2016 PTI Convention
Long Beach, California

Technical Session 5

PT Buildings II

1976-2016 40 years

POST-TENSIONING INSTITUTE ™

Advancing Anchorage Performance and Technology

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PRECISION-HAYES INTERNATIONAL

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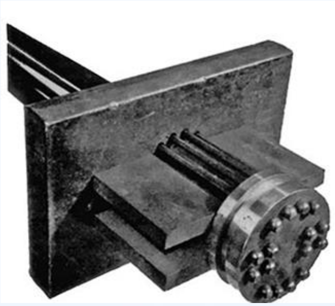
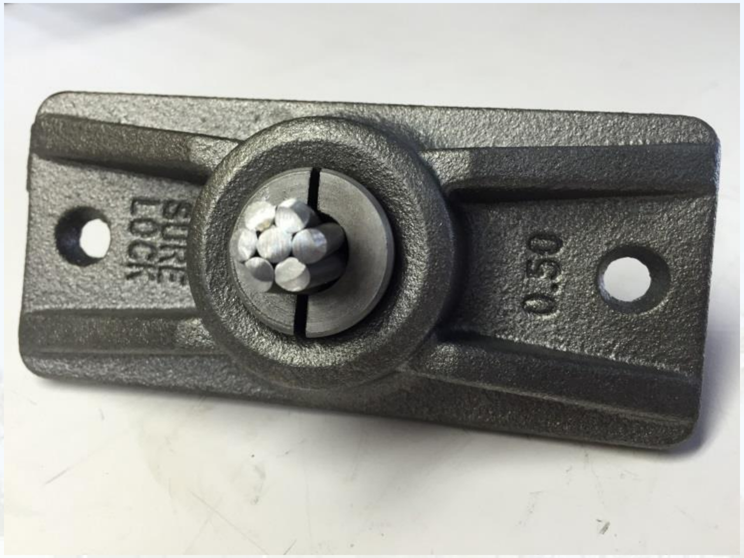
Presentation Goals:

- Briefly review performance criteria for gripping PC strand in anchorages
- Identify design variables affecting anchorage performance
- Discuss opportunities for enhanced anchorage performance in buildings and other structures
- Demonstrate advances in anchorage design and performance

History





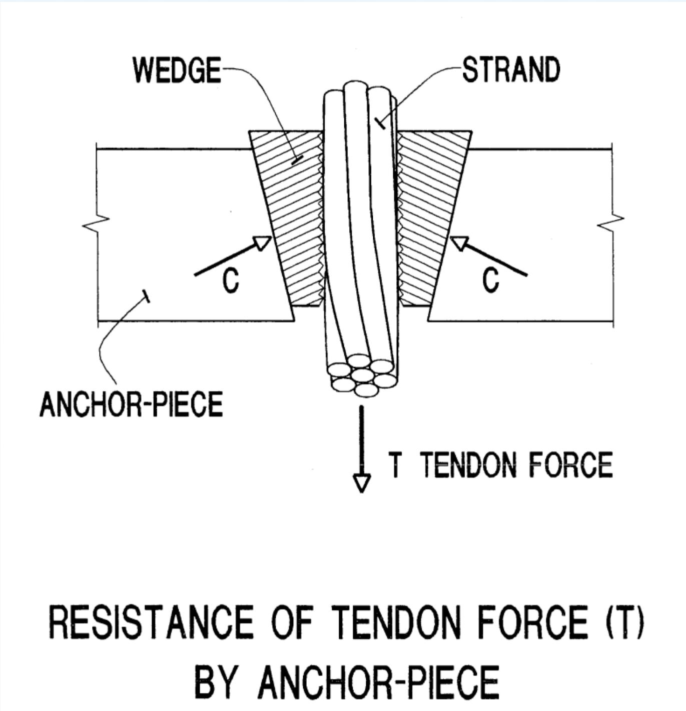
Performance Criteria for Anchorages

Standard	Static [4]	Ductility	Fatigue 1	Fatigue 2	Notes
PTI M-10	≥ 95%	≥ 2%	500k cycles 60% ↔66% f_{pu}	50 cycles 40% ↔ 85% f_{pu}	1
ACI 423.7	≥ 95%	≥ 2%	500k cycles 60% ↔66% f_{pu}	50 cycles 40% ↔ 85% f_{pu}	2
EOTA ETAG 013	≥ 95%	≥ 2%	2M cycles to 65% f_{pu}	N/A	3

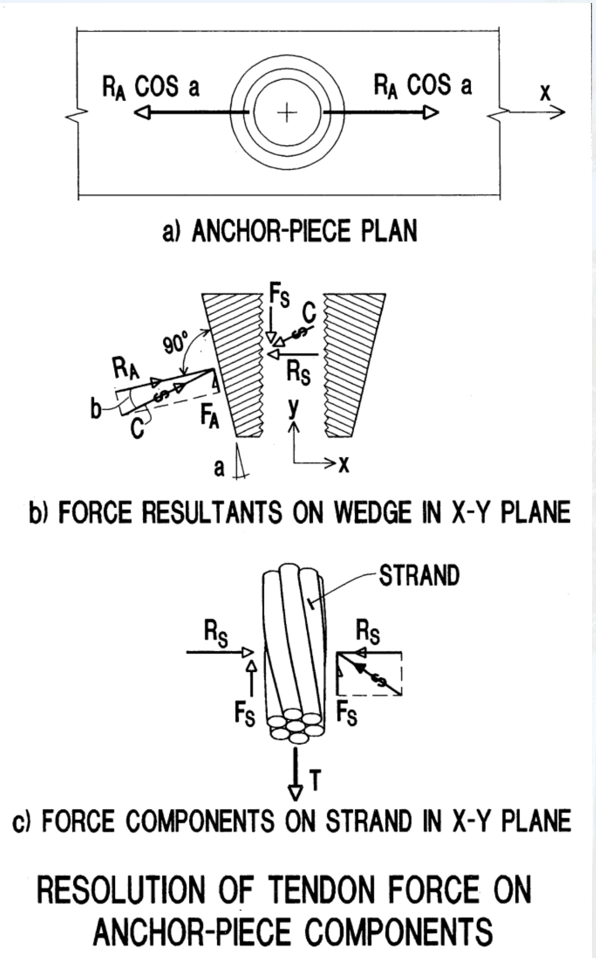
Notes:

1. Force at strand rupture of at least 95% of specified strength of strand is a requirement for anchorage components.
2. Force at rupture of at least 95% of specified strength of strand is a requirement for prestressing steel.
3. Force of rupture of at least 95% of specified strength as well as AUTS. Displacement of anchorage components during load application shall vary inversely with load. Deformations stabilize within 30 minutes at 80% load.
4. Changes from GUTS to MUTS, to AUTS, and finally to Specified Strength have improved specifications dramatically (Bondy, 2008)

Anchorage Assembly Forces



Chacos, 1993



Chacos, 1993

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Mathematical Model

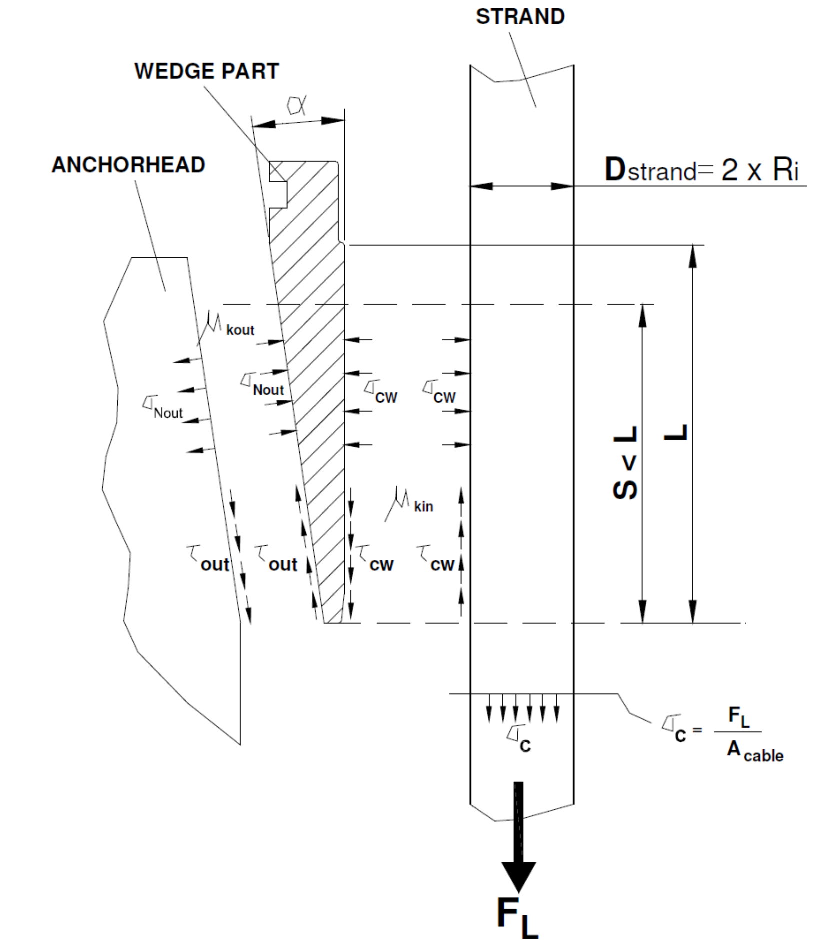


Figure 17 : Schematic presentation of mathematical wedge model

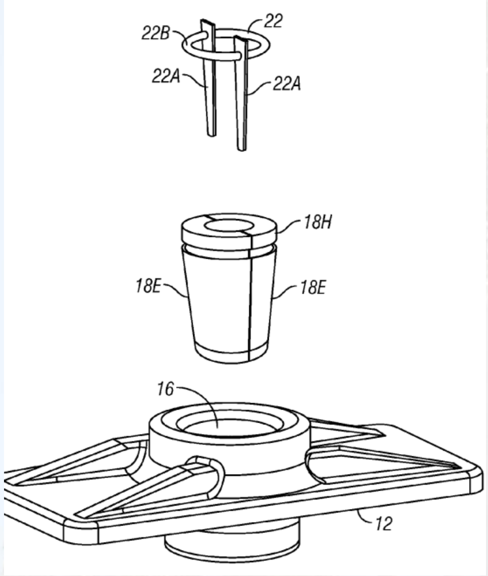
H.G.M.R van Hoof, 2005

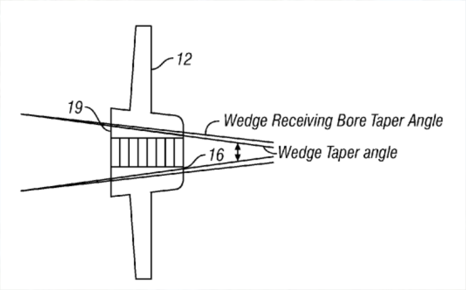
"It is important to recognise that the basic concepts of anchoring prestressing steels mostly are quite simple, however, that the actual behaviour is significantly more complex, and often is beyond mathematical or even numerical analysis. Hence, much of the design and confirmation of the anchorage concepts still relies on experience and detailed testing."

Fuzier, Ganz, and Matt, 2005
Fib bulletin 33

Variable Design Aspects

- Wedge segment gap control
- Coaxial gripping
- Forward movement
- Indention control
- Equalized clamping
- Surface finishes





Hayes Draginis US pat 7360343B2, 7726082B2, 7765752B2

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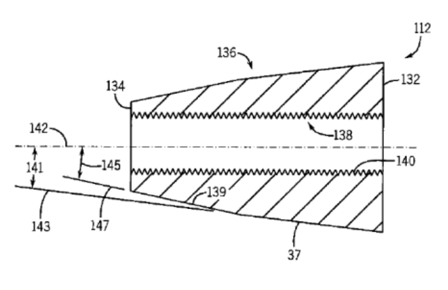
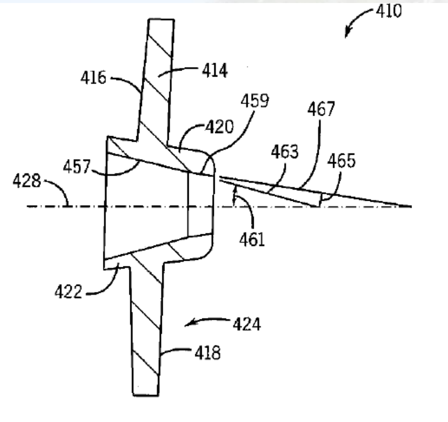
Variable Design Aspects

- Geometry
  - Internal anchor angle(s)
  - External wedge angle(s)
  - Relative angle of both
  - Length of gripping section





Walsh and Kurama, 2009; 2010;2012
Walsh, Draginis, Estes and Kurama 2015

Mathews, Landry, and Hohensee US pat 8,756,885, 9,163,405

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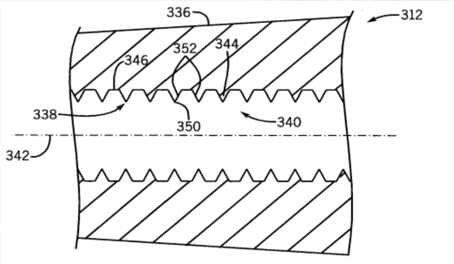
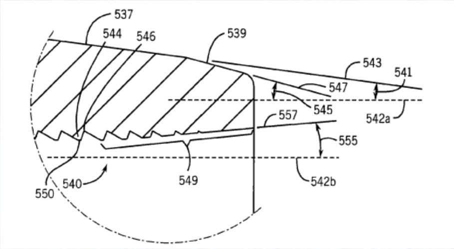
Variable Design Aspects

- Grip Design
  - Frequency of gripping teeth
  - Distance between teeth
  - Angle of gripping teeth
  - Direction of angle
  - Shape of gripping teeth
  - Shape of the space between teeth
  - Height of teeth
  - Graduated formation

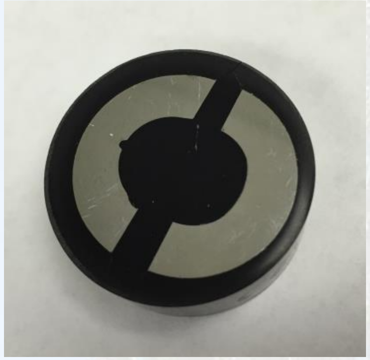




Mathews, Landry, and Hohensee US pat 8,756,885, 9,163,405

Variable Design Aspects

- Alloy
  - Machinability
  - Malleability
  - Chemical composition
- Thermal Treatment
  - Core hardness
  - Case hardness
  - Case depth



Other Critical Factors

- Strand
  - The base metal shall be carbon steel of such quality that when drawn to wire, fabricated into strand, and then thermally treated, shall have the properties and characteristics prescribed in this specification. (ASTM A416/416M-16)
  - Base material (1080, 1084, 1084m, SWRH82B, SWRH72A, SWRH77B, etc.)
  - Rod size (total reduction required)
  - Drawing approach angle, lubrication, speed
  - Number of dies (influences wire hardness)
  - Die friction (shear deformation)
  - Die pressure / Die wear (potential bulging and delamination)
  - Back-pull (potential stretching deformation and reduced ductility)

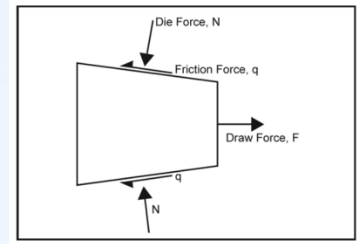


Fig. 1. Free body diagram showing the primary forces operating in wiredrawing.

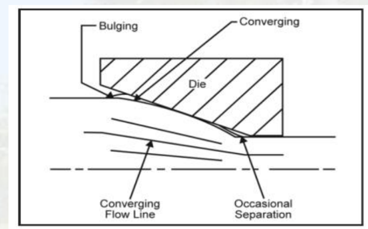


Fig. 8. Wire bulging that occurs at the throat in drawing dies.[16]

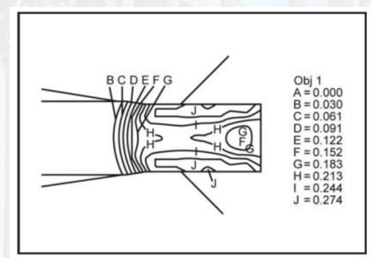


Fig. 13. Effective strain distribution in a drawn wire obtained by using finite element simulation.

Nugraha, 2013

Anchorage Failure Modes

- Strand / wire fracture
  - Single or multiple wires
  - Normally occurs at or near the tip of wedge
  - Stresses greatest at first few fully engaged gripping teeth
- Outer wire slip
  - Complete force release

Abramson, 2013

Preferred Rupture Mode

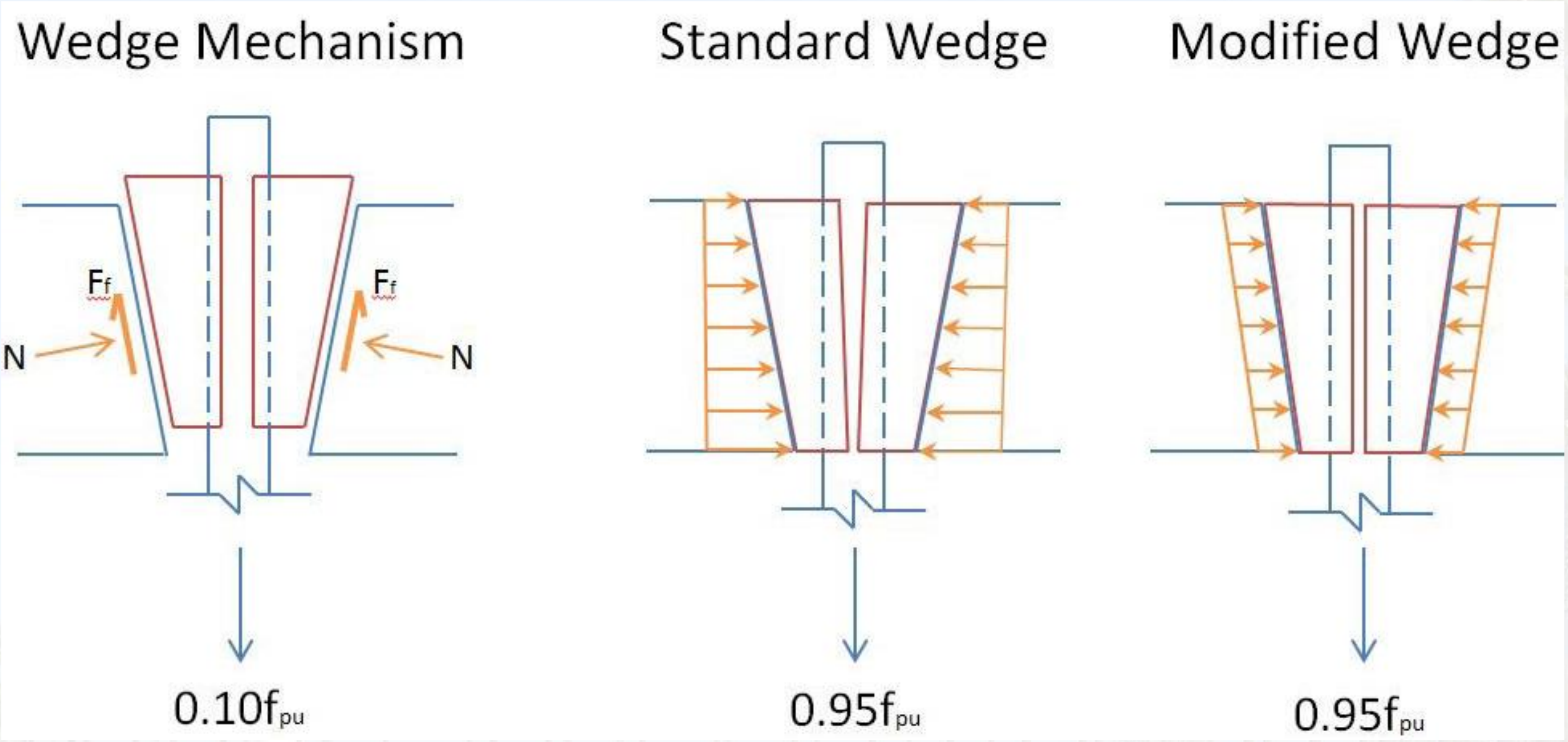
- Wire rupture outside the anchorage connection
- Multiple wire rupture (7)
- Above specified strength
- Approaching 100% efficiency

Ruhr-Universität
Bochum, 2015

Testing and Development

- Comprehensive review of scholarly research since 1960's
- Sponsored 2013 research at Notre Dame as follow-up to 2009 assessments of PT systems
- Participated in research at University of Minnesota
- Realization of over a decade of active internal research and development

Testing and Development



Abramson, 2013

New Developments

- High Efficiency Anchorage
  - Optimized compact SURE-LOCK® III anchor and HE wedge
  - Mass distribution in casting based on FEA
  - Combination of proprietary features in geometry, grip design, and materials
  - Repeatable efficiency of >99% of AUTS well above MUTS

Stanford US pat D635,278S; Hayes Draginis US pat 7,360,343, 7,726,082, 7,765,752; Mathews, Landry, and Hohensee US pat 8,756,885, 9,163,405

Other Recent Developments

- Anchor casting control
  - Foundry selection based on performance
  - Quality audits at foundries
  - 100% inspection

EBAA Iron 100% Laser Inspection and Quantity Control
ET Bradley, US pat 9,114,434, 2015

Other Recent Developments

- Posi-Lock ® Plus[10]
  - Simple attachments to existing Posi-Lock® system provides an additional active compression seal for 10 psi applications
  - Provides restraint to sheathing movement
  - Pocket-formers that allow for all cutting methods (plasma, torch, PocketShear®) and mechanical interface with grout

Hayes US pat 6,883,280; 7,174,685; 7,275,347; and pats. pending

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Other Recent Developments

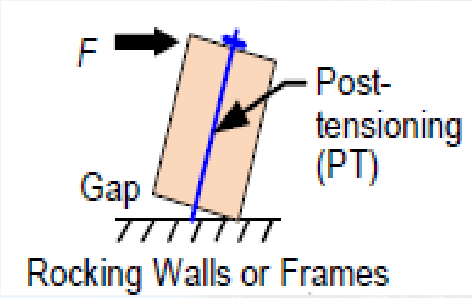
- GRABB-IT® Rail
  - Imbedded in columns, walls for ease of anchoring barrier cables
  - Pre-dimensioned spacing and reduction of installation time
- Articulated GRABB-IT® Barrier Anchor
  - Spherical connection
  - Compensates for ramp angles
  - Allows for lubrication / corrosion protection maintenance without disassembly

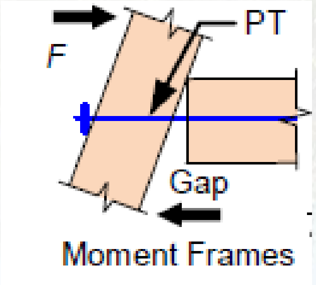
Landry US pat 9,194,155

Mathews, Landry, Van Noord US pat 8,051,615

Practical Application

- Increase durability of PT systems and structures
- Reduce complexities in the field
- Reduce critical variances of castings used in anchorages
- Optimize the best combination of performance features to improve reliability
- Improve anchor / strand efficiency ratio for improved performance in catastrophic events
- Push the envelope on the practical potential for higher grades of strand as well as new Advanced High Strength Steels with improved ductility and strength to weight ratios
- Potential contribution to stay-cable anchorage systems





Chancellor, Eatherton, Roke and Akbas, 2014

Thank You!

Questions ?