## AGENDA

**DC-45: Cable Stayed Bridge Committee**  
Tuesday, October 20, 2020  
10:00 a.m. - 2:00 p.m. Eastern

### Voting Members Present (x of 24)

<table>
<thead>
<tr>
<th>Name</th>
<th>Company</th>
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<tbody>
<tr>
<td>Gregory Hasbrouck</td>
<td>Parsons</td>
<td>Julien Erdogan</td>
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<tr>
<td>Tim Christle NV</td>
<td>Post-Tensioning Institute</td>
<td>Christian Glaeser</td>
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<td>Amy Dowell, NV</td>
<td>Post-Tensioning Institute</td>
<td>Alex Gutsch</td>
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<td>Miroslav Vejvoda, NV</td>
<td>Post-Tensioning Institute</td>
<td>Hans Hutton</td>
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<td>Mike Schwager, TAB Contact, NV</td>
<td>Schwager Davis, Inc.</td>
<td>David Jeakle</td>
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<td>Rachid Annan</td>
<td>VSL Schweiz AG</td>
<td>Michael L Kiggins</td>
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<td>Don Bergman</td>
<td>COWI North America Ltd.</td>
<td>Christopher Ligozio</td>
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<td>Werner Brand</td>
<td>Dywidag-Systems International Gmbh</td>
<td>Hans Lund</td>
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<td>Antonio Caballero</td>
<td>BBR VT International</td>
<td>Andrew Micklus</td>
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<td>Tommaso Ciccone</td>
<td>Tensacciai Srl</td>
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### Associate Members Present

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<tr>
<th>Name</th>
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<tr>
<td>Erwan Allanic</td>
<td>IBT</td>
<td>Langston Bates</td>
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<tr>
<td>Miguel Aviles</td>
<td>Flatiron Construction Group</td>
<td>Zhen Cai</td>
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<tr>
<td>Yosbany Ballate</td>
<td>Structural Technologies, LLCVSL</td>
<td>John Crigler</td>
</tr>
<tr>
<td>Name</td>
<td>Company/Institution</td>
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<tr>
<td>David Goodyear</td>
<td>Consulting Engineer</td>
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<tr>
<td>Eddie He</td>
<td>Parsons</td>
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<tr>
<td>Reggie Holt</td>
<td>Federal Highway Administration</td>
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<tr>
<td>Akio Kasuga</td>
<td>Sumitomo Mitsui Construction</td>
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<tr>
<td>Dale King</td>
<td>Bekaert Corp</td>
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<tr>
<td>Larry Krauser</td>
<td>General Technologies Inc.</td>
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<tr>
<td>Marcos Lozias</td>
<td>Jacobs</td>
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<tr>
<td>Guoqiang Luo</td>
<td>Shanghai Pujiang Cable Co., Ltd.</td>
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<tr>
<td>Behzad Manshadi</td>
<td>BBR VT International Ltd</td>
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<td>Erik Mellier</td>
<td>Freyssinet</td>
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<tr>
<td>Pietro Paolo Mossone</td>
<td>Grandi Strutture</td>
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<td>Jacob Perkins</td>
<td>HDR Engineering</td>
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<tr>
<td>Guido Schwager</td>
<td>Schwager Davis Inc</td>
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<td>Mike Schwager</td>
<td>Schwager Davis, Inc.</td>
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<tr>
<td>Khaled Shawwaf</td>
<td>Dywidag-Systems International</td>
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<tr>
<td>Joseph Smith</td>
<td>WSP</td>
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<tr>
<td>Uwe Starossek</td>
<td>Technical University of Hamburg</td>
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<td>Teddy Theryo</td>
<td>FDOT</td>
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<tr>
<td>Morgan Trowland</td>
<td>McElhanney</td>
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<tr>
<td>Peter Walser</td>
<td>Leonhardt, Andra and Partner</td>
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ACTION ITEMS FROM LAST / THIS MEETING

<table>
<thead>
<tr>
<th>Item #</th>
<th>Subject</th>
<th>Action</th>
<th>Responsible</th>
<th>Deadline / Completed</th>
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<tbody>
<tr>
<td></td>
<td>Dual units conversion</td>
<td>Organizing and assembling markup as administrative change</td>
<td></td>
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<tr>
<td></td>
<td>References</td>
<td>Send reference updates to GH</td>
<td>All</td>
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<td></td>
<td>Bending Fatigue</td>
<td>TG schedule meetings to discuss updates to next version of DC45.1</td>
<td>Bending Fatigue TG</td>
<td>Update in Fall 2020 meeting</td>
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<td></td>
<td>Filler testing</td>
<td>TG schedule meetings to discuss updates to next version of DC45.1</td>
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<td>Pipe Requirements</td>
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<td>Performance Monitoring</td>
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<table>
<thead>
<tr>
<th>Agenda Item</th>
<th>Expected Outcome / Actions Taken</th>
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<tbody>
<tr>
<td><strong>A. General</strong></td>
<td>A.3 Eddie He, Haifeng Fan, Behzad Manshadi, and Pietro Paolo Mossone joined as associate members. Jacob Myer has moved from associate to voting membership.</td>
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<tr>
<td>A.1 Call to Order</td>
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<td>A.2 Roster Review</td>
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<td>A.3 Committee Roster / Changes</td>
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<td>A.4 PTI Antitrust Policy</td>
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<tr>
<td><strong>B. Agenda &amp; Minutes</strong></td>
<td>B.2 Vote on Minutes from 11/3/2019 approval Motion / Second: Name / Name Result: X-X-X (Y-N-A)</td>
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<tr>
<td>B.1 Approval of Agenda</td>
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<td>B.2 Approval of Minutes from 11/3/2019 (Meeting ballot required)</td>
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<td><strong>C. Actions Taken Between Meetings</strong></td>
<td>C.1</td>
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<td>C.1 Letter Ballots (none)</td>
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<td>C.2 Web Meetings (multiple TG)</td>
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<tr>
<td>Agenda Item</td>
<td>Expected Outcome / Actions Taken</td>
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<tr>
<td>1. <strong>Action Item 1: (Bending Fatigue TG Update)</strong>&lt;br&gt;1.1. Update on TG progress</td>
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<td>2. <strong>Action Item 2: (Filler TG Update)</strong>&lt;br&gt;2.1 Update on TG progress</td>
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<td>3. <strong>Action Item 3: (HDPE Pipe Requirement TG Update)</strong>&lt;br&gt;3.1 Update on TG progress</td>
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<td>4. <strong>Action Item 4: (Performance Monitoring TG Update)</strong>&lt;br&gt;4.1 Update on TG progress</td>
<td>4.1</td>
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<td>5. <strong>Action Item 5: (Dual Unit Conversion)</strong>&lt;br&gt;5.1 Update on TG progress</td>
<td>5.1</td>
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<td>6. <strong>Action Item 6: (References)</strong>&lt;br&gt;6.1 Update on TG progress</td>
<td>6.1</td>
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<td><strong>D. New Business</strong>&lt;br&gt;D.1 Protective tape repair</td>
<td>D.1 Discussion – start TG as needed</td>
</tr>
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<td><strong>E. Next Meeting</strong>&lt;br&gt;2021 PTI Convention, Weston Indianapolis, IN April 18-21, 2021&lt;br&gt;Web Meetings: as needed</td>
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<td><strong>F. Adjourn</strong></td>
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**AGENDA / MEETING EXHIBITS**

<table>
<thead>
<tr>
<th>Exhibit #</th>
<th>Subject</th>
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<tbody>
<tr>
<td>Roster / A.4</td>
<td>Sign-In Sheet / PTI Anti-Trust Policy</td>
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<tr>
<td>B.2</td>
<td>Minutes from 11/3/2019</td>
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<tr>
<td></td>
<td>Check the committee website prior to the meeting for attachments relating to Items 1-6</td>
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PTI POLICY STATEMENT ON COMPLIANCE WITH ANTITRUST LAWS

At a meeting on October 8, 1980, the Board of Directors first discussed the Institute's status and policies regarding compliance with antitrust laws. After review of both the internal and external compliance procedures, the following resolution was approved:

"The staff, officers, directors and members of the Post-Tensioning Institute are reminded that they are required to comply with the spirit and specific requirements of the antitrust laws on all activities within the scope of, and related to, the official functions of PTI. Further, this restated position, along with appropriate explanatory material, should be placed in all meeting folders/books periodically, beginning with the 8th of October meeting of PTI."

On July 24, 2012 and again on October 7, 2015, the Executive Committee authorized Legal Counsel to review and update this Policy Statement in the perspective of the Department of Justice Business Review Letter of July 30, 1997 and current case law. As a continuing guide for your participation in PTI's meetings, please review and continue to adhere to the following "Legal Limitation on Discussions at PTI Meetings."

LEGAL LIMITATION ON DISCUSSIONS AT PTI MEETINGS AND EVENTS

A free exchange of ideas on matters of mutual interest to the members is necessary for the success of all meetings. Indeed, such an exchange of views is essential to the successful operation of every trade association and the law specifically allows legitimate exchange of views pertaining to, e.g., quality control, safety, building design and construction integrity, etc.

It is not the purpose of this memorandum to discourage the exploration in depth of any matters of legitimate concern to meeting participants. Nevertheless, to ignore certain antitrust ground rules, either through ignorance or otherwise, is to create a civil and criminal hazard businessmen simply cannot afford.

It is for these reasons that PTI provides you with a reminder that certain areas of formal and informal communication between competitors or between manufacturers and their suppliers and customers must be avoided, as posing potential antitrust problems.

The Sherman Antitrust Act, the Clayton Act, the Federal Trade Commission Act, and the Robinson-Patman Act comprise the basic federal antitrust laws, which set forth the broad areas of conduct considered illegal as restraints of trade. In general, agreements or understandings between competitors that operate as an impediment to free and open competition are forbidden. Federal antitrust prohibitions forbid any "agreement or understanding...to substantially lessen competition or tend to create a monopoly in any line of commerce." An important point to keep in mind is that communications and discussions between competitors or between sellers and customers, about matters which may be considered anti-competitive, often comprise the evidence from which courts infer antitrust violations. It is the policy of the Post-Tensioning Institute that such agreements, understandings or communications shall not be tolerated at any formal or informal meetings or social events of the Institute.

The general prohibitions contained in the federal antitrust laws, have been particularized in the form of a series of consent decrees, originally entered against a number of member companies of various trade associations and the associations themselves. It is important to note that these laws not only apply to PTI members, but also to PTI itself. Often trade associations have been and are presently co-defendants in cases brought by the Justice Department and the Federal Trade Commission ("FTC"). Recently, the FTC has stated: "Because trade associations are by their nature collaborations among competitors, the Commission and courts have long been concerned with anti-competitive restraints imposed by such organizations under the guise of codes of conduct. Competing for customers, cutting prices, and recruiting employees are hallmarks of vigorous competition. Agreements among competitors not to engage in these activities injure consumers by increasing prices and reducing quality and choice." Similar "codes" or policies and requirements that encourage directly or indirectly members' unlawful activity are strictly forbidden by PTI in the course of its business with its members.
SPECIFIC EXAMPLES OF ACTIVITIES AND PRACTICES PROHIBITED
AT ALL PTI MEETINGS AND EVENTS:

Included in activities and practices which are forbidden, and are contrary to the policy of the Institute, both under the general antitrust laws and the consent decrees, subject to the said Business Review Letter, are the following:

- Agreeing to allocate markets, customers or suppliers among competitors, classify certain customers or suppliers being entitled to preferential treatment by manufacturers, and establish geographic trading areas.

- Participating in any plan designed to induce any manufacturer or distributor to sell or refrain from selling, or discriminate in favor of, or against any particular customer or class of customers.

- Agreeing in any manner to fix or otherwise establish bids, prices (including price increases, decreases, standardization or stabilization), profits, costs, contract terms affecting price (such as discounts and credit terms), etc. because, e.g. prices were too low, with the exception of certain resale pricing agreements between manufacturers and retailers or distributors.

- Agreeing in any manner to limit or restrict the quality of products to be produced (e.g., restrictions on selling coated strand to certain customers).

- Participating in any plan which has the effect of discriminating against, or excluding competitors, suppliers or customers.

These examples are provided to guide you in your discussions during formal and informal PTI meetings and social events. If the occasion arises, more specific advice will be provided by legal counsel, who is required by Article IV, Section 7 of the PTI By-Laws to be present at all meetings of the Board of Directors and the Executive Committee.
Ben Soule (BS) called the meeting to order at approximately 8:00 AM. The list of attendees is included as Attachment A. BS introduced Greg Hasbrouck (GH) as new chairman. GH recognized and thanked for former chairman Ben Soule for his commitment and diligence in leading the committee.

I. PTI Antitrust Policy

GH referred to the PTI Antitrust Policy for the Committee. There can be no discussions regarding pricing or bidding at the meeting. Sign-in on circulating attendance sheets and initial acknowledgement of and adherence to the PTI Antitrust Policy.

II. Meeting Minutes and Membership

Confirm your membership status. Attendance rules are in effect for voting status for 8th Edition.

The minutes from May 2019 were reviewed by the Committee. One correction was noted by GH. Motion by BS to approve, second by Dave Jeakle (DJ). Minutes were unanimously approved (12-0-0).

III. General Update / Administrative Tasks

1. Units – working on organizing and assembling markup for dual units conversion, make as administrative change
2. References – still in progress, assigned at previous meeting, few people have provided, send to GH
3. Bending Fatigue Data – no data has been provided yet, specific projects assigned, list will be sent out – need data to ensure our bridges generally comply with any provisions introduced

IV. Bending Fatigue Discussion

- Objective: Establish testing regime to eliminate design for bending effects for prequalified systems.
- FIB has instituted bending test – design uses test with 1.25 factor of safety
- BS – How did FIB relate test and design? Clear process documented for axial fatigue, not clear for bending
- FIB is more of a robustness test, unsure how it correlates to actual bridges.
- Werner Brand (WB) – Grew from Eurocode (3-1-11), in Eurocode it is not clear what to do with bending demands, also lack of observed problems from bending fatigue, is typically ignored by designers
- Raschid Annan (RA) – Axial fatigue testing creates failure in the length, not at anchorages – not possible currently in laboratory for bending fatigue, failure always at anchorages, how do you apply a bending demand and instrument the strand away from the load application point? How to extend Wohler curve?
- BS – Why are provisions pointing to 2,000,000 cycles when we greatly exceed this number of cycles for a 75 to 100 year life? FIB provisions are unclear above 2 million cycles.

Julien Erdogan (JE) – SETRA Approach (presentation)
- Overview of SETRA Provisions (Chapter 6 & 14 for bending provisions)
- Bending formula (similar to PTI) is conservative, ignores non-linear behavior in multi-wire strands (interwire slippage)
- Includes/References primary work on fatigue cracking
- Has calculation of bending stress @ anchor (wedge)
- Tension element inertia – same stress but longer effected zone
- Guides reduces peak stress
- Guides usually included in anchor – large bridges may require supplementation, more like saddle
• Filtering black box in front of wedges is capable of having > 50% reduction in strand bending stresses, but limit to 50%.
• Fretting more important than bending for initiating failure, therefore bending neglected, stress-slip instead
  • 1st approach – Contact stress-slip parameter
  • 2nd approach – Crack initiation mechanics
• Criteria for “special” cases is based on axial stress from bending, not angle or cycles

Further Discussion Points
• Brian Kozy (BK), FHWA – Are we going to deep into technical issues? Suggests study of existing bridges to see if there are problems or damage that are being observed in the field. Is there a problem or is status quo OK?
• Don Bergman (DB) – Cautioned that our bridges are not necessarily that old
• BS – Tests are already being done on all systems due to FIB, we should try to use that information, current design rules on bending are not clear and need to be clarified in any case.
• BS – Options: A) No changes; B) FIB test and desktop devised design rules; C) Research project justifying our own test and design rules.
• Julien’s presentation was only partial information, he has much more info available, some in English, JE to share background papers
• RA to share article on linking tension to bending stresses.
• WB – suggest getting Winkler to give FIB presentation at future meeting
• BK – translating FIB rules to AASHTO philosophy is not an insignificant task since they may be fundamentally different, need to evaluate implications
• WB – monitoring data would be interesting, what rotations actually occur? Uncertainty in demand – wind load, live load fatigue, damper performance. Any cases available?
• BK – Indian River Is heavily instrumented with monitoring by Univ. Delaware
• Guy Larose (GL) – Instrumentation data is available for inclined suspension bridge hanger for rotations, Humber is instrumented for angular.

V. Break

VI. Bending Fatigue Action Plan

1. Morgan Trowland (MT) will attempt to draft proposal for incorporating FIB test into PTI provisions with advice from JE and WB. Suggest how section 5 design provisions would be revised if using FIB test.
2. Gary Gan (GG) – SN curve / theory not finished, has gathered test statistics
3. WB will contact Antonio / Winkler for presentation for next meeting.
4. MT noted he researched safety buffer but was not able to correlate failure rate to safety buffer, how the current provisions were arrived at, background is inconclusive.
5. Gather existing bridge data – specific bridges and volunteers were assigned at last meeting.

VII. Filler Test

Currently have two test requirements in provisions in different areas for qualification and production and it is confusing.
• BS – History – Water test is production test but was included in qualification, switched to production air test, last minute objections and doubt on validity, kept both water test & air test, water test takes longer.
• GH – Suggest keep water test as a qualification test for a system, keep air test in production with a higher defined frequency
• Drew Micklus (DM) – Suggested another test, weigh the amount of wax injected, detects hiccup in production, Freyssinet does this evaluation for QC
• BS – Suggested project based qualification with water test and alternate to demonstrate equivalence
• Bob Sward (RS) will draft proposed revised changes

Discussion on Sections 3.3.2 and 3.3.8 regarding filler material
• WB – 3.3.2 reference to single unbonded strand coating application, does anyone know why this is stated in our document? WB thinks reference isn’t needed and suggests deleting, but also need to reconsider provisions of 3.3.8.
• Discussion of grease vs. wax filler – WB and JE think grease strands for inclined cables is bad since the grease will migrate. RA thinks the grease issues observed may be associated with grease material properties. VSL still uses grease for stay cables in the US. FDOT is requiring wax for stay cables on current projects and won’t allow grease.
• Recommendation for deleting the reference to Table 2.2.2.1 in Section 3.3.2 (entire last sentence). Probably will not create any issues but needs to be voted on.
• Recommendation for 3.3.8 to make reference to updated FIB bulletin and delete reference to PTI M10.2-17.
• In 3.3.8, remove wording about laboratory approval status and state a “qualified” lab instead of “approved” lab. Add “for approval” after Engineer in last sentence.
• WB – Currently provisions don’t mention material requirements for filling caps. Should we address? What types of products are being used? No consensus on making any additional provisions for caps. It is directly covered by the need to pass the water tightness test. Some suppliers fill caps with something other than wax or grease.
• Recommendation to delete 1st sentence of C3.3.8 that mentions PTI M10.2. No objections.
• GH to put together markups to ballot revisions. Can make these changes in an Addendum.

VIII. HDPE pipe requirements
• Jacob Myer (JM) – Dug into the subject a bit and described differences between cell class and table. Some minor difference with upper limits. Melt index could be an issue since it is too high.
• JM – Will pull data together in table for committee’s information.
• William Nickas (WN) – Recommended someone reach out to Dr. Grace Swan (Drexel University) to help us re-evaluate our recommendations.
• BS – Asked if they were conservative or not – hard to tell. Why can’t we delete our table and rely on ASTM data table? Why are our values more conservative than ASTM? Do we need to retain them? Who set our values and why? Are the suppliers meeting our table currently?
• JM – Some things not in ASTM. Our density is higher.
• WB – Most suppliers are using HDPE 100 which doesn’t meet our requirements. HDPE 100 is better than HDPE 80. Referred to Holga letter. WB to provide comments from Holga.
• WB – Does anyone use PP material (3.3.7)? Suggest possibly deleting this section. Are the 3.3.7 provisions up to date?
• John Crigler (JC) – Why should we exclude PP material?
• GL – Asked about pipe retaining shape and effects for dry galloping. Do we need to study this issue, test for it, or put limits on it? GL volunteered to look into this subject.
• BK – East Huntington Bridge is currently being evaluated for issues with pipes changing shape.
• GH – Will check with WVDOH for more information.

IX. Performance Monitoring
• BS and Chris Ligozio (CL) to draft monitoring paper for next time with possible presentation.

X. Reports from Field
• BS to check on ASTM on galvanized strand.
• Tommaso Ciccone (TC) noted error with Scruton number greater than vs. less than (C5.3.2)
• MT noted error with stress risers in Figure 3.1 notes on $\Delta_1$ and $\Delta_2$.
• WB – Need to clarify clause on internal & external barrier – next meeting

XI. Next Meeting / Housekeeping

The next meeting is scheduled to coincide with the PTI convention to be held in Miami. **Time will be on Sunday, May 3 at 8AM.** Tentatively scheduled for full day.

Meeting adjourned at 12:00 PM.
attachment 1 – meeting attendance
attachment 2 – general meeting slides
attachment 3 – je slides – setra bending provisions

<p>| First     | Last       | Company                     | Status       | Present |
|-----------|------------|                                                                          |--------------|---------|
| Amy       | Dowell     | PTI                         | PTI          |         |
| Miroslav  | Vejvoda    | PTI                         | PTI          | X       |
| Mike      | Schwager   | SDI                         | TAB Contact  | X       |
| Gregory   | Hasbrouck  | Parsons                     | Chair        |         |
| Rachid    | Annan      | VSL                         | Voting       | X       |
| Don       | Bergman    | COWI                        | Voting       | X       |
| Werner    | Brand      | Dywidag                     | Voting       | X       |
| Antonio   | Caballero  | BBR VT                      | Voting       |         |
| Tommaso   | Ciccone    | Tensa                       | Voting       | X       |
| Julien    | Erdogan    | Freyssinet                  | Voting       | X       |
| Christian | Glaeser    | Dywidag                     | Voting       |         |
| Alex      | Gutsch     | MPA Braunschweig             | Voting       |         |
| Hans      | Hutton     | HNTB                        | Voting       |         |
| David     | Jeakle     | McElhanney                  | Voting       | X       |
| Michael   | Kiggins    | Kiewit                      | Voting       |         |
| Christopher | Ligozio | KPFF                        | Voting       | X       |
| Hans      | Lund       | T.Y. Lin                    | Voting       |         |
| Andrew    | Micklus    | Freyssinet                  | Voting       | X       |
| Jose      | Quintana   | Mexpresa                    | Voting       | X       |
| Benjamin  | Soule      | IBT                         | Voting       | X       |
| Steven    | Stroh      | AECOM                       | Voting       | X       |
| Bob       | Sward      | Structural Tech.            | Voting       | X       |
| Habib     | Tabatabai  | UW Milwaukee                | Voting       |         |
| Brian     | Tetzlaff   | T.Y. Lin                    | Voting       |         |
| Joseph    | Tse        | AECOM                       | Voting       | X       |
| Erwan     | Allanic    | IBT                         | Associate    |         |
| Miguel    | Aviles     | Flatiron                    | Associate    |         |
| Yosbany   | Ballate    | Structural Technologies     | Associate    | X       |
| Langston  | Bates      | Bekaert                     | Associate    |         |
| Zhen      | Cai        | Dywidag                     | Associate    |         |
| John      | Crigler    | ST VSL                      | Associate    | X       |
| Quan Gary | Gan        | CTL Group                   | Associate    |         |
| Hans      | Ganz       | VSL                         | Associate    |         |
| David     | Goodyear   | T.Y. Lin                    | Associate    |         |
| Reggie    | Holt       | FHWA                        | Associate    |         |
| Akio      | Kasuga     | Sumitomo Mitsui Construction| Associate    |         |
| Dale      | King       | Bekaert                     | Associate    | X       |</p>
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<th>Role</th>
<th>Guest</th>
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<tr>
<td>Larry</td>
<td>Krauser</td>
<td>GTI</td>
<td>Associate</td>
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<td>Guy</td>
<td>Larose</td>
<td>RWDI</td>
<td>Associate</td>
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## Committee Attendance Sheet

**Committee:** DC-45 Cable Stayed Bridge Committee  
**Date:** November 3, 2019

**Meeting Location:** Disney's Contemporary Resort, Orlando, FL

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*I have read, understand, and agree to comply with PTI Anti-Trust Policy (See reverse).*

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Committee Attendance Sheet

Committee: DC-45 Cable Stayed Bridge Committee   Date: November 3, 2019
Meeting Location: Disney’s Contemporary Resort, Orlando, FL

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PTI POLICY STATEMENT ON COMPLIANCE WITH ANTITRUST LAWS

At a meeting on October 8, 1980, the Board of Directors first discussed the Institute's status and policies regarding compliance with antitrust laws. After review of both the internal and external compliance procedures, the following resolution was approved:

"The staff, officers, directors and members of the Post-Tensioning Institute are reminded that they are required to comply with the spirit and specific requirements of the antitrust laws on all activities within the scope of, and related to, the official functions of PTI. Further, this restated position, along with appropriate explanatory material, should be placed in all meeting folders/books periodically, beginning with the 8th of October meeting of PTI."

On July 24, 2012 and again on October 7, 2015, the Executive Committee authorized Legal Counsel to review and update this Policy Statement in the perspective of the Department of Justice Business Review Letter of July 30, 1997 and current case law. As a continuing guide for your participation in PTI's meetings, please review and continue to adhere to the following "Legal Limitation on Discussions at PTI Meetings."

LEGAL LIMITATION ON DISCUSSIONS AT PTI MEETINGS AND EVENTS

A free exchange of ideas on matters of mutual interest to the members is necessary for the success of all meetings. Indeed, such an exchange of views is essential to the successful operation of every trade association and the law specifically allows legitimate exchange of views pertaining to, e.g., quality control, safety, building design and construction integrity, etc.

It is not the purpose of this memorandum to discourage the exploration in depth of any matters of legitimate concern to meeting participants. Nevertheless, to ignore certain antitrust ground rules, either through ignorance or otherwise, is to create a civil and criminal hazard businessmen simply cannot afford.

It is for these reasons that PTI provides you with a reminder that certain areas of formal and informal communication between competitors or between manufacturers and their suppliers and customers must be avoided, as posing potential antitrust problems.

The Sherman Antitrust Act, the Clayton Act, the Federal Trade Commission Act, and the Robinson-Patman Act comprise the basic federal antitrust laws, which set forth the broad areas of conduct considered illegal as restraints of trade. In general, agreements or understandings between competitors that operate as an impediment to free and open competition are forbidden. Federal antitrust prohibitions forbid any "agreement or understanding...to substantially lessen competition or tend to create a monopoly in any line of commerce." An important point to keep in mind is that communications and discussions between competitors or between sellers and customers, about matters which may be considered anti-competitive, often comprise the evidence from which courts infer antitrust violations. It is the policy of the Post-Tensioning Institute that such agreements, understandings or communications shall not be tolerated at any formal or informal meetings or social events of the Institute.

The general prohibitions contained in the federal antitrust laws, have been particularized in the form of a series of consent decrees, originally entered against a number of member companies of various trade associations and the associations themselves. It is important to note that these laws not only apply to PTI members, but also to PTI itself. Often trade associations have been and are presently co-defendants in cases brought by the Justice Department and the Federal Trade Commission ("FTC"). Recently, the FTC has stated: "Because trade associations are by their nature collaborations among competitors, the Commission and courts have long been concerned with anti-competitive restraints imposed by such organizations under the guise of codes of conduct. Competing for customers, cutting prices, and recruiting employees are hallmarks of vigorous competition. Agreements among competitors not to engage in these activities injure consumers by increasing prices and reducing quality and choice." Similar "codes" or policies and requirements that encourage directly or indirectly members' unlawful activity are strictly forbidden by PTI in the course of its business with its members.
SPECIFIC EXAMPLES OF ACTIVITIES AND PRACTICES PROHIBITED
AT ALL PTI MEETINGS AND EVENTS:

Included in activities and practices which are forbidden, and are contrary to the policy of the Institute, both under the general antitrust laws and the consent decrees, subject to the said Business Review Letter, are the following:

- Agreeing to allocate markets, customers or suppliers among competitors, classify certain customers or suppliers being entitled to preferential treatment by manufacturers, and establish geographic trading areas.

- Participating in any plan designed to induce any manufacturer or distributor to sell or refrain from selling, or discriminate in favor of, or against any particular customer or class of customers.

- Agreeing in any manner to fix or otherwise establish bids, prices (including price increases, decreases, standardization or stabilization), profits, costs, contract terms affecting price (such as discounts and credit terms), etc. because, e.g. prices were too low, with the exception of certain resale pricing agreements between manufacturers and retailers or distributors.

- Agreeing in any manner to limit or restrict the quality of products to be produced (e.g., restrictions on selling coated strand to certain customers).

- Participating in any plan which has the effect of discriminating against, or excluding competitors, suppliers or customers.

These examples are provided to guide you in your discussions during formal and informal PTI meetings and social events. If the occasion arises, more specific advice will be provided by legal counsel, who is required by Article IV, Section 7 of the PTI By-Laws to be present at all meetings of the Board of Directors and the Executive Committee.
PTI Committee on Cable-Stayed Bridges

Orlando, FL, November 3, 2019

New Committee Chair

- Greg Hasbrouck
- Parsons
- 10 S Riverside Suite 400
- Chicago, IL 60606
- Gregory.Hasbrouck@parsons.com
- 312-930-5258
Recognition of former Chair

- We’d like to thank Ben Soule for his commitment and diligence in leading the committee over the last 6+ years

Introductions / PTI Policy

- Fill in the circulating attendance sheet and acknowledge the PTI Policy
- No discussion of pricing or bidding of work
Membership

☐ Please check the web site to verify your status.

☐ Please advise Amy, Miroslav and myself of any future change requests.

☐ Note that for the eighth edition, attendance rules will be in effect for voting. Effectively must attend one meeting a year, or will lose voting status.

☐ PTI membership required

May 2019 Minutes

- May meeting minutes – corrections and adoption

- Vote for approval of minutes from May 2019
Today’s Purpose

- Advancing our four major discussions from the Spring
- Bending Stress – moving forward
- Filler Tests – cleanup required, drafting changes
- HDPE – we have not stayed current on the ASTM references
- Monitoring – drafting white paper
- Administrative assignments status

Administrative Projects

- Provide US or Dual units
- Have gotten feedback for most chapters.
- No Voting required for adding dual units
- Next steps – assemble feedback and draft markup
Administrative Projects

- We have tons of storage on the committee page!
- Last meeting we assigned names for every reference in the back
- Status of finding references
- Follow up emails?

Bending Fatigue Project

- Gather data on existing projects – worst typical stay
- Stay angle range (max and min relative to deck)
- Fatigue cycles (# of design cycles)
- Fatigue angle range (zero to peak, + LL & -LL angle)
- Fatigue bending stress (if available)
- Strength angle range (+ and - )
- Strength bending stress (if available)
- Service angle range (if available)
- DL tension stress (typ. stay, specify range)
Bending Fatigue

- The dream – to establish a testing regime that will allow us to remove design checks of bending entirely for qualified systems.

- fib is replacing the design for bending by a test which removes the need for the calc check

- The reality – the test that is in fib is inherently limited. What conclusions for design are we willing to draw from the data we get from the tests?

Background - fib

System using free deviator

System using guiding device

System using clevis anchorage
Bending Fatigue

- **Background – fib**
  - First fatigue loading phase: 100,000 bending fatigue cycles with an angular deviation of $\alpha = \pm 25$ mrad.
  - Second fatigue loading phase: 2 million bending fatigue cycles with an angular deviation of $\alpha = \pm 10$ mrad.

- Axial load is a constant 45% GUTS.
- Strength and leak tests are performed after the fatigue phase.
- There is no angle break during this test.

Bending Fatigue

- **Fib – Design**
  
  The cable rotations at the anchorage and saddle exit shall be calculated. When using cable systems designed and tested in accordance with these recommendations, fatigue angular deviations applied at the anchorage or saddle up to $\pm 0.6^\circ$ ($\pm 10$ mrad) with 2 million cycles and service angular deviations up to $\pm 1.4^\circ$ ($\pm 25$ mrad) with 100,000 cycles are covered by the system design and testing, and do not need to be considered in the design by the Designer, see Chapter 6. In consequence, it is not required to add bending stresses to axial stresses. The same principle can be applied to extradosed cable systems subjected to fatigue and service angular deviations up to $\pm 0.6^\circ$ ($\pm 10$ mrad).

- External to fib – Euronormes apply a factor of safety of 1.25.
- **fib** discussion is to remove this 1.25 factor of safety.
Bending Fatigue

Questions

- Why is 2M cycles enough?
- How do you correlate 2M @ 10mrad to a demand of 10M @ 5mrad
- Curve established for axial
- No curve established for bending, just one point
- Sources of bending – misalignment, live load cycles, wind load cycles

Current Situation

- Void in knowledge for determining bending stresses
  - Dependent on detailing, axial stress, effectiveness of filtering
- No S/N Curve for bending
- Do not know how shim in fib test correlates with actual demand on bridge
- More of a robustness test
Bending Fatigue

- SETRA – Bending Stress Provisions approach
- Julien to present

Bending Fatigue

- Are any SETRA provisions worth adopting?
- Do they solve any of our concerns?
- Action items?
Bending Fatigue

Background – PTI

4.2 – Acceptance testing of stay cables

Stay cable specimens shall have a minimum length of 3.5 m. The anchorage(s) of the stay cable specimen shall be supported on wedge-shaped shims plates, creating angular deviations of 0.01 radians, and oriented such as to create an S-shaped cable profile. After fatigue loading, the test specimen (except the specimen used for corrosion testing) shall be reloaded, with the wedge-shaped shim plates remaining in place, and shall develop a minimum tensile force equal to 90% of the ultimate tensile strength of the cable or 95% of the ultimate tensile strength of the cable, whichever is greater.

5.3.3 – Resistance factors

For the limit states referred to in Table 3.4.1-1 of AASHTO LRFD, the following resistance factors shall apply:

- Strength A - Axial Only $\phi = 0.65$ to 0.75 per diagram Fig. 5.1
- Strength B - Axial and Bending combined $\phi = 0.78$
- Extreme Event $\phi = 0.95$
- Fatigue $\phi = 1.0$

Both a pure axial and a combined axial plus bending condition are to be checked and the phi factors set for each stay once for the entire project; phi factors do not vary by load case. The bending case shall be checked for all angular deviations of the stay element as a unit, including construction tolerances for stay assembly. Angular deviations of strands within stay anchorage assemblies are addressed through the stay anchorage fatigue performance testing, and are not added to the deflections of the general stay element.

Maximum resistance factor for extreme limit state is 0.95 to reflect minimum strength requirements for qualification of anchorage design in Chapter 4. At the strength limit state only, the combination of axial plus bending effects may be based on an interaction diagram for the MFE that considers strain compatibility for net curvature strains on the element. At the fatigue limit state, elastic bending and axial stresses should be added directly.
Bending Fatigue

- Background – PTI

5.3.4 — Bending effects—free length
Bending stresses in stay cables shall be monitored or calculated and combined with the axial stresses for the verification of the design limit states, Eq. (5-2).

Bending stresses shall be calculated from the stay cable curvature (1g) determined for a cable under the design axial force and with flexural stiffness as follows:

$$f = (1/g)ry$$ (5-2)

Where:
- $r$ is the relevant distance of the strand extreme fiber to the neutral axis for bending and
- $y$ is the local radius of curvature in the cable at the local detail being examined.

C5.3.4 — Bending effects—free length
The intention of this provision is to include local bending stresses in the axial limit states, rather than to establish limit states for axial-flexure interaction.

Bending stresses typically occur near anchorages, saddles, and attachments to the stay cables which impose some lateral displacement. Bending effects in anchorages are considered by testing and anchorage design by the stay system supplier in Sections 4.2 and 5.3.4.1, respectively.

5.7.2.3 — Cable bending stresses
Cables shall be sized such that the bending stress, when added to the other service stresses acting along the saddle do not exceed the limits given in Section 5.3.

Bending stress from curvature may be determined by the expression in Eq. 5-2, where $y$ is the radius of the saddle bend.

A bundle is considered bent as a unit only in the case where sections remain plane during bending. This is generally not the case with saddle cables, since most cable assembly is performed strand by strand.
Bending Fatigue

- Background – PTI (0.3 deg ~ 0.005 rad)

---

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 = 2.5% 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 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 0.3 degrees (+/-) of the planned pipe alignment. Materials and fabrication requirements shall be consistent with strength and fatigue demand requirements.

---

Bending Fatigue

- Question – should we fix our current language to accurately capture the interface between designer and supplier?

- Similarly, should we address the formula for bending stresses, given that the radius is rarely known, and the effective diameter of the strand debatable?

- Introduce Setra formula as a fallback?
Bending Fatigue

- Single element basis – largely Winkler tests.
- What do we know, and how valid are these tests?
- Need to develop better understanding of the state of knowledge on bending fatigue
- Action item to get Winkler to come to Miami – Antonio to contact Winkler?

Bending Fatigue

- What is our current buffer for axial, and what can that tell us?
- Length effect is not relevant, as the effects are generally localized.
- What is left? Current 35MPa is about 22% below tested value.
- What level is even useful? This is why project data is helpful. No benefit in setting a line that captures zero bridges.
Bending Fatigue

- How can we relate a strength criteria to a service test?
- There is no way to extrapolate from the current test to a higher value.
- At a minimum, we should be sure that we do not yield the strand, or if we do, that we then test the resulting fatigue life.
- 65% axial plus 25mrad bending may well yield the strand.

Bending Fatigue

- Do we need production tests of the strand itself?
- What should that test look like? Should it match the current basis for the fatigue curve in bending only?
- Does this unconservatively ignore fretting?
- How to prove the sheathing can take the number of bending cycles and not break leading to corrosion / durability issues
Bending Fatigue

- Should we worry about low-amplitude high cycle effects, primarily wind?
- Seems that this depends on our confidence in an infinite fatigue life.
- No matter what, it is not currently possible to design around a wind rotation or cycle #

Bending Fatigue

- Options – from previous meeting
  - 1 – Stick with current philosophy and improve (add SETRA formula, etc.)
  - 2 – Establish S/N curve for each system as a design tool
  - 3 – Establish the current fib test and establish safe design limits from this
Bending Fatigue

- Action Plan from last meeting
- Draft rewrite of existing provisions (Julien)
- Contact Winkler to present (Antonio)
- How to integrate fib style test in PTI specifications
- Understand delta on axial fatigue limits – safety buffer assessment (Morgan)
- SN Curve / Theory (Gary)
- Gather data on existing bridges (Designers)

Filler Test

- Watertightness test:
  - Production test run by manufacturer. It is not required but the water test is strongly recommended
  - Issues with practicality
  - Issues with reliability
  - Historically, test passes at factory but does not pass on site
  - It is also in Section 3.3.2.1 as part of quality control
Filler Test

- **Purpose of test**

- Quality test to ensure that the sheathing is filled with wax at the factory.
- It is not done to check that voids don’t appear over time, after the strand is coiled for a year for example.
Filler Test

3.3.9 — Performance tests for individually sheathed polyethylene or polypropylene strand

The Contractor shall furnish to the Engineer, a test report prepared by an independent laboratory documenting compliance with Items A through E below. HDPE or MDPE sheathed strand shall meet the following requirements:

A. Chemical resistance test — The chemical resistance of the sheathing shall be evaluated in accordance with ASTM D25—Standard Test Method for Chemical Resistance of Pipeline Coatings, by immersing coated strands in each of the following: a 3M (Molar) aqueous solution of Ca(OH)₂, a 3M (Molar) aqueous solution of H₂SO₄, and a solution saturated with Ca(OH)₂. In addition, to simulate cementitious grout, an aqueous solution of potassium hydroxide and an aqueous solution of sodium hydroxide shall be utilized for this test. Tests with specimens without damage to the sheathing and specimens with internal 6 mm diameter holes drilled through the sheathing shall be performed at 24 ± 2°C. Minimum test time shall be 45 days. The polyethylene must not:

F. Watertightness Test — The stay cable supplier shall propose a watertightness test to the approval of the Engineer. One test of the void filling manufacturing process of the sheathed strand as per the approved test procedure shall be carried out per production run or portion thereof.

C.3.9.9 — Performance tests for individually sheathed polyethylene or polypropylene strand

These requirements are adapted from ASTM A802/A802M.

For tests A through E, results from previous tests taken at the Engineer’s discretion, be accepted for a current project in consideration of the length of time needed to complete these types. Information should be provided to the Engineer to demonstrate that the materials and procedures proposed for the current project are representative of those tested.

For Test F, one such test is the Static Watertightness Test set forth in the French Standard NF A35-017-2 and described below:

The test consists of an imposed load of water on the end of a test piece of the delivered product. (see Fig. C.3.9.9) and to measure the mass change of the test piece after a given time and the product quantity obtained at the other end.

The length of the test piece is equal to 1 m. It is weighed before the test. The balanced load for weighing shall be equal at least within +0.5 g.

COMMENTARY

After testing, the mass variation of the test piece and the quantity of product obtained at the beaker shall be equal to zero.

Figure C.3.9.9 test

Filler Test

Fig. C.3.9 — Static watertightness test. (Note: 1 is division; 2 is water; 3 is seal; 4 is HDPE or MDPE sheath; and 5 is beaker.)
Filler Test

- Results from Seattle:
  - Debate inconclusive
  - No desire to remove the water test
  - Air test is a production test

Filler Test

- Proposal from Seattle:
  - Maintain water test in 3.3.9 as a qualification test; define frequency
  - Keep the air test in 3.3.2 as a production test; define high frequency
  - Develop draft language (Bob)
Filler Test

- Additional Assignments

Break
DSI Recommendations to discuss:

3.3.2 is addressing the application – here we should delete the reference to PTI M10.2-17 – see yellow marking.

3.3.2 -Application of corrosion-inhibiting coating

The amount of corrosion-inhibiting coating used shall be sufficient to ensure essentially complete filling of the annular space between the strand and the sheathing and between the wires. The coating shall extend over the entire strand length.

The performance specification for the corrosion inhibiting coating shall comply with the requirement of Table 2.2.2.1 from the PTI M10.2-17, "Specification for Unbonded Single Strand Tendons."

Reason:

PTI M10.2-17 is dealing with Monostrands for unbonded PT! There a grease is used and specified. For stay cable strands usually a wax is being used. Grease may de-oil and is not usually not used for stay cables!
Filler Material

- DSI Recommendations to discuss:
  - 3.3.8 is specifying the material – here we also should delete the reference to PTI M10.2-17 and should update the reference to fib Bulletin 89 Section 5.5.
  - Also the wording “approved testing laboratory” should be reviewed. Who will approve the laboratory and according to which standard? Maybe just “independent” laboratory?

- 3.3.8 - Corrosion-inhibiting coating material
  The corrosion-inhibiting coating material shall have the following properties:
  - Provide corrosion protection to the prestressing steel.
  - Resist flow from the sheathing within the anticipated temperature range of exposure including the temperature of the manufacturing process of the sheathed strand.
  - Provide a continuous non-brittle film at the lowest anticipated temperature of exposure.
  - Be chemically stable and nonreactive with the prestressing steel and the sheathing material or any other material it is permitted to come in contact with as part of the stay.

Tests for the corrosion-inhibiting coating shall meet the requirements of Table 2.2.2.1 of the PTI M10.2-17 "Specification for Unbonded Single Strand Tendons" or the provisions of fib Bulletin 30, Section 5.6, and be conducted by a qualified approved testing laboratory. All test data shall be furnished to the Engineer for approval prior to shipment of the strand.
Filler Material

☐ C3.3.8 - Corrosion-inhibiting coating material

This section is based on PTI M10.2, "Specification for Unbonded Single Strand Tendons."

The tests for corrosion-inhibiting material are considered to be baseline tests to ensure that minimum corrosion protection properties of active blocking agents are provided. New developments of materials may not meet some of these test requirements, and in such case, other and more comprehensive tests or review of the acceptance criteria may be necessary to ascertain their adequacy.

Filler Material

☐ PTI M10.2-17, “Specification for Unbonded Single Strand Tendons” Table 2.2.2.1
Filler Material

- Should we be replacing PTI M10.2-17, “Specification for Unbonded Single Strand Tendons” with something instead of just deleting?
- Addendum?
- Action Items

HDPE Requirements for Pipe

- Stay pipe requirements are in Section 3.5.3.2 with 2 cell classes permitted. Table 3.3 data in not consistent with the classes specified in 3.5.3.2.
HDPE Requirements for Pipe

3.5.3.2 — Material specifications
A. HDPE pipe material shall meet the specific cell category requirements for class PE 325443 and class PE 345444 materials as defined by Table 1 of ASTM D3350. The resultant acceptable range of primary properties for these HDPE materials is as shown in Table 3-3.

Table 3-3 — Acceptable properties of high-density polyethylene pipe material

<table>
<thead>
<tr>
<th>Property</th>
<th>ASTM test method</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density, g/cm³</td>
<td>D1505</td>
<td>&gt;0.940</td>
</tr>
<tr>
<td>Melt index, g/10 minutes</td>
<td>D1238</td>
<td>0.35 to 1.4</td>
</tr>
<tr>
<td>Flexural modulus, MPa</td>
<td>D790</td>
<td>&gt;750</td>
</tr>
<tr>
<td>Elongation at break test (at 23°C, test speed 50 mm/minute)</td>
<td>D638</td>
<td>350%</td>
</tr>
<tr>
<td>Tensile strength at yield, MPa</td>
<td>D638</td>
<td>&gt;21</td>
</tr>
<tr>
<td>Environmental stress crack resistance (F20, hours)</td>
<td>D1693       (Cond C)</td>
<td>600</td>
</tr>
<tr>
<td>Max hydrostatic design basis as applied to filled pipes only, MPa</td>
<td>D2837</td>
<td>8.6 to 11.03</td>
</tr>
</tbody>
</table>

Note 5 — The manner in which materials are identified in the cell classification is illustrated for Class PE233424B as follows (refer also to Table 1 and 6.2):

- Class 2
- Class 3
- Class 4
- Class B
- Density (0.926—0.940 g/cm³)
- Melt Index (<0.4—0.15)
- Flexural Modulus (276—552 MPa)
- Tensile Strength at yield (21—24 MPa [3000—3500 psi])
- Slow Crack Growth Resistance
  - I. ESCR D1693
  - II. PENT F1473
- Average 1 h failure
- Hydrostatic design basis at 23°C (11.03 MPa [1600 psi])
- Color and UV stabilizer (colored)
HDPE Requirements for Pipe

Assignments:
- Get an expert speaker to present HDPE properties and what is relevant:
  - Cell class
  - Significance of the properties
  - What is available and can be supplied
- TG: Jacob, Chris, Freyssinet, Alex
Performance Monitoring

- White paper by Ligozio, LaRose, Soule
- Brainstorming – Owner Actions, Measurable Data, connections

Reports From the Field

- Problems, errors, issues so far with new edition?
- ASTM on galvanized strand?
Next Meeting

- PTI Conference – Tentative Date May 3, 2020
- Miami, FL
- Duration?

Bending Fatigue

- Background – PTI
- What do we do now for axial?
- There are two main goals:
  1. **Avoid direct fatigue failure**
  2. **Ensure adequate strength at the end of a fatigue life.**
Bending Fatigue

- Background – PTI

- This is why our tests are set up as they are – the fatigue portion of the test directly demonstrates fatigue capacity, and then the following strength test shows the remaining capacity.

- Why do we have the test values that we do?

<table>
<thead>
<tr>
<th>Allowable Stress Range (ksi)</th>
<th>For 100,000 cycles</th>
<th>For 500,000 cycles</th>
<th>For 2,000,000 cycles</th>
<th>For Over 3,000,000 cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A-1L</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ASMEF Category A (redundant)</td>
<td>50</td>
<td>32</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>ASMEF Category B (redundant)</td>
<td>60</td>
<td>36</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>ASMEF Category A (nonredundant)</td>
<td>45</td>
<td>27.5</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>ASMEF Category B (nonredundant)</td>
<td>36</td>
<td>24</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Committee 215, CR 250 (1)</td>
<td>27*</td>
<td>27*</td>
<td>27*</td>
<td>27*</td>
</tr>
<tr>
<td>Committee 215, CR 270 (1)</td>
<td>27*</td>
<td>27*</td>
<td>27*</td>
<td>27*</td>
</tr>
<tr>
<td>Committee 215, CR 250 (2)</td>
<td>10*</td>
<td>10*</td>
<td>10*</td>
<td>10*</td>
</tr>
<tr>
<td>Committee 215, CR 270 (2)</td>
<td>10, 8*</td>
<td>10, 8*</td>
<td>10, 8*</td>
<td>10, 8*</td>
</tr>
</tbody>
</table>

*Committee 215 does not differentiate between number of cycles in its design recommendations.
Bending Fatigue

- Background – PTI
- These values were reduced on the basis of the Birkenmaier paper (ref 46). This is based on the % fractile values for a large number of strands in a single stay – effectively bounding the fatigue life with a 5% fractile curve.

So – how does this relate to design? Two major things.

- The axial stress allowed in the strand is limited to the peak stress in the fatigue test. This was 45% GUTS in service, but has been increased for strength. 0.65/0.45 = 1.44.
Bending Fatigue

- Then the calculated fatigue stress is limited to a value below the test. This is the $\Delta 2$ in the figure below.

---

So what is $\Delta 2$? Combines “length effects, anchorage riser, safety”.

- Length effect is a statistical effect, in that a chain is only as strong as its weakest link (Stallings, ref 9).
- Anchorage riser ??? Possibly an installation tolerance.
- Safety – generally thought to be based on the low number of test samples.
Bending Fatigue

**Then lower line in figure C3.1 is then turned into the design limits for fatigue.** The baseline value is the infinite design life, and the formula is based on the design cycles. Gives the reduced values from the tests.

\[ B = \left( \frac{A}{N} \right) \]

\[ A = \text{constant (see Table 5-1)} \]
\[ N = 365 \text{ days} \times N_y \times 1 \text{ cycle} \times (ADTT)_{dl} \]
\[ (ADTT)_{dl} = \text{Average daily truck traffic in one direction and in one lane} \]
\[ N_y = \text{Design life of cables in years} \]

<table>
<thead>
<tr>
<th>Table 5-1—Fatigue constants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of stay</td>
</tr>
<tr>
<td>Parallel strands</td>
</tr>
<tr>
<td>Parallel wires</td>
</tr>
<tr>
<td>Uncoupled bars</td>
</tr>
<tr>
<td>Epoxy-coated bars</td>
</tr>
</tbody>
</table>

Bending Fatigue

- Are we able to follow a similar path for bending? Some relevant questions are:
  1. What is the single-element fatigue curve? Is it reliable enough? Should it be expanded?
  2. What are the relevant offsets that we should apply for an anchorage test? Is this all a function of angle?
  3. Do we need quality control bending fatigue tests of single strands?
  4. Should we put in a hard limit that will prevent strand yield at Strength?
Bending stress provision:
Overview of SETRA approach

PTI – DC 45: Cable Stayed Bridge Committee
2019 Fall Meeting

1. SETRA CIP BACKGROUND
   1. CIP general considerations
   2. Cable stay bending (§ 6.)
   3. Cable stay design and verification rules (§ 14.)

2. CHAPTER 6. Cable stay bending
   1. Parameters of the bending stress calculation in stay cable
   2. Cable flexural stiffness at the anchorage
   3. Bending fatigue

3. CHAPTER 14. Cable stay design and verification rules
   1. General considerations
   2. Cable stay strength (§14.3)
   3. Ultimate limit states (§14.4) & Serviceability limit states (14.5)
   4. Verification of fatigue (§14.6)
**Background: Setra stay cable recommendation 1/2**

- **Document reference:**
  - « Cable stays. Recommendations of French Interministerial Commission on Prestressing »
  - Also known as « CIP recommendations on cable stays »

- Dated 2001, french version; 2002 for english version

- Covers MLS / PWS / PSS stay cables & durability aspects, technology evolution background, system description (anchorage, free length)

- CIP divided into 4 parts
  - Part 1 ($§2$. to $§8.$), Review of current scientific knowledge with substantiation of recommended choices
  - Part 2 ($§9$. & $§10.$), Cable-stay systems description with recommendations on durability
  - Part 3 ($§11$. to $§13.$), Qualification test, installation, maintenance & monitoring recommendations
  - Part 4 ($§14.$), Cable stay design & verification rules

**Background: Setra stay cable recommendation 2/2**

- CIP presents stay cable background
  - Evolution of cable technology from MLS to PSS
  - Challenges of durability
  - Description of main components (anchorage & free length)

- CIP describes behaviour of stay cables
  - Static & dynamic
  - Stay cable bending & vibration
  - During construction & service

- CIP gives recommendations for
  - Qualification testing for material & system
  - Installation, maintenance & monitoring
  - Cable stay design & verification rules
1. Parameters for bending stress calculation in stay cable

Bending stress at a saddle location

For a saddle of radius \( R \), with curvature of \( 1/R \), the bending moment set up in the cable is simply

\[
M = EIR^2R, \quad \text{where } I = \text{moment of inertia of the sectional area of the cable.}
\]

The flexural stress in the outer fibres of a cable of radius \( r \) is therefore (in absolute terms):

\[
\sigma = \frac{1}{r} \left( \frac{EIR^2R}{R} \right) \quad \text{(68)}
\]

- Stress values given for typical cables (MLS / PWS / PSS)

6.1.2 Orders of magnitude

Cable-stay saddles generally have a radius of about 3 to 5 m. The minimum diameter of the wires used in cable stays is about 5 mm. The equivalent diameter of seven-wire strand is about 10 mm. Multi-layer strands generally have a diameter of about 50 mm. The modulus of elasticity of wires is 200 GPa, that of strands 195 GPa, and that of a multi-layer strand can be estimated to be 155 GPa. The following maximum flexural stresses (in MPa) are deduced from these figures:

<table>
<thead>
<tr>
<th>Saddle radius (m)</th>
<th>2.5</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mm dia. wire</td>
<td>200</td>
<td>167</td>
<td>125</td>
<td>100</td>
</tr>
<tr>
<td>15 mm dia. strand (T15)</td>
<td>390</td>
<td>325</td>
<td>244</td>
<td>195</td>
</tr>
<tr>
<td>50 mm dia. multi-layer strand</td>
<td>1650</td>
<td>1375</td>
<td>1031</td>
<td>825</td>
</tr>
</tbody>
</table>

CIP acknowledge these values are not satisfactory (to conservative) and do not reflect the necessary wire re-arrangement phenomenon which occurs;

CIP proposes alternative approaches to take into account inter wires friction and slippage, detailed 6.4.
1. Parameters for bending stress calculation in stay cable

- Acknowledgement of necessity to consider impact of inter wire contact in flexural stress reduction

  => impact of:
  - friction / slippage
  - lip-stick behaviour
  - radial pressure

Whatever the saddle radius and the MTEs used, these flexural stresses are considerable, and often higher than the stress variations in cable stays due to imposed loads. The particularly high values for multi-layer strand—close to the elastic limit of the steel of which the wires are made—evidence the need for rearrangement of wires, which can reduce these flexural stresses somewhat but which can also be accompanied by wear.

At the very least, therefore, bending should be taken into account when substantiating the design of cable stays deviated over a saddle (see Chapter 14). In addition, radial pressure plays a leading role in contact between wires, as is described in Article 6.4.

1. Other important parameters in cable bending calculation

- Type of anchorage => with or without guiding ahead of the anchorage
- Type of cable’s main tensile element (MTE) => monolithic section behaviour / inter-wire slippage
- Initial stress in MTE before bending => behaviour of stay cable bending & vibration
- filler material, inter-wire friction & contact stress => fretting fatigue & fretting corrosion

- Significant data provided for cable bending and fatigue, in particular following research works:
  - LCPC (IFSTTAR) works on bending fatigue through crack initiation of fatigue crack, supported by experimental works of P.BREVET and D.SIEGERT, as well as PATZAK and WATERHOUSE
  - M.RAOOF works on bending fatigue through contact-slip parameter approach
2. **Cable flexural stiffness at the anchorage**

- Necessity to consider the cable flexural stiffness at its anchorage for taking into account angular deviation coming from:
  - Installation error (position and/or orientation)
  - Cable vibration (the ones causing variable rotation)
  - Rotation of anchorage due to structure displ. (caused initial stress in MTE before bending)
  - Overtension in cable due to Live loads (impact on sag and related angular deviation at anchor)

- **Bending in a cable without guiding ahead of the anchorage**

\[
M(x) = EI \frac{d^2 y}{dx^2} = F y 
\]
\[
M(x) = M_{\text{max}} \exp(-kx) 
\]

With \( M_{\text{max}} = \sigma_{\text{r}} \sqrt{EI} \) \( k = \frac{F}{\sqrt{EI}} \)

![Figure 18: Bending of a cable without guides ahead of the anchorage](image)

---

2. **Overtension in cable without guide** for a given angular deviation:

- Greatest flexural stress concentrated at cable outer fibers, calculated as:
  \[
  \sigma_{\text{max}} = \frac{M_{\text{max}}}{I/r} = \sigma_{\text{r}} \sqrt{\frac{E}{F}} 
  \]

- Inertia value depends on the type of cable, particularly on whether its MTE can slide over each other or not in service condition
- In practice actual cable behaviour lies between two extreme behaviour: monolithic cable and parallel-wire cable

1. **Conservative case of Monolithic cable**:

   Max flexural overtension at anchor

   Characteristic length of overtension prevailing

   \[
   \sigma_{\text{max}} = 2\sigma_{\text{r}} \sqrt{\frac{E}{F}} 
   \]

   \[
   l_c = \frac{\sqrt{\frac{E}{F}}}{\frac{r}{2}} \sqrt{\frac{E}{2\sigma_r}} 
   \]

2. **Case of cable with separate parallel MTE**:

   \[
   \sigma_{\text{max}} = 2\sigma_{\text{r}} \sqrt{\frac{E}{F_{\text{net}}}} = 2\sigma_{\text{r}} \sqrt{\frac{E}{2\sigma_r}} 
   \]

   \[
   l_c = \frac{\sqrt{\frac{E}{F_{\text{net}}}}}{\frac{r_{\text{net}}}{2}} \sqrt{\frac{E}{2\sigma_r}} 
   \]
2. Cable flexural stiffness at the anchorage

Overtension in cable without guide for a given angular deviation:

Order of magnitude: 1770 MPa class - 37 strands units cable, tensioned at 40% GUTS, $\omega = 10$ mrad

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>Mean stress $\sigma$ (MPa)</th>
<th>Angle of deviation $\omega$ (mrad)</th>
<th>Overtension $\sigma_{\text{max}}$ (MPa)</th>
<th>Characteristic length $l_c$ (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monolithic cable</td>
<td>200</td>
<td>708</td>
<td>10</td>
<td>238</td>
</tr>
<tr>
<td>Separate strands</td>
<td>15</td>
<td>708</td>
<td>10</td>
<td>238</td>
</tr>
<tr>
<td>Parallel wires</td>
<td>5</td>
<td>708</td>
<td>10</td>
<td>238</td>
</tr>
</tbody>
</table>

1. High curvature overtension (238 MPa), same level of magnitude as stress variation due to imposed loads (LL)
2. Identical overtension for monolithic cable and cable made of parallel MTE
3. Different characteristic length of overtension prevailing for monolithic cable and cable made of parallel MTE

2. Cable flexural stiffness at the anchorage

Bending in a cable without guiding ahead of the anchorage

at anchorage

$$M_A = \frac{k l - \sinh k l}{2 + k/(\exp k l) - 2 \cosh k l - \sinh k l} = \beta_A M_{\max} \quad (77)$$

at guide

$$M_0 = M_A \frac{k/(\cosh k l) - \sinh k l}{k l - \sinh k l} = \beta_G M_{\max}$$

with

$$\beta_G = \frac{k/(\cosh k l) - \sinh k l}{2 + k/(\exp k l) - 2 \cosh k l - \sinh k l} \quad (78)$$

1. Significant reduction of bending moment at anchorage (>80% for $k.l > 3$)
2. However reduction of bending moment limited at 50% at guide location
3. Importance of guide position
3. Bending fatigue

- Reference to many cable bending-fatigue test carried out to correlate fatigue life to bending moment due to angular deviation:

  1. No single correlation between fatigue bending load and nb of cycle to fracture the 1st or 2nd wire
  2. Flexural stress or maximum bending moment not the main parameter determining the fatigue life of cable stay
  3. Fretting corrosion & fretting fatigue resulting from contact on wires have greater effect on fatigue life

- Evidenced in multi-layer strands fatigue tests for which the 1st wire failure occurs near the mean fibre, not in the outermost layer, where there is combination of
  - Inter-wire sliding maximum amplitude which initiate cracks
  - Bending which propagates the cracks

- 2 approaches are detailed to describe these phenomena
  1st approach: Contact stress-slip parameter (§ 6.4.2)
  2nd approach: Initiation of fatigue cracks (§ 6.4.3)

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CIP Chapter 6. Cable stay bending

3. Bending fatigue

1st approach: Contact stress-slip parameter (§ 6.4.2)

- Bending-fatigue curve established by M.RAOOF, published in Design of Steel Cables against Free-Bending Fatigue at Terminations The Structural Engineer, volume 71/n° 10/18 May 1993, pp. 171-178

- Calibrated on numerous experimental results of multi-layer strands made of 3,5 mm wires

- RAOOF uses the « contact stress – slip » parameter \( \sigma_x \frac{U}{X} \), where
  - \( \sigma_x \), tensile stress engendered by friction
  - \( U \), magnitude of relative displacement between 2 successive layers at mean fibre
  - \( X \), distance between 2 contact points on the wire

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3. Bending fatigue

1st approach: Contact stress-slip parameter (§ 6.4.2)

Graph 4: correlation between contact stress-slip and number of cycles to second wire fracture

1. Correlation between contact stress-slip parameter and nb of fatigue cycle to 2nd wire fracture
2. Cable fatigue limit at 10 million cycles corresponds to contact stress-slip value of 0.10 MPa

2nd approach: Initiation of fatigue cracks (§ 6.4.3)

• Developed at LCPC (IFSTTAR) by BREVET and SIEGERT
• Applies to multi-layer or 7-wire strands
• Based on fatigue crack initiation criteria adapted to fretting fatigue
• Uses the fatigue-strength characteristics of the wire of which strands are made
  (wire fatigue limit & wire compliance factor, k)

• Crack initiation criterion based on
  \[ \sigma_{\text{dri}} \quad \text{stresses generated at wire surface due to the driving force} \]
  \[ \sigma_f \quad \text{pure flexural stress} \]
  Cracks are initiated if for any point beneath inter-wire contact, \( \sigma_{\text{dri}} + \sigma_f \) exceeds the fatigue-strength characteristics

• Crack propagation criterion based on
  Maximum depth within wire at which the crack is initiated
  Assessment of the geometrical concentration of stress at the base of the crack.
CIP Chapter 6. Cable stay bending

3. Bending fatigue

2nd approach: Initiation of fatigue cracks

Experiments show that
1. For multi-layer strand loaded at 50% of GUTS, the 100 million cycle fatigue limit is 100 Mpa
2. For shorter lifetime involving contact fatigue, the fatigue strength at 2 million cycles (50% GUTS), can attain 150 MPa

These values do not consider inter-wire friction reduction and contact pressure reduction due to galvanization or lubricant

CIP §14. Cable stay design & verification rules

1. General considerations

- Cable-stay design based on limit state verification with partial safety factors

- To simplify matters, design of straight cables essentially considers stresses due to axial tension…
  But bending forces applied at straight cable anchorages are considered in the design and verification rules

- in case bending force reduction disposition (as detailed in §12) are implemented,
  angular deviation introduced in the mechanical test covers the bending forces at the anchorage of a straight stay cable in common cases.

- In some special cases, closer verification of the effect of stay cable vibration might be necessary

- For non straight cables the situation is different and the partial safety factor must be specially adapted.
CIP §14. Cable stay design & verification rules

2. Stay cable strength

- 2 partial safety factors are applied on cable strength ($F_{GUTS}$):
  - $\gamma_{m1}$ covering differences between qualification test conditions and actual use of the cable stay in the structure
  - $\gamma_{m2}$ covering uncertainties of construction and of cable stay ageing (in particular effect of bending at anchorage)

- $\gamma_{m1} = 1.15$ if qualification tests fulling compliant with procedure described in § 11. (in particular angular deviation)
  - $1.20$ if fatigue test performed without angular deviation but others compliant with § 11.
  - $1.30$ other cases

- $\gamma_{m2} = 1.25$ if necessary precaution taken to limit flexural forces at the ends of cable stays
  - $\geq 1.30$ when significant flexural forces can reach the anchorage, value to be adapted to the residual flexural stress

- § 14.3.2.2
  For $\gamma_{m2}$ in case special detailing used to limit flexural forces, the residual flexural force reaching the anchorage (wedge) should be assessed according § 6.
  If residual flexural stresses are lower than 50 MPa, these flexural stresses can be neglected.

3. ULS and SLS

- **ULS**
  \[ F_{ULS} \leq \frac{F_{GUTS}}{\gamma_{m1} \gamma_{m2}} \]
  In case necessary precautions are taken to limit flexural forces at anchorages and qualification test carried out as per § 11., $\gamma_{m1} = 1.15$ and $\gamma_{m2} = 1.25$, then during service condition (ULS) tension of a cable stay should satisfy
  \[ F_{ULS} < 0.70 F_{GUTS} \]

- **SLS**
  if recommendation § 14.3.2.2 is applied to limit flexural forces at anchorages and related fatigue, then during service condition (rare SLS) tension of a cable stay should satisfy:
  \[ F_{SLS} < 0.50 F_{GUTS} \]
  In other cases, it should satisfy
  \[ F_{SLS} < 0.45 F_{GUTS} \]
4. Verification of fatigue

- Cable stay fatigue damage occurs at anchorages, resulting of:
  1. varying axial load
  2. repeated bending caused by angular deviation at the anchorages

- However importance of angular deviation effect on fatigue strength of cable stays and difficulties in quantifying it has led to make provision for eliminating the greater part of the effects of localized bending through 3 main provisions:
  - Cable guide systems near anchorages
  - Cable-stay vibration damping
  - Limitation of permanent angular deviation at anchorages

- When provisions described in § 14.3.2.2 are implemented (residual flexural stress < 50 MPa), the structure's fatigue strength is guaranted if the 2 conditions are met:
  1. Cable system qualified by testing as per §11.
  2. Cable stays designed no to be excessively sensitive to fatigue

- Condition N°2 involves verifying only the axial stresses in the stay cable under axial fatigue loading

Justification for the simplified fatigue verification (§14.6.3)

- This simplified verification is valid only for straight cables (not for saddle, nor when project constraints do not allow implementation of bending limitation systems)

- § 14.3.2.2 Simplified fatigue verification call for a partial safety factor $\gamma_{mf}$ applied on fatigue strength of the cable.

$$\Delta\sigma_{\text{LM3}} \leq \frac{0.52 \Delta\sigma_{\text{TEST}}}{\gamma_{mf}}$$

In practice the fatigue verification of a road-bridge cable stay consists in limiting the tensile stress range due to the LM3 traffic load to 70 MPa.