# Arizona Veterans Memorial Coliseum Roof Repairs

***ICRI Award of Merit 2009***

Dennis Wipf P.E.

Gervasio & Assoc. Inc.
Consulting Engineers
Phoenix, AZ

# History

- Built in 1965 for the Arizona State Fair Commission.
- Price:  $7,000,000

# Notable Events

- Opened in Nov. 3, 1965 with Ice Follies with Bob Hope as host.
- Rolling Stones Concert later that month.
- Elvis was there.
- Pope John Paul was there.
- Mother Theresa was there.
- All of the US Presidents since 1965

# Phoenix Suns

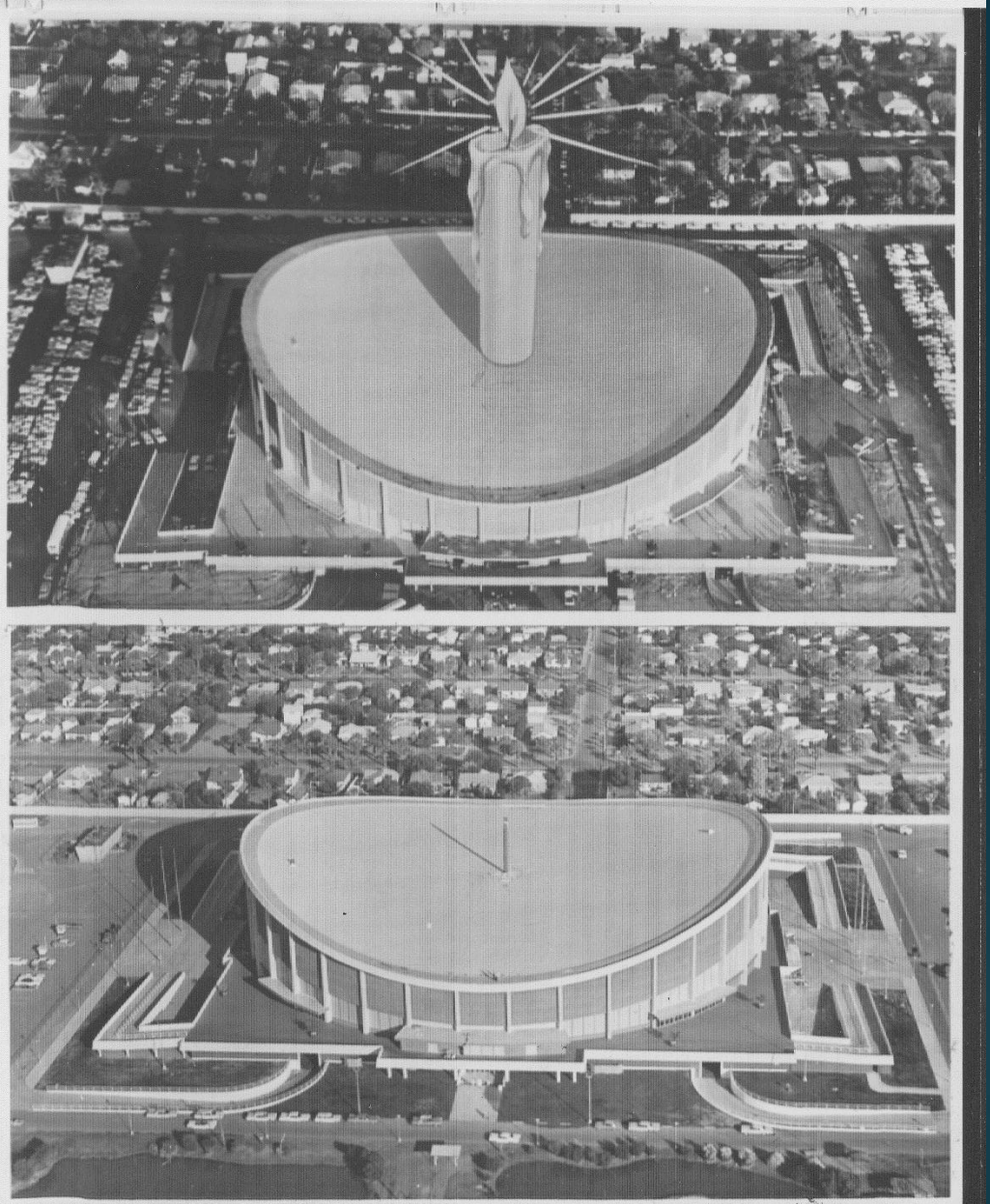
- Pro Basketball Team
- 1968-1992
- Became known as the ***"Madhouse on McDowell"*** – Located on McDowell Road
- NBA Allstar game 1975
- NBA Finals 1976

# Other Fun History

- 1 year after opening, celibrated the Colisuem's "first Birthday".
- A candle on the roof.

The Artist's Rendering

What it Actually Looked Like



(PN1) PHOENIX, Ariz., Nov. 4 - WOULD YOU BELIEVE...A MATCH? - Veterans Memorial Coliseum was one year old today, starting date of the Arizona State Fair. Press agents for the fair announced that a six-story "candle" would be erected atop the Coliseum, which DOES look like a cake from the air, for its birthday. They said it would look like the artist's drawing above. The lower photo shows the candle as it appeared when the steel pipe was erected. Well, anyhow, it showed up well xxx at lighting ceremonies last night and the fair still is expected to be "the biggest and best in history."
AP WIREPHOTO (ta61000REPUBLIC) 1966

# 1970's

- A "Smiley Face" was painted on the roof.
- Exacerbated thermal movements at the roof membrane and lead to additional roof leaks.

# A Leaky Roof

- Known for roof leaks.
- "A Suns game against the Portland Trail Blazers had to be canceled because the roof leaked during a rainstorm".
- Mopping off the basketball court during games during rainstorms was all to common.

# Arizona Veterans Memorial Coliseum

- It was ***" Thee Venue"*** in Phoenix, and all of Arizona in the 1960's, '70's and '80's.
- Basketball, Hockey, Concerts, State Fair, the Circus, Trade Shows, and other events.
- ***Everything*** came to the Coliseum!

# Phoenix Suns Leave

- By late 1980's Coliseum is the oldest and smallest arena in the NBA.
- 1992 Suns move to a new Arena, the America West Arena, (now US Airways Center).
- The Coliseum becomes the "C" rate building in town.

# Events Continue

- Located on the State Fair Grounds, the Coliseum continues host the fair and other events.
- In 2005, the Coliseum sheltered over 2,500 evacuees from New Orleans in the wake of Hurricane Katrina.

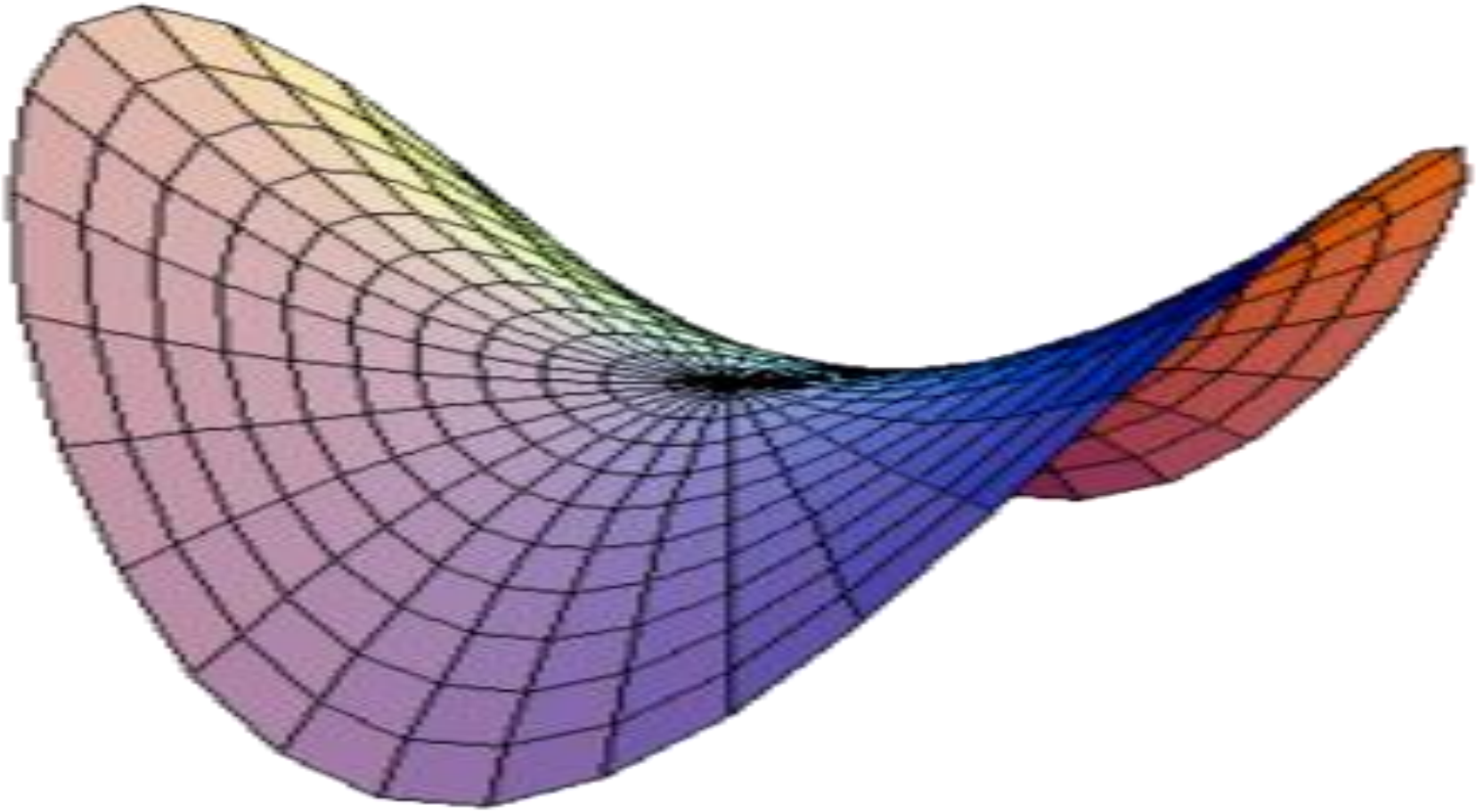
# Concerts at the Coliseum

- Concerts are frequent.
- Lights and Speaker Equipment is suspended from the roof.
- 40,000 – 50,000 lbs of equipment is hung from the roof for a show.

# So How was it Built?

- Hyperbolic Parabiloid shape.
- In plan view, a perfect circle.
- 36 post-tensioned cables each way.
  - Like a tennis racket.
- Tensioned to 420,000 lbs force each.

# What the heck is a Hyperbolic Parabolid?

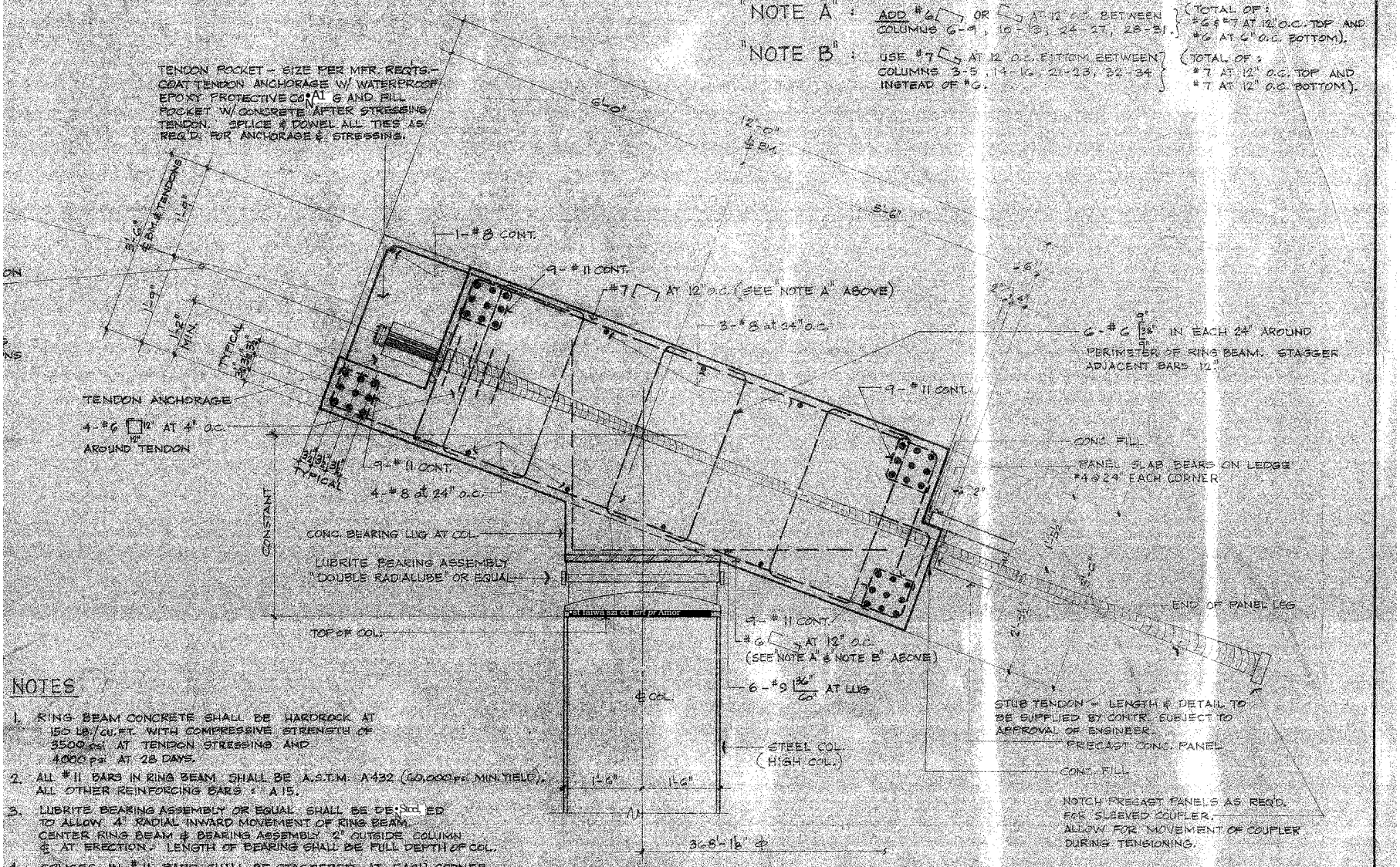


*Pringles potato chip shape.*

# Original 1965 Construction Photo

# So How was it Built?

- Concrete Compression Ring around perimeter.
  - 4 feet thick, 12 feet wide.
  - Cast in place concrete.




## NOTES

1. RING BEAM CONCRETE SHALL BE HARDROCK AT 150 LB./cu.FT. WITH COMPRESSIVE STRENGTH OF 3500 psi AT TENDON STRESSING AND 4000 psi AT 28 DAYS.
2. ALL #11 BARS IN RING BEAM SHALL BE A.S.T.M. A432 (60,000 psi MIN. YIELD). ALL OTHER REINFORCING BARS = A15.
3. LUBRITE BEARING ASSEMBLY OR EQUAL SHALL BE DESIGNED TO ALLOW 4" RADIAL INWARD MOVEMENT OF RING BEAM. CENTER RING BEAM & BEARING ASSEMBLY 2" OUTSIDE COLUMN ℄ AT ERECTION. LENGTH OF BEARING SHALL BE FULL DEPTH OF COL.
4. SPLICES IN #11 BARS SHALL BE STAGGERED AT EACH CORNER OF RING BEAM.
5. ALL REINF. 2" CLR. MIN.

## SECTION (2/S15)

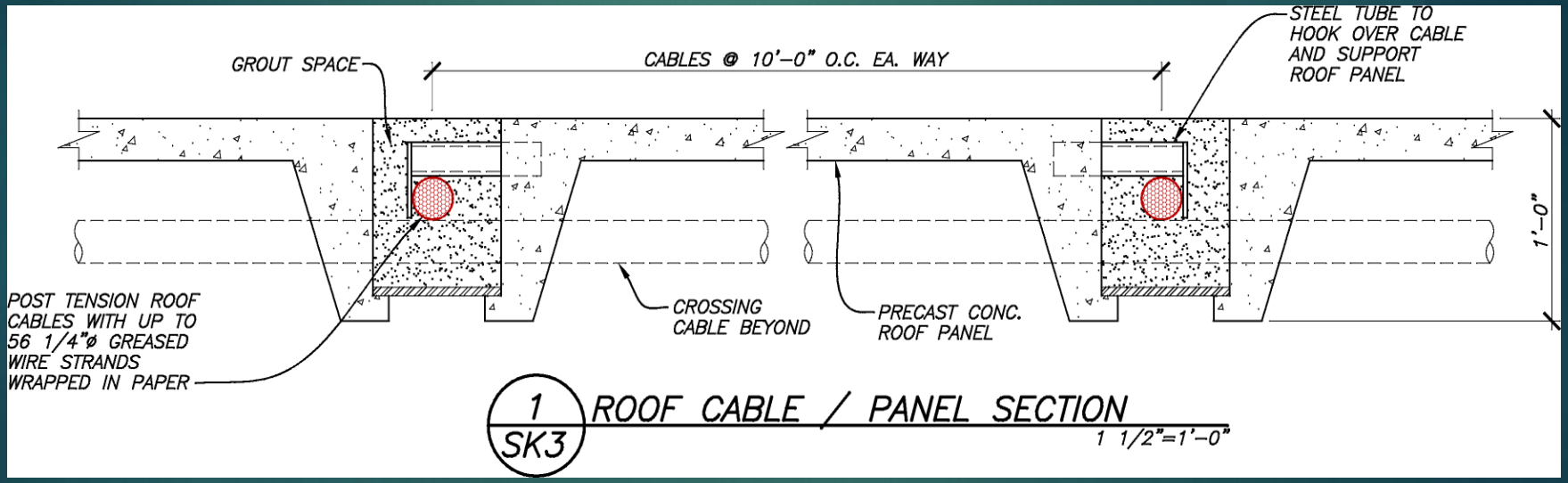
AT HIGH COLUMN & TENDON STRESSING POCKET

3/4" = 1'-0"

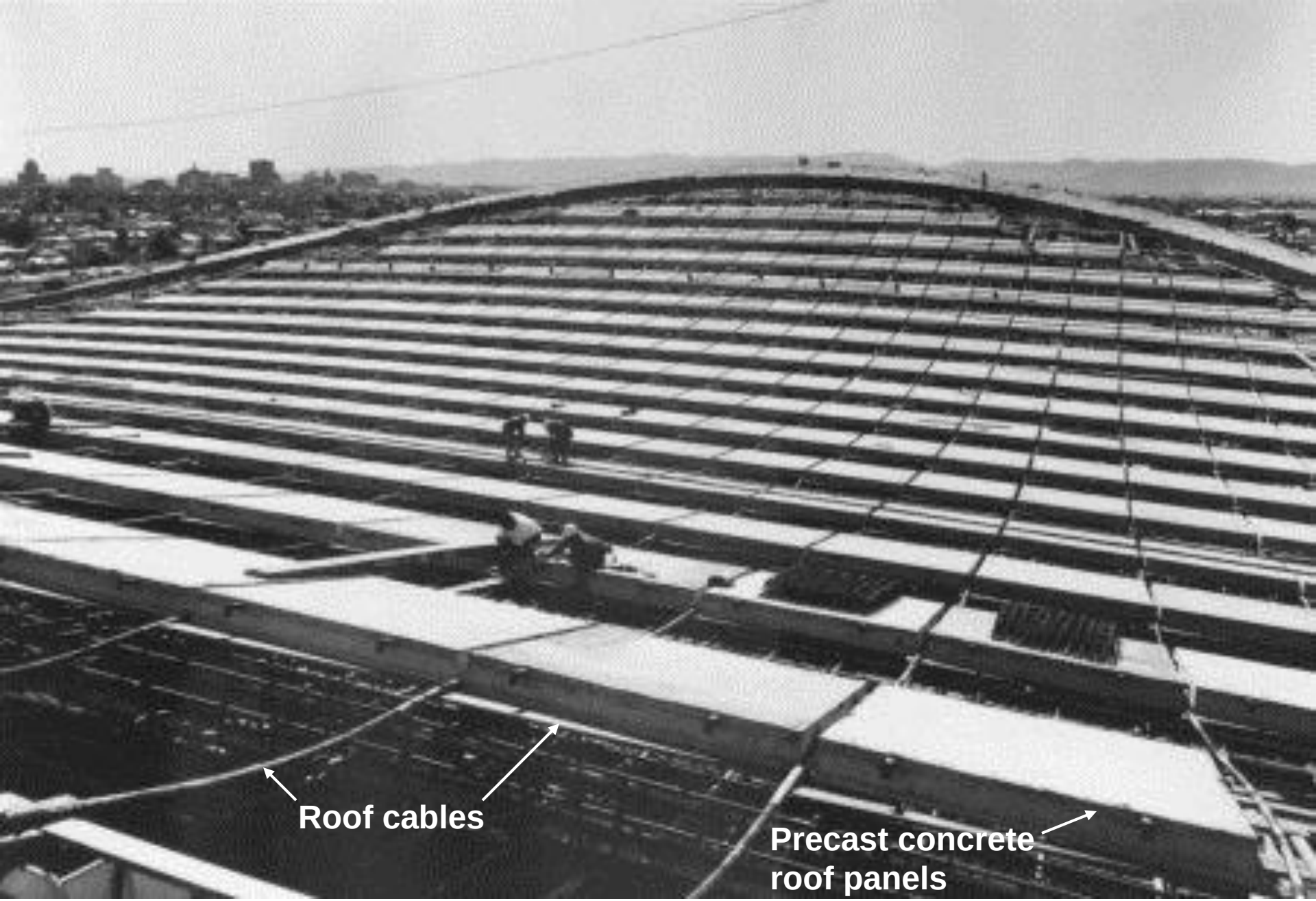
# So How was it Built?

- Precast concrete roof panels hung between and off of the roof cables.
  - Over 1000 panels.
  - Each Panel Weighs over 3000 Lbs.

# Original Construction Section Through Roof Panel



Typical Bottom Side of Roof Panels




Historic overall photo of roof structure during construction in 1965.

# •THESE BIG, BOLD ROOFS

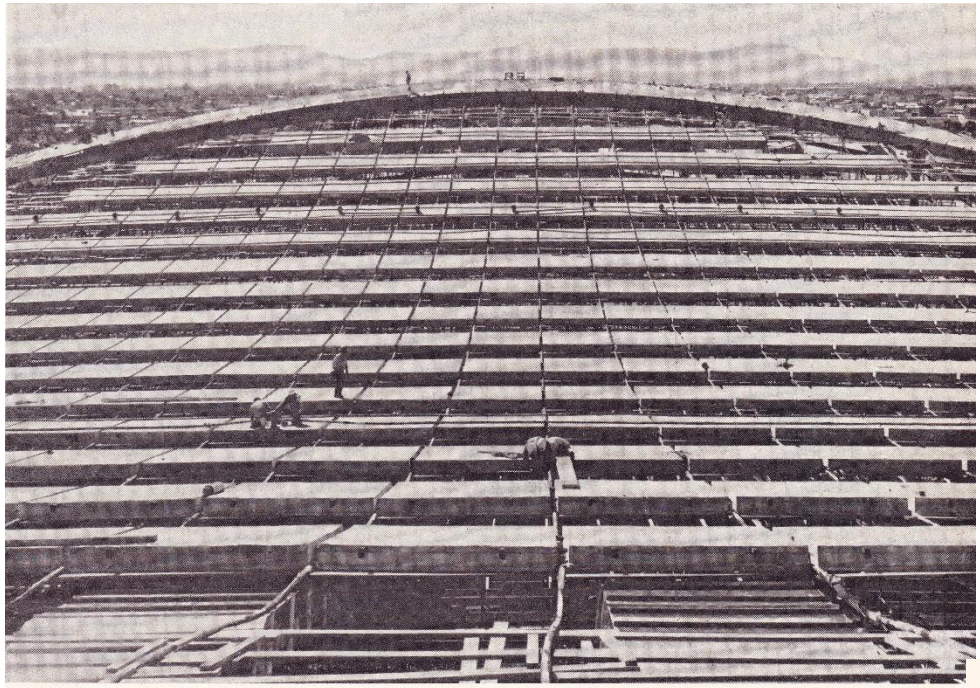
# •PROVE THE POINT...

## •BBRV POST-TENSIONING BY RYERSON

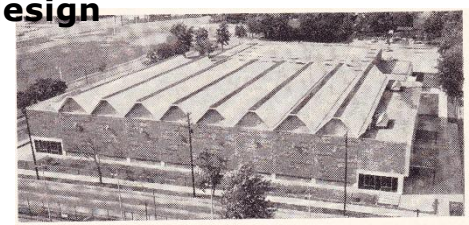
## •minimizes support requirements

## •maximizes freedom of design

## •at reasonable cost

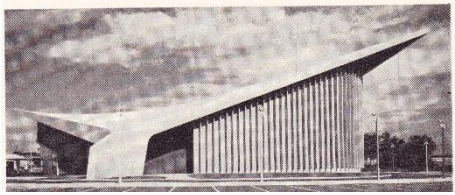


**•LONGEST SINGLE SPAN FOLDED PLATE ROOF** is a distinctive architectural feature of the Physical Education Building at Indiana State University in Terre Haute. Longitudinally the span is 160' between support points with a 3' overhang at each end. In the transverse direction each of eight segments has a horizontal span of 26' and a vertical rise of 11Y'. Each side of each segment is post-tensioned by six Ryerson tendons. **Architects:** Ewing Miller &Assoc.• **Architectural Designer:** David J. Field. **Structural Engineer:** Homer Howe • **Contractor: J. L.** Simmons Co.



**•CANTILEVERED HYPERBOLIC PARABOLOID—The** dramatic saddle shell roof of Edens Theatre at Northbrook, Ill. (also probably the largest of its type) stretches 159' between working points at abutments; 221' from tip to tip, The entire shell (only 4" thick) is rotated about the abutment points so that one tip is 59',/,' above floor level; the other only 39/'. Vertical Ryerson post-tensioning tendons prestressed the abutment walls, and these rest on post-tensioned foundation pads. To absorb horizontal thrust, the pads are connected by a post-tensioned tie beam.

**•Architect:** Perkins and Will • **Engineer:** The Engineers Collaborative. **Contractor:** Chell and Anderson.



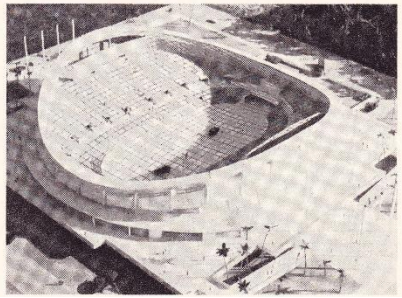
**•SUSPENDED HYPERBOLIC PARABOLOID—Believed** to be by far the world's largest of its type, the circular saddle-type roof of the Arizona Veteran's Memorial Coliseum at Phoenix boldly spans a column-free area of 119,500 square feet, giving an unobstructed view from all 15,000 seats in the arena. The roof structure consists of a reinforced concrete compression ring of 380' diameter with a 10' x 10' gridwork of Ryerson post-tensioning tendons strung across its center. Precast panels are hung on the tendons and the spaces between them filled with grout. The north-south tendons sag 33' from ends to center. East-west tendons rise 5' from ends to center and serve as tie-downs to overcome aerodynamic lift. Tensioning to a range of 462,000 to 544,000 lb. was applied in stages before, during and after grouting.

**Management and Operations Consultant:** Emmett Race.

**•Architects and Engineers:** Associated State Capitol Architects; Lescher & Mahoney; Place & Place.

**•Consulting Engineer** on roof structure; T.Y. Lin & Associates, Dallas, Tex. **General Contractor:** Manhattan-Dickman Construction,

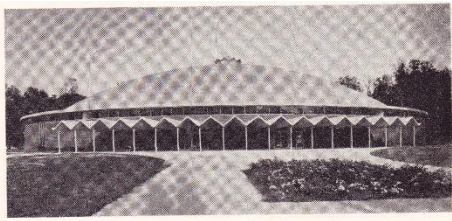
**•Arizona State Fair Commission.**

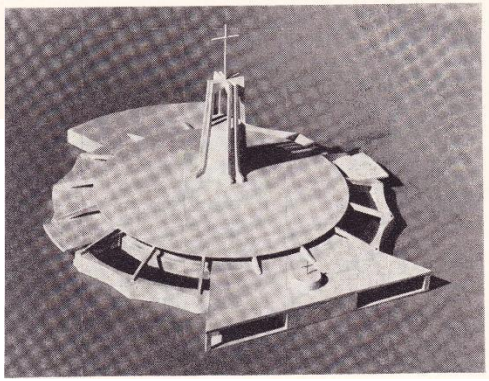


**•GRACEFUL SWEEP OF THIS THIN-SHELL DOME** spans 268' and covers an auditorium seating 7200, with provision for a balcony seating 5000 more. Yet, cost of structural elements was only $178,000 and total building cost only $6.50 psf. The concrete dome, cast on the ground and lifted into place, is circled by a tension ring in which twelve Ryerson post-tensioning tendons of 40 wires each supply a force of 720,000 lb. Warner Auditorium for The Church of God, Anderson, Indiana.

**•Architect:** Johnson, Ritchhart & Associates.

**•General Contractor:** Lewis Construction Co.

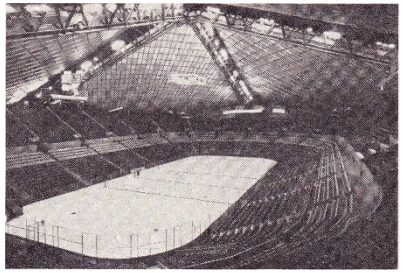




**•STRUCTURAL STEEL POST•TENSIONED—contributing** to the eloquent forms of this structure is a less common use of post-tensioning. The WF beam tension ring (which resists the horizontal thrust of 32 big triangular steel space trusses supporting the dome) is circled by 8 Ryerson post-tensioning tendons. These are anchored at staggered points so that a complete ring, 4-tendons deep, exerts a force of 400 kips, with 300 kips more in reserve for live load. Result: Weight of the WF ring beam could be reduced by two-thirds and, of course, supporting structure also lightened. St. John Brebeuf Church, Niles, Illinois.

**•Architect:** Gaul and Voosen. • **Engineer:** Paul Rogers & Associates, **General Contractor:** Valenti Builders, Inc.

**•Steel Subcontractor:** Pittsburgh-Des Moines Steel Co.



**•ANOTHER OF THE WORLD'S LARGEST CLEAR-SPAN BUILDINGS—the** Seattle Center Coliseum, also makes use of post-tensioning by Ryerson. Four triangular steel trusses and a post-tensioned concrete edge beam form four hyperbolic paraboloids and support a two-way system of tensioned tendons. These tendons provide rigid support tot aluminum panels that cover the **400-foot** square roof.

**•Architect:** Paul Thiry.

**•Structural Engineer:** Peter H. Hostmark and Associates.

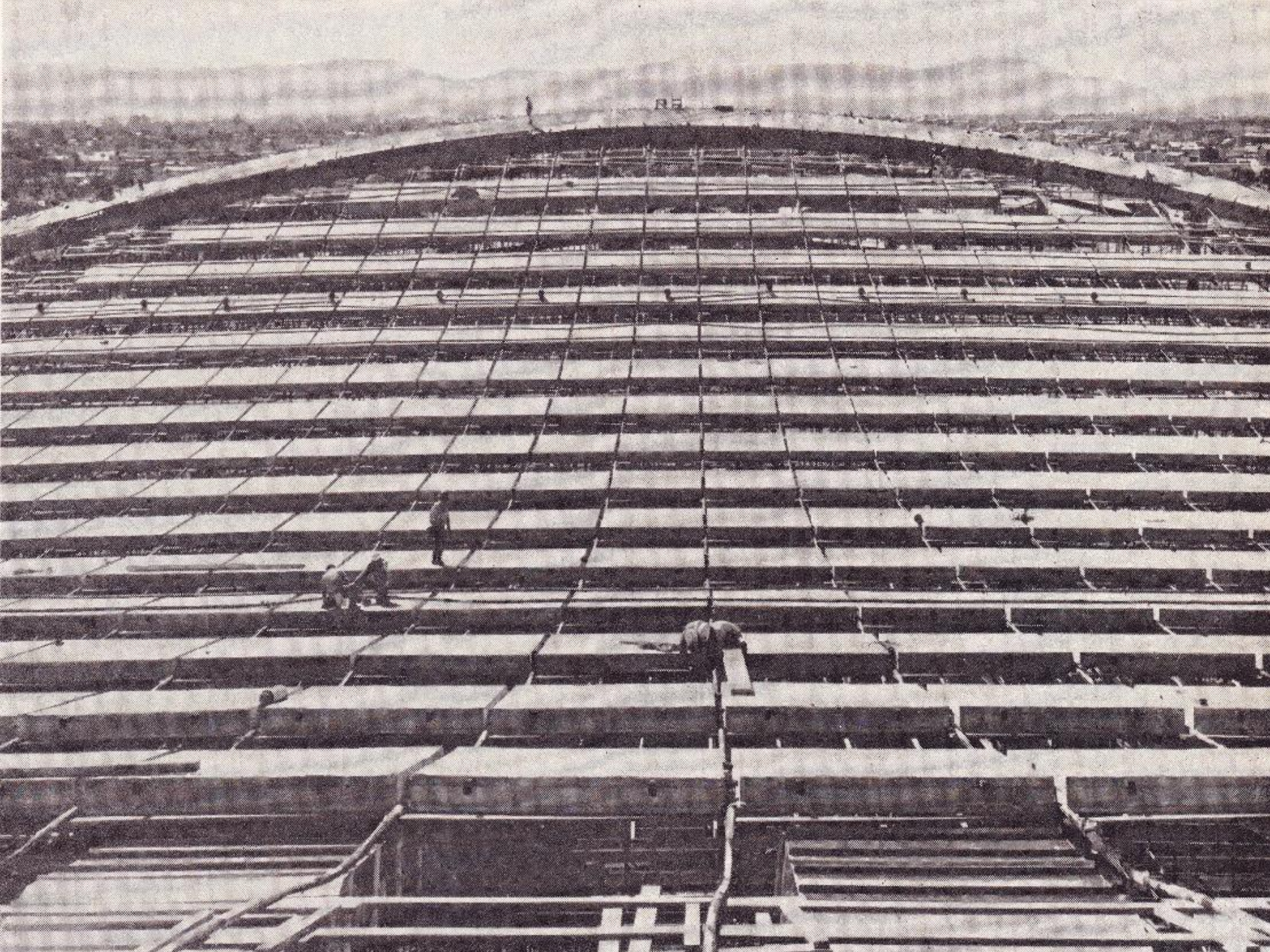
**•Contractor:** Howard S. Wright Construction Co.

*•If you would like more information on Ryerson post-tensioning service or help on a current project, call your nearby Ryerson plant or write Box 8000-A, Chicago, Illinois 60680.*

# •Ryerson

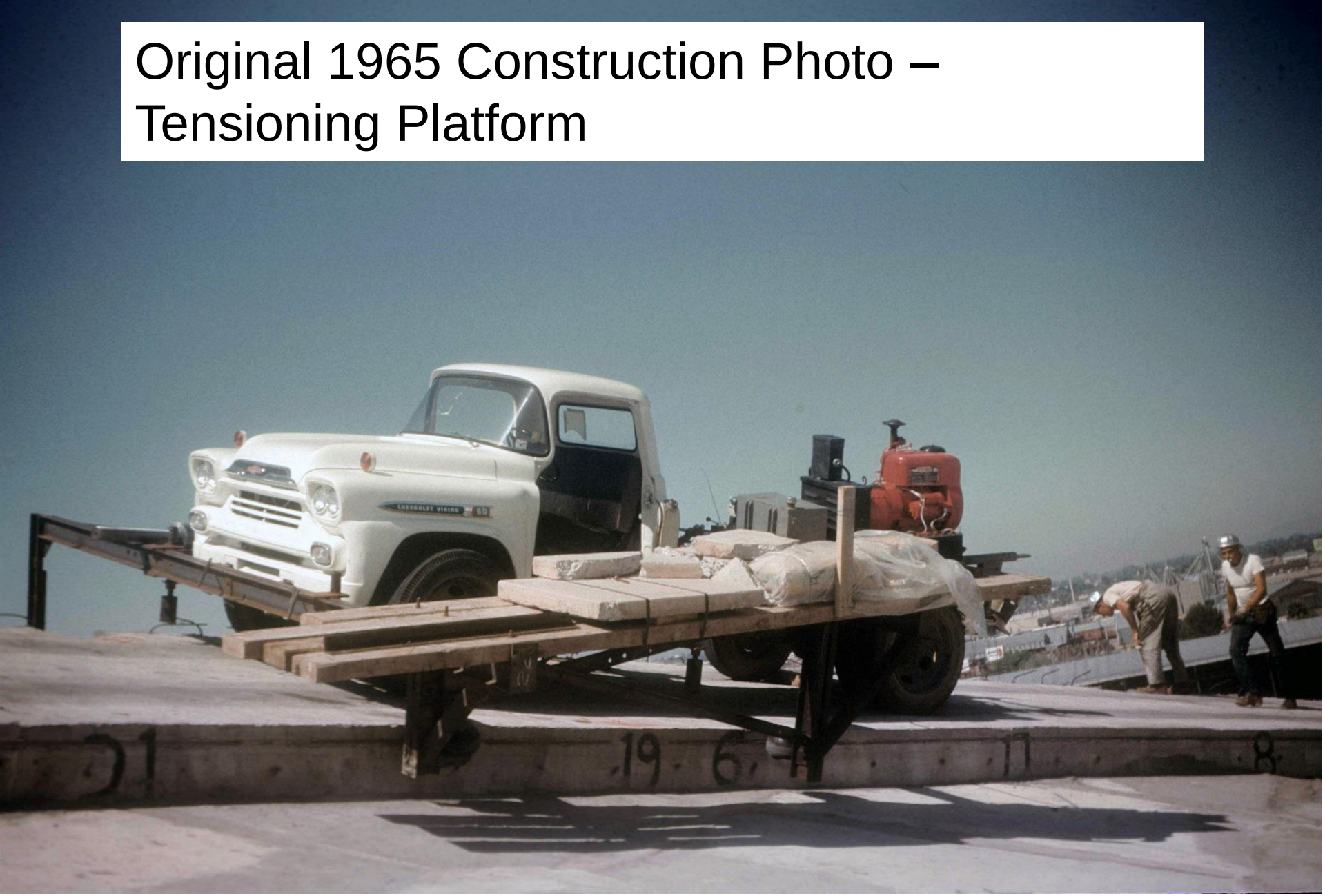
•JOSEPH T. RYERSON & SON, INC., MEMBER OF THE STEEL FAMILY

- **SUSPENDED HYPERBOLIC PARABOLOID** - Believed to be by far the world's largest of its type, the circular saddle-type roof of the Arizona Veterans Memorial Coliseum at Phoenix boldly spans a column-free area of 119,500 ft.$^2$, giving an unobstructed view from all 15,000 seats in the arena. The roof structure consists of reinforced concrete compression ring of 380 foot diameter with a 10' x 10' grid work of Ryerson post-tensioning tendons strong across its center. Precast panels are hung on the tendons and the spaces between them filled with grout. North-south tendons sag 33 feet from ends to center. East-west tendons rise 5 feet from ends to center and serve as tie-downs to overcome aerodynamic lift. Tensioning to a range of 462,000 to 544,000 pounds was applied in stages before during and after grouting.



# Original 1965 Construction Photo

# Original 1965 Construction Photo – Tensioning Platform



# Original 1965 Construction Photo – Tensioning Platform

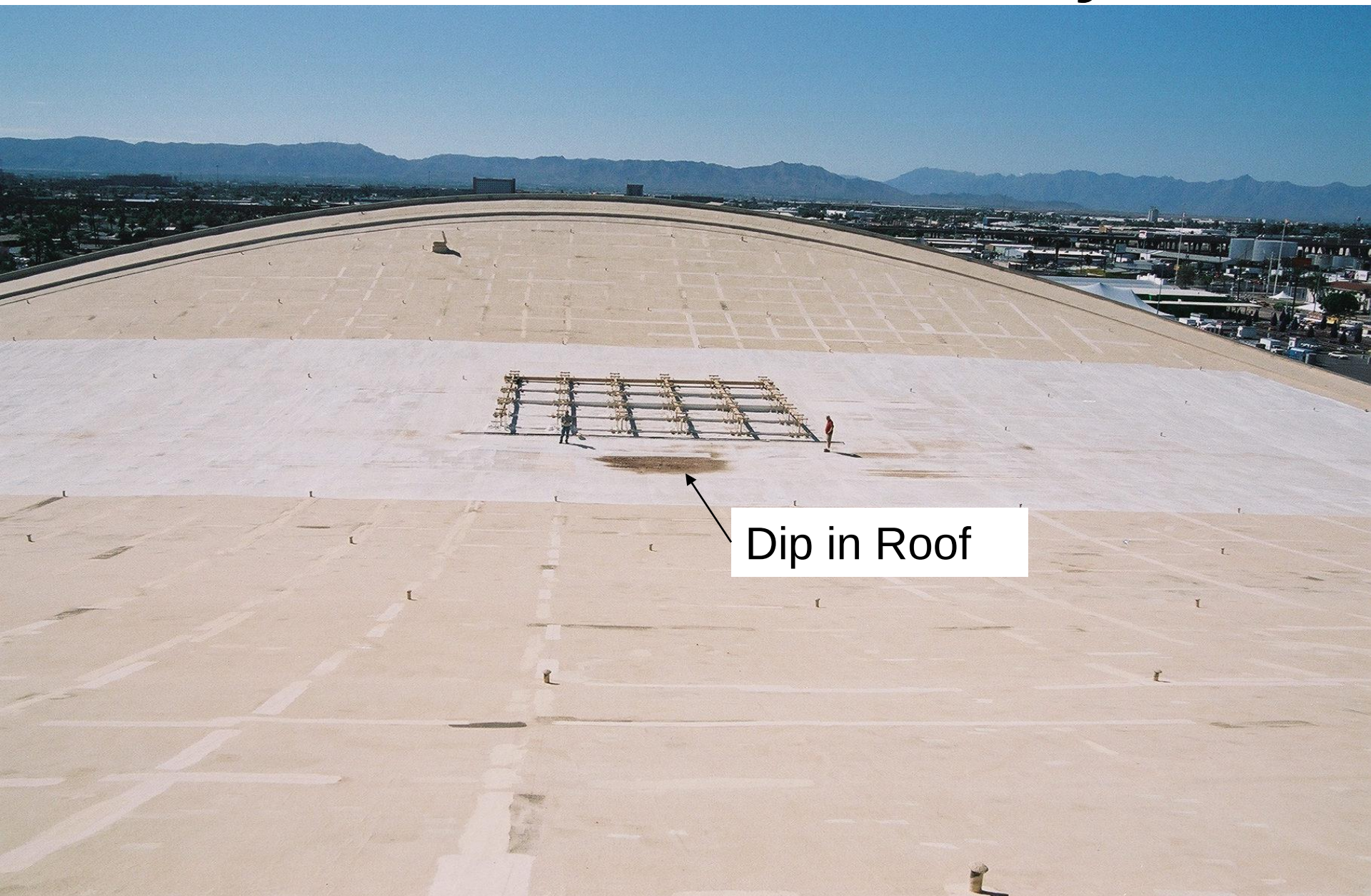
# 1980 Roof Repairs

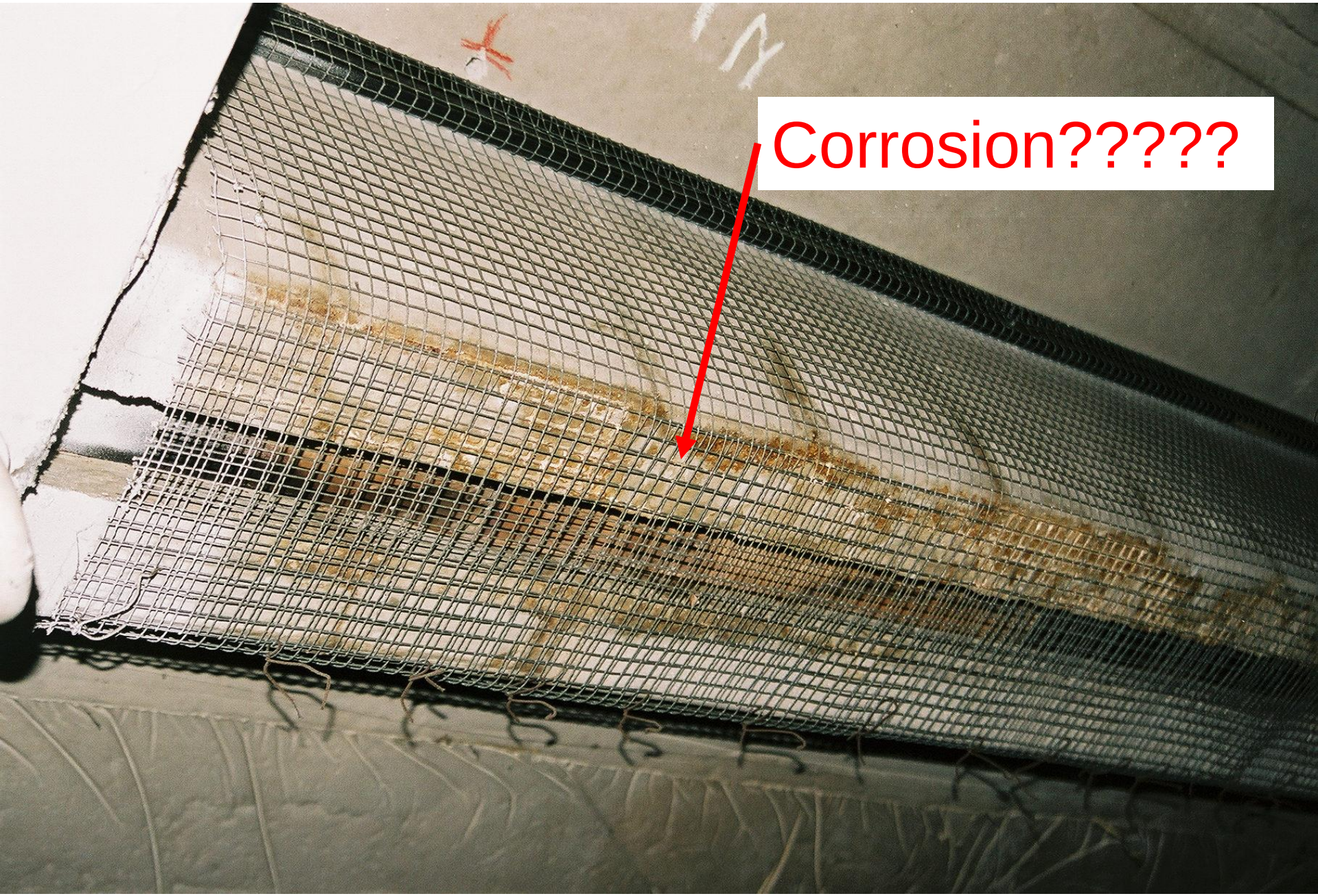
- A “dip” is discovered in the roof.
- Cause:  ?????
- Solution:  Put steel beams across the roof and “jack” up the dip.
- ***Maybe Not Such a Good Idea***

# “Reinforcing” Grid


Approx 30,000 Lbs of
Steel Added to the Roof

# 2006 Initial Discovery

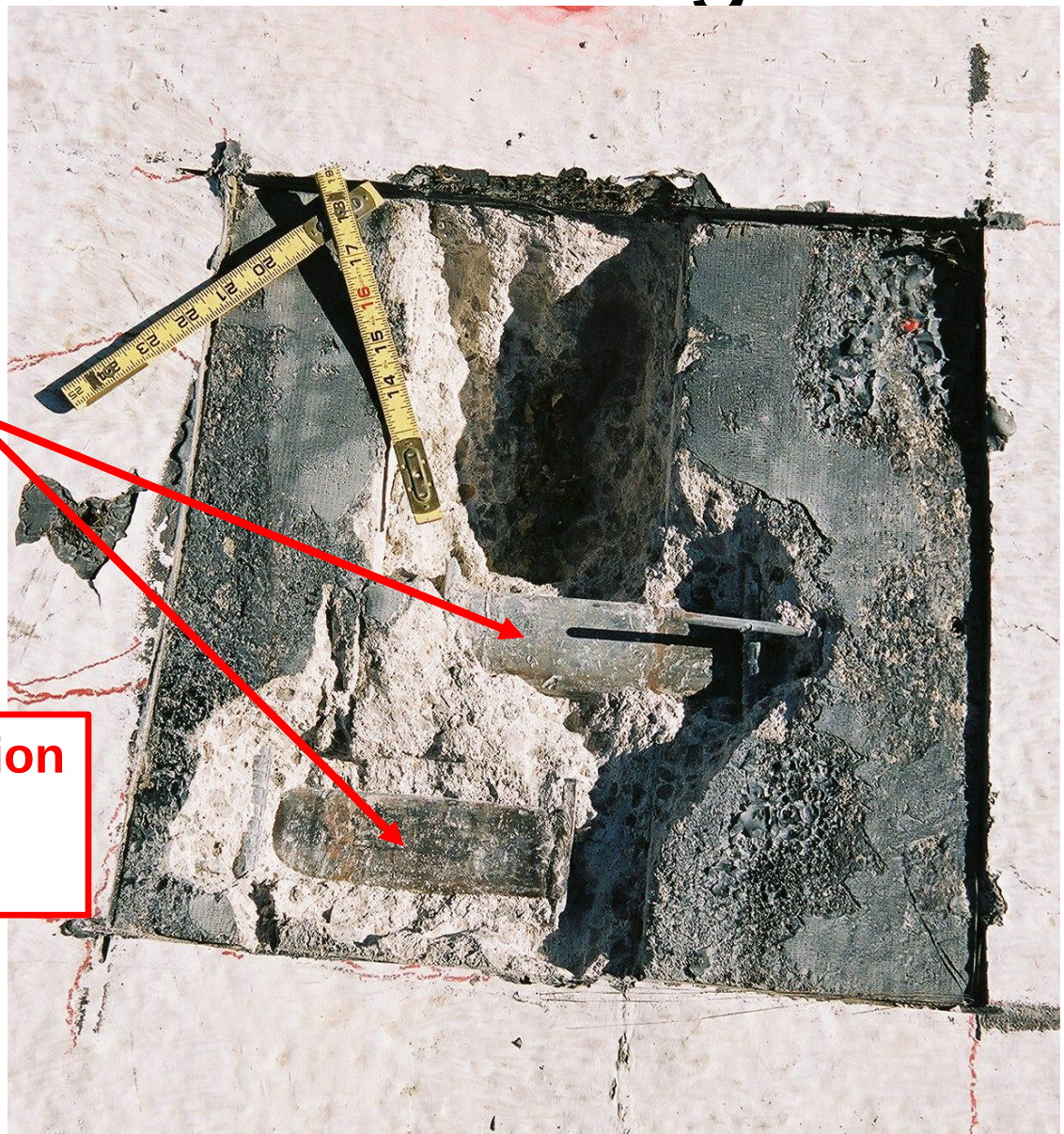



Corrosion?????

# Emergency Repair

# Further Investigation

Steel Tube Brackets that hook over cables to support the roof panels.



**Not much Corrosion**

**Not Failed!**

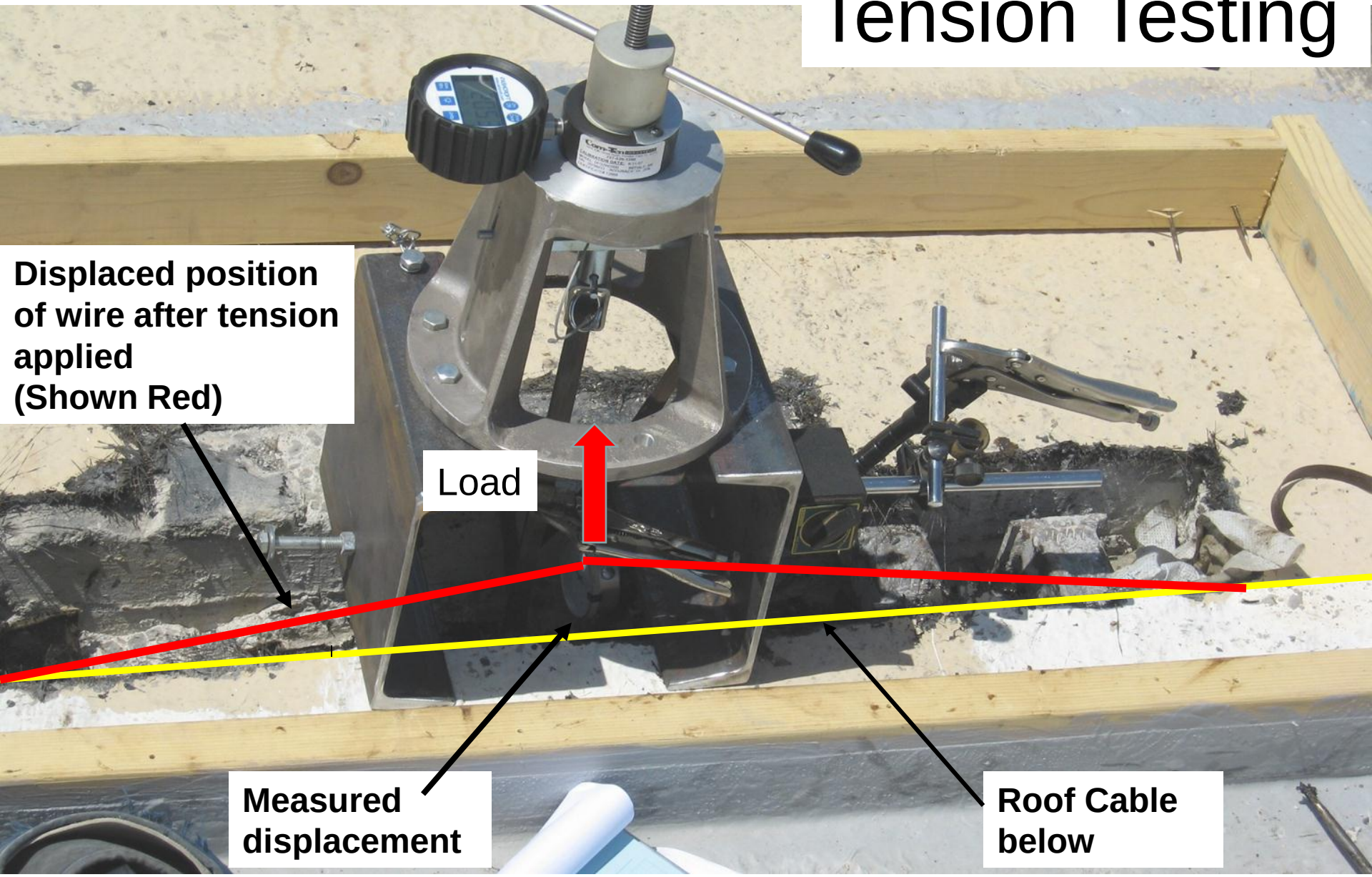
# Bottom Side Under Brackets -- No Failures!

# Wire Tendons — Not Corroded

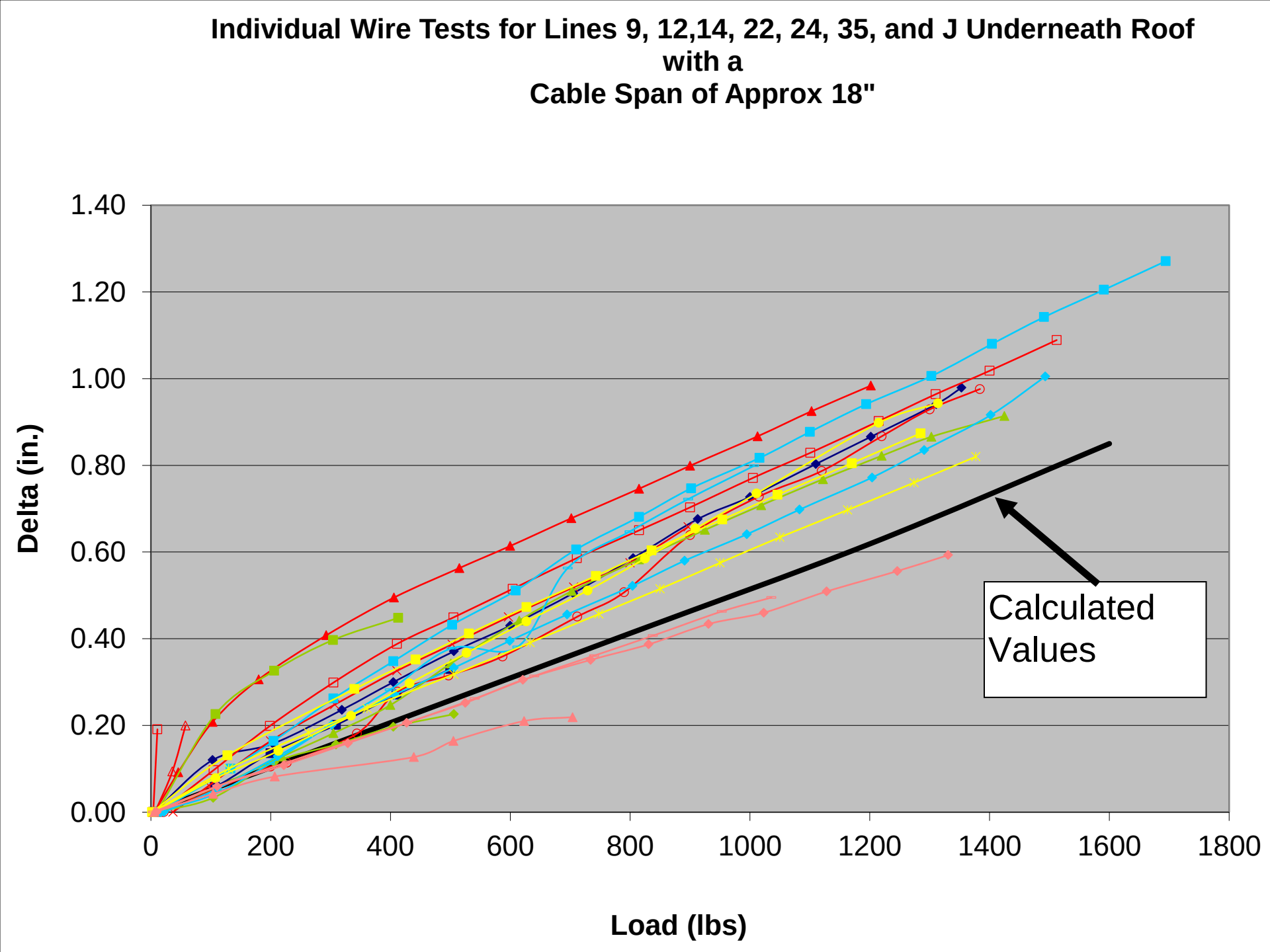
# Screwdriver Penetration Test

## ***Is there Still Tension on the Tendons?***

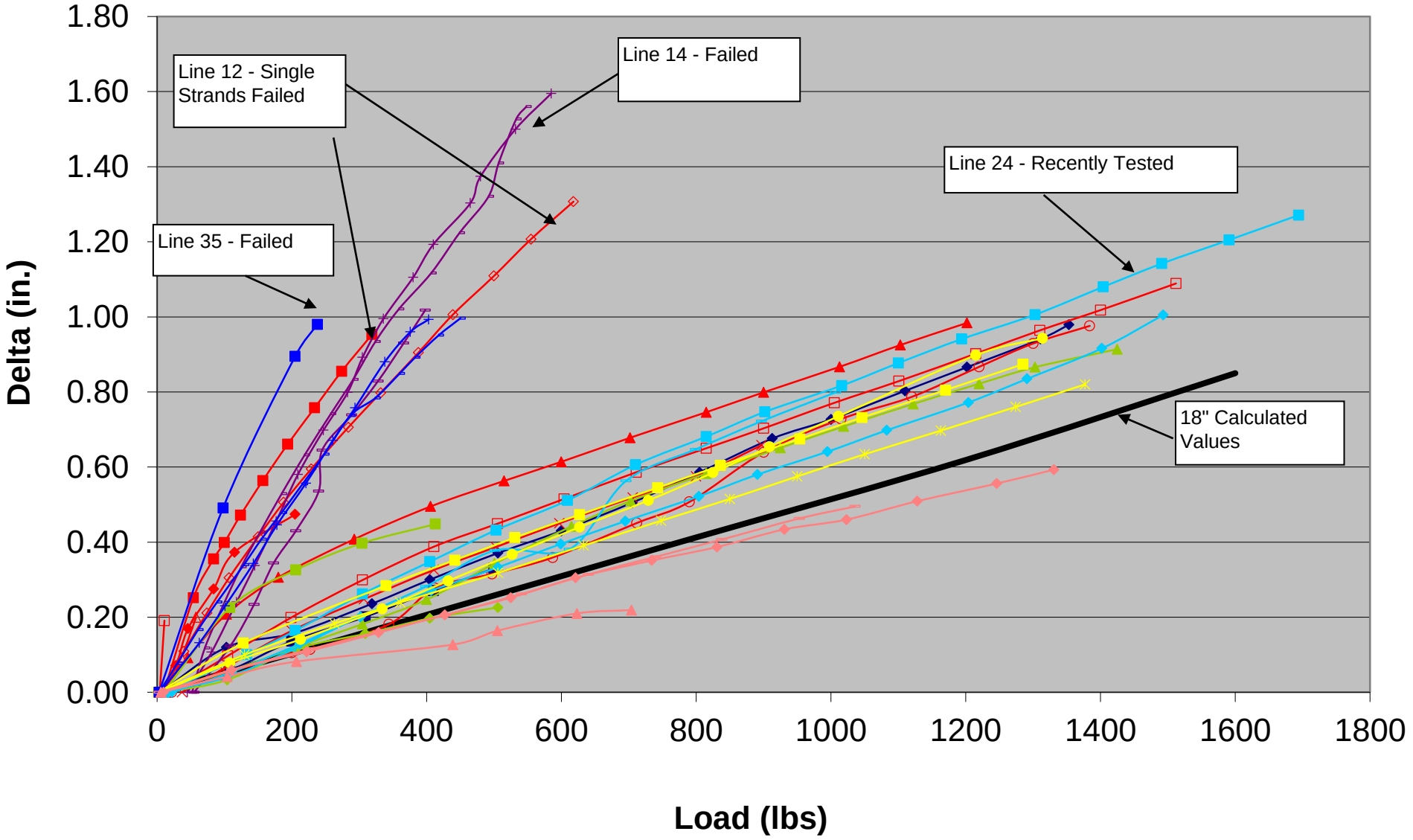
# Tension Testing




Individual wire tension testing. Pull off testing equipment used to pull up on individual wire strand of cable. Dial Indicator measured displacement (below tension tester). This was used to confirm tension or failure of the cables.

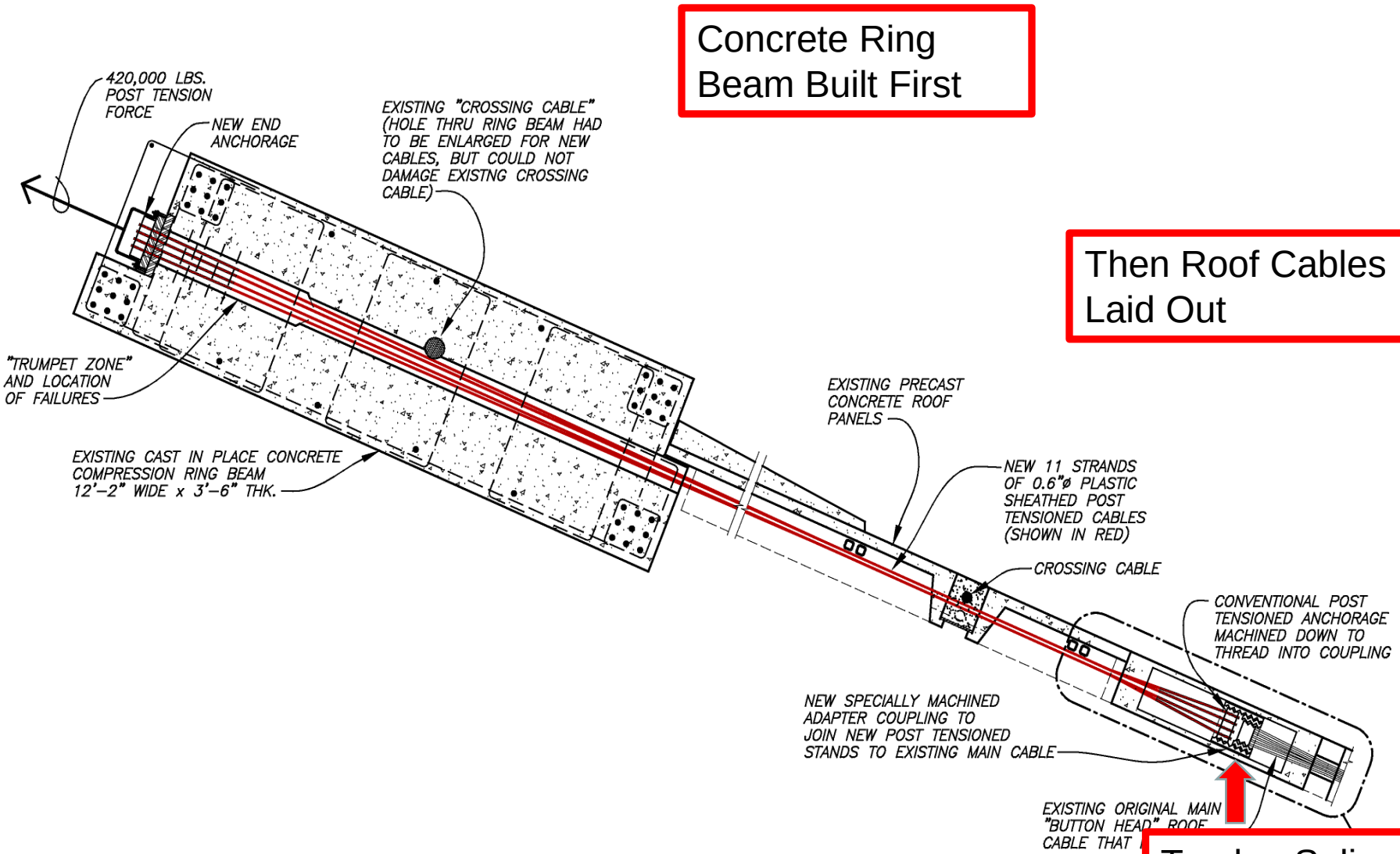

Individual Wire Tests for Lines 9, 12,14, 22, 24, 35, and J Underneath Roof with a Cable Span of Approx 18"
Delta (in.)
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
0
200
400
600
800
1000
1200
1400
1600
1800
Load (lbs)
Calculated Values

# Individual Wire Tests for Lines 9, 12,14, 22, 24, 35, and J Underneath Roof with a Cable Span of Approx 18"



# What is the Bump out in the Roof Panels????

# Construction Sequencing – How would You Build It???




SECTION THRU RING BEAM AND COUPLING

N.T.S.

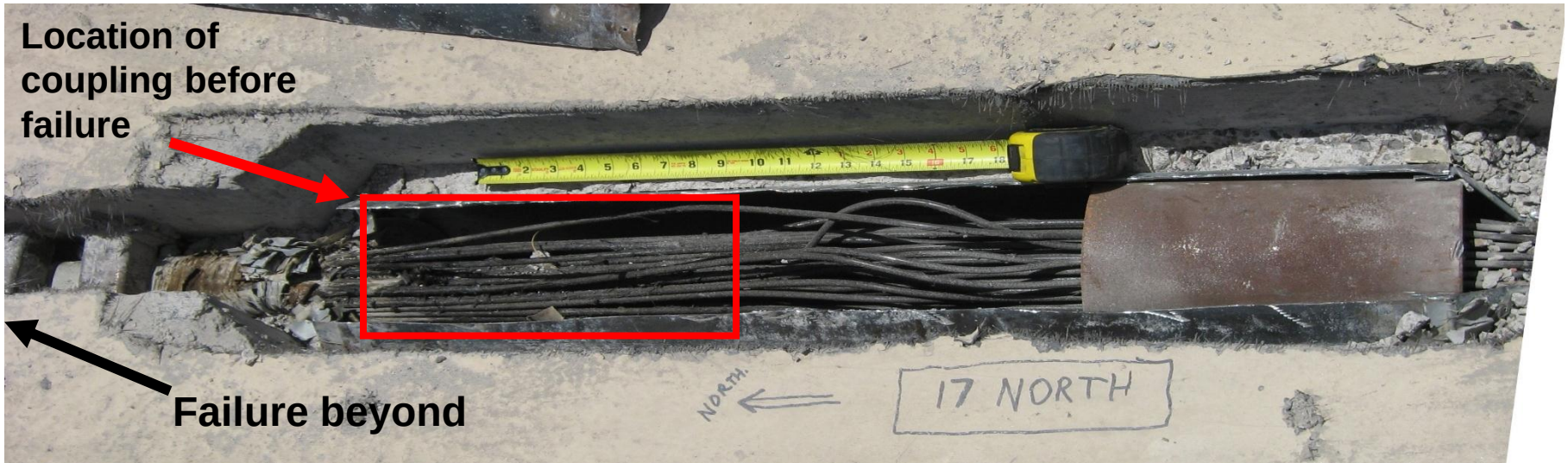
Concrete Ring Beam Built First

Then Roof Cables Laid Out

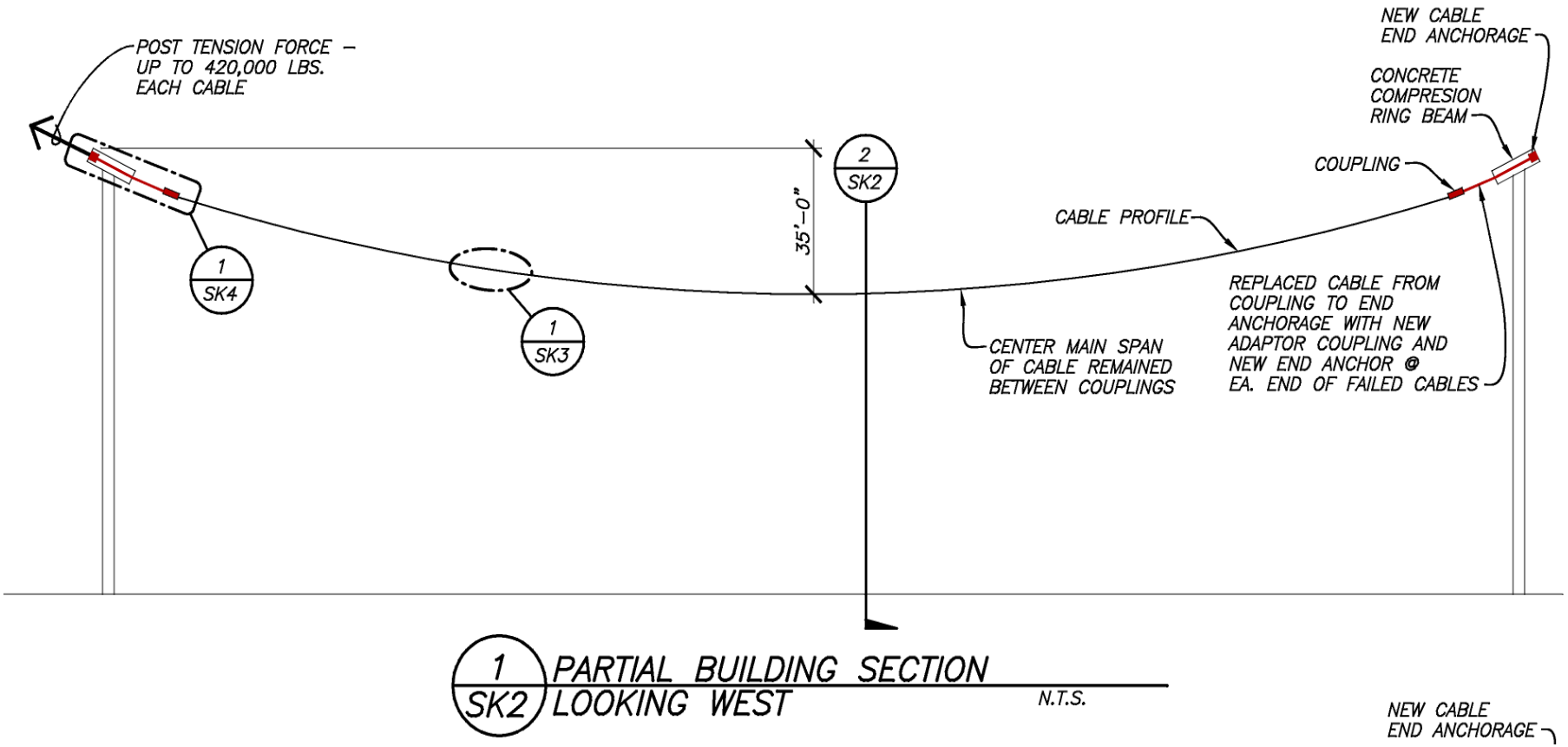
Tendon Splice Coupling


**Photo #3 (above)** shows cable coupling in normal position, with straight parallel wires. This occurred at the un-failed end.

**Photo #4 (below)** shows cable after failure at end anchorage, with wires deformed due to recoil from the failure and loss of 420,000 pounds post tensioned force. This occurred at the end with the failure.

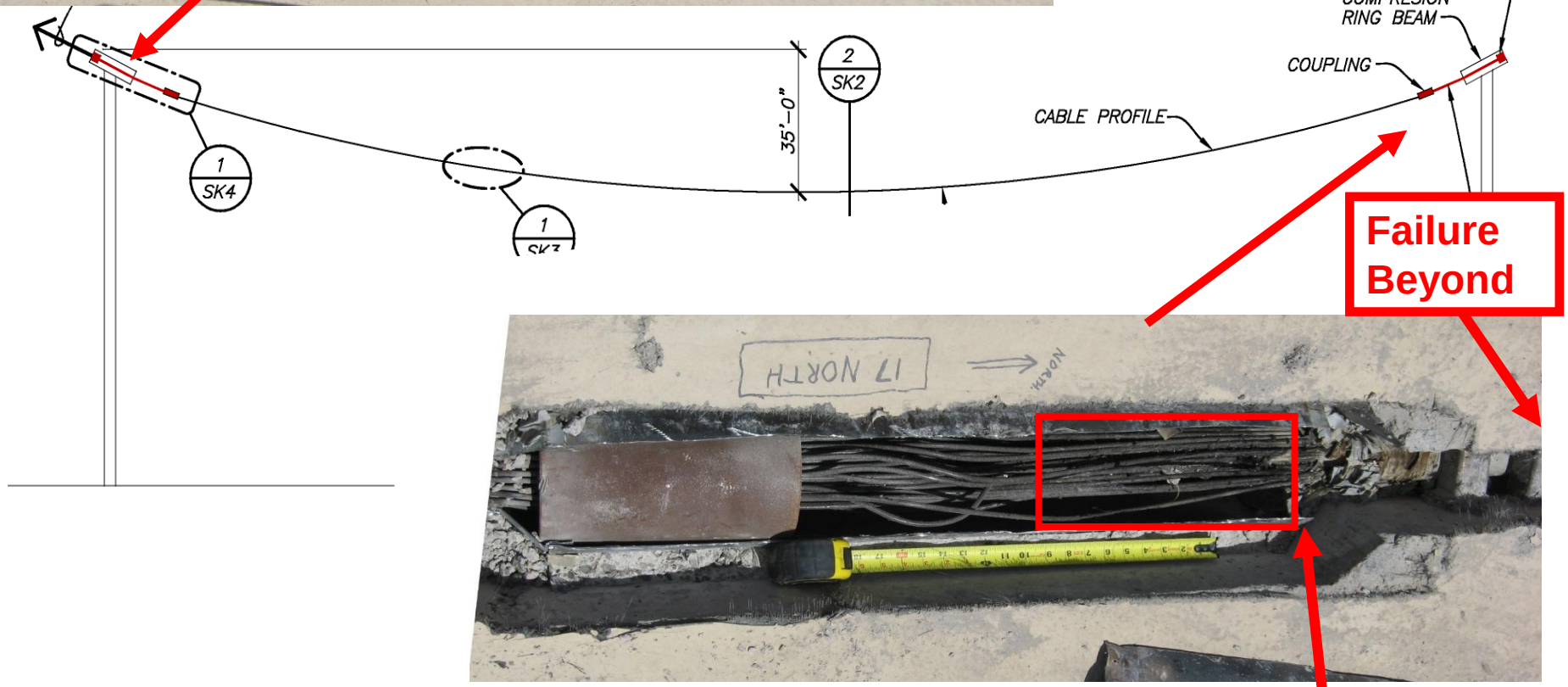


# Roof Profile



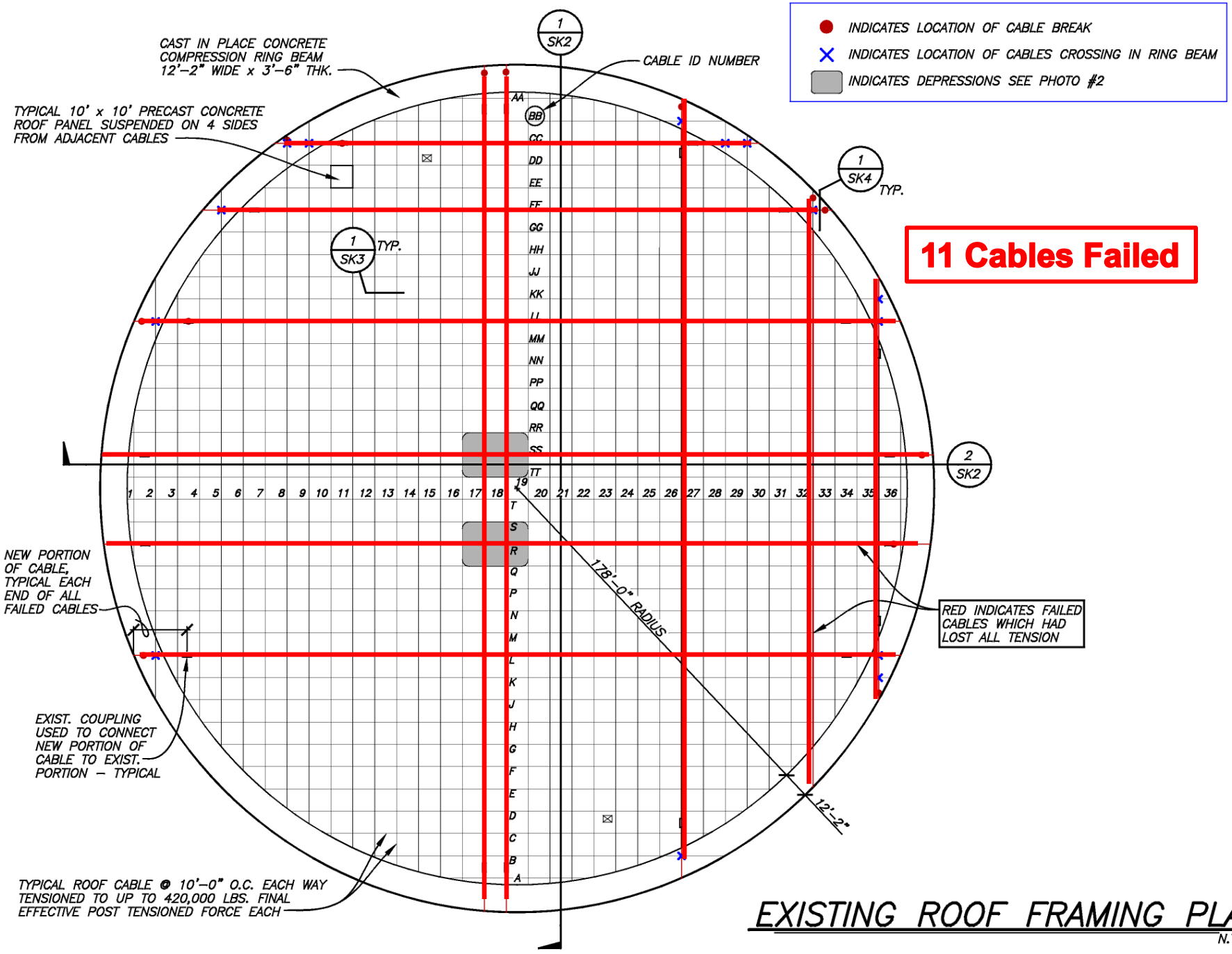

1/SK2 PARTIAL BUILDING SECTION LOOKING WEST N.T.S.


17 SOUTH


NEW CABLE
END ANCHORAGE
CONCRETE
COMPRESION
RING BEAM
COUPLING
CABLE PROFILE
35'-0"
2
SK2
1
SK4
1
Failure
Beyond
17 NORTH
NORTH
Location of
coupling
before failure

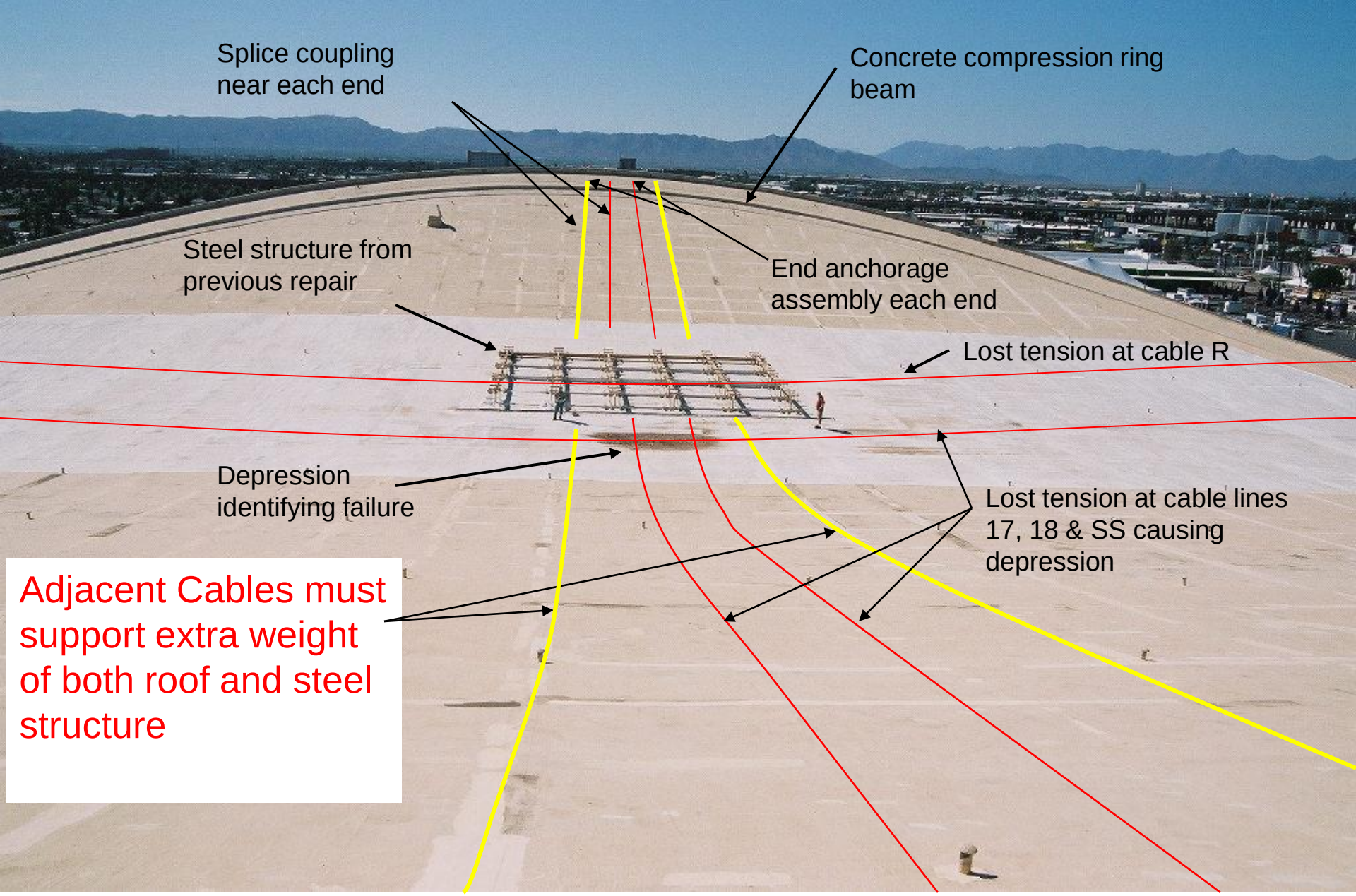
# The Only Tendon Failed because of Roof Leaks

# Failures Due to Tension Overload – Failure of Wires at End Anchorage Caused these Wires to be Overloaded




# EXISTING ROOF FRAMING PLAN

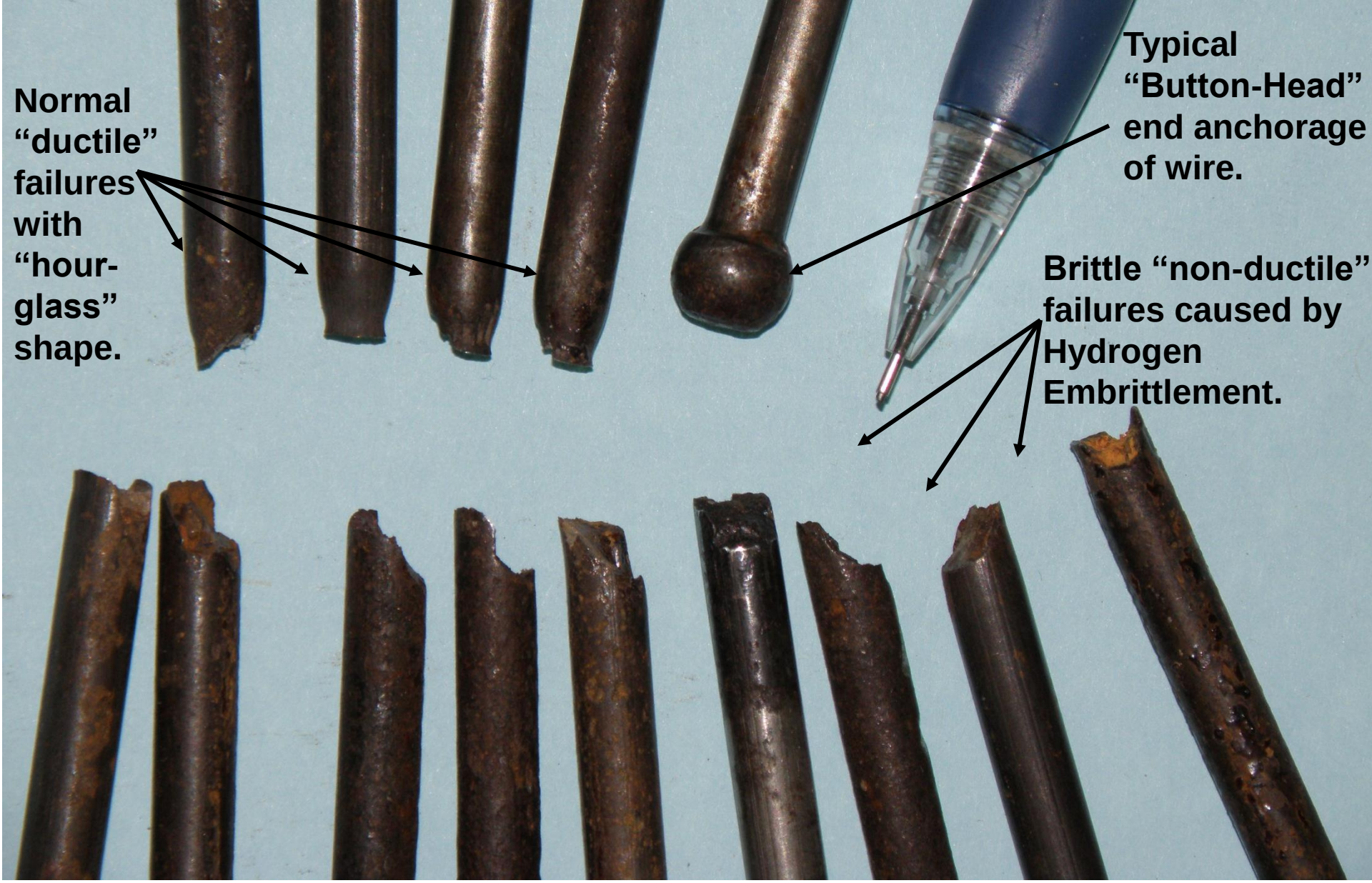
N.T.S.




Overall view of the roof showing the depression which initially identified the failure, adjacent cables supporting the extra weight, locations of the splice couplings, end anchorages and compression ring beam.

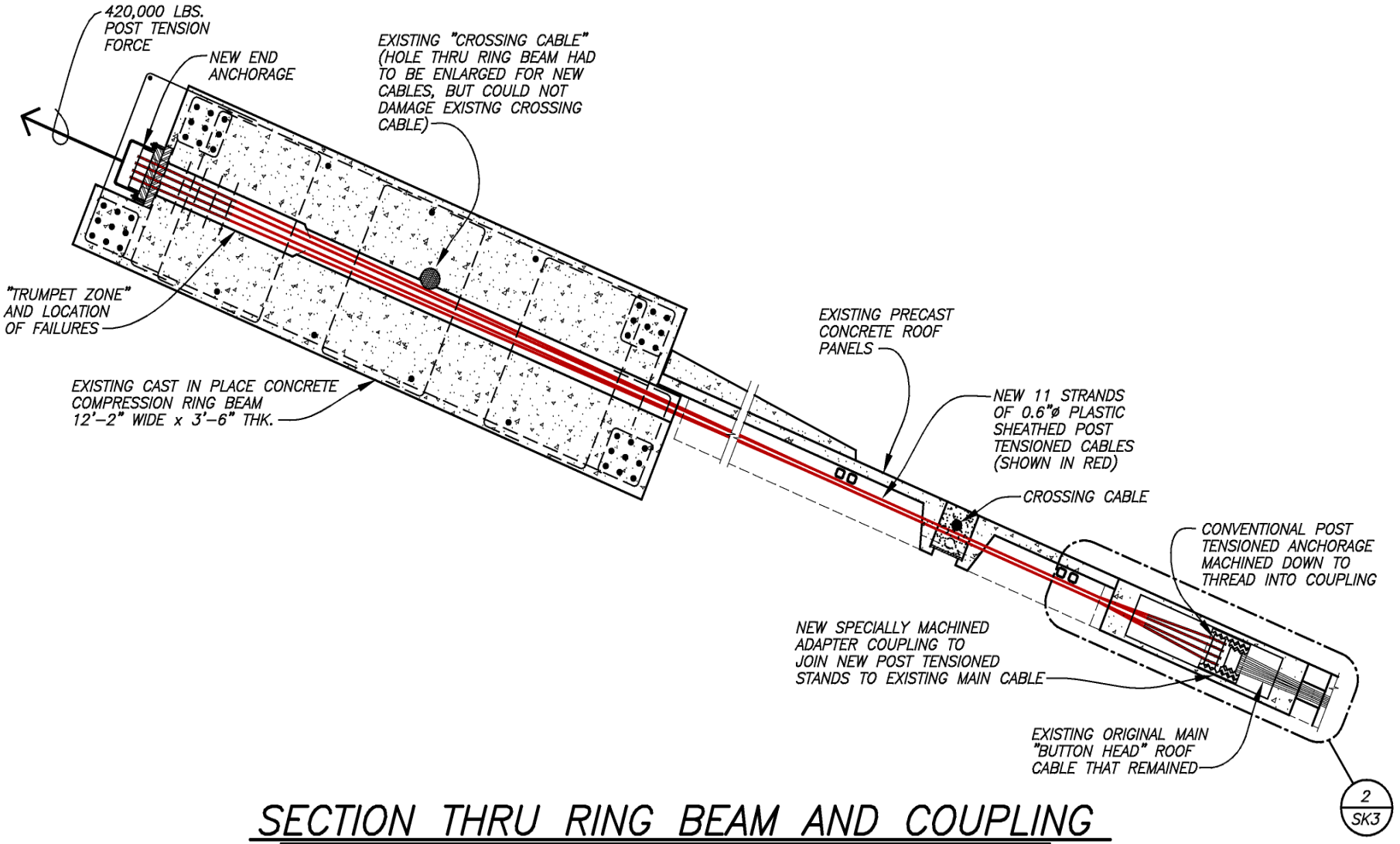
The steel structure was installed because of a similar depression in 1980 to redistribute the load beyond to the adjacent cables.


Failed end anchorage of post-tensioned cable. Failure caused by Hydrogen Embrittlement. Post-tensioned force 420,000 pounds.



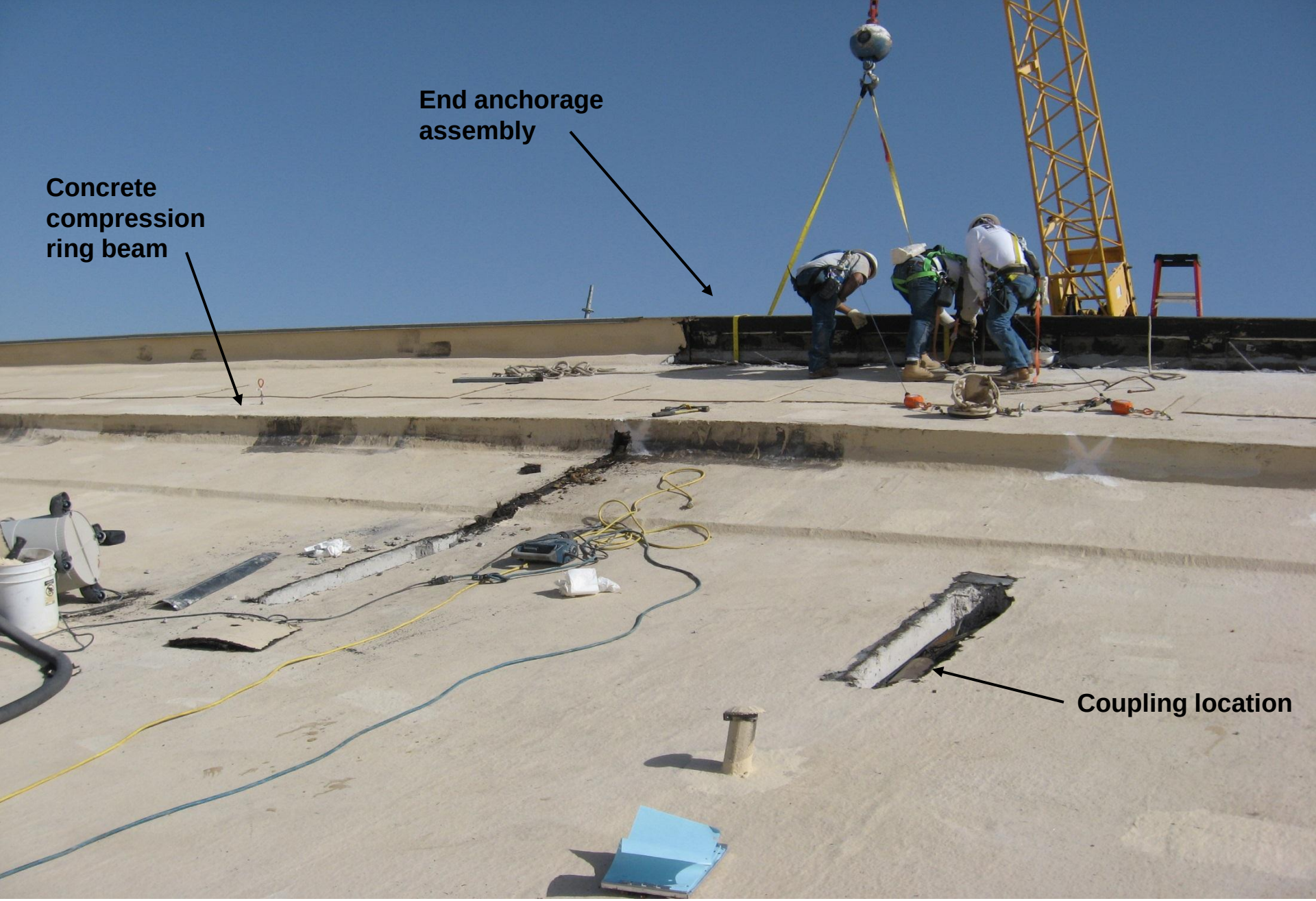

***Ultimate strength failure occurred at less than 50% of design strength due to Hydrogen Embrittlement***

# Repairs – Replace PT from End Anchorage to Coupling

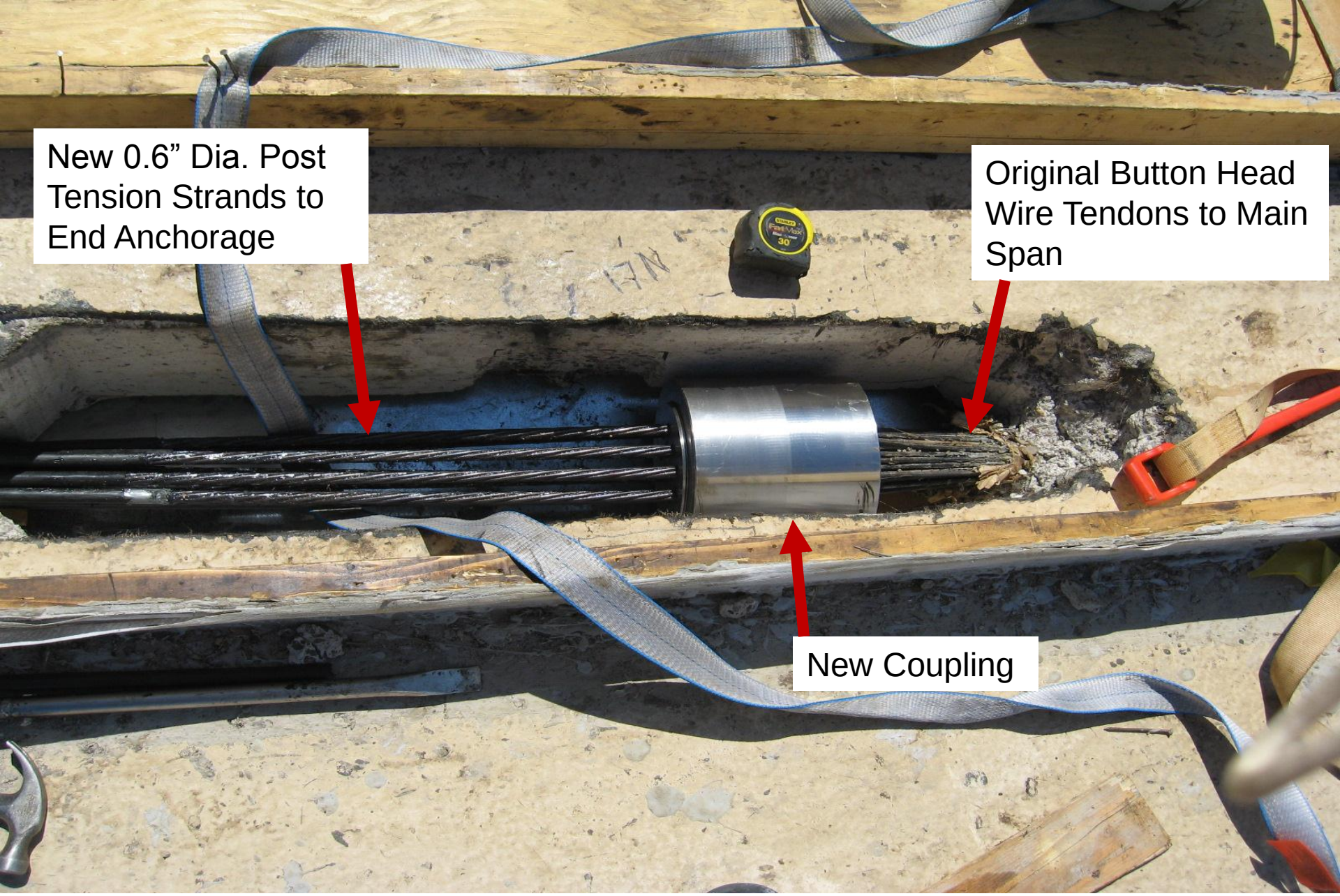



SECTION THRU RING BEAM AND COUPLING

N.T.S.



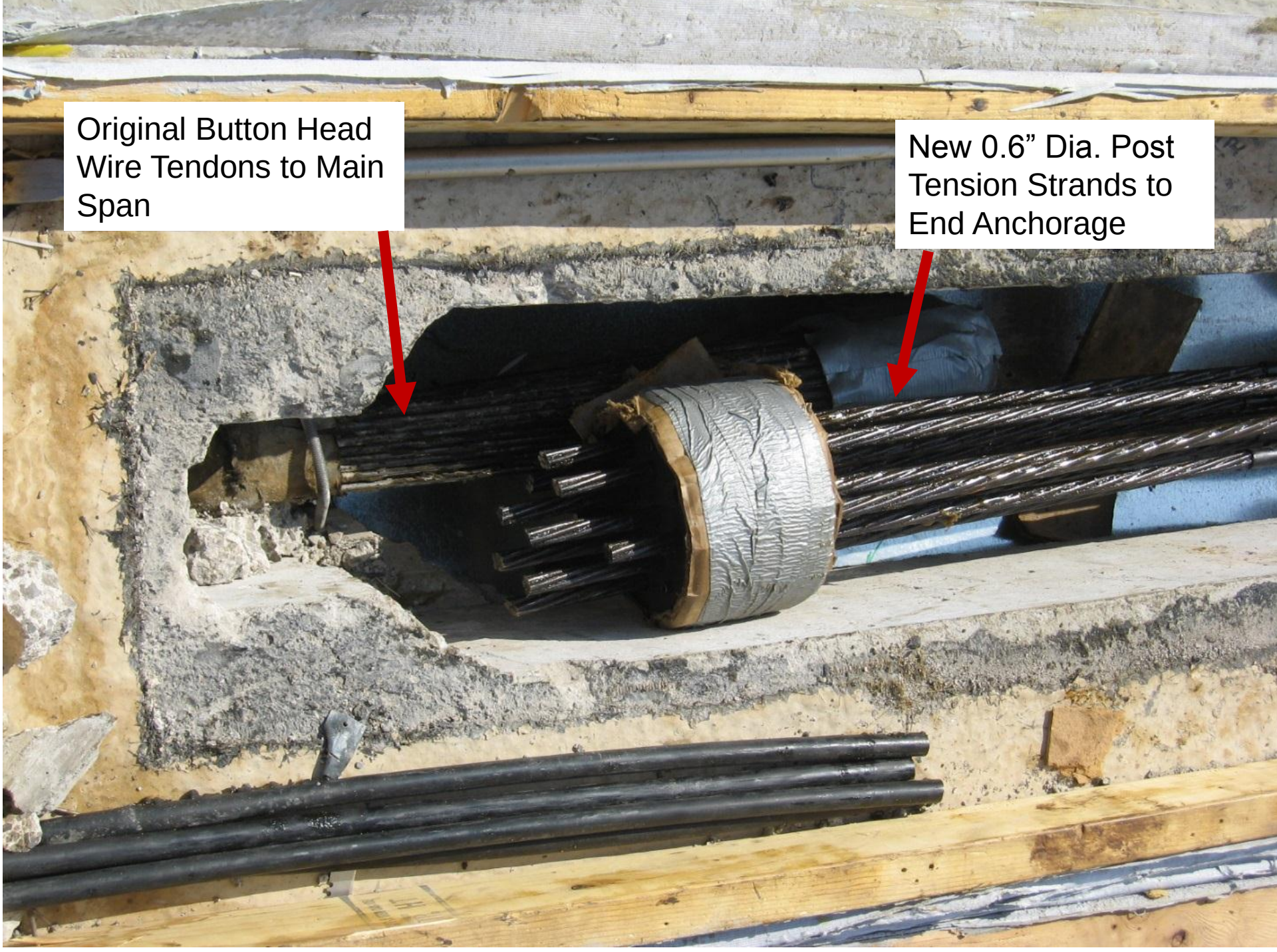

Coupling to end anchorage area. Coupling on left has slot chipped in roof to allow replacement of roof cable from the coupling to the end anchorage with new post tension strand. Contractor in process of removing fascia panels to expose end anchorage.




New coupling joining new post-tension cables on the left to the original button head wire cable on the right.

# New Specially Machined Coupling, End Anchors

# Installation of the New Coupling


Original Button Head Wire Tendons to Main Span
New 0.6” Dia. Post Tension Strands to End Anchorage

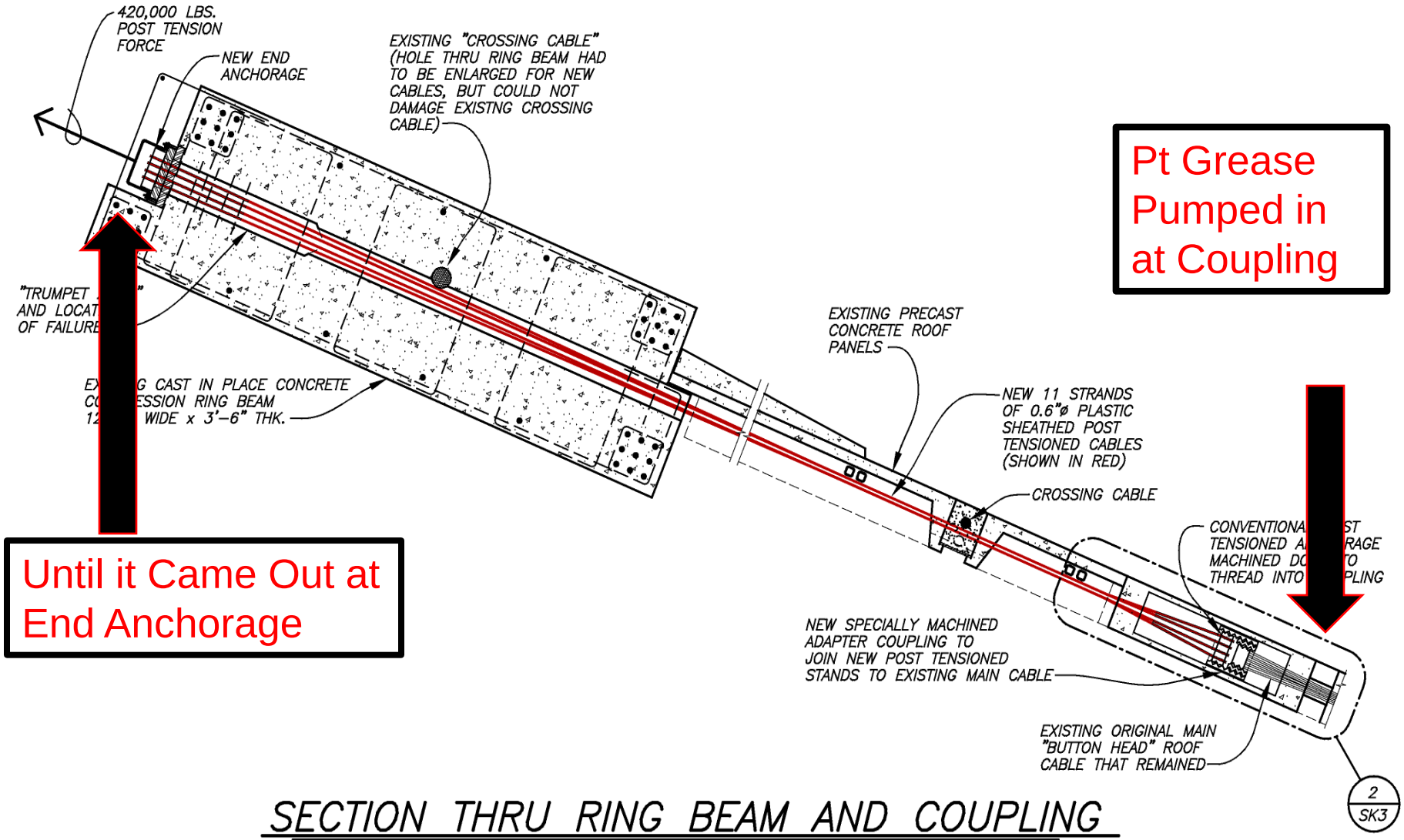

End Anchor Locations

# New End Anchorage Assembly


New End
Anchorage
Assembly

Final tensioning of cable tendon,  420,000 pounds of force.

# Final Protection from Future Corrosion



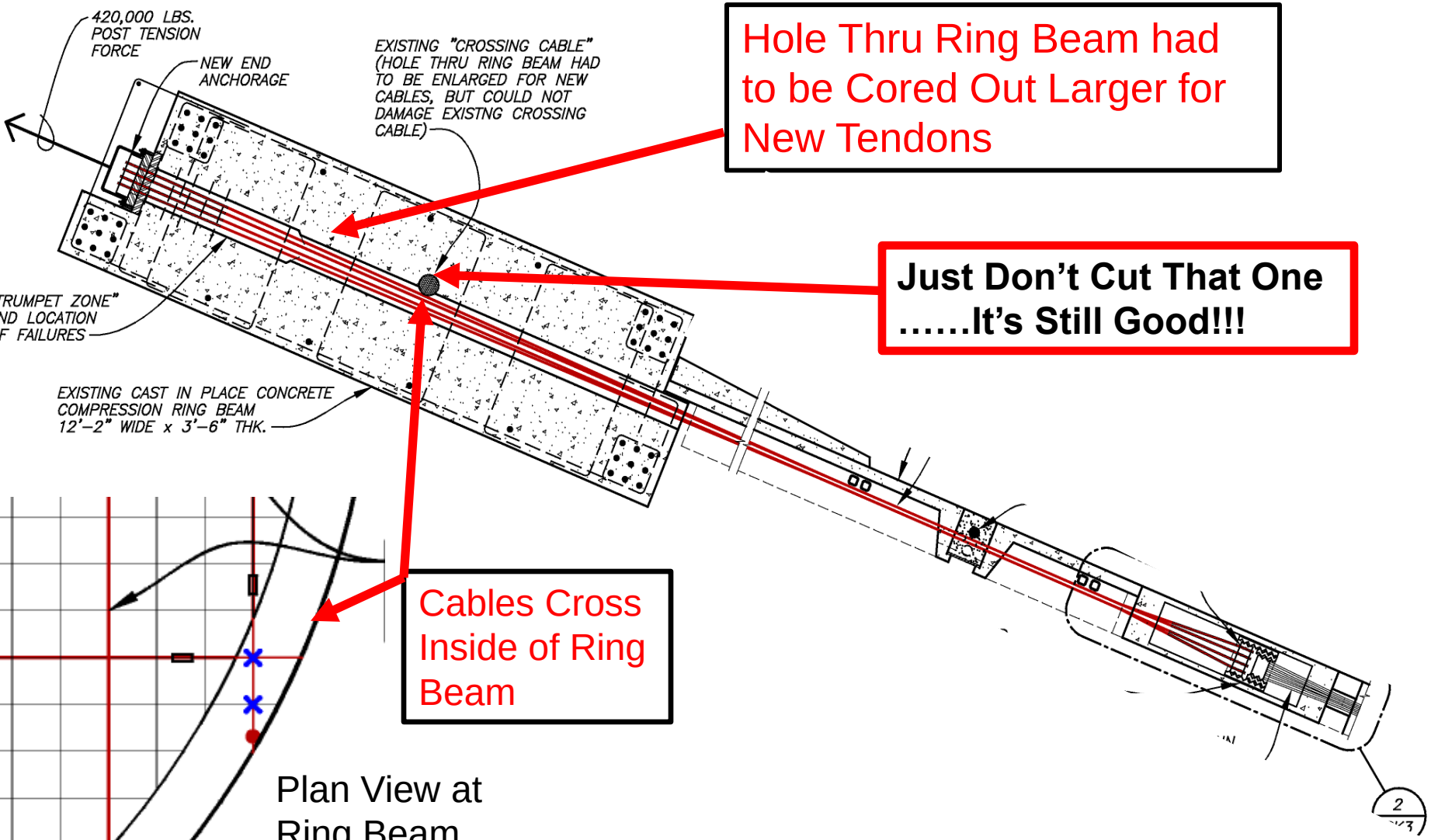

Pt Grease Pumped in at Coupling

Until it Came Out at End Anchorage

SECTION THRU RING BEAM AND COUPLING

N.T.S.

# Crossing Cables at Ring Beam




Hole Thru Ring Beam had to be Cored Out Larger for New Tendons

**Just Don't Cut That One ……It's Still Good!!!**

Cables Cross Inside of Ring Beam

Plan View at Ring Beam

# Challenges

- First Cables Known to have Failed – June
- State Fair Opens – Sept.
- Emergency Repairs
- 11 Cables Repaired – *Short Schedule*!

In Summer,

In Phoenix Arizona,
On a Roof
Hyperbolic Parabaloid = Reflector Oven

***Daytime Temperatures measured at 145°F***

# Arizona Veteran's Memorial Coliseum Roof Repairs

ICRI Award of Merit 2009

Dennis Wipf P.E.

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