

Project 0-1264, Corrosion Protection of Cable-Stay Systems [Presentation Slides]

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"Corrosion Protection for Post-Tension Tendons and Cable Stay Systems"

Sponsoring Agency: Texas Department of Transportation

Performing Agency: University of Texas at Austin. Center for Transportation Research

Report Date: August 1993

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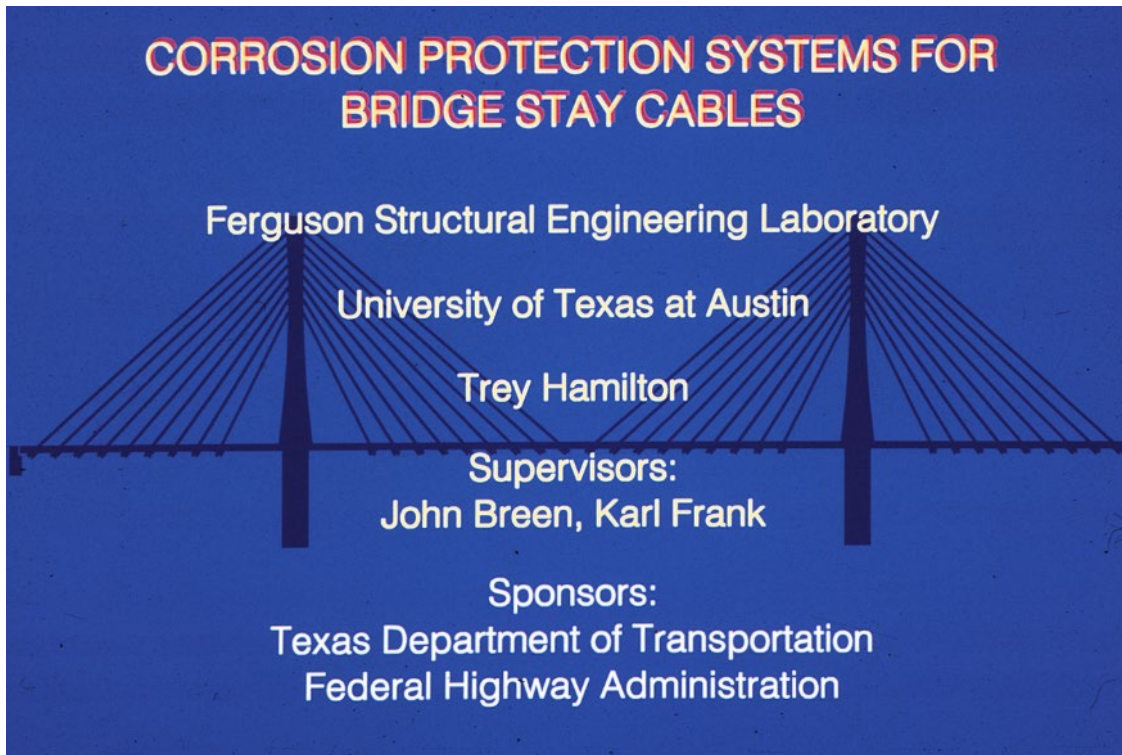
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Section 1. Dissertation Defense Presentation



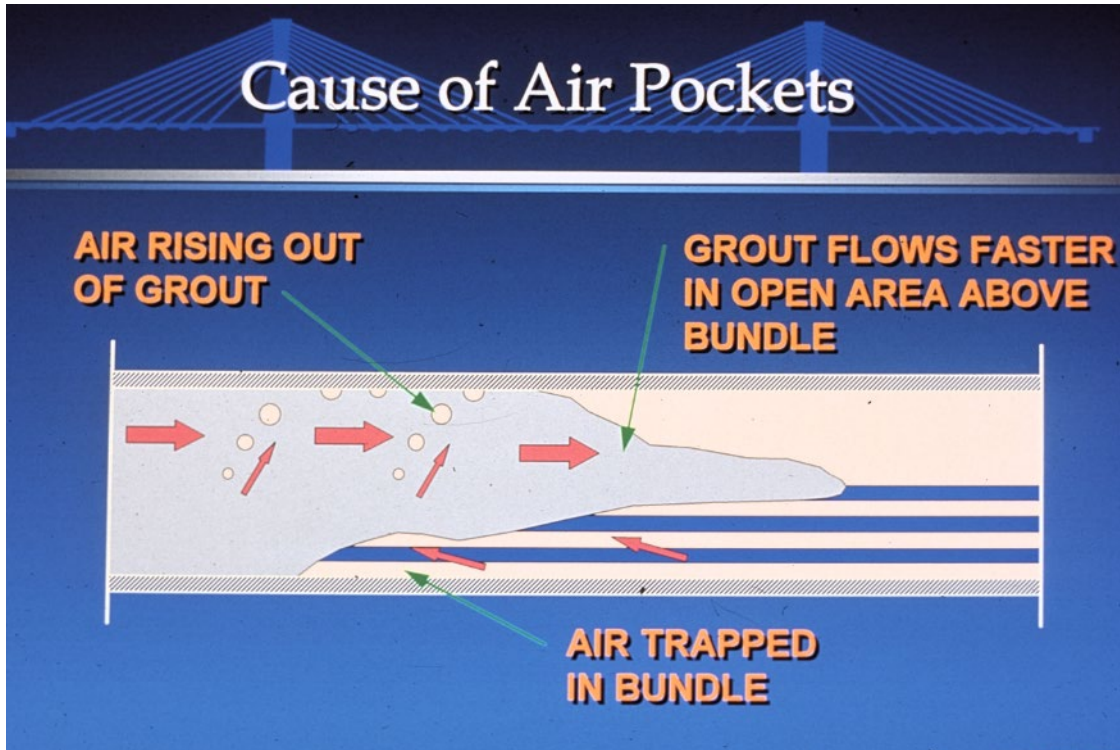
Slide 1. Corrosion Protection Systems for Bridge Stay Cables

Large Scale Test Objectives and Parameters

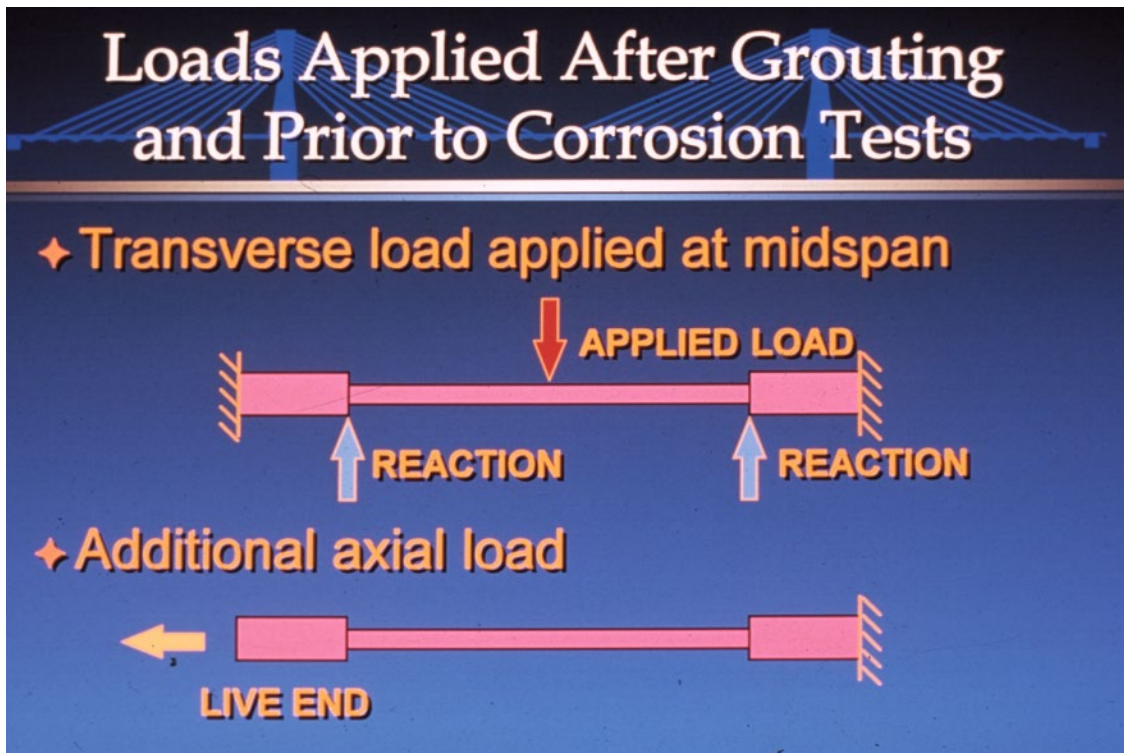
- ✦ Stress Maintained at 30% GUTS
- ✦ Stay Grouted at 35 deg. Angle
- ✦ Transverse Load Applied
- ✦ Additional Axial Load Applied:
Loaded From 30% to 45% GUTS
- ✦ Severe Exposure in Short Time

Slide 2. Large Scale Test Objectives and Parameters

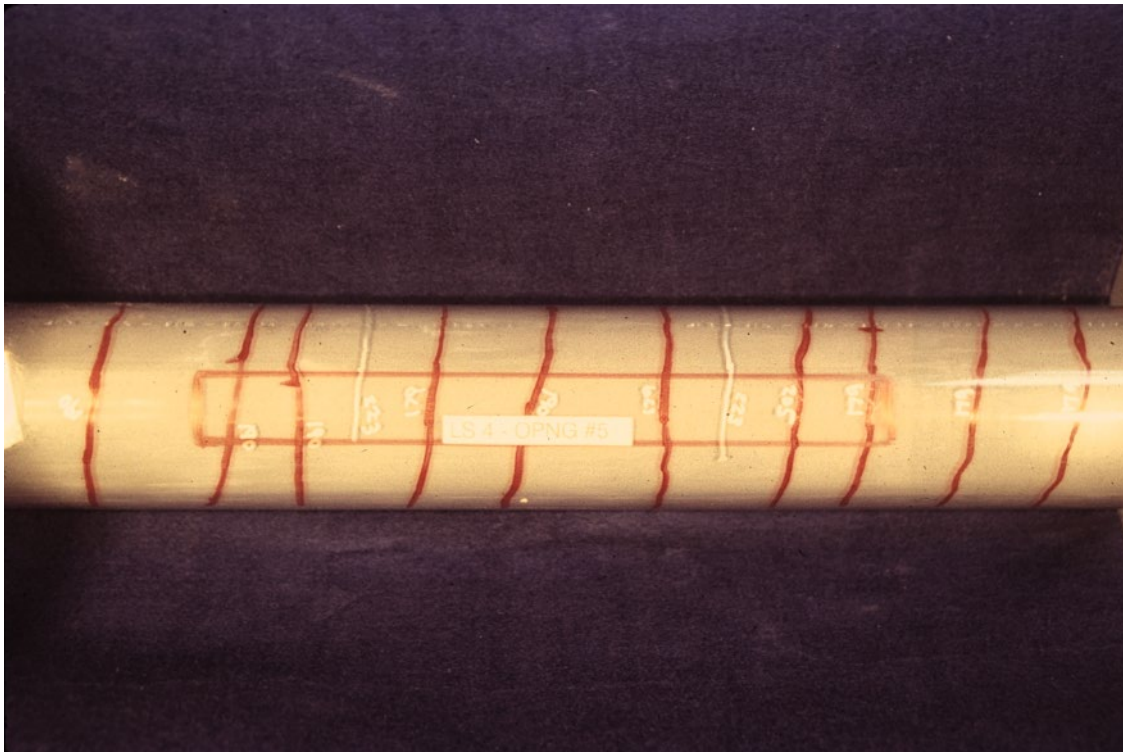
Cause of Air Pockets



Slide 3. Cause of Air Pockets



Slide 4. Loads Applied After Grouting and Prior to Corrosion Tests



Slide 5. Large scale test four (LS-4), number 5. March 8, 1994.



Results of Load Tests

- ✦ Grout cracking caused by lateral load was generally not visible
- ✦ Grout cracking caused by added axial load occurred early
- ✦ Crack widths and spacing varied with strand coatings

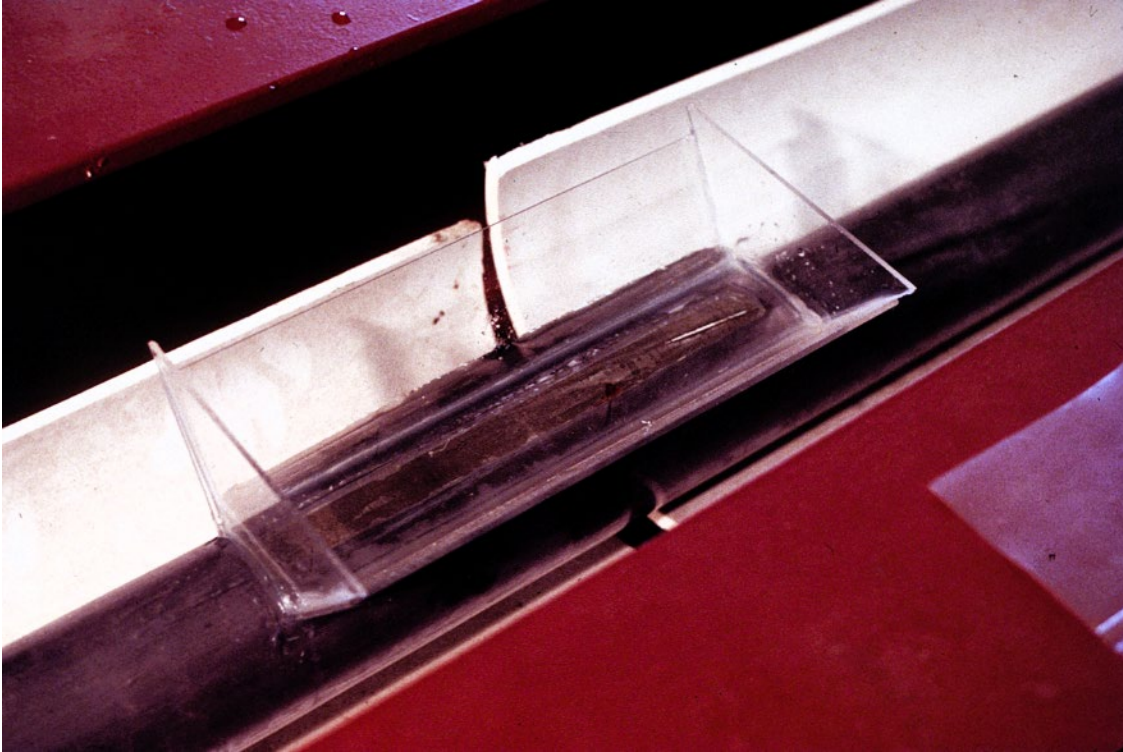
Slide 6. Results of Load Tests



Accelerated Corrosion Tests

- ✦ Impose Severe Exposure Condition
- ✦ Remove Sections of Sheathing
- ✦ Pond 5% NaCl in Wet/Dry Cycles
- ✦ Addition Axial Load During Test
- ✦ Monitor Half-Cell on Grout Surface

Slide 7. Accelerated Corrosion Tests



Slide 8. Large scale test three (LS-3). Acrylic dam. January 27, 1994.



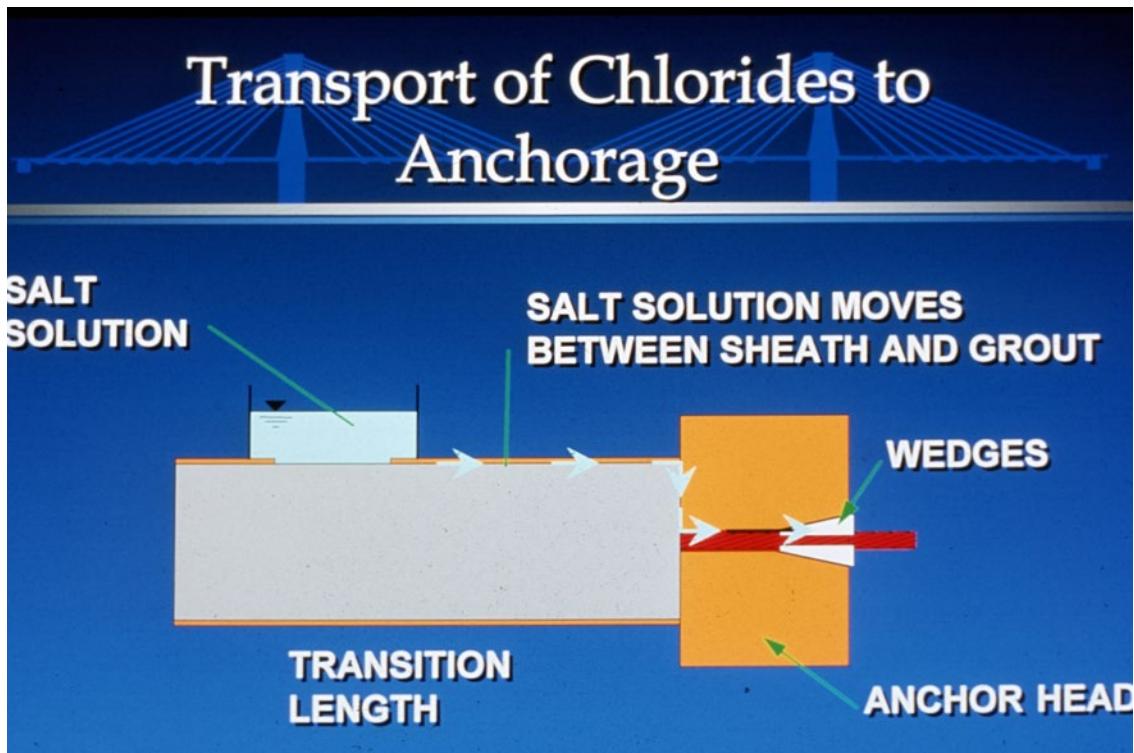
Slide 9. Corrosion product on surface of grout during accelerated corrosion test (Specimen LS-5 opening 5).



Slide 10. Corroded metal strand.



Slide 11. Corrosion at the interface between the strand and wedge and between tooth marks.



Slide 12. Transport of Chlorides to Anchorage

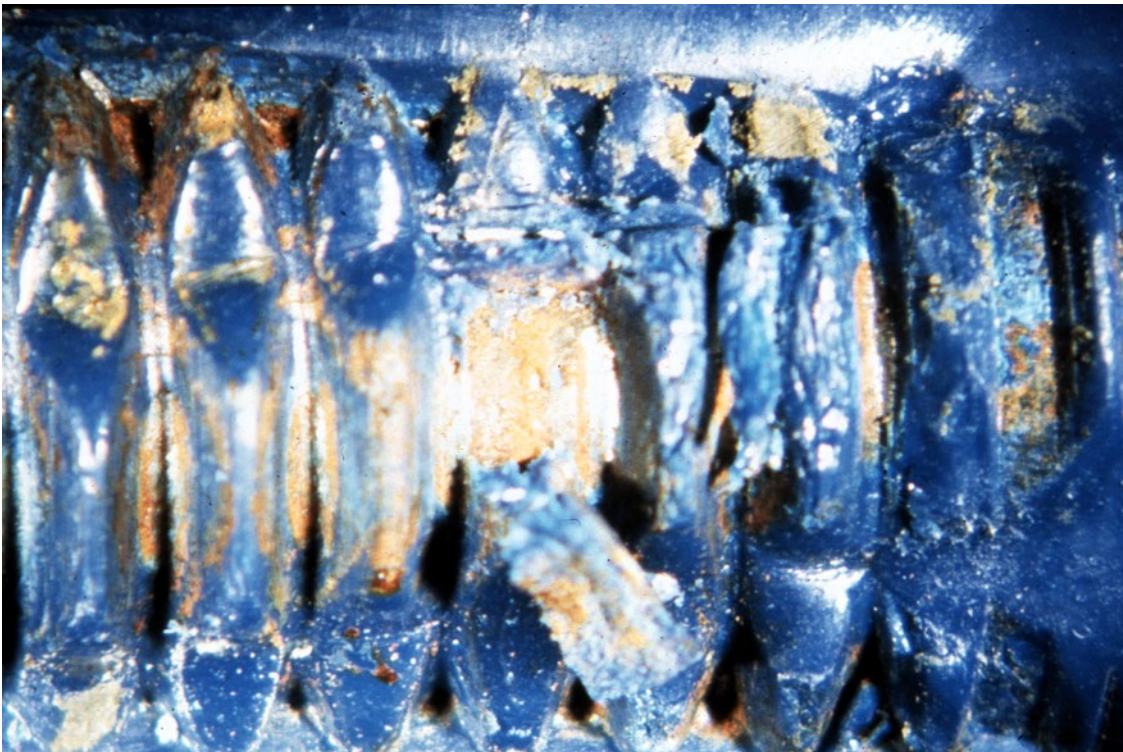
Conclusions and Recommendations

- ✦ Two Barrier System is Reduced to One Barrier
- ✦ Recommend Improving Corrosion Protection Systems
- ✦ Second Series Evaluating Individual Barriers and Improved Grouts

Slide 13. Conclusions and Recommendations



Slide 14. Large scale test six (LS-6). December 13, 1994.



Slide 15. Corrosion of strand at tooth mark.



Recommendations

- ✦ Do not consider pc grout a corrosion barrier
- ✦ Use of an individual barrier on the strands is highly recommended
- ✦ Prohibit the use of epoxy-coated strand which is unfilled

Slide 16. Recommendations



Recommendations - cont.

- ✦ Adequate protection in the anchorage zone for epoxy-coated/filled strand
- ✦ Careful detailing of individual sheath-to-anchor head seal for greased/sheathed
- ✦ Careful detailing of deviator ring to prevent damage of individual protection systems

Slide 17. Recommendations -- Continued

Grout Development Series - Results

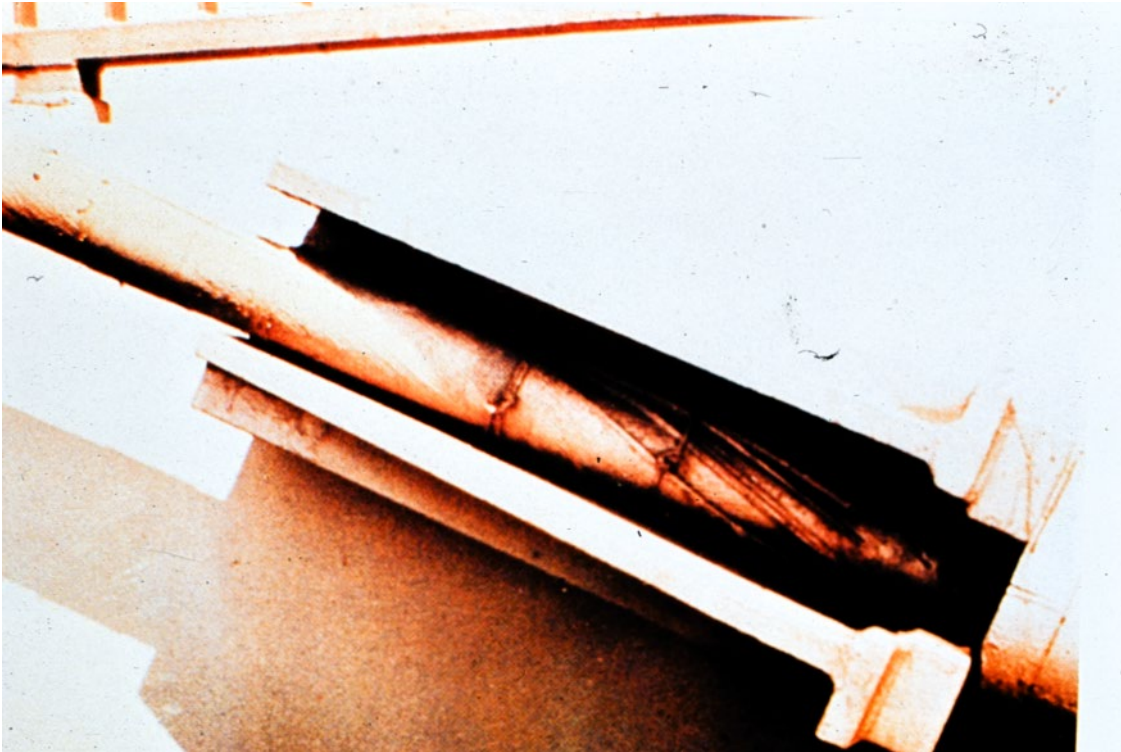
- ✦ Developed an optimum mix design using anti-bleed admixture
- ✦ Tested corrosion inhibitors in optimum grout mix
- ✦ Developed a low-bleed mix design using silica fume

Slide 18. Grout Development Series -- Results

Why Study Durability of Stay Cables?

- ✦ Loss of a stay can be catastrophic
- ✦ Required design life over 100 years
- ✦ Replacement possible but expensive
- ✦ Stays often in corrosive environments (salt water, polluted air, road salts)
- ✦ Texas: Neches and Baytown Bridges
- ✦ U.S.: 21 cable-stayed bridges

Slide 19. Why Study Durability of Stay Cables?

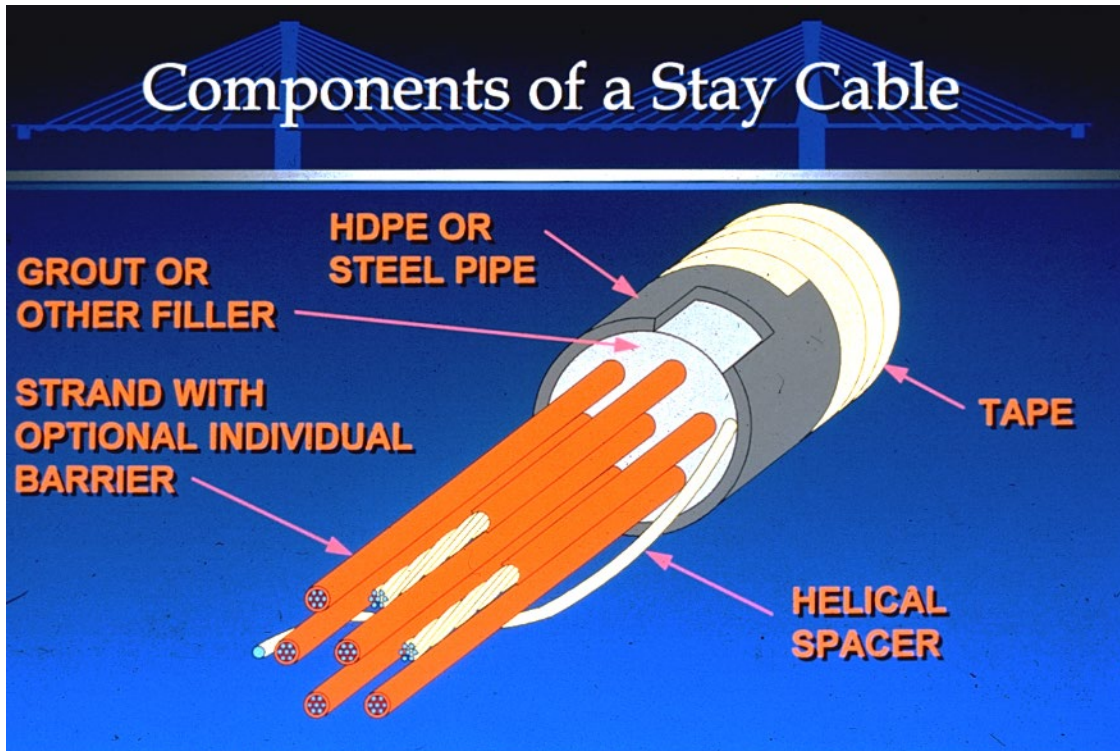


Slide 20. Detail of unknown specimen.

Two Barrier Corrosion Protection System

- ♦ Prestressing strand protected by two barriers
- ♦ First barrier: sheathing
- ♦ Second barrier: portland cement grout
- ♦ If first barrier is broken how well does grout protect strand?

Slide 21. Two Barrier Corrosion Protection System



Slide 22. Components of a Stay Cable

What Problems Exist in the Field?

- ✦ Lake Maracaibo Bridge, Venezuela and Kohlbrand Bridge, Germany: Stays had to be replaced
- ✦ Grouting problems with the Luling Bridge
- ✦ Numerous problems with corrosion during fatigue acceptance tests in U.S.

Slide 23. What Problems Exist in the Field?



Slide 24. Detail of pipe in a box.



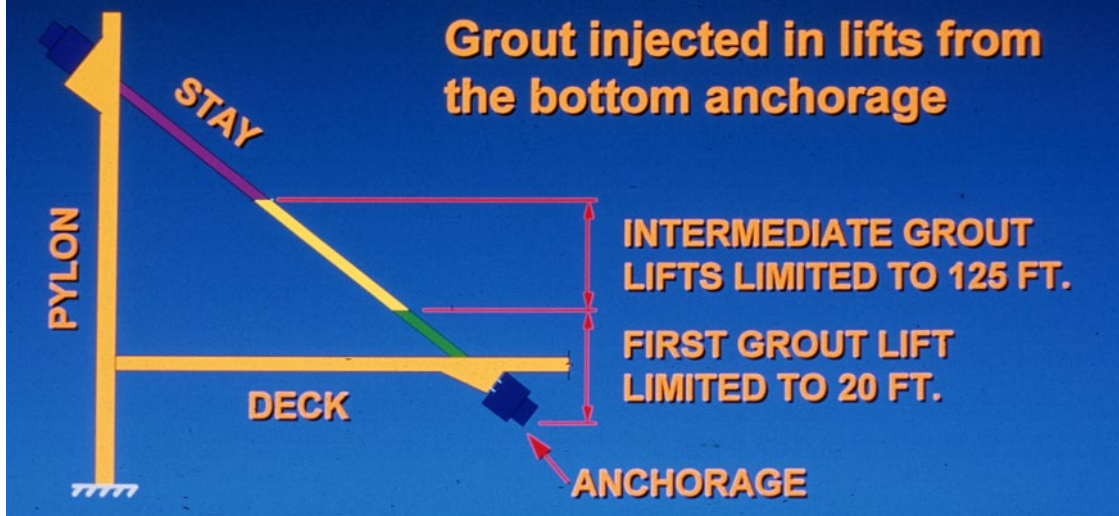
Slide 25. Stay cable detail.

Other Areas of Concern

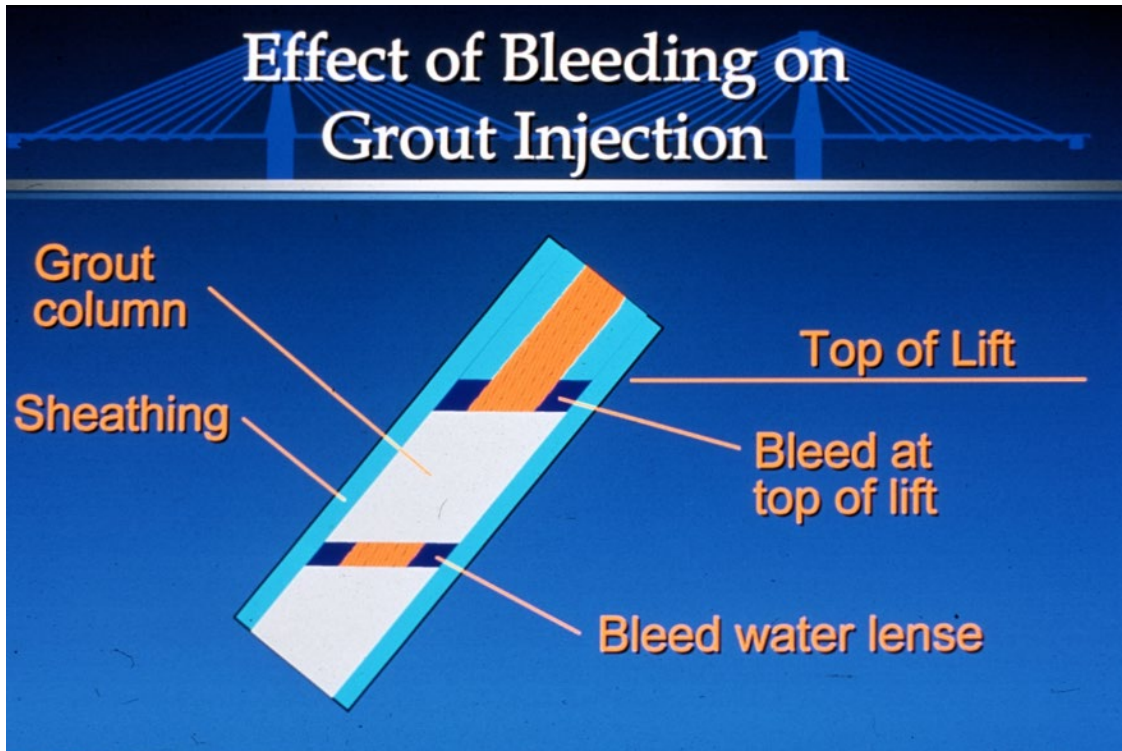
- ◆ Current system is relatively young
- ◆ Little information available from demolition of existing stay cables
- ◆ Suppliers introducing many different systems with little testing
- ◆ No effective method of non-destructive testing to give an indication of performance

Slide 26. Other Areas of Concern

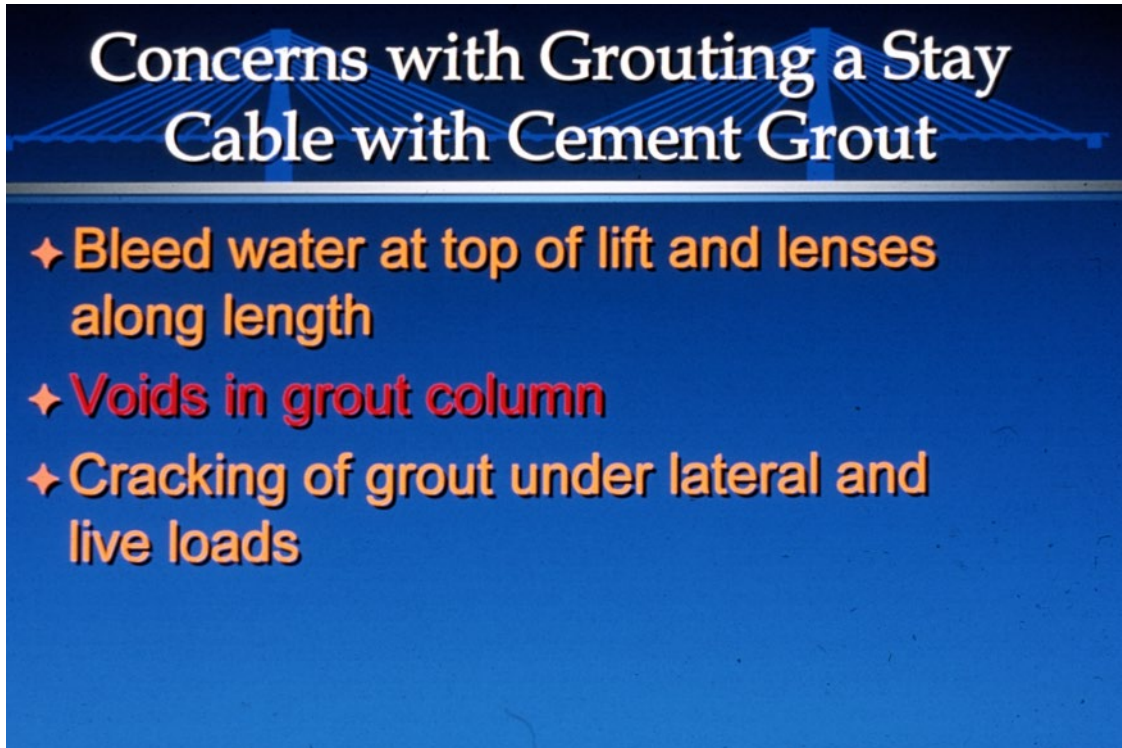
Injection of a Stay Cable with Portland Cement Grout



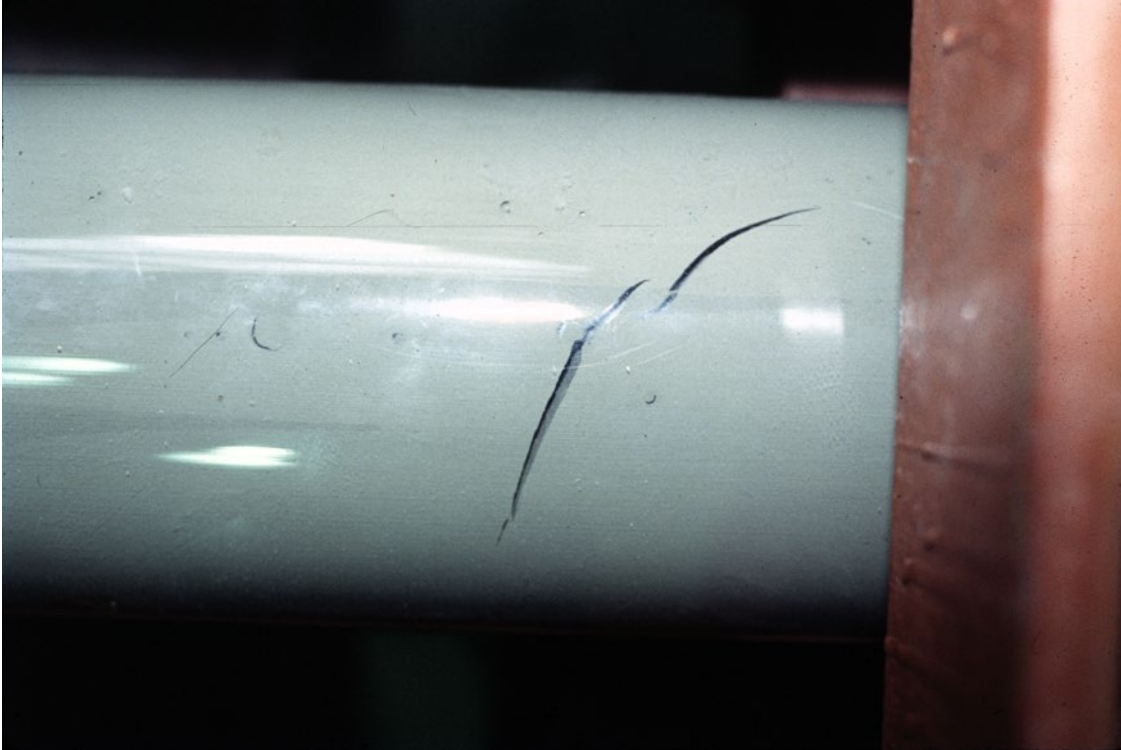
Slide 27. Injection of a Stay Cable with Portland Cement Grout



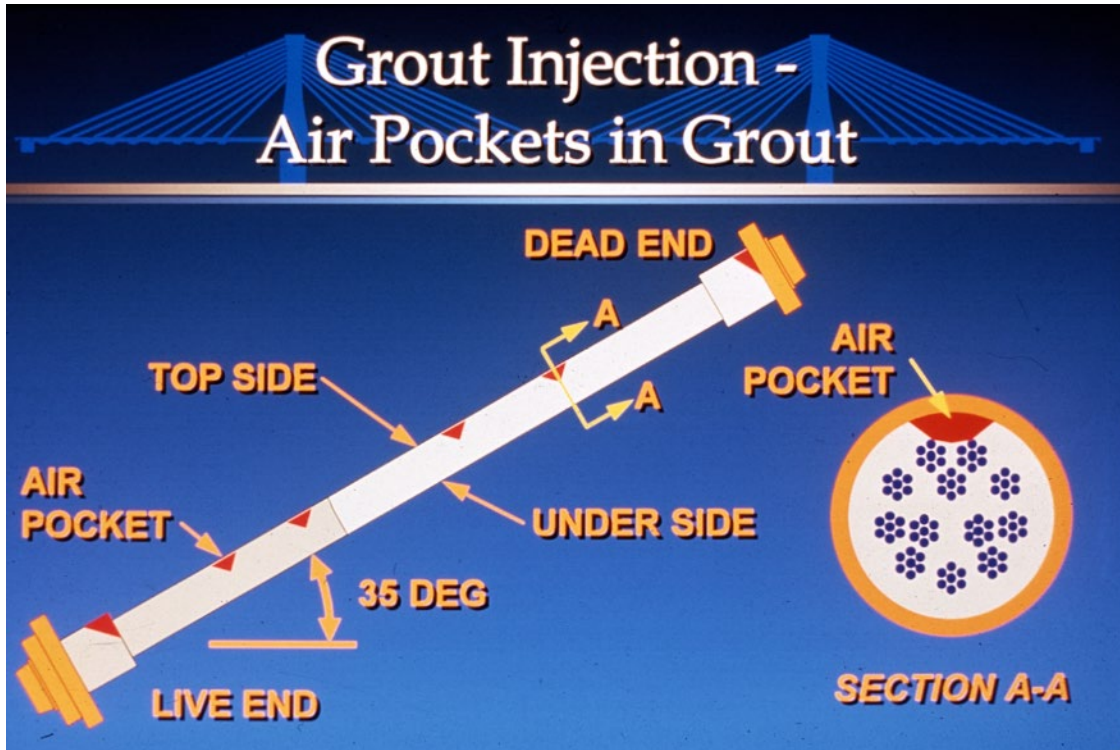
Slide 28. Effect of Bleeding on Grout Injection



Slide 29. Concerns with Grouting a Stay Cable with Cement Grout



Slide 30. Large scale test two (LS-2). Grout. 2:35. December 22, 1993.

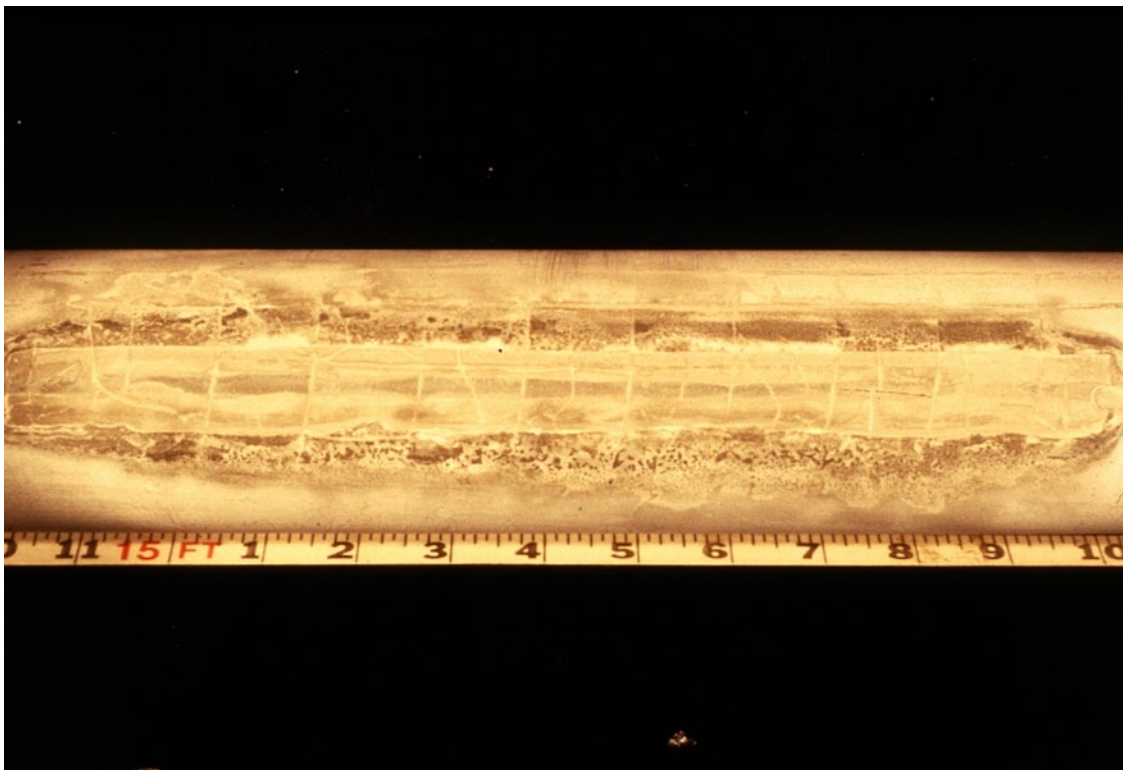


Slide 31. Grout Injection – Air Pockets in Grout

Concerns with Grouting a Stay Cable with Cement Grout

- ✦ Bleed water at top of lift and lenses along length
- ✦ Voids in grout column
- ✦ Cracking of grout under lateral and live loads

Slide 32. Concerns with Grouting a Stay Cable with Cement Grout



Slide 33. Grout column (?) detail.



Slide 34. Stay cable detail.

Organization of Research

- ♦ Literature review
- ♦ Survey of opinion
- ♦ Portland cement grout series
- ♦ Modified accelerated corrosion test method
- ♦ Large scale corrosion tests

Slide 35. Organization of Research

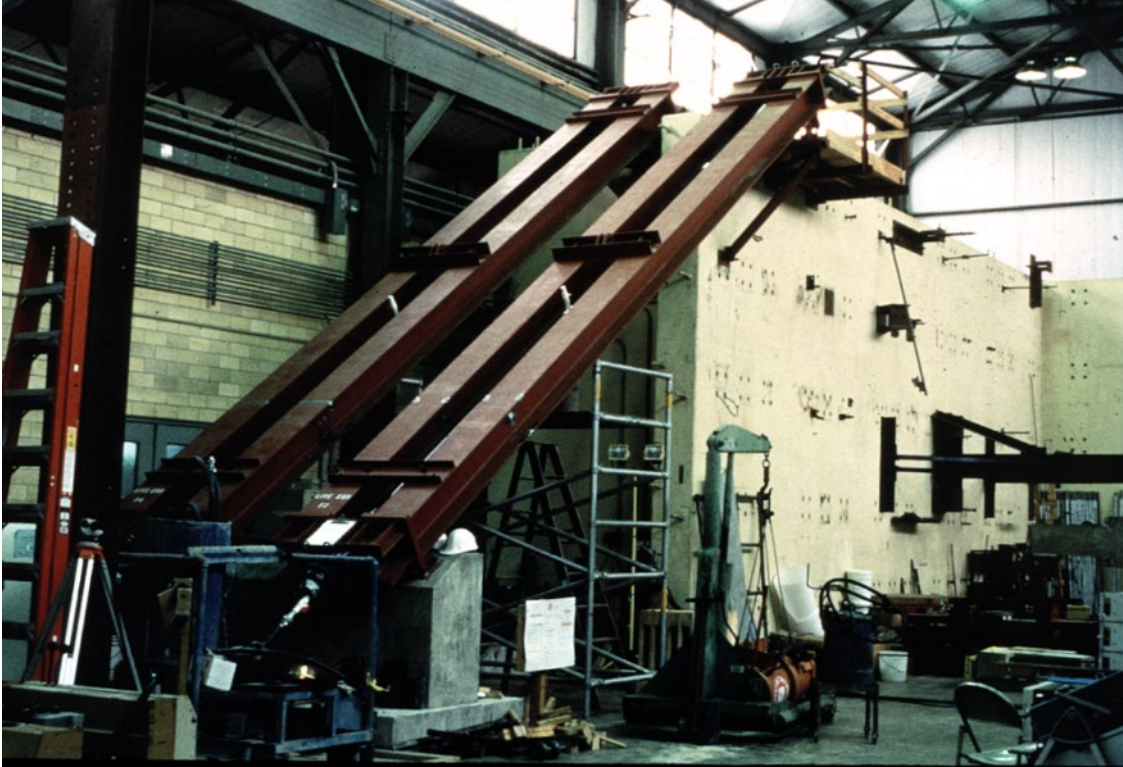
Modified ACTM - Results

- ✦ Use of anti-bleed admixture reduced corrosion protection (CP)
- ✦ Calcium nitrite reduced CP
- ✦ Rheocrete and silica fume improved CP
- ✦ Test needs method to compensate for different IR Drop in grouts

Slide 36. Modified ACTM -- Results



Slide 37. Cable stays at East Huntington, West Virginia.



Slide 38. Ferguson Structural Engineering Laboratory, Austin, Texas.



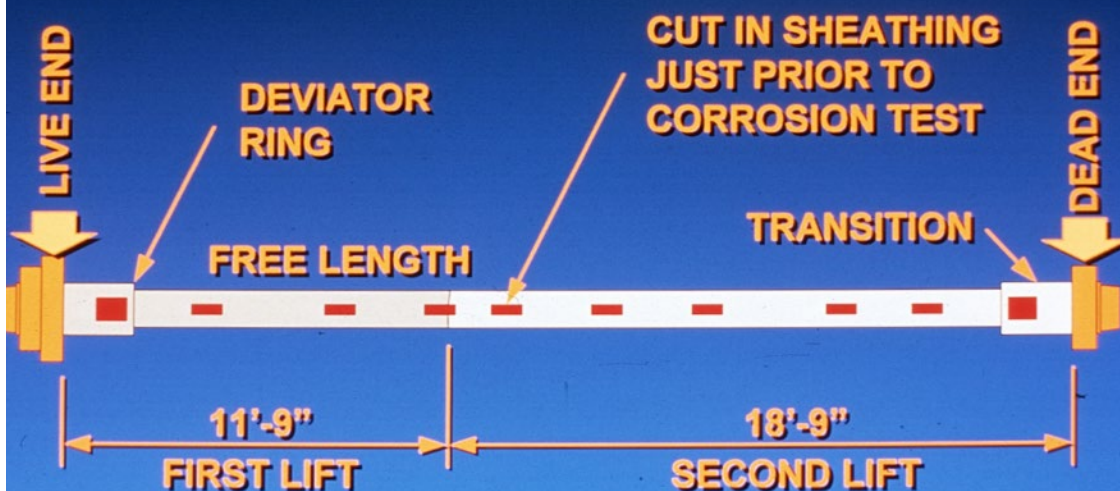
Slide 39. Sitka Harbor Bridge, Sitka, Alaska.

Large Scale Test Specimens First Series

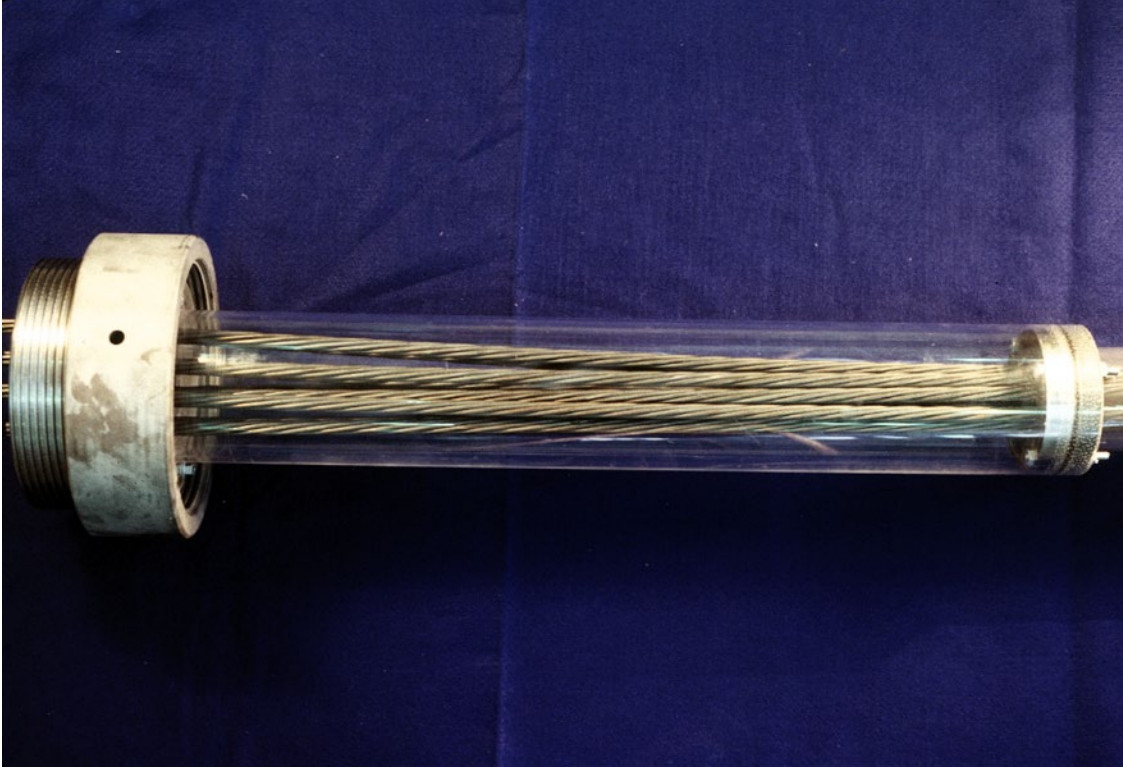
- ✦ Bare Strand - No additional load
- ✦ Bare Strand - Loaded prior to and during corrosion test
- ✦ Strand w/ TCP - No additional load
- ✦ Strand w/ TCP - Loaded prior to and during corrosion test

Slide 40. Large Scale Test Specimens First Series

Large Scale Specimen Schematic



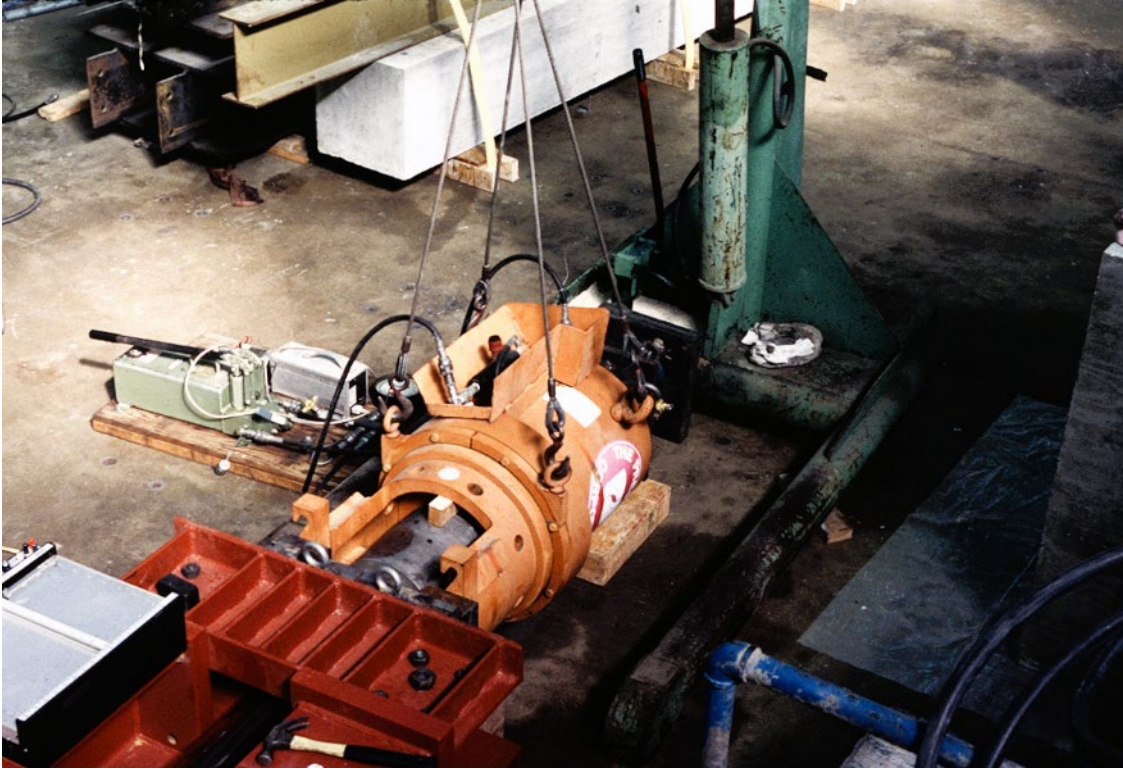
Slide 41. Large Scale Specimen Schematic



Slide 42. Large scale test three (LS-3). Parts. Live end transition.



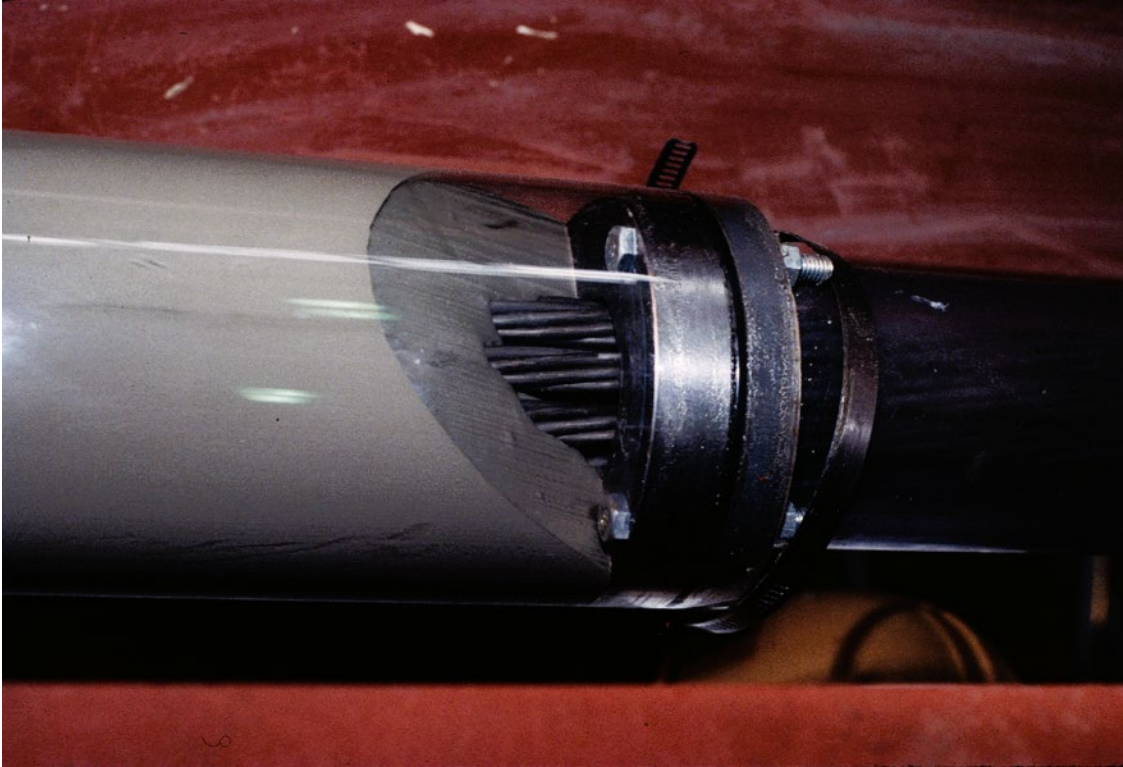
Slide 43. Large scale test three (LS-3). Assembly. Installed strands from live end.



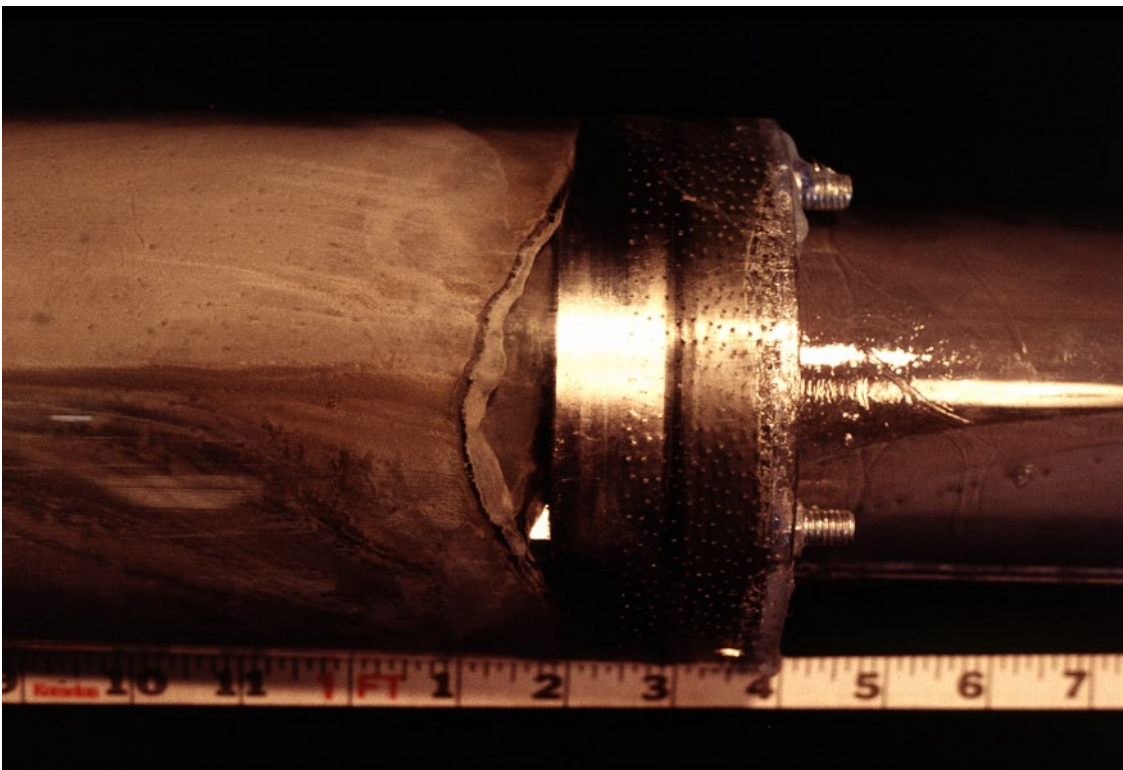
Slide 44. Large scale test three (LS-3). Assembly. Live end stressing assembly.



Slide 45. Large scale tests two (LS-2) and four (LS-4). Grouting.



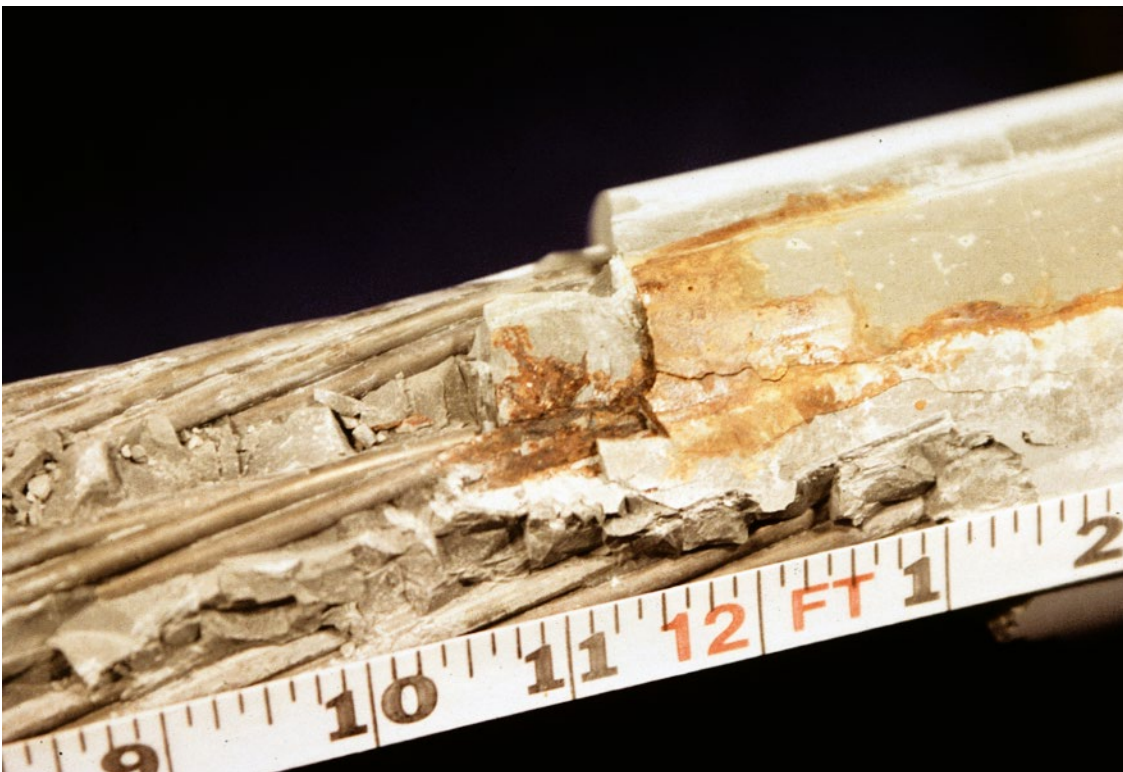
Slide 46. Large scale tests two (LS-2) and four (LS-4). Groutly. Grout in pipe.



Slide 47. Large scale test three (LS-3).



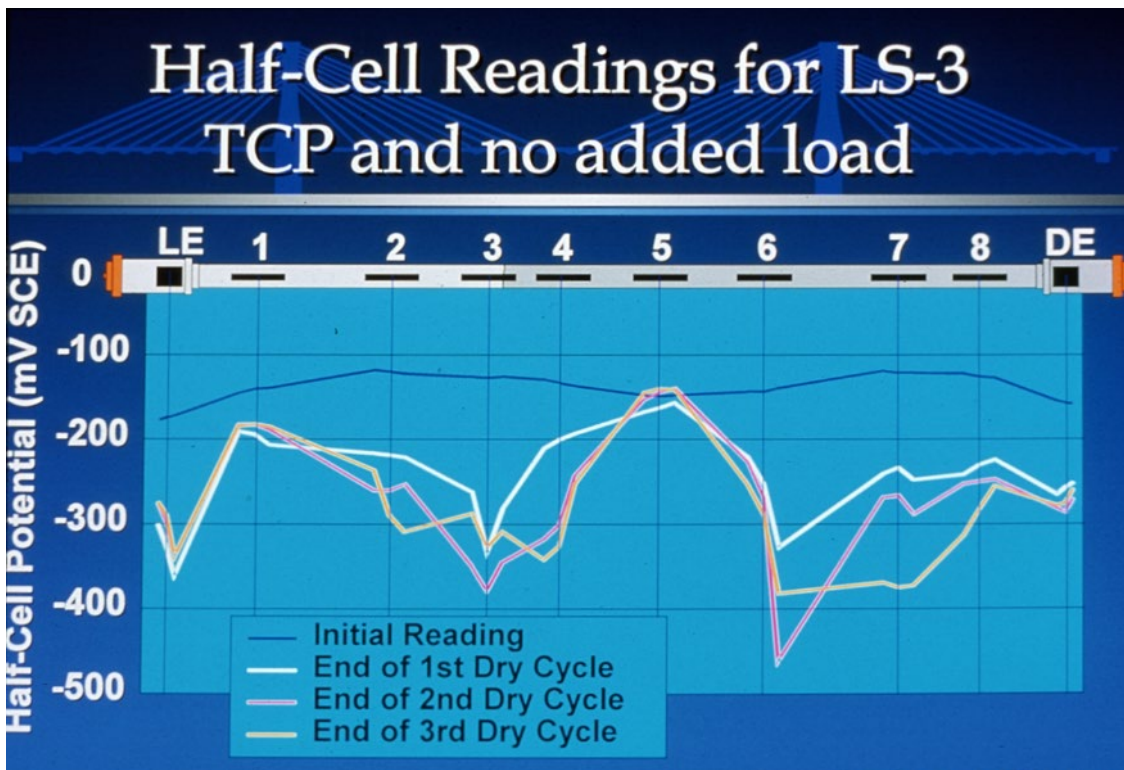
Slide 48. Large scale test two (LS-2). Void at the top.



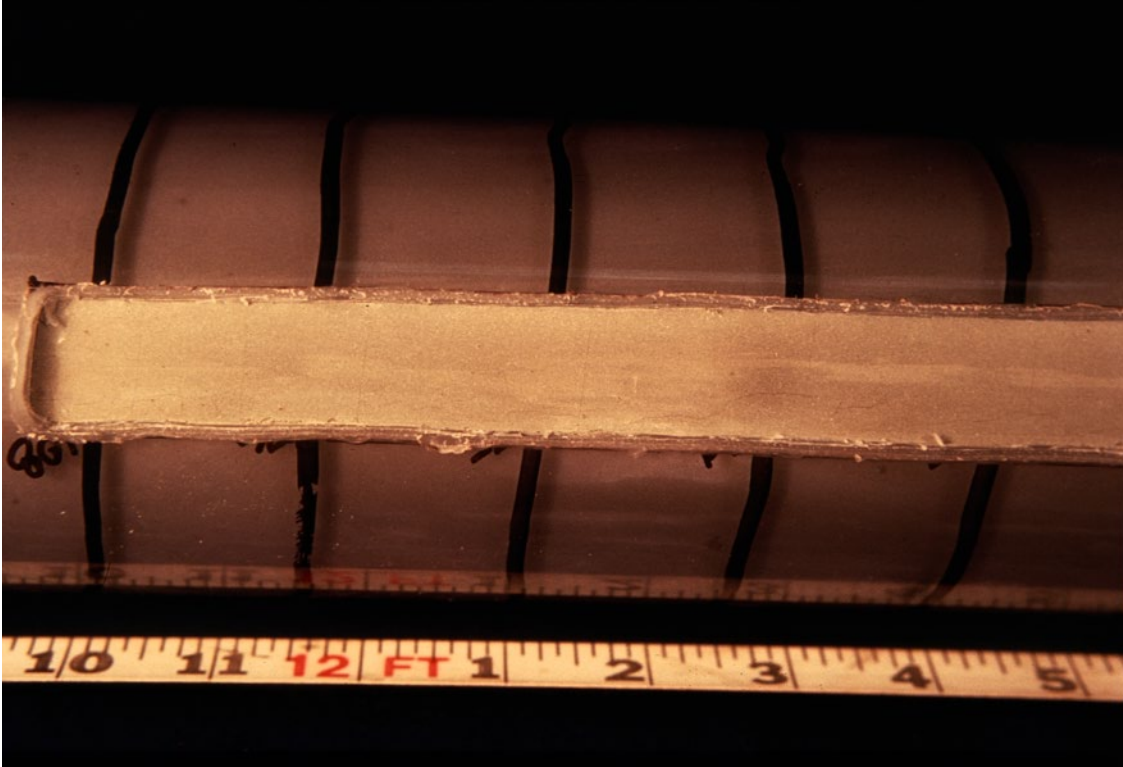
Slide 49. Large scale test three (LS-3). Diss.. Corrosion in crack. February 28, 1994.



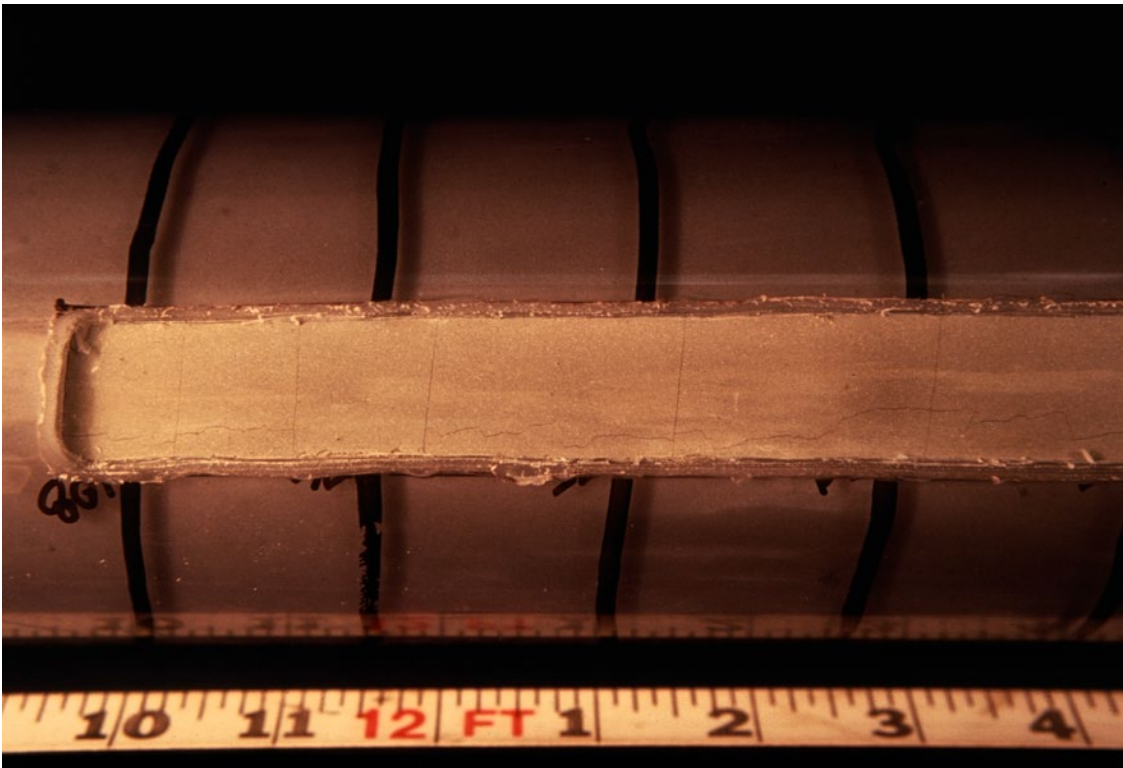
Slide 50. Large scale specimen – half-cell potential measurement. February 2, 1994.



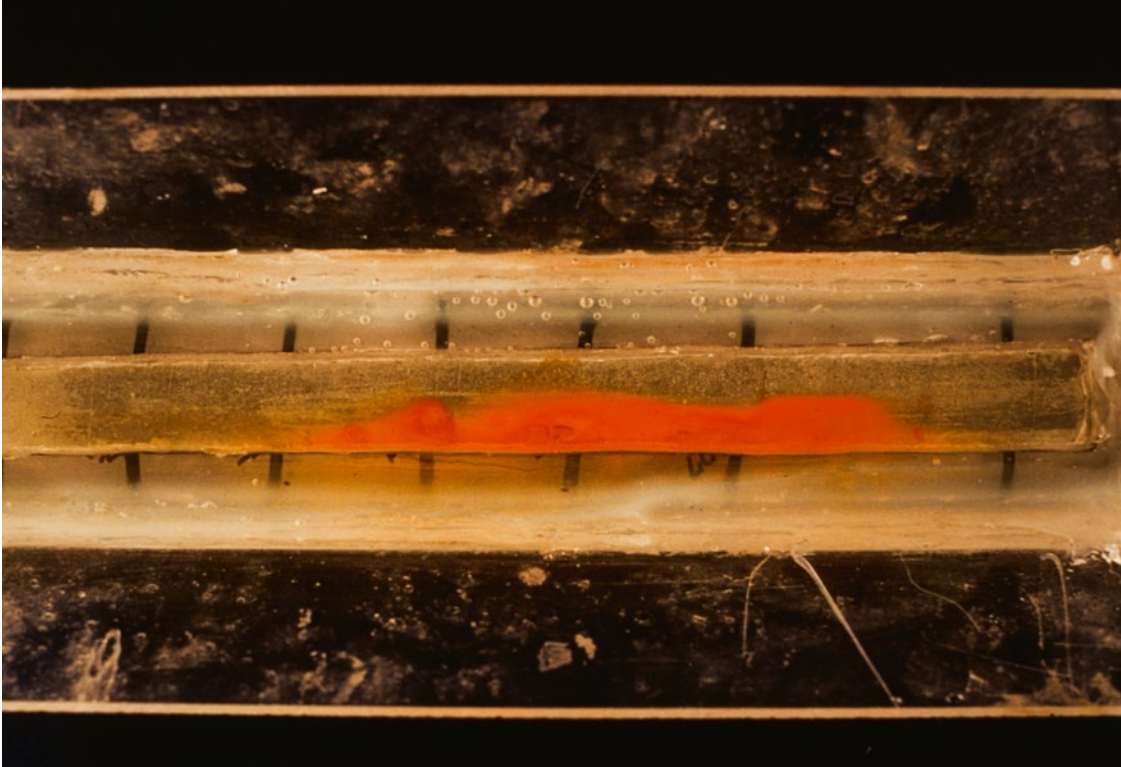
Slide 51. Half-Cell Readings for LS-3 TCP and no added load



Slide 52. Grout shrinkage cracks. Longitudinal cracks visible.



Slide 53. Grout shrinkage cracks. Longitudinal and transverse cracks visible.



Slide 54. Corrosion product on grout during accelerated corrosion test (LS-5 opening 5).

Summary of Findings

- ✦ Air Pockets in Grout
- ✦ Early Cracking of Grout With Added Load
- ✦ Shrinkage Cracking of Grout
- ✦ TCP Did Not Effect Protection
- ✦ Rapid Initiation of Corrosion
- ✦ Corrosion Occurred Away From Openings

Slide 55. Summary of Findings



Large Scale Test Specimens Second Series

- ✦ Strand w/ TCP and Silica Fume grout
- ✦ Epoxy-Coated Strand (w/ damage)
- ✦ Galvanized Strand
- ✦ Greased/Sheathed Strand (w/ damage)

All specimens had additional loads applied prior to and during corrosion test

Slide 56. Large Scale Test Specimens Second Series



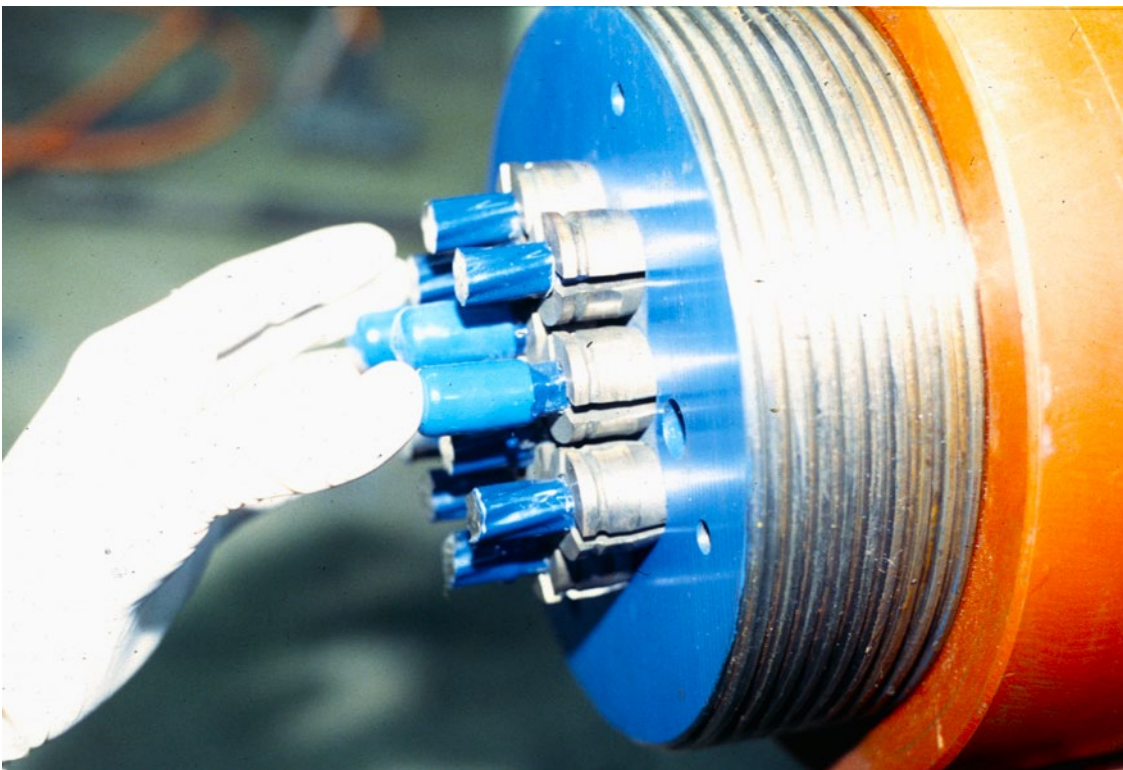
Improved Grout

- ✦ Silica fume grout provided slight increase in protection
- ✦ Improvement possibly due to increase in grout electrical resistance
- ✦ Precompression of grout did not prevent cracks from opening when sheathing removed

Slide 57. Improved Grout



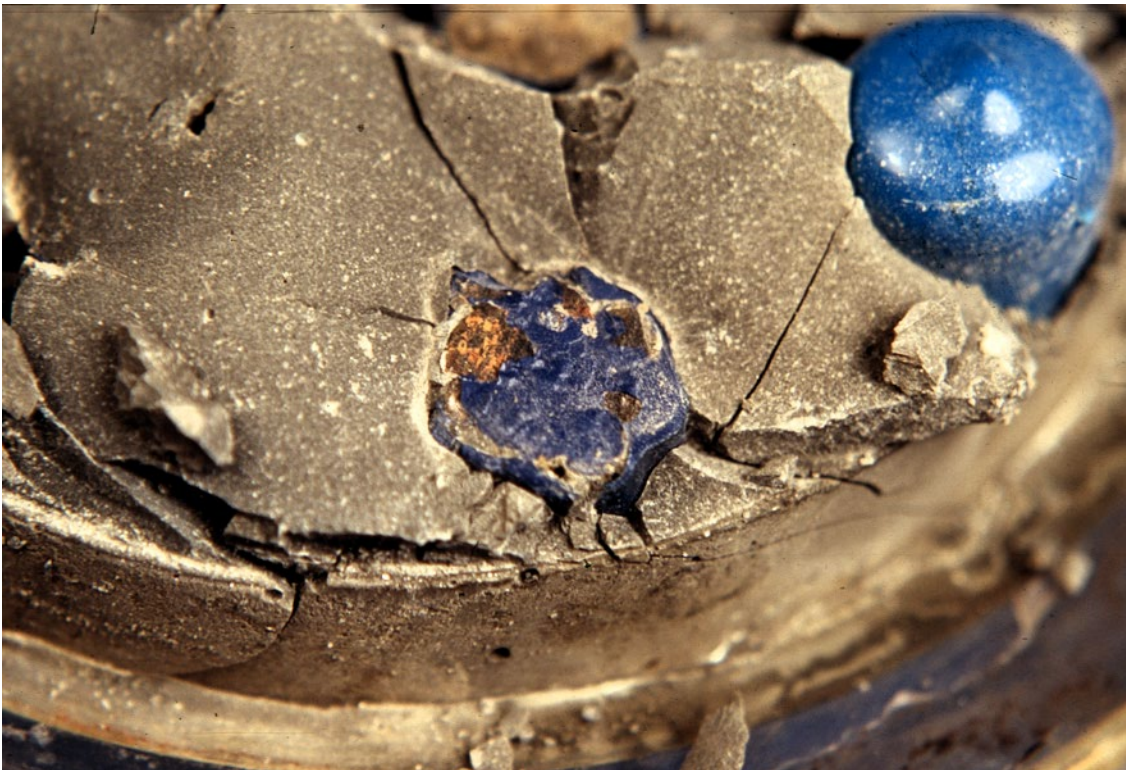
Slide 58. Large scale test six (LS-6). End repair. June 30, 1994.



Slide 59. Large scale test six (LS-6). Installing cap.



Slide 60. Large scale test six (LS-6). Moisture visible. December 14, 1994.



Slide 61. Large scale test six (LS-6). March 10, 1995.



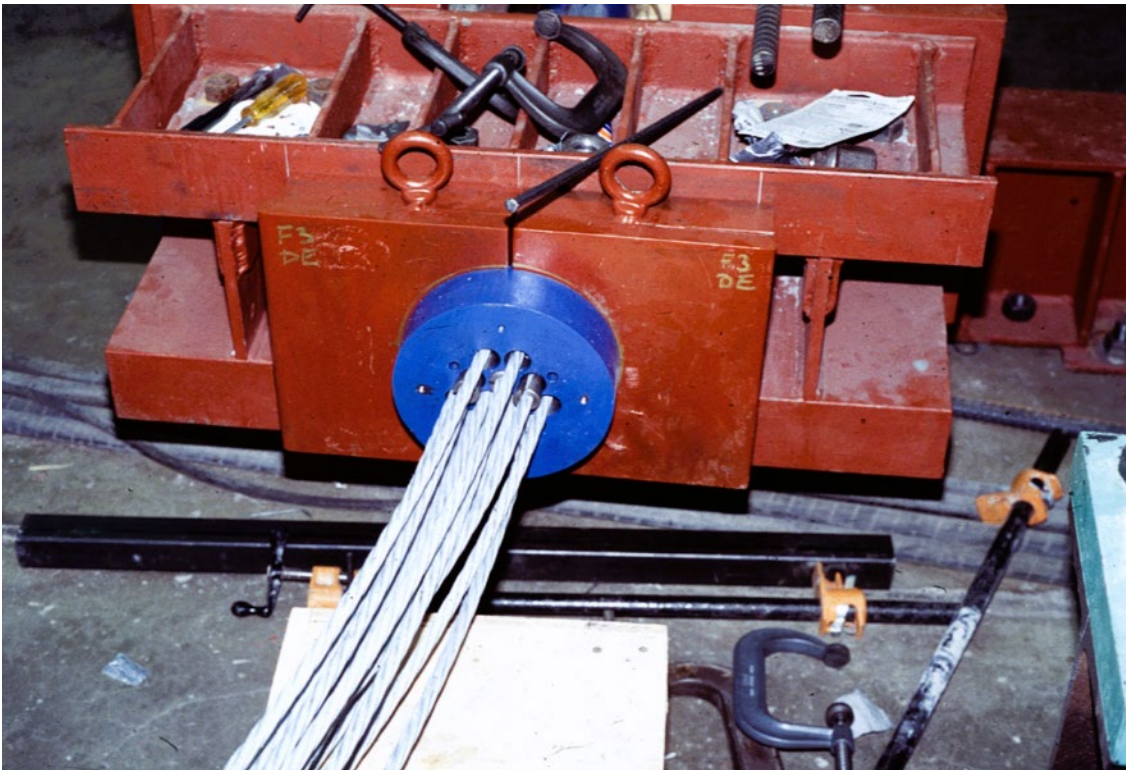
Slide 62. Large scale test six (LS-6). March 10, 1995.



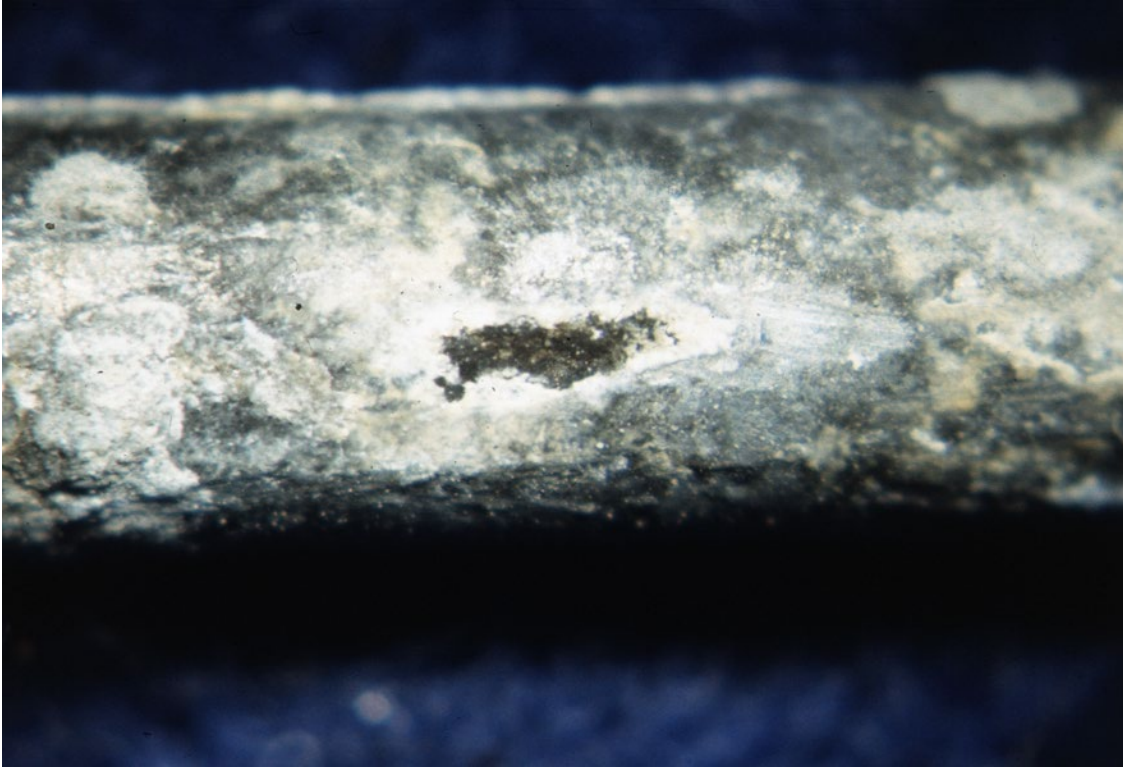
Slide 63. Tooth marks.



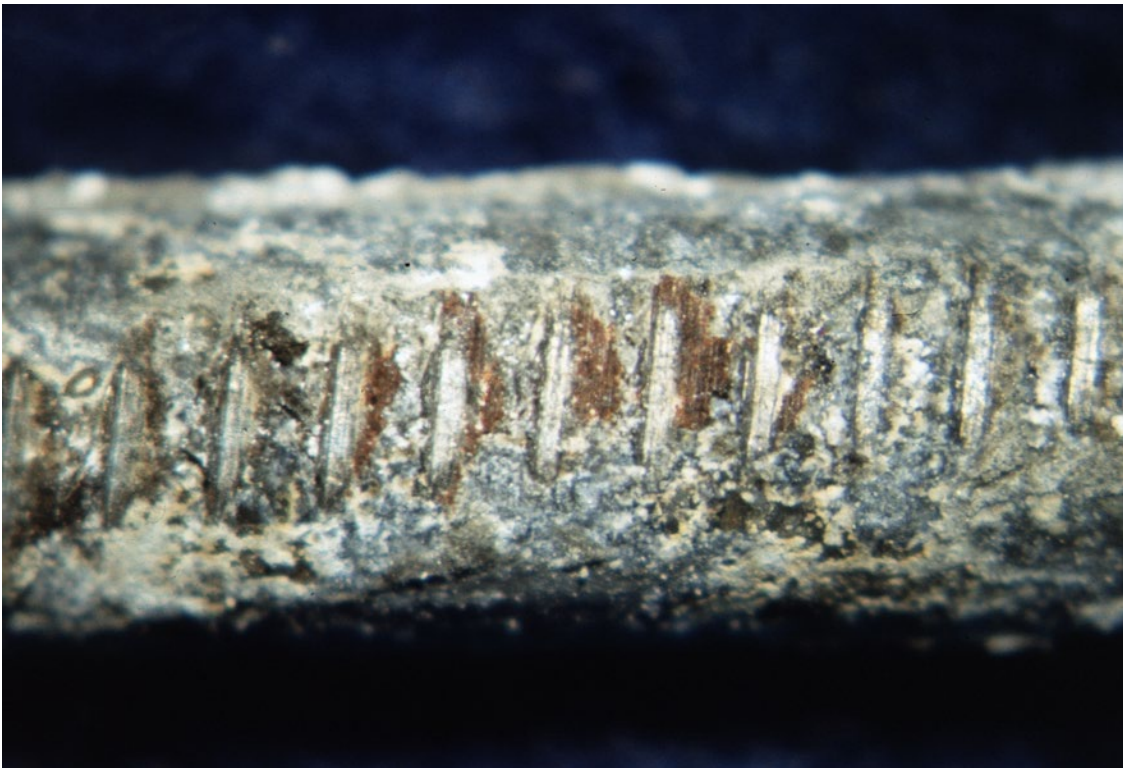
Slide 64. Corrosion of strand at tooth mark.



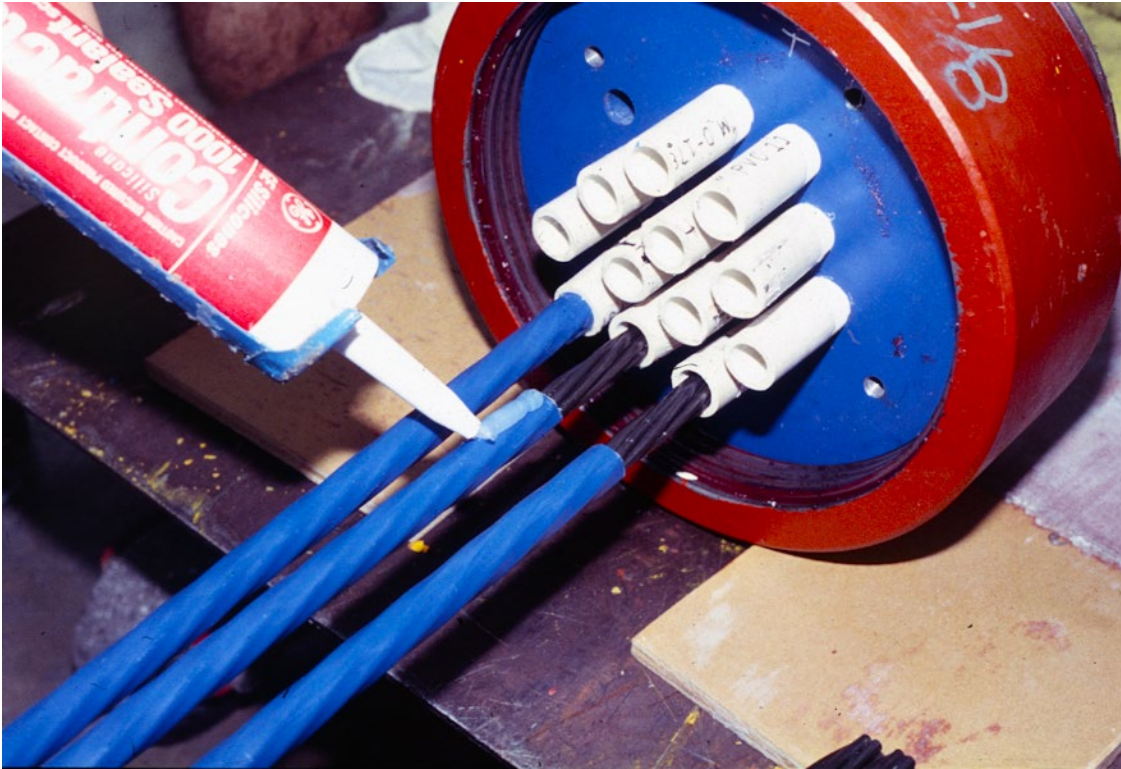
Slide 65. Large scale test seven (LS-7). Assembly. April 11, 1994.



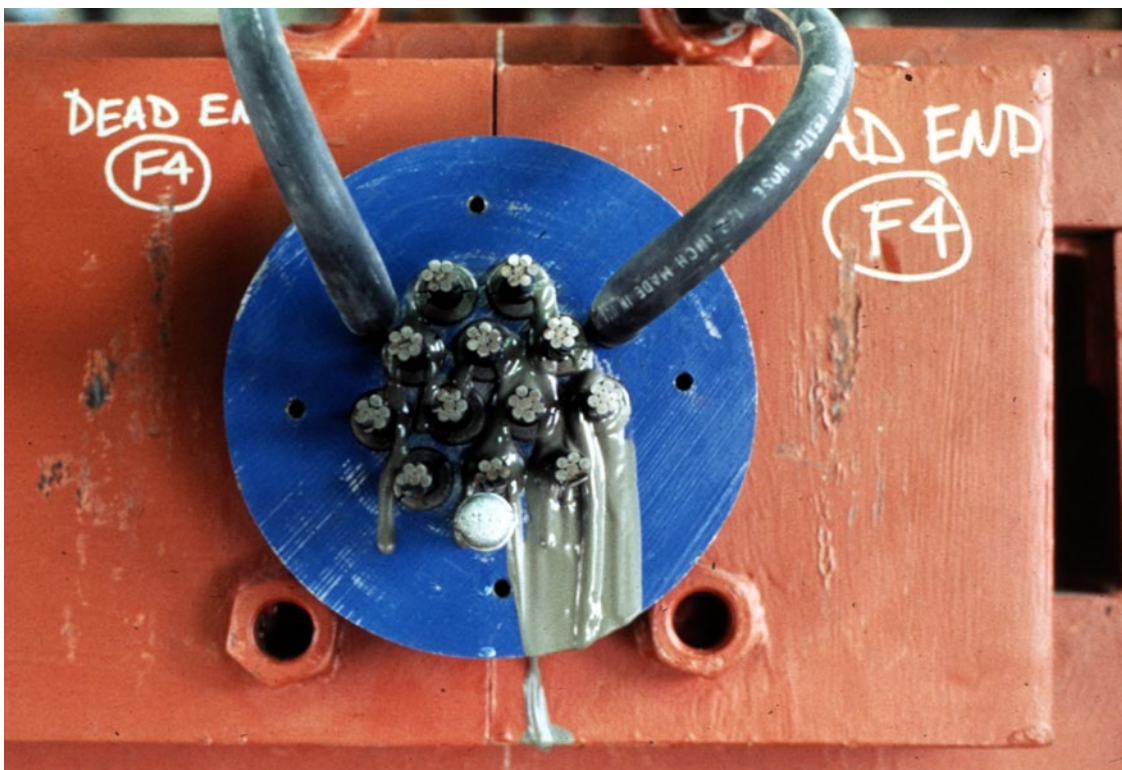
Slide 66. Large scale test seven (LS-7). April 7, 1995.



Slide 67. Large scale test seven (LS-7). April 7, 1995.



Slide 68. Large scale test eight (LS-8). Assembly. August 29, 1994.



Slide 69. Specimen LS-8 grout leak through anchor head.



Slide 70. Large scale test eight (LS-8). March 30, 1995.




Slide 71. Large scale test eight (LS-8). March 30, 1995.



Concerns with Grouting a Stay Cable with Cement Grout

- ✦ Bleed water at top of lift and lenses along length
- ✦ Voids in grout column
- ✦ Cracking of grout under lateral and live loads

Slide 72. Concerns with Grouting a Stay Cable with Cement Grout



Future Work

- ✦ Investigate other stay cable anchorage systems such as HIAM and bond socket
- ✦ Effect of different grout additives on the corrosion fatigue
- ✦ Survey indicated greased/sheathed/galvanized system is gaining popularity. Investigate with further tests

Slide 73. Future Work

Improving Corrosion Protection for Post-Tensioning Tendons and Cable Stay Systems

Project 1264

Principal Investigators:

J. E. Breen
K. H. Frank

Research Assistants:

Rodney Davis
Trey Hamilton
William Kittleman
Truc Tran
Rene Vignos

TxDOT Technical Coordinator: Jeff Wouters

FHWA Technical Coordinators:

Paul Virmani - Washington, D.C.
James Craig - Ft. Worth, TX

Slide 74. Improving Corrosion Protection for Post-Tensioning Tendons and Cable Stay Systems; Project 1264

Section 2. Pasco-Kennewick



Slide 75. Breaking open stay cable.



Slide 76. Stay cable.



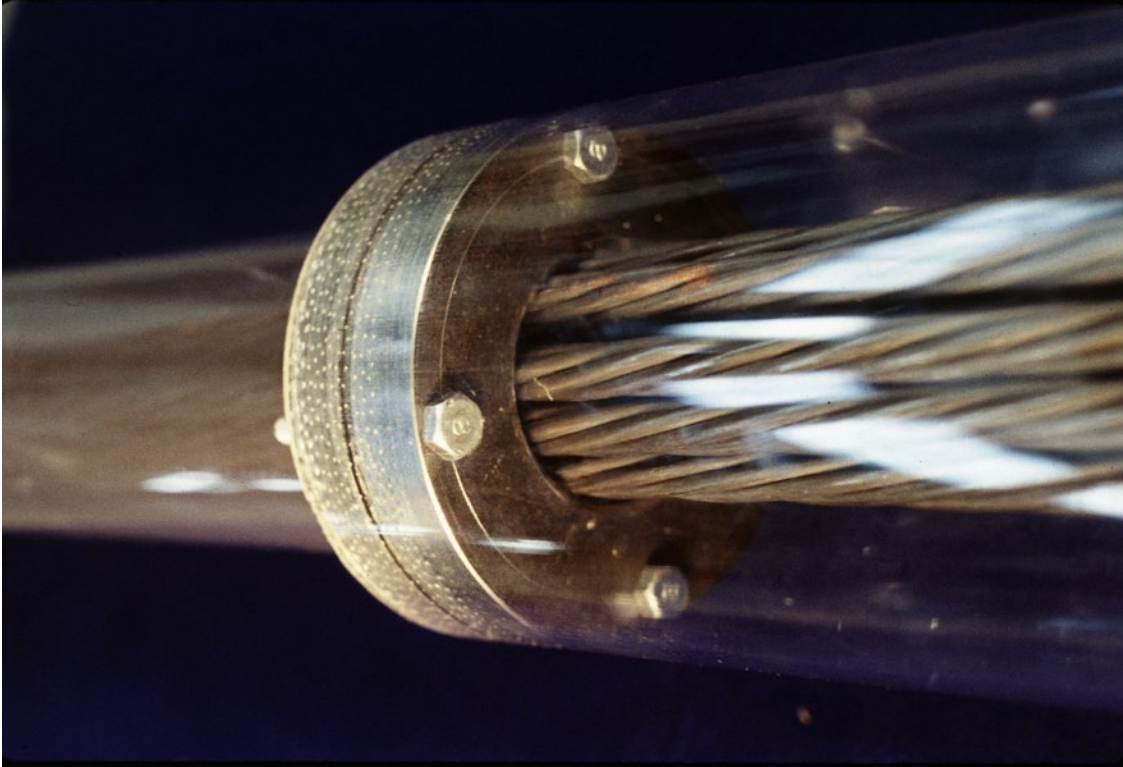
Slide 77. Stay cable (interior view).

Section 3. Stay Cable Large-Scale Corrosion Tests

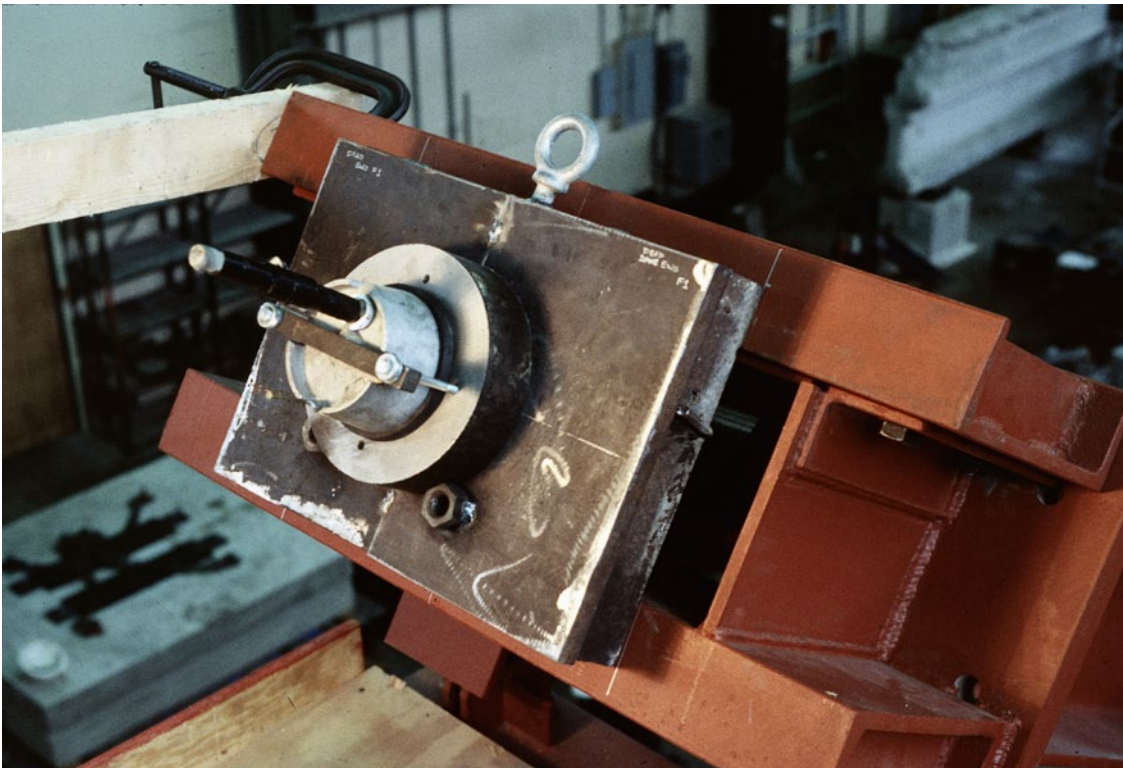
Part 1. Assembly and Grafting



Slide 78. Large scale test three (LS-3). Assembly. Installation of live end anchor head.



Slide 79. Large scale test three (LS-3). Parts. Transition assembly deviator ring.



Slide 80. Large scale test one (LS-1). Top anchor head.



Slide 81. Large scale test three (LS-3). Assembly. Dead end transition pipe and plate.



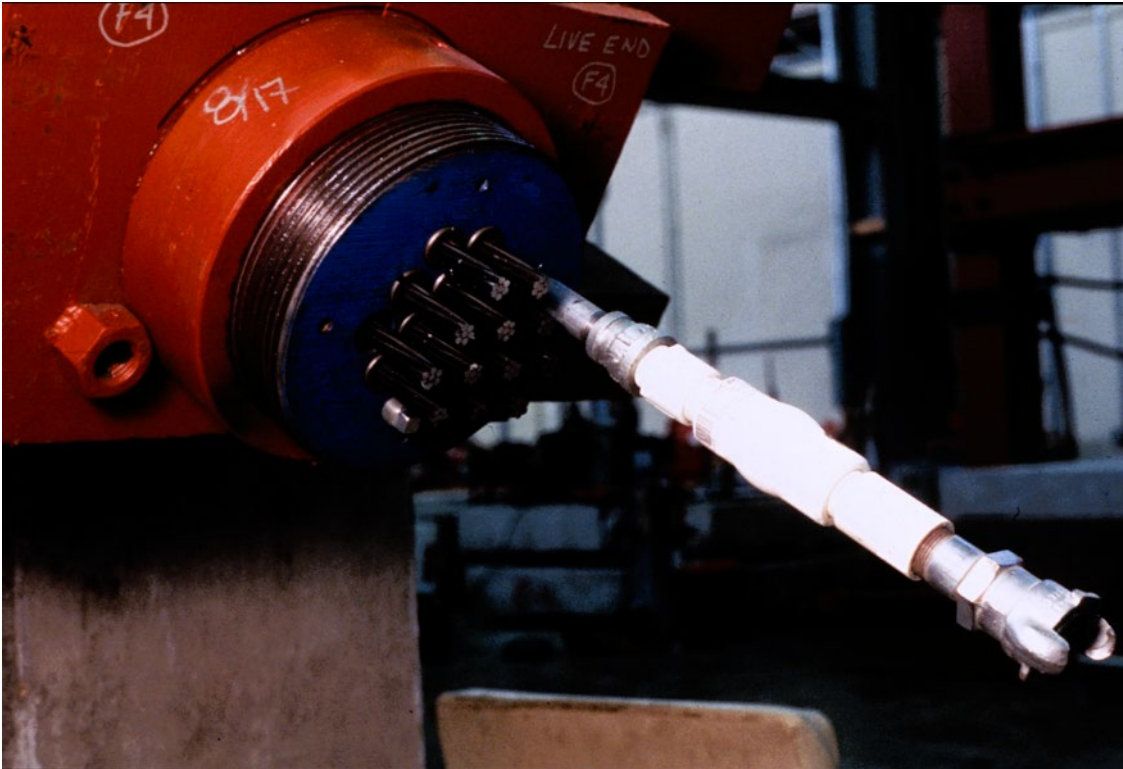
Slide 82. Large scale test three (LS-3). Installation. Coating strand with oil.



Slide 83. Large scale test three (LS-3). Assembly. Dead end stressing assembly.



Slide 84. Specimen LS-8.



Slide 85. Anchor head.



Slide 86. Mixing.



Slide 87. Agitating.



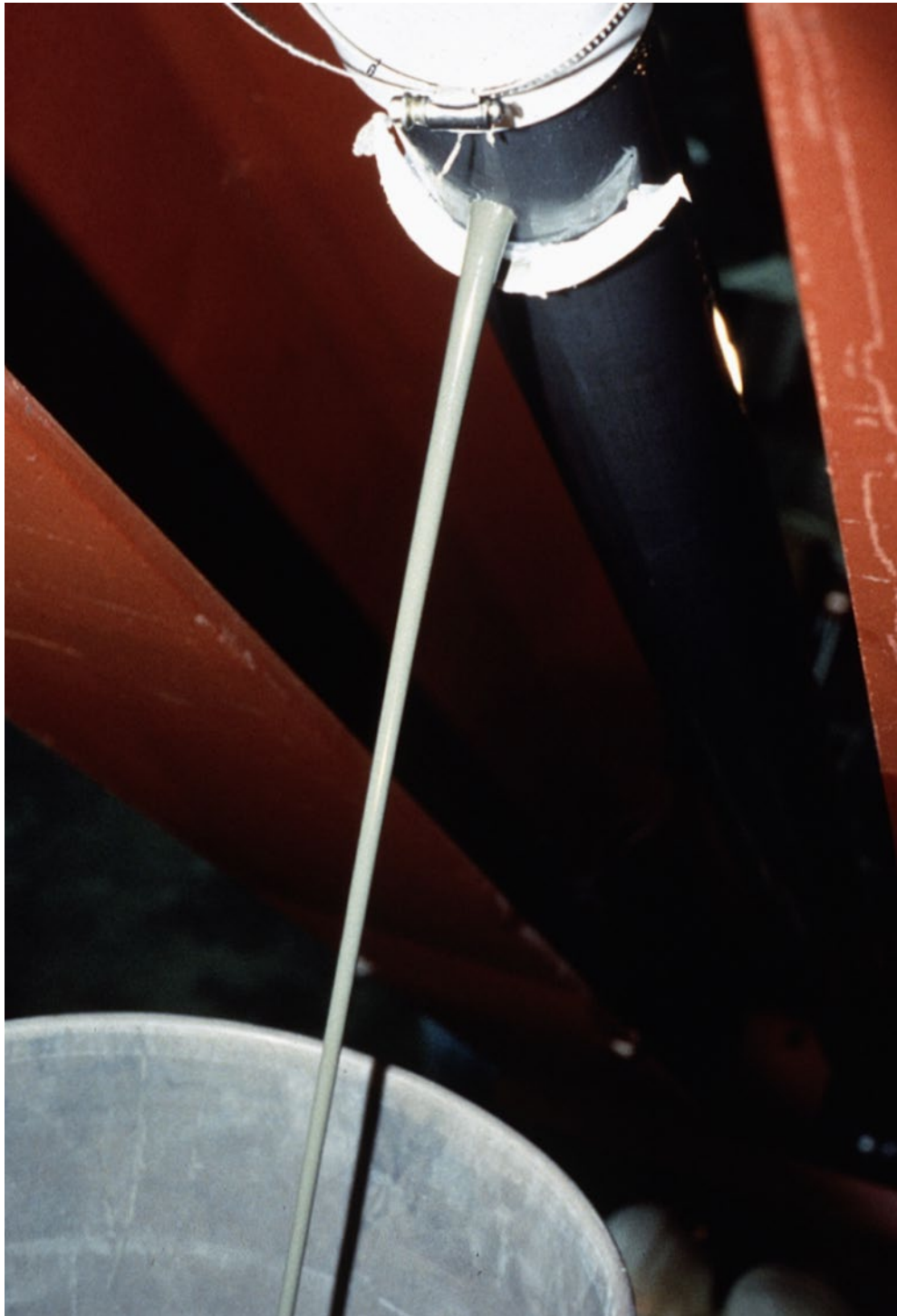
Slide 88. Straining grout.



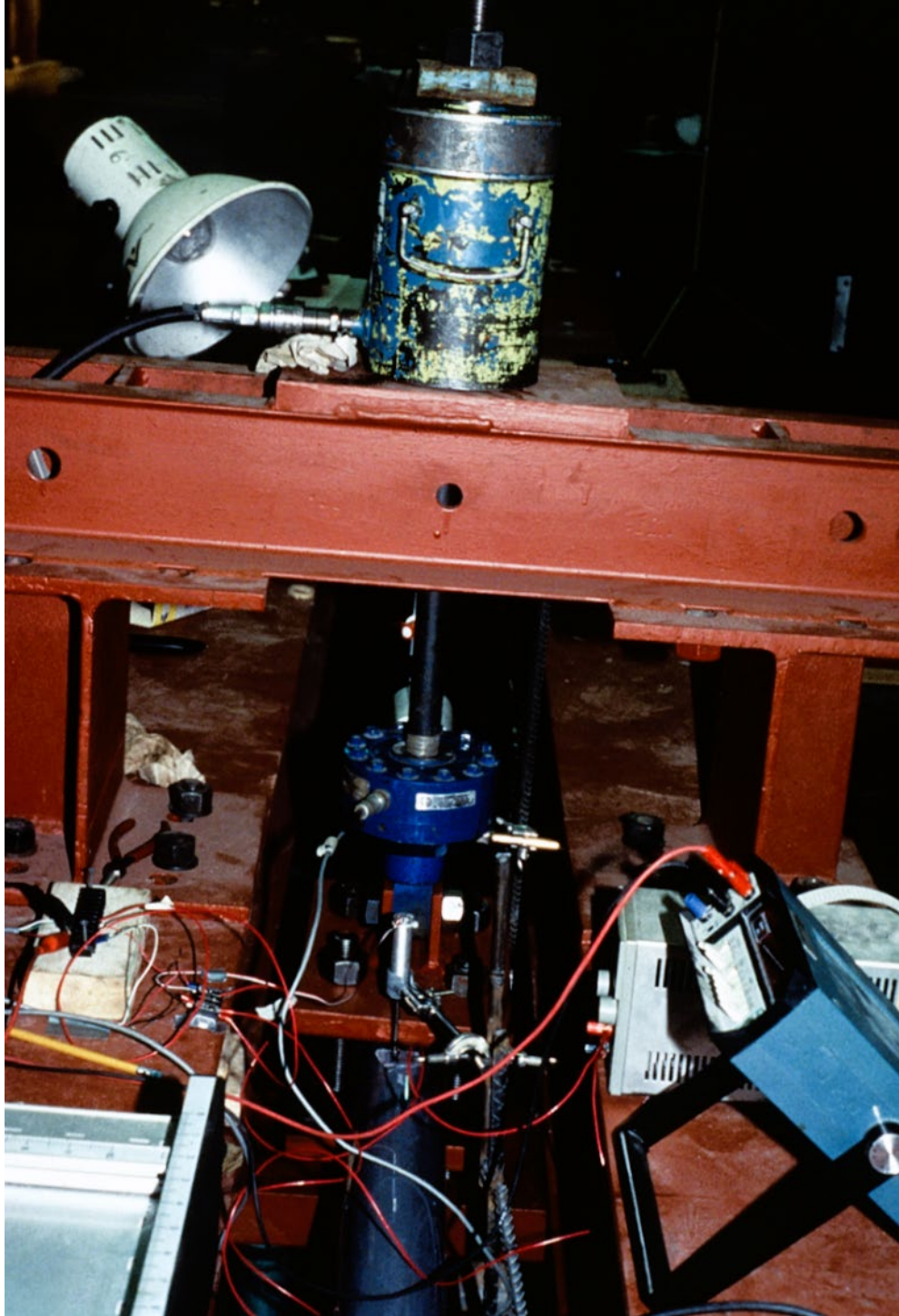
Slide 89. Recirculating to remove air.



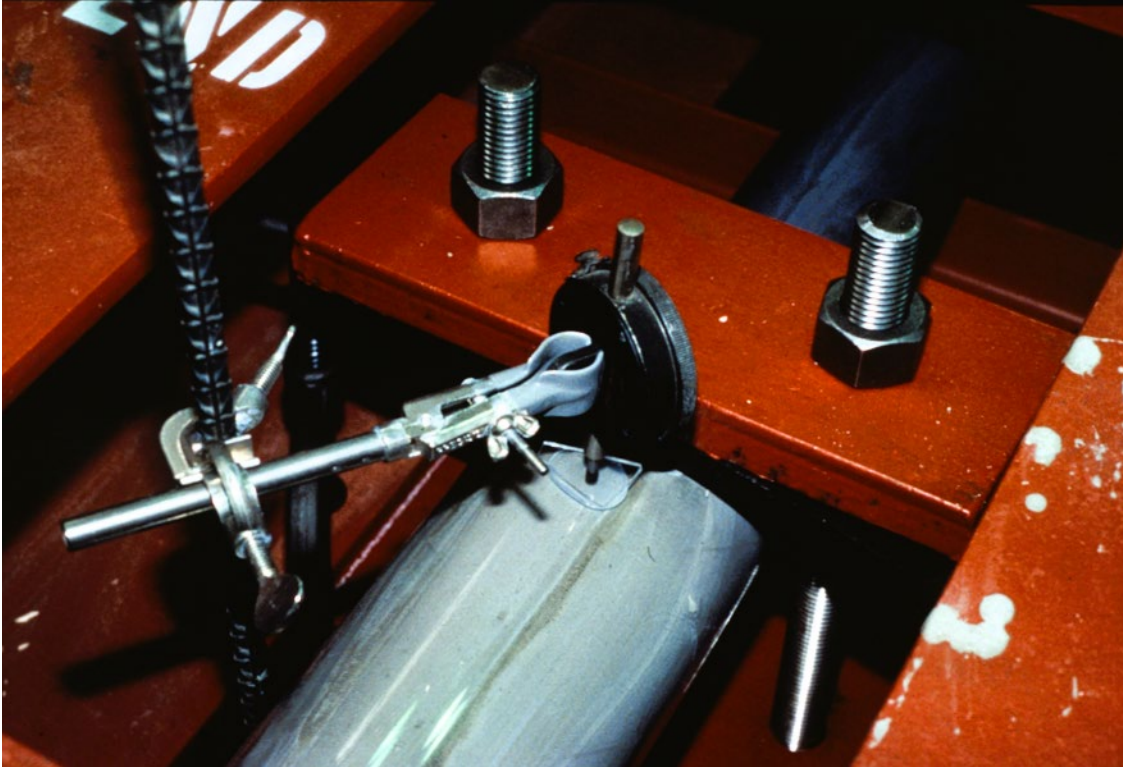
Slide 90. Removing attachment (?).



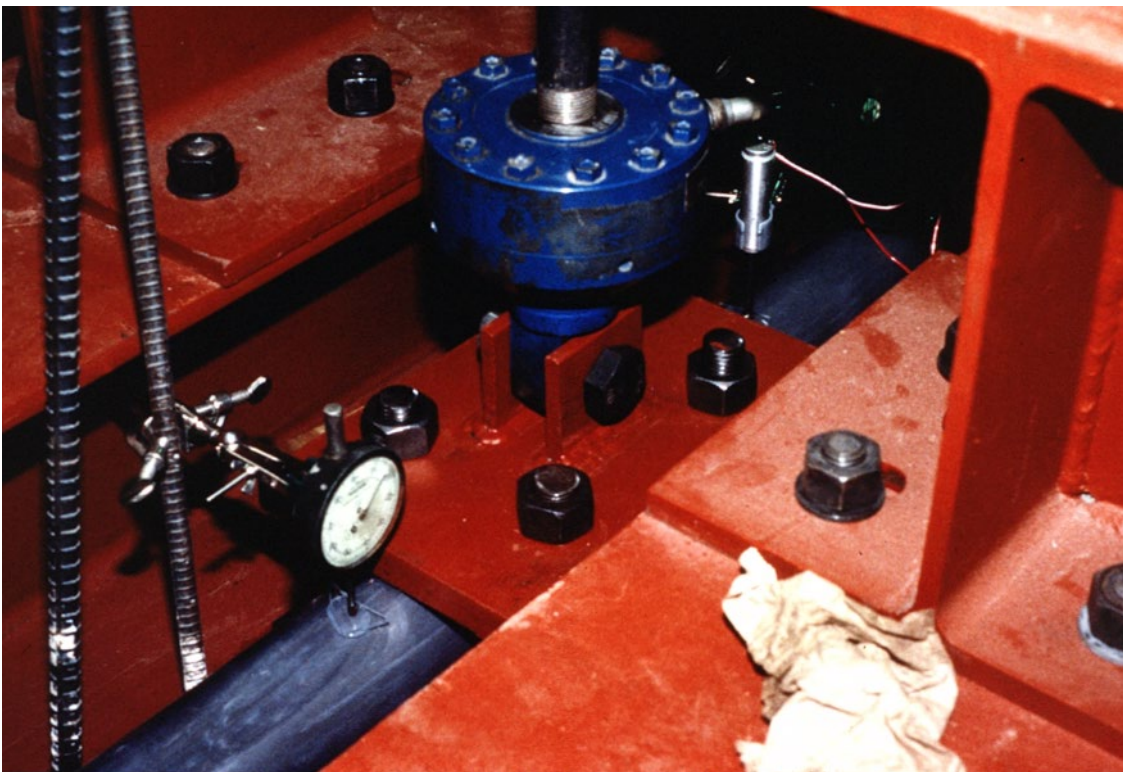
Slide 91. Discharge of first lift.



Slide 92. Test set-up.



Slide 93. Test set-up (detail).



Slide 94. Test set-up (detail).

Part 2. Miscellaneous Pictures from Dissection of LS-1-LS-5



Slide 95. Large scale. Overall of grouting and assembly.



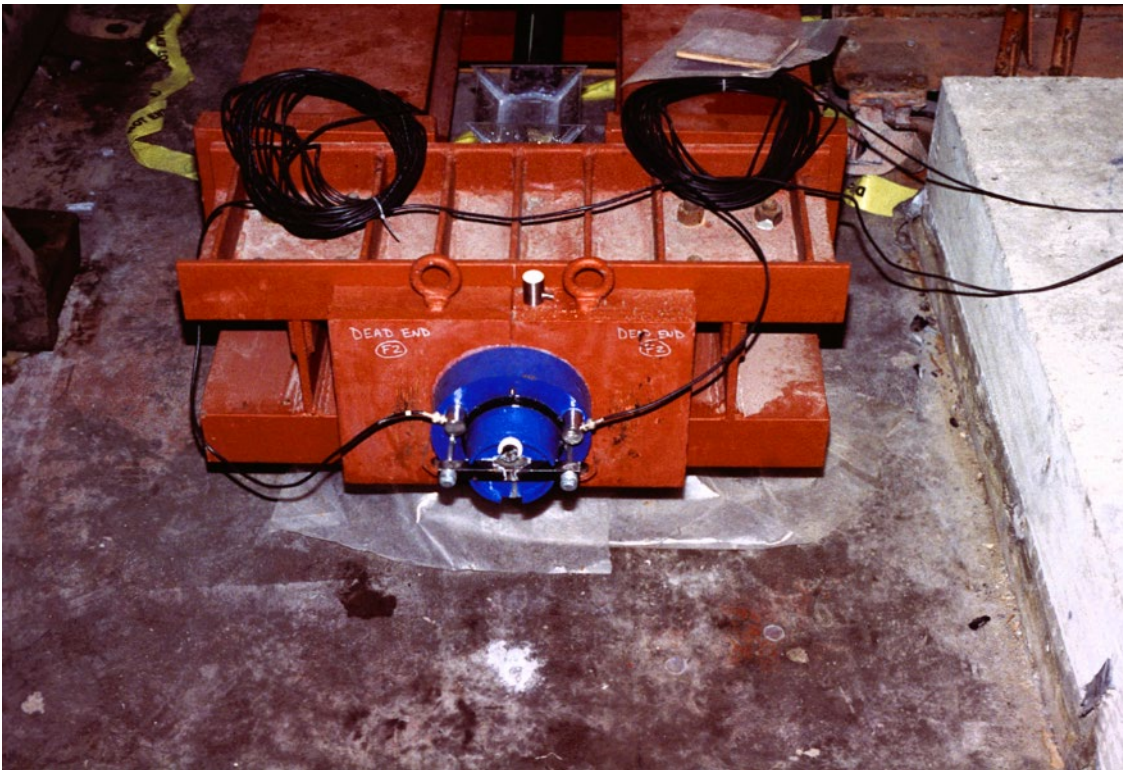
Slide 96. Large scale test five (LS-5).



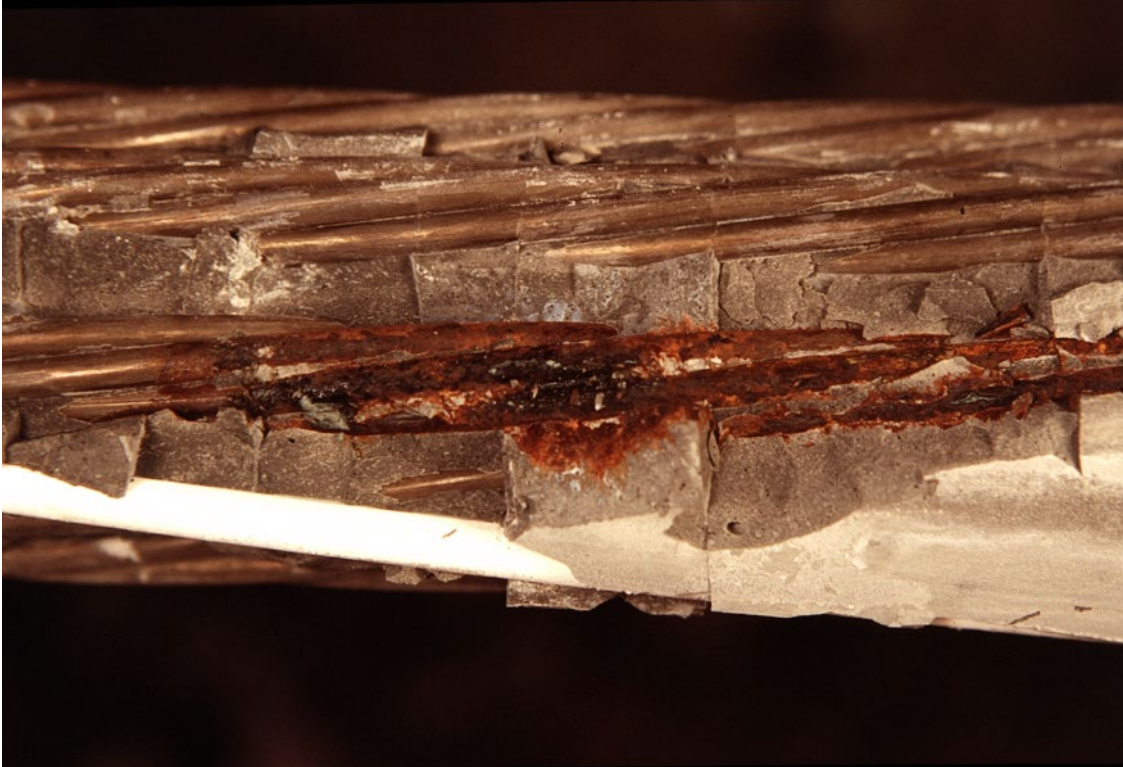
Slide 97. Large scale test one (LS-1). Break in grout at bott [?] trans. in third after grout.



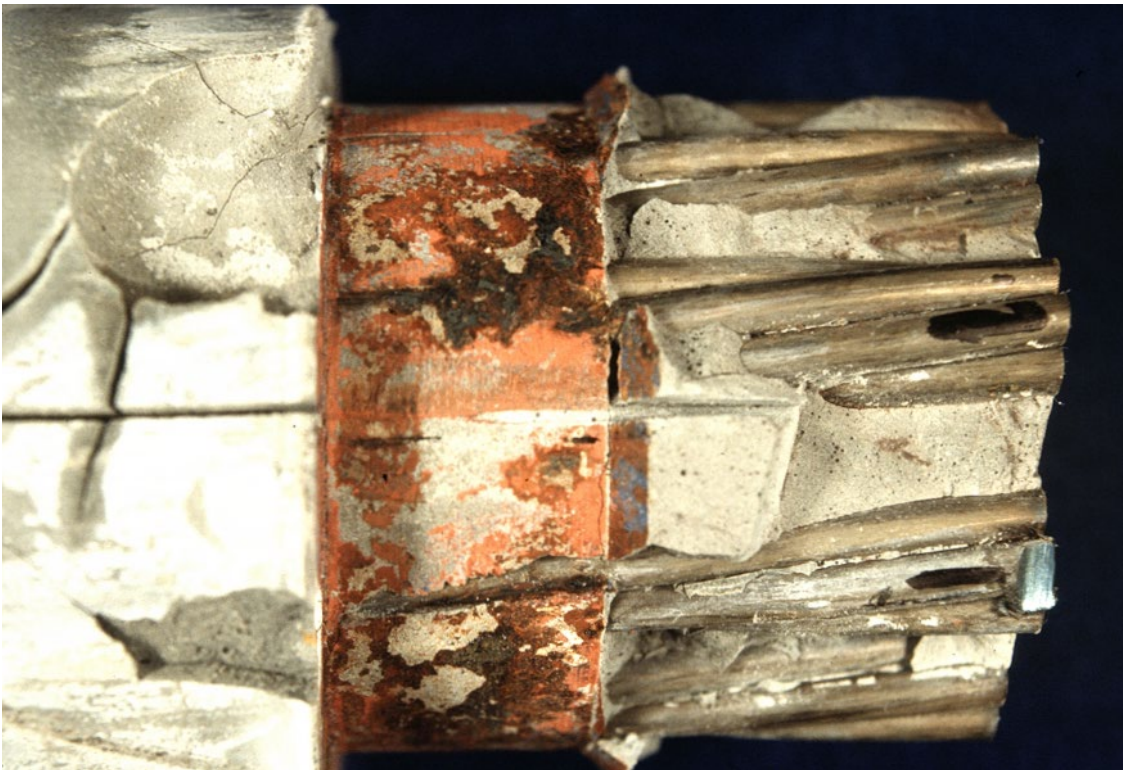
Slide 98. Large scale test five (LS-5). May 2, 1995.



Slide 99. Large scale test five (LS-5). D.E. leaking grout cap. February 22, 1995.



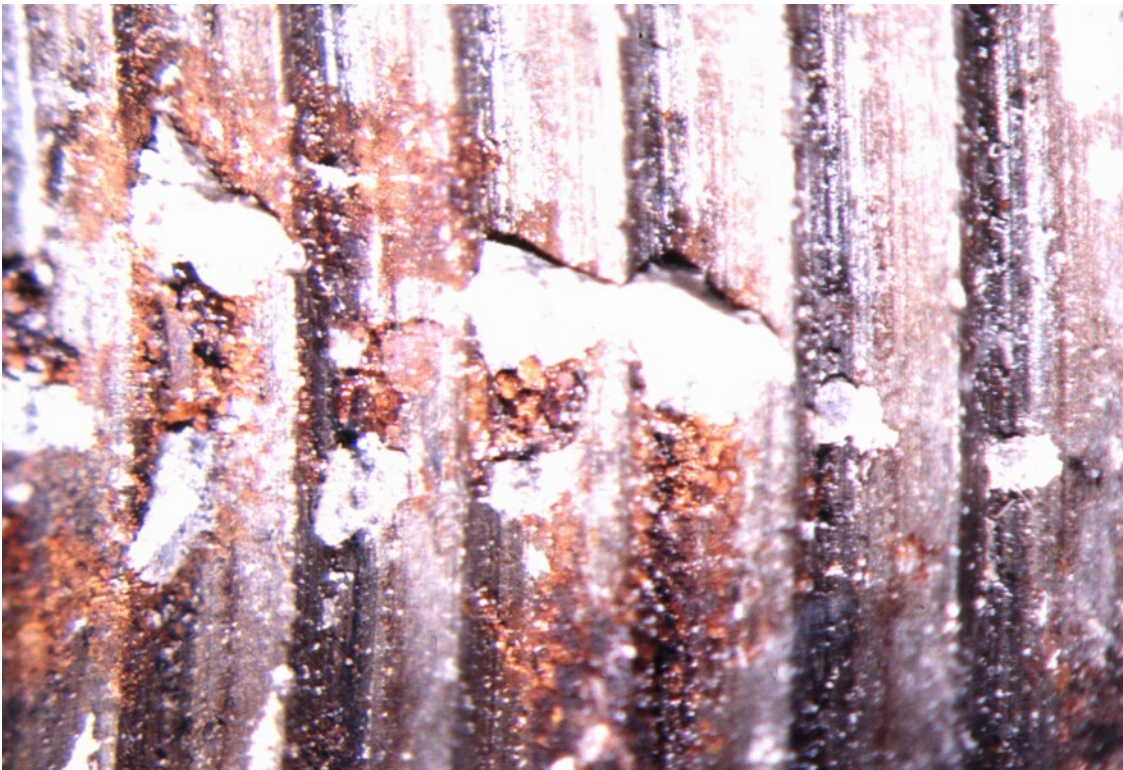
Slide 100. Large scale test five (LS-5). May 2, 1995.



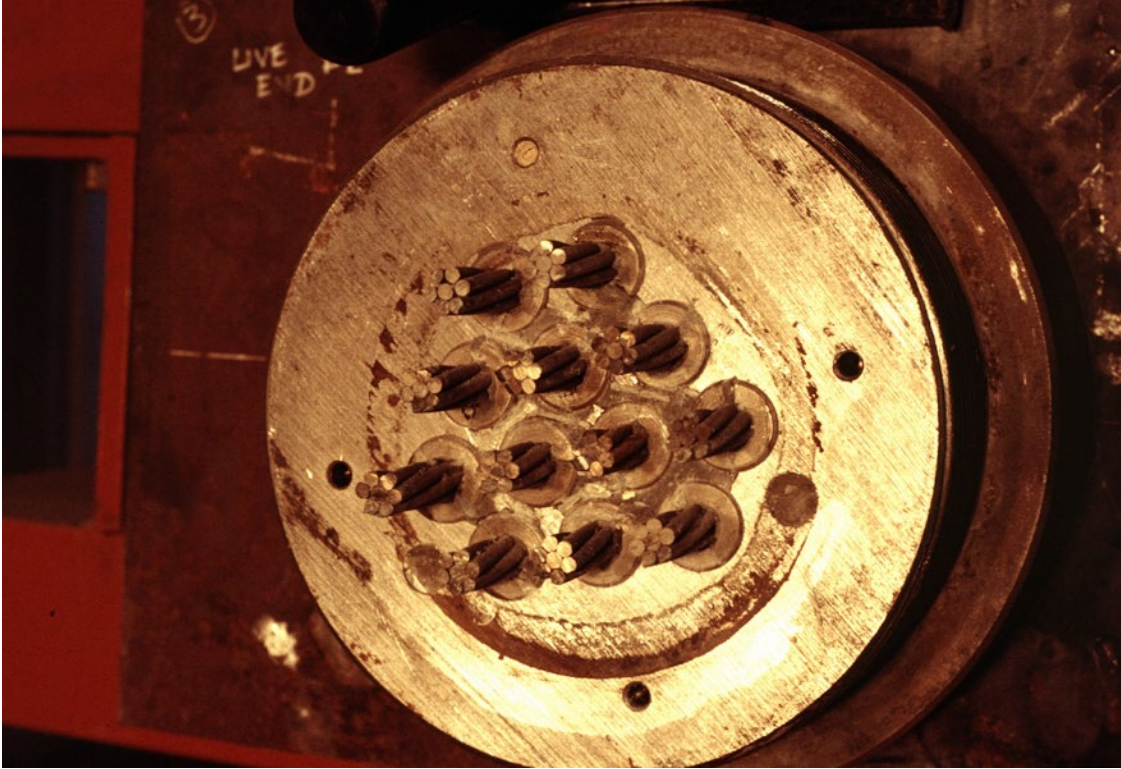
Slide 101. Large scale test five (LS-5). May 2, 1995.



Slide 102. Large scale test four (LS-4). L.E. July 6, 1994.



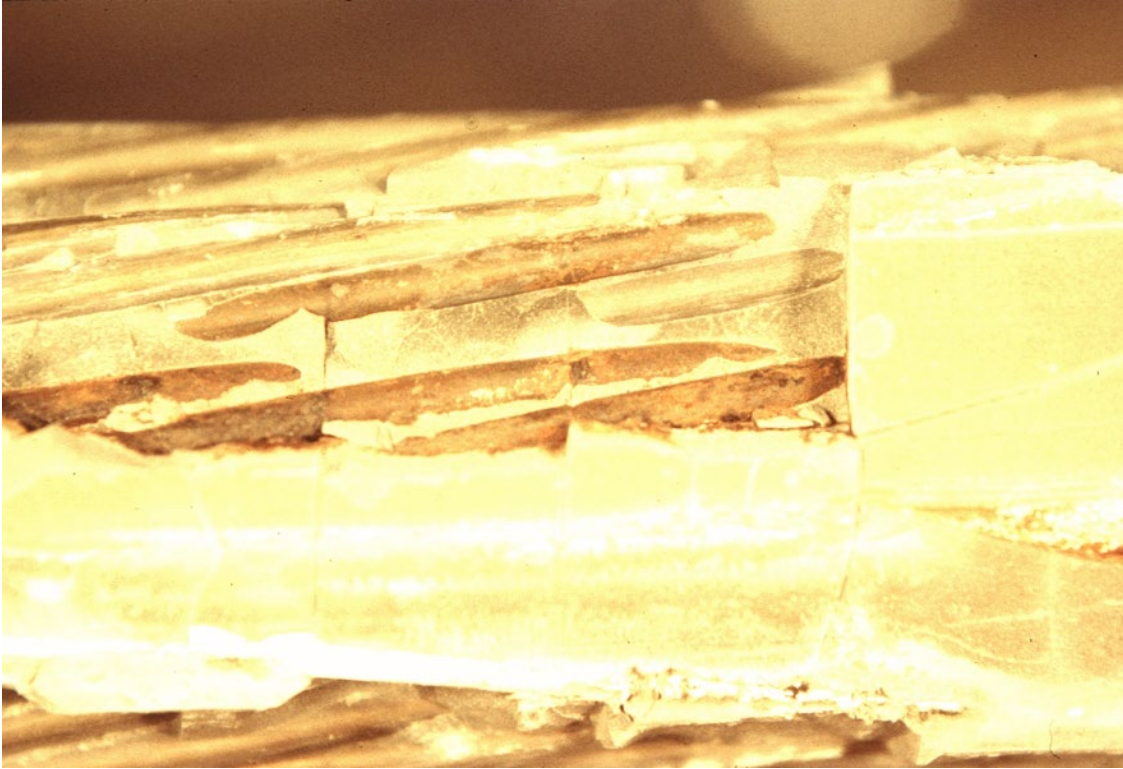
Slide 103. Large scale test two (LS-2)/4. Wedge. August 23, 1994.



Slide 104. Large scale test four (LS-4). L.E. Under grout cap. July 6, 1994.



Slide 105. Large scale test three (LS-3). Diss. L.E. February 24, 1994.

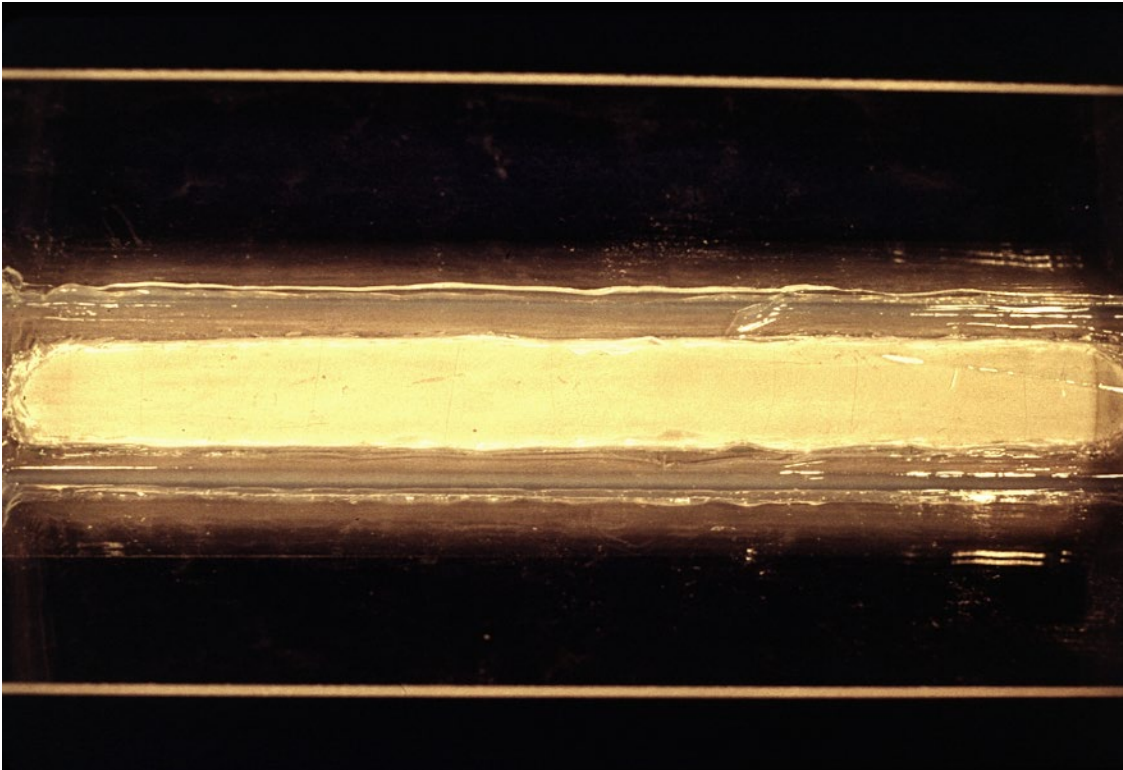


Slide 106. Large scale test one (LS-1). Corrosion at crack. Copy #6. March 28, 1994.



Slide 107. Large scale test two (LS-2). September 30, 1994.

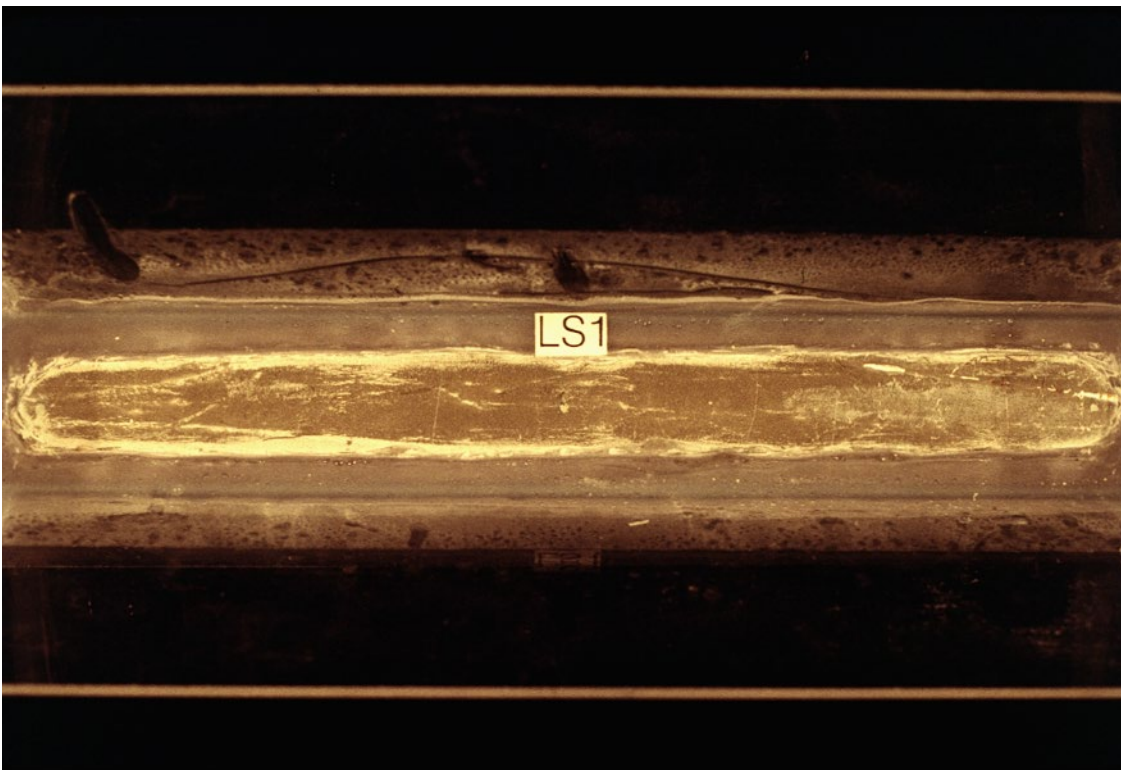
Part 3. OPNG#2: LS-1 from Start to Finish [and LS-3]



Slide 108. Large scale test one (LS-1). Corrosion. L.E. 2nd copy. November 5, 1993.



Slide 109. Large scale test one (LS-1). Corrosion. L.E. 2nd copy. November 19, 1993.



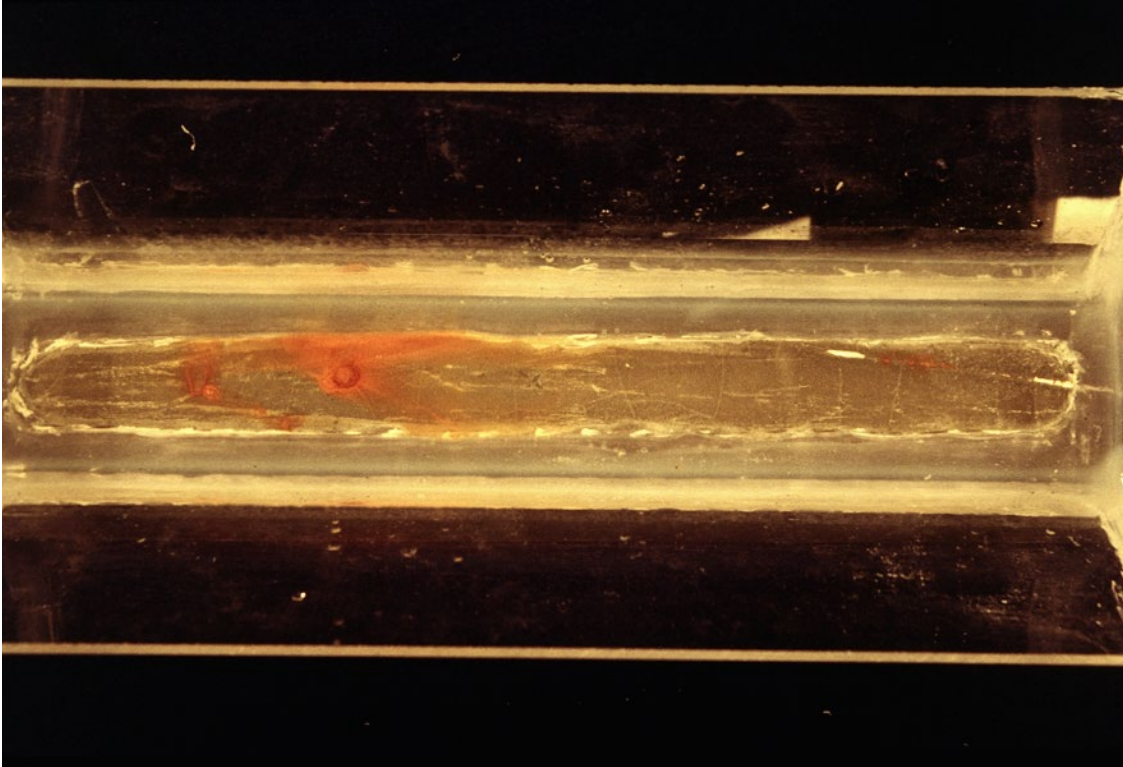
Slide 110. Large scale test one (LS-1). Corrosion. L.E. 2nd copy. December 3, 1993.



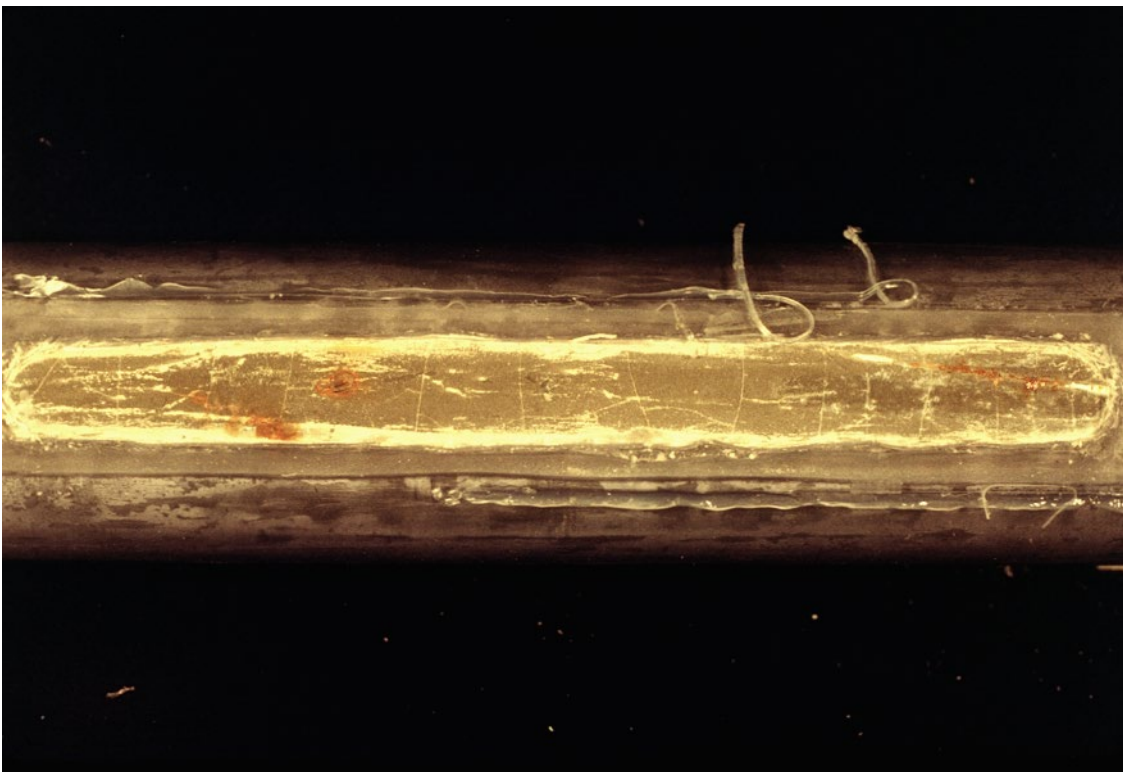
Slide 111. Large scale test one (LS-1). Corrosion. #2. December 17, 1993.



Slide 112. Large scale test one (LS-1) #2. December 31, 1993.



Slide 113. Large scale test one (LS-1) #2. January 12, 1994.



Slide 114. Large scale test one (LS-1) #2. January 31, 1994.



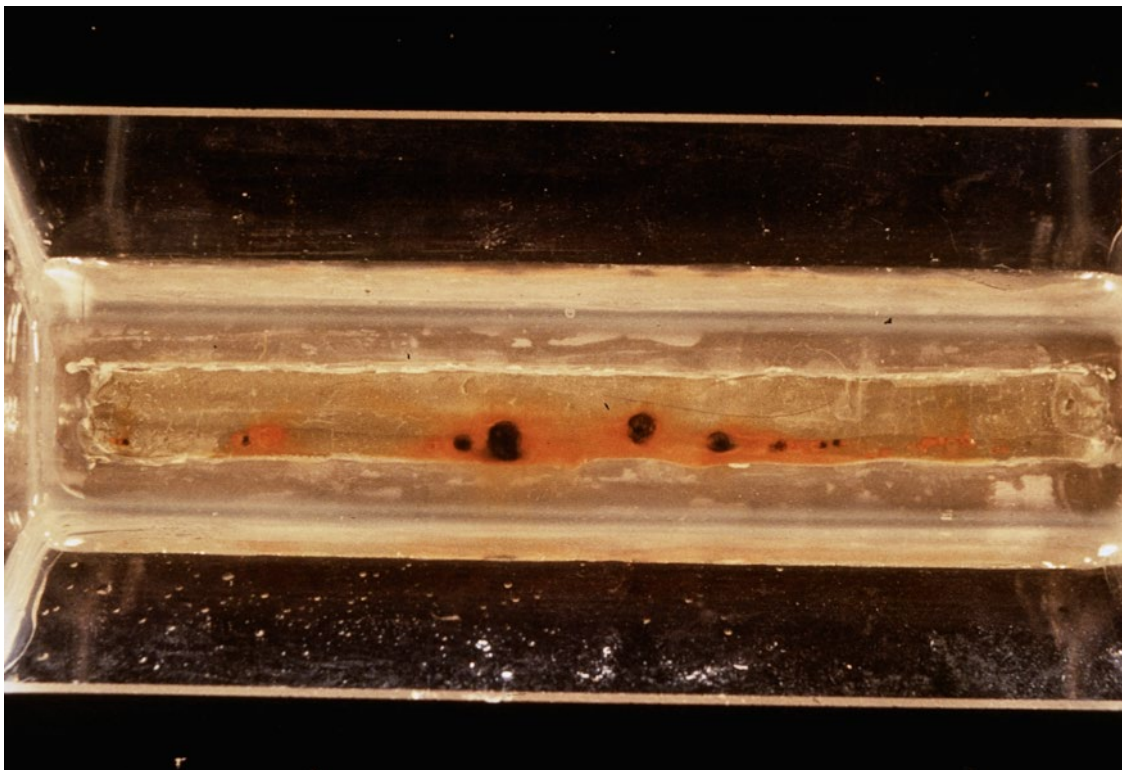
Slide 115. Large scale test one (LS-1). Corrosion. 2nd copy. March 28, 1994.



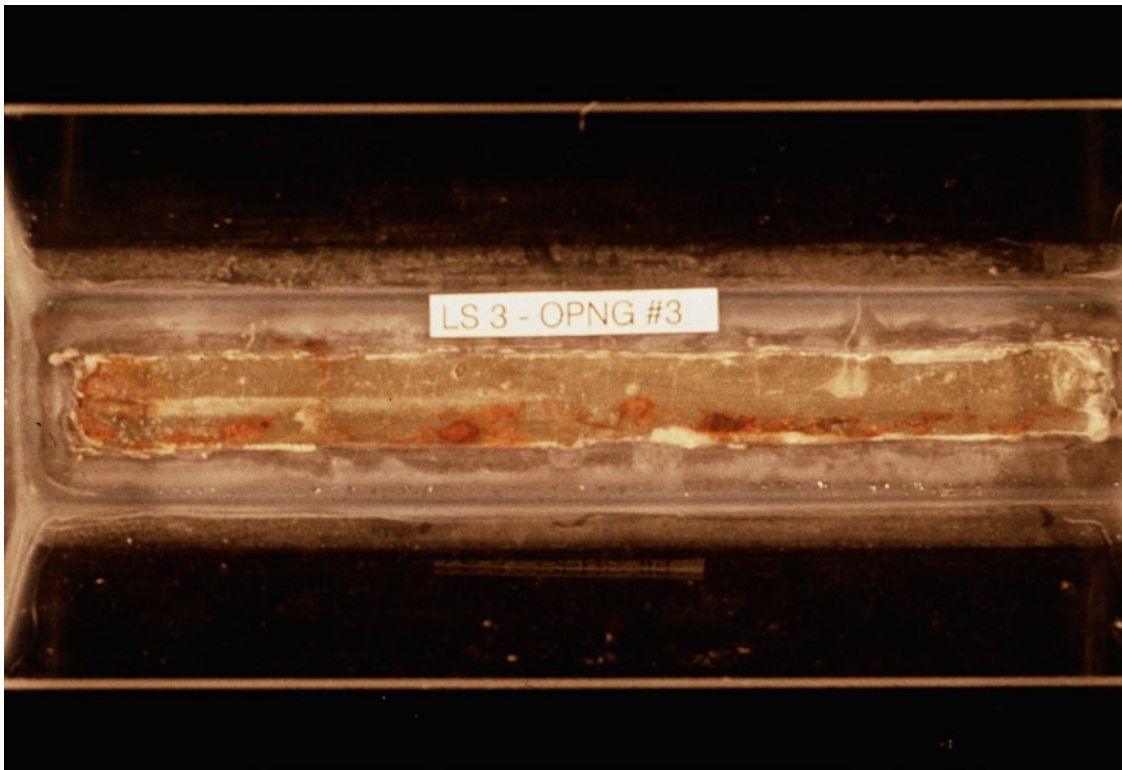
Slide 116. Large scale test one (LS-1). Corrosion. 2nd copy. March 28, 1994.



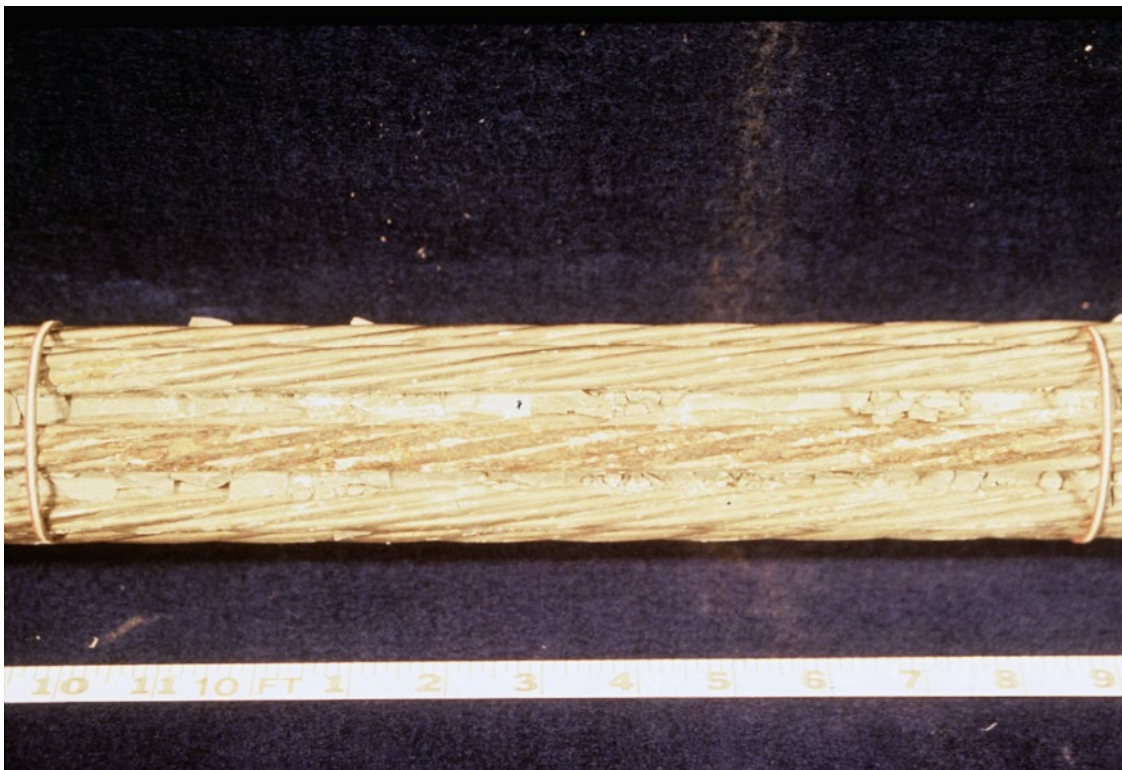
Slide 117. Large scale test three (LS-3). Copy 3.



Slide 118. Large scale test three (LS-3). Copy 3.

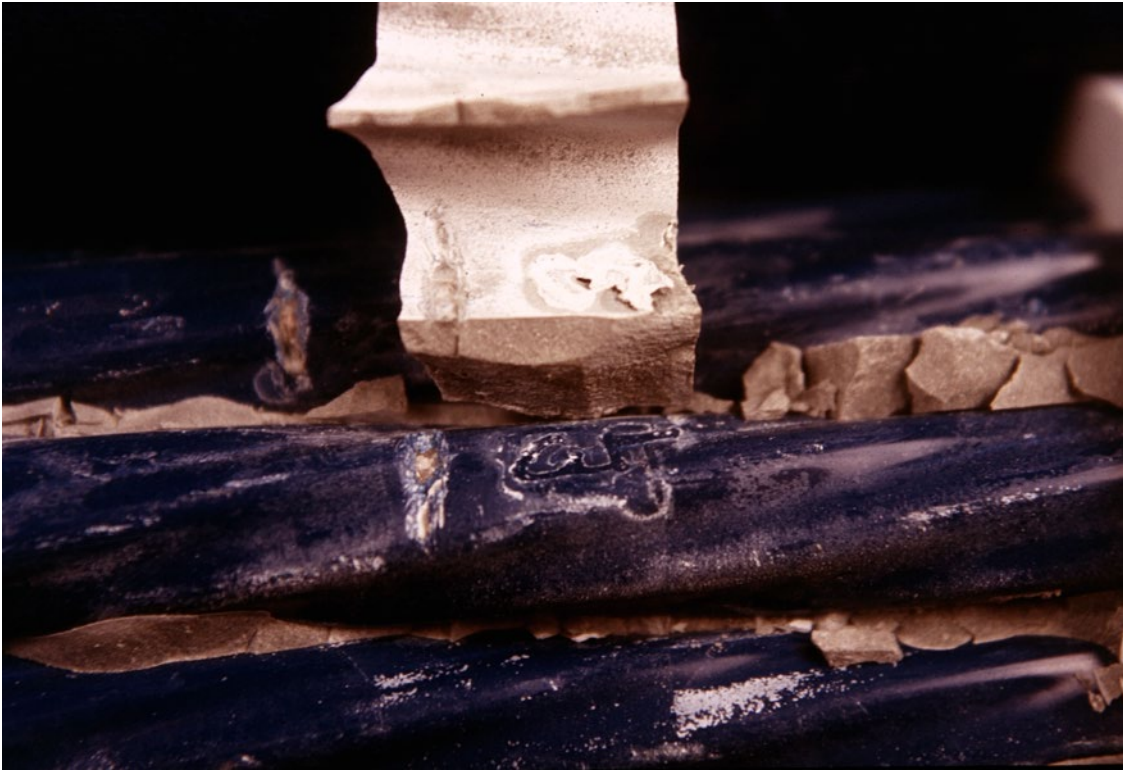


Slide 119. Large scale test three (LS-3). Copy 3.

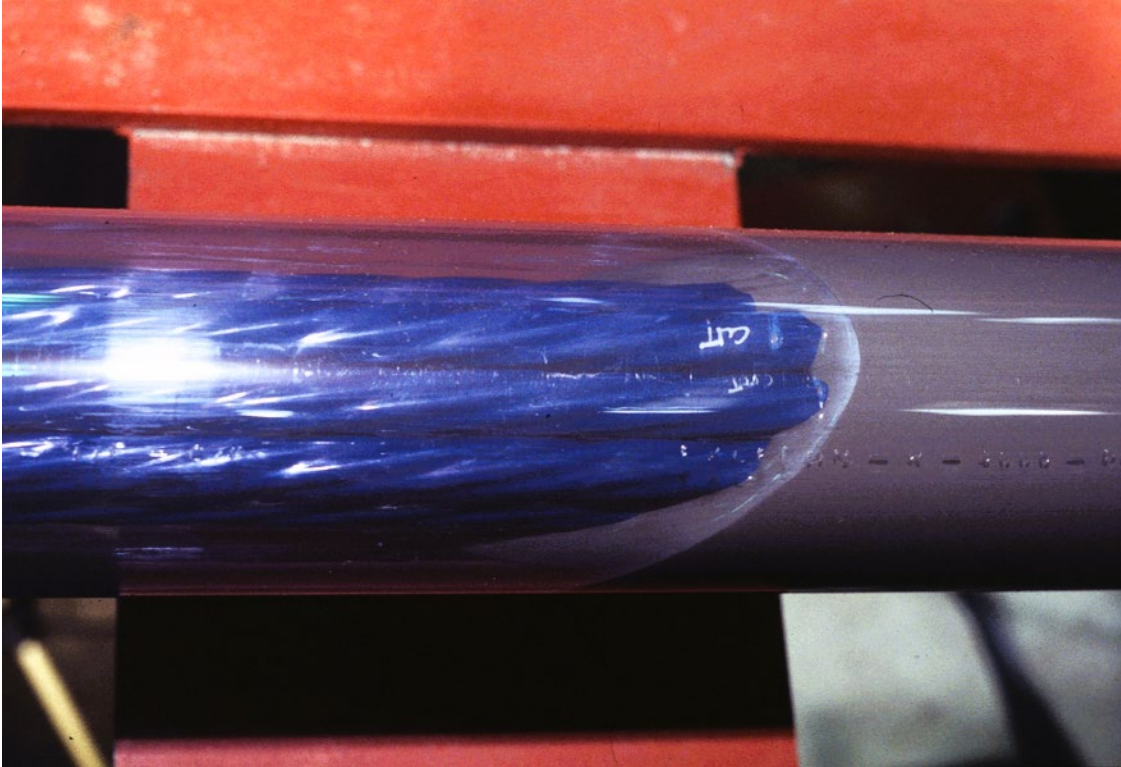


Slide 120. Large scale test three (LS-3). Copy 3.

Part 4. LS-6: Epoxy



Slide 121. Large scale test six (LS-6). December 13, 1994.



Slide 122. Large scale test six (LS-6). Grout in pipe. June 30, 1994.



Slide 123. Large scale test six (LS-6). December 13, 1994.



Slide 124. Large scale test six (LS-6). March 10, 1995.



Slide 125. Grout in epoxy repair cap. February 20, 1995.



Slide 126. Large scale test six (LS-6). March 10, 1995.

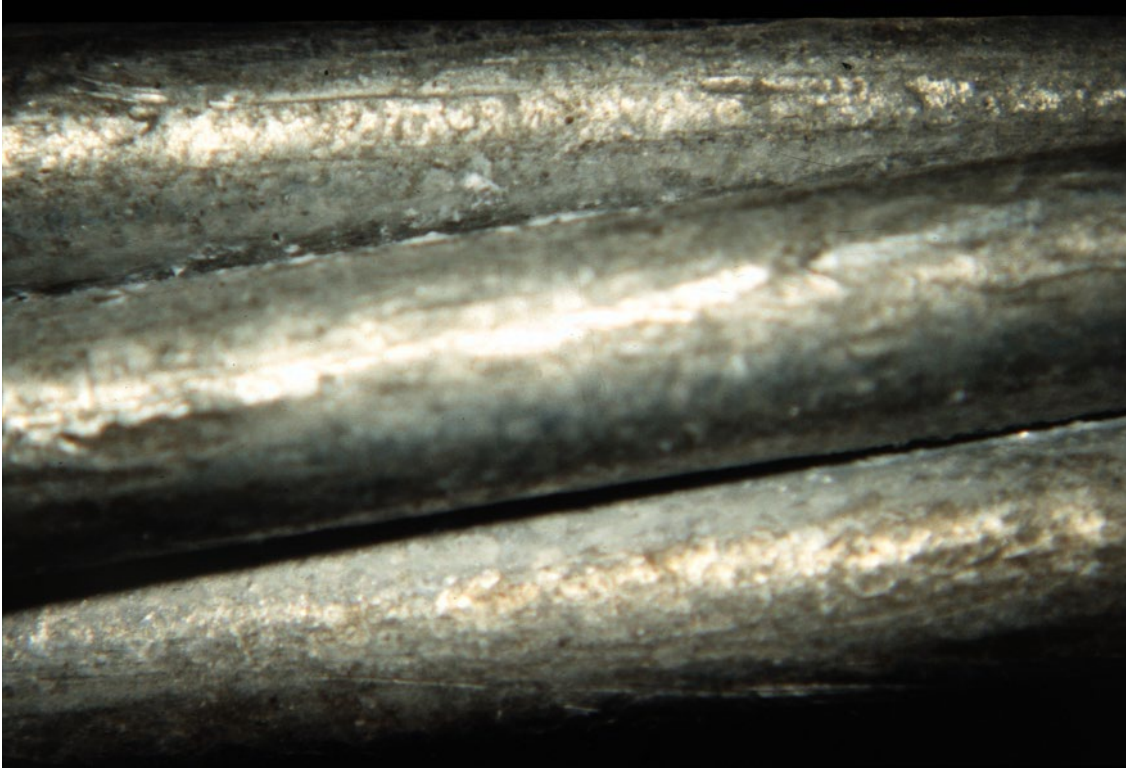


Slide 127. Large scale test six (LS-6). March 10, 1995.



Slide 128. Large scale test six (LS-6). March 10, 1995.

Part 5. LS-7: Galvanized



Slide 129. Large scale test seven (LS-7). April 7, 1995.



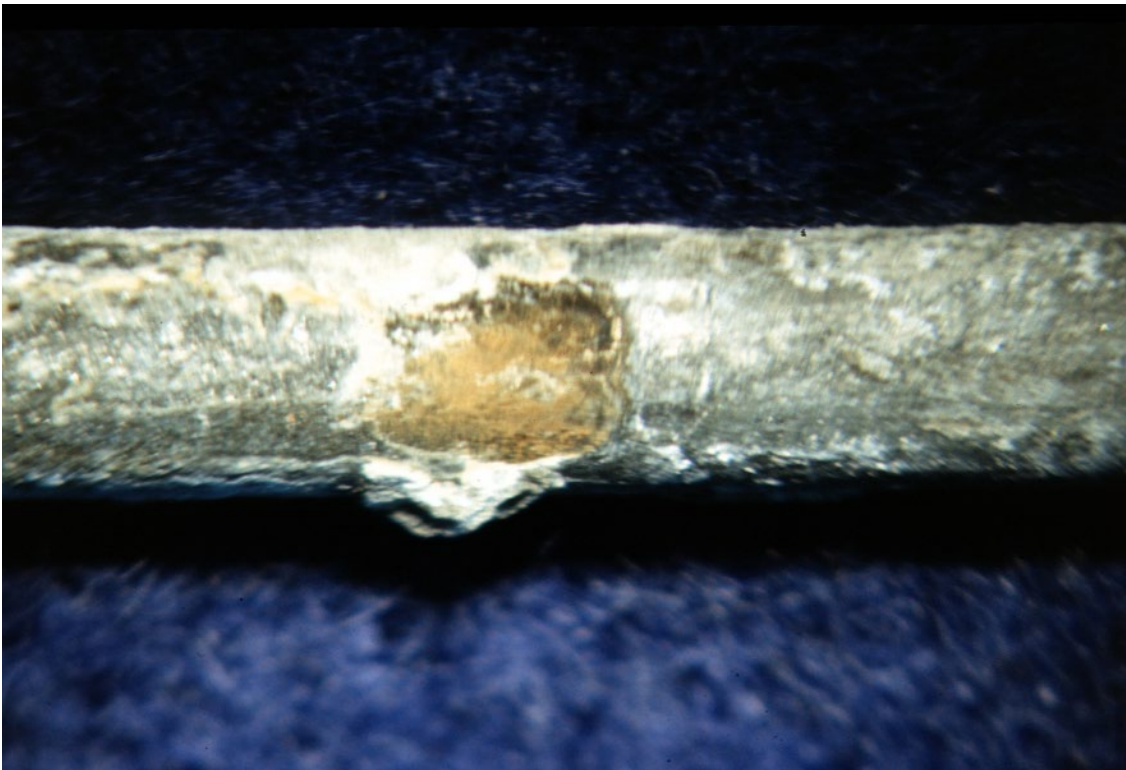
Slide 130. Large scale test seven (LS-7). March 23, 1995.



Slide 131. Large scale test seven (LS-7). March 30, 1995.



Slide 132. Large scale test seven (LS-7). April 7, 1995.



Slide 133. Large scale test seven (LS-7). April 7, 1995.



Slide 134. Large scale test seven (LS-7). March 23, 1995.



Slide 135. Large scale test seven (LS-7). March 17, 1995.

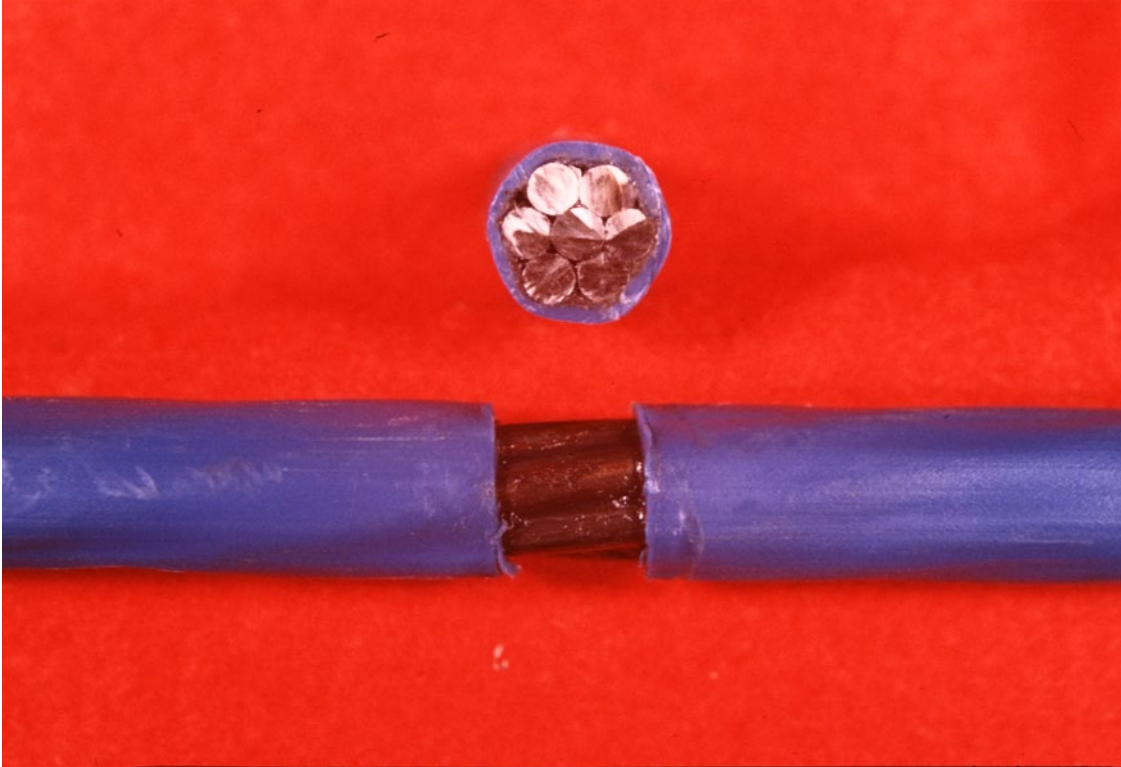


Slide 136. Large scale test seven (LS-7). March 17, 1995.

Part 6. LS-8: Greased/Sheathed



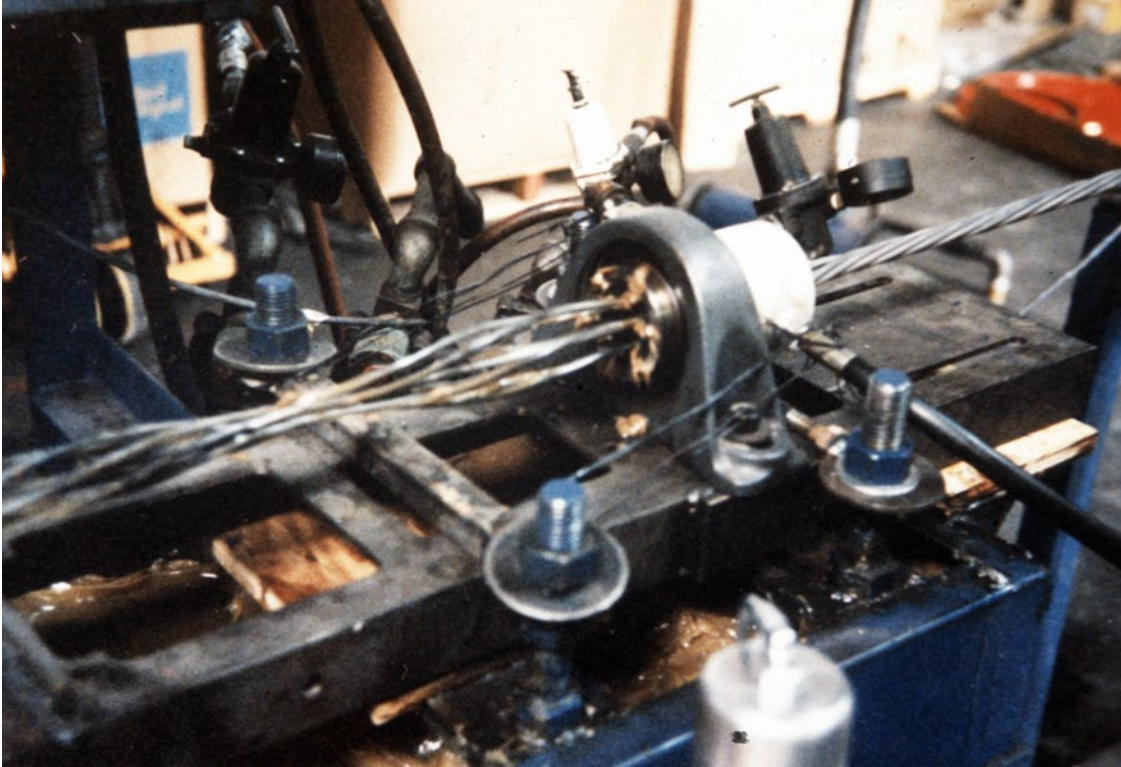
Slide 137. Large scale test eight (LS-8). Damage. August 23, 1994.



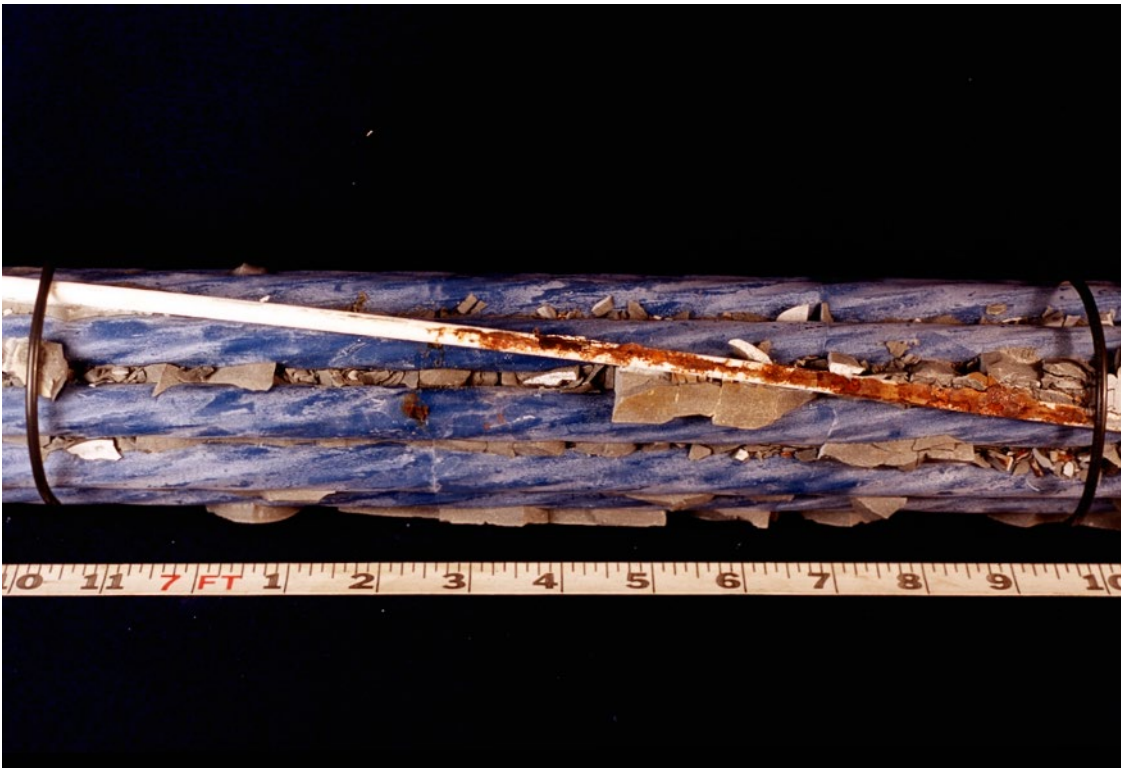
Slide 138. Large scale test eight (LS-8). Typical. August 23, 1994.



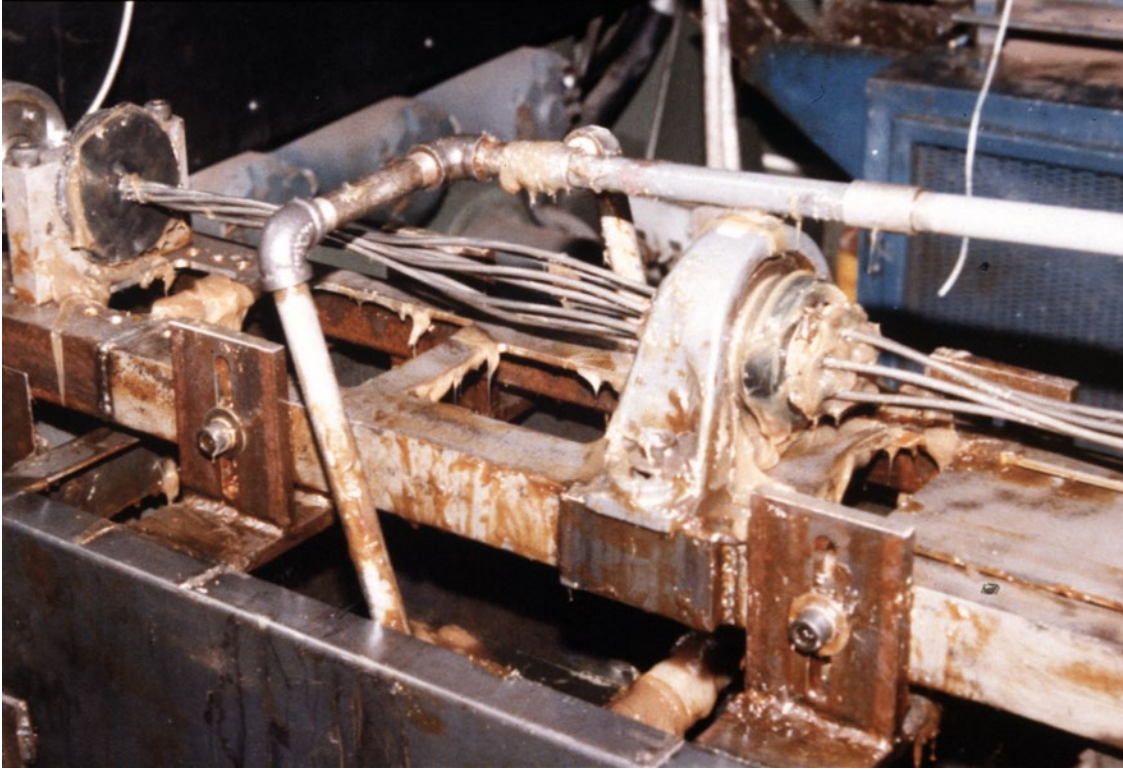
Slide 139. Large scale test eight (LS-8). Tape repair. February 20, 1995.



Slide 140. Picture from VSL.



Slide 141. Large scale test eight (LS-8). Copy 2. March 24, 1995.



Slide 142. De-stranding and application of grease to strand prior to extrusion of sheathing.



Slide 143. Large scale test eight (LS-8). March 30, 1995.



Slide 144. Large scale test eight (LS-8). March 24, 1995.



Slide 145. Large scale test eight (LS-8). March 24, 1995.



Slide 146. Large scale test eight (LS-8). March 24, 1995.



Slide 147. Large scale test eight (LS-8). April 7, 1995.



Slide 148. Large scale test eight (LS-8). March 24, 1995.



Slide 149. Large scale test eight (LS-8). March 24, 1995.



Slide 150. Large scale test eight (LS-8). March 24, 1995.

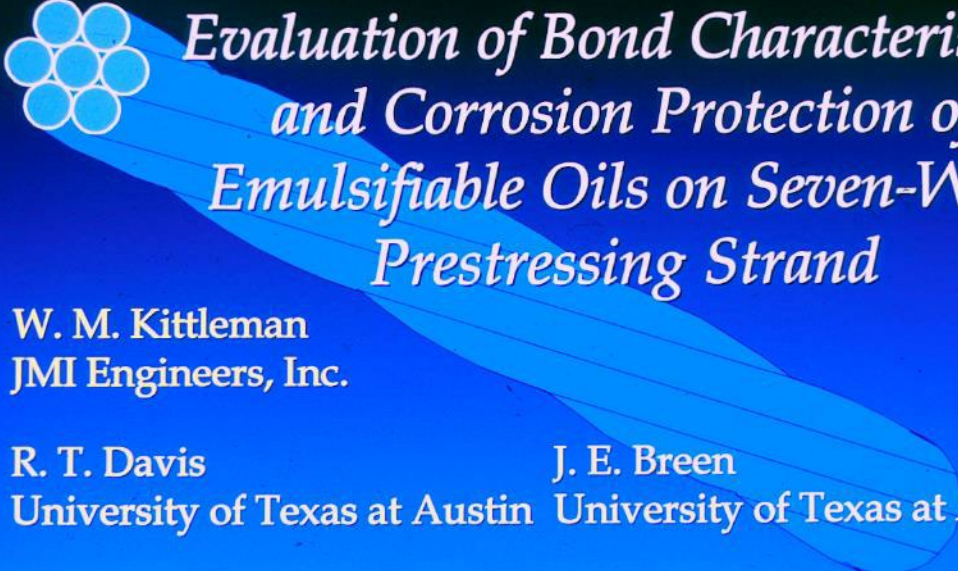


Slide 151. Large scale test eight (LS-8). March 24, 1995.



Slide 152. Large scale test eight (LS-8). March 30, 1995.

Section 4. Lubrication, Bond and Corrosion Protection of Emulsifiable Oils (Kittleman)

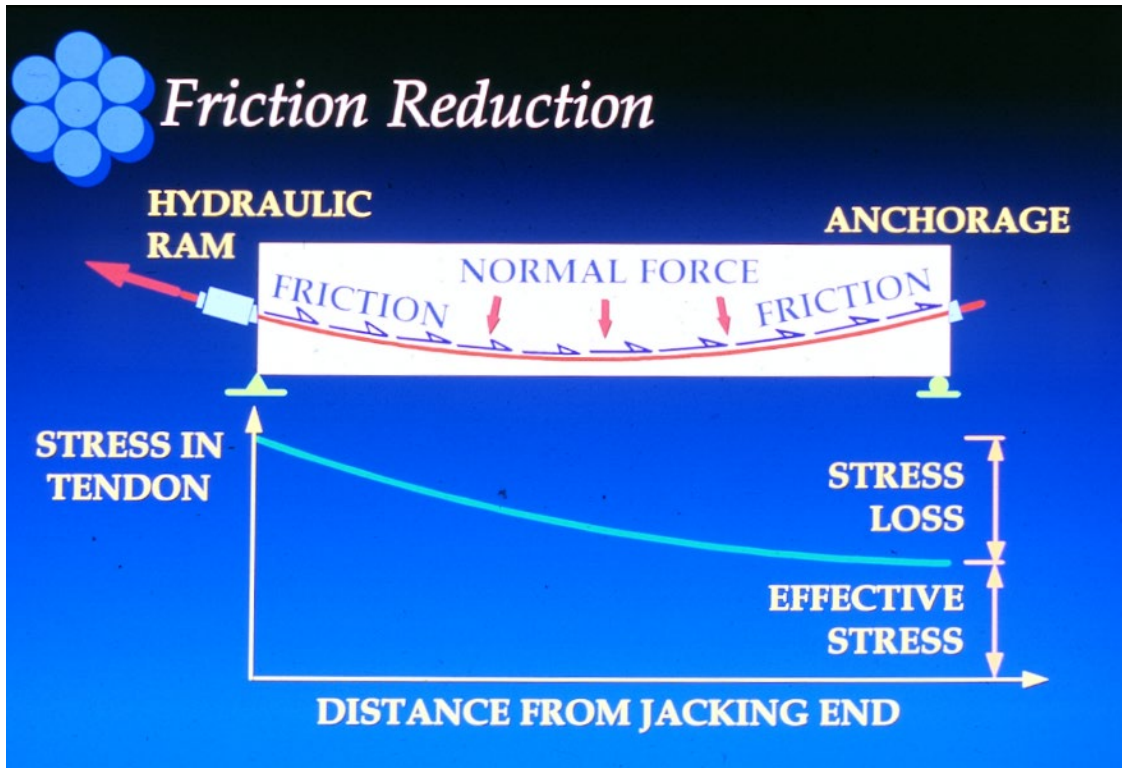


*Evaluation of Bond Characteristics
and Corrosion Protection of
Emulsifiable Oils on Seven-Wire
Prestressing Strand*

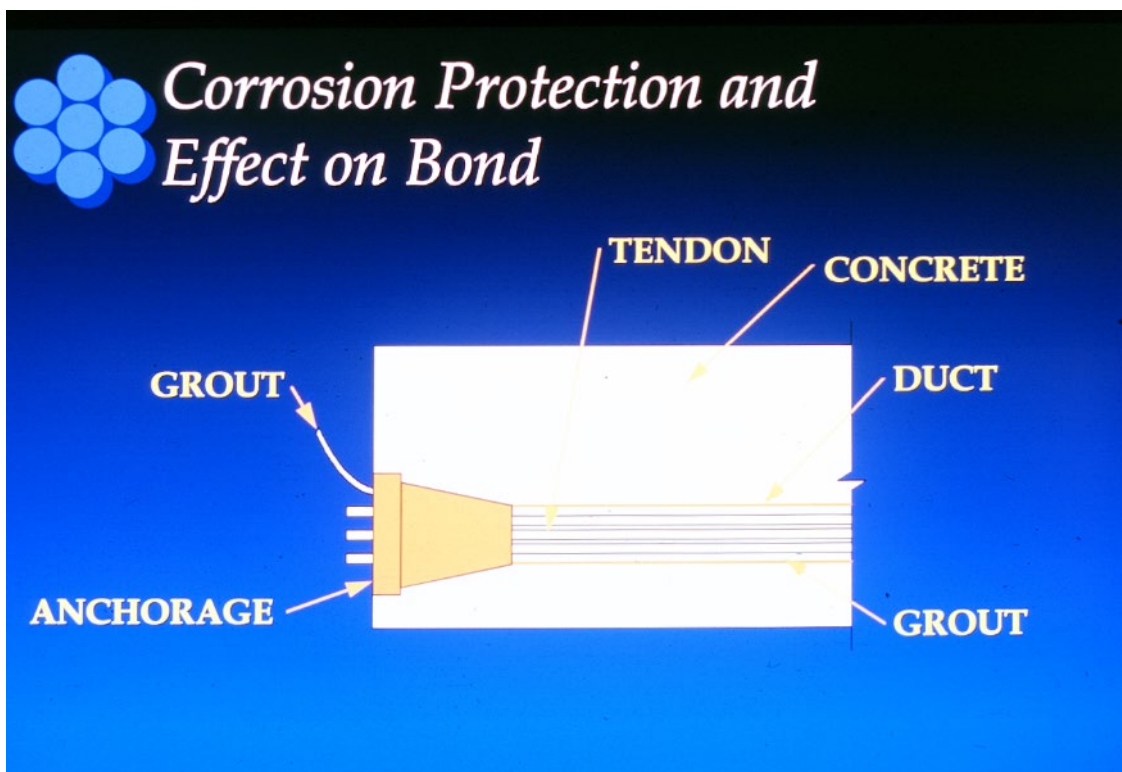
W. M. Kittleman
JMI Engineers, Inc.

R. T. Davis University of Texas at Austin	J. E. Breen University of Texas at Austin
H. R. Hamilton III University of Texas at Austin	K. H. Frank University of Texas at Austin

Slide 153. Evaluation of Bond Characteristics and Corrosion Protection of Emulsifiable Oils on Seven-Wire Prestressing Strand



Slide 154. Friction Reduction



Slide 155. Corrosion Protection and Effect on Bond



Agents Evaluated

- ❖ Visconorust 8415E
- ❖ Dromus B
- ❖ Unocal 10
- ❖ Unocal MS
- ❖ Texaco Soluble D
- ❖ Rust-Veto FB-20
- ❖ Hocut 737
- ❖ Hocut 4284
- ❖ Nalco 6667
- ❖ Wright 502
- ❖ Aqualube MX
- ❖ Bare Strand
- ❖ Graphite Flakes
- ❖ Sodium Silicate

Slide 156. Agents Evaluated



Outline of Experimental Program

- ❖ Small-Scale Friction Tests
- ❖ Accelerated Wire Corrosion Tests
- ❖ Exposure Tests
- ❖ Pull-Out Tests

Slide 157. Outline of Experimental Program



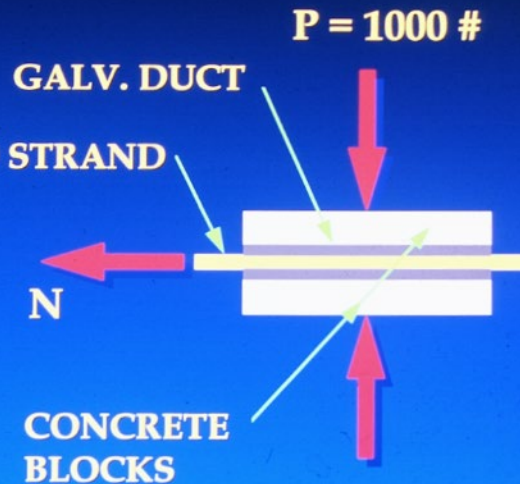
Small-Scale Friction Tests

❖ Simple Test to Model Friction

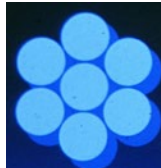
$\frac{1}{2}'' \phi$ STRAND

❖ Dynamic and Static Friction

$$\mu = N/P$$



Slide 158. Small-Scale Friction Tests



Reduction of Dynamic and Static Friction in Small-Scale Test



Slide 159. Reduction of Dynamic and Static Friction in Small-Scale Test



Accelerated Wire Corrosion Tests

- ❖ Accelerated Corrosion Test of Individual Wires of Strand
- ❖ Two Tests per Lubricant
- ❖ Immersion in Two Corrosive Environments
 - 3.5% Salt Solution
 - Deionized Water
- ❖ Corrosion Monitored During Test
- ❖ Corrosion Visually Inspected at Completion

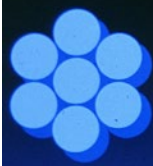
Slide 160. Accelerated Wire Corrosion Tests



Results of Accelerated Corrosion Tests

- ❖ Half-Cell Potential Was Not Effective in Determining Initiation of Corrosion
- ❖ Eight of the Fourteen Lubricants Provided Good to Excellent Corrosion Protection
- ❖ Similar Amounts of Corrosion Were Observed on Bare Wires Tested in Deionized and Salt Solution

Slide 161. Results of Accelerated Corrosion Tests



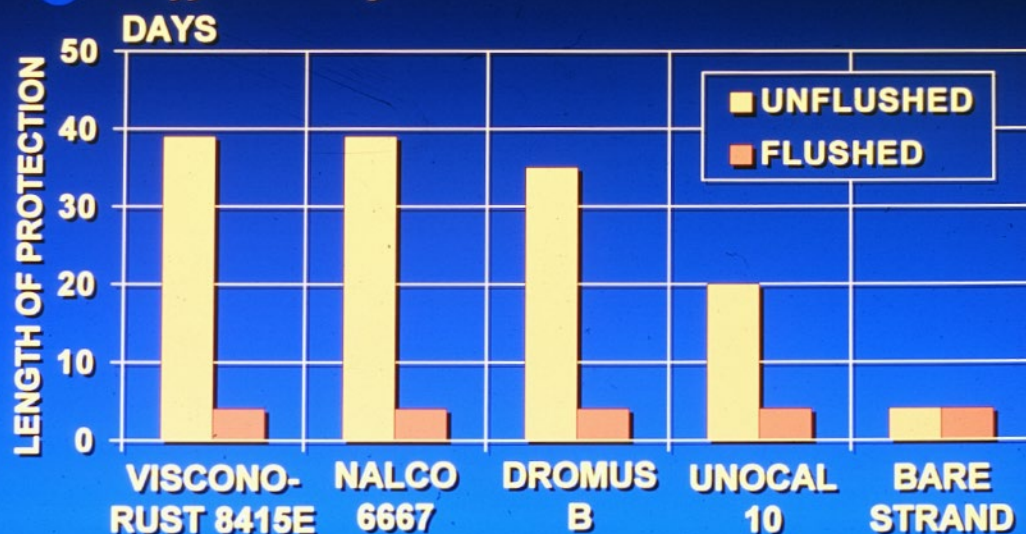
Exposure Tests

- ❖ Specimens of Strand and Wire
- ❖ Two Specimens Immersed in Lubricant
 - One Flushed
 - One Unflushed
- ❖ Placed Outside and Wet Daily for 46 Days
- ❖ Visual Observations Recorded Twice Per Week

Slide 162. Exposure Tests



Length of Corrosion Protection Offered by Lubricants



Slide 163. Length of Corrosion Protection Offered by Lubricants



Results of Exposure Tests

- ❖ **15 To 39 Days of Protection Provided**
- ❖ **Sodium Silicate Protected After Flushing**
- ❖ **Agents That Provided Corrosion Protection for 14 to 18 Days Allowed 10% or Less Corrosion in the Accelerated Wire Corrosion Tests**
- ❖ **Grout Immediately After Flushing**

Slide 164. Results of Exposure Tests

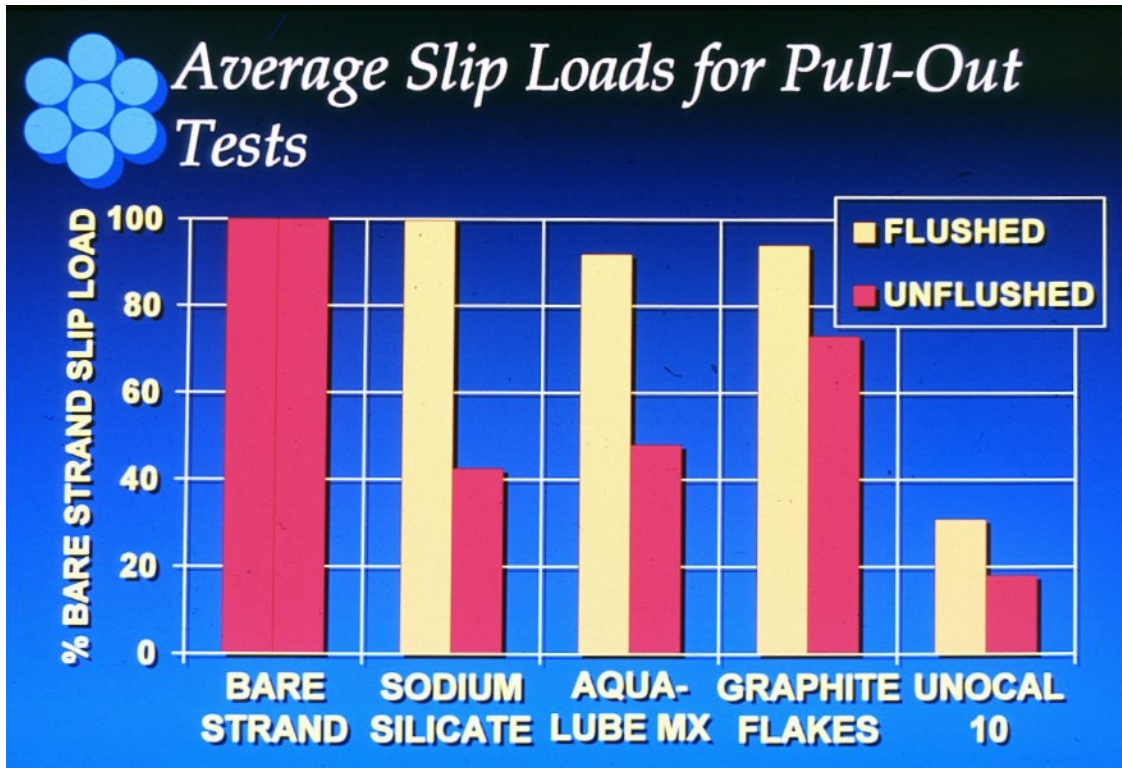


Pull-Out Tests

- ❖ **8"X 8"X 12" CONCRETE BLOCK**
- ❖ **SINGLE STRAND CENTERED IN DUCT**
- ❖ **GALVANIZED STEEL DUCT**
- ❖ **PORTLAND CEMENT GROUT**
- ❖ **LUBRICATED THEN FLUSHED PRIOR TO GROUTING**
- ❖ **STRAND ALLOWED TO TWIST RELATIVE TO BLOCK**



Slide 165. Pull-Out Tests



Slide 166. Average Slip Loads for Pull-Out Tests

Lubricant Evaluation

❖ **Evaluation Criteria**

- FRICTION REDUCTION
- EFFECT ON ADHESION
- TEMPORARY CORROSION PROTECTION
- SAFETY
- COST
- DIFFICULTY OF USE

❖ **Top Four Lubricants**

- DROMUS B
- TEXACO SOLUBLE D
- WRIGHT 502
- HOCUT 4284

❖ Graphite Flakes Performed Well

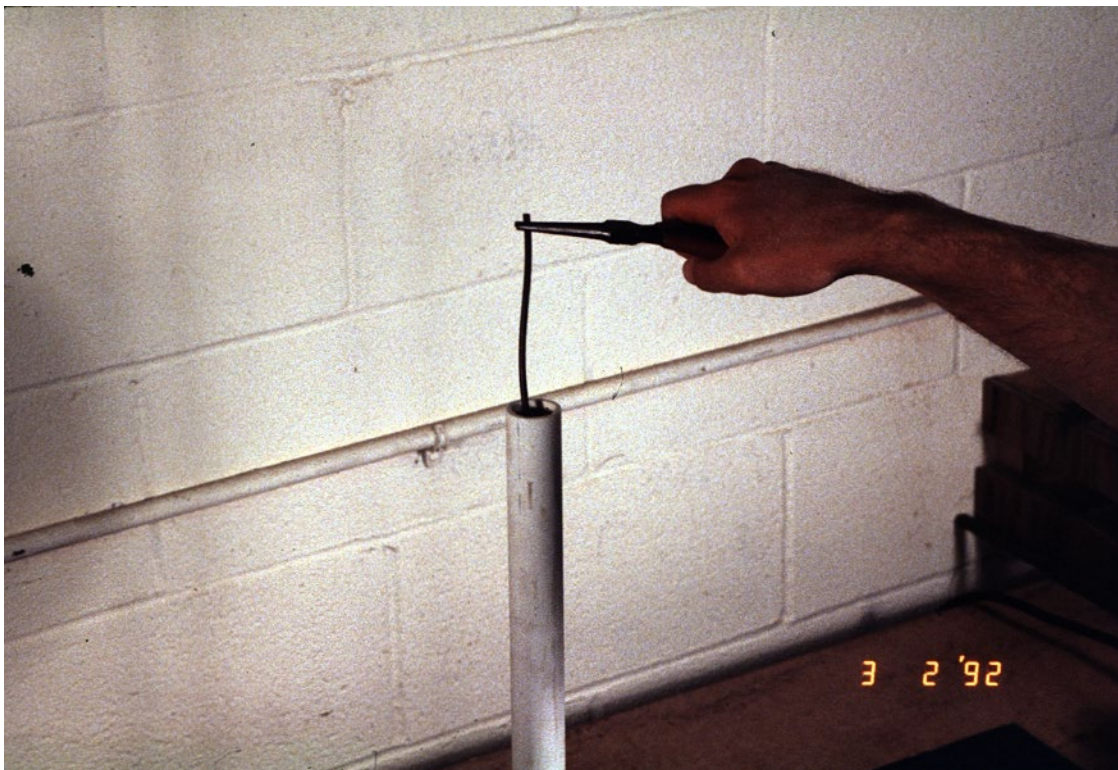
Slide 167. Lubricant Evaluation



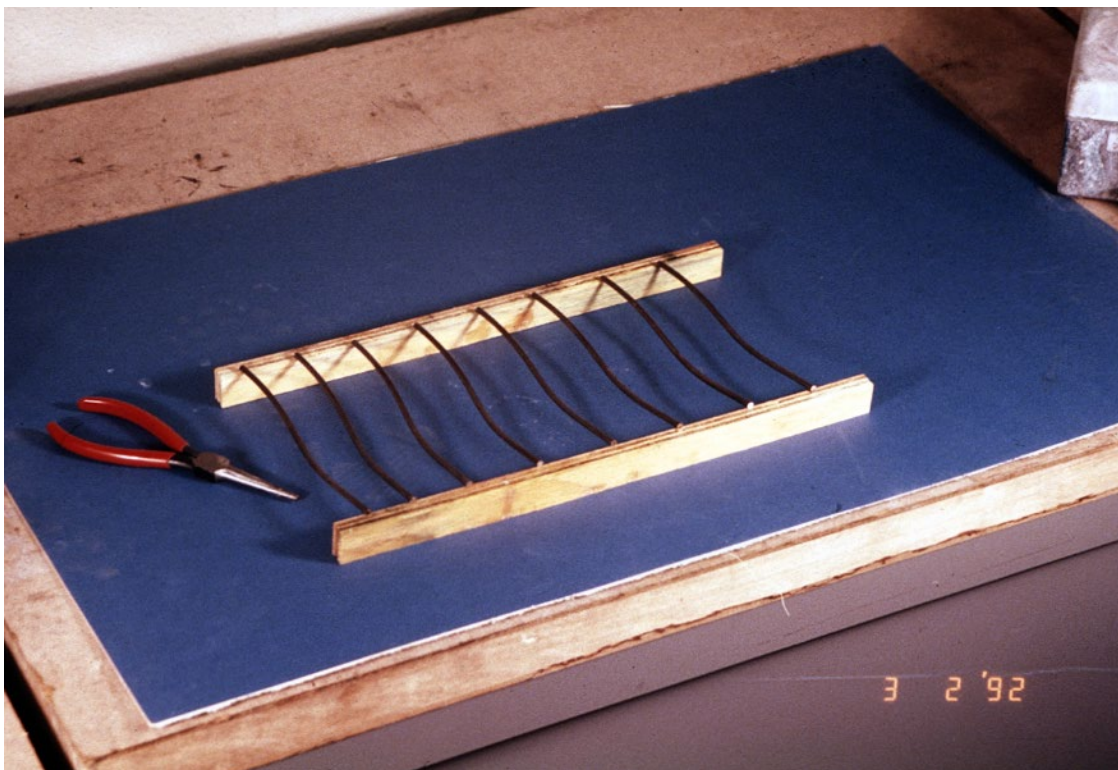
Summary

- ❖ **Several Lubricants Performed Well Overall**
- ❖ **Most Candidates Significantly Reduced Bond Even With Intense Flushing**
- ❖ **Graphite Provided Good Friction Reduction and Little Loss of Bond**
- ❖ **Most of the Emulsifiable Oils Provided Good to Excellent TCP**

Slide 168. Summary



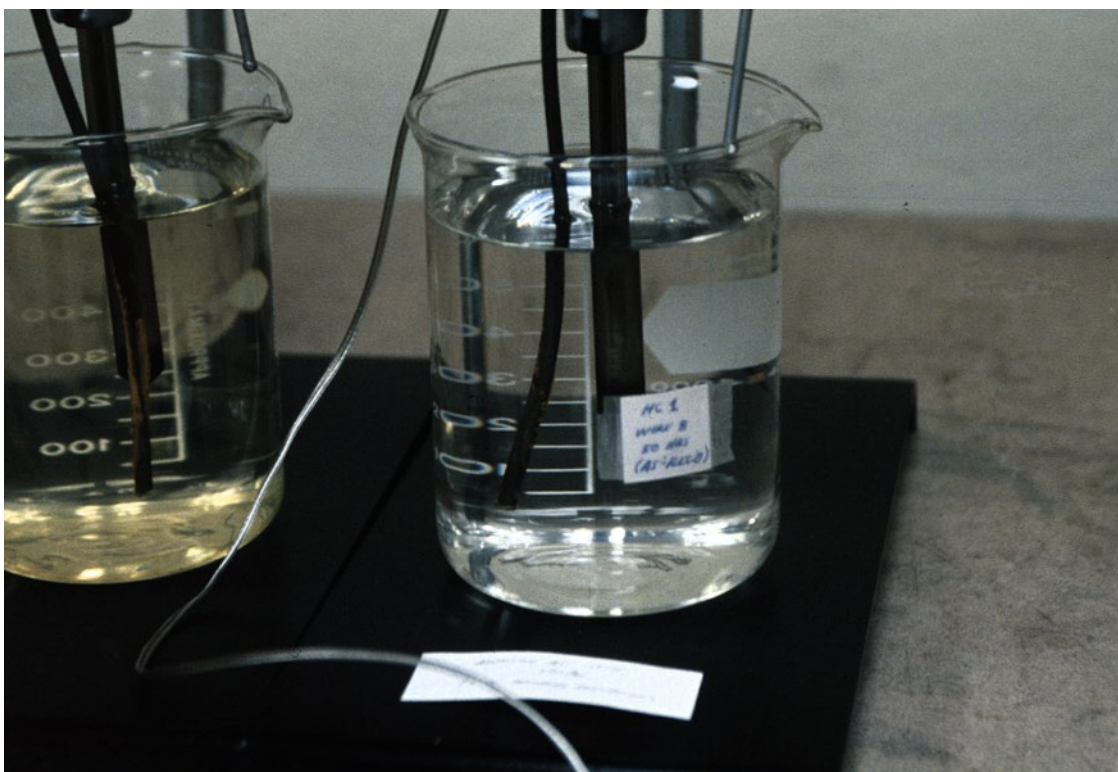
Slide 169. Dipping of wire. March 1992.



Slide 170. Drying rack for wires. March 1992.



Slide 171. Half-coil test set-up. March 1992.



Slide 172. Miscellaneous. HCl, wire 8, 50 hours, As-R[?] ... H₂O. July 1991.



Slide 173. Lubrication. March 1992.



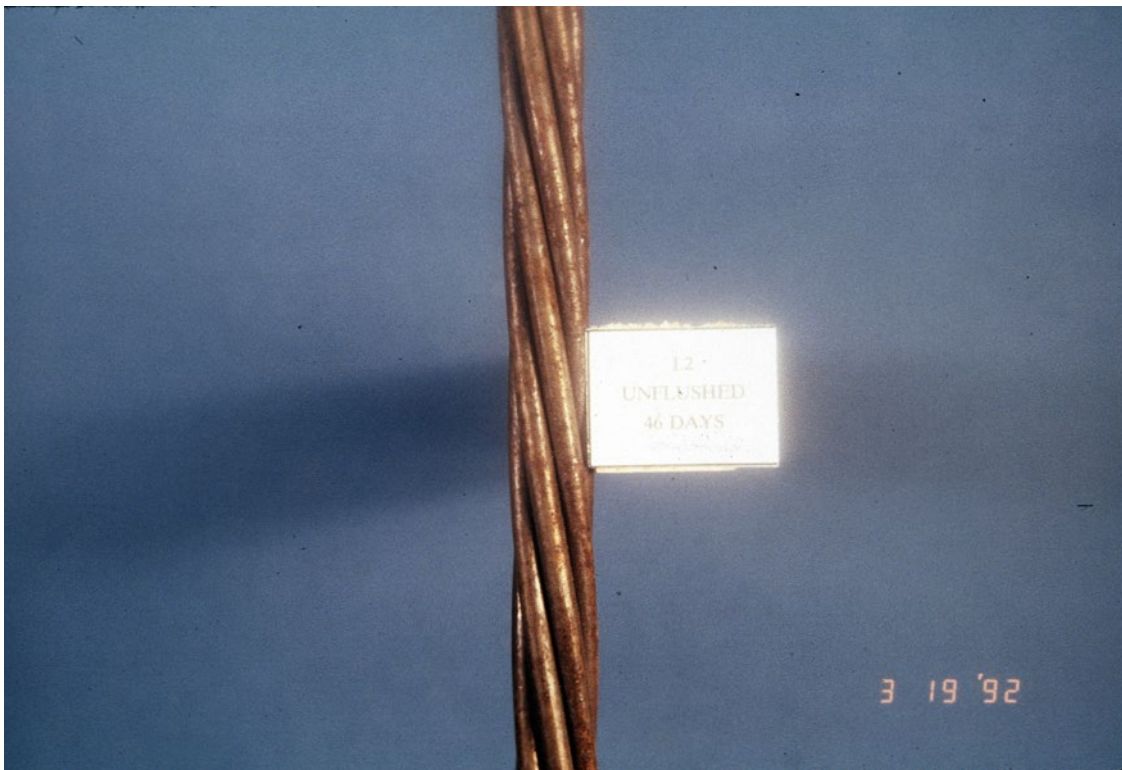
Slide 174. Flushing process. March 1992.



Slide 175. Test OE-2 set-up (unflushed wires). July 1991.



Slide 176. Lubricant two (L2). Flushed 46 days. March 1992.



Slide 177. Lubricant two (L2) . Unflushed 46 days. March 1992.



Slide 178. November 1991.



Slide 179. Mock grouting. D.O. 1 [?]. November 1991.