Cable-Stayed Bridges

PTI Recommendations for Stay Cable Design, Testing and Installation

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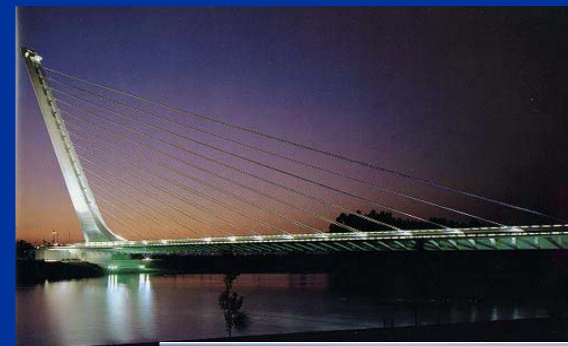
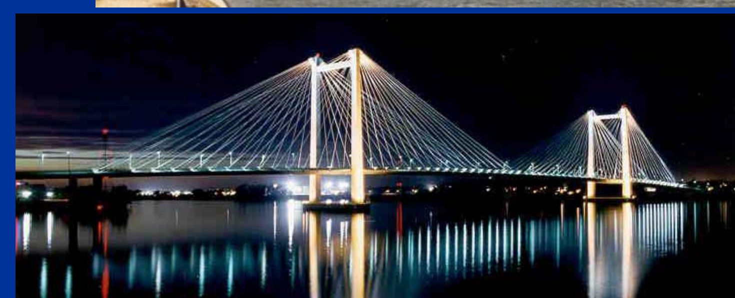
Design of Stay Cables

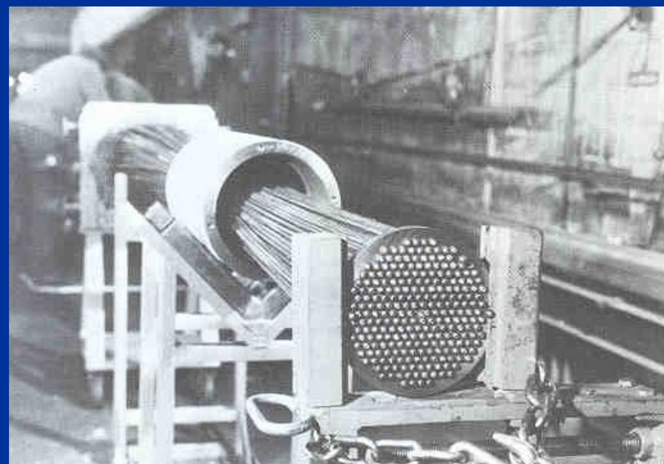
- A Simple, efficient structural element
- Complex design demands and design criteria

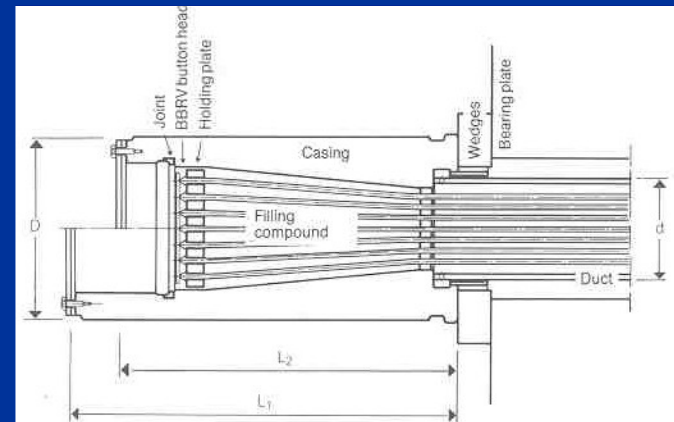




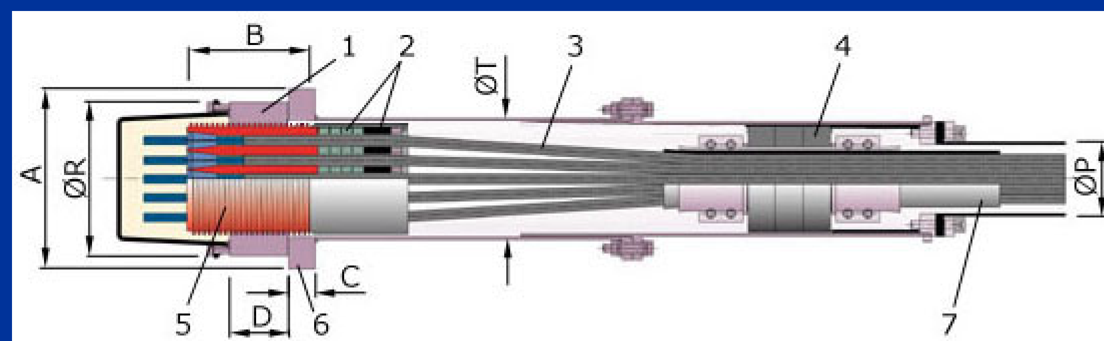
Modern Stay Cable Anchorages

Hi-Am Anchor





- HiAm socket anchor largely replaced with strand anchors
- HiAm generally reserved for rail; strand is typical for highway



Strand Anchor

1 - Ring Nut
2 - Sealing / Spacer
3 - Strands
4 - elastomeric Bearing
5 - Anchor Block
6 - Bearing Plate
7 – HDPE Tube

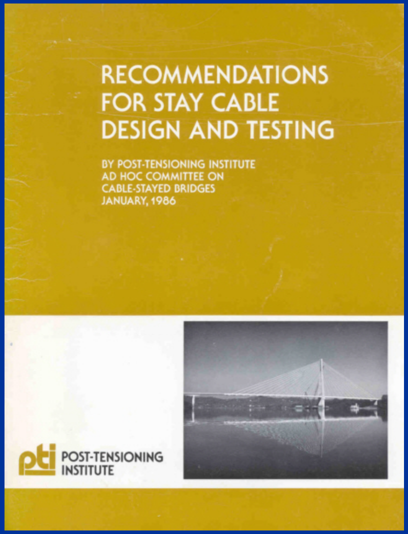
The Stay Cable – Path of Progress

- Pre-1983 Specifications all custom (and different)
- After East Huntington bid (1980), PTI organized a standing committee for stay cables

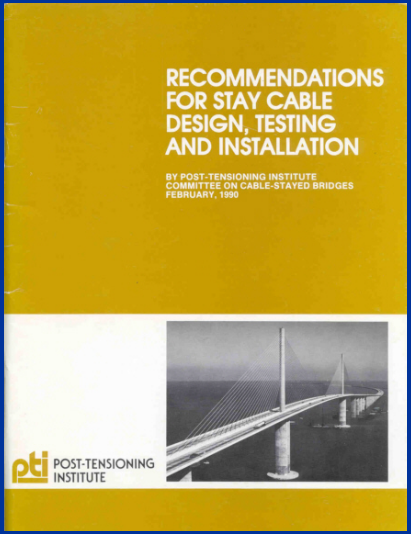
"The disadvantage of men not knowing the past is that they do not know the present." (G. K. Chesterton, 1933)

PTI – 1st Edition

- Primary focus on fatigue
- Recommendations in context of AASHTO
- Recognition of stay anchorage as proprietary supplier item
- Established fatigue and strength performance criteria for anchorage
- Adopted methods specifications for more conventional aspects of supply

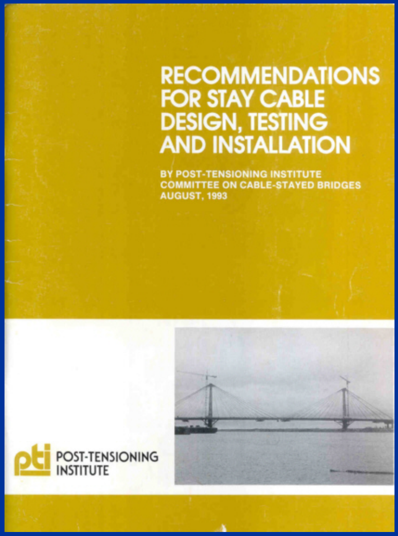


PTI – Second Edition



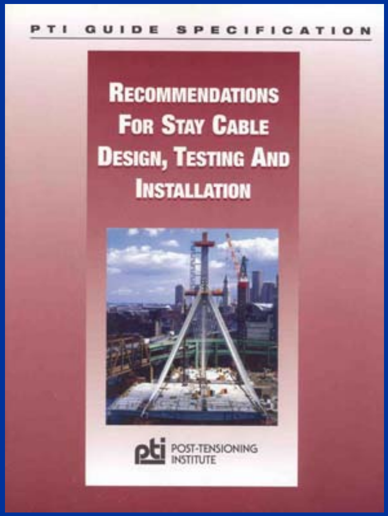
- Reacted to challenges of implementation
  - Details of fatigue testing
  - Disparity of “white gloves vs. sledge hammers”
  - Recognized fatigue testing as a measure of design quality control
- Increased focus on corrosion (fretting)
  - Added methods specs for materials and grouting
- Added provisions for Installation and Erection

PTI – Third Edition



- Major expansion in coverage of ancillary items
- More focus on corrosion, but retained reference to PT methods
- Introduction of erection to grade (vs. cable force or length)
- Fatigue acceptance lowered from 95% AUTS to 95% of GUTS

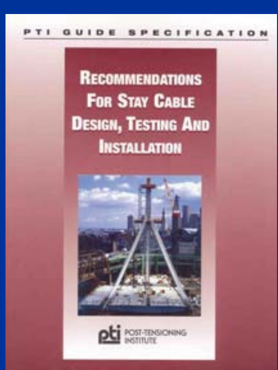
PTI – Fourth Edition



- Major revision in format and form – LRFD/Metric and major content
- Added performance criteria for corrosion protection
- Added design provisions for saddle design
- Added cable vibration/wind provisions
- Refined 95% fatigue acceptance criteria to > 93% AUTS, 95% GUTS

Corrosion Protection – Key to Maintenance

- Abandoned the methods specs, and developed a new performance spec
- Variety of approaches to spec testing criteria explored
- Adopted two stage barrier, with each held to performance standard
- Large-scale leak test of fatigue specimen



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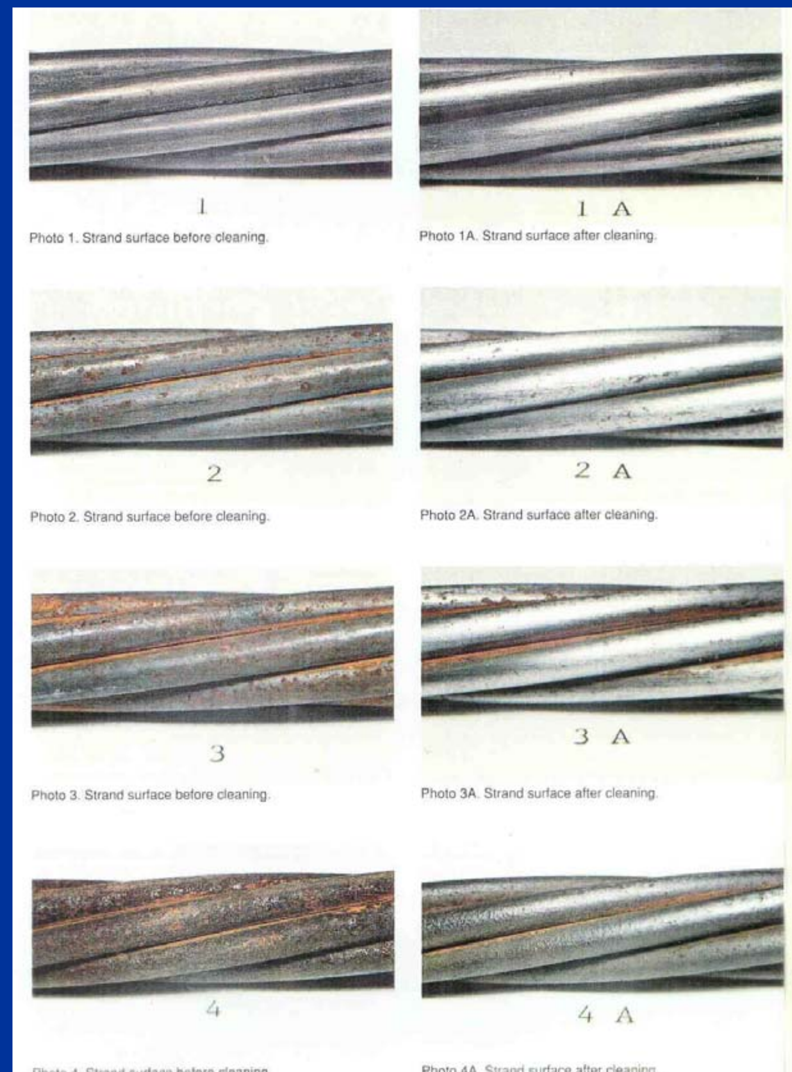
Corrosion Performance Criteria

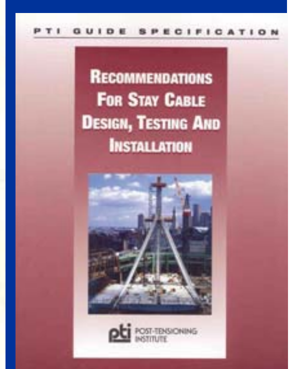
4.1.7 Acceptance Criteria

4.1.7.1 Barriers:

4.1.7.2 Anchorage Assembly:

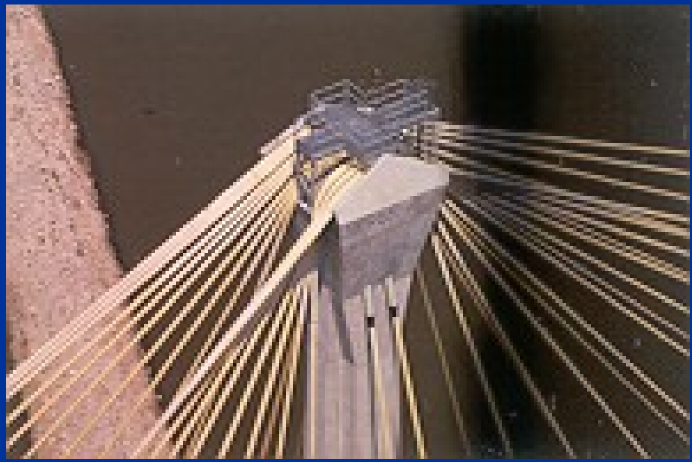
<u>Fretting corrosion in test is automatic failure</u>

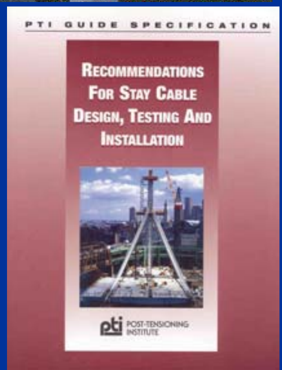




Saddle Design

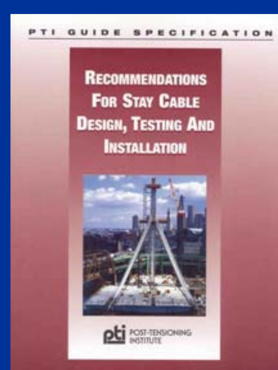
- Recognized that saddles are a designer item
- Established design rules to remove from realm of vendor qualification testing
- Design rules address effect of lateral pressure on fatigue strength
  - Added bending to stress allowable
  - Added criteria for mono-tube or sheath cushioning for lateral pressure
  - LRFD design for components





Cable Vibration Provisions

- Primary focus on rain-wind stability criteria
- Galloping (inclined cable) criteria
- Provisions for stabilizing cables
- Wind studies and monitoring



The following tentative stability criterion for rain-wind induced vibrations of smooth circular cables has been proposed: [16]

$$\frac{m\xi}{\rho D^2} \geq 10 \qquad (5\text{-}1)$$

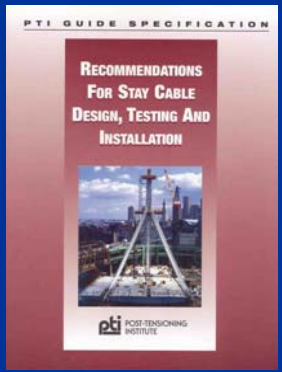
where m is the cable mass per unit length, ξ is the damping ratio-to-critical, ρ is the air density, and D is the cable diameter. The expression $\left(m\xi / \rho D^2\right)$ is

$$U_{crit} = cND\sqrt{\frac{m\xi}{\rho D^2}} \qquad (5\text{-}2)$$

where c is a constant, N is the fundamental natural frequency of the cable, D is the cable diameter, and $\left(m\xi / \rho D^2\right)$ is the mass-damping parameter defined

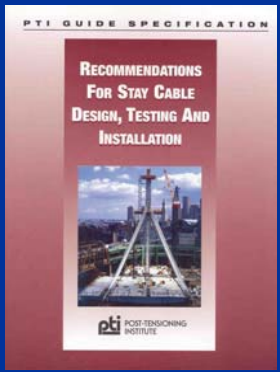
Wind Vibration Design Considerations

- Provision for damping is critical for rain-wind and inclined galloping vibration control.
- Surface treatment is effective for rain-wind vibration control, and now standard practice.
- Damping less effective for parametric vibrations. Effects long spans and light decks. Solution using stiffening ropes is often required.



4th Edition Addenda

- Inclined cable galloping commentary addresses current research – as yet inconclusive
- Clarified cable loss design criteria
- Deleted service limit state
- Stay guide pipe connection design
- Modified inter-stay MTE variation



Cable Loss Criteria

- Confusion regarding statical system for analysis
- Address the ‘analysis factor’ – the potential for analysis methods to compromise safety index

5.5 Loss of Cable

Modify the second paragraph as follows “The impact dynamic force resulting from the sudden rupture of a cable shall be 2.0 times the static force in the cable, or the force as determined by non-linear dynamic analysis of a sudden cable rupture, but in no case less than 1.5 times the static force in the cable. This force shall be applied at both the top and bottom anchorage locations.”

C.5.5 Loss of Cable

Modify the loss of cable Extreme Load case as follows:

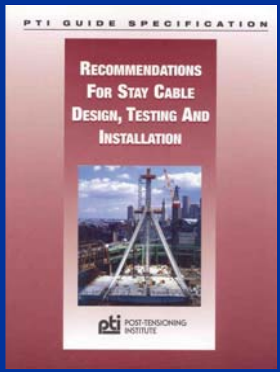
1.1 DC + 1.35 DW + 0.75(LL**+IM) + 1.1 Cable Loss Dynamic Forces

Add the following to the commentary:
“The load factor of 1.1 on the Cable Loss Dynamic Force is to account for a variation of final cable force in construction relative to the force level assumed in design.

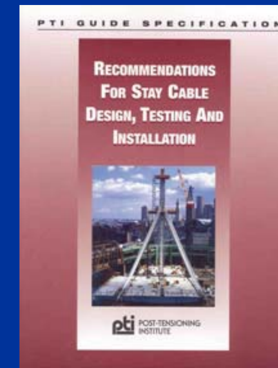
For analysis using elastic superposition and the static equivalent 2.0 factor, the initial statical system prior to cable rupture should be used to compute the effects of all permanent and live loads. A second statical system without the ruptured cable should be used to compute the effects of the dynamic force to be superimposed on the initial system. If a non-linear dynamic analysis is used, the dynamic model should be initialized with the full permanent load and live load condition for the bridge.

Service Limit State - Deleted

- Service Limit State for steel design is primarily a deflection control criteria
- With LRFD strength design basis and empirical fatigue design basis, LRFD service level strength reduction factor was redundant (and confusing)



Guide Pipe Connection Design



- Limited examples of pipe failure
- Assembly tolerance on a few projects raised concern over force demand and durability
- Support for damper design required – force and low amplitude fatigue

5.9 Guide Pipe Minimum Design Forces

Cable guide pipe assemblies and all their components shall be designed for the following minimum lateral loads applied at the centerline of cable support at the exit point of the guide pipe:

i) Strength Limit States = 2% of the maximum static cable force

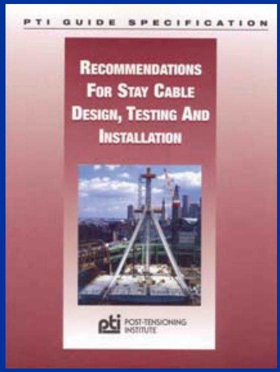
ii) Fatigue Limit State = 4% of the cable fatigue load or 1.5% of the maximum LL cable force, whichever is greater.

The "Guide Pipe" is defined as the structural assembly that aligns the cable at either the deck or the tower, and against which the cable damper or alignment device acts to resist lateral motion of the cable.

The wall thickness of the guide pipe shall not be less than 9 mm. The guide pipe shall be fabricated perpendicular to the face of the bearing surface of the cable anchorage within 0.15 degree tolerance. The guide pipe assembly shall be installed within 0.4 degrees of the planned pipe alignment.

Additional corrosion protection measures are recommended for the guide pipe above and below the embedment point into a concrete bridge deck.

MTE Variation



- Origins of old criteria in monostrand stressing without computation or control
- Modern systems warranted new criteria
- Tolerance of measurement on the order of old criteria – effect varies with length
- Practical considerations – variation itself not significant

6.9.4 Stressing

Modify the provision as follows:

"Cables consisting of bars or strand individually anchored shall be permitted to be tensioned one by one provided that it can be demonstrated in advance, to the satisfaction of the Engineer, that the final tension and elongation of each tensile element will be equalized within a range of +/- 2.5% MUTS for the tension element."

Modification of this provision is to clarify the application for strands with low stress, where stressing is below the tolerance threshold for jacking equipment and variance is relatively greater due to strand modulus. Additional considerations may be necessary for very short cables, where tolerances on installation methods are amplified by the short gage length of the cable.

PTI – 5th Edition

- Work in Progress – Draft due next fall
- Developing Topics
  - Bending fatigue
  - Updated Materials
  - Extrados Criteria
  - High seismic criteria

PTI 5th Edition – Bending Fatigue

Problem Statement: Tolerance on fabrication and erection can effect service condition of stay. Parametric vibrations, live load movement and wind vibrations of stay all have a bending component.

General Approach:

1. Add imposed anchorage angle for fatigue test
2. Add lateral force design requirements at dampers

5^{th} Edition – Extrados Design Criteria

Problem Statement: Extrados bridges appear as a subset of cable-stayed bridges, using much of the same hardware and technology. Yet, depending upon the design parameters, stay demands can differ.

General Approach:

1. Define threshold(s) of behavior to distinguish a full cable-stayed bridge from an extrados bridge.
2. Define exemptions to or modification of stay criteria for extrados category.

5th Edition – High Seismic Criteria

Problem Statement: Stay anchorage design is based on performance testing. The current testing range is based on a minimum tensile load on the anchorage (nominal dead load).

General Approach:

1. Identify force threshold where standard testing conditions do not apply.
2. Identify supplemental testing requirements when minimum anchor tension is not met, with consideration for variability between computations and service.

Summary

- Demands and criteria are interdependent
- Performance Criteria need to be best quality to address unknowns, such as low amplitude high cycle effects from wind and other influences
- Not a cookbook – designers need to understand and address behavior in design