Design and Construction of P/T Concrete Structures

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Plan Design Enable

Session Outline

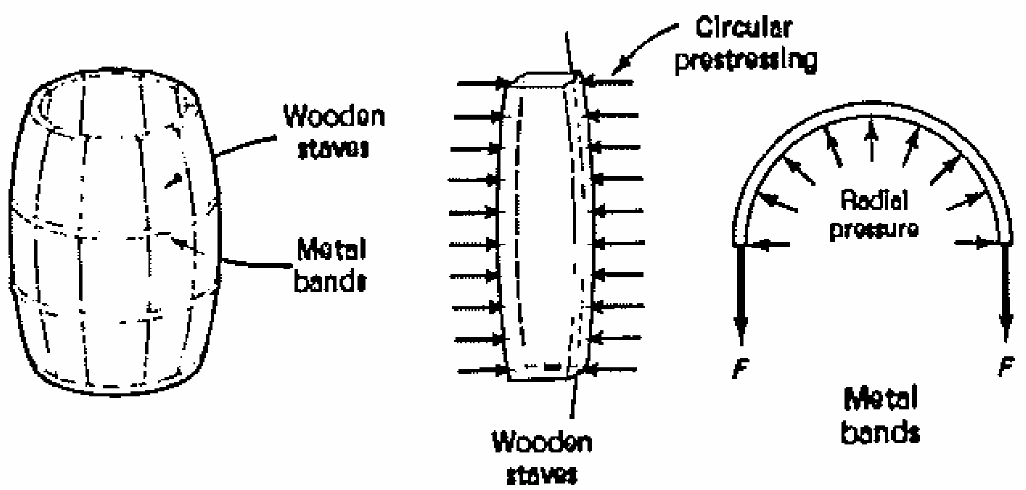
- **What is Prestressing?**
- **Materials For Post-Tensioning Work**
- **Overview of Post-Tensioning Systems**
- **Myths about Post-Tensioning**
- **Basic Design Concept, Load Balancing**

Session Outline

- **Advantages of Post-Tensioning**
- **Construction of Post-Tensioned Slabs**
- **Application of Post-Tensioning to transfer Girders**
- **ACI Provisions on Prestressed Concrete Design**
- **BS 8110 and TR 43 Provisions for Prestressed Concrete**

What is Prestressing?

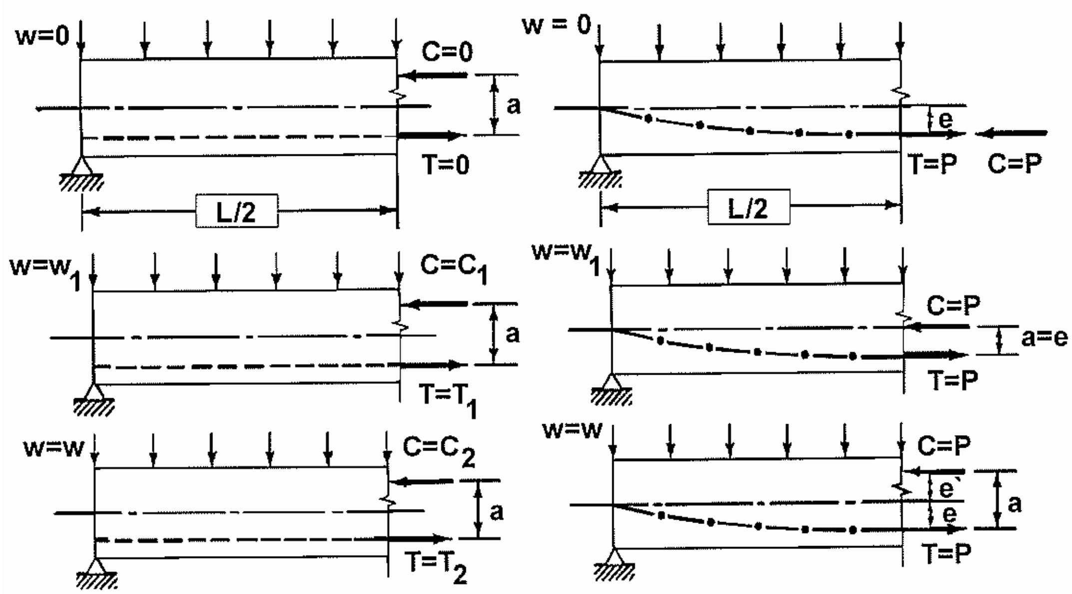
Prestressing is a method of reinforcing concrete. The concrete is prestressed to counteract the applied loads during the anticipated loads during the anticipated service life of the member



Wooden Barrel

Prestressed concrete (PC) vs. Reinforced Concrete (RC)

The main difference between RC and PC is the fact that the steel reinforcement in the Prestressed Concrete is ACTIVE and the same is PASSIVE in Reinforced Concrete



(a) Non-Prestressed

(b) Prestressed

Application of Prestressed Concrete

Nuclear Containment

Bridges

Water Tanks

Storage Structures

Pre-Cast Members

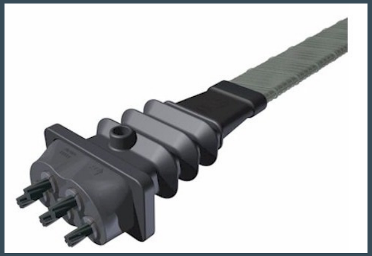
Buildings

Components of P/T work

Strand (0.5”/0.6” Diameter)
Confirming to BS 5896/ prEN 10386 / ASTM

Duct (Flat / Circular Ducts)
HDPE / Metal

Anchorage (Dead /Live End)



Grout

High Strength Concrete $f_{cu} \geq 35MPa$

Description of P/T material

- 7 Wire Strands

Strand Type	Nominal Tensile Strength (MPa)	Nominal Diameter (mm)	Nominal Steel Area (mm^2)	Minimum Breaking Strength (kN)	0.1% Proof Load (kN)
12.9 Super	1860	12.9	100	186	158
12.7 Drawn	1860	12.7	112	209	178
15.7 Super	1770	15.7	150	265	235
15.7 Euro	1860	15.7	150	279	237

Pre and Post – Tensioned Concrete

Pre – Tensioning :

Steel reinforcement are stressed prior to concrete placement, usually at a precast plant remote from the construction site

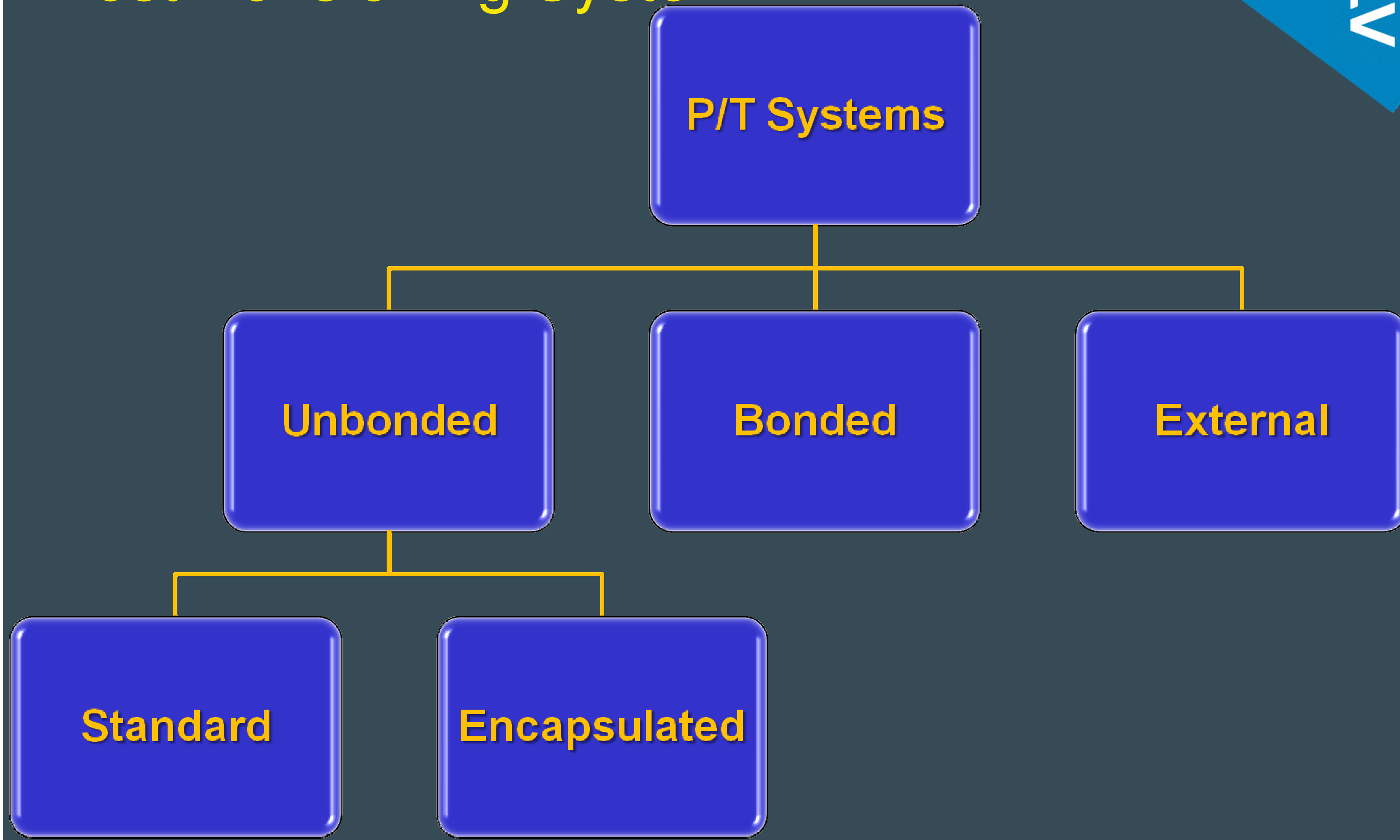
Example : Hollow Core Slab, Bridge I Girders

Post – Tensioning :

Steel tendons are stressed after the concrete has been placed and gained sufficient strength at the construction sites

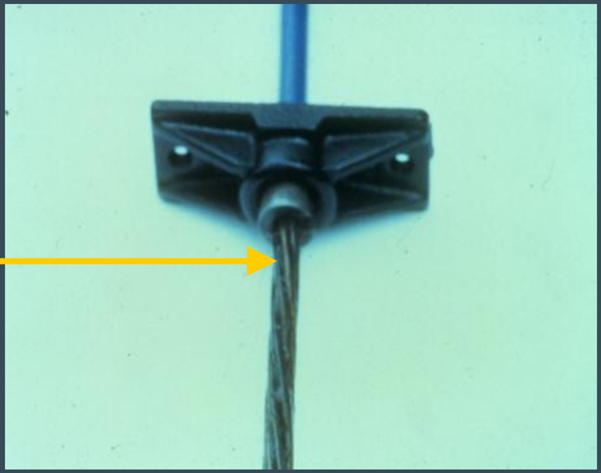
Example : Post – Tensioning of Floor Slab, Dubai Metro

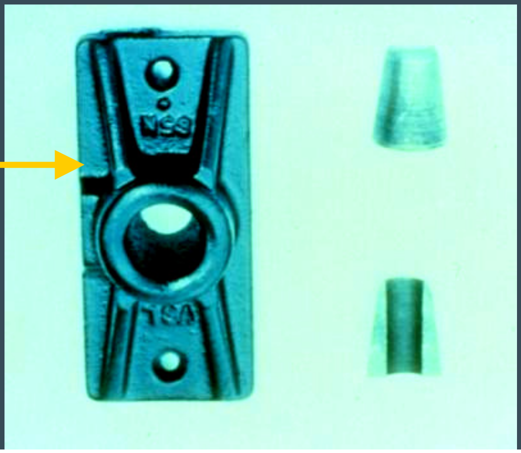
Post-Tensioning System



What is Unbonded Tendon?

- Prestressing Steel is prevented from bonding to concrete and is free to move, relative to the surrounding concrete
- Consists of 7 Wire Strands most commonly used sizes are 0.5” Diameter Strands
- The Prestressing Force is transferred to the Concrete through the anchorage **ONLY**





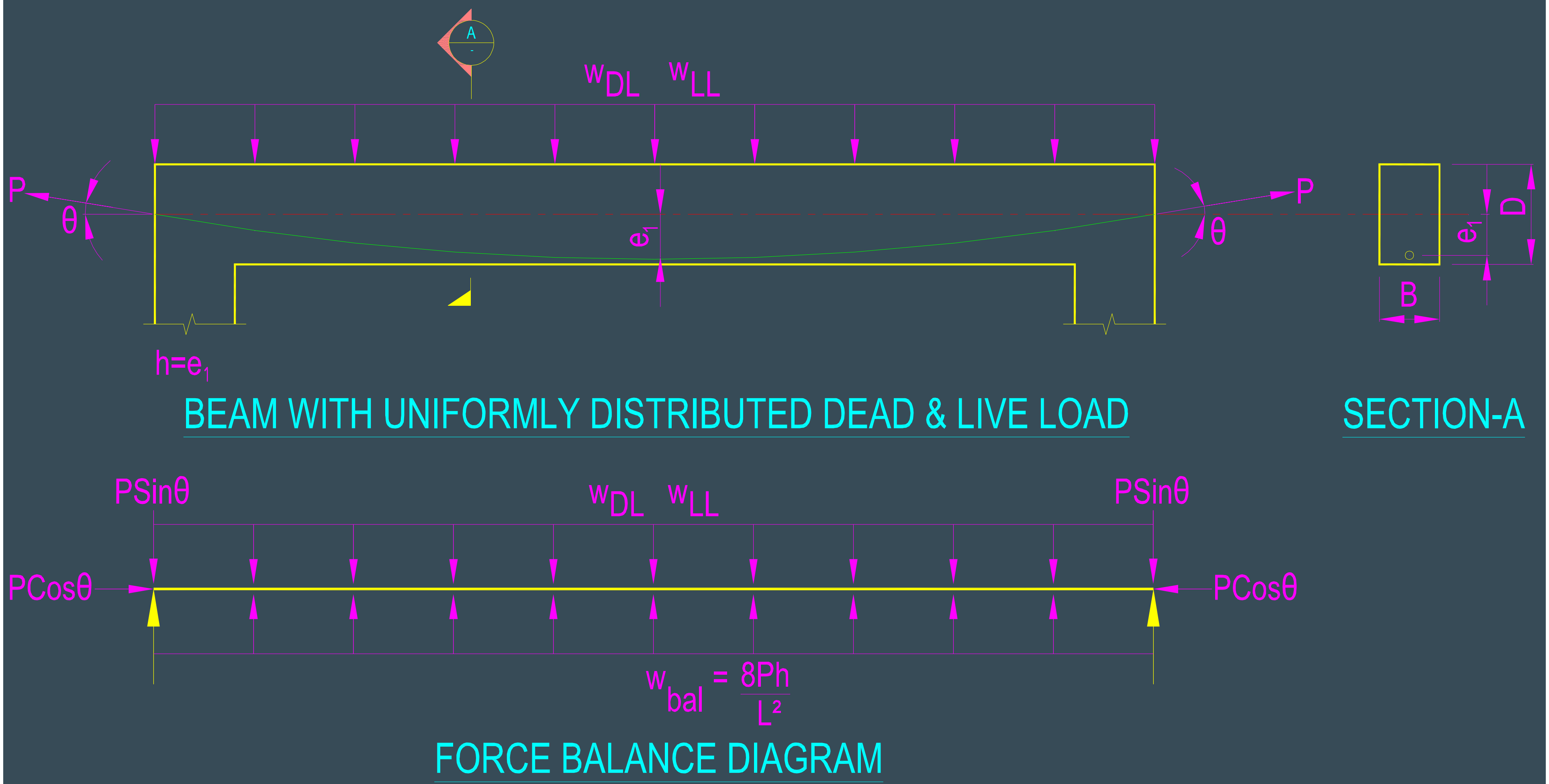
Post – Tensioning Systems

Unbonded vs. Bonded

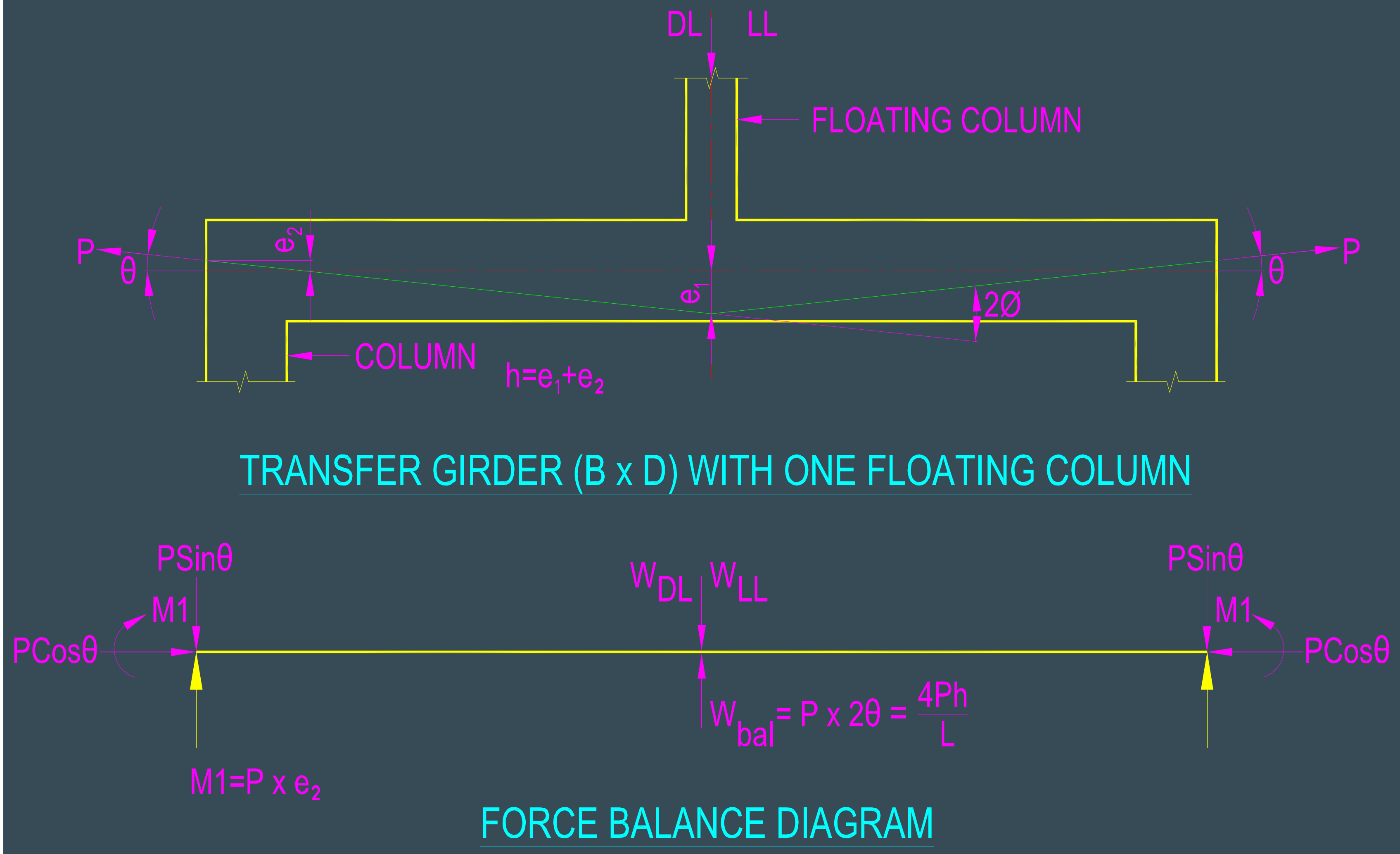
- ❑ Unbonded
  - ✓Force transmitted solely by the anchors
  - ✓Total force limited by anchor spacing
  - ✓Replaceable
  - ✓Retrofit Openings require more care

- ❑ Bonded
  - ✓Force transmitted by anchors and bond to concrete
  - ✓Greater force can be applied
  - ✓Strain compatibility with concrete
  - ✓Minimizes need for Un-tension Reinforcement
  - ✓Openings less Difficult

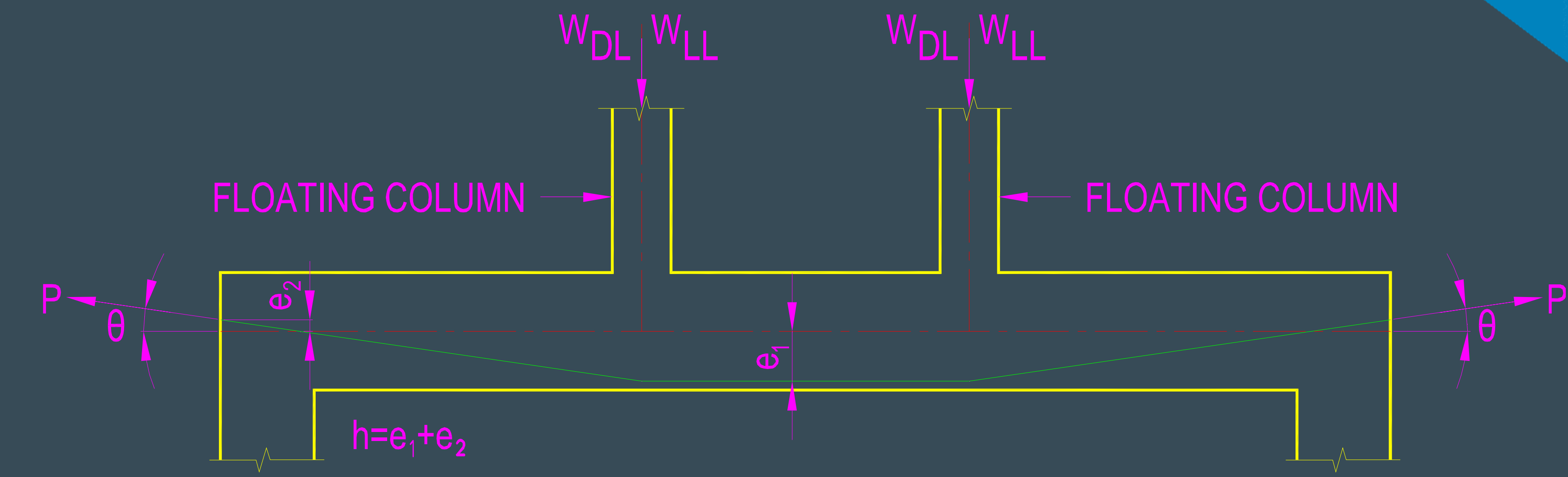
Force Balance : Example 1



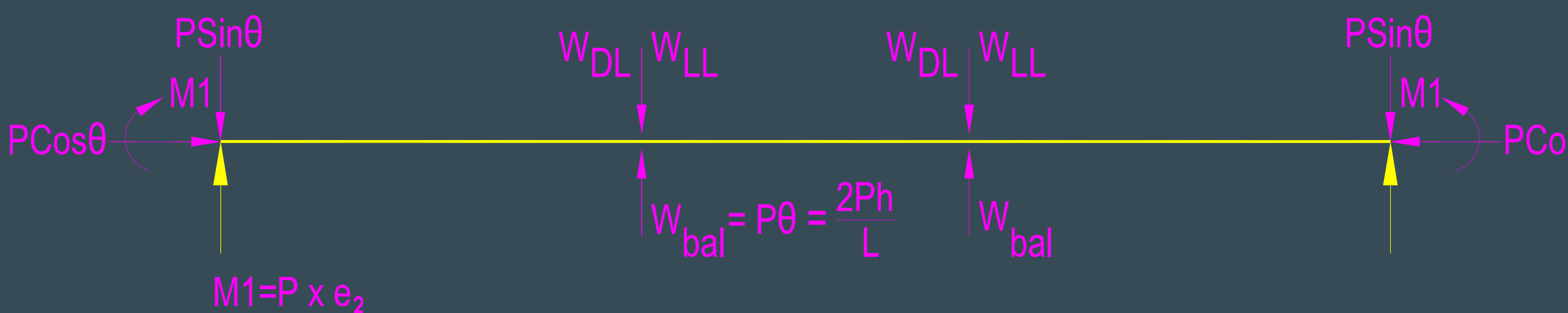
Force Balance : Example 2



Force Balance Example 3

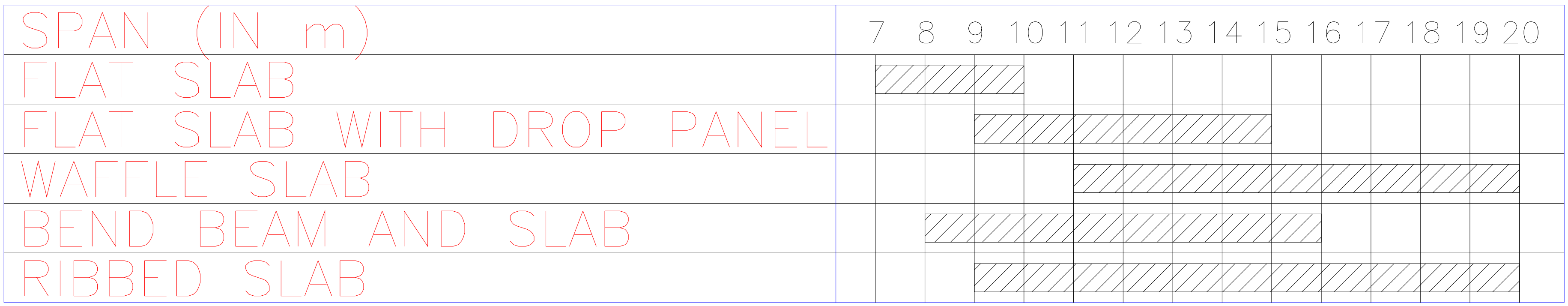


TRANSFER GIRDER (B x D) WITH TWO FLOATING COLUMN

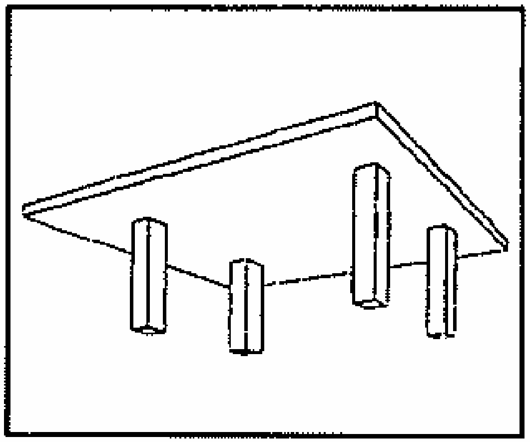


FORCE BALANCE DIAGRAM

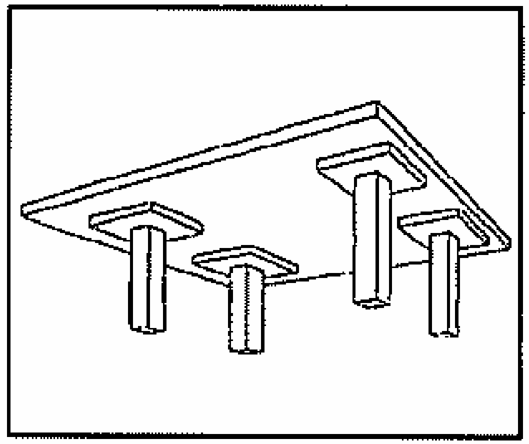
Post- Tension Slab Scheme



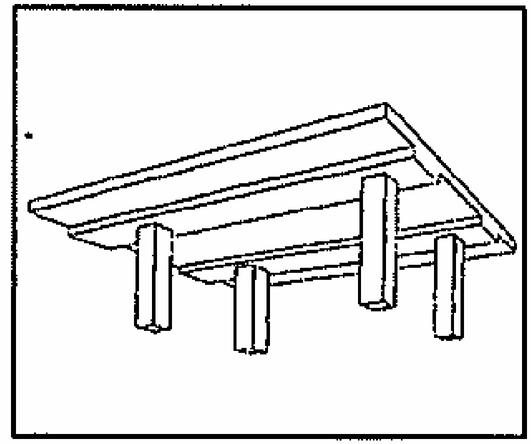
Typical Two-Way Spanning Floors



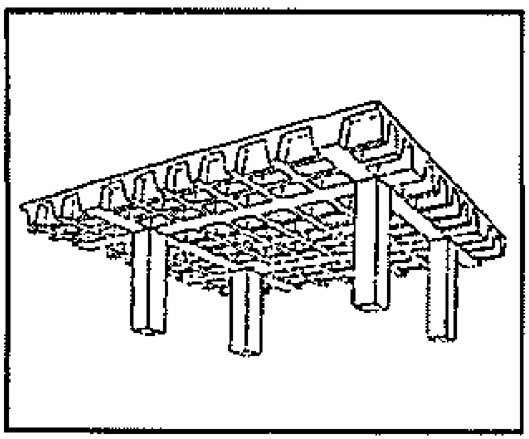
Solid flat slab



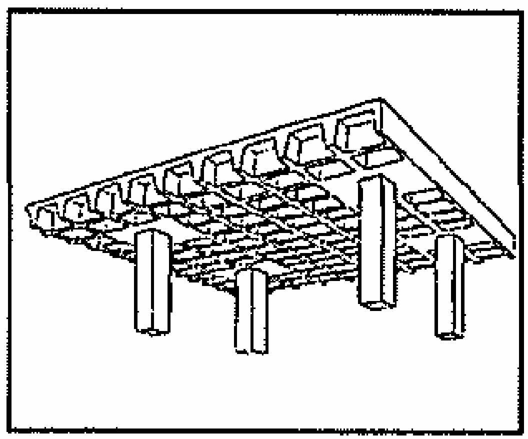
Solid flat slab with drop panel



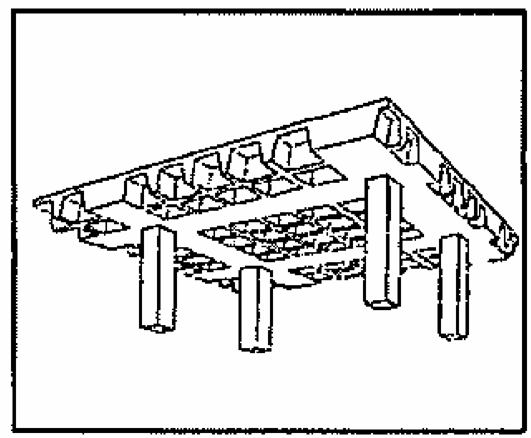
Broad beam flat slab



Coffered flat slab

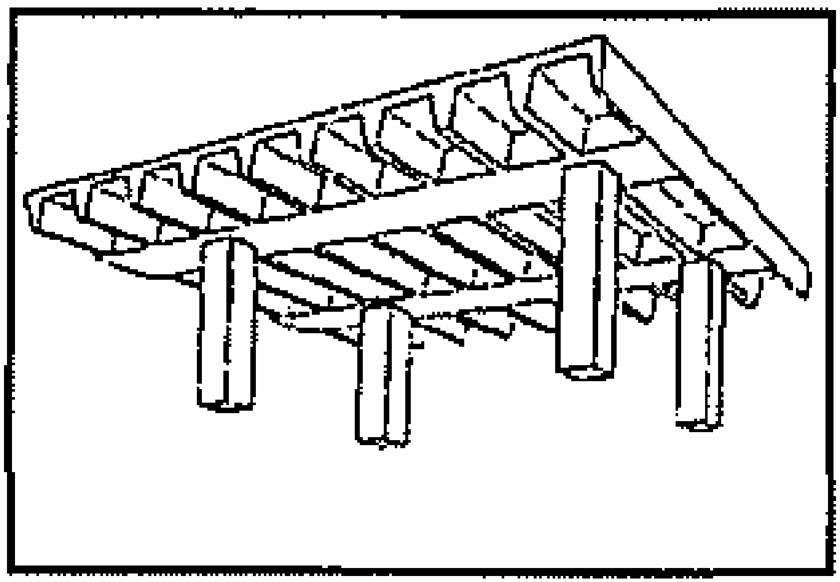


Coffered flat slab with solid panels

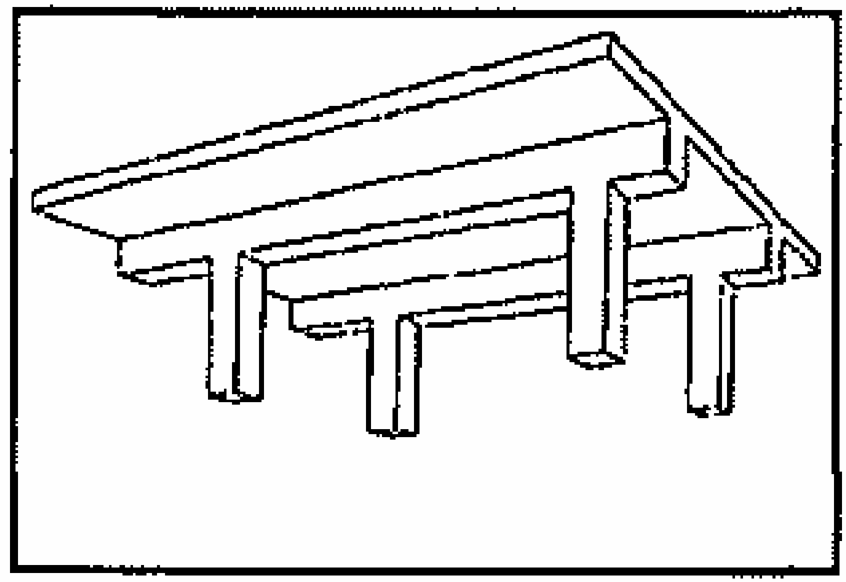


Banded coffered flat slab

Example slide



Ribbed slab



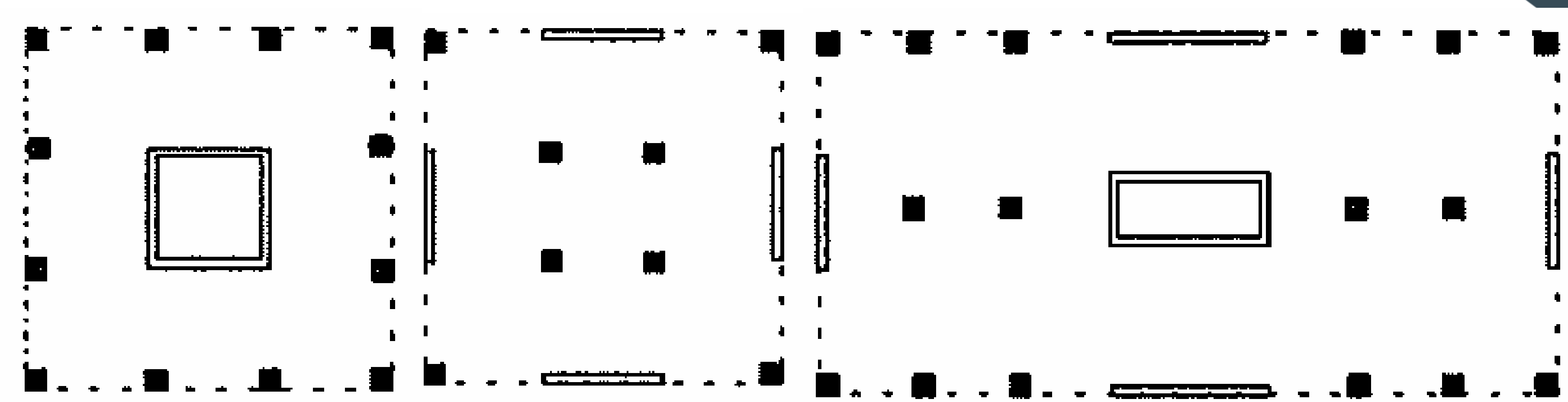
Beam and slab

Initial Sizing of Post – Tension Members

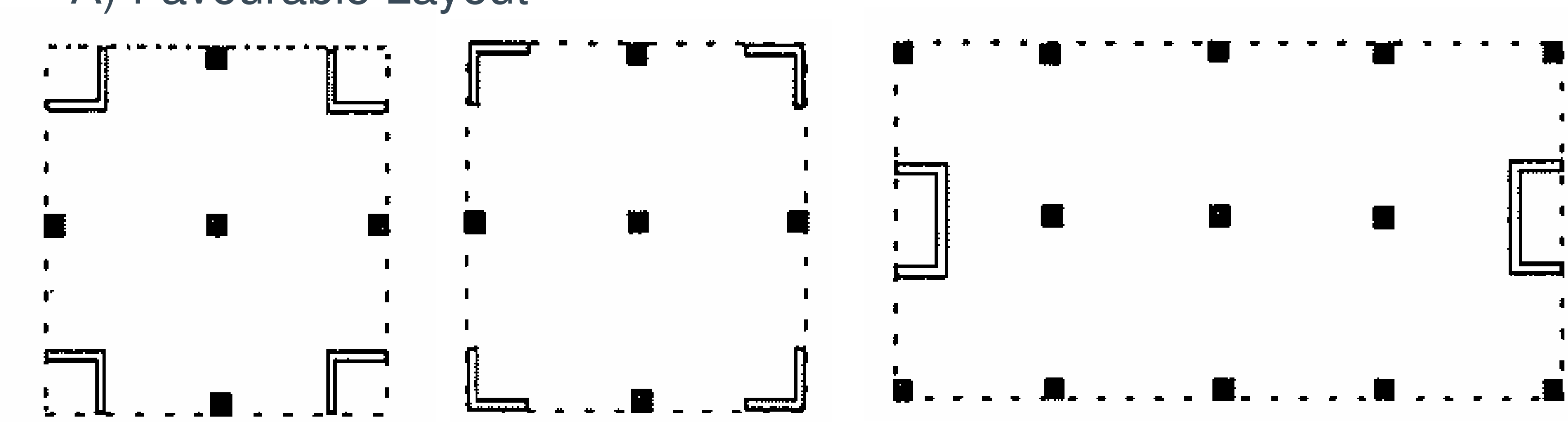
Span to Depth Ratio

Characteristic Imposed Load Q_k kN/m²	Flat Slab	Flat Slab with drop panel	Flat Slab with Band Beams		Ribbed Slabs	Waffle Slab	One Way Slab on deep beams	
			Slab	Beam			Slab	Beam
2.5	40	44	45	25	30	28	42	18
5.0	36	40	40	22	27	26	38	16
10.0	30	36	33	18	24	23	34	13

Layout of shear walls to reduce loss of Prestress and Cracking Effect



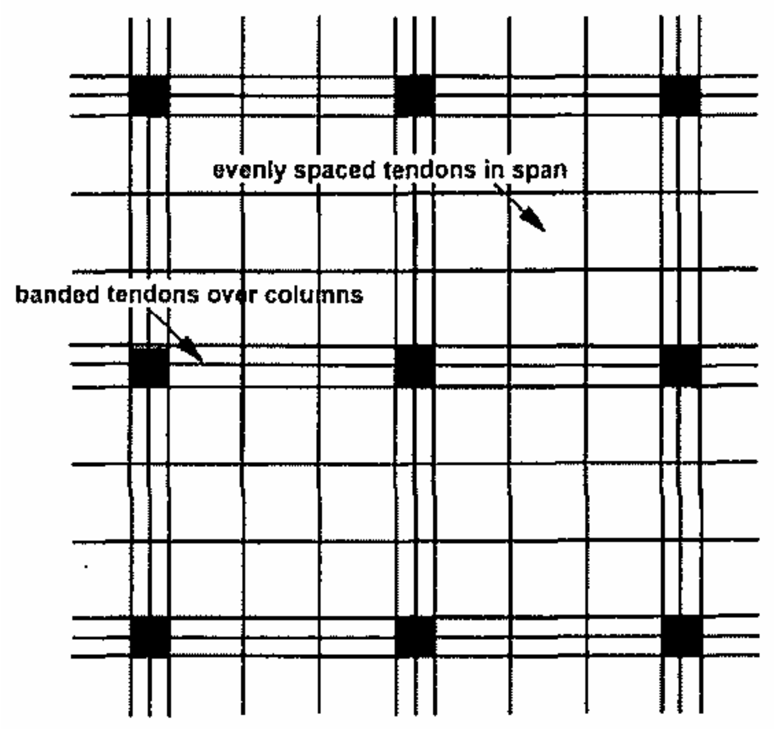
A) Favourable Layout



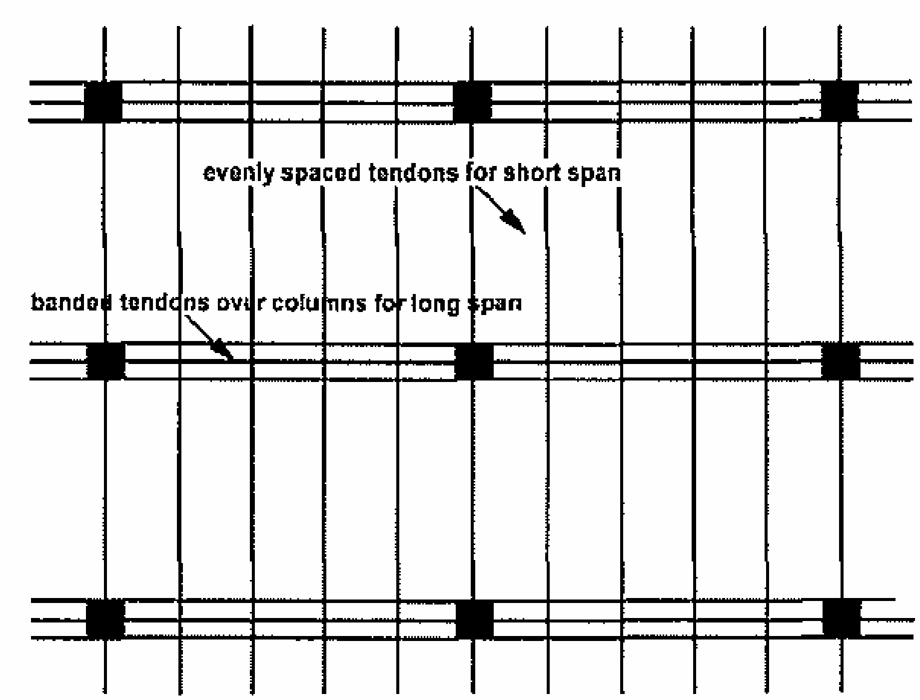
B) Unfavourable Layout

Tendon Arrangement

Tendons Geometrically Banded in Each Direction



Tendons Fully Bonded in One Direction & Distributed in other Direction



Input required by P/T contractor

- Floor General Arrangement Drawings
- Loading Diagrams (Live Load and Superimposed Dead Load)
- Un-tension Reinforcement Required at junction of Core / Shear Wall / Columns with Post Tension Slab
- Design Code ACI / BS 8110 / TR 43
- Flexural Member Type Classification
- Permissible Crack Width

Advantages of Prestressed Concrete Floors

- Increased Clear Span
- Thinner Slabs
- Reduced Floor Loads, Lighter Structures, Reduced Seismic Forces
- Reduced Cracking and Deflection
- Reduced Storey Height
- Rapid Construction
- Large reduction in conventional reinforcement

Method of Analysis of P/T Slab

- Equivalent Frame Analysis (2D Analysis)
- 3D Finite Element Analysis
  - Design Strips (EC2)
  - Full Tributary Width (ACI and BS)

Classification of P/T Beams

It is based on Flexural Tensile Stress under Service Loads

BS 8110	ACI 318
Class 1 : No Tensile Stress	Class U : Uncraked $f_t \leq 0.62\sqrt{f_c^{'}}$
Class 2 : Tensile Stress $\leq 0.36\sqrt{f_{cu}}$	Class T : Transient $0.62\sqrt{f_c^{'}} < f_t \leq 1.0\sqrt{f_c^{'}}$
Class 3 : Higher Tensile Stress compared to Class 2 based on Crack width Limitations (0.1mm/0.2mm)	Class C : Cracked $f_t > 1.0\sqrt{f_c^{'}}$

Post – Tension Member Design

- Checks for Service Load Combinations
  - Bending Tension and Compression Stresses at Transfer and Service
  - Minimum Average Pre-compression in Member
  - Crack width at location exceeding Permissible Tensile stress Limit

- Checks for Ultimate Loads
  - Flexure
  - Shear

Ultimate Flexure Design

- The Ultimate Flexure Check for following Combination
  - 1.4DL + 1.6LL + 1.0 Hyper static Moments
- Hyperstatic Forces
  - Generated in Indeterminate Structure

Secondary Moment

M_2 = Secondary Moment

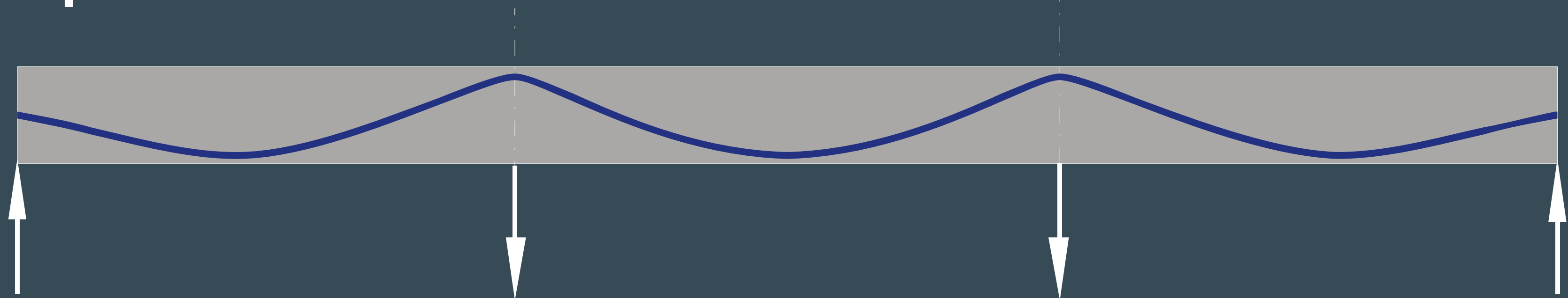
- Developed in Post-Tensioned Concrete members due to Prestressing forces
- Consequence of constraint by the supports to the free movement of the member
  - Only develops in Indeterminate members
  - Simply Supported Beams have zero secondary

Significant: Must be accounted for in the design of Prestressed Concrete Indeterminate Structures

Secondary Moment (cont'd.)

$M_{bal} = M_1 + M_2 = Pe + M_{sec}$

M_{bal} = Balanced moment by post-tensioning equivalent loads



Secondary reactions at supports due to prestressing

Secondary Moments, M_2, vary linearly between supports

Post-Tensioning Slab Procedure

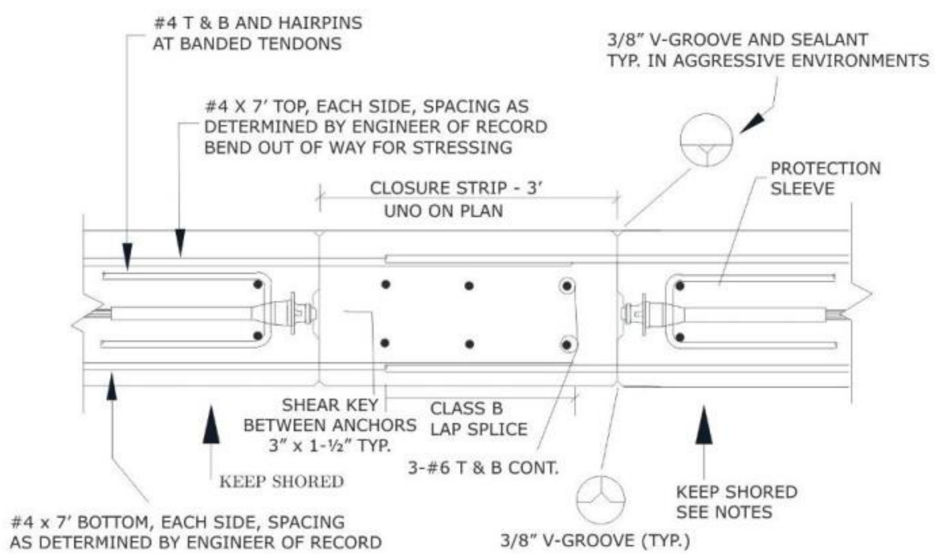
- Placement of Bottom Reinforcement Mesh
- Placing Flat Duct along with Strands in both Directions
- Concreting
- After 3 Days Transferring 25% of Total Prestress Force to avoid Shrinkage and Temperature Cracks
- Transferring remaining 75% of Prestress
- Grouting of Duct

Two Way Slab with Bonded P/T

Banded in One Direction and Distributed in Another

Stressing Tendons

Closure Strip



NOTES:

1. RETAIN SHORING UNTIL CONCRETE IN CLOSURE STRIP REACHES 75 PERCENT OF SPECIFIED SLAB CONCRETE STRENGTH.
2. CLOSURE STRIP TO BE FILLED WITH NON-SHRINK CONCRETE.
3. ROUGHEN AND CLEAN JOINTS. WET PRIOR TO PLACING CONCRETE.
4. ELIMINATE ACCIDENTAL MISALIGNMENT BETWEEN EDGE OF SLABS THAT ARE TO BE JOINED WITH A CLOSURE STRIP. USE MECHANICAL METHODS SUCH AS JACKING IF NECESSARY.
5. PROVIDE WATERPROOFING MEMBRANE IF REQUIRED FOR WATER-TIGHTNESS.
6. IF CLOSURE STRIP WILL BE IN AN AGGRESSIVE ENVIRONMENT, SEAL ANCHORAGE POCKETS PER THE PROJECT SPECIFICATIONS AND CAULK JOINT ALL THE WAY AROUND WITH FLEXIBLE SEALANT.
7. CONTRACTOR SHALL NOTE THAT THERE ARE SPECIAL SHORING CONDITIONS ON EITHER SIDE OF THE CLOSURE STRIP, ESPECIALLY FOR MULTI-STORY STRUCTURES.

- Slab is temporarily allowed to cure in smaller segments
- Can locate the lateral system in the middle of the individual pour
- Allows for internal stressing – may be critical on subterranean projects
- Typically remain open for 30 to 60 days. Deck will still move for many months/years

Loss of Prestress

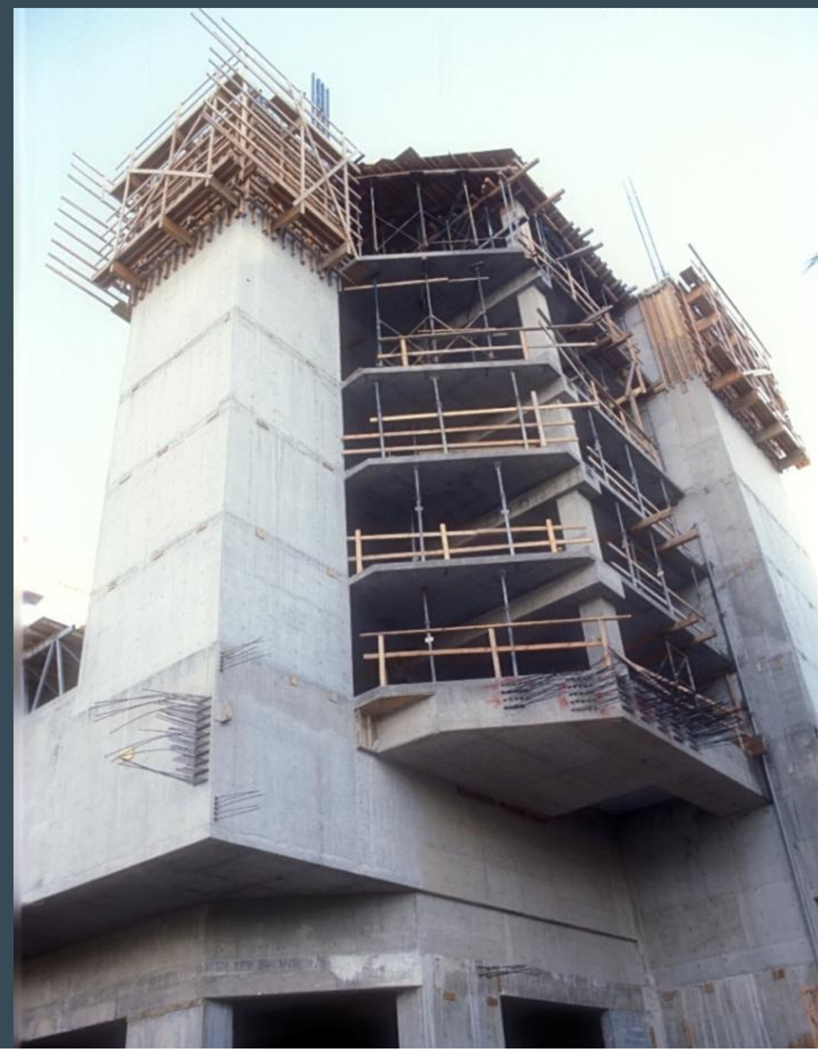
1. Short Term Losses
   1. Slip Loss (Pre-Stressing Steel Seating at Transfer)
   2. Elastic Shortening
   3. Friction Loss
2. Long Term Losses
   1. Creep of Concrete
   2. Shrinkage of Concrete
   3. Relaxation of Prestressing Steel

ATKINS

Transfer Girder

- Harped Profile may be more efficient to resist concentrated loads
- P/T Forces can balance the dead loads.
- Stage stressing to avoid overstressing the beams
- Multi Strand tendons when large forces are required

Transfer Girder



ACI Provisions on P/T Slab Design

- Minimum Average Pre-compression 0.85MPa
- Maximum Spacing of Tendons in any one direction shall not exceed lesser of 8 Times Thickness of Slab or 1.5m
- Maximum Permissible Tensile Stress limit is $0.5 \times (f_c')^{0.5}$ (for $f_{cu} = 50MPa$ $f_t = 3.16MPa$)

Myths about P/T

- P/T Concrete is crack free
- You can not drill / make openings in P/T Slab
- It is impossible to upgrade / repair a P/T Structure
- P/T structures are not durable
- If you drill into a tendon, it will fly out of the building

Reasons to Consider P/T

- P/T slab is typically 30% thinner
- Long-term creep problems are virtually eliminated by load balancing
- Moment of inertia approaches I_{gross}
- The slab can be stressed and the forms removed in 2-3 days
- The 21 to 28 day shoring time for rebar concrete does not apply to P/T
- Flexibility in Column Layout
- Large Cantilevers

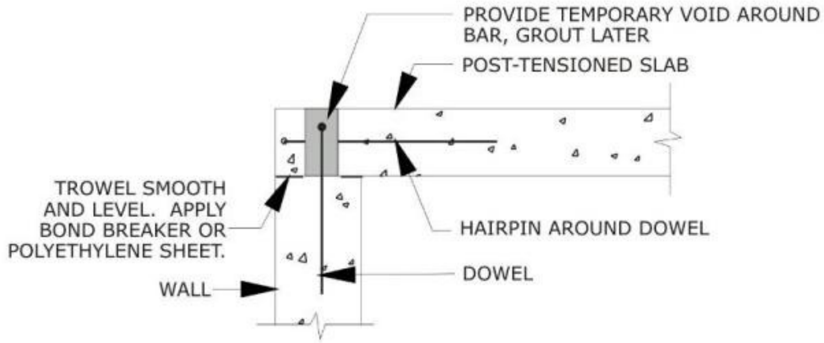
Thank You for your Attention

Plan Design Enable

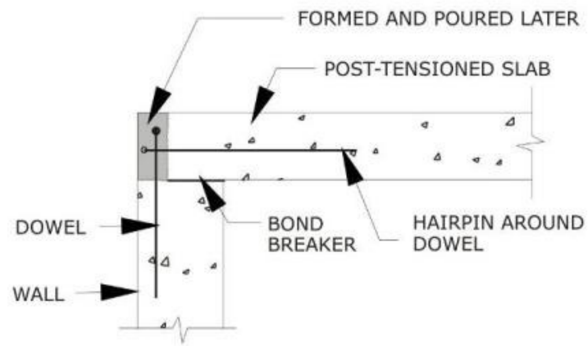
Date

Plan Design Enable

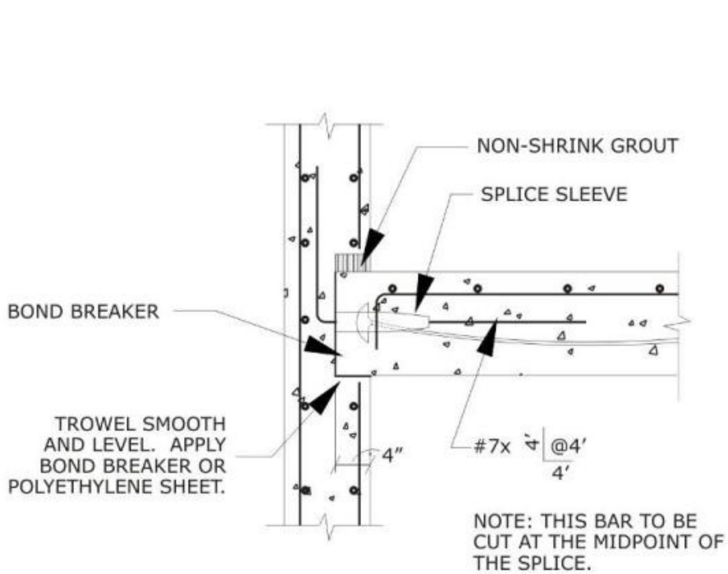
Movement Joint



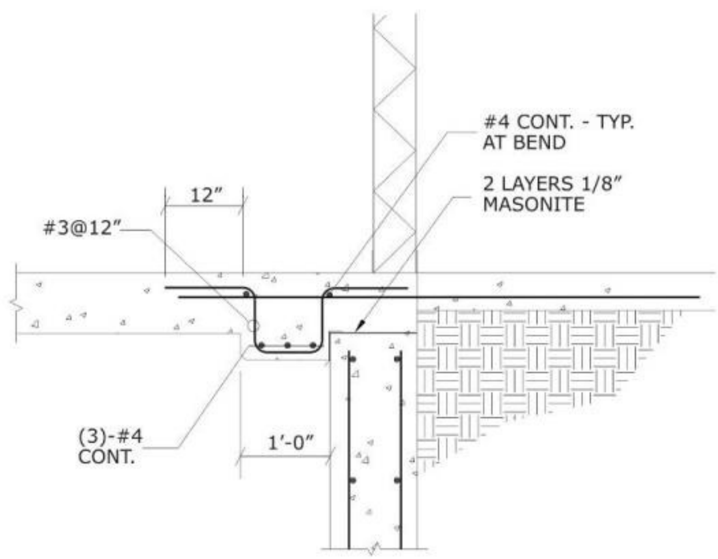
(a) Wall-Slab Release Connection Detail (Option #1)



(b) Wall-Slab Release Connection Detail (Option #2)



(c) Connection of Post-Tensioned Slab To Wall With Splice Sleeves



(d) Connection of Post-Tensioned Slab to Basement Wall