Post-Tensioned Concrete in Buildings

A 40+ Year Overview

By

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ACI Fall Convention
San Francisco, October 2004
41 Years Ago…

- It was the fall of 1963
- I was 23 years old
- I had completed my MSCE course work at UCLA
- I was almost finished with my thesis
- I was being supported by my wife and my meager Teaching Assistant salary
- All things considered, it was time to…..
Get a Job!!!
Out Came the Yellow Pages

Any structural firms hiring in the San Fernando Valley?

One was, and they hired me!!!

Their name was.....
T. Y. Lin and Associates
Exciting Time for P/T Concrete

- Had been used in buildings for only a few years
  - Mostly in lift-slab construction
- Prestressed concrete had just been introduced into ACI Building Code (1963) for first time
- In the next 41 years my career spanned every major landmark in the development of p/t concrete in buildings
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 deflections and slab weight in long 2-way spans
- To solve deflection and weight problems, lift-slab companies changed to post-tensioned slabs
No Existing U.S. P/T Systems

- Lift-slab companies went to Europe for help.
- Most existing hardware was for multistrand tendons in bridges.
- Only European system feasible for building construction was the BBRV “button-headed” tendon system.
- Each lift-slab company returned with a license to market the button-headed tendon system.
- Some “independent” companies (Prescon, Ryerson, others) also obtained BBRV licenses.
Button-Headed (BBRV) Anchorage

Fig. 2-3 — Button-head anchorage, stressing end, non-grouted
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 (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 US!
Relied on Tensile Strength of Concrete

- Many breakouts occurred, particularly in lightweight concrete
- Atlas field superintendent (Tom Anderson) suggested chaining anchors together
- Led to award
  - Recognized Tom’s contributions
  - Recognized subsequent contributions of other Atlas employees
The Thomas E. Anderson Memorial Award
Replaced by Ductile Iron Castings in 1963
7-WIRE 270 ksi STRAND TENDON

1/2” - φ

W = 0.525 #/ft.
A = 0.153 in²
F_ult = 41.3 kips

0.6”φ

0.745 #/ft.
0.217 in²
58.6 kips

PLASTIC SHEATH

ANCHOR

GROMMET

GRIPPER
Small, lightweight stressing equipment

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Bearing Anchor in Use

- SOG application (largest US use of p/t)
- Tendon shown is encapsulated
Strand System vs. Button-Head System

- Atlas vs everybody else
  - Prescon
  - Ryerson
  - Western Concrete Structures

- After fierce 5-6 year struggle, Atlas wins battle of marketplace by late 1960s

- Button-headed tendons became extinct

- Virtually all building p/t has been with strand tendons ever since.
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 we do…..???
Formed Alliances With Emerging Flying Form Industry
Direct Competition

- Joint promotion between p/t companies and flying form companies 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.
Short-Sighted?

If lift-slab companies had not originally tried to exclude independent p/t companies

Lift-slab construction would be a significant factor in today’s medium-rise building market.
Landmarks in P/T Buildings

- Introduction of strand systems
  - Replaced “button-head” tendon system
- Development of ductile iron castings for single-strand tendons
- Introduction of “load-balancing” design method
- Introduction of “banded” tendon layout for 2-way slab systems
- Formation of Post-Tensioning Institute
- Improvements in corrosion resistance
Most Important Single Development

- The introduction of the “load-balancing” design method by T.Y. Lin in 1963
- T.Y. wasn’t the first to use it but did more than any other individual to explain it and disseminate information about it.
- Made the design of prestressed concrete as easy as the design of non-prestressed concrete
Promotion of P/T in Buildings

Atlas Prestressing Corp. recognized in mid 1960s that the most effective way to increase the market for p/t was…

…to teach engineers how to design it

…and to assist them in their designs

With this marketing philosophy, Atlas grew from smallest to largest p/t firm in less than ten years.
Seminars

- Atlas sponsored over 100 one-day design seminars between 1965 and 1976
- Held in most major US cities and in western Europe
- Attended by more than 2000 practicing engineers
- Often resulted in p/t building within 6 months of seminar
Building Codes

- Post-tensioning virtually absent from ACI 318-71 (“ignore secondary moments”)
- ACI 318-77 and 83 were greatly improved
  - Reflected testing at Texas and Washington
  - Banded tendon distribution
  - Minimum bonded reinforcement requirements
  - More attention to indeterminate structures
- Codes have continued to improve with more p/t expertise on ACI committees
Formation of PTI

- Post-tensioning was represented as a division within PCI in late 1960s through mid 1970s
- PTI formed as an independent institute in 1976
- PTI gives contractors and engineers a single unified source and voice for p/t design and construction information
- Establishes a standard of care in many areas of design and construction
Construction Advances

- High-rise construction in Hawaii
- Banded tendons in 2-way p/t slabs
Honolulu Skyline circa 1977
Wall Jump-Forms and Flying Deck Forms
Slabs Hung From Walls
3 Days per Floor

- Place slab concrete on Monday morning
  - Walls and columns are two lifts above
- Stress tendons on Tuesday morning
  - Oversize anchors (4x6) to permit stressing at 1,500 psi – achieved in 24 hours
- Fly forms on Tuesday afternoon
- Install tendons and rebar on Wednesday
  - Placed through sleeves in walls and columns
- Place slab concrete on Thursday morning
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.
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
Some Above, Some Below…
Sequencing

- Detailer had to find the single tendon which was below all other tendons
  - Sequence #1
- Then had to find tendon in perpendicular direction which was below all remaining tendons
  - Sequence #2
- Typical slab would have 30-40 sequence numbers
Tendons Had to be Installed in Sequence

Any errors in placing sequence resulted in “birds-nest” when chaired
Back to Watergate...

In the Watergate building, columns didn’t line up in either direction.

Spans were short (22’ max) but columns were located where they could be hidden with no regard to a grid system.

Column/middle strip concept meaningless.

Load path virtually impossible to follow.
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
  – Hundreds of millions of square feet in service
  – Behavior studied and verified in numerous laboratory tests
4-Panel Test at University of Texas
Simple Light Tendon Layout
Notice Anything Unusual?
Complicated Tendon Layout
Problems

- Restraint-to-shortening
  - Mechanics of RTS different in prestressed and non-prestressed members
  - Engineers had to learn how to design p/t floor systems with levels of cracking normally accepted in non-prestressed floor systems
- Methods
  - Joinery details
  - Non-prestressed reinforcement
Biggest Problem

- Tendon Corrosion
  - Early sheathing and grease were inadequate for aggressive corrosion environments

- Material specifications developed by PTI have largely solved early corrosion problems
  - Improvements in sheathing material, coatings, complete encapsulation
The Future

- Strengthening existing buildings with externally applied p/t tendons
- Tall concrete buildings
Strengthening With External Post-Tensioning

- Existing Structure To Be Strengthened
- Saddle
- Existing Support
- Cored Hole
- Bearing Plate/Anchorage
- Stressed P/T Tendon

Components of External P/T System
Loads

Loads Applied by External P/T System
One-Way Slabs

One-Way Slab Supported on Beams or Walls

Trusses Spaced @ 6 +/- o/c
Beams and Girders
2-Way Slabs

Plan View - 2-Way Slab Supported on Columns
Orthogonal Trusses

- "B" Saddle
- Column
- Beam Truss
- "B" Saddle
- Girder Truss
- "A" Saddle

Orthogonal Trusses
Two-Way Slab with Load at Mid-Panel
Fireproofing
Fireproofing Options
10-Story Building Strengthened From Below First Floor
Tall Buildings

- P/T reduces weight of floor systems
- High-strength concrete makes column sizes reasonable

Advantages
- Cost
  - Exposed exterior frame beams and columns
- Fire and blast resistance
- Sound and vibration
3900 Alameda Burbank, CA

Tallest Concrete Building Ever Built in Seismic Zone 4 (at time of construction – late 1980s)
Thank You!!