



SEMINAR SERIES 2018

DESIGN & CONSTRUCTION OF POST-TENSIONED CONCRETE

Presented by

Concrete NZ – Learned Society

Seminar Notes

(TR68)

Presented by
Concrete NZ – Learned Society

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EARTHQUAKE ENGINEERING

Se s o c

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Presenters:

Bijan Aalami, Adapt Corporation
Florian Aalami, Adapt Corporation
Juan Maier, BBR VT International Ltd
Jeff Matthews, Holmes Consulting
Marc Stewart, BBR Contech

Design & Construction of Post-Tensioned Concrete Buildings

May/June 2018

SEMINAR NOTES DIRECTORY

DAY 1: Wednesday 30 May 2018

- Session 1 Post-Tensioning Introduction: Key Benefits, Applications & Systems
Juan Maier
- Economics of Post-Tensioned Construction and Quantities
Florian Aalami
- Session 2 Design Basics of Post-Tensioned Structures
Bijan Aalami
- Building Code Requirements for Design of Post-Tensioned Members
Bijan Aalami
- Session 3 Building Code Requirements for Design of Post-Tensioned Members (cont.)
Bijan Aalami
- 10-Step Design of Post-Tensioned Floor Systems, followed by Long-Hand
Calculation (*refer to chapter 7 of the book Post-Tensioned Buildings; Design
and Construction*)
Bijan Aalami
- Session 4 Expeditious Design of Post-Tensioned Floors and Beams using 2D Strip
Method
Florian Aalami

DAY 2: Thursday 31 May 2018

- Session 5 Design for Shortening of Post-Tensioned Members
Bijan Aalami
- Advanced Design of Post-Tensioned Floor Systems using 3D FEM Software (ADAPT-Builder)
Florian Aalami
- Session 6 NZ Post-Tensioned Buildings: Market Activity and Case Studies
Marc Stewart
- Stress Losses in Post-Tensioning (*refer to chapter 10 of the book Post-Tensioned Buildings; Design and Construction*)
Bijan Aalami
- Session 7 Workflow for Integrated Design of Concrete Buildings with Post-Tensioned Slabs
Florian Aalami
- Design of Post-Tensioned Floor Systems in High-Seismic Zones
Bijan Aalami
- Session 8 Seismic Design Considerations for Post-Tensioned Floor Systems in NZ
Jeff Matthews
- Assessment and Evaluation of Vibration Response of Concrete Floor Systems
Florian Aalami
- Construction Detailing: Layout of Post-Tensioning Tendons and Detailing of Non-Prestressed Reinforcement
Bijan Aalami

DAY 3: Friday 1 June 2018

Hands-on experience and exposure to the efficient design of post-tensioning buildings and becoming familiar with the latest design tools and methods
Florian Aalami

Session 1

Wednesday 30 May

Post-Tensioning Introduction: Key Benefits, Applications & Systems

Juan Maier

Design & Construction of PT Buildings

Intro to PT, key benefits, applications & systems

**Juan Maier, Head of Business Development
BBR VT International Ltd, Switzerland**

Outline

- Introduction to post-tensioning
- Key benefits of using post-tensioning
- Terminology of post-tensioning parts
- Post-tensioning materials & properties
- Testing & approval of post-tensioning systems
- Typical post-tensioning systems & their applications
- Benchmarking post-tensioning system performance

Outline

- Introduction to post-tensioning
- Key benefits of using post-tensioning
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Post-tensioning

“A dream for engineers and architects, a delight for developers and a great tool for builders.”

Towers (Emirates Towers, UAE)



Car parks (Sylvia Car Park New Zealand)



Shopping centers (Europark Austria)



Industrial slabs (New Zealand)

Hospitals (Fiona Hospital Australia)



Stadiums (Zagreb Arena Croatia)





University buildings (Plymouth UK)

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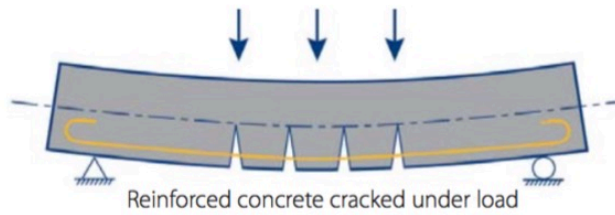
History of post-tensioning

Slab post-tensioning (PT) has expanded greatly since 1950
Starting in the US, Australia, Middle East, Asia and Europe
Significant benefits for all stakeholders of a project, just to name a few:

- Large uninterrupted floor space (maximum freedom)
- Flexibility of internal layout
- Versatility of use and movement
- Large clear spans
- Fewer columns and supports and reduced floor thickness
- Construction speed

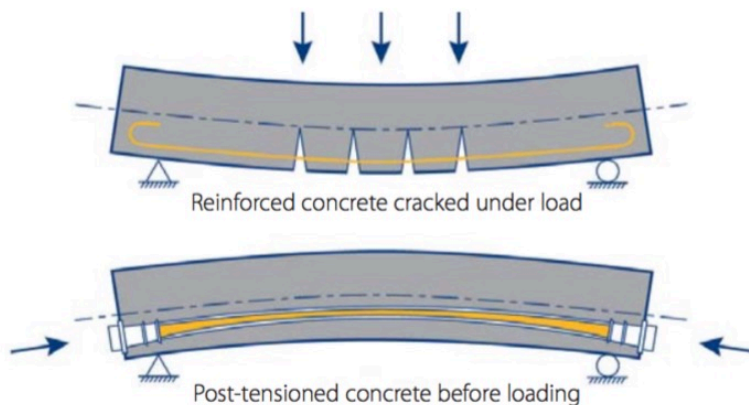
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How does post-tensioning work?



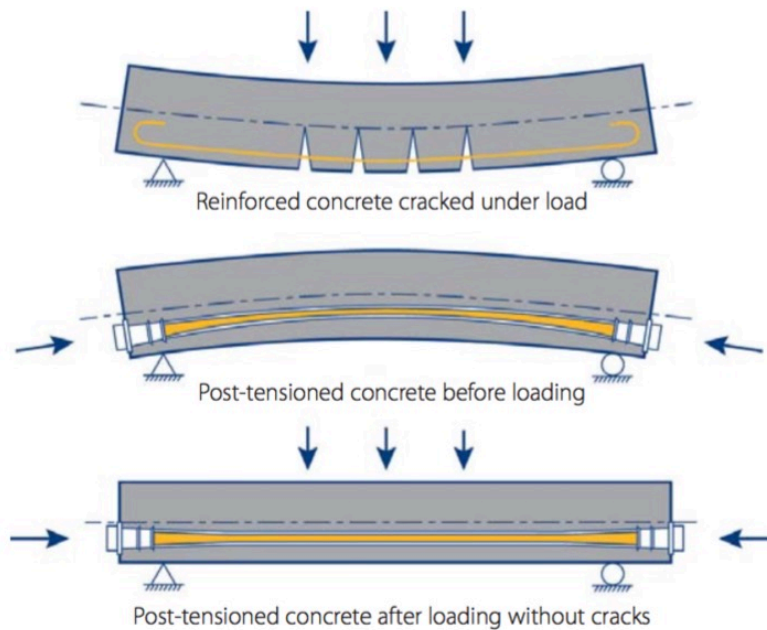
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How does post-tensioning work?



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How does post-tensioning work?



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Outline

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- **Key benefits of using post-tensioning**
- Terminology of post-tensioning parts
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Post-tensioning

**Value Engineering in construction!
Maximizes value on one hand and
reduces costs on the other hand.**

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Key benefits

Longer spans

- Standard RC slab spans range from 4 to 8 meters
- PT slab spans range from 7 to 15 meters
- Reduced number of columns
- Larger column free areas
- Increase flexibility of use
- Result in higher rental returns for developer
- More comfort in car parks

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Key benefits

Structural costs

- Savings in material, labor and formwork

Thinner slabs

- Typically 20-30%* reduction in thickness/concrete
- Usually 70-80%* less reinforcement
- Minimum building height, savings in façade costs
- More floors within same building envelope

*varies by region and country

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Key benefits

Deflection/ crack free slabs

- Crack free design, waterproof
- Increased durability

Early stripping

- Faster construction
- Re-use of formwork

Materials

- Less handling on site
- Green rating

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Key benefits

Footing design

- Reduced dead loads from superstructure
- More economical footings and columns

Joint free design

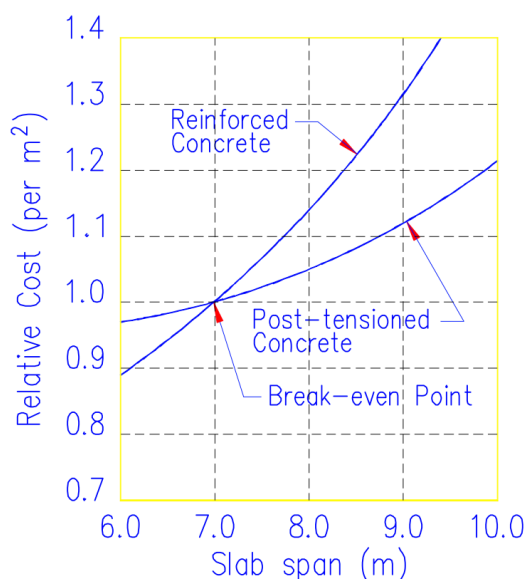
- Less maintenance costs
- Less prone to water leakage

Seismic design

- Lower center of gravity, reduced lateral loads and overturning moments
- Restores building geometry after a major earthquake

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When is PT cost effective



- On average, 30%* of structural costs are for slabs
- Cost-effective from spans exceeding 7 meters
- In general, savings >\$15* per square meter can be achieved (direct costs) with PT, compared to reinforced concrete (RC)

*varies by region and country

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Speed of construction

- Usually flat plate design
- Initial stressing after 1 day
- 3-5 days after pour, formwork can be stripped and reused
- 5 day cycle
- Reduced construction schedule (several months), less financing costs



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Economical PT design

- Usually 8 to 10 meter grids most economical
- Optimized layout of formwork to reduce costs
- FEA methods
- Experienced PT designer
- Min. effective prestress in concrete of 1.0 MPa
- Max. of 3.0 – 3.5 MPa
- Typically 1.4 – 2.0 MPa
- For watertight construction, min. of 2.0 MPa

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Key benefits of post-tensioning

- Direct **savings** in concrete, rebar, formwork and other building materials
 - Joint free design, high crack **control**, high **durability** and less prone to water leakage
 - **Smaller** foundations
 - **Reduced** maintenance
 - **Fastest** construction method
 - **Longer** spans & functional **flexibility**
 - **Reduced** structural depth & **lighter** structure weight
 - **Excellent** seismic behaviour with lower centre of gravity
 - Deflection & vibration **control**
-
- Key benefits for single storey buildings
- Key benefits for multi-storey buildings

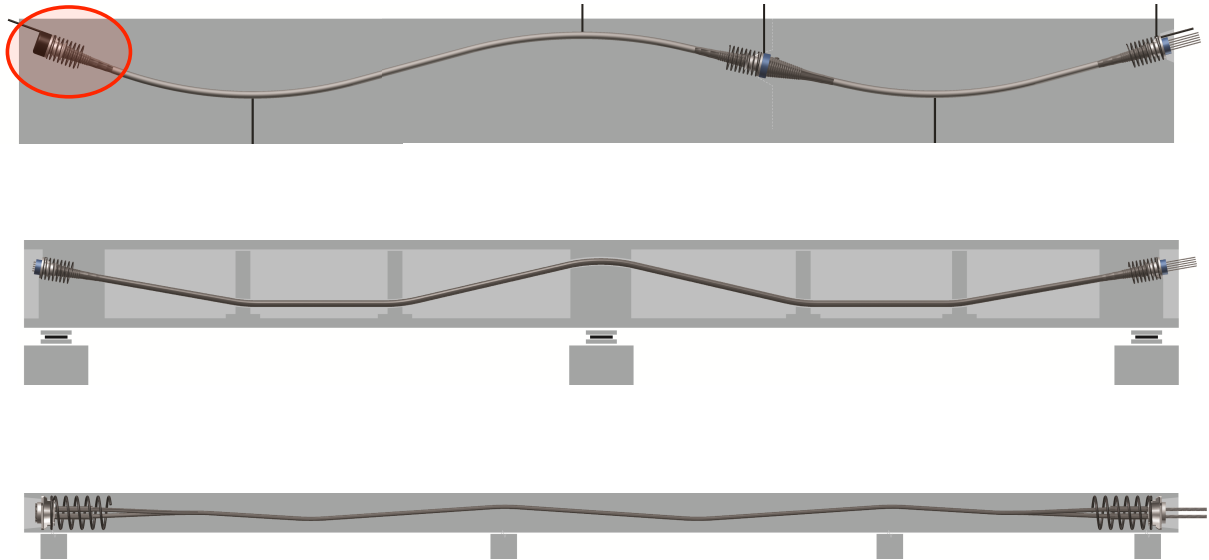
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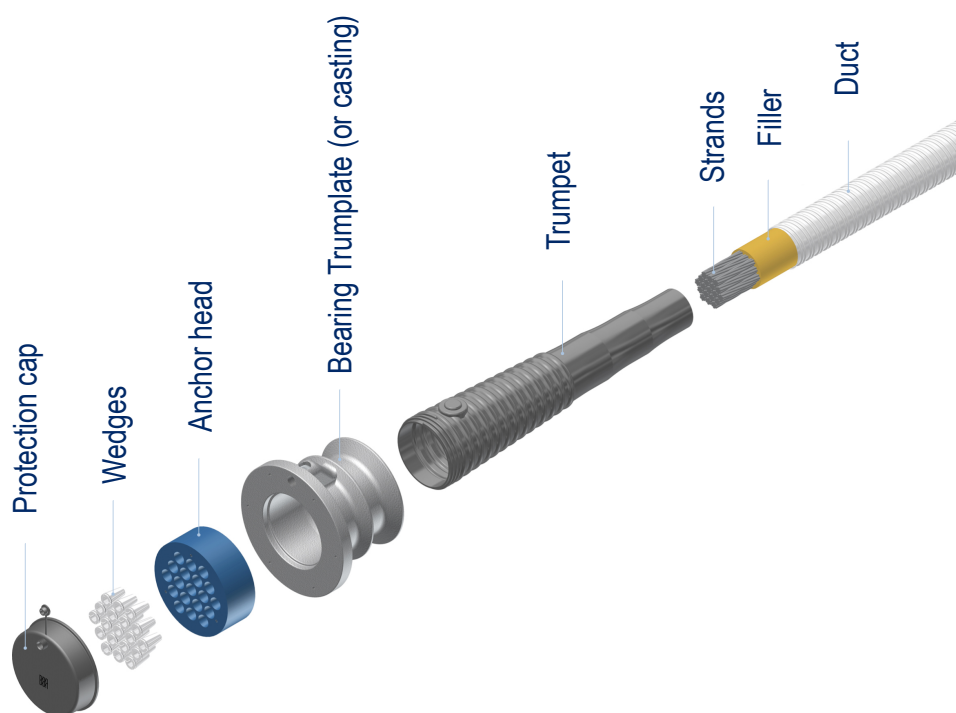
26

Terminology of parts



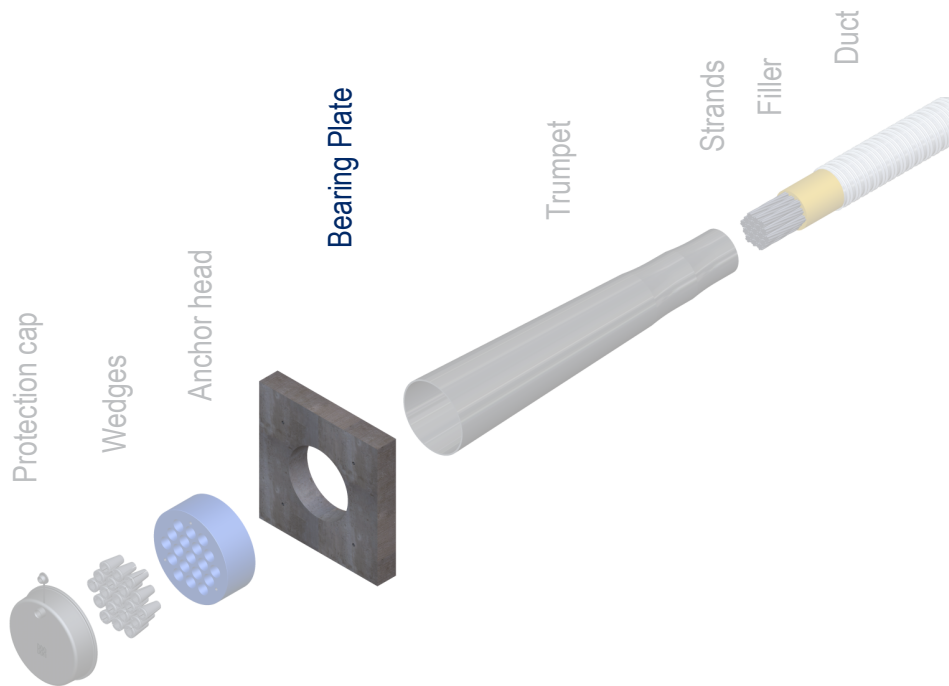
27

Terminology of parts



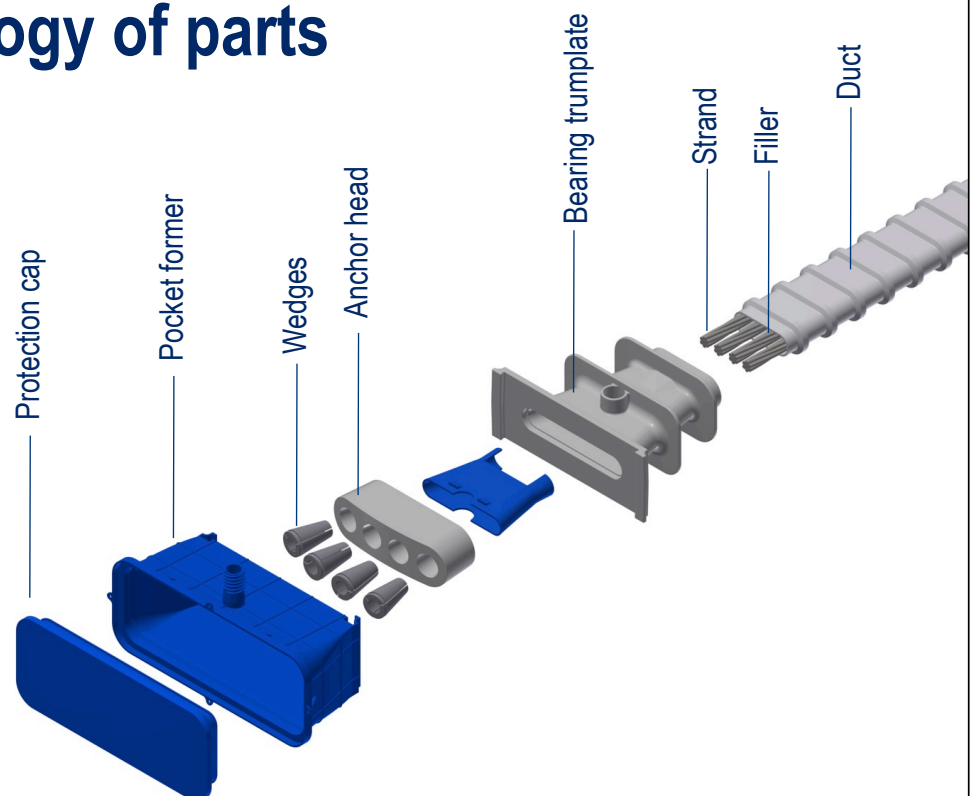
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Terminology of parts



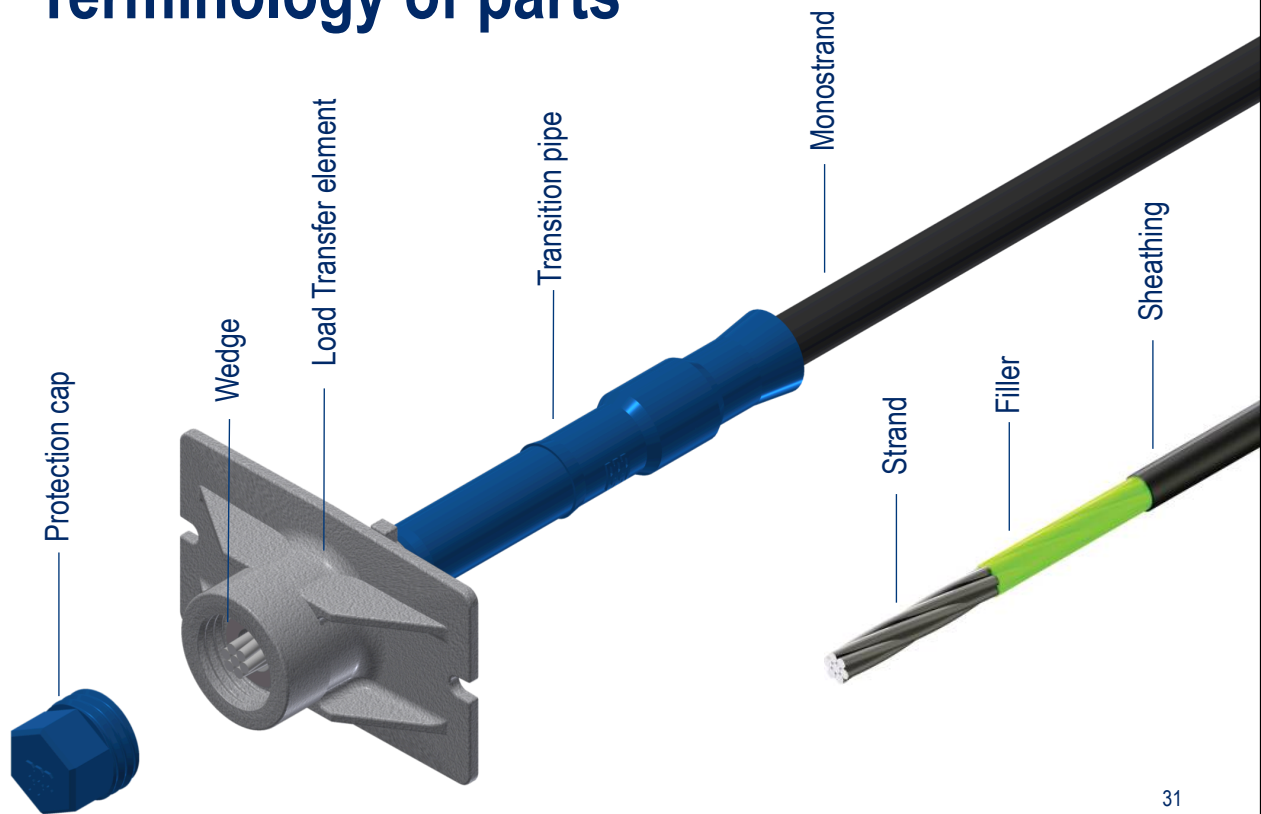
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Terminology of parts



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Terminology of parts



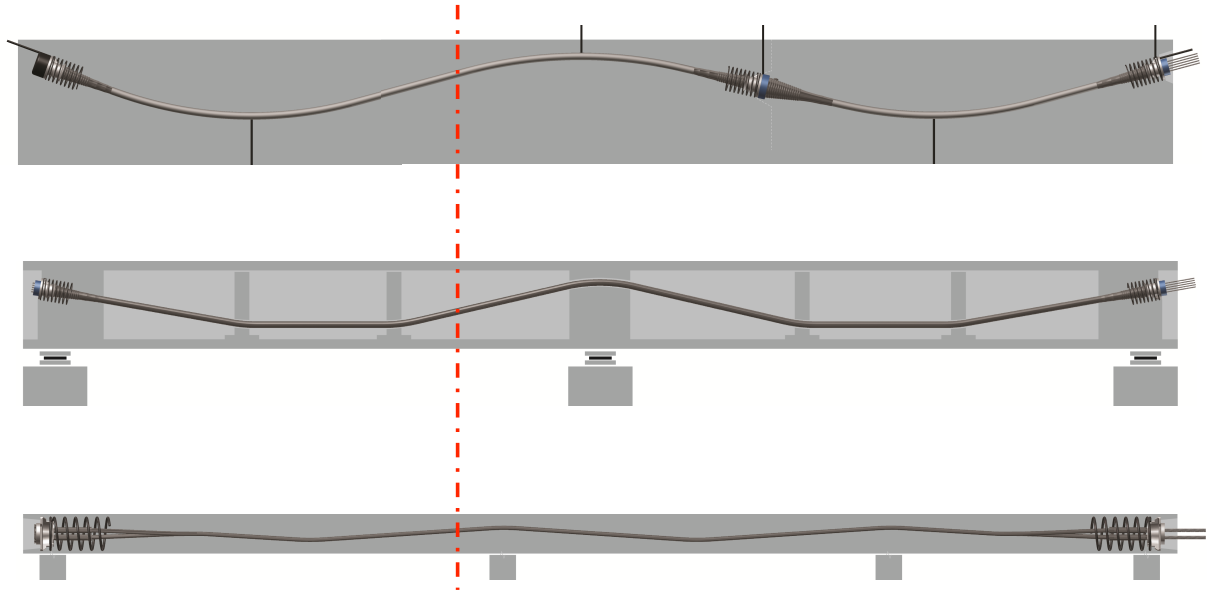
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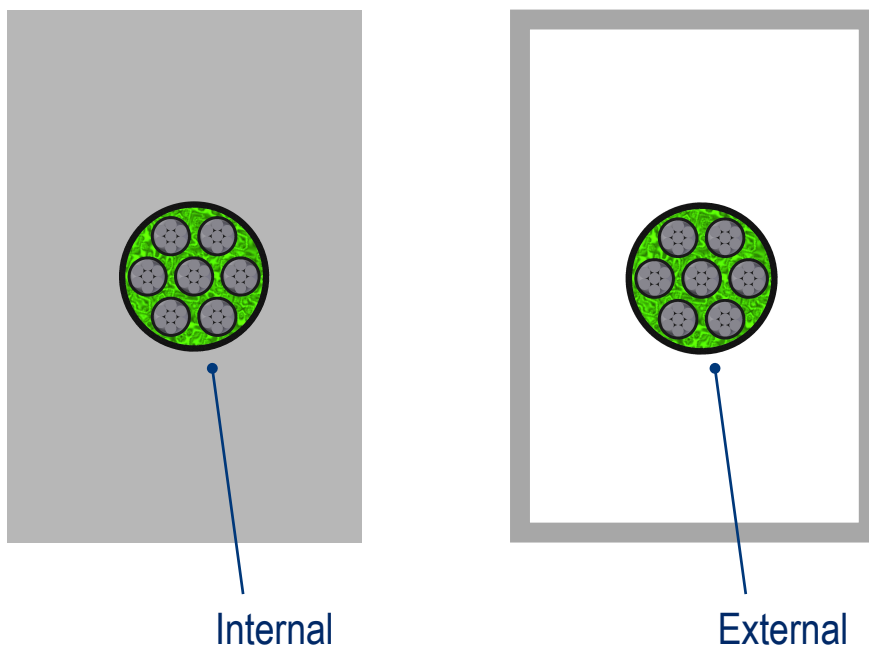
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Materials



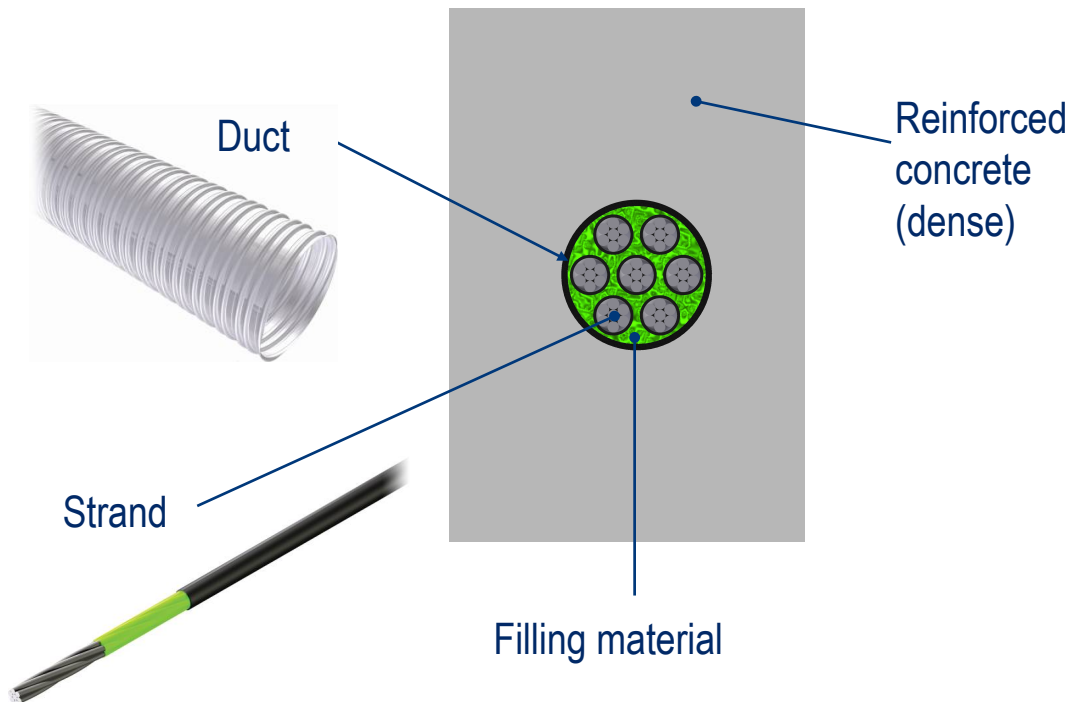
33

Materials



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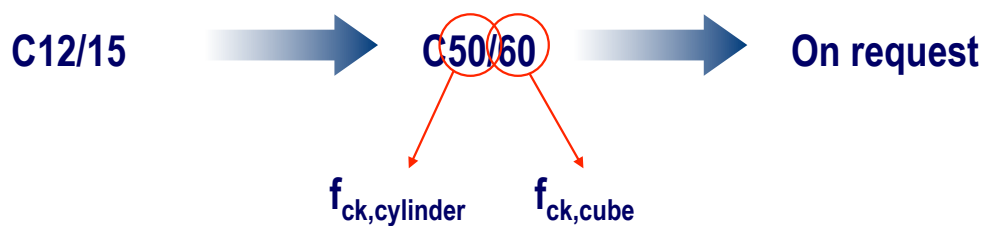
Materials



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Concrete

- The “core” of a structure
- Designated with cylinder & cubic strength

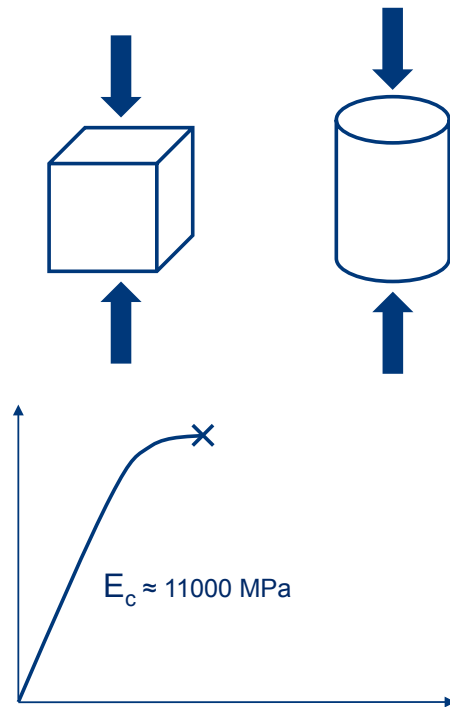


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Concrete: testing

- $f_{ck,cube}$
 - 15 x 15 x 15 cm
- $f_{ck,cylinder}$
 - Ø15 x 30 cm

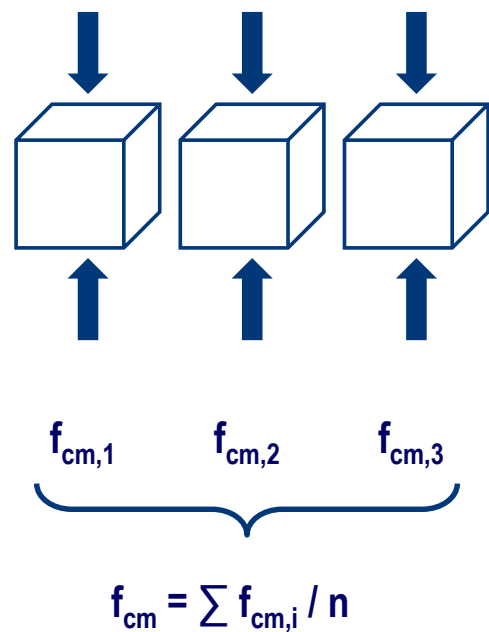
Tested 28 days after casting



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Concrete: project specific

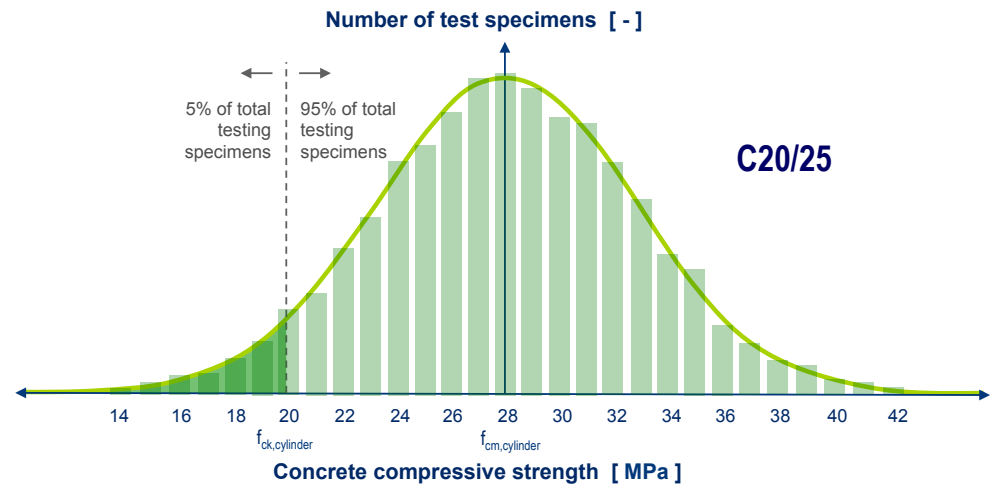
- f_{cm}
- Specimens subjected to the same conditions as the structure



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Concrete: evaluation

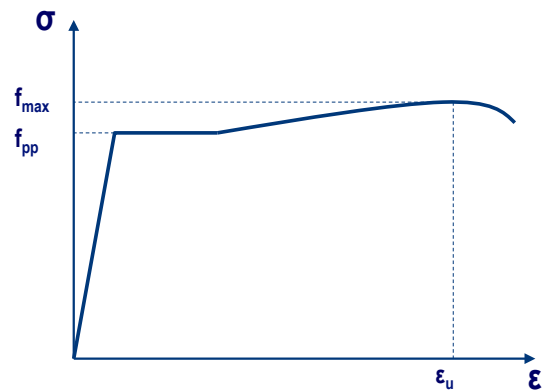
- $$f_{ck,cylinder} + 8 \text{ MPa} = f_{cm,cylinder}$$



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Reinforcement

- Ribbed
- $f_{pp} = 500 \text{ MPa}$
- $f_{max} / f_{pp} \geq 1.08$
- $\epsilon_u \geq 5 \text{ [%]}$



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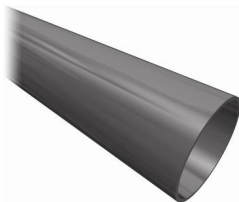
Duct

- Creates void for the strands
- Creates conduit for correct alignment
- Provides bond behavior (corrugated duct)
- Provides protection
- Provides electrical isolation



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Duct

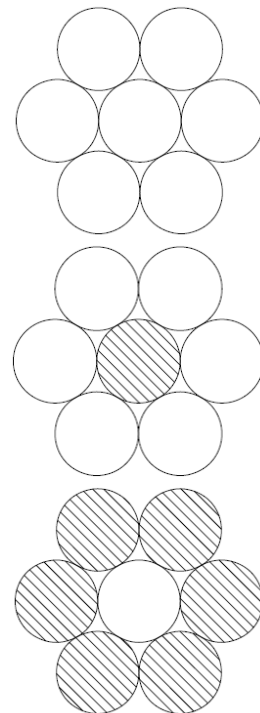
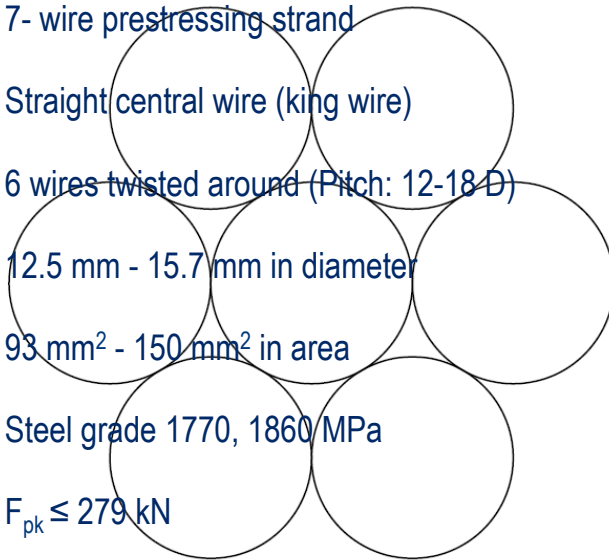
	Plastic*	Steel
Smooth (external)		
Corrugated (internal)	 	 

*refer to *fib* bulletin 7 & 75

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Strand

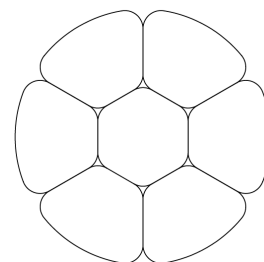
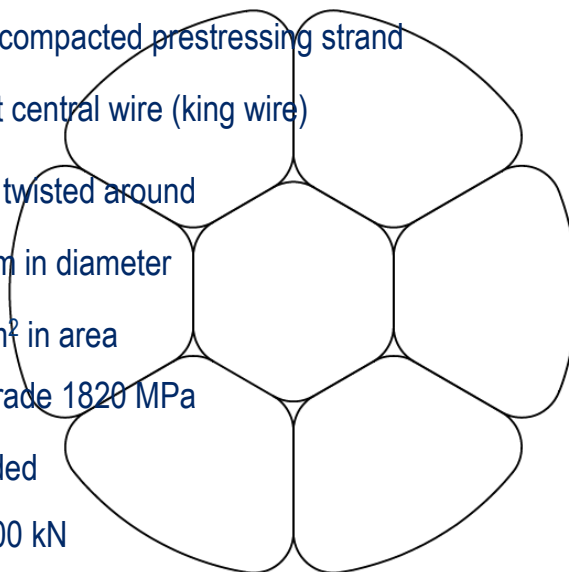
- 7- wire prestressing strand
- Straight central wire (king wire)
- 6 wires twisted around (Pitch: 12-18 D)
- 12.5 mm - 15.7 mm in diameter
- 93 mm² - 150 mm² in area
- Steel grade 1770, 1860 MPa
- $F_{pk} \leq 279 \text{ kN}$



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Strand

- 7- wire compacted prestressing strand
- Straight central wire (king wire)
- 6 wires twisted around
- 15.2 mm in diameter
- 165 mm² in area
- Steel grade 1820 MPa
- Unbonded
- $F_{pk} \leq 300 \text{ kN}$



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Strand

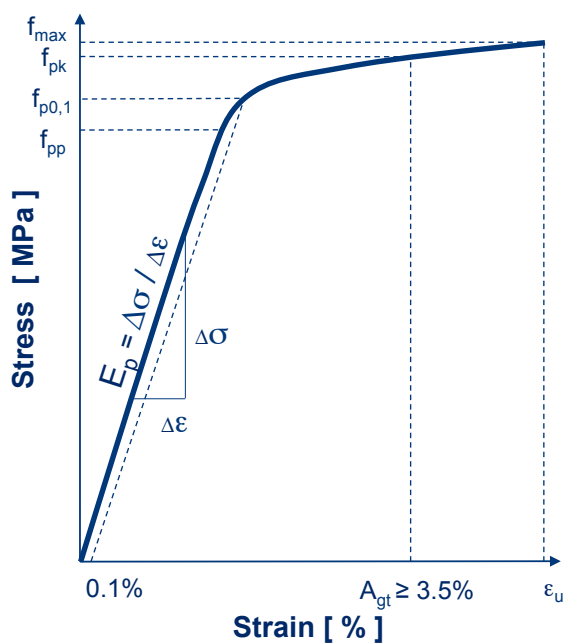
2 Basic strand types



	Bare strands	Monostrands
Bonded	Yes	No
Unbonded	Yes	Yes

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Strand behavior



f_{max} Ultimate Tensile Strength

f_{pk} Guaranteed Ultimate Tensile Strength of (GUTS)

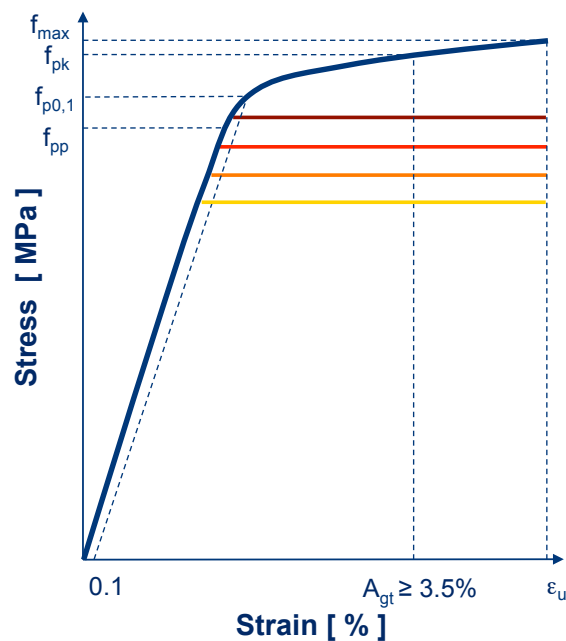
$f_{p0,1}$ Yield strength; irreversible strain of 0.1%

f_{pp} Limit of proportionality

	MPa		
f_{pk}	1,770	1,820	1,860
$f_{p0,1}$	≈1,560	≈1,600	≈1,640
$f_{p0,1} / f_{pk}$	≈0.88		

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Typical prestressing forces



$f_{p0,1}$	Yield strength	246 kN
$0.95 \cdot f_{p0,1}$	Max. overstressing force according to EN	234 kN
$0.9 \cdot f_{p0,1}$	Max. prestressing force according to EN	221 kN
$0.85 \cdot f_{p0,1}$ $\approx 0.75 \cdot f_{pk}$	Max. prestressing force according to DIN	209 kN
$0.7 \cdot f_{pk}$ $\approx 0.8 \cdot f_{p0,1}$	Max. prestressing force according to SIA	195 kN

0106-150 1860

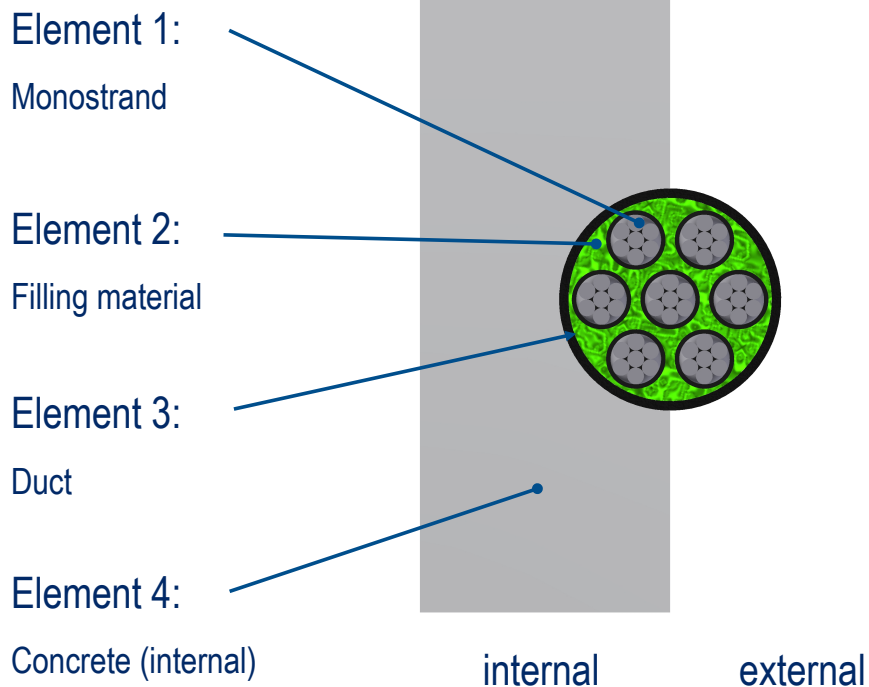
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Filling Material

- Fills the void between duct and strands
- Provides corrosion protection
- Provides bond (grout / bare strand)

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Corrosion protection



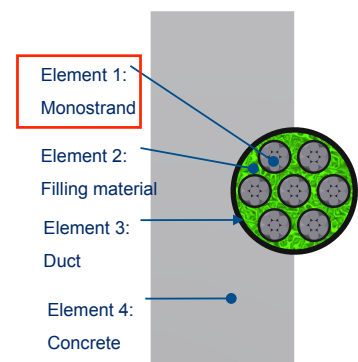
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Monostrand

- Factory provided HDPE-sheathing
- Grease

Recommendations

- Wall thickness ($\geq 1.0\text{mm}$)
- Tensile strength ($\geq 18\text{MPa}$)
- Friction between sheathing and strand ($\leq 60\text{N/m}$)
- No leaking through specimen



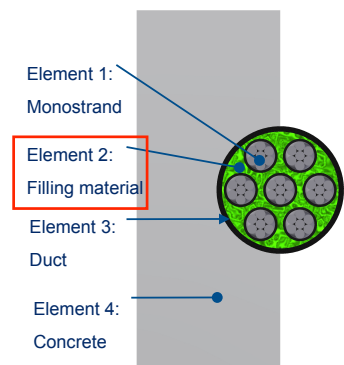
Grout *

- For bonded applications
- Creates an alkaline environment

Recommendations:

- Bleeding ($\leq 0.3\%$)
- Strength (≥ 30 MPa)

*according to EN 445, 446 & 447 or similar

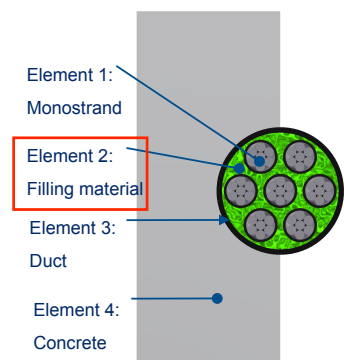


Grout *

Remarks:

- The effectiveness of the grout depends on the propriety of the execution!
- Poor grouting can cause fatal damages!

*according to EN 445, 446 & 447 or similar



Grout *



www.pbworld.com

*according to EN 445, 446 & 447 or similar

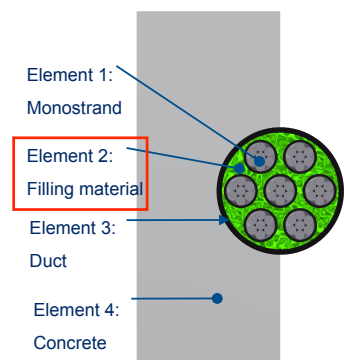
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Grease

- For unbonded applications

Recommendations:

- Dropping point (≥ 150 °C)
- Oil separation ($\leq 2.5\%$ at 40 °C, 72 h)
- No corrosion after 168h at 35 °C

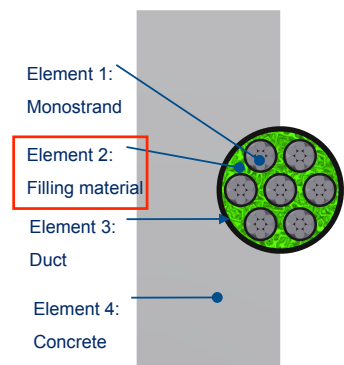


Wax

- For unbonded applications

Recommendations:

- Congealing point (≥ 65 °C)
- Cracks at penetration (at 20 °C)
- Bleeding ($\leq 0.5\%$ at 40 °C)



Circulating dry air

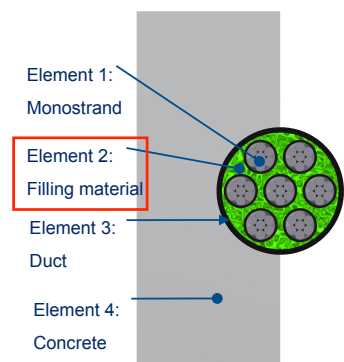
- For unbonded applications
- Applicable only for important structures

Recommendations:

- Monitoring (fulltime)
- Circulating (fulltime)

Remarks:

- High costs!

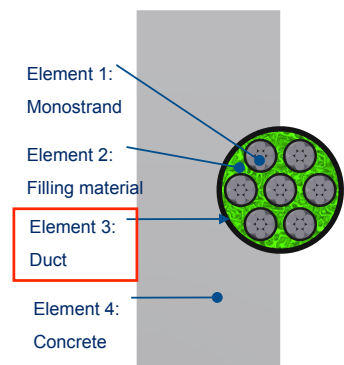


Duct

- Mechanical protection
- Barrier for chlorides
- Plastic > Steel

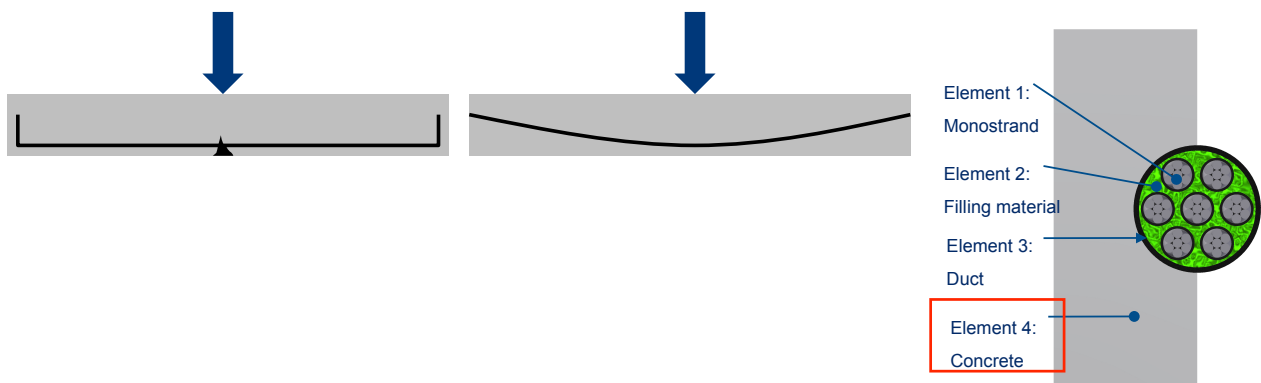
Recommendations:

- Wall thickness
- Material



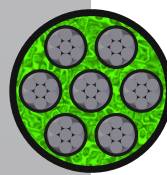
Concrete cover

- Dense → no cracks
- Provides an alkaline environment
- Mechanical protection



Layer combinations

- Combination is decisive
- Different combinations → different protection



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Layer combinations

application		strand		duct		duct filler		concrete		layers
internal	bonded	bare	0	steel	I	grout	I	cover	I	3
				plastic ¹⁾	I+					3+
	unbonded	bare	0	steel	I	grease / wax	I	cover	I	3
				plastic	I+					3+
		monostrand ¹⁾	2	none	0	none	0			3+
				steel	I	(filler)	0			4
				plastic	I+					4+
				steel	I	grout	I			5
				plastic	I+					5+
				external		bare	0			steel
plastic	I+	2+								
bare	0	steel	I			grease / wax	I	2		
		plastic	I+					2+		
monostrand ¹⁾	2	none	0			none	0	none	0	2+
		steel	I			(filler)	0			3
		plastic	I+							3+
		steel	I			grout	I			4
plastic	I+	4+								

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Example of testing guidelines

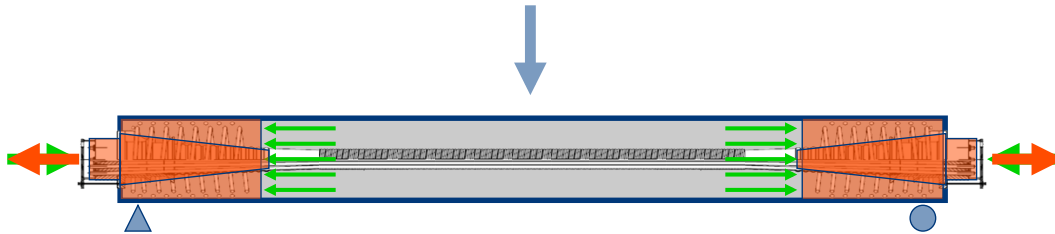


- European Technical Approval / Assessment
- Assessment & testing to ETAG 013 (EAD 16)
- One of the most stringent testing criteria in the world
- Very high quality control & performance
- Factory production control
- CE marking



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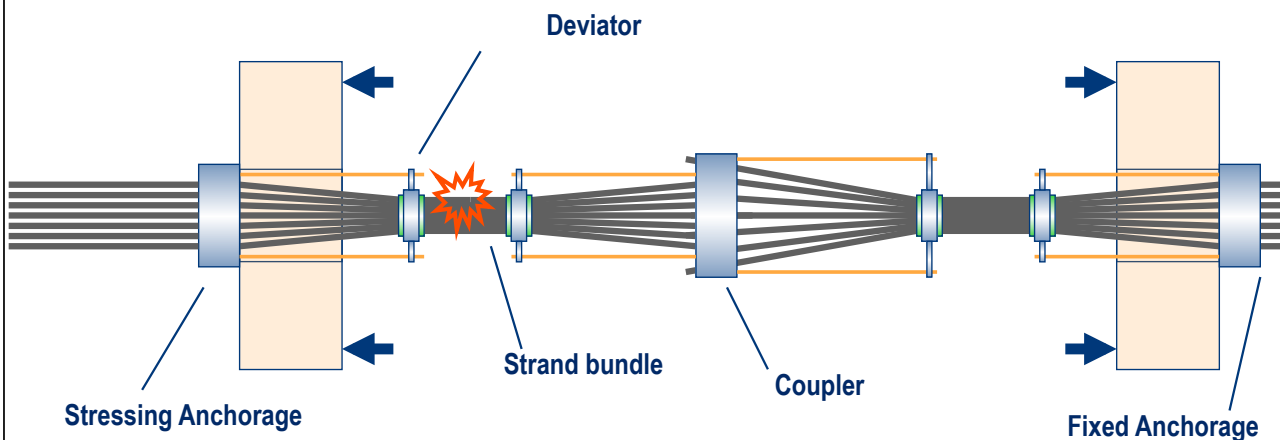
Testing to ETAG 013



1. Resistance to static load
2. Resistance to fatigue
3. Load transfer to the structure

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Static load test



Loading method:

- Loading to 95% AUTS



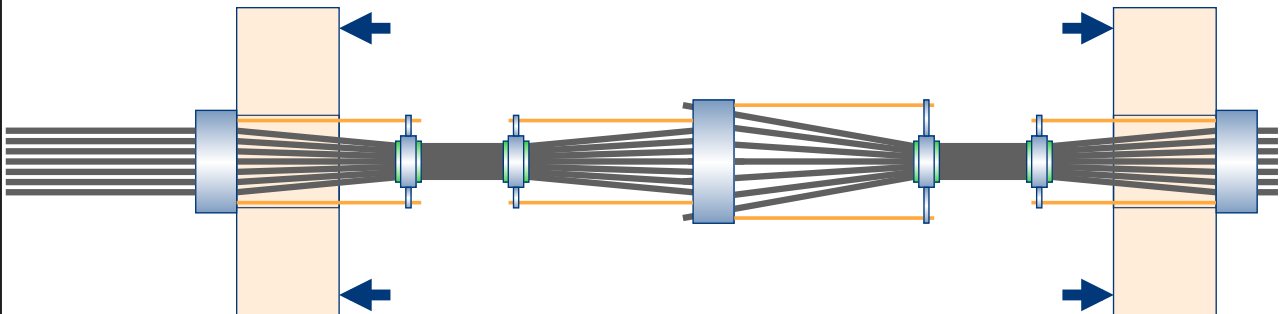
Passing criteria:

- No failure of component anchorages

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Fatigue test

1 Hz Testing Frequency = 23 day test !!!



Loading method:

- 2,000,000 load cycles
- Stress range 80 Mpa
- Upper load 65% GUTS

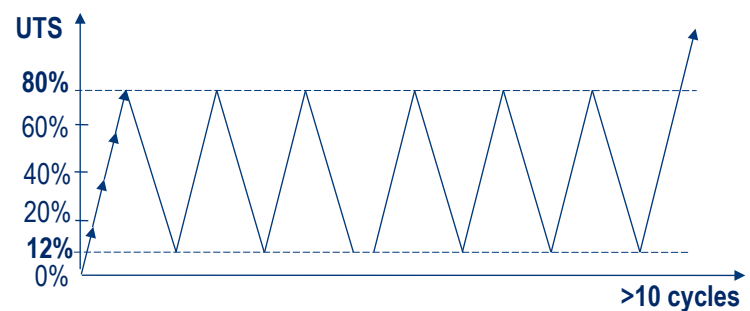
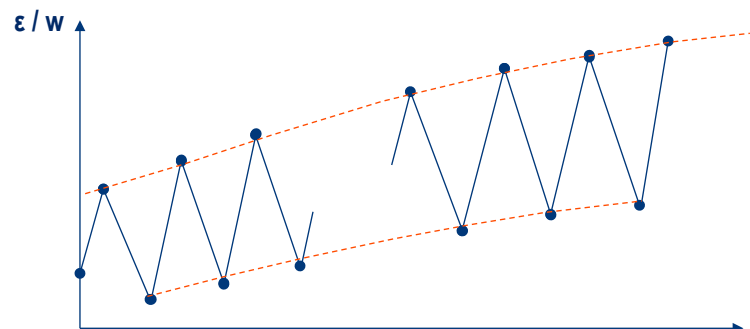
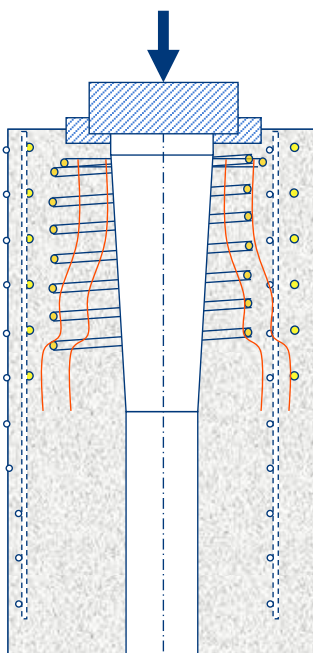


Passing criteria:

- No failure of component anchorages
- <5% wire failures

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Load transfer test



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Load transfer test

Maximum Crack Width:

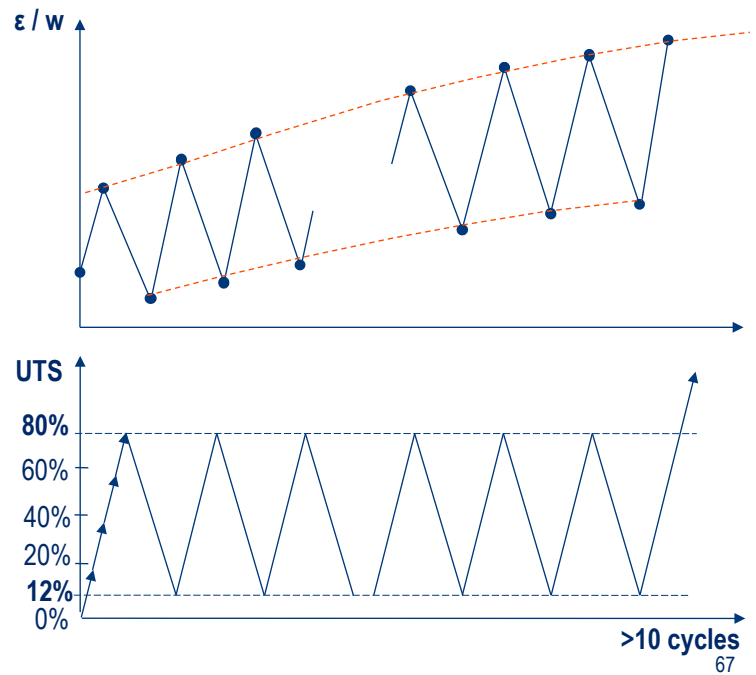
- UL: 0.15 mm
- n. LL: 0.15 mm
- n. LL: 0.25 mm

Stabilization:

- Strains
- Cracks

Passing Criteria:

- Failure Load > 110% UTS



Many tests required to pass ETAG 013

European Technical Assessment

ETA-06/0147
of 31.05.2016

General part

Technical Assessment Body issuing the European Technical Assessment

Österreichisches Institut für Bautechnik (OIB)
Austrian Institute of Construction Engineering

Trade name of the construction product

BBR VT CONA CMI – Bonded Post-tensioning
System with 04 to 31 Strands

Product family to which the construction product belongs

Post-tensioning kit for prestressing of structures
with internal bonded strands

Manufacturer

BBR VT International Ltd
Ringstrasse 2
8603 Schwerzenbach (ZH)
Switzerland

Manufacturing plant

BBR VT International Ltd
Ringstrasse 2
8603 Schwerzenbach (ZH)
Switzerland

This European Technical Assessment contains

58 pages including Annexes 1 to 32, which form
an integral part of this assessment.

This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of

ETAG 013, Guideline for European technical
approval of Post-Tensioning Kits for Prestressing
of Structures, edition June 2002, used according
to Article 66 (3) of Regulation (EU) No 305/2011
as European Assessment Document.

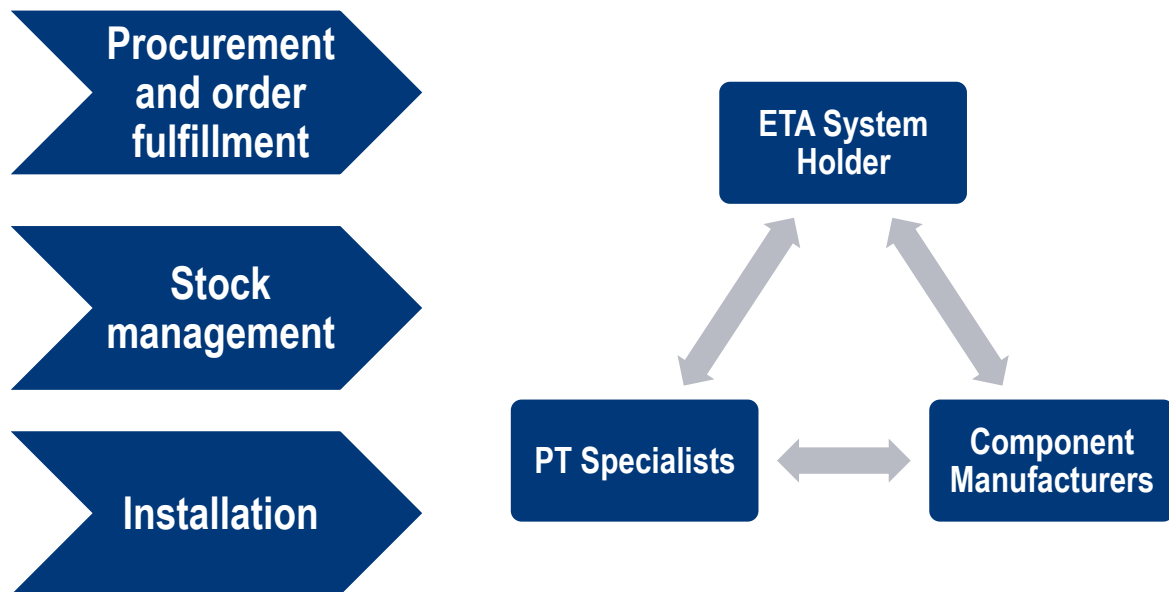
This European Technical Assessment replaces

European technical approval ETA-06/0147 with
validity from 04.03.2013 to 03.03.2018

State-of-the-art PT certification

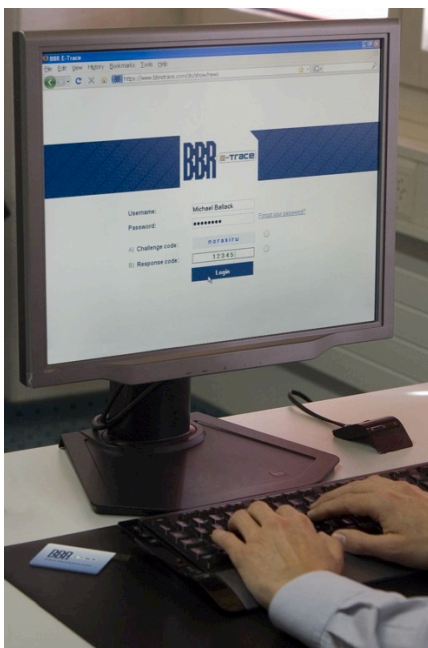


Factory Production Control (FPC)



71

Quality Control Systems



- Engineering database
- Procurement
- Stock management
- Installation
- User management
- Communication
- Integrated FPC



72

Qualified and certified

- Trained and audited by the ETA Holder on a regular basis
- List of all certified PT Specialists
- Certified for assigned territories



73

Outline

- Introduction to post-tensioning
- Key benefits of using post-tensioning
- Terminology of post-tensioning parts
- Post-tensioning materials & properties
- Testing & approval of post-tensioning systems
- Typical post-tensioning systems & their applications
- Benchmarking post-tensioning system performance

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Primary Applications of PT

- Floor slabs
 - Flat slabs
 - Beam and one-way slab frames
- Ground supported slabs
 - Mat foundations
 - Slabs on expansive soil
 - Industrial slabs
- Transfer plates; heavy loads
- Podium slabs (light framing)
- Repair/retrofit (deflection control or added strength)
- Correction of seismic deformation
- Modification of load path
- Redistribution of reactions

75

Main categories of PT



1. Floor systems
→ Flat anchorage or monostrand systems
2. Large structural elements such as raft foundations, transfer plates, beams etc.
→ Multi-strand PT systems
3. Repairs and retrofit work
→ Special PT systems

76

Main categories of PT



1. Floor systems
→ Flat anchorage or monostrand systems
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Typical floor systems

Top: Flat plate

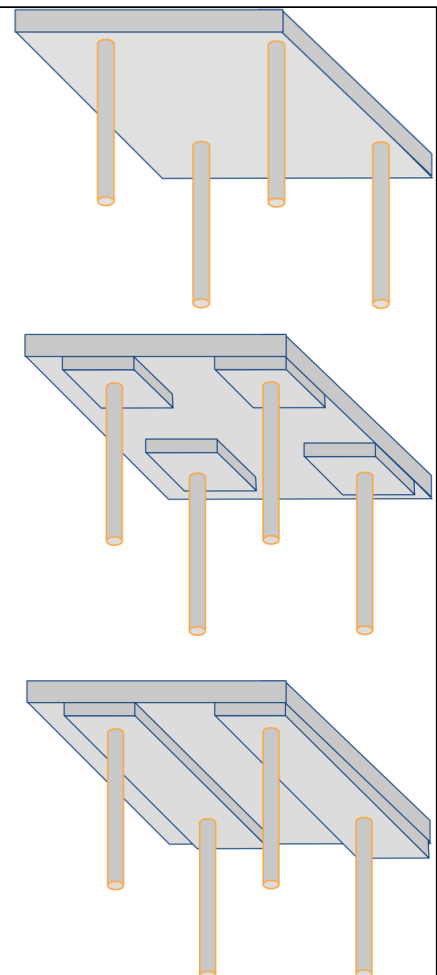
Span 7 – 10 m, imposed loads 2.0 – 7.5 kPa,
Span/depth ratio 32 – 45

Middle: Flat slab

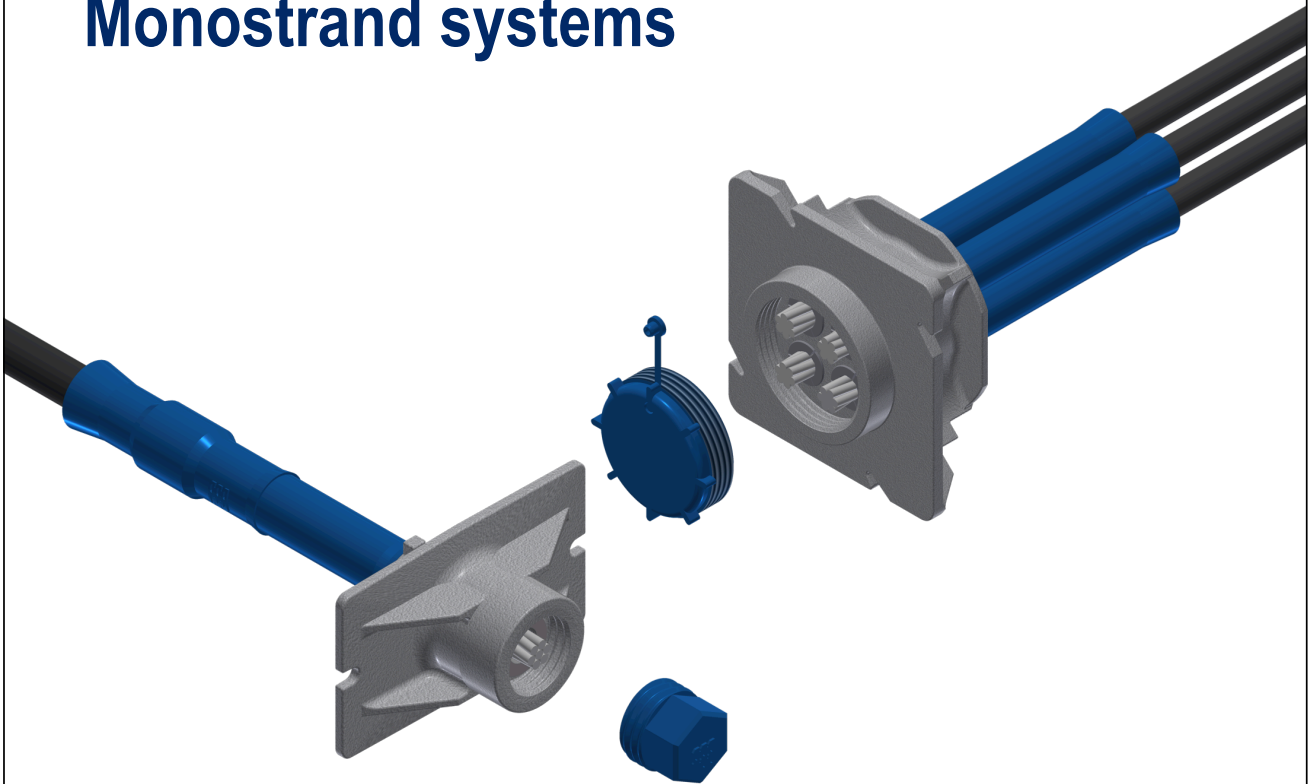
Span 8 – 13 m, imposed loads 2.0 – 10 kPa,
Span/depth ratio 40 – 52

Bottom: Banded system

Span 10 – 20 m (6 – 10 m), imposed loads <15 kPa, Span/depth ratio 19 – 27 (40 – 52)



Monostrand systems

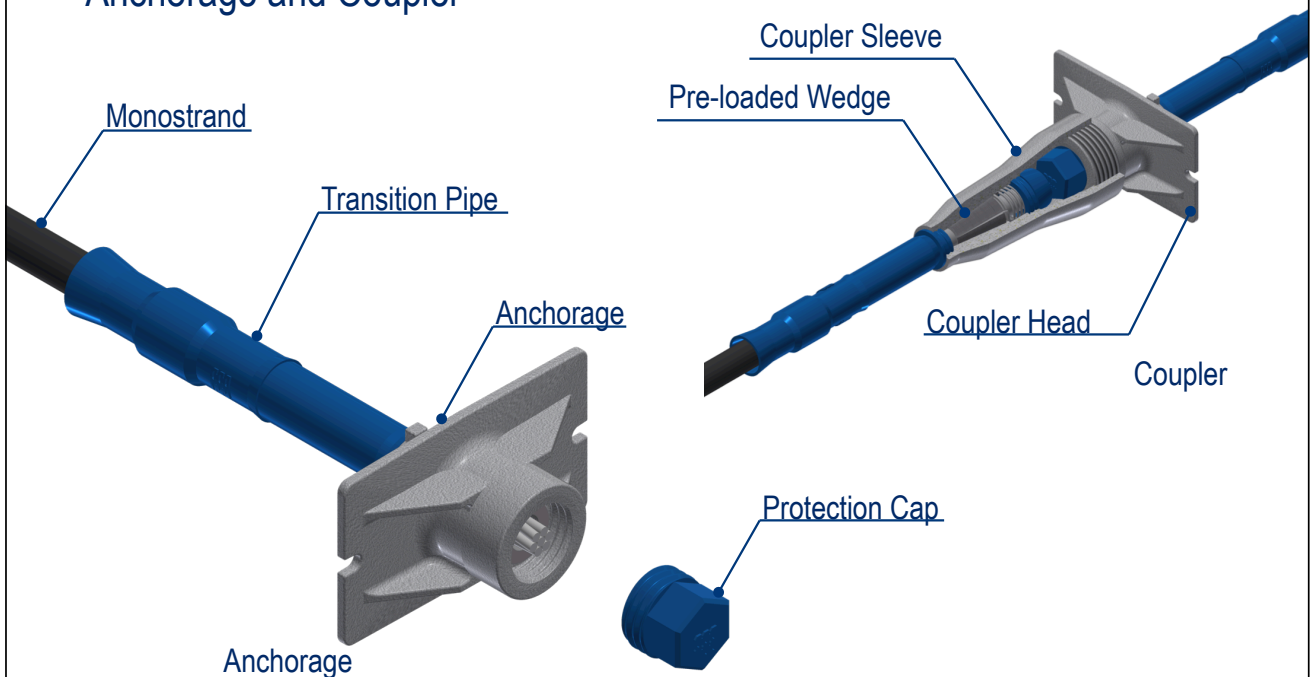


examples shown of the BBR VT CONA CMM range

79

Monostrand systems

Anchorage and Coupler

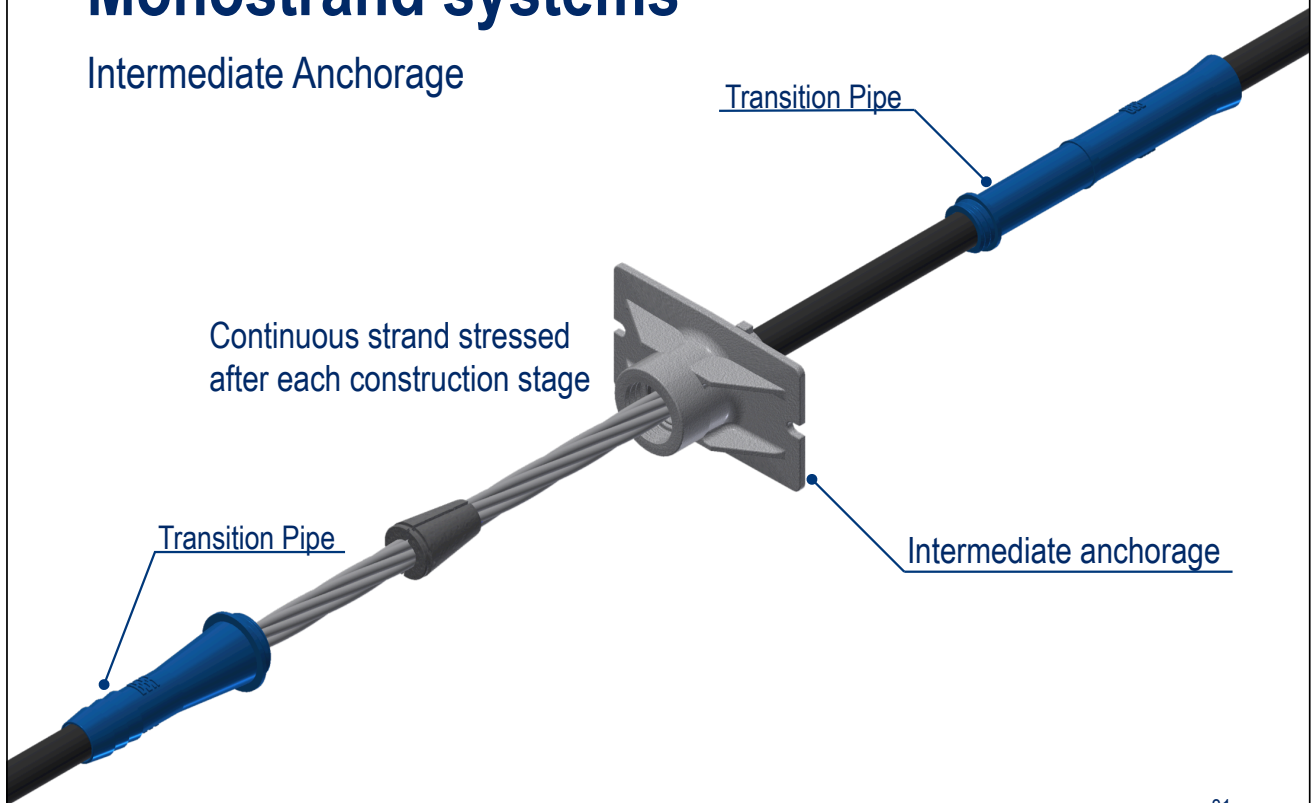


example shown of the BBR VT CONA CMM Single – S2 system

80

Monostrand systems

Intermediate Anchorage

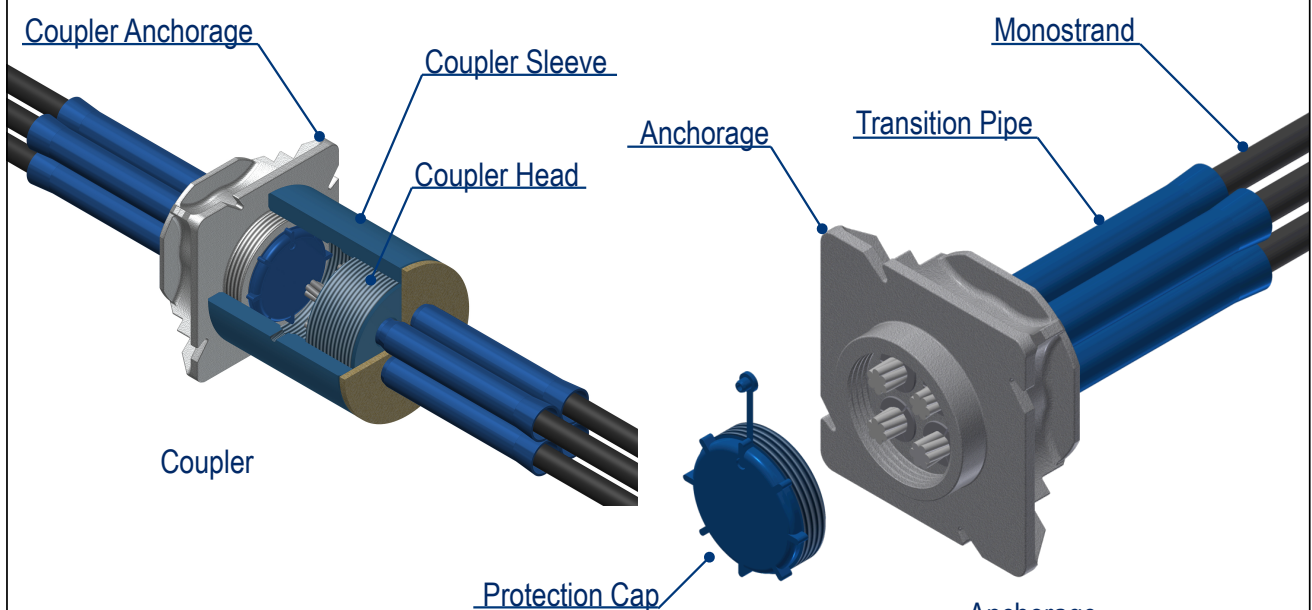


example shown of the BBR VT CONA CMM Single – S2 system

81

Monostrand systems

Anchorage and Coupler



example shown of the BBR VT CONA CMM Two/Four system

82

Monostrand systems

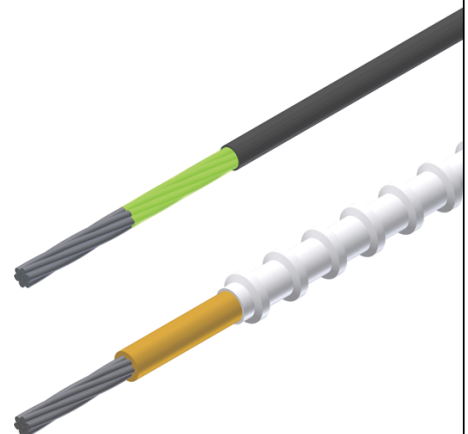


examples shown of various encapsulated monostrand systems

Monostrand systems

Features

- Unbonded or bonded tendons
- 12.9mm or 15.7mm dia. strands, and 15.2mm dia. compacted strand
- Optional fully encapsulated anchorage
- Different centre spacings and edge distances depending on amount of anti-bursting reinforcement
- Low concrete strengths at transfer



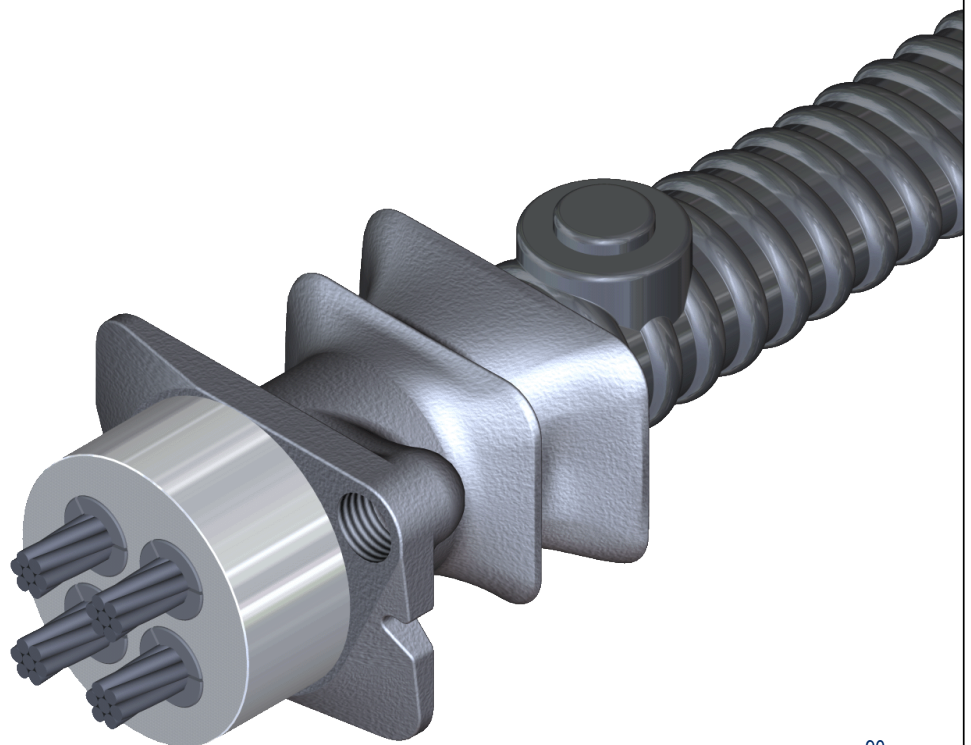






89

Flat systems

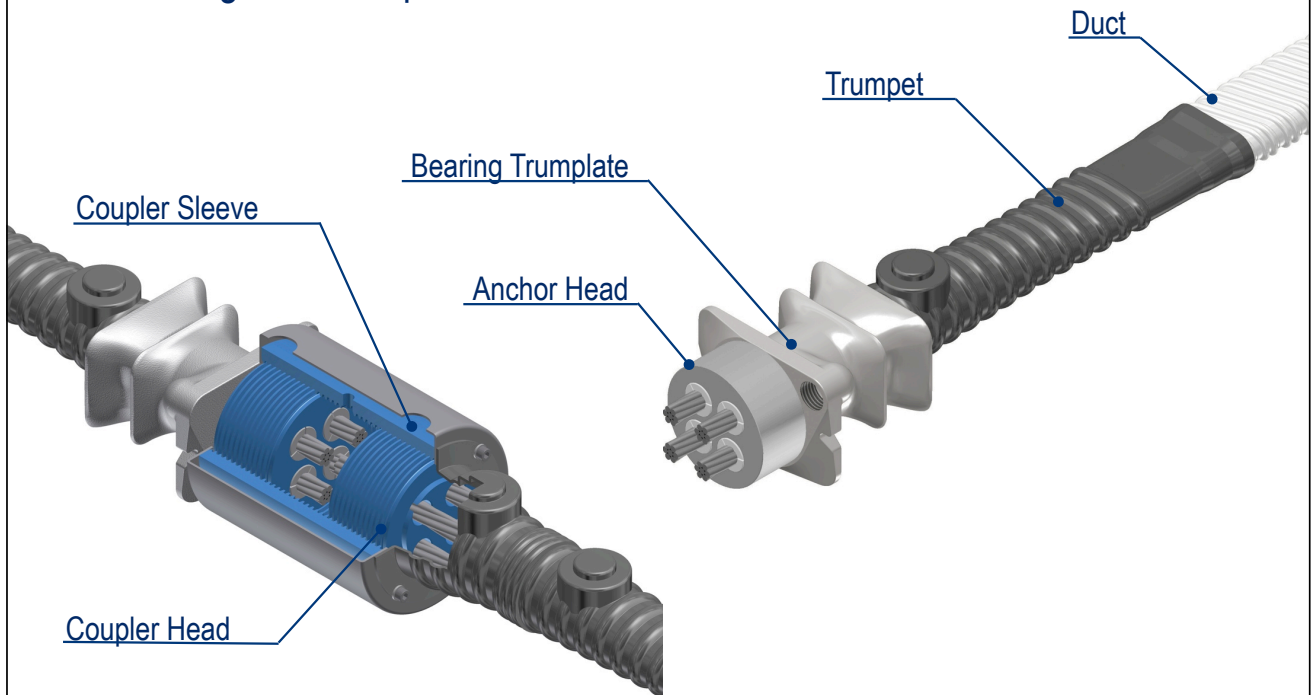


example shown of the BBR VT CONA CMF – S1 system

90

Flat systems

Anchorage and Coupler

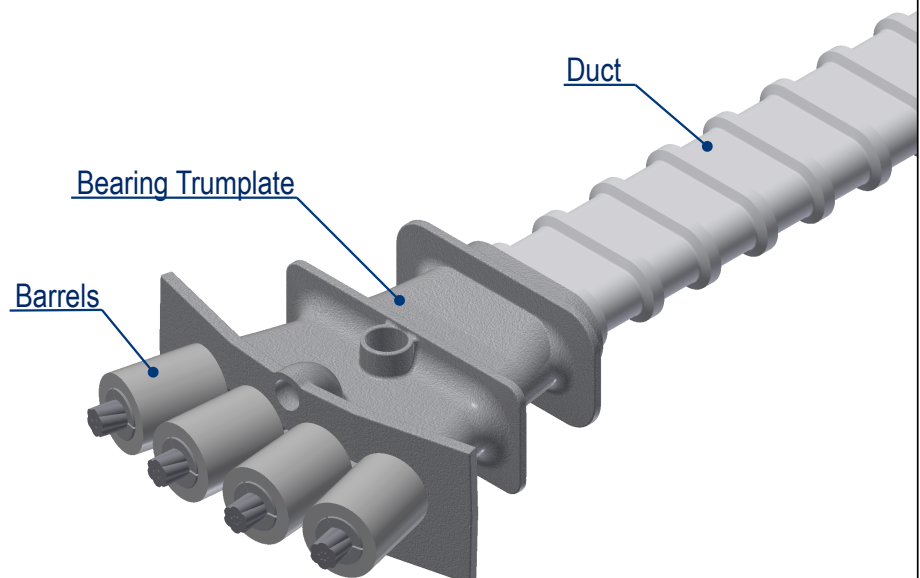


example shown of the BBR VT CONA CMF – S1 system

91

Flat systems

Anchorage



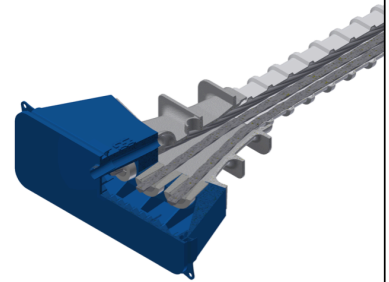
example shown of the BBR VT CONA CMF – S2 system

92

Flat systems

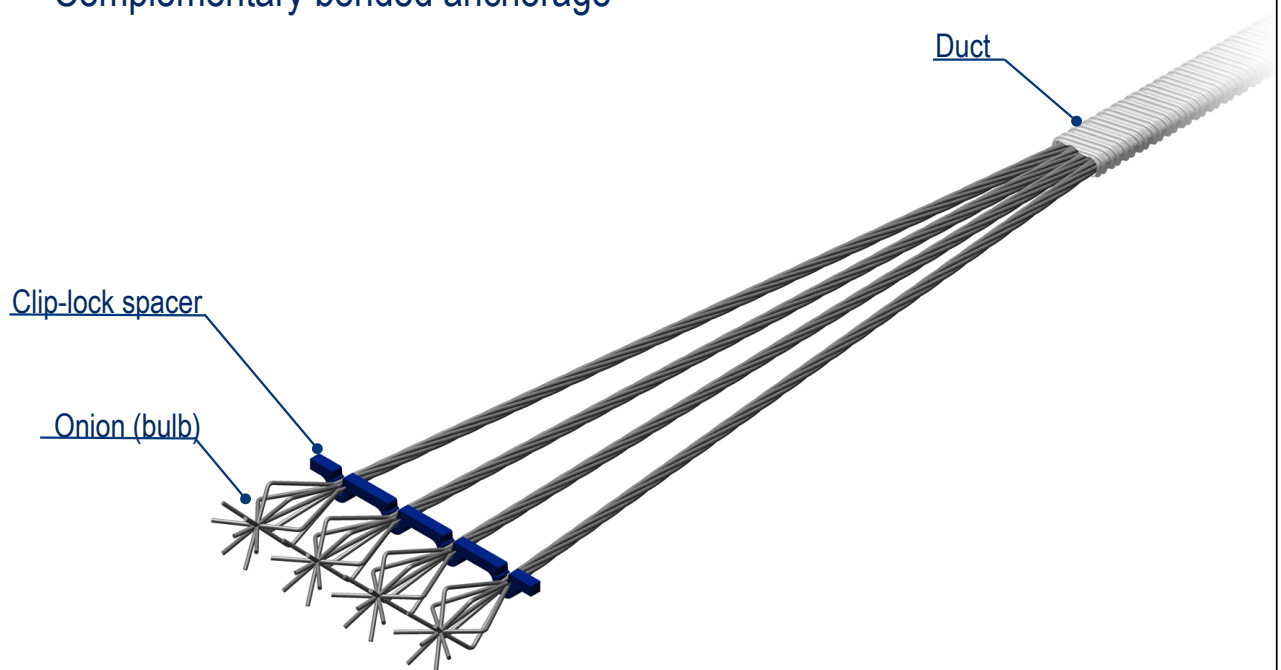
Features

- From 2 to 6 strands
- 12.9mm or 15.7mm dia. strands
- Bonded or unbonded tendon or monostrands
- Plastic or steel ducts
- Different centre spacings and edge distances depending on amount of anti-bursting reinforcement
- Low concrete strengths at transfer



Flat systems

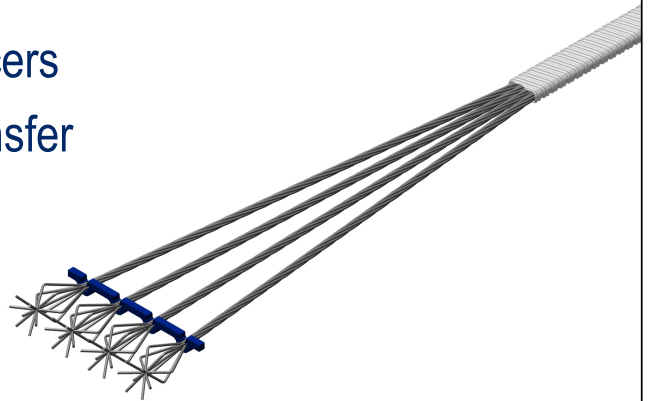
Complementary bonded anchorage



Flat systems

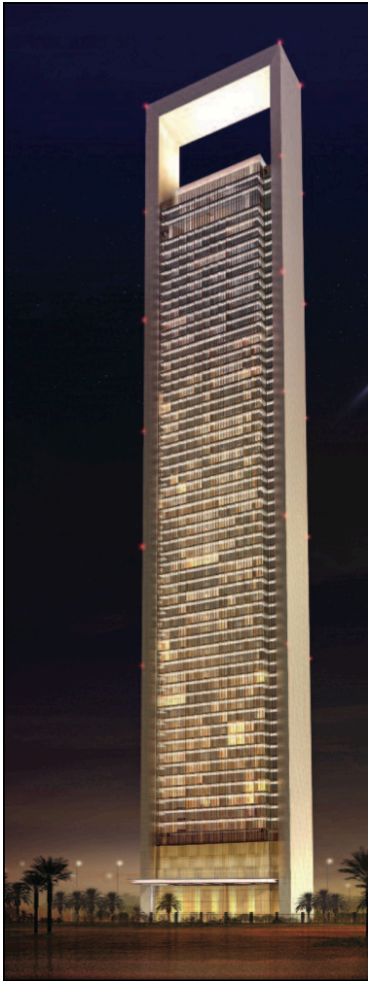
Complementary bonded anchorage

- From 2 to 6 strands
- 12.9mm or 15.7mm dia. strand
- No need for local anti-bursting reinforcement (check – refer to the relevant ETA)
- Efficient clip-lock strand spacers
- Low concrete strength at transfer



95









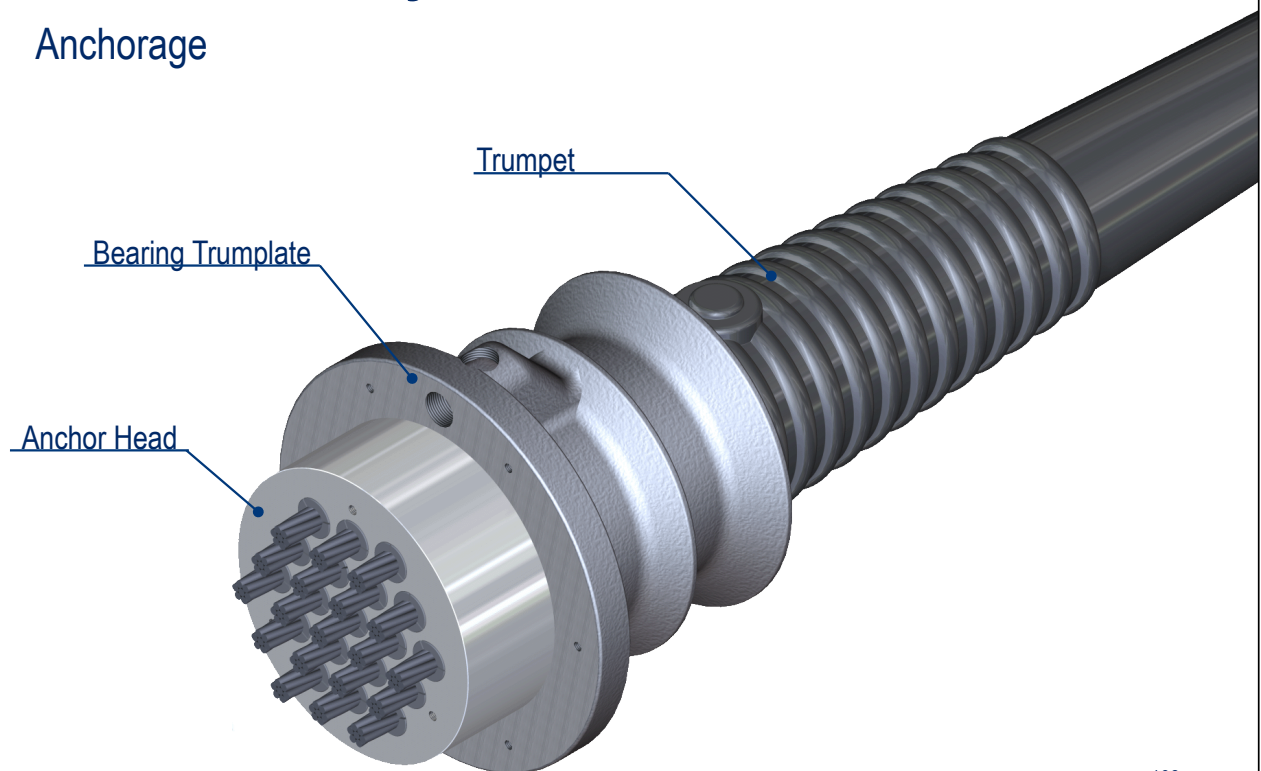
Main categories of PT



1. Floor systems
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→ Special PT systems

Multistrand systems

Anchorage

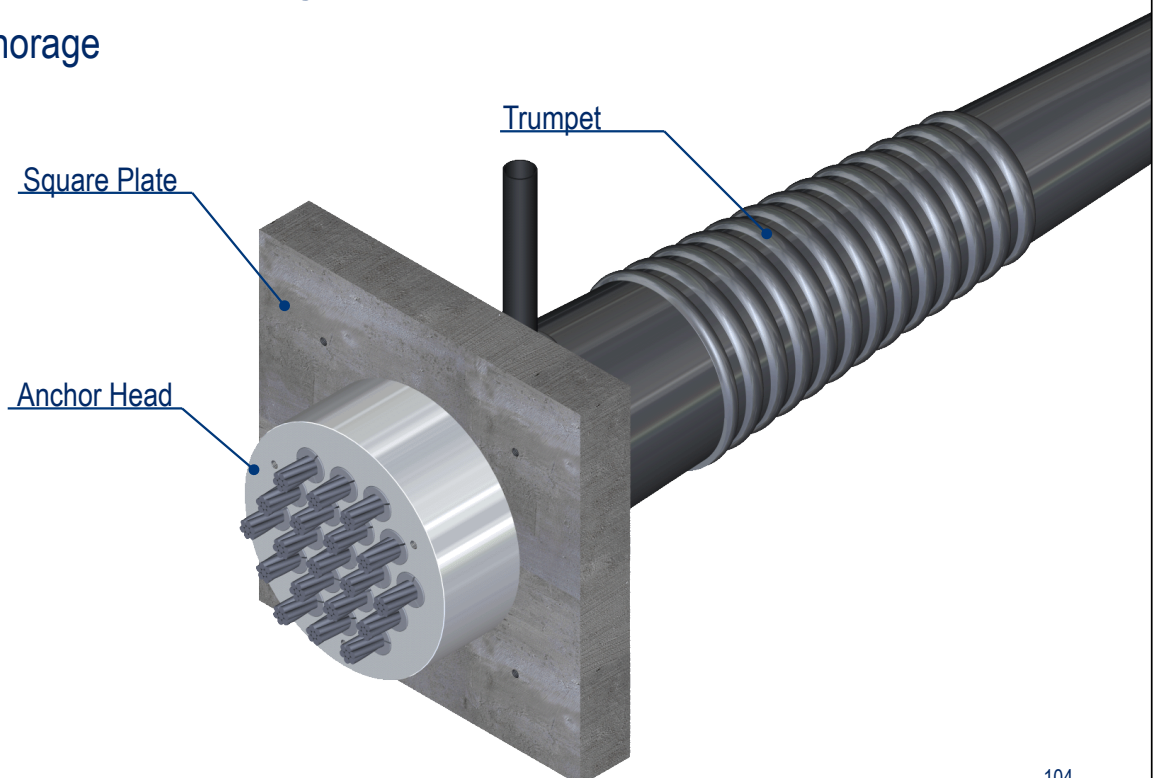


example shown of the BBR VT CONA CMI BT system

103

Multistrand systems

Anchorage



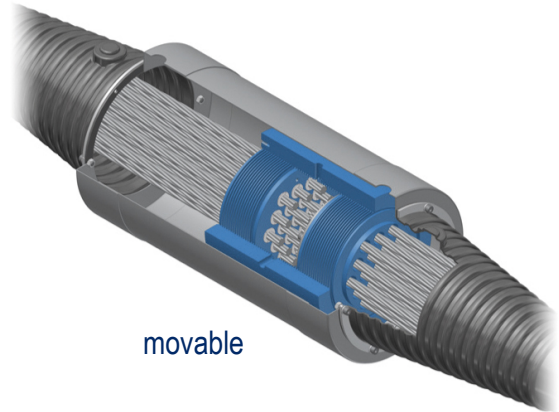
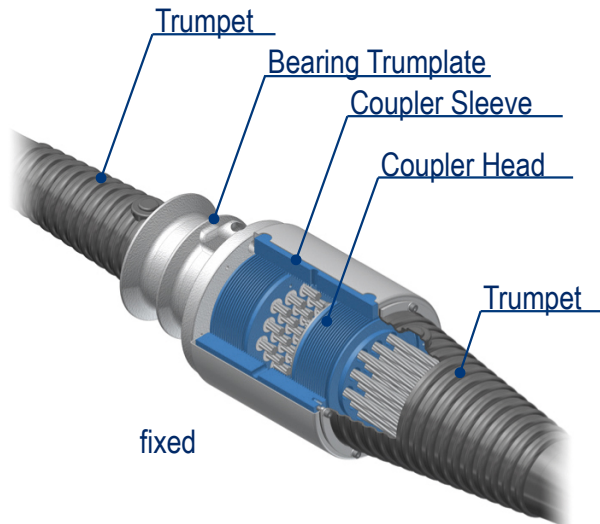
example shown of the BBR VT CONA CMI SP system

104

Multistrand systems

Anchorage & Coupler

2 plane coupler



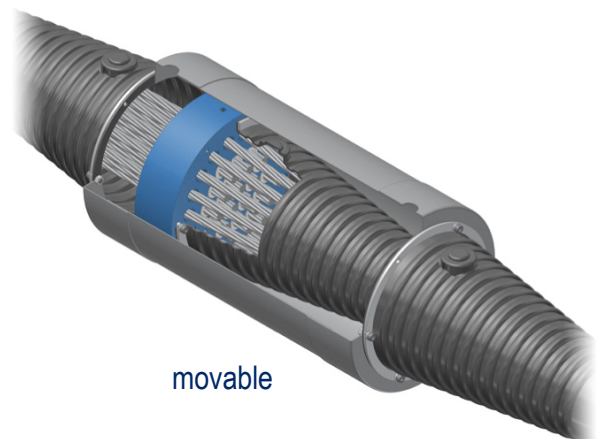
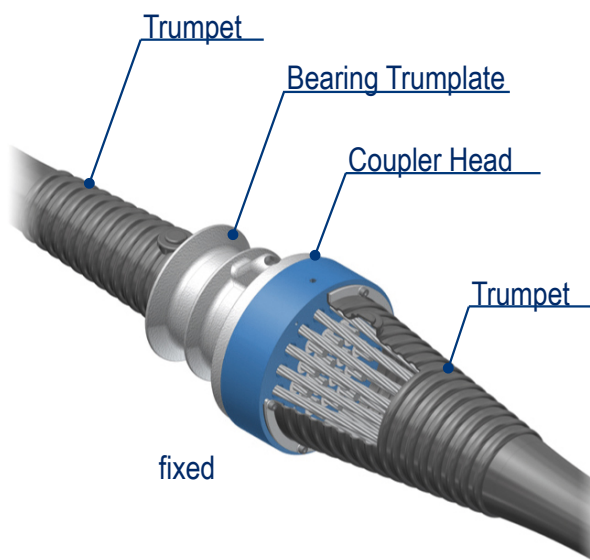
examples shown of the BBR VT CONA CMI couplers

105

Multistrand systems

Anchorage & Coupler

Single plane coupler



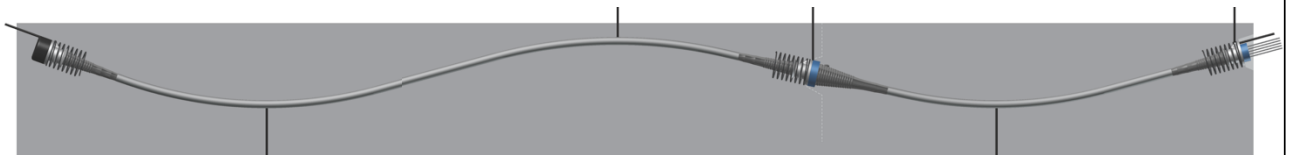
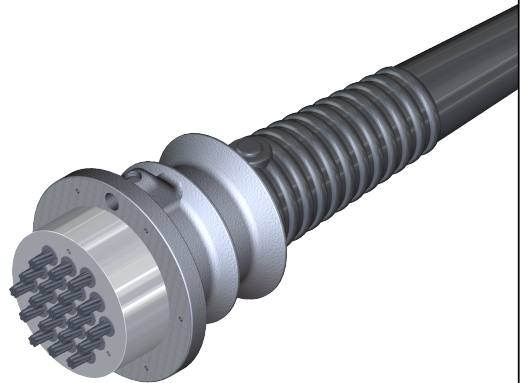
examples shown of the BBR VT CONA CMI couplers

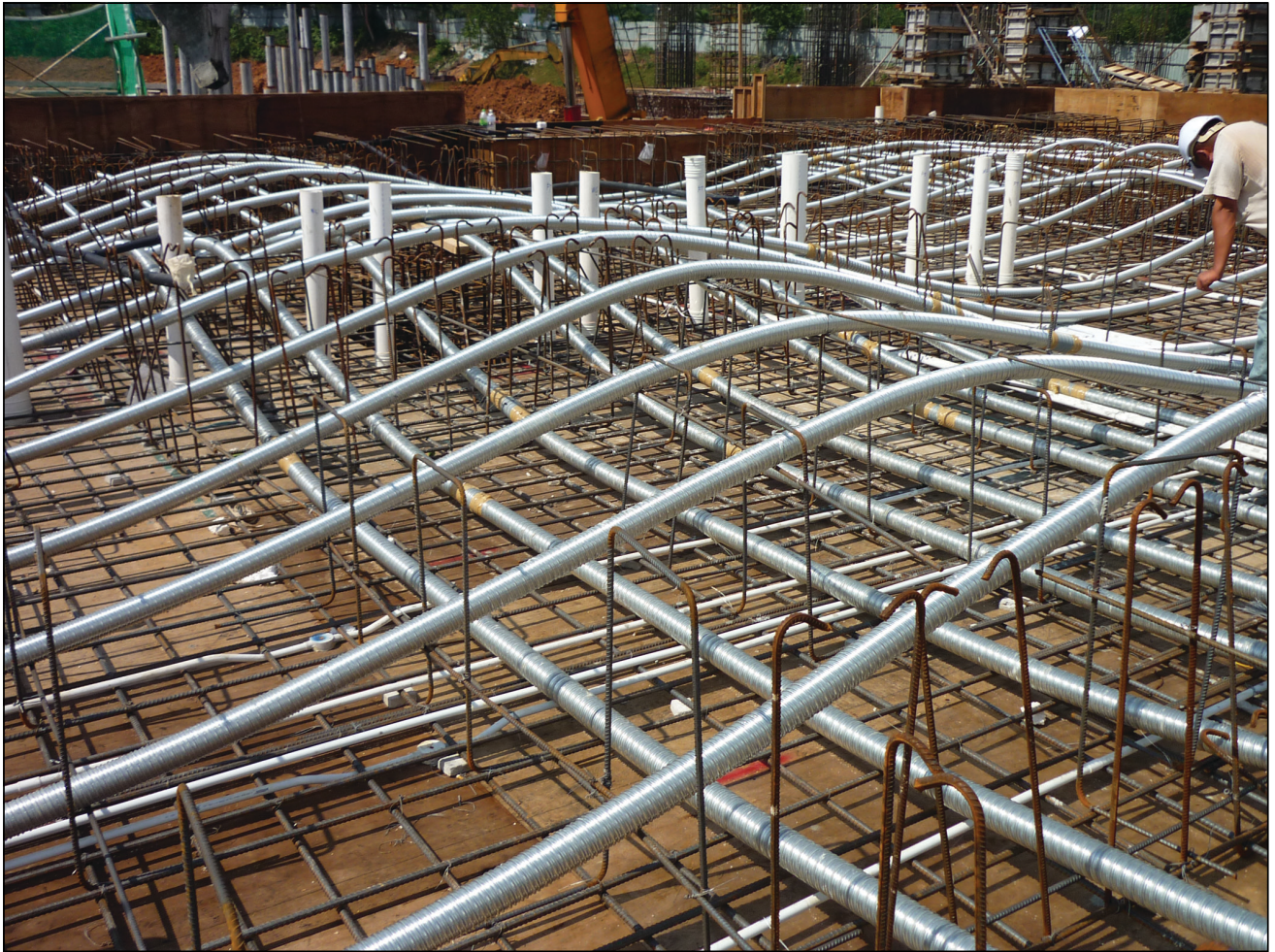
106

Multistrand systems

Features

- From 1 to 91 strands (larger sizes on request)
- 15.7mm dia. strands are more common (12.9mm also possible)
- Bonded or unbonded tendons
- Plastic or steel ducts
- Low concrete strength at transfer
- Staged stressing is common



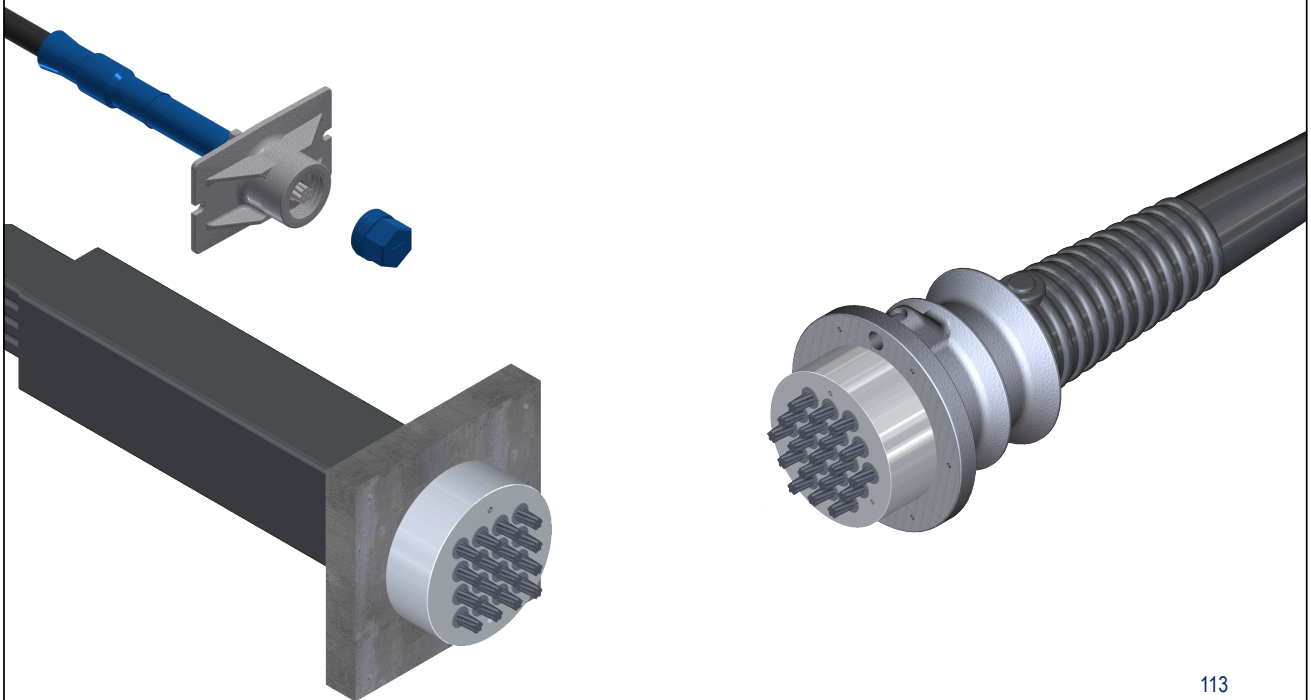




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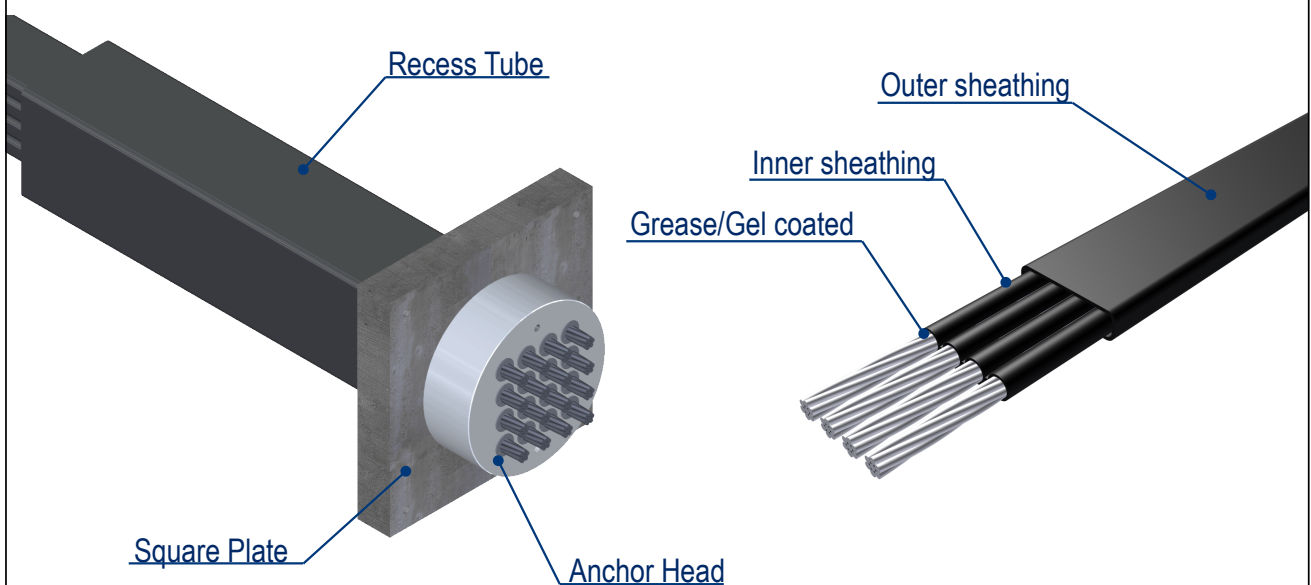
Repair & retrofit



113

Repair & retrofit

Anchorage and strand band

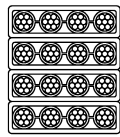


example shown of the BBR VT CONA CMB system

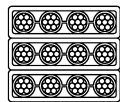
114

Repair & retrofit

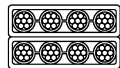
Strand arrangement



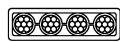
04x04



03x04



02x04



01x04



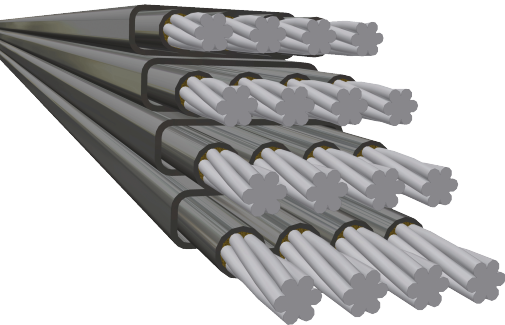
03x02



02x02



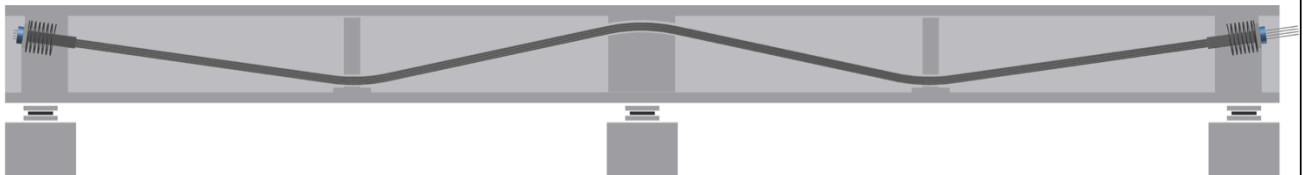
01x02



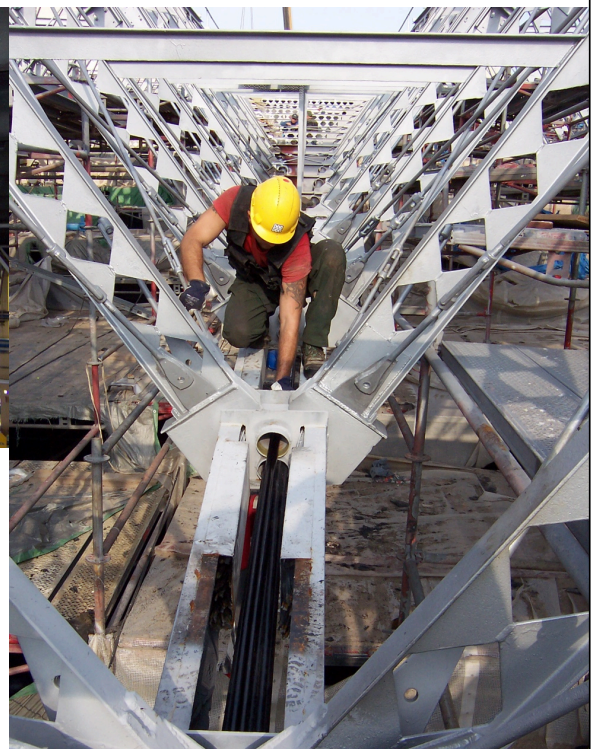
01x01



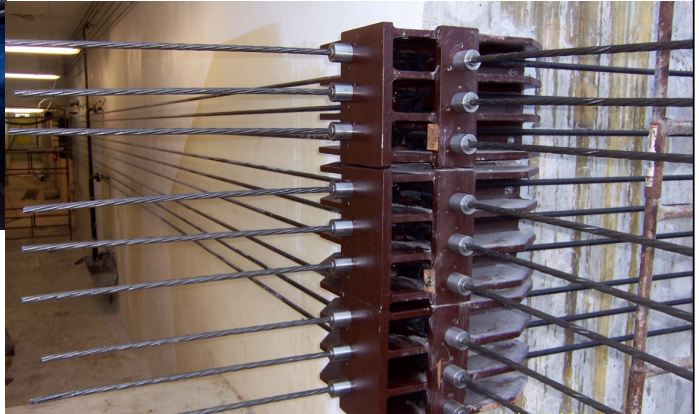
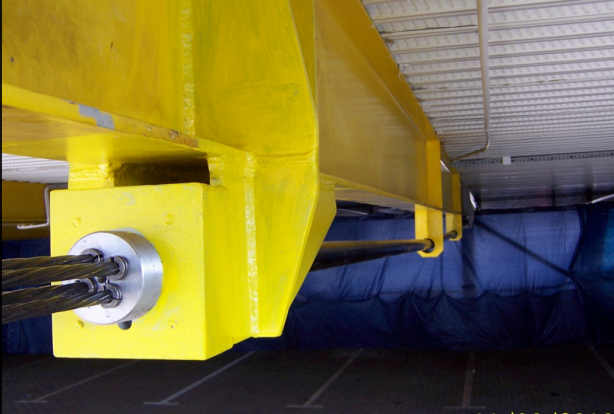
Monostrand



Repair & retrofit



Repair & retrofit



117

Repair & retrofit



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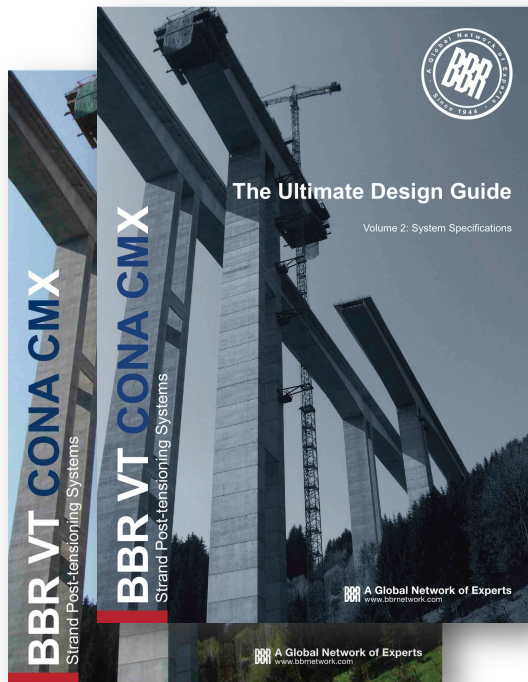
Repair & retrofit



Outline

- Introduction to post-tensioning
- Key benefits of using post-tensioning
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- Testing & approval of post-tensioning systems
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Design Guide



- All about post-tensioning
 - Definition of PT systems
 - Materials
 - Design
 - Detailing
 - Calculations

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What to compare when benchmarking?

- Testing, approvals and level of quality control
- Range of strand and tendon sizes
- Optimized and compact anchorages
- Minimum center spacing distances between tendons
- Minimum tendon to concrete edge distance
- Quantity of anti-bursting reinforcement
- Minimum concrete strength at transfer
- Design features leading to construction productivity enhancements

122

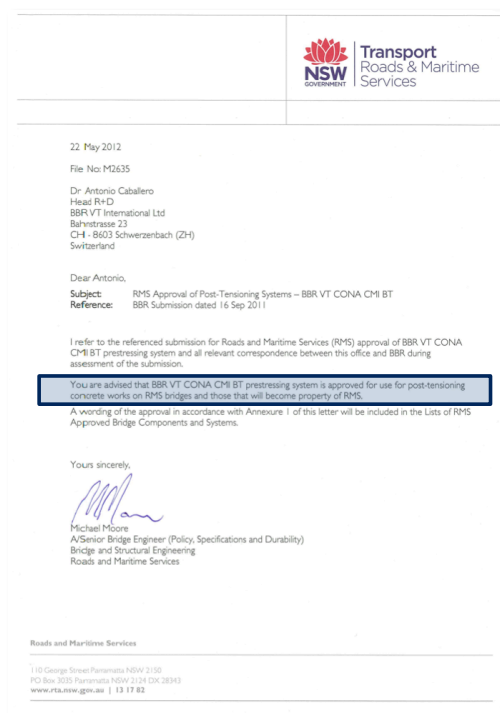
ETA & CE marking



123

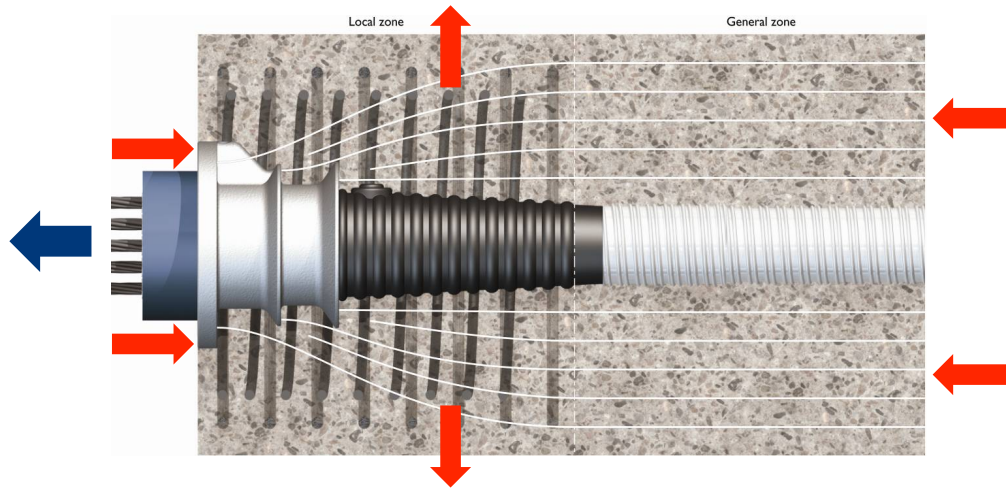
Local back-to-back approvals (RMS)

- Approved as per ETA approval ETA-09/0286
- BBR VT CONA CMI BT system
- Range from 2 to 61 strands
- Spheroidal cast iron load transfer element (500 MPa)
- Anti-bursting steel, anchorage spacing and concrete strength as per ETA approval



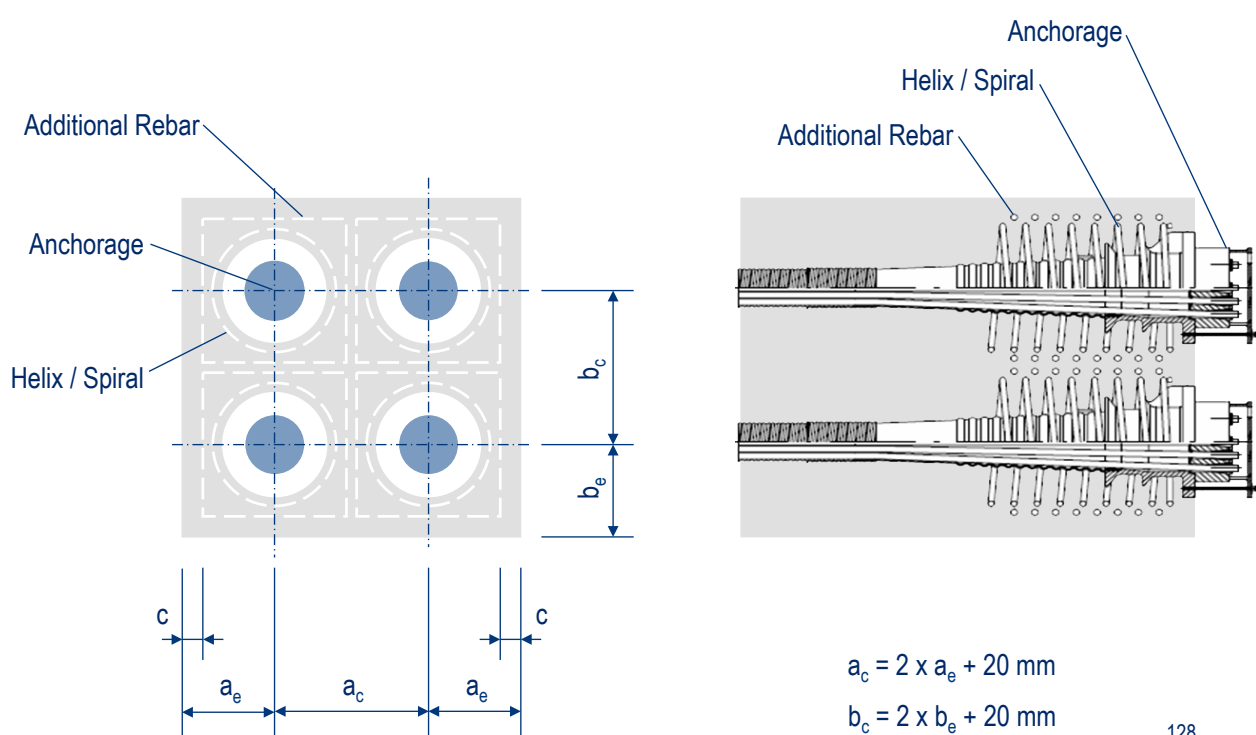
124

Anchorage Zone



127

Anchorage spacings & reinforcement



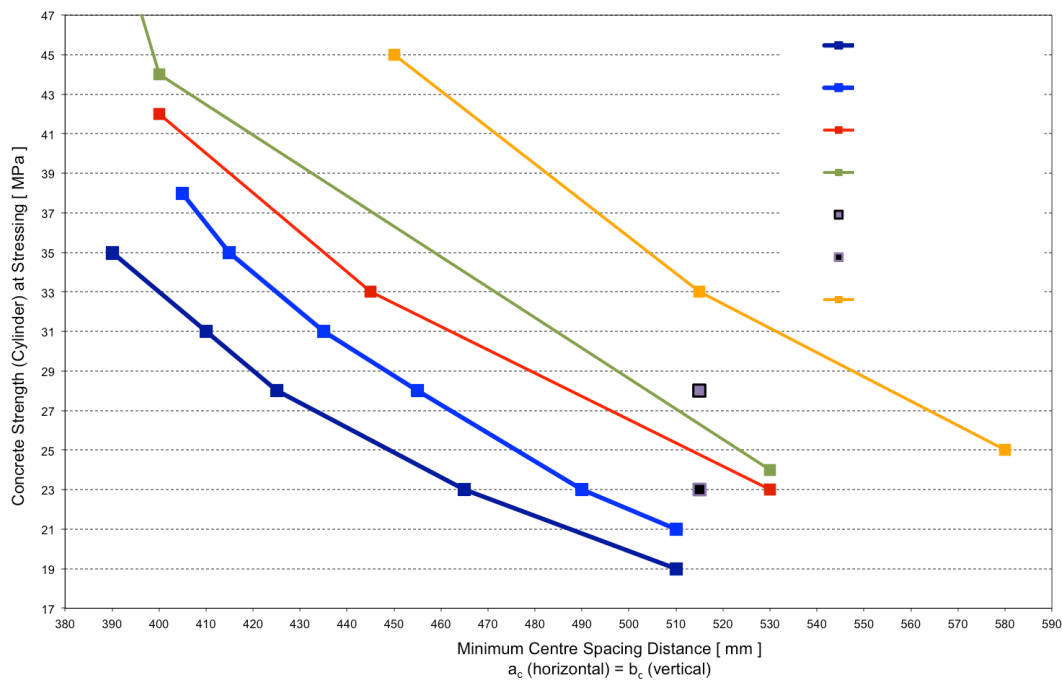
128

Tendon centre spacing efficiency

CE

Anchorage: Size 1906 with 15.7mm strands (1,860MPa)

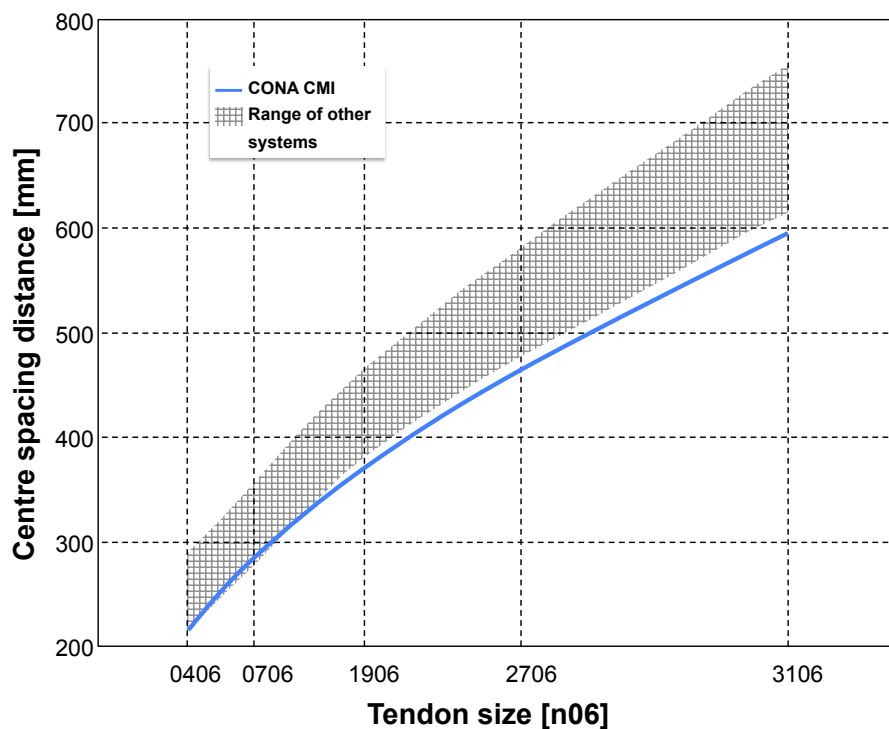
ETA



Note: All information provided is publicly available. Refer to the relevant ETA.

129

Tendon centre spacing efficiency

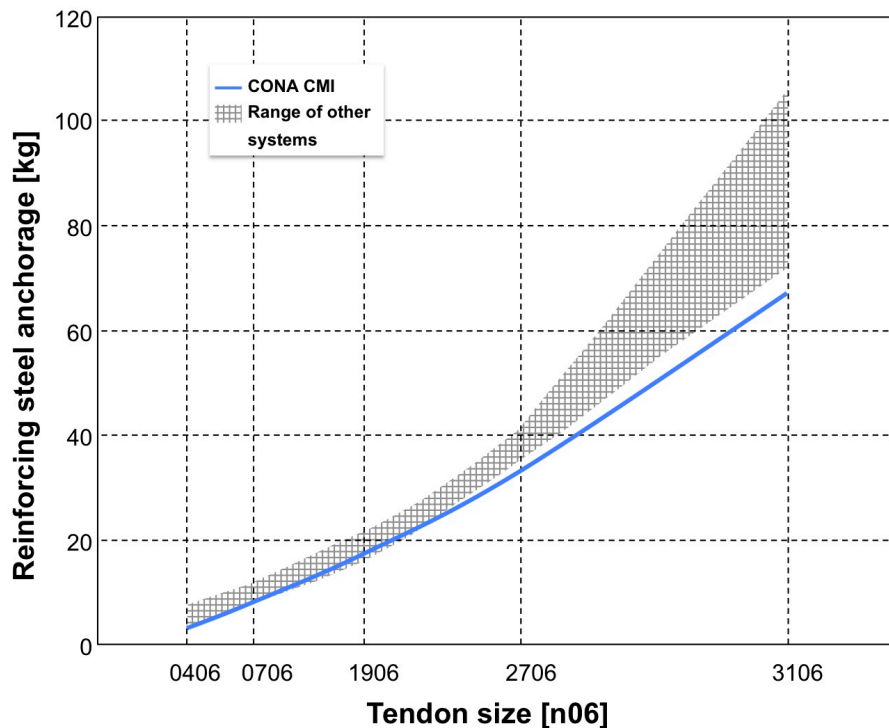


Different systems offer large variations in center-spacing and edge distances

Note: All information provided is publicly available. Refer to the relevant ETA.

130

Anti-bursting reinforcement efficiency



Different systems require varying degrees of anti-bursting reinforcement

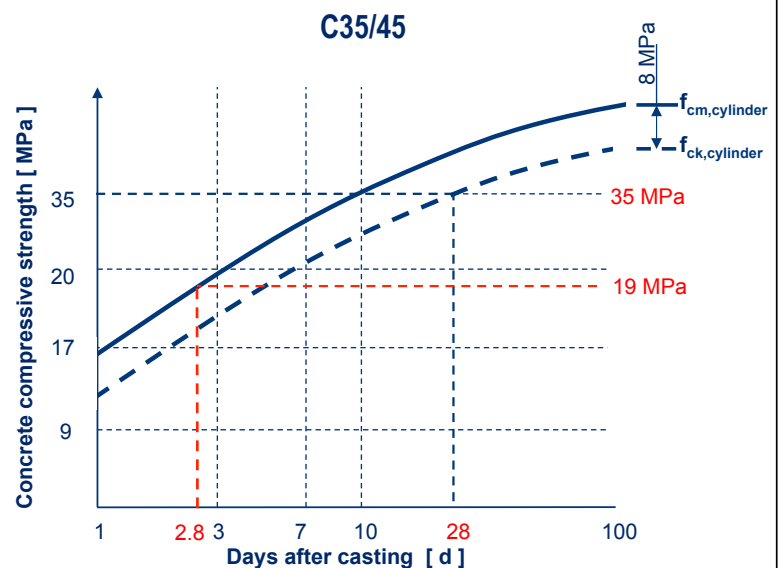
Note: All information provided is publicly available. Refer to the relevant ETA.

131

Early prestressing

$f_{cm,0,min_cylinder} = 19 \text{ MPa}^*$

→ Full prestressing
after 2.8 days!



*example given of the BBR VT CONA CMI BT system

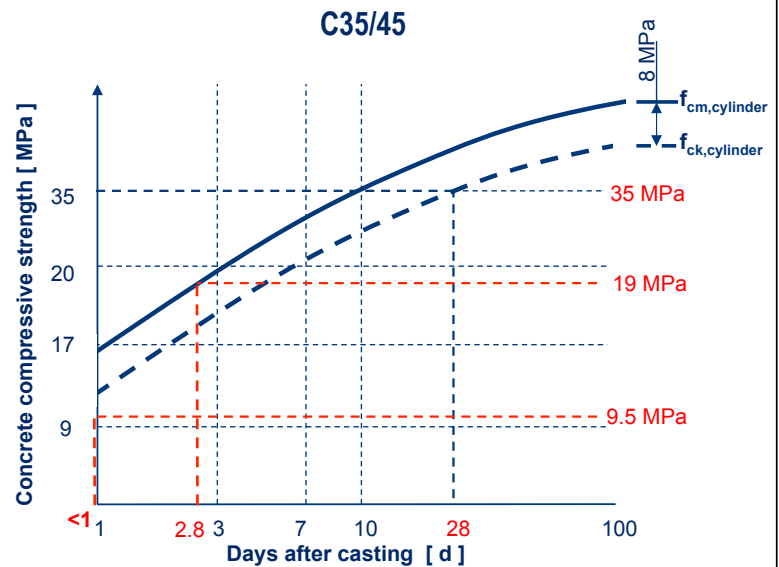
132

Partial prestressing

$f_{cm,0,min_cylinder} = 19 \text{ MPa}^*$

30% of $F_{pm,0}$ might be applied when concrete strength is 50% $f_{cm,0}$

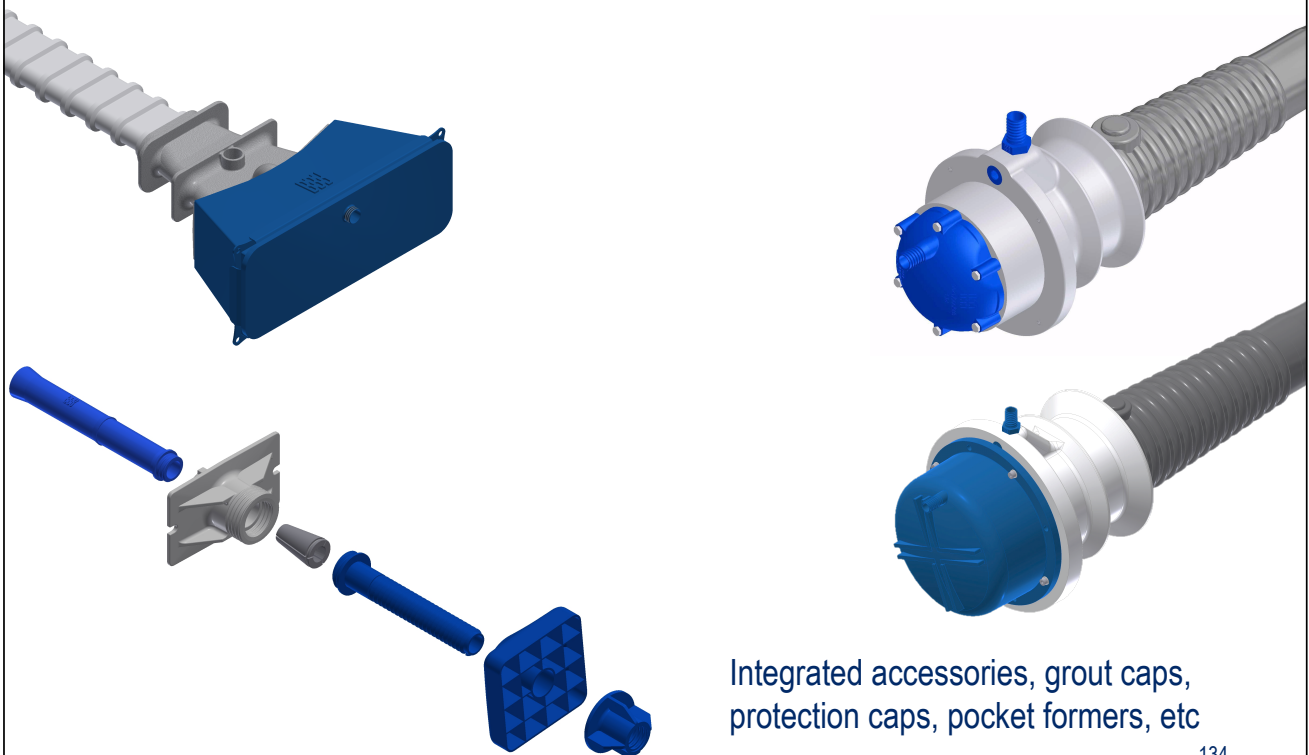
→ Partial prestressing
in less than 1 day!



*example given of the BBR VT CONA CMI BT system

133

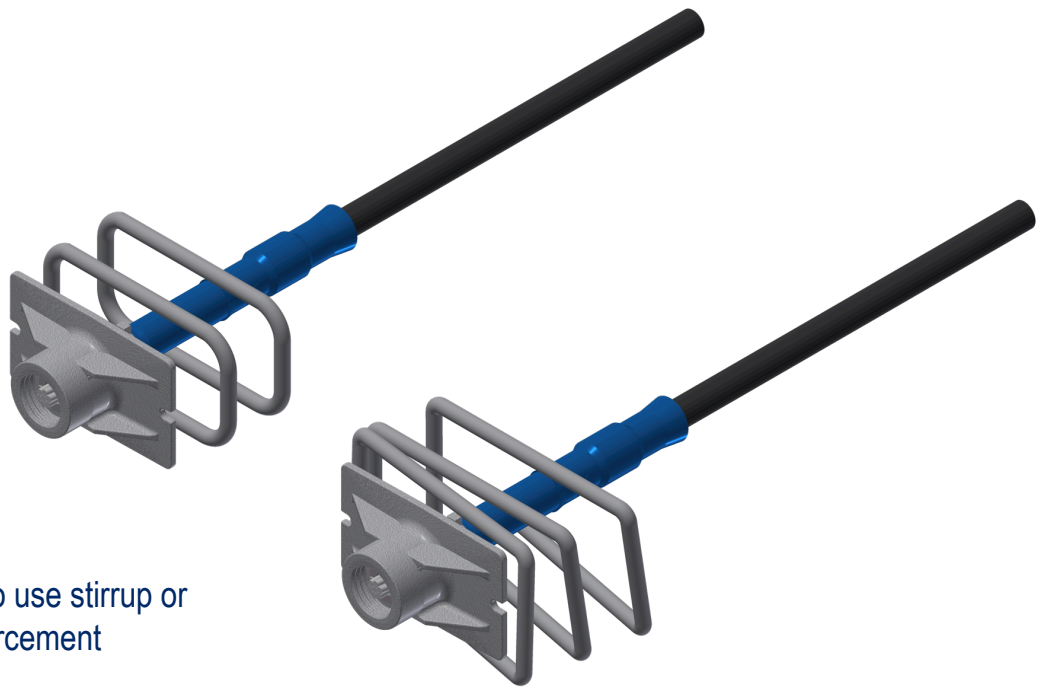
Enhanced productivity on site



examples shown of various BBR PT systems

134

Enhanced productivity on site

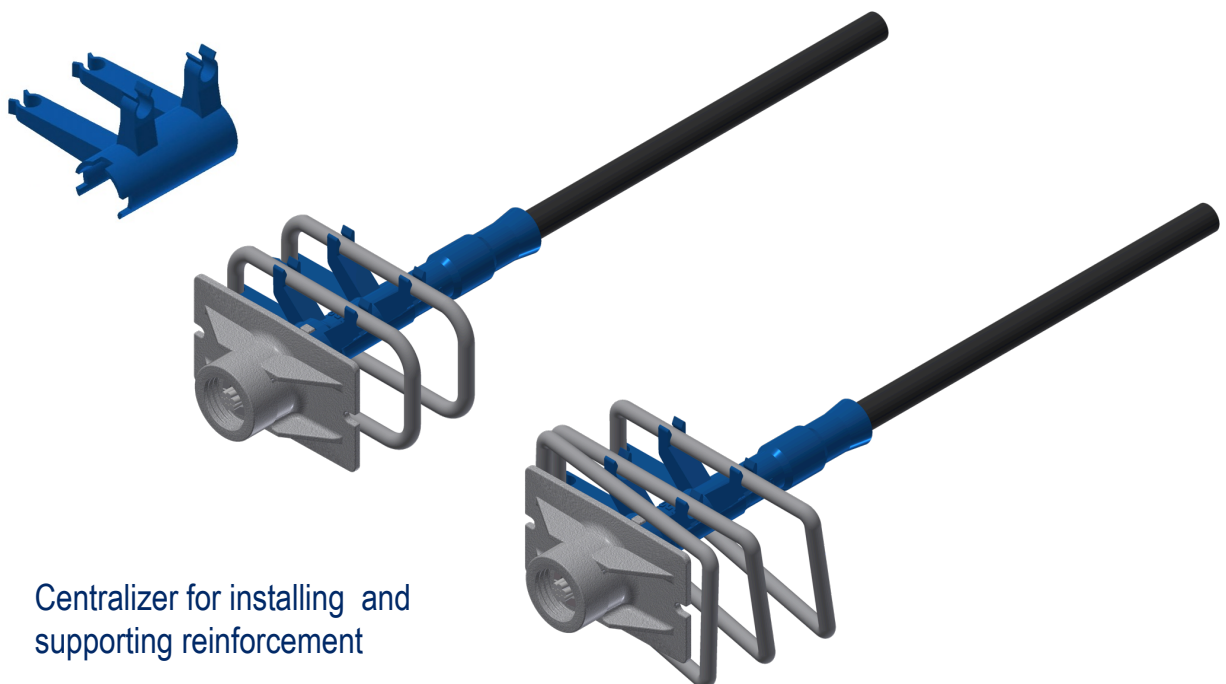


Flexibility to use stirrup or
helix reinforcement

example shown of the BBR VT CONA CMM – S2 system

135

Enhanced productivity on site



Centralizer for installing and
supporting reinforcement

example shown of the BBR VT CONA CMM – S2 system

136

Enhanced productivity on site

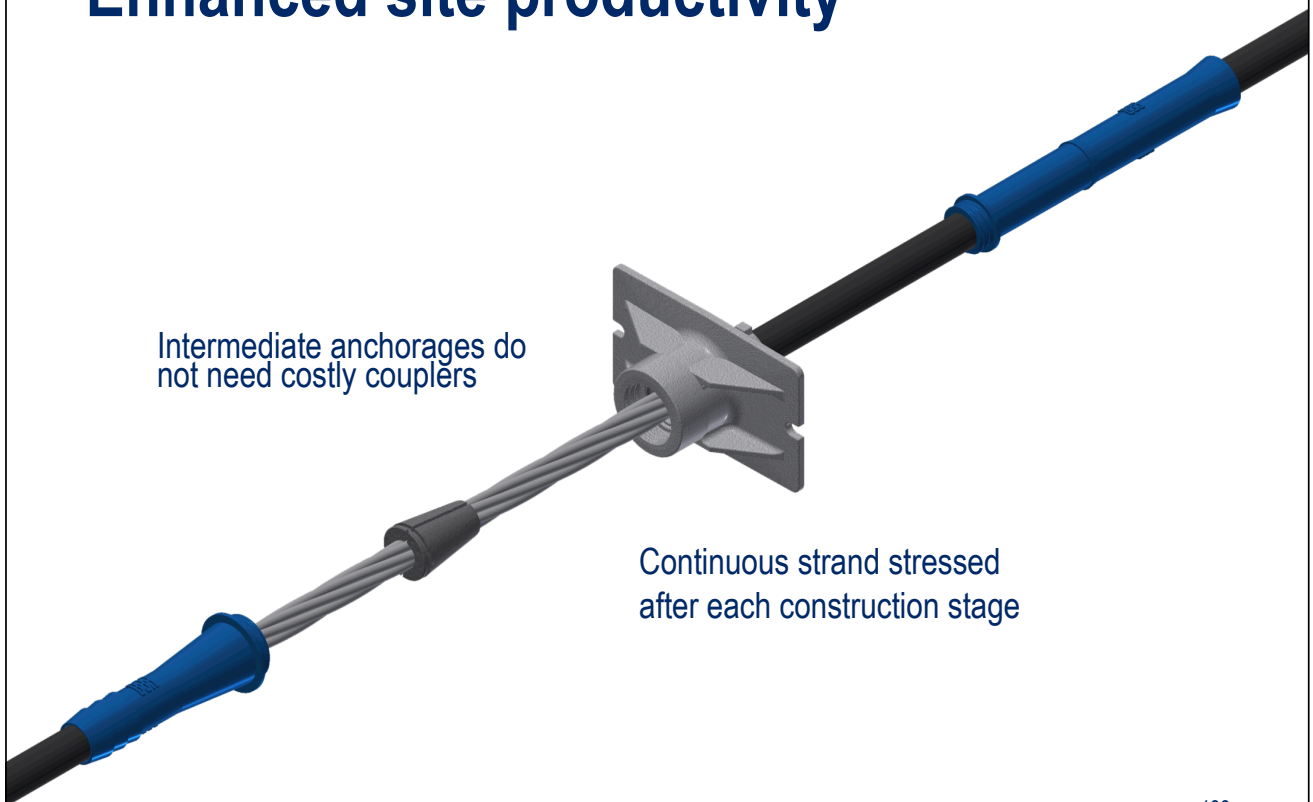


Some systems do not require any anti-bursting reinforcement!

example shown of the BBR VT CONA CMM – S2 system

137

Enhanced site productivity



Intermediate anchorages do not need costly couplers

Continuous strand stressed after each construction stage

example shown of the BBR VT CONA CMM Single – S2 system

138

Enhanced site productivity

Time saving clip-lock spacer



Some systems do not require any anti-bursting reinforcement!

example shown of the BBR VT CONA CMO system

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Working table references – ETA

CONA CMI BT n06		02 06				03 06				04 06				05 06				06 06				07 06				08 06				09 06			
Cube strength	f_{cm2} MPa	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43		
Cylinder strength	f_{cm0} MPa	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35		
Outer diameter HELIX	mm	160	160	160	160	155	160	160	160	160	155	180	160	160	160	155	200	195	195	195	195	200	200	195	195	195	230	200	200	200	200		
Bar diameter	mm	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	12	12	12	12	12			
Pitch	mm	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	50	50	60	50	45	50	50	50	50	50	50	50	50	50			
Number of pitches		3	5	5	5	5	3	5	5	5	5	3	5	5	5	5	6	5	5	5	5	6	6	5	5	5	6	6	6	6	6		
Distance	E mm	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	18	18	18	18	18	18	18	18	18	18	20	20	20	20	20		
Number of STIRRUPS		3	3	3	3	3	4	3	4	4	3	3	3	4	4	3	4	4	5	3	4	5	4	4	4	4	4	6	5	4	5		
Bar diameter	mm	8	8	8	8	8	10	8	8	10	10	12	12	10	10	12	12	12	12	12	12	14	14	12	14	12	12	12	14	14	12		
Spacing	mm	55	55	55	55	55	45	55	45	45	55	60	55	45	45	55	55	50	50	65	50	50	55	45	65	50	55	70	45	50			
Distance	F mm	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	33	33	33	33	33	33	33	33	33	33	33	33	33	35	35		
Minimum outer dimensions	A = B mm	190	190	190	190	190	190	190	190	190	190	220	200	190	190	190	250	230	230	230	230	270	250	230	230	230	290	270	240	240	240		
Centre spacing	$a_k = b_k$ mm	210	210	210	210	205	210	210	210	210	205	235	215	210	210	205	265	250	250	250	250	290	265	250	250	250	310	285	260	255	255		
Edge distance (+ c)	$a_k' = b_k'$ mm	95	95	95	95	95	95	95	95	95	95	110	100	95	95	95	125	115	115	115	115	135	125	115	115	115	145	135	120	120	120		
CONA CMI BT n06		12 06				13 06				15 06				16 06				19 06				22 06				24 06				25 06			
Cube strength	f_{cm2} MPa	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43	23	28	34	38	43		
Cylinder strength	f_{cm0} MPa	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35	19	23	28	31	35		
Outer diameter HELIX	mm	330	280	275	260	250	375	330	300	280	270	375	330	315	305	305	375	330	320	310	305	420	360	360	330	325	475	420	390	360	340		
Bar diameter	mm	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14		
Pitch	mm	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50		
Number of pitches		7	7	7	7	6	8	8	8	7	6	9	9	8	7	7	9	9	9	8	7	10	10	9	9	8	11	11	10	9	11		
Distance	E mm	20	20	20	20	20	23	23	23	23	23	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	31	31	31	31	31		
Number of STIRRUPS		7	6	5	5	6	7	6	6	6	7	7	6	5	6	5	7	6	5	6	6	7	7	7	7	7	6	7	7	7	7		
Bar diameter	mm	12	14	16	16	14	12	14	14	14	14	14	16	16	16	16	14	16	16	16	16	16	16	16	16	16	20	20	20	20	20		
Spacing	mm	60	55	70	70	50	55	60	55	60	45	60	65	65	55	60	60	65	65	60	60	80	75	65	65	60	80	70	65	65	60		
Distance	F mm	35	35	35	35	35	40	40	40	40	40	42	42	42	42	42	42	42	42	42	42	46	46	46	46	46	47	47	47	47	50		
Minimum outer dimensions	A = B mm	390	350	320	310	290	410	370	340	320	310	440	400	360	350	350	450	410	370	360	350	490	450	410	390	370	530	480	440	420	400		
Centre spacing	$a_k = b_k$ mm	405	370	340	325	310	425	390	355	340	325	455	415	380	365	365	470	430	390	375	365	510	465	425	410	390	550	500	460	440	420		
Edge distance (+ c)	$a_k' = b_k'$ mm	195	175	160	155	145	205	185	170	160	155	220	200	180	175	175	225	205	185	180	175	245	225	205	195	185	265	240	220	210	200		

Note: Example table given for the BBR VT CONA CMI BT system

140

Questions?



Session 1

Wednesday 30 May

Economics of Post-Tensioned Construction and Quantities

Florian Aalami

Economics of Post-Tensioned Construction and Quantities for Buildings

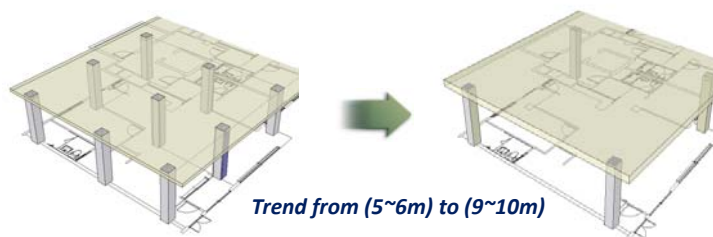
ADAPT Corporation | Redwood City, CA, USA
ADAPT Latin America | Miami, FL, USA
ADAPT International Pvt. Ltd. | Kolkata, India

Dr. Florian Aalami
www.adaptsoft.com
May 2018

Post-Tensioning in Building Structures

Owners, Developers, Engineers, Architects and Contractors are demanding more from buildings today:

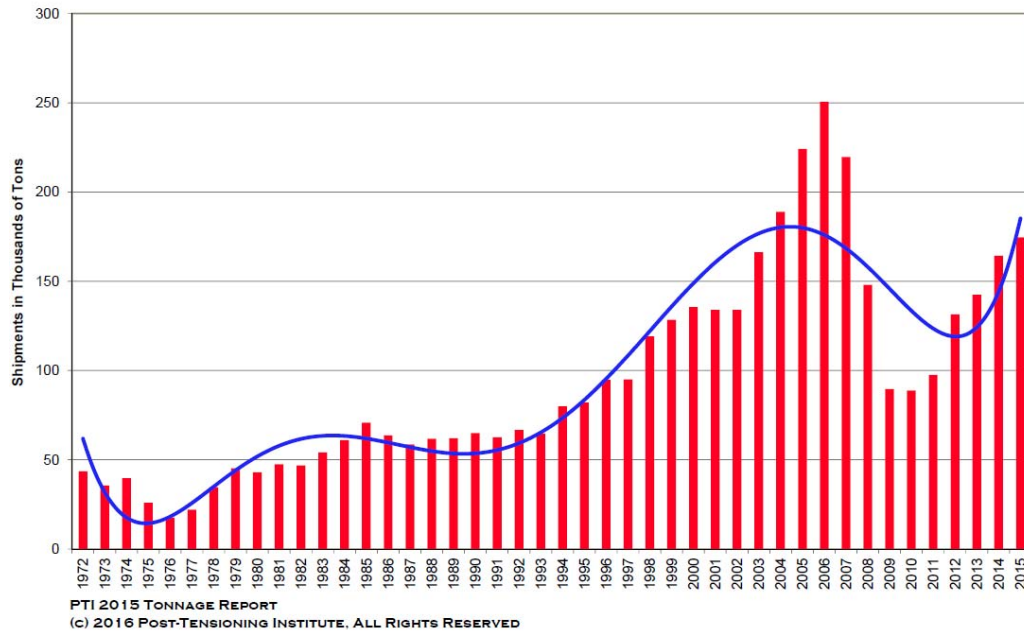
- Cheaper
- Flexible floor layouts: less columns & longer spans



- Unique designs: irregular shapes
- Faster Construction
- Sustainable design

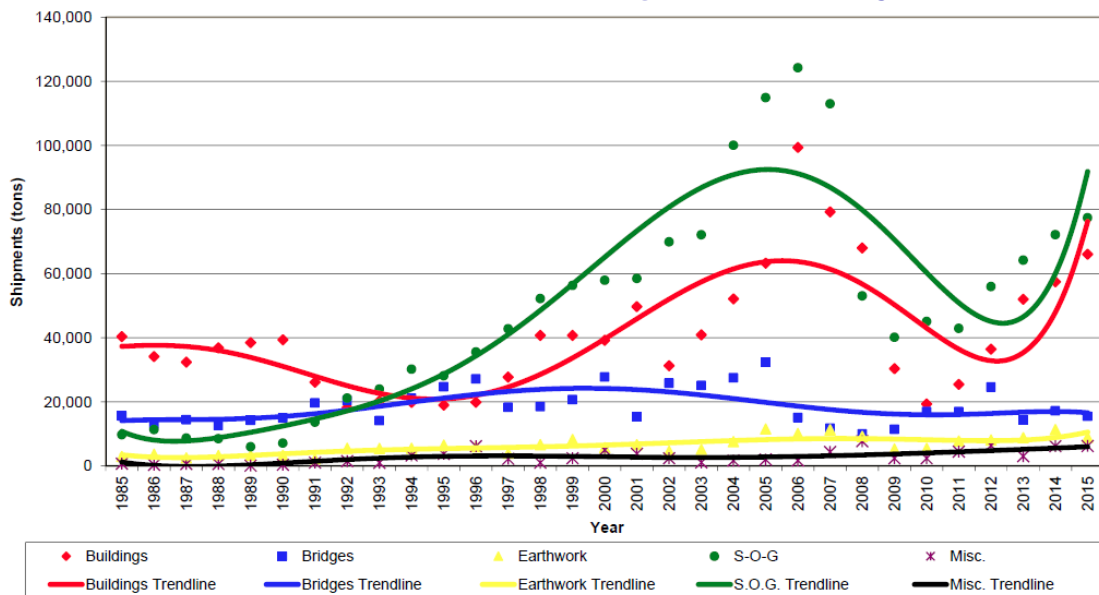
ADAPT Post-Tensioning Usage in North America

North American Post-Tensioning Shipments 1972 - 2015



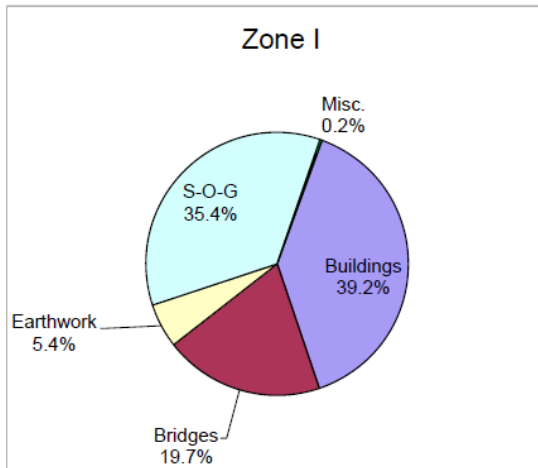
ADAPT Post-Tensioning Usage in North America

North American Post-Tensioning Trend Analysis

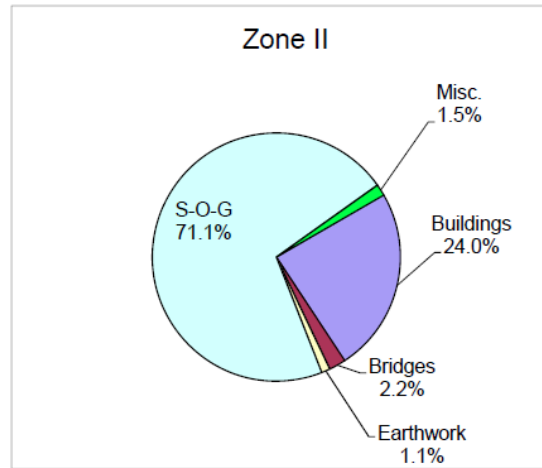


ADAPT Post-Tensioning Usage in North America

Usage of post-tensioning varies greatly by region



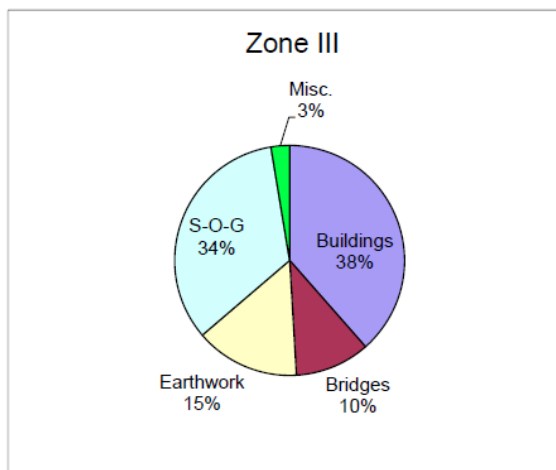
West Coast



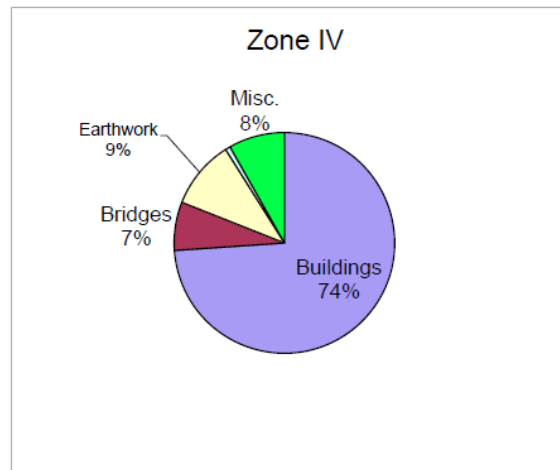
Rocky Mountain States & Southwest

Courtesy PTI Report

ADAPT Post-Tensioning Usage in North America



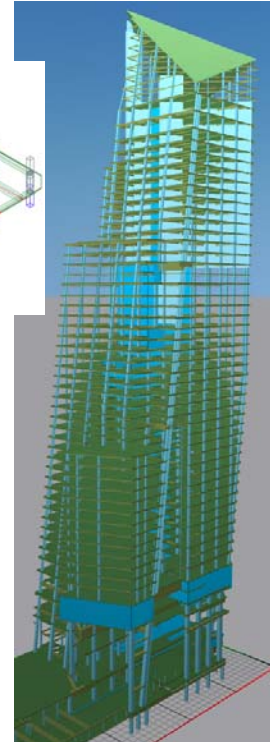
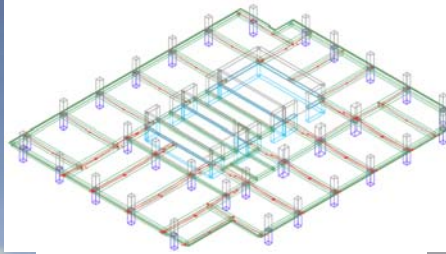
Southeast



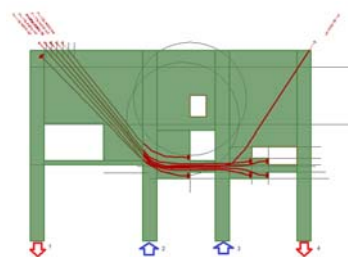
Northeast

Courtesy PTI Report

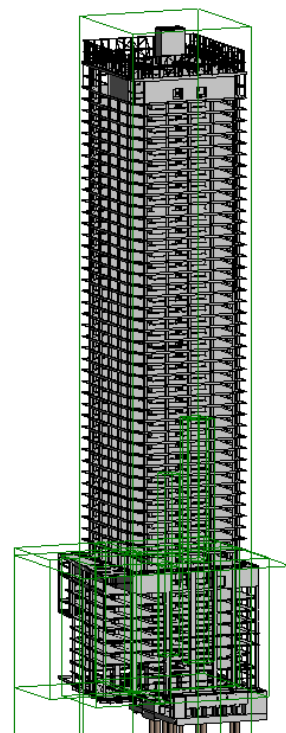




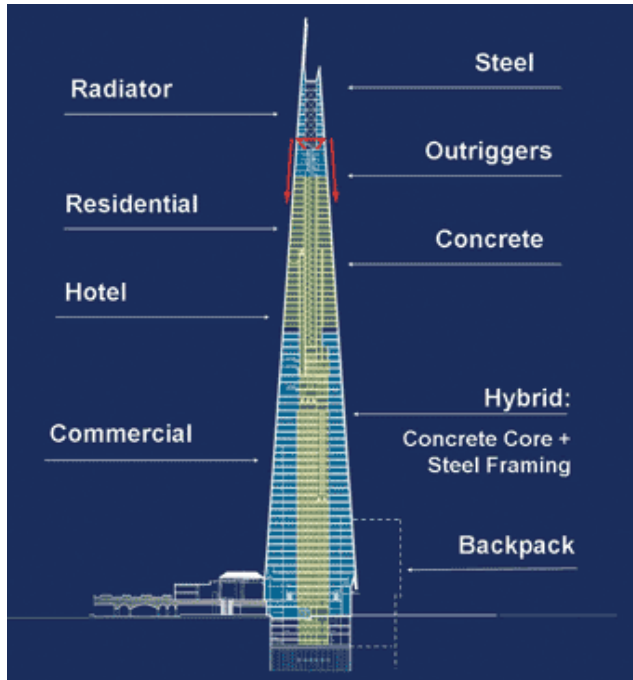
New York, NY



Load transfer



New York, NY



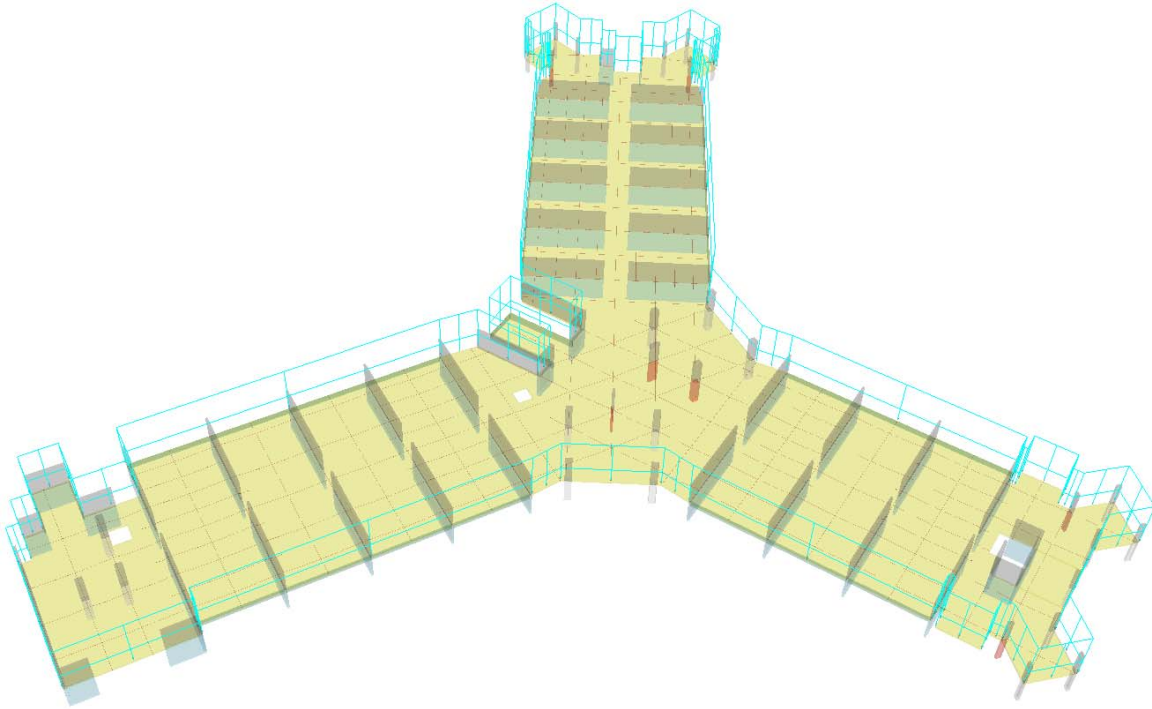
At the lower retail and office levels above ground, composite steel framing (Levels 3 to 39) was designed for spans of up to 15 meters (50 feet) from the perimeter to the concrete cores (Figure 4). At the upper hotel and residential levels, 200-millimeter (8-inch) thick post-tensioned concrete slabs (Levels 40 to 72) were designed for spans of up to 9 meters (30 feet) from the perimeter to the concrete core. These post-tensioned slabs will provide the maximum number of floors within the limit of the building height, as well as providing the required acoustic separation between the residential levels.

London, UK



San Francisco, CA





Bangkok, Thailand



San Francisco, CA



Dubai, UAE



Miami, FL



San Francisco, CA



San Francisco, CA



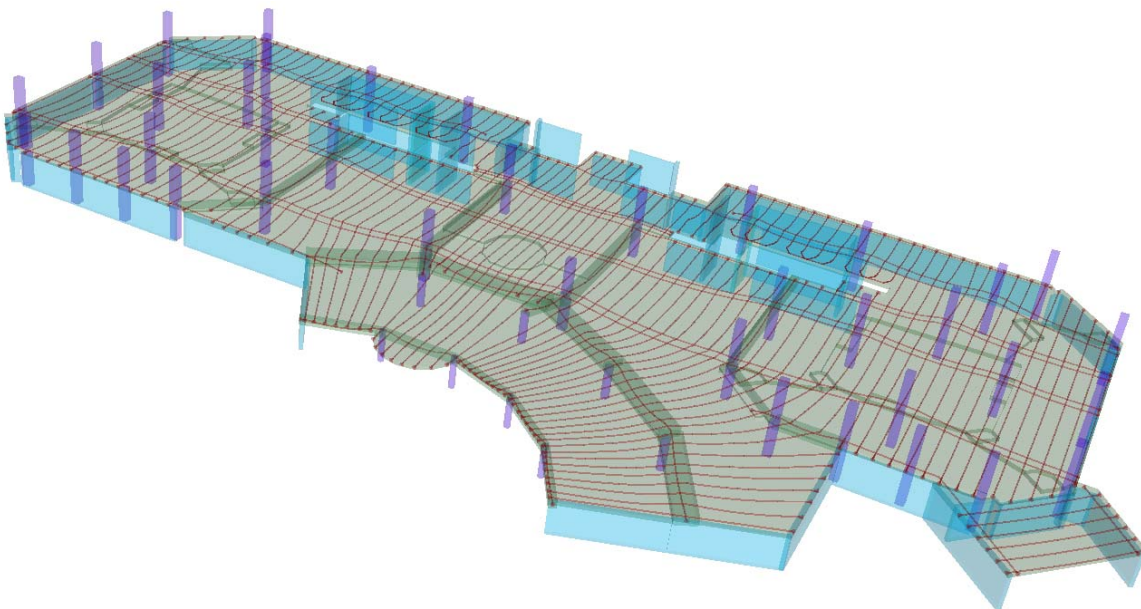
Dubai, UAE



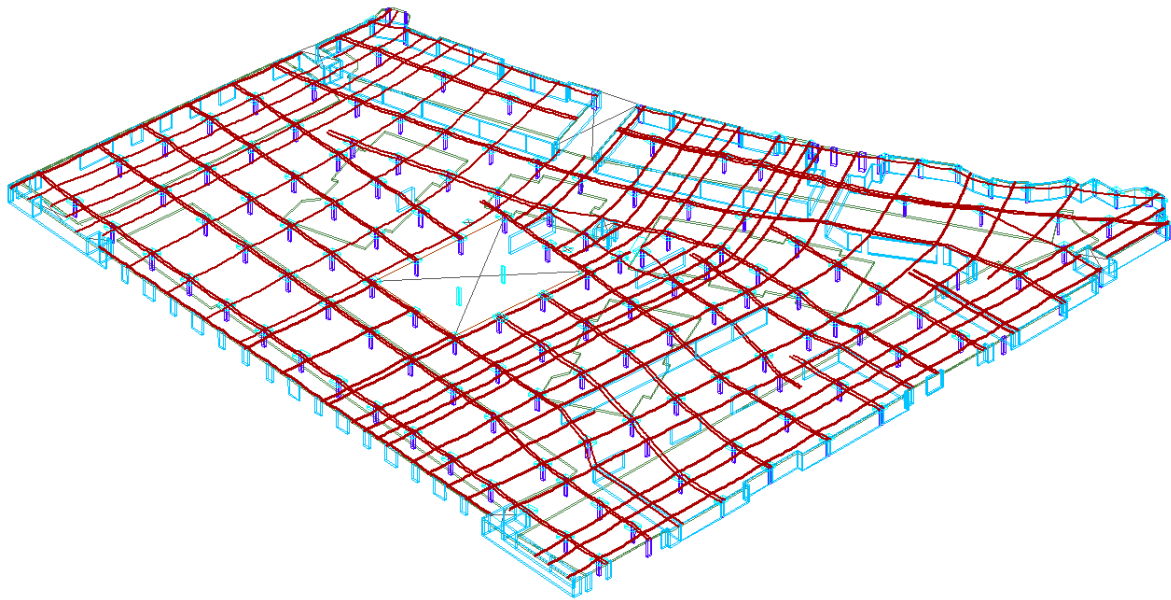
Amman, Jordan



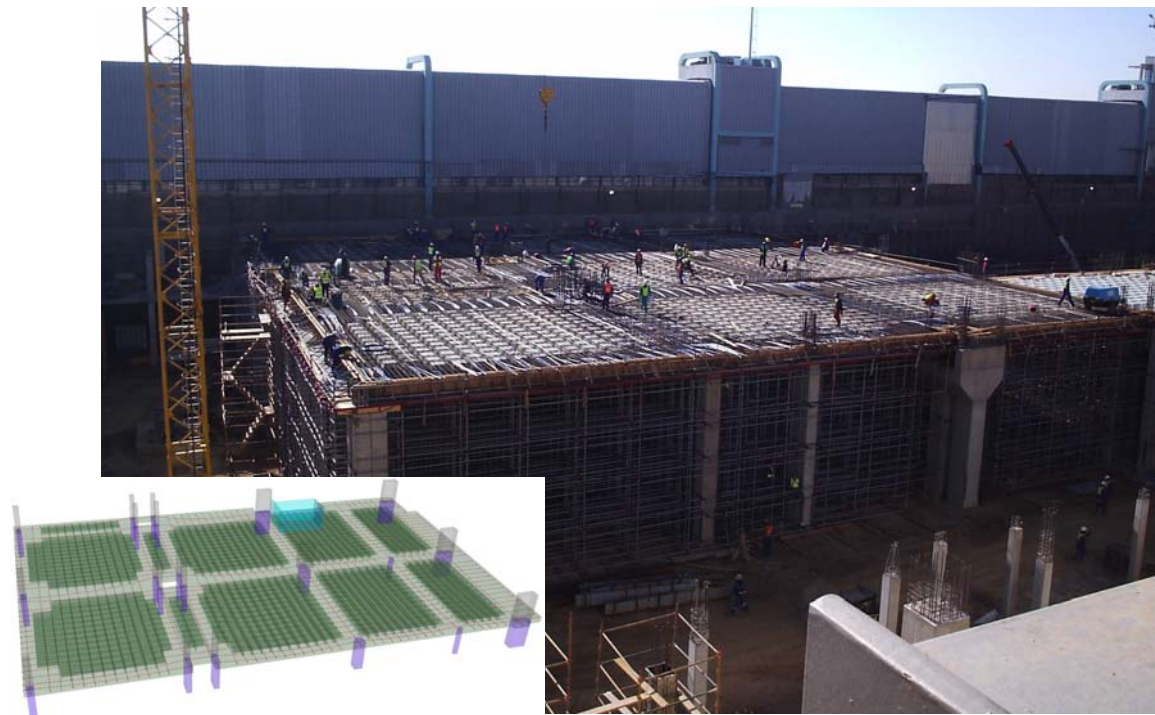
London, UK



Phoenix, AZ



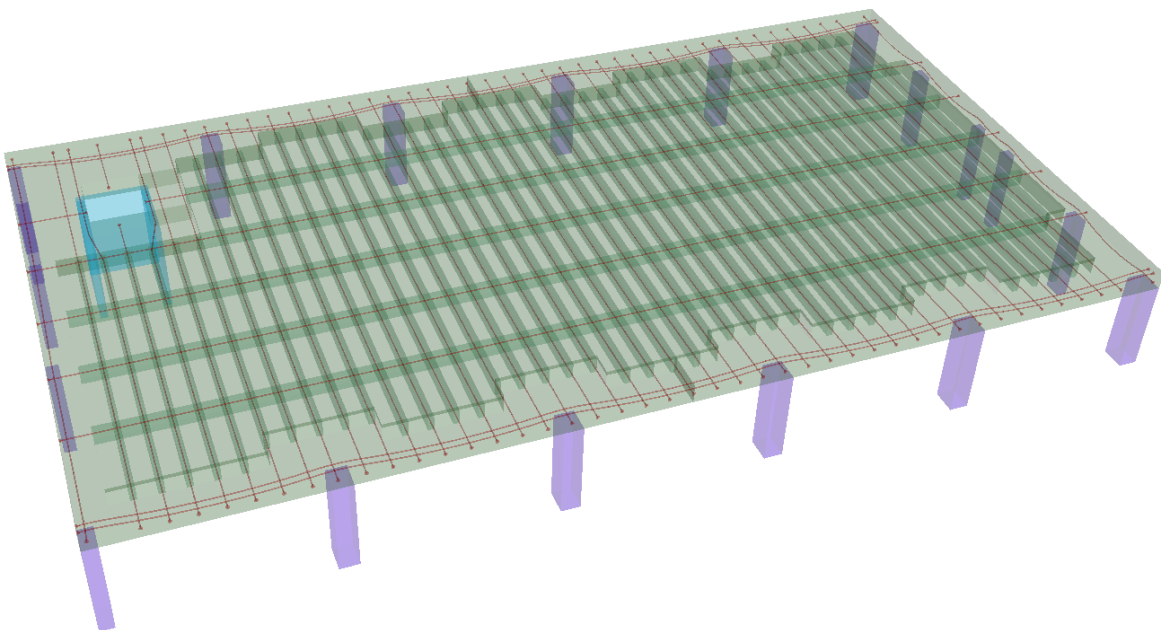
Cupertino, CA



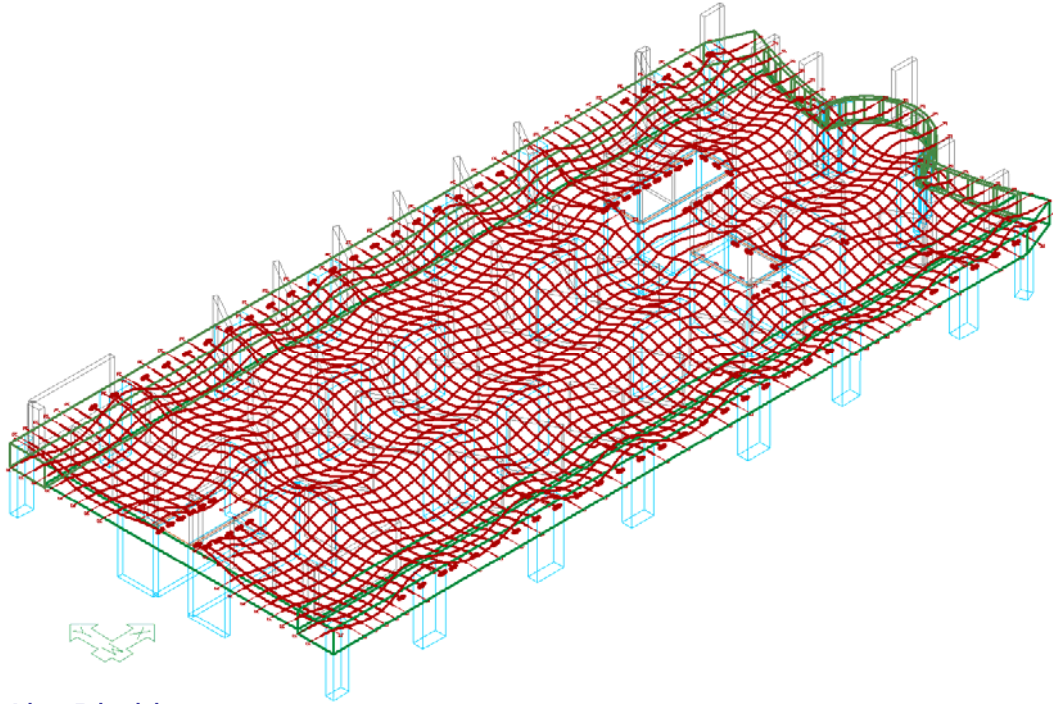
Johannesburg, South Africa



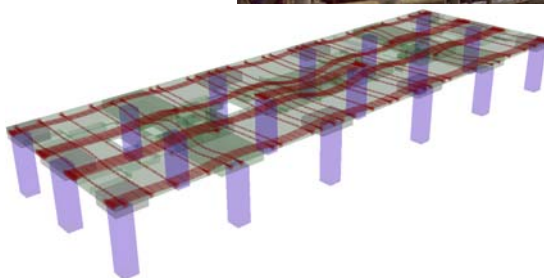
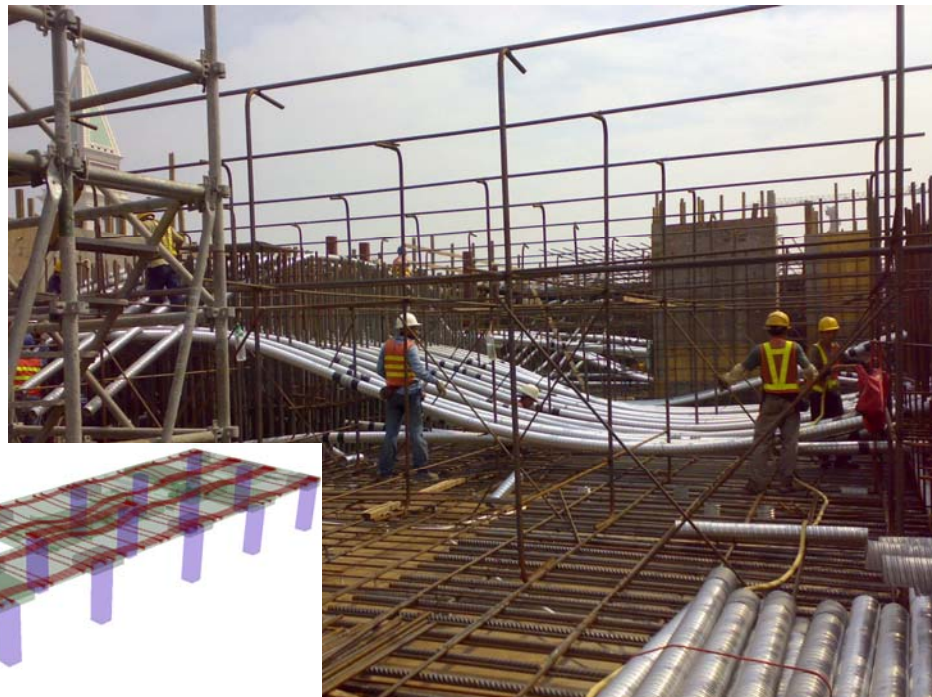
Johannesburg, South Africa



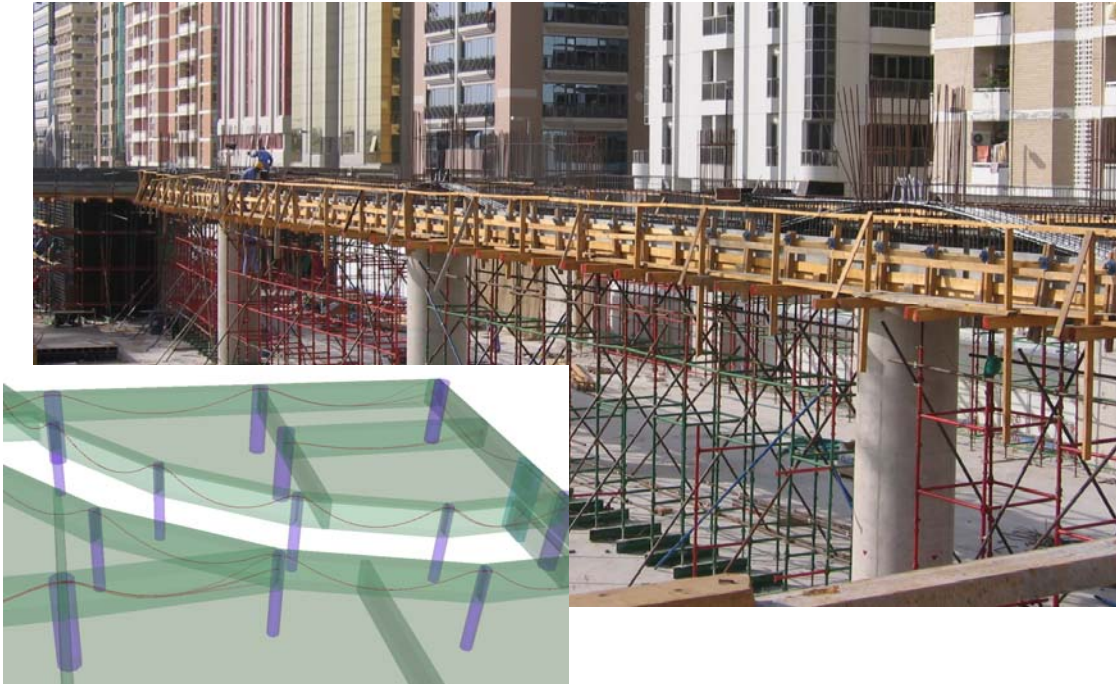
Lisbon, Portugal



Abu Dhabi



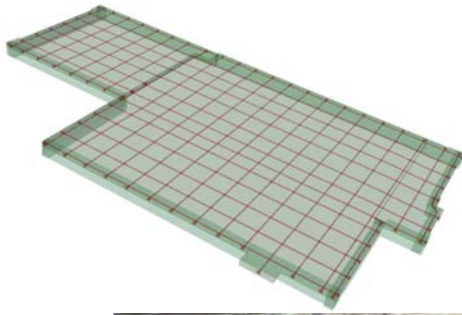
Macau



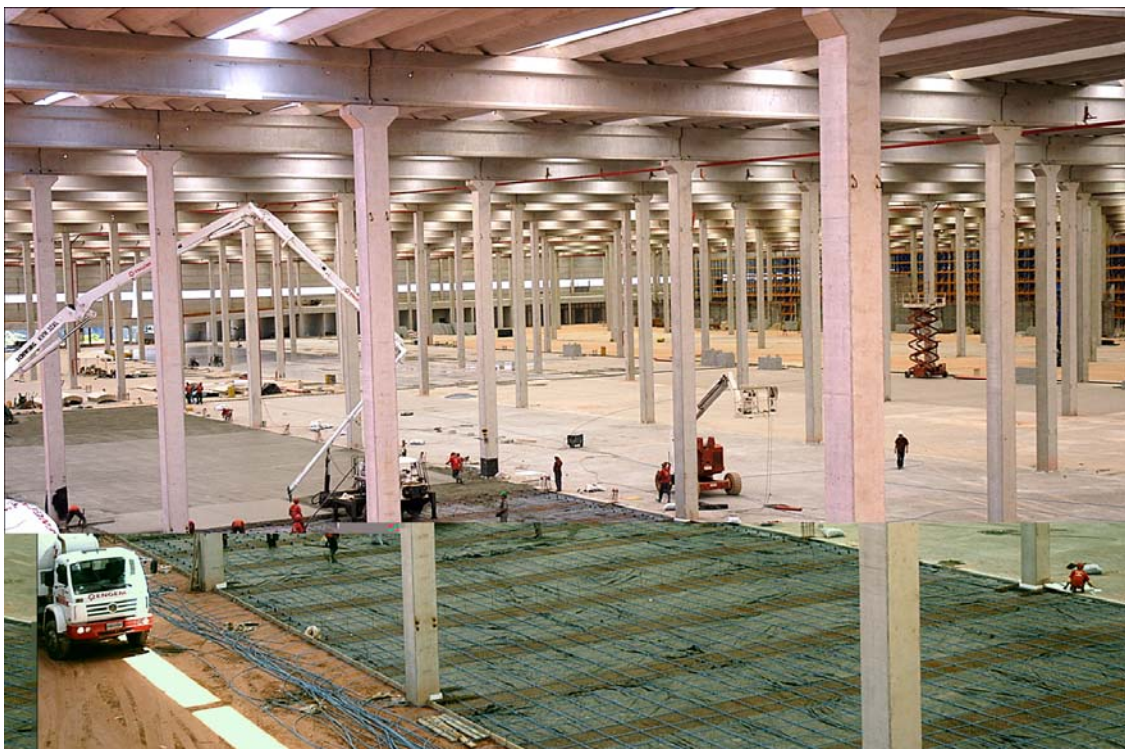
Abu Dhabi, UAE



Dallas, TX

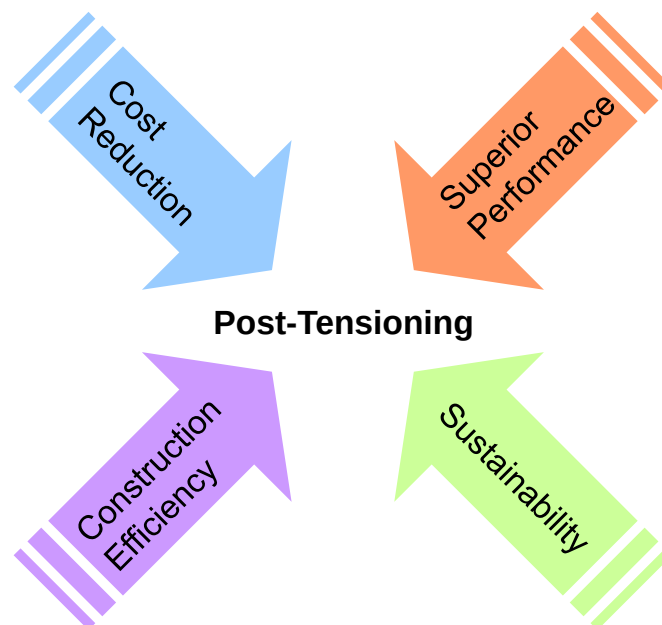


Los Angeles, CA





Post-Tensioning offers 4 key advantages:



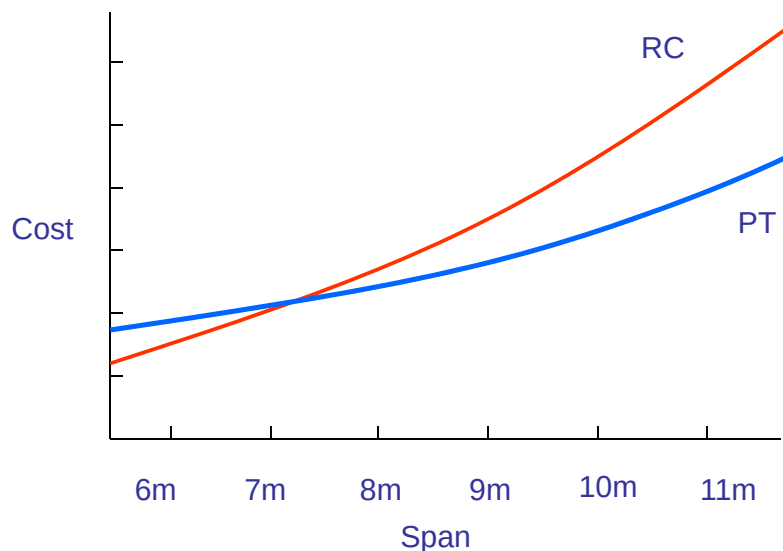
Post-tensioning offers direct cost reduction over conventionally reinforced slabs primarily by reducing concrete and rebar material quantities as well as rebar installation labor. Typically, savings between 10% - 20% in direct cost are achieved

Factors contributing to direct cost reduction:

- Thinner slab (1/3 of RC alternative) with less reinforcement
 - Reduction of material quantities and cost
 - Reduction of labor and material handling costs
 - Reduced total building height and cladding cost
- Reduction of beams and steps
 - Simplified and cheaper formwork
- Rapid reuse of formwork
 - Less formwork needed on jobsite

ADAPT Cost Comparison Between RC & PT Slabs

As a rule, the break even mark between conventional and prestressed solutions is approx. 7m spans



ADAPT Cost Comparison Between RC & PT Slabs

The breakeven point for post-tensioning in buildings varies from country to country depending on the relative cost of:

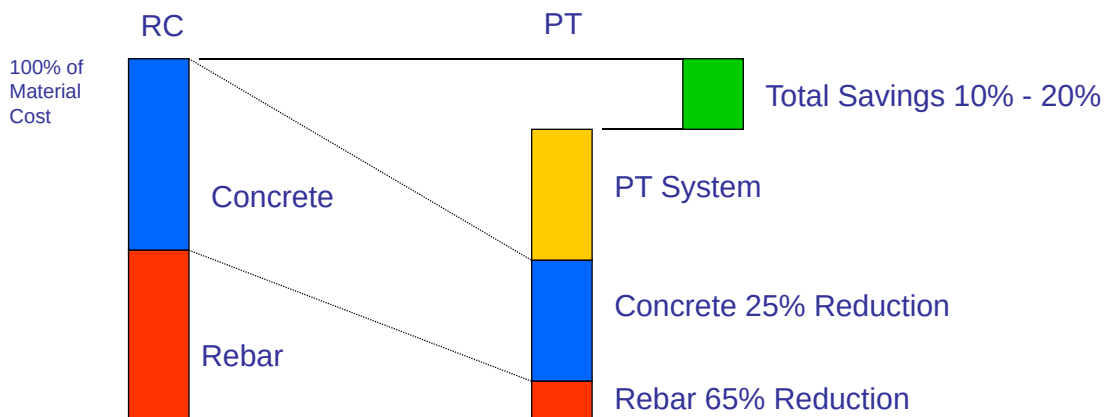
- Rebar
- Tendon
- Concrete
- Labor

	Swiss	Korea	Middle East	Spain	Vietnam	Hong Kong	Malaysia	Singapore	Thailand	USA
Tendon	11,100	4,550	3,805	5,472	3,300	4,260	3,333	3,499	2,667	2,200
Rebar	1,550	890	800	1,176	850	1,160	1,167	1,229	1,000	1,000
Ratio	7.2	5.1	4.8	4.7	3.9	3.7	2.9	2.8	2.7	2.2

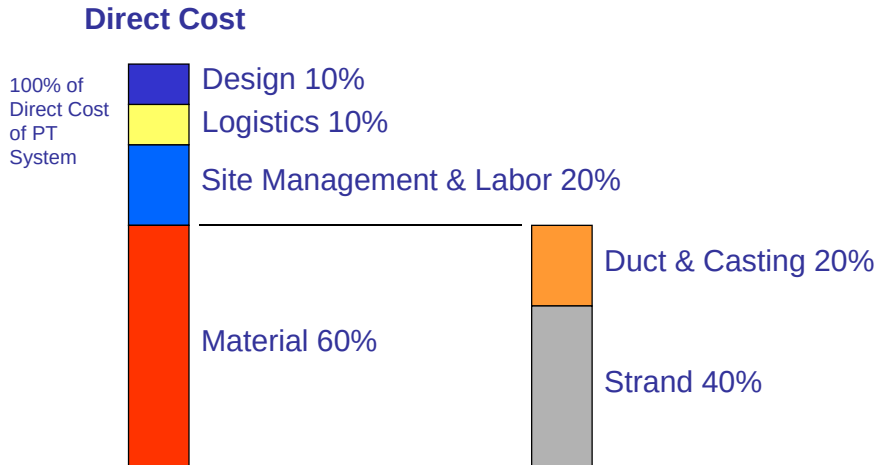
(Representative cost of one ton of material USD)

ADAPT Cost Structure of RC vs. PT Slabs

In a typical slab with spans over 7 meters, the net savings in material cost can range between 10% - 20% of original RC alternative



Material represents 60% of direct cost of a post-tensioning system



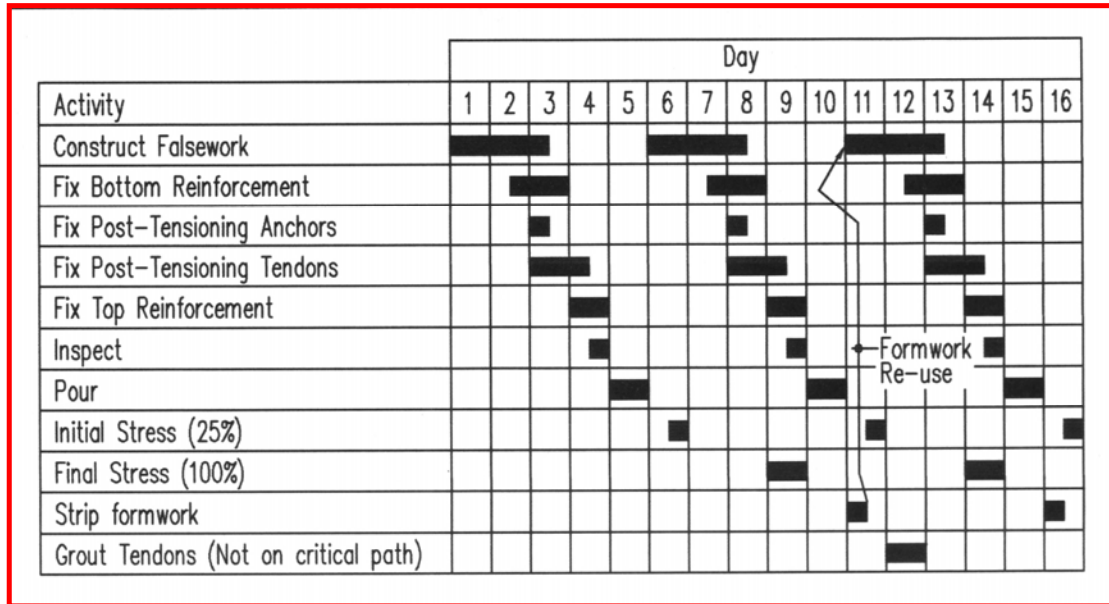
2. Improved Construction Efficiency

Since post-tensioned slabs are designed to carry their own weight at time of stressing, they can significantly improve construction efficiency and deliver an additional 5%-10% of indirect savings

Factors contributing to improved construction efficiency:

- Shorter construction cycles
- Less material handling and impact on other trades
- Simpler slab soffit – less beams and drop caps/panels
- Quicker removal of shoring gives more access to lower slabs

3-day cycle achievable with early strength concrete and industrial formwork



Schedule for 800 – 1,000 m2 slab

Critical planning considerations:

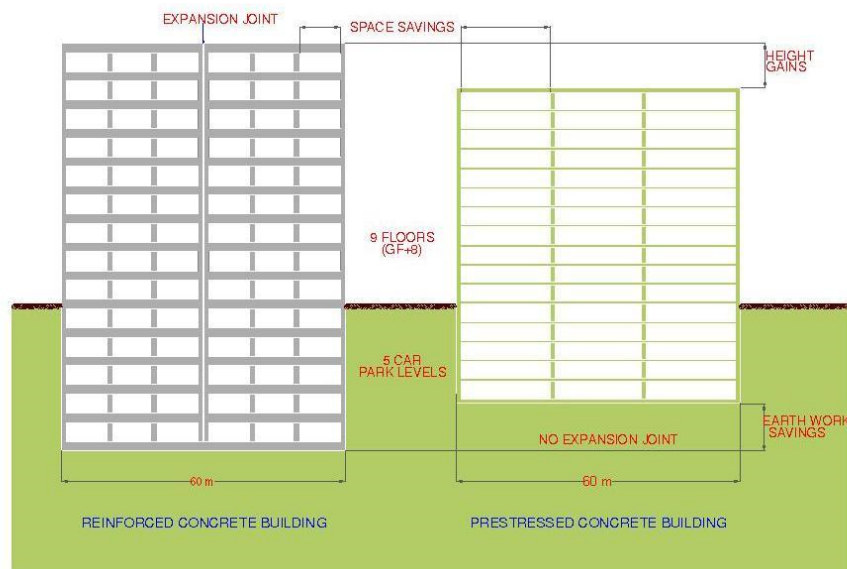
- Installation is simple, but a sequence has to be maintained
- Stressing of cables is done 3-4 days from concreting of slab
- Stressing is normally done at one stage
- Staged stressing is introduced when final loads are much higher than at time of initial stressing (mat slabs and transfer levels)
- Formwork can be removed after stressing of cables
- Temporary propping is only needed for construction loads
- Grouting of bonded tendons can be done at any time after the stressing

The prestressing in post-tensioned slabs takes optimal advantage of tendon, rebar and concrete properties to deliver an economical structural system

Factors contributing to superior structural performance:

- Use of high-strength materials
- Longer spans are achieved (L/40 – 45 vs. L/30 for RC alternative)
- Deflection control (DL is balanced by P/T)
- Crack control and water-tightness
- Reduced floor-to-floor height
- Lighter structure requires lighter lateral load resisting system
- Economy in column and footing design
- Reduced noise transmission compared to RC
- Lower total cost of ownership (maintenance) compared to RC alternatives

To maximize the benefits of post-tensioning at the building project level, the effects of reduced member sizing should be applied early in the design process



Post-Tensioning and rebar rates vary greatly depending of span configuration and loading. Compared to other countries, PT projects in US are designed with less loading and lower PT and rebar rates

Bonded System

US values (1 kN/m² SDL & 2.5 kN/m² LL)

- 3 – 4 kg/m² of PT
- 5 kg/m² of Rebar

With higher loading (3 kN/m² SDL & 3 kN/m² LL)

- 3.5 – 5 kg/m² of PT
- 7 – 9 kg/m² of Rebar

Unbonded System

US values (1 kN/m² SDL & 2.5 kN/m² LL)

- 3.75 kg/m² of PT
- 6 kg/m² of Rebar

Compared to conventionally reinforced structures, post-tensioned buildings offer a more sustainable design alternative

Factors contributing to sustainability:

- Less material use than RC
- Reduced carbon footprint
- Lower cost of ownership
 - Less cracking
 - Lower deflection values
 - Reduced cost for corrosion maintenance



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Session 2

Wednesday 30 May

Design Basics of Post-Tensioned Structures

Bijan Aalami

Basics of Post-Tensioning Design



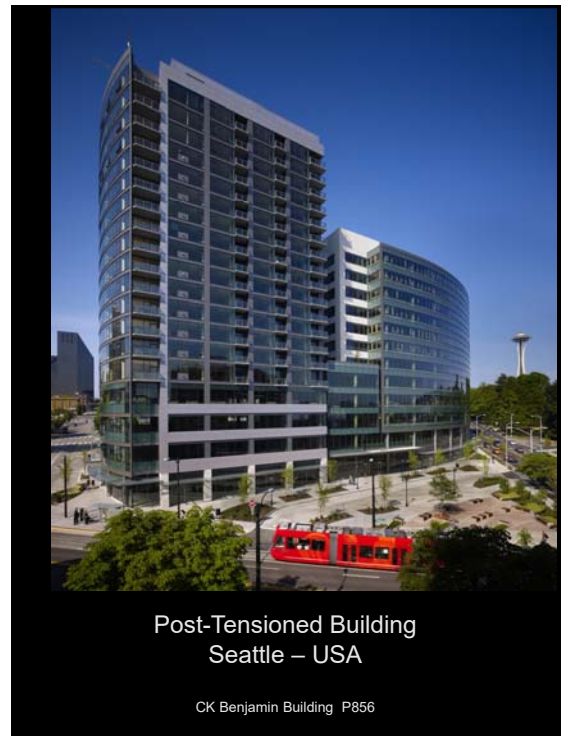
Bijan O Aalami

Professor Emeritus, San Francisco State University
Principal, ADAPT Corporation

ADAPT

P872

bjan@PT-Structures.com copyright PT-Structures 2015



Post-Tensioned Building
Seattle – USA

CK Benjamin Building P856

Structural Modeling of POST-TENSIONING

Options to Account for Post-Tensioning

Modeling tendons as **applied loads**

- ❖ **Balanced** loading
- ❖ Modeling using **primary** moments
- ❖ **Equivalent** loads

Modeling tendons as **resisting reinforcement**

- ❖ **Discrete** tendon modeling

Treatment of post-tensioning and **hyperstatic**
(secondary) actions



Structural Modeling of POST-TENSIONING

TENDON MODELING AS **APPLIED** **LOADING**

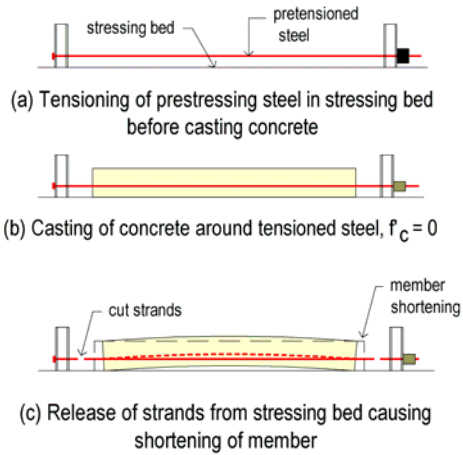
- ❖ **Simple** load balancing [T Y Lin, 1963]
- ❖ **Extended** Load Balancing [Aalami, 1990]
- ❖ Modeling Through **Primary Moments**
- ❖ Modeling Through **Equivalent Forces**

Aalami, B. O. "Structural Modeling of Post-Tensioned Members," Journal of Structural Engineering, ASCE, Vol. 126, Nov. Feb 2000, pp. 157-162

PRESTRESSING

- ❖ Pretensioning
- ❖ Post-tensioning

PTS197

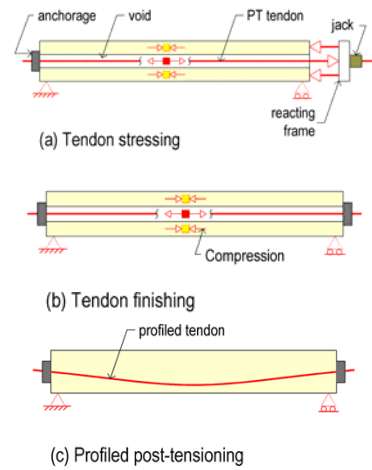


Basics of Pre-Tensioning Steps

PRESTRESSING

- ❖ Pretensioning
- ❖ Post-tensioning

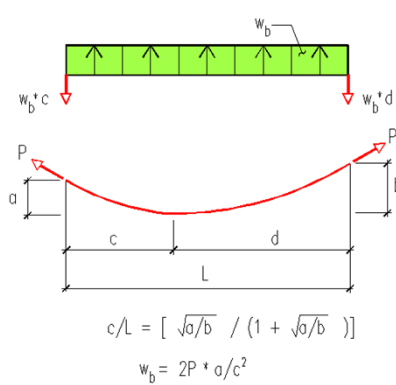
PTS196



Basics of Post-tensioning Construction

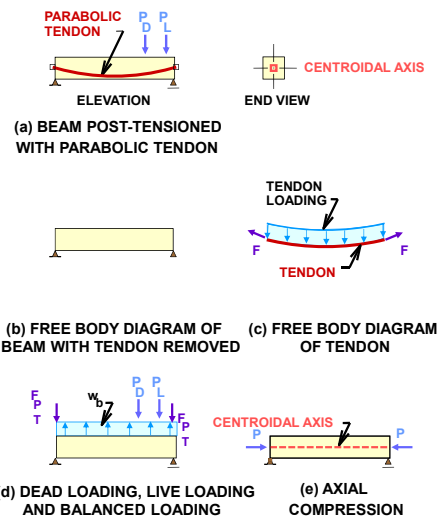
MODELING OF PT TENDONS

PTS107_022311

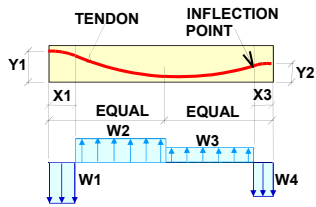


FORCE DIAGRAM OF A SIMPLE PARABOLA

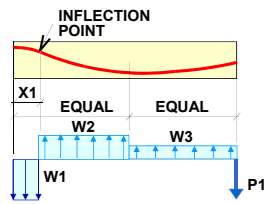
SIMPLE LOAD BALANCING



SIMPLE BALANCED LOADING



(a) REVERSED PARABOLA WITH TWO INFLECTION POINTS



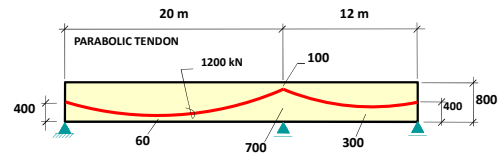
(b) REVERSED PARABOLA WITH ONE INFLECTION POINT

Examples of Balanced Loads

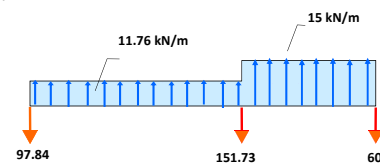
SIMPLE LOAD BALANCING

Based on:

- ❖ Constant force
- ❖ Decoupling of axial and bending effects



(a) PROFILE IDEALIZED AS PARABOLA



(b) BALANCED LOADING

EXTENDED LOAD BALANCING

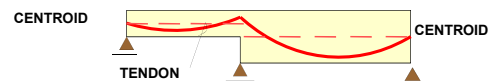
Based on:

- ❖ Constant force
- ❖ Decoupling of axial and bending effects

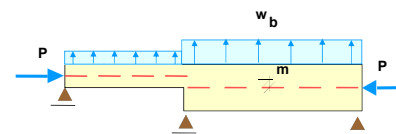
Added feature

- ❖ Recognition and allowance for change in centroidal axis of member

EXTENDED LOAD BALANCING



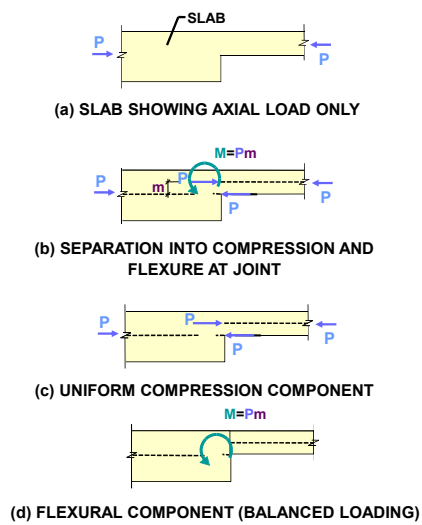
(a) BEAM ELEVATION



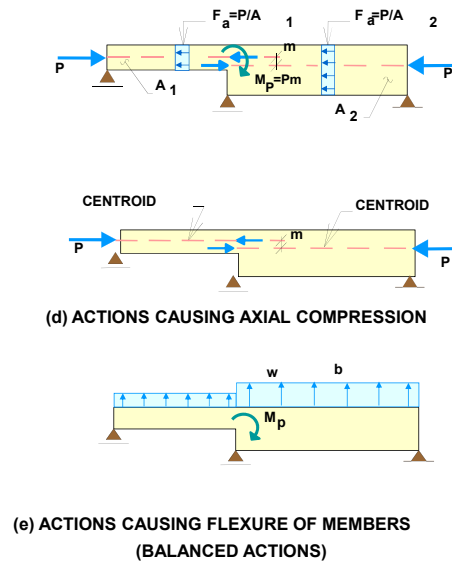
(b) BALANCED LOADING

BEAM WITH CHANGE IN CENTROID

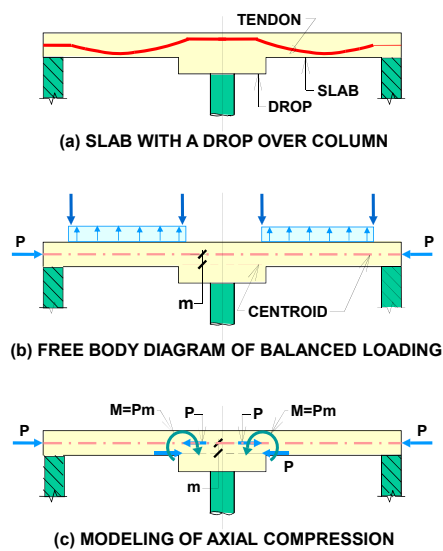
SEPARATION OF PRESTRESSING INTO FLEXURE AND AXIAL COMPONENTS



BALANCED LOADING AND CHANGES IN MEMBER THICKNESS



BALANCED LOADING AT DROP CAPS/PANELS



MODELING OF POST-TENSIONING TENDONS

LOAD BALANCING

Summary

- Tendon is replaced by the force it exerts to its container
- It necessitates the computation of hyperstatic actions and inclusion in design as a separate quantity

POST-TENSIONING AND STRENGTH CHECK

- ❖ If **load balancing** is used to model post-tensioning, **hyperstatic** actions from post-tensioning should be **added** to effects of other externally applied loads

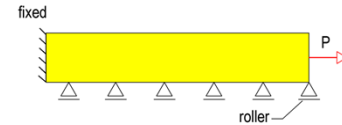
- ❖ Load combination for safety

$$U = k_1 DL + k_2 LL + k_3 HYP$$

Question

Why hyperstatic actions should be calculated and added to the load combination for safety check?

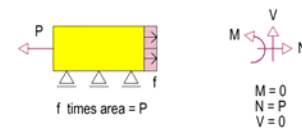
Review of Serviceability and Safety of Post-Tensioned Members



(a) Element under axial load (PTS817)

Is this structure **safe**?

- ❖ strong in compression
- ❖ low tension capacity

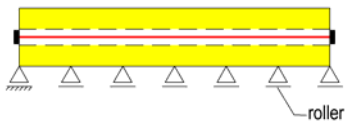


(i) Resistance (ii) demand

Element is safe if capacity to develop resistance exceeds demand

(b) Force demand/resistance

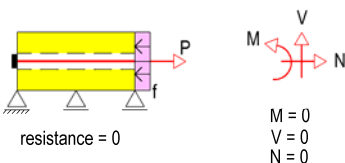
Review of Serviceability and Safety of Post-Tensioned Members



(a) Post-tensioned element (PTS816)

Is this structure **safe**?

- ❖ strong in compression
- ❖ no tension capacity

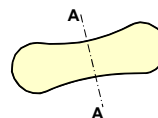


(i) Force diagram (ii) Demand

(b) Force demand/resistance

Element is **safe**, since there is **"no demand"** on the section

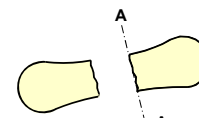
Review of Serviceability and Safety of Post-Tensioned Members



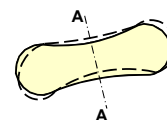
Given: Object under **NO** external force

Question: Will this object break apart at A-A?

(a) Weightless object in equilibrium

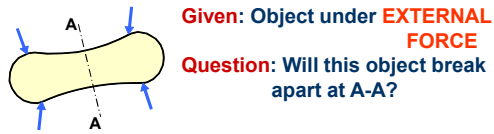


(b) Free body diagrams



(c) Deformed object

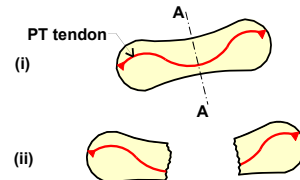
Member Collapse Mechanism



(a) Weightless object in equilibrium



Post-Tensioned Member With No External Loading

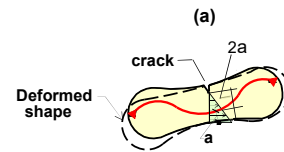


Given:

- ❖ Weightless object
- ❖ No external force
- ❖ Concrete zero tension, infinite compression capacity

Question:

- ❖ Will this object break apart at A-A?



ADAPT

Safety of Post-Tensioned Members

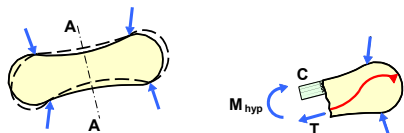
Given:

- ❖ Weightless object
- ❖ Body **restrained** externally
- ❖ Concrete zero tension, infinite compression capacity

Question:

- ❖ Will this object break apart at A-A?

(a) Weightless member in equilibrium



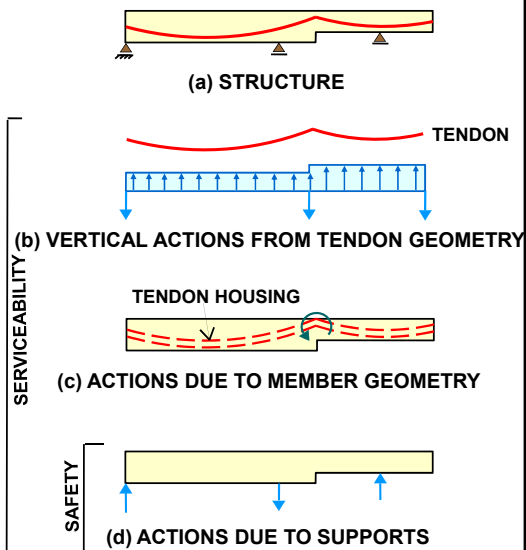
(b) Hyperstatic moment at A-A

CONTRIBUTION OF POST-TENSIONING

SUMMARY

- ❖ For **SERVICE** (SLS) conditions use the **post-tensioning (balanced)** values
 - Deflection
 - Stresses
 - Cracking
- ❖ For **SAFETY** (ULS) conditions use the **hyperstatic** (secondary) values
 - Ultimate strength

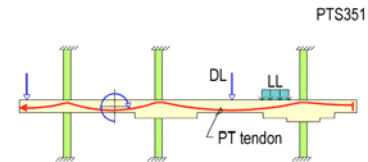
LOAD BALANCING ACTIONS FROM POST-TENSIONING



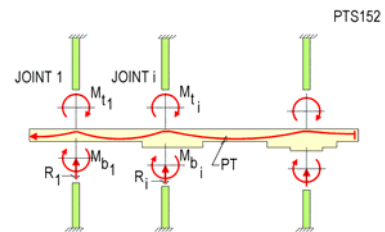
ADAPT

COMPUTATION OF HYPERSTATIC ACTIONS

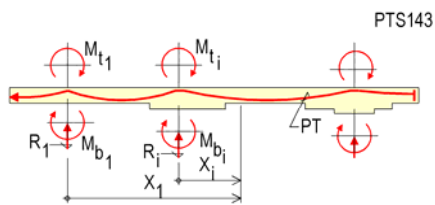
Computation of hyperstatic actions from post-tensioning



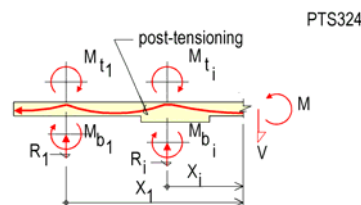
Post Tensioned Member Under Loading



COMPUTATION OF HYPERSTATIC ACTIONS



(a) Reactions from post-tensioning



$$M_{hyp} = \sum [M_{ti} + M_{bi}] + (R_i X_i)$$

(b) Hyperstatic actions at a section in member

ANALYSIS OPTIONS

❖ Analysis options and limitations

➤ Assumptions

- Gross cross-section
- Linear elastic

➤ Methods

➤ Strip Methods

- Simple Frame Method (SFM)
- Equivalent Frame Method (EFM)

➤ Finite Element Method (FEM)

- Single Level
- Multi Level

ANALYSIS OPTIONS

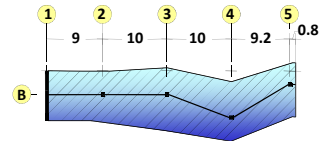
- ❖ Analysis options and limitations
 - Simple Frame Method (SFM)
 - Equivalent Frame Method (EFM)



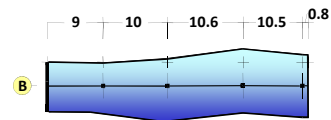
Floor slab is subdivided into strips in both directions

ANALYSIS OPTIONS

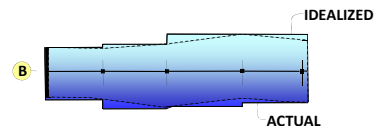
Each design strip is extracted and idealized in isolation



(a) DESIGN STRIP IN PROTOTYPE



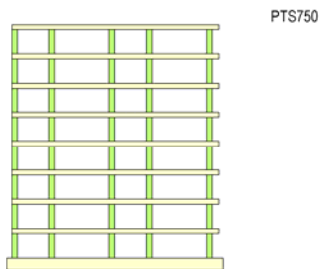
(b) STRAIGHTENED DESIGN STRIP



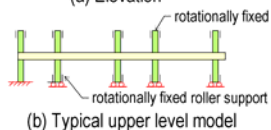
(c) IDEALIZED TRIBUTARY FOR DESIGN

ANALYSIS OPTIONS

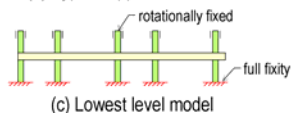
Extraction of single levels and assignment of boundary conditions



(a) Elevation



(b) Typical upper level model

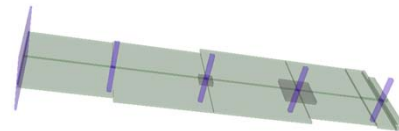


(c) Lowest level model

Single Level Design Strip Analysis Model

ANALYSIS OPTIONS

- Methods of Analysis
 - Simple Frame Method (SFM)
 - Equivalent Frame Method (EFM)
 - Finite Element Method (FEM)



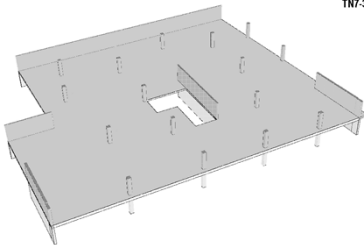
In Simple Frame Analysis, the stiffness of the elements is based strictly on the bending properties governed by the cross-sectional geometry of each

ANALYSIS OPTIONS

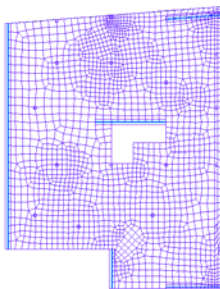
Finite Element Method

Single level modeling

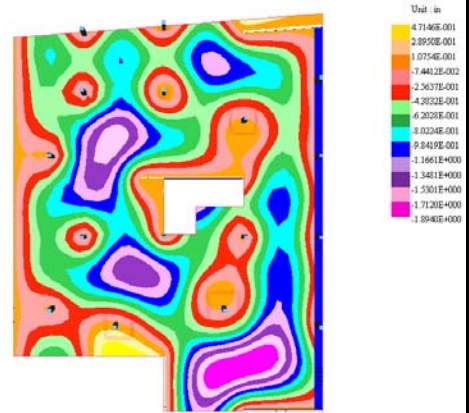
TN7-369



3D view of the floor



Discretization of the floor to FEM cells



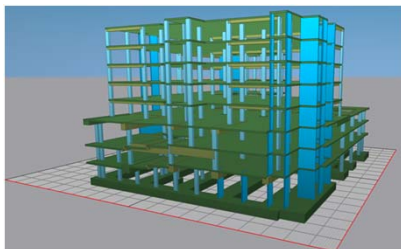
Display of a finite element (FEM) solution of the structure

The basic solution has to be **post-processed** to extract “**design Values**” for computation of reinforcement and code check.

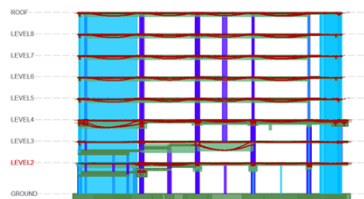
ANALYSIS OPTIONS

Multi-Level Analysis Option

In this option, the entire building, including tendons is modeled in 3D



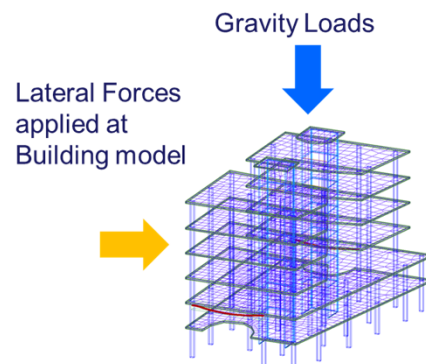
3D Analysis Model



Analysis Model with Tendons

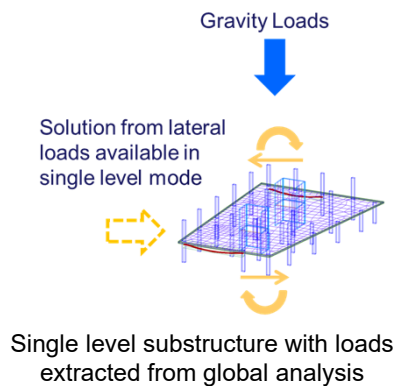
ANALYSIS OPTIONS

- The **entire building** is meshed
- **Gravity, lateral** and other loads applied
- A **global solution** for the entire building is obtained



ANALYSIS OPTIONS

- Optionally, as a **sub-structure**, single levels can be extracted and re-analyzed in greater detail, using applied forces obtained from the global analysis
- A **single level** follow up analysis affords expeditious focus on, and optimization of critical elements of the structure



EXTRACTION OF DESIGN VALUES

Irrespective of the method of analysis, the **design values** for code check are based on **design strips** and design sections.

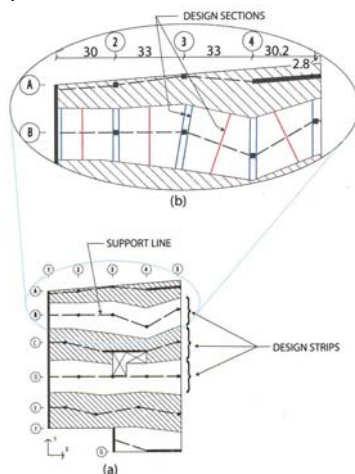


Breakdown of a Floor to Design Strips

EXTRACTION OF DESIGN VALUES

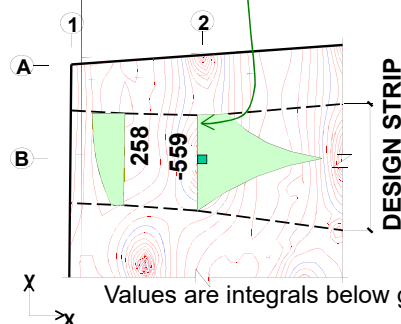
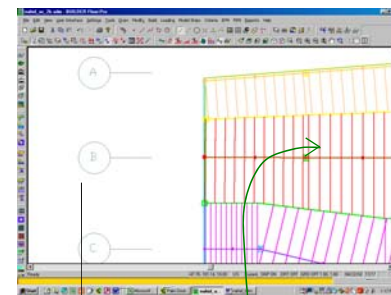
Design sections

- Design sections extend over the **entire design strip** and are considered at critical locations, such as face of support and mid-span



EXTRACTION OF DESIGN VALUES

Design strip; design section; design value



Values are integrals below graphs



Thank you for your attention

any questions?

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Session 2

Wednesday 30 May

Building Code Requirements for Design of Post-Tensioned Members

Bijan Aalami

Building Codes for Design of Post-Tensioned Buildings



Dr Bijan O Aalami

Professor Emeritus, San Francisco State University
Principal, ADAPT Corporation

ADAPT

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bijan@PT-Structures.com

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Building Codes and Post-Tensioning

1 - Current codes

USA

- ACI 318-14; for general design requirements
- ASCE 7-16; for loads and analysis options
- IBC 2015; International Building Code (umbrella code)

European

- EC2 EN 1992-1-1:2004; for general design
- EC: EN 1881-1.1, 2,3,4 for loads
- EC8 EN 1998-1-3 for design for seismic forces

In both cases, there are also specified requirements for post-tensioning systems and material

ADAPT

Building Codes and Post-Tensioning

Contents of presentation

1. Currently applicable building codes
2. Code objectives
3. Code approach to design; philosophy/methodology
4. Common US and European code provisions
5. ACI-318 specific provisions
6. EC2 specific provisions
7. Notable differences between ACI and EC2 code provisions
8. Essential aspects of PT design not covered by either of the codes
9. Engineering design aspects of post-tensioning
10. Comparison of designs based on ACI and EC2
11. ACI-318 design steps
12. EC2 design steps
13. Summary

Building Codes and Post-Tensioning

2 – Code Objective

As perceived by design engineers

- ACI 318
 - Safety of the public, supported by practical evidence
 - Economic considerations with lesser priority
- EC2
 - Safety with due considerations to engineering principles

Building Codes and Post-Tensioning

3 – Code **approach** to design; **philosophy** and **methodology**

➤ ACI 318

- **Practical demonstration** of safe design overrides engineering calculations
- Generally follows **three tier** approach
 - 1 - **Simple and expeditious**; mostly not the economical alternative
Example: service deflection
Select recommended span/depth ratio – no calculation required
 - 2 - **Medium**: Allow for loss in secondary moment resulting from cracking of concrete
 - 3 - **Rigorous**: Detailed analysis for cracked sections and improved economy

Building Codes and Post-Tensioning

3 – Code **approach** to design; **philosophy** and **methodology**

➤ EC2

- **Prescriptive** approach for practically all instances, based on principles of mechanics of solids
- **Mostly one** prescriptive **approach** for each design scenario

Building Codes and Post-Tensioning

3 – Code **approach** to design; **philosophy** and **methodology**

ACI 318

- **Performance**-based design; non-prescriptive approach
 - **Engineer selected** methodology, supported by computation or tests to:
 - (i) meet the ultimate **serviceability** and **safety** requirements of the code; and
 - (ii) obtain the **approval** of the building **official** having jurisdiction over the project

Building Codes and Post-Tensioning

4 – **Common** code **provisions** and **practice** of ACI 318 and EC2

- Design requirements
 - **Serviceability** Limit State (SLS)
 - Sustained (quasi permanent)
 - Total (Frequent)
 - **Safety**; Ultimate Limit State (ULS)
 - **Initial** condition (transfer of prestressing)

Building Codes and Post-Tensioning

4 – Common code provisions and practice of ACI 318 and EC2

- ❖ Load path
 - Strip method – primary focus of both code provisions
- ❖ Analysis
 - The primary option is elastic solutions based on
 - Stiffness based on gross cross-section
 - Linear elastic material property
 - Yield line analysis
 - Experimental evidence

Building Codes and Post-Tensioning

4 – Common code provisions and practice of ACI 318 and EC2

- ❖ Crack control
 - ACI 318; cracks are greatly limited; controlled through low allowable hypothetical tensile stresses
 - EC2; explicit selection of crack width for design and crack width calculation

Building Codes and Post-Tensioning

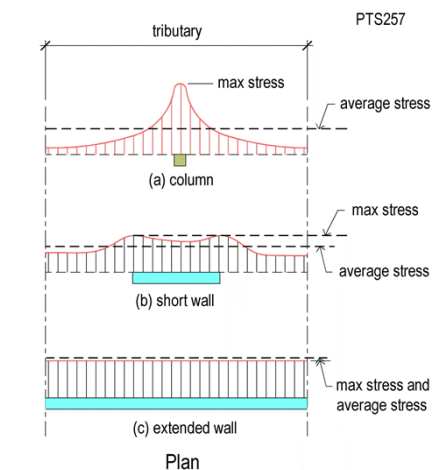
4 – Common code provisions and practice of ACI 318 and EC2

- ❖ Computation of design values for code compliance
 - Design section values, such as moments based on smeared distributions (total)
 - Stresses based on hypothetical values
- For EC2, the approach is outlined in appendix I

Building Codes and Post-Tensioning

4 – Service Check - SLS

- Crack control through hypothetical extreme fiber tensile stresses



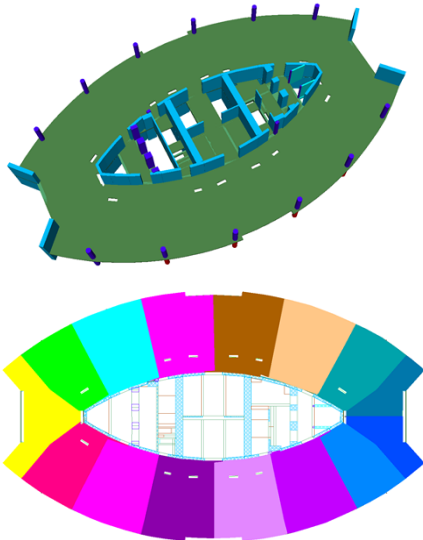
(Average = Hypothetical value used for code check)

Distribution of Maximum Bending

Building Codes and Post-Tensioning

4 – Service Check - SLS

- Crack control through hypothetical extreme fiber tensile stresses



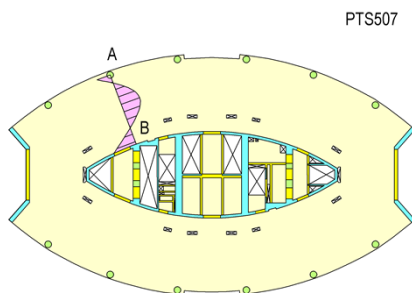
Building Codes and Post-Tensioning

4 – **Common** code provisions and practice of ACI 318 and EC2

- ❖ Deflection control for
 - **Visual**/sense of comfort
 - Cause **damage** to non-structural brittle elements
- ❖ Minimum **Strength**
 - **Bending**
 - Punching **shear**

Building Codes and Post-Tensioning

- Crack control through hypothetical extreme fiber tensile stresses



at point A, two-way stress check
at point B, one-way stress check

Floor Plan of a Mixed Structural System

Building Codes and Post-Tensioning

4 – **Common** code provisions and practice of ACI 318 and EC2

- ❖ Section **strength**
 - Recognition of **uncertainty** in **material** properties
 - **ACI strength reduction factor** ϕ
 - Bending 0.9
 - Punching shear 0.75
 - Axial compression 0.7
 - **EC material properties**
 - Concrete 0.65
 - Non-prestressed steel 0.85
 - Prestressing steel 0.85

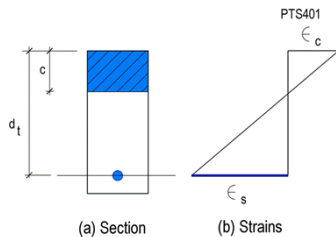
Building Codes and Post-Tensioning

4 – Common code provisions and practice of ACI 318 and EC2

❖ Section strength

➤ Provision for ductility

Ductility check through limitation on depth of compression zone



Depth of compression zone c is limited to 0.35 to 0.5 d_t to ensure section failure through yielding of tension reinforcement

Building Codes and Post-Tensioning

4 – Common code provisions and practice of ACI 318 and EC2

❖ Safety against cracking moment

➤ ACI Design capacity should exceed the cracking moment of the section by a code specified safety factor

➤ ACI 318 1.20

➤ EC2 1.15

■ The computation is controversial

■ The application is different

❖ Initial condition; transfer of prestressing

➤ Both codes require control of tensile and compressive stresses at stressing

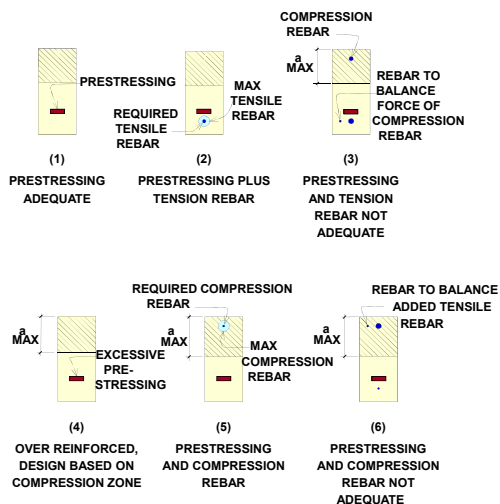
■ ACI 318 values ??

■ EC2 values ??

❖ Both require anti-bursting reinforcement at anchorage. In practice the hardware supplier provides the details

Building Codes and Post-Tensioning

Limiting the depth of compression zone leads to six design options for design moment capacity of a section



Building Codes and Post-Tensioning

5 - ACI-318 specific provisions

❖ Minimum precompression

➤ Applies to two-way systems

➤ 125 psi (0.86 MPa)

➤ Method of computation is based on tendon tributary

➤ None is specified for one-way systems

❖ Minimum rebar based on stress values

➤ If hypothetical tensile stresses in span exceeds span $f_t \leq 0.16\sqrt{f'_c}$ SI ($f_t \leq 2\sqrt{f'_c}$ US)

❖ Tendon layout

➤ Maximum spacing between tendons

➤ Banded/banded not permitted

Building Codes and Post-Tensioning

5 - ACI-318 specific provisions

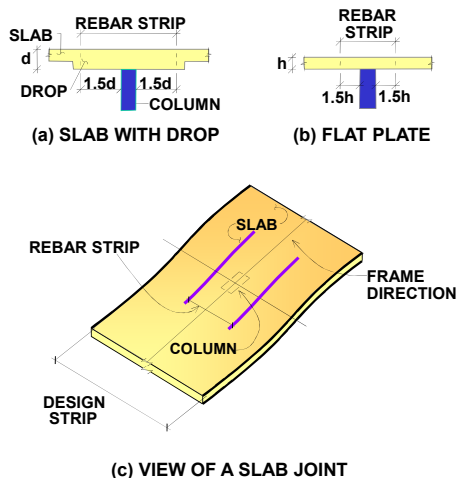
- ❖ Transfer of **column moment**
- ❖ Limited **redistribution of moment** to account for post-elastic reserve of strength
- ❖ Arrangement of tendon and rebar, including **integrity steel** (detailing)
 - Specific statement that **column strip/middle strip** does **not apply**
 - All **top rebar** on and **around the column**
 - **Minimum of 4 bars** within 4 ft of column top
 - **Integrity steel**
 - Specific statement on **bar length**

Building Codes and Post-Tensioning

6 – EC2-Specific Provisions

- ❖ **Minimum reinforcement** based on **cross-sectional area**
- ❖ **Maximum reinforcement** based on **cross-sectional area**
- ❖ **Design crack width**
 - Suggested values for bonded and unbonded members
- ❖ **Rebar for crack width control**

Building Codes and Post-Tensioning



Building Codes and Post-Tensioning

7 – Notable differences between ACI and EC2

- ❖ Contribution of tendon to section strength
 - **Unbonded** tendons
 - ACI 318 allows gain in stress up to 60 ksi (413 MPa) over service
 - EC2 allows 100 MPa (14.5 ksi)
 - **Grouted** tendons
 - ACI 318 allows 413 MPa (60 ksi) over service
 - EC2 allows full value, which can be as much as 700 MPa (100 ksi)
- ❖ Punching shear
 - ACI 318 focus is on control of fictitious stresses make up of shear and bending stresses
 - EC2's focus is on area top rebar

Building Codes and Post-Tensioning

7 – Notable differences between ACI and EC2

- ❖ Application of minimum flexural stress over cracking moment
 - Both codes have the requirement, but the specified application differs

Building Codes and Post-Tensioning

ACI 318-14

“8.6.2.2.2 – For slabs with bonded prestressed reinforcement, total quantity of A_s and A_{ps} shall be adequate to develop a factored load at least 1.2 times the cracking load calculated on the basis of f_r defined in 19.2.3.”

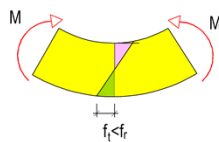
EN 1992-1-1:2004, Section 9.2.1-1(4)

“For members prestressed with permanently unbonded tendons or with external prestressing cables, it should be verified that the ultimate bending capacity is larger than the flexural cracking moment. A capacity 1.15 times the cracking moment is sufficient.”

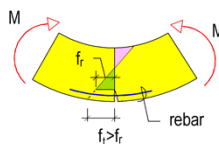
(Canadian code A23.3 18.4)

Building Codes and Post-Tensioning

PTS827



(a) $M < M_{cr}$



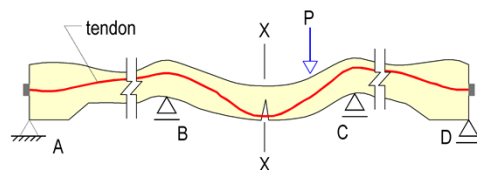
(b) $M > M_{cr}$

f_t = tension stress ; f_r = cracking stress

Section Response to Pre and Post-Cracking Moment

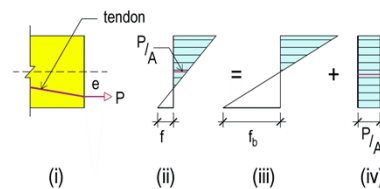
Building Codes and Post-Tensioning

PTS798



Post-Tensioned Member and Initiation of Cracking

PTS799



Building Codes and Post-Tensioning

Cracking Moment

- Nominal capacity => cracking moment using **PTI's formula** and literature

$$M_{cr} = \left(f_t + \frac{P}{A} \right) S + M_{pt}$$

M_{cr} = cracking moment;

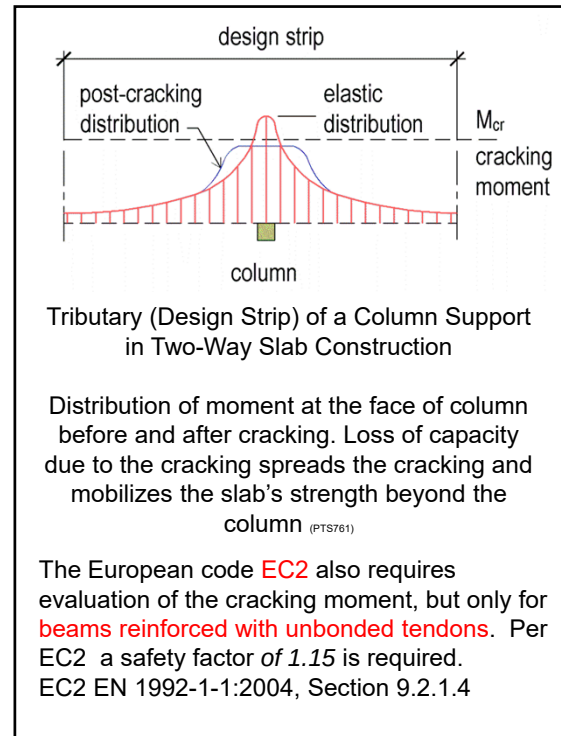
S = section modulus;

f_t = cracking stress; and

A = cross-sectional area

M_{pt} = moment from post-tensioning,
(includes hyperstatic moments)

(Canadian code A23.3 18.4)



Building Codes and Post-Tensioning

Cracking Moment

- Nominal capacity => cracking moment

$$M_{cr} = \left(f_t + \frac{P}{A} \right) S$$

M_{cr} = cracking moment;

S = section modulus;

f_t = cracking stress; and

A = cross-sectional area.



Slab construction with **unbonded** tendons. **Neither** ACI, nor EC2 require strength check at initiation of cracking (P998)



Slab construction with **bonded** tendons **ACI** requires strength check at initial of cracking. EC2 does not (P999)

Building Codes and Post-Tensioning

8 - Essential **post-tensioning** design **Aspects not covered** in either of the **two codes**

❖ Analysis

- **Tendon modeling** for structural design
 - Tendon considered as an **applied force**
 - There are several **alternatives**. Most popular is load balancing; give reference
 - Tendon considered as a **resisting reinforcement**

❖ Layout

- Tendon **profile**
 - **ADAPT** has a **library** that includes reverse parabola; straight and more
 - **Other profiles**, such as profile assumed under **gravity** can work but are not yet implemented

Building Codes and Post-Tensioning

8 - Essential **post-tensioning** design **Aspects not covered** in either of the **two codes**

❖ Detailing: support **restraint**

- Contribution of **precompression** from post-tensioning is essential in **moment capacity** of post-tensioned sections
- Support **restraints** at the **first** and possibly second **levels** of post-tensioned buildings **can compromise** the contribution of prestressing and need to be recognized in design.

Building Codes and Post-Tensioning

8 - Essential **post-tensioning** design **Aspects not covered** in either of the **two codes**

❖ Vibration

- Application of improved and **higher strength** concrete property properties; advances in **computational technology** has resulted in **longer spans** and inspirational **irregular layouts** have resulted in the floor **vibration** from **footfall** becoming a part of many designs

❖ Detailing: support restraint

- Contribution of precompression from post-tensioning is essential in moment capacity of post-tensioned sections
- Support restraints at the first and possibly second levels of post-tensioned buildings can compromise the contribution of

Building Codes and Post-Tensioning

9 - **Comparison** of designs based on **ACI** and **EC2**

- ❖ Both codes result in **serviceable** and **safe** designs
- ❖ In general a floor slab can be designed with **less prestressing** using **EC2**.
- ❖ The **economic** evaluation depends on the **unit price** of prestressing and non-prestressing steel in place – **labor** component..
- ❖ **EC2 is more economical**, where prestressing is more expensive.
- ❖ In the **US**, depending of the location and construction the cost of **installed unit rebar** and **PT** can be the **same**. Since **PT** can provide **3 to 4 times more strength** than rebar, in practice it is almost always economical to use PT.

Building Codes and Post-Tensioning

10 – General design steps

- Detailed in 10-step design presentation

11 – ACI-318 design steps

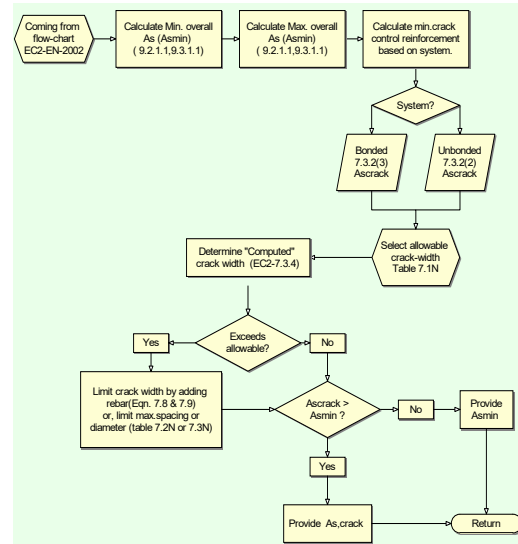
Outlined in 10-steps

12 - EC2 design steps

Outlined in detailed flow chart provided.

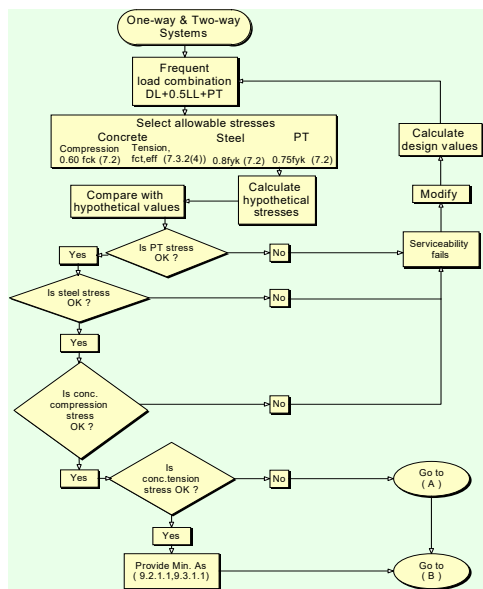
(A)

EC2-EN 2002



ADAPT

Post-Tensioned Members Serviceability Check According to EC2-EN 2002

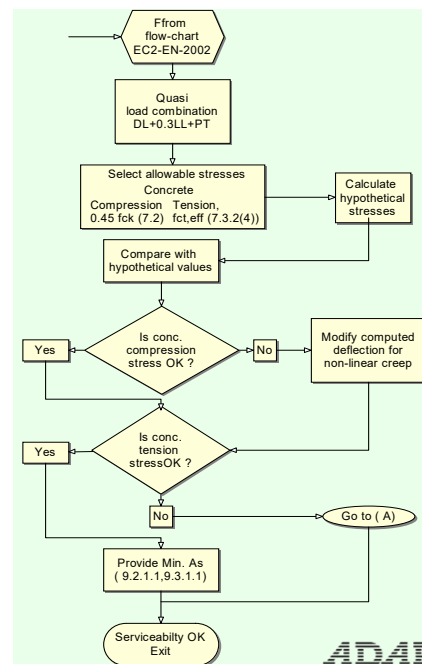


* EN 1992-1-1:2004(E), section 7.2

ADAPT

(B)

EC2-EN 2002

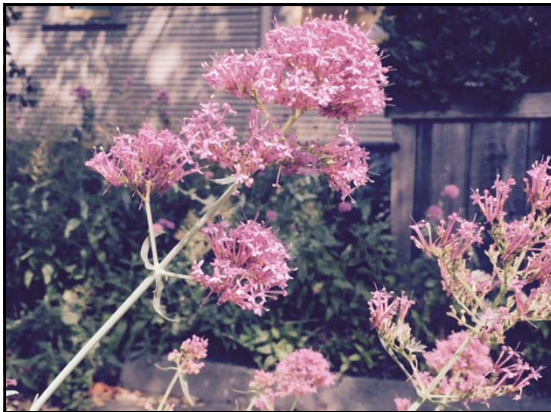


ADAPT

Building Codes and Post-Tensioning

Summary

1. Currently **applicable** building **codes**
2. Code **objectives**
3. Code approach to design ;
philosophy/methodology
4. **Common** US and European code **provisions**
5. **ACI-318 specific** provisions
6. **EC2 specific** provisions
7. Notable **differences** between ACI and EC2
code provisions
8. **Essential aspects of PT** design not covered
by either of the codes
9. **Engineering design aspects** of post-
tensioning
10. **Comparison of designs** based on ACI and
EC2
11. **ACI-318 design steps**
12. **EC2 design steps**



Thank you for listening

any questions?

bijan@PT-Structures.com

Session 3

Wednesday 30 May

10-Step Design of Post-Tensioned Floor Systems, followed by Long-Hand Calculation

Bijan Aalami

***(refer to chapter 7 of the book Post-Tensioned
Buildings; Design and Construction)***

Session 4

Wednesday 30 May

Expeditious Design of
Post-Tensioned Floors
and Beams using 2D Strip
Method

Florian Aalami



ADAPT

Expeditious Design of Post-Tensioned Floors and Beams Using Strip Method Simple Frame and Equivalent Frame Approaches

- Featuring -

ADAPT-PT[®]

ADAPT Corporation | Redwood City, CA, USA

ADAPT Latin America | Miami, FL, USA

ADAPT International Pvt. Ltd. | Kolkata, India

Dr. Florian Aalami

www.adaptsoft.com

May 2018



ADAPT

Agenda

Post-Tensioned Slab Design using Equivalent Frame Method

- **Applicable Project Types**
- **Review of Design Process**
- **When to use 2D Strip Approach**
- **Design Example using ADAPT-PT**



ADAPT

Complete Solution for Slabs & Beams

Column supported two-way flat slab systems



ADAPT

Complete Solution for Slabs & Beams

One-way beam and slab design





ADAPT

Complete Solution for Slabs & Beams

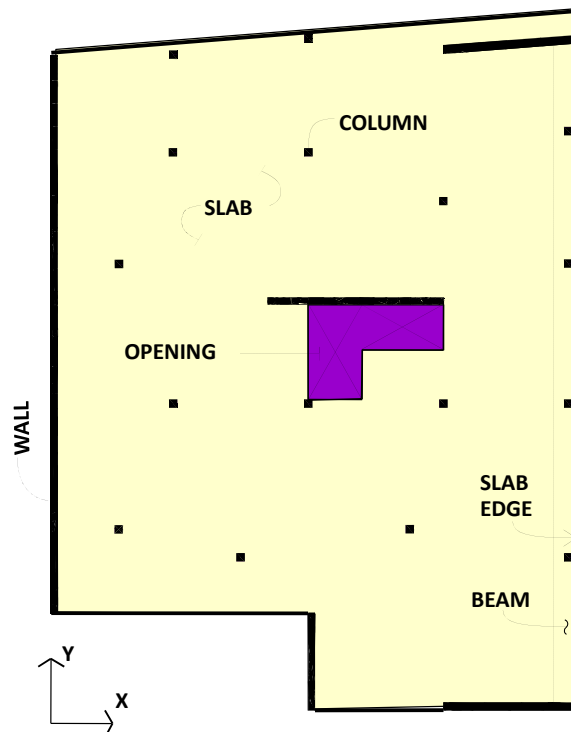
Beam frames and grids



ADAPT

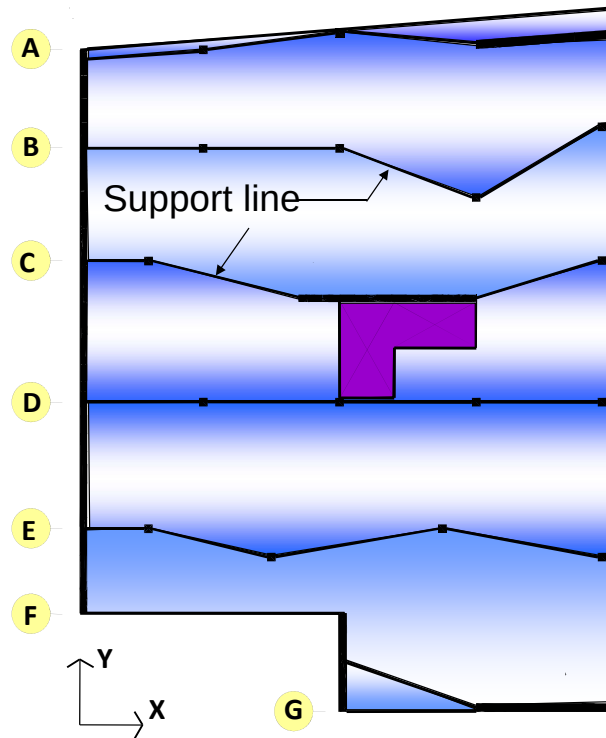
Review of Design Approach

Typical layout of
column supported
floor system

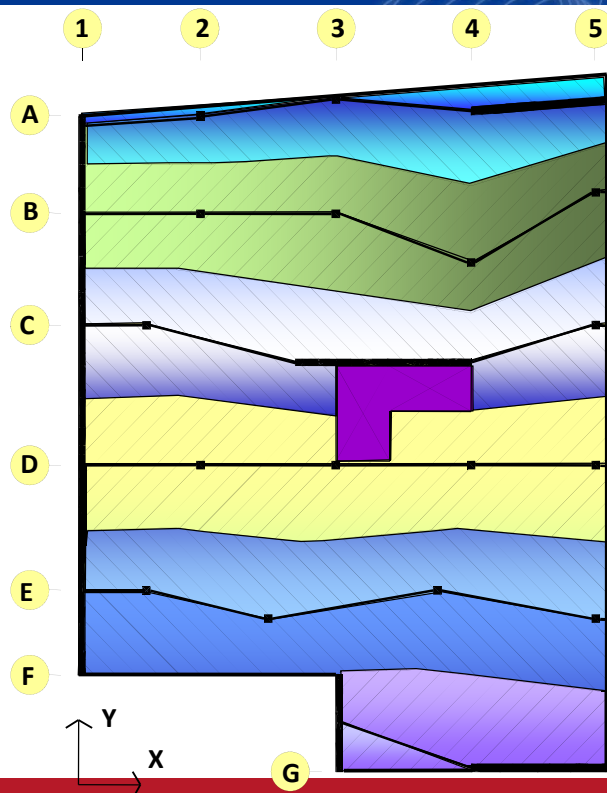




1st Step:
Determine
support lines



2nd Step:
Determine
tributaries and
create
“design strips”



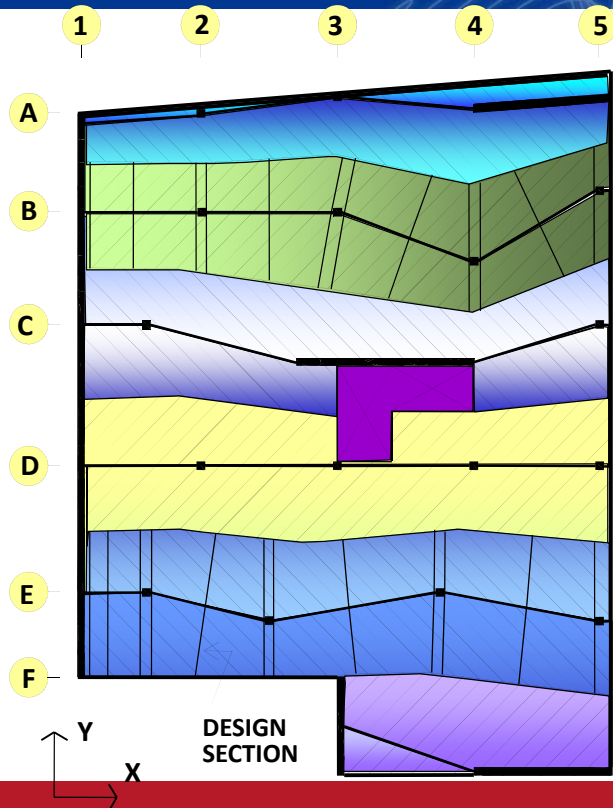


ADAPT

Review of Design Approach

3rd Step:
Determine
design sections

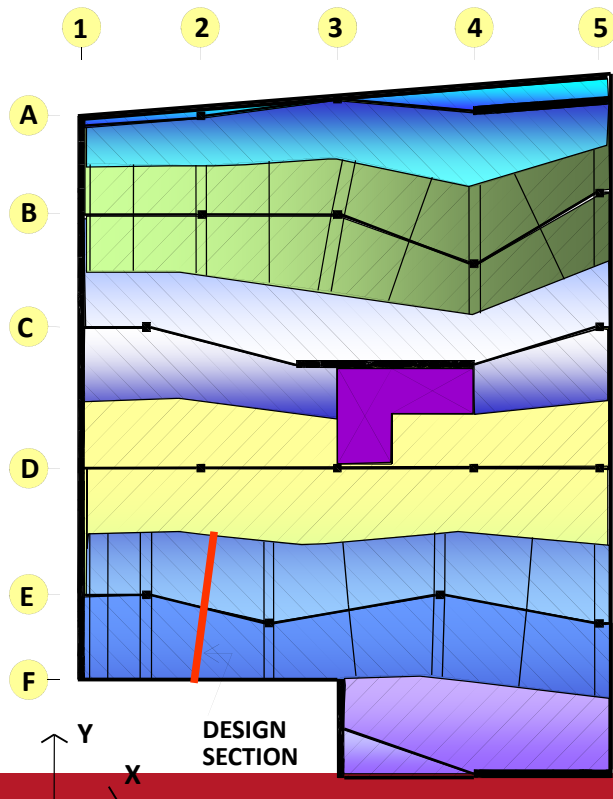
Sections for
strips B & E
shown



ADAPT

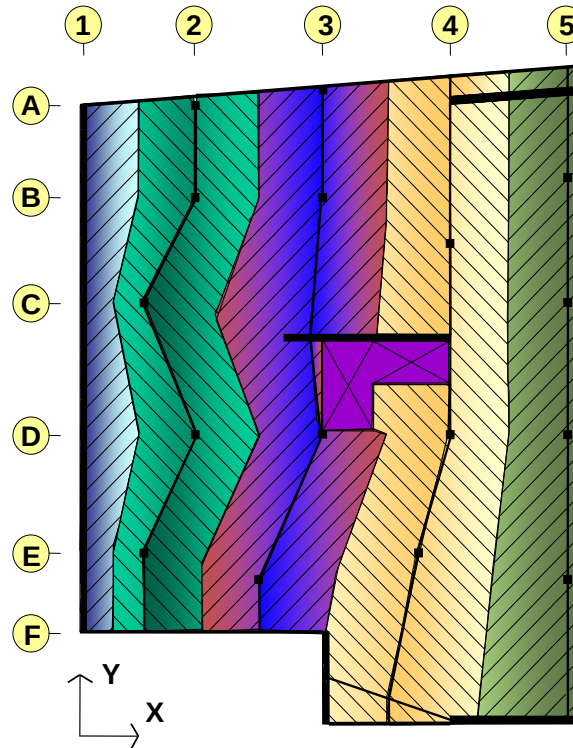
Review of Design Approach

4th Step:
Design each
section to provide
adequate capacity
and meet code
compliance





5th Step:
Design other
direction of slab

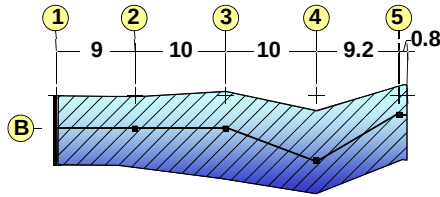


- Easy to learn and use
- Quickly produces preliminary designs
- Produces optimized PT designs for each strip
- Great learning tool if new to post-tensioning

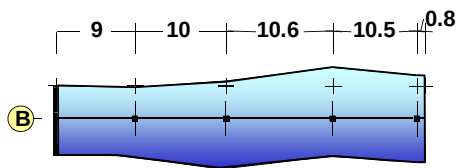


ADAPT

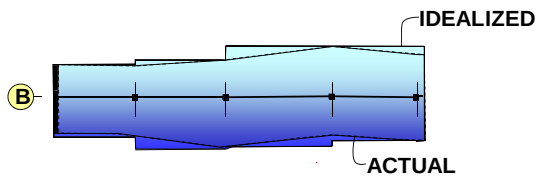
Strip Method Approach to Design



(a) DESIGN STRIP IN PROTOTYPE

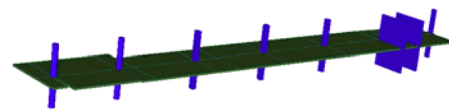
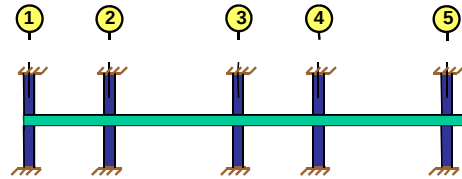


(b) STRAIGHTENED DESIGN STRIP



(c) IDEALIZED TRIBUTARY FOR DESIGN

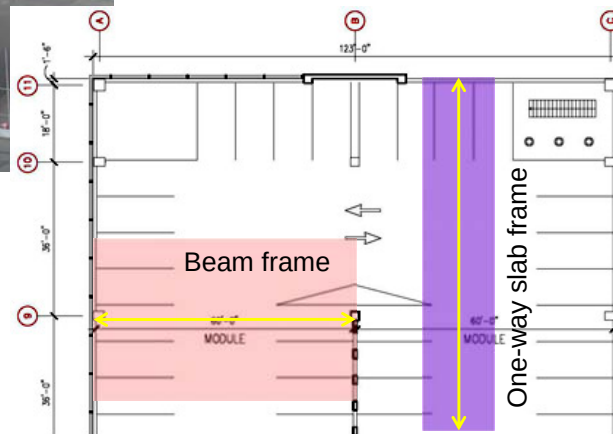
If using ADAPT-PT, develop and model idealized design strips



ADAPT

Traditional Design of 1-Way Systems

The parking structure is broken down into typical beam and one-way slab frames. A beam frame can span several parking modules.





ADAPT

Traditional Design of 1-Way Systems

Start ADAPT-PT modeling process by selecting appropriate structural system.

General Settings

General Title: [AU2010 parking]
Specific Title: [Grid B]

Structural System:

☒ Two-Way Slab ☐ One-Way Slab ☐ Beam

Geometry input:
☒ Conventional ☐ Segmental

Effective Width in Bending:
Do you want to consider effective flange width? ☒ Yes ☐ No

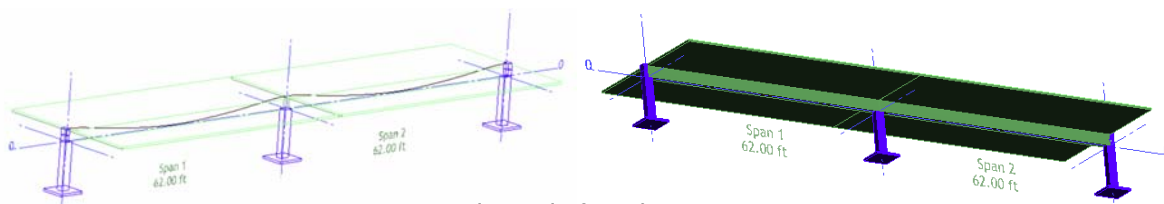
Cancel OK Next >>



ADAPT

Traditional Design of 1-Way Systems

Use geometry table to easily model your design frame.



Design strip for a beam spanning 2 parking modules

Span Geometry

Number of Spans: [2] [CTRL +/-]

Legend:
L-Cant = Left Cantilever
R-Cant = Right Cantilever
NP = Non-Prismatic
PR = Prismatic
Sec = Section
Seg = Segments
D-O = Reference plane
L = Span Length
Rh = Distance from reference plane
M = Left Multiplier
M = Right Multiplier

Label	PR	Sec	Seg	L	b	h	bf	hf	bm	hm	Rh	M	M
Typical	PR			62.00	20.00	36.00	420.00	6.00			36.00	0.50	0.50
L-Cant													
SPAN 1	PR			62.00	20.00	36.00	420.00	6.00			36.00	0.50	0.50
SPAN 2	PR			62.00	20.00	36.00	420.00	6.00			36.00	0.50	0.50
R-Cant													

<< Back OK Cancel Next >>

**ADAPT**

Traditional Design of 1-Way Systems

Select appropriate tendon profile.

Criteria - Tendon Profile

Legend

1 = Reversed Parabola 2 = Partial Parabola 3 = Harped Parabola 4 = Straight 5 = Extended Reversed Parabola

Tendon A profile		Tendon B profile		Tendon C profile	
Span	Type	X1/L	X2/L	X3/L	A/L
Typical	1	0.100	0.500	0.100	0.000
Span 1	1	0.100	0.500	0.100	
Span 2	1	0.100	0.500	0.100	

Option for tendons...

Default extension of terminated tendon as fraction of span:
Left end Right end

Shape of tendon extensions:

Tendon C (Left end)
☒ Downward parabola; anchor at centroid
☐ Follow shape specified in above table

Tendon B (Right end)
☒ Downward parabola; anchor at centroid
☐ Follow shape specified in above table

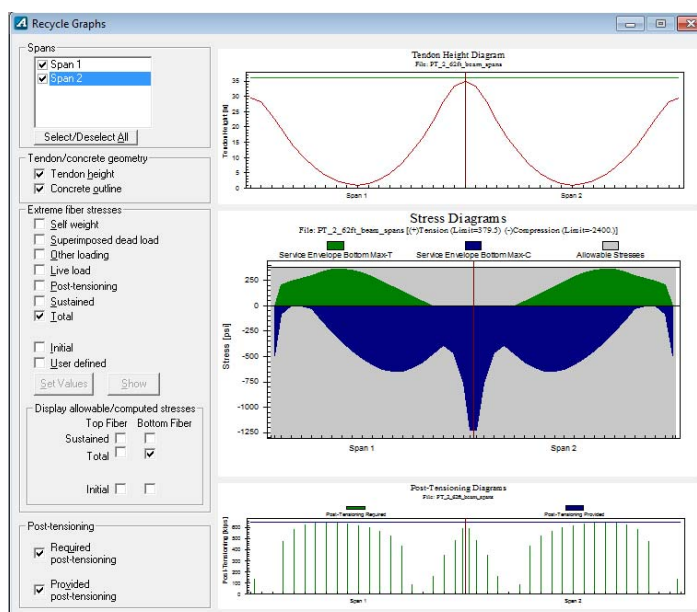
☐ Set tendon ends using CG of effective section

<< Back OK Cancel Next >>

**ADAPT**

Traditional Design of 1-Way Systems

Each design strip is designed to meet strength and service requirements of the code.

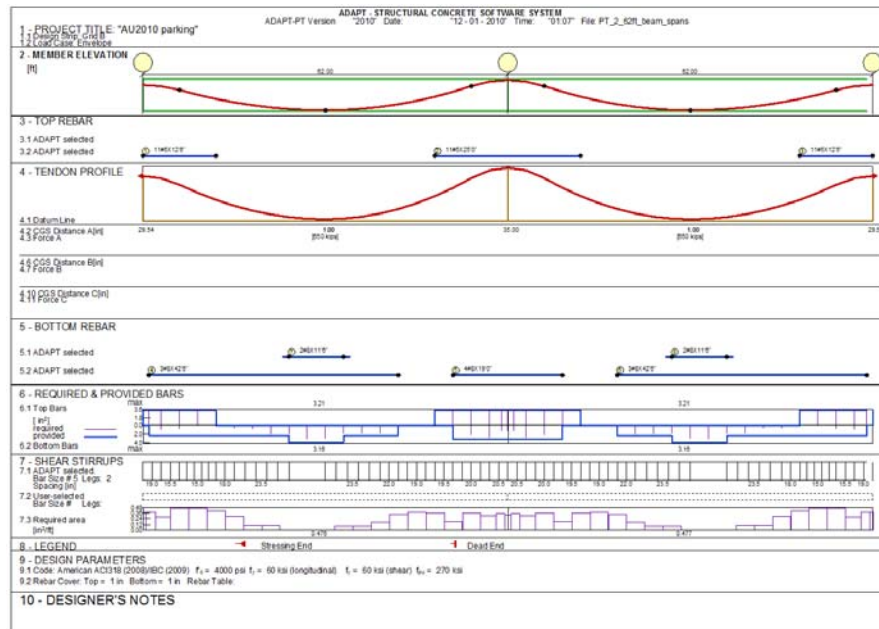




ADAPT

Traditional Design of 1-Way Systems

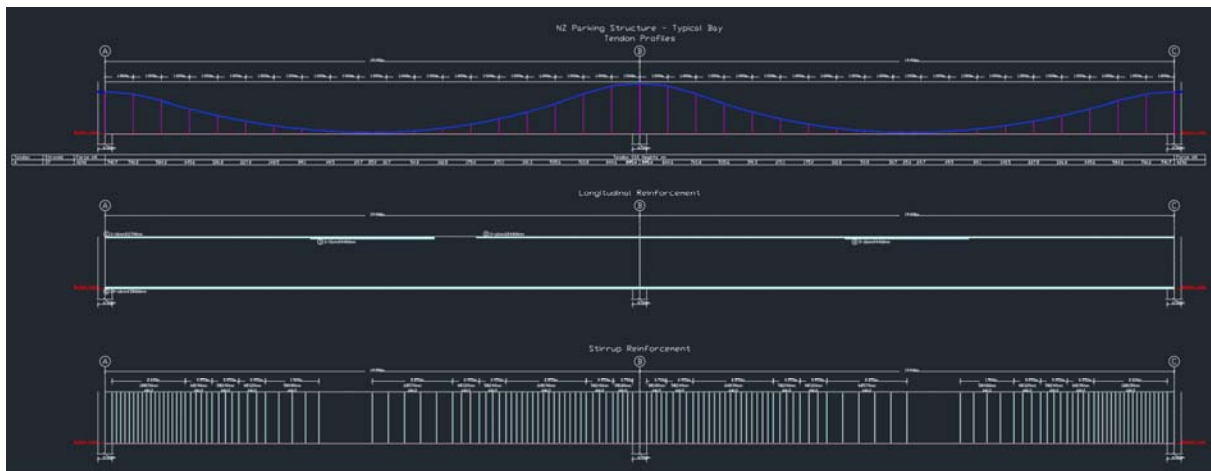
Amount of post-tensioning and profile are determined as well as any additionally required flexural and shear reinforcement.



ADAPT

Traditional Design of 1-Way Systems

Export layout of post-tensioning and any required additional reinforcement in DWG CAD format.





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Session 5

Thursday 31 May

Design for Shortening of Post-Tensioned Members

Bijan Aalami

Shortening of Post-Tensioned Elements



Dr Bijan O Aalami

Professor Emeritus,

San Francisco State University

Principal, ADAPT Corporation; bijan@PT-structures.com

ADAPT

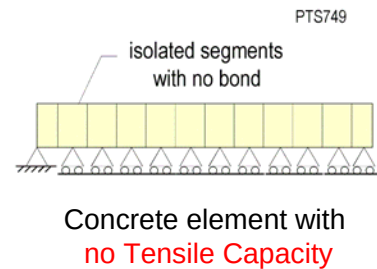
www.PT-Structures.com

P856

PT-Structures copyright 2015

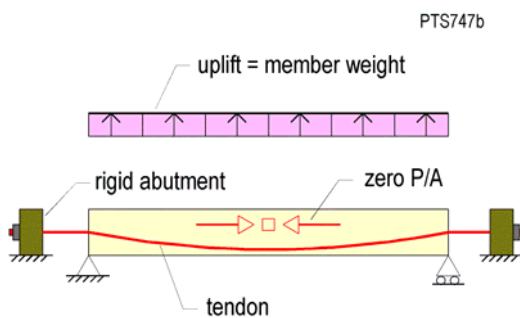
Shortening Post-Tensioned Elements

A **question** on **safety** of concrete elements



- Element is **contiguous**. The vertical lines are for visualization
- Will this element collapse, if the **interior supports are removed**?

Shortening Post-Tensioned Elements

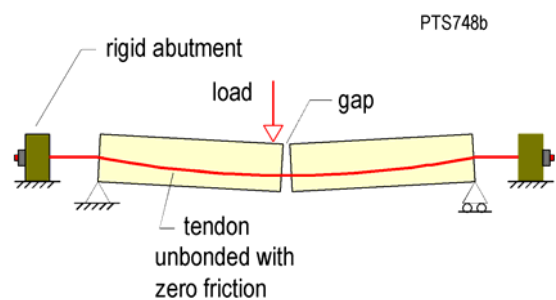


- Concrete has **zero tension capacity**
- Post-tensioning tendon is anchored at **rigid abutments**. No abutment movement.
- Tendon **uplift** is equal to element **weight**
- Tendon is unbonded.
- There is **no friction** between tendon and its sheathing
- Tendon profile is **simple parabola**

QUESTION?

- 1 - Will this element **deflect**?
- 2 - Will this element **collapse**, if **load** is added?

Shortening Post-Tensioned elements

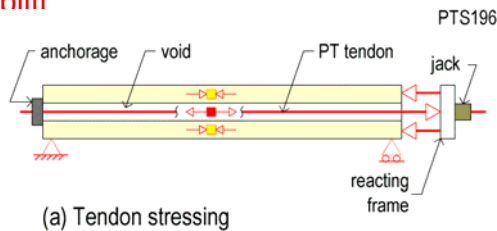


- Concrete has **zero tension capacity**
- Post-tensioning tendon is anchored at **rigid abutments**. Zero abutment movement.
- Tendon is unbonded.
- There is **no friction** between tendon and its sheathing
- Tendon profile is **simple parabola**
- ❖ Element will **collapse** under added load
- ❖ **No compression**, hence **no** resisting **moment** can develop in the element

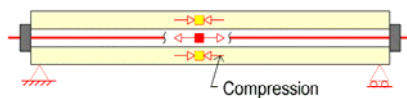
Shortening Post-Tensioned elements

❖ Post-tensioning is generally **designed to** provide:

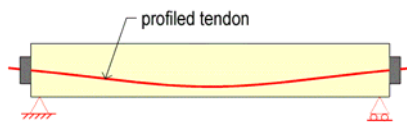
- **Precompression**
- **Unlift**



(a) Tendon stressing



(b) Tendon finishing



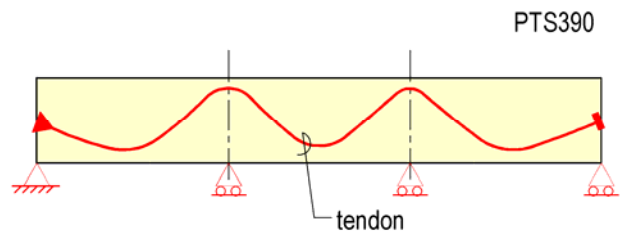
(c) Profiled post-tensioning

Basics of Post-tensioning Construction

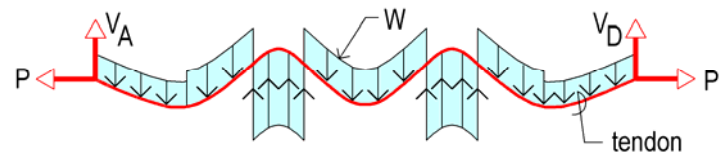
Shortening Post-Tensioned elements

Uplift of tendon is function of

- Tendon **geometry**
- Tendon **force**



Three Span Post-Tensioned element

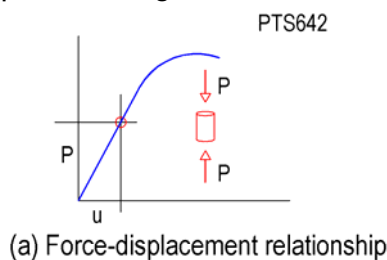


Free Body Diagram of Tendon (PTS391)

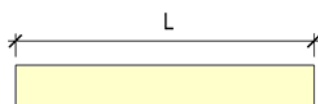
Shortening Post-Tensioned elements

Precompression is achieved through

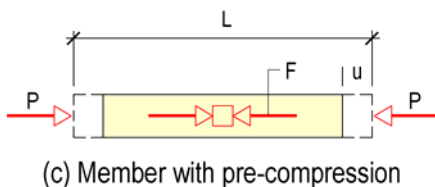
- **Shortening** of element under prestressing force



(a) Force-displacement relationship



(b) Member with no pre-compression

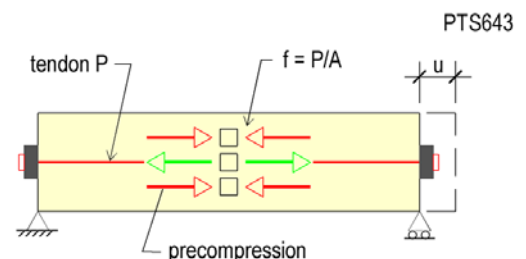


(c) Member with pre-compression

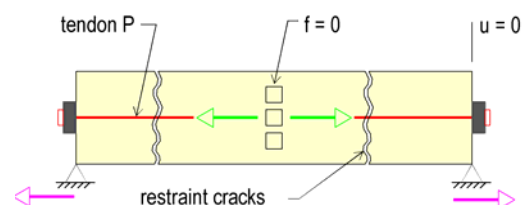
Pre-compression and Shortening

Shortening Post-Tensioned elements

- The primary **obstacle** to shortening is the **restraint** of element **supports**
- **Excessive restraint** can lead to loss of precompression and **through cracks** in element resulting from **shrinkage**



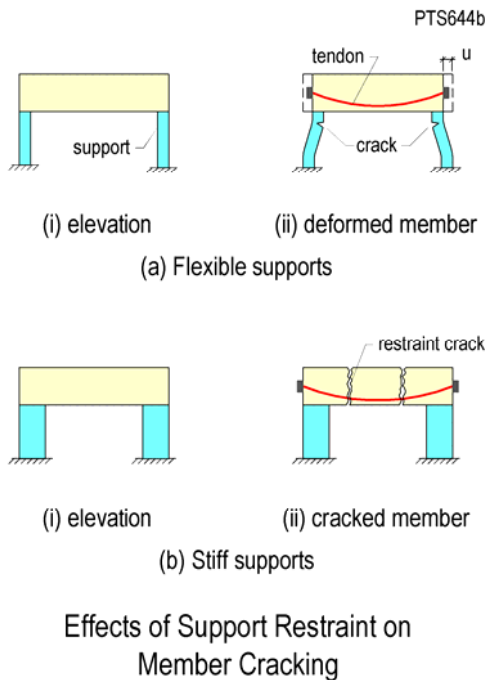
Element Free to Shorten



Element Restrained at Supports

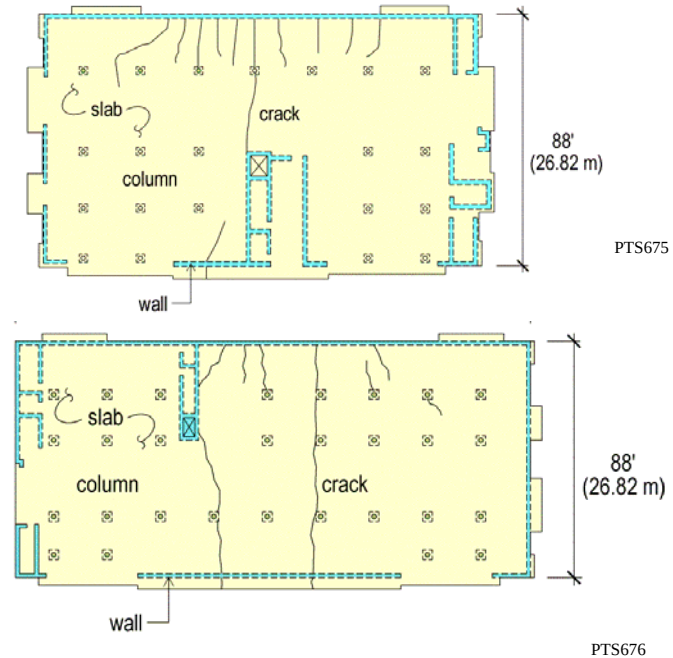
Shortening Post-Tensioned elements

- Depending on the **stiffness of supports** and the **construction sequence**, cracking can occur in the supports or the element



Shortening Post-Tensioned elements

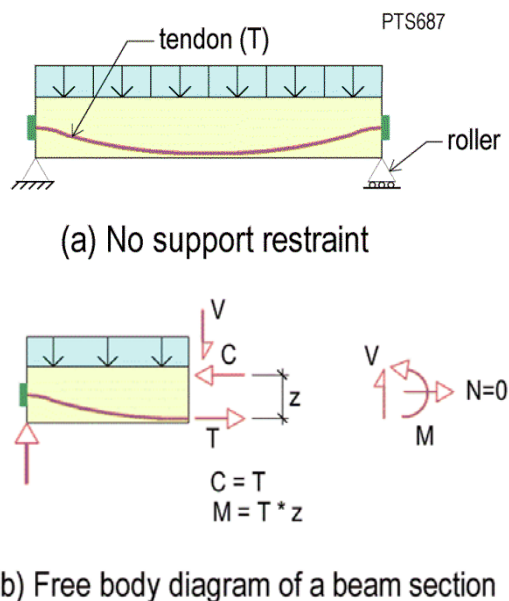
- Examples of **through cracks** resulting from **restraint of walls**
- Through cracks **eliminate** the **precompression** across the crack



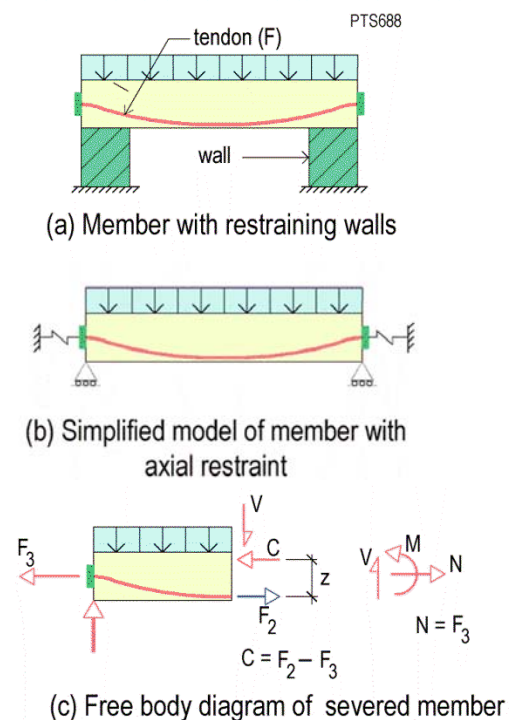
Shortening Post-Tensioned elements

Why precompression is central to the **safety** of post-tensioned elements?

Review the design **capacity** of the following element



Shortening Post-Tensioned elements



Contribution of tendon force to provide resistance is reduced by the force **diverted to the supports**

Shortening Post-Tensioned elements

What do we **need to know**?

- ❖ **How much** is the shortening ?
- ❖ **How to allow** for shortening – crack mitigation
- ❖ How to evaluate the **impact of cracking**, if any?

Shortening Post-Tensioned elements

The **shortening** of a post-tensioned element is **due to**:

- ❖ **Shrinkage**;
- ❖ **Creep**;
- ❖ **Elastic Shortening**; and
- ❖ **Temperature change**

There are **different techniques** to estimate the shortening. These are:

- ❑ **Quick**, generally conservative and for **preliminary** estimates
- ❑ **Design engineer's procedure** for common residential and commercial building structures; and
- ❑ **Rigorous procedure** for non-conventional and critical structures

Shortening Post-Tensioned elements

- ❖ For a **quick and preliminary** estimate of common building construction consider 10 mm for every 15 m of slab; 0.75 inch for every 100 ft of slab
- ❖ **Design engineer's procedure** is based on ACI 423, corroborated through **observation of satisfactory** application. It is outlined in the following with numerical examples

Reference:

SHORTENING ESTIMATE OF POST-TENSIONED ELEMENTS
Bijan O. Aalami, 2014; www. PT-Structures.com
TN458

- ❖ **Rigorous** procedure is based on **detailed** material properties and geometry of the element as outlined in ACI; EC2 and implemented in ADAPT-ABI

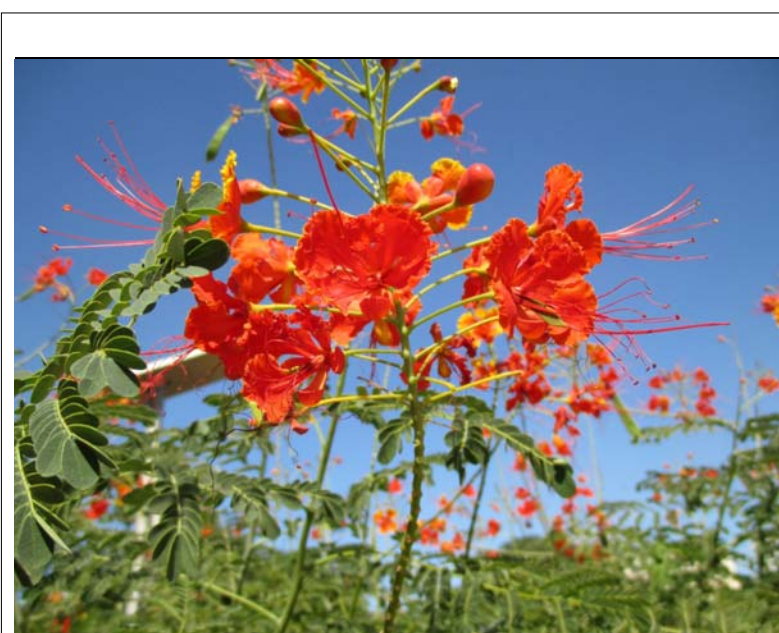
Shortening Post-Tensioned elements

What do we **need to know**?

- ❖ How to **allow** for shortening ?
- ❖ What are the **crack mitigation options**?
- ❖ How to **evaluate the impact of cracking** on serviceability and safety of the element?

Reference:

*Crack Mitigation and Evaluation;
Shortening of Post-Tensioned elements
and Restraint of Supports*
Bijan O. Aalami, 2014; www. PT-
Structures.com TN451

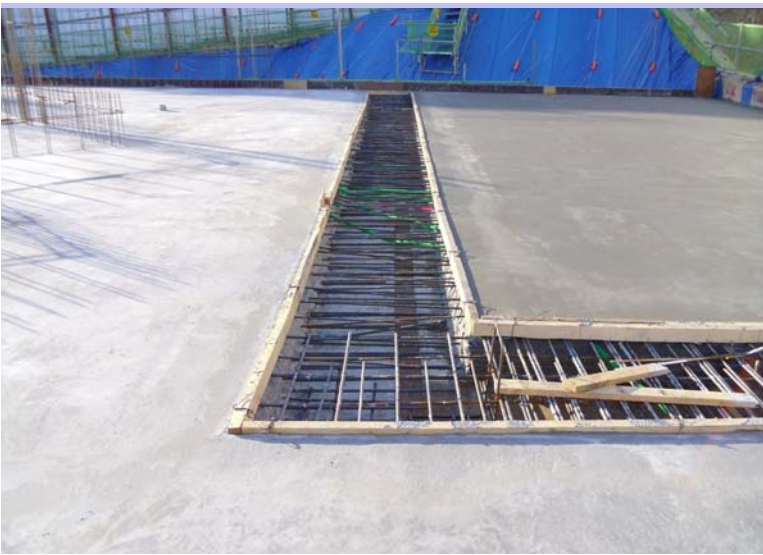


Thank you for listening

any questions?

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Crack Mitigation in Post-Tensioned Floors



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Professor Emeritus,
San Francisco State University
Principal, ADAPT Corporation; bijan@adaptsoft.com
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Crack Mitigation Schemes

- ❖ This presentation covers the **practical measures** followed in North America to allow for shortening of post-tensioned slabs and **avoid excessive cracking**
- ❖ The objective of crack mitigation schemes is to **allow shortening** of a post-tensioned floor to an amount that would ensure the design-intended contribution of post-tensioning to the strength of the floor

Crack Mitigation Schemes

- ❖ Post-tensioned **floors shorten**
- ❖ **Shortening is necessary** for full contribution of post-tensioning
- ❖ For common residential and commercial floor slabs, the anticipated floor shortening is approximately 10 mm for every 15 m slab length; (0.75 in. for every 100 ft slab length)
- ❖ Where slab supports restrain shortening, **shrinkage** of concrete results in **cracking**.
 - Addition of **rebar disperses cracks** and reduces crack width, but does **not** compensate for loss in **contribution from post-tensioning**.

Crack Mitigation Schemes

Adverse effects of support restraints is pronounced in the following instances:

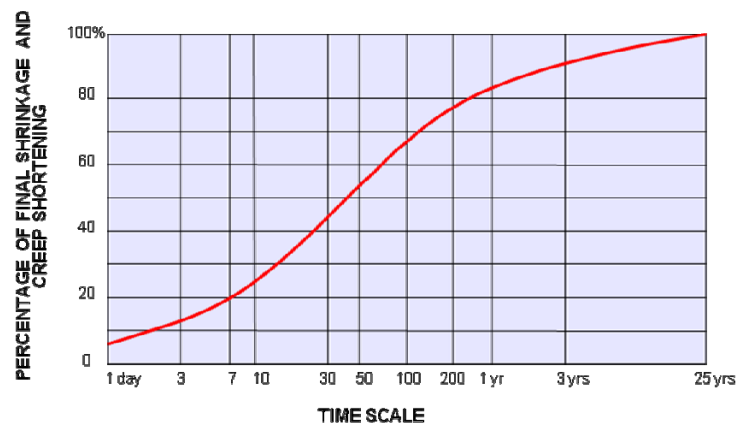
- **Subterranean** floors with restraining perimeter walls
- **First level** of elevated floors supported on stiff walls and columns
- To a **lesser extend** the **second** and possibly third elevated floors

Crack Mitigation Schemes

- ❖ Generally, **upper floors** of a building are **not subject** to support restraint to the extent that it would compromise the strength of the floor slab
- ❖ In **most cases**, crack mitigation for **upper levels** is **not required** and not practiced.

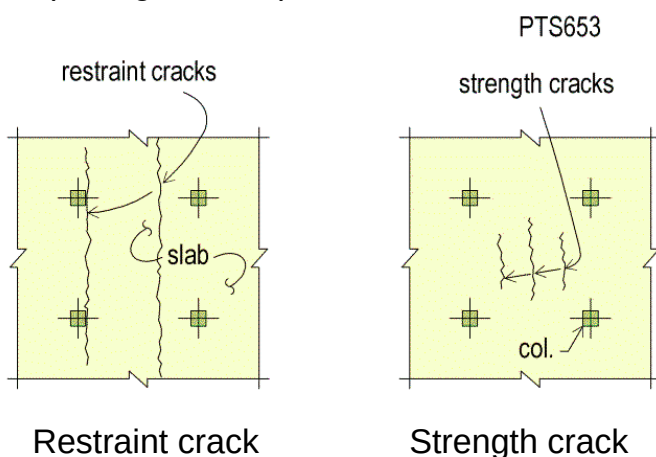
Crack Mitigation Schemes

- ❖ In detailing for crack mitigation, it is often necessary to also estimate the **short-term shortening** of a slab
- ❖ Short-term shortening can be estimated from the following graph



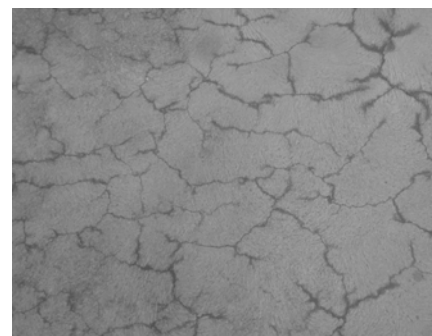
Characteristics of Restraint Cracks

- ❖ Restraint cracks are **long**
- ❖ Do **not** necessarily occur at locations of **maximum moment**
- ❖ **Occur where axial strength is least**, such as where bars terminate
- ❖ Generally extend through the **depth of slab** (through cracks)



Characteristics of Restraint Cracks

- ❖ Restraint cracks are **long**, **deep** and **few**
- ❖ Plastic shrinkage cracks are shallow on surface, many and irregular

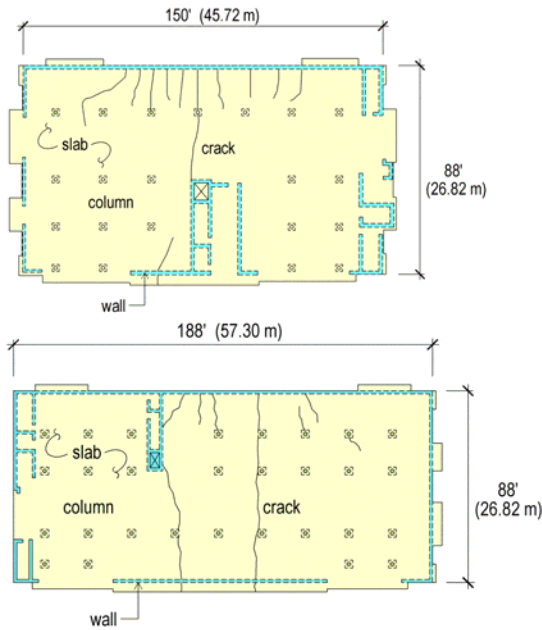


Shallow plastic shrinkage cracks



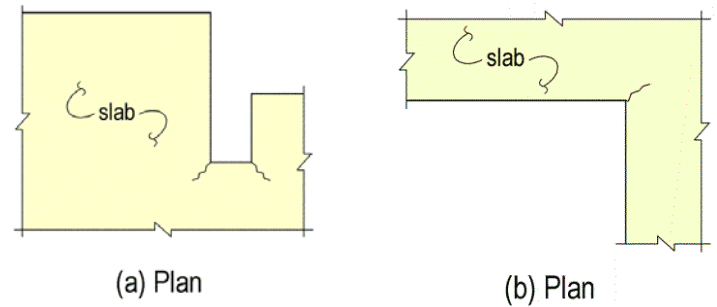
Long deep restrain cracks

Characteristics of Restraint Cracks



- ❖ Restraint cracks generally extend through the depth of the member
- ❖ In the above first level post-tensioned floors on perimeter walls the restraint cracks have fully interrupted the precompression

Characteristics of Restraint Cracks



- ❖ Cracks at **discontinuities** are **not** necessarily related to the **restraint** of supports
- ❖ Cracks at discontinuities **do not have** the same **adverse effect** on safety of the floor as cracks from restraint of supports

Characteristics of Restraint Cracks



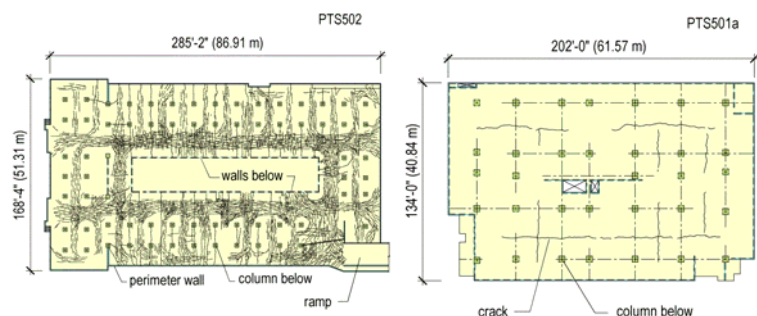
Trim bars at joint

Crack formation at joint

- ❖ Example of discontinuity cracks at re-entrant corner of a post-tensioned ground-supported slab.
- ❖ Addition of rebar at discontinuity has been partially successful

Characteristics of Restraint Cracks

Crack formation resulting from
lack of strength



RC slab

Unbonded PT slab

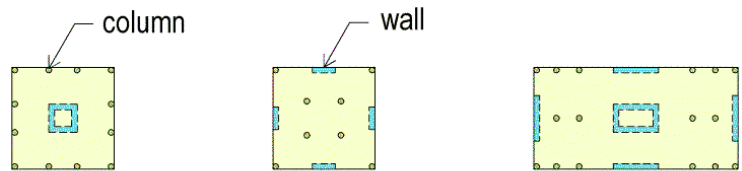
- ❖ **RC** slabs develop **numerous** short and thin cracks
- ❖ Slabs with **unbonded tendons** develop **single** long and wide cracks

Crack Mitigation Options

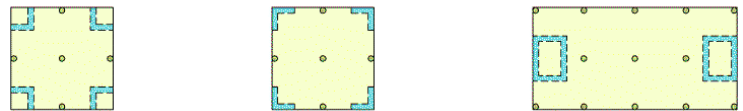
- 1 – Favorable **layout** of restraining supports
- 2 – Structural **separation** breaking up the floor slab
- 3 – **Delay (closure) strips; joints**; favorable pour sequence
- 4 – **Temporary release** between the restraining supports and floor slab
- 5 - **Permanent released** connections between the restraining supports floor slab

Crack Mitigation Options

1 - Favorable arrangement of walls allow the slab parts to move toward the point of zero movement



(a) Favorable arrangement of restraining walls



(b) Unfavorable arrangement of restraining walls

Crack Mitigation Options

2 – Structural separation

For floor slabs on stiff supports, such as subterranean and first elevated

❖ Unless special provisions are made, limit the length of contiguous post-tensioned slabs to 375 ft (115 m). For **slabs longer than 375 ft (115 m)**, provide a **structural separation**

❖ For slabs **longer than 250 ft (76 m)**, but not exceeding 375 ft (114 m), provide a **central delay strip**

❖ For slabs **shorter than 250 ft (76 m)**, **design** the slab for the anticipated shortening

Crack Mitigation Options

2 – Structural separation



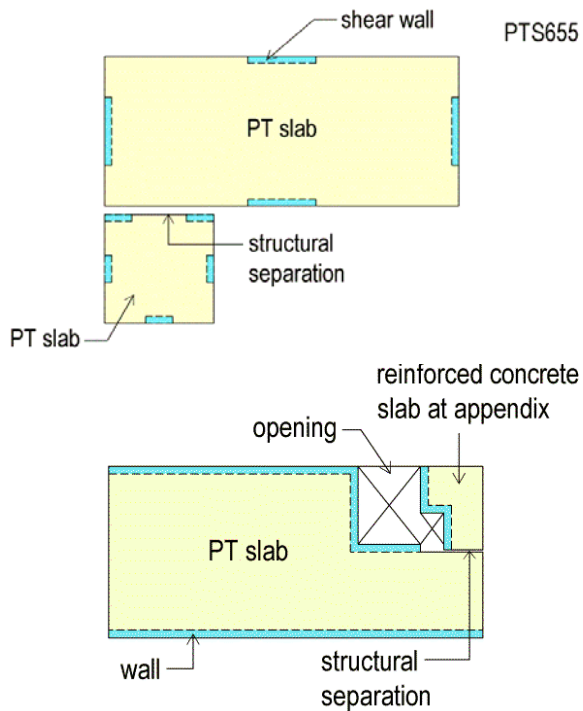
Separation allowing horizontal movement only



Separation allowing movement in all directions

Crack Mitigation Options

2 – Structural separation



At lower levels between movement-unfavorable slab segments

Crack Mitigation Options

3 – Delay strips; joints; pour sequence

- ❖ Delay strips are bands of about 3 ft (1 m) wide that subdivide a larger slab area into isolated segments.
- ❖ Segments on each side of the strip are cast and allowed to shorten, before the gap is closed
- ❖ **Reinforcement does not continue** from concrete on one side of the strip to the other
- ❖ Overlapping reinforcement from the sides to the delay strip provides the continuity

Crack Mitigation Options

3 – Delay strips; joints; pour sequence



Concrete cast on one side

Concrete cast on both sides



Crack Mitigation Options

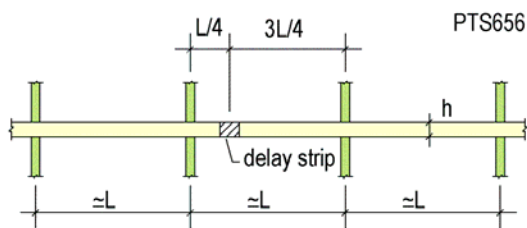
3 – Delay strips; joints; pour sequence



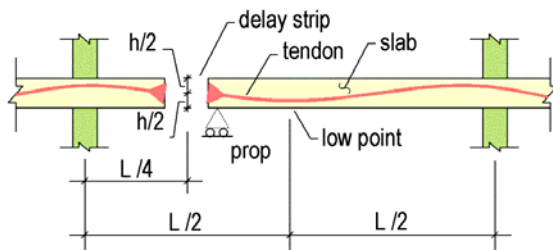
Delay strip in podium slab

Crack Mitigation Options

3 – Delay strips; joints; pour sequence



(a) Elevation ; approx. equal spans

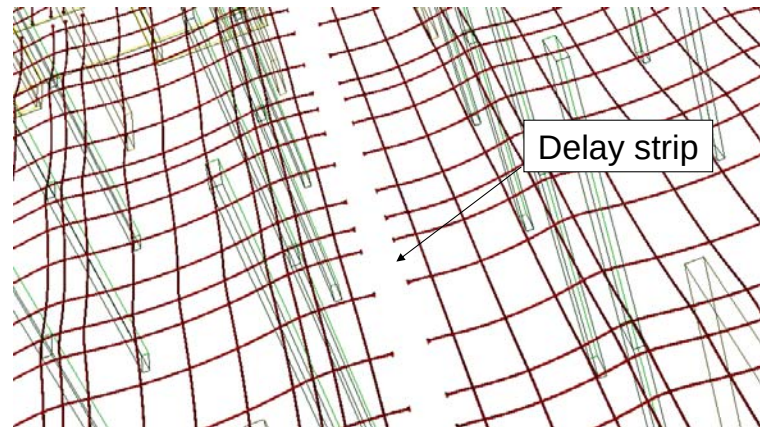


(b) Delay strip at quarter span

- ❖ **Equal spans:** position strip at $\frac{1}{4}$ point
- ❖ Anchor tendon at centroid

Crack Mitigation Options

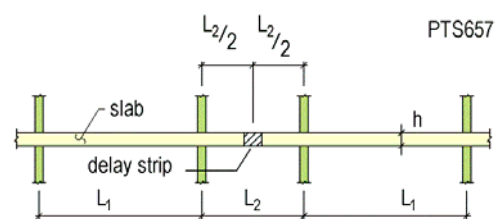
3 – Delay strips; joints; pour sequence



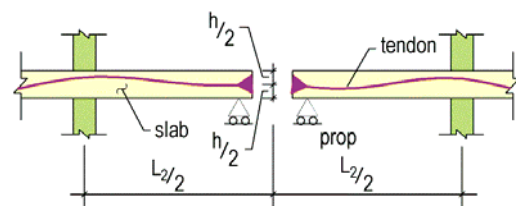
- ❖ View of interrupted tendons at a delay strip of an analysis model

Crack Mitigation Options

3 – Delay strips; joints; pour sequence



(a) Elevation $L_2 \ll L_1$



(b) Delay strip at mid span

- ❖ **Unequal spans:** position strip at mid-depth
- ❖ Anchor tendon at centroid
- ❖ Prop both sides

Crack Mitigation Options

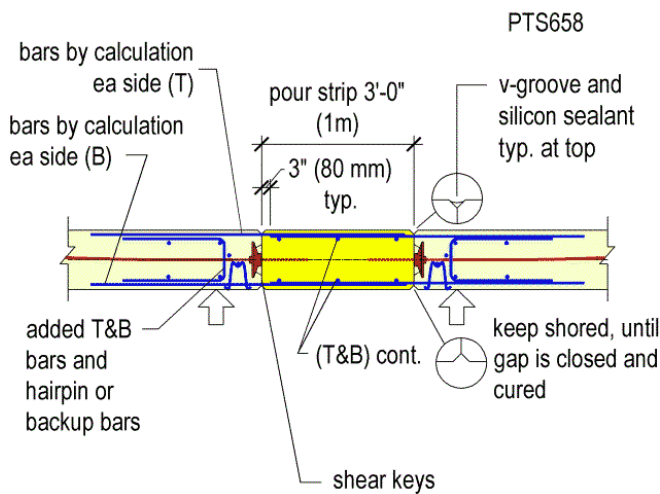
3 – Delay strips; joints; pour sequence



- ❖ Typically, delay strips are required for the first and possibly second and third elevated slabs
- ❖ It is **not generally necessary to continue** them to **upper levels**

Crack Mitigation Options

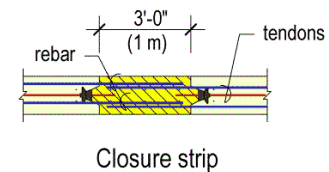
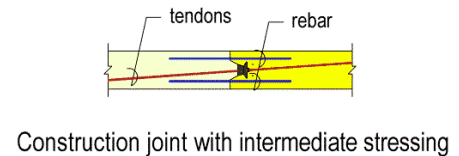
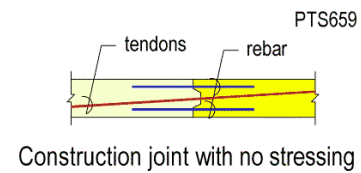
3 – Delay strips; joints; pour sequence



- ❖ Typical detail example from construction drawings
- ❖ The v-grooves are intended to hide anticipated cracks

Crack Mitigation Options

3 – Delay strips; joints; pour sequence



- ❖ Construction joints allow time for one side to shorten, before the second side is cast
- ❖ For long pours, tendons are stressed at the joint

Crack Mitigation Options

3 – Delay strips; joints; pour sequence



Without intermediate stressing



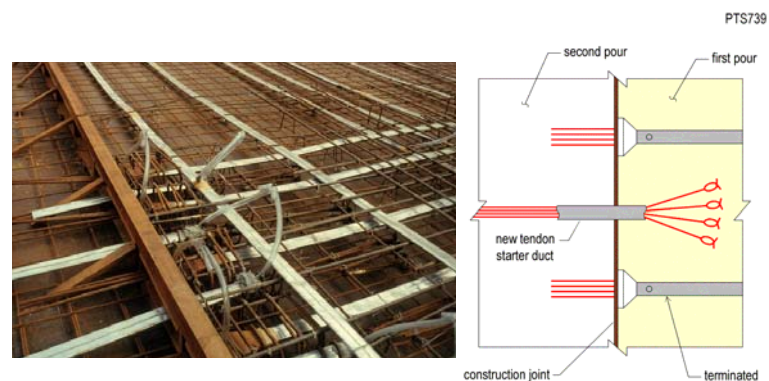
With intermediate stressing



With intermediate stressing; finished on one side

Crack Mitigation Options

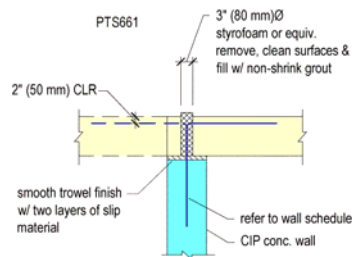
3 – Delay strips; joints; pour sequence



Construction joints of bonded tendons with intermediate stressing is done either using special couplers, or overlapping tendons

Crack Mitigation Options

4 – Temporary release



- ❖ A bond breaker is placed over the wall
- ❖ After slab has undergone the design-intended shortening, the fill in the corrugated tube is removed and the void is filled with strong epoxy

Crack Mitigation Options

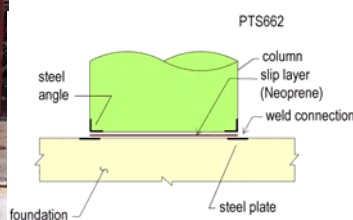
4 – Temporary release



- ❖ A bond breaker is placed over the wall
- ❖ After slab has undergone the design-intended shortening, the fill in the corrugated tube is removed and the void is filled with strong epoxy
- ❖ The dowels through the tube extend to the wall above

Crack Mitigation Options

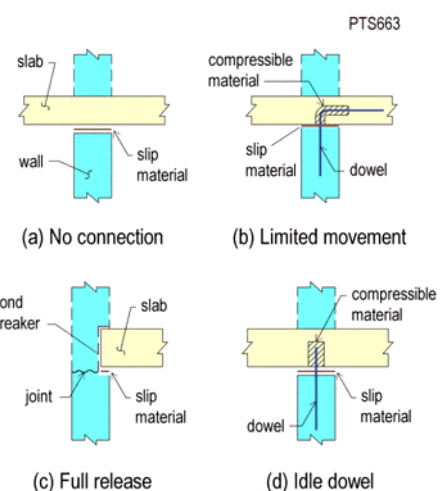
4 – Temporary release



- ❖ The stubby column supporting a long-massive post-tensioned exhibition roof is initially supported on Neoprene pads to allow it slide over the foundation.
- ❖ Column is welded to the base, once the anticipated shortening of the post-tensioned roof has taken place

Crack Mitigation Options

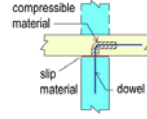
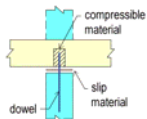
5 – Permanent release



- ❖ Permanent release is practical, where shear transfer between the slab and its support is not required

Crack Mitigation Options

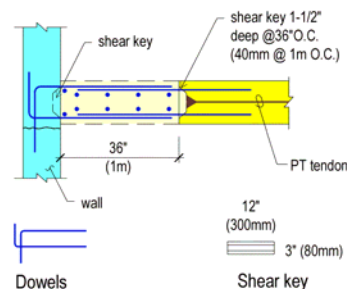
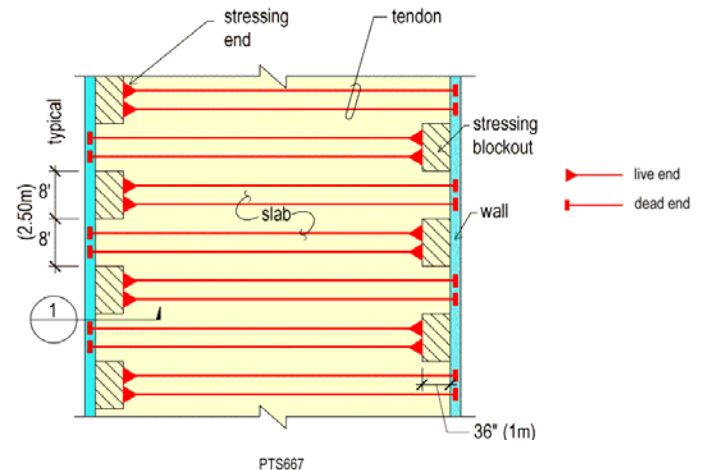
5 – Permanent release



- ❖ In both options above, the supporting wall is covered with a bond breaker
- ❖ On the left detail, the dowel from the wall terminates within the compressible cover.
- ❖ On the right, the dowel is bent into the slab and engages in extreme events

Crack Mitigation Options

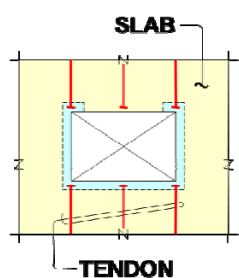
Other release options



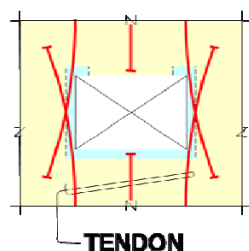
Tendons are stressed alternatively from each side between constructed retaining walls

Crack Mitigation Options - Detailing

A . Favorable arrangement of tendons



CRACK PROMOTING LAYOUT

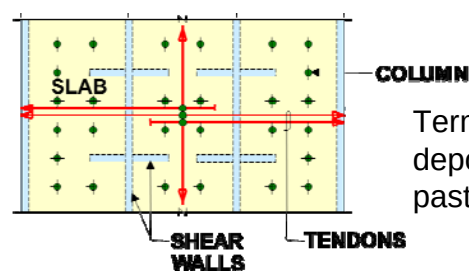


CRACK INHIBITING LAYOUT

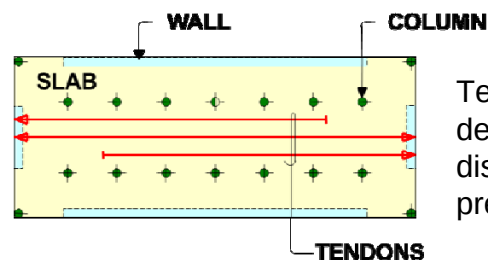
- ❖ Arrangement of tendons around opening

Crack Mitigation Options - Detailing

A . Favorable arrangement of tendons



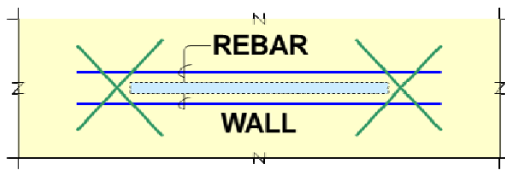
Terminated tendons deposit precompression past the shear walls



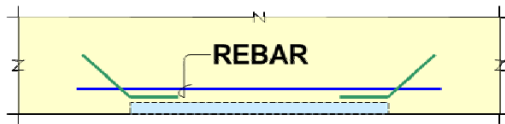
Terminated tendons deposit improve distribution of precompression

Crack Mitigation Options - Detailing

B . Addition of rebar



(a) INTERIOR SHEAR WALL



(b) EXTERIOR SHEAR WALL

- ❖ Small diameter rebar next to restraining elements disperses cracks and reduces crack width
- ❖ This does not compensate for loss from contribution of prestressing to strength of the slab

Crack Mitigation Post-Tensioned Floors

Summary

- ❖ Post-tensioned **slabs shorten**
- ❖ Slabs can crack, if shortening is restrained
- ❖ Cracks caused by restraint of support impair the design-intended function of post-tensioning
- ❖ Common schemes for crack mitigation of slabs are:
 - Favorable arrangement of restraining supports
 - **Structural separation** (first couple of levels)
 - **Delay strips** (first couple of levels)
 - **Joints**; with or without intermediate stressing
 - **Releases**: temporary; permanent
 - Favorable **arrangement of tendons**
 - **Addition of rebar** to disperse cracks

Crack Mitigation Design of Post-Tensioned Floors



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Crack Control Design

- ❖ This presentation covers the **practical measures** followed in North America to mitigate the formation of unacceptable cracks in post-tensioned slabs, caused by restraint of supports
- ❖ The objective of the crack control design is to allow for shortening of post-tensioned member by an amount that would not lead to
 - Unacceptable cracks from visual and functional standpoint

Crack Control Design

- ❖ Post-tensioned **floors shorten**
- ❖ **Shortening is necessary** for full contribution of post-tensioning to the safety of floor slab
- ❖ For common residential and commercial floor slabs, the anticipated floor shortening is approximately 10 mm for every 15 m of slab length; (0.75 in. for every 100 ft slab length)
- ❖ Where slab supports restrain shortening, shrinkage cracks can form.
 - Addition of rebar disperses cracks and reduces crack width, but does not restore the full function of post-tensioning

Crack Control Design

Adverse effects of support restraints are pronounced in the following instances:

- ❖ Subterranean floors with restraining perimeter walls
- ❖ First level of elevated floors supported on stiff walls and columns
- ❖ To a lesser extent the second and possibly third elevated floors

Crack Control Design

- ❖ Upper floors of a building are not generally subject to support restraint to the extent that it would compromise the safety of the floor slab
- ❖ In most cases, crack mitigation for upper levels is not required, and not practiced.



Upper levels of multi-story buildings do not generally require crack mitigation measures

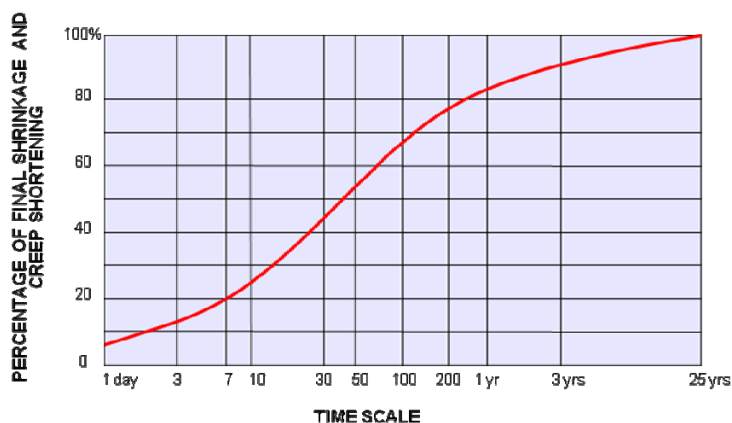
Crack Control Design

Methods for calculating the shortening of floor slabs, with numerical examples are available in the literature



Crack Control design

- ❖ In designing for crack mitigation, it is necessary to estimate the **short-term** shortening of the post-tensioned member
- ❖ Short-term shortening can be estimated from the following graph



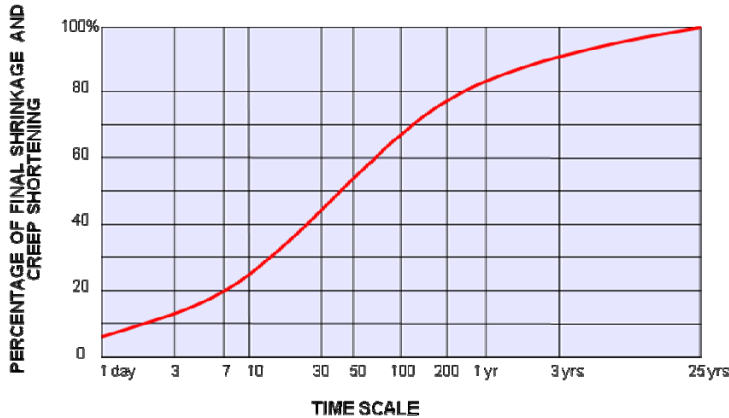
Aalami, B. O. and Barth, F. G. (1988) "Restraint Cracks and Their Mitigation in Unbonded Post-Tensioned Building Structures," Post-Tensioning Institute, Phoenix, AZ, 49 pp.

Crack Control Design

- ❖ The design procedure is entirely **empirical**
- ❖ The **validity** of the design procedure is based on the **satisfactory performance** of post-tensioned members that have been detailed accordingly
- ❖ The basic assumptions and the steps to follow are:
 1. **Estimate the total shortening** of the member
 2. Determine what **fraction** of the estimated shortening has to be **accommodated** through special detailing
 3. **Provide detailing** that allows the estimated shortening to take place

Crack Control design

- ❖ For a first and approximate estimate, assume 10 mm for every 15 m of the member (0.75" for every 100 ft)
- ❖ For **interim shortening**, use the curve below



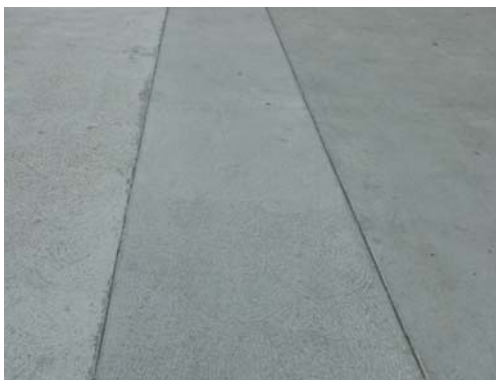
Design for Crack Control

steps for shortening design

- 1 – **Estimate the total shortening** of the member
- 2 – Based on the long-term nature of shortening, it is impractical to allow for the entire shortening to take place, before the member is locked to the rest of the structure
- 3 – Determine what **fraction** of the **shortening** must be **accommodated** through special **detailing** for satisfactory performance of the member
- 4 – **Provide detailing** that allows for the estimated shortening to take place

Design for Crack Control

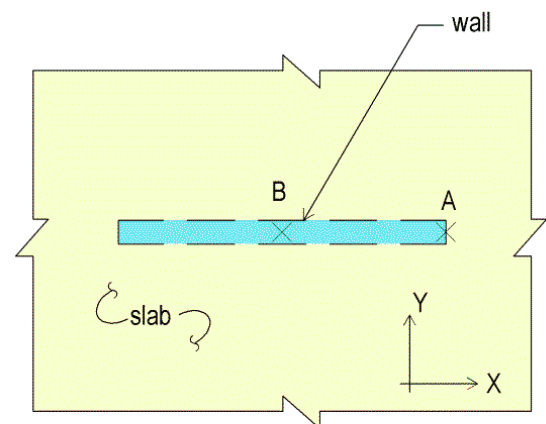
- ❖ The underlying assumptions and steps are based on observation
- ❖ If the computed displacement of a point on a floor does **not exceed 0.25-in.** (6 mm), the floor is deemed to perform satisfactorily
- ❖ Provide detailing such that at no point on the floor, the computed, but not accounted for displacement does not exceed the above limit.



View of a closure strip

Design for Crack Control

- ❖ For the first elevated slab above grade and for subterranean slabs assume:
 - ❖ Points on slab adjacent to a wall such as A and B in the figure, cannot move in direction of the wall (X-direction), but are free to move normal to the wall (Y-direction). The wall is free to bend about its weak axis



Partial plan

Design for Crack Control

- ❖ At **upper levels walls provide less restraint** to shortening. Slabs are considered to perform satisfactorily, if shortening restrained by wall does not exceed the table below:

Level	Single walls	Core/ compound walls
1 st level	0	0
2 nd level	0.125 in. (3 mm)	0.06 in. (2 mm)
3 rd level	0.25 in. (6 mm)	0.12 in. (3 mm)
4 th level	No restraint	0.18 in. (5 mm)
5 th level	No restraint	0.25 in. (6 mm)
6 th level	No restraint	No restraint

Example

For **3rd level** above grade a slab attached to a **core wall** is assumed to work satisfactorily, if its design shortening restrained by the wall does **not exceed 0.12-in.** (3 mm)

Design for Crack Control

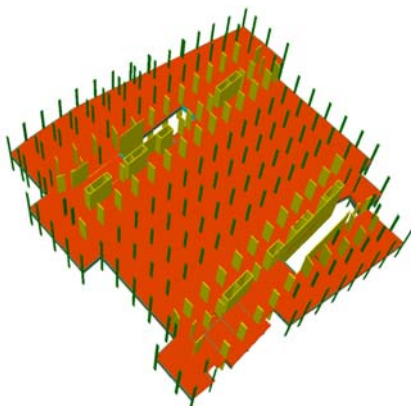
Review the geometry of the first slab above grade, or subterranean slabs

- ❖ If **longer than 375 ft (115 m)**, provide a **structural separation**, in the first and possibly second levels
- ❖ If **longer than 250 ft (76 m)**, provide a **delay strip** in subterranean slabs, and one in the first and possibly the second levels above grade
- ❖ For slabs **shorter than 250 ft (76 m)** design for **crack mitigation**
- ❖ If the geometry of the slab is irregular and complex, it may require to add separation or delay strips

Design for Crack Control

Design Example

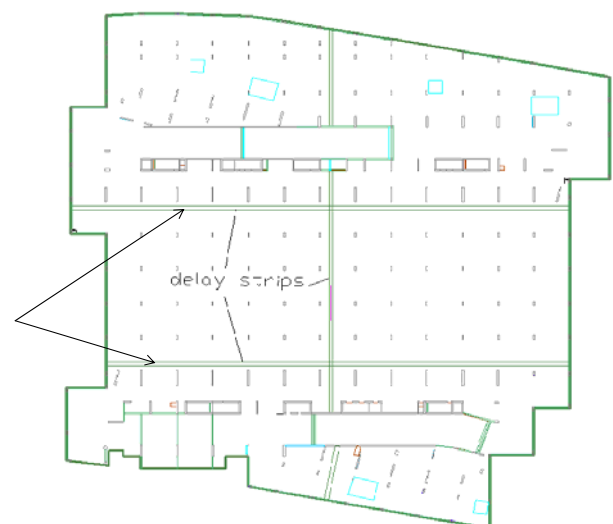
- ❖ the graphic shows the first elevated slab of a **two level parking structure** with a towers on each side.
- ❖ Delay strips are provided to allow for shortening of the slab
- ❖ Based on the arrangement of the delay strips, the contractor needs to know the number of days that the strips must be left open, before they are cast



Design for Crack Control

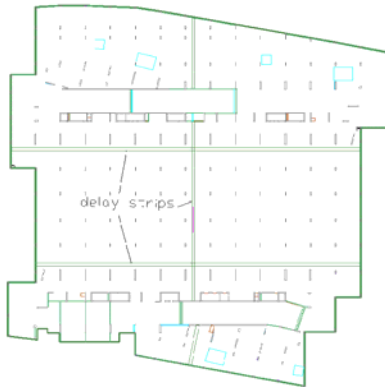
Design Example

- ❖ The distance between the two delay strips marked is 112 ft (34.13 m)
- ❖ When should the delay strip be cast ?



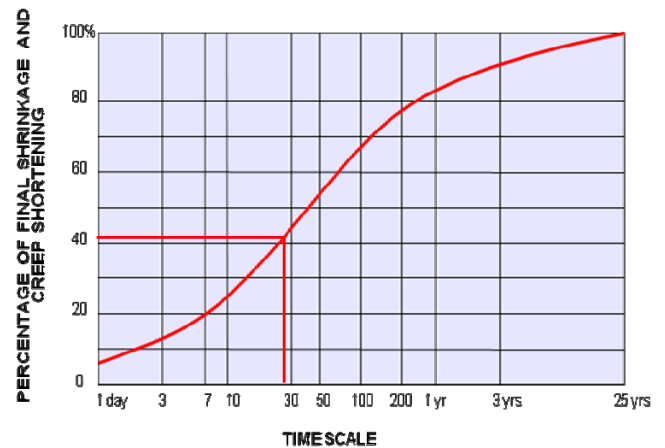
Design for Crack Control

- ❖ Using the 0.75-in./100 ft (10 mm/15 m) approximate value, the total shortening is estimated as:
 $0.75(112/100) = 0.84\text{-in.}$ (21.3 mm)
- ❖ Shortening at each end = $0.5 \times 0.84 = 0.42\text{-in.}$ > 0.25-in. (11 mm > 6 mm)
- ❖ Shortening to take place before closing the gap is
 $(0.42 - 0.25) = 0.17\text{-in.}$ (4 mm)
- ❖ Ratio of unrestrained to restrained shortening
 $0.17/0.42 = 0.41$ 41%
- ❖ The delay strip has to remain open until 41% of its estimated shortening is taken place



Design for Crack Control

- The percentage of shortening that needs to take place is 41%
- This requires 25 days delay before gap is closed
- From the long-term shortening graph, 41% of shortening takes place over approximately 25 days.
- The gap has to remain open for 25 days



Crack Mitigation Design Example

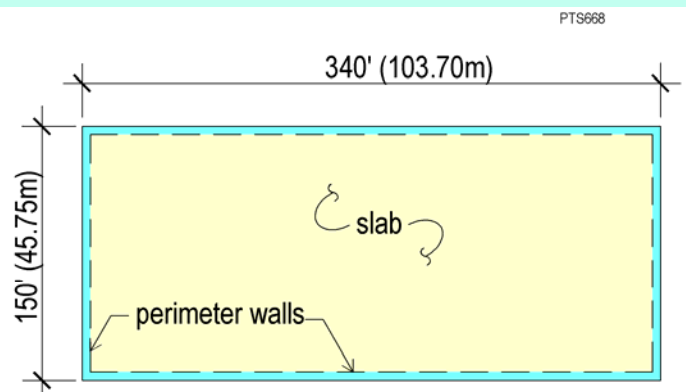
Post-tensioned subterranean slab on perimeter walls



Example of a building with

- post-tensioned underground parking floors
- An elevated post-tensioned podium slab roofing the street level retail; and
- Podium slab that supports four levels of residential light framing superstructure.

Crack Mitigation Design Example



Simplified Plan
Column layout and openings not shown

Construction requirements

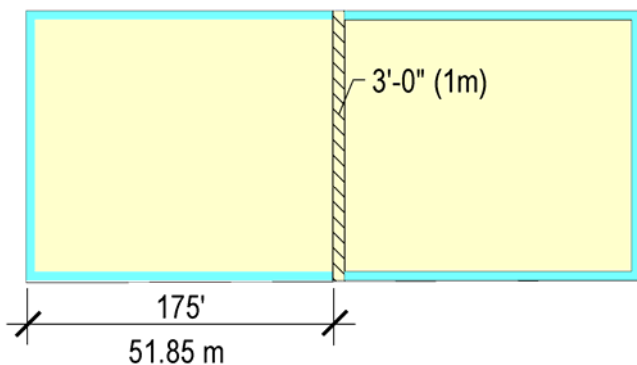
- ❖ Each long wall requires a minimum of 150 ft (45.75 m) of shear wall; full connection of slab to wall.
- ❖ Each of the short walls a minimum of 100 ft (30.5 m) shear walls.
- ❖ Closure strips, if any, should be closed not later than 20 days to avoid delay in construction

Crack Mitigation Design Example

Consult Crack Mitigation Guidelines:
(reference PTI publication on crack mitigation)

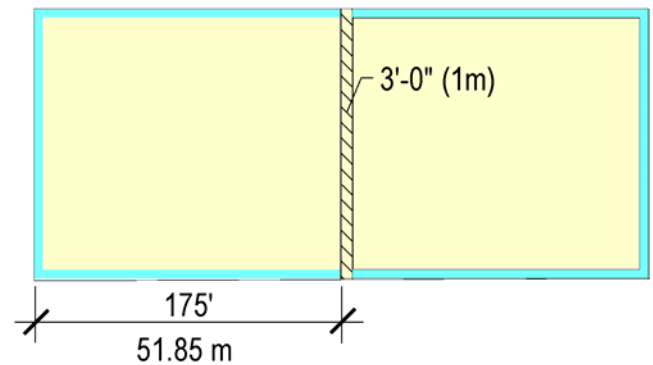
- Slab less than 375 ft (114 m), but longer than 250 ft (76 m) requires a delay strip.
- A delay strip at center reduces the length for shortening design to

$$340/2 = 170 \text{ ft (51.85 m)}$$



PTS669c

Crack Mitigation Design Example

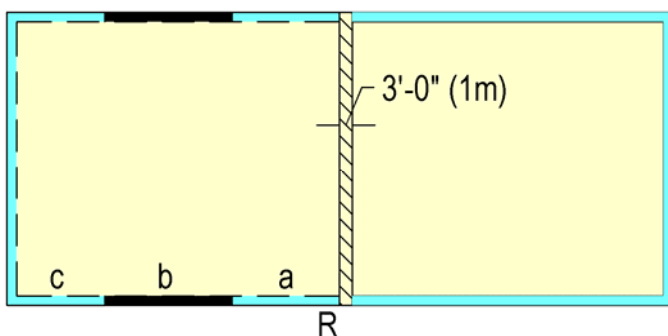


- In the absence of detailed computation, for preliminary designs, assume 0.75 in. of shortening for every 100 ft of slab length (10 mm shortening for every 15 m of slab length).
- Total shortening at each end of each slab segment =

$$170 \times 0.75 / (100 \times 2) = 0.64 \text{ in. (16 mm)} \\ > 0.25 \text{ in. (6 mm)} \quad \text{NG}$$

Crack Mitigation Design Example

Design of connections along the long wall



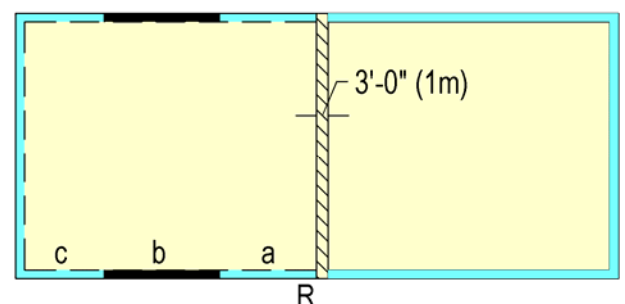
The length of the wall "b" is determined such that its long-term shortening at each end will be limited to 0.25-in. (6 mm)

$$b = [(2 \times 0.25) / 0.75] \times 100 = 67 \text{ ft (20.44 m)}$$

PTS599d

Crack Mitigation Design Example

Determine the position of long wall's initial connection

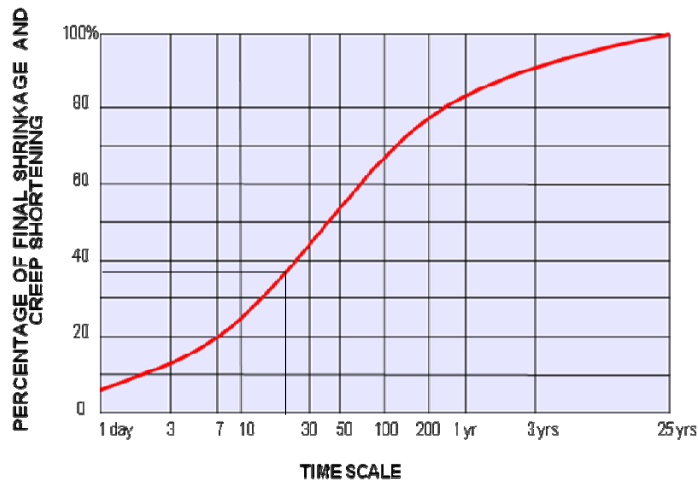


- Once the in 20 days the closure strip is cast, the point R is locked in position.
- Hence, at the time of casting the delay strip, the balance of long-term shortening of point R shall not exceed 0.25-in. (6 mm)
- Determine the distance "a" with the assumption that in 20 days all if it shortening minus 0.25-in (6 mm) is taken place.

PTS599d

Crack Mitigation Design Example

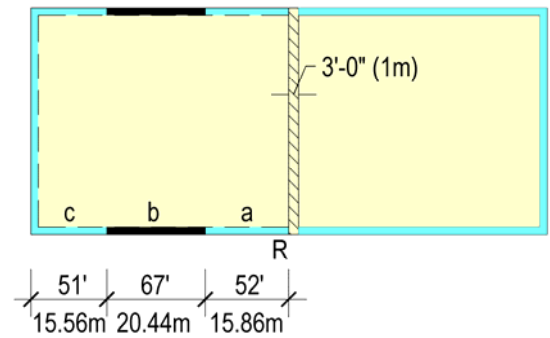
From the following graph on day 20 approx.
36% of the shortening takes place



Distance "a" is given by:

$$a = 100(0.39/0.75) = 52 \text{ ft (15.85 m)}$$

Crack Mitigation Design Example



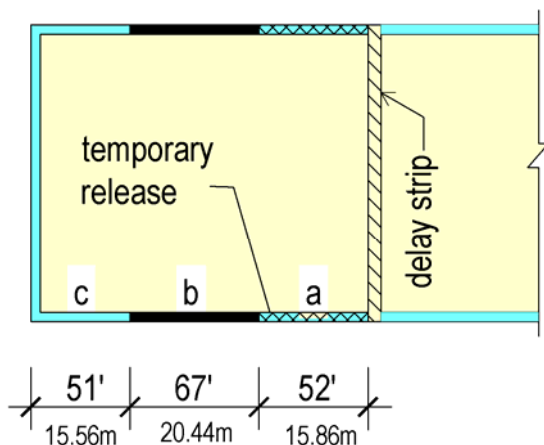
Position of initial slab to wall connection

Next, the adequacy of full shear transfer between the slab and wall needs to be verified

pts699

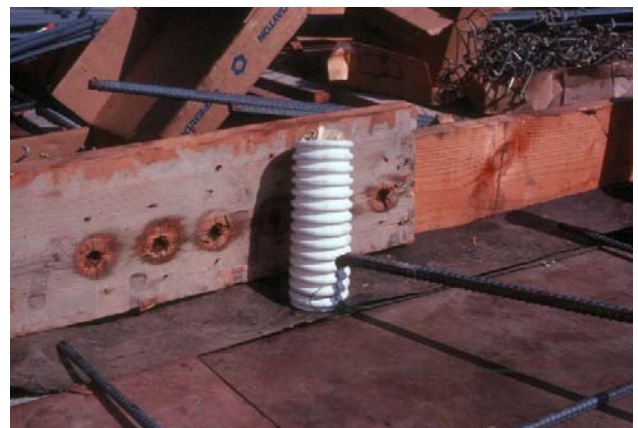
Crack Mitigation Design Example

- 150 ft (45.75 m) shear connection is required for each long wall
- The full connection (b=67 ft; 20.44 m) has to be increased to 75 ft (22.88 m) on each side of the delay strip
- Select temporary release connection:
The length for shear transfer will be:
- $67 + 52 = 139 \text{ ft (36.30 m)}$ OK

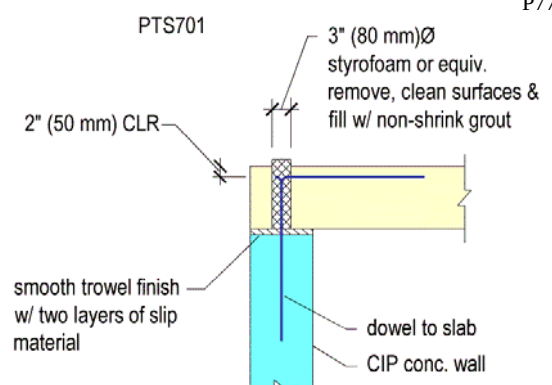


PTS670

Crack Mitigation Design Example



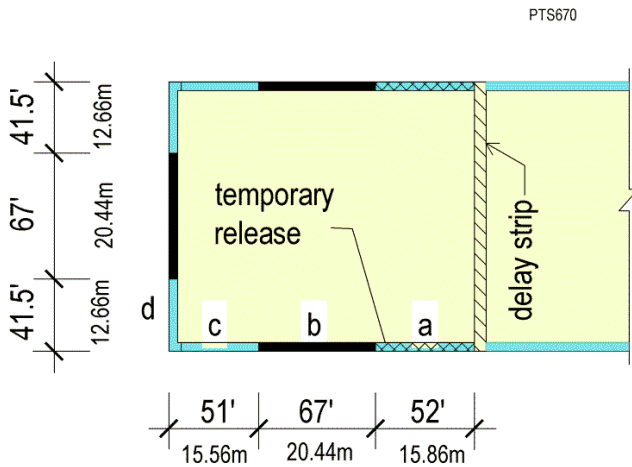
P773



Examples of Temporary Release Connection

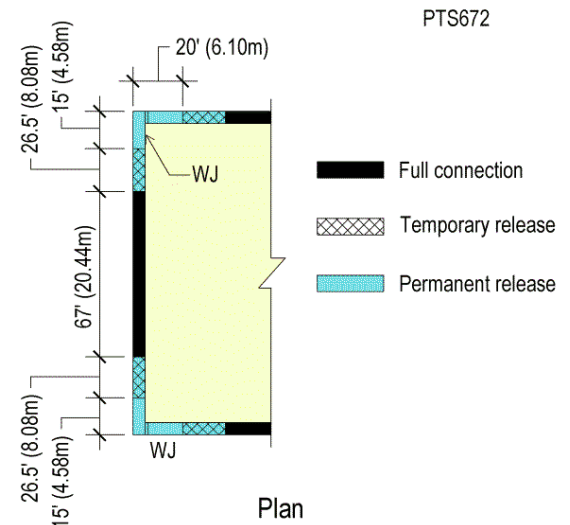
Crack Mitigation Design Example

The remainder of the wall connections are worked out in a similar manner



Crack Mitigation Design Example

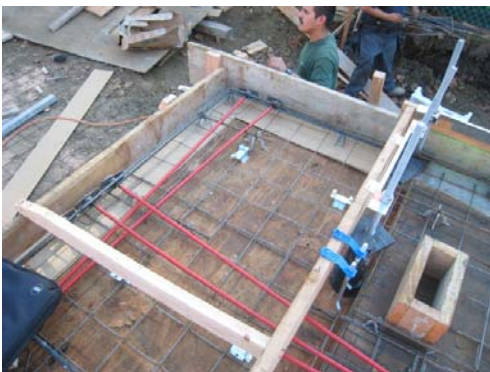
For improved performance the slab/wall connections are finished as detailed in the following:



Wall joints and permanent releases are also implemented

Crack Mitigation Design Example

Details of a corner release example, using two layers of Masonite as bond breaker



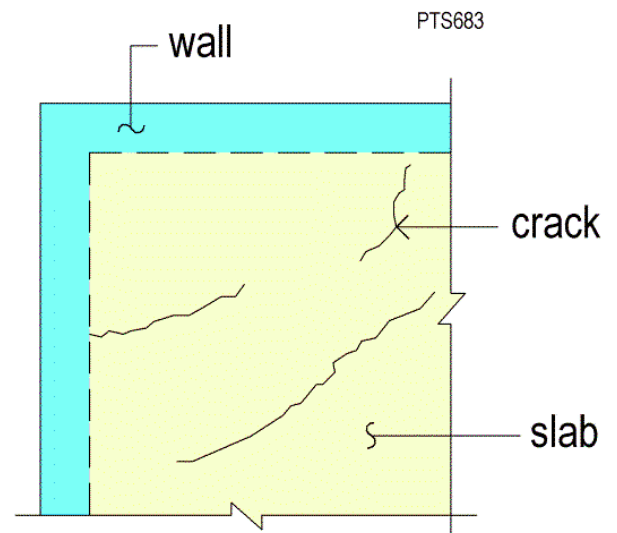
P809



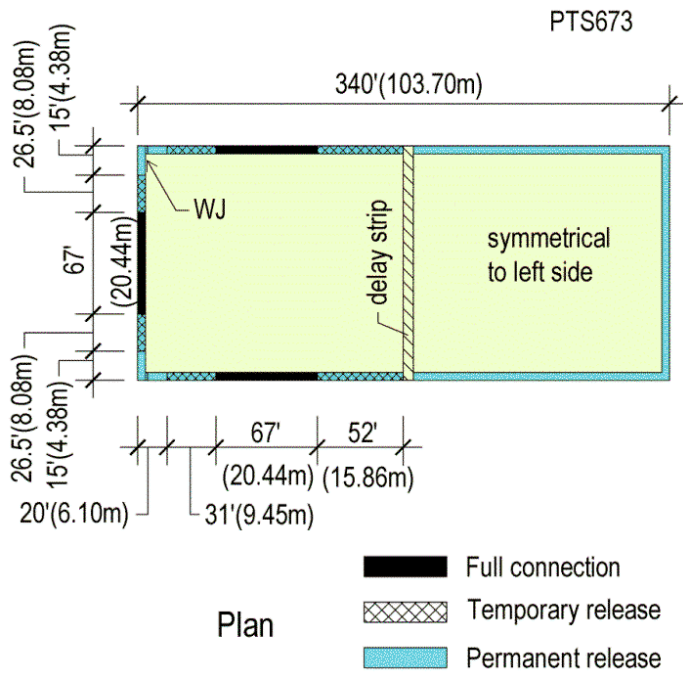
P775

Crack Mitigation Design Example

Provision of corner release, wall joint, and added rebar help to mitigate they type of cracking shown below



Crack Mitigation Design Example



View of completed design showing the position of wall joints

Crack Mitigation Design Example



P778

Slip joint viewed from below



P779

Wall joint viewed from inside

Design for Crack Control

Summary

- Post-tensioned members must shorten under the precompression, in order to develop their design-intended response
- It is not always practical for the entire shortening to take place, before a member is locked to its supports
- From standpoint of safety and crack formation, experience has shown that post-tensioned members have performed satisfactorily, if unaccounted shortening of members under precompression is limited to a small value.
- Support release and other measures are generally implemented to limit the unaccounted shortening of a post-tensioned member to the admissible target

Design for Crack Control

Summary

- Delay (closure) strips is one option to allow unrestrained shortening
- Using a numerical example it was demonstrated how many days a delay strip needs to remain open for the computed shortening to take place.
- A subterranean slab supported on perimeter walls was used as an example to demonstrate the engineering design procedure for crack mitigation

Session 5

Thursday 31 May

Advanced Design of Post-Tensioned Floor Systems
using 3D FEM Software
(ADAPT-Builder)

Florian Aalami

3D Finite Element Modeling and Design of Multistory Post-Tensioned Floor Systems for Gravity and Lateral Loads

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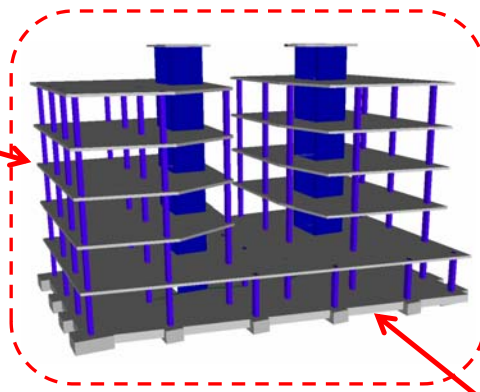
May 2018

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- Post-Tensioned
- Fiber Reinforced
- Hybrid

Floor Systems



Complete
Concrete
Buildings

Industrial Slabs on Grade

Foundation Systems



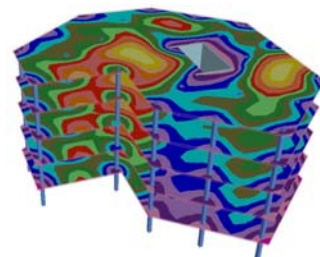
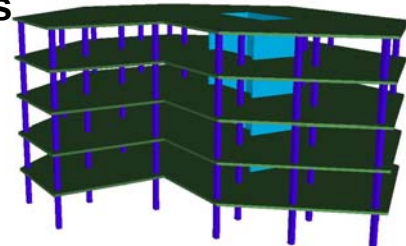
Advanced 3D FEM Solutions are Best Used To:

- Design complex floor and foundation systems
- Optimize performance of complete slab system
 - Quantities (economics)
 - Vibration
 - Deflections (cracking)
 - Temperature fluctuations
- Efficiently produce high-volume projects (Model to CAD)
- Implement BIM design workflow
- Investigate existing structures



Multi-story Analysis is Needed to:

- Evaluate effects of PT on complete Structure
- Determine displacement btwn. levels
- Design transfer slabs or beams
- Efficiently take down loads
- Integrate lateral and gravity loads
 - Wind
 - Earthquake
- Integrated column and wall design





ADAPT

ADAPT-Builder Suite

ADAPT-Builder is a 3D Finite Element Based Modeling, Analysis and Design Software Platform Specifically Created for Concrete Structures

Specialized Modules of ADAPT-Builder Suite:



Edge: Multistory analysis of concrete buildings



Floor Pro: Design of concrete floor systems



MAT: Design of foundations systems



SOG: Design of post-tensioned slabs on expansive soils



S-Concrete: Design of columns and walls

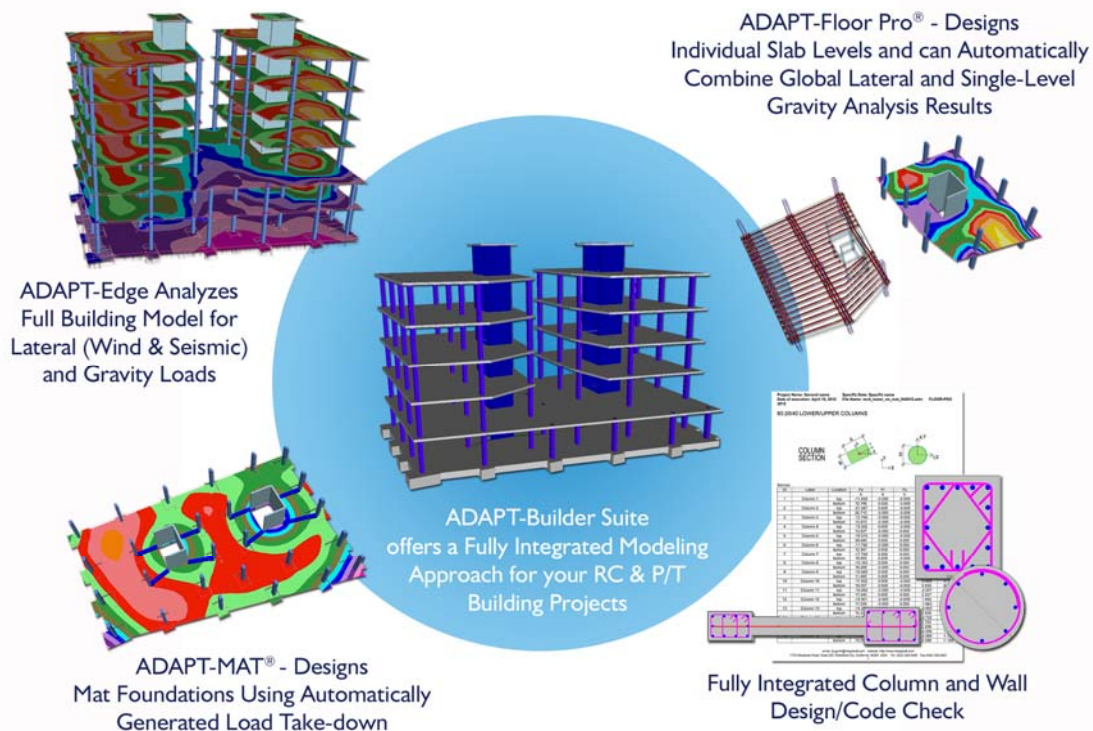


Tekla Structural Designer: Design of general buildings



ADAPT

Integrated Concrete Building Design

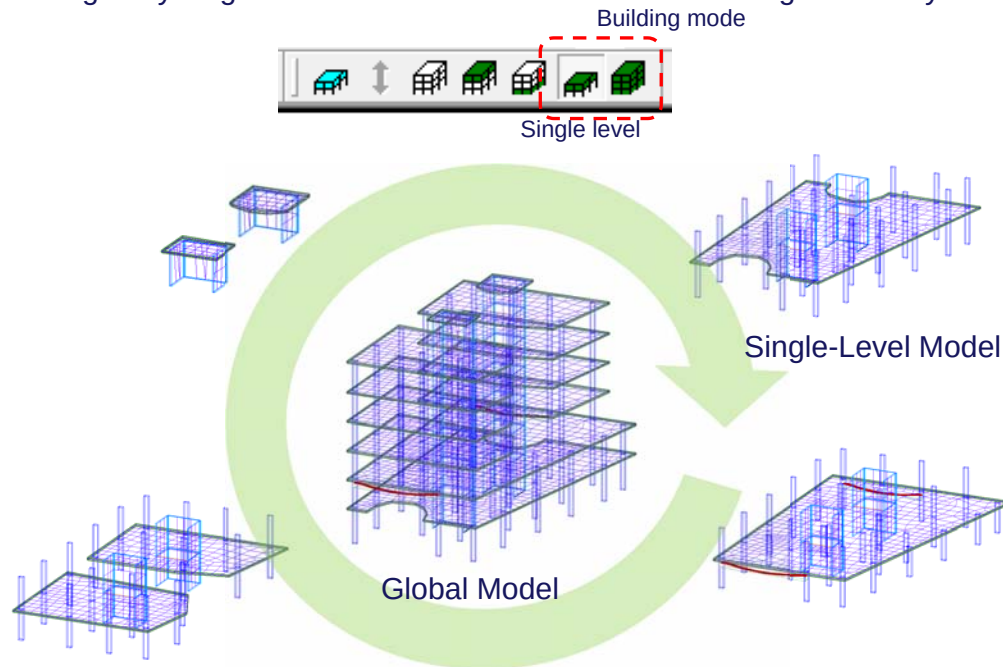




ADAPT

One-Click Switch: Global & Slab/Mat

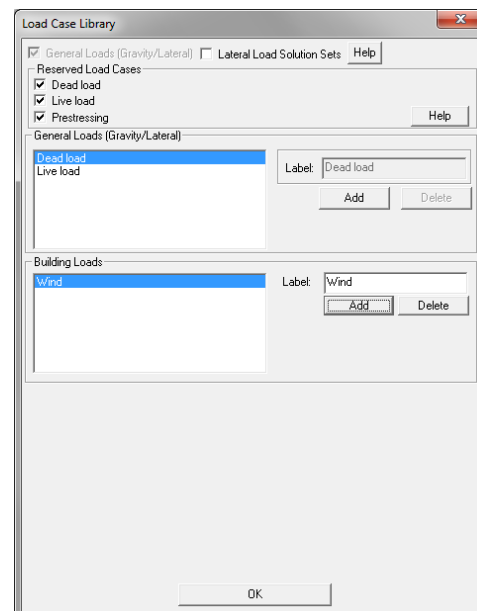
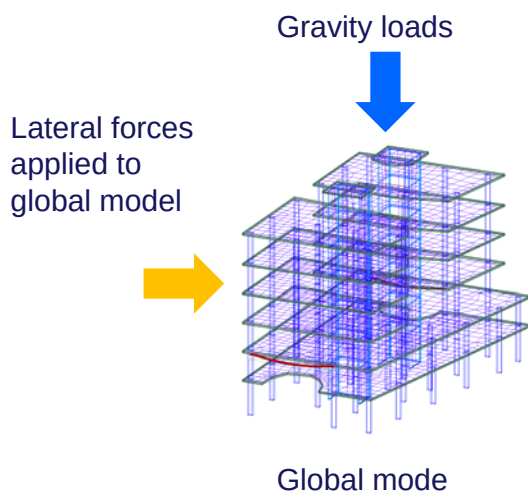
Switch between global and single-level modes with one click. Modify, analyze and design any single level with its own solution or that from global analysis.



ADAPT

Global 3D FEM Analysis

Edge analyzes models using 3D FEM in their complete global configuration. Loads are either classified as general gravity loads or building lateral loads.

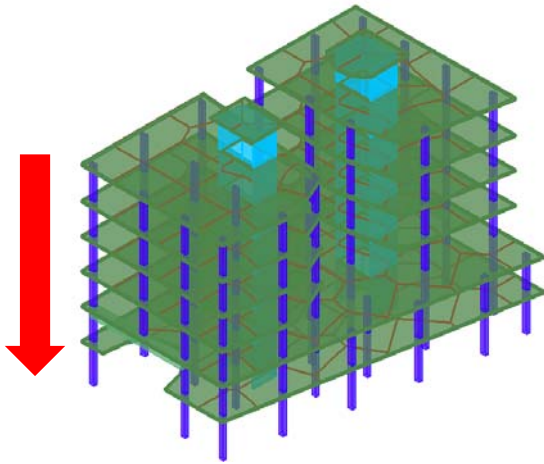




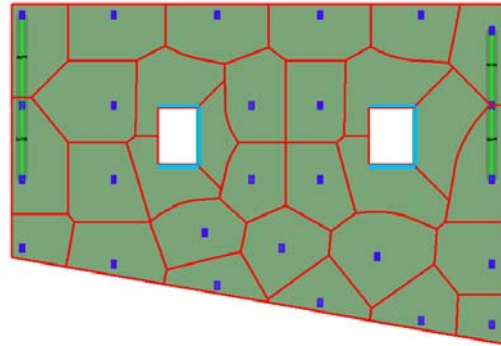
ADAPT

Global Tributary-Based Load Takedown

For quick load takedowns or alternative load path calculation, Edge uses geometry-based tributary regions to calculate gravity loads in vertical elements.



Tributary-based load takedown in global mode



Tributary area breakdown of one level of model

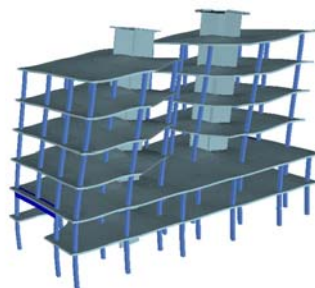


ADAPT

Integrated Lateral / Gravity Design

Efficiently design slabs for combined gravity and lateral forces by combining the internal reactions from global lateral analysis with the gravity analysis of individual floors.

3D FEM analysis results from lateral global analysis



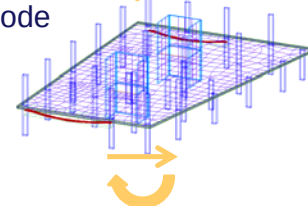
Global analysis results

Gravity loads



+

Solution from lateral loads available in single level mode



Single-level mode can combine global lateral results + single-level gravity analysis



ADAPT

Transfer Slab/Beam Design

Design transfer slabs or beams using the tributary-based loads.

Options to include global analysis results

Apply all reactions from global FEM analysis None

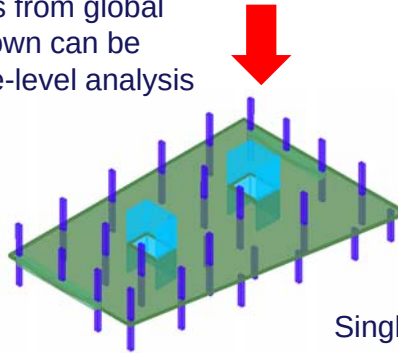
Apply Fz (vertical) for gravity load cases only None

None

FEM building solution

Tributary method solution

Vertical gravity loads from global tributary load takedown can be applied to any single-level analysis



Single-level mode



ADAPT

Integrated Column Design

Columns can be designed using an integrated approach with multiple loading options and automatic incorporation of post-tensioning effects.

Different sources for the design forces:

Force Source Tributary Method (Axial Gravity Only)

FEM

Tributary Method (Axial Gravity Only)

Envelope of FEM and Tributary

FEM Moments and larger of Tributary/FEM Axial

Global or local FEM analysis results:

FEM Source Global analysis governs

Global analysis governs

Level analysis governs

Hyperstatic forces based on global or single-level analysis:

Hyperstatic Source Level analysis governs

Level analysis governs

Global analysis governs

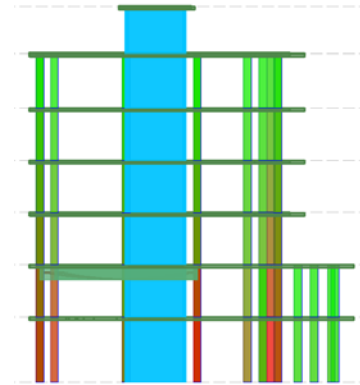
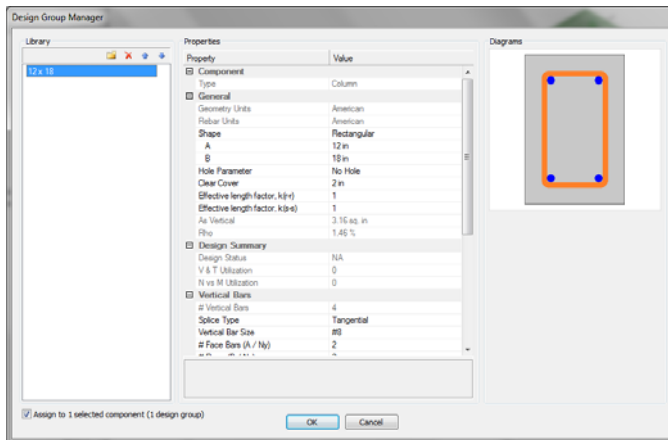


ADAPT

Integrated Column Design

ADAPT-Builder runs S-CONCRETE in the background to carry out column design or detailed code check based on the user options selected.

Columns are defined using Design Groups



Utilization of columns
color coded in model

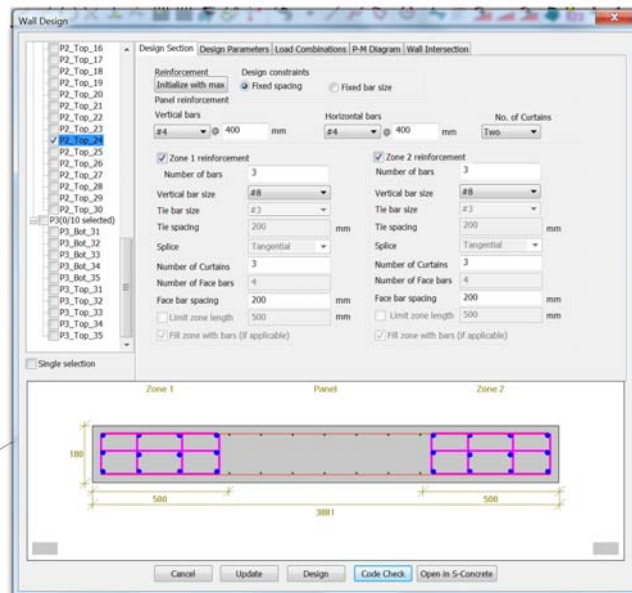
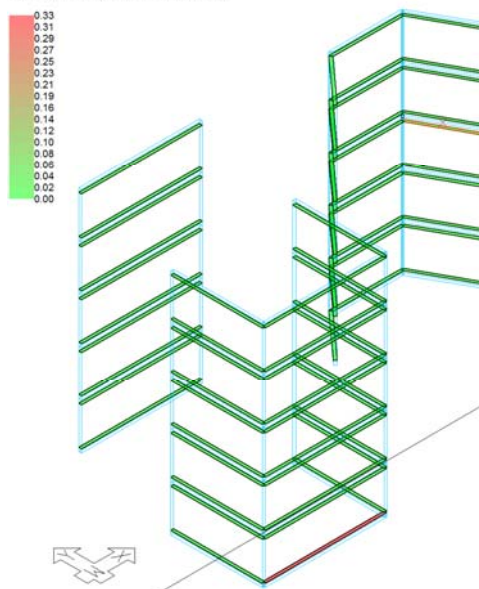


ADAPT

Integrated Wall Design

ADAPT-Builder checks and design concrete shear walls

Wall, Design Section Results, NvsM Utilization





ADAPT

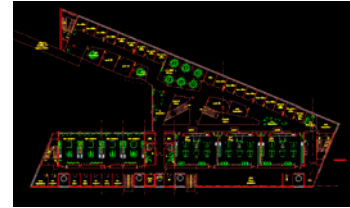
Review of Design Process

Leverage existing project information

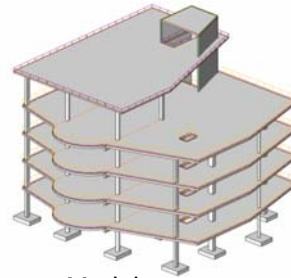
Import

Import Geometry & Loading from Existing Models

- Revit® Structure
- AutoCAD®
- ETABS
- Tekla Structural Designer



AutoCAD Information



Intelligent Revit Structure Models



ADAPT

Efficient Design of Slab Systems

Create true 3D slab model

Import

Model

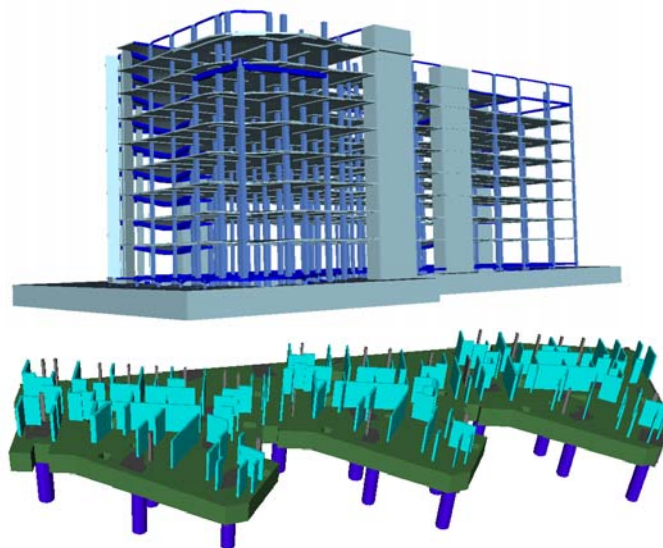
*Geometry
& Loading
Models*

- Revit® Structure
- AutoCAD®
- ETABS®



**ADAPT-
Modeler**

True 3D
Concrete
Modeling
Environment



*True 3D Model of Slab System or
Entire Structure in ADAPT*

**ADAPT**

Efficient Design of Slab Systems

Carry out detailed analysis and design using one of 4 integrated 3D FEM analysis modules

Import

Model

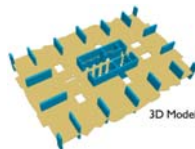
Analyze & Design

Geometry
& Loading
Models

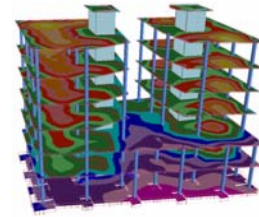
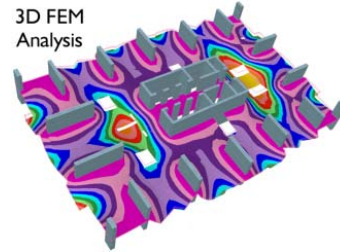
- Revit® Structure
- AutoCAD®
- ETABS®

**ADAPT-Modeler**

True 3D
Concrete
Modeling
Environment

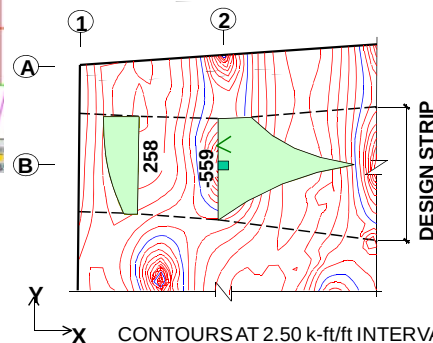
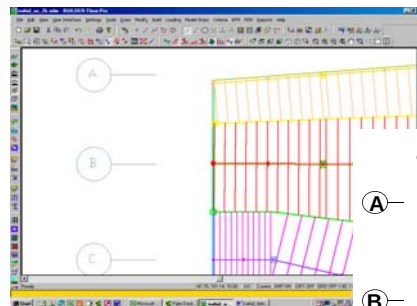


3D Model

ADAPT-Edge
For Building Analysis**ADAPT-Floor Pro**
For Elevated Slab Systems**ADAPT-MAT**
For Foundation Systems**ADAPT-SOG**
For Slabs on Expansive Soils3D FEM
Analysis**ADAPT**

Analysis and Design Process

Similar to EFM method, design of floor / foundation systems is based on design strips, however, design values are extracted from detailed 3D



CONTOURS AT 2.50 k-ft/ft INTERVALS



ADAPT

Efficient Design of Slab Systems

Use Advanced DRD™ module to optimize rebar design and prepare rebar layout ready for generation of structural drawings

Import

Model

Analyze & Design

Create Structural Drawings

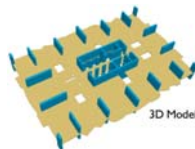
Geometry
& Loading
Models

- Revit® Structure
- AutoCAD®
- ETABS®



ADAPT-Modeler

True 3D
Concrete
Modeling
Environment



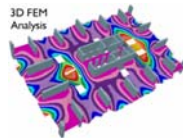
3D Model

ADAPT-Edge
For Building Analysis

ADAPT-Floor Pro
For Elevated Slab Systems

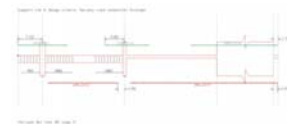
ADAPT-MAT
For Foundation Systems

ADAPT-SOG
For Slabs on Expansive Soils



3D FEM
Analysis

Advanced DRD™
Rebar Module



ADAPT

Efficient Design of Slab Systems

Use the PT Shop Drawing module to automate the generation of post-tensioning shop drawings

Import

Model

Analyze & Design

Create Structural Drawings

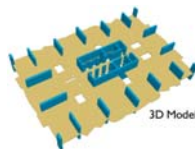
Geometry
& Loading
Models

- Revit® Structure
- AutoCAD®
- ETABS®



ADAPT-Modeler

True 3D
Concrete
Modeling
Environment



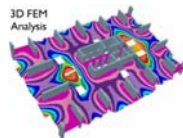
3D Model

ADAPT-Edge
For Building Analysis

ADAPT-Floor Pro
For Elevated Slab Systems

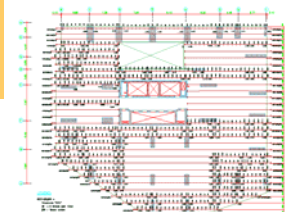
ADAPT-MAT
For Foundation Systems

ADAPT-SOG
For Slabs on Expansive Soils



3D FEM
Analysis

PT Shop Drawing
Module



**ADAPT**

Efficient Design of Slab Systems

ADAPT-Builder supports an intuitive design process from basic structural modeling through to creation of structural drawings and reports

Import

Model

Analyze & Design

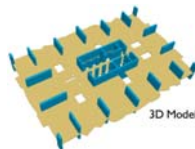
Create Structural Drawings

Geometry
& Loading
Models

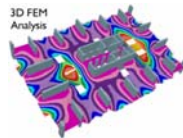
- Revit® Structure
- AutoCAD®
- ETABS®

**ADAPT-Modeler**

True 3D
Concrete
Modeling
Environment



3D Model

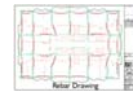
ADAPT-Edge
For Building Analysis**ADAPT-Floor Pro**
For Elevated Slab Systems**ADAPT-MAT**
For Foundation Systems**ADAPT-SOG**
For Slabs on Expansive Soils

3D FEM Analysis

Advanced DRD™
Rebar Module**PT Shop Drawing**
Module

Structural
drawings
(PT & Rebar)

- Revit® Structure
- AutoCAD®



Rebar Drawing

**ADAPT**

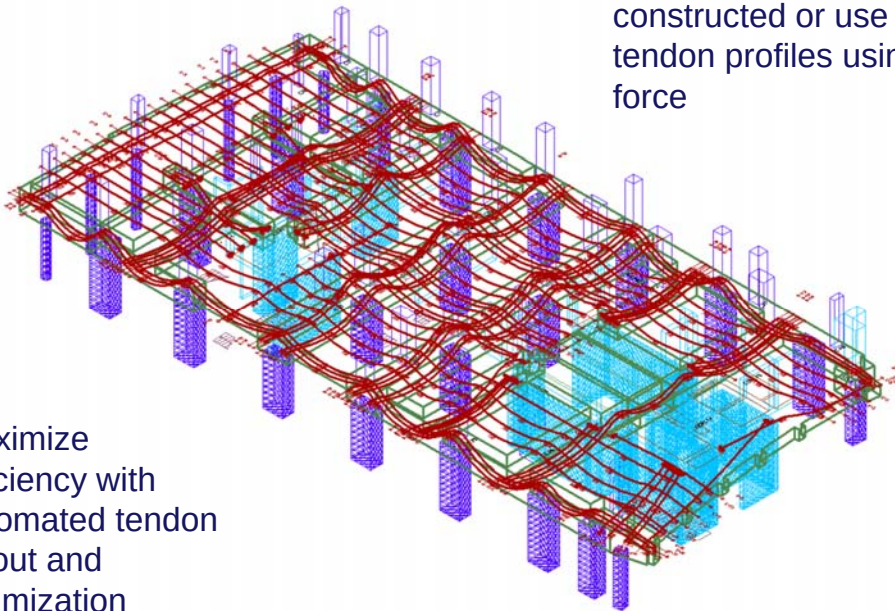
ADAPT-Builder Launch Screen

The launch screen gives user configuration options





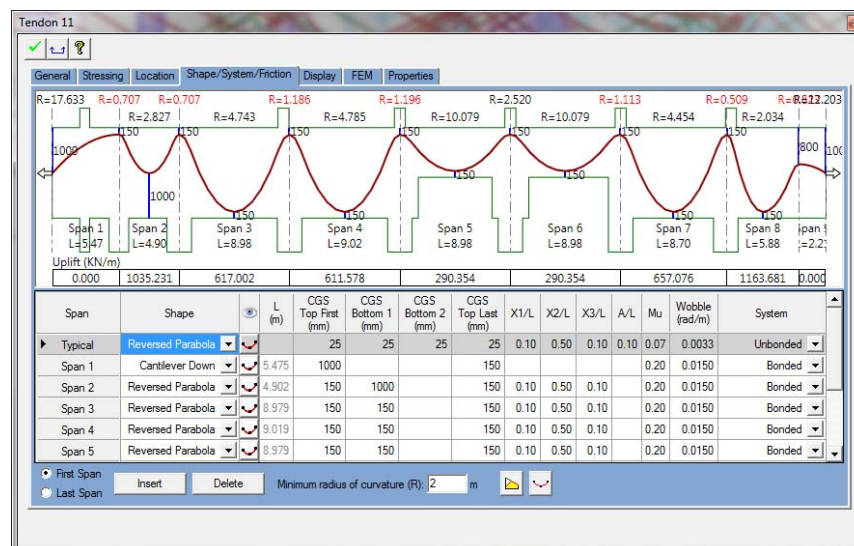
Lay out tendons as they will be constructed or use schematic tendon profiles using effective force



Maximize efficiency with automated tendon layout and optimization options

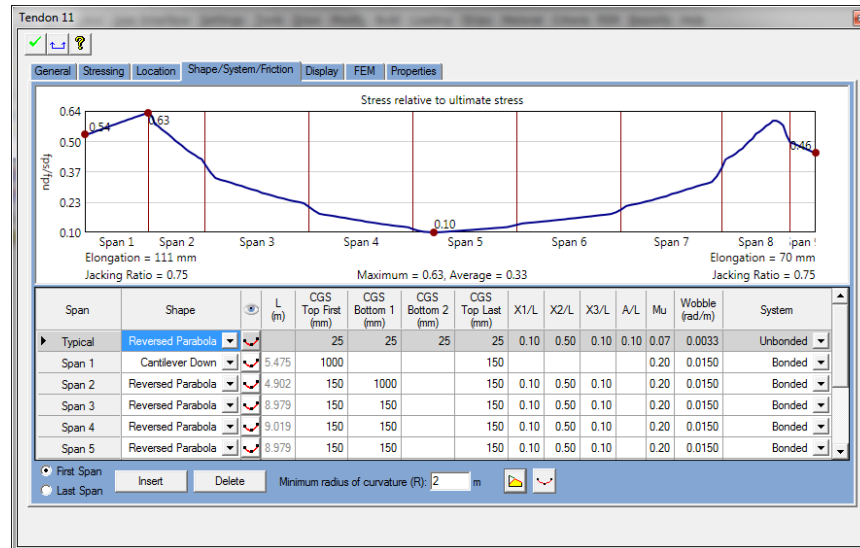


All tendon properties and profiles are viewable and editable, with clear relation to slab geometry

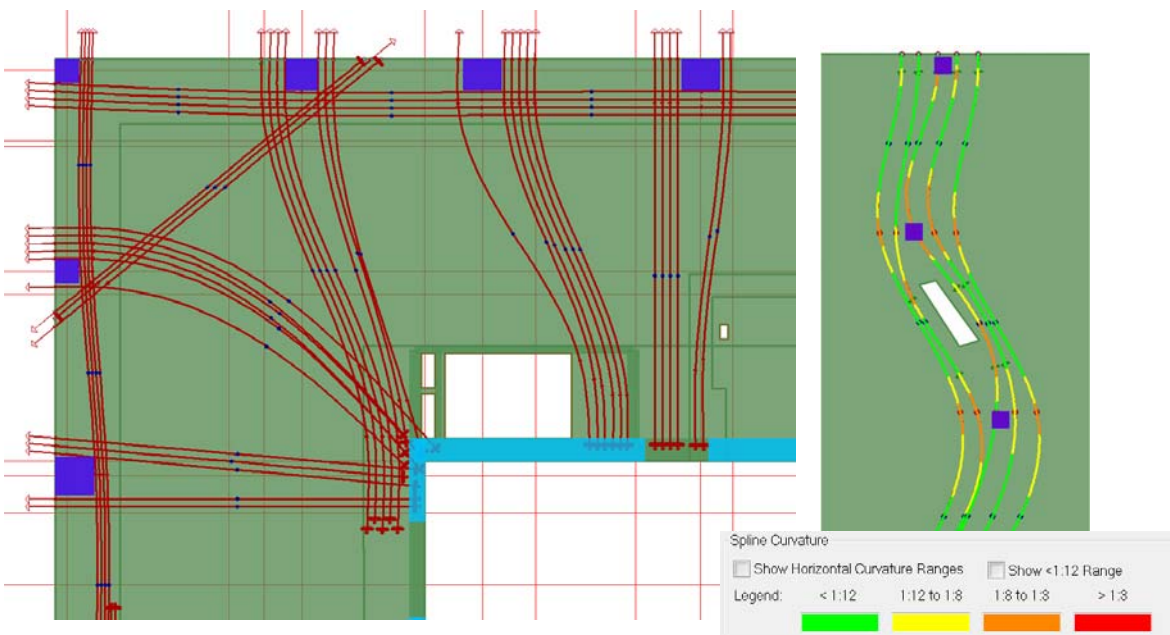




Force along tendon is clearly shown during modeling



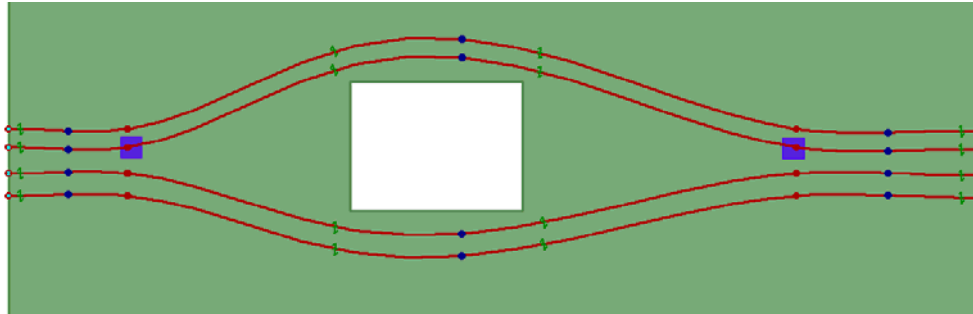
Swerve tendons horizontally





Swerve tendons horizontally

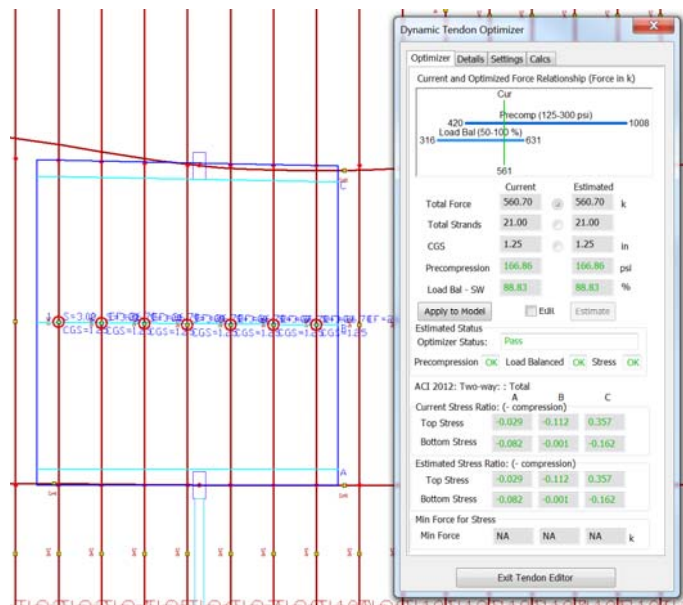
Plan View



Elevation



Tendon optimizer assists user in design of post-tensioning

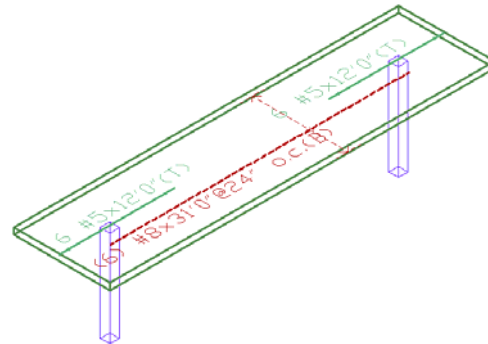
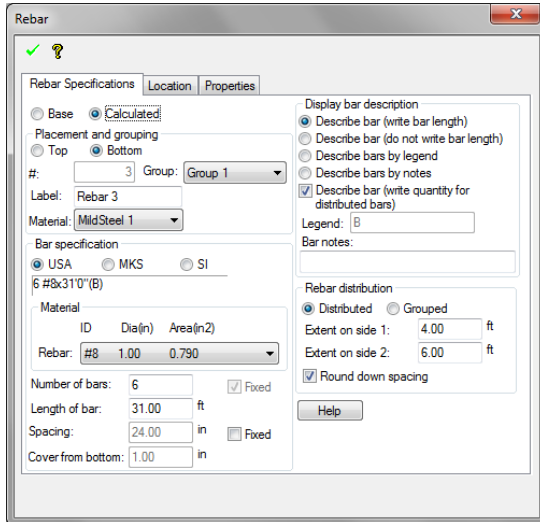




ADAPT

BIM-Based Rebar Modeling

All reinforcement bars in Floor Pro are intelligent, BIM-based objects that are fully editable by user



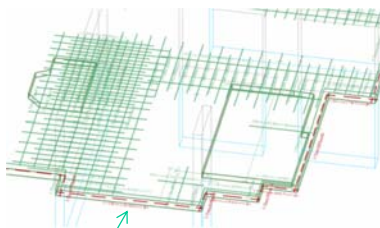
Designate reinforcement as automated (program calculated) or base (user defined) to save your design



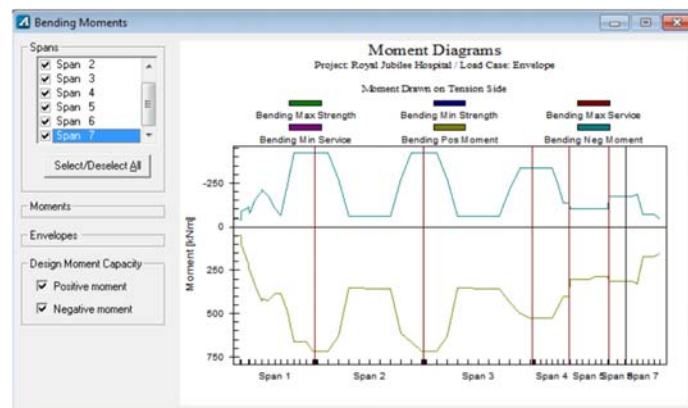
ADAPT

Investigate Existing Structures

Model all as-built reinforcement and/or post-tensioning to determine capacity of floor system and use this information to develop strengthening or re-use designs



Reinforcement modeled in slab



Moment capacity for a design strip



Enhance the performance of elevated and ground supported slabs with the addition of Dramix 3D/4D/5D steel fibers



Combined with post-tensioning, steel fiber offers advantages

- Increased flexural strength
- Increased one-way and two-way shear strength
- Increased post-cracked member stiffness
- Increased serviceability performance, including reduced crack width
- Increased simplicity and speed of construction

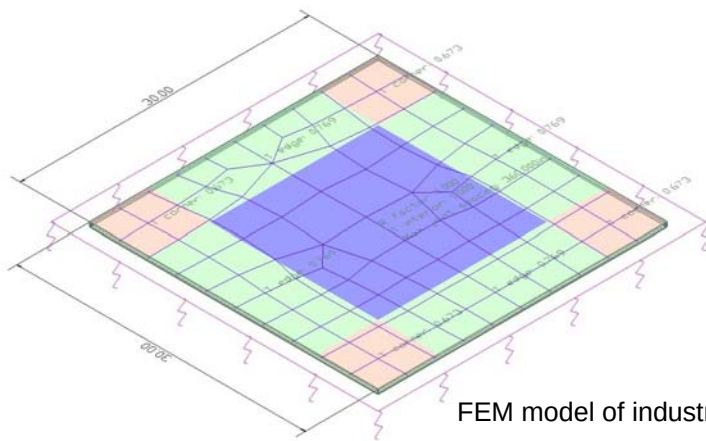


Post-tensioned project in Norway using steel fiber and no other regular reinforcement



Design process for industrial slabs on grade:

- 1) Select Dramix material and dosage
- 2) Review region input and create load regions
- 3) Perform non-linear analysis and determine joint load transfers

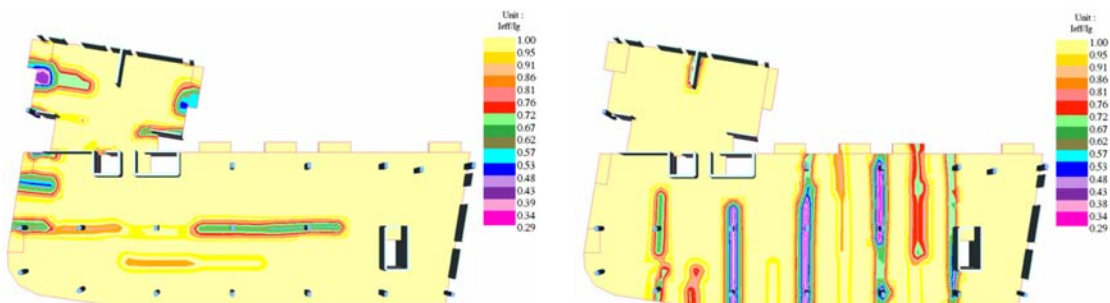


FEM model of industrial slab on grade panel



Cracked deflection calculation based on actual disposition of reinforcement and iterative redistribution of moment capacities

- Option to design for specific crack width
- Reporting of crack width
- Long-term deflections considering load history



Graphical display of location and extent of cracking

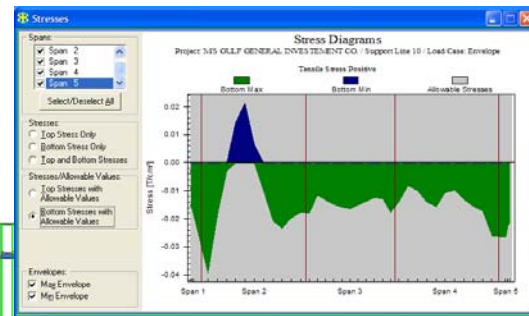
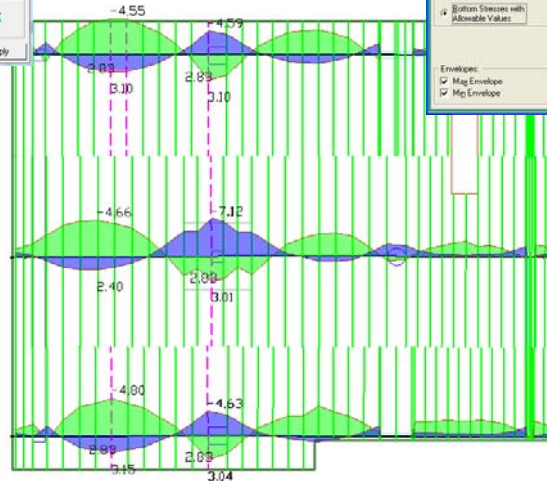


ADAPT

Easy To Follow Code Checks

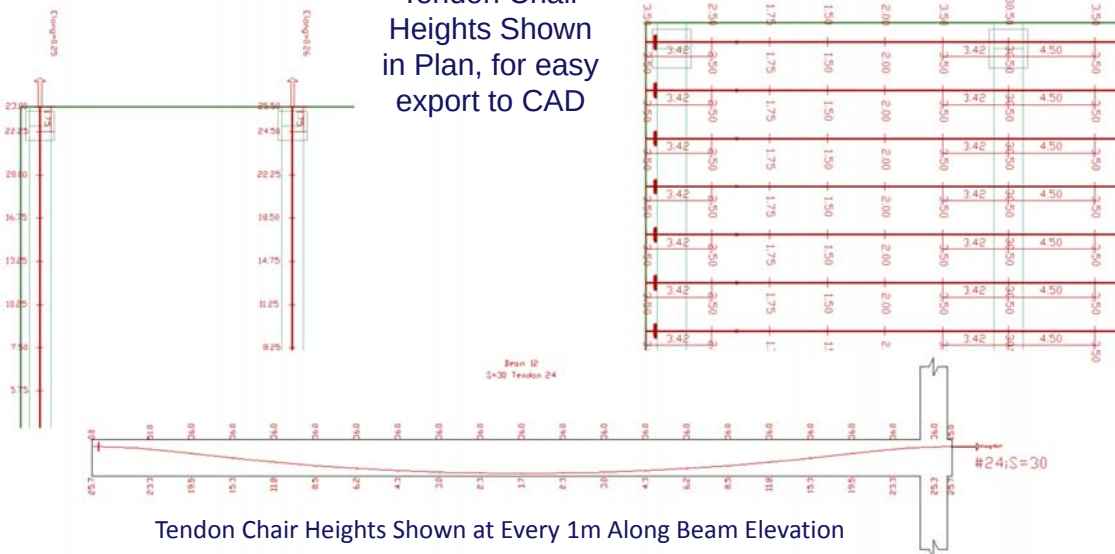


Design results can be checked for each support line



Automated P/T Shop Drawing Generation

Tendon Chair Heights Shown in Plan, for easy export to CAD



Tendon Chair Heights Shown at Every 1m Along Beam Elevation

**ADAPT**

Tendon Quantities and Elongations

Project Name: General name Specific Data: Specific name
 Date of execution: July 16, 2009 File Name: Camp_Springs_Model_raw_071509.adm
 FLOOR.PRO 2009

10.60 TENDON ELONGATION, INDIVIDUAL TENDONS

Tendon(ID,Label)	Jack(1st,2nd)	Seating(1st,2nd)	Elongation(1st,2nd,Total)
	k	in	in
1.Tendon 1	N/A,66.096	N/A,0.25	N/A,9.29,9.29
2.Tendon 2	991.440,N/A	0.25,N/A	5.28,N/A,5.28
3.Tendon 3	694.008,694.008	0.25,0.25	10.59,0.05,10.64
4.Tendon 4	396.576,396.576	0.25,0.25	10.59,0.04,10.64
5.Tendon 5	N/A,991.440	N/A,0.25	N/A,5.24,5.24
6.Tendon 6	66.096,N/A	0.25,N/A	7.09,N/A,7.09
7.Tendon 7	N/A,66.096	N/A,0.25	N/A,9.29,9.29
8.Tendon 8	66.096,N/A	0.25,N/A	7.09,N/A,7.09
9.Tendon 9	66.096,N/A	0.25,N/A	7.09,N/A,7.09
10.Tendon 10	66.096,N/A	0.25,N/A	7.09,N/A,7.09
11.Tendon 11	66.096,N/A	0.25,N/A	6.18,N/A,6.18
12.Tendon 12	66.096,N/A	0.25,N/A	7.09,N/A,7.09
13.Tendon 13	66.096,N/A	0.25,N/A	6.18,N/A,6.18
14.Tendon 14	N/A,66.096	N/A,0.25	N/A,3.35,3.35
15.Tendon 15	N/A,66.096	N/A,0.25	N/A,3.36,3.36
16.Tendon 16	N/A,66.096	N/A,0.25	N/A,9.29,9.29
17.Tendon 17	N/A,66.096	N/A,0.25	N/A,9.29,9.29
18.Tendon 18	66.096,N/A	0.25,N/A	7.09,N/A,7.09
19.Tendon 19	991.440,N/A	0.25,N/A	5.28,N/A,5.28
20.Tendon 20	N/A,991.440	N/A,0.25	N/A,5.24,5.24
21.Tendon 21	991.440,N/A	0.25,N/A	5.28,N/A,5.28
22.Tendon 22	N/A,991.440	N/A,0.25	N/A,5.24,5.24
23.Tendon 23	991.440,N/A	0.25,N/A	5.28,N/A,5.28
24.Tendon 24	N/A,991.440	N/A,0.25	N/A,5.24,5.24
25.Tendon 25	991.440,N/A	0.25,N/A	5.28,N/A,5.28
26.Tendon 26	N/A,991.440	N/A,0.25	N/A,5.24,5.24
27.Tendon 27	N/A,66.096	N/A,0.25	N/A,9.29,9.29
28.Tendon 28	N/A,66.096	N/A,0.25	N/A,9.29,9.29
29.Tendon 29	N/A,66.096	N/A,0.25	N/A,9.29,9.29
30.Tendon 30	N/A,66.096	N/A,0.25	N/A,9.29,9.29
31.Tendon 31	N/A,66.096	N/A,0.25	N/A,9.29,9.29
32.Tendon 32	N/A,66.096	N/A,0.25	N/A,9.29,9.29
33.Tendon 33	N/A,66.096	N/A,0.25	N/A,9.29,9.29
34.Tendon 34	N/A,66.096	N/A,0.25	N/A,9.29,9.29
35.Tendon 35	N/A,66.096	N/A,0.25	N/A,9.29,9.29
36.Tendon 36	N/A,66.096	N/A,0.25	N/A,9.29,9.29
37.Tendon 37	N/A,66.096	N/A,0.25	N/A,9.29,9.29
38.Tendon 38	N/A,66.096	N/A,0.25	N/A,9.29,9.29

Easily extract tendon, rebar and concrete quantities from your design model

Tendon elongation reports provide information needed for installation

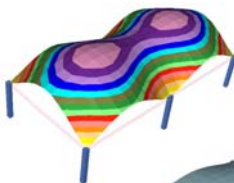
**ADAPT**

Integrated Modal Vibration Analysis

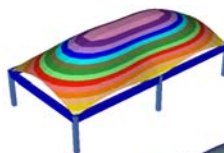
Floor Pro automatically calculates and reports the vibration response of any concrete floor system

Factors considered include:

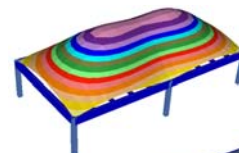
- Post- or pre-stressing
- Cracking
- Contribution of any load case in x,y,z direction



8" flat slab
5.18 Hz



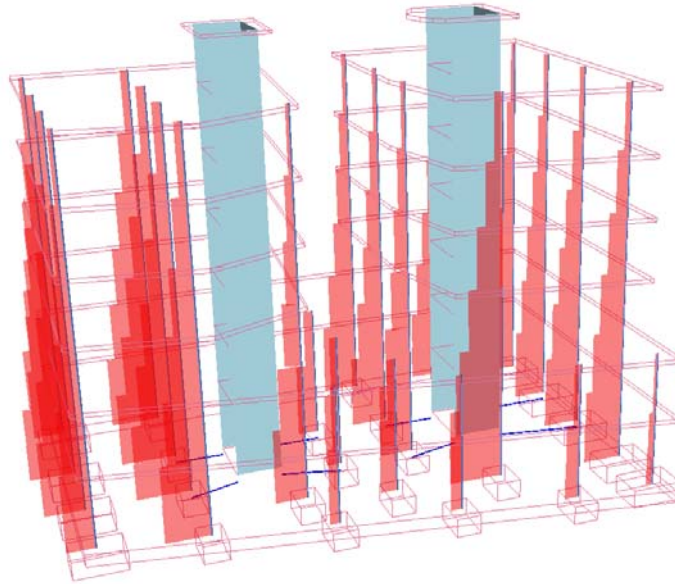
8" flat slab with
perimeter beams
6.55 Hz



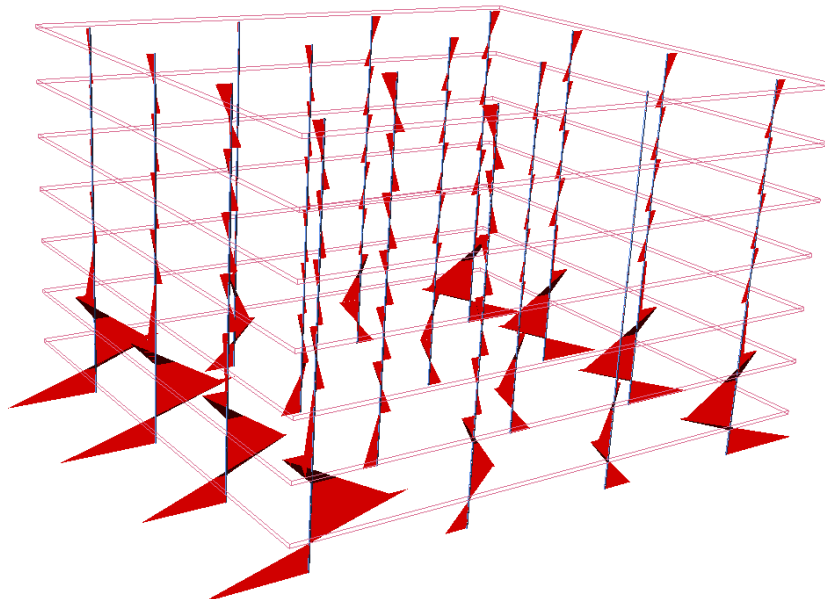
5" slab with 6" joists
6.63 Hz



Diagram showing axial loads in columns. The mat foundation or any intermediate transfer element is automatically designed for these building loads.



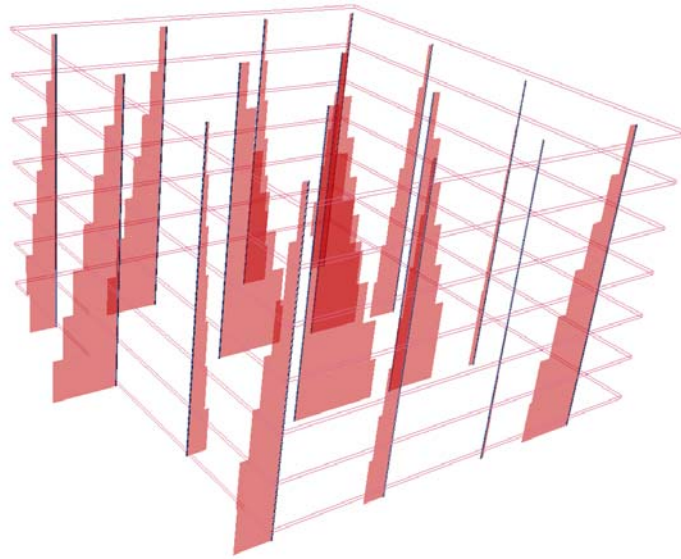
This diagram shows increasing effect of Hyperstatic (secondary) moments at lower supports of a multi-level post-tensioned structure. A multi-level analysis automatically takes these into consideration.





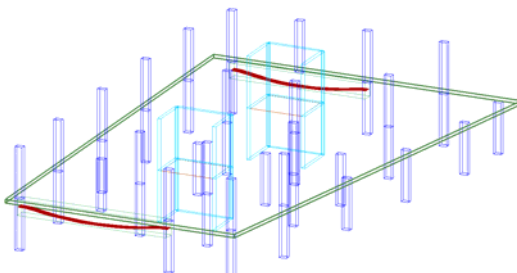
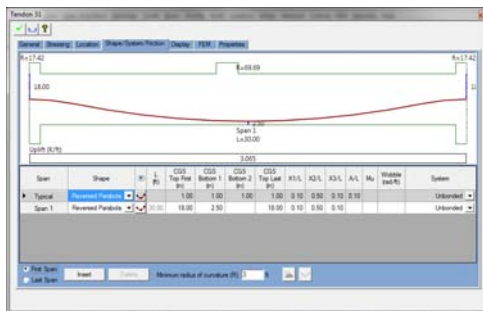
ADAPT Effects of PT in Multi-Level Applications

This diagram shows increasing effect of Hyperstatic (secondary) axial moment at lower supports of a multi-level post-tensioned structure. A multi-level analysis automatically takes these into consideration.



ADAPT Integrated Design of PT Transfer Beams

ADAPT-Builder supports the accurate modeling, analysis and design of post-tensioned transfer structures in building applications.



Single level view of model showing post-tensioned transfer beams



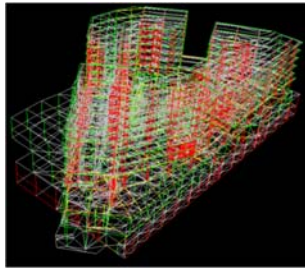
Building model showing global deflected shape from integrated analysis results



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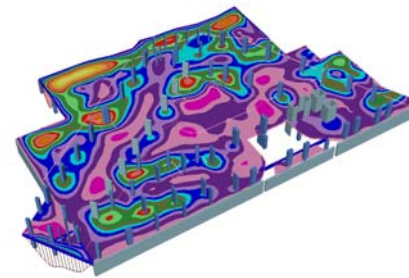
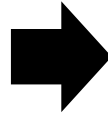
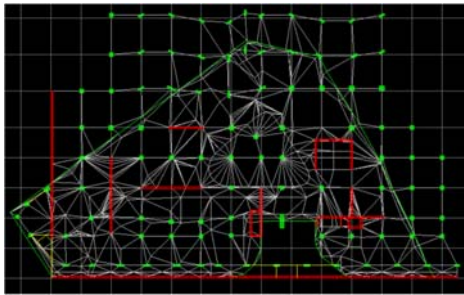
Efficient Design of ETABS Slabs

ADAPT offers efficient and more accurate process for detailed design of slabs modeled in ETABS



Easily extract model info from ETABS to ADAPT:

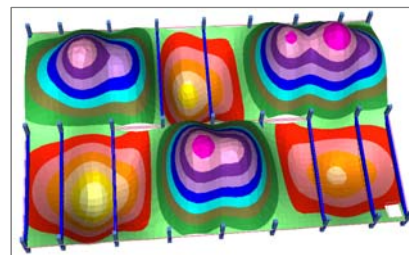
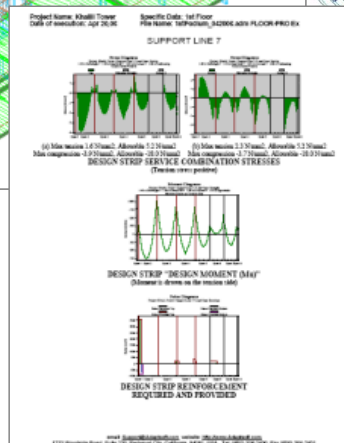
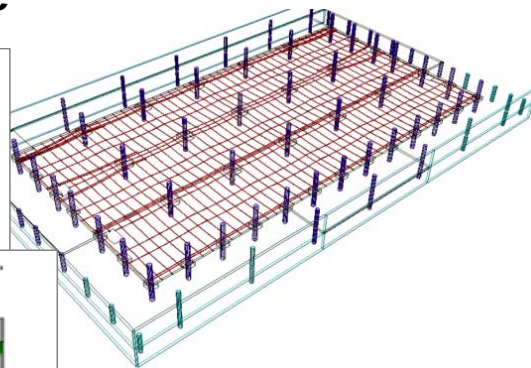
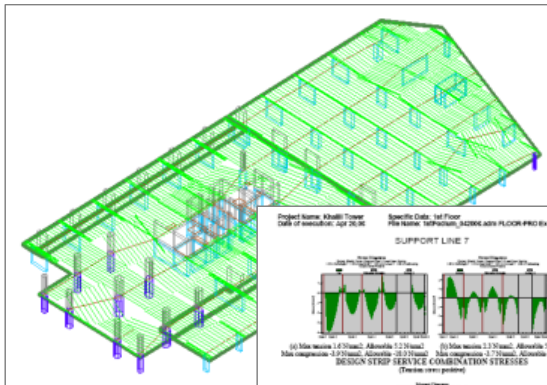
- Geometry
- Gravity Loads
- Lateral Loads



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Software Demonstration

ADAPT-Floor Pro® & Edge™



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Structural Concrete Software

www.adaptsoft.com

Session 6

Thursday 31 May

NZ Post-Tensioned Buildings: Market Activity and Case Studies

Marc Stewart

NZ post-tensioned buildings: Market activity and case studies



DESIGN & CONSTRUCTION OF POST-TENSIONED CONCRETE BUILDINGS

Content

- Building and Construction Forecast
- Elevated PT Adoption
 - Market Opportunity
 - Current Perspective
- Case studies:
 - Grant Thomas, South Island Construction Manager, Dominion Constructors



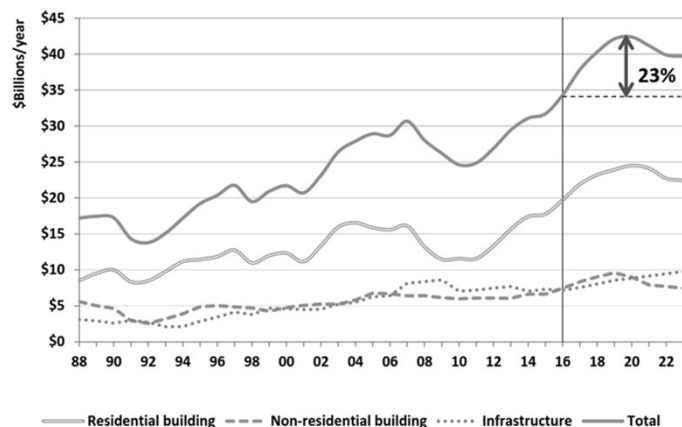
Building and Construction Forecast

Activity Types:

- Residential building – detached and multi-unit dwellings
- Non-residential building – structures of a building type (vertical), other than residential
- Infrastructure – structures of a non-building type (horizontal) eg roads, subdivisions, infrastructure and civil works. Infrastructure projects do not typically require a building consent.



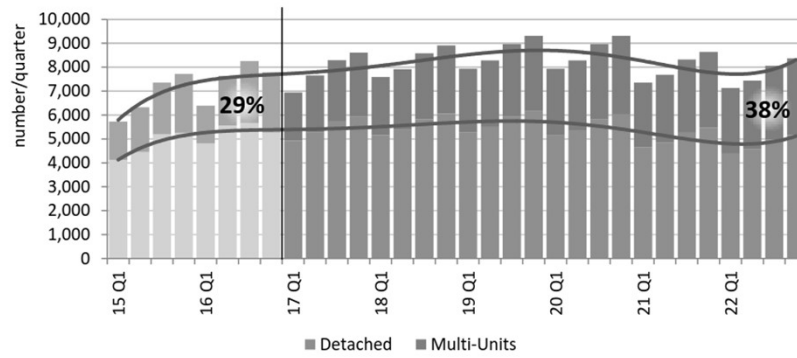
National construction, by value



Source: BRANZ / Pacificon

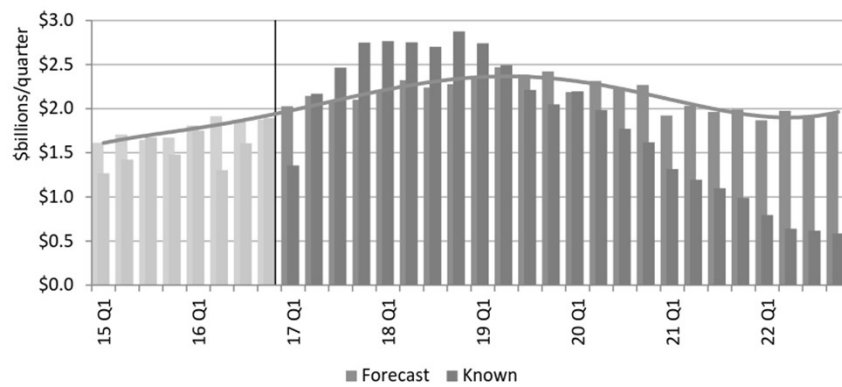


National residential building, by dwelling number



Source: BRNZ

National non-residential building



Elevated PT Adoption

- Industry Opportunity
- Current Perspective

Market Opportunity

- Unitary Plan
- Tourism Demands
- Wider Seismic Awareness
- Material leadtime constraints

Unitary Plan

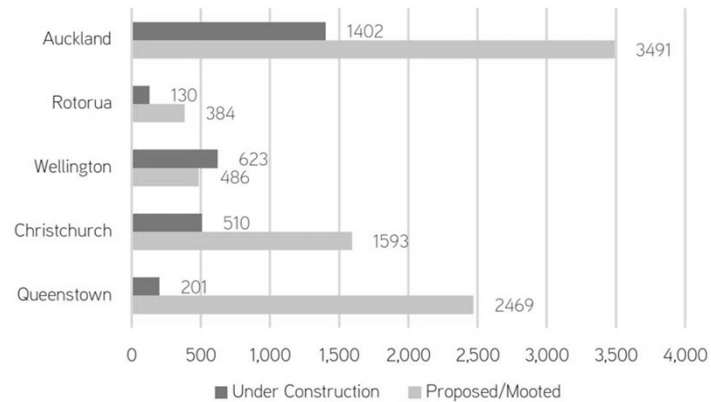
Brown is my favourite colour...



Tourism Demands

“Auckland in the lead
with nine hotel projects
and 30 more in the
pipeline...”

Tourism Demands

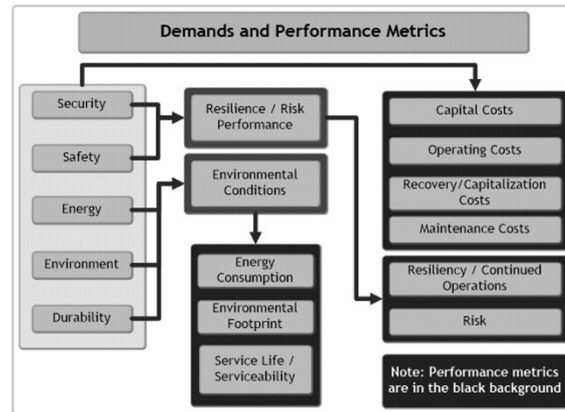


<http://www.colliers.co.nz/news/2017>

Wider Seismic Awareness

Life cycle and cost/benefit
considerations in
Resilience-based designs

Wider Seismic Awareness



<https://www.wbdg.org/resources/building-resiliency>

Material leadtime constraints



<http://www.precastnz.org.nz/precaster-nz-publications/>

Current Perspective

Engineers –

“We would love to, but....”

Current Perspective

- Design responsibility demarcation ✓
- Code compatibility ✓
- Mass Constraint ✓
- Who will build it?

Who will build it?

- Guest Speaker
 - Grant Thomas, South Island
Construction Manager, Dominion
Constructors

Session 6

Thursday 31 May

Stress Losses in Post-Tensioning

Bijan Aalami

(refer to chapter 7 of the book Post-Tensioned Buildings; Design and Construction)

Session 7

Thursday 31 May

Workflow for Integrated Design of Concrete Buildings with Post- Tensioned Slabs

Florian Aalami

Workflow for Integrated Design of Concrete Buildings with Post-Tensioned Slabs

- Featuring -

ADAPT-Builder® Design Suite

ADAPT Corporation | Redwood City, CA, USA

ADAPT Latin America | Miami, FL, USA

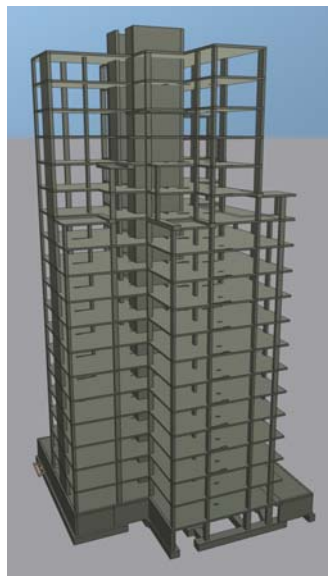
ADAPT International Pvt. Ltd. | Kolkata, India

Dr. Florian Aalami

www.adaptsoft.com

May 2018

Live software demonstration



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Structural Concrete Software

www.adaptsoft.com

Session 7

Thursday 31 May

Design of Post-Tensioned Floor Systems in High- Seismic Zones

Bijan Aalami

Seismic Design Post-Tensioned Buildings



Dr Bijan O. Aalami

Professor Emeritus, San Francisco State University
Principal; ADAPT Corporation

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www.adaptsoft.com

bijan@PT-Structures.com Copyright ADAPT Corporation 2016

Seismic Design of Post-Tensioned Buildings

Presentation

- ❖ Objectives; **scope**; examples
- ❖ Why **post-tensioning** is the **preferred** construction system
- ❖ Past **performance** of post-tensioned buildings
- ❖ **Codes** and Specifications
- ❖ Seismic **Design Categories** (SDC)
- ❖ Seismic **design steps**
- ❖ **Drift** calculation
- ❖ Design of floors in
 - **High** seismic for risk (SDC D, E, F)
 - Moderate seismic risk (SDC C)
 - Low seismic risk (SDC A,B)
- ❖ Diaphragm design of floors
- ❖ Detailing
- ❖ Summary

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Seismic Design of Post-Tensioned Buildings

OBJECTIVE

The **objective** of the presentation is to describe the **participation** and **design of floor systems** in building structures under lateral loads

The presentation **assumes**:

- ❑ Knowledge to determine the seismic risk of the building and the magnitude of lateral force (base shear);
- ❑ Distribution of lateral forces over the height of the building; and
- ❑ Frame/stability analysis of the structure to determine the force demand on each member

Hence, little or no reference is made to the above. Focus remains on the **role of floor systems in resisting effects of seismic forces**

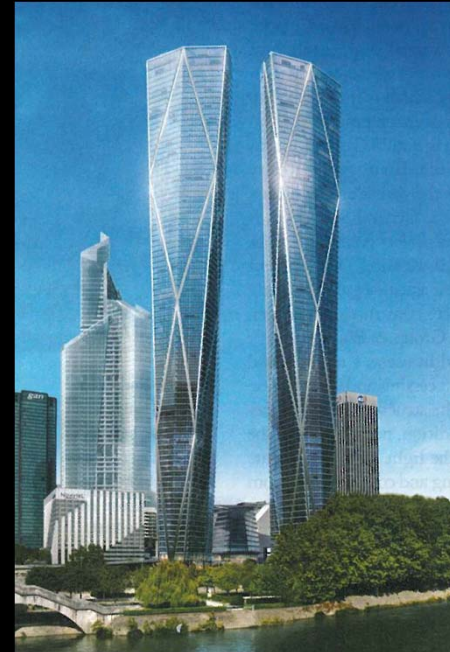
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The Metropolitan; San Francisco
Post-tensioned flat slab construction



St Regis; San Francisco
Post-tensioned flat slab construction



Hermitage Plaza
San Francisco, California

Post-tensioned flat slab
construction



Rincon Tower
San Francisco, California
Post-tensioned flat slab construction



301 Mission Street
San Francisco, California
post-tensioned flat slab construction



W Hotel, San Francisco, California
post-tensioned flat slab floors



Infinity Towers (36 story + 4 underground)
San Francisco, California

Post-tensioned flat slab construction



Red Lion Inn, Modesto, California

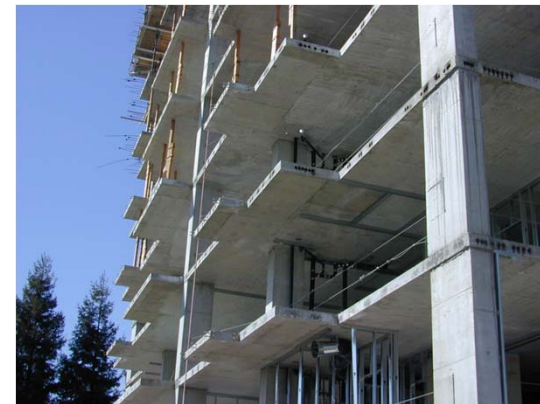
Medium rise hotel in region of
high seismic risk (near San Francisco)
constructed with unbonded

Post-tensioned flat slab construction

Seismic Design of Post-Tensioned Buildings

Why
flat slab construction and post-tensioning ?

- seismic force depends on:
 - ❖ Building weight – PT floors are typically 1/3 lighter than RC
 - ❖ Weight of building can be reduced to 1/2 if lightweight concrete is used



P994

Seismic force (V) is proportional to the weight of building (W)

$$V = CS * W$$

Seismic Design of Post-Tensioned Buildings

Why
flat slab construction and post-tensioning ?



- ❑ Reduced slab thickness leads to lighter columns, walls and foundation
- ❑ Thinner slabs and elimination of beams leads to shorter buildings, hence smaller overturning moment
- ❑ Precompression in slabs from post-tensioning improves the diaphragm action of the floors

OBSERVED PERFORMANCE IN PAST EARTHQUAKES

Post-tensioned floor systems have performed well in both the highest seismic risk regions and regions of high wind forces

Currently, the high-rise buildings in San Francisco, one of the highest seismic regions of the USA are mostly designed and being built using flat slab concrete floor systems, in particular post-tensioning.

STATE OF ENGINEERING KNOWLEDGE

After the damage assessment of the last major earthquake in California (Northridge, 1994) the consensus among the engineering community was that, with some notable exceptions, the majority of engineered structures performed well. Adding confidence and credibility to the current engineering knowledge and design procedures for earthquake resisting buildings.

OBSERVED PERFORMANCE IN PAST EARTHQUAKES

- ✓ Structures reinforced with post-tensioning **bonded** systems perform similarly to **conventionally reinforced** floors, with improved **diaphragm action** resulting from precompression
- ✓ **Focus** of observation has been on performance of buildings reinforced with **unbonded** tendons.



OBSERVED PERFORMANCE OF POST- TENSIONED BUILDINGS IN PAST EARTHQUAKES



Anchorage assembly in crushed concrete. The assembly was highly stressed, but retained its integrity

An acceptance requirement of an anchorage assembly is to withstand tests of **one-half million cycles of force reversal** equal to 50% of anchorage capacity (PTI specifications)

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OBSERVED PERFORMANCE OF POST-TENSIONED BUILDINGS IN PAST EARTHQUAKES



Anchorage assembly in crushed concrete. The assembly was highly stressed, but retained its integrity

The above observation was repeated in all the damaged buildings inspected. There was no instance of anchorage failure in traditionally constructed buildings

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OBSERVED PERFORMANCE OF POST-TENSIONED BUILDINGS IN PAST EARTHQUAKES



The **group of tendon** anchorages, tightly placed against one another, have retained their integrity after the complete destruction of the concrete around them. Each tendon has a force of approximately 11 tons. Slabs are typically 7 to 8 in (180-200 mm)

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OBSERVED PERFORMANCE OF POST-TENSIONED BUILDINGS IN PAST EARTHQUAKES



Another example of closely spaced anchorage devices, highly stressed, yet maintaining their full integrity

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End view of a post-tensioned beam that is dislodged from its support on top of column

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The precompression provided through post-tensioning has confined the beam end and helped to prevent it from disintegration and failure

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CURRENT BUILDING CODES FOR EARTHQUAKE AND WIND DESIGN

- ❑ ASCE 7-10
 - ❖ Describes how to determine seismic risk (SDC) or exposure;
 - ❖ what method of analysis is applicable; and
 - ❖ how to calculate lateral force (base shear).
- ❑ ACI 318 - 14
 - ❖ Describes how to define a lateral force resisting system (load path) in a building;
 - ❖ how to determine and validate the lateral stiffness of a building (drift);
 - ❖ how to determine the required reinforcement of each member; and
 - ❖ how to detail each member.
- ❑ IBC-15 (International Building Code)
 - ❖ Integrates the requirements of ASCE 7-10 and ACI 318-14 and other agencies; adds or deletes as required to conclude with a single and coherent set of requirements

UBC 97 is phased out

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CURRENT BUILDING CODES FOR EARTHQUAKE AND WIND DESIGN

□ Eurocode 8 EN 1988-1:2004 (E)

- ❖ Describes how to determine **seismic risk** (SDC) or exposure;
- ❖ what **method of analysis** is applicable; and
- ❖ how to calculate lateral force (**base shear**)
- ❖ includes detailing options for regions of high seismic risk and members designated to resist seismic forces

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CURRENT BUILDING CODES FOR EARTHQUAKE AND WIND DESIGN

CORRELATION BETWEEN VARIOUS SEISMIC DESIGN CODES RISK EXPOSURE CATEGORIZATION

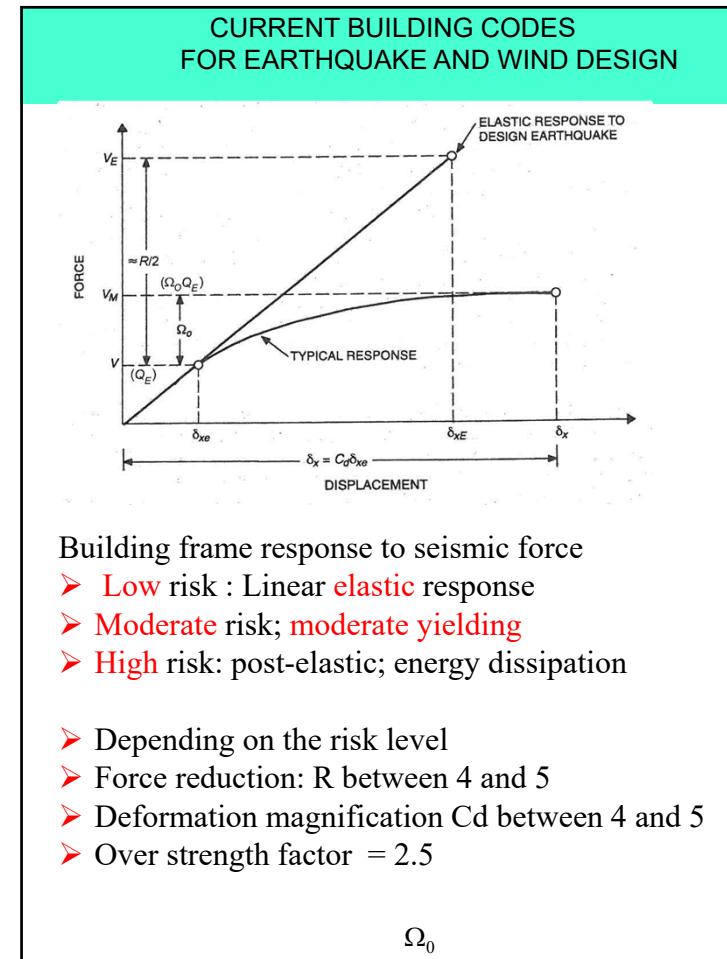
Code Standard Resource	➤ Level of Seismic Risk ➤ Assigned Seismic Performance ➤ Code Defined Category		
IBC 2015 ASCE 7-10 ACI 318-14	SDC A,B,	SDC C	SDC D, E, F
UBC 1997	Zone 0,1	Zone 2	Zone 3,4
Eurocode 8	Very Low Seismicity	Low Seismicity	Seismically Active
Other	Low	Moderate	High

Based on current codes

- ❖ A building in San Francisco is in Seismic Design Category F (SDC F)
- ❖ Buildings in UAE is in Seismic Design Category C (SDC C)

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CURRENT BUILDING CODES FOR EARTHQUAKE AND WIND DESIGN			
Permissible Seismic Force Resisting Systems			
Code Standard Resource	➤ Level of Seismic Risk ➤ Assigned Seismic Performance ➤ Code Defined Category		
IBC 2015 ASCE 7-10 ACI 318-14	SDC A,B,	SDC C	SDC D, E, F
Eurocode 8	Very Low Seismicity	Low Seismicity	Seismically Active
Seismic Frame	Ordinary	Intermediate	Special
ADAPT			



SEISMIC DESIGN STEPS

1. Determine seismic design risk
Low; moderate; high (SDC)
2. Select a designated seismic force **resisting system**
3. Calculate design base shear **V**
 $V = CS * W$
4. **Distribute** base shear among levels of the building
5. Select applicable **reduced member stiffness** for frame analysis (allowance for cracking)
6. Calculate inter-story **drift** and validate it
7. Determine seismic **force demand** on each designated seismic force resisting member
8. Design force resisting members for **strength and ductility**
9. Design the remainder of structural members for **deformation compatibility; over strength, where needed**
10. **Detail** for reinforcement

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SELECTION OF DESIGNATED LATERAL FORCE RESISTING SYSTEM

- ❖ There shall be a well defined and **uninterrupted designated load path** from the point of generation of lateral forces to the foundation
- ❖ The load path **need not**, and generally does not **include** all the structural members of a building
- ❖ Seismic force resisting load path **categories** defined in current codes are:
 - ✓ Ordinary moment frames; low risk (SDC A, B)
 - ✓ Intermediate moment frames; moderate risk (SDC C)
 - ✓ **Special** moment resisting frames; high risk (SDC DEF)

Examples:

- ☐ Buildings in **San Francisco** and **Tehran** require “**special** moment resisting frames.”
- ☐ Buildings in **Hawaii** require “**intermediate** moment frames,” or better.

SELECTION OF DESIGNATED LATERAL FORCE RESISTING SYSTEM

Special Moment Frames High seismic risk (SDC D,E,F)

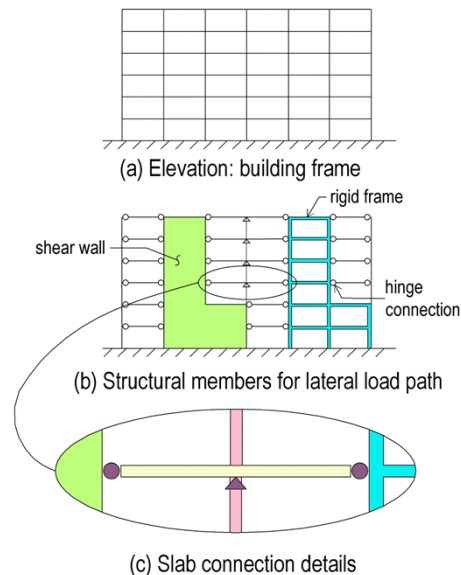
- ❖ Can resist the design earthquake in **post-elastic** regime;
- ❖ Will undergo extensive **damage** in event of the design earthquake, **but will not collapse**;
- ❖ Is required to comply with **special design provisions** for ductility and detailing (ACI 318);
- ❖ **Floor slabs** are **not permitted** to be part of the designated force resisting system;
- ❖ Post-tensioning is **permitted** to be considered as part of the **primary** lateral force resisting **system** of the building in **beams** and **walls**, with some **restrictions** (IBC)

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SEISMIC FORCE RESISTING SYSTEMS

There shall be a **designated lateral force resisting system**

PTS797c



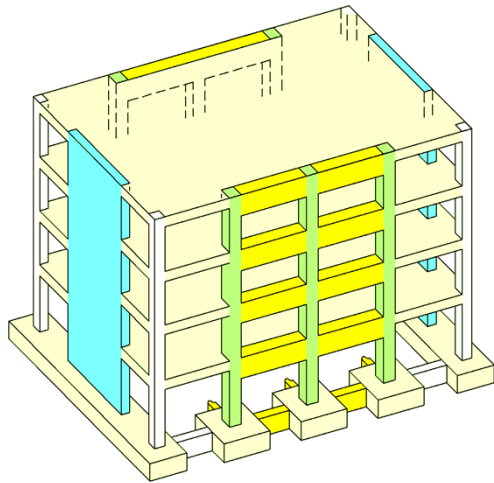
Lateral Force Resisting Structural Model

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SEISMIC FORCE RESISTING SYSTEMS

Designated lateral force resisting system

PTS693



Seismic force resisting system is identified as **shear wall** and **moment frame**

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POST-TENSIONED MULTI-STORY BUILDING
IN SAN FRANCISCO UNDER
CONSTRUCTION.

Members **designated** to resist seismic forces
are clearly identifiable from those intended to
resist only the gravity forces



VIEW OF CONCRETE FRAME

Observe the two **lateral force resisting frames** on the two sides of the building (thicker members), and an interior lateral force resisting frame (visible on the top of the structure). The gravity columns are noticeably thinner than those of the seismic frames

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Multistory building in San Francisco.
Note the difference between seismic frames and gravity columns

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Close up of a flat slab post-tensioned concrete frame in San Francisco

Observe that no beams connect the gravity columns to the seismic frames

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Concrete frame under construction in San Francisco

Designated seismic force resisting frame in foreground, gravity columns visible on the left

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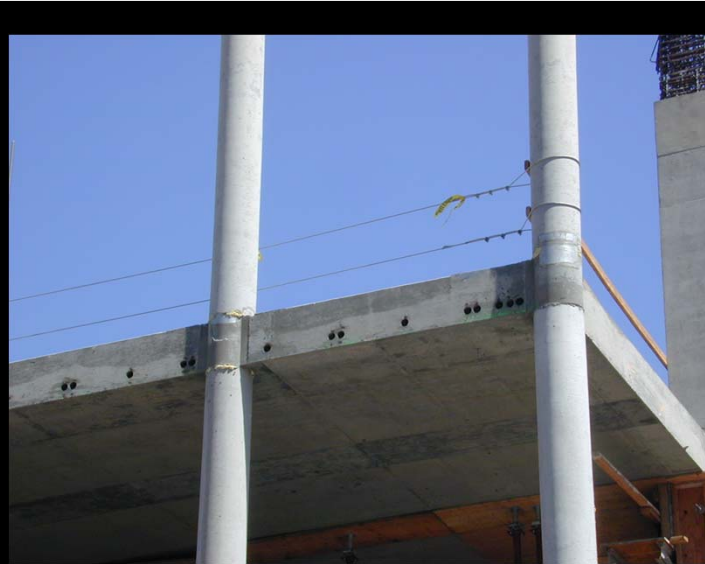
Note the distinct difference between the gravity columns (round) and those that are part of the lateral force resisting system (rectangular).

Floor slab is flat. No beams connect the non-seismic columns to the seismic frames, nor are there beams connecting gravity columns.

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Designated seismic force resisting frame is used as an architectural feature in the building (San Francisco)



Connection detail between gravity columns
and slab edge/corner

The figure shows the stressing pockets of
unbonded post-tensioning tendons at the
slab edge

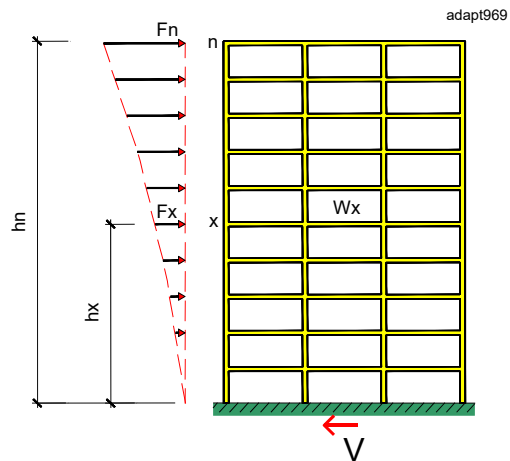
SEISMIC FORCE ANALYSIS MODELS

Create 3 Structural Models for Analysis

- 1 – Structural model for drift calculation for validation of the concrete frame stiffness
All members participate with reduced stiffness
- 2 – Structural model for strength design of lateral force resisting system
 - > Entire seismic force resisted by designated lateral force resisting system
 - > Non-seismic members receiving load to be designed with over-strength (omega factor)
- 3 – Structural model for floor slab design
 - For low and moderate seismic risk (SDC A,B and C) act with columns and walls
 - For high seismic risk (D, E, F) design for gravity only

SEISMIC FORCE RESISTING SYSTEMS

Distribute the seismic force (base shear) over the height of the building

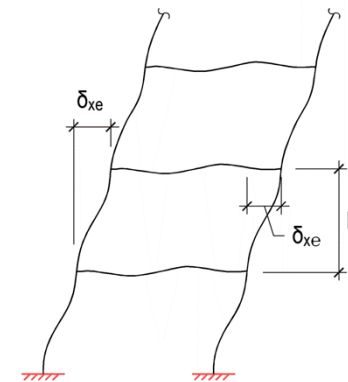


DRIFT CALCULATION/VALIDATION

- ❖ From a frame analysis
 - Includes **all structural members**
 - Use **reduced stiffness**
 - Use load **combination**

$$U = 1.0DL + 0.3LL + 1.0E$$

PTS782



$$C_d \delta_{xe} / h_i \leq 2\%$$

If drift not satisfied, increase frame **stiffness**

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DRIFT CALCULATION/VALIDATION

- ❖ Use one of the following options for reduction of stiffness to calculate drift (ACI 318)

Option 1

- Use 50% of stiffness values based on gross area

Option 2

- Use the following values for moment of inertia (I_g = gross moment of inertia)

■ Columns	0.70 I_g
■ Walls (uncracked)	0.70 I_g
■ Walls (cracked) *	0.35 I_g
■ Beams	0.35 I_g
■ Slabs (RC)	0.25 I_g
■ Slabs (PT)	0.50 I_g

Option 3

- Use more rigorous relationship as suggested in ACI-318

* If first run indicates cracking of walls

FLOOR SLAB DESIGN

Floor slab design depends on the one of the following two options:

- Floors that do NOT participate in frame action (Seismic Design Categories D,E,F high seismic risk regions)
- Floors that DO participate in frame action (low and medium seismic risk A, B and C)

- ❖ Design for diaphragm action of all floors (All seismic categories)

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FLOOR SLAB DESIGN

For floor that are **not designated** to participate in resisting seismic forces (Seismic categories D,E and F; **high seismic regions**) consider the following

- **Wall to slab** connection
 - Do not calculate and design for force transfer. **Slab is not intended to resist seismic forces**
 - **Detail** the connection for adequate **ductility** for design drift
- **Column to slab** connection:
Use one of the following options
 - **Release** connection
 - **Detail** for adequate **ductility**
 - **Calculate actions** for design drift and **reinforce accordingly**

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FLOOR SLAB DESIGN

First: wall to slab connection

- **Wall to slab** connection
 - Do not calculate the force at connection. **Slab is not intended to resist seismic forces**
 - **Detail** the connection for adequate **ductility** for design drift
- **Column to slab** connection:
Use one of the following **3 options**
 - **Release** connection
 - **Detail** for adequate ductility
 - **Calculate** actions for design drift and **reinforce accordingly**

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Details of core wall connection to
post-tensioned slab
Post-tensioning does not go through the wall



Details of core wall connection to
post-tensioned slab

12 mm bars at 300 mm on center top and bottom
#4 bars @ 12" o.c. (T and B)

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Multi-story tower in high seismic zone
Shear wall construction with post-tensioned
slabs and connection details shown in the
previous slide

301 Mission Street, San Francisco

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Core wall constructed ahead of floor slabs.
Dowels attached to the wall provide the
connection to the slab (San Francisco)

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Details of core wall connection to
post-tensioned slab
Slab reinforcement terminates at the
face of the wall

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Details of core wall connection to
post-tensioned slab

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View of full-size test of post-tensioned slab with core wall and column connection

- ❖ Full scale tests for similar connections have withstood up to **10% drift without failure**.
- ❖ Maximum permissible drift is 2%
- ❖ Actual design drifts for concrete multistory buildings is generally around 0.5 to 1%

University of California (Berkeley)



View of full-size post-tensioned slab with core wall and column connection under test

- Crack formation at slab core wall connection for 2.5% drift
- Maximum permissible design drift is about 2%

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FLOOR SLAB DESIGN

For floor that are **not designated** to participate in resisting seismic forces (High seismic risk; SDC D,E, F) consider the following

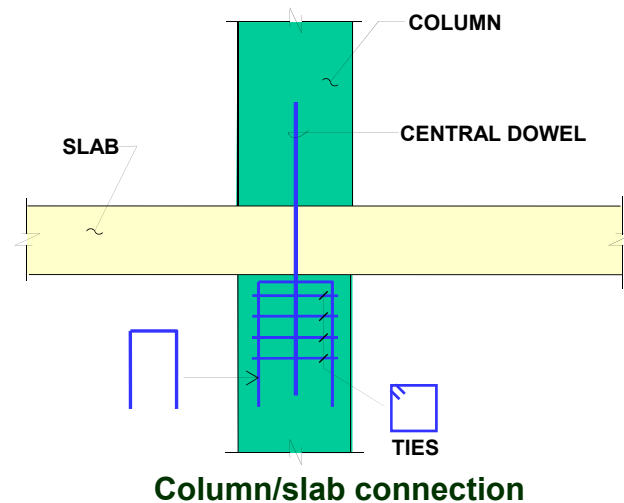
- **Wall to slab** connection
 - Do not calculate and design for force transfer
 - Detail the connection for adequate ductility for design drift
- **Column to slab** connection:
Use one of the following **3 options**
 - **Release** connection
 - **Detail** for adequate ductility
 - **Calculate** actions for design drift and reinforce accordingly

ADAPT

FLOOR SLAB DESIGN FOR SEISMIC FORCES

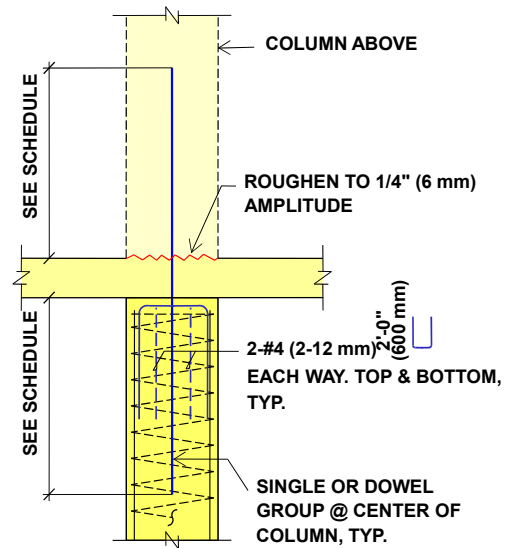
Option 1 for column/slab connection

- ❖ Provide **release** at connections.
Applicable to low and moderate high buildings



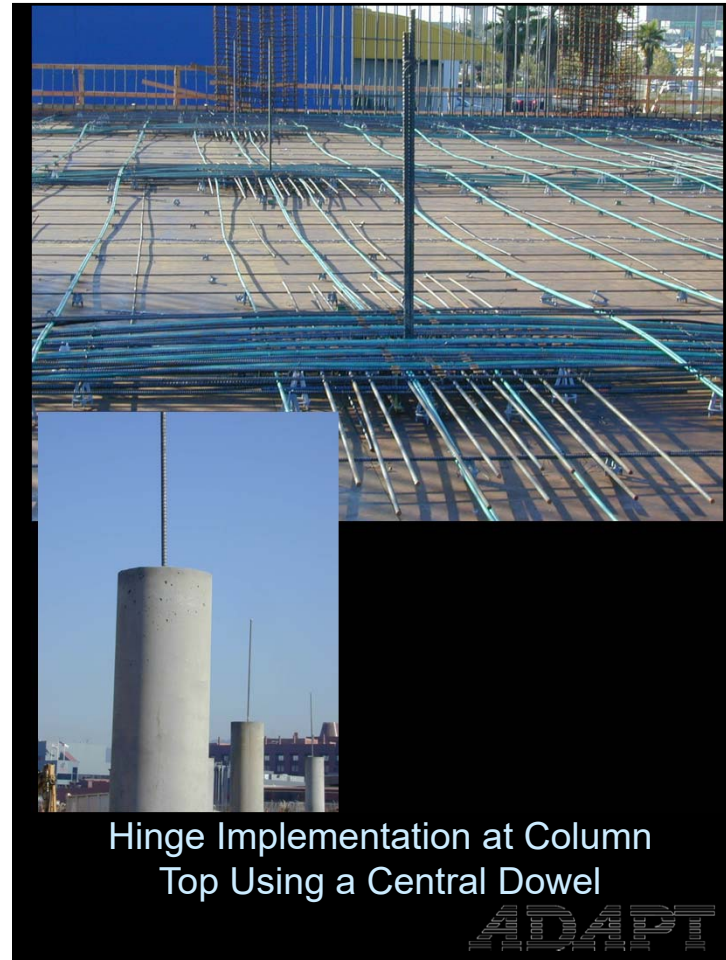
ADAPT

FLOOR SLAB DESIGN FOR SEISMIC FORCES



**COLUMN-SLAB RELEASE DETAIL
TO PROVIDE ARTICULATION AND
REDUCED MOMENT**

ADAPT



**Hinge Implementation at Column
Top Using a Central Dowel**

ADAPT

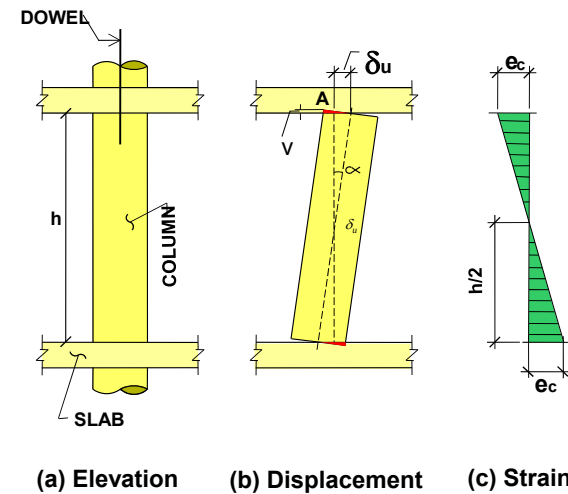


Column with central dowel and punching shear reinforcement



Upper column reinforcement is placed on top of slab

FLOOR SLAB DESIGN FOR SEISMIC FORCES



Analysis Model for Displacement Compatibility of Hinged Columns

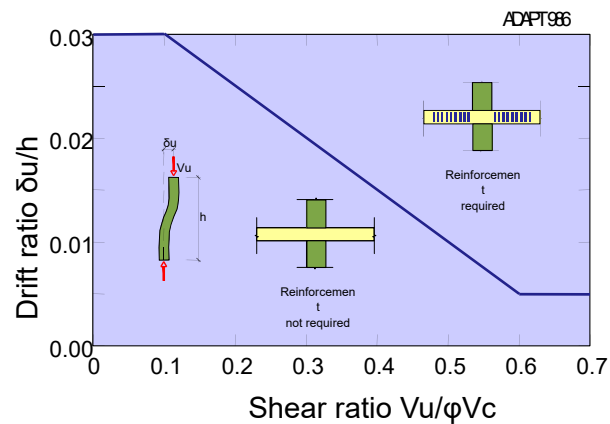
From design drift δ_u , **calculate** the **interference** strain ϵ_c . If larger than 0.003, provide elastomeric pad

ADAPT

FLOOR SLAB DESIGN FOR SEISMIC FORCES

Option 2: Detail for Ductility

- ❖ Detail for ductility, if values fall **above the line** in the following diagram. Otherwise, no specific measures required (ACI 318 – 11; Ch. 21)

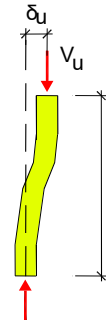


$$\frac{\Delta}{h} \leq \text{larger of } \begin{cases} 0.005 \\ 0.035 - 0.05 \left(\frac{V_u}{\phi V_c} \right) \end{cases}$$

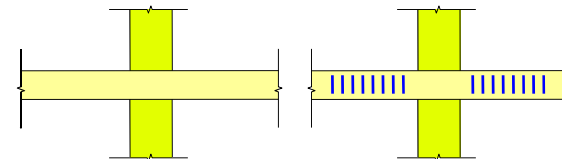
No limit on punching shear ratio if drift ratio is less than 0.005

ADAPT

FLOOR SLAB DESIGN FOR SEISMIC FORCES



(a) Displaced column



(b) Reinforcement not required

(c) Reinforcement required

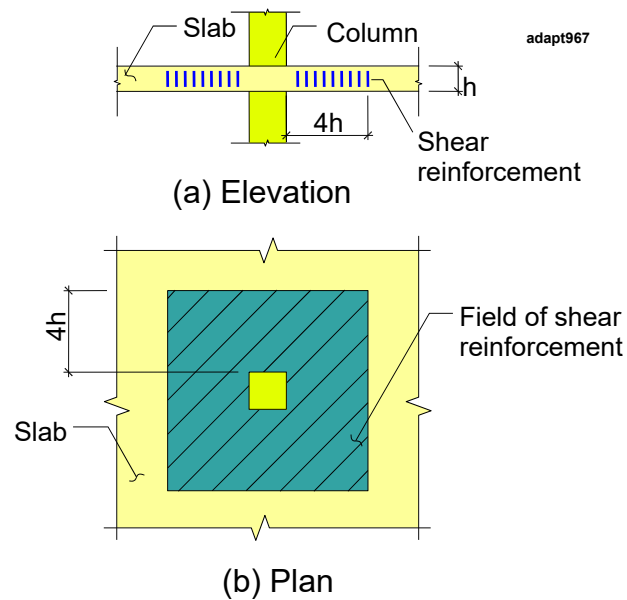
$$\frac{\Delta_u}{h} < \text{threshold}$$

$$\frac{\Delta_u}{h} \geq \text{threshold}$$

Column-Slab Junction Design for **Deformation Compatibility**

FLOOR SLAB DESIGN FOR SEISMIC FORCES

Option 2: Detail for ductility



Provide of Punching Shear Reinforcement
to Meet **Ductility Requirements**

ADAPT

FLOOR SLAB DESIGN FOR SEISMIC FORCES

Option 2: Detail for ductility

Minimum punching shear **reinforcement** to
satisfy deformation compatibility

$$\frac{A_v}{s} \geq \frac{0.29\sqrt{f'_c}b_0}{f_{yt}} \quad \begin{array}{l} \text{US units} \\ \text{lb; inch} \end{array}$$

$$\frac{A_v}{s} \geq \frac{3.5\sqrt{f'_c}b_0}{f_{yt}} \quad \begin{array}{l} \text{SI units} \\ \text{N; mm} \end{array}$$

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FLOOR SLAB DESIGN FOR SEISMIC FORCES

OPTION 2: DETAIL FOR DUCTILITY

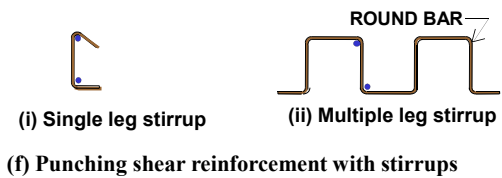
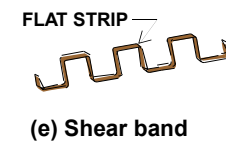
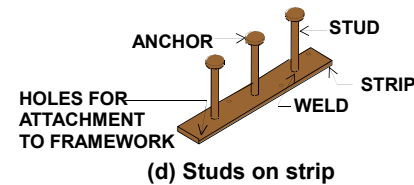
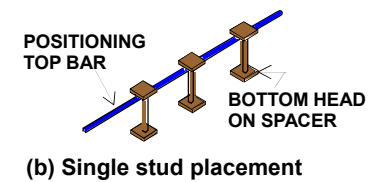
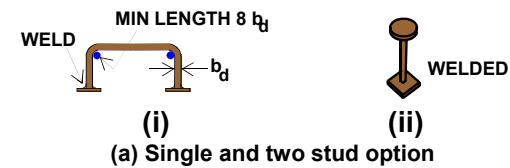


Provide punching shear reinforcement to enable the joint undergo its design drift while keeping its integrity to carry gravity loads

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FLOOR SLAB DESIGN FOR SEISMIC FORCES

SHEAR REINFORCEMENT OPTIONS

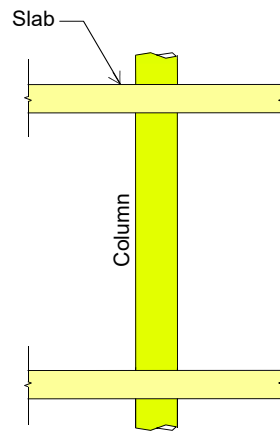


FLOOR SLAB DESIGN FOR SEISMIC FORCES

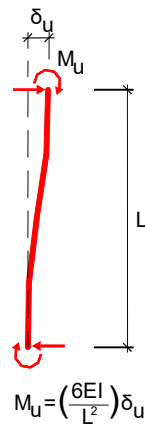
Option 3: Calculate the Moment and Shear and Design for them

Using design displacement δ_u , calculate the associated moment M_u and design for it

adapt974



(a) Elevation



(b) Deformation

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FLOOR SLAB DESIGN FOR SEISMIC FORCES

- ❖ Floors that DO participate in frame action
Low and moderate seismic risk (SDC A,B,C)
- ❖ Floors are assumed to remain elastic in resisting the lateral forces.
- ❖ Cracking is moderate and is accounted for in drift calculation.
- ❖ Static Equivalent lateral force analysis applies in calculating the floor's design forces

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FLOOR SLAB DESIGN FOR SEISMIC FORCES

Summary

- ❖ Examples in **San Francisco**
- ❖ Why **post-tensioning**
- ❖ **Performance** in past earthquakes
- ❖ Applicable **codes**
- ❖ Determination of **seismic risk** to design for SDC
- ❖ Seismic design **steps**
- ❖ **Drift** calculation
- ❖ Function of floor **slabs**
- ❖ Design of floors slabs
 - ❖ **High seismic** risk regions
 - ❖ Low and moderate risk regions
- ❖ Floor action as diaphragm
- ❖ Detailing
- ❖ Specific code provisions for application of post-tensioning

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Thank you for listening

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Session 8

Thursday 31 May

Seismic Design Considerations for Post- Tensioned Floor Systems in NZ

Jeff Matthews

Seismic Design Considerations for Post-Tensioned Floor Systems in NZ

Presented by
Dr Jeff Matthews
Holmes Consulting

Potential Design Efficiencies

- Residual PT available to contribute to diaphragm reinforcement:
Gravity ULS
1.2G&1.5Q
- Different load cases for seismic vs gravity:
Gravity for seismic
G & xQ (x depends on building usage)

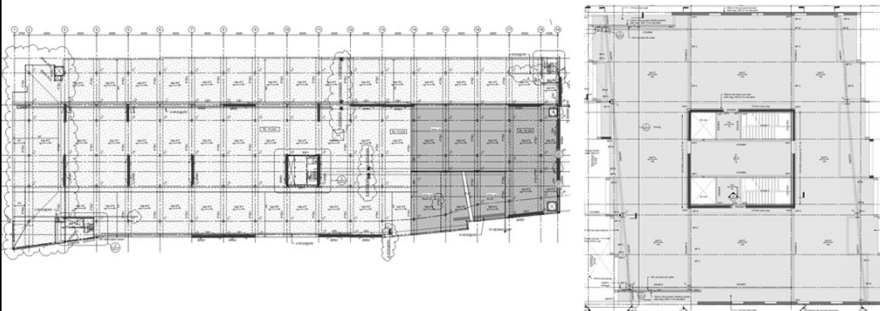
Building Configurations

- What is the lateral system?
 - Walls
 - Braces
 - Frames



Building Configurations

- Where are the bracing elements located



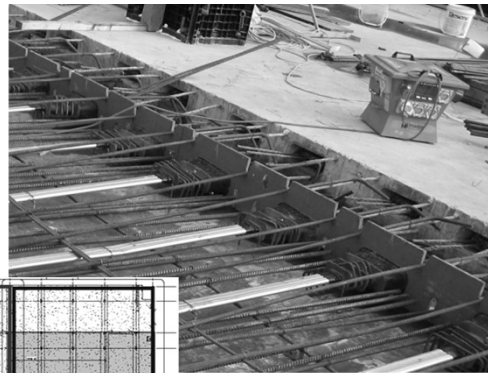
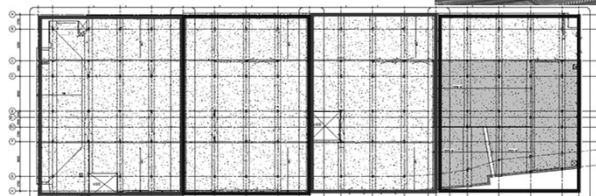
Building Configurations

- What impact does this have on the construction and/or stressing process



Building Configurations

- How large is the floor plate?
- Are delayed pour strips required?



NZS 1170.5 Cl. 2.1.4

Avoidance of Collapse @ ULS

- Avoidance of collapse of structure or parts of structure
- *Commentary* NZS 1170.5:
 - account for *drifts* or forces from the 2500-year return event (MCE?),
 - for determining if there is an acceptably low probability of collapse.

Avoidance of Collapse

NZS 1170.5

Cl.2.2.4 Brittle structures

- Brittle structure or brittle parts of structures having limited capacity to sustain inelastic deformation

Commentary to NZS 1170.5 points to *components* and *connections* that could be *brittle*.

Connection Failure

Floor to walls & frames



Northridge -1994

Connection Failure

Column punching shear failure - floors to columns



Christchurch-2011

Beam Elongation

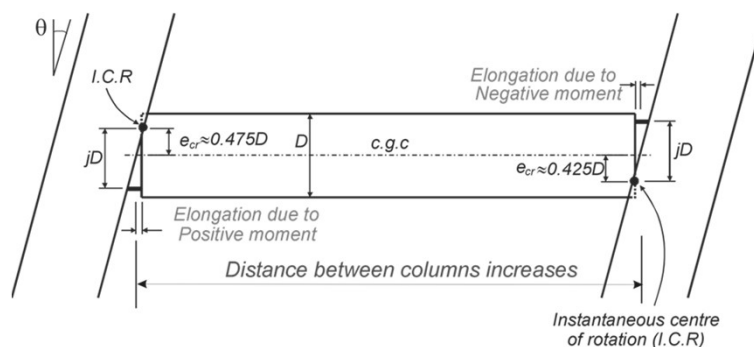
Consider the effect this has on the PT strands.

- What are consequences of failure?
- Will floor drop?

Grouted versus un-grouted

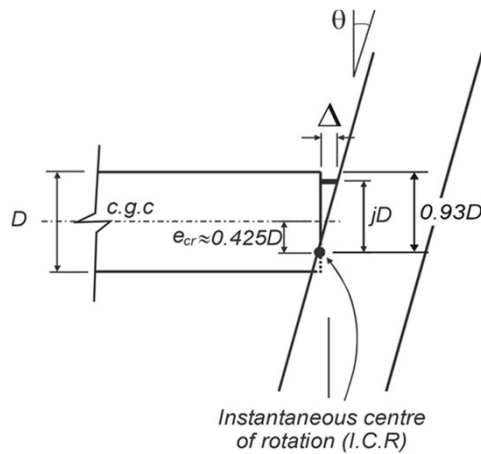
- Un-grouted can allow movement, lower strains

Beam Elongation



Beam Elongation occurs (independent of convention or P/T):

- Elastically up to Yield
- In-elastically post-yield



Beam Elongation Δ occurs at floor support :

1.5% D @ 2% Drift - D = 1000mm $\rightarrow \Delta \approx 14\text{mm}$

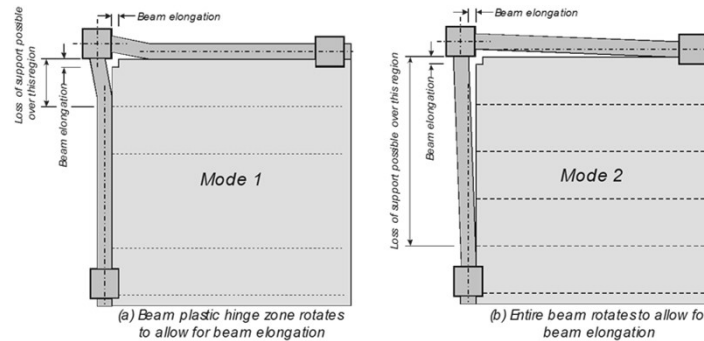
2.5% D @ 3% Drift - D = 1000mm $\rightarrow \Delta \approx 25\text{mm}$

Beam Elongation

- How is this accommodated in the design?
- De-bonding can help. Does have flow on effects (deconstruction, SiD).

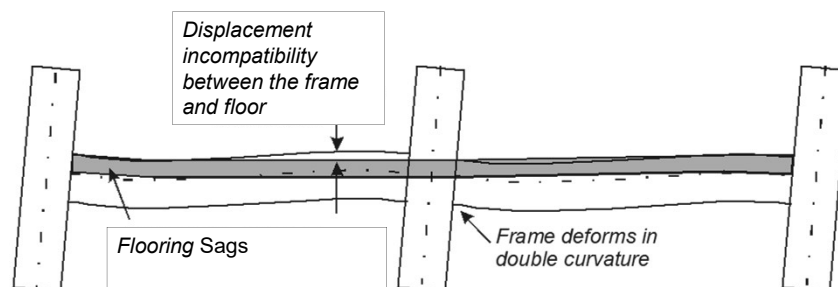
Why is the determination of Beam Elongation so important?

Effects the potential induced stresses into the PT floor. Similar to seating details for pre-cast suspended floors



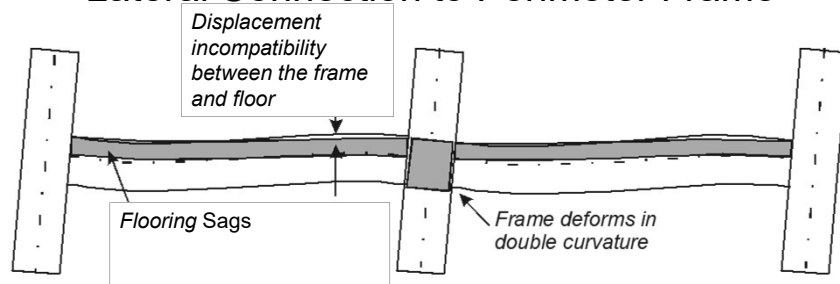
Displacement Compatibility considerations

Lateral Connection to Perimeter Frame



Displacement Compatibility Considerations

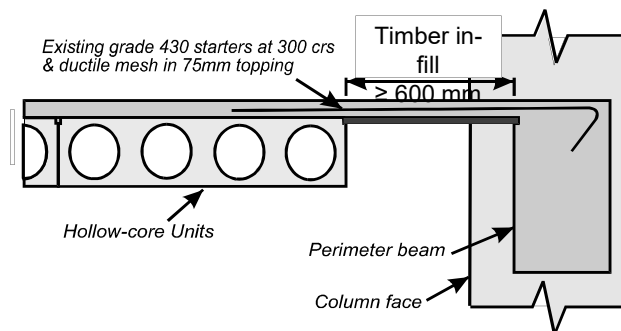
Lateral Connection to Perimeter Frame



Displacement between wall and floors are similar

How precast deals with this?

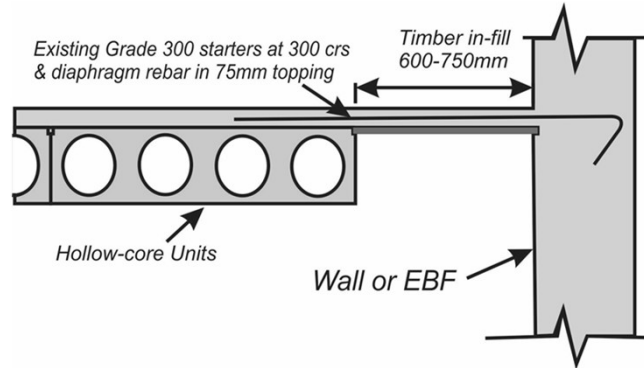
Lateral Connection to Perimeter Frame



NZS3101 requires this for precast flooring.
Consider its effect on the PT floor system.

Link Slab – Wall or EBF

NZS 3101:2006 – *strongly recommended*



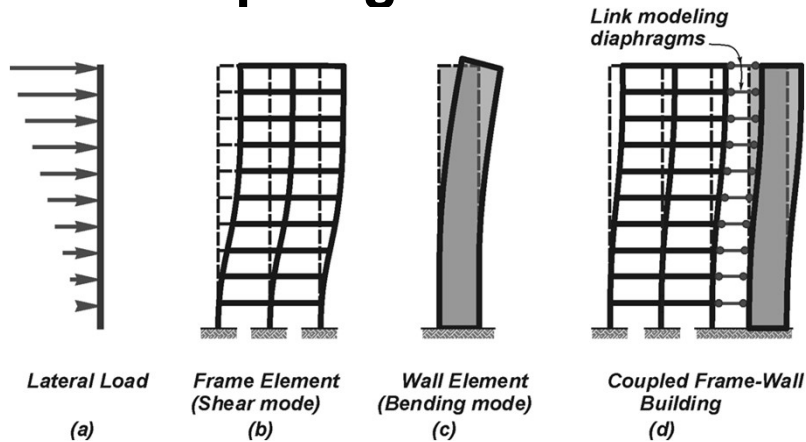
Diaphragms: Forces

‘Inertia’ & ‘Transfer’ forces are COUPLED

These can not be treated in isolation.

- *Inertia* causes the building to deform.
- *Transfer forces* across the diaphragms arise from the incompatibility of deformed shapes of each vertical structural system.

Diaphragm: Forces



After
Paulay & Priestley 1992

Diaphragms: Forces NZS 1170.5

Cl.6.1.4.2 Actions for design of diaphragms

- Actions to be used in the design of diaphragms shall be the sum of actions from the 2-D and 3-D analysis, plus the actions derived from considering how the inertia of the diaphragm elements are distributed to the lateral force resisting structural elements.
- Actions within the diaphragms shall account for higher modes effects and influence of overstrength actions (in accordance with Clause 5.6.3.3), generated from within the structure as a whole.

Diaphragms: Forces

NZS 1170.5

Cl. 6.1.4.2 Actions for design of diaphragms

- Actions to be used in the design of diaphragms shall be the sum of actions from the 2-D and 3-D analysis, plus the actions derived from considering how the inertia of the diaphragm elements are distributed to the lateral force resisting structural elements.

- **MODAL Analysis does NOT help**
- **MODAL Analysis provide maxima:**
 - these have no sign & local maxima occur at different points in time - *USELESS*

Floor Plates/Diaphragms

- Relatively thin but stiff horizontal structural systems which transmit in-plane lateral forces to, or between, vertical lateral force resisting elements.
- The diaphragms tie the whole structure together

Floor Plates/Diaphragms

- Strut and Tie is generally the test method to design these diaphragms.
- Enables detailing penetrations
- Recommended by NZS1170.5
- Potential efficiencies if PT can be used
 - Consider consequences of over load

Session 8

Thursday 31 May

Assessment and Evaluation of Vibration Response of Concrete Floor Systems

Florian Aalami

Vibration Analysis/Design of RC and PT Floors



Florian Aalami

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VIBRATION DESIGN OF CONCRETE FLOORS

SCOPE

Part 1 – Basic information and practical approach

- ❖ Why are we **concerned** about vibration;
- ❖ What are the **causes** of vibration;
- ❖ What are the **allowable** limits of vibration;
- ❖ How to **evaluate** the vibration acceptability of a floor
 - Numerical Example

Part 2 – Past practice; alternative methods

- ❖ Semi **empirical** and simple methods of vibration evaluation
 - Numerical Example

Part 3 – Impact of secondary factors

- ❖ Post-tensioning
- ❖ Cracking of concrete

cont..



VIBRATION DESIGN OF CONCRETE FLOORS

SCOPE

Part 4 – Other causes of vibrations

- ❖ rhythmic motions; dance; aerobics
- ❖ Impact of vibrations on sensitive equipment
- ❖ References

Question and Answer

VIBRATION DESIGN OF CONCRETE FLOORS

Part 1 – Basic information and practical approach

- ❖ Why are we **concerned** about vibration;
- ❖ What are the **causes** of vibration;
- ❖ What are the **allowable** limits of vibration;
- ❖ How to **evaluate** the vibration acceptability of a floor
 - Numerical Example

Why are we **concerned** about vibration ?

- ❖ Vibrations may be considered as “**annoying**” by occupants
 - Threshold of “**perception**”
 - Threshold of “**annoyance**”
- ❖ Vibrations may **interfere** with the proper **function** of equipment and instruments

VIBRATION DESIGN OF CONCRETE FLOORS

What are the causes of vibration ?

- ❖ Most common cause is “**foot fall**” (heel drop) occupants;
- ❖ Dynamic impact from **rolling** object.

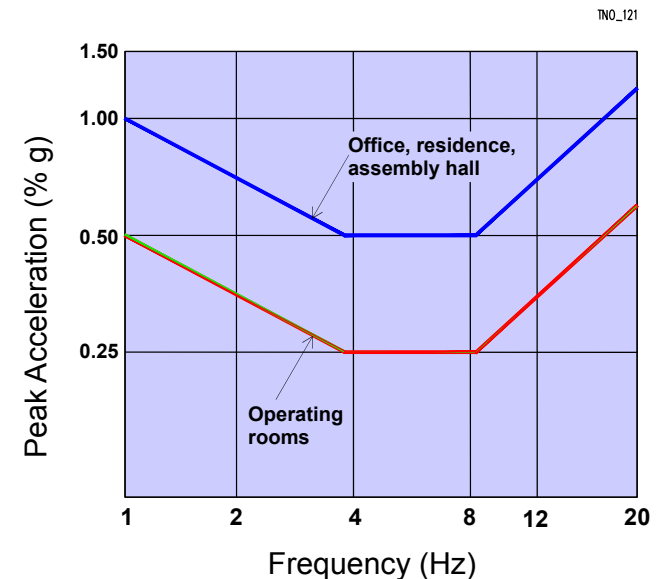
What are the allowable limits of vibration for human's comfort?

- ❖ **Perception** of vibration depends on:
 - **Frequency** (cycles per second, **Hz**); and
 - **Peak acceleration** (expressed as percentage of gravitational acceleration %g)
- ❖ Consensus is that humans are most **sensitive** to vibration for frequencies **between 4 to 8 Hz**.
- ❖ Higher accelerations can be tolerated at higher or lower frequencies.

PERCEPTION OF VIBRATION

What are the allowable limits of vibration?

- **Frequency** (Hz); and
- **Peak acceleration**



Threshold of Human Sensitivity to Vertical Vibration (ATC)

ATC = Applied Technology Council

VIBRATION DESIGN OF CONCRETE FLOORS

How to evaluate the vibration acceptability of a floor?

6 steps for complete evaluation

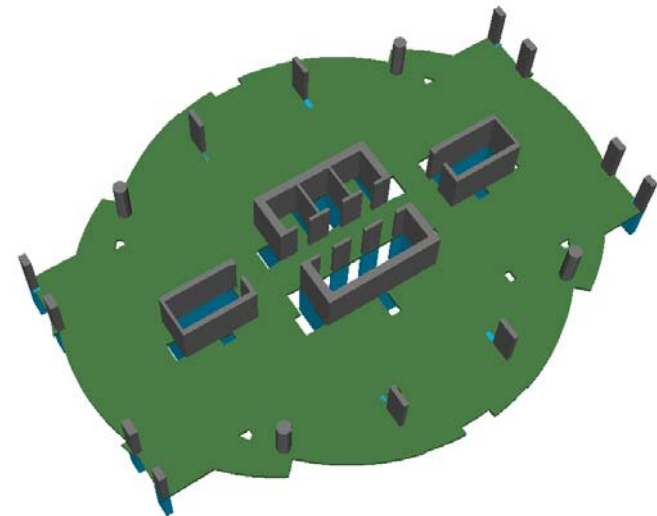
- Step 1 - Determine **natural frequencies** (Hz)
- Step 2 – Select **exciting force** of vibration
- Step 3 - Select **floor type**
- Step 4 – Calculate the **weight of vibrating panel**
- Step 5 – Calculate **peak acceleration**
- Step 6 - **Evaluate** the floor

Numerical example

NATURAL FREQUENCIES

Step 1 - Determine **natural frequencies** (Hz)

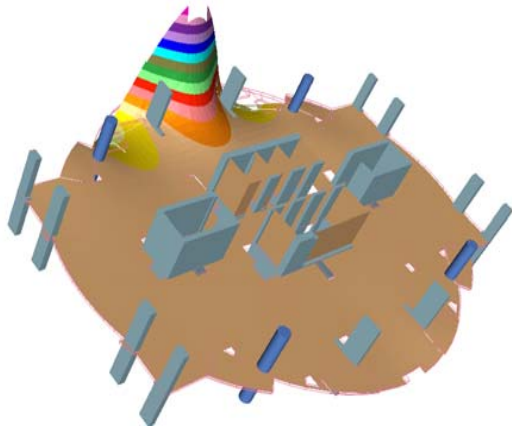
- ❖ Use Finite Element Method with **plate elements**, or empirical formulas
- ❖ For specific areas, such as a lab or operating room, determine the “**dominant**” frequencies of the location of interest.



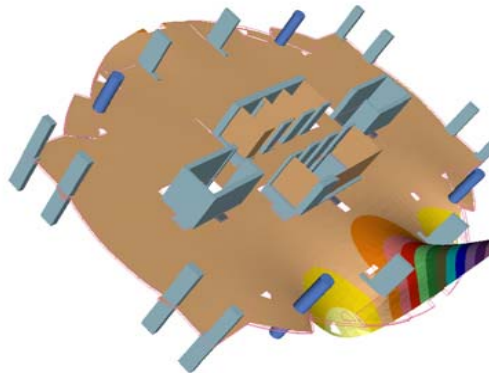
Observe vibration modes of the above floor system, assuming that the **location of interest** is at **bottom left** of the floor

NATURAL FREQUENCIES

Identify **applicable frequency** (Hz)



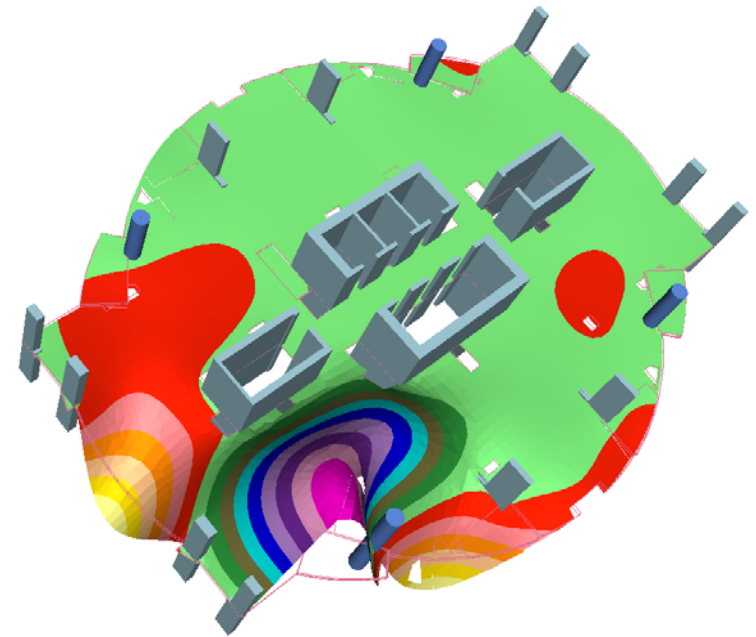
Mode 1 – Not the panel of interest



Mode 2 – Not the panel of interest

NATURAL FREQUENCIES

Identify the **governing frequency** (Hz)

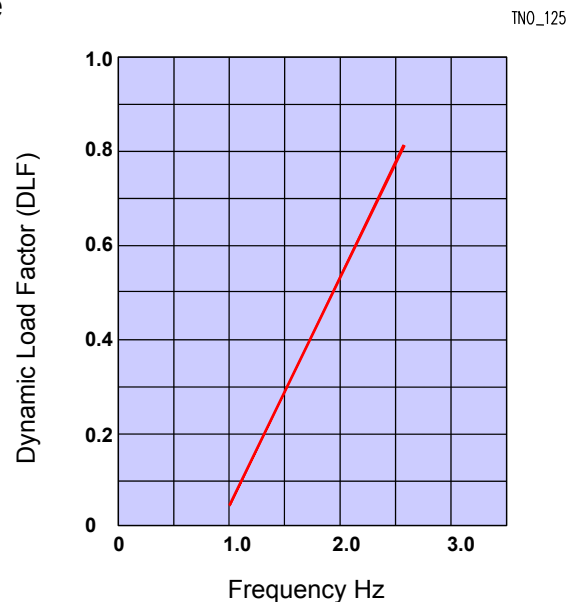


Mode 5 is the first mode that excites the region of interest (bottom left). The frequency associated with this mode will be used as **basis for evaluation**

EXITING FORCE OF VIBRATION

Step 2 - Select **exciting force** of vibration

- ❖ Use the following graph to determine the exciting force



Dynamic Load Factor for First Harmonic of Walking Force

Exciting force = DLF * (Weight of Person)

TRANSMISSION PATH OF VIBRATION

Step 3 - Select **floor type**

- ❖ Refer to the table to select damping factor (β); in **most cases 0.03 applies**
- ❖ The recommended values vary from 2-3% for bare concrete floors to 5-8% for furnished rooms with partitions extending full height.

RECOMMENDED DAMPING FACTORS FOR VARIOUS OCCUPANCIES

Occupancy	Damping factor β
Bare concrete floor	0.02
Furnished, low partition	0.03
Furnished, full height partition	0.05
Shopping malls	0.02

PEAK ACCELERATION

Step 4 – Calculate **weight** of target **panel** (W)

- ❖ Include superimposed load that follows the vibration (stones; tiles)

Step 5 – Calculate **Peak Acceleration** (a_p/g)

- ❖ Use an empirical relationship, such as the one below for footfall

$$\frac{a_p}{g} = \frac{P_0 e^{-0.35 f}}{\beta W} \quad (1)$$

a_p = peak acceleration;

g = gravitational acceleration [32.2 ft/sec²; 9.81 m/sec²];

P_0 = constant force representing the walking force (from Step 2 and weight of walking person);

β = modal damping ratio, from previous table

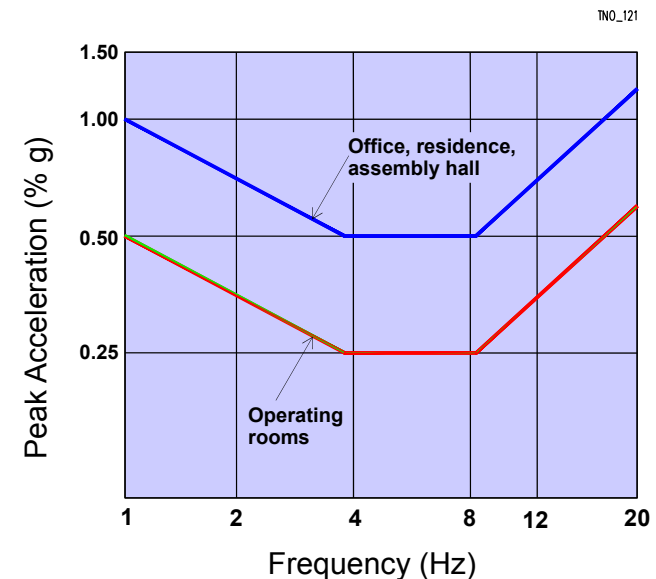
W = effective weight of the panel and the superimposed load; and

f = governing natural frequency (Hz).

PERCEPTIBILITY OF MOTION

Step 6 – **Evaluate** the floor

- ❖ Use natural frequency from Step 1; and
- ❖ Peak ground acceleration (a_g/g) from Step 5; and
- ❖ Chart below from ATC to determine acceptability



Threshold of Human Sensitivity to Vertical Vibration (ATC)

NUMERICAL EXAMPLE

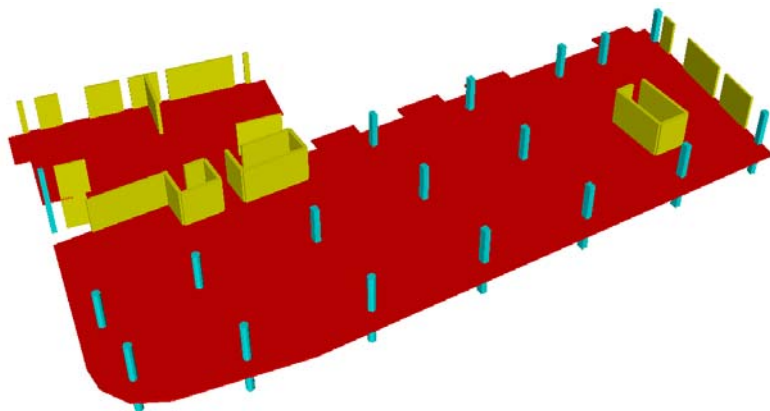
Numerical Example

Given

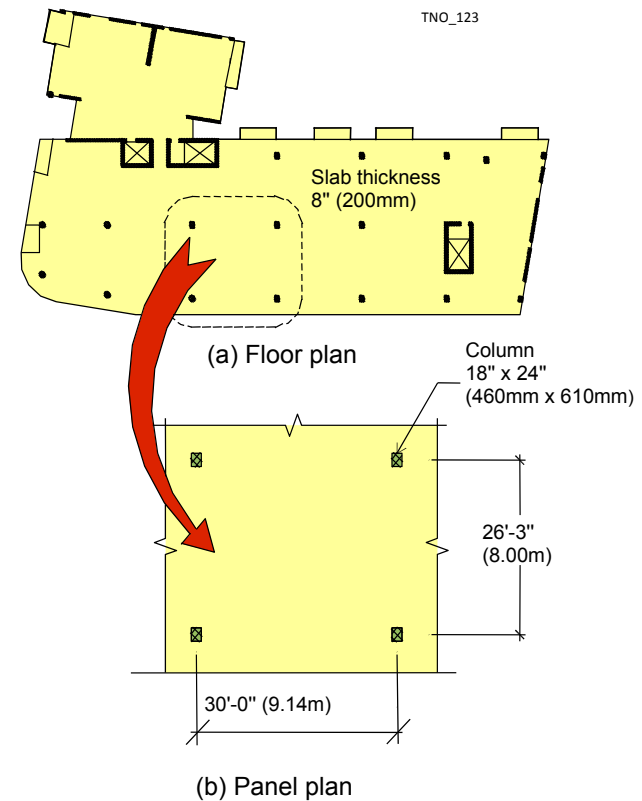
- ❖ Concrete floor system
- ❖ Slab thickness 8" (203 mm)
- ❖ Superimposed DL 20 psf (1 kN/m²)
- ❖ Concrete f'_c 5000 psi (33.8 MPa)
- ❖ Modulus of Elasticity 1.2 E_c

Required

- ❖ Evaluate vibration compliance of the floor panel identified under foot drop



NUMERICAL EXAMPLE

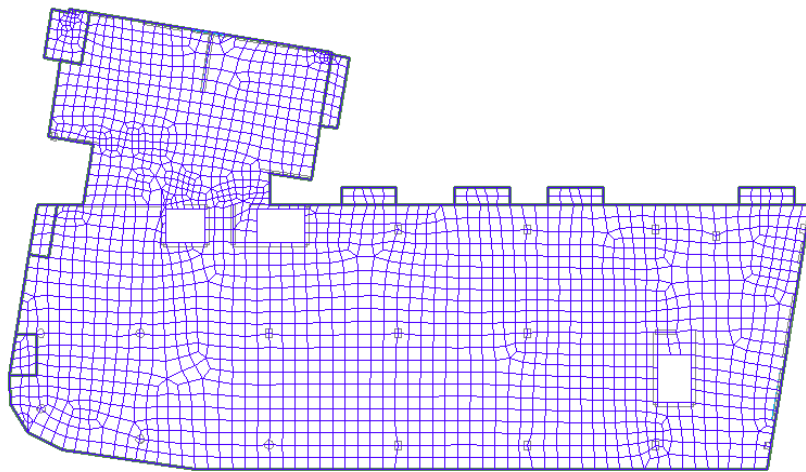


Identification of Panel for Vibration Evaluation

VIBRATION DESIGN OF CONCRETE FLOORS

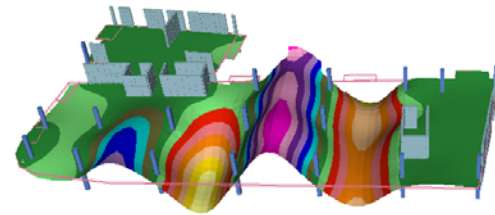
Step 1 – Determine **natural frequencies (Hz)**

- Generate model of the **entire floor**
- Use modulus of elasticity $1.2E_c$
- Include weight of objects attached to floor
- Obtain first few natural frequencies

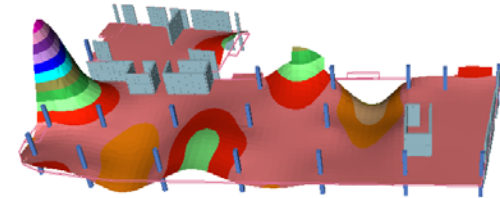


Discretization of the Floor for a
Reliable Frequency Values

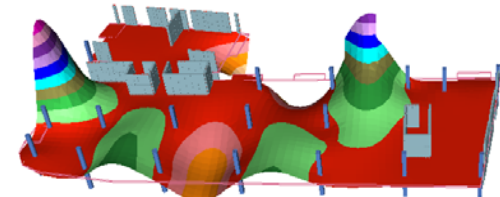
VIBRATION DESIGN OF CONCRETE FLOORS



(a) First mode – frequency 5.79 Hz



(b) Second mode – frequency 6.33 Hz



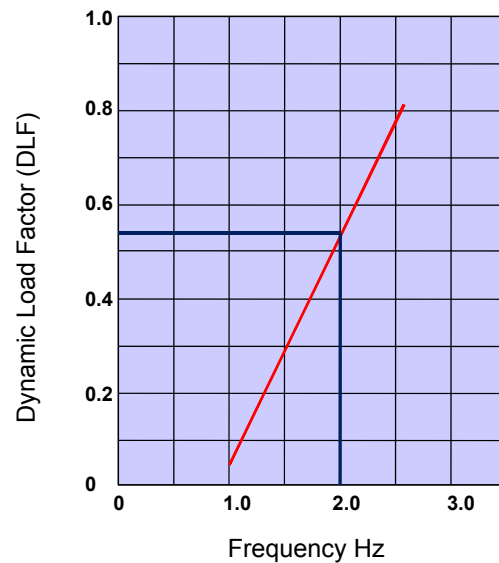
(c) Third mode – frequency 6.44 Hz

VIBRATION DESIGN OF CONCRETE FLOORS

Step 2 - Select **exciting force** of vibration

- ❖ Weight of person 150 lb (667 N)
- ❖ Walking speed: 2 steps per second
- ❖ From the chart:
 $DLF = 0.53$
 $P_o = 0.53 * 150 = 79.5 \text{ lb (354 N)}$

TNO_125



Dynamic Load Factor for First Harmonic of Walking Force

VIBRATION DESIGN OF CONCRETE FLOORS

Step 3 - Select **floor type**



Office furnished; low partitions

From below select (β) = 0.03 From table

Occupancy	Damping factor β
Bare concrete floor	0.02
Furnished, low partition	0.03
Furnished, full height partition	0.05
Shopping malls	0.02

VIBRATION DESIGN OF CONCRETE FLOORS

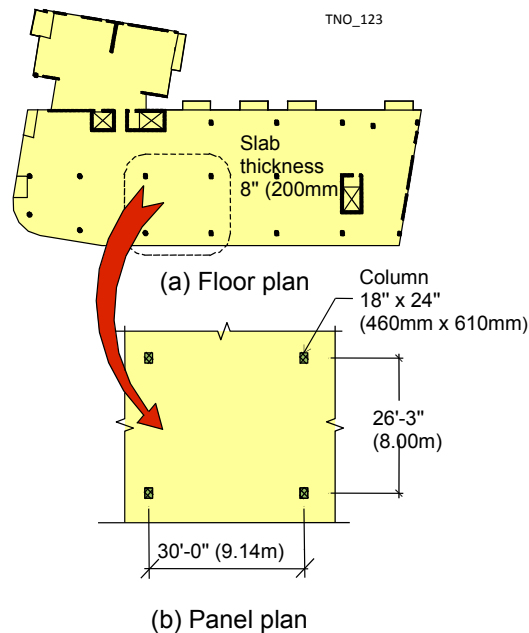
Step 4 – Calculate **weight** of target panel (W)

- ❖ Dimensions of panel as shown below
- ❖ Mortar, stone, firmly attached to floor 20 psf (1 kN/m²)
- ❖ Concrete weight: 150 pcf; (25 kN/m³)

The total weight of the panel W is

$$W = (26.25 \times 30)[(8/12)0.15 + 0.02] = 94.50 \text{ k (421 kN)}$$

:



VIBRATION DESIGN OF CONCRETE FLOORS

Step 5 – Calculate **Peak Acceleration** (a_p/g)

- ❖ Use an empirical relationship, such as the one below for footfall

$$\frac{a_p}{g} = \frac{P_o e^{-0.35 f}}{\beta W}$$

a_p = peak acceleration;

g = gravitational acceleration [32.2 ft/sec²; 9.81 m/sec²];

P_o = 0.53 * 150 = 79.5 lb (0.354 kN) (step 2)

β = damping ratio 0.03 (step 3)

W = 94.5 k (421 kN) (step 4)

f = first natural frequency (Hz) = 5.79 Hz (step 1).

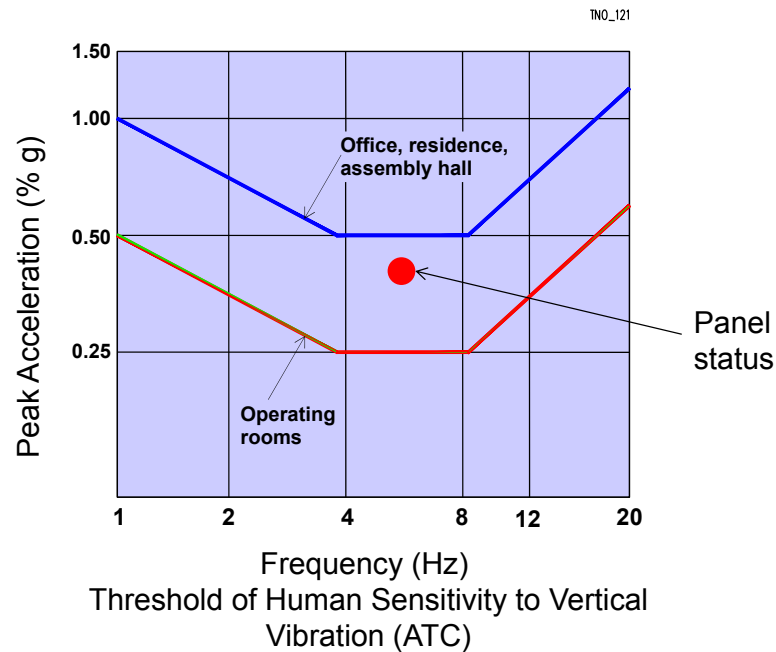
$$\frac{a_p}{g} = \frac{79.5 \times e^{-0.35 \times 5.79}}{0.03 \times 94.50 \times 1000} = 0.00367 = 0.37\%$$

Peak ground acceleration (a_p) is calculated to be **0.37% of gravitational acceleration (g)**

VIBRATION DESIGN OF CONCRETE FLOORS

Step 6 – Evaluate the floor

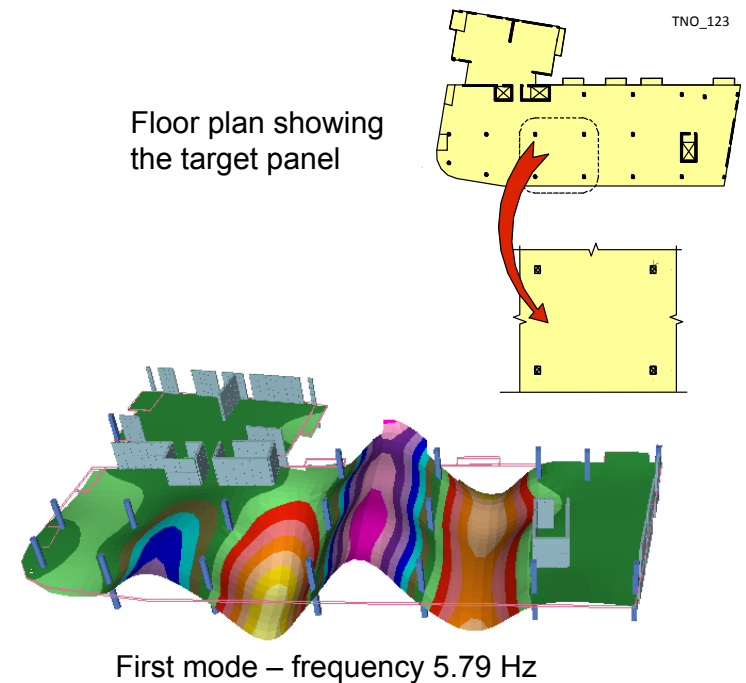
- ❖ Use natural frequency from Step 1; **5.79 Hz**; and
- ❖ Peak ground acceleration from Step 5; **0.37% g**; and
- ❖ Chart below from ATC to determine acceptability



The target panel is acceptable for office and residential occupancies, but not for hospital operating room

VIBRATION DESIGN OF CONCRETE FLOORS

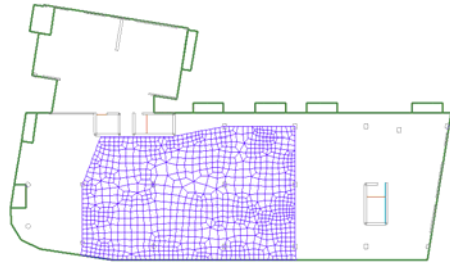
Eliminate the noise (disturbance) from non-targeted floor regions



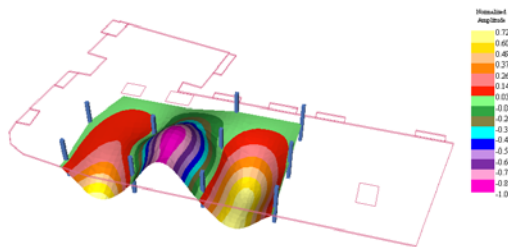
Note that the first mode is primarily due to excitation of a non-targeted region of floor

VIBRATION DESIGN OF CONCRETE FLOORS

- **Isolate the target area** for vibration analysis
- The response of the isolated region is greatly **influenced by the boundary conditions** specified around the cut
- **Extend** the sub-region at least one panel on each side beyond the panel of interest



(a) Selection of an extended region



(b) First mode of vibration – Frequency 6.07 Hz

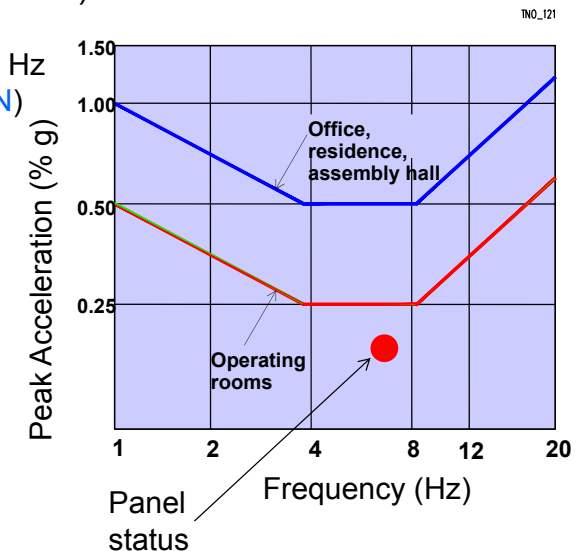
VIBRATION DESIGN OF CONCRETE FLOORS

How can we **bring** the vibration of a given floor **to compliance**?

- ❖ Increase in stiffness increases the frequencies
- ❖ Increase in weight reduces the frequencies
- ❖ Increase in frequency, reduces the peak acceleration
- ❖ Increase in weight reduces the peak acceleration
- ❖ Increase in restraint of boundary conditions, reduction in span increases frequency

For the given example, **increase slab thickness** from 8" (203 mm) to 10" (250 mm)

- ❖ Frequency $f = 7.72$ Hz
- ❖ $W = 115.3$ k (514 kN)
- ❖ Peak acceleration $(a_p/g) = 0.154$ %



VIBRATION DESIGN OF CONCRETE FLOORS

SCOPE

Part 1 – Basic information and practical approach

- ❖ Why are we **concerned** about vibration;
- ❖ What are the **causes** of vibration;
- ❖ What are the **allowable** limits of vibration;
- ❖ How to **evaluate** the vibration acceptability of a floor
 - **Numerical Example**

Part 2 – Past practice; alternative methods

- ❖ Semi **empirical** and simple methods of vibration evaluation
 - **Numerical Example**

Part 3 – Impact of secondary factors

- ❖ Post-tensioning
- ❖ Cracking of concrete
- ❖ Floor covers/tiles/stones
- ❖ Installed equipment/machinery

cont..

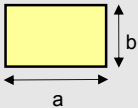
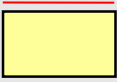
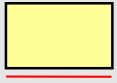
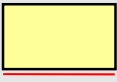
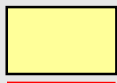
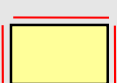
VIBRATION DESIGN OF CONCRETE FLOORS

Part 2 – Past practice; alternative methods

- ❖ Semi **empirical** and simple methods of vibration evaluation
 - **Numerical Example**
- **Estimate** the natural frequencies using **empirical** relationships
- Make a good **engineering judgment** on the probable **shape** of the first natural frequency

FORMULAS FOR NATURAL FREQUENCIES

FIRST NATURAL FREQUENCY CONSTANT ϕ

Case	Boundary Conditions	Constant ϕ
1		$\phi = 1.57(1 + \gamma^2)$
2		$\phi = 1.57\sqrt{1 + 2.5\gamma^2 + 5.14\gamma^4}$
3		$\phi = 1.57\sqrt{5.14 + 2.92\gamma^2 + 2.44\gamma^4}$
4		$\phi = 1.57\sqrt{1 + 2.33\gamma^2 + 2.44\gamma^4}$
5		$\phi = 1.57\sqrt{2.44 + 2.72\gamma^2 + 2.44\gamma^4}$
6		$\phi = 1.57\sqrt{5.14 + 3.13\gamma^2 + 5.14\gamma^4}$

-  rigidly supported, rotationally free
 rigidly supported, rotationally fixed
 a span length in x-direction
 b span length in y-direction
 γ a/b

DETERMINATION OF NATURAL FREQUENCIES

The parameters for the Table are:

$$f = \frac{c}{a^2} \phi$$

Where

$$c = \sqrt{\frac{Eh^3}{12(1 - \nu^2)}} \times \frac{g}{q}$$

f = first natural frequency [Hz];

a = span length in X-direction;

E = dynamic modulus of elasticity [1.2 static E in psi; MPa];

h = slab thickness [in; mm];

ν = Poisson's ratio [0.2];

g = gravitational acceleration [32.2 ft/sec² ; 9810 mm/sec²]; and

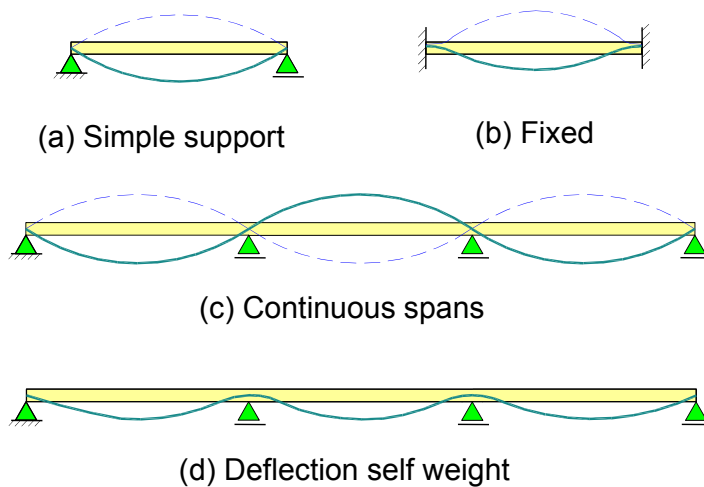
q = weight per unit surface area of the slab.

DETERMINATION OF NATURAL FREQUENCIES

Shape of first Natural Frequency Mode

- ❖ The first mode of vibration is affine to that of a single panel simply supported plate. The shape is **not analogous to the deflected profile under selfweight**

TNO_122



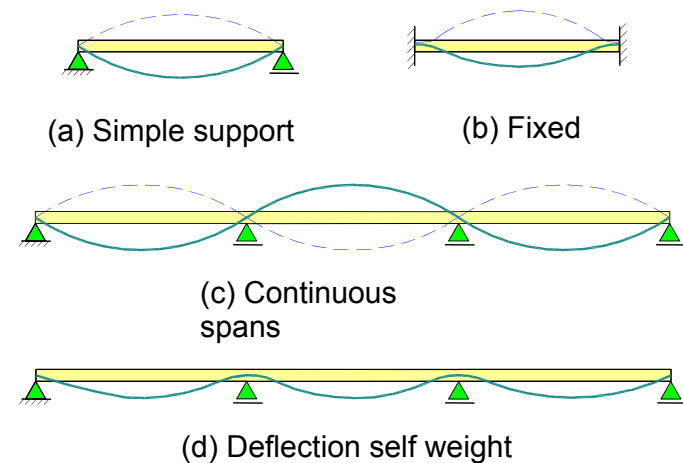
First Mode Shapes and Deflection of Simple and Continuous Spans

DETERMINATION OF NATURAL FREQUENCY

Shape of first Natural Frequency

- ❖ Use a **simply supported boundary** conditions along the four sides of an interior panel
- ❖ Where columns are on a regular orthogonal grid, the first mode is likely to be in form of a **one-way slab** deflecting in a **cylindrical** form.
- ❖ Panels bounded by smaller spans, may vibrate analogous to a rotationally fixed plate

TNO_122

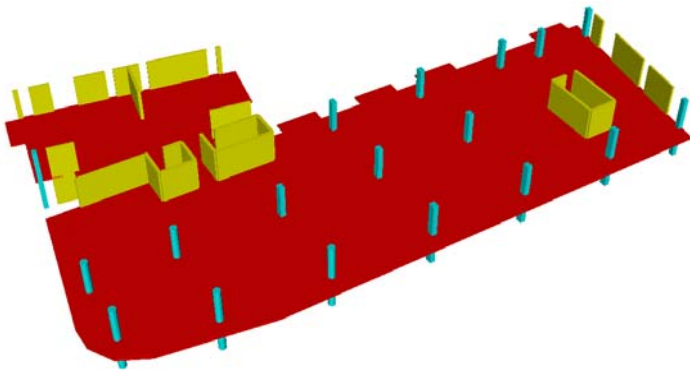


First Mode Shapes and Deflection of Simple and Continuous Spans

VIBRATION DESIGN OF CONCRETE FLOORS

Numerical Example

Evaluate the vibration compliance of the floor slab below, for foot drop having the same details in former example, using empirical formulas



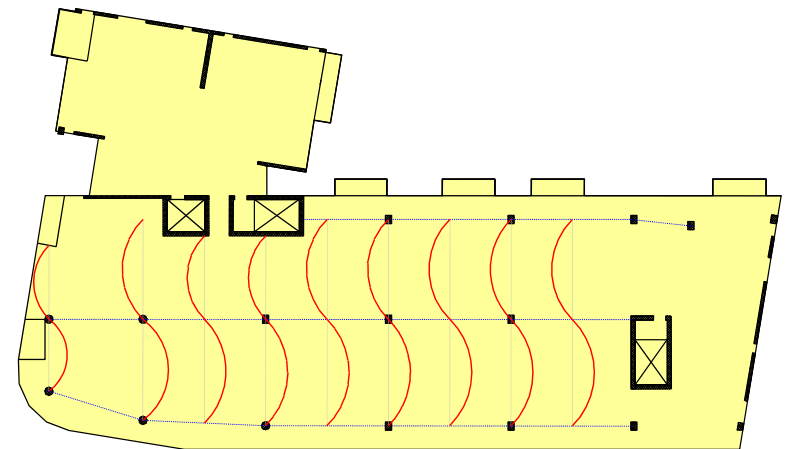
View of the Floor System

VIBRATION DESIGN OF CONCRETE FLOORS

Step 1

Envisage the probable **shape** of the **first mode** of vibration.

A column supported slab, such as the floor system under consideration is likely to vibrate in form of a **cylinder** (one-way system)



Probable Shape of First Mode

VIBRATION DESIGN OF CONCRETE FLOORS

Step 2

Select from the Table of frequency formulas, the case that can **best simulate the envisaged shape** of first mode of vibration

Find the First Natural Frequency

Using the parameters of frequency table:

$$g = 9.81 \text{ m/sec}^2 ; 32.2 \text{ ft/sec}^2$$

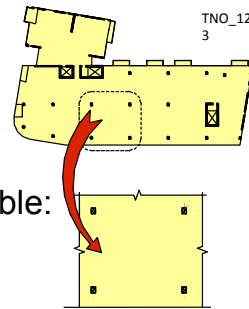
First natural frequency, f :

$$f = \frac{c}{a^2} \phi$$

$$c = \sqrt{\frac{Eh^3}{12(1-\nu^2)}} \times \frac{g}{q}$$

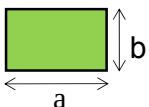
$$E_{st} = 29,000 \text{ MPa} \\ = 4287 \text{ ksi}, \text{ using ACI-318}$$

$$\text{Assume } E_{dyn} = 1.2 E_{st} = 1.2 E_{st}$$



CALCULATE NATURAL FREQUENCY

FIRST NATURAL FREQUENCY CONSTANT ϕ

Case	Boundary Conditions	Constant ϕ
1		$\phi = 1.57(1 + \gamma^2)$

— rigidly supported, rotationally free

a span length in x-direction

b span length in y-direction

$\gamma = a/b$

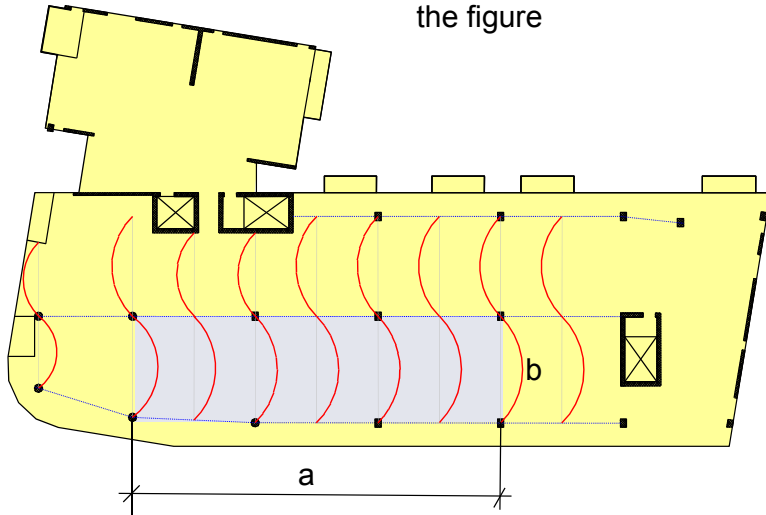
$$c = \sqrt{\frac{Eh^3}{12(1-\nu^2)}} \times \frac{g}{q}$$

$$\phi = 1.57(1 + \gamma^2)$$

$$f = \frac{c}{a^2} \phi \quad (\text{frequency of first mode})$$

CALCULATE NATURAL FREQUENCY

Consider a region as shown in the figure



$$a = 3 \times 90 \times 12 = 1080 \text{ in (42.5 m)}$$

$$\Phi = 1.57(1 + \gamma^2) = 1.57 \left[1 + \left(\frac{90}{26.25} \right)^2 \right] = 20.03$$

$$c = \sqrt{\frac{Eh^3}{12(1 - \nu^2)}} \times \frac{g}{q}$$

$$E_{dyn} = 1.2 E_{st} = 1.2 \times 4287 = 5144 \text{ ksi (35,477 MPa)}$$

CALCULATE NATURAL FREQUENCY

$$h = 8 \text{ inch (203 mm)}$$

q = weight/unit area

$$q = \frac{150 \times 8}{12 \times 144} + \frac{20}{144} = 0.833 \text{ lb/in}^2 \text{ (5.54} \times 10^{-3} \text{ MPa)}$$

$$c = \sqrt{\frac{5144 \times 1000 \times 8^3}{12(1 - 0.2^2)}} \times \frac{32.2 \times 12}{0.833} = 325653 \text{ in}^2/\text{sec}$$

(2.1 × 10⁸ mm²/sec)

$$f = \frac{325653}{1080^2} \times 20.03 = 5.59 \text{ Hz}$$

$$\frac{a_p}{g} = \frac{P_0 e^{-0.35 f}}{\beta W}$$

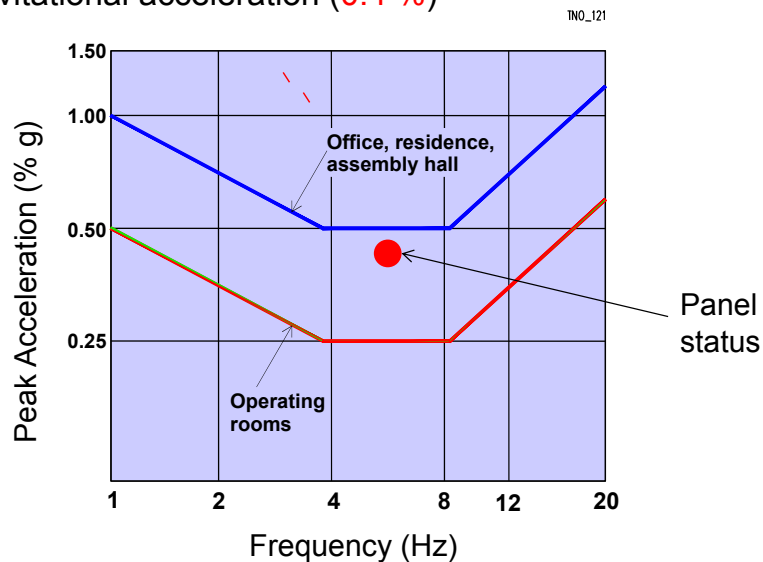
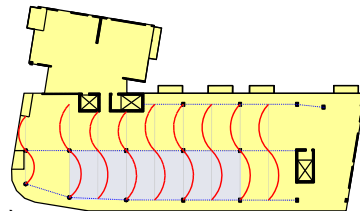
$$\frac{a_p}{g} = \frac{79.5 \times e^{-0.35 \times 5.59}}{0.03 \times 94.5 \times 1000} = 0.004 \text{ ; 0.4 \%}$$

Note that the weight of one panel is used for W

VIBRATION DESIGN OF CONCRETE FLOORS

Check the Results for Acceptability

- ❖ First natural frequency (5.59 Hz)
- ❖ Peak response acceleration relative to gravitational acceleration (0.4 %)



Acceptable for office and residential, but not for operating rooms

VIBRATION DESIGN OF CONCRETE FLOORS

SCOPE

Part 1 – Basic information and practical approach

- ❖ Why are we **concerned** about vibration;
- ❖ What are the **causes** of vibration;
- ❖ What are the **allowable** limits of vibration;
- ❖ How to **evaluate** the vibration acceptability of a floor

➤ Numerical Example

Part 2 – Past practice; alternative methods

- ❖ Semi **empirical** and simple methods of vibration evaluation

➤ Numerical Example

Part 3 – Impact of secondary factors

- ❖ Post-tensioning
- ❖ Cracking of concrete

cont..

VIBRATION DESIGN OF CONCRETE FLOORS

Part 3 – Impact of secondary factors

❖ Post-tensioning

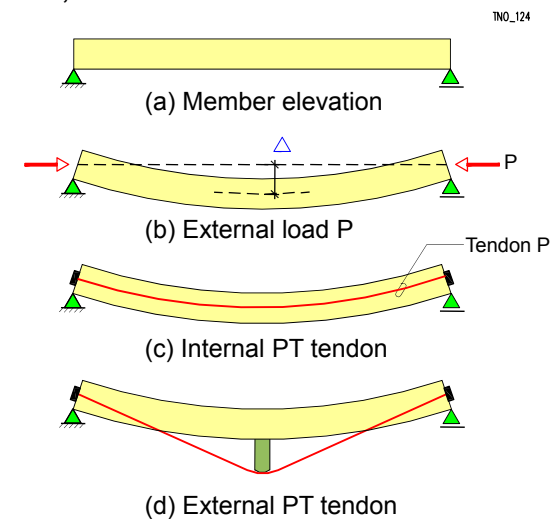
- Post-tensioned slabs are generally **thinner** than their conventionally reinforced counterparts; hence, they have lower frequencies
- Precompression from post-tensioning inhibits, or reduces crack formation. Post-tensioned slabs are **stiffer** than RC slabs of the same thickness



TRANSMISSION PATH OF VIBRATION

Post-Tensioning

- ❖ Post-tensioning imparts axial compression.
- ❖ Axial force from external source causes ($P\Delta$) moment; reduces flexural stiffness.
- ❖ Internal post-tensioning does not cause ($P\Delta$) moment, and does not reduce flexural stiffness.



P – Δ Effect for PT and Externally Loaded Members

VIBRATION DESIGN OF CONCRETE FLOORS

Part 3 – Impact of secondary factors

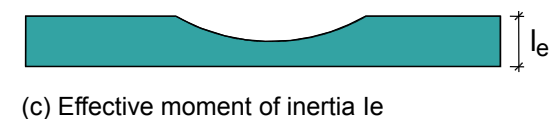
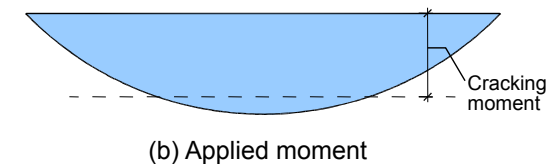
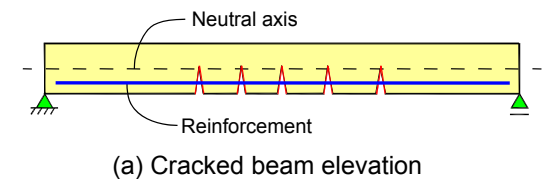
❖ Cracking of concrete

- **Cracking** of concrete, in particular in conventionally reinforced concrete, where hair cracks under service condition are common and numerous in number result in **reduction of local stiffness**.
- Concentration of local cracks over the supports and at midspan can result in a **change** in the natural mode **shape of vibration**

VIBRATION DESIGN OF CONCRETE FLOORS

Part 3 – Impact of secondary factors

❖ **Cracking** of concrete



Loss of stiffness due to cracking results
in **shorter frequencies**

VIBRATION DESIGN OF CONCRETE FLOORS

Part 3 – Impact of secondary factors

❖ Cracking of concrete

Extent of cracking under dead load. Max local reduction in stiffness 69%



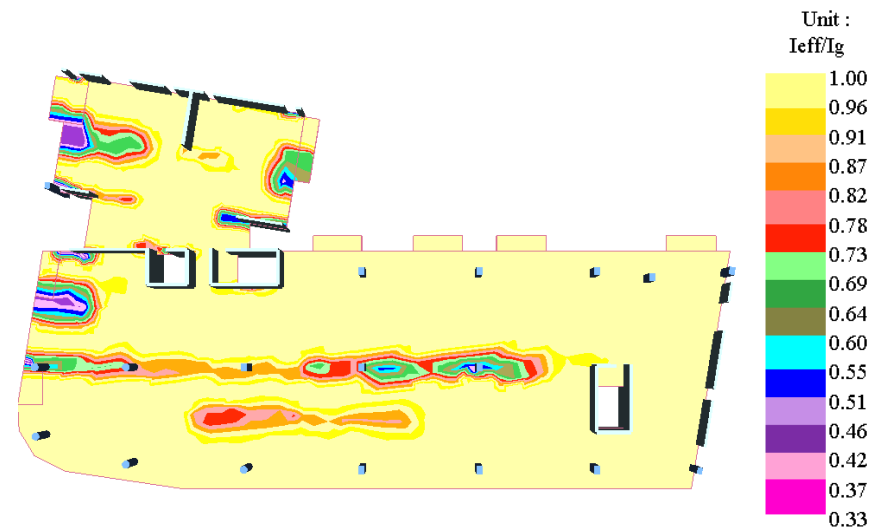
EXTENT OF CRACKING SHOWN THROUGH REDUCTION IN STIFFNESS FOR MOMENTS ABOUT Y-Y AXIS

VIBRATION DESIGN OF CONCRETE FLOORS

Part 3 – Impact of secondary factors

❖ Cracking of concrete

Extent of cracking under dead load. Max local reduction in stiffness 67%



EXTENT OF CRACKING SHOWN THROUGH REDUCTION IN STIFFNESS FOR MOMENTS ABOUT X-X AXIS

VIBRATION DESIGN OF CONCRETE FLOORS

Part 4 – Other causes of vibrations

- ❖ rhythmic motions; dance; aerobics
- ❖ Impact of vibrations on sensitive equipment
- ❖ References

Rhythmic motions; dance; aerobics

The same 6-steps apply with the following two differences

- Exciting force P_o is larger
- Tolerance of vibration is more

Exciting Force P_o for Rhythmic Activities

Activity	Forcing frequency Hz	Weight of participants w_p (psf) (kN/m ²)	Dynamic load factor DLF	Dynamic load intensity $P_o = DLF w_p$ psf (kN/m ²)
Dancing	1.5 – 3.0	11.1* (0.531)	0.5	5.55 (0.266)
Lively concert or sports event	1.5 – 3.0	30.0** (1.44)	0.25	7.50 (0.359)
Aerobics	2.0 – 4.0	3.6*** (0.172)	1.5	5.40 (0.258)

Average weight of a person assumed 150 lb (79.5 kg)

* assuming each dancing couple taking 27 ft²; (2.51 m²);

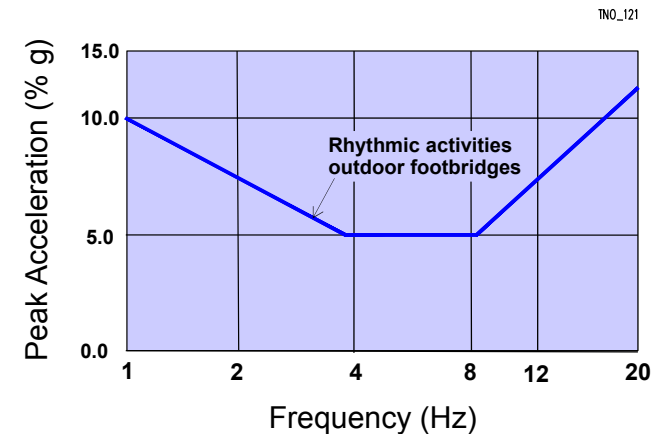
** assuming 5 ft²; (0.464 m²) per person

*** assuming 42 ft²; (3.90 m²) per person

PERCEPTION OF VIBRATION

Rhythmic motions; dance; aerobics

- Exciting force P_o is larger
- Tolerance of vibration is more



Threshold of Human Sensitivity to Vertical Vibration from Rhythmic Activities (ATC)

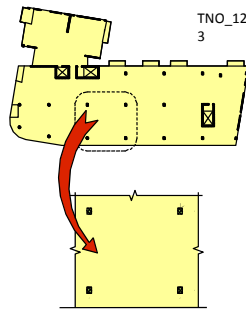
Note that the threshold of acceptable peak acceleration is about 10 times more than regular foot fall on residential and commercial buildings

VIBRATION DESIGN OF CONCRETE FLOORS

Rhythmic motions; dance; aerobics

Numerical Example

- Determine the adequacy of the floor panel identified for aerobic activities



- 1 - Frequency $f = 5.97$ Hz
- 2 - Exciting force from the table is 5.36 psf (kN/m²)
Panel size 26.25x30 ft

$$P_o = 5.36 \times 26.25 \times 30 = 4221 \text{ lb (18.78 kN)}$$

- 3 - Floor type $\beta = 0.03$

- 4 - Weight $W = 94500$ lb (420.36 kN)

- 5 - Calculate peak acceleration a_p/g

$$\frac{a_p}{g} = \frac{4221e^{-0.35 \times 5.97}}{0.03 \times 94500} = 0.184 = 18.4\%$$

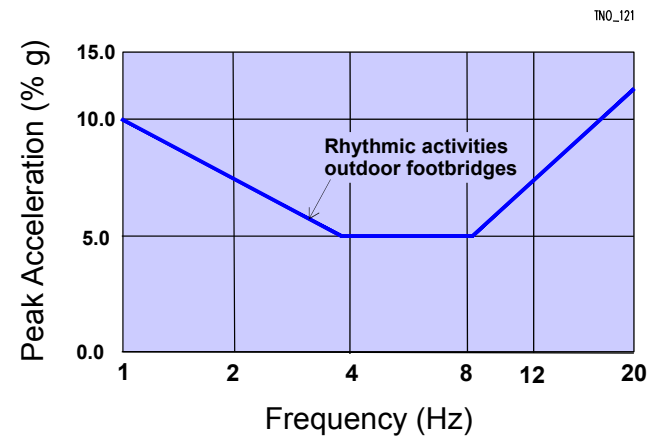
$$\frac{a_p}{g} = \frac{P_o e^{-0.35 f}}{\beta W}$$

- 6 - Evaluate (see next slide)

PERCEPTION OF VIBRATION

Rhythmic motions; dance; aerobics

- Computed values:
 - frequency $f = 5.97$ Hz
 - Peak acceleration ratio 18.4%



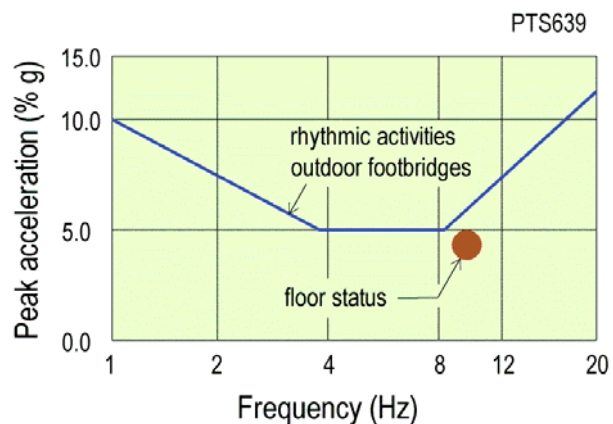
Threshold of Human Sensitivity to Vertical Vibration from Rhythmic Activities (ATC)

- ❑ With 10% being the maximum, the sensitivity diagram clearly indicates that the calculated 18.4% is not acceptable.
- ❑ One option is to increase the slab thickness.

PERCEPTION OF VIBRATION

Rhythmic motions; dance; aerobics

- Increase slab thickness to 11" (280 mm)
- Computed frequency $f = 9$ Hz
- Weight $W = 124.04$ k (551.71 kN)
- Peak acceleration $a_p/g = 4.9\%$

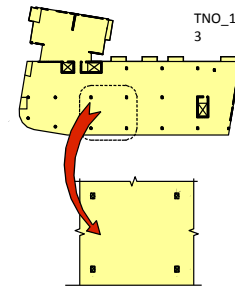


The chart indicates that **increase in thickness** makes the floor panel **suitable** for rhythmic activities

VIBRATION DESIGN OF CONCRETE FLOORS

Impact of Vibration on Sensitive Equipment Numerical Example

- Determine the adequacy of the floor panel identified under foot fall for general laboratory



- 1 - Frequency $f = 5.97$ Hz
- 2 - Exciting force for foot fall $P_o = 45$ lb (0.20 kN)
- 3 - Floor type $\beta = 0.035$ (for densely equipped laboratory)
- 4 - Weight $W = 94500$ lb (420.36 kN)
- 5 - Calculate max velocity

$$v = \frac{P_o g}{2\pi\beta W f e^{0.35 f}}$$

$$v = \frac{45 \times 384}{2 \times 3.14 \times 0.035 \times 94500 \times 5.97 e^{0.35 \times 5.97}} = 0.017 \text{ in/sec} \quad (0.43 \text{ mm/sec})$$

$$= 17000 \text{ mips (0.43 mm/sec)}$$

- 6 - Evaluate the response of the floor

VIBRATION DESIGN OF CONCRETE FLOORS

Impact of Vibration on Sensitive Equipment Numerical Example

6 – Evaluate the response of the floor

National Institutes of Health's Recommended Velocities

Function	Maximum velocity micro meter/sec	Maximum velocity Micro in/sec
General laboratory	50	2000
Ordinary surgery	25	1000
Bench scope up to 100X mag	50	2000
Bench scope up to 400X mag	25	1000
Electron microscope greater than 30,000X; mass spectrometer	6	240
Electron microscope up to 30,000 mag	12	480

Calculated velocity = 0.017 in/sec = 17,000 mips = 432 micro meter/sec >> 2000 mips, or 50 micro m/sec NG

- Increase of slab thickness to 12 in (300 mm) brings the velocity to the acceptable range

FREQUENCIES

Factors affecting the natural frequencies:

- ❖ Floor's mass
- ❖ Modulus of elasticity
- ❖ Damping
- ❖ Extent of cracking; post-tensioning

Mass

- ❖ Expresses as (W/g),
 - "W" is the weight of the objects that are attached to the floor and faithfully follow its displacement; the **greater** the **weight** the larger is the period; the **smaller is the frequency** (Hz)
 - "g" is the gravitational acceleration taken as 32.2 ft/sec² (9.81 m/sec²).

Modulus of Elasticity

- ❖ The elastic **modulus for vibration** analysis is **larger than the static values**, in particular when high strength concrete is used.
- ❖ Recommended values are **25% higher** than the static modulus.

VIBRATION DESIGN OF CONCRETE FLOORS

References

Aalami, B., (2014), "*Vibration Design of Concrete Floors*," PT-Structures Technical Note TN290, www.PT-Structures.com, 29 pp., 2014

ADAPT Technical Note TN388, 2010," *Vibration Evaluation of a Floor System for Foot Fall*," www.adaptsoft.com, 9 pp., 2010

AISC/CISC, (1997) ,"*Steel Design Guide Series 11, Floor Vibrations Due to Human Activity*," American Institute of Steel Construction, Chicago, IL, 1997.

ATC, (1999) "ATC Design Guide 1," *Minimizing Floor Vibration*," Applied Technology Council, Redwood City, CA, 1999, 49 pp.

Bares, R., (1971), "Tables for the Analysis of Plates, Slabs and Diaphragms Based on the Elastic Theory," Bauverlag GmbH, Wiesbaden und Berlin, 1971, pp. 626

Farzad, N., (1991), "Design Practice to Prevent Floor Vibrations," Steel Tips, Structural Steel Educational Council, Walnut Creek, CA ,25 pp.

VIBRATION DESIGN OF CONCRETE FLOORS

References

Mast, F. R., (2001),"*Vibration of Precast Prestressed Concrete Floors*," PCI Journal, November-December 2001, 2001, pp. 76-86.

NIH, (2012), "Design Requirement Manual," The National Institute of Health, Division of Technical Resources, www.nih.gov

Source: Allen, D. E., and Murray, T. M., (1993) "*Design Criterion for Vibrations Due to Walking*," Engineering Journal, Fourth Quarter, American Institute of Steel Construction, 1993, pp. 117-129.

TR43, (2005)," Post-tensioned concrete floors: Design Handbook," Second edition, The Concrete Society , Surrey GU17 9AB, UK.

Sziland, R., (1974), "*Theory and Analysis of Plates-Classical and Numerical Methods*," Prentice-Hall, Inc., New Jersey, 1974, 724 pp.

VIBRATION DESIGN OF CONCRETE FLOORS

Other work by the author on vibrations

Aalami, B. O., (1984) "*Large Amplitude Vibrations of Rectangular Plates*," Journal of Applied Mechanics, ASME, 1984, pp 935-937.

Aalami, B. and Atzori, B. "*Flexural Vibrations and Timoshenko's Beam Theory*", Journal of the American Institute of Aeronautics and Astronautics, May 1974, pp 679-685

Aalami, B. "*Waves in Prismatic Bars of Arbitrary Cross-Section*", Journal of Applied Mechanics, ASME, December 1973, pp 1067-1072.

Aalami, B. O., and Javaherian, H., "*Free Vibrations of Rectangular Plates*," Fourth Australasian Conference on the Mechanics of Structures and Materials, University of Queensland, Brisbane, 20-22nd, Aug, 1973, pp.1-8.

Aalami, B. "*Analysis and Behavior of Acoustic Surface Wave Guides*", Institute of Electronics and Electrical Engineers, Transactions on Sonics and Ultrasonics, July 1973, pp 252-260.



Thank you for listening

Session 8

Thursday 31 May

Construction Detailing:
Layout of Post-Tensioning
Tendons and Detailing of
Non-Prestressed
Reinforcement

Bijan Aalami

Post-Tensioning Tendon Detailing



P1219

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ADAPT
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1 – Distinguishing features between RC and PT detailing

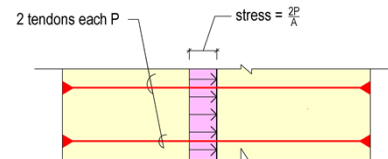
- i. Crack formation **not sensitive** to distance from tendon
- ii. **Biaxial** stress from post-tensioning helps to resist lateral loads
- iii. At ultimate strength, **failure** occurs through formation of **hinge lines**
- iv. Column strip/middle strip **does not apply** for reinforcement layout

Contents of presentation

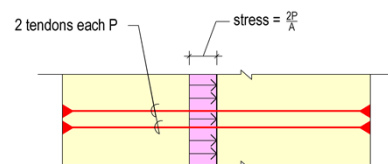
1. **Distinguishing features** in detailing PT and RC slabs
2. Tendon **layout**
3. Tendon **profiles**
4. Tendons in **beams**
5. **Stressing/dead end** details
6. **Setting** tendon profile in construction
7. **Recording/marking** tendon locations

1 – Distinguishing features between RC and PT detailing

PTS854



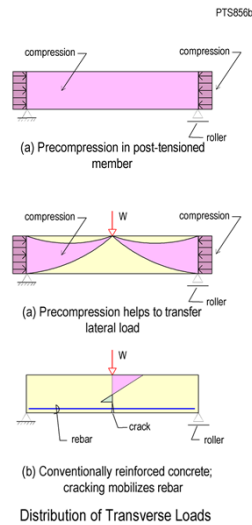
(a) Tendons distributed along the edges



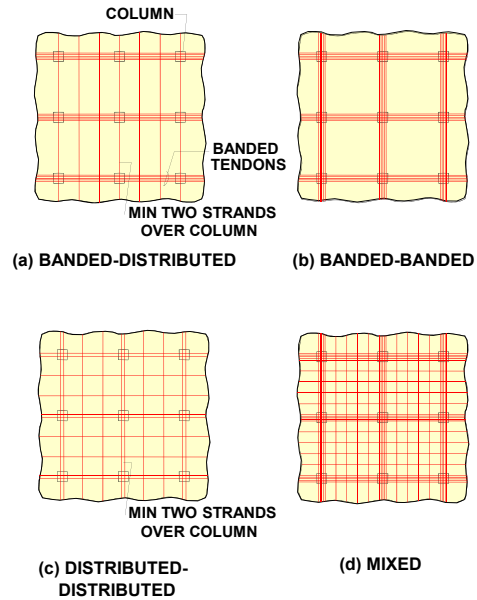
(b) Tendons banded at center

Partial plans, showing two tendon arrangements and the resulting distribution of stress in slab

Precompression enables concrete to carry transversely applied load over a **longer distance**

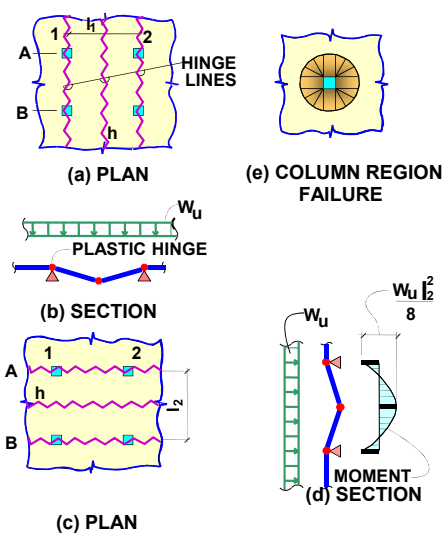


Tendon layout options



Failure modes of column-supported slabs

- ❖ Slabs fail along **hinge lines**
- ❖ Slabs do **not** collapse (fail) from **stresses** at a point



Preferred layout from **construction** standpoint for unbonded tendons is "**banded**" in one direction and **distributed** parallel in the other direction



Example of **banded-distributed** tendon layout in **USA**, using unbonded tendons

Bottom mesh is not common in USA

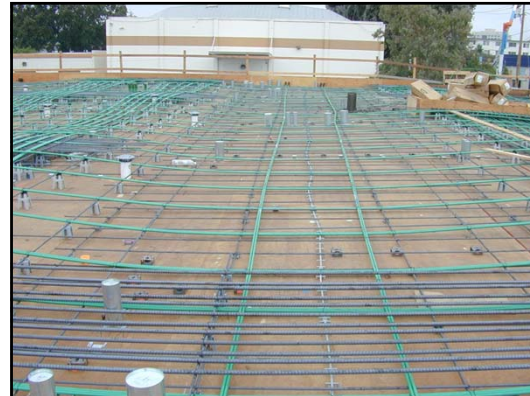
Preferred layout from construction standpoint for unbonded tendons is “banded” in one direction and distributed parallel in the other direction



Example of banded/distributed layout using unbonded tendon in Brazil

Bottom mesh is generally added for detailing

P1145



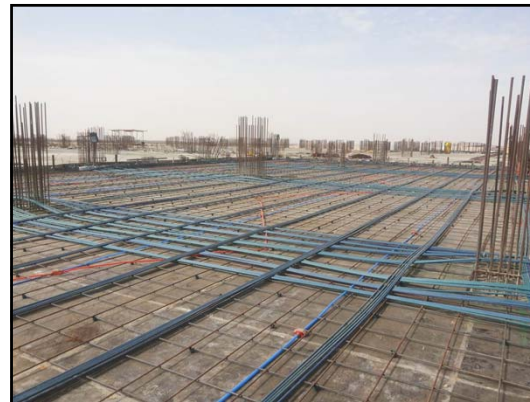
➤ Banded – Distributed tendon layout, using unbonded tendons

➤ The benefit of straight tendons at mid-depth between the bands is at best questionable



P1139

Close up of banded/distributed over column unbonded USA



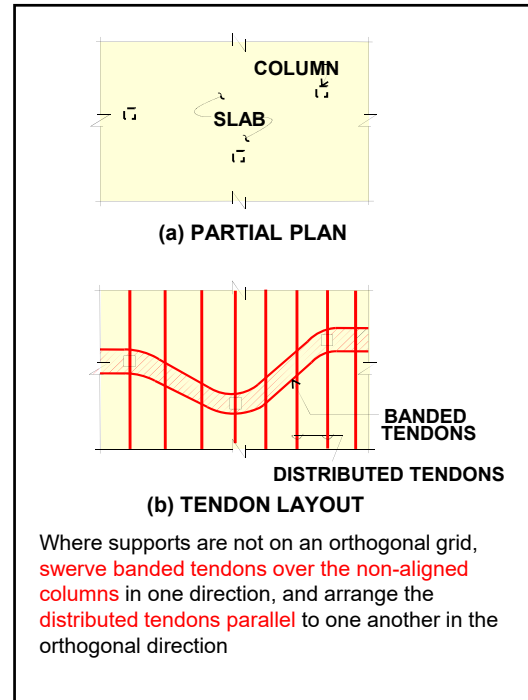
P1152

Banded – distributed tendon layout, using unbonded tendons in Egypt



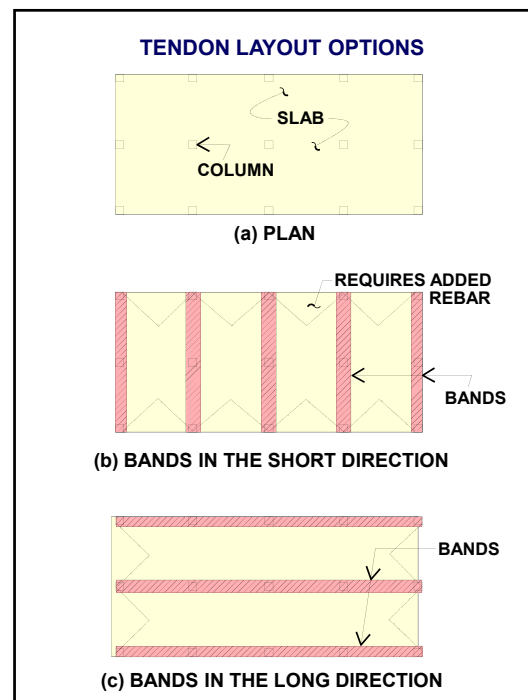
Banded-distributed layout using **grouted tendons** with **plastic ducts** – USA

No bottom mesh was used in this project

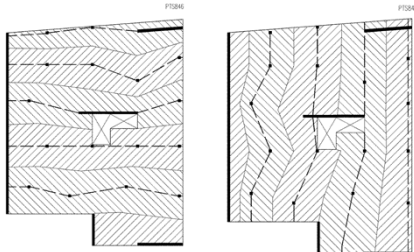


Band/distributed tendon layout using **grouted tendons** (Egypt). Each tendon holds one strand.

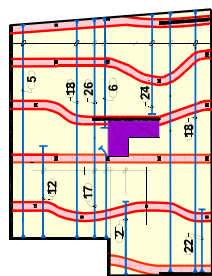
Bottom mesh is used as part of detailing



At design time follow the line of supports. When detailing, group tendons over the supports in one direction, and distributed tendons parallel in the orthogonal direction



Design



Detailing



- Swerve the bands over supports in one direction over non-aligned columns
- Place the distributed tendons parallel in the other direction



- Swerve the bands over supports in one direction over non-aligned columns
- Place the distributed tendon parallel in the other direction



Banded-banded distribution of tendons, Space between the bands is intended for inter-story access.

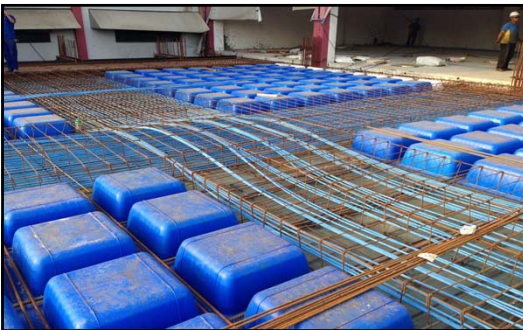
55 Hudson Yards – New York



- Banded-banded layout using unbonded tendons (Scandinavia)
- Voided inserts reduce selfweight of slab



- Distributed – distributed layout, using unbonded Tendon
- The arrangement requires weaving of tendons at installation



Banded – Banded distribution of tendon, using unbonded tendons and waffle slab (Brazil)



An unbonded and a bonded example of distributed-distributed tendon layout showing the weaving of tendons



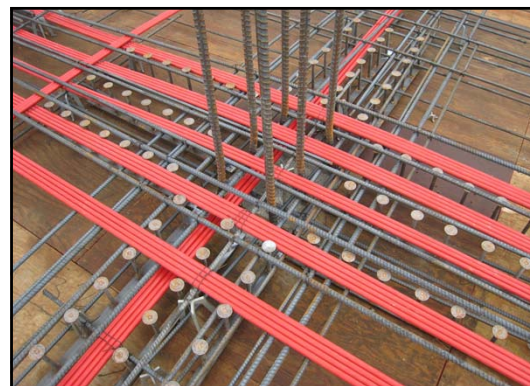
- **Joist slab** construction
- Tendons are grouped in one direction and placed in stem of the joists in the orthogonal direction



Construction with widely spaced tendons (Egypt)



Sparsely positioned tendons (bonded system; Morocco)



Integrity steel is required to mitigate progressive **collapse** resulting from failure of a slab panel

- **Either two tendons** in each direction shall pass through **column cage** and be anchored beyond the next column, **or**
- There shall be **continuous bottom bars** from one column to the next. These bars shall develop at the face of column



Integrity Steel

In this example, the tendon passing over the column helped to prevent the slab fall through the column (Northridge earthquake)



Tendon bundling

Limitation on grouping of tendons together is practiced for:

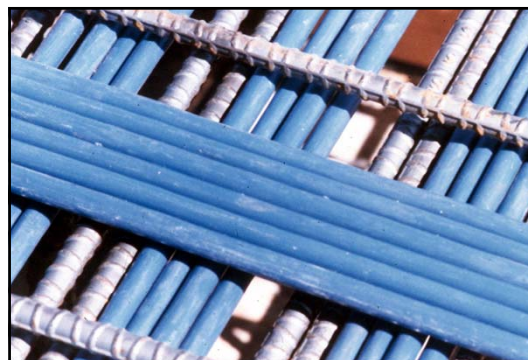
- proper **consolidation** of concrete; and
- to avoid **lamination** of the section

For unbonded tendons, ideally not more than 4 tendons are bundled



Integrity Steel

- In this example, the **congestion** of column bars does not allow the wide ducts of the grouted tendons to pass through the column cage
- Also, **continuous bottom bars** with the strength necessary to act as integrity steel from one column to the next are not present



Bundling of tendons

In this example, too many tendons are grouped together. Grouping of tendons, coupled with inadequate spacing between the reinforcement can lead to poor consolidation of concrete



Bundling of Tendons

Bundling of nine tendons in this construction can lead to **delamination** of concrete



Examples of closely bundled and adequately spaced grouted tendons

PTS875

Lamination from **bundled** tendons leading to crack formation on the top of slab with **change in elevation** between the two sides of the crack

The crack does **not** extend **through** the **depth** of the member

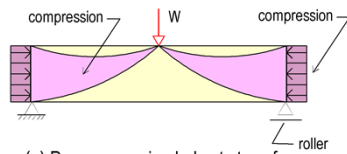
Tendon Spacing

(a) MAXIMUM SPACING OF DISTRIBUTED TENDONS

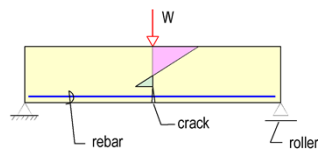
(b) MINIMUM SPACING BETWEEN BUNDLED TENDONS

- **Minimum** spacing is based on **placing** and **consolidation** of concrete
- **Maximum** spacing is based on transfer of **lateral loads** in the absence of other reinforcement

Precompression helps to carry transversely applied loads over **longer distance**



(a) Precompression helps to transfer lateral load



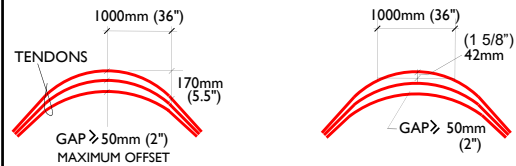
(b) Conventionally reinforced concrete; cracking mobilizes rebar

Distribution of Transverse Loads

PTS856

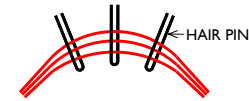
Tendon Curvature

At high and low points, where cover is least suggested for **unbonded 0.5" (13 mm)**



(a) LAYOUT OPTION 1

(b) LAYOUT OPTION 2



(c) PLACEMENT OF HAIR PINS

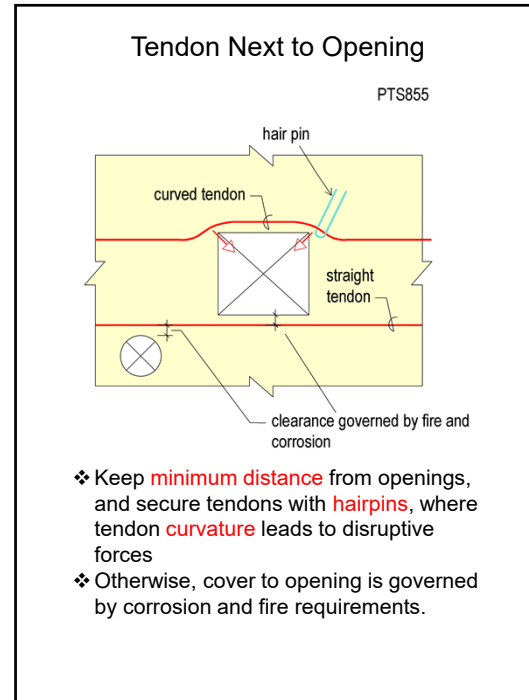
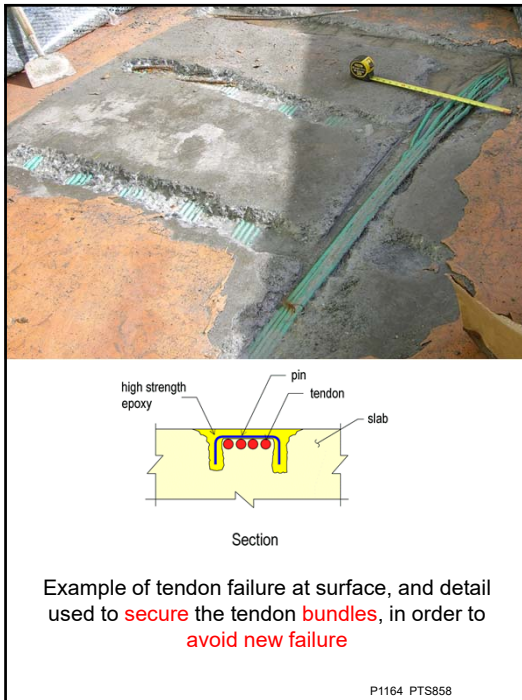
To avoid blowouts, at **high and low points where cover allows, place hairpins**. Otherwise
 ➤ **tendon curvature should be controlled**;
 ➤ Tendons should be **kept apart**; and not exceeding the **curvature shown**



In this construction, the design relies on the **contribution of non-prestressed reinforcement for distribution** of lateral loads. Hence, tendon spacing is not a critical design consideration.



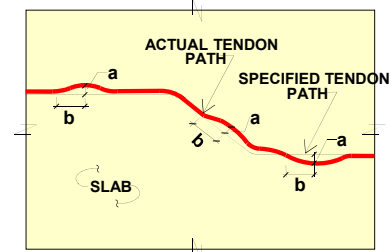
Lack of adequate spacing between tendons at high or low points can lead to local failure at moderate tendon curvature





In this detail **hairpins** restrain the tendon from causing blowout

Tolerance in tendon layout



- ❖ In plane of the slab tendons can be moved laterally to avoid obstructions, so long as (i) they are within the strip used for the slab design, and (ii) they keep their design geometry on plan
- ❖ **Wobbling** beyond that shown on plan, leads to friction losses in excess of commonly assumed in industry values
- ❖ $a/b \leq 1/12$



Looped tendon not adequately secured in plane of the slab slipped out of position at bottom of slab upon removal of forms.

3 Tendon profile

Primary contributions of post-tensioning tendons are:

- **Precompression**
- **Uplift** (lateral forces)

This results in

- **Added strength**
- **Reduced deflection**

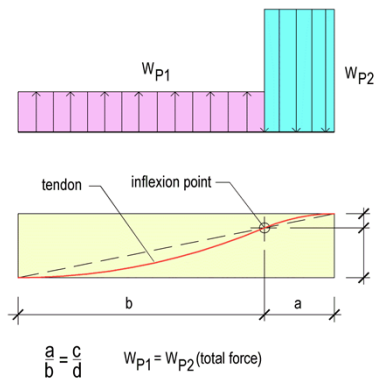
The optimum profile provides an uplift that best counteracts the effects of lateral forces (commonly gravity) .

The optimum profile from performance standpoint follows the **shape** of the bending **moment diagram** that the tendon is intended to counteract.

Since in most instances dead load moment is largest, the tendon profile is ideally selected to counteract the dead load of the member.

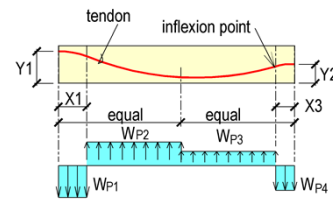
Due to **computational complexities** before the advent of computers, engineers selected tendon shapes that are segments of straight lines, or **parabolas**. These provide point or **uniformly** distributed loads that can be **readily analyzed**.

PTS315

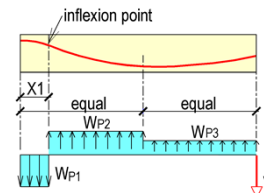


Geometry and force distribution of a half reversed parabola

PTS318

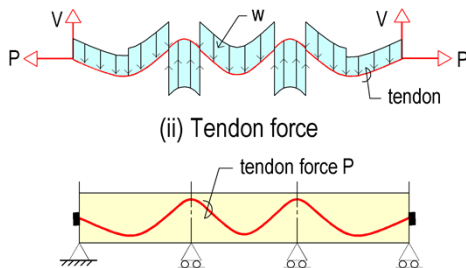


(a) Reversed parabola with two inflexion points



(b) Reversed parabola with one inflexion point

Two Examples for Tendon Profiles and Balanced Loads

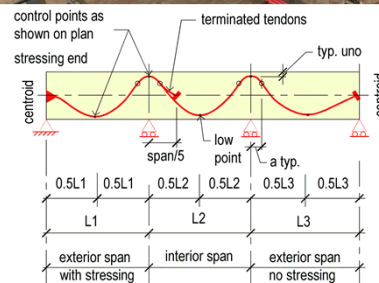


Tendon forces from reversed parabola shapes, with low points at mid-spans

Engineers commonly refer to tendon forces shown in (ii) as balanced loading Wp

Tendon forces are **always in static equilibrium**

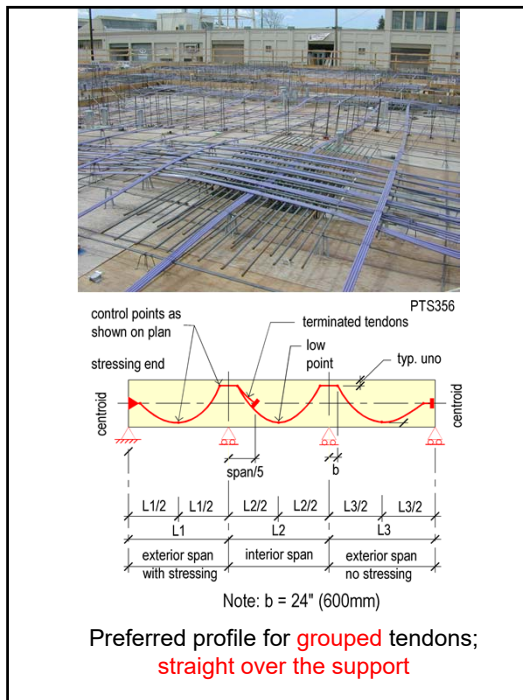
- Sum of **forces** in each direction is **zero**
- **Moment** of tendon forces about any point is **zero**



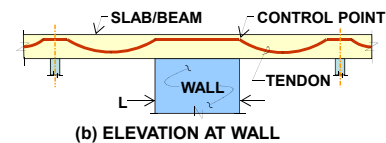
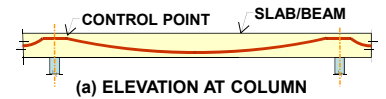
Notes: $a = 0.1 L$

PTS355

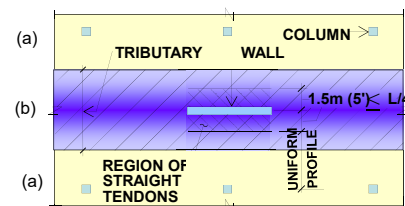
Preferred profile for **beams** and **distributed** tendons; **curved over the support**



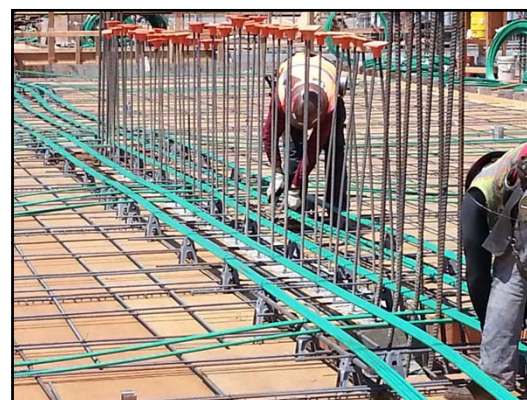
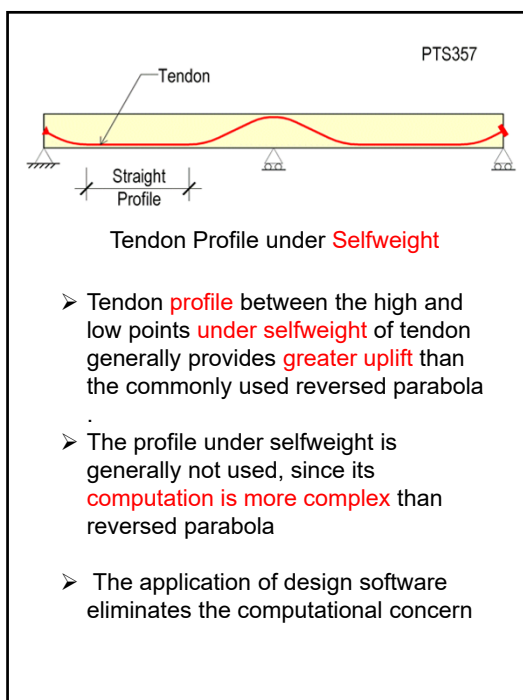
Tendon Layout Over and Adjacent to a Wall



Place tendon straight at **high point over the wall**

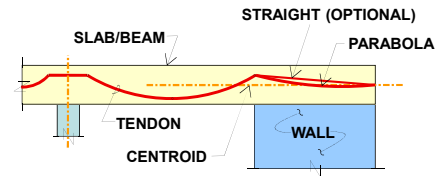


Partial plan: **Transition** the tendon profile from straight over the wall to the profile of the adjacent strip

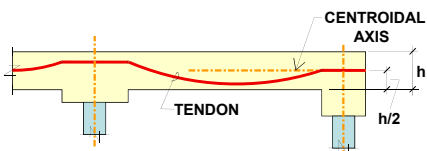


Lay tendons straight and high over interior walls (P1177)

Tendon Profile and Anchorage at Exterior Support



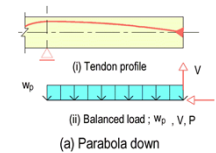
(a) SLAB/BEAM AND EXTERIOR WALL



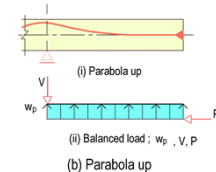
(b) ANCHORAGE AT EXTERIOR SUPPORT

Cantilever Tendon Profile

- Irrespective of the profile, the tendon moment at the support is equal to the tendon force times its eccentricity at support
- But, cantilever deflection depends on the tendon profile along the cantilever



(a) Parabola down



(b) Parabola up

PTS828

Cantilever Tendon Profile,
and its Balanced Loads

For the same tendon force, parabola down provides a larger upward deflection at cantilever tip



Tendon profile in ground-supported-slabs (SOG)

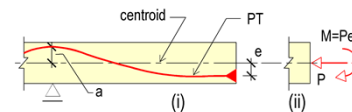
Place tendons straight at mid-depth

Refer to the following reference for details

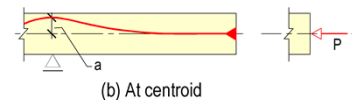
Aalami, B.O., (2015) "Post-Tensioning in Ground-Supported Slabs," PTI Journal, Post-Tensioning Institute, December 2015, pp. 5-16

The largest upward deflection is achieved, if tendon is straight and at the top of the cantilever. This is not always practical.

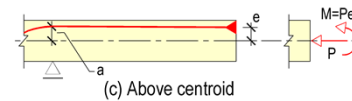
PTS825



(a) Below centroid



(b) At centroid

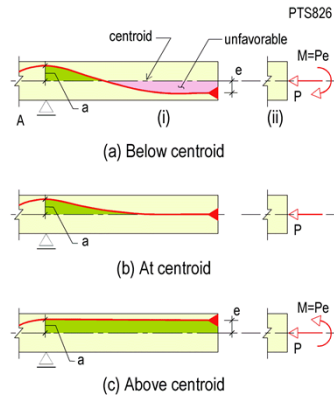


(c) Above centroid

In all cases moment at support $M=Pe$

Effects of Tendon Profile Options in
Cantilevers

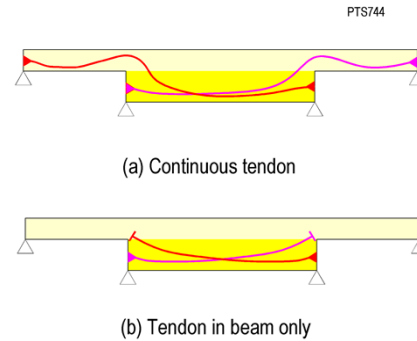
- Cantilever deflection is proportional to the “moment of the tendon's bending moment diagram about the support.”
- Profile shown in (c) provides the largest upward deflection



In all cases moment at support $M=Pa$

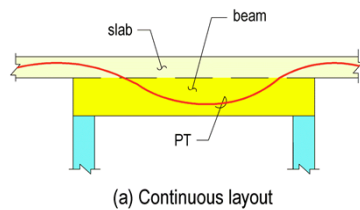
Favorable and Unfavorable Moment Areas for Upward Deflection

In beam and slab construction, where practical, stressing of beam tendons as shown in (b) is structurally more beneficial

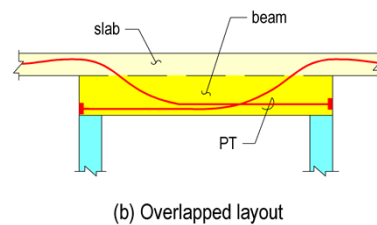


Arrangement Options for Beam and Slab Tendons

Beam and slab construction



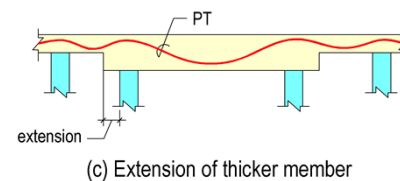
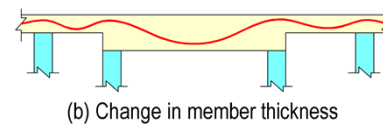
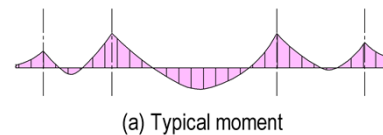
High position of tendon over the support leads to unfavorable moment at beam's midspan



Overlapped tendons improve midspan moments

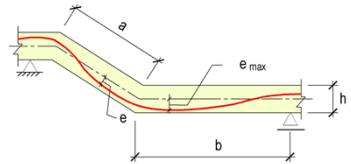
PTS821

At abrupt change in member thickness, it is beneficial to extend the thicker member beyond the support to better resist the moment transition from the thick to thin member

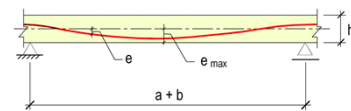


PTS822

Approximate modeling of ramps for design



(a) Prototype



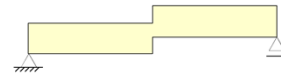
(b) Approximated model

- Model the ramp as a straight member of uniform thickness with adjusted length as shown in (b).
- Detail the tendon in the prototype (a) according to the eccentricities obtained from the analysis model in (b)

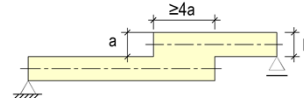
PTS818

Simplified structural modeling and construction of steps

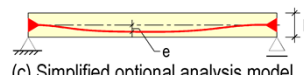
PTS829



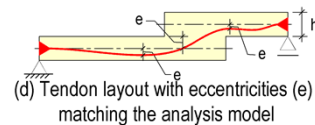
(a) Intended functional geometry



(b) Construction geometry



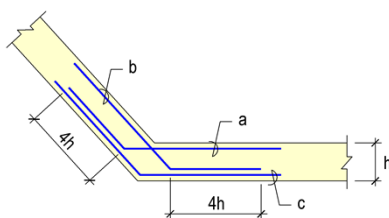
(c) Simplified optional analysis model



(d) Tendon layout with eccentricities (e) matching the analysis model

Approximate modeling of ramps for design

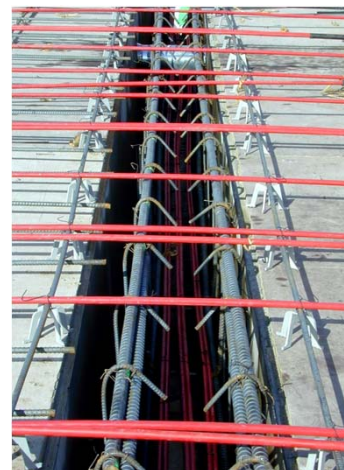
PTS819



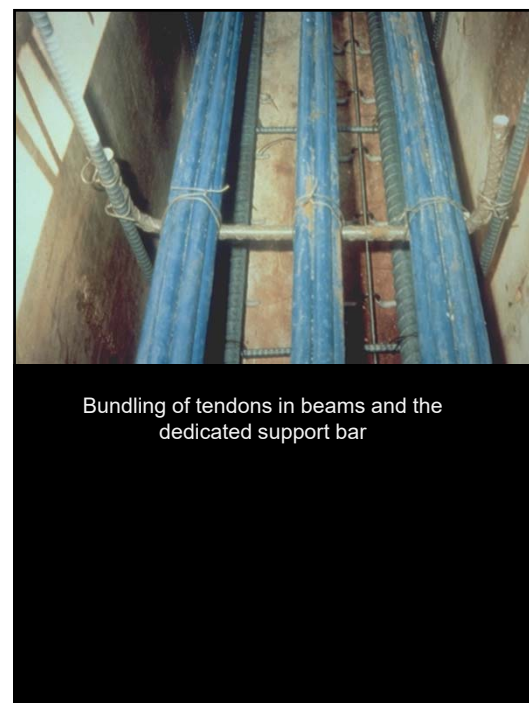
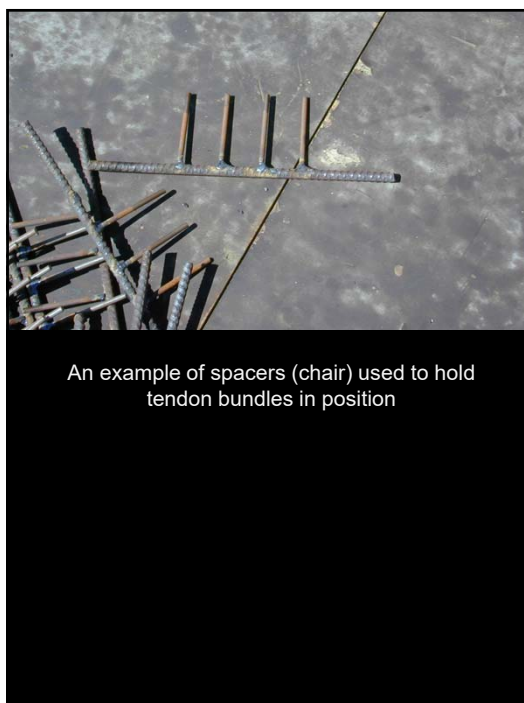
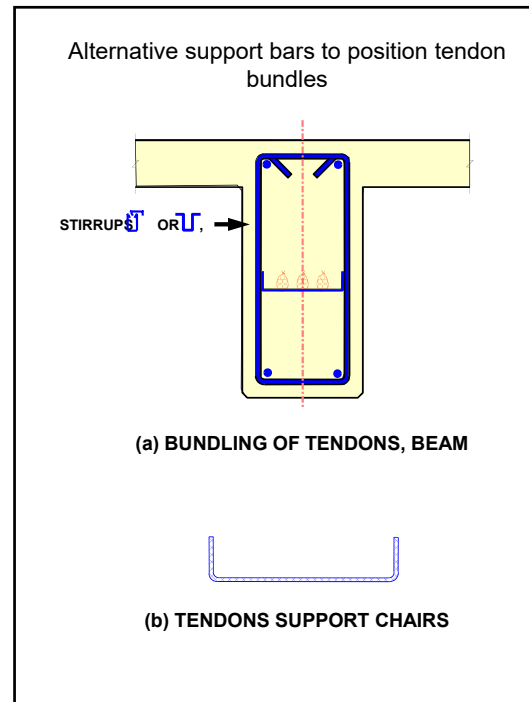
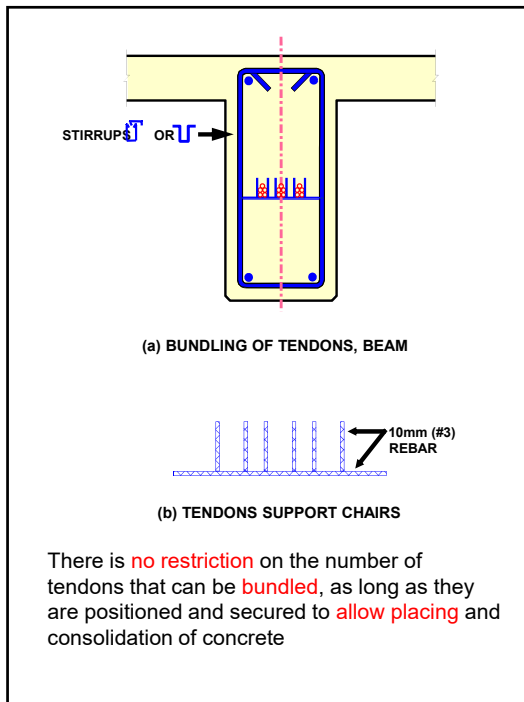
add 3#4 (12mm) bars per 0.5 inch (13mm) tendon
Added reinforcement at bent

Added Reinforcement at Angle Change
in Slab

4 Tendons in beams



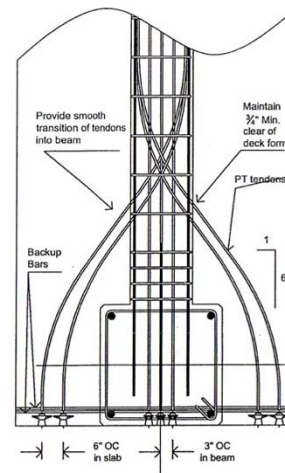
- Except where required for seismic detailing, or to resist torsion, open stirrups are used to facilitate tendon placing





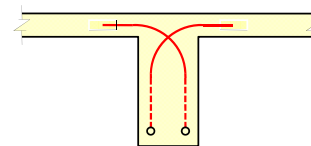
- In the above condition, use of multi-strand tendons is more practical.
- Multistrand tendons require hardware and stressing equipment that are different for single strand execution, and often not as readily available

- In flanged beam construction, often a number of tendons have to be raised and anchored in the slab, in order to maintain the resultant of the tendon force at, or near the centroid of the flanged beam geometry
- In exiting the beam stem, tendons should flip to the opposing side to avoid local rupture

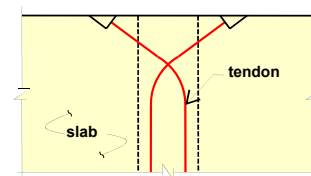


An example, where multi-strand bonded tendons are used in the beam and unbonded mono-strands in slab (P1168).

Profiling of beam tendons that are stressed at slab edge

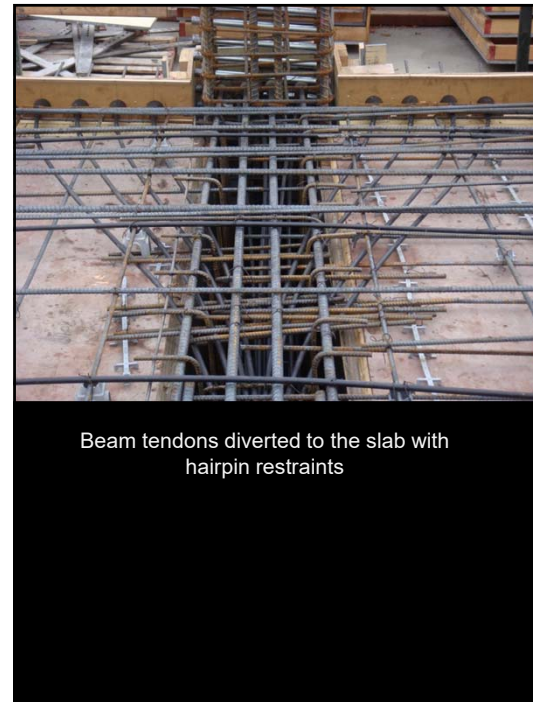
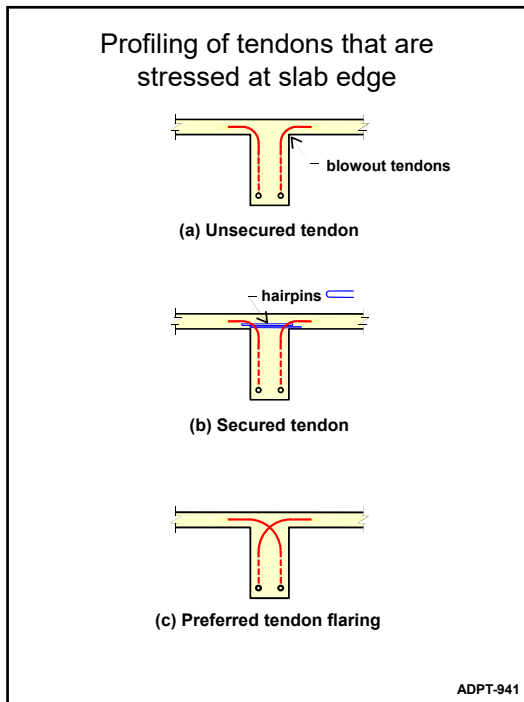


(a) Elevation



(b) Plan

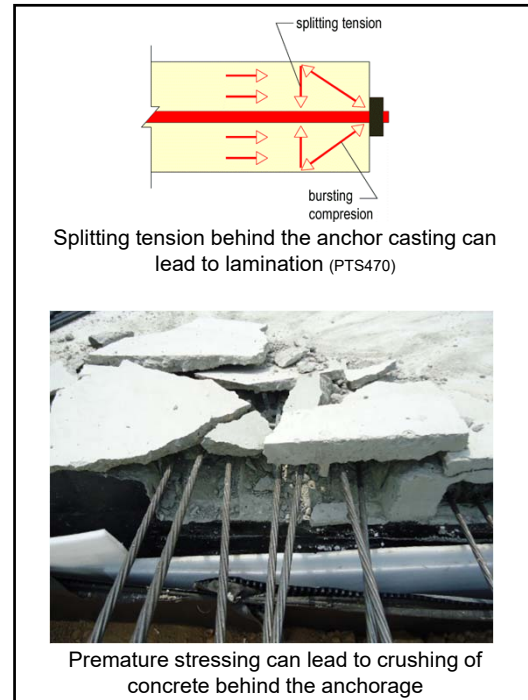
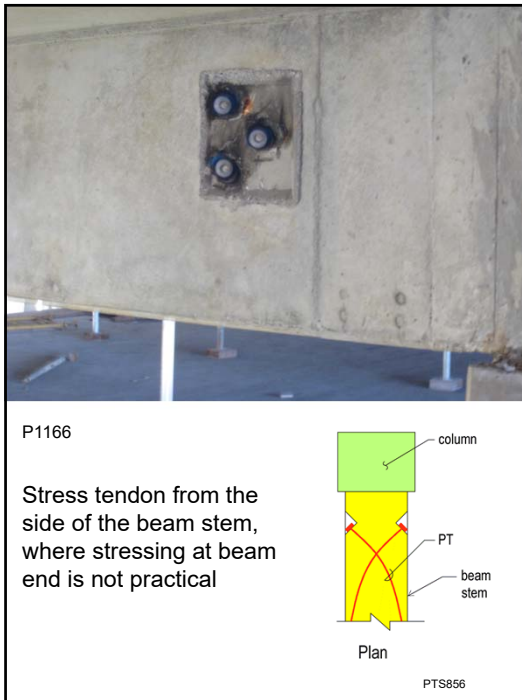
ADPT-940



- In exiting the beam stem, tendons from each side are **moved to the opposing face**.
- Hairpins help to prevent rupture of concrete



Beam tendon diverted into the slab without adequate restraint

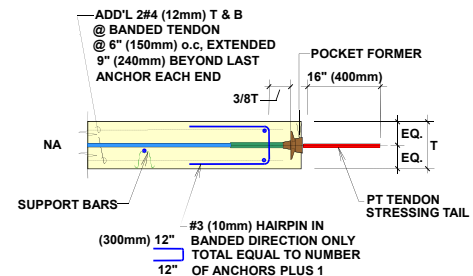


6 Stressing and dead end details

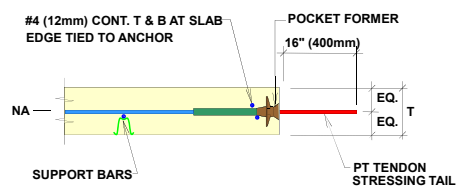
The stressing and dead end are detailed with the following **objectives**

- **Avoid crushing** of concrete behind the anchorage casting; and
- **Distribute** the tendon **pressure** behind the anchorage casting, such as to avoid excessive **splitting tension**, leading to cracking and lamination of concrete
- **Detailing** for unbonded and bonded construction are somewhat **different**, as illustrated in the following.

REINFORCEMENT AT TENDON ANCHORAGE



Stressing End Detail for **Grouped** Tendons



Stressing End Detail for **Distributed** Tendons



Arrangement of anti- bursting reinforcement at live ends of grouped tendons, prior to installation of tendons

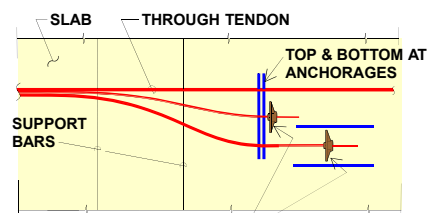


Stressing End Detail for Grouped Tendons



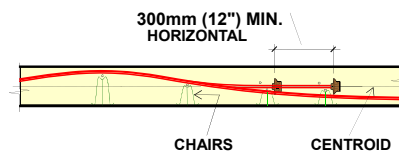
Hair pins and additional rebar recommended at ends of grouped tendons

Installation of Terminated Tendons



Fixed end anchorage staggered and placed horizontally
Place anti-bursting bars normal to anchor (shown on right)

(a) PLAN



(b) SECTION



Staggered dead end tendons and reinforcement.

Add reinforcement (not shown) in direction of tendon extending from the strand side to the back side of the anchorage block



Poor dead end detailing

- ✓ Dead ends are best staggered; and
- ✓ Provide rebar along the tendons extending on each side of the anchorage block



Improperly detailed dead ends

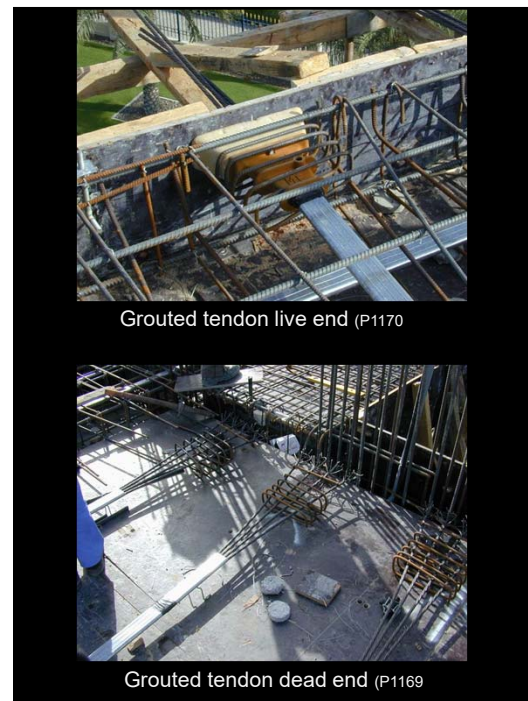
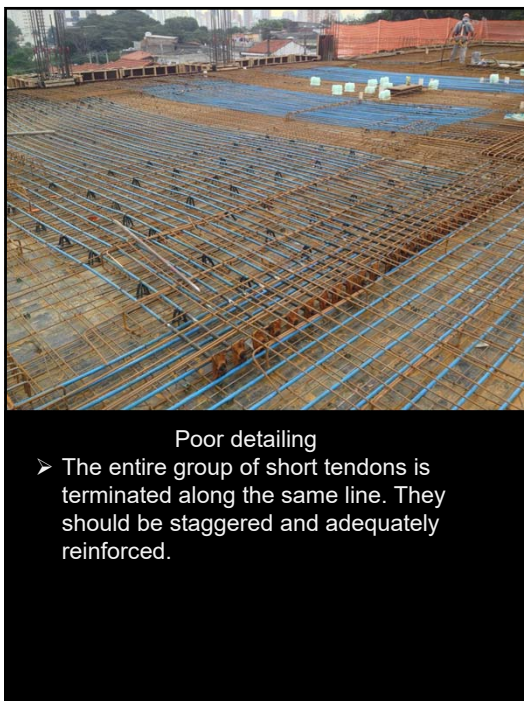
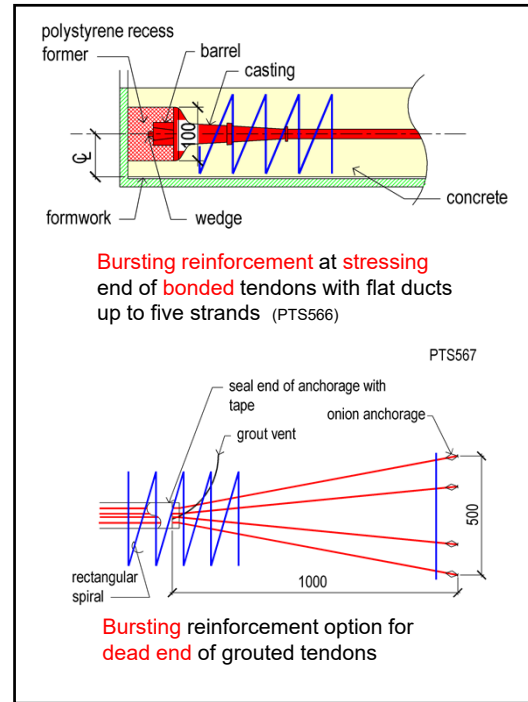
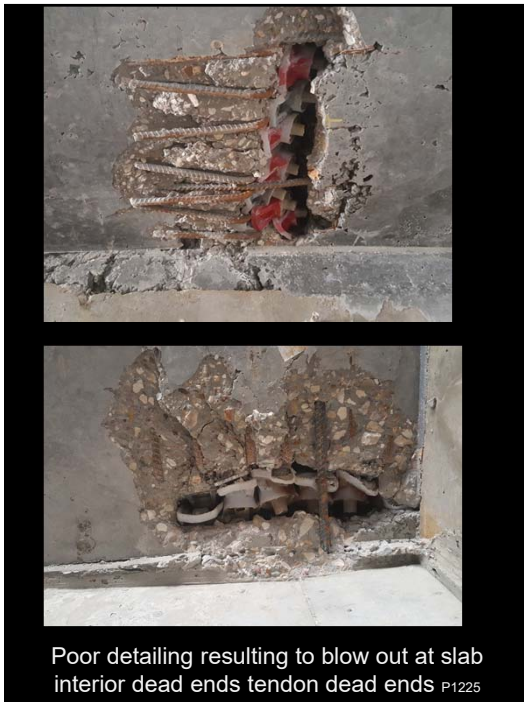
- At stressing the backside of the anchor blocks in this detail is likely to be subjected to over 50 tons of force from the five tendons, while concrete is not fully cured

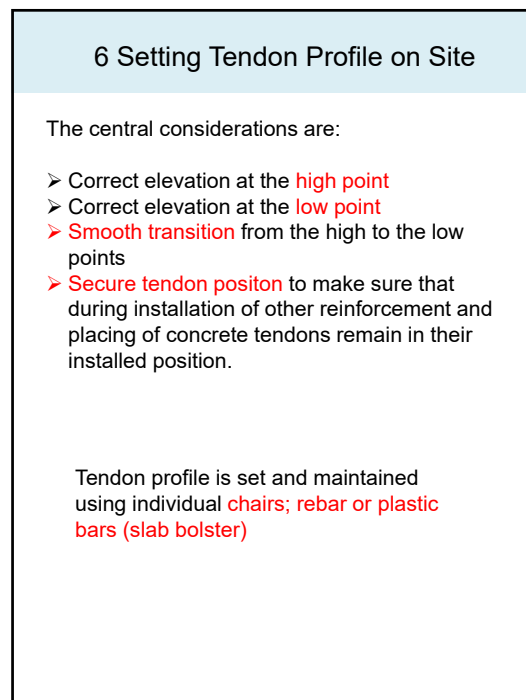
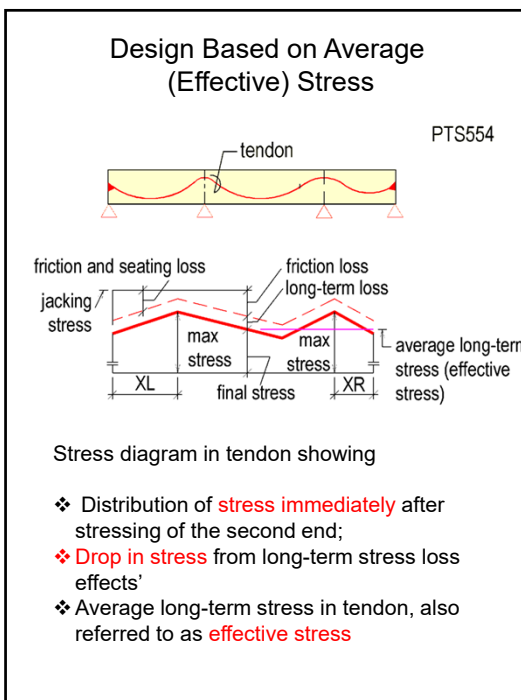
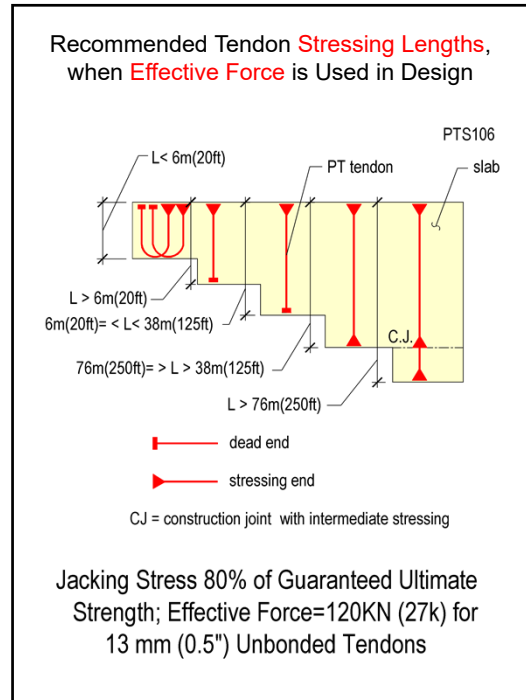
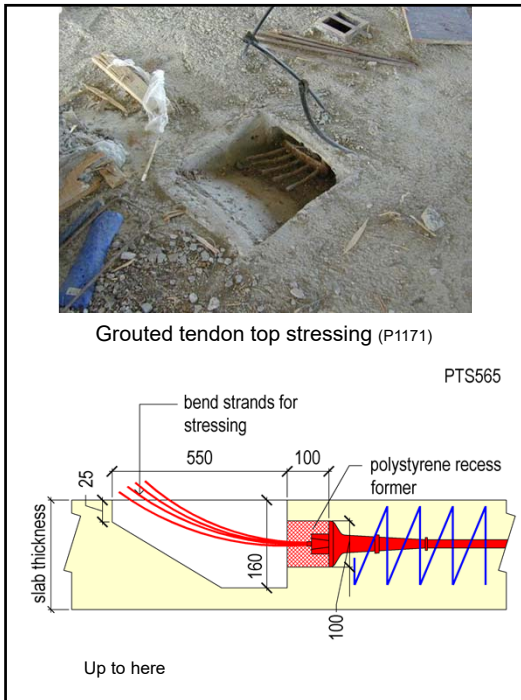


P1205

Crushing and failure of concrete at interior dead ends during stressing, due to inadequate anti-bursting reinforcement.

Rebar along the tendon straddling the anchor casting is missing







In this construction, **slab bolster at low point** (plastic strip at center of the view), combined with **chairs** and #4 (12 mm) **bars** set the profile of the distributed tendons in the left-right direction



Setting of tendon profile, using chairs of different heights and support bars over the chairs



Grooved plastic bars and chairs of different heights set the tendon profile



By **adjusting** the **distance** between the legs of the chair, the tendon height is set at the value marked on the tendon duct



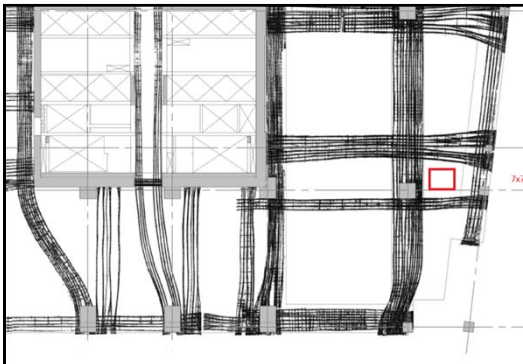
Marking of tendons at slab soffit

P1178

Detailing of Post-Tensioning and Rebar

Summary

- 1 – Distinguishing features of PT and RC slabs
- 2 – Tendon layout options and practice
- 3 – Tendon profiles
- 4 – Tendons in beams
- 5 – Stressing and dead end detailing
- 6 – Maintaining tendon profile in construction



- Using laser scanning, tendons are mapped prior to placing of concrete.
- The scanned images are then converted to drawings showing the position of tendons on plan

P1218



Thank you for listening

Questions?

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Bijan@PT-Structures.com

Hands-On Workshop

Friday 1 June

Florian Aalami

ADAPT

Structural Concrete Software

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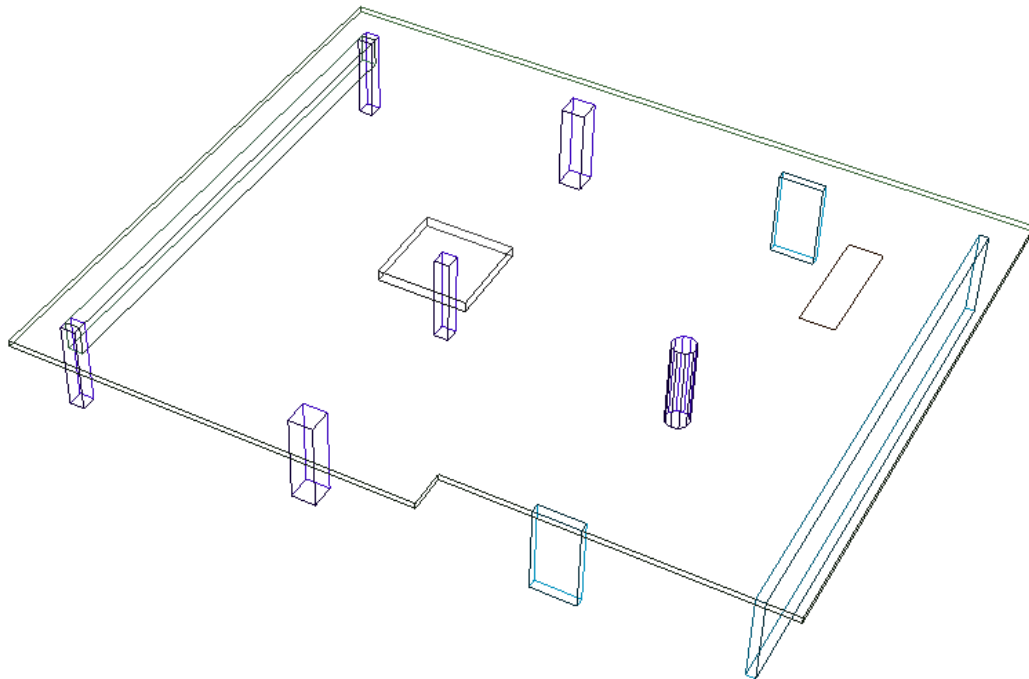
Hands-on Slab Design Workshop Manual

Reinforced Concrete and Post-Tensioned design of a Floor System

using



ADAPT-Builder Floor Pro® 2017.2 Software



Update:
March 2018

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DESIGN OF CONCRETE FLOOR SYSTEMS
using
ADAPT-Builder Design Suite

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OVERVIEW

This workshop/tutorial package is tailored to the needs of design engineers who are seeking to become familiar with the latest developments in design of concrete floor systems. In particular, the workshop covers in detail the process of designing reinforced concrete and post-tensioned floor systems using ADAPT-Builder Floor Pro software. Long regarded as a difficult engineering challenge, designing concrete floor systems is greatly simplified with ADAPT-Builder, which provides significant efficiencies throughout the design process.

This self-contained package includes all the programs, cad files, data and the documentation needed to get started with ADAPT-Builder. You can download a PDF version of this document and all supporting files at www.adaptsoft.com/workshop/slab-desing.zip. To supplement the information provided in this workshop manual, you can access technical notes on various design topics on our website.

The workshop is broken into several convenient sessions. When supervised, the entire workshop is likely to take five to six hours. If you plan to go over it on your own, the sessions are likely to take one hour on average.

This tutorial/workshop uses the following programs of the ADAPT-Builder Design Suite:

- ❖ ADAPT-Modeler® 2017.2
- ❖ ADAPT-Floor Pro® 2017.2
- ❖ ADAPT-Post-Tensioning (Shop) Fabrication Drawing Extension Module
- ❖ ADAPT-Edge 2017.2
- ❖ S-CONCRETE 12.x (requires separate license and will only be demonstrated by instructor)

The scope of the example is chosen such that you can use the 15-day evaluation version of ADAPT-Builder programs to run through the sessions of this workshop.

Contact ADAPT at info@adaptsoft.com if you need additional information.



INTRODUCTION

This tutorial walks you through the complete modeling, analysis, design and detailing of a reinforced concrete and post-tensioned floor system. It starts from the architect's drawings and concludes with the construction drawing, showing the tendons and the nonprestressed reinforcement. It also includes the automatic generation of a set of structural calculations, compiled and ready for submittal to building officials. A session on fabrication drawings (shop drawing; installation drawing) concludes with the generation of a detailed tendon layout on site, showing tendon grouping, chair heights and tendon elongation. For those of you interested in the economics of your design, the tutorial shows you how to obtain a report on the quantity of reinforcement and post-tensioning obtained in your design.

If you are not well versed in the design of post-tensioned structures, and hence not able to initiate the design with an economical selection of tendons for a finite element analysis, we recommend you use ADAPT-PT to carry out a preliminary design for this project. The ADAPT-PT software ships with several easy-to-follow tutorials that cover the design of beams, one-way and two-way slab systems. This tutorial provides some basic guidelines for the initial selection of a post-tensioned system.

The tutorial is broken down into a number of sessions, each intended to guide you through a specific aspect of design. The Tutorial CD has all the information you will need to complete each of the sessions, including the necessary program modules of the Builder software platform, the tutorial instructions, program manuals and technical notes of interest, and program utilities. The Builder platform programs included in the Tutorial CD are 15-day evaluation versions of ADAPT-Floor Pro and ADAPT-MAT. They are time limited versions of the fully functional commercial programs.

The floor system selected is small enough for you to complete all steps of this tutorial, and at the same time complex enough to contain enough of the essential features of a real floor system, such as walls, columns, beam, drop cap, and opening. Its overall dimensions are approximately 24.4x20m (80 x 65.75 ft). The project data comes in two systems of units, American and SI.

Both the SI and the American systems of units versions of the tutorials are based on the current ACI-318 and the International Building Code (IBC). The stress check in this tutorial is based on the allowable values of ACI-318, and IBC. However, the programs provided in your CD, allow you to change the design code. It is recommended that you follow the tutorials to the end, as provided in your CD, and then experiment with other design codes, if you so wish.

IMPORTANT NOTE:

In some Windows versions, the folders copied from a memory stick or downloaded will have "Read Only" attribute. To open and run the data you have copied, you must remove the "Read Only" attribute from the files you copied. Go to the appendix of this document if you need assistance to do so. If you do not remove the "Read Only" attribute, the tutorial programs will not function properly.



SUMMARY OF TUTORIAL SESSIONS

Session One

Generation of 3D Structural Model: Using the simplified DWG from your session folder and the Modeler module of the Builder platform, you will learn how to import the DWG drawing into the Builder program, and rapidly convert it into a complete 3D structural model.

Session Two

First Finite Element Method (FEM) Solution: The rational start for a FEM design is to validate the structural model you have created, before going into the details of design. In this session, you will validate the 3D model of Session One by:

- (i) meshing the structure;
- (ii) obtaining an FEM solution for the self weight of the structure; and
- (iii) viewing the solution to visually examine and verify its validity.

Session Three

Enter Design Criteria: In this session, you will enter all relevant design criteria into the model you created and re-validate the analysis results:

- (iv) material properties;
- (v) design codes;
- (vi) design preferences and
- (vii) loads / combinations.

Session Four

Design Slab with Mild Reinforcement Only: In this session, you will design the slab system using mild reinforcement only. First you will calculate all of the required reinforcement for the slab and then you will rationalize your design by specifying base reinforcement and re-designing. You will run a quantity takeoff report to establish the baseline reinforcement requirement for your project. Design steps include:

- (i) define support lines;
- (ii) generate design strips;
- (iii) design slab;
- (iv) generate rebar layout;
- (v) add base reinforcement and
- (vi) redesign considering base reinforcement.

Session Five

Design Slab with Post-Tensioning: This is the core session for the design of a post-tensioned floor system. You will be guided to layout tendons; review the design criteria; perform a code check; view stress results; and finally obtain the rebar necessary to supplement the post-tensioning you assumed. This session may require several design iterations.

Session Six

Generation of Structural Drawings – Rebar and PT: In this session, the rebar module of the program will be used to automatically generate the structural drawings for both the tendon layout and the nonprestressed reinforcement. You will learn how to adjust and optimize the calculated reinforcement in order to produce practical and constructible structural drawings.

Session Seven

Preparation of the Package of Structural Calculations: You will learn to automatically compile a professionally packaged report that contains the complete information on the details of the floor system, loading, criteria for design, analysis and design values, and the outcome of the code check.



Session Eight

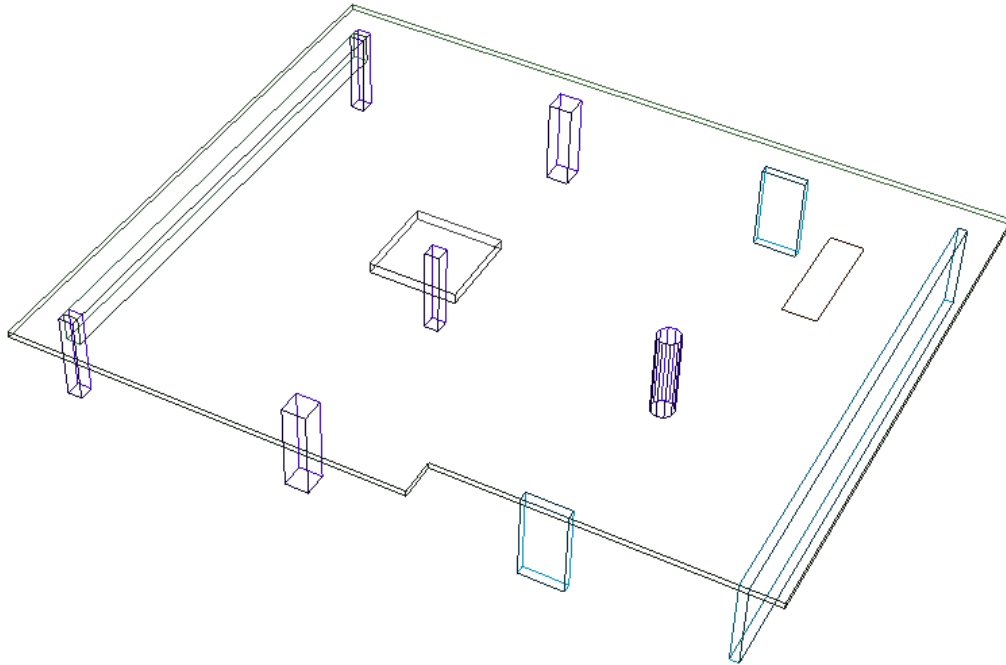
Fabrication (Installation, Shop) Drawings: Finally, for those of us involved in the generation of fabrication drawings, this session provides you with the skill to automatically create drawings that show chair heights for tendons and elongations, along with other information generally included in fabrication drawings.

DESIGN SCOPE AND CRITERIA

This outlines the criteria to be used for the structural engineering design of a typical floor system (Fig. 1) of the subject matter project.

The calculations performed for the post-tensioning design of the project are governed by the following considerations.

- The structural calculations are limited to gravity load design of the post-tensioned floor(s), and the transfer of the lateral forces through the floor system, provided the loads due to lateral forces are specified.
- The structural model for the design of the floor system includes the beams, balconies, slab depressions, and openings, if any. The floor will be modeled and analyzed with a story of columns and walls immediately below and above it, where applicable.



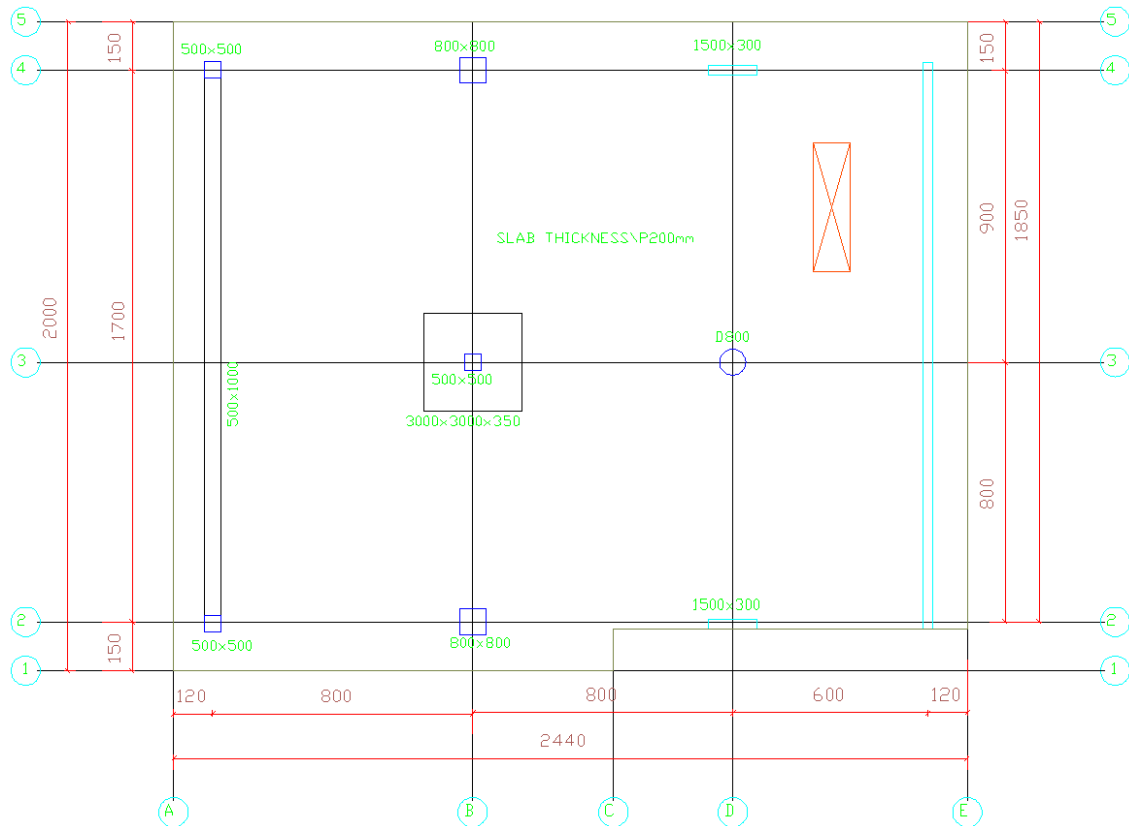


FIGURE 1 GENERAL STRUCTURAL PLAN OF TYPICAL FLOOR

DESIGN CONSIDERATIONS

Structural System

The structural system consists of both one-way and two-way, flat slab concrete floors, supported by beams, columns, and shear walls. The floor system will be post-tensioned in two orthogonal directions, unless noted otherwise. A drop panel provided over one of the central columns is used to mitigate excessive punching shear stresses. Post-tensioning tendons used are banded in one direction and distributed in the orthogonal direction.

The analysis can be based on the Equivalent Frame Method (EFM) or Finite Element Method (FEM) developed specifically for design of post-tensioned floor systems¹. The structural model of each floor includes the entire concrete outline and its supports. The non-prestressed concrete regions of each floor, if any, are included in the model and analysis. The connections of the slab to the columns and shear walls are considered fixed (capable of transferring moments), unless noted otherwise for released connections.

Applicable Codes

The design is based on ACI-318-2014. Where this code is mute, the recommendations of the International Building Code (IBC-2015) will be used.

Structural Documents

The calculations and structural drawings conclude with:

¹ ADAPT-PT (Equivalent Frame Method) software; ADAPT-FLOOR Pro (Finite Element Method); www.adaptsoft.com

Aalami, B. O. (2001) "Software for the Design of Concrete Buildings," American Concrete Institute, Concrete International Journal, December 29, 2001, pp. 28-35

- The total number of tendons, or the total of effective force required at each location;
- The profile of the tendons, including the low and high points, inflection points and overall shape;
- The overall layout of the tendons in the slab; and
- The mild reinforcing required over and above the post-tensioning tendons, at all locations on the slab.

MATERIAL PROPERTIES

Concrete:

Weight	= 2400kg/m ³
Cylinder Strength (f'_c) at 28 days	= 32 ² MPa
Modulus of Elasticity	= 25.4 kN/mm ²
Creep Coefficient	= 2

Post-Tensioning:

MATERIAL

Low Relaxation, seven wire strand	
Strand Diameter	= 12.7 mm nominal
Strand Area	= 98 mm ²
Modulus of Elasticity	= 200000 MPa
Guaranteed ultimate strength (f_{pu})	= 1860 Mpa
Average effective stress (f_{se})	= 1200 Mpa

SYSTEM

System	grouted
Maximum number of strands per tendon	= 5 (per anchorage device)
Duct width and depth	= 80x20 mm
Distance of duct centroid to centroid of strand	$z = 3$ mm

STRESSING

Angular friction	= 0.20
Wobble friction	= 0.007 rad/m
Jacking stress	= 0.80 f_{pu} = 1488 MPa
Seating loss (draw-in)	= 6 mm
Minimum concrete strength at stressing	= 14 MPa (cylinder)

Non-prestressed Reinforcement:

Yield Strength	= 460 MPa
Modulus of Elasticity	= 200000MPa

² Where cylinder strength is required, it is assume to be 0.8* f_{cu}

DESIGN LOADS

DEAD LOAD³

Typical Residential Levels:

Self weight	= based on volume
Superimposed dead load	= 2.0 kN/m ²
Total	= 2.0 kN/m ² + self weight

LIVE LOAD

Typical Residential Levels:

Uniformly Distributed ⁴	= 2.50 kN/m ²
------------------------------------	--------------------------

LOAD CASES; LOAD COMBINATIONS AND STRESSES

Strength Load Combinations

The strength requirement for each member is established using the following factored load combinations:

To resist dead load (DL) and live load (LL):
 $U = 1.20DL + 1.60LL + 1.00\text{Secondary}$

Where “secondary” consists of the hyperstatic moments, shears and reactions due to post-tensioning.

Serviceability Load combinations

- (i) Average Precompression: The post-tensioning design targets an average precompression in the post-tensioned members that is not less than 0.90 MPa and does not exceed 2.0 MPa. Higher values are permissible, but in general do not lead to economical designs.
- (ii) Final Stresses:

Maximum tensile stress

- Due to prestress plus sustained loads = $0.5 \sqrt{f_{ci}}$
- Due to prestress plus total loads = $0.5 \sqrt{f_{ci}}$

Maximum compressive stress

- Due to prestress plus sustained loads = $0.45 * f'_c$
- Due to prestress plus total loads = $0.60 * f'_c$

Load Combinations For Serviceability Check

“Total” in-service load combination (stress check):
 $U = 1.00DL + 1.00LL + 1.00\text{Prestressing}$

“Sustained” in-service load combination (stress check)

³ Perimeter walls and claddings will be supported by beams designed by the prime structural engineer

⁴ Live load is conservatively not reduced

$$U = 1.00DL + 0.30LL + 1.00\text{Prestressing}$$

Load combination for long-term deflection due to creep and shrinkage assuming total gross cross sectional properties of members without cracking:

$$UL = 3.00SW + 1.96DL + (1.44 \times 0.30)LL + 3.00\text{Prestressing}$$

Assumptions used to modify baseline creep and shrinkage factor of 2:

- DL is applied after 45 days
- LL is applied after 180 days
(Refer to Appendix B-TN 380)

Load combination for total long-term deflection due to long-term effects and the instantaneous action of live load:

$$UTL = UL + 0.70LL$$

Load combination for checking deflection under live load:

$$U = 1.00LL$$

(iv) Initial Stresses (Transfer):

$$\begin{aligned} \text{Maximum Tension} &= 0.25 \sqrt{f_{ci}} \\ \text{Maximum Compression} &= 0.60 * f'_c \end{aligned}$$

Load combination for stress check at transfer of prestressing:

$$U = 1.00\text{Selfweight} + 1.15\text{Prestressing}$$

DEFLECTION AND CAMBER

Deflections

Having maintained the hypothetical tensile stresses within the limits stated in the preceding, the deflections will be calculated assuming gross cross-sectional properties. Long-term deflections are estimated using a baseline creep coefficient of 2 for loads immediately applied to a member after casting and reduced appropriately for loads applied later in time.

For the floor slabs and beams the maximum deflections are maintained below the following values with the understanding that the floor structure is not attached to nonstructural elements likely to be damaged by large deflections of the floor:

MEMBER	TOTAL LONG-TERM*	LIVE LOAD
SLABS	L/250	L/360
BEAMS	L/250	L/360

*Due to self-weight and superimposed dead load, and prestressing.
L = length of clear span.

Camber

Camber will be specified for spans equal to less than 10 m, where maximum long-term deflection due to total dead load exceeds span/500, or 20 mm, whichever is less.



COVER

Nonprestressed Reinforcement - Slab	
Cover to top bars (enclosed areas)	= 25 mm
Cover to bottom bars (enclosed areas)	= 25 mm
Cover to top bars (exposed area)	= 45 mm
Cover to bottom bars(exposed areas)	= 45 mm
Prestressed Ducts – in Slab	
Top cover	= 25 mm
Bottom cover	
Interior spans	= 25 mm
Exterior spans	= 25 mm

TENDON PROFILE AND LAYOUT

Tendon Profiles

Interior spans	= reversed parabola with inflection point ratio of 0.1
Exterior spans	
With no cantilever	= low point at center; exterior half simple parabola; interior half reversed parabola with inflection point at 0.1 ratio
With cantilever	= same as interior span
Cantilevers	= single simple parabola with center of curvature at bottom

Tendon Layout

Banded (grouped) in one direction and distributed in the other direction.

Horizontal deviation of rigid ducts limited to 1 in 5 (10 degrees)

SESSION (1) – Generation of 3D Structural Model

The steps to follow for the generation of a 3D structural model of the floor system are compiled in this session.

Launch ADAPT-Builder in Floor Pro and PT Design Mode

To begin this session, launch the ADAPT-Builder software by double clicking on its desktop icon . Once clicked, and if either an evaluation or valid commercial license is available on your computer, you will see the initial configuration screen as shown in **Figure 1-1**. Make sure to select all software options as shown in the figure and your desired system of units.



FIGURE 1-1 ADAPT-BUILDER CONFIGURATION SCREEN

Review of ADAPT-Builder User Interface

Figure 1-2 shows the full-screen display of the ADAPT-Modeler program.

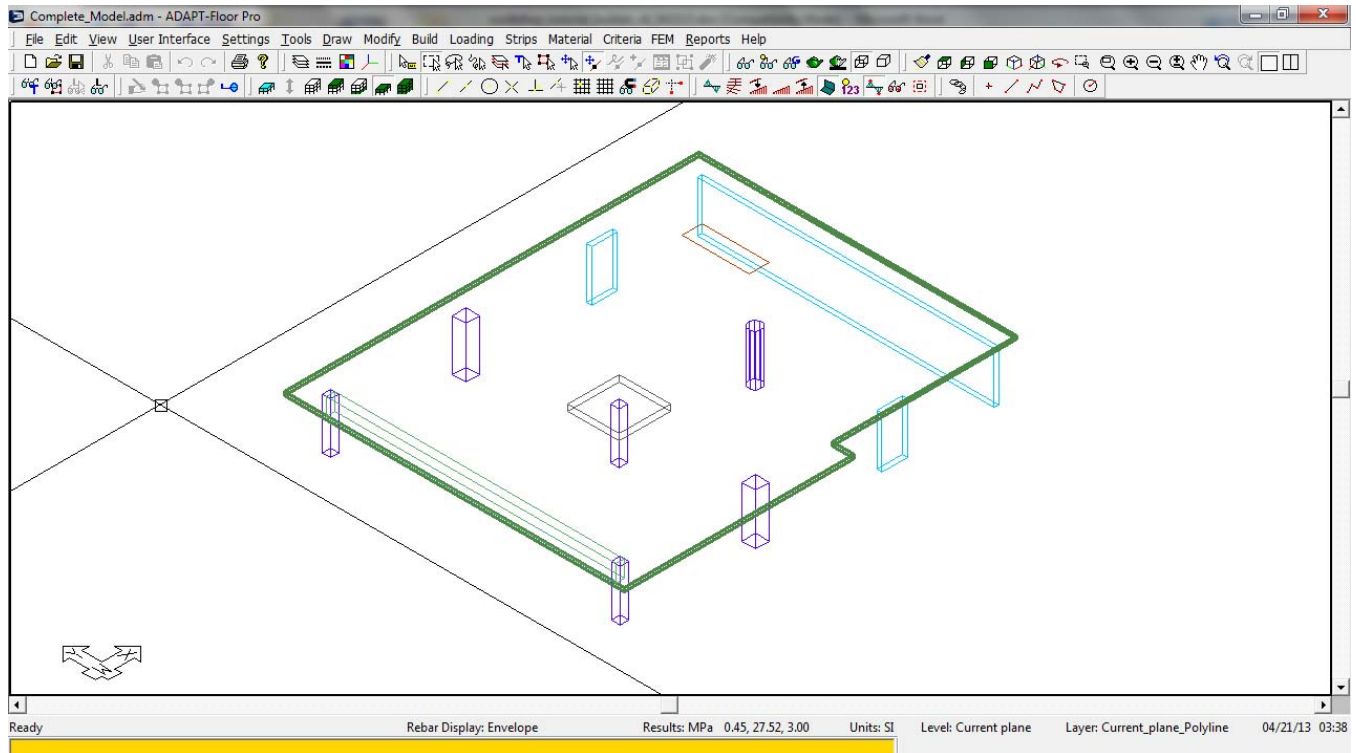


FIGURE 1-2: ADAPT-BUILDER USER INTERFACE

ADAPT-Builder operates the same way as other Windows programs. All program tools are accessed from one of the toolbars provided by the program or through the menus provided in the menu bar at the top of the screen. Toolbars may be opened, closed, “docked” to the edge of the screen or dragged to any position on the screen as View menu item. Tools can also be accessed by clicking the right mouse button while the cursor is in the Menu Bar or Toolbar areas of the screen.

The *User Information Bar* that is found at the bottom of the screen displays tool-specific information and any coordinate values that may be typed by the user for specific program procedures.

The *Status Bar* that is found right above the User Information Bar displays such information as the mouse cursor coordinates, current unit system, snapping status, and gridline spacing and status. A short description of each specific tool also appears in this area when the mouse cursor is placed over the corresponding tool button.

Mouse Function and Operation

The primary function of the mouse is through its left-click. Depending on the mode of the program, as outlined in the next section, the left-click will result in selecting the entity below the cursor, inserting an entity or performing an operation at the location of the cursor.

How to Abandon an Operation

To abandon an operation you have already started, such as drawing a polygon, press the *Esc* key or right-click and select Exit.

Main Menu

The items appearing on the Main Menu depend on the configuration of the program. The common menu items to all programs are as follows: File; Edit; View; etc.

Selection Toolbar



This toolbar contains all tools related to selecting specific elements, objects and structural components in the model. Each tool is described below.

 **Hint Mode.** When activated, the arrow displays the identification of the entities to which it points. In this mode you cannot select an entity by clicking on it.

 **Window Selection.** When this tool is highlighted, the *Pick/Select* mode is active. You can select an entity by clicking on it, or a group of entities by opening a window around the items while the left mouse key is held down.

Double-clicking on an entity opens its properties dialog box.

 **Lasso Selection.** This tool allows you to draw an arbitrary polygon around a series of entities. When the lasso is closed, all entities located within or along the lasso perimeter are selected. To use this tool, do the following:

Click on the *Lasso Selection*  tool.

Draw segments of the polygon around the entities to be selected.

Press C to close the lasso. The entities inside the lasso are selected automatically.

 **Path Selection.** With this tool you can select entities by drawing a polyline through them. To use this tool, do the following:

1. Click on the *Path Selection*  tool.
2. Draw polyline through the entities to be selected.
3. Press C to end the line. The entities through which the line passes will be selected automatically.

 **Select All.** This tool selects all the entities visible on the screen.

 **Move Selection.** This tool enables you to move the entire group of entities that are currently selected. Pick a vertex of one of the entities in the selection and drag the entire group to the new location

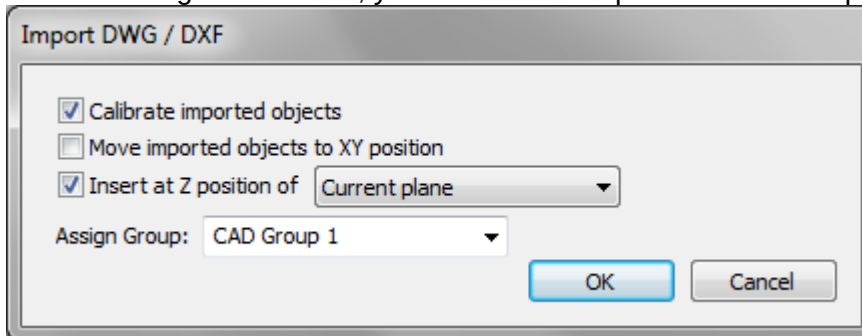
 **Move Selected Point.** With this tool you can move only the vertex of an entity to a new location, while the positions of the remainder of the entity's vertices remain unchanged.

Generate 3D Structural Model

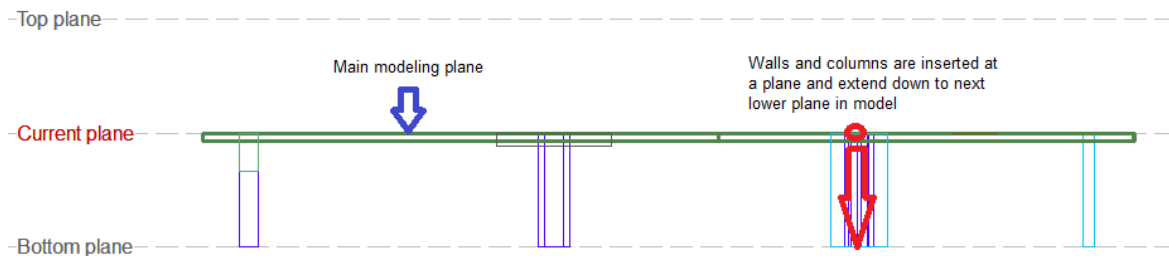
At this step, the simplified architect's drawing will be imported to the Builder program and converted to structural model. Follow the steps below:

Import and Calibrate Drawing

- ADAPT-Builder should be open in the configuration as described in the previous section.
- From File pull down menu select File/Import/ DXF/DWG
- Open the “Structural_dimensions.dwg” from the Session_1 folder.
- After selecting the CAD file, you will see the Import DWG/DWF options window.



Select the option to calibrate imported objects. This option will allow you to calibrate the imported CAD objects without affecting the scale of any other objects already created in your model file. Also select to insert the imported CAD objects at the Z position of Current plane; this is where you will model your slab. All models are defaulted to include 3 planes: Bottom, Current and Top.



- Calibrate the drawing using the 24.40m (80 ft) distance shown on the bottom. Before calibration, select snap to intersection.



Click on the dimension line and then enter 24.4 when prompted in the User Information Bar.

Enter the correct distance in meters between the two Points you Selected.

- The imported CAD files may shift off of your screen when you complete the calibration step. Use the View/Zoom/Extents function  to re-center the model on your screen.
- If you make a mistake, you can re-calibrate the model or change the project origin using the functions found under the Tools menu.

Configure CAD Transformation Rules for Columns

- Newly introduced in Builder 2015, columns can now be managed more efficiently using Design Groups. In its default mode, the program creates new Design Groups for columns when they are converted from imported CAD objects. It is good practice to review the conversion settings and adjust them to your preferences.
- To access the transformation rules (Type Assignment properties), open the Design Group Manager by selecting the Build/Design Group menu option. This will open the window shown in **Figure 1-3**.

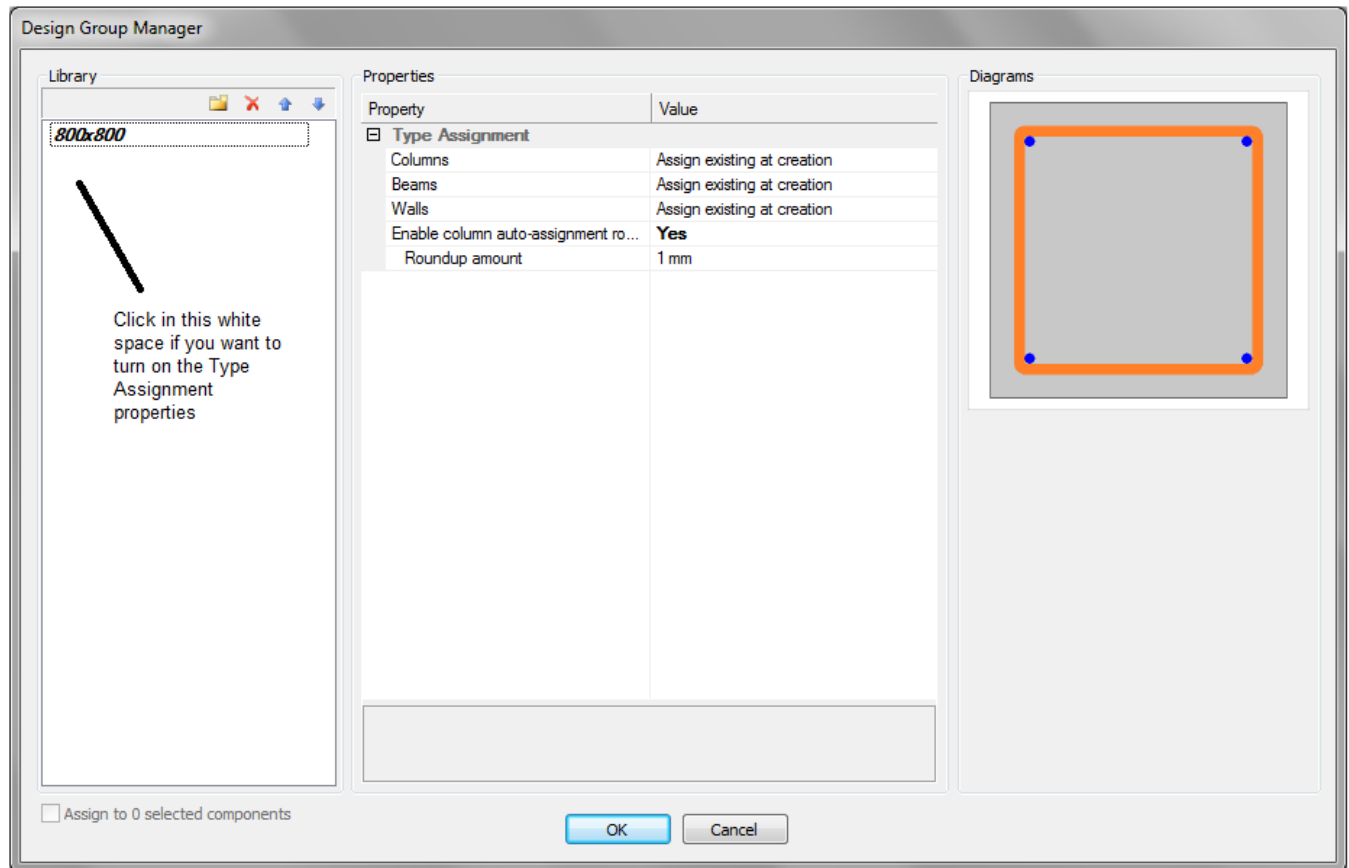


FIGURE 1-3 DESIGN GROUP MANAGER

- Your options for type assignment of columns include:
 - Assign existing at creation
 - Assign new at creation
 - Do not assign types
- Select *Assign existing at creation*. Note that grouping of columns into the same group is done by geometry only.
- Set *Enable columns auto assignment round off* to Yes and select a roundup amount. For example, this setting will round up imported CAD polygons that may be 399mm x 599mm to 400mm x 600mm.

Isolate Selected Layers and Transform Columns

- All software functions are accessible from the pulldown menu options. However, if you prefer to have frequently used functions available on floating toolbars, you can select and activate them from the User Interface drop down menu (or right-click on the top menu). The primary modeling functions are available on these toolbars:
 - Transform To Structural Component Toolbar* for converting graphical entities into Structural Components.

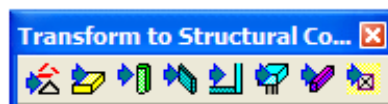


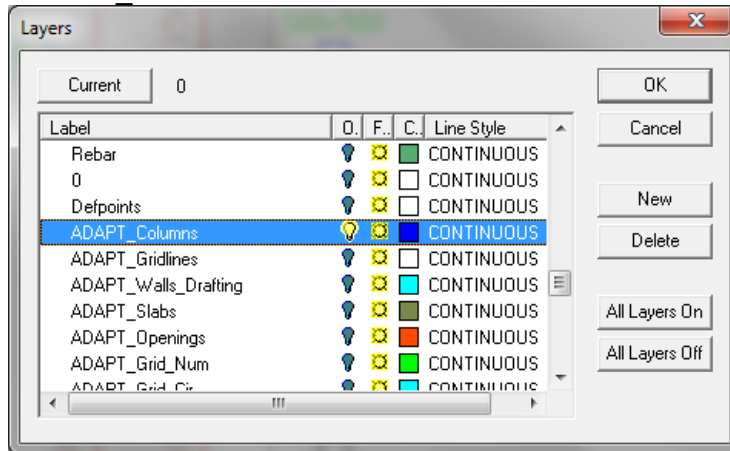
FIGURE 1-4 TRANSFORM TO STRUCTURAL COMPONENT TOOLBAR

- o *Build Toolbar* for creating Structural Components.



FIGURE 1-5 BUILD TOOLBAR

- Open the layers dialog window and turn all the layers off, except the layer "ADAPT_COLUMNS."



- Select Top-Front-Right-View for better viewing.
- Select all.
- Under the Build/Transform Drawing Entities menu, click on "Transform Column .

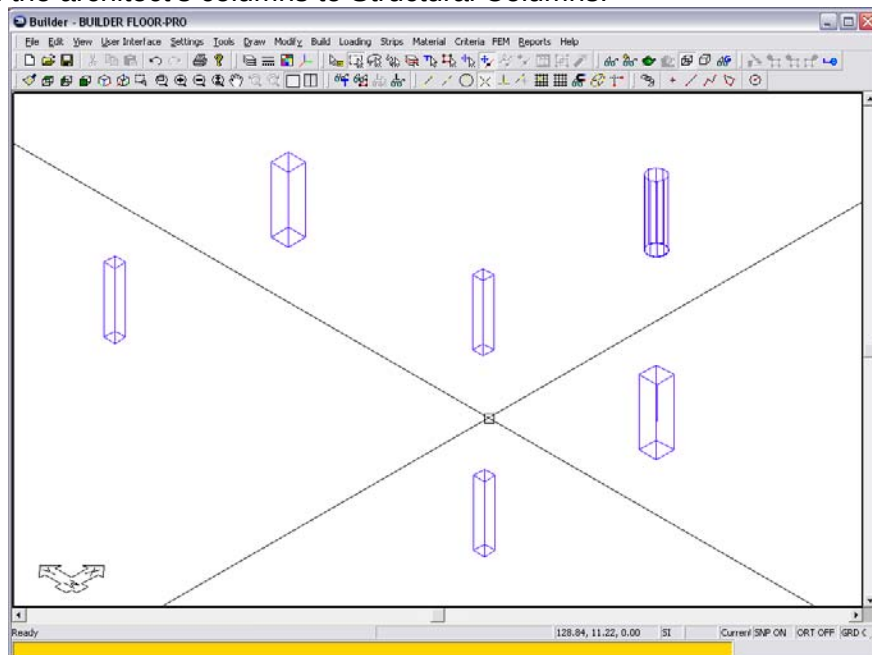
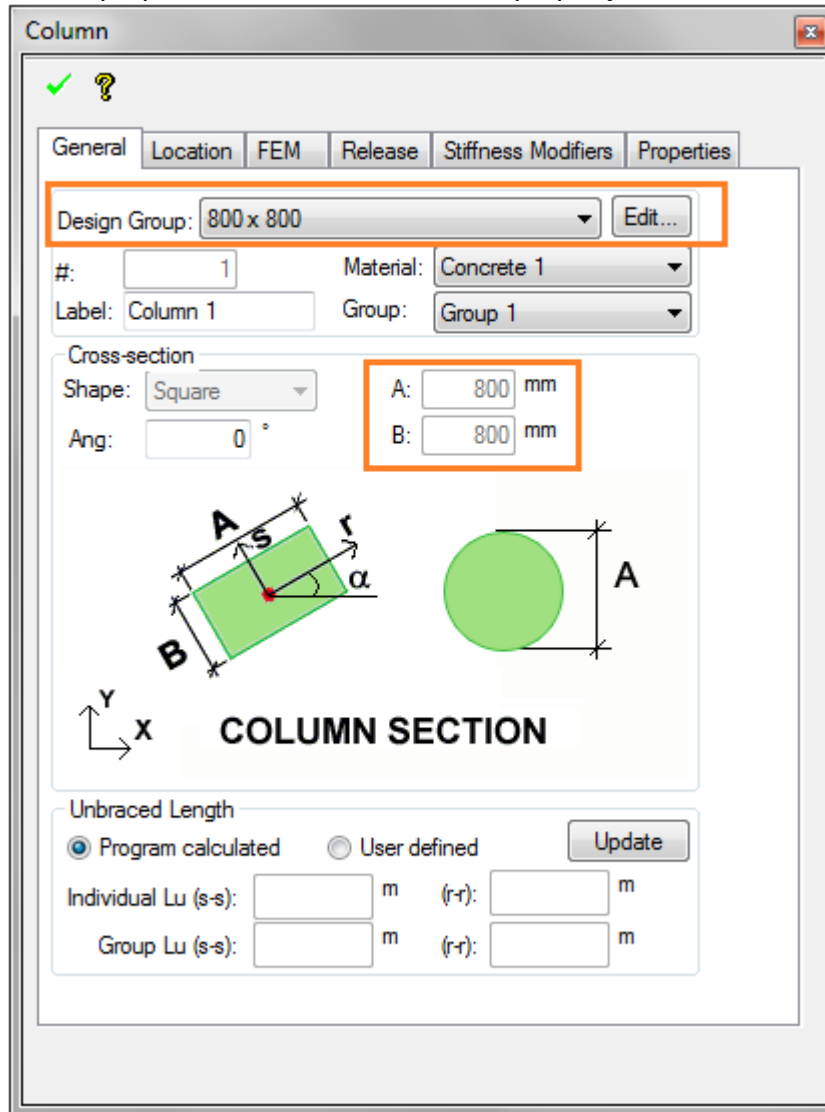


FIGURE 1-6 VIEW OF TRANSFORMED COLUMNS

- Double click on one of the columns to open up its property box. Observe the dimensions of the column for verification. Figure 1-6 shows what your columns should look like. You can also access any selected component's properties by clicking the icon. The image shows a sample column property window where the cross-sectional dimensions are being managed by a

Design Group. You must edit the Design Group to change the column's dimensions. Removing the association between a column and a specific design group will revert the management of the cross-sectional properties back to the column's property window.



NOTE:

You may have wrongly calibrated your model if you cannot see extruded columns after completing the "Transform Column" function and viewing the model in Top-Right-Front-View perspective.

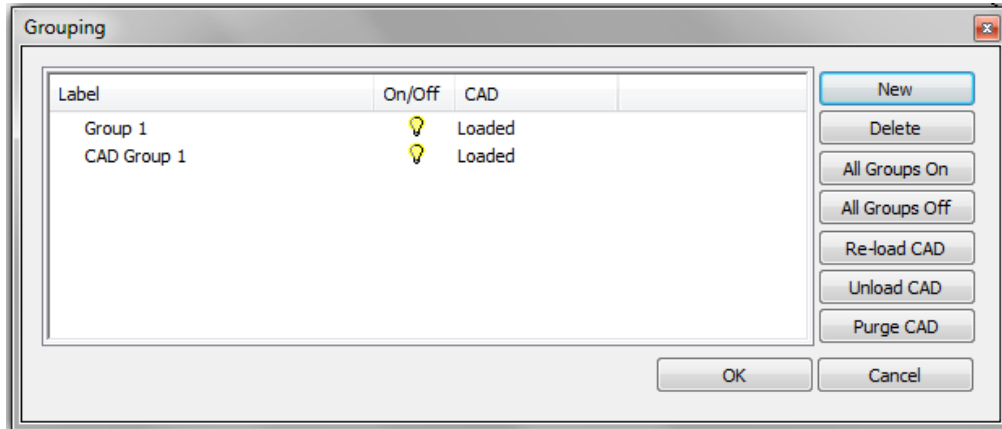
Transform Remaining CAD Objects into Structural Components

- Repeat the same steps for other components: Slab, Walls, Beams, Drop Caps and Openings.

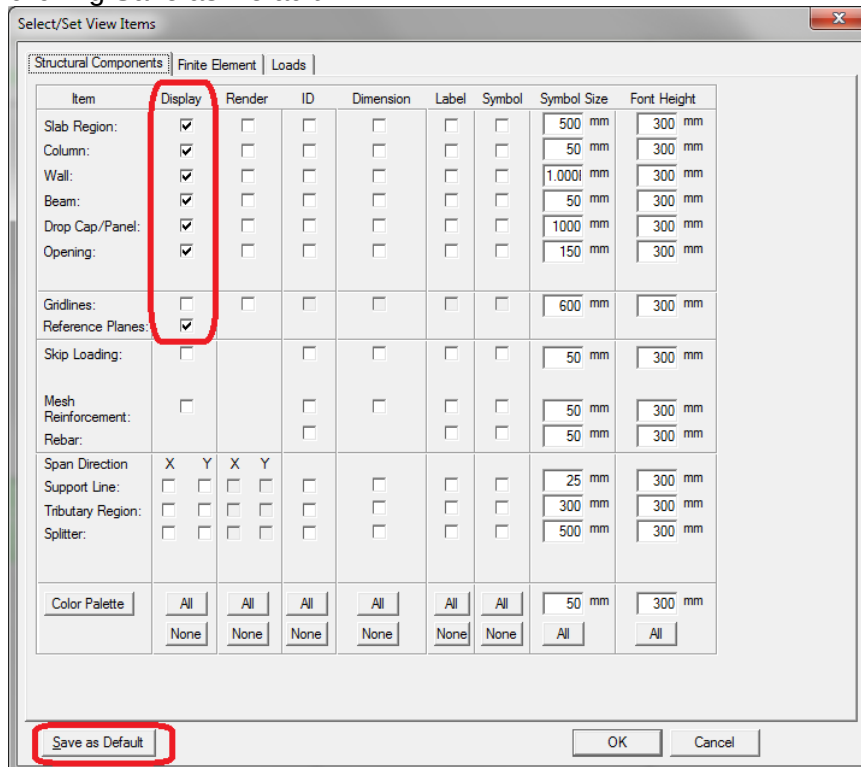
Controlling Visibility of Components in your Model

- It is recommended to turn off all imported CAD elements in your model after you have transformed them into structural components. This avoids any accidental snapping to CAD elements instead of structural components when working in your model.
- One option of managing the visibility of the imported CAD objects is through the Grouping window. When importing CAD objects, you are given the chance to associate imported CAD objects to their own group. The default group for imported CAD objects is *CAD Group 1*. To easily turn on/off the visibility of the imported CAD objects associated with a group, use the

Grouping  function that is accessible under the Settings menu. An image of the Grouping window is shown below.



- As an alternative, you can turn off CAD elements layer by layer using the Layers Setting  window. Using layers, you must turn all layers off. Turning all layers off will also turn off any structural components you created.
- Visibility of structural components is managed through the Select/Set View Items window .
- Open the View Items window and set a Default Item View as shown below. Our default item view for this workshop will only display primary structural components and reference planes. Go to the Finite Element and Load tabs and deselect any items that may be selected there before clicking Save as Default.



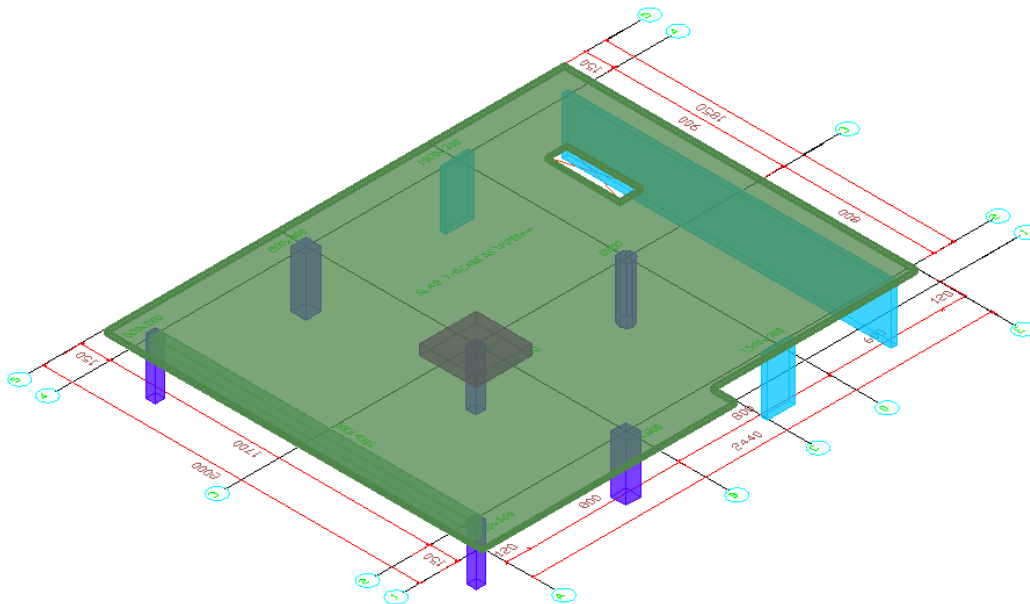
- Once the Default View has been set, you can activate the default view at any time by clicking the  icon.

Manual Modeling of Structural Components

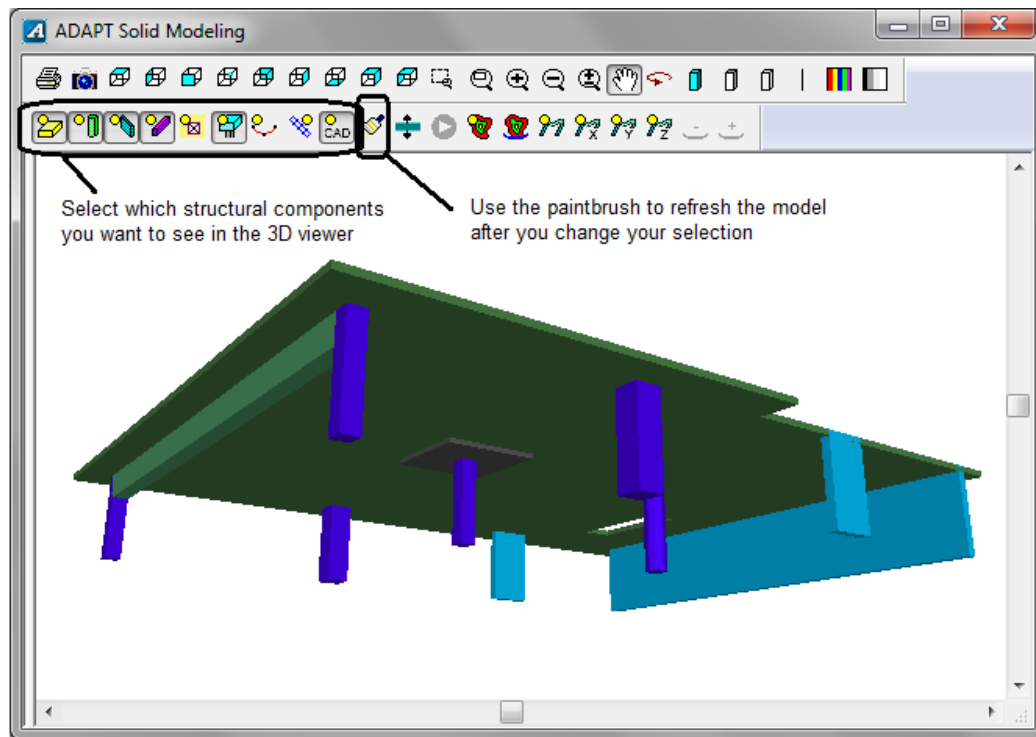
- Sometimes, you may be working with a CAD file that is not properly prepared and where the structural components, like slab, are not represented as continuous closed polygons. In such cases, you have to model structural components manually.
- For example, to model a slab manually, select the “Create Slab Region”  function and start tracing the slab boundary by clicking at the vertices of the slab.
- Do not worry, if you miss a vertex, or you click at the wrong location – continue to the end. You will edit/correct the mistakes at the next stage. When done, exit the creation mode.
- Tip: all continuous modeling operations like the entering of multiple slab vertices continue until you right click and select the Close/End/Accept option.
- Using the zoom and pan tools, go over the slab region you have created. Use the  “Delete Point,” and  “Add Point,” tools, or  select and drag to edit the slab region you have created to match that of the architect’s slab outline.
- Tip: The Tab key will toggle between different objects that are at the same mouse click location and difficult to select individually.
- Continue, until the entire floor system is created, including openings.

Viewing and Verification of 3D Model

- For better visualization of your model, turn on the shaded view using . To revert back to wireframe mode, click the wireframe  icon. Sometime, the front-to-back order of components in the shaded mode can be affected if you select components. To reset the front-to-back order of components, cycle one between the wireframe and shaded modes of the model. This should reset the correct visibility settings.



- Use the View Model tool  for viewing the model generated in three dimensions. Examine the model in detail, by rotating it, to make sure that it is a faithful generation of the architect’s drawing in three dimensions.



NOTE:

The View Model tool opens a new window called ADAPT Solid Modeling. You can view 3D solid model in this mode of the software. To return to the regular ADAPT-Floor Pro modeling environment, close the ADAPT Solid Modeling window by clicking  at the top right corner of the window.

SESSION (2) – First Finite Element Method (FEM) Solution

In this step we mesh the structure, obtain a finite element (FEM) solution, and view the results. The objective is to make sure that the model we have generated is valid and works well. You will find, the validation of the structural model is a critical and time-saving step, before moving to other steps, such as applying loads, changing boundary conditions, if necessary.

Meshing

- From the FEM pull-down menu select “Automatic Mesh Generation,” to open the mesh generation dialog box (**Fig. 2-1**).
- Select 1.60m (5ft) for suggested cell size.
- Select the “Maximum distance” for node shift 0.5m (1.5 ft).
- Click OK.

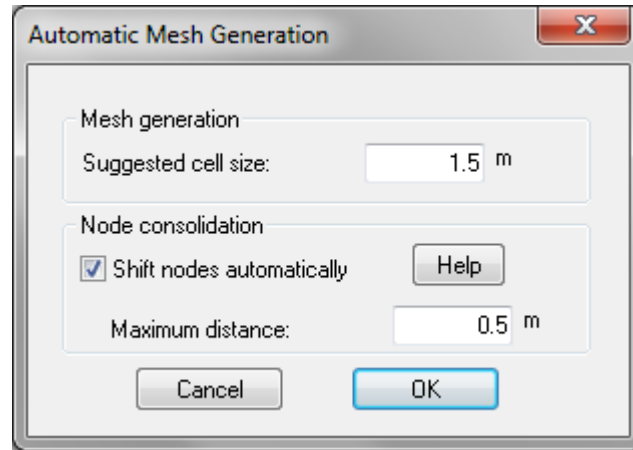


FIGURE 2-1 AUTOMATIC MESH GENERATION DIALOG WINDOW

The mesh displayed in **Fig. 2-2** will be generated. Save the data and move to the next step.

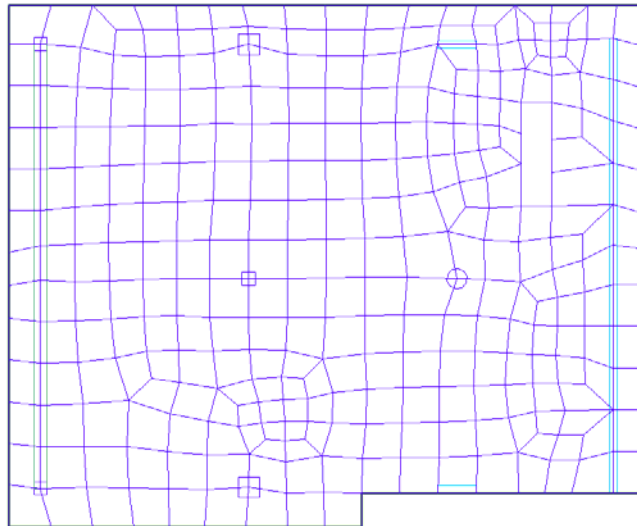


FIGURE 2-2 ADAPTIVE FEM MESH GENERATED AUTOMATICALLY

Generate FEM Solution

- From the FEM pull down menu (**FIG. 2-3**) select “Analyze Structure.”

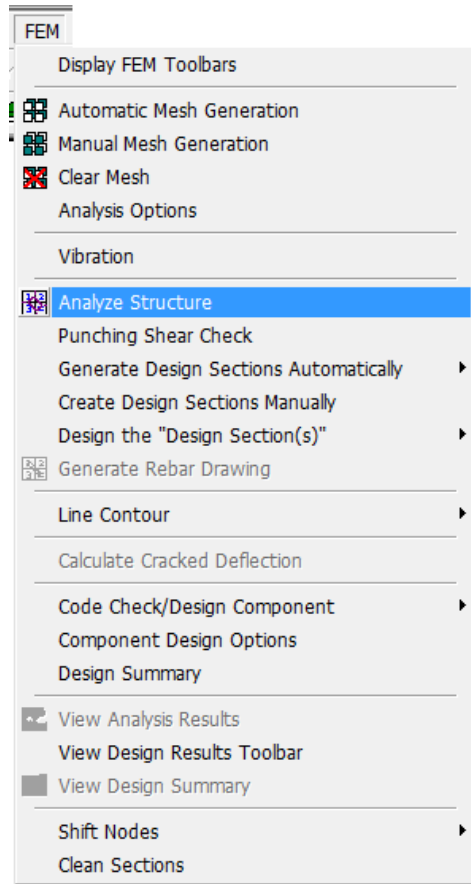


FIGURE 2-3 FEM PULL-DOWN MENU

- The Analysis Options window (**FIG. 2-4**) gives the user several analysis options:
 - o Selection of load combinations to include in analysis.
 - o Options to include global analysis results. These options only apply when solving a multistory structure in single level mode.
 - Include lateral reactions: This option is available if you have analyzed your model in global mode with lateral loads.
 - Include load takedown: This option is available if you have analyzed your model in global mode with gravity loads or have run the tributary load takedown module. It limits the application of loads to the Fz component.
 - Include gravity reactions: This option is available if you are in MAT mode and analyzing a foundation model. With this option selected, all internal reactions from walls and columns are applied to the foundation.
 - If any of these options are selected, the user is asked to choose which saved solution should be used in the analysis.
 - Apply live load reduction. This option should be used when applying vertical takedown loads to foundations or transfer elements that allow live load reduction.
 - o Apply stiffness modifiers. This option allows you to apply the stiffness profile defined for individual Usage types defined in your model.
 - o Compression spring/soil support options
 - Substitute soil compression springs with fixed supports. This option is a useful feature when analyzing a structure that has soil support modeled at its foundation level but the user does not want to include the deformation of the foundation in the building's analysis.

- Analyze structure with compression springs. This option retains the compression springs in the model during analysis.
 - o Vibration analysis option applies to both multistory and single level analysis.
 - o Stabilize against lateral in-plane translation and rotation – this option is used to stabilize the default boundary condition of Fixed Rollers for the single level mode.
 - o Show this dialog whenever I analyze structure. Use this option to automatically launch the analysis options window.
 - o Warning if load case for selected load combination does not contain any loads. Use this as an added quality control check in your model.

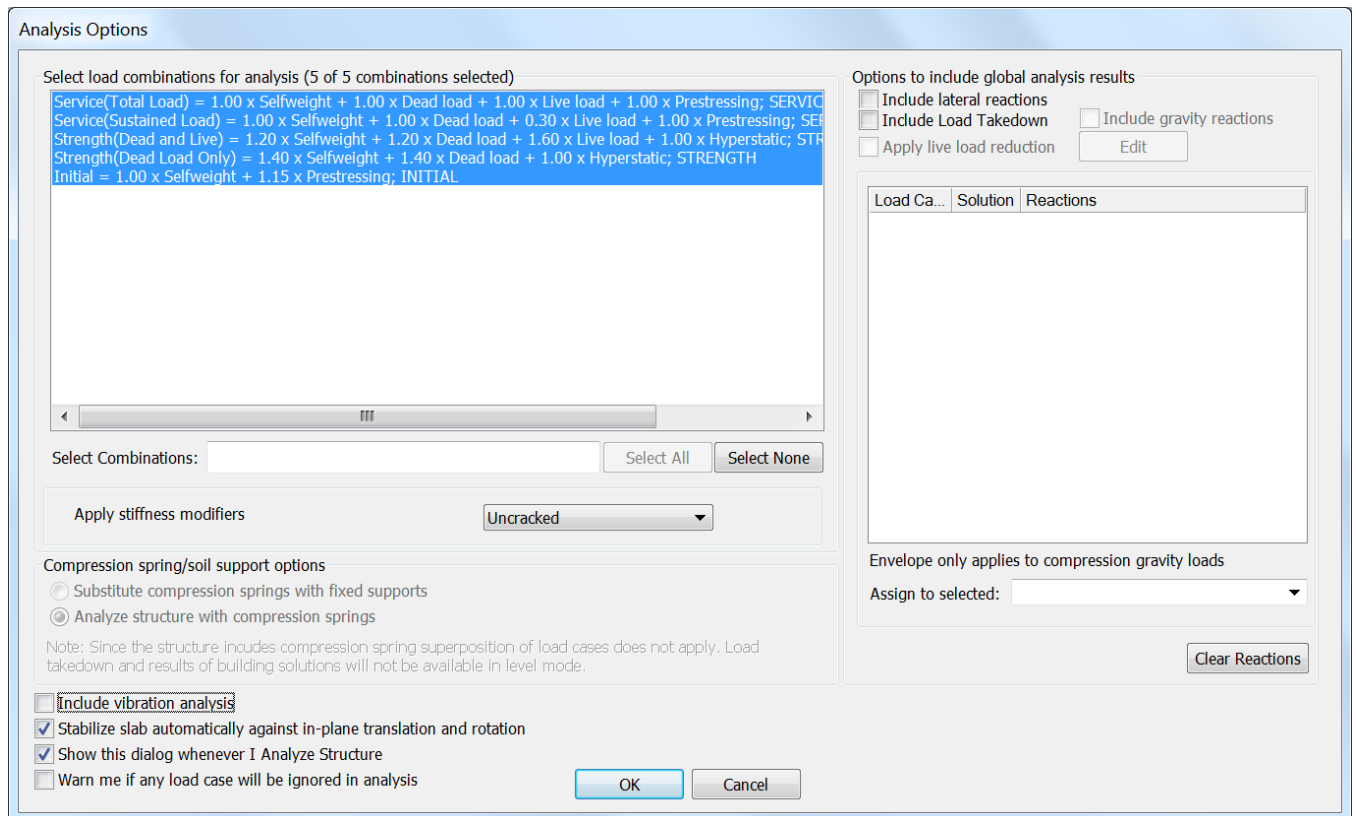
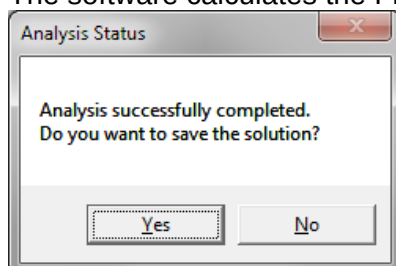


FIGURE 2-4 ANALYSIS OPTIONS WINDOW

- The software calculates the FEM solution unless it encounters a discrepancy.



View Analysis Results

While it is not necessary to view and examine the results for the purposes of code check and determination of rebar, it is always a good idea to do so, in order to validate the structural modeling. In particular, view the deflected shape of the structure. Many of the errors in modeling can be readily detected from a close examination of the deflection of the floor system.

Using Traditional FEM Viewer

Follow the steps below to view analysis results using the traditional FEM Viewer. Skip to the next section if you want to view results within the model.

- From the FEM pull-down menu (**Fig. 2-3**), select “View Analysis Results.” When the 3D view screen (**Fig. 2-5**) opens, do the following to display deflection contours:
 - o On the tabs of the left margin select “Load Case Combinations.”
 - o Select “Service (Total Load)” from the list of the load cases.
 - o On the top of the same margin, click on “Results.”
 - o From the list of results, select “Z-translation.” This is the vertical deflection of the structure.
 - o Click on the “Contour”  and “Display Results”  buttons. This will display the model as shown in **Fig. 2-6**. Your solution might look slightly different, depending on the system of units selected, value of the loads and the load combinations. But, make sure that the deflection at supports is essentially zero (there will be shortening of columns and walls that the program reports).

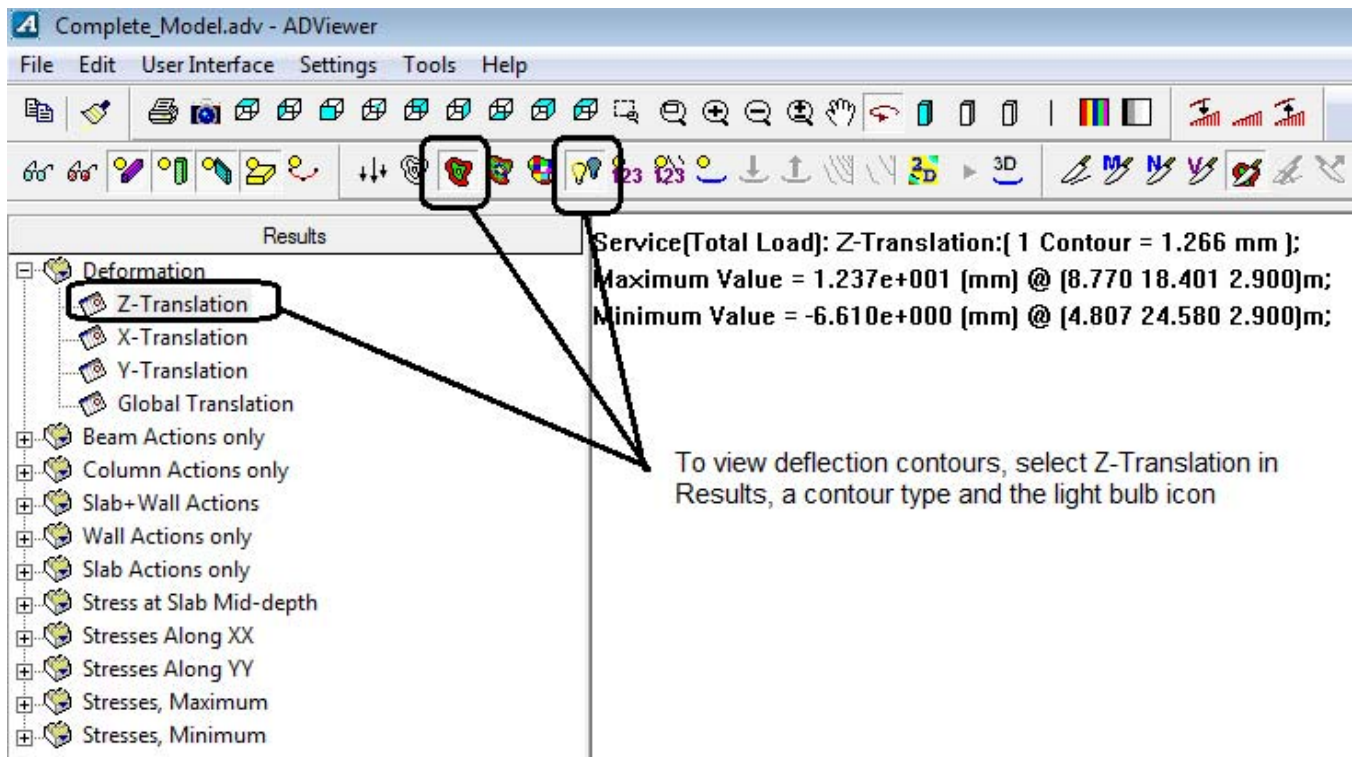


FIGURE 2-5 SETTINGS TO DISPLAY DEFLECTED CONTOUR

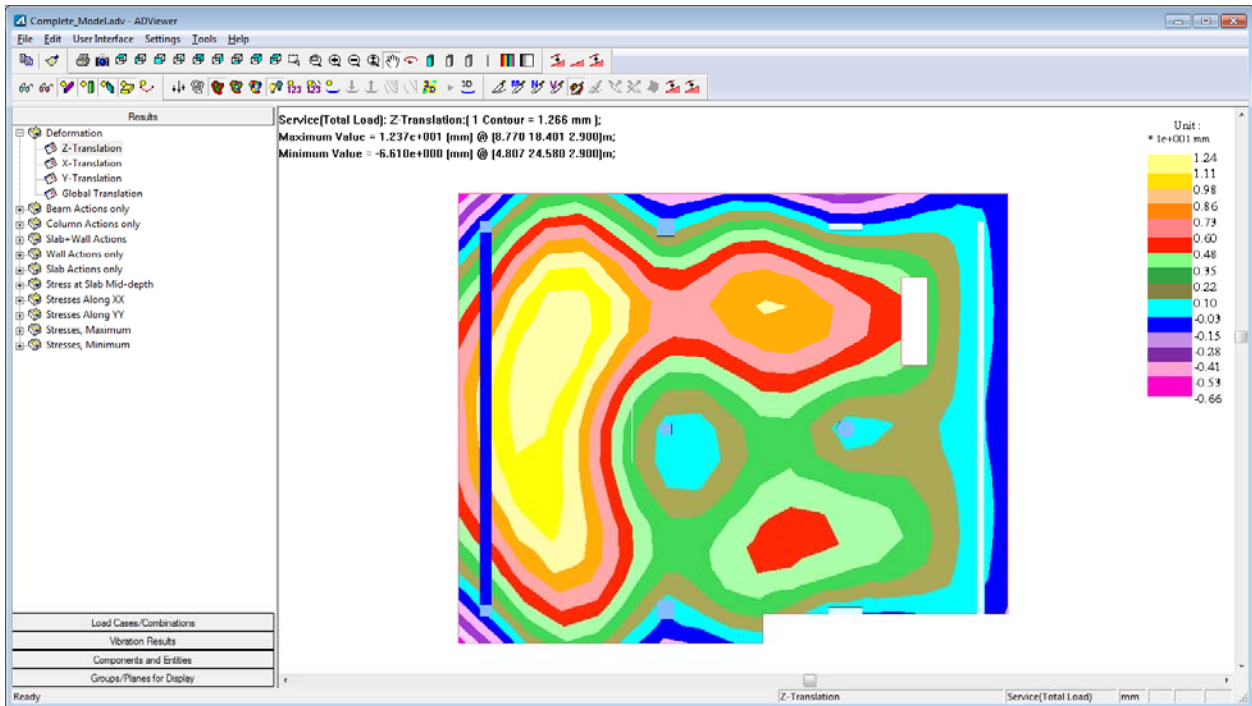


FIGURE 2-6 DISPLAY SCREEN OF FEM SOLUTIONS SHOWING DEFLECTION CONTOUR

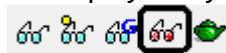
- o Use the warping () and rotate () tools on the screen to examine the deflected shape of the model.
- o Use the 3D  deformed shape option with Global Translation selected under Results to display the realistic 3D deformed shape and structural response of the model.

NOTE:

The View Analysis Results function opens a new window called ADViewer. You can view your FEM analysis results in this mode of the software. To return to the regular ADAPT-Floor Pro modeling environment, close the ADViewer window by clicking  at the top right corner of the window.

Viewing of Analysis Results in Model Space

To display analysis results in the model space, open the Results Display Settings window



(Fig. 2-7). Depending on your settings, this window may automatically display itself after you complete analysis. Follow these guidelines when using the Results Display Settings window:

- The *Analysis* tab contains a list of all analysis results you can display on the model.
- Select a category to display its values on the model.
- You can only show one result type per category at a time, but it is possible for you to display multiple results from different categories at the same time.
- Use the Combo pull-down list to switch between different sets of analysis results.
- The floating scale in the model space displays the range of values shown in the model for the last results category selected.
- If displaying multiple result sets, use the Scale pull-down list to select which scale to display in the model space.
- The *Result Display Settings* tab contains setting for the display of design strip and column values.
- The *Settings* tab contains general display configuration options.

- Use Clear All to deselect all selections in the Analysis tab.
- Use the Apply button to update the display of analysis results after making a selection and the display does not automatically update.

To display the deflected shape of your slab, select the option of *Z-Translation Deformation* under the Slab category.

Selected the *Teapot* icon  to turn on the 3D Solid Modeling view. Selected analysis results being displayed in the model space as contours can also be shown in the 3D solid modeling view. Figure 2-8 shows the solid modeling window and explains its main features.

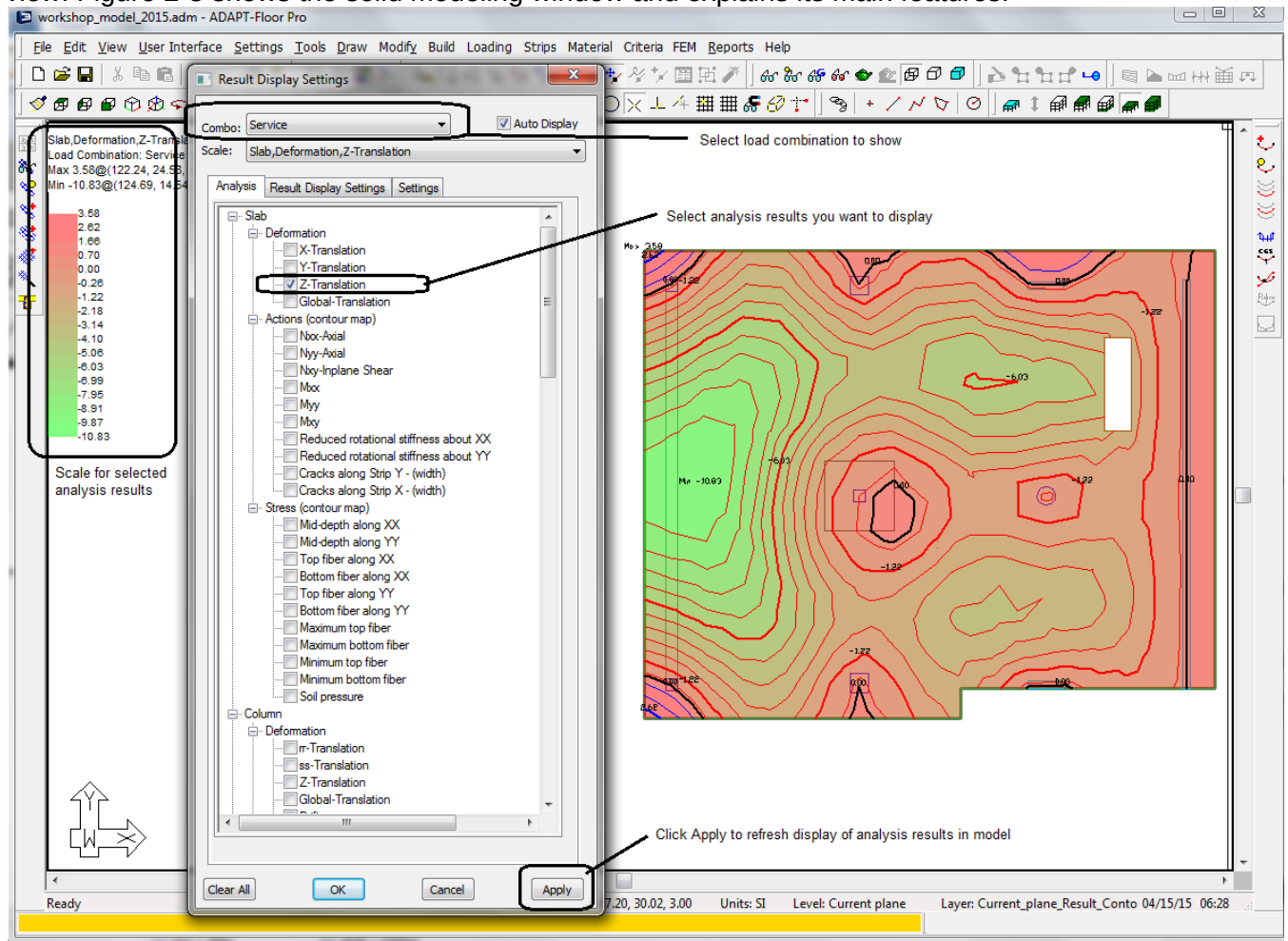


FIGURE 2-7 SHOWS RESULTS DISPLAY SETTINGS WINDOW

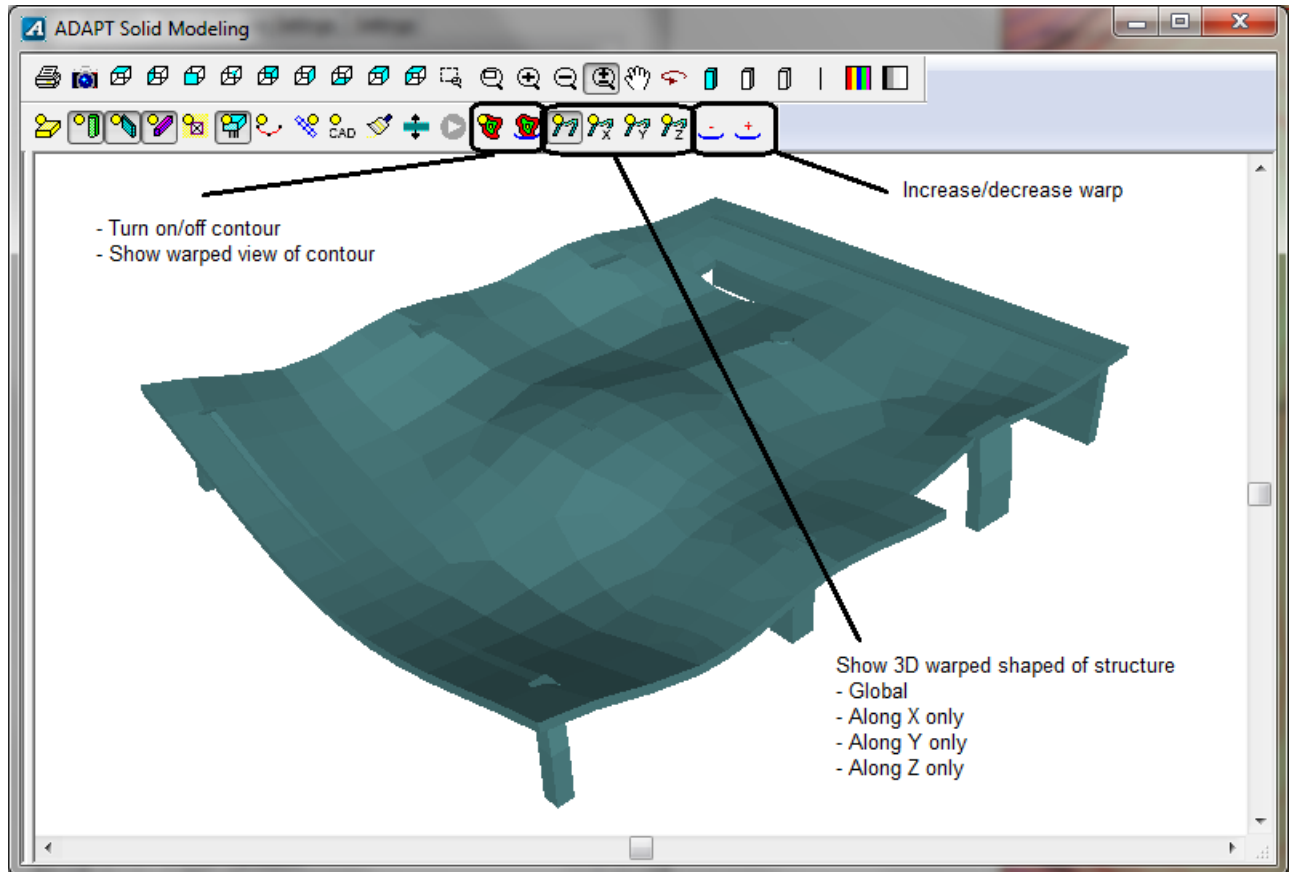


FIGURE 2-8 SOLID MODELING WINDOW USED TO SHOW SELECTED ANALYSIS RESULTS

SESSION (3) – Entering of Design Criteria

In this session, you will review and enter all relevant design criteria, loads and load combinations in your model.

Design Criteria

- From the “Criteria” pull-down menu select “General.” This will open the input tabs shown in **Fig. 3-1**, which list the code and design criteria used by the program.
- Browse through the tabs in the Criteria window and edit the default values of the program as required – refer to the Design Criteria section at the beginning of this workshop handout for details.

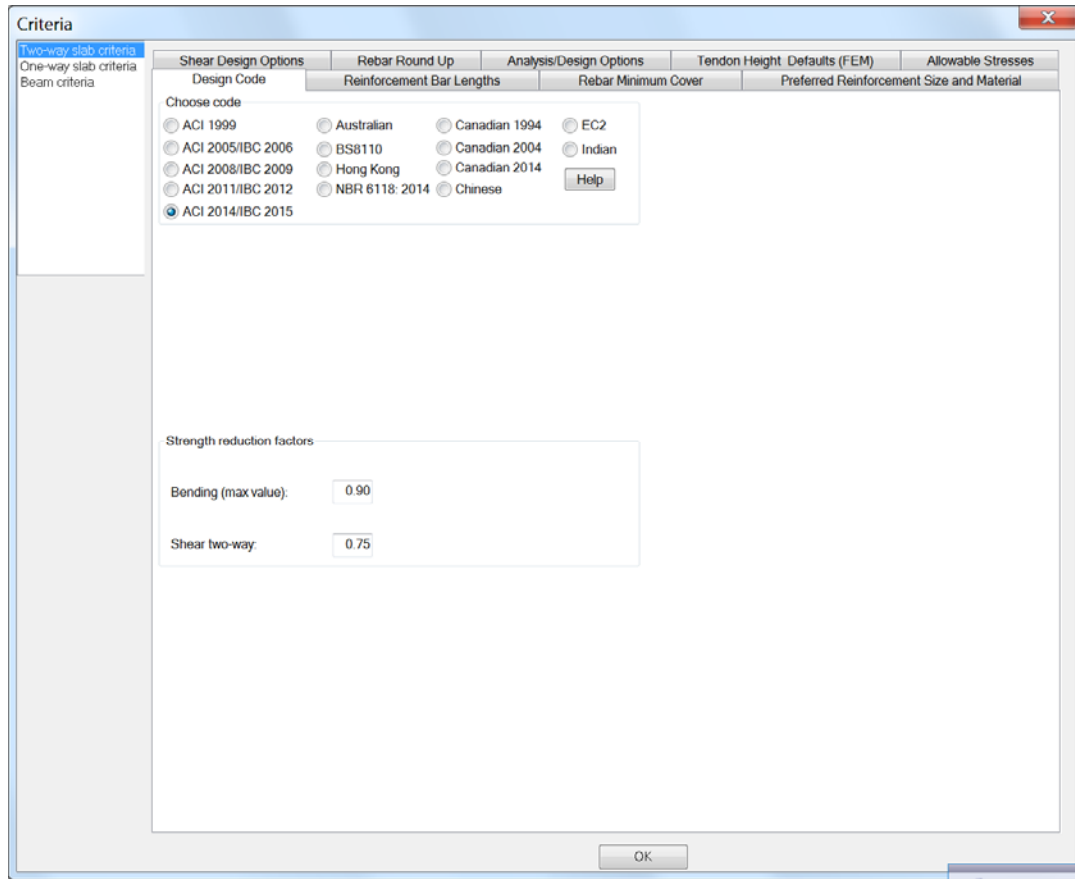


FIGURE 3-1 DESIGN CRITERIA INPUT TABS

NOTE:

For each tab, make sure you review and update design values for each of the 3 primary structural system types: Two-way slab criteria, One-way slab criteria, and Beam criteria. To review and set the value for each structural system, first select the structural system at the left side of the window and then review, edit its associated values.

Apply Loads

- Open the loading toolbar.



FIGURE 3-2 LOADING TOOLBAR

- Select the “Create Patch Load”  tool.
- Draw a polygon that contains the entire floor system or using the intersection snap , trace the boundary of the slab. To close the area for the applied load, either right-click and select “Close/End/Accept”, or press the C key on your keyboard. This operation will create an area load. The software will only apply loads to areas below a patch load where it finds actual structural components; it will ignore any area of the patch load that fall outside of slab and beam boundaries.

- To define the magnitude and load case of the just created load, open its property box **FIG 3-3** by either double-clicking on the load or by highlighting it and then selecting the Property Box icon .
- Enter the Load Case as “Dead load” and specify its magnitude Fz1 (2 kN/m²; 0,04⁵ k/ft²). Then, click the green check box  to accept it.
- Repeat the same for “Live Load” (2.5 kN/m²; 0.05⁶ k/ft²).

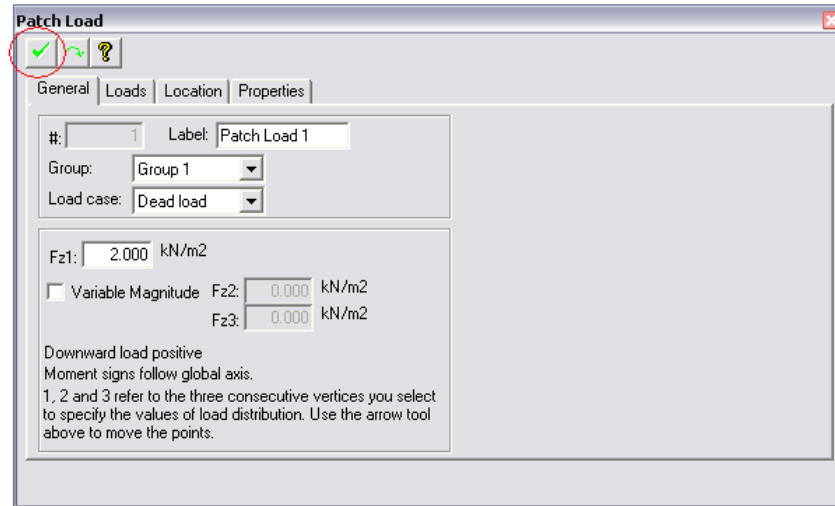


FIGURE 3-3 PROPERTY BOX FOR PATCH LOAD

NOTE:

Changes made in any Property Box are not saved unless the user clicks the green check box  at the top left hand corner of the window.

- Verify the applied loads by viewing their distribution and values.
- Loads are best viewed when the model is in the Top-Front-Right-View .
- If loads are not visible, click on the Display Loads icon  found on the Loading Toolbar or open the Select/Set View Items window using the eyeglass icon . The visibility of loads can be defined on the Loads tab.
- Once visible, double-click on each of the loads to verify their magnitude and load case.

Load Combinations

The program automatically generates the basic load combinations of serviceability and strength check for the building code you have selected. You can view, modify and create new load combinations in the load combination window.

- To open the Load Combination window, go to Loading menu and select “FEM Tabular”. This opens the load combination dialog window shown in **Fig. 3-4**.

⁵ Most US codes require only 0.02 k/ft² of superimposed dead load (partitions), in addition to selfweight.

⁶ For residential buildings, most US codes specify 0.04 k/ft². The higher values selected are intended to maintain a close correlation between the designs in the two systems of units (SI, American) presented in this work.

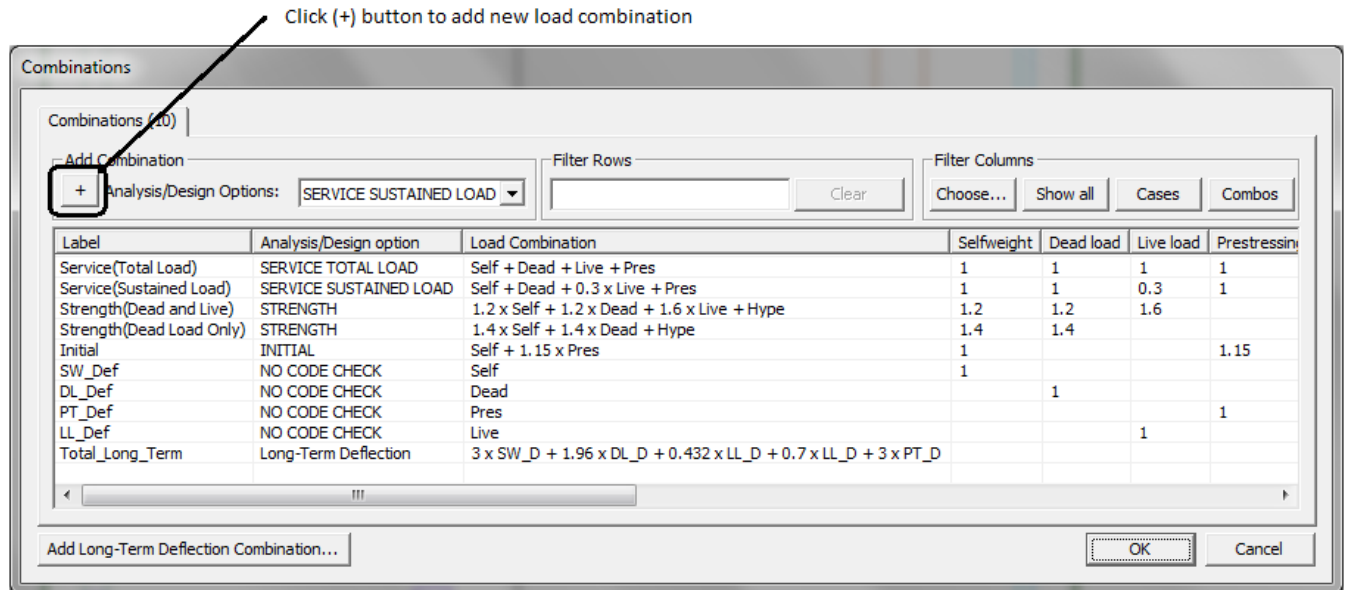
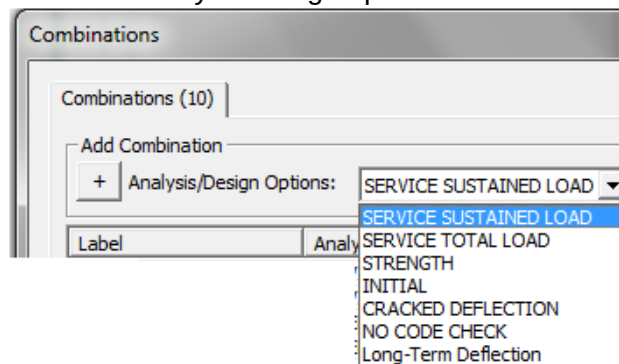
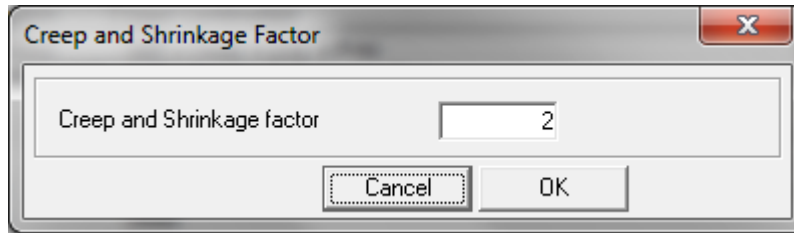


FIGURE 3-4 LOAD COMBINATION DIALOG WINDOW

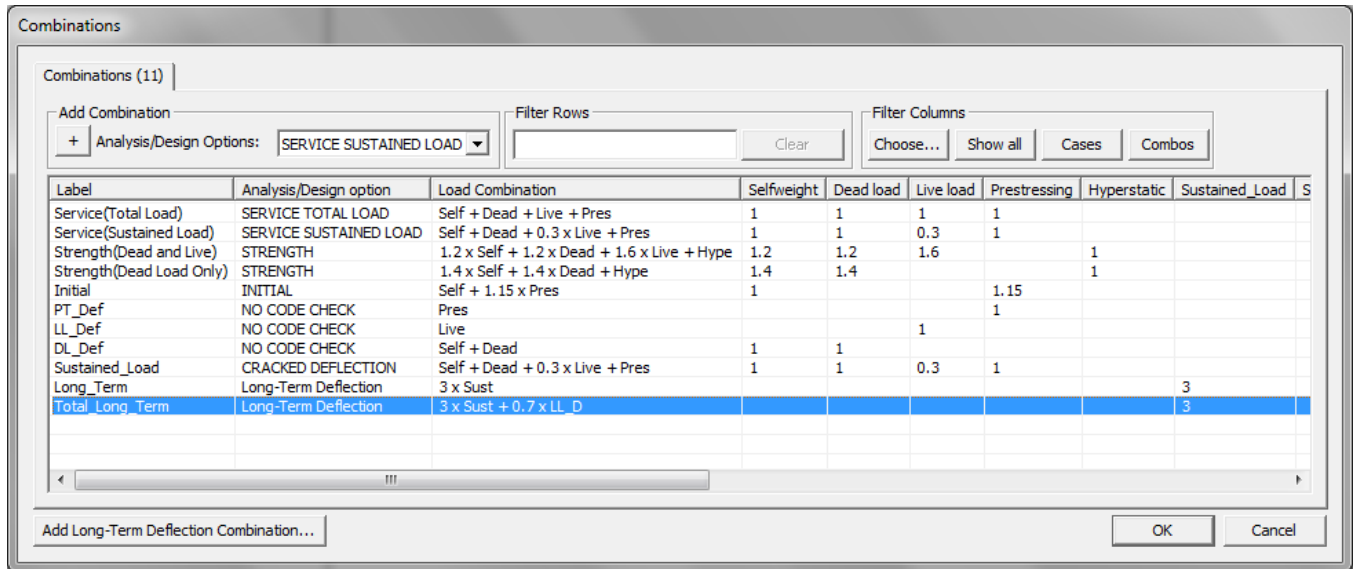
- Select any cell in the Label or Load Combination rows to select an entire load combination. With a load combination activated, use the Delete key on your keyboard to delete it or right click to clone it.
- Select any other cell in the matrix to modify its value.
- To create a new load combination, click the (+) button. This will create a new, blank load combination with the selected analysis/design option.



- Each load combination should be classified with the appropriate Analysis/Design Option:
 - Load combinations used for the calculation of deflections only should have their Analysis/Design Option set to either NO CODE CHECK or CRACKED DEFLECTION. The No Code Check options uses gross cross sectional properties of the members to calculate deflections, while the Cracked Deflection option accurately calculates the deflection of the floor system based on the reduced effective moment of inertia after cracking. This analysis option considers the contribution and location of mild and prestress reinforcement when calculating a member's I_{eff} . The calculation of cracked deflections is a post-process and needs to be invoked separately.
- Use the **Add Long-Term Deflection Combination...** button to create a special type of load combination that is a combination of combinations. When selected, enter the creep and shrinkage factor you want to use. This will create a new "Sustained_Load" combination that is set for cracked deflection calculation as well as a "Long_Term" combination that is based on your creep factor and a multiple of the newly created Sustained_Load combination.



Use the load combination window to create the load combinations listed below:



- Hint: use the right click / clone option to create your 2nd Long-Term Deflection combination. Once created, rename and add 0.7 LL_Def.
- Press OK to close the window after you have entered all of your load combinations.

SESSION (4) – Design Slab with Mild Reinforcement Only

Support Lines Defined

Support lines connect the “supports” of the structure in a given direction and represent the engineer’s intended load path. Support lines are used by the software to generate design strips that in turn are used to design your slab. To have a complete design, you must define support lines in two primary directions – X & Y. The designations X & Y do not have to correspond to the global X and Y axis.

Several rules apply to the proper definition of support lines. They include:

- Support lines of the same direction (X or Y) cannot cross each other.
- Ideally, support lines should start and end at the slab edge.
- If needed, support lines can end at a Splitter. Splitters are an advanced modeling feature that can be accessed under the Strips menu item.
- To consider a structural component, such as a wall, beam, or column as a “support”, you must snap a vertex of a support line to it.
- Use the following snapping rules:
 - o For columns and end of walls and beams use snap to end
 - o for slab edge, use snap to nearest ; and
 - o for beam and wall centerlines use snap to nearest .

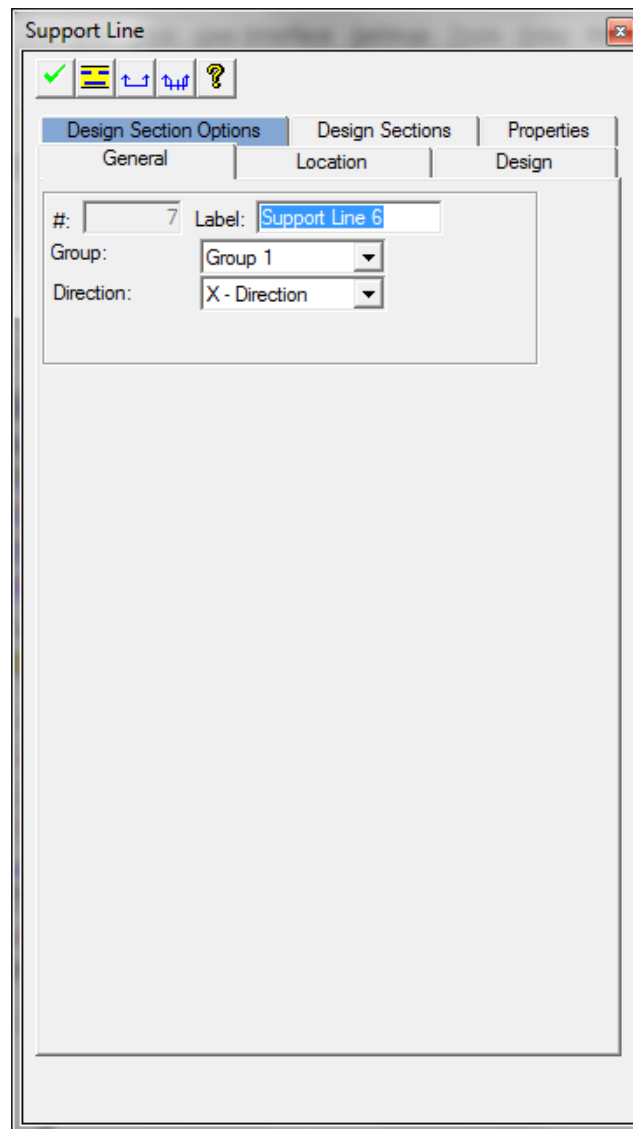
NOTE:

"Support Line" and "Design Strip" concepts and procedures are central to the design of floor systems. If you are not familiar with the procedures, refer to the document "Design of Concrete Floors, with Particular Reference to Post-Tensioning." This publication can be downloaded from the ADAPT website.

Generate Support Lines in X Direction

Follow these steps to create support lines in the X direction.

- To create a support line, click Create Support Line under the Strip menu
- Make sure you are defining support lines in the X direction. To check, click the property box icon  and make sure the Direction is set to X-Direction. If it is not X, like in **Fig 4-1**, change it to X-Direction and click the green check box  to save the new direction.



The image shows a software dialog box titled "Support Line". At the top, there is a toolbar with icons for a green checkmark, a yellow and red striped box, a blue arrow pointing up, a blue arrow pointing down, and a yellow question mark. Below the toolbar are three tabs: "Design Section Options" (which is selected), "Design Sections", and "Properties". Under the "Design Section Options" tab, there are three sub-tabs: "General", "Location", and "Design". The "General" sub-tab is active and contains the following fields:

- A field labeled "#" with the value "7".
- A field labeled "Label:" with the text "Support Line 6".
- A field labeled "Group:" with a dropdown menu showing "Group 1".
- A field labeled "Direction:" with a dropdown menu showing "X - Direction".

 The rest of the dialog box is a large, empty light gray area.

FIGURE 4-1 SUPPORT LINE PROPERTY BOX

- Draw your X-direction support lines, paying particular attention to snap the support lines as shown in **Fig 4-2**.

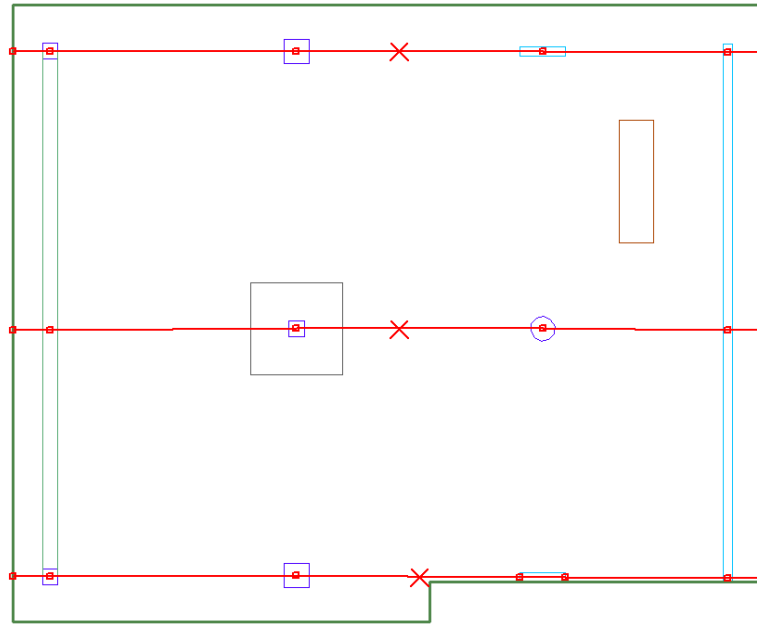


FIGURE 4-2 SUPPORT LINES IN X-DIRECTION
(NOTE SNAP LOCATIONS AT SUPPORT BOUNDARIES)

Generate Support Lines in Y Direction

Follow these steps to create support lines in the Y direction.

- To create a support line, click Create Support Line under the Strip menu
- Make sure you are defining support lines in the Y direction. To check, click the property box icon  and make sure the Direction is set to Y-Direction. If it is not X, change it to Y-Direction and click the green check box  to save the new direction.
- Follow the snap locations as shown in **Fig 4-3**.

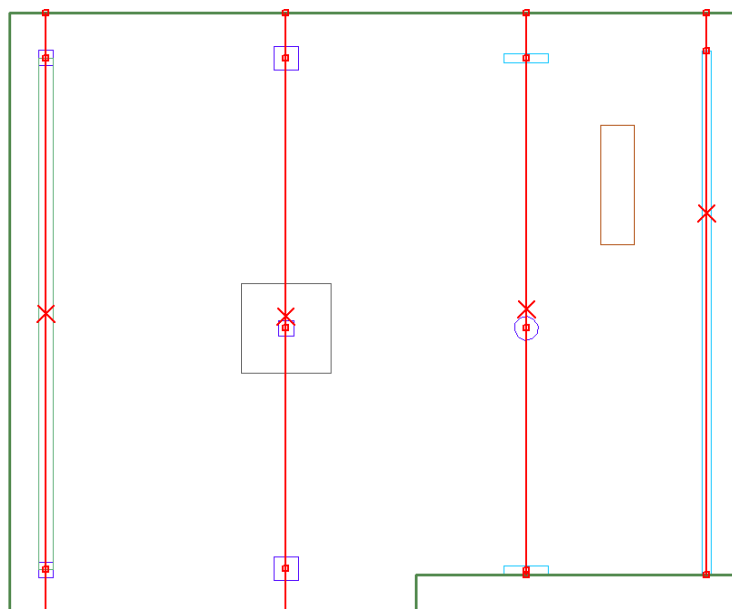


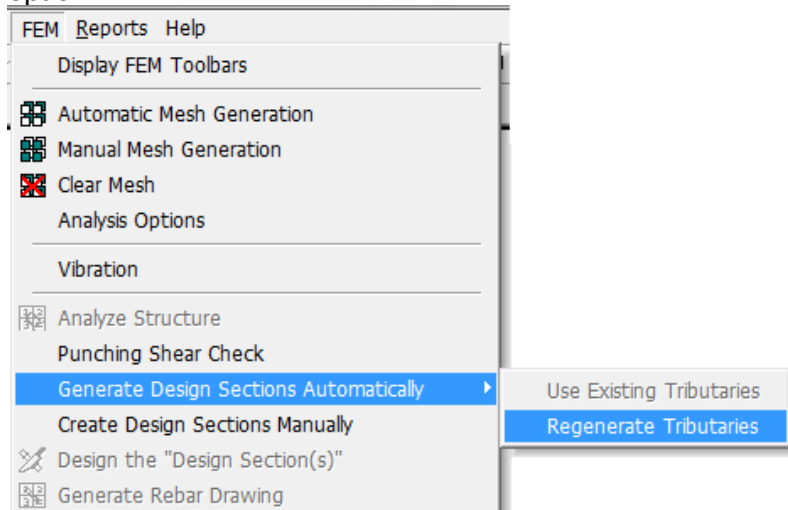
FIGURE 4-3 SUPPORT LINES IN Y-DIRECTION

(NOTE SNAP LOCATIONS AT SUPPORT BOUNDARIES)

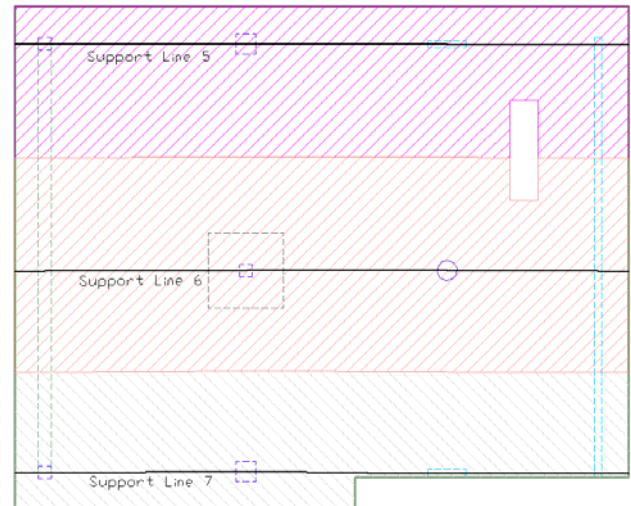
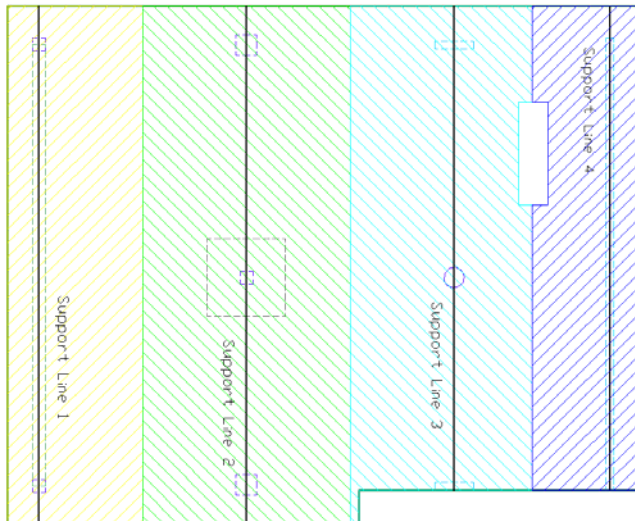
Generate Design Strips

Follow these steps to create design strips and sections from the support lines you just created in your model.

- Click on the “Generate Design Sections Automatically / Regenerate Tributaries” tool in the FEM menu. With this function the program breaks the slab boundary down into tributaries based on the support line and splitters defined. Previously generated tributary regions are deleted and regenerated using this option.



- Starting with Builder version 2012 build 1, users can manually create tributaries or manipulate the boundary of automatically generated ones.
- To generate Design Sections using existing tributaries, invoke the Use Existing Tributaries function.
- To view the design strips generated by the software, select the following reports under the Reports menu: Reports | Single Default Reports | Graphical | Design Plans | Design Strips X-direction.
- Figure 3-9 shows the design strips generated by the program in X- and Y-directions.
- Adjust your support lines and repeat the steps in this section if you are not satisfied with the design strips generated in your model. Use the Set / Select View icon  to turn on and off support lines and other components.



(b) Design Strips in X-direction

(a) Design Strips in Y-direction

FIGURE 4-4 DESIGN STRIPS IN X- AND Y-DIRECTIONS

Design the Slab

To design the slab, follow these steps:

- Select “Design the Design Sections” in the FEM menu.
- From the User Interface pull down menu, turn on the “Support Line Result Scale Toolbar” (**Fig. 4-5**)



FIGURE 4-5 SUPPORT LINE RESULTS SCALE TOOLBAR

- To turn on and off support lines and their associated design sections, select the Display Design Sections  icon.
- The floating toolbar shown in **Fig 4-6** appears whenever the Display Design Sections mode is active. You can toggle between the X & Y direction support lines by selecting the respective icons.



FIGURE 4-6 FLOATING TOOLBAR

- To graphically view and superimpose design values for each design strip and load combination on the model, start by selecting the Result Display Setting  icon. This opens the *Result Display Settings* window (**Fig 4-7**) that allows you to select which design values or checks you want to superimpose on the design strip.
- Select the Bending option under Design Sections Actions to display the moment diagram along design strips.
- To turn off displayed results in the model, deselect the option in the Result Display Settings window. Clicking the  icon is an alternative method to turn selected options on/off in the model.

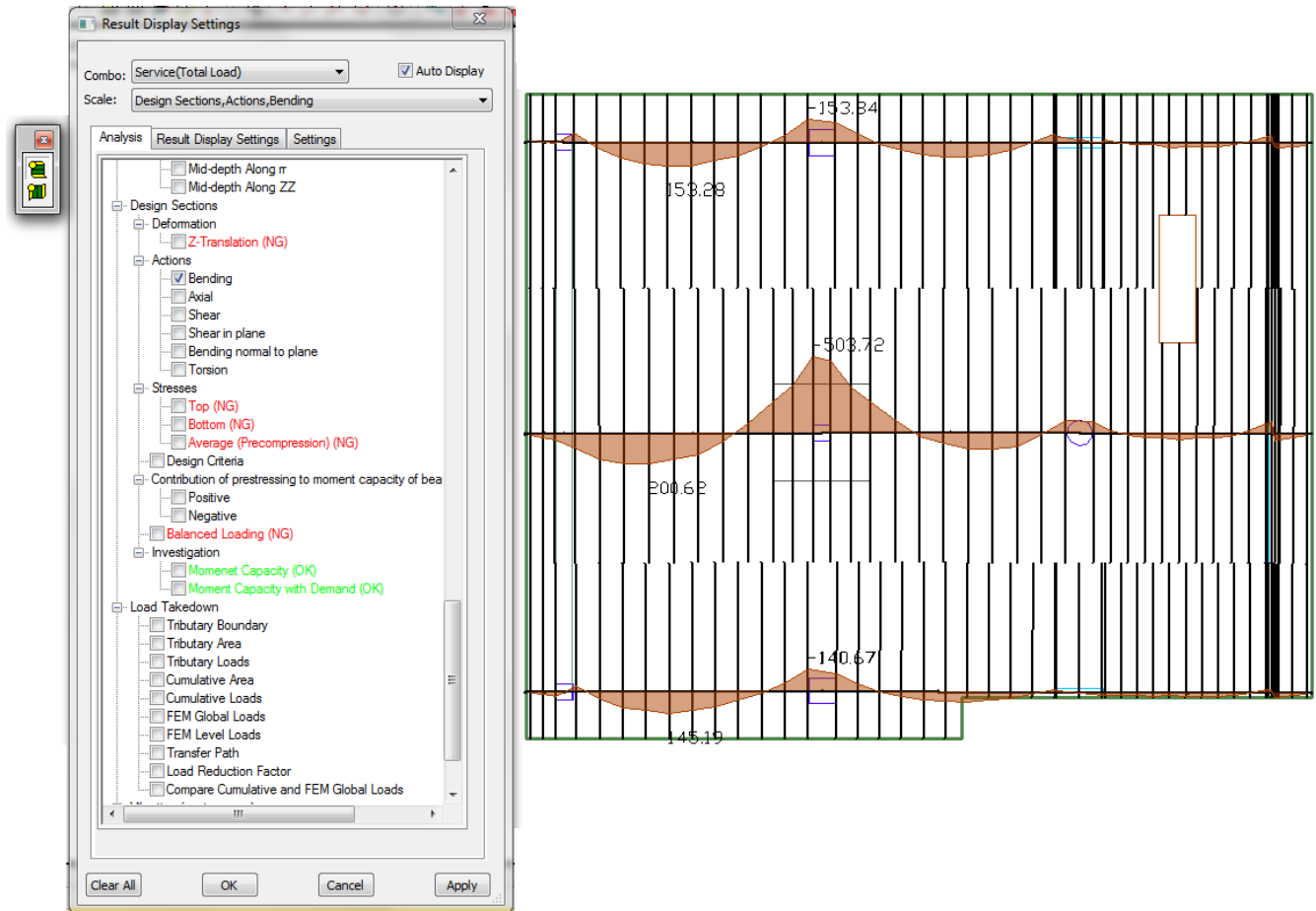
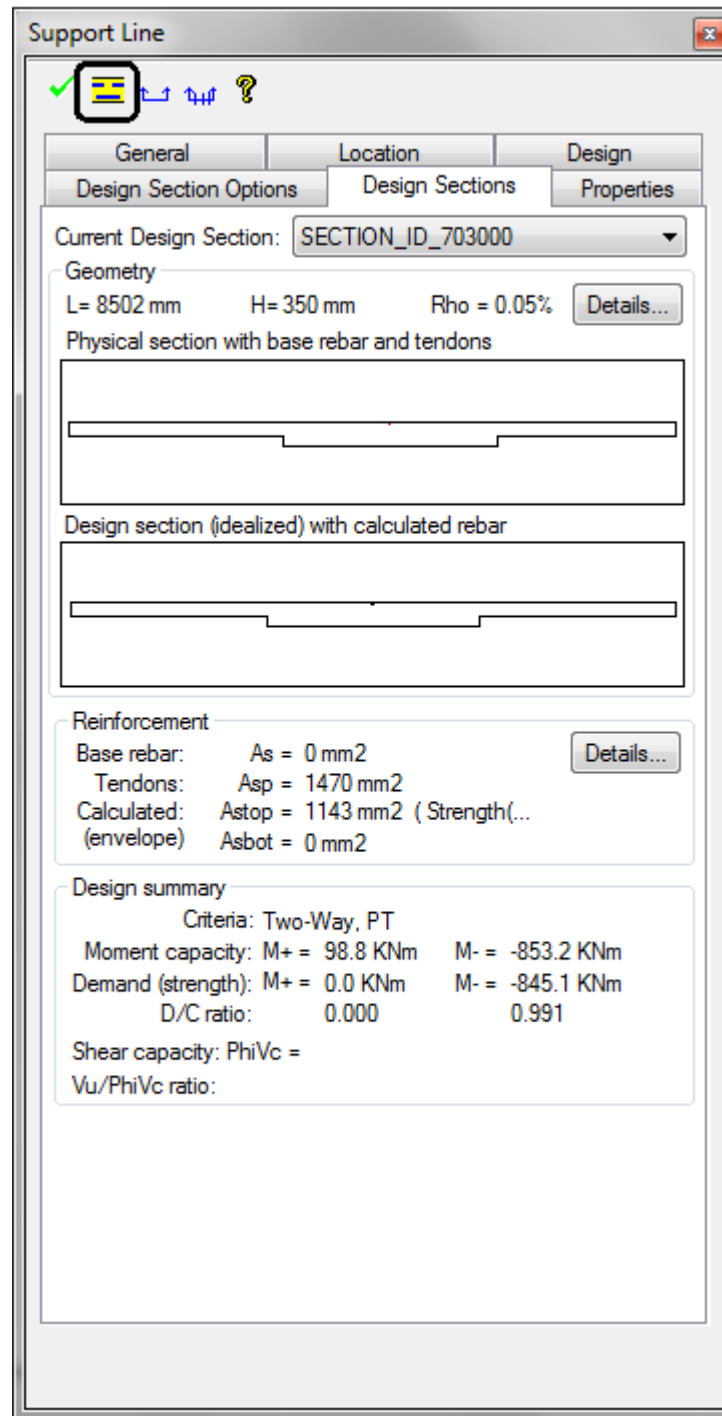


FIGURE 4-7 RESULT DISPLAY SETTINGS WINDOW SHOWING CONFIGURATIN THAT DISPLAYS BENDONG MOMENT ALONG X SUPPORT LINES IN MODEL

View Required Reinforcement for Each Design Strip

Follow these steps to view the reinforcement needed for a particular design strip:

- Select the support line (it should turn red)
- Open its property box



- The *Design Sections* tab shows the details of geometry, reinforcement and other useful design information for each design section along the support line. You can move along the support line by using the mouse scroll function. Using this scroll function moved the display from design section to design section. Alternatively, one can select a particular design section to move to using the Current Design Section pull-down option.
- As an alternative, you can select the Show Builder Sum  icon.
- Once in ADAPT-Builder Sum, select the  icon again to open up a graphic report showing the required reinforcement for that design strip.

SESSION (5) – Design Slab with Post-Tensioning

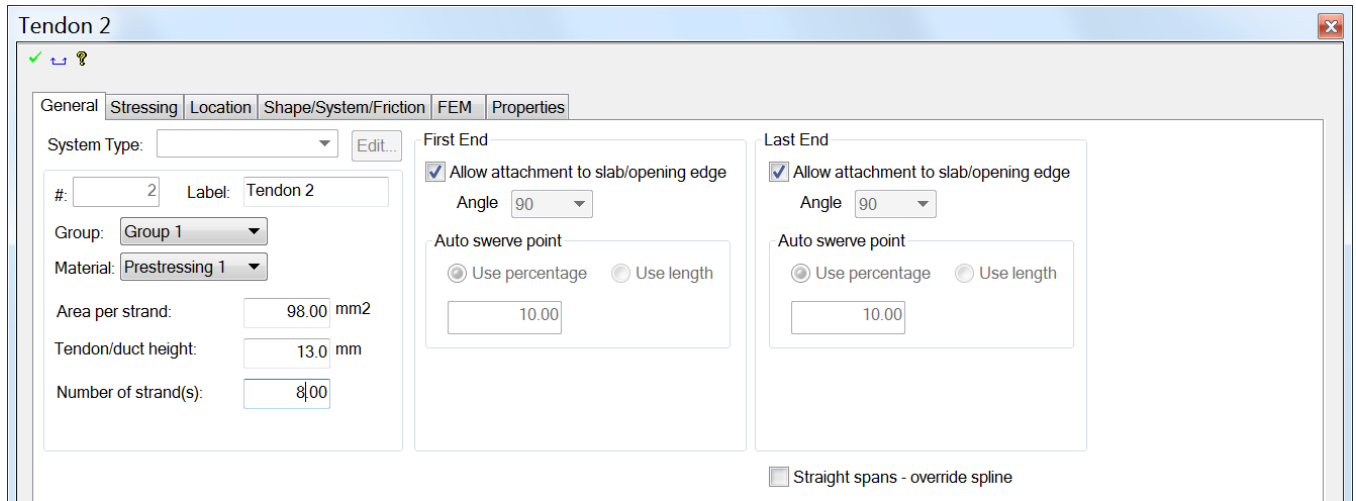
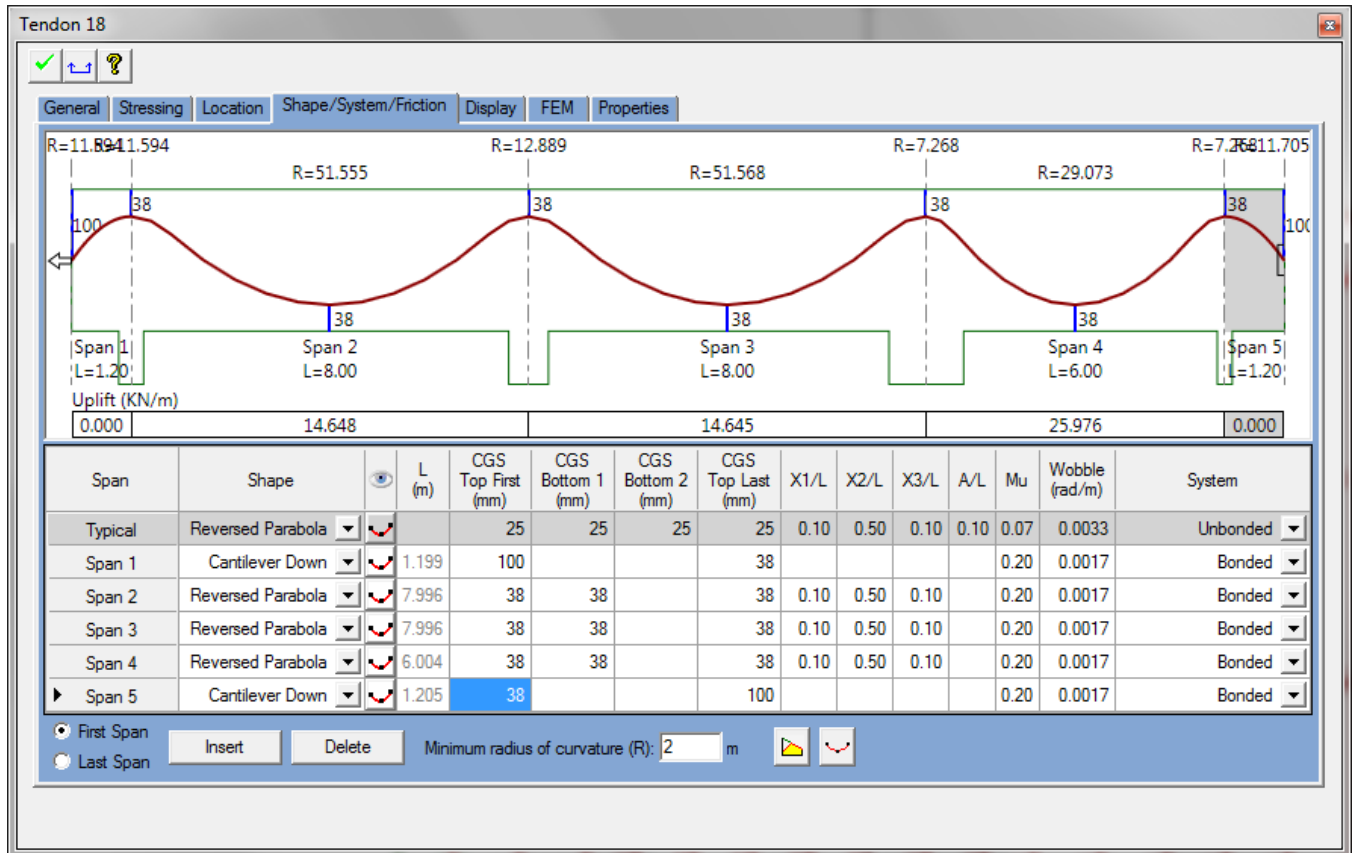


FIGURE 5-2 TENDON PROPERTY BOX – GENERAL TAB

- We finalize the shape of tendon, by specifying the distance of its centroid from the top and bottom of the slab at its extremes. For a 25mm (0.75 “)⁷ clear distance to a 20mm duct (0.5” tendon diameter), the distance will be 38 mm (1”). Obviously, at the slab edge, the tendon will be anchored at the centroid of the slab. This information is reflected in the “Shape/System/Friction” tab of the tendon property box (**Fig. 5-3**). In the same property box, we specify the tendon to be “bonded” (unbonded for US units) and enter its friction coefficients. The information on tendon particulars, including the friction parameters, is included in the “Design Criteria” of the workshop tutorial. Leave the other parameters that define the shape of a tendon in each span unchanged (**Fig. 5-4**).

⁷ The values in the parenthesis are not direct conversions of SI to American system of units. The parentheses refer to typical values for “unbonded” tendons.



(a) SI units

FIGURE 5-3 TENDON PROPERTY BOX – SHAPE/SYSTEM/FRICTION

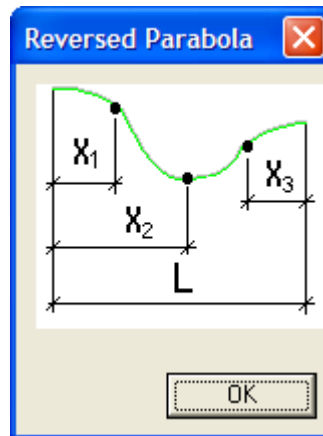


FIGURE 5-4 TENDON SHAPE PARAMETERS

NOTE:

In the above example, we selected “bonded” tendons. If you prefer to use “unbonded” tendons, you will use the same tendon property boxes, but enter the parameters associated with unbonded tendons. The primary differences are: (i) distances of tendon CGS from top and bottom is typically 25mm (1”), instead of 38 used above; (ii) the angular coefficient of friction is 0.07, and (iii) the wobble coefficient of friction is typically 0.001 rad/ft.

- Under the stressing tab (**Fig. 5-5**) we specify the stressing end, seating loss (draw-in), the jacking force, and the anticipated long-term losses. Based on the information provided, the program calculates the distribution of stress along each tendon and uses the local tendon stress for its code check. For most projects 75 MPa long-term loss specified in **Fig. 5-5** is a conservative estimate. (For US units, select 'effective force' and specify the force per strand after all losses to be 26.5 k)
- Specify jacking stress to be 80% of strand's ultimate strength (fpu).

Tendon

Display FEM Properties

General Stressing Location Shape/System/Friction

Post-Tensioning Design Option

☒ Calculate force ☐ Effective force

First end: Live Dead Last end

First End

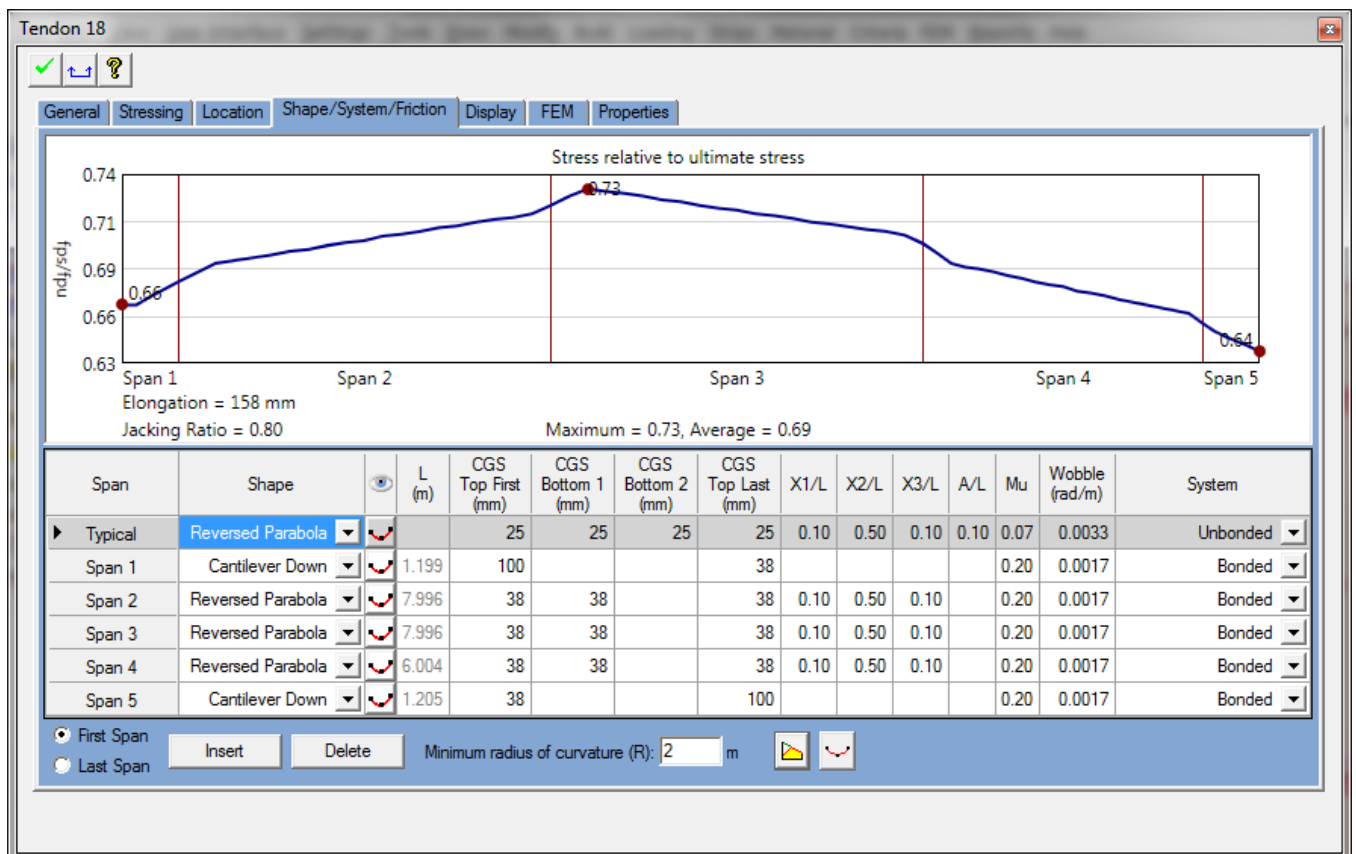
Seating loss: 6 mm

(Jacking Force)/fpu

Stress/fpu: 0.80

Long-term stress loss: 75.000 N/mm2

(a) Stressing parameters are entered under the Stressing tab.



(b) Calculated effective force after friction losses can be shown along tendon by clicking the  icon in the Shape/System/Friction tab.

FIGURE 5-5_SI TENDON PROPERTY BOX – STRESSING PARAMETERS AND CALCULATED EFFECTIVE FORCE ALONG TENDON

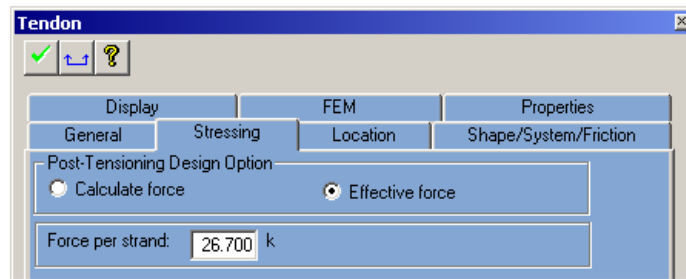


FIGURE 5-5_US TENDON PROPERTY BOX – STRESSING

- In a similar manner, generate banded tendons along grid line 3 with 15 strands and grid line 2 with 8 strands.

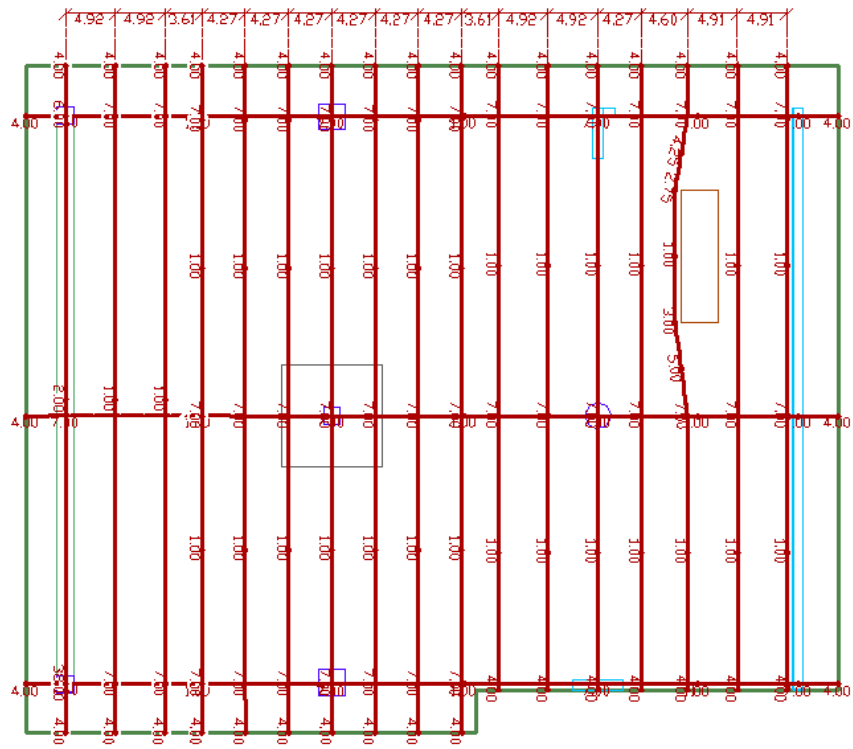
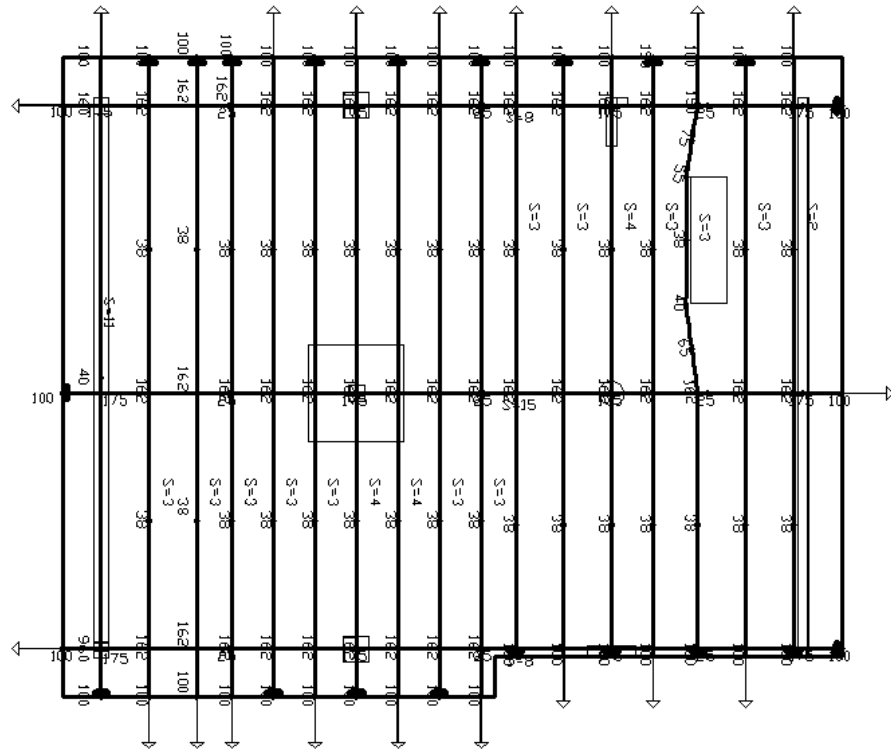
Model Distributed Tendons

- For the distributed direction, create a single tendon and use the Modify | Copy/Move command to replicate it. Or use the Map distributed tendon tool . Position the distributed tendons similar to the arrangement shown in **Fig. 5-6**.
- The guideline for arrangement of tendons shown in the figure was: (i) number of strands selected provide approximately 1.0 MPa (150 psi), (ii) they will be bundled to be spaced at not more than eight times slab thickness (1.60 m; 64”), (iii) nor more than 1.50 m (5 ft), and (iv) minimum of two strands pass over each column.
- The tendon layout for the distributed direction is shown in **Fig. 5-6**. Note that the distance between the tendons is less than the maximum stated in the above. For the legend, S=3, means 3 strands in the tendon, the numbers, such as 162, or 100 give the distance from the soffit of the slab to the centroid of tendon. The arrows along the edges indicate the stressing ends of tendons. **Figure 5-6** was obtained by going to the Report pull-down menu, selecting single default reports, graphical and finally tendon plan.

Model Tendon in Beam

- With the objective of obtaining approximately 0.9 MPa of precompression in the T-beam's cross section, place 11 strands in the beam with the profile of control points as indicated in **Fig. 5-7**.
- In addition to the graphical tendon profile available in the Tendon Property window, one can view the elevation and profile of any tendon by having it drawn in the modeling are. To achieve this, open the property box of a tendon by double clicking on it. Next, click on the second button on the top left of the property box () and select the left insertion point of where the elevation should be drawn in your model space by clicking somewhere in the background away from your main model. You may have to adjust the vertical scale to improve this display⁸.

⁸ The vertical scale for display can be adjusted by selecting the “distortion scale” menu item from the “Settings” pull-down menu



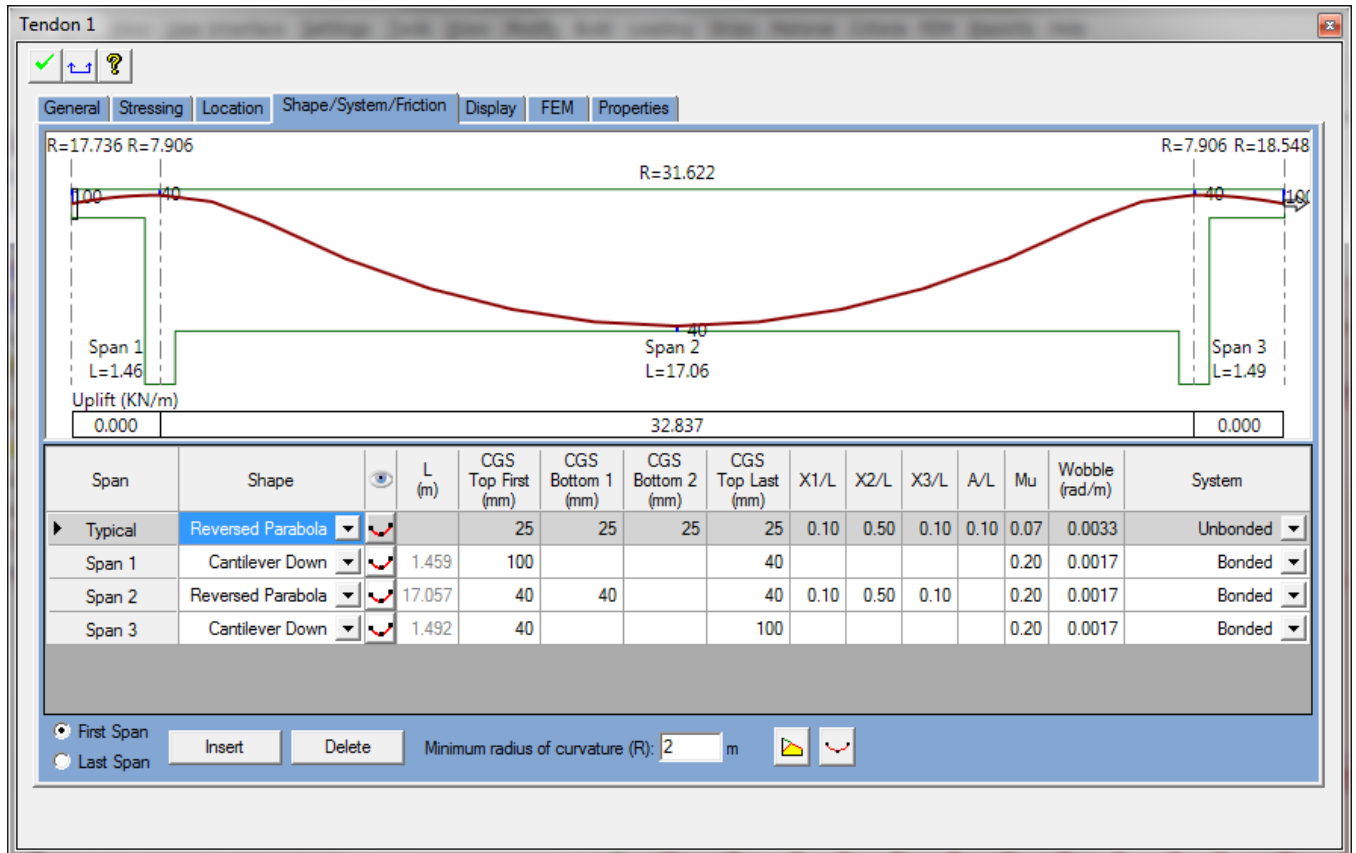


FIGURE 5-7_SI DETAILS OF TENDON IN BEAM

NOTE: At first, some of the text displayed on the screen (such as in **Fig. 6-6**), in this case tendon control heights, may overlap. To eliminate overlap, you can pick each of the text items and move it by click and drag of the mouse.

The tendon that is to the left of the opening was created by selecting a span from the support to each side of the opening, and a span along the opening. To create a profile for this tendon, display it in elevation (as described for the tendon in the beam), increase the vertical scale (distortion factor in Z-direction⁹), and move its control points (hot spots) with the mouse, until you obtain a smooth profile.

Verify Tendon Layout in 3D

We now view the tendon layout in three dimensions to closely examine their arrangement.

- o From the main menu, click on the left teapot (View Model). This opens the display of the structure in 3D.
- o Select "Display in Wire Frame" ().
- o Turn off the wall and beam display ().
- o Change the scale factor in Z-direction to 6, in order to magnify the slab thickness for better viewing ().

⁹ The vertical scale for display can be adjusted by selecting the "distortion scale" menu item from the "Settings" pull-down menu

- o Finally, click on “Redraw ()” button.
- o Rotate and zoom the model to examine the tendon layout (**Fig. 5-8**).

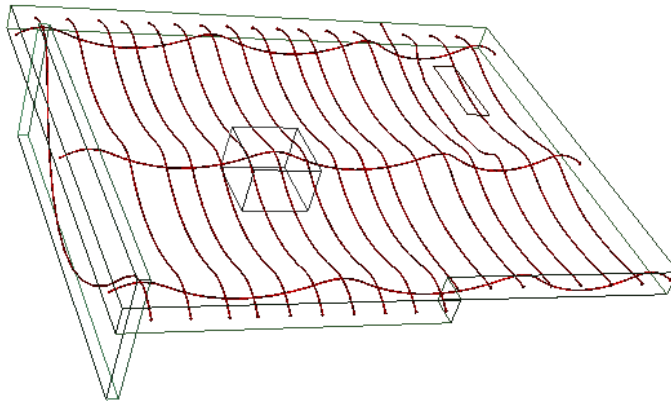


FIGURE 5-8 VIEW OF TENDON ARRANGEMENT

Code Check

The code check part of the design process consists of: (i) determining the actions (moments, shears, etc.) acting on the centroid of each design section, due to each of the load combinations specified by you, (ii) for each load combination, applying the associated forces to the cross-sectional geometry of the design section, (iii) depending on the load combination, calculating the associated stresses, and/or the reinforcement necessary to supplement the prestressing available in that design section, (iv) comparing the stresses with the allowable values of the code selected by you, (v) adding reinforcement or taking other measures as stipulated in the code you have selected, and (vi) preparing a graphical and summary report of the calculations and findings.

- o From FEM pull down menu, click on “Design the Design Sections.”
- o From “Display Strip X”  turn on design strips in the X-direction (**Fig. 5-9**).
- o To display stresses along visible support lines, select one of the Stress options (Top or Bottom) under Design Sections in the Results Display Settings window.

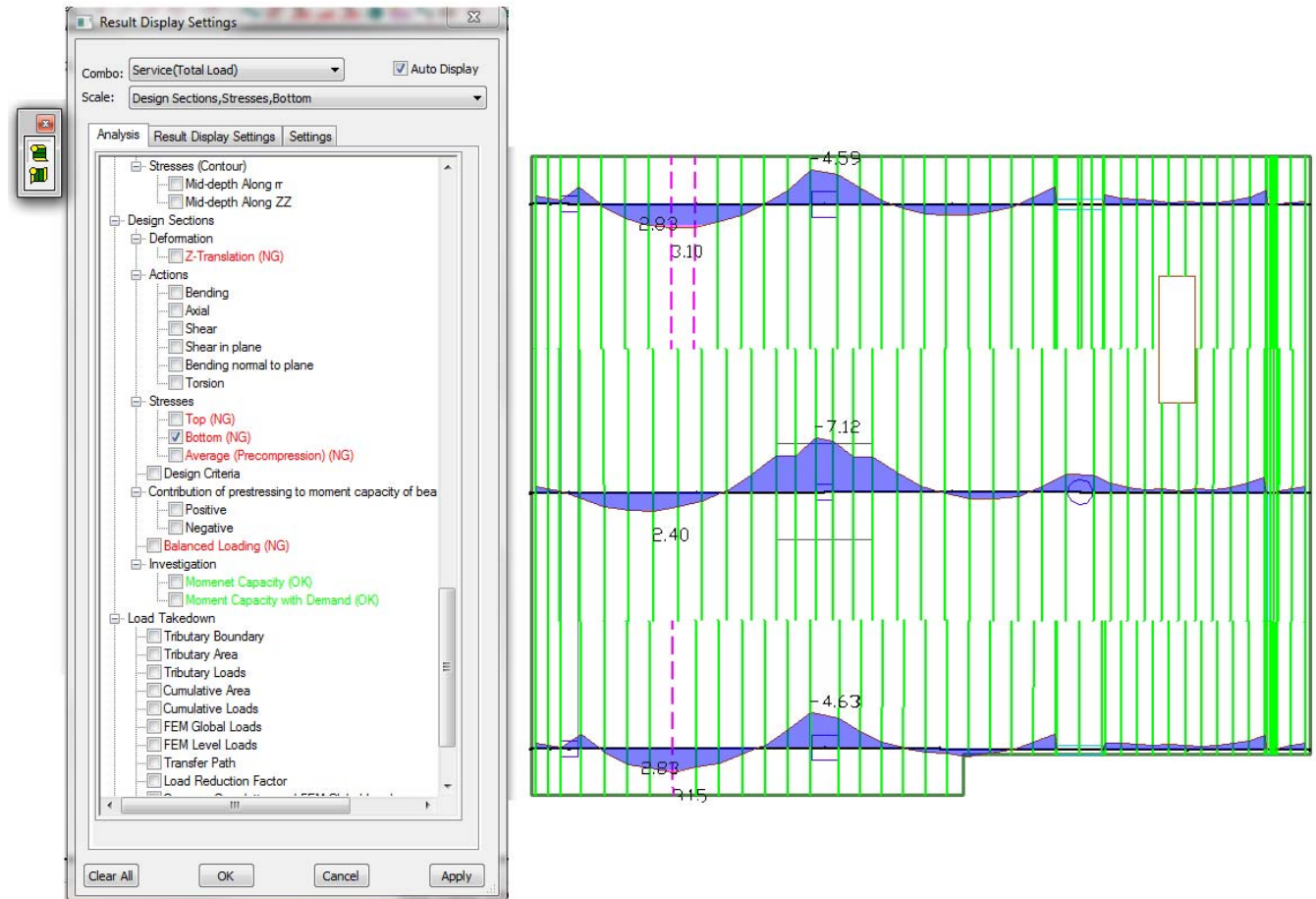
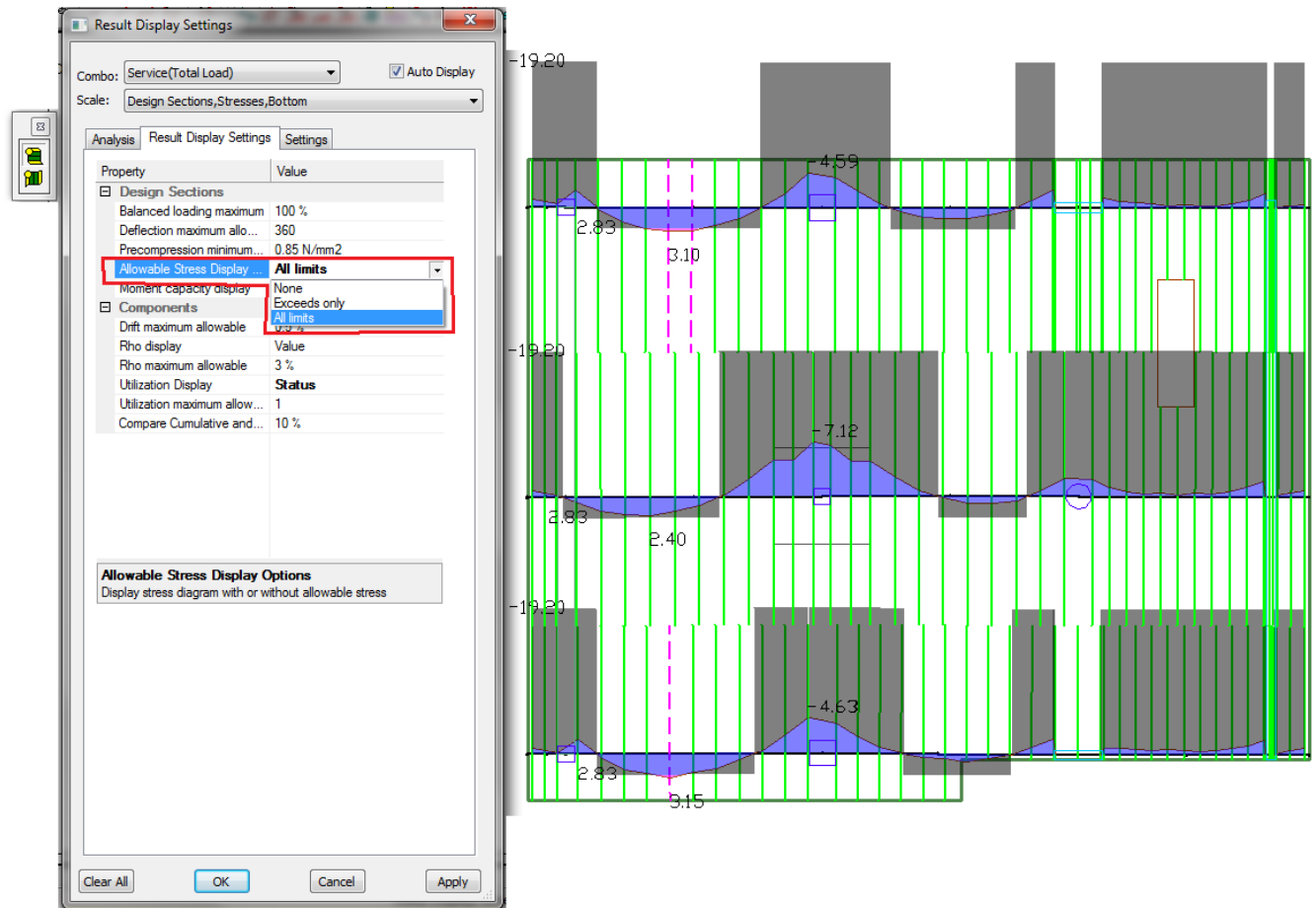


FIGURE 5-9 DISPLAY STRESS CHECK RESULT

In the above diagram, the design sections in which the calculated stresses exceed the allowable values are shown with broken magenta lines. For example in the support line at the top (support line 5), the mid-span sections at the left span are marked with a broken line. This indicates that at the location shown the computed stresses exceed the allowable values specified by you (this is generally the code specified values).

In the Result Display Setting tab, you can change the design strip stress display from not showing any limits that are exceeded, color coding what has exceeded only, or display the allowable limit against the actual calculated stresses. These provide useful variations to how a user can interpret the performance of the slab. The image below shows the same support lines as in **Fig. 5-9** but with all allowable limits.



Follow the steps outlined next to examine the stress distribution in your design strip in more detail.

- o Double click on the Support Line to open its property box.
- o Click on the “BuilderSum”  tool, to display **Fig. 5-10**.

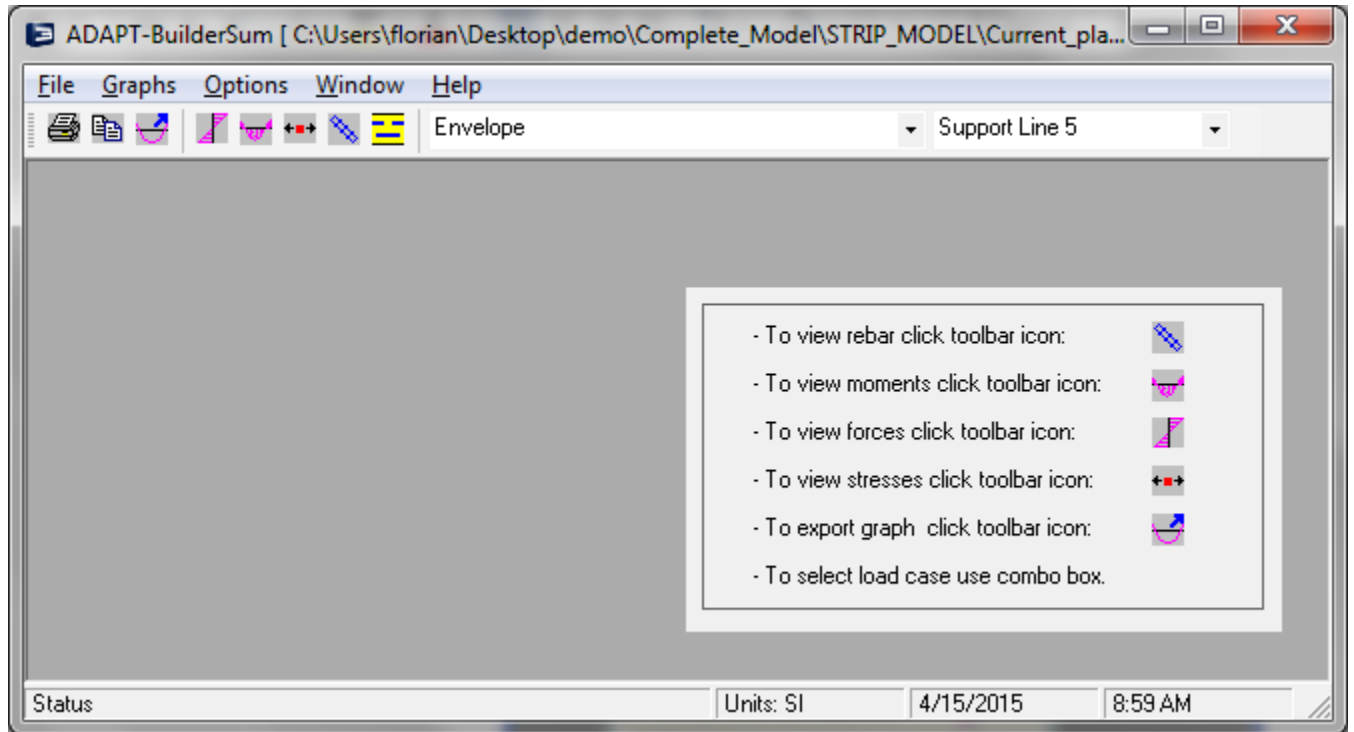


FIGURE 5-10 DESIGN SUMMARY MAIN WINDOW

- o Click on the "Stresses Diagram"  tool, to open the stress diagram (**Fig. 5-11**). Depending on the specific values you have used so far, the stress diagram from your work might look slightly different. The stress diagram in the figure shows the top fiber stresses over the background of allowable stress that is shown with gray background. Tension is shown above the datum line (positive), compression below the datum line. Note that at the left of the second support, the calculated stress exceeds the allowable value, hence the display of broken line at this location in **Fig. 5-19**.

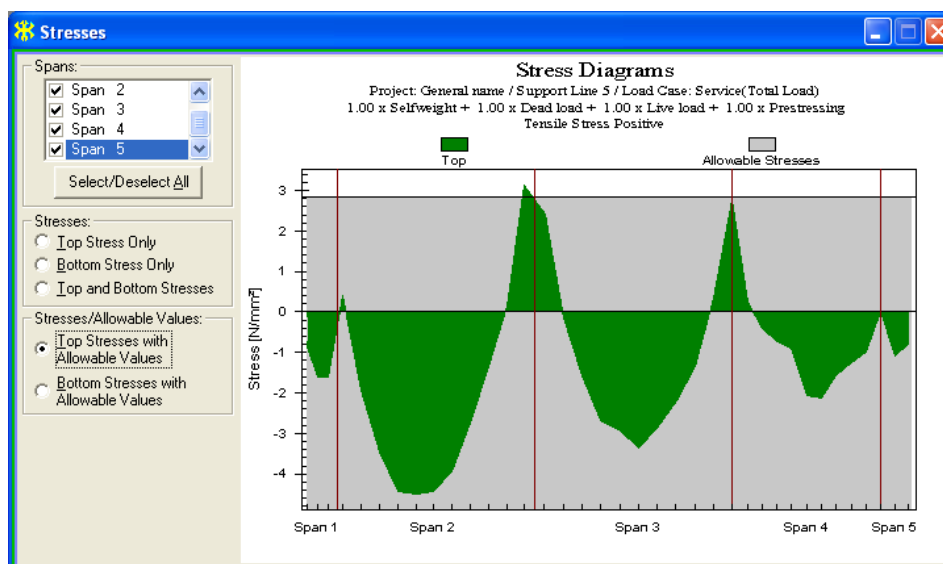


FIGURE 5-11 STRESS DIAGRAM FOR SELECTED STRIP

Experiment with other tools at the top of the screen to see the average precompression, distribution of rebar, moments, shear and other design values. From the combo box at the top of the screen, you can select the display of values for each of the load combinations, or the envelope of all load combinations.

At this stage, you can view and print a summary sheet for the amount, length and layout of the reinforcement of the design strip by clicking on the  tool. This will display the rebar summary shown in **Fig. 5-12**. Again, the figure displayed from your work might look slightly different from Fig. 5-12. Note that the reinforcement shown is for the load combination displayed at the top of the screen and reported as item 1.2 in the figure.

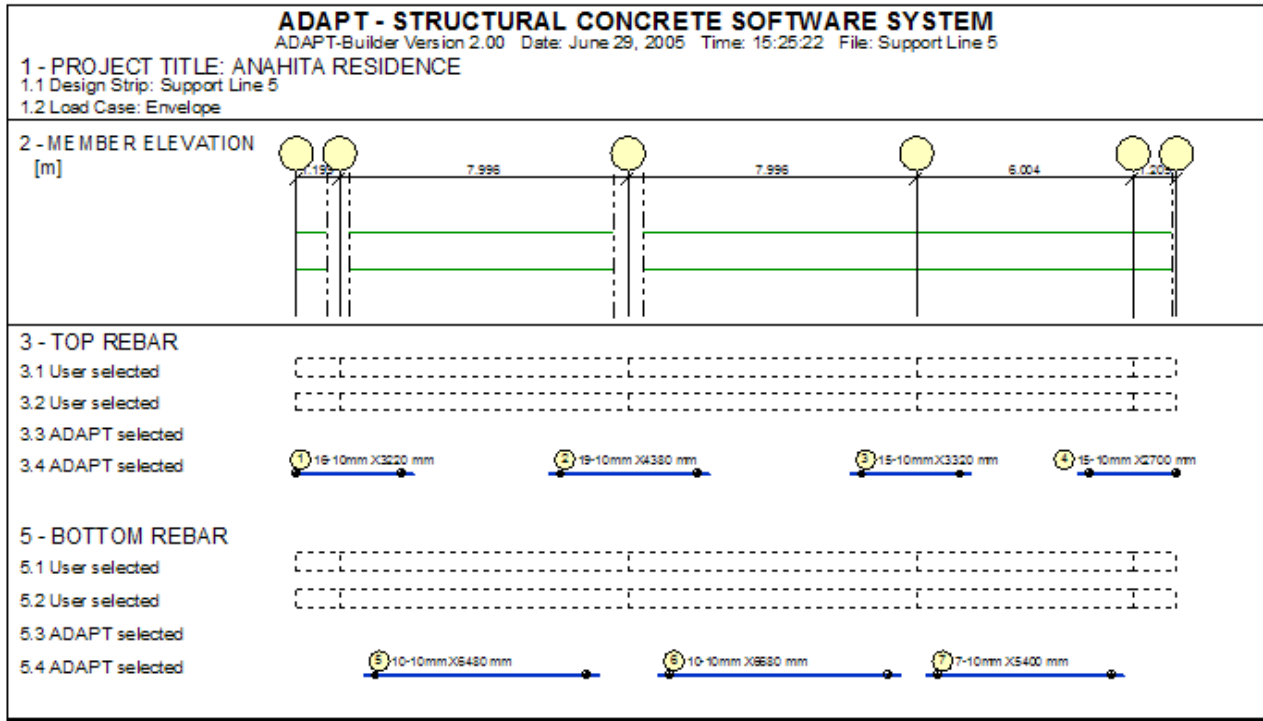


FIGURE 5-12 REBAR SUMMARY SHEET

Rebar Generation

In addition to generating a rebar summary sheet for each of the design strips, Floor-Pro can automatically generate rebar in your model. The rebar generated in your model displays the envelope of all the reinforcement calculated by the program. It displays the location of the reinforcement, the number of bars, the length and the range over which the reinforcement must be distributed.

We will now generate the reinforcement drawing of the floor system we have designed.

- o From the FEM pull down menu click on the “Generate Rebar Drawing.”
- o If the calculated reinforcement does not appear automatically on the screen, from the “User Interface” pull down menu, turn on the “Reinforcement Toolbar” (**Fig. 5-13**).

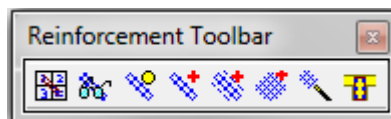


FIGURE 5-13 REINFORCEMENT TOOLBAR

- NOTE: In the general case, the bottom rebar in the banded direction of the tendons is banded below the band. Unlike the diagram in Fig. 6-14, this is recognized by the program automatically and so displayed. In the rebar plan, you can select the size of the displayed text (font), such as to make it legible and clear for the size of drawing you plan to plot.*

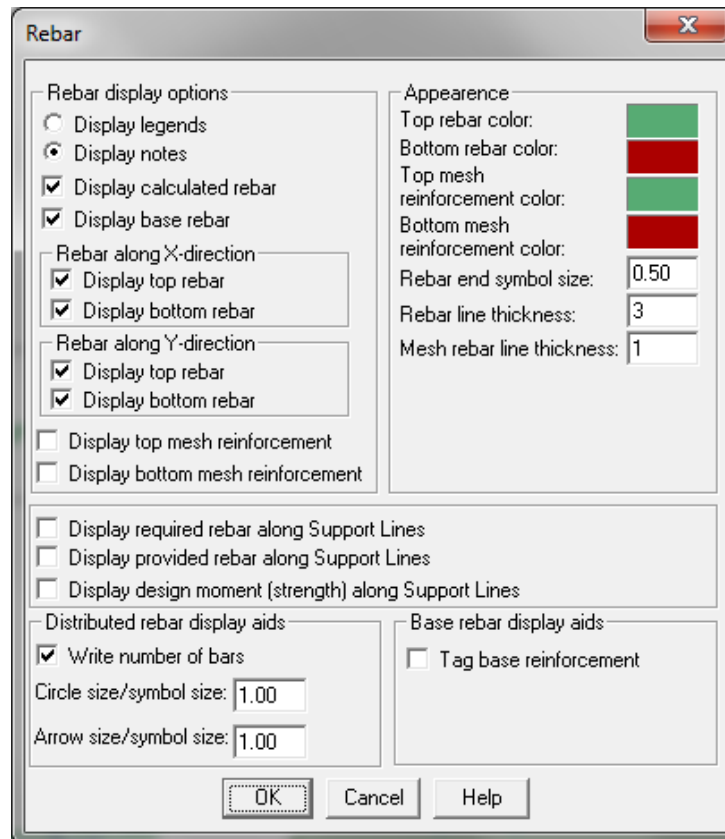


- o To change the size of the text displayed, use the “Select/Set View Items” . For “Rebar” entities, change the font size to 200mm (8in) for convenient viewing on computer screen.
- o The following helps you to manipulate the graphical display of rebar.
 - To change the length of a bar graphically, select the bar, pick one of its hot spots (identified near each end) and drag it to the length of your choice. Note that the text will automatically adjust itself to the new length. Later, you will learn how to change the length to an exact value of your choice by entering the new length in a data cell.
 - To change the orientation of a bar, pick one of its hot spots and rotate it to the new orientation.

- To move a bar, select it, pick one of its hot spots (identified near each end) and move it to the location of your choice while “control” key is depressed.
 - To move a text to a new location, select the text, pick its hot spot, and move it to the new location.
 - To change the extent of a bar, pick the end of the arrow that indicates its limit and drag it to the new location. The bar spacing will adjust itself automatically, such as to maintain the total area of reinforcement associated with the bar distribution you edit.
- o Open the rebar property box (**Fig. 5-15**) by clicking on the “Open Rebar Display Options” tool  from **Fig. 5-13**.

NOTE:

If you are not going through this tutorial in a supervised workshop, read the User Manual Rebar Module to learn more about the rebar plan.



(a) SI units

FIGURE 5-15 REBAR DISPLAY OPTOINS

- o Try the various display options shown in **Fig. 5-15**.

Figure 5-16 shows the close up of rebar display over one of the columns for user selected SI system of units.

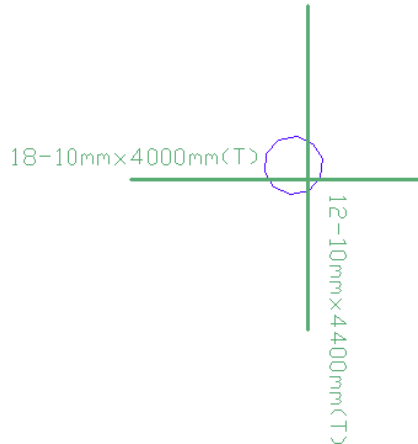


FIGURE 5-16 CLOSE UP OF REBAR DISPLAY OVER A COLUMN

Let us change the bar size and length of one of the top bars shown over the column in **Fig. 5-16**.

- o Double click on the bar that you want to change to open its property box (**Fig.5-17**). This figure is for SI system of units. The figure for the American units is similar.
- o Using the combo box, change the bar size and its length. Note that when you change the bar size, the number of bars is automatically adjusted to maintain the total area of rebar reported by the calculation.

Rebar

✓ ?

Rebar Specifications | Location | Properties

☐ Base ☒ Calculated

Placement and grouping
☒ Top ☐ Bottom

#: 3 Group: Group 1

Label: Rebar 3

Material: Mild Steel 1

Bar specification
☐ USA ☐ MKS ☒ SI

17-10mmx3000mm(T)

Material	Size	Dia(mm)	Area(mm ²)
Rebar: 10mm	10.0	78.5	

Number of bars: 17 ☒ Fixed

Length of bar: 3.000 m

Spacing: 50 mm ☐ Fixed

Cover from top: 25 mm

Display bar description
☒ Describe bar (write bar length)
☐ Describe bar (do not write bar length)
☐ Describe bars by legend
☐ Describe bars by notes
☒ Describe bar (write quantity for distributed bars)

Legend: D

Bar notes:

Rebar distribution
☒ Distributed ☐ Grouped

Extent on side 1: 0.500 m

Extent on side 2: 0.500 m

☒ Round down spacing

Help

FIGURE 5-17 REBAR PROPERTY BOX

In the forgoing, the program selected reinforcement for the entire amount required by the code you specified. Many engineers provide a base reinforcement in their projects, regardless of the outcome of design. A common practice is to place a mesh of bars at the bottom, at the top, or on both sides of a slab, or at selected locations. The program gives you the full flexibility to pre-specify reinforcement at selected locations. In this case, the program will report the computed reinforcement that is necessary in addition to the base reinforcement you have specified. Next, we will review the steps that are required to specify base reinforcement.

Let us add a mesh reinforcement. For mesh reinforcement to be used as “base reinforcement” by the program do the following:

- Select the slab region over which you intend to add mesh reinforcement.
- Click on “Mesh Rebar Wizard”  from the “Reinforcement Toolbar- Fig. 5-13.” Specify information on the dialog box as shown below.

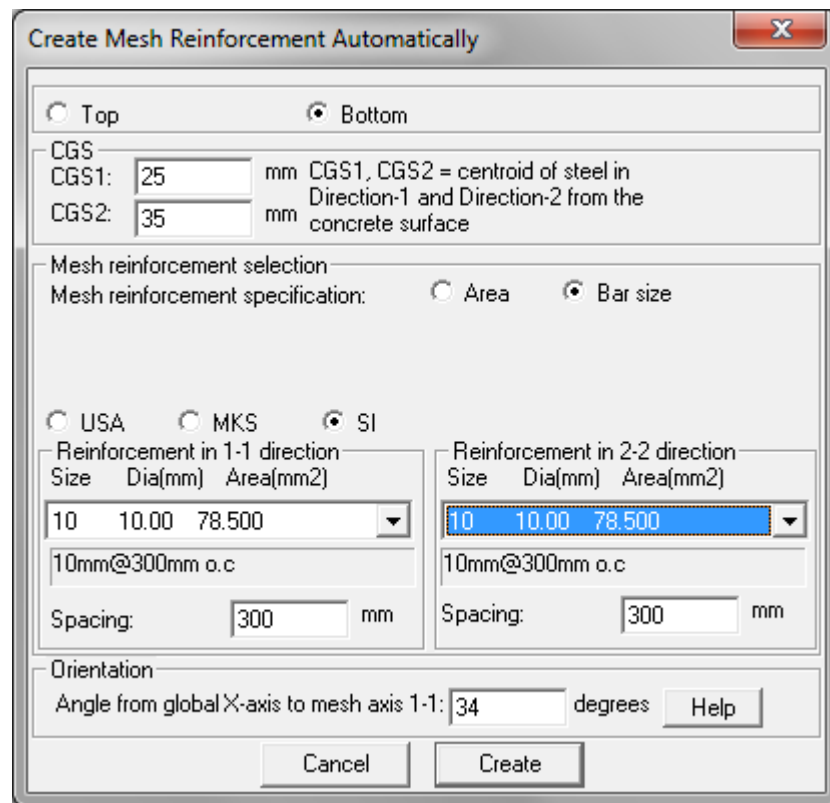


FIGURE 5-18 MESH REBAR WIZARD DIALOG BOX

NOTE:

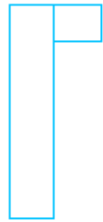
Mesh rebar you specify at this stage will be shown on your drawing, but will not be accounted for as part of your calculation. If you want to provide a top or bottom mesh, and you intend the area of steel of the mesh to be included in your calculation, you must either specify the mesh before the design stage of the program, or go to FEM pull down menu and re-design the structure. If a mesh reinforcement is specified before the design stage, the program will recognize its presence and report only the reinforcement that is needed in addition to that provided by the mesh.

Likewise, you may specify individual bars or group of bars as “base reinforcement” to be included in your design. Refer to DRD manual for the details.

The rebar plan that was generated, viewed and edited, will be converted into a structural drawing in the next Session.

SESSION (6) – Generation of Structural Drawings

In this session we will generate a set of professional-quality structural drawings for the tendon layout, and the supplemental reinforcement. We will export these drawings to AutoCAD, ready for plotting. A critical criterion in the generation of the structural drawings is that they should detail all the features that are intended for construction. For example, for the purposes of analysis, walls may be modeled as shown in **Fig. 6-1(a)**. But for construction they should appear as illustrated in (b) of the same figure. Likewise, an opening that on the structural model appears like in (c) is generally shown as in (d) on construction drawing.



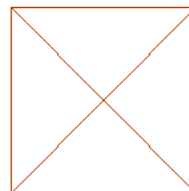
(a) Representation of wall in structural analysis model from layer (Current_plane_wall)



(b) Representation of wall in structural drawing from layer (ADAPT_walls_draftng)



(c) Opening as it appears on the analysis model from layer (Current_plane_wall)



(d) Representation of wall in structural drawing from layer (ADAPT_walls_draftng)

FIGURE 6-1 REPRESENTATION IN ANALYSIS MODEL AND STRUCTURAL DRAWING FOR CONSTRUCTION

Further, the rebar on top of a wall will appear as shown in **Fig. 6-2**, where only the outline of the wall is detailed.

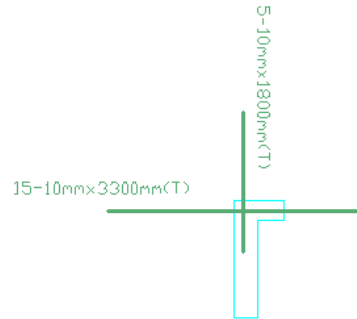


FIGURE 6-2 REPRESENTATION OF REINFORCEMENT OVER WALL ON STRUCTURAL DRAWING

Prior to importing the DWG drawing into the Builder environment, or subsequent to the import of the drawing in the Builder environment, we duplicated several layers of the drawing for the purpose of generating structural drawings. For example, as explained in Session Three, we copied the walls that we wanted to appear on our structural drawing in a layer called “ADAPT_Walls_Drafting.” This is the layer that contains the compound walls in the manner shown on **Fig. 6-1(b)**. In this workshop tutorial we do not have compound walls, but in most cases there will compound walls made up of several segments. Compound walls for analysis are idealized as shown in Fig. 7-1(a) when brought to the layer “ADAPT_Walls.”

Once we organize the information on the screen, as we want it to appear on the structural drawings, we must turn off the layer we used for analysis and turn on the layers that we want to use for structural drawing. For example **Fig. 6-3**, shows the Select Layers dialog window and how all layers can be turned off and only one selected for display.

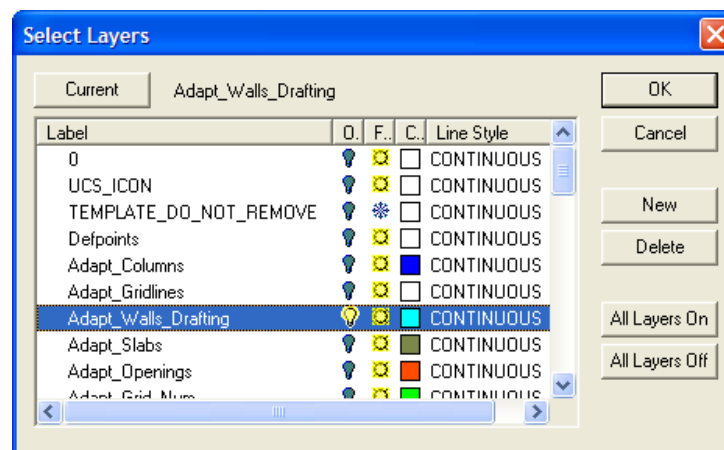


FIGURE 6-3 LAYER DISPLAY DIALOG WINDOW

We can add dimensions, text, copy and paste, and edit the plan on the computer screen in the manner we want it to appear on the structural drawings. Before, exporting it to AutoCAD, however, we must change the font, font size, line color and thickness to the selection we prefer on our DWG drawings. This is explained in greater detail further on and in Appendix A.

Rebar Drawing

For rebar drawing, (i) display on the screen the rebar information you wish to appear on your structural drawing, (ii) if needed, edit the rebar displayed (bar size, length, orientation, color, line type, etc), (iii) add reinforcement to the plan, if needed, (iv) turn off the structural model layers, (v) turn on the drafting layers, (vi) select the line types and color suitable for DWG drawing¹⁰, save and export to DWG.

To change the properties of a group of bars, (i) select them all, (ii) from “Modify” pull down menu, select (iii) Modify Item Properties menu item. The dialog box shown in **Fig. 6-4** appears. . Enter the modification for the bar selected, press OK to close and implement your selection.

FIGURE 6-4 MODIFY ITEM PROPERTY WINDOW FOR REBAR

¹⁰ You can pre-define the font, line color, and line thickness that are suitable for the size of the hardcopy you plan to use once, and save them. The program will automatically select the hardcopy print properties you have pre-defined, each time you send the information to the printer. To pre-define the print options, click on the “Plot/Print Settings” from the “Settings” pull-down menu.

Once you are satisfied with the arrangement of reinforcement on the computer screen, go to the “File” pull-down menu and choose the ‘Export DXF/DWG’ option. Then choose the version of the AutoCAD file you wish to use, and click Ok.

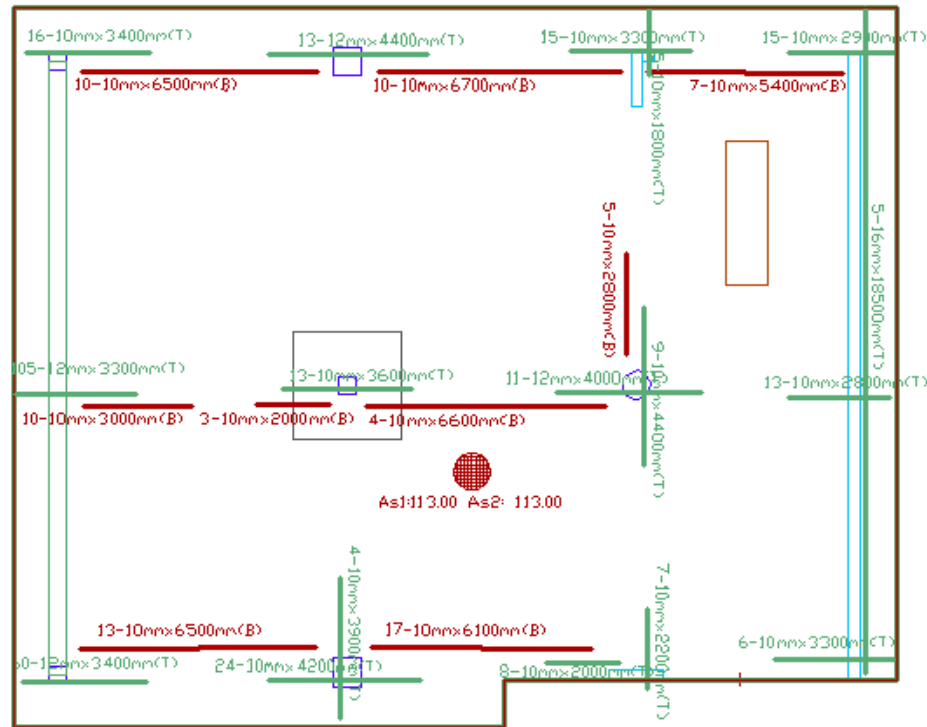


FIGURE 6-5 AUTOMATICALLY GENERATED REBAR DRAWING
IN BUILDER ENVIRONMENT

Tendon drawing

To select the information you want to be displayed on the post-tensioning drawings, open the ‘Tendon Plans’ dialog window (**Fig. 6-6**).

- From Reports pull-down menu select “Single Default Reports.”
- From the side menu that opens, select “Graphical.”
- Finally select “Tendon Plan.” The Tendon Report dialog window displayed in **Fig. 6-6** will open.

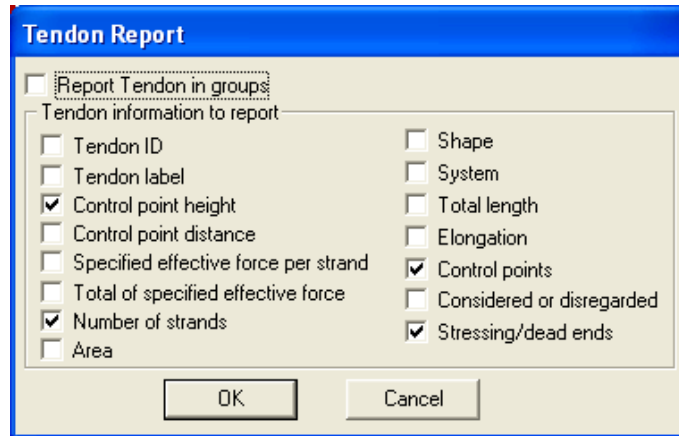


FIGURE 6-6 TENDON REPORT DIALOG WINDOW

You can either display the information on each tendon individually, or you can organize the tendons that are identical into groups, and display the information on each group only once. The latter option of display will result in a less-congested display of values.

- On the Tendon Report dialog window, make the selection shown in **Fig. 6-6**. The tendon drawing shown in **Fig. 6-7** will be generated.

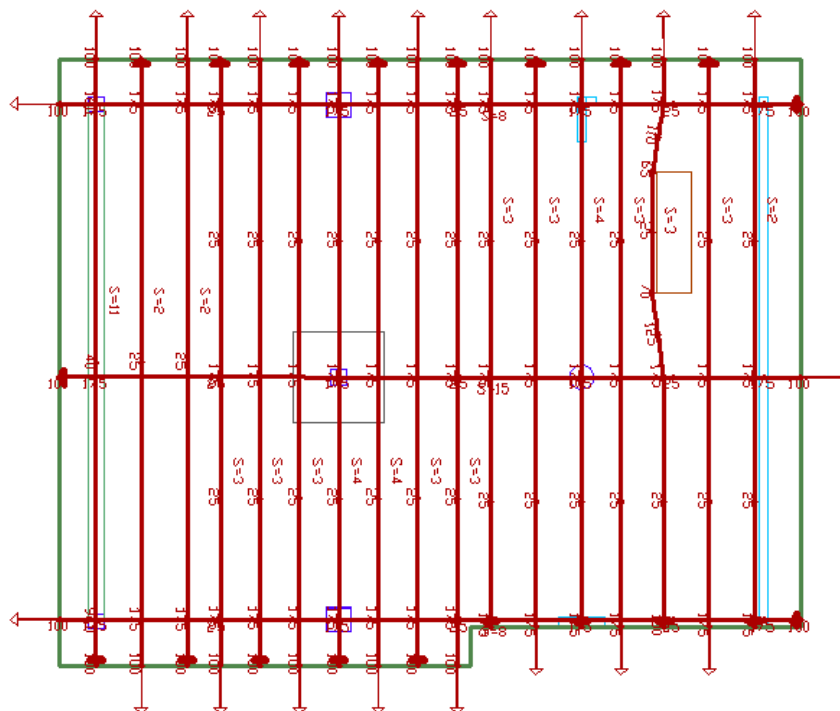


FIGURE 6-7_SI TENDON GRAPHICAL REPORT

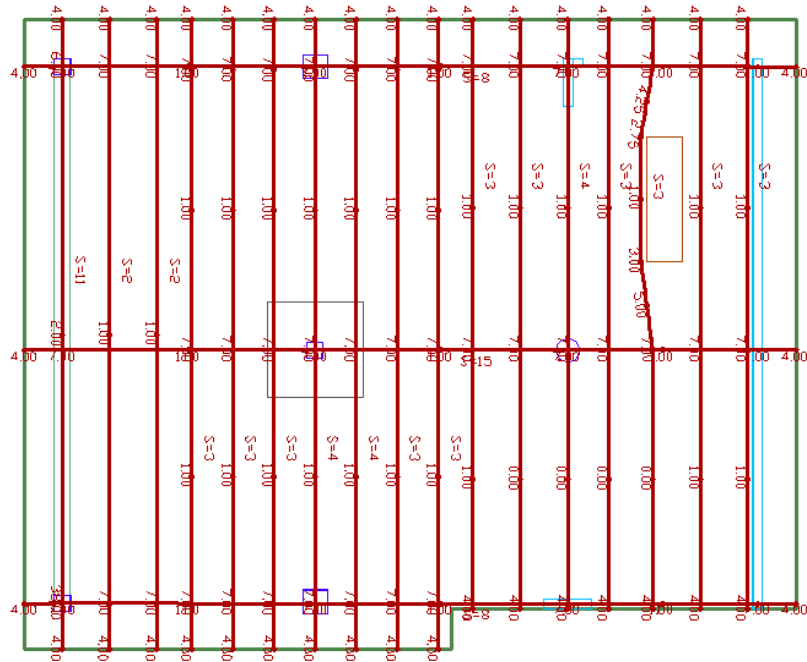


FIGURE 6-7_US TENDON GRAPHICAL REPORT

Once you are satisfied with the tendon information on the screen, and you want to export it to AutoCAD, you must go to the “File” pull-down menu and choose the “Export DXF/DWG” option. Then choose which version of AutoCAD file you wish to create and click OK.

Preparation for Exporting Floor-Pro Files to AutoCAD

The following steps will help to minimize the amount of editing needed, once a Floor-Pro solution is exported to AutoCAD for generation of structural drawings.

- Use the Grouping option of the program to group tendons that have the same profile and length, hence the same chair (support) arrangement and elongation. The following explains how to create groups and assign entities, such as tendons, to it.
 - From the “Settings” pull down menu, select “Grouping.” The dialog window shown in **Fig. 6-8** opens.
 - The  icon indicates whether items in a group are visible or not.
 - Use the New button to create new groups. Select the group name to rename it.
 - To assign an entity to a group, open the property window of the entity, scroll down the combo box that lists the groups and select the group of your choice.
 - Alternatively, you can assign multiple objects in your model to a group using the Modify Item Properties  function that is available under the Modify menu.

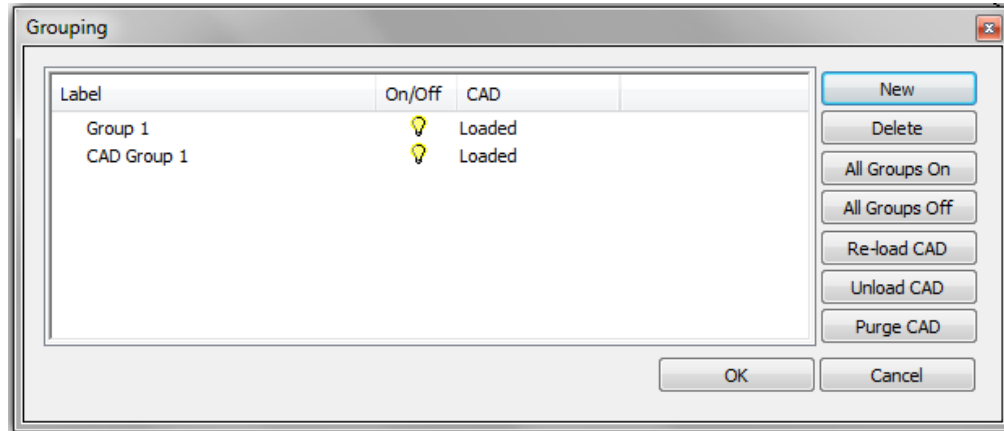
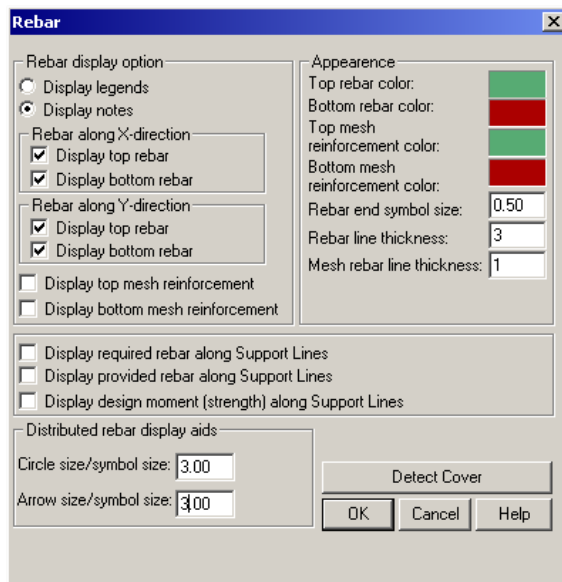
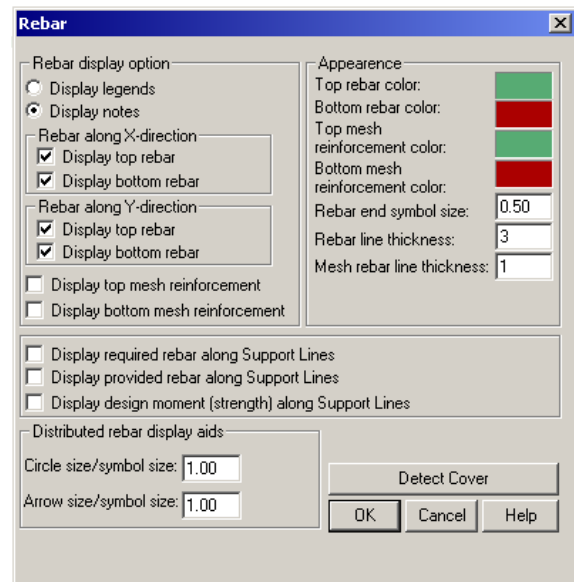


FIGURE 6-8 GROUPING DIALOG WINDOW

- For the entities that you want to be displayed on the paper drawings, such as tendon or rebar, set font height to be 250mm (10in) and symbol size to 50mm (2in). These values are set in the "Select/Set View Items" tool (Fig. 6-7). These font sizes are suitable for drawings that will be printed on large sheets (approximately 1000 mm; 36" dimension). Obviously, the suitable font size for viewing on the computer screen in Floor-Pro will be different
- Using the rebar tools, place any additional rebar that you consider is necessary to be shown on your drawing.
- For the rebar drawing, open up the rebar property dialog window (Fig. 6-9) and set the "Circle" and "Arrow" size to 3 (1). These two symbols control the clarity of display of the range of distributed reinforcement.



(a) SI units



(b) US units

FIGURE 6-9 REBAR PROPERTY DIALOG WINDOW

- Turn on the layer ADAPT_Slab_Drafting, and others that you created for drafting.

SESSION (7) – Preparation of Package of Structural Calculations



The structural calculation package generally consists of a lead part that briefly describes the structure and its design criteria. This is followed by a detailed report for each of the levels. In this tutorial, the two packages are provided separately, since it is assumed that at the start of the tutorial only the design criteria are available.

Report Setup

The program generates several types of reports. These include reports intended to check the validity of the solution, and a comprehensive report for submittal to building officials. The reports can be tabular, graphical or combined. Reports can include text and graphics (bitmaps) that you may have generated outside the environment of Builder Platform, as well as graphics and text that in the course of the analysis and design of your current project you may have found of interest. The sample report that is included in your CD for this tutorial includes text and graphics that were imported into the Builder program at time of report generation. For this tutorial, however, we will limit ourselves to a basic report that can be compiled directly from the default pages of the program.

It is recommended that you first review the sample report generated for this project, before attempting to generate your own report. There are two sample reports saved on your tutorial CD. One is more comprehensive and includes graphics captured during the modeling and execution. The other is simple. It is limited to the default pages that you can select directly from the report generation manager of the program. To view the sample reports, open the folder "Compiled Report" on the tutorial CD. The report in this folder is saved in PDF format. You need to have Acrobat Reader installed on your computer to open the report. If the program is not already installed in your computer, you can install the copy included in the "Utilities" folder of your tutorial CD¹¹.

The program generates its tabular and text information in "RTF" format, which can be opened and edited by practically all word processors. But, for ease of viewing, it is converted to the electronic file with PDF format.

NOTE:

A detailed account of how to generate reports automatically; how to import text and graphics in your report; and how to compile a professional report is given in the Floor-Pro User Manual. It is recommended that you review this document if you are not following this tutorial in a supervised workshop.

The compiled report can be organized using the following report generation window that is accessible from the "Reports" pull down menu:

¹¹ Open the Utilities folder and click on AdbeRdr70enu.exe

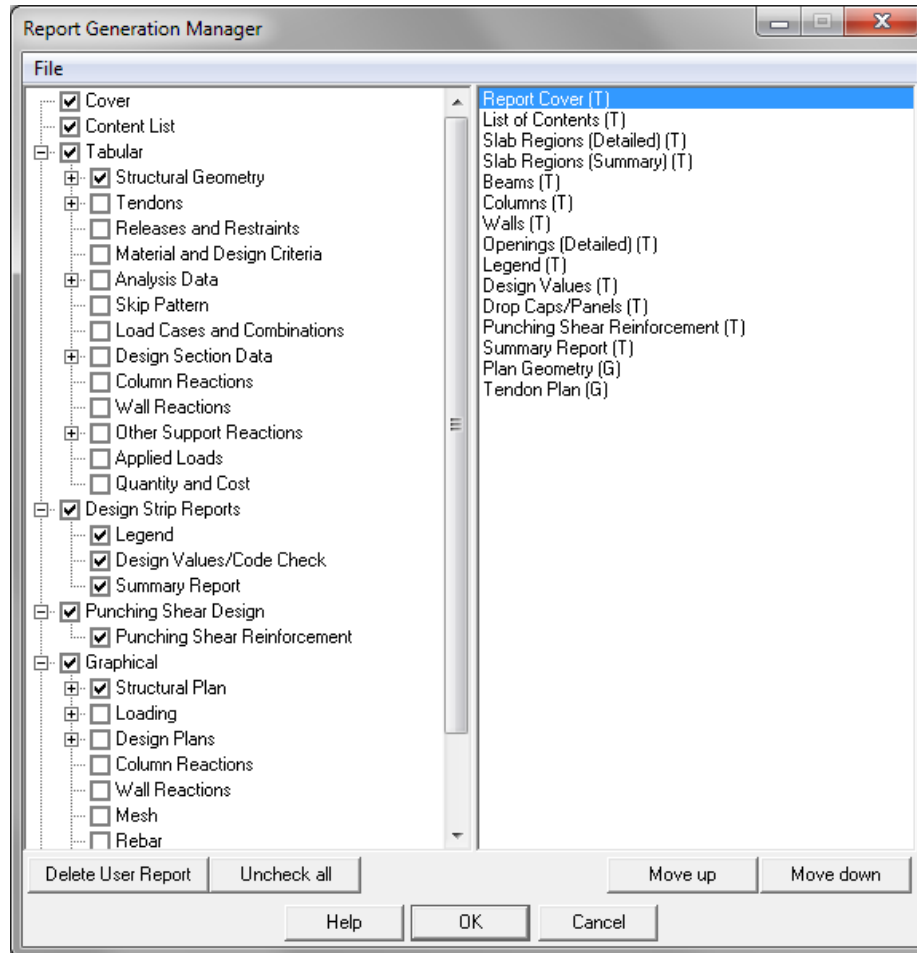
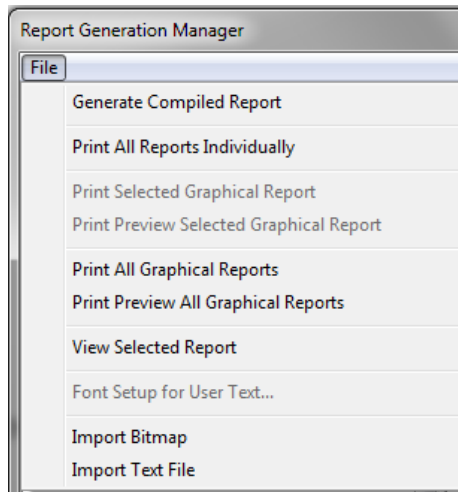


FIGURE 7-1 WINDOW FOR THE GENERATION OF COMPILED REPORTS

- From Report pull-down menu, select “Compiled Reports.” The “Reports Generation Manager” shown in **Fig. 7-1** opens. If during a previous run of the program you had already set up the selection and arrangement of your report, this will automatically appear on the right hand side of the Report Generation Manager.
- Click on the boxes next to the report types you wish to have in your complete report. Selected report components are automatically listed in the right pane.
- You can move individual reports up and down to organize them in the order you want the final report to appear.
- Use the options under the File menu to view/print individually selected report components or generate the complete compiled report with all of its sections.



Estimate Quantities

The quantities of concrete, rebar and post-tensioning tendons are calculated automatically. These are available from the list of reports. Details of these reports are being finalized.

The program provides you with a list of all tendons used. The list includes the number, diameter and length of each tendon, as well as total strand length and weight. A partial table for the current project is displayed below.

TABLE 7-1_SI 300.00 PT TOTALS

Tendon ID	Length	Strand Diameter	Number Of Strand	Total Length
	m	mm		m
1	20.007	13	11	220.081
2	20.007	13	2	40.015
3	20.007	13	2	40.015
4	19.997	13	4	79.988
5	18.713	13	4	74.851
6	18.713	13	3	56.138
7	18.713	13	3	56.138
8	19.997	13	4	79.988
9	19.997	13	3	59.991
10	19.997	13	3	59.991
11	19.997	13	3	59.991
12	19.997	13	3	59.991
13	19.997	13	3	59.991
14	18.713	13	3	56.138
15	18.713	13	3	56.138
16	18.713	13	2	37.425
17	18.767	13	3	56.300
18	24.400	13	8	195.200
19	24.400	13	15	366.000
20	24.400	13	8	195.200

SUMMARY

Strand Diameter	Total Length
mm	m
13	1909.567

TABLE 7-1_US 300.00 PT TOTALS

Tendon ID	Length	Strand Diameter	Number Of Strand	Total Length
	ft	in		ft
1	65.75	0.50	11	723.25
2	65.75	0.50	2	131.50
3	65.75	0.50	3	197.25
4	65.75	0.50	2	131.50
5	65.75	0.50	3	197.25
6	65.75	0.50	3	197.25
7	65.75	0.50	4	263.00
8	65.75	0.50	4	263.00
9	65.75	0.50	3	197.25
10	65.75	0.50	3	197.25
11	61.53	0.50	3	184.59
12	61.53	0.50	3	184.59
13	61.53	0.50	4	246.12
14	61.53	0.50	3	184.59
15	61.72	0.50	3	185.16
16	61.53	0.50	3	184.59
17	61.53	0.50	3	184.59
18	80.19	0.50	8	641.49
19	80.19	0.50	15	1202.79
20	80.19	0.50	8	641.49

SUMMARY

Strand Diameter	Total Length
in	ft
0.50	6338.49

To generate the tendon quantities table, do the following:

- From the Reports pull-down menu, select “Single Default Reports,” followed by “Tabular,” and “Tendon Totals.”
- Using the same pull-down menu, you can create Rebar Totals, Quantity and Cost reports (**Fig. 7-2**).

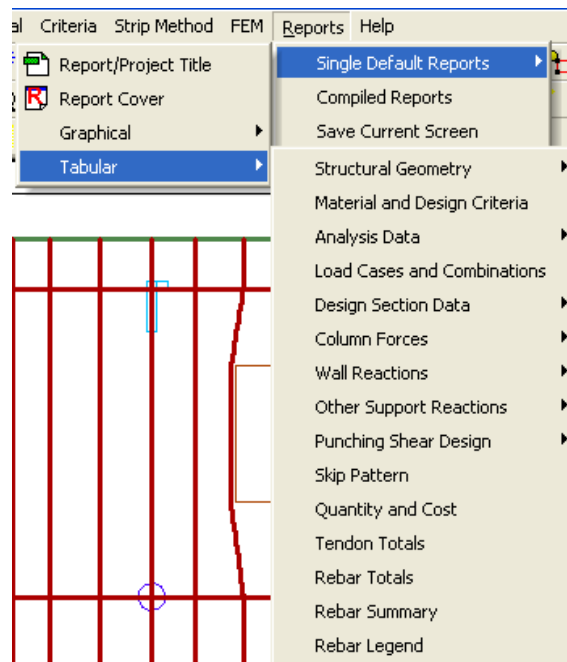


FIGURE 7-2 SINGLE DEFAULT REPORTS OPTIONS

SESSION (8) – Fabrication (Installation, Shop) Drawings

In this session we will generate a set of professional-quality structural drawings for the tendon layout on site.

To access the tools for the generation of shop drawings, turn on the “Fabrication (Installation) Toolbar” from the User Interface pull down menu (**Fig. 8-1**).

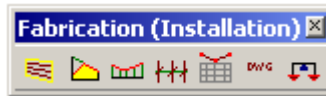


FIGURE 8-1 FABRICATION (INSTALLATION) TOOLBAR

- Click on “Display Tendon’s Chair Height ” tool.
- On the dialog window, selected the information displayed in **Fig. 8-2**.
 - Once you have selected the spacing between chairs to be 1.0m (3ft) make sure you click the “Apply to All” button just above where you entered the spacing value, in order for the change to take effect over all tendons.
- In order to show Chair Heights of tendons within a beam elevation, double click the tendon going through the beam. Then click on the  button, and follow the instructions on the screen.
- Make sure again that you turn on all the Layers created for drafting.
- Click on Export DXF/DWG option in the “File” pull-down down menu.

ID	Dia(mm)	z-offset(mm)	Spacing(mm)	Label
1	13	0	1000	Tendon 1
2	13	0	1000	Tendon 2
3	13	0	1000	Tendon 3
4	13	0	1000	Tendon 4
5	13	0	1000	Tendon 5
6	13	0	1000	Tendon 6
7	13	0	1000	Tendon 7
8	13	0	1000	Tendon 8
9	13	0	1000	Tendon 9
10	13	0	1000	Tendon 10
11	13	0	1000	Tendon 11
12	13	0	1000	Tendon 12
13	13	0	1000	Tendon 13
14	13	0	1000	Tendon 14

z-offset: 0 mm Apply to all

☐ Divisions between high and low points 10

☒ Spacing between chairs 1.000 m

Setting

Round up/down to the nearest: 5 mm

OK Help Cancel

(a) SI units

ID	Dia(in)	z-offset(in)	Spacing(in)	Label
1	0.50	0.00	36.00	Tendon 1
2	0.50	0.00	36.00	Tendon 2
3	0.50	0.00	36.00	Tendon 4
4	0.50	0.00	36.00	Tendon 3
5	0.50	0.00	36.00	Tendon 5
6	0.50	0.00	36.00	Tendon 6
7	0.50	0.00	36.00	Tendon 7
8	0.50	0.00	36.00	Tendon 8
9	0.50	0.00	36.00	Tendon 9
10	0.50	0.00	36.00	Tendon 10
11	0.50	0.00	36.00	Tendon 11
12	0.50	0.00	36.00	Tendon 12
13	0.50	0.00	36.00	Tendon 13
14	0.50	0.00	36.00	Tendon 14

z-offset: 0.00 in Apply to all

☐ Divisions between high and low points 10

☒ Spacing between chairs 3.00 ft

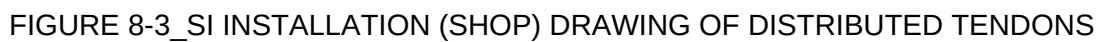
Setting

Round up/down to the nearest: 0.25 in

OK Help Cancel

(b) US units

FIGURE 8-2 DIALOG WINDOW FOR GENERATION OF SHOP DRAWINGS



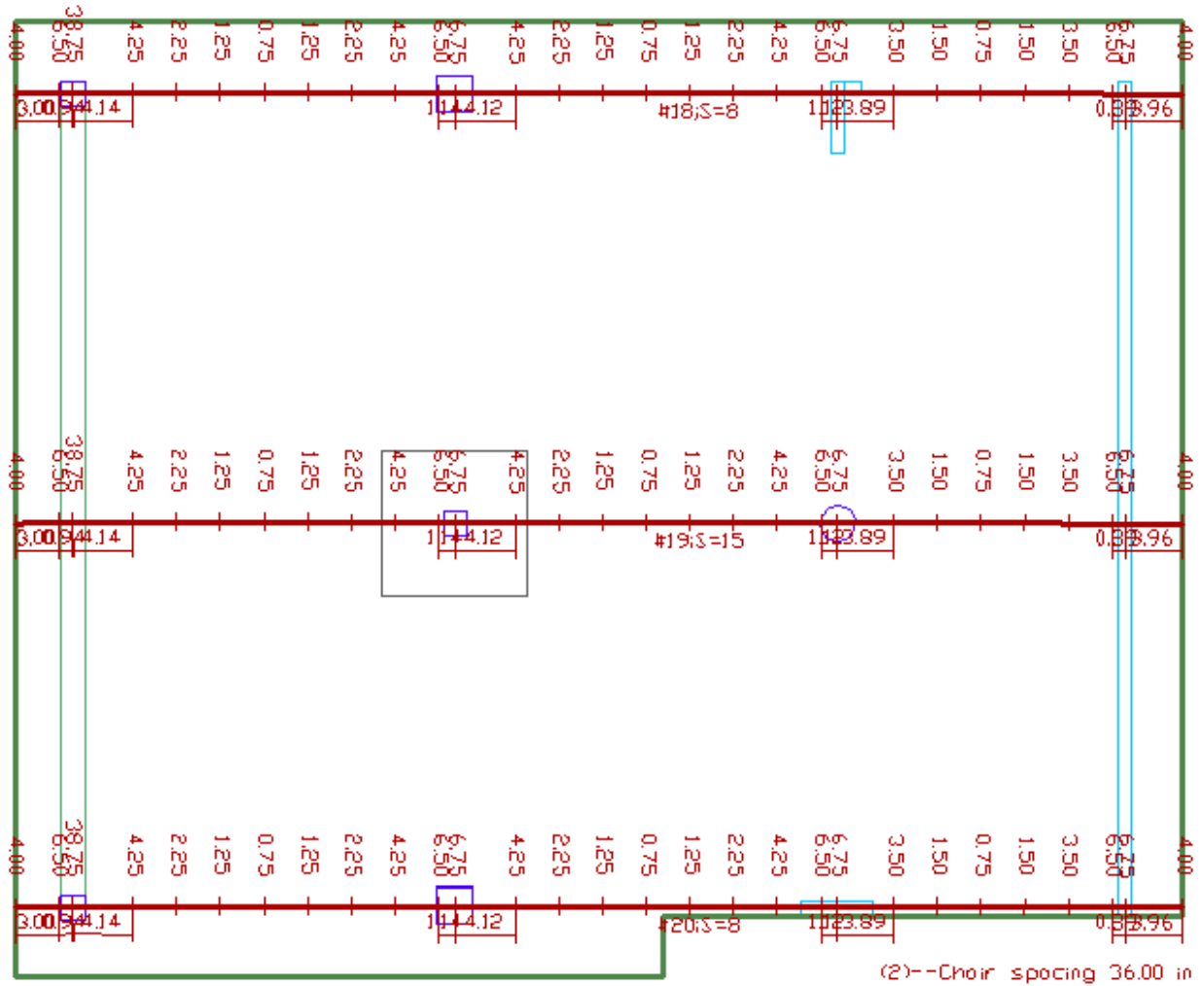
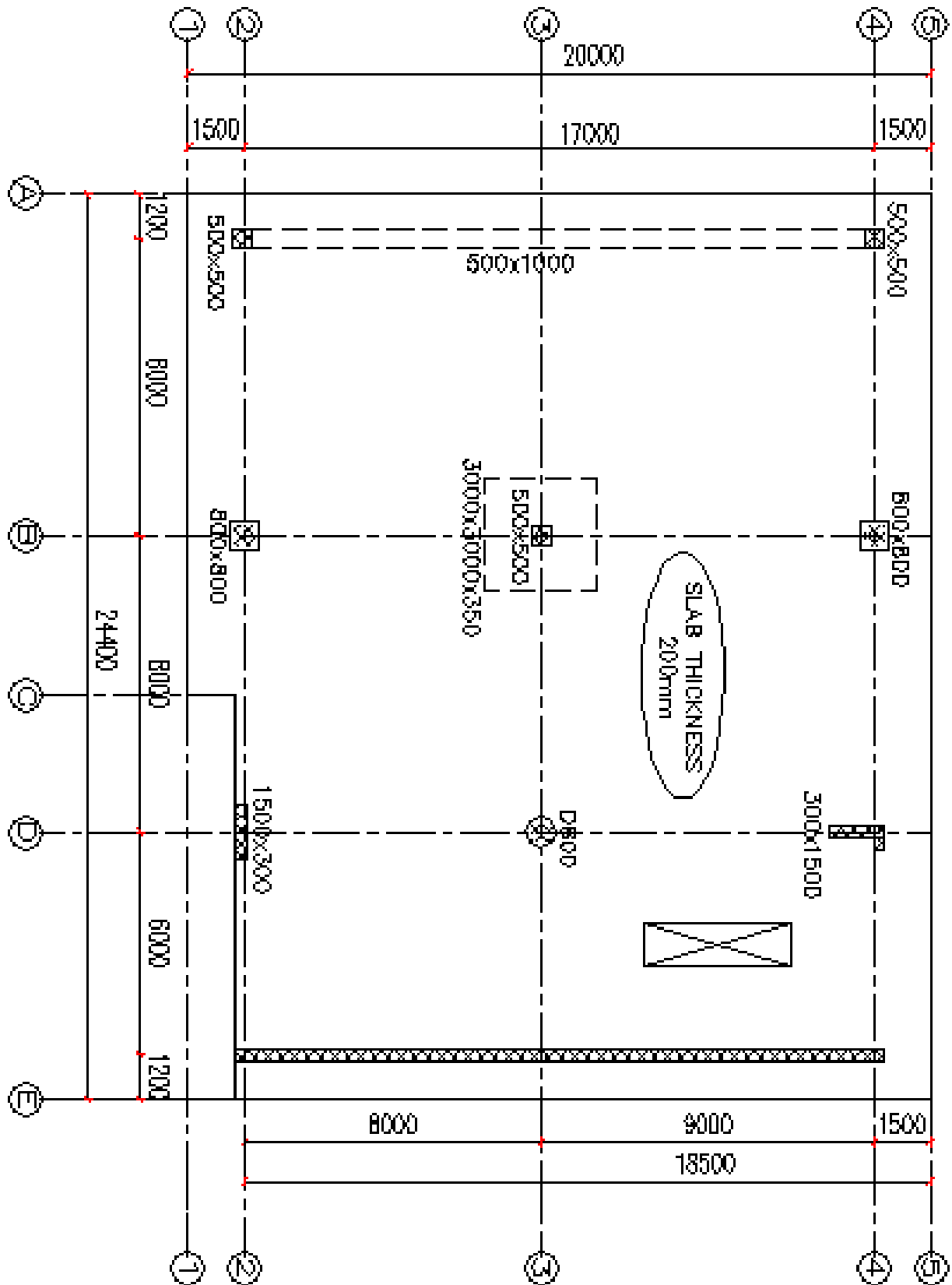
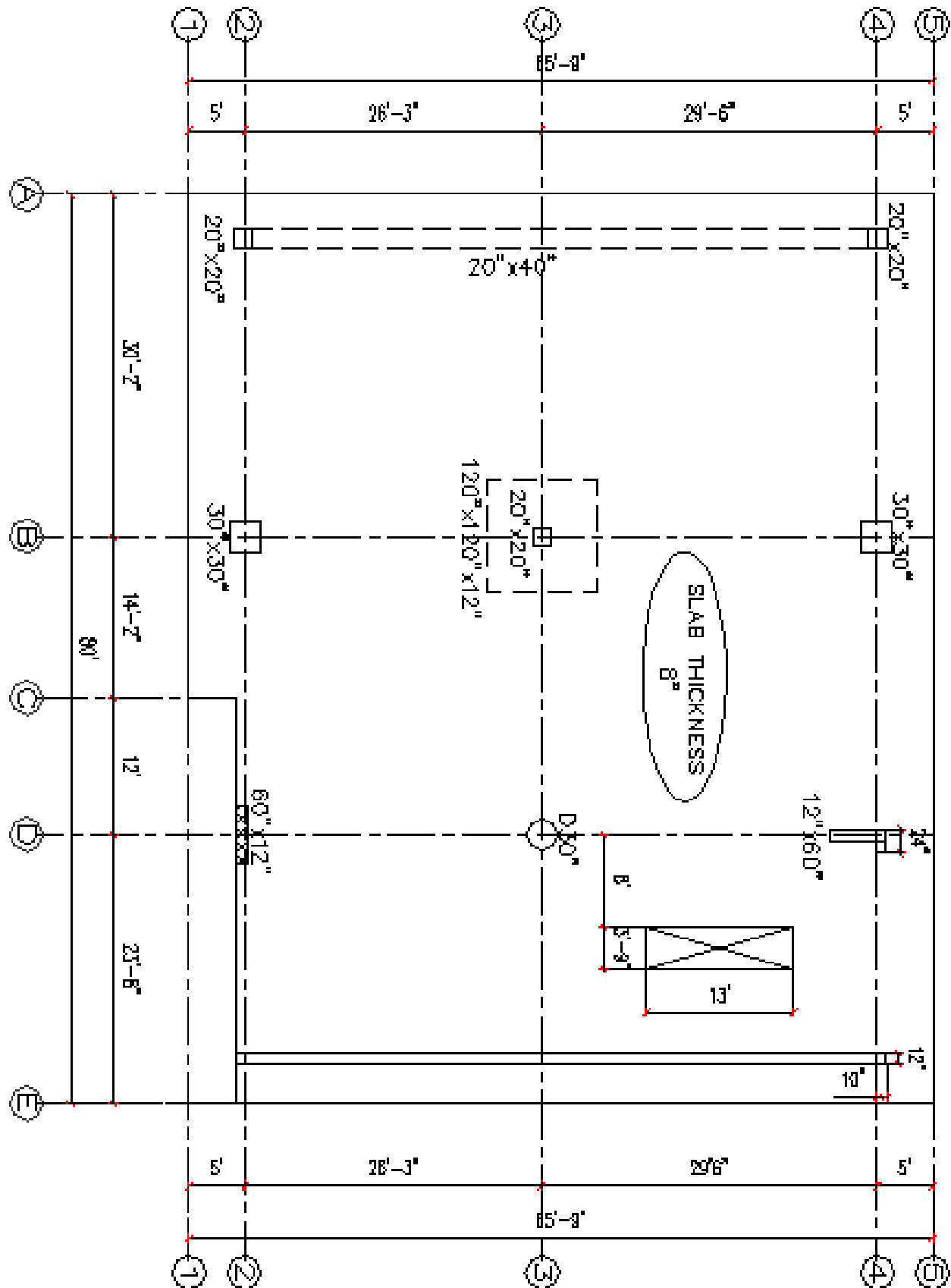


FIGURE 8-3_US INSTALLATION (SHOP) DRAWING OF BANDED TENDONS



STRUCTURAL_DIMENSIONS_SI



STRUCTURAL_DIMENSIONS_US

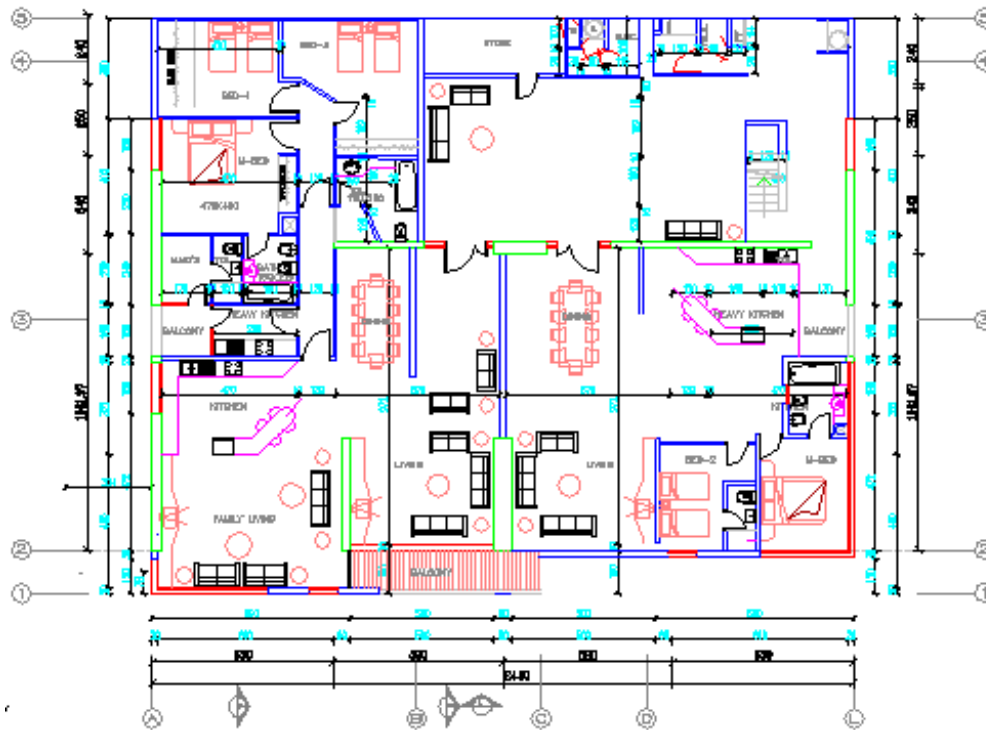
APPENDIX A: PREPARATION OF DWG DRAWING FOR IMPROVED IMPORTING

The folder of this session includes two drawings in DWG format. One is the architect's drawing, and the other is its simplified version. The objective of this session is to demonstrate how an original and involved drawing can be stripped of the information that is not relevant to the design and construction of its concrete frame. Thus, creating a version that helps to expedite the structural engineering design, and the creation of construction documents.

In idealized conditions, this step of design is performed by experienced draftsmen – not the design engineer. However, for completeness of the design process, it is included in this tutorial as a separate session. If you are not familiar with AutoCAD, and are not likely to perform the simplification explained herein yourself, it suffices that you just open the two versions of the drawings with the tool provided, view them, observe the differences, and move to the next Session. This provides you with the background needed to judge what to expect from a simplified drawing.

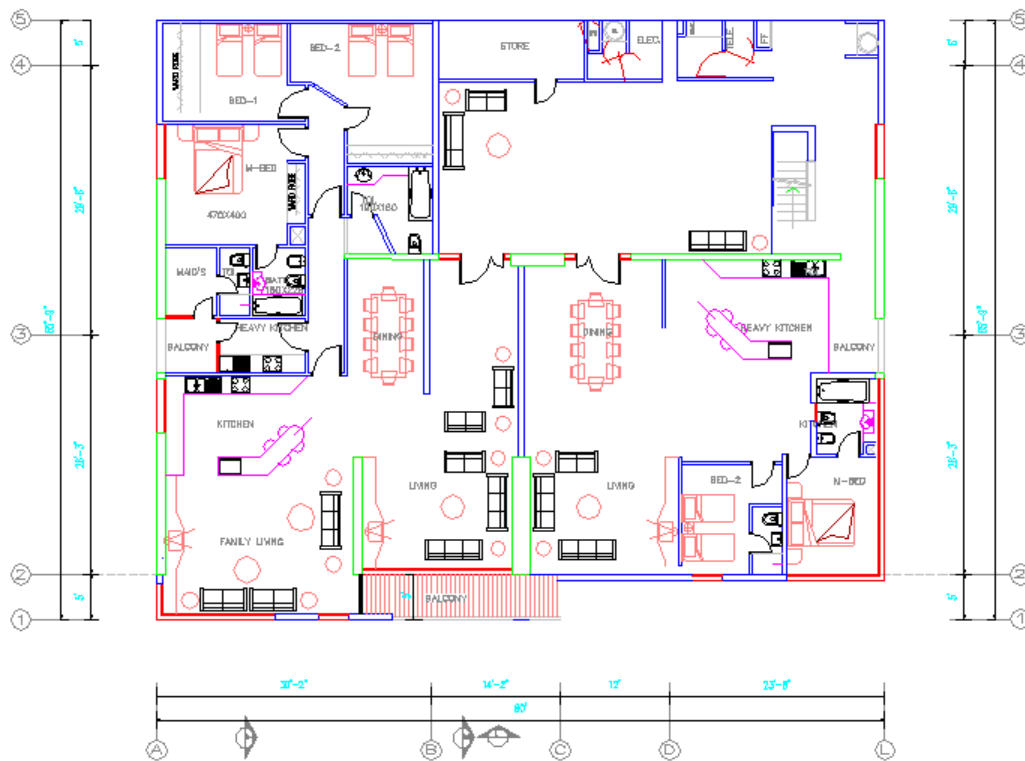
Architect's Original Drawing (Original DWG)

The architect's original drawing (**Fig. A-1**) is saved in AutoCAD version 14, in order to make it accessible to a wider audience. It shows the plan of the floor system to be designed, and other information of general interest to architects and construction. You can open the plan with the DWG viewer included in the training CD.



TYPICAL FLOOR PLAN (1ST TO 30TH FLOOR)
SCALE - 1:100

FIGURE A-1-SI VIEW OF ARCHITECT'S PLAN OF THE FLOOR



TYPICAL FLOOR PLAN (1ST TO 30TH FLOOR)
SCALE - 1:125

FIGURE A-1-US VIEW OF ARCHITECT'S PLAN OF THE FLOOR

Simplified Drawing (DWG)

For a better understanding of the floor systems and its structural elements, the architect's drawing is simplified. The simplification consists of turning off the layers that are not relevant to the structural design and erasing the entities that are not critical from a structural standpoint, such as position of furniture. Some of the layers can be erased altogether, with no loss of information for structural design.

The simplified drawing is shown in **Fig. A-2**.

The next step is to prepare the simplified drawing for importing it to the Builder program. Strictly speaking, this step is not necessary for the import of your DWG drawing to the Builder program. But the suggested work will lead to a substantial time saving in subsequent stages of your work. Moreover, the additional preparation can be done by your draftsman, who will also benefit from the preparations at this stage, when it comes to creating the structural drawings.

The purpose of the preparation is to create layers that are specific to the structural design of the project. Each layer would contain a pre-defined group of information. At a later stage, by turning the layers on or off, you will rapidly generate structural components, or specific information on your drawings.

NOTE:

If you are not familiar with AutoCAD, or are not likely to be doing the additional preparation described below yourself, it is suggested that you go to the next Session. The next session starts with a summary that helps you to achieve the same objective in the Builder environment.

Identify the entities that impact the load-carrying function of the floor. These are slab regions, openings, beams, walls and columns. Create a layer for each of these entities with the names listed below. Copy or move the entities identified to their respective layers. You will note that some of the entities have two layers, such as ADAPT_Slabs, and ADAPT_Slabs_Drafting. The first layer is intended to be used for the generation of the analysis and design of the structural model, and the second layer for drafting of the structural drawing. Appendix A explains the difference between the two. In many cases, the two layers will be identical. The folder of this session includes an edited version of the architect's files (Simplified_drawing.dwg), prior to its import to the Builder platform.

The suggested layers are:

- o ADAPT_Slabs
- o ADAPT_Openings
- o ADAPT_Beams
- o ADAPT_Columns
- o ADAPT_Walls
- o ADAPT_Drops

- o ADAPT_Slabs_Drafting
- o ADAPT_Columns_Drafting
- o ADAPT_Beams_Drafting

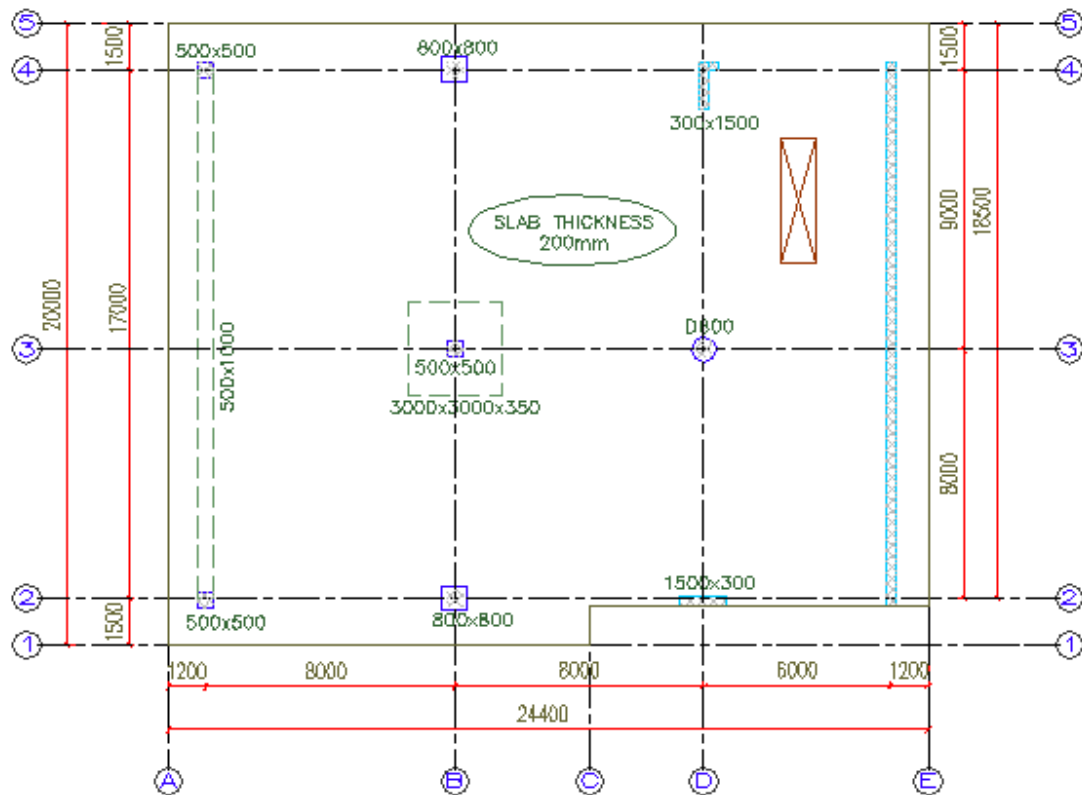


FIGURE A-2-SI SMLIFIED ARCHITECT'S DRAWING

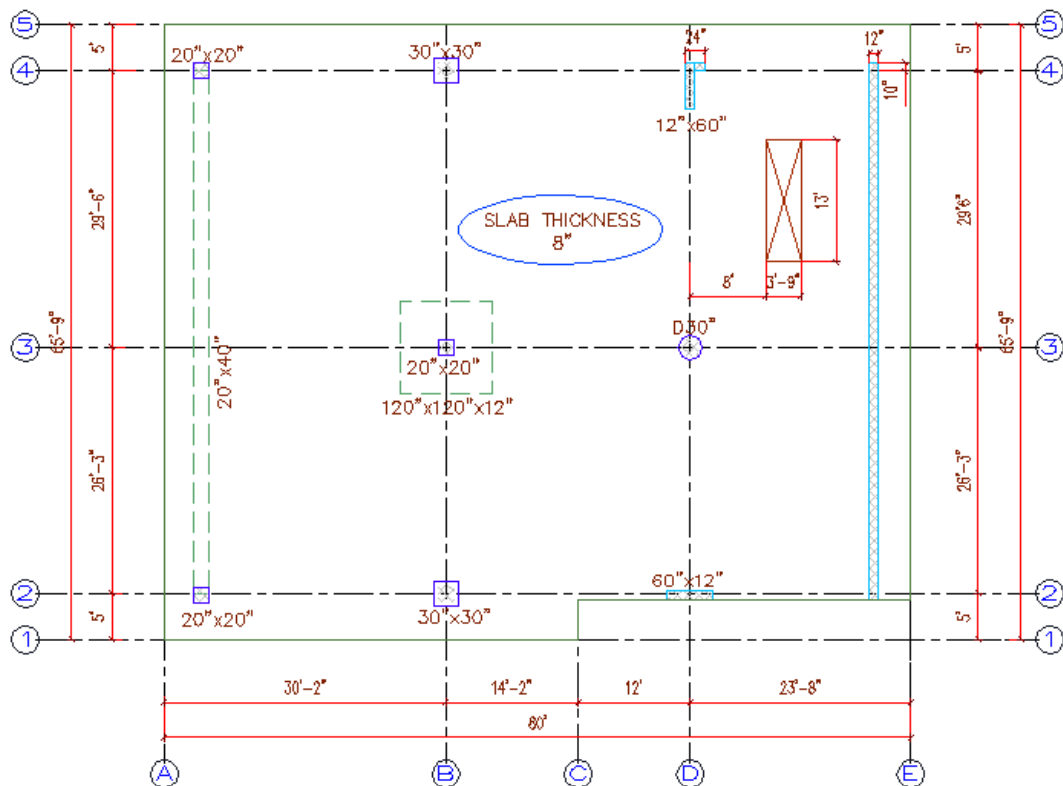


FIGURE A-2-US SMLIFIED ARCHITECT'S DRAWING

ADAPT

- o ADAPT_Walls_Drafting
- o ADAPT_Openings_Drafting
- o ADAPT_Drops_Drafting

- o ADAPT_Gridlines
- o ADAPT_Grid_Num (for numerical grid line annotation)
- o ADAPT_Grid_Cir
- o ADAPT_Dim (for dimensions)

Not all the layers listed might be necessary for a given project. The first group helps in creating the 3D structural model for analysis and design. The second group will be used to generate your structural drawings through the Builder platform. There are two reasons why you would need to have designated layers for drafting. In AutoCAD the line thickness, type and color are best handled through the layers. Placing the beams in a different layer than the slab enables you to show the beams with different line type on your structural drawings. The second reason is for automated transfer of the architectural details that are essential to the concrete frame, but not required for structural design. This is illustrated through an example in Appendix A. The third group is used to enter the grid lines on the structural drawings you prepare.

NOTE:

If you are not going through this tutorial in a supervised workshop, but are interested in knowing more about the generation of the layers in the AutoCAD environment, read Appendix A of this document before proceeding.

If you are not likely to work in the AutoCAD environment, you will not be generating the above-mentioned layers in this Session. Proceed with the next Session.



APPENDIX B: USEFUL HINTS

Use of Consistent Modeling Convention

All entities, such as beams, walls, support lines and tendons are best created from left to right and from bottom to top (direction of the coordinate system). Doing so will facilitate the identification of first and last spans while editing these entities. Also, the text associated with each will appear consistently in the same orientation.

How to Remove the “Read Only” Attribute of a Folder

- Right click on the folder which contains the files and subfolders you wish to undo the read only attribute.
- Click the properties option at the bottom of the list.
- Under the Attributes section of the window that opens uncheck Read-Only and click OK.
- Select the button which states “Apply changes to this folder, subfolders and files;” then click the button.
- Then click OK on the Properties dialog box.

APPENDIX C: TREATMENT OF COMPOUND (INTERCONNECTED) WALL ASSEMBLIES

Walls are not always isolated, simple and rectangular in shape. In many cases walls are assemblies of two or more wall segments, such as (a) in **Fig. 1**. Both ADAPT-Modeler and Floor-Pro can faithfully model, and account for the structural features of an entire wall assembly. This Technical Note describes the modeling procedure.

STRUCTURAL MODELING

In your structural model, a wall assembly must be broken down into rectangular wall segments. There are two options as illustrated in **Fig. 1**. In option 1, each wall segment butts against the side of an adjoining wall, with no overlap of wall segments. In option 2, the wall segments are connected to one another at their centerlines. In both modeling options, the program treats the segments working together as one whole. Option 2 places less demand on computer resources for analysis and design. If you follow the modeling procedure outlined in the Modeler User Manual, the structural drawing you will generate from either of the two options will show the wall in its true form (**Fig. 1-a**).

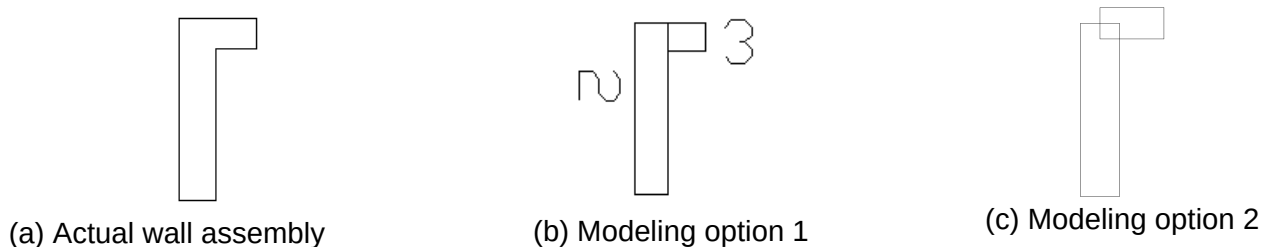


FIGURE 1 MODELING OPTIONS OF WALL ASSEMBLIES

SUPPORT LINES AND DESIGN STRIPS

As much as practical, you will use the support line wizard () to generate support lines. For compound wall assemblies, it would not be practical to consider each wall segment as a separate support. Ideally, you would like to identify a point that is the beginning of wall support, and another one at the end of the wall support. Again, there are two options for you to achieve this, when you use the support line wizard.

Option 1

In this option, you can change the property of a wall segment, such as wall segment marked “3” in **Fig. 2-b** to “disregard.” You do so, by opening the property window of the wall marked “3,” and under the FEM tab change its property from “consider” to “disregard.” This change in property will result in the wall segment not to be accounted for, when the support line wizard automatically creates a support line. The outcome will be similar to **Fig. 2-e**. If the wall segment 3 is not disregarded, the support line created automatically will be as shown in **Fig. 2-d**.

Option 2

In this option you do not “disregard” a wall segment. After the support line is generated, you will eliminate the support line segments that zigzag over the interconnected wall segments. Do the following.

- Turn the support line symbol on. The small circles are the “support” locations of the support line.
- Retain the first and the last support points, and delete the support points (circles) in between.

Do so by using the delete vertex tool () . The outcome will be a view, similar to **Fig. 3**.

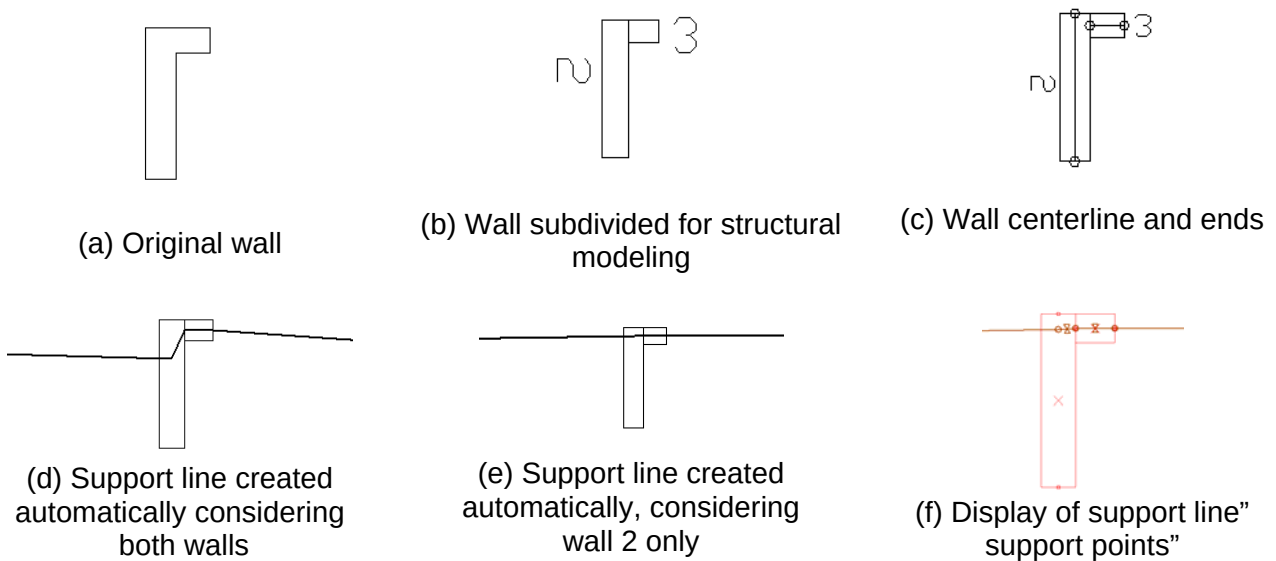


FIGURE 2 TREATMENT OF SUPPORT LINES FOR COMPOUND WALL SEGMENTS

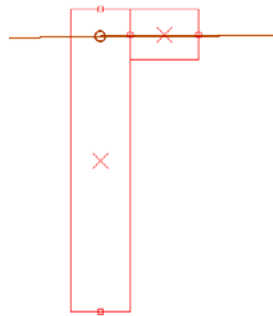


FIGURE 3 SUPPORT LINE WITH TWO SUPPORT POINTS OVER COMPOUND WALL

If you disregard a wall segment prior to the analysis, its stiffness will not be included in the analysis of the floor system. But, at design time, its presence will be recognized. Wall segments that are primarily for architectural reasons and do not provide a significant support to the structure are best disregarded in the analysis. Otherwise, in creating support lines, use option 2, whereby you would edit the automatically generated support lines.