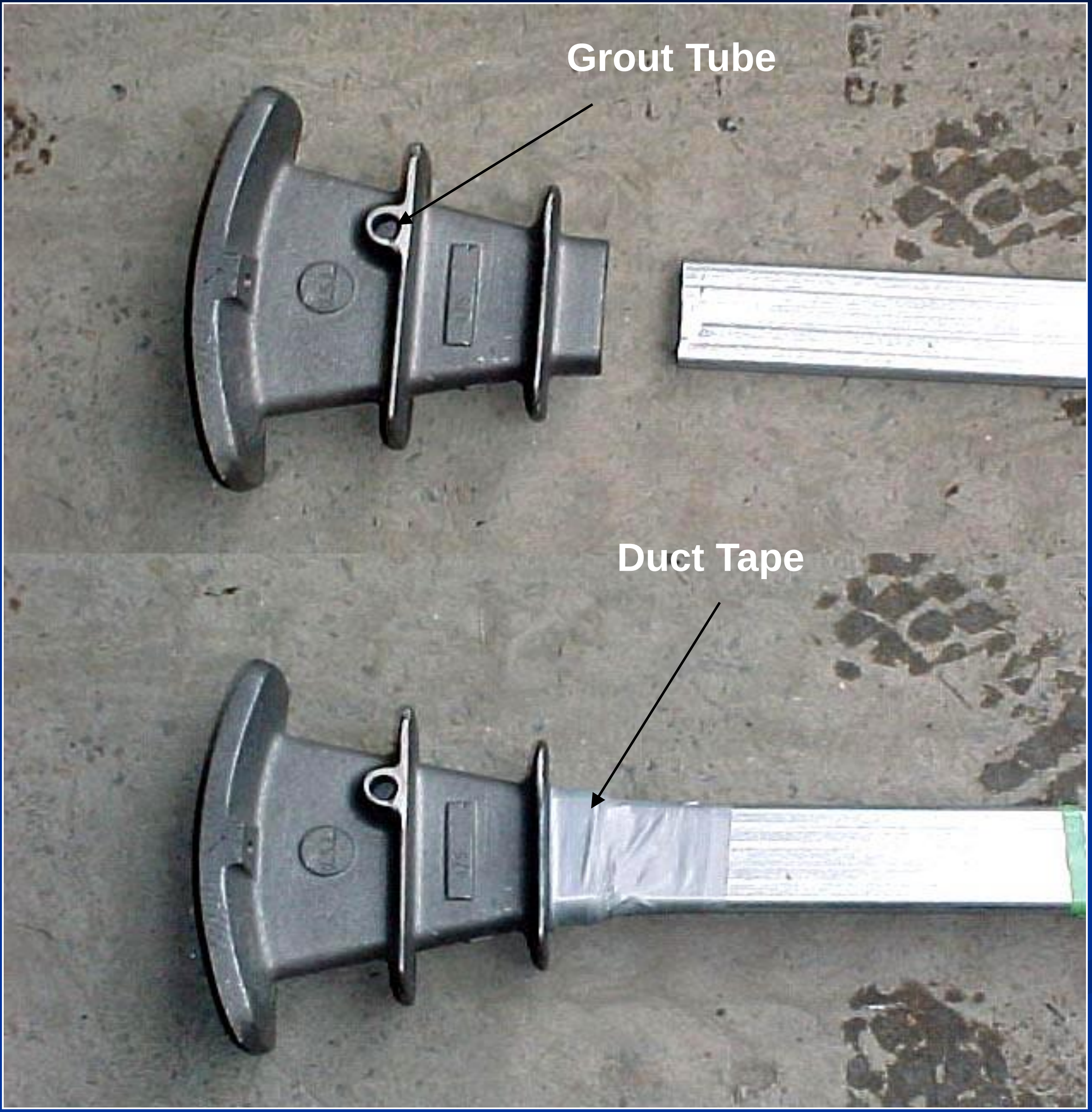


Development of PT Anchorages

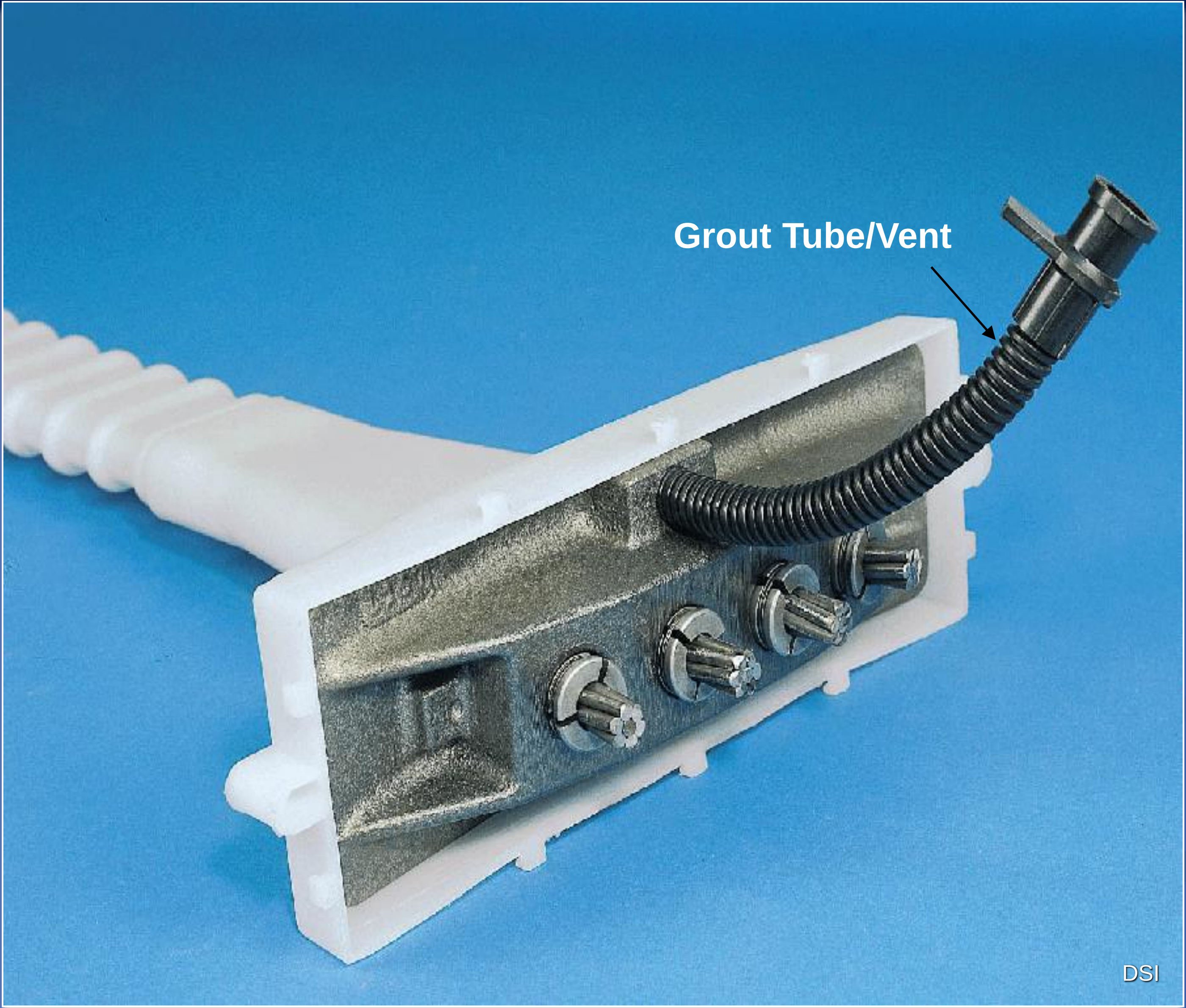




Development of PT Anchorages



Development of PT Anchorages



Development of PT Anchorages

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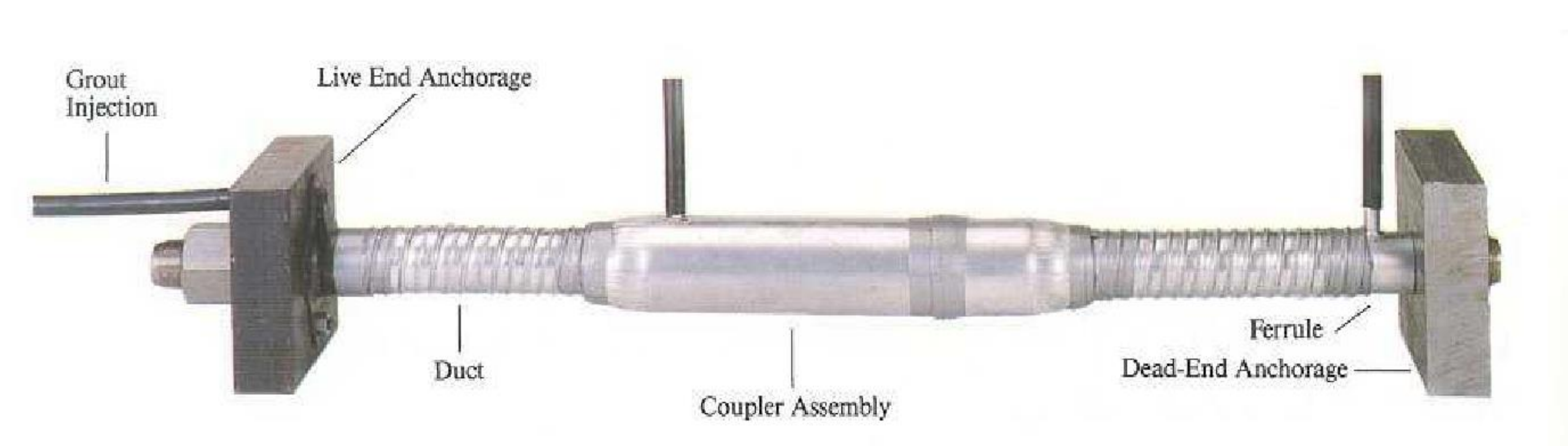


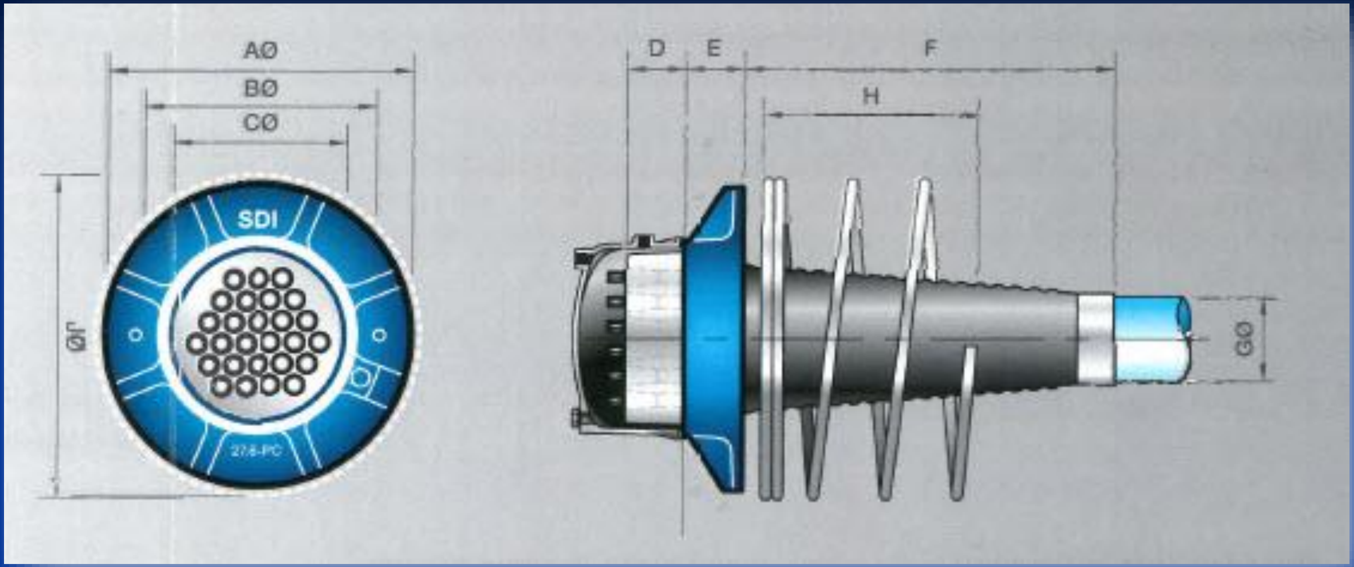
Development of PT Anchorages

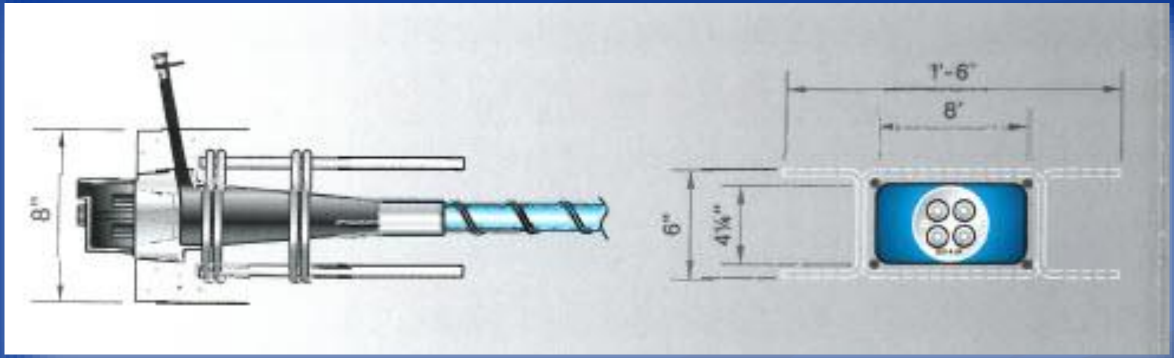
VSL Composite Anchorage System

Development of PT Anchorages

VSL PT anchorage for flexible filler

Development of PT Anchorages





SDI PT Anchorage Systems

Development of PT Anchorages

Tensa PT Anchorage System

Development of PT Anchorages

Concrete Strength Limit for Post-Tensioned Structures

AASHTO LRFD (8^{th} Edition, 2017)
Section 5.4.2.1: Limit of f'c for structural concrete from 4,000 psi to 10,000 psi.

FDOT Structures Design Guidelines (January 2018)
SDG Section 1.4.3: Limit of f'c for Prestressed Concrete from 5,000 psi (Class III) to 10,000 psi.

Development of PT Anchorages

Concrete Strength Limit for Post-Tensioned Structures (cont.)

Notes:

- Concrete strength is directly related to the size of bearing plates and local zone reinforcement.
- Typically tendons are stressed in a few days after concreting. 5000 psi concrete can reach about 4000 psi (0.8 f'c) in one or two days. Therefore, 5000 psi is the absolute minimum concrete strength recommended.
- Most proprietary PT anchorage systems are designed for a minimum of 3500 psi to 4000 psi concrete strength.

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Design Methods for General Zone

- Elastic Stress Analysis (Mörsch, Guyon, Magnel, Leonhardt)
  - Classical / Photo-elastic
- Strut and Tie Models (equilibrium based plasticity models)
- Approximate Method
  - Deep Beam Analogy (Proposed by Gustave Magnel of Belgium)
- Combined Methods

Notes: Finite Element Method is not commonly used for General Zone design (use as supplementary analysis for complex general zone)

Design Methods for General Zone

Anchorage Zone Design Procedures

- Understanding the flow of stress distributions for different anchorage configurations.
- Design is based on the maximum jacking force (0.8 U.T.S)
- Assume stiff bearing plate (square, rectangular, and circular shapes)
- Determine the bursting, spalling, splitting and longitudinal edge tension forces in both vertical and transverse directions (the concrete tensile strength shall be ignored).

Design Methods for General Zone

Anchorage Zone Design Procedures (cont.)

- Compute / estimate the tension forces based on simplified / practical methods.
- Provide ample (robust) of reinforcement confinement and tension ties at the correct location to assure structural safety and serviceability. These reinforcement shall be provided in addition to the shear and torsion reinforcement required for the girder / beam design.
- Good detailing practices are the key to successful and safe anchorage zone design.

Design Methods for General Zone

Bursting Reinforcement Calculations

1. **Working Stress** (AASHTO Guide Spec. for Design and Construction of Segmental Concrete Bridges, 1st Edition, Section 14.2)

Reinforcement for busting forces shall be designed based on maximum jacking force at time of stressing with allowable steel stress

$$f_s = 0.6\, f_y \quad (f_y \leq 60 \text{ ksi})$$

Design Methods for General Zone

Bursting Reinforcement Calculations (cont.)

2. Load and Resistance Factor (LRFD)

LRFD 3.4.3.2

The design force for post-tensioning anchorage zones shall be taken as 1.2 times the maximum jacking force

LRFD 5.5.4.2

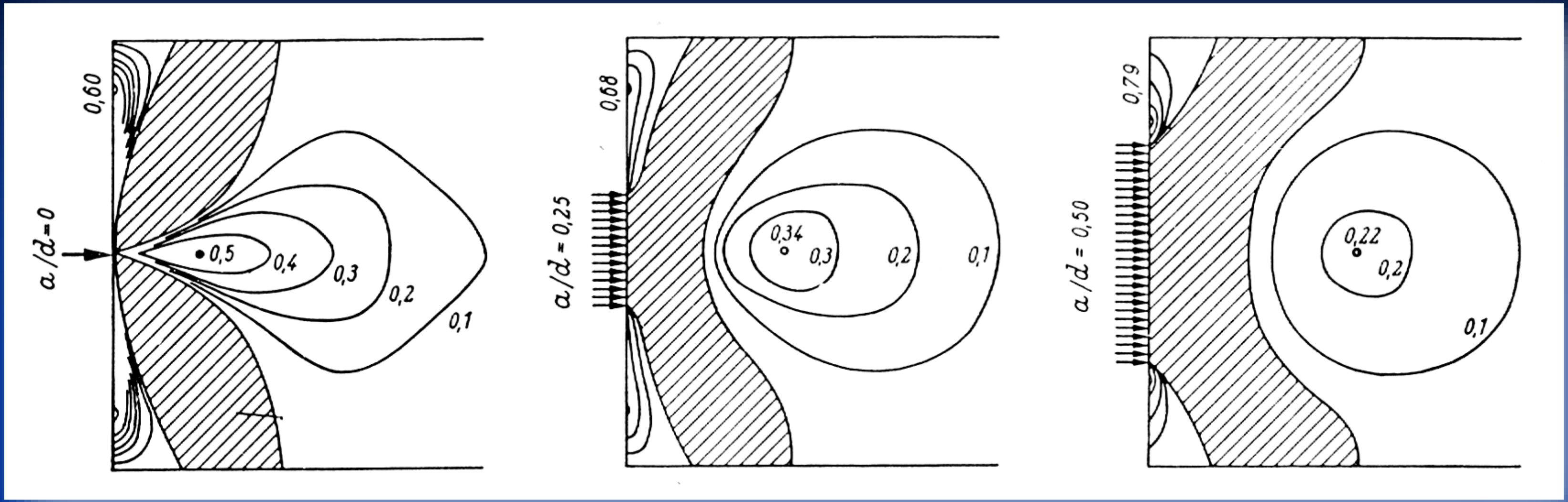
Resistance Factors Φ for compression in anchorage zones:

Normal weight / lightweight concrete: 0.80

Resistance Factor Φ for tension in steel anchorage zones: 1.0 (?)

(Note: in the past Φ = 0.8 to 0.85 has been used)

Design Methods for General Zone



Isobars diagram for various values of a/d (Guyon and Tesar)

Isobars with the Value $\dfrac{\sigma_y}{\sigma_o}$, *where* $\sigma_o = \dfrac{P}{b\,.\,d}$

Where: a=Bearing plate width
d=Member depth
b=Member width
P=Concentrated Force

Isobars: points of equal transverse stresses

Lessons Learned: The smaller a/d ratios, the larger the bursting force

Design Methods for General Zone

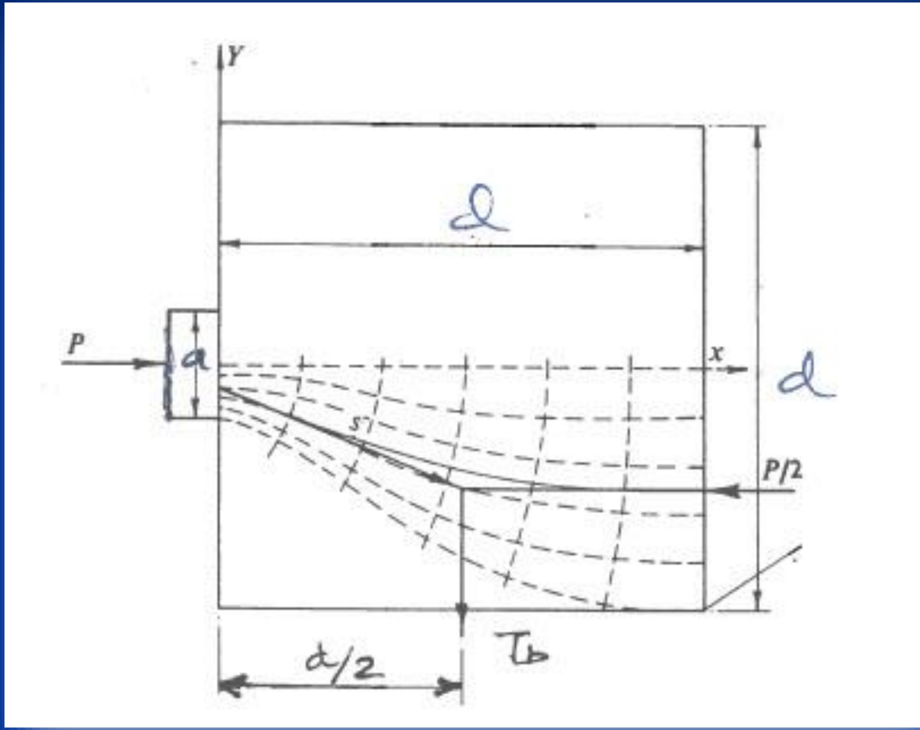
Since each proprietary system has its own anchorage dimensions, shapes and the selected system is unknown during the design phase, the best strategy:

- Select the smallest size of anchorage from approved PT systems for computing bursting forces.
- Select the largest size anchorage from approved PT systems for setting up anchorages layout and detailing.

Notes: The bearing plates must meet the edge distance and anchorages center to center for a particular system

Design Methods for General Zone

Mörsch's Theory (1924)

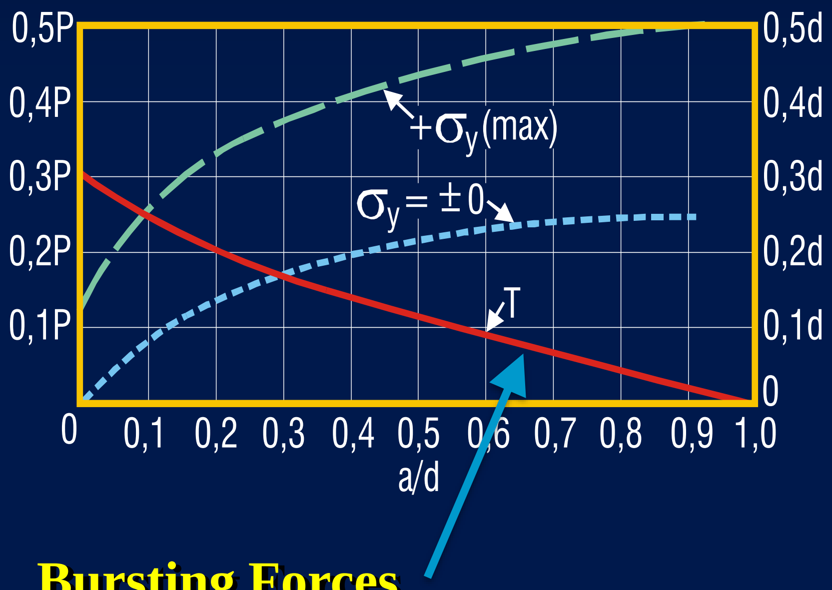


Mörsch theory for concentric load follows parabolic stress trajectories distributed uniformly at distance d from the face. Mörsch theory was the earliest application of strut and tie model in computing the bursting force T_b

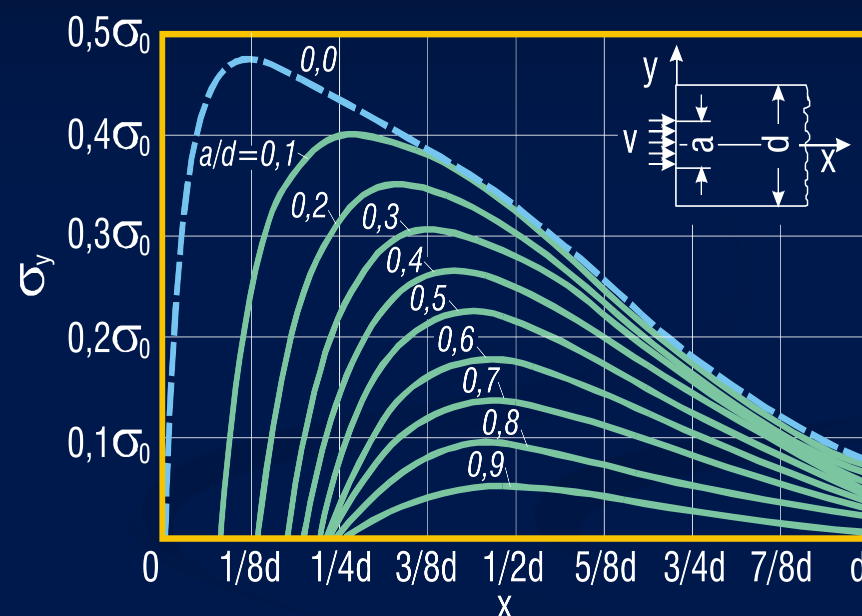
$$T_b = P/(4d)\ (d-a) = 0.25\ P\ (1- a/d)$$

Design Methods for General Zone

Single Concentric Force



Bursting Forces

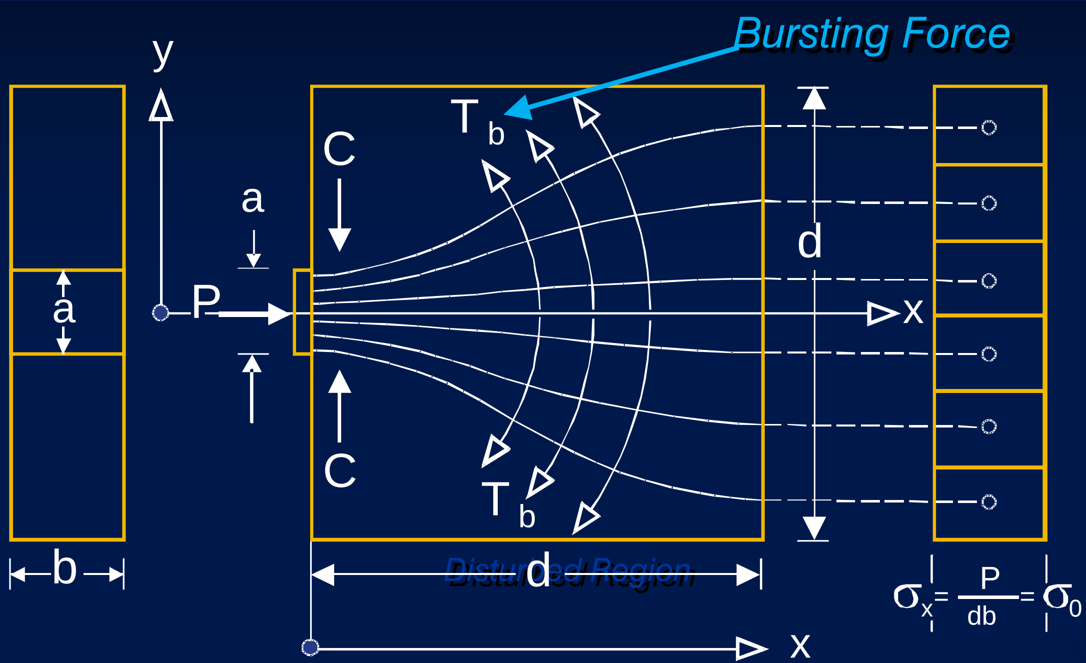


Transverse Tensile Stresses σ_y

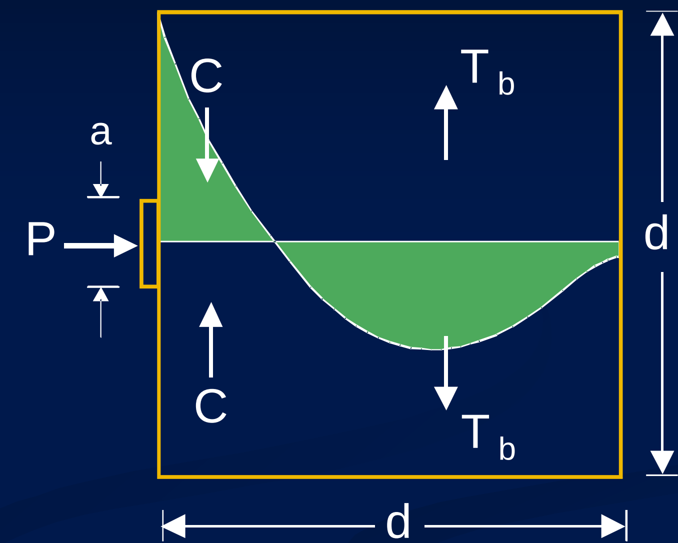
The above diagrams were produced by Iyengar [16]

Design Methods for General Zone

Single Concentric Force



Principal Tension and Compression Stresses



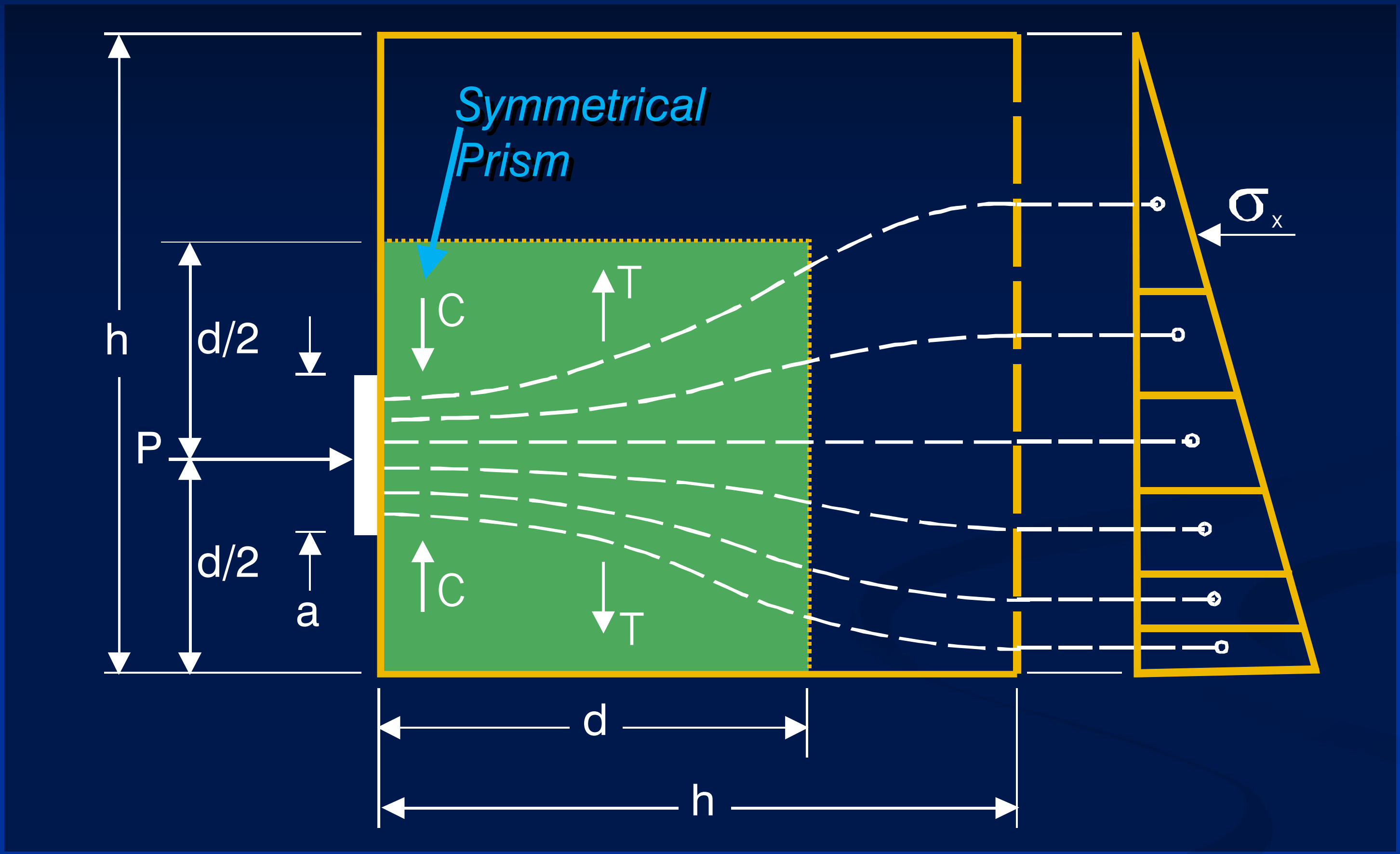
Transverse Compressive and Tensile Stresses distribution

Bursting Force T_b

- Fritz Leonhardt: $T_b = 0.30\,P\,(1 - a/d)$ for $a/d < 0.2$
- E. Mörsch: $T_b = 0.25\,P\,(1 - a/d)$ for $a/d > 0.2$

Design Method for General Zone

Guyon's Method for Single Anchorage (Small Eccentric)

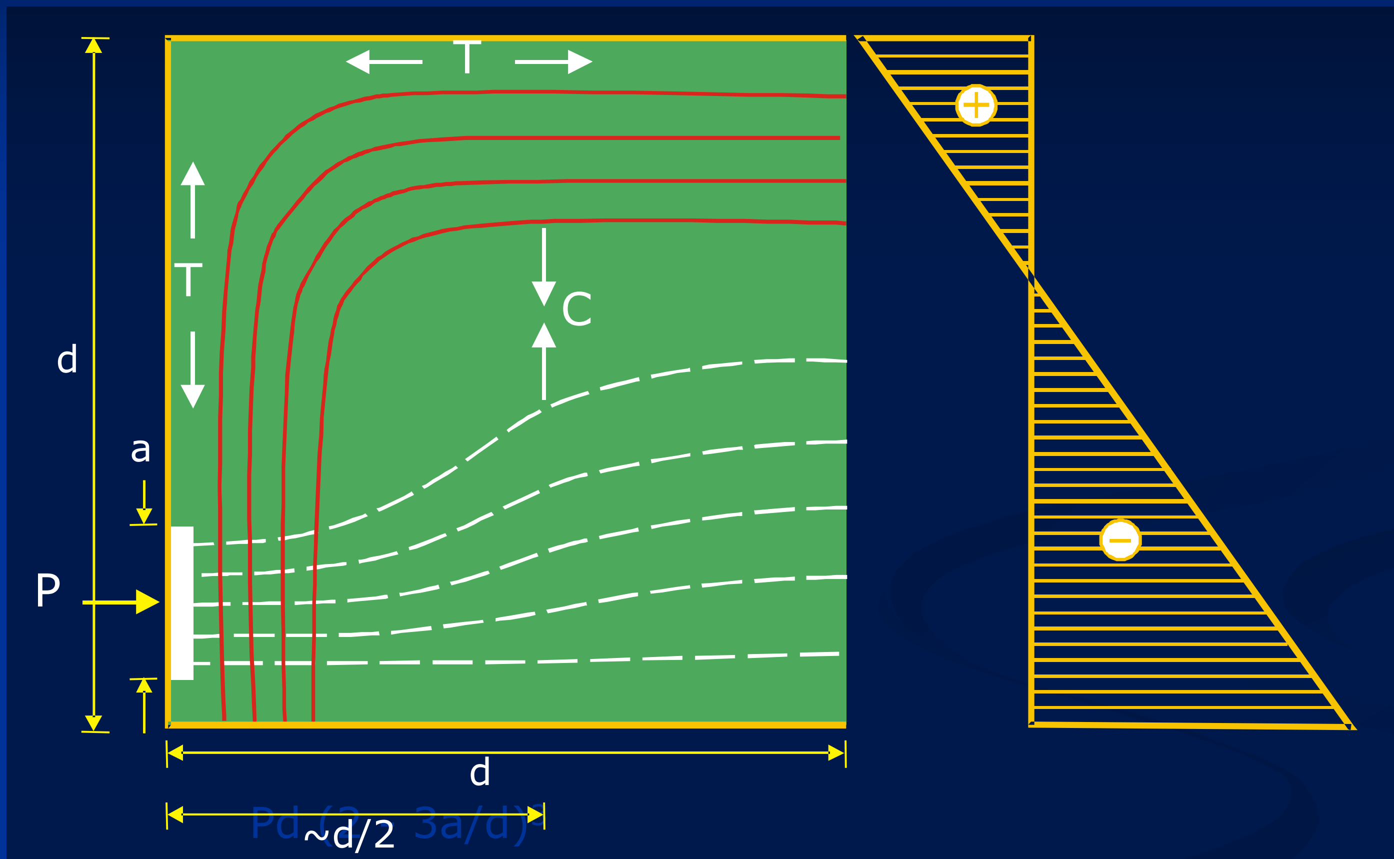


Bursting Force: $T_b = 0.30\ P\ (1 - a/d\ )$

Notes: small eccentric force when the center line of PT force falls inside the kern zone of the beam section

Design Method for General Zone

Single Anchorage (Large Eccentricity)



For large single eccentric force, use strut and tie or deep beam theory

Design Method for General Zone

Guyon's Theory for Multiple Anchorages

(1) Linear Distribution of Prestressing Force

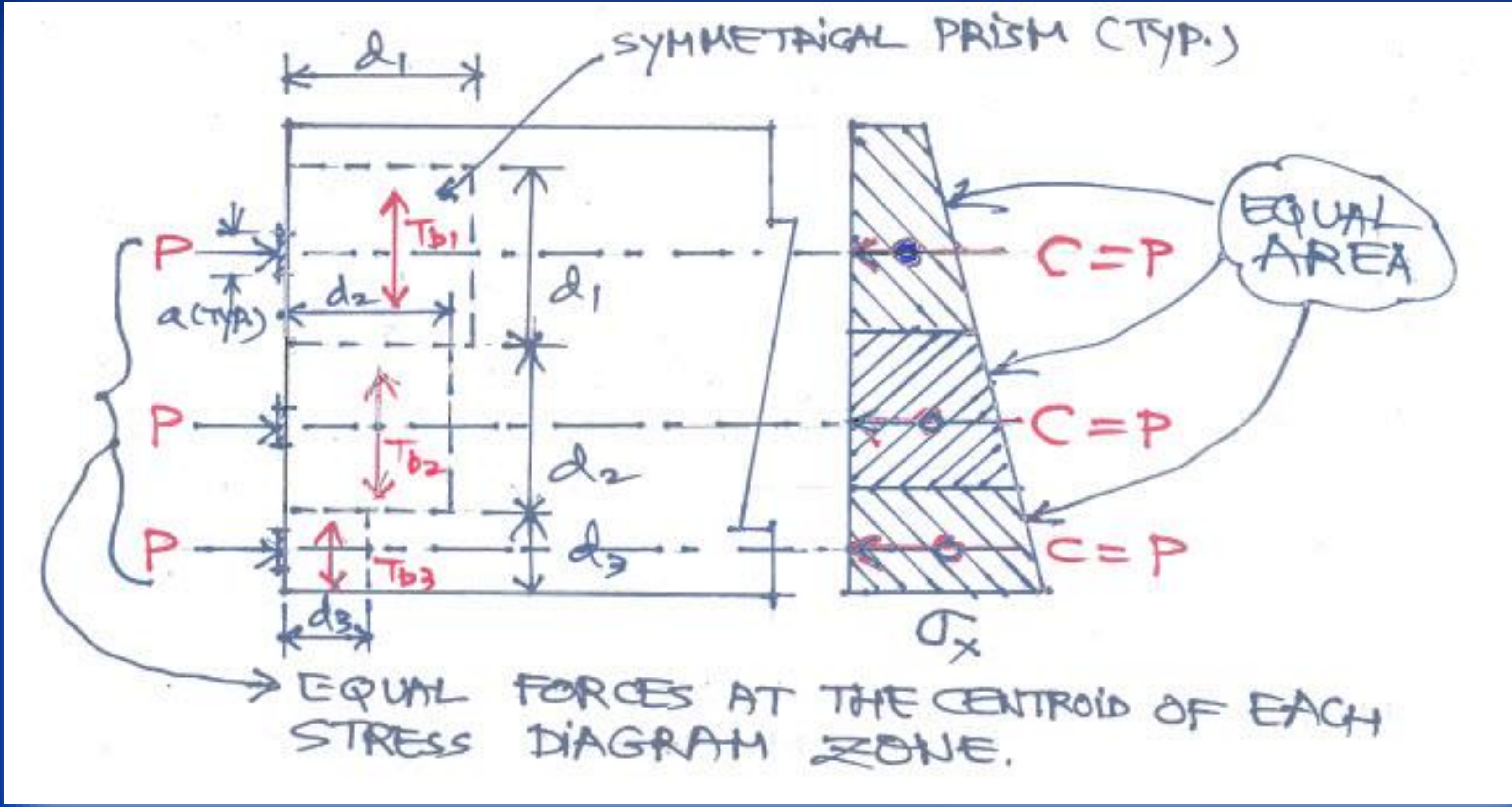
Multiple Forces Case 1

If the PT force is applied by anchorages which are linearly distributed along the end of the member in a manner corresponding to the distribution of stress at the beam section (end of general zone) each anchorages is considered to consist of prism which is in equilibrium under the action of the PT force at one end and linear stress in the other end as shown below.

Design Method for General Zone

Guyon's Theory for Multiple Anchorages

(1) Linear Distribution of Prestressing Force (Multiple Forces Case 1)



Notes: The Bursting Force T_b equation for each symmetrical prism is similar to concentric single force

Design Method for General Zone

Guyon's Theory for Multiple Anchorages

(1) Linear Distribution of Prestressing Force

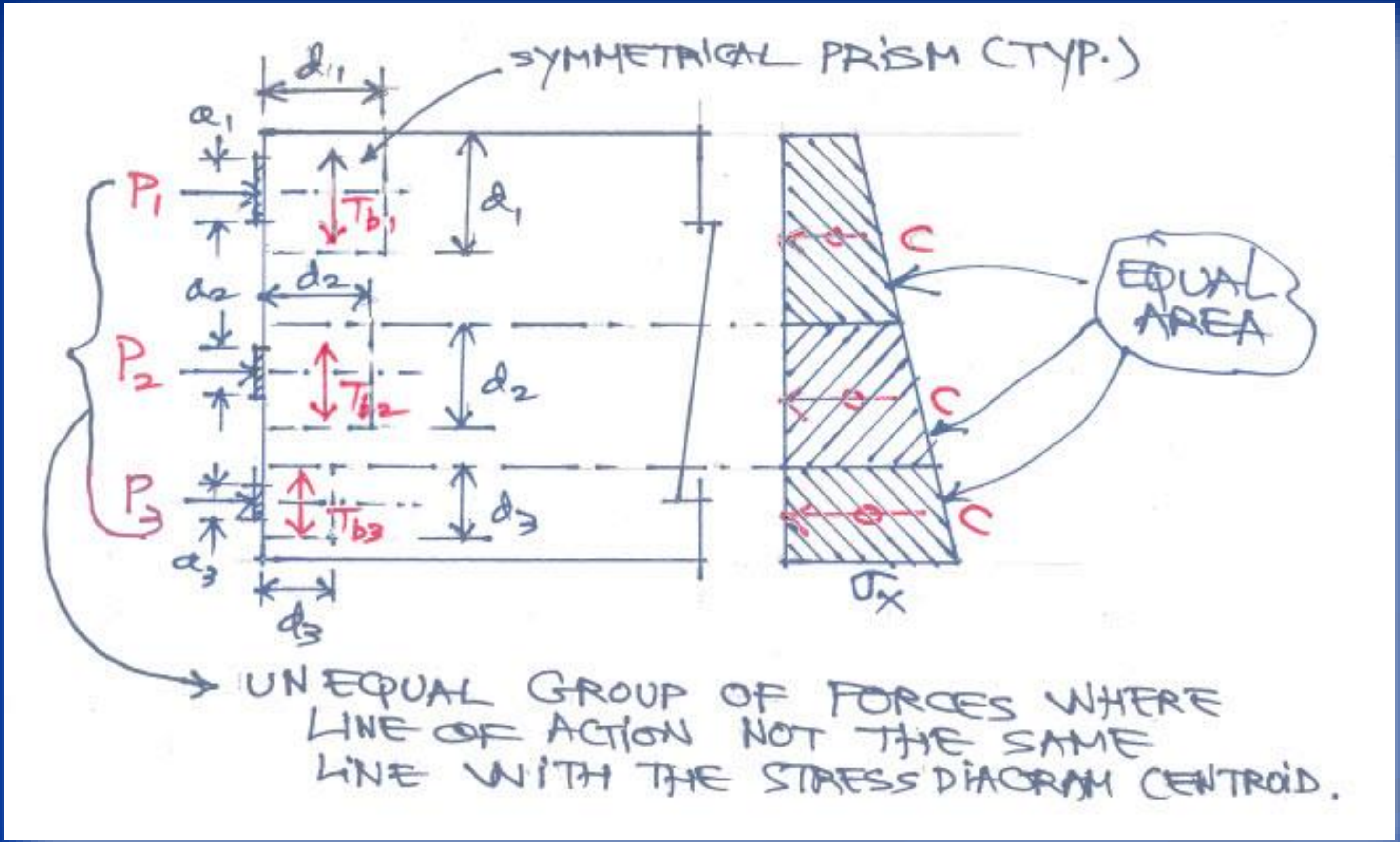
Multiple Forces Case 2

If the PT forces are not the same line of action with the equal stress area resultant, each prism is formed based on the horizontal line separated each stresses zone.

Design Method for General Zone

Guyon's Theory for Multiple Anchorages

(1) Linear Distribution of Prestressing Force (Multiple Forces Case 2)



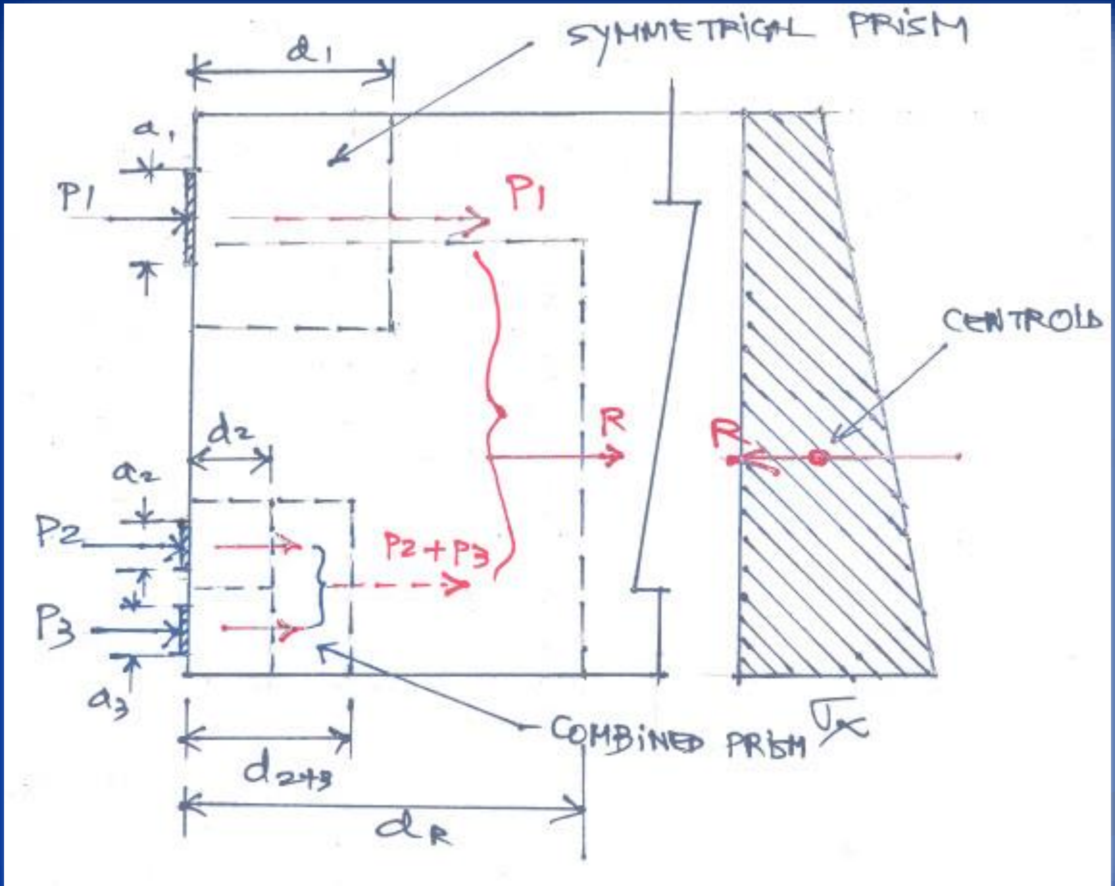
Notes: The Bursting Force T_b equation for each symmetrical prism is similar to concentric single force

Design Method for General Zone

Guyon's Theory for Multiple Anchorages

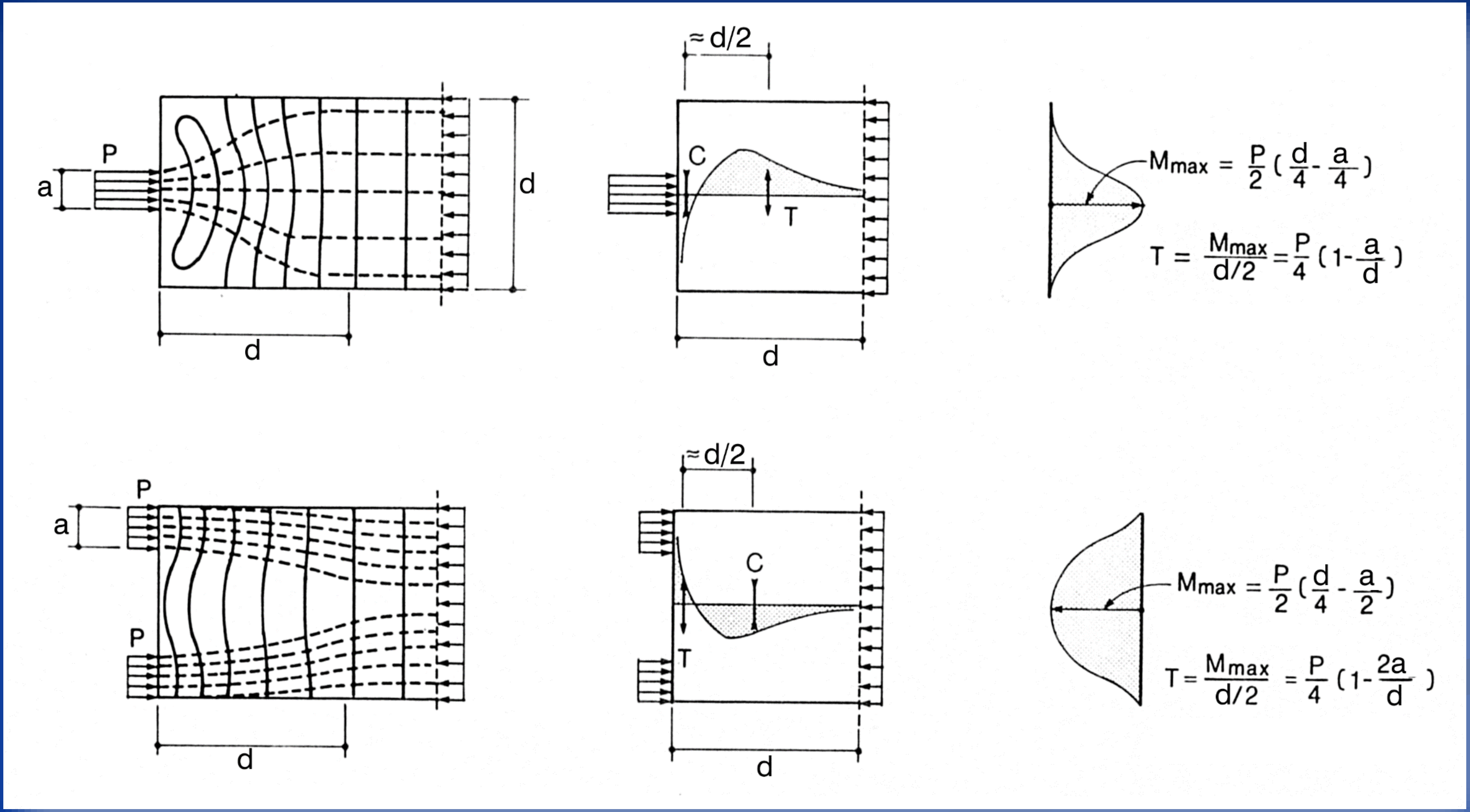
(2) Non-Linear Distribution of Prestressing Force (successive resultant)

If the anchorages are arranged in groups, it is assumed that the bursting stresses reach their largest values first on the line of action each separate group, then on the line of action of the resultant for each group, and finally the line of action for the total resultant. This method called the Guyon's "Law of Successive Resultants".



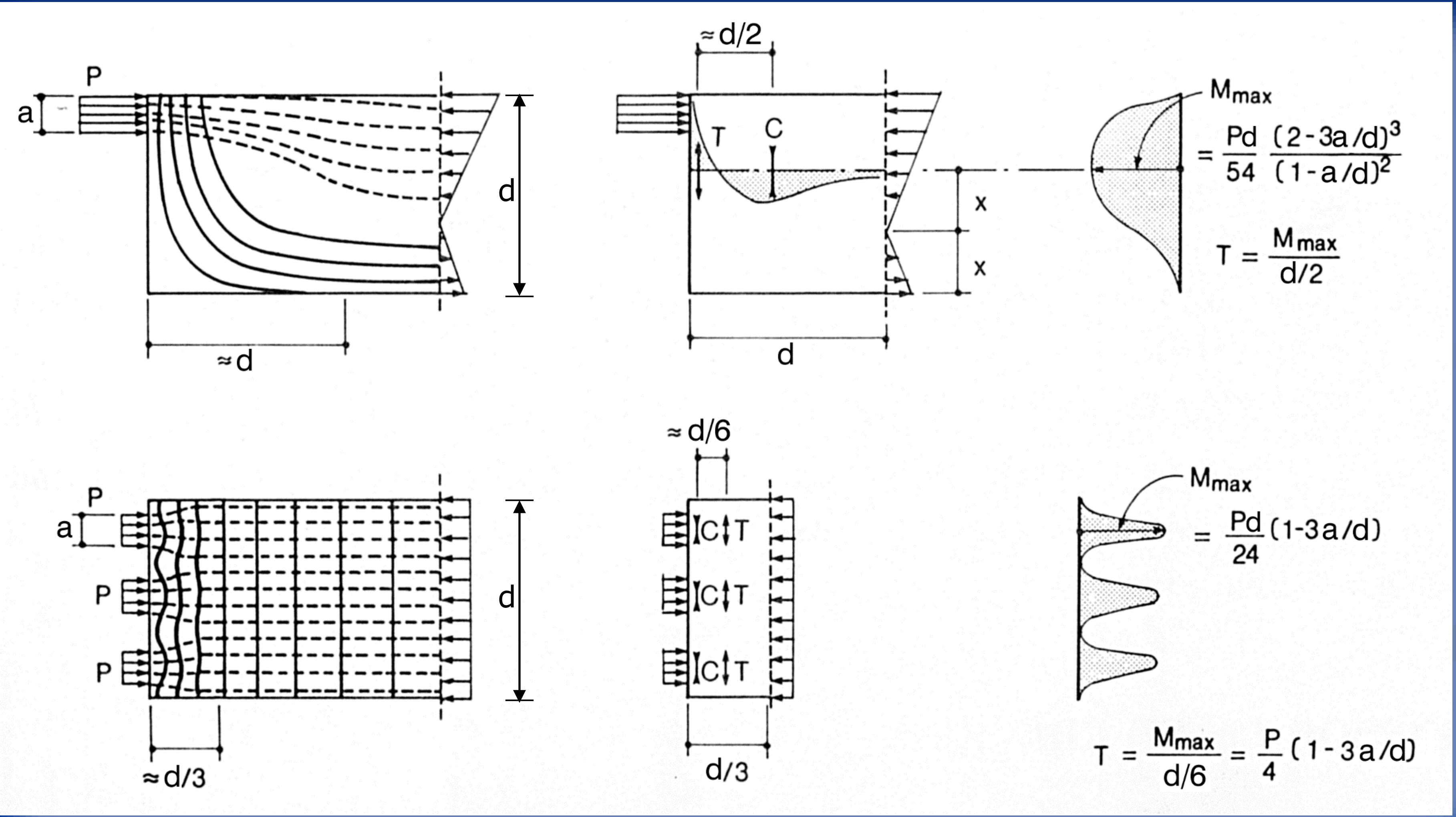
Design Method for General Zone

Deep Beam Analogy (1 of 2) [8]



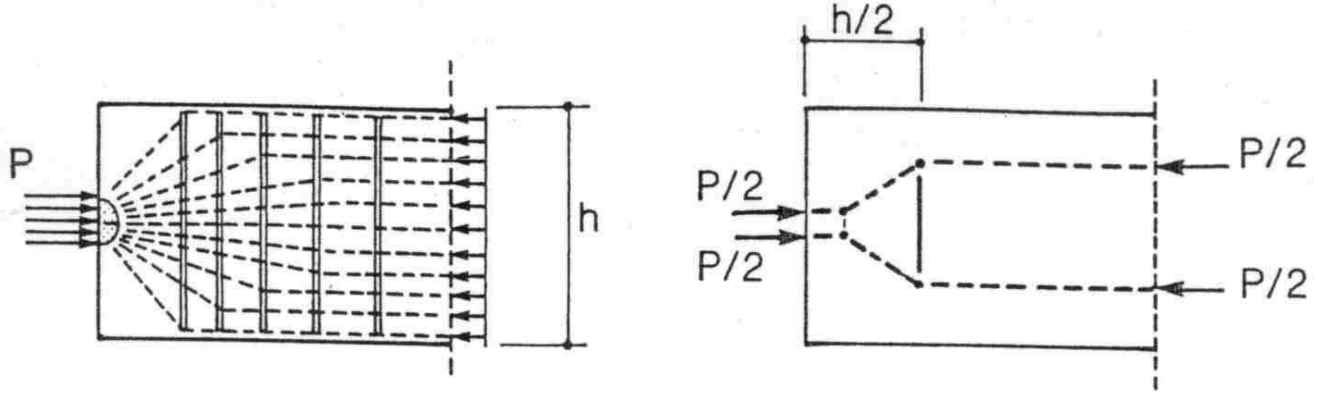
Design Method for General Zone

Deep Beam Analogy (2 of 2) [8]

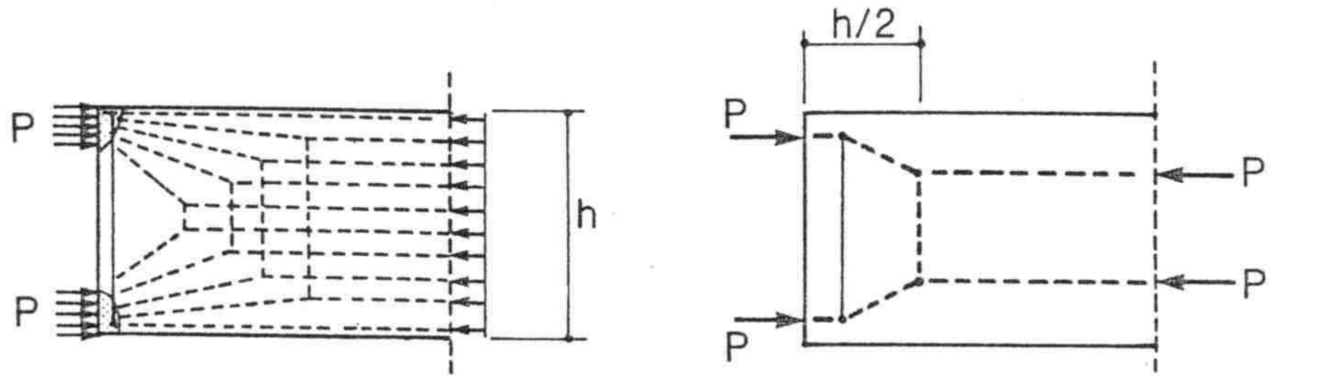


Design Method for General Zone

Strut and Tie Model (1 of 2) [8]



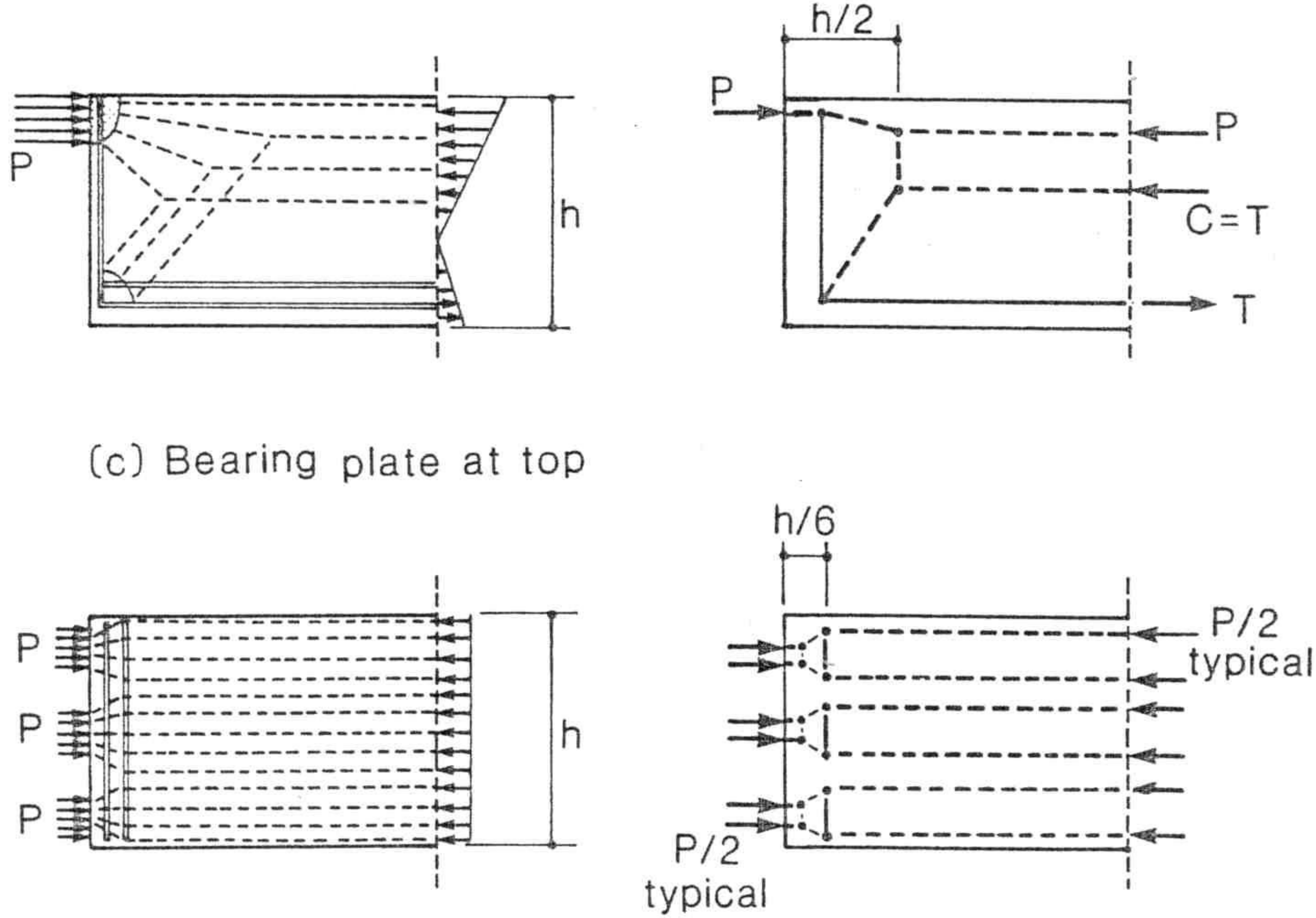
(a) Centrally located bearing plate



(b) Bearing plates at top and bottom

Design Method for General Zone

Strut and Tie Models (1 of 2)



(c) Bearing plate at top

(d) Three symmetrically located bearings

Design Method for General Zone

Spalling Reinforcement

- AASHTO LRFD Spec. 5.9.5.6.5 b

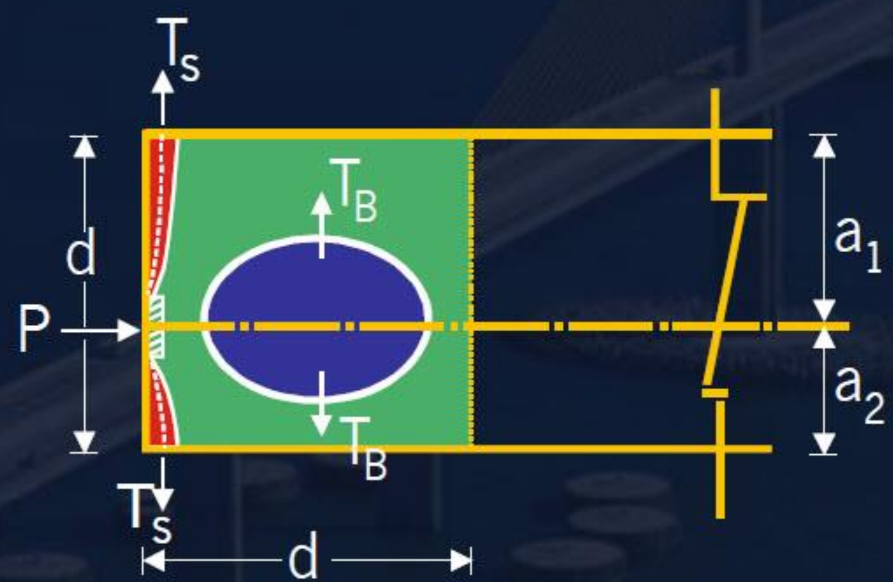
  The minimum spalling force for design is 2% of the total post-tensioning force.

- Y. Guyon in 1953 proposed that the minimum spalling force for design is 4% of the total post-tensioning force or the equation below.

- For multiple anchorages it is sufficient to considered the total PT force from a single largest anchorage force.

Design Method for General Zone

Spalling Reinforcement (cont.)

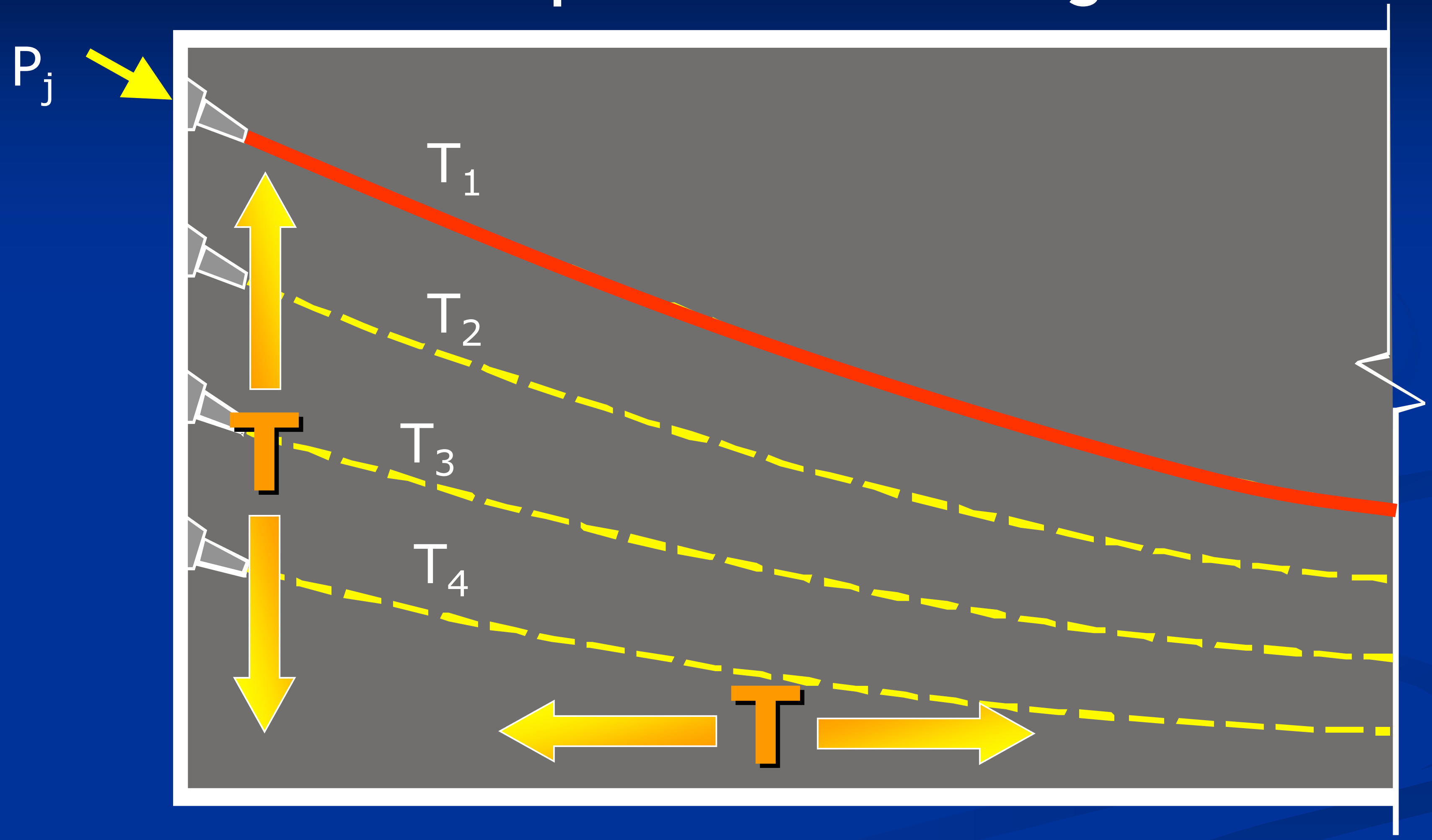


1. *The spalling reinforcement shall be provided in the form of reinforcing bar mesh and place as close as possible to the concrete surface.*
2. *The spalling reinforcement shall be provided in both directions.*

Spalling Force: $$T_s = \left[0.04 + 0.20 \left| \frac{a_1 - a_2}{a_1 + a_2} \right|^3 \right] P$$

Design Method for General Zone

Sequence of Stressing

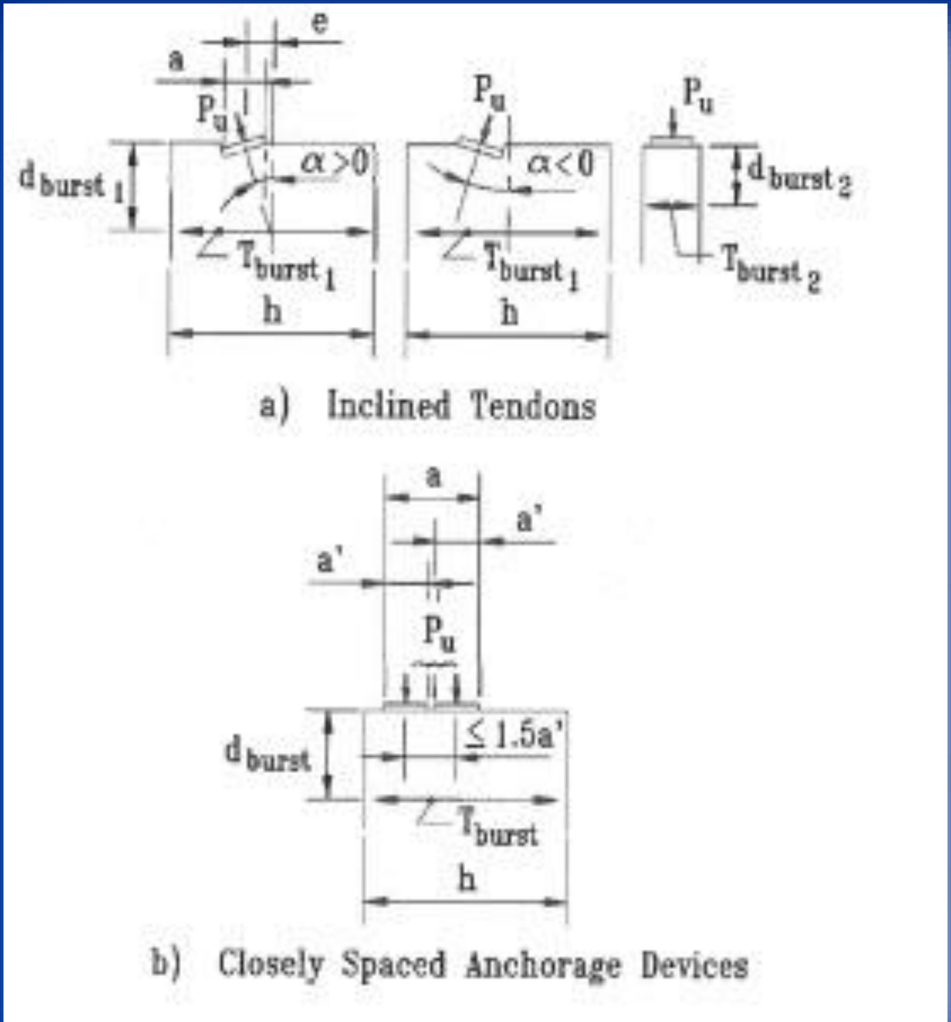


Tension T is generated as a result of the stressing of tendon T_1.

Anchorage Zone Design Methods

AASHTO LRFD Section 5.8.4.5.3 (8th Edition, Sept. 2017)

$$T_{burst} = 0.25 \Sigma P_u (1 - a/h) + 0.5 \left| \Sigma (P_u \sin \alpha) \right| \quad \text{......(5.8.4.5.3-1)}$$

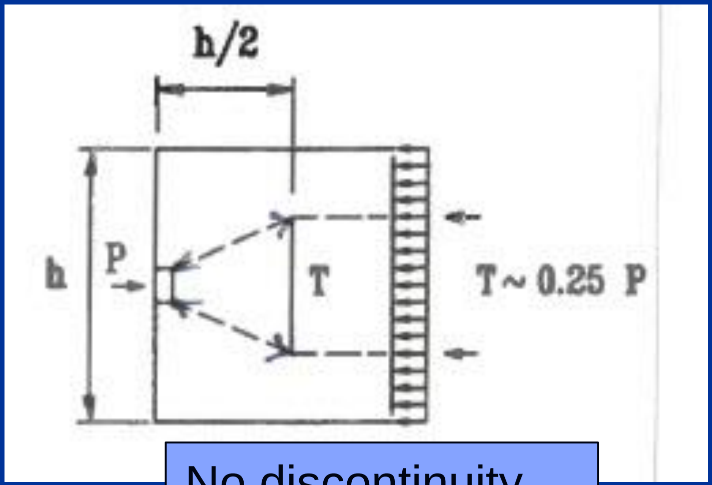


Anchorage Zone Design Methods

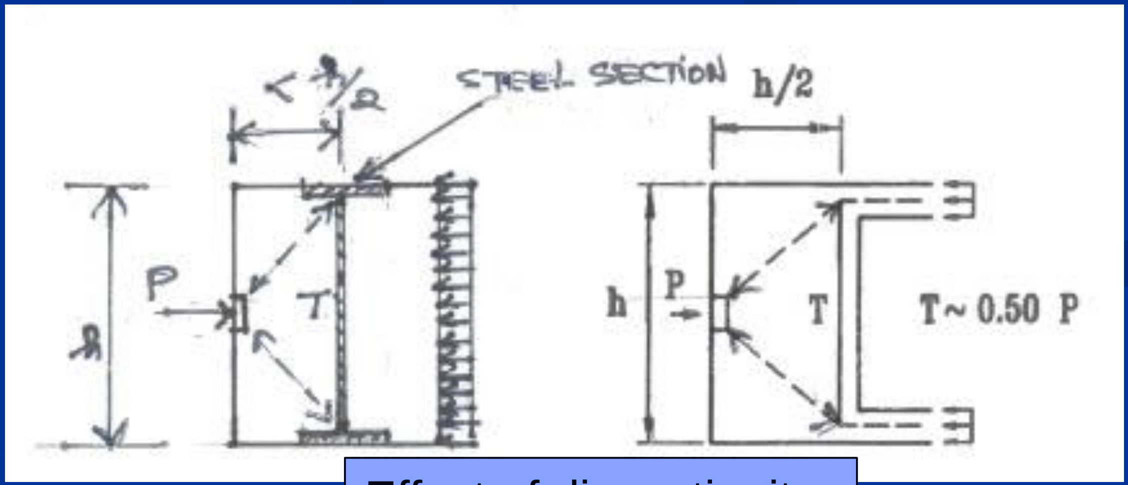
Limitations of LRFD Equation 5.8.4.5.3-1

Per LRFD 5.8.4.5.1 The above equation is valid provided:

- The member is a rectangular cross section and the length wise is larger than the transverse section dimension
- The member has no discontinuity within or ahead of the anchorage zone
- The minimum edge distance ≥ 1.5 a
- Only one anchorage device or one group of closely spaced anchorage devices
- The inclination angle α is between -5 degrees to + 20 degrees



No discontinuity



Effect of discontinuity

Presentation Outlines

- Introduction
- Case Study of Anchorage Zone Failure
- Development of PT Anchorages
- Design Methods for General Zone
- The Art of Proper Detailing
- Design Examples
- References

The Art of Proper Detailing

Recommendations for Good Detailing Practice

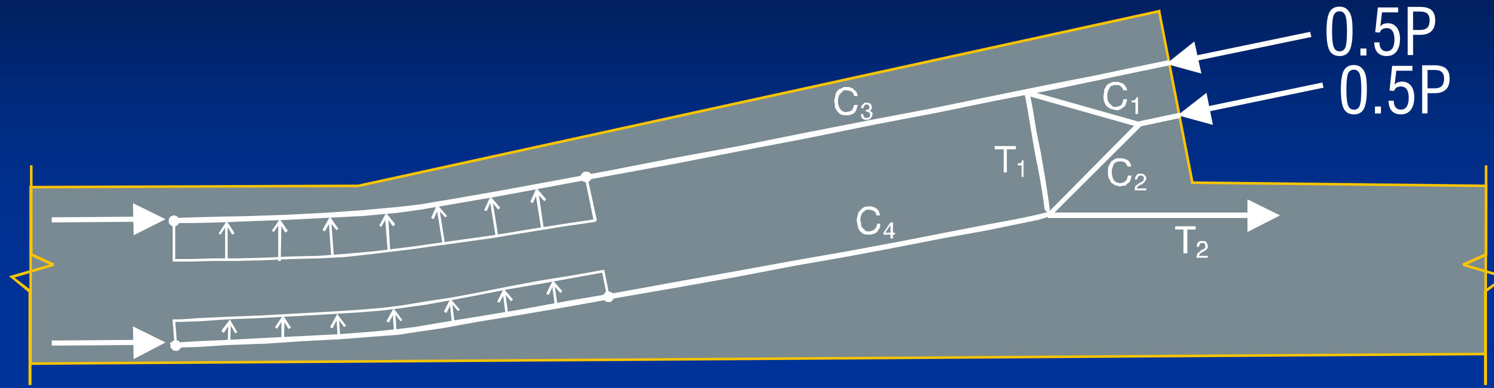
- Bursting reinforcement consists of closed stirrups for the whole depth of end block.
- Bursting reinforcement shall be uniformly distributed in the tension disturbed zone.
- It is better to use more smaller size reinforcing bars distributed in the bursting zone than large size of bars at a specific concentrated point.
- For large bursting forces, it may be necessary to provided four legs stirrups.

The Art of Proper Detailing

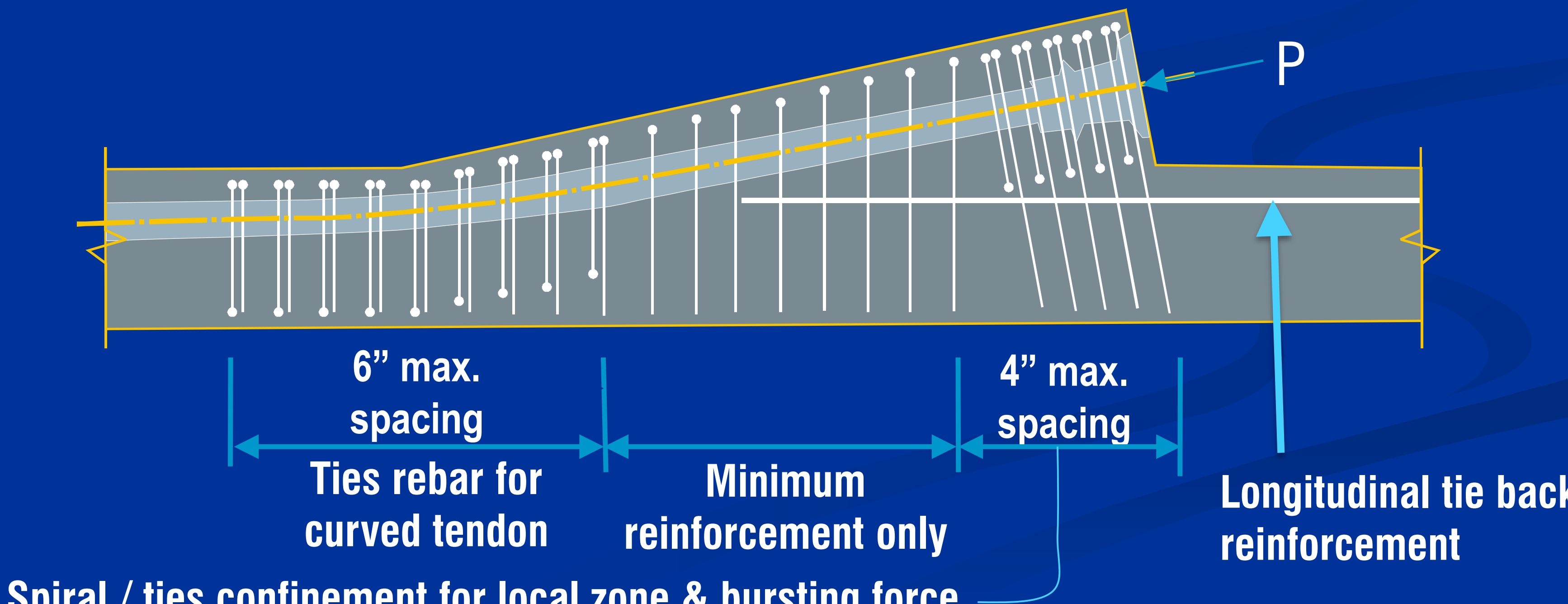
Recommendations for Good Detailing Practice (cont.)

- Lap spliced stirrup legs are not recommended.
- Transverse bursting reinforcement is provided through smaller closed stirrups cage inside the main bursting steel.
- Spalling reinforcement consists of orthogonal hair pin reinforcement grid placed as close as possible to the tension face (in the 0.15 d zone from the loaded face)

The Art of Proper Detailing

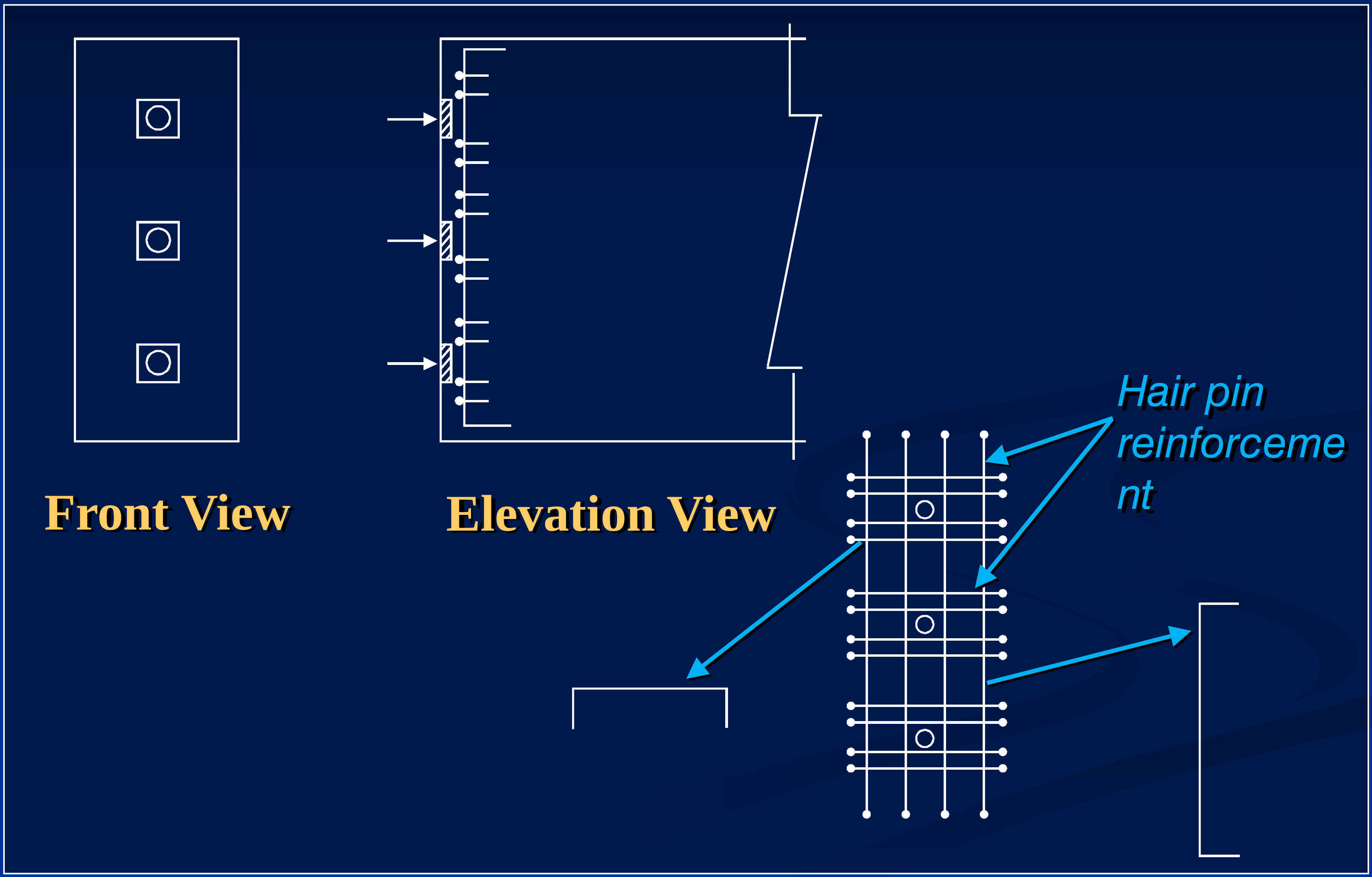


Strut and Tie Model for a blister

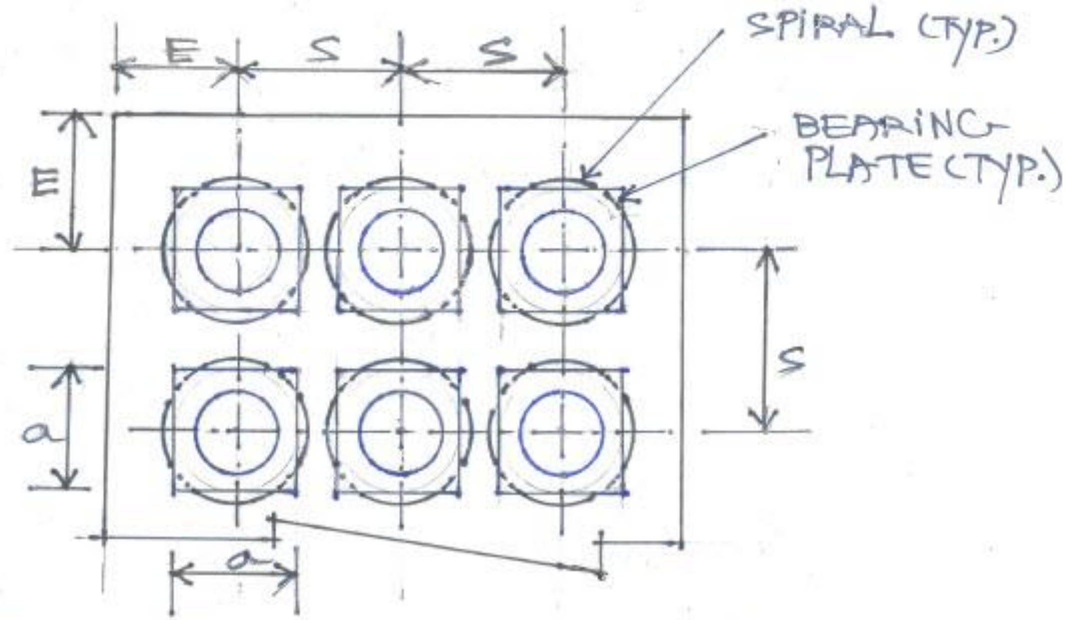


The Art of Proper Detailing

Spall reinforcement



The Art of Proper Detailing



PARTIAL FRONT VIEW OF MULTIPLE ANCHORAGES

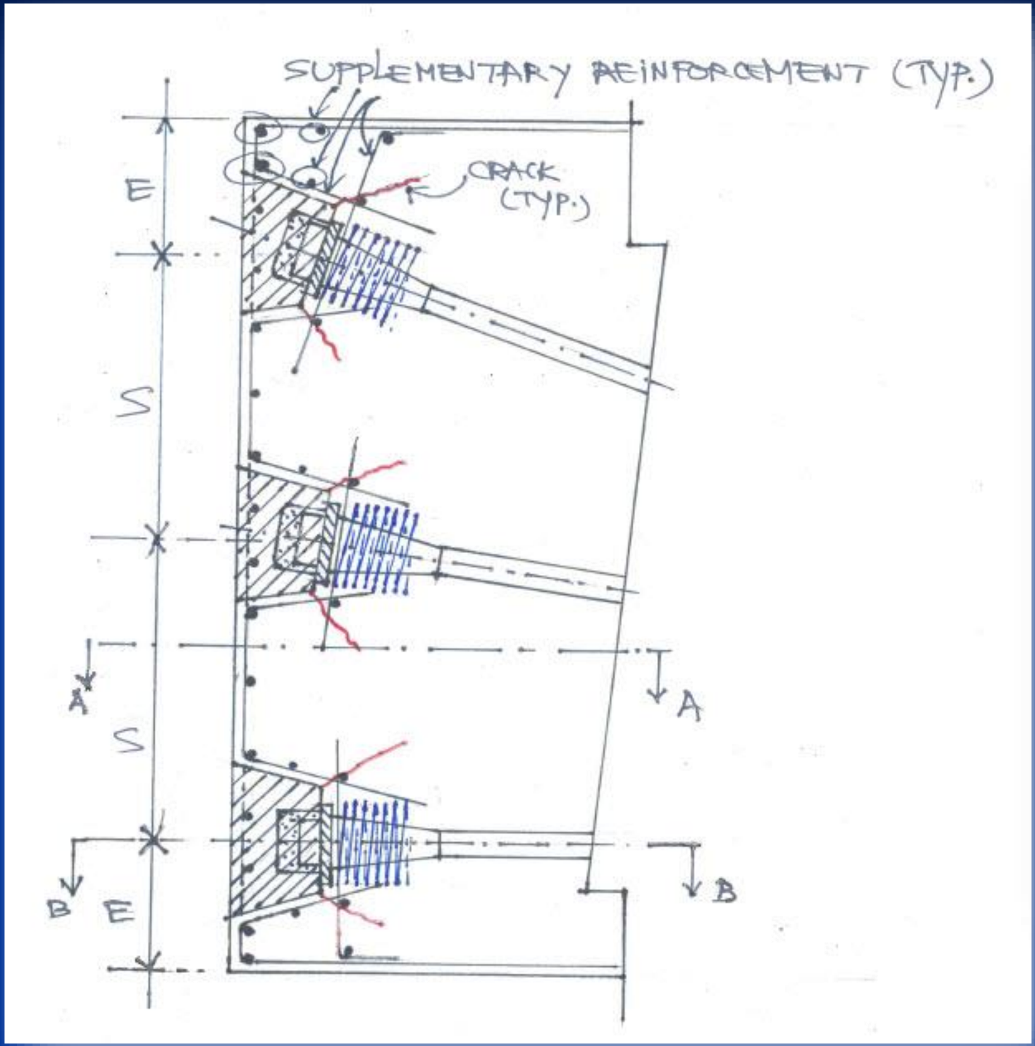
WHERE: E = MINIMUM EDGE DISTANCE
S = MINIMUM ANCHORAGES SPACING FROM CENTER TO CENTER
a = BEARING PLATE DIMENSION

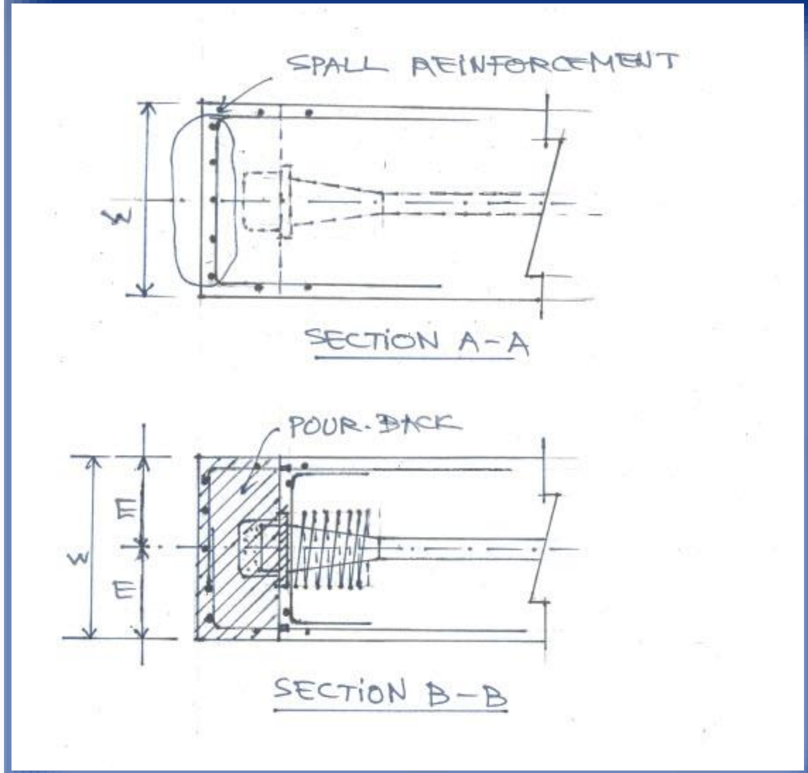
LRFD 5.8.4.5.1

- DIMENSION $E \geq 1.5a$
- IF $S \leq 1.5a$, THE ANCHORAGE DEVICES CAN BE CONSIDERED AS CLOSELY SPACED.

Multiple anchorages minimum spacing and edge distance

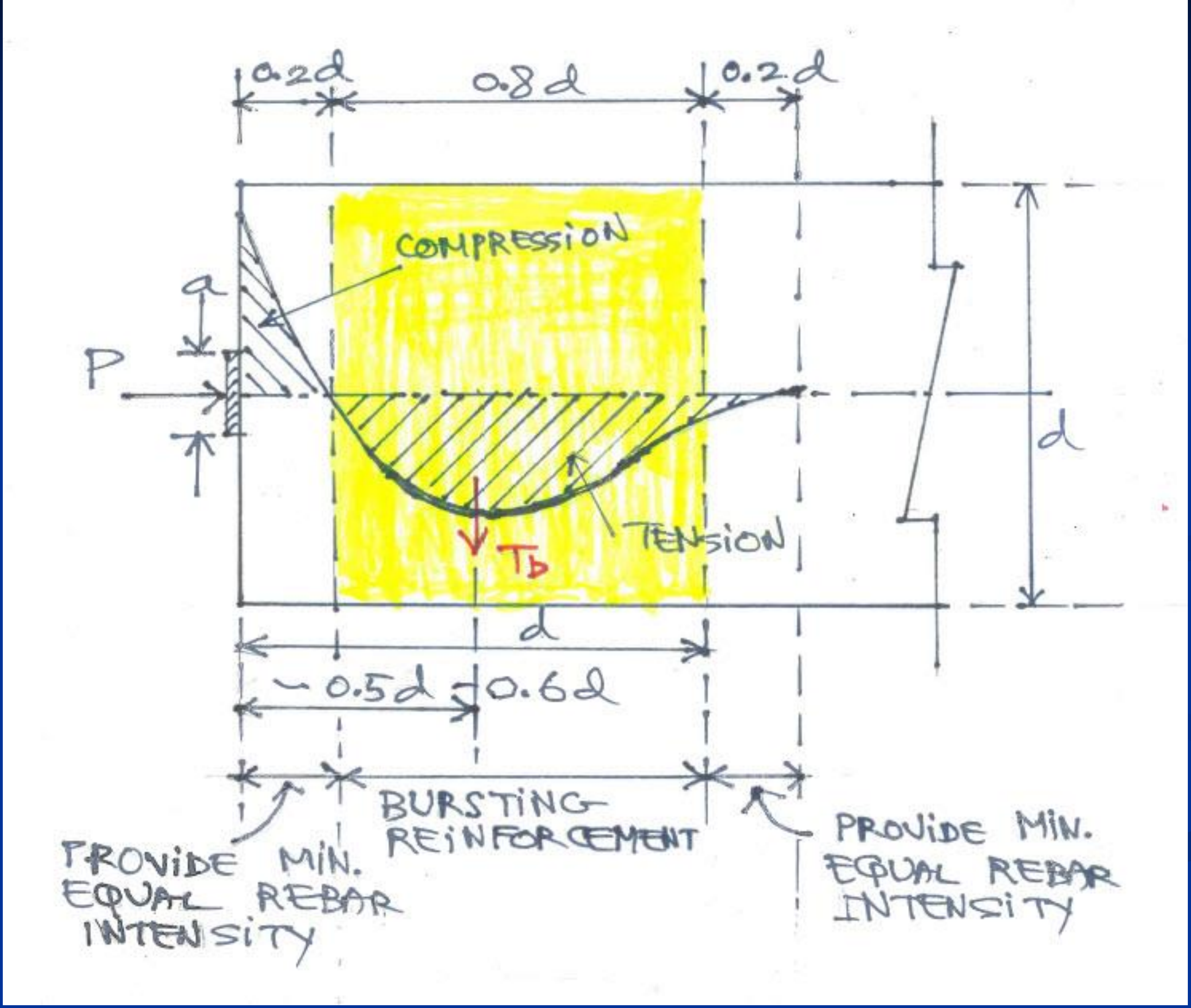
The Art of Proper Detailing





Spall and supplementary reinforcement

The Art of Proper Detailing



Presentation Outline

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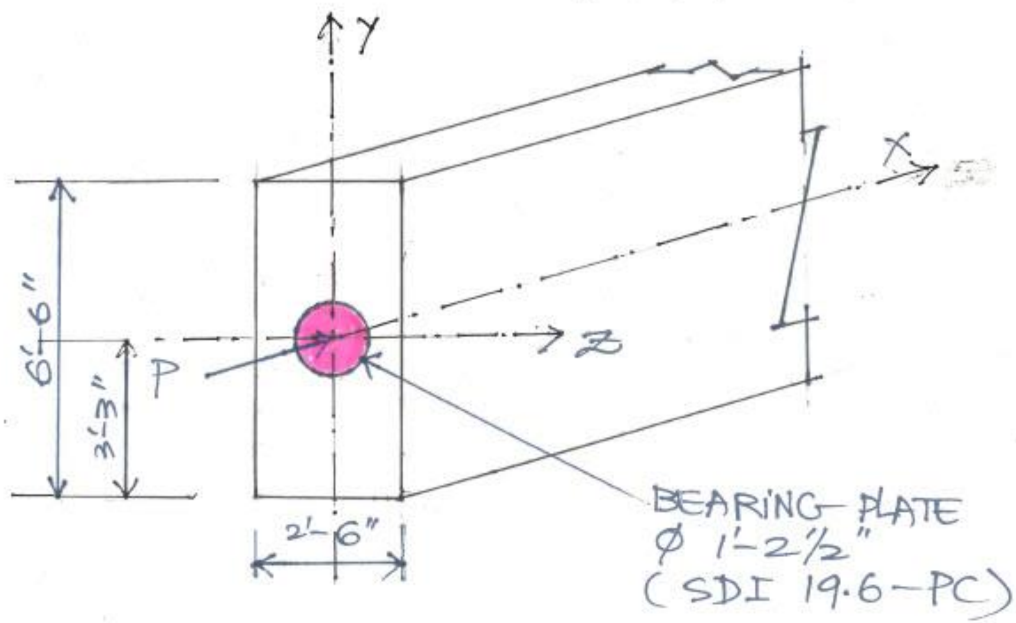
Design Examples

EXAMPLE 1 : CONCENTRIC SINGLE ANCHORAGE

GIVEN :

- RECTANGULAR SECTION POST-TENSIONED GIRDER WITH 6'-6" DEPTH BY 2'-6" WIDE
- CONCRETE STRENGTH : $f'c = 6000$ PSI
- PT TENDON : 19-0.6" STRANDS GRADE 270
- REINFORCING STEEL : GRADE 60

REQUIRED : GENERAL ZONE REINFORCEMENT AND DETAILING



SOLUTION

SELECT BEARING PLATE SIZE
(SDI 19.6 – PC)

BEARING PLATE : ϕ 1'-2½" (14.5")

COMPUTE EQUIVALENT SQUARE BEARING PLATE DIMENSIONS (axa)

$$a = \sqrt{\pi R^2}$$
$$= \sqrt{\pi (14.5/2)^2}$$
$$= 12.85''$$
$$\approx 1.07'$$

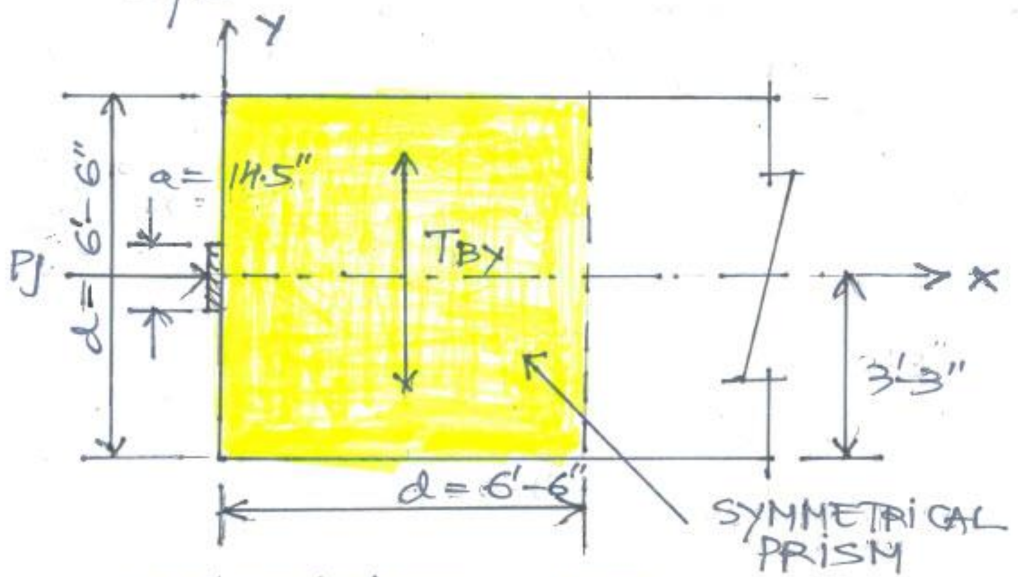
CHECK MINIMUM EDGE DISTANCE OF THE BEARING PLATE.

ASSUME EDGE DISTANCE OF THIS BEARING PLATE IS 10". (TYPICALLY PROVIDED BY PT SYSTEM MANUFACTURE)

GIRDER WIDTH = 2'-6" > 2x10" = 20"

O.K.

COMPUTE VERTICAL BURSTING FORCE (T_{BY})



CONVENTIONAL METHOD

Jacking force at 80% U.T.S.

$P_j = 0.8 \times 19 \times 58.6 = 891$ Kips

$T_{BY} = 0.3\, P_j \left(1 - \frac{a}{d}\right)$

$= 0.3\,(891)\left(1 - \frac{12.85}{78}\right)$

$= 223.26$ Kips.

Bursting steel area :

$A_{SBY} = \frac{T_{BY}}{0.6\, f_{sy}} = \frac{223.26}{0.6 \times 60} = 6.2\ in^2$

(20 # 5 or 14 # 6)

AASHTO LRFD METHOD

$$T_{BY} = 0.25\, P_j \cdot \left(1 - \frac{a}{2}\right) \text{ ---- } (5.8.4.5.3-1)$$

$$= 0.25(891)\left(1 - \frac{12.85}{78}\right)$$

$$= \underline{186 \text{ Kips.}}$$

Bursting steel area required:

$$A_{sBY} = \frac{1.2\, T_{BY}}{\phi\, f_{sy}}$$

Where: PT anchorage zone load factor = 1.2 (3.4.3.2)

T_{BY} = Bursting force in Y direction.

$\phi = 1.0$ (Resistance factor for steel in anchorage zone per 5.5.4.2)

$f_{sy} = 60$ ksi.

$$A_{sBY} = \frac{1.2(186)}{1.0\,(60)} = \underline{3.72 \text{ in}^2}.$$

(60% of conventional)

Use $\phi = 0.85$ (original ϕ proposed by researchers at UT)

$$A_{sBY} = \frac{1.2\,(186)}{0.85\,(60)} = 4.376 \text{ in}^2$$

(70% of conventional)

Use conventional bursting force equation & $\phi = 0.85$

$$A_{sBY} = \frac{1.2\,(223.26)}{0.85\,(60)}$$

$$= 5.25 \text{ in}^2$$

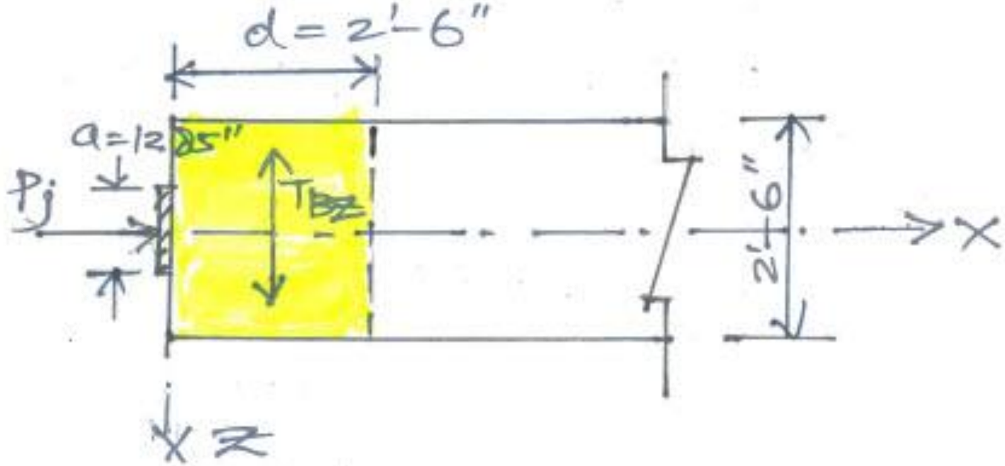
(85 % of conventional)

This approach will be used in this design example forward.

$A_{sBY} = 5.25 \text{ in}^2$

(≈ 18 #5 or 12 #6)

HORIZONTAL BURSTING FORCE (T_{BZ})



$$T_{BZ} = 0.3\,P_j\left(1-\frac{a}{d}\right)$$

$$= 0.3\,(891)\left(1-\frac{12.85}{30}\right)$$

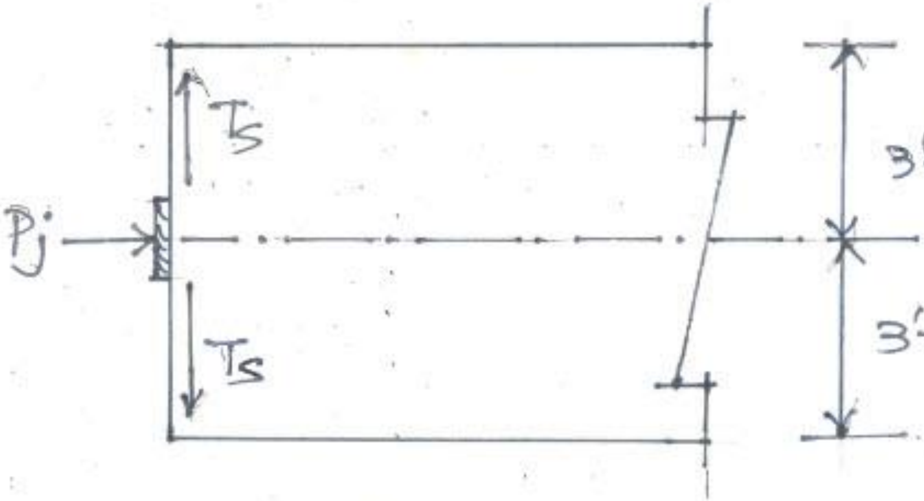
$$= 152.8 \text{ Kips.}$$

Compute transverse / Horizontal bursting reinforcement.

$$A_{sBZ} = \frac{1.2\,(152.8)}{0.85\,(60)}$$

$$= 3.59 \text{ in}^2 \quad \left(\begin{matrix} 12 \# 5 \text{ or} \\ 8 \# 6 \end{matrix}\right)$$

SPALLING REINFORCEMENT



According to AASHTO LRFD SECTION 5.9.5.6.5.b

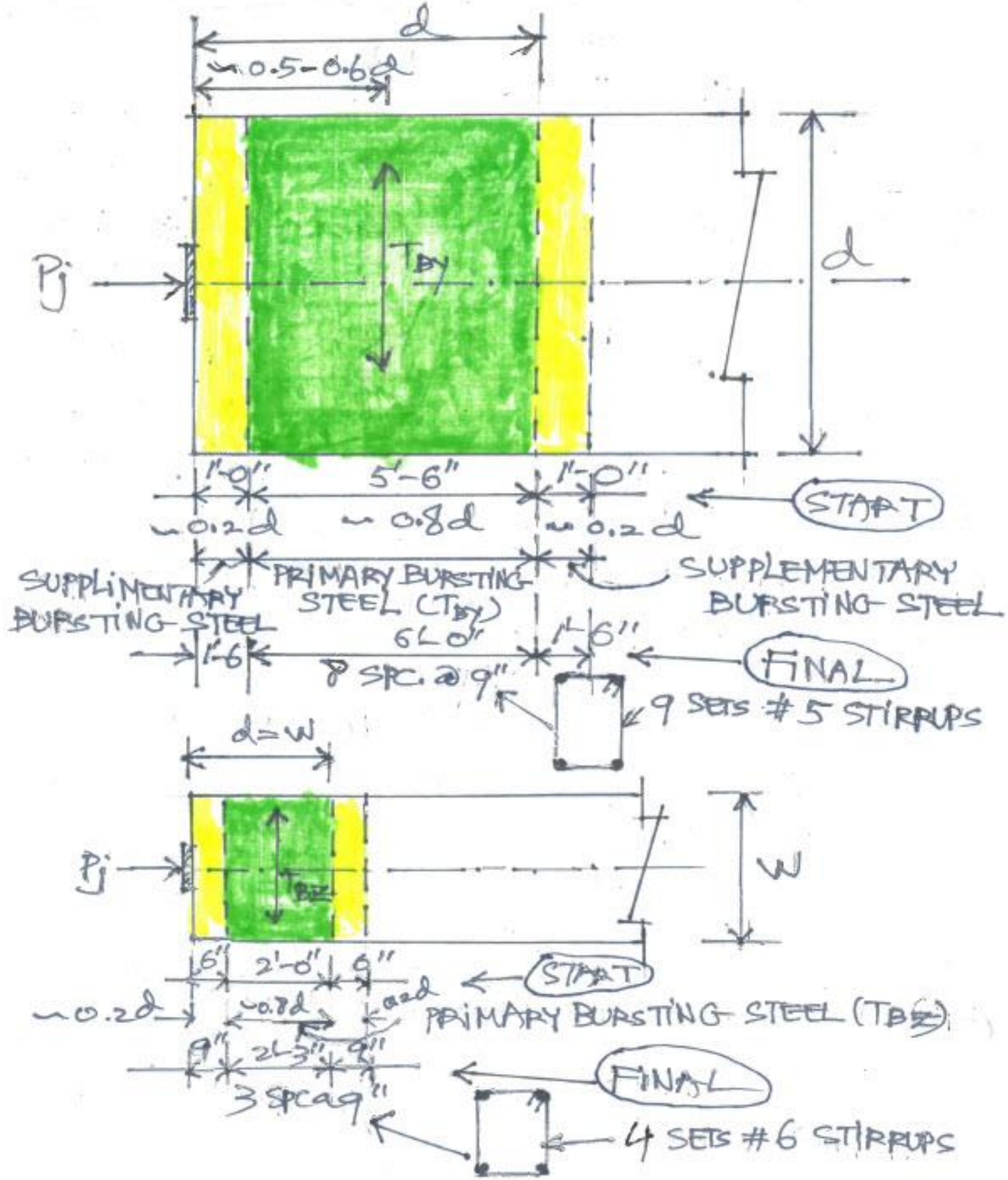
SPALLING FORCE T_s = 2% P_j.
VS 4% PER GUYON

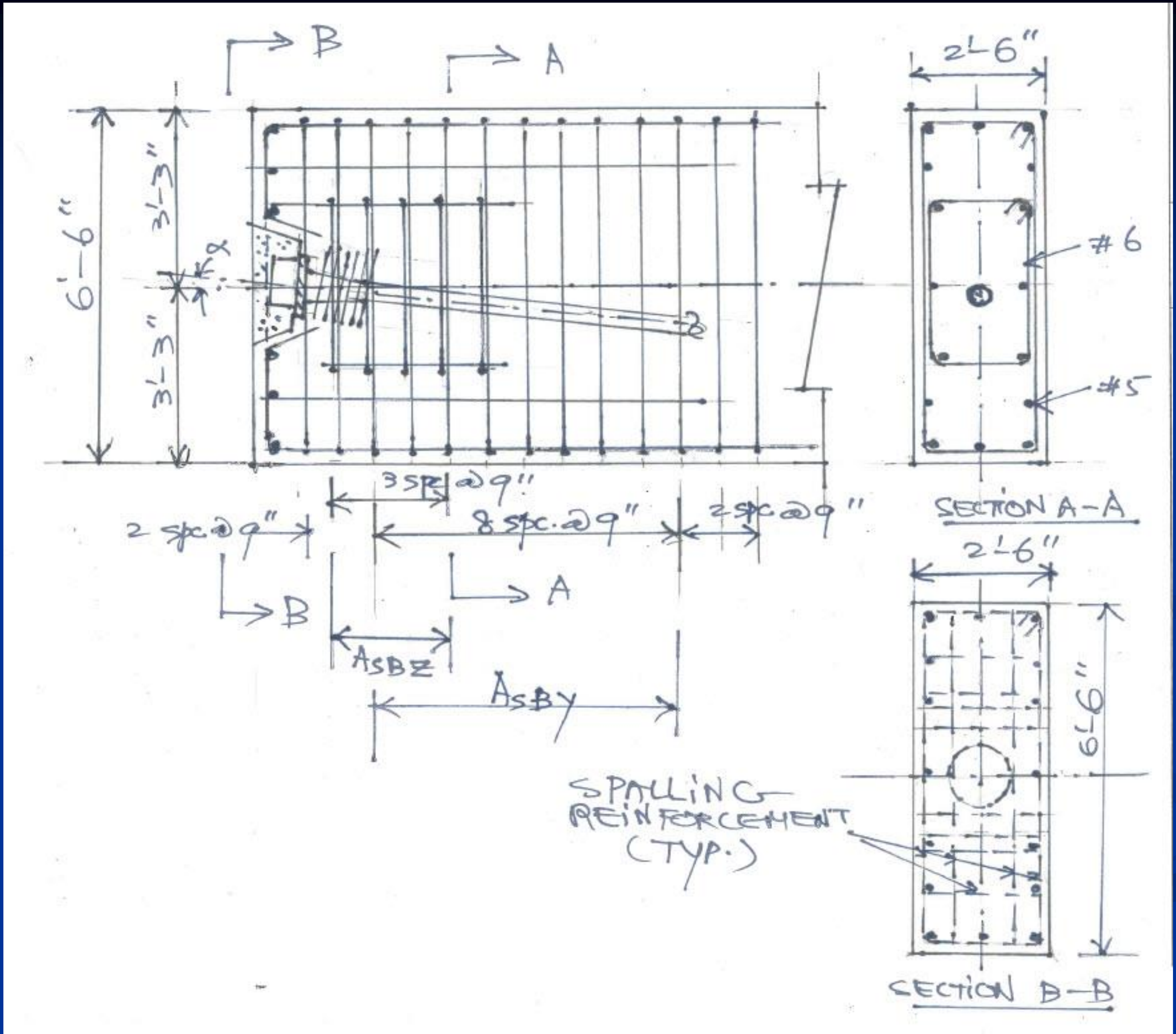
Use T_s = 2% P_j.
= 0.02 (891)
= 17.82 Kips.

$$A_s = \frac{1.2\,T_s}{\phi\, f_y} = \frac{1.2\,(17.82)}{0.85\,(60)}$$

$= 0.419 \text{ in}^2$ (= 4 #4)

DETAILING STRATEGY



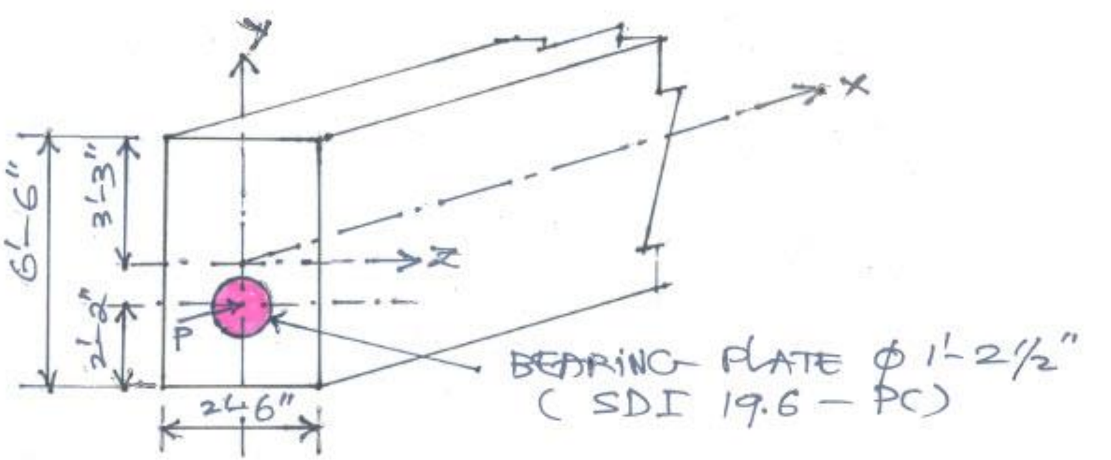

B
A
6'-6"
3'-3"
3'-3"
α
#6
#5
2'-6"
SECTION A-A
3 SPC @ 9"
2 spc. @ 9"
8 spc. @ 9"
2 spc. @ 9"
B
A
ASBZ
ASBY
2'-6"
6'-6"
SPALLING REINFORCEMENT (TYP.)
SECTION B-B

EXAMPLE 2: SINGLE ANCHORAGE WITH SMALL ECCENTRICITY

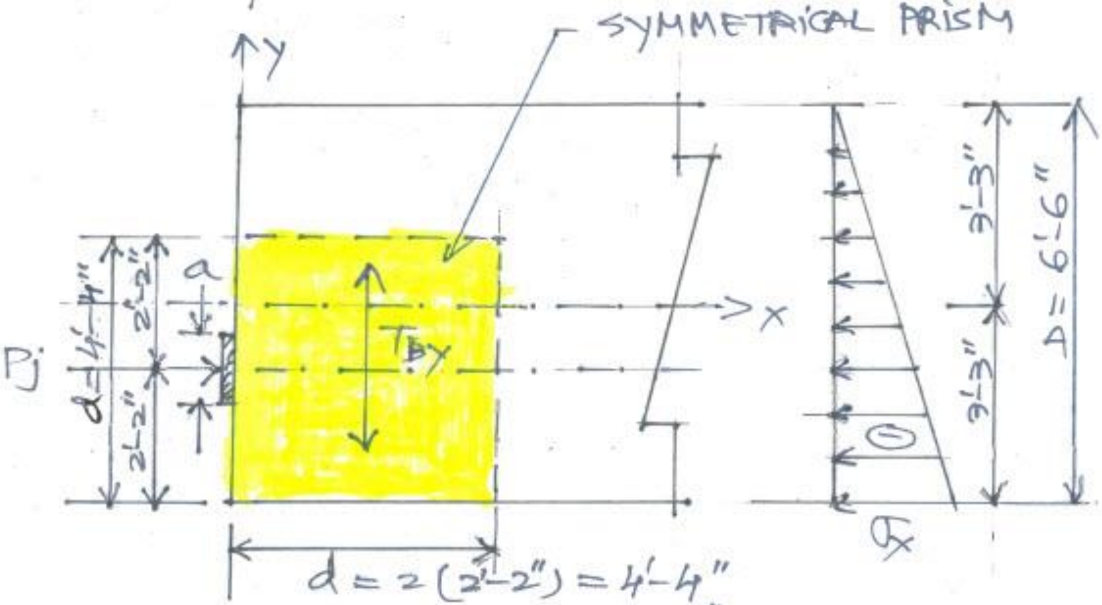
GIVEN:

- RECTANGULAR SECTION POST-TENSIONED GIRDER WITH 6'-6" DEPTH BY 2'-6" WIDE
- CONCRETE STRENGTH f'c = 6000 PSI.
- PT TENDON: 19-0.6" STRANDS GRADE 270.
- REINFORCING STEEL: GRADE 60.
- THE ANCHORAGE C.G.S. IS 2'-2" MEASURED FROM THE BOTTOM OF THE GIRDER

REQUIRED: GENERAL ZONE REINFORCEMENT AND DETAIL



COMPUTE VERTICAL BURSTING FORCE (T_{By})



$d = 2(2'-2") = 4'-4"$
$= 52"$

$a = 12.85"$ (Example 1)

Jacking force $P_j = 891$ Kips (Example 1)

$$T_{By} = 0.3\,P_j\left(1 - \frac{a}{d}\right)$$
$$= 0.3(891)\left(1 - \frac{12.85}{52}\right)$$
$$= 201 \text{ Kips.}$$

Bursting steel area required:

$$A_{sBy} = \frac{1.2(T_{By})}{\phi f_y} = \frac{1.2(201)}{0.85(60)}$$
$$= 4.73 \text{ in}^2 \quad (\sim 16 \# 5 \text{ or } \sim 12 \# 6)$$

Design Examples

HORIZONTAL BURSTING FORCE (T_{BZ})

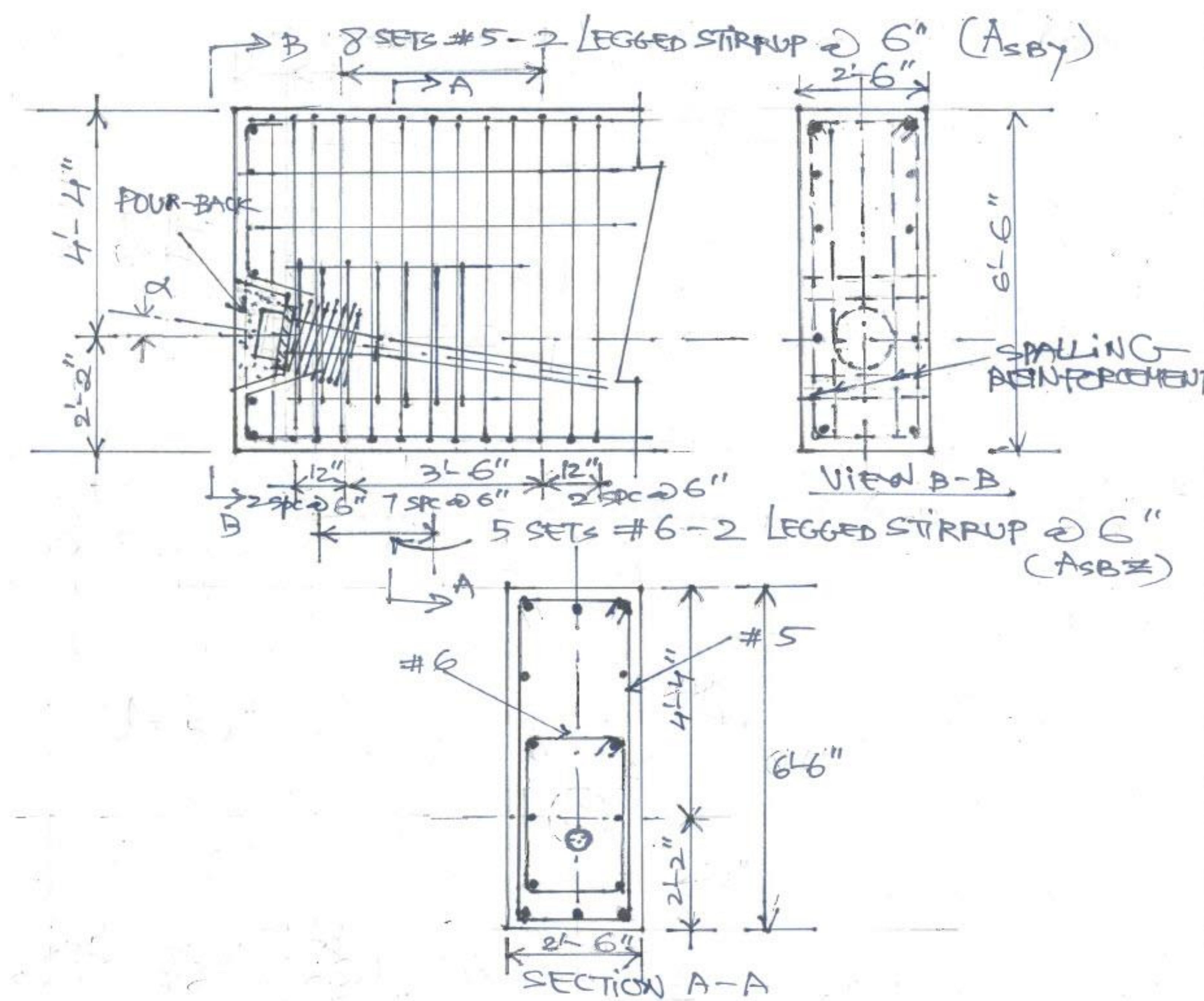
SIMILAR TO EXAMPLE 1.

T_{BZ} = 152.8 Kips.

A_{sBZ} = 3.59 in^2 (12 #5 or 8 #6)

SPALLING REINFORCEMENT

SIMILAR TO EXAMPLE 1.



B 8 SETS #5-2 LEGGED STIRRUP @ 6" (AsBY)
A
2'-6"
4'-4"
POUR-BACK
α
2'-2"
6'-6"
SPALLING REINFORCEMENT
12" 3'-6" 12"
2 SPC @ 6" 7 SPC @ 6" 2 SPC @ 6"
B
VIEW B-B
5 SETS #6-2 LEGGED STIRRUP @ 6" (AsBZ)
A
#5
#6
4'-4"
6'-6"
2'-2"
2'-6"
SECTION A-A

Presentation Outline

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18. Zielinski, J, Rowe, R.E., "The Stress Distribution Associated with Group of Anchorages in Post-Tensioned Concrete Members", Research Report 13, Cement and Concrete Association, October 1962, UK.

Closing

Thank you for your attention!
Any questions?