Post-Tensioning Best Practice Update and New Directions for Post-Tensioned Structures

Ben Goldsberry, P.E.
Florida Department of Transportation
Structures Design Office

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Outline

- Florida's History with Post-Tensioning
- Investigation Status and Corrosion Findings
- Grout as Corrosion Protection System
- Specification Changes
- Alternative Corrosion Protection Systems

Florida's History with Post-Tensioning

Florida's History with Post-Tensioning

1954

- **First post-tensioned bridge in Florida**
- Sunshine Skyway Approaches (Tampa)
- I-beams post-tensioned with bars

1965

- **First drop-in span structure**
- Dupont Bridge over St. Andrew Bay (Panama City) - Post-tensioned segments over piers
- Cantilever suspended spans (not continuous)

1971

- **Corrosion found in a few of the girders on Sunshine Skyway**
- Water penetrated anchor blocks and initiated local pitting in PT bars
- Corrosion due to insufficient concrete cover at anchor blocks, exposing the PT to salt spray and deck runoff through deteriorated deck joints

Florida's History with Post-Tensioning

1979

- **First draped PT tendons in webs of precast girder sections**
- Chipola Nursery Road (New Hope Road) over I-10 (near Marianna)
- Two-span continuous girders

- **First segmental** (span-by-span)
- Long Key Bridge (Keys)
- Three more span-by-span bridges in the Keys:
  - Seven Mile Bridge
  - Channel Five Bridge
  - Niles Channel Bridge

1984

- **First precast segmental balanced cantilever**
- Ramp I over I-75 (Fort Lauderdale)

Florida's History with Post-Tensioning

1987 - 98

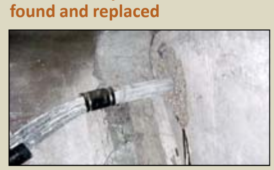
- New Sunshine Skyway
- Eau Gallie Bridge
- Dodge Island Bridge
- Acosta Bridge
- Mid-Bay Bridge
- Garcon Point Bridge

1999

- **1 of 6 tendons failed on Niles Channel Bridge (Keys)**
- Tendon immediately replaced
- **Emergency investigations of other PT bridges**

2000

- **2 tendons failed on Mid-Bay Bridge (Destin) – built in 1993**
- **11 excessively corroded tendons found and replaced**



Florida’s History with Post-Tensioning

2000

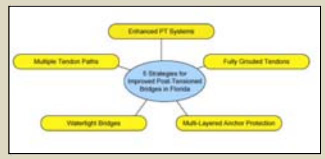
- FDOT temporary design memoranda:
- Pre-bagged grouts
- Inspection of anchorages after grouting

2000

- **Failed tendon in precast segmental column of Sunshine Skyway high level approaches**

2002

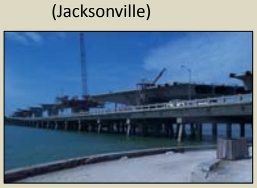
- The FDOT makes changes to policies and procedures to ensure long-term durability of PT tendons
- 5-part strategy for PT durability



Florida’s History with Post-Tensioning

2003

- Ringling Causeway Bridge (Sarasota)
- Wonderwood Connector (Jacksonville)



2011

Ringling Causeway

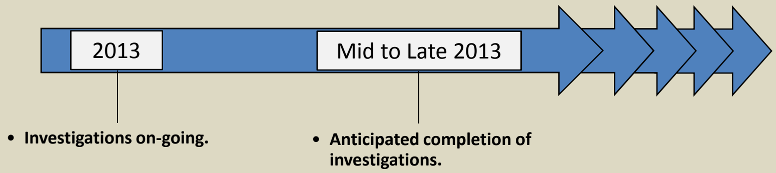
- **2 tendons failed on Ringling Causeway Bridge**
- Warranty repair made by contractor
- **New series of PT investigations**

2012

Wonderwood Connector

- **Extensive soft grout and corrosion found.**

Florida's History with Post-Tensioning



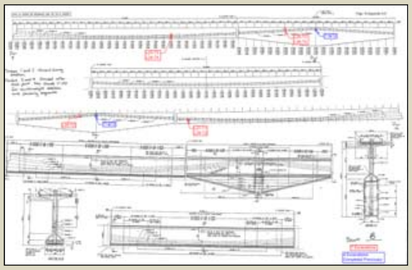
Investigation Status

Investigation Status

Post-Tensioned Structure Type	Completed	Remaining	Total
Segmental – External PT	9	0	9
Segmental – Internal PT	16	7	23
Concrete Girders with Continuity PT	5	7	12
Simple Span PT	4	0	4
Bridges with Substructure PT	15	1	16
Total	**49**	**15**	**64**

Inspection of Internal Grouted Tendons

- Internal tendons not easily inspectable
  - Full inspection not achievable
  - Spot inspection only
  - Limited view
  - Slow and expensive



Inspection of External Grouted Tendons

- External tendons on segmental bridges
  - Spot inspection only
  - Boroscope inspection of trumpets
  - Manual soundings
  - Observable failure

Investigation Status

- Segmental Bridges with External PT
- 9 of 9 investigations completed
  - One 8-year old bridge
    - 2 failed tendons
    - 17 tendons replaced
    - Over 500 voids re-grouted or repaired with epoxy
  - One 3-year old bridge
    - 6 of 32 tendons with soft grout
  - One bridge owned by expressway authority
    - Sand in duct caused minor corrosion to strand

Investigation Status

- Segmental Bridges with Internal PT
- 16 of 23 investigations completed
  - One bridge with small amount of soft grout in trumpet found

Investigation Status

- Concrete Girders with Continuity PT
- 5 of 12 investigations completed
  - 4 bridges with minor issues
  - One 9-year old bridge with significant problems found
    - Extensive soft grout
    - Corrosion in haunched areas of sloped tendons

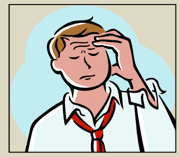
Investigation Status

- Simple Span Post-Tensioned Bridges
- 4 of 4 investigations completed
  - No problems found

Investigation Status

- Bridges with Substructure PT
- 15 of 16 investigations completed
  - 14 bridges with no problems found
  - One bridge
    - High chloride content in PT straddle bent
  - 19 bridges with substructure PT
  - 3 with PT below ground line will not be investigated

Investigation Status



- Summary of Investigations
  - 49 investigations complete
    - 3 Bridges with soft grout/corrosion issues found
  - 15 investigations remaining
  - **$1.7 million contract cost to date**
    - Not included in this cost:
      - FDOT employees
      - Extensive warranty repair on one bridge
      - **Repairs to be performed**

  - Problems on vertically deviated tendons
  - Top slab tendons in segmental bridges
    - Simpler duct geometry
    - Shorter length for grouting

Past, Present, Future

- Post-Tensioning History and Current Investigation
  - Questioned durability unwarranted?
    - Apprehensive owners
    - Potential loss of credibility with tax payers
- Future goals based on past experience and current investigation
  - Greater confidence with nearly zero chance of leaving defects behind
  - Tendon repair or replacement
    - Less difficult, economical
  - Routine inspection and maintenance only
    - No emergency investigations of PT inventory

> *"The past does not repeat itself, but it rhymes."*
>
> \- Mark Twain

Grout as Corrosion Protection System

Grout as Corrosion Protection System

Why fill the duct with grout?

- Fills a void
- Bond to surrounding concrete
  - Internal tendons with corrugated duct
- Chemically passivating alkaline environment
- Economical

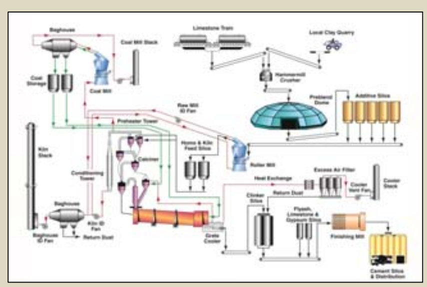
Grout as Corrosion Protection System

- Cement ingredient issues
- Prebagged grout product issues
- Project storage issues
- Mixing issues on project site
- Pumping grout into deviated duct

Grout as Corrosion Protection System

Cement ingredient issues

- Elevated chlorides?
  - Cement dust contaminated with chlorides?
- Partially hydrated cement?
  - Climate controlled <u>storage</u> at the cement producer?
  - Climate controlled <u>transport</u> of cement to grout manufacturer?



vs.

Grout as Corrosion Protection System

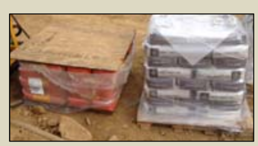
Prebagged grout product issues

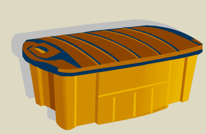
- Bag weights?
- Contaminants?
- Inert fillers?
  - Segregation?
  - Sulfates?
- Shelf life?
- Partial hydration?
  - Climate controlled storage for cement and grout at grout manufacturer?
  - Climate controlled transport of prebagged grout to project site?

Grout as Corrosion Protection System

Prebagged grout storage on project site

- Proper storage?
  - Climate controlled storage?
  - Raised platform with waterproof covering?
  - Seal in “air tight” containers?



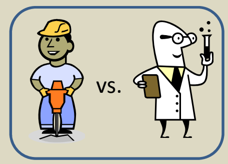


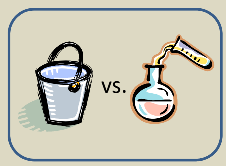
Grout as Corrosion Protection System

Mixing of prebagged grout on project site

Grout sensitivity to water and temperature

- Water in pump and hose from previous cleaning and/or priming of pump?
- Water content?
- Temperature?
  - Water temperature?
  - Prebagged grout temperature?
  - Temperature of mixed grout prior to injection?
  - Temperature of grout inside of duct?
  - Temperature of grout at outlet?





Grout as Corrosion Protection System

Pumping grout into deviated ducts

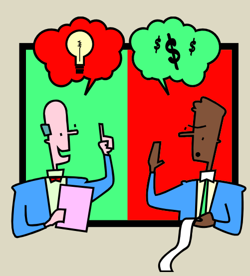
- Contamination in duct?
  - Debris, sand?
- Water in duct?
- Pumping pressures?
  - Pressure monitored at inlet?
  - Too much pressure in hose and at the pump?
  - Grout speed?
- Filtering effect?

Grout as Corrosion Protection System

- Summary
  - Results mostly good
  - Finicky process
    - Many variables
    - Human factors
  - Lessons learned
  - Continued learning
    - Questions to answer
    - Issues to resolve

Maintenance's "Wish List"

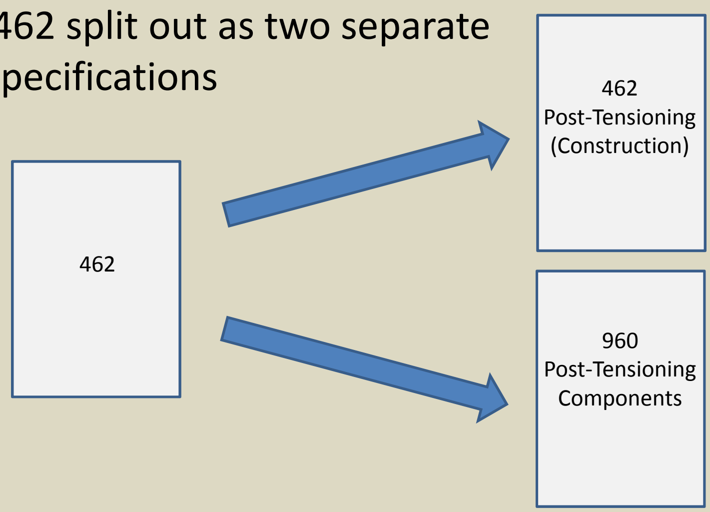
- Improved Design, Construction and Materials
- Replaceable tendons
  - Internal and External
- Easier tendon inspection
  - NDE (Non-Destructive Examination)
  - Economical, Practical, Effective



Specification Changes

Specification Changes

- January 2013 Workbook
- 462 split out as two separate specifications



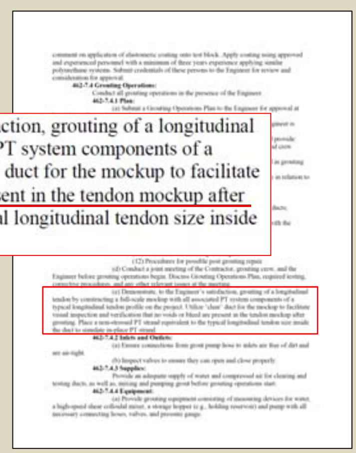
Specification Changes

- Separation of 462 and 960 was primarily a reformatting of the existing specifications.
  - Consistent with AASHTO spec format
- Changes to highlight:
  - 462
    - Full scale mock up test
  - 960
    - Vent hole in wedge plates
    - Combined wear/creep test for corrugated plastic duct

Specification Changes

- Full scale mock up test
- 462-7.4(e)

(e) Demonstrate, to the Engineer's satisfaction, grouting of a longitudinal tendon by constructing a full-scale mockup with all associated PT system components of a typical longitudinal tendon profile on the project. Utilize 'clear' duct for the mockup to facilitate visual inspection and verification that no voids or bleed are present in the tendon mockup after grouting. Place a non-stressed PT strand equivalent to the typical longitudinal tendon size inside the duct to simulate in-place PT strand.

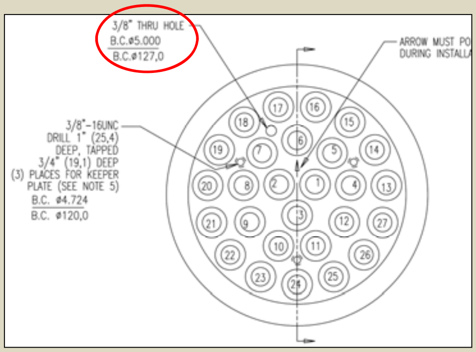


Mock up test on VDOT cast-in-place segmental project

Specification Changes

- Vent hole in wedge plate
- 960-2(f) Component Standards

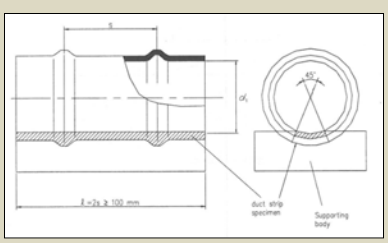
(f) Geometry of grout outlets must facilitate access for endoscope inspection directly behind wedge plate using a straight 3/8 inch diameter drill bit. *For all PT systems other than 4 strand flat configurations, place vent hole(s) of 3/8 inch minimum diameter through wedge plate to allow for passage of grout and inspection.*



Specification Changes

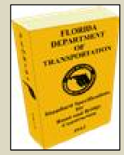
- Combined wear/creep test
  - Wear resistance test (*fib*) followed with short-term creep test on <u>same</u> specimen
- 960-3.2.2

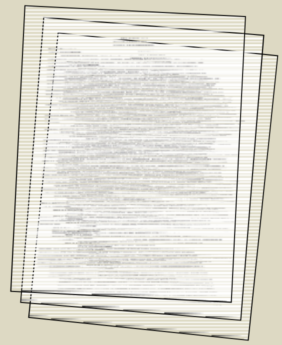
(a) Modify procedure as follows: After the specimen has reached its final position, remove the specimen and confirm that the residual thickness is adequate. With confirmation that the residual thickness is acceptable, <u>immediately (within 30 minutes) reapply the original clamping force for 14 days.</u>



Specification Changes

- Changes to 462 in the works…
  - Revise limits on grouting temperatures
  - Revise maximum pumping pressure to reduce grout flow rate
  - Revise location for grout pressure monitoring
  - Revise grout discharge quantity from vents and anchorages

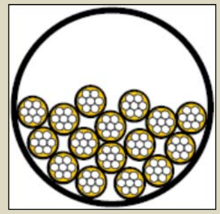




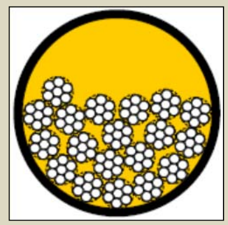
Alternative Corrosion Protection Systems

Unbonded Greased PT Systems

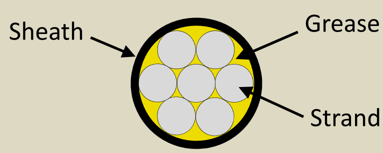
Greased and Sheathed Monstrand



Grease Filled Duct

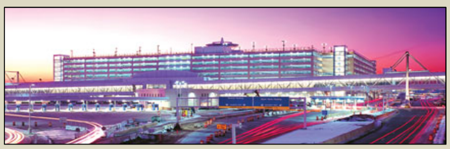


Greased and Sheathed Monostrand



Greased and Sheathed Monostrand

Used in buildings and parking structures since the 1950s



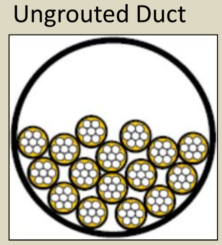
Greased and Sheathed Monostrand

- Bridge tendon
  - Larger duct
  - Larger anchorage
  - Larger members

Grouted Duct

Anchorage for Greased and Sheathed

Ungrouted Duct



Greased and Sheathed Monostrand

- Strands can be replaced one-by-one
- Installing new strand into existing sheath could be challenging

Greased and Sheathed Monostrand

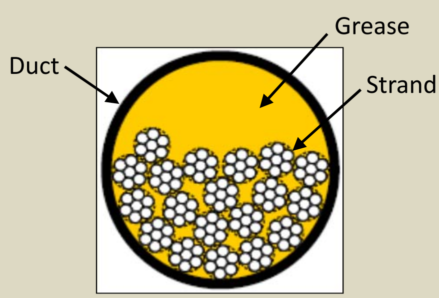
- Challenges at deviators for external tendons
- Problem on recent European bridge

Greased and Sheathed Monostrand

- Summary
  - Larger members (larger duct)
  - Sheathing
    - Deviations
    - Splitting
  - Inner strands of tendon bundle
    - Not easily inspectable
    - Access for repair?
  - Replacing failed deviated strands?

Grease Filled Duct

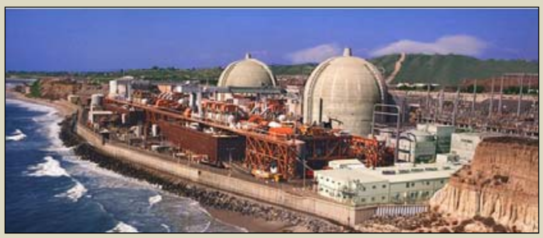
- Advantages
  - High level of corrosion protection
  - Replaceable
  - Inspectable
    - External tendons can be mechanically detensioned and removed for inspection
  - Grease injection can be restarted later

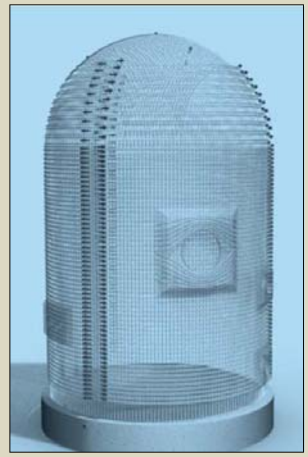


Grease Filled Duct

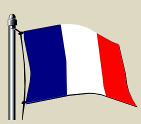
Nuclear containment structures

- Grease as PT corrosion protection has a 40+ year history of successful use around the world
- USA, Canada, England, Sweden, Spain, Japan, South Korea, China, Taiwan





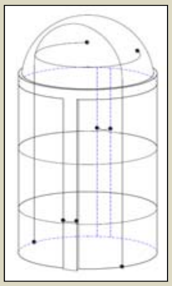
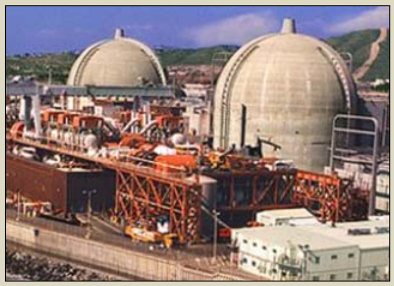
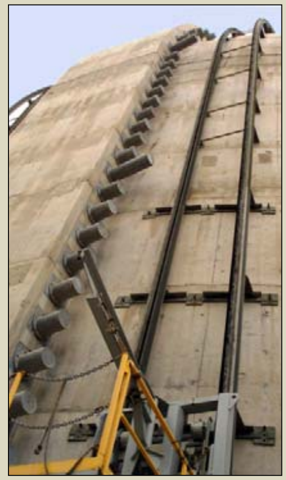
Grease Filled Duct



- **European Bridge Post-Tensioning**
  - France and Germany both require grease as corrosion protection for unbonded tendons.
  - Germany requires all unbonded tendons to be replaceable.

Grease Filled Duct

Tendon Replacement Project (2009)
- California nuclear generating station
- Four steam generators replaced
- Removal of horizontal and vertical tendons
- Grease filled ducts

Grease Filled Duct

Tendon Replacement Project
- Total of 164 tendons de-tensioned and removed
- 82 tendons in each structure
  - 46 horizontal
  - 36 vertical
- Remove and replace steam generators
- Temporary 28-ft opening cut in 4-ft thick concrete containment structure


Grease Filled Duct

Tendon Replacement Project
- Containment structures built in 1979/80
- 65-70^{o}F ambient temperature at the time of cap removal
- Existing tendon condition after 30 years

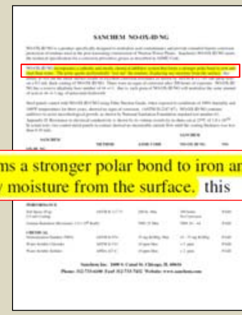
Grease Filled Duct

Tendon Replacement Project
- Complex tendon geometries
- Limited access conditions
- QA program in compliance with Nuclear Regulatory Commission (NRC) regulations
- On-site tendon demonstration program

Grease Filled Duct

Grease Material

- Corrosion protection
  - Cathodic and anodic chemical inhibitor system
  - Forms stronger polar bond to steel than water
- Pumping
  - 135°F melting point
  - Once melted, flows readily below melting point
- Multiple suppliers
  - No sole-source product issues



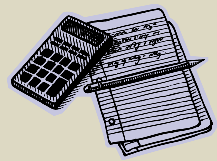
NO-OX-ID NG incorporates a cathodic and anodic chemical inhibitor system that forms a stronger polar bond to iron and steel than water. The polar agents preferentially "wet out" the tendons, displacing any moisture from the surface. this

Grease Filled Duct

- Challenges
  - Unbonded design
  - Anchorage access
  - De-tensioning

Grease Filled Duct

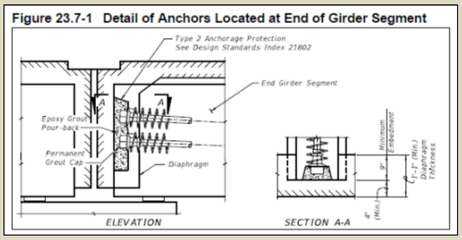
- Unbonded design
  - External tendons
    - No change
  - Internal tendons
    - Change from bonded to unbonded design may require additional tendons

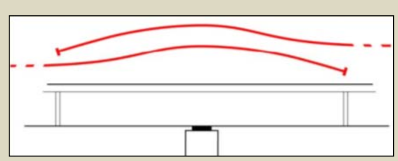


Grease Filled Duct

- Future anchorage access
  - Offset beam ends?
  - Consider new potential blister locations?

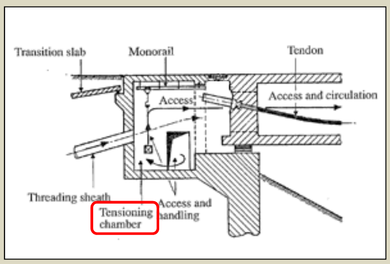
Figure 23.7-1 Detail of Anchors Located at End of Girder Segment





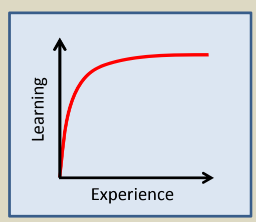
Grease Filled Duct

- De-tensioning
  - Strand tails
  - Mechanical de-tensioning
  - Tensioning chamber at end of bridge?



Grease Filled Duct

- **New application of existing technology**
  - New to bridge contractors
- **Initial Cost**
  - Estimated 15%-20% increase on PT system only
  - Recent segmental mega-project example:
    - 20% cost increase applied to external PT only
    - About 25% of tendons are external
    - Total PT bids increased by about 5%
    - Total bridge bids increased by less than 1%
- **Potential to reduce life cycle costs**
  - Corrosion protection
  - Replaceable



Grease Filled Duct

- **Implementation**
  - Research
  - Structures Manual
    - Design/detailing requirements
  - Specifications
    - Construction
    - Materials
  - Work with PT vendors
  - Pilot construction project
  - Hybrid system
    - Grease for certain tendons
    - Grout for simple geometries

Existing technology…
Not reinventing the wheel

"I'm waiting for them to work out the bugs first."

Thank you

Questions?