40 years of PT Construction in Buildings

By

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Post-tensioned Concrete Specialty Engineering Firm

POST-TENSIONING INSTITUTE

Stressing the Stronger Concrete Solution™

2016!!!

- The 40th anniversary of the founding of…

The Post-Tensioning Institute

40 years of PT Construction

- Evolution of PT Systems
- Evolution of construction of PT buildings
- Evolution of Codes and Specifications pertaining to construction
- Where are we going from here – BIM, automation, new materials, green buildings.....

Real quick – My background in the PT Industry

- Started career in 1994 in post-tensioning after doing doctoral research work in the area of pre-tensioned prestressed concrete at The University of Texas at Austin
- Worked for 2 PT suppliers for combined 18 years involved in design and construction of hundreds of buildings
- Since 2011 - Consultant specializing in all aspects of post-tensioning: analysis, design, construction, repairs, forensic etc…
- Enjoyable, challenging and fulfilling so far….

Let us go back to how Post-tensioning was in the US prior to 1976

Thanks to Lift-Slabs!!

- US post-tensioning industry owes its existence to lift-slab construction
- First lift-slab buildings in the US were built in the mid 1950s using non-prestressed slabs

Problems With Early Lift-Slabs

- Problems with deflections and slab weight in long 2-way spans
- To solve deflection and weight problems, lift-slab companies changed to post-tensioned slabs
  - Reduce slab weight by +/- 30%
  - Eliminate dead load deflection

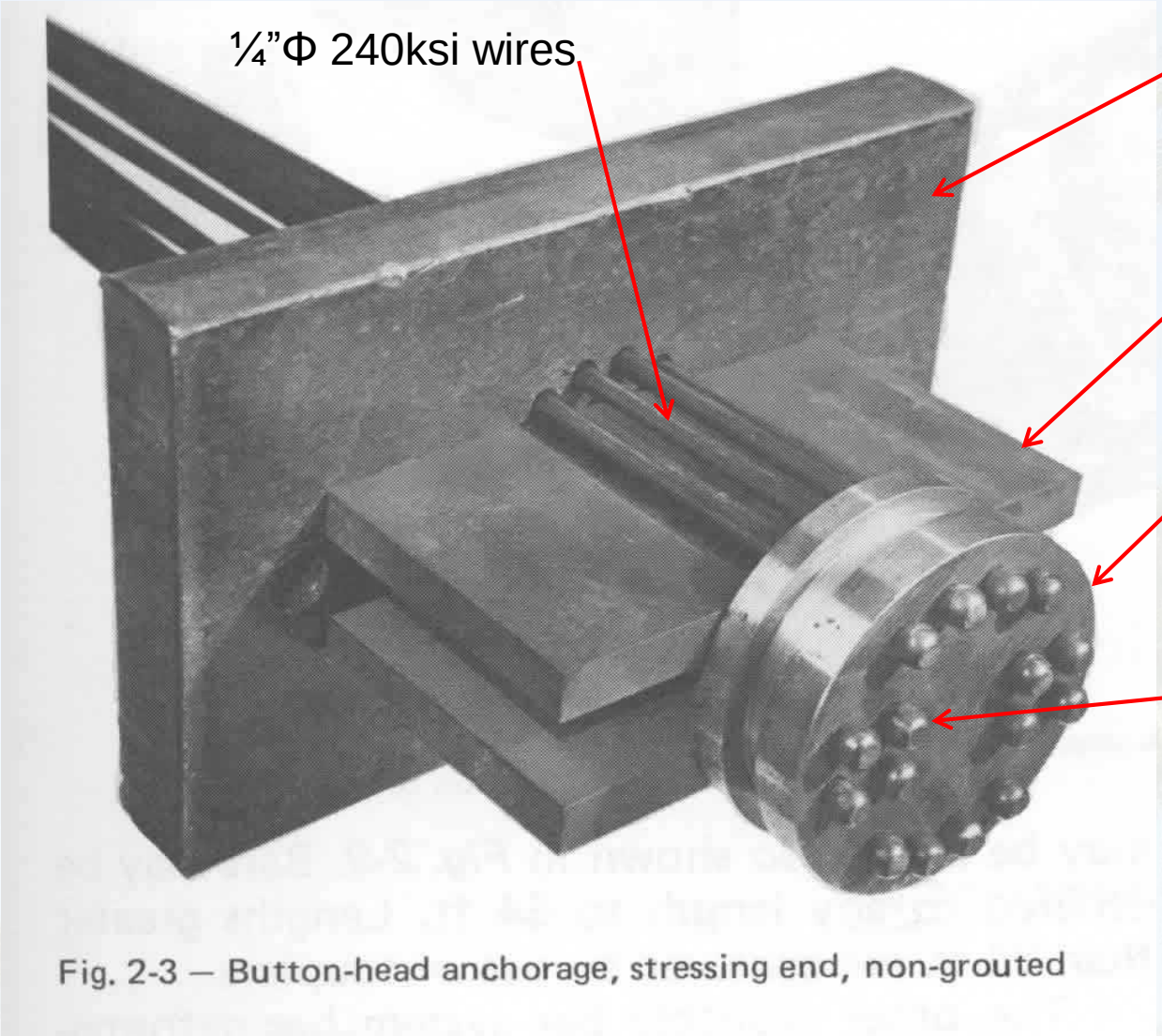


Fig. 2-3 — Button-head anchorage, stressing end, non-grouted

Lift companies and others started using Button-Headed (BBRV) Anchorage

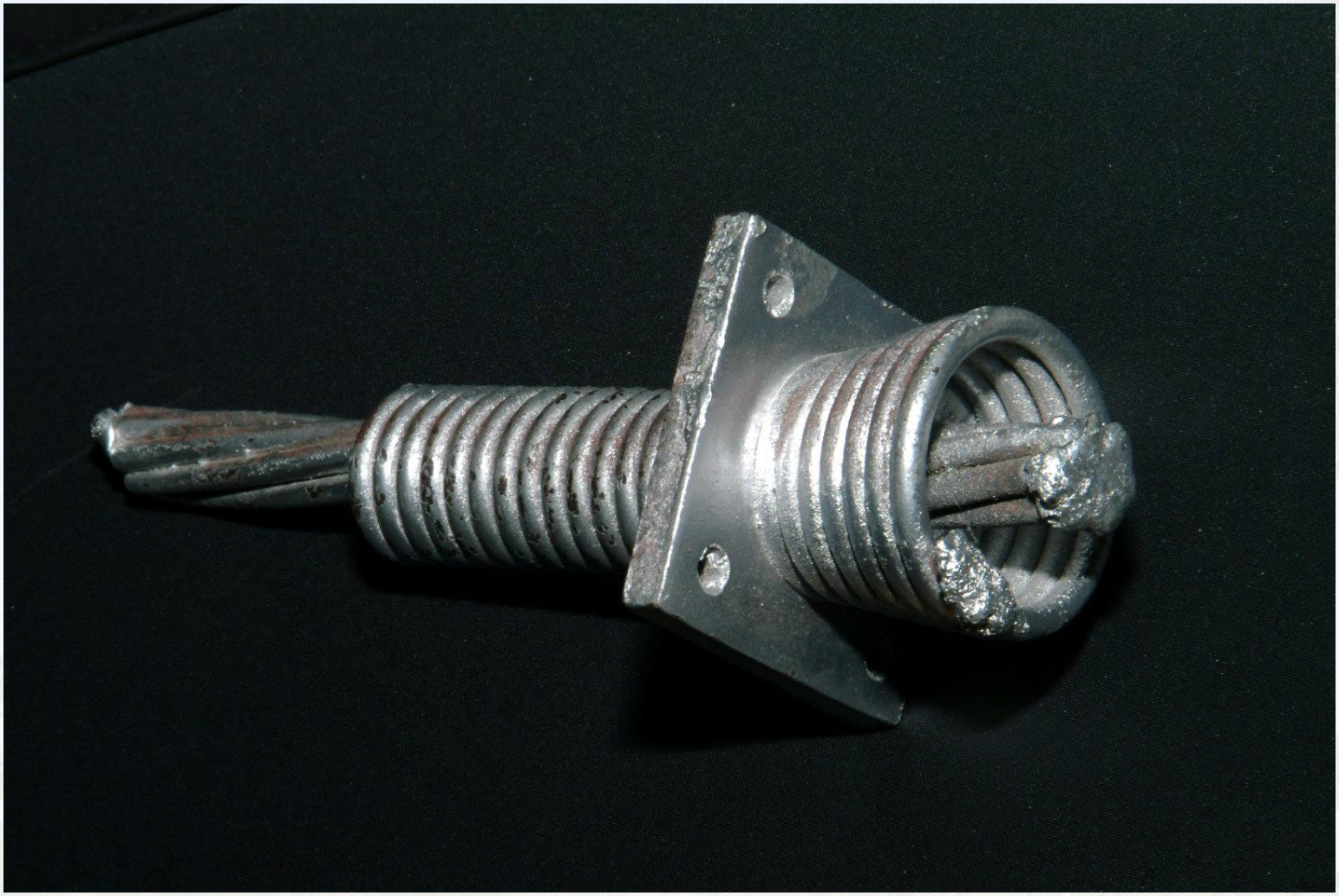
P/T Solved Deflection Problems But BBRV Tendons Created Others

- Both stressing and dead-end anchors attached in the factory
- Required exact length
- Required stressing pockets to cover shims
- Bulky and expensive couplers when intermediate stressing required

Strand P/T System Introduced in 1962

- Developed by ***Ed Rice*** (PTI Legend, president of T.Y. Lin & Associates)
- Introduced by Atlas Prestressing Corp.
- Did not require precise length
  - Tendons could be cut several feet longer than concrete length
- Did not require stressing pockets
- Did not require couplers (intermediate "slide-on" anchors)

The First Strand/Wedge Anchorage Used in the U.S.!



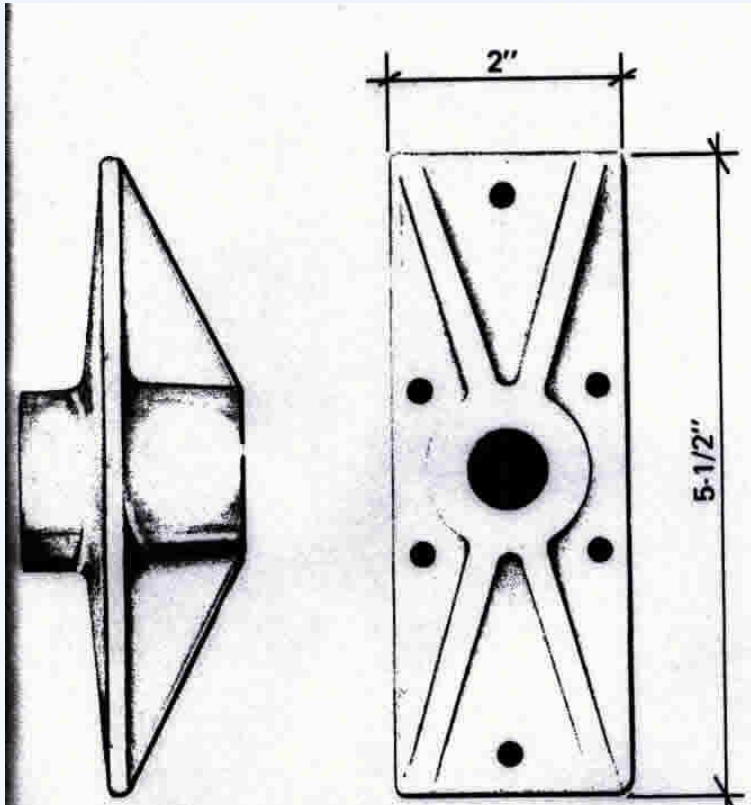
Relied on Concrete Tensile Strength

- Many breakouts occurred during stressing, particularly in lightweight concrete
- Not safe and required constant repair of breakouts
- NEEDED SOMETHING BETTER

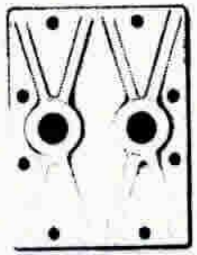
Time For a New Anchorage

- Atlas developed a bearing anchorage made of ductile iron, combined the bearing surface with the wedge cavity
- Designed by PTI Legend Richard Martter
- Introduced in 1963

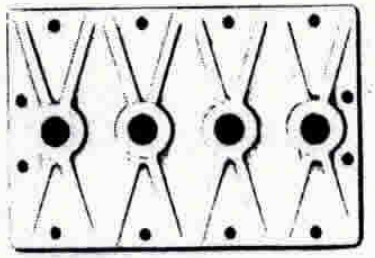
Ductile Iron Castings



H – 122 (1/2" STRANDS)



H – 222



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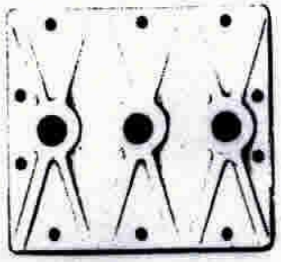

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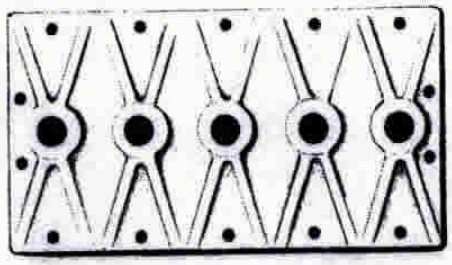
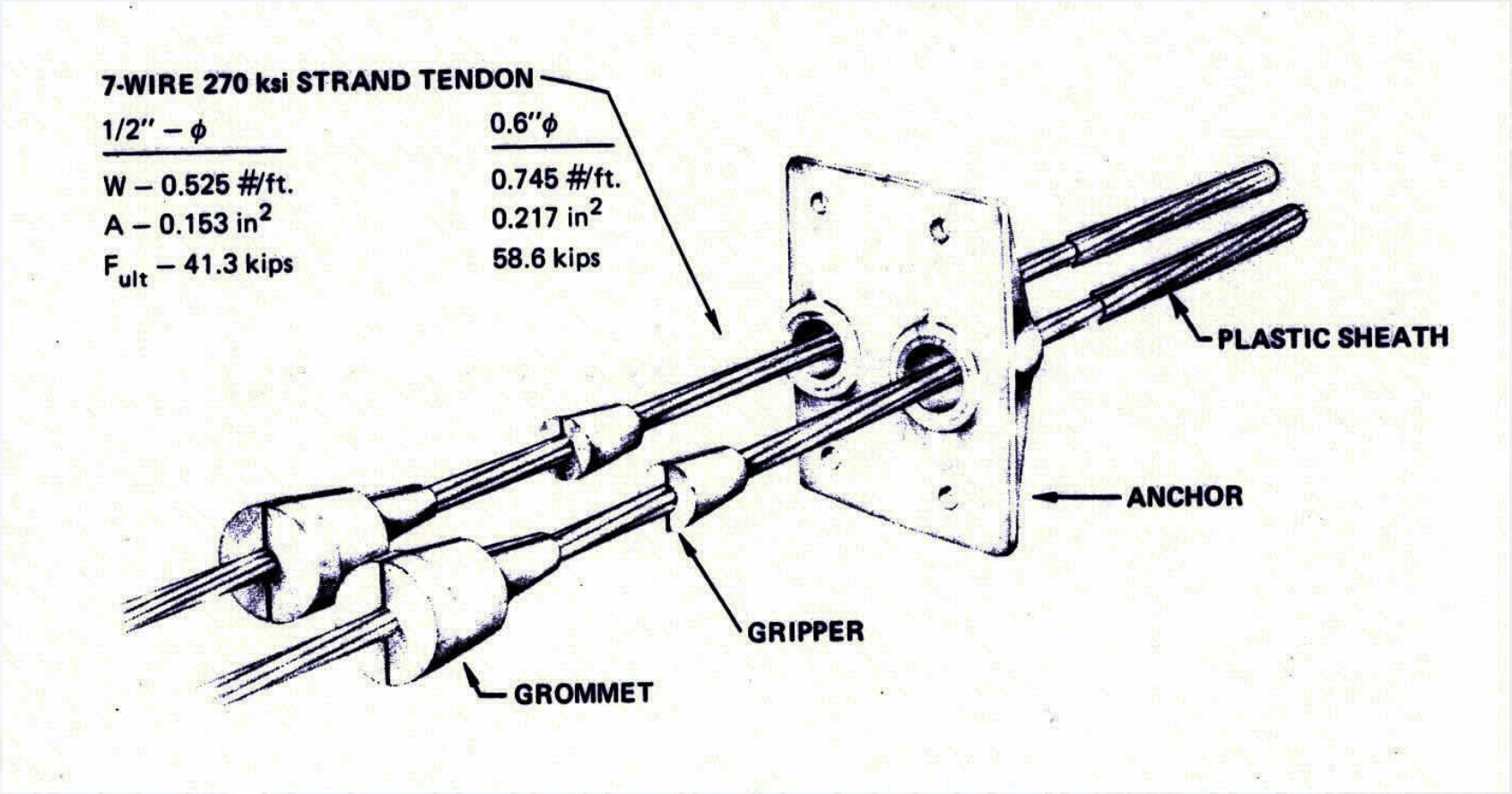


H – 522

"22" SERIES MULTIPLES (1/2" STRAND)

The Original Atlas Strand PT System



What Happened to Lift-Slabs?

- Lifting companies ***combined*** lifting and tendons in their bids
  - Excluded independent p/t companies (like - Atlas Prestressing Corp.)
- Independent p/t companies couldn't bid on lift-slab jobs
- What did they do…..???

Formed Alliances With Emerging Flying Form Industry

Direct Competition

- Joint promotion between p/t companies, flying form companies, and progressive concrete contractors allowed direct competition with lifted buildings
- Cast-in-place p/t buildings using large-panel flying form systems were highly competitive with lifted buildings
- By late 1960s c.i.p. buildings became preferred and lift-slab buildings became rarely used.

Timing is Everything…

- Huge input in foreign investment
  - China and Japan
- Tremendous construction boom
  - High-rise hotels and condominiums
- Faster completion meant more revenue
- Construction time became most important factor
- Is there a faster and better way to do two-way slabs

Construction Advances

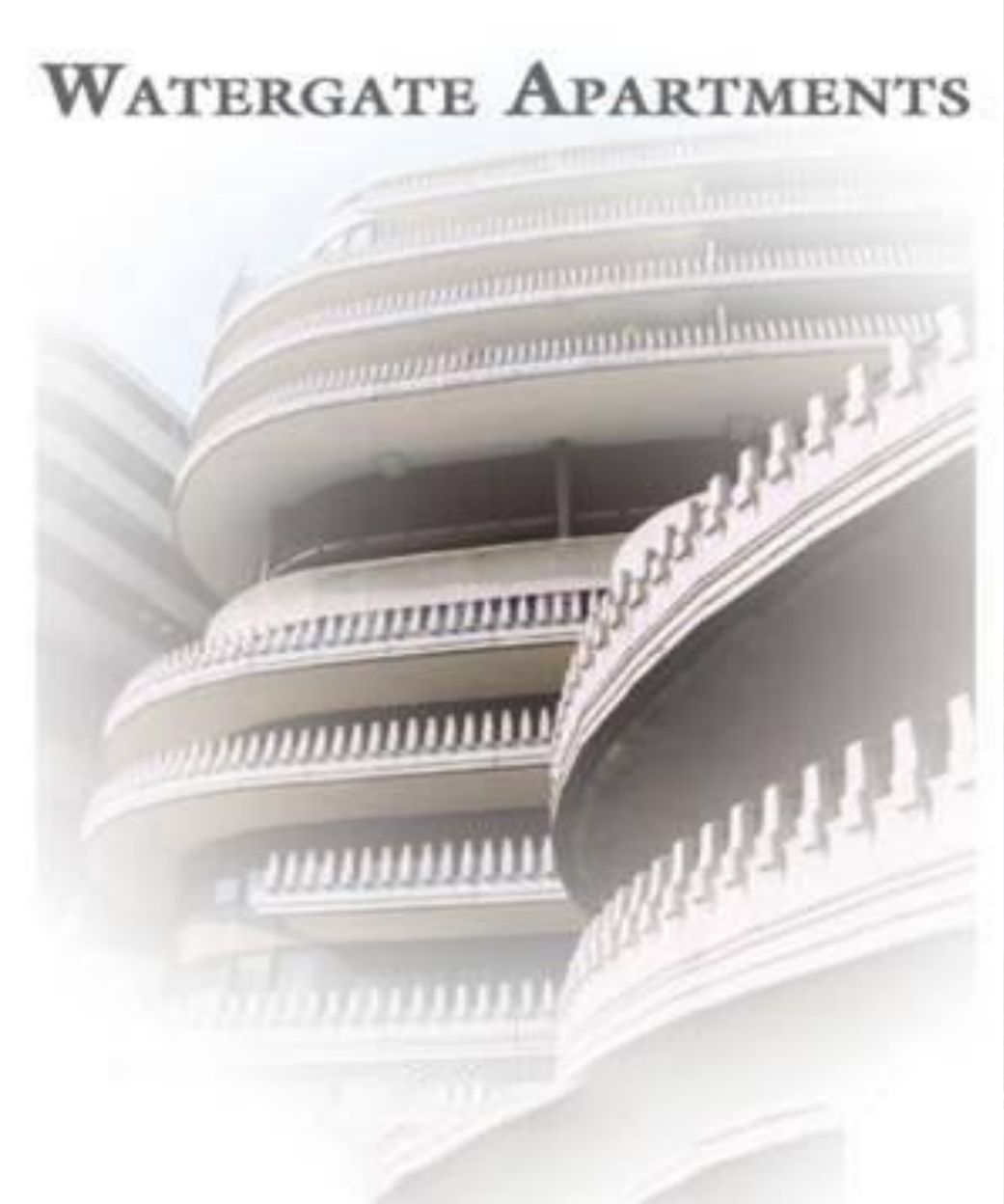
- Banded tendons in 2-way p/t slabs

Banded Tendons in 2-Way Slabs

- First used in the most famous post-tensioned concrete building ever built…

The Watergate Apartments in Washington, D.C.

(1968)



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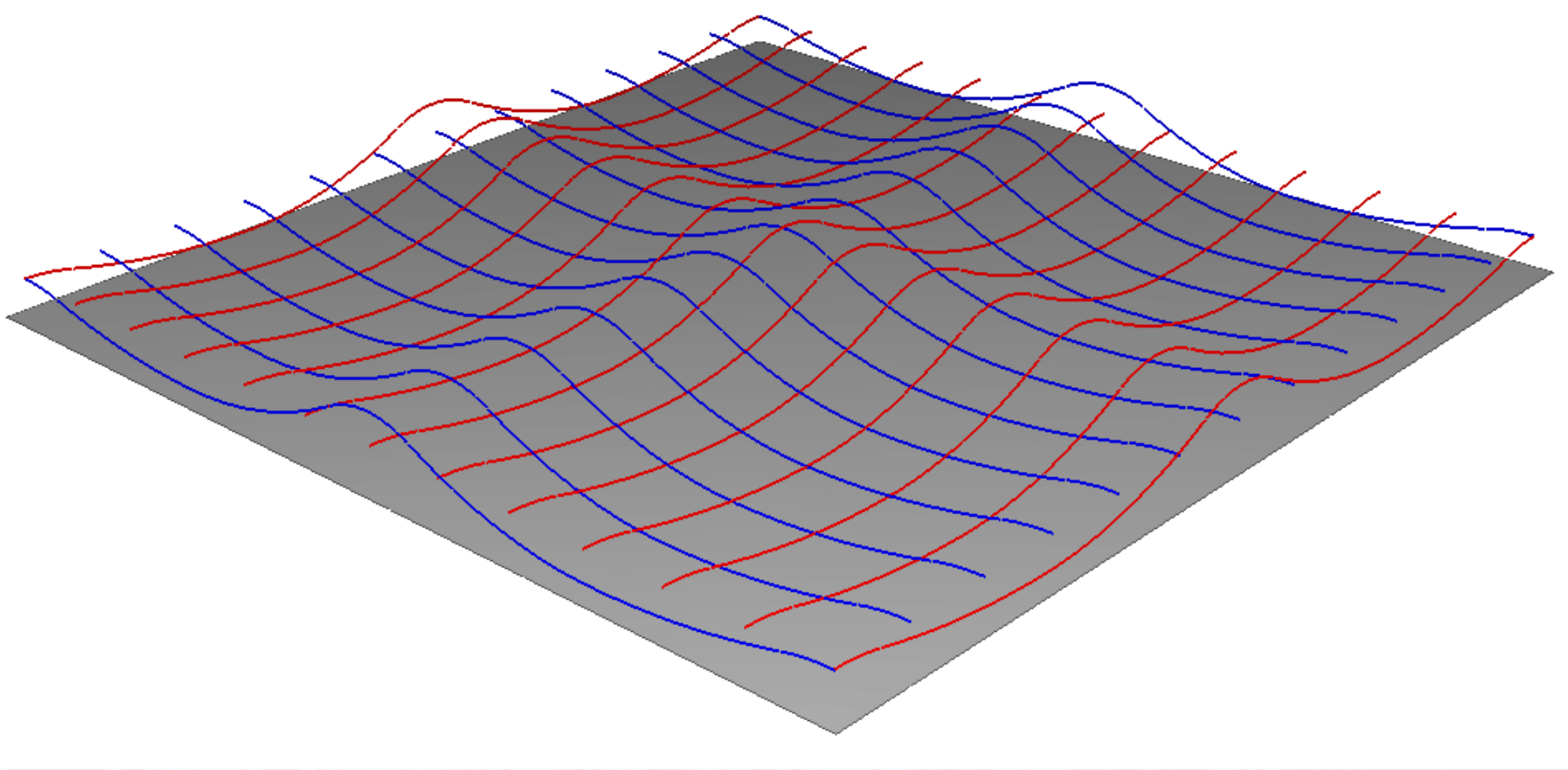
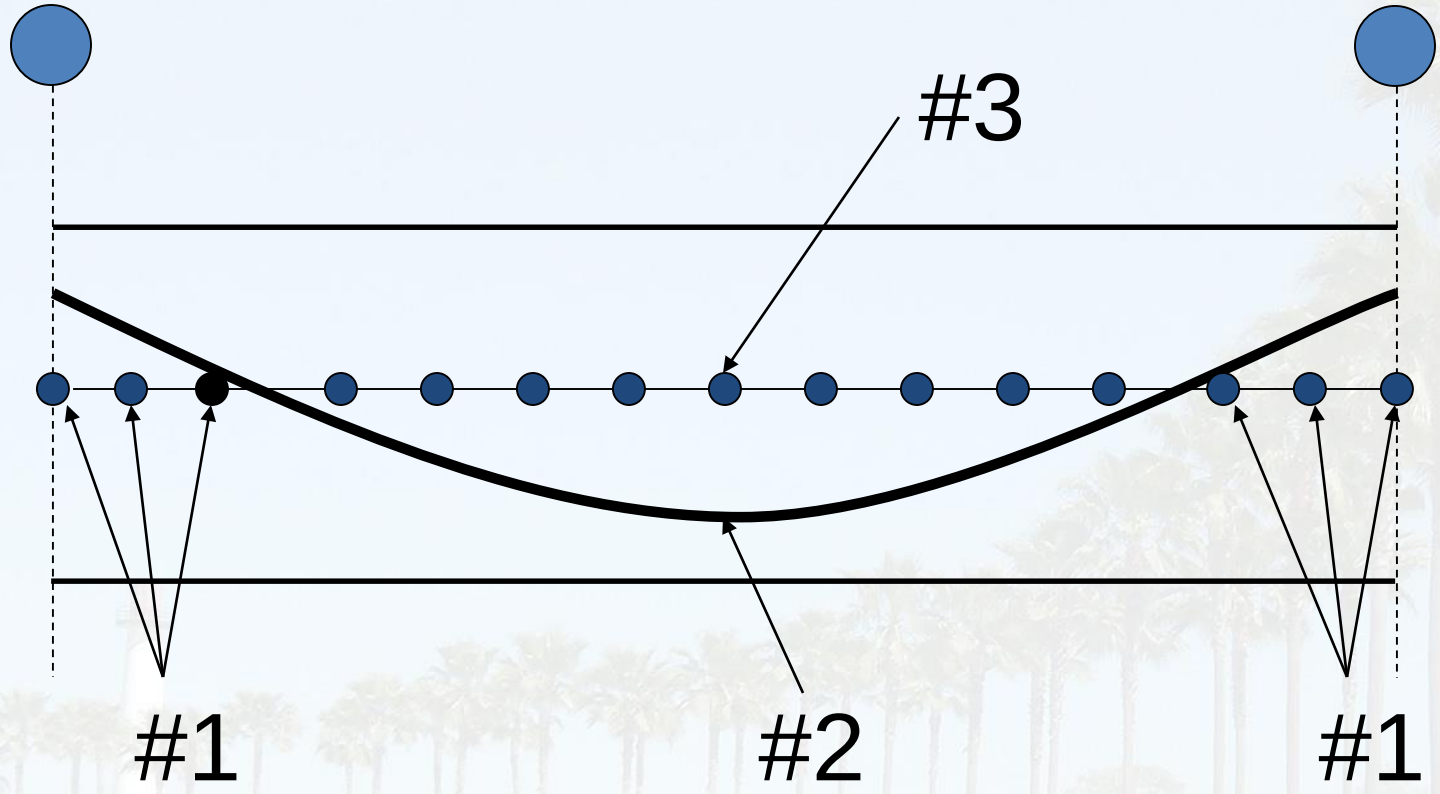
Basket-Weave Tendon Layout for 2-Way Slabs

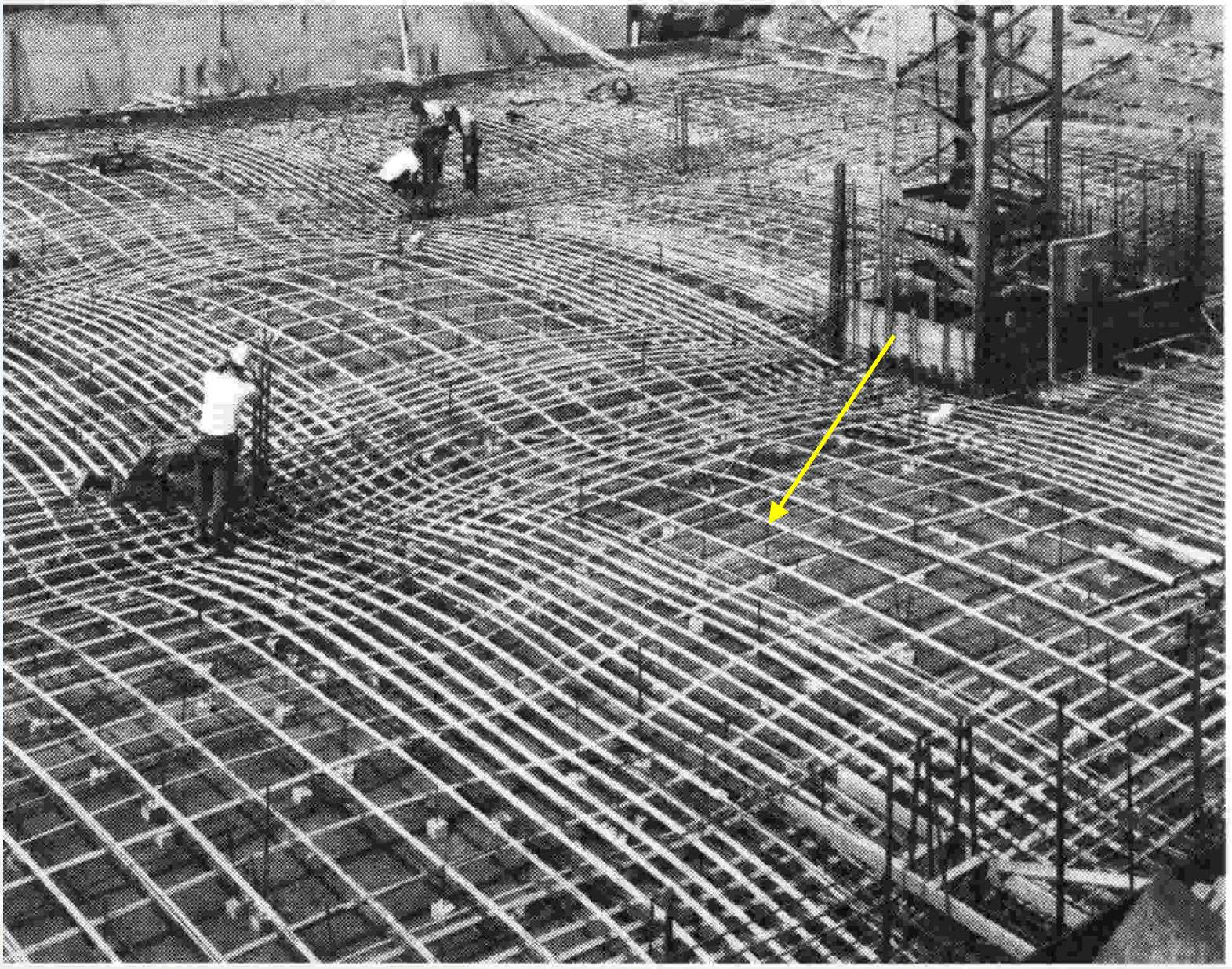
- Some in “column-strips”
- Some in “middle strips”
- Tendons were “draped” in curved vertical profile
  - High at column lines
  - Low at midspans
- A single tendon profile had some orthogonal tendons above it and some below it

Basket Weave Layout

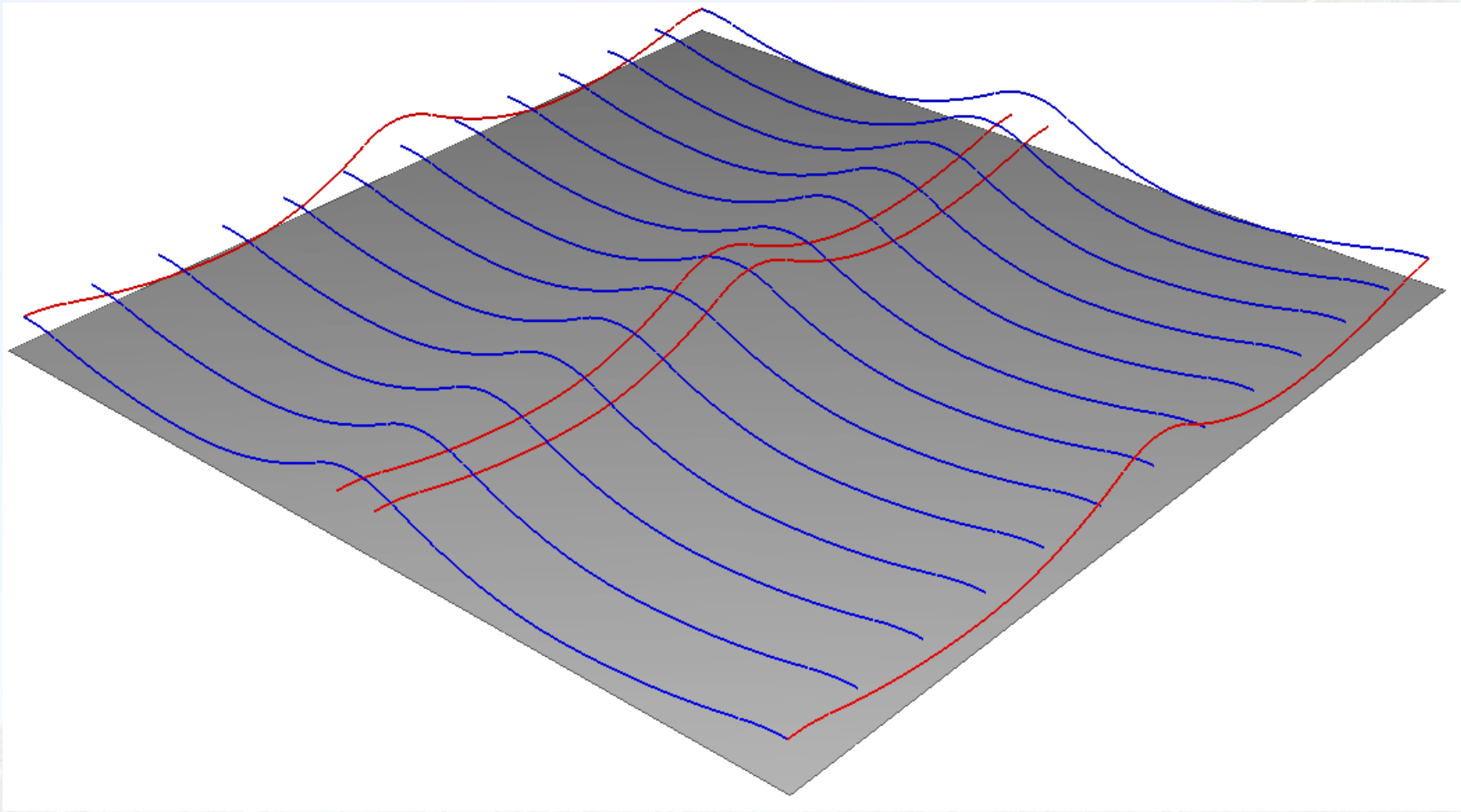


Some Above, Some Below…





Banded/Uniform Layout



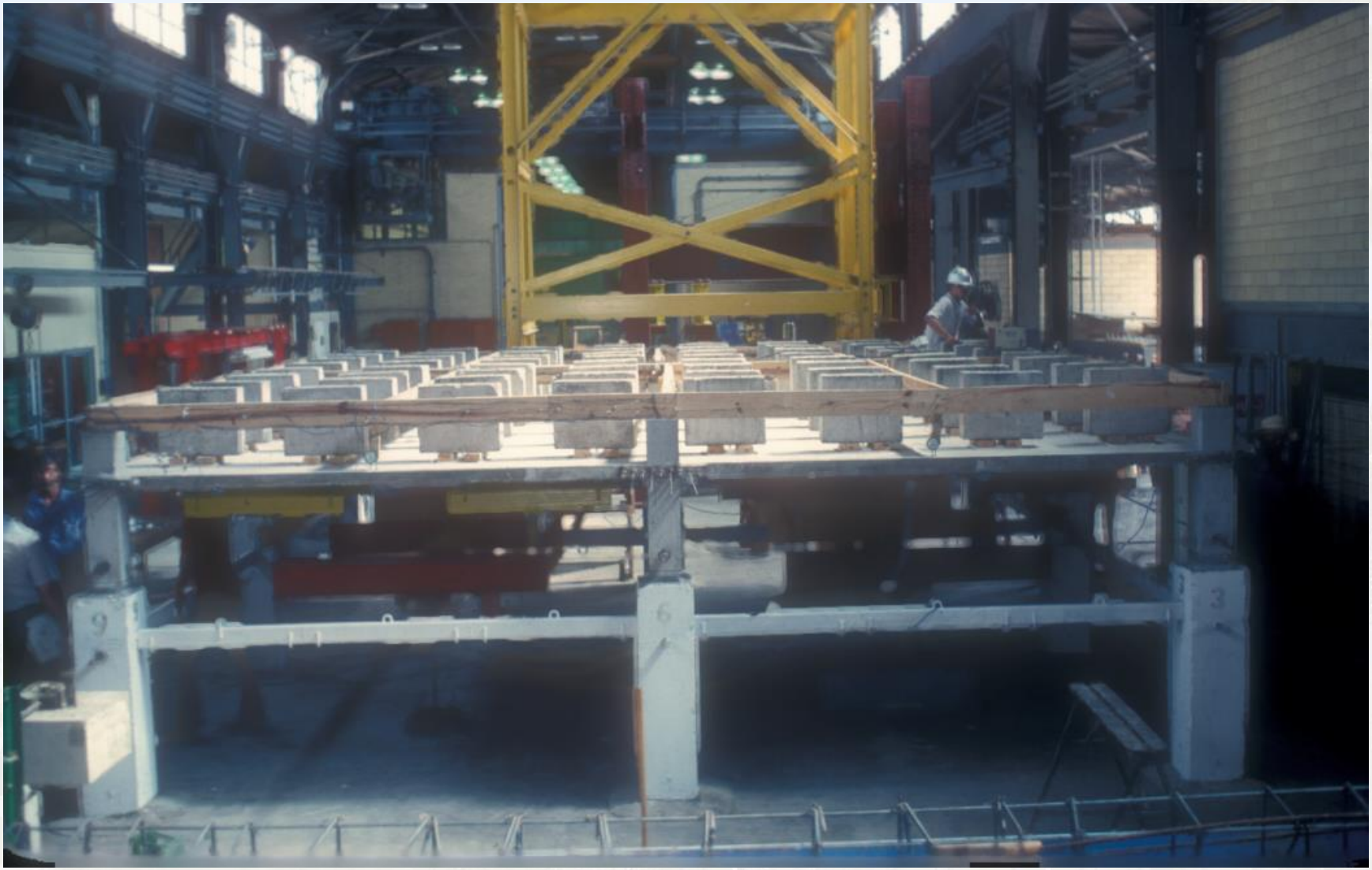
Slab Design Engineers (T.Y. Lin and Atlas Prestressing Corp.)

- Conceived the load path as a one-way slab
- Developed a tendon layout where all of the tendons in one direction were placed in a narrow “bent” band connecting columns
- All of the tendons in the orthogonal direction were uniformly distributed.
- Load path was easy to follow, like in a one-way beam and slab system

It Worked!

- And it resulted in a significant savings in labor costs
  - Eliminated tendon sequencing
  - All band tendons installed first
  - All uniform tendons installed next
- Has become standard method for tendon layout in 2-way slabs for more than 40 yrs
  - Hundreds of millions of square feet in service
  - Behavior studied and verified in numerous laboratory tests

4-Panel Test at University of Texas



Where were we at in 1976

- Strand systems already introduced
  - Replaced “button-head” tendon system
- Ductile iron castings for single-strand unbonded tendons were being used
- “Load-balancing” concept well established for analysis and design
- “Banded” tendon layout for 2-way slab systems was becoming the standard layout
- **Formation of Post-Tensioning Institute**

What has changed since then

- Evolution of PT Systems
- PT Manufacturing
- PT Applications
- Evolution of PT Analysis and Design Tools
- Changes in Codes and Specifications
- Evolution of PT Construction
- PT Structure Performance
- Repairs and Strengthening

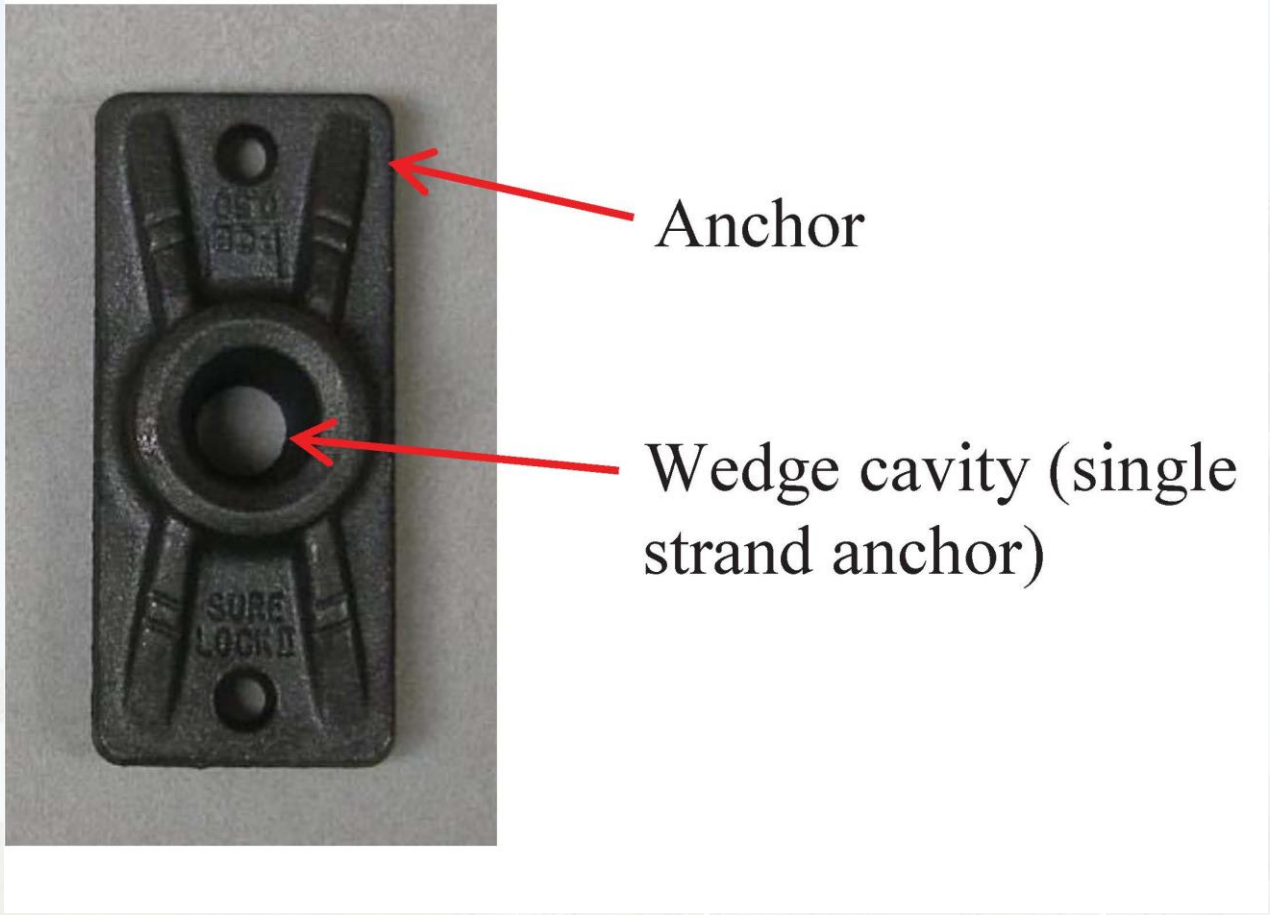
Evolution of PT Systems

- Anchor
  - Basic anchor has not changed except for refinements in the metallurgy, weight, dimensional efficiencies
  - Most significant development has been in the encapsulation of the anchorage system for corrosion protection
- Sheathing
  - Paper-wrap
  - Plastic – heat shrink
  - HDPE – extruded – 40 mil (standard systems)
  - HDPE – extruded – 50 mil (encapsulated systems)

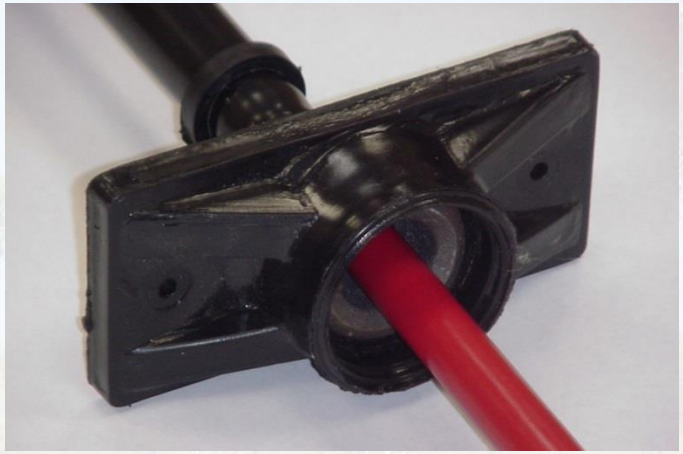
Evolution of PT Systems

- Transition Components
  - Standard system - Hybrid
  - Initial encapsulation systems (more pieces, tubes to be filled with grease)
  - Current encapsulations systems (fewer pieces, tubes no longer need to be filled with grease - ???)
- Advances in bonded post-tensioning systems
- FUTURE – Performance based systems

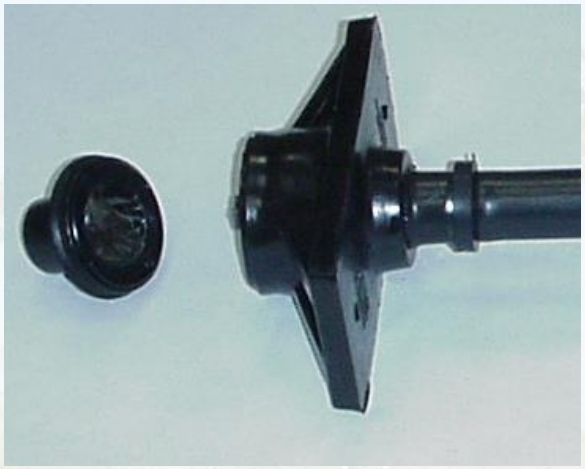
Standard Anchor



Older Encapsulated Anchorage System



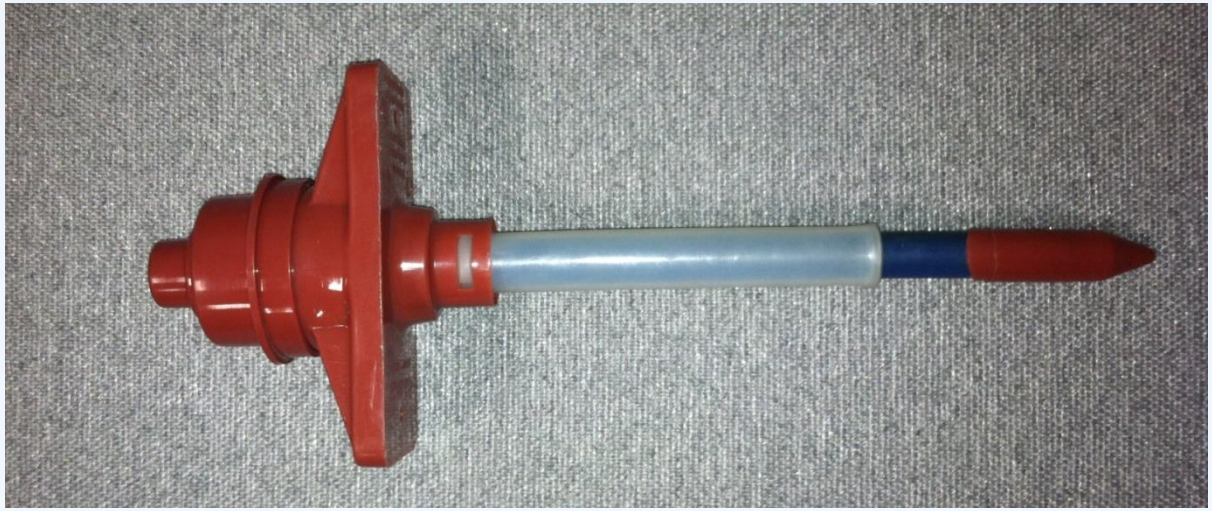
Fixed-End Assembly



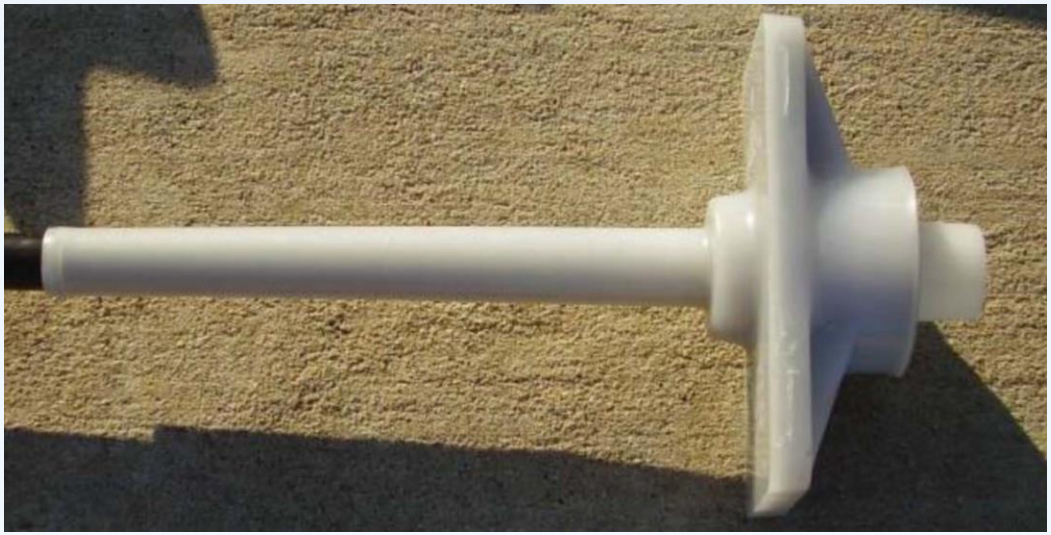
Stress-End Assembly

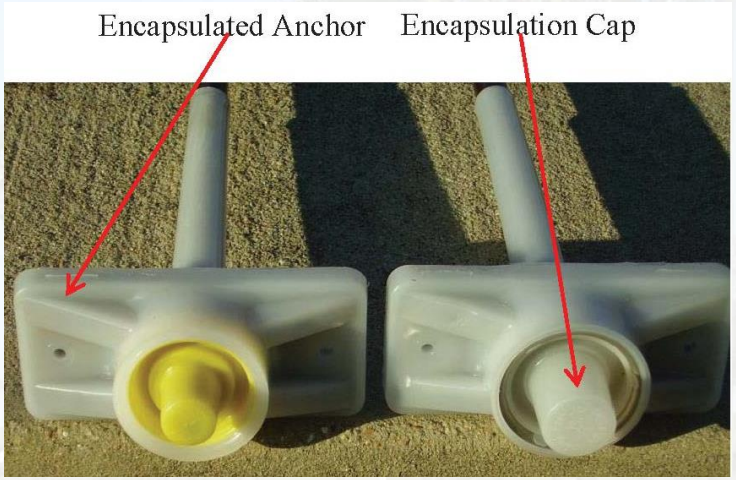
Intermediate Assembly

Newer Encapsulated Anchorage Systems



Newer *Encapsulated* Anchorage Systems





PT Manufacturing

- Many developments and efficiencies in manufacturing, storage and shipping of tendons
- Refinements to accommodate manufacturing of encapsulated systems
- Single biggest change to ensure quality of materials is the requirement for PTI Plant Certification

PT Applications

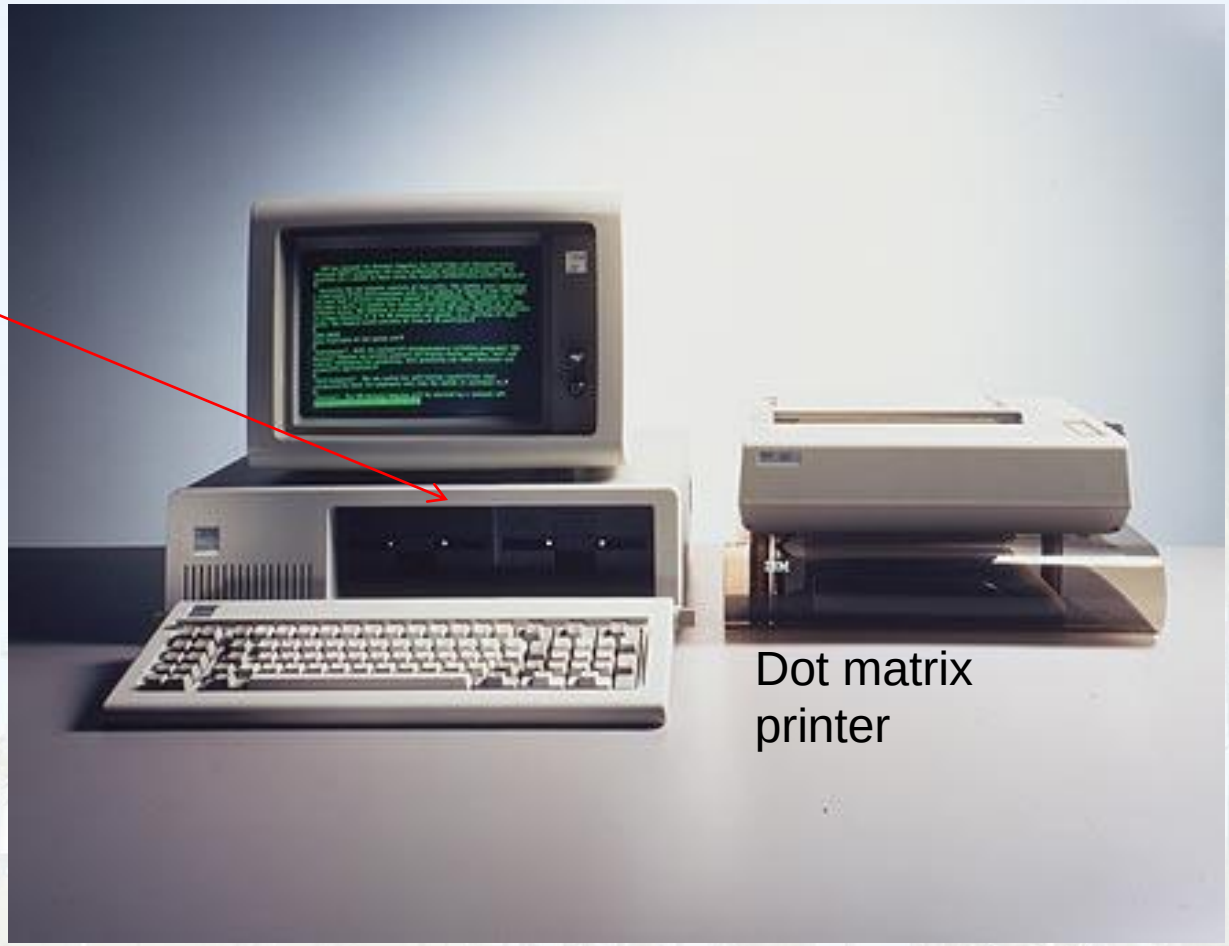
Prestressing is the solution to everything - almost

- Number of applications of post-tensioning has grown tremendously
  - Buildings
  - Bridges
  - Stay Cables
  - Containment structures
  - Slab-on-ground: residential, tennis courts
  - Industrial Slabs
  - Rock and Soil Anchors
  - Barrier Cable Applications
  - Vertical post-tensioning in walls to resist seismic loads
  - Others - ???

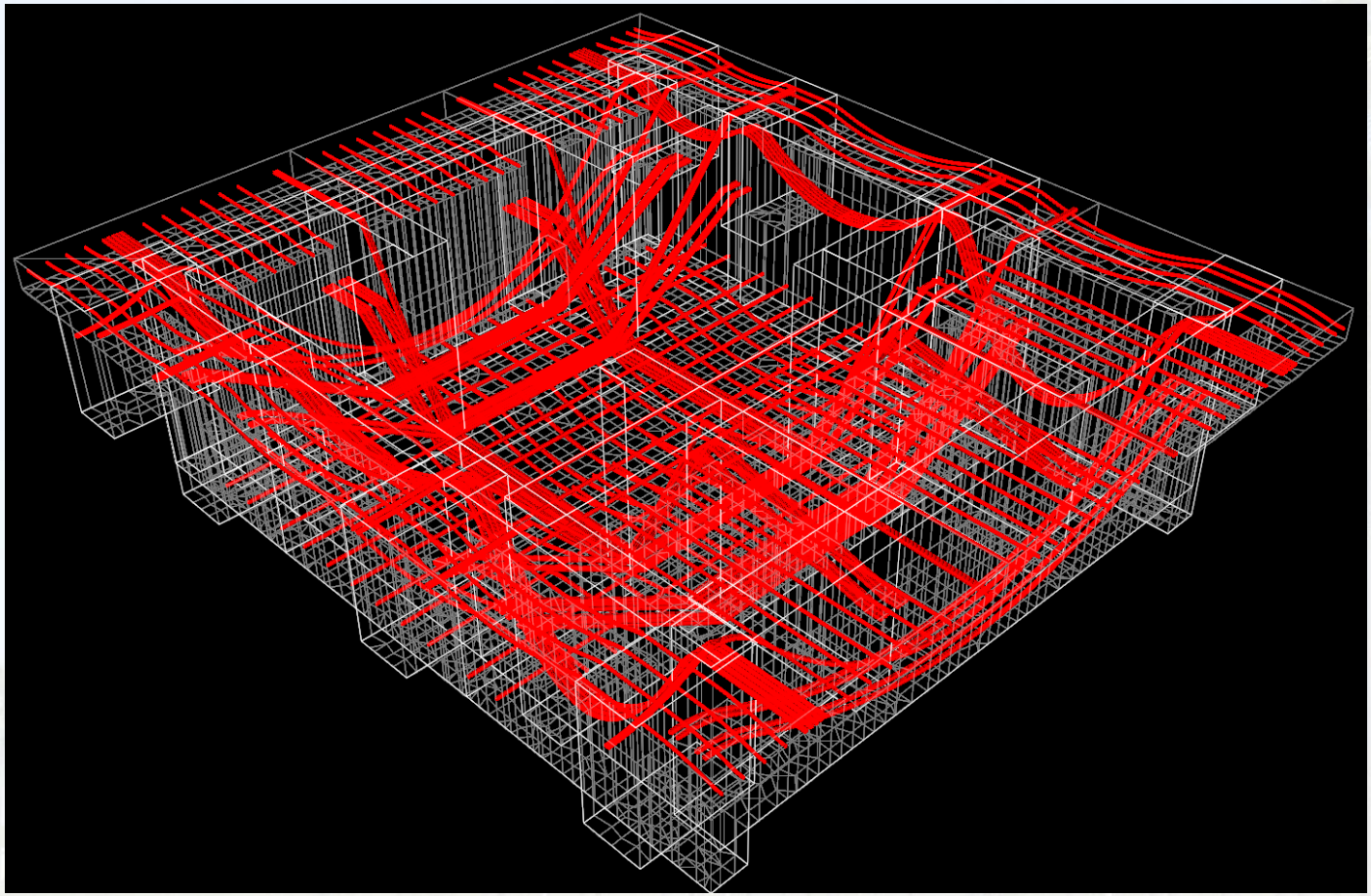
Evolution of PT Analysis and Design Tools

- Analysis and design tools have developed as computers and computing power has developed
- Complex structures can be modeled with ease and very quickly
- Structural behavior can be observed in great detail
- Although basic concepts are the same – Engineers should not lose the ability to perform a back of the envelope calculation

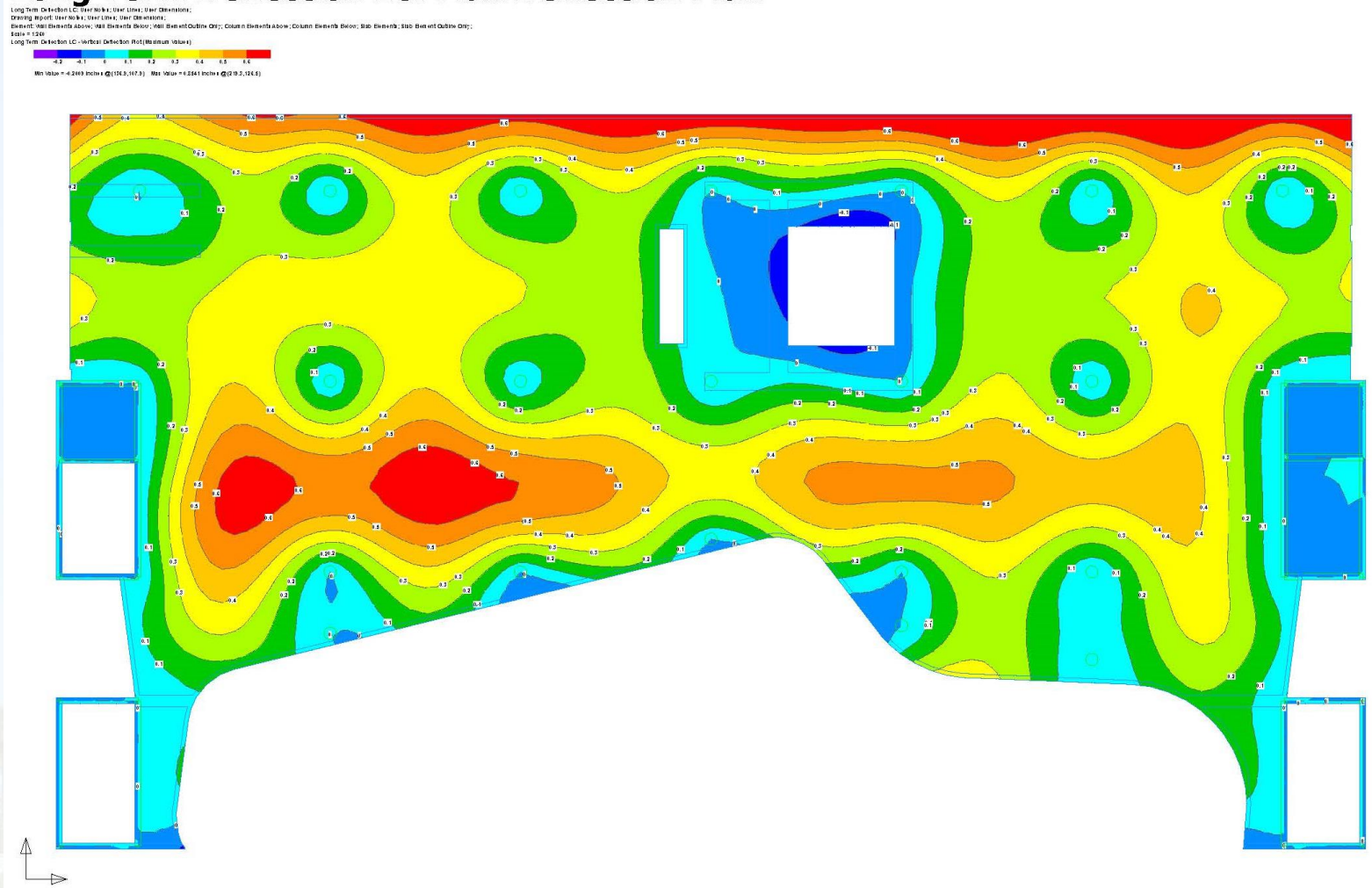
IBM Personal Computer (1981)



Evolution of PT Analysis and Design Tools



Long Term Deflection LC: Max Deflection Plan



Changes in Codes and Specifications

Entities involved

- Post-tensioning Institute (PTI)
- American Concrete Institute (ACI)

Changes in Codes and Specifications

- PTI
  - Numerous PTI Technical and Certification Committees
  - Specifications
    - Specification for unbonded single strand tendons (elevated)
    - Specification for unbonded single strand tendons (SOG)
    - Specification for grouted tendons
    - Specification for seven-wire strand in barrier cable applications
  - Trove of technical documents produced through the technical committees
    - Signature document is “Post-tensioning Manual” in its sixth edition. Seventh edition being worked on

Changes in Codes and Specifications

- ACI
  - 318 - Building Code Committee
    - Prestressed concrete first introduced in 1963 code
    - Major improvements in 1977 and 1983 codes
    - Anchorage zone provisions added in 1999 code
    - Major re-write of code in 2014 from structural action to a member based code
    - PTI well represented in ACI Committees
  - 423 – Prestressed Concrete Committee
    - Specification for unbonded single strand tendons (material spec.)
      - **Most significant development is that starting with the 2014 code – all buildings designed per ACI 318 required to use ENCAPSULATED TENDONS**
    - Guide for design of buildings with unbonded tendons
  - 301 – Specifications for Structural Concrete
    - Construction specification for post-tensioning using unbonded and bonded tendons

Evolution in PT Construction

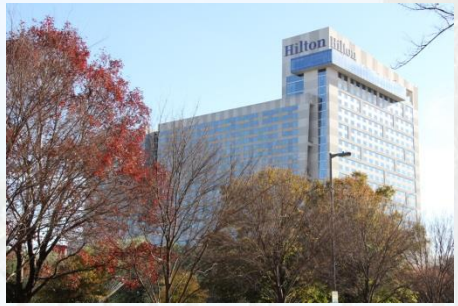
- Submittals - Shop Drawings, calculations, grouting procedures
- Materials – Unbonded and Bonded (Grouted)
- Product delivery, handling and storage
- Execution
  - Field Procedures Manual (Unbonded – Elevated, SOG)
  - Guide Spec for Bonded PT and Spec. for Grouting
  - **Installer Certification**
    - PTI – Level 1 Field Installation (Unbonded)
    - PTI Level 1 and 2 – Iron worker (Unbonded)
    - PTI Level 1 and 2 – Bonded PT Field Specialist
  - **Inspector Certification**
    - PTI – Level 2 – Inspector (Unbonded)

Evolution in PT Construction

- Tendon Tolerances
- Concrete Placement
- Tensioning
  - Stressing equipment greatly improved since the early days
  - Problems with elongations (marking) and approval still persist and consume enormous time for PT suppliers, contractors and engineers
  - This area needs more work. Use new technologies
- Tendon Finishing
  - Improvement by going to encapsulated systems
  - Criteria for tendon finishing (elongation approval, tendon cutting, installation of encapsulation caps and grouting of pockets) now in code
  - This can be further improved by inspection of the encapsulation cap installation and grouting of the pockets

How Much Post-Tensioning?

- Based on PTI tonnage statistics from 1972 and reasonable estimates before that…
  - About 5 billion square feet of building construction with unbonded post-tensioning
  - About 50,000 post-tensioned buildings in the US
- Does not include bridges, earth applications, residential foundations



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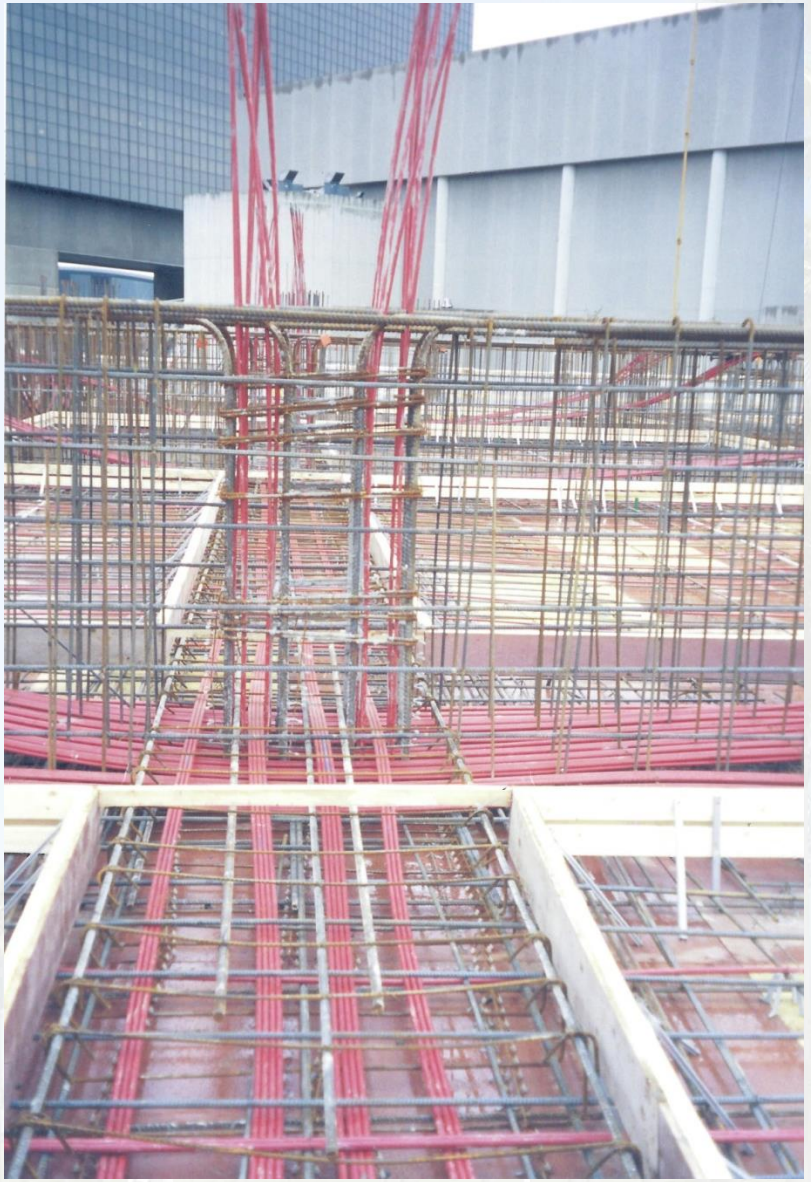
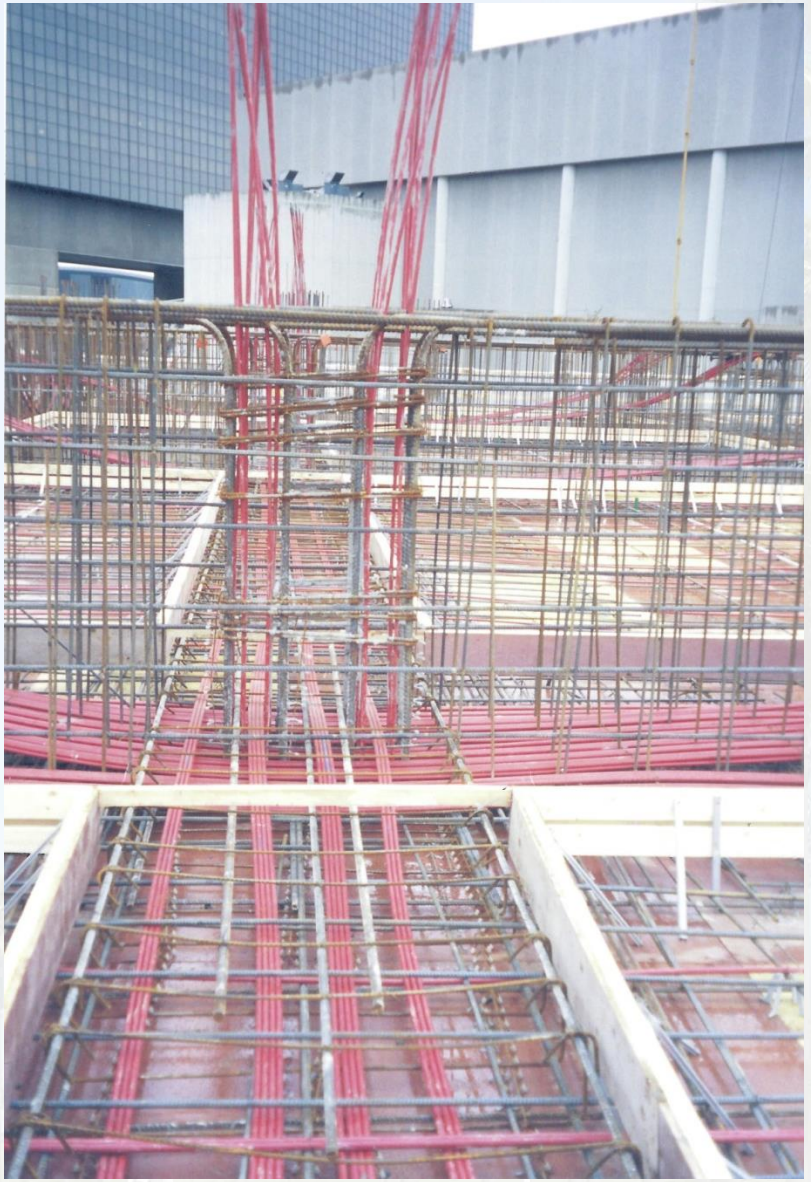
Post-tensioning in all three directions

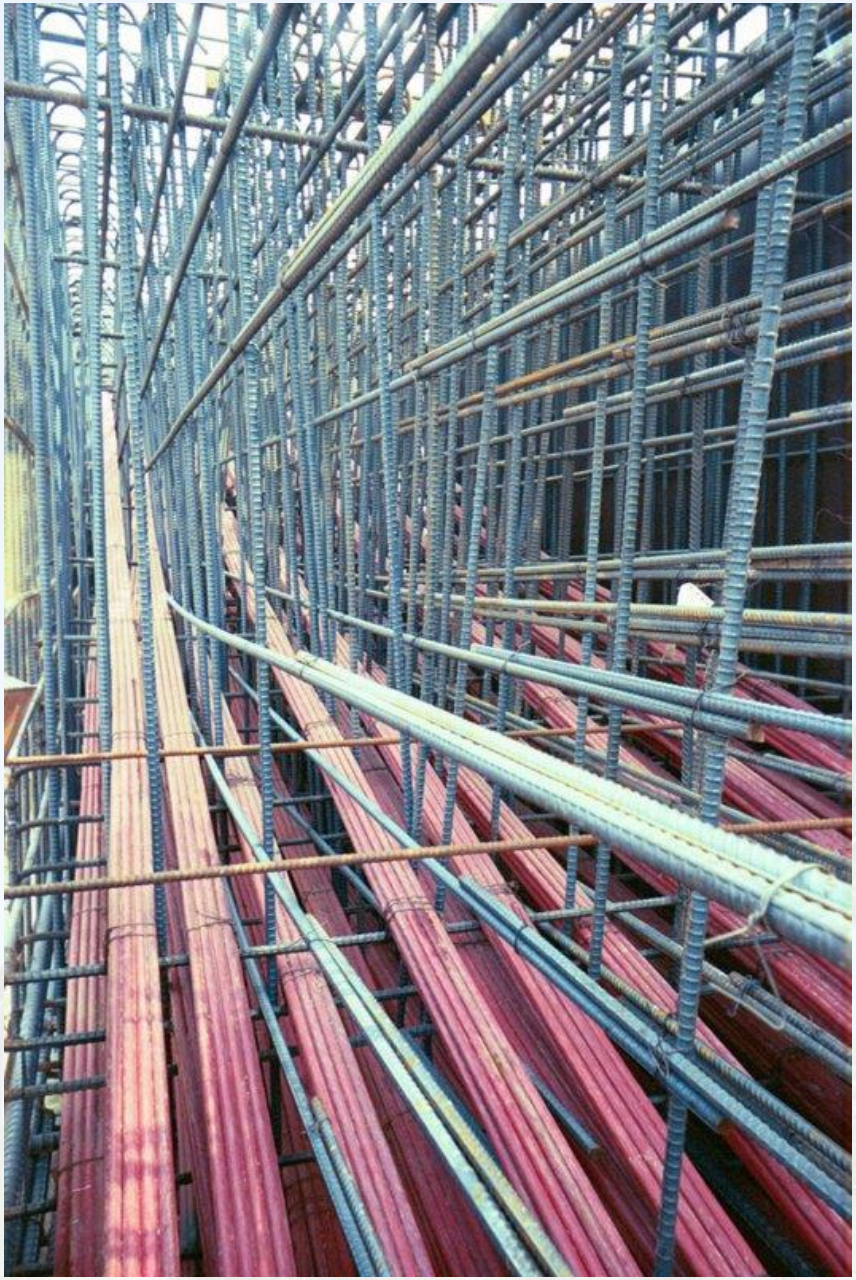


Post-tensioning in all three directions



Transfer Girders with 20,000 kips force each

FIS Garage, IAH Houston, TX (2005)



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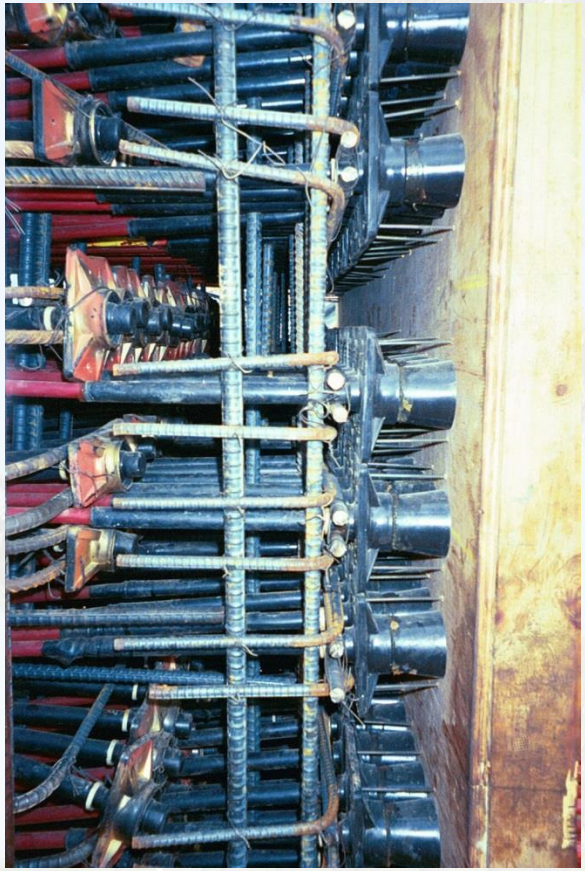
532 – 0.6 inch dia – Unbonded Tendons



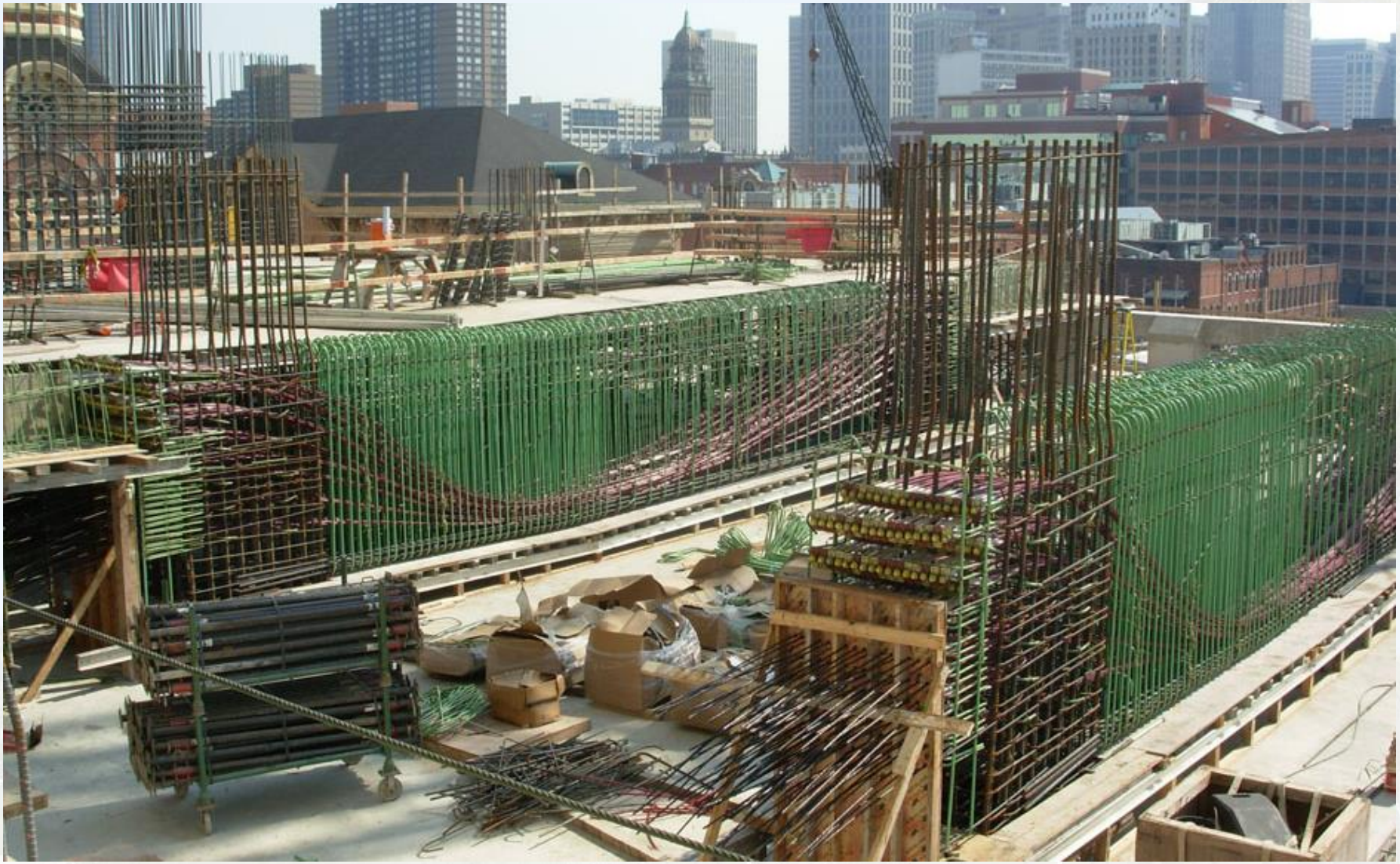
532 – 0.6 inch dia –
Unbonded Tendons

Two way flat plate with wide-shallow beams

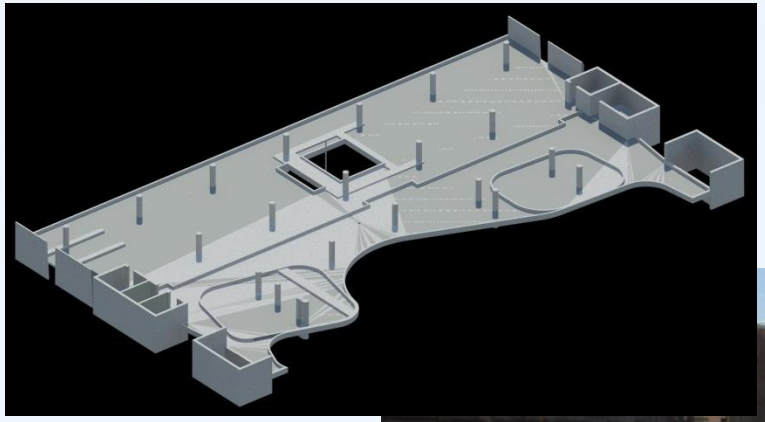
Long cantilevers

Post-tensioned Vierendeel Frame System

Large Transfer Girders



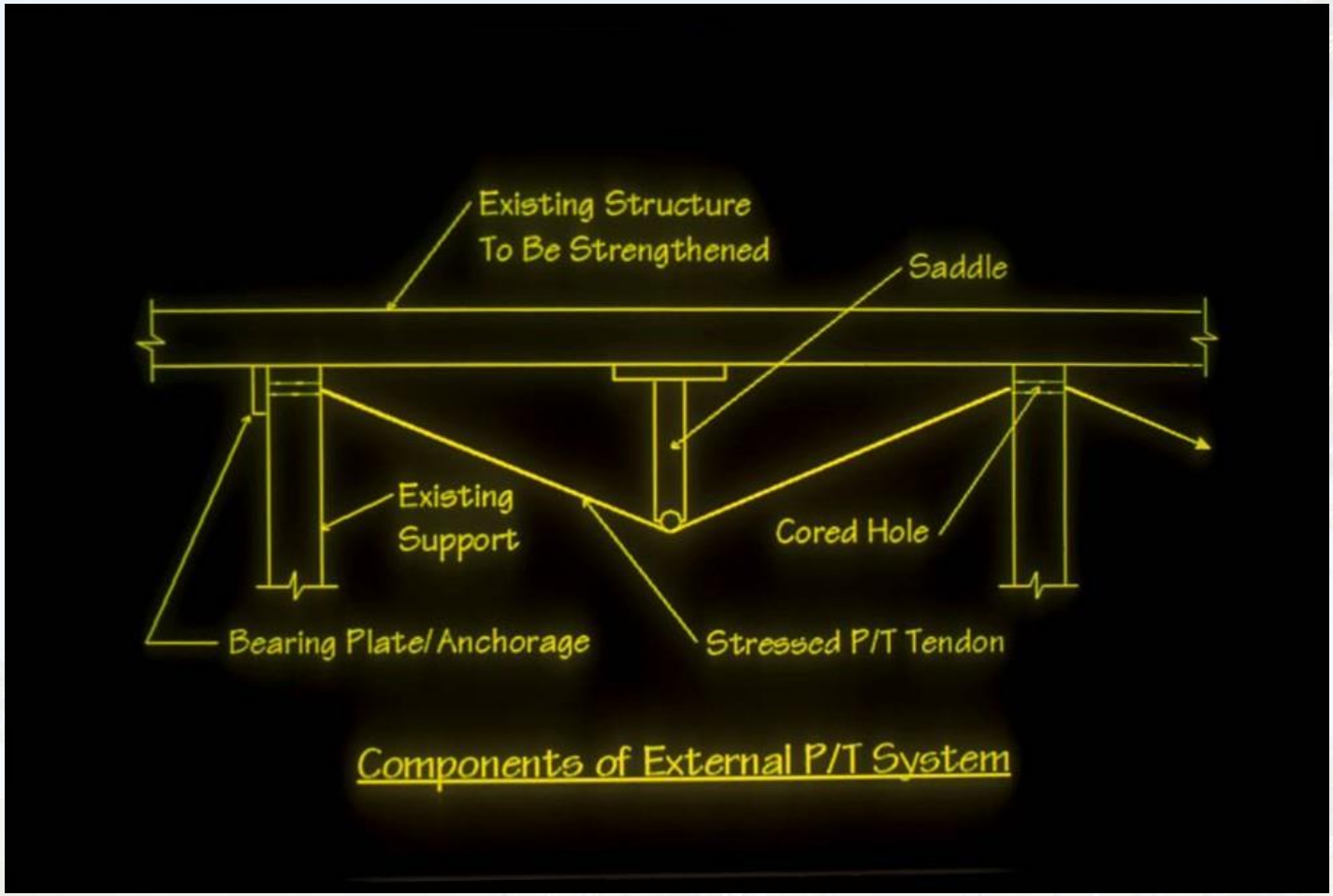
Complex Geometry



Discussion on Construction not complete without mentioning

- PT Structure Performance
  - Durability
  - Fire resistance
- Repairs and Strengthening – As structures built in the 60's and 70's start approaching the 30 to 50 year life cycle – structures need repair, strengthening etc.
  - Repairs of existing buildings (PTI, ACI has many technical documents and specs to address this)
    - Tendon repairs
    - Tendon replacement
    - External post-tensioning

Strengthening With External Post-Tensioning



Two-Way Slab with Load at Mid-Panel

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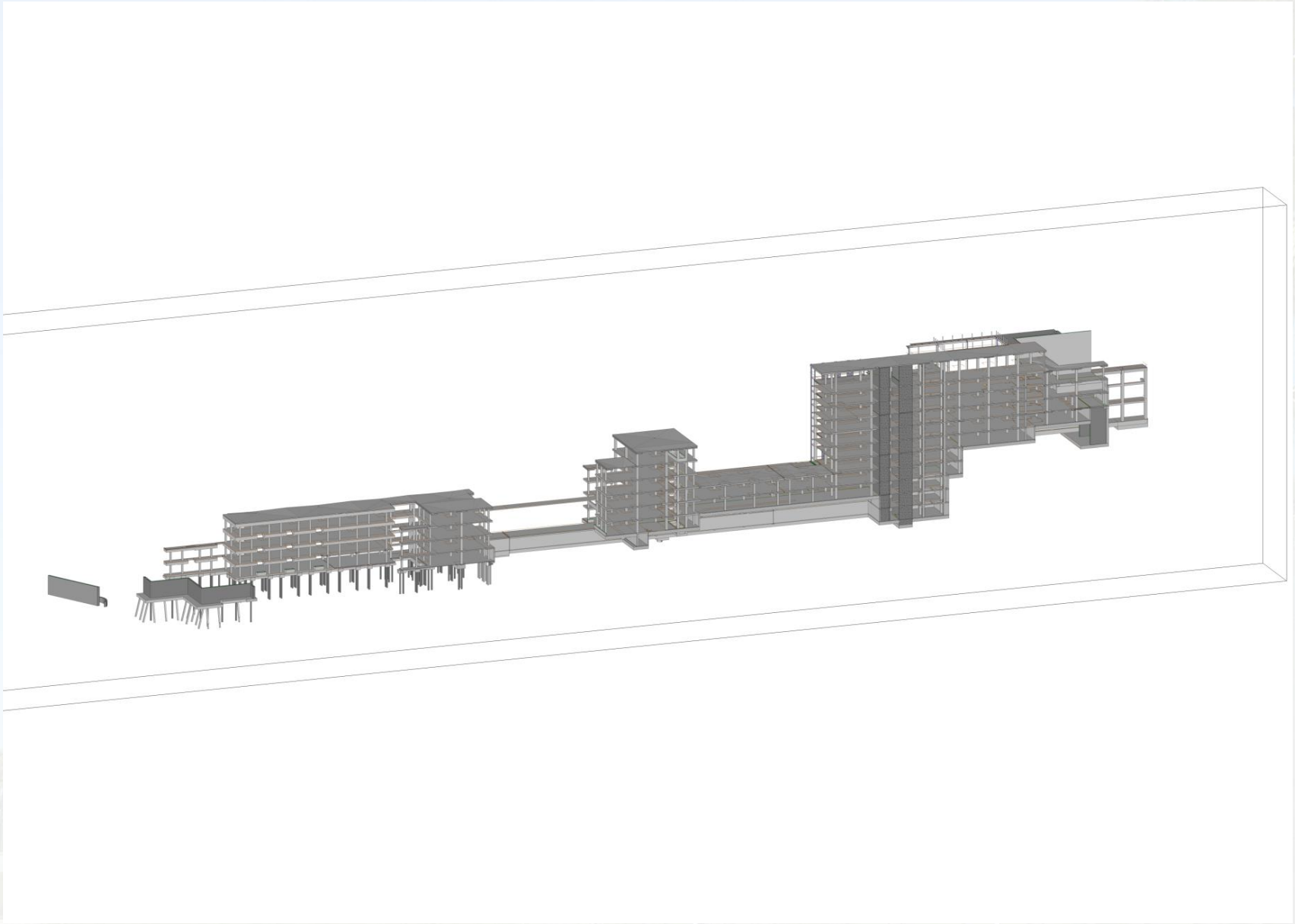
Where are we going ?

- New and better PT Systems for corrosion protection
  - Unbonded tendons - Anchors, sheathing, strand
  - Multi-strand tendons – grouting, flexible fillers
- PT Manufacturing
- PT Applications
- ***Sustainability - GREEN***
- Evolution of PT Analysis and Design Tools
  - Integration of design and shop preparation use of 3-D technologies – BIM Modeling

Where are we going ?

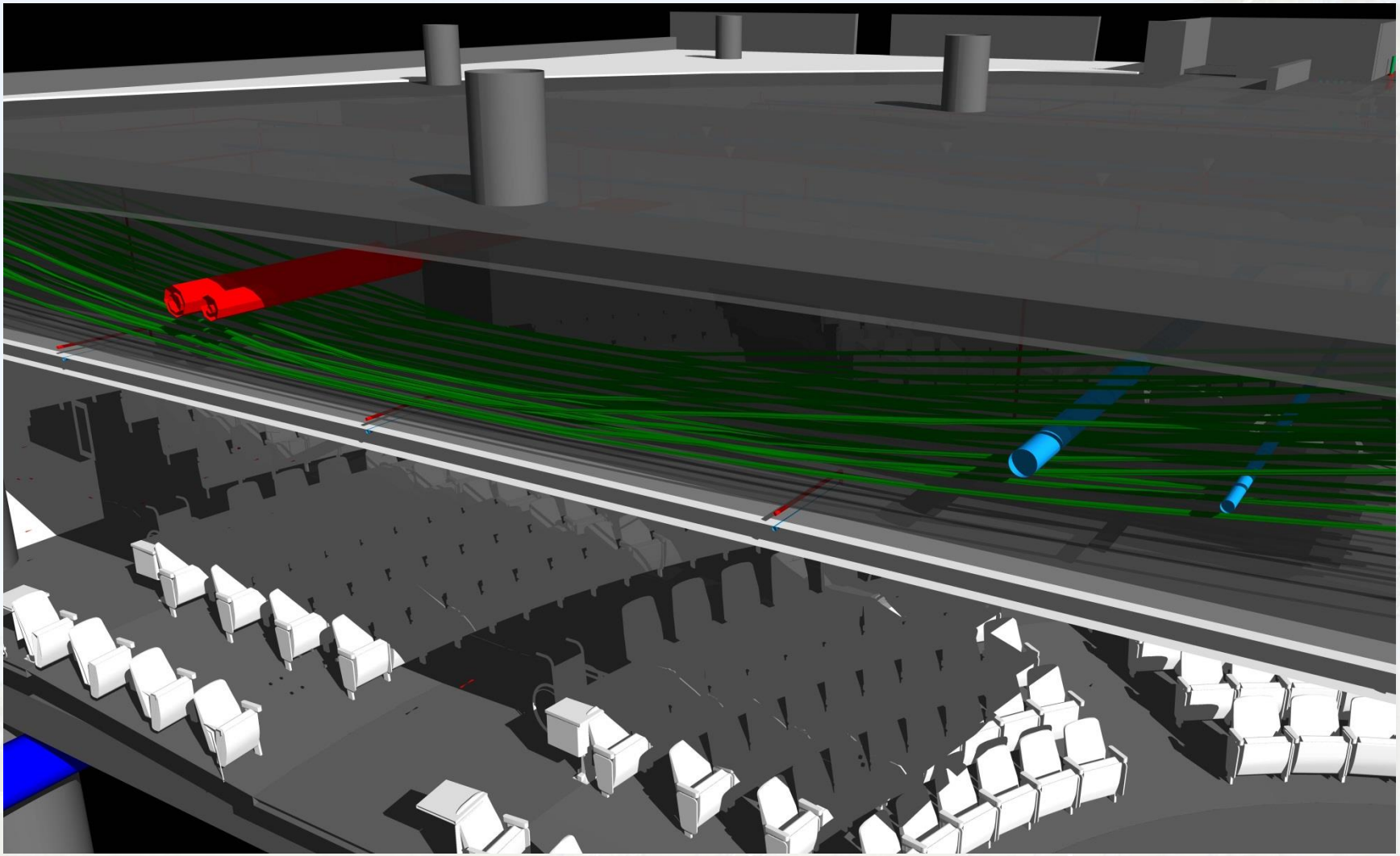
- Changes in Codes and Specifications
- Evolution of PT Construction
  - BIM technology becoming the de-facto standard in few years from start to finish of a project
    - Initial BIM Models – Project conception stage
    - Design Stage
    - Construction Stage
      - Contracts, planning scheduling, quantity and cost estimating and verification
      - RFI's, changes, additions, modifications, repairs during construction
      - Verification of design and implementation of standards of compliance
    - As-builts – **permanent facilities model**
    - **SMART TENDONS, STRUCTURE – HEALTH MONITORING**

BIM TODAY

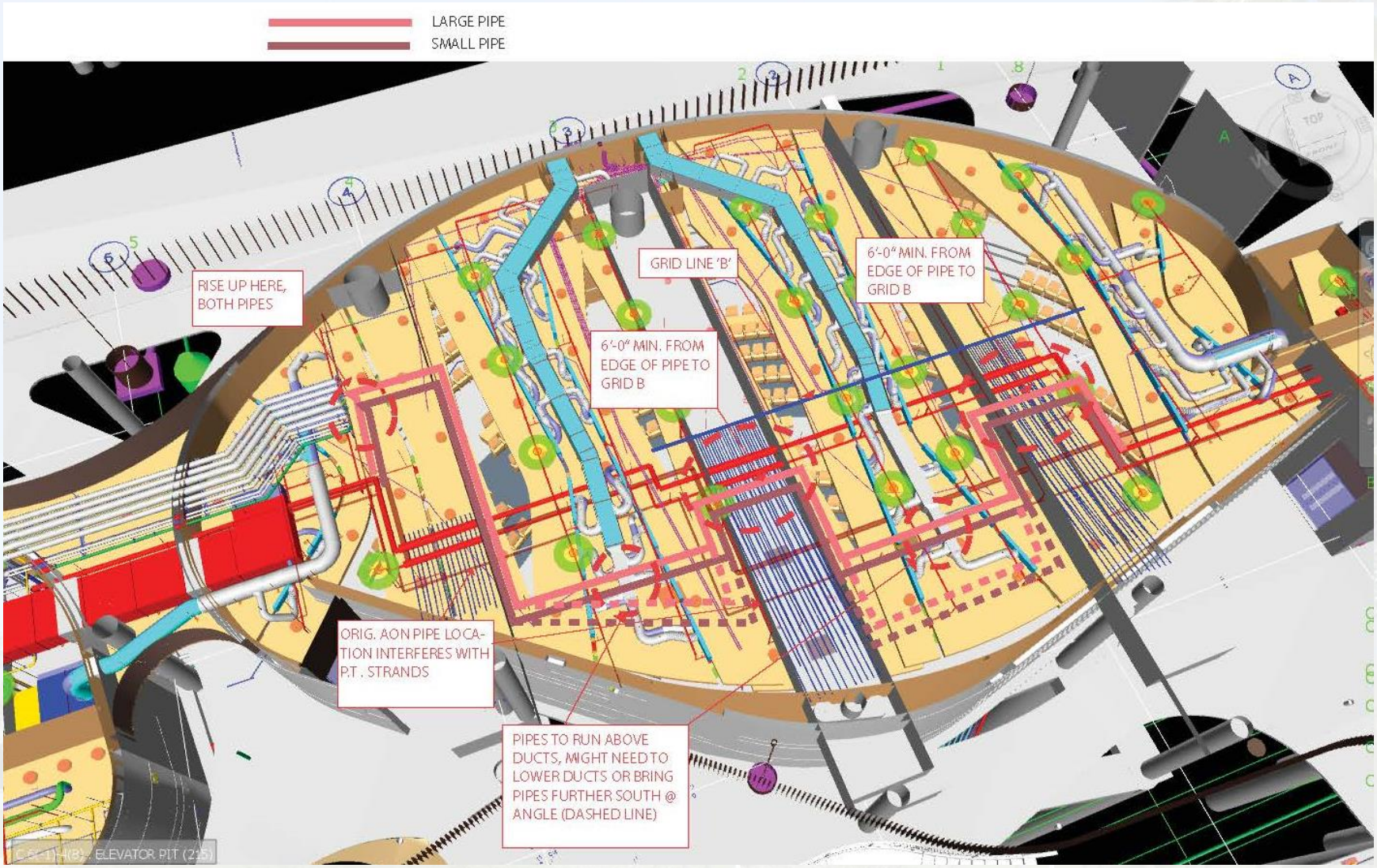


Structural BIM Full Building Section

Transfer Girder with 130 tendons



USE OF BIM FOR CLASH DETECTION



Use of Laser Scans

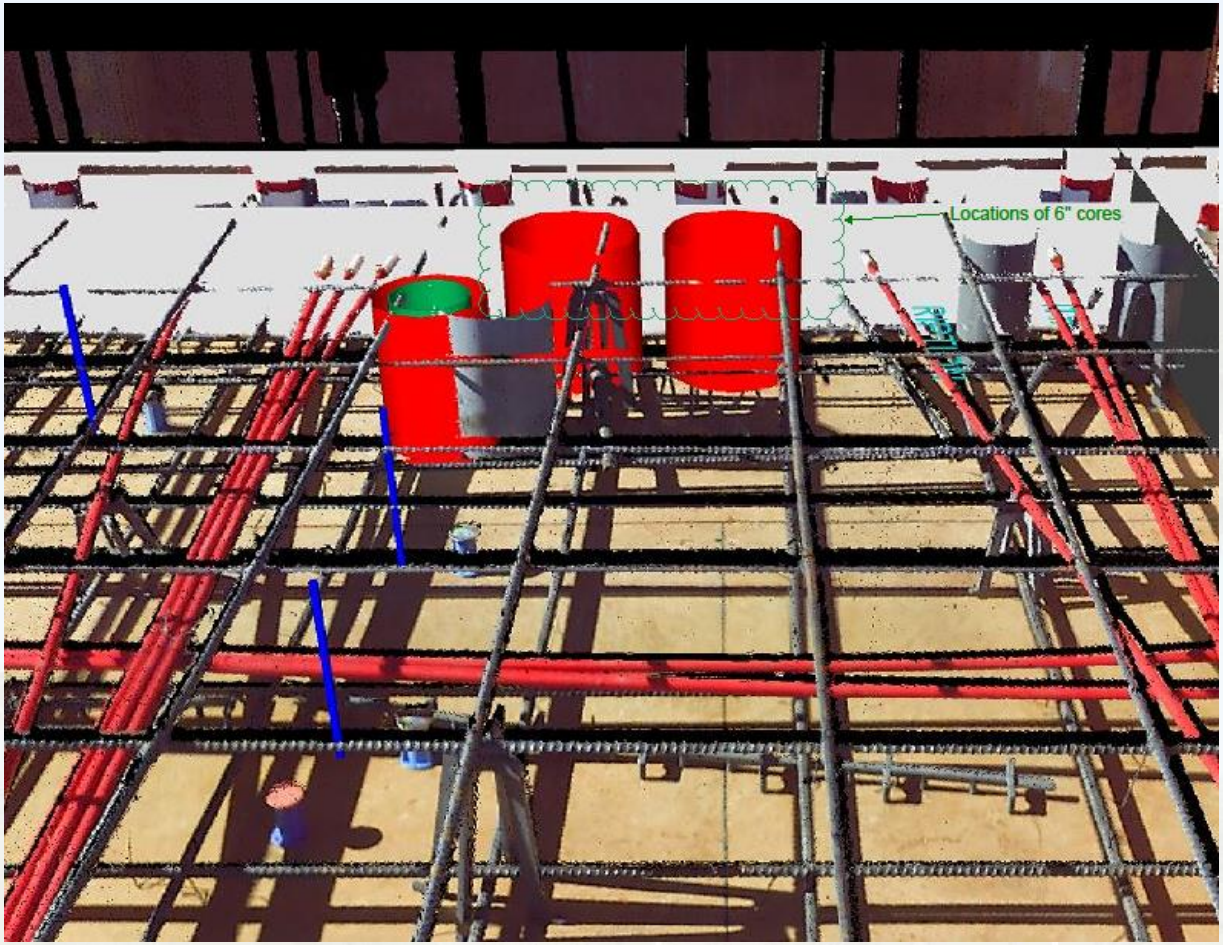
- Useful during various stages of construction
- Verify standards of compliance – check tolerance, nuanced code requirements, equipment clearances etc.
- Repairs, retrofits, additions & modifications, fix errors during construction
- Design validation
- Provides a **Permanent Facilities Model** for the Building Owner
- FOR CONTRACTORS: Planning, scheduling, quantity& cost – Saves $$$$$$

EXAMPLE of Laser Scans

- SEE VIDEO (insert video clip)

Use of Laser Scans – Example#1

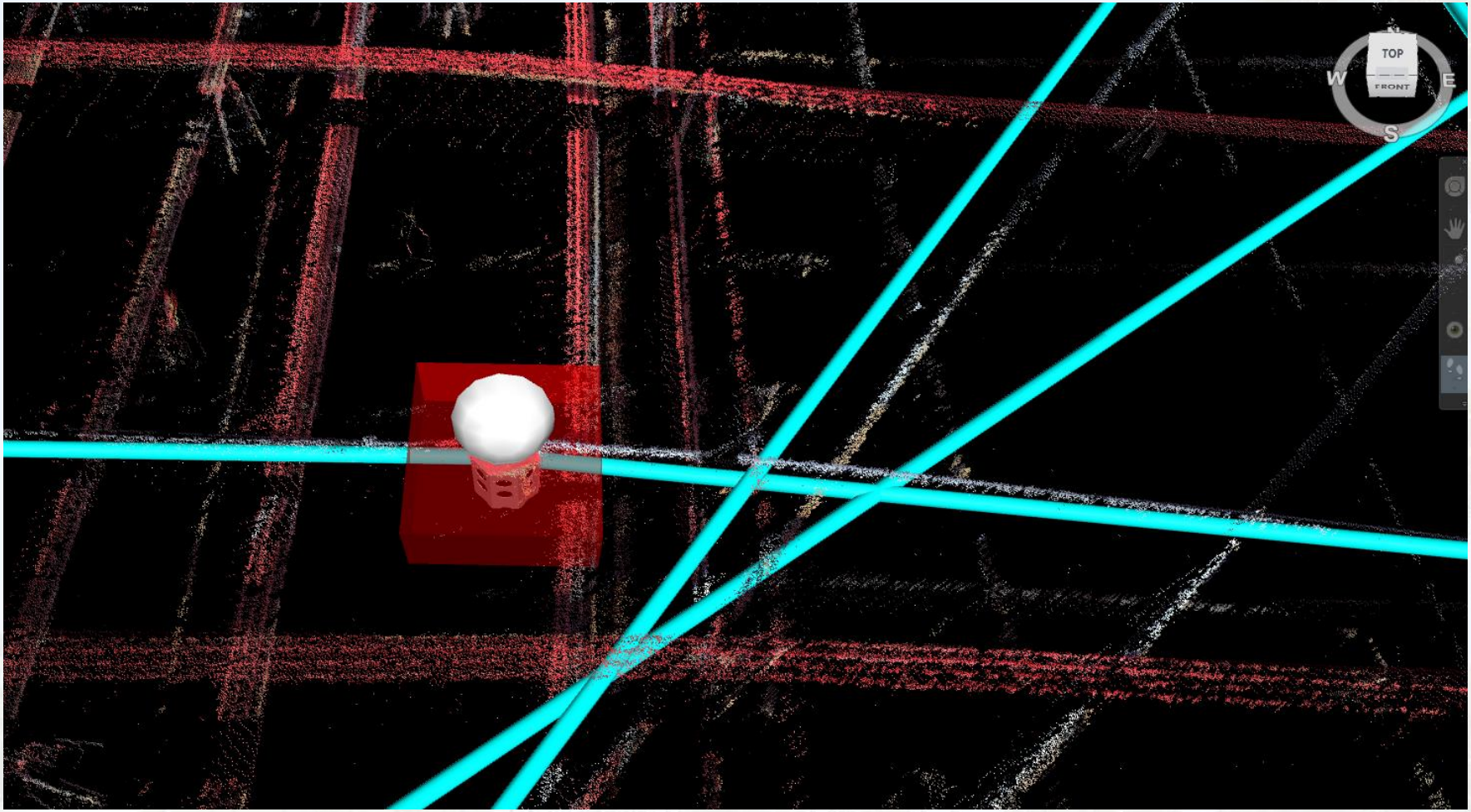
- Fix errors during construction



Use of Laser Scans – Example#2

- Fix repairs during construction

Question
Reference attached images Three electrical conduits have broken off in the concrete deck pour at the electrical box. Is it acceptable to repair the conduits with the following procedure? 1 - Review laser scanner with Dallas and verify there are no PT cables above the box. (photos are attached). 2 - Shoot the total station point on the deck. 3 - Core a 6" diameter hole 4" deep. 4 - Chip away concrete on broken conduit. 5 - Clear and repair broken conduit. 6 - Patch the hole


TOP
FRONT
W
E
S

Use of Laser Scans – Example#3

- Additions or modifications during construction

Question
Reference MH162 and attached sketches. The roof level ducts installed per plans are in conflict with the roofing manufacturers specifications. A minimum of 12" is needed between the ducts and the parapet walls. The new locations (on attatched sketch) have been coordinated with the 3D laser scans to eliminate conflicts with the post tensioned cables. Please confirm that the locations specified in the attached sketches for saw cutting are acceptable. Please provide details for relocating the exhaust fans on the roof if necessary, and all under deck and above ceiling modifications.


3' - 11 1/2"

Where does the future look like?

I AM OPTIMISTIC!!!

There is a lot of innovation to be done and the future is very promising

Join the PTI folks and become a part of this endeavor

Thank You

Thanks to Ken Bondy, Frank Malits, PTI Staff and Suncoast Post-tension for some of the slides