SPECIAL SPECIFICATION

4604

Stay Cables

1. Description. Supply, fabricate, deliver, test, store, install, stress, re-stress, adjust, repair and/or replace damaged components (if necessary), and permanently protect stay cables. Stay cables include, but are not limited to, main tensile elements (strands), strand sheathing, complete anchorage components, wedges, bearing plates, sealing components, damping devices, anti-vandalism tubes, temporary and permanent corrosion protection provisions, and components which are part of the structure, such as the anchor pipes/guide pipes, cable stay saddles in the pylons, erection devices and equipment, and all incidental materials and labor necessary to construct the stay cables in accordance with the Plans, Standard Specifications, and Special Provisions.

Conform the stay cable system to the following criteria:

A. Install and tension each strand individually (mono-strand tensioning).

B. Protect each strand individually against corrosion. Coat and fill the strands and interstices that are extruded through high density polyethylene (HDPE) sheath with petroleum wax.

C. Ability to remove and replace each strand individually.

D. Prepare the outer sheath using two layers of co-extruded HDPE pipe, un-grouted, inner black layer, outer layer color to be selected by Owner, and double external helical ribs.

E. Install anti-vandalism tubes on the lower part of the cables.

F. Install internal dampers to control stay vibrations.


A. General. Provide stay cables that consist of parallel, individually polyethylene coated seven-wire strands, placed inside an external polyethylene stay pipe.

Provide redundant protection against corrosion of the strands, by means of two complementary, nested barriers:

1. Make the first or internal barrier an internal envelope and an intermediate medium between the internal envelope and the main tensile element (MTE) to protect each strand individually. Make the internal envelope completely airtight, watertight and qualified as a corrosion barrier. Maintain the airtight, watertight, and corrosion barrier internal envelope between the end anchorages, or throughout the free length, transition areas and through the pylon saddle.
Use an intermediate medium to prevent any water or moisture that might get inside a damaged internal envelope from migrating along the length of the individual MTE’s.

2. Use a second or external barrier that is a continuous external stay pipe protecting the internal barrier over the free length of the cable.

3. Additional corrosion protection may be provided by hot dip galvanic coating applied directly to the wires of the strand over their entire length without interruption. If provided, comply galvanized strand with the French Norm NF A 35-035 and make strand meet or exceed the requirements of ASTM A416.

If the stay cable and anchor heads and/or the individual stay cable strands proposed have different dimensions and/or support details other than those shown on the Plans, re-design the stay cable anchorage areas and details at the box girders such that they are compatible with the remainder of the structure, subject to approval by the Engineer.

B. Strand. Use 0.62-inch diameter, Grade 270, $f_y = 0.90$ ksi, weldless grade, low-relaxation seven-wire strand for stay cables. Conform to the requirements of ASTM A416.

Strand will have relaxation losses of not more than 2.5% when initially loaded to 70% of specified minimum breaking strength, or not more than 3.5% when loaded to 80% of specified minimum breaking strength of the strand after 1000 hours when tested under conditions of ASTM A416.

Furnish the strand in coils on wooden or steel reels with padded contact areas, wherever possible. Protect each coil with a manufacturer approved method so that a strand has no adhering foreign matter or damage to the corrosion protective coating, including that from ultraviolet exposure. Seal the ends of the strand to prevent intrusion of moisture into the annular space between the seven wires. Make no welds or joints in the finished strand.

Upon delivery, properly store the strand in a weatherproof enclosure. Mark each coil with the order number, coil number and heat number. Also mark the starting end of each coil. When uncoiled, the strand will lay straight with a maximum deviation not exceeding ½-inch offset from a theoretical centerline in any ten feet of length. The Engineer may reject any strands with sharp kinks or short radius bends.

The Engineer may reject any strand represented by test samples that do not meet the requirements of this specification. Replace the strand or, alternatively, strip it of coating, reclean, recoat and resubmit it for acceptance testing in accordance with the requirements of this specification.

Cut strands using abrasive saws or shear. Do not use flame cutting.

C. Internal Corrosion Barrier. Produce the internal barrier using a high-density polyethylene (HDPE) sheath extruded directly onto the strand, previously coated and filled with petroleum wax. The HDPE sheathing need not extend through the cable stay saddle provided the strand within the saddle area is protected with two complementary, nested barriers similar to the requirements for the stay cable free length.
1. **Individual HDPE sheath.** Make the individual HDPE sheaths of high density black polyethylene classified PE 80. Do not use recycled materials. Comply with the following physical and mechanical specifications regarding extruded sheath:

<table>
<thead>
<tr>
<th>Character Specified</th>
<th>Value Specified</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 23°C</td>
<td>&gt; 950 kg/m³</td>
<td>NF EN ISO 1183</td>
</tr>
<tr>
<td>Melt flow Index of 5 kg at 190°C</td>
<td>&lt; 0.25 gram per 10 minutes</td>
<td>NF EN ISO 1133</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>&gt; 800 MPa on average</td>
<td>ISO 178</td>
</tr>
<tr>
<td>Tensile stress at yield point at 23°C</td>
<td>18 MPa</td>
<td>NF EN ISO 527</td>
</tr>
<tr>
<td>Ultraviolet radiation stability</td>
<td>condition E</td>
<td>ASTM D 3350</td>
</tr>
<tr>
<td>Carbon-black content</td>
<td>2.3 ± 0.3% by weight</td>
<td>ISO 6964</td>
</tr>
<tr>
<td>Carbon-black dispersion index</td>
<td>&lt; 3</td>
<td>ISO 11420</td>
</tr>
<tr>
<td>Carbon-black distribution level</td>
<td>&lt; C2</td>
<td>ISO 11420</td>
</tr>
<tr>
<td>Anti-oxidant content in the final composition of the HDPE</td>
<td>&gt; 1000 ppm</td>
<td></td>
</tr>
<tr>
<td>Melting temperature</td>
<td>&gt; 130°C</td>
<td>ISO 3146</td>
</tr>
<tr>
<td>Oxidative induction time at 200°C</td>
<td>&gt; 20 minutes</td>
<td>ISO/TR 10837 or ASTM D 3350</td>
</tr>
<tr>
<td>Elongation at fracture at 23°C</td>
<td>500%</td>
<td>NF EN ISO 527</td>
</tr>
<tr>
<td>Elongation at fracture at -20°C</td>
<td>100%</td>
<td>NF EN ISO 527</td>
</tr>
<tr>
<td>Izod impact strength at 23°C</td>
<td>&gt; 20 kJ/m²</td>
<td>NF EN ISO 180</td>
</tr>
<tr>
<td>Stress cracking resistance at stress F 50</td>
<td>&gt; 1000 h</td>
<td>ASTM 1693, condition B</td>
</tr>
<tr>
<td>Shore D hardness</td>
<td>&gt; 55 points</td>
<td>ISO 868</td>
</tr>
</tbody>
</table>

Make the thickness of the individual HDPE sheaths greater than 1.5 mm (0.06 inches), and the outer diameter of sheathed seven-wire strands less than 19.5 mm (0.77 inches).

2. **Petroleum Wax Filler.** Fill the intermediate space among the wires and between the wires and the individual sheath of each stay strand with microcrystalline wax, i.e. a malleable crystallized solid consisting of saturated hydrocarbons which are injected in a liquid state. Do not use grease in the void filler in order to prevent problems of thermal stability and bleed.

Inject the void filler material in the workshop of the strand extrusion facility. Completely fill the internal voids between the constituent wires of the strand and the voids between the wires and the individual sheath. Ensure no voids appear in the intermediate medium, due to thermal shrinkage, creep, setting or aging of the void filler.

Make the filling material continuous and durably stable. Make the weight of filler per unit length between 6 and 12 g/m. For individually sheathed strands, compare weights of a factory-made strand length before and after cleaning and de-waxing the wires and the HPDE sheath which has been cut longitudinally to allow the operations.
Comply with the following specifications with regard to wax filling material:

<table>
<thead>
<tr>
<th>Character Specified</th>
<th>Value Specified</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pour point</td>
<td>&gt; 77°C</td>
<td>NF T 60-128</td>
</tr>
<tr>
<td>Penetration at 25°C</td>
<td>No cracking</td>
<td>NF T 60-119</td>
</tr>
<tr>
<td>Viscosity at 100°C</td>
<td>&gt; 20 mm²/s</td>
<td>ASTM D 445</td>
</tr>
<tr>
<td>Bleeding at 40°C</td>
<td>At 7 days &lt; 0.5%</td>
<td>NF T 60-191 modified by conducting the test for 7 days without the 100-gram weight</td>
</tr>
<tr>
<td>Oxidative resistance 100 hours at 100°C</td>
<td>&lt; 0.03 MPa</td>
<td>ASTM D 942-02</td>
</tr>
<tr>
<td>Copper strip corrosion 100 hours at 100°C</td>
<td>Level 1 a (no corrosion)</td>
<td>NF EN ISO 2160</td>
</tr>
</tbody>
</table>

D. **Outer Stay Pipe.** Thread the strands through the outer casing of a one-piece stay pipe. Do not fill the void within this outer casing.

Use an outer casing of appropriate thickness and chemical composition to ensure good aging performance against environmental degradation including satisfactory resistance to ultraviolet radiation. Ensure that the outer casing withstands the mechanical actions that might be exerted on it, notably the bending and axial force caused by the installation, and the buckling force that could be caused by compression of the pipe under its self weight when it rests on the bottom anchorage of the stay cable.

The Owner will determine the color of the external sheath, UV stabilized pipe. Submit evidence as to the UV resistance and color stability of the pipe for the approval of the Engineer. Ensure the co-extruded pipe is capable of being joined by fusion welding in accordance with this Special Specification.

Manufacture the outer stay pipe with a surface carrying relief, for example two helically wound ribs at 180° apart around the cable, with a demonstrated efficiency against rain and wind induced vibration. Make any such ribs the same color as the external sheath.

1. **Material Specifications.** Make the outer stay pipe a co-extruded high-density polyethylene (HDPE) pipe, with a colored external layer and a black internal layer.
Manufacture the stay pipe with high density polyethylene classified PE 344433 C (if black), or PE 344434 E (if other than black) as per ASTM D3350. Comply with the following physical and mechanical specifications regarding the pipe:

<table>
<thead>
<tr>
<th>Character Specified</th>
<th>Value Specified</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density at 23°C</td>
<td>&gt; 941 kg/m³</td>
<td>ASTM D 1505</td>
</tr>
<tr>
<td>Melt flow index of 5 kg at 190°C</td>
<td>&lt; 0.15 gram per 10 minutes</td>
<td>NF EN ISO 1133</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>&gt; 800 MPa on average</td>
<td>ISO 178</td>
</tr>
<tr>
<td>Tensile stress at yield point at 23°C</td>
<td>21 MPa</td>
<td>NF EN ISO 527</td>
</tr>
<tr>
<td>Ultraviolet radiation stability</td>
<td>Condition E</td>
<td>ASTM D 3350</td>
</tr>
<tr>
<td>Carbon-black content (inner layer only in the case of a co-extruded color stay pipe)</td>
<td>2.3 ± 0.3% by weight</td>
<td>ISO 6964</td>
</tr>
<tr>
<td>Carbon-black dispersion index</td>
<td>&lt; 3</td>
<td>ISO 4437</td>
</tr>
<tr>
<td>Carbon-black distribution level</td>
<td>&lt; C2</td>
<td>ISO 4437</td>
</tr>
<tr>
<td>Anti-oxidant content in the final composition of the HDPE</td>
<td>&gt; 1000 ppm</td>
<td>ISO 4437</td>
</tr>
<tr>
<td>Thermal stability</td>
<td>&gt; 220°C for 20 minutes</td>
<td>ASTM D 3350</td>
</tr>
<tr>
<td>Oxidative induction time at 200°C</td>
<td>&gt; 20 minutes</td>
<td>ISO/TR 10837 or ASTM D 3350</td>
</tr>
<tr>
<td>Elongation at fracture</td>
<td>350%</td>
<td>NF EN ISO 527</td>
</tr>
<tr>
<td>Izod impact strength at 23°C</td>
<td>&gt; 20 kJ/m²</td>
<td>NF EN ISO 180</td>
</tr>
<tr>
<td>Stress cracking resistance at stress F 50</td>
<td>&gt; 1000 h</td>
<td>ASTM 1693, condition B</td>
</tr>
<tr>
<td>Shore D hardness</td>
<td>&gt; 55 points</td>
<td>ISO 868</td>
</tr>
</tbody>
</table>

Do not use recycled polyethylene. The stay pipe supplier will be a quality management organization in accordance with the NF EN ISO 9001 standard.

In addition to the above requirements, make stay pipe thickness at least $\Omega_{\text{ext}}/32$ (SDR 32) or 6 mm (0.24 inches), whichever is greater, where $\Omega_{\text{ext}}$ is the stay pipe outside diameter.

2. **Fusion Welds.** Obtain the required pipe length for each cable by continuous extrusion or by fusion welding of standard length sections of pipe. When the stay pipe is made up of sections assembled end-to-end, assemble the sections by butt fusion welding (hot-plate welding in accordance with ASTM D2657). Make the cut ends of sections of the joined pipe perpendicular to the pipe axis. Make the strength of a joint more than 90% of the intact pipe. Perform proposed welds on a test section of polyethylene pipe for the cable cross section used on the project and perform the necessary tests to ensure that the weld develops the required strength and that the joint is hydrostatically sealed. Submit the results of fusion weld tests to the Engineer for approval. Do not weld the pipe when the stay strands are in the pipe.
3. **Expansion Sleeves.** Design and provide a polyethylene pipe system that can accommodate the full range of thermal expansion and contraction for the temperature range specified in the Plans. Provide an overlapping expansion system that prevents water from entering the stay pipe. Submit the expansion system to the Engineer for approval along with adequate evidence that demonstrates the ability of the system in preventing water from entering the stay pipe.

E. **Cable Stay Anchorages.** The anchors for the cable stay system shown on the Plans are schematic. The Manufacturer will supply for review and approval by the Engineer all material specifications not specified herein or on the Plans.

Use an anchorage device capable of transmitting the full ultimate tensile force of the cable. Use all other components such as bearing plates, guide pipes, and deviators shown on the drawings of suitable type and sufficient strength for the intended use.

Use material for filling the void between the strand bundle and the anchors that will permit monitoring and replacement of individual strands during the entire service life of the bridge. Do not use hard material filling or cement grouting in the anchorage area.

1. **Stay Anchor Assembly.** Supply anchorage components that meet the requirements as specified herein. Use anchorage components specified by the vendor furnishing the anchorages at the time of acceptance testing of the stay cable. Supply stay anchor assemblies consisting of an externally threaded steel socket, anchor head, tension ring, load bearing ring nut, protective cap and filler. Ensure the anchorage assembly allows for complete detensioning of the stay and subsequent removal for the anchorage components (except the load bearing nut) through the guide pipe. Furnish all material and testing specifications to the Engineer for review and approval. Ensure each component of the assembly, including wedges, has an AASHTO ASTM, or EN material and test specification.

Make the threaded portion of the anchorage of sufficient length for the installation of the cable and for the future force adjustment of 2.5%± of the guaranteed ultimate tensile strength (GUTS) of the stay cable. Make this tension adjustment by means of a threaded tube and ring nut assembly. Do not use shims for stay tension adjustments.

Submit shop drawings to the Engineer for approval showing all dimensions, materials and operations for fabrication of the anchor assembly. Develop and submit to the Engineer for approval detailed procedures for installing all assembly components, insertion of the strands, installation of wedges, and stressing the assembly. Submit complete shop drawings with supporting calculations showing all equipment (jack, stressing chair, etc.) and procedures required for stay force adjustments and for complete detensioning. Sign and seal all shop drawings by a Professional Engineer registered in the state of Texas. No approval will be given to any portion of the stay anchor assembly or procedures until all required submittals are made and found acceptable. If the vendor’s patented anchorage requires stripping of the HDPE sheath within the anchorage zone, use filler that provides adequate corrosion protection in accordance with these Special Specifications.
All other components such as bearing plates, wedges, protective caps, extension pipes, tension rings, etc. shown on the Plans, but not specified herein, are only shown schematically. Provide these in suitable type and sufficient strength suitable for the intended use. Submit material specifications, calculations and detail drawings for the sizes, types and materials for such components to the Engineer for review and approval.

a. Filtering Out Angular Deviations. Comprise the anchorage with cable guide systems in order to prevent significant bending stresses due to angular deviations of the strand to extend to the anchorage device or wedges. Make the anchorages capable of accepting static angular deviations in excess of the installation tolerances of the connecting parts.

Account for in the design of the cable guide system transverse and flexural forces resulting from: deck and pylon anchorage rotation under live loads, inaccuracy of anchorage placing and shuttering tube misalignment, permanent angles due to the fanning out of the strands, and bending of strand in the anchorage head due to manufacturing tolerances of anchorage parts.

Do not use guide deviators placed in the transition area, which impose a transverse force on the structure ahead of the stay anchorage in the above cases. Make the anchorage capable of handling by itself the following combination of deviation angles, as a minimum, without damaging the cable:

- +/- 20 milliradians (Mrad) static angle or the installation tolerances of the connecting parts (shuttering tube misalignment), whichever is greater;
- +/- 10 milliradians dynamic angle.

Document the efficiency of such means to satisfy the following criteria:

- the angle of deviation of any strand in the anchorage or transition zones will not exceed 25 milliradians.
- the bending stresses in each strand will be less than 250 MPa (36 ksi) in the transition zone at the entrance of the anchorage under a deviation of 30 milliradians and a load of 45% GUTS.
- the bending stress in each strand at the anchorage will be less than 50 MPa (7.3 ksi).

Calculate the bending stress with the maximum service tension in the cable.

If the anchorages require a deviator to be placed at the guide tube to reduce the deviation induced bending stresses at the anchorages, do not substitute any device to dampen the cable for the deviator. Keep the deviator to provide a fixed point to avoid deviation induced bending stresses from reaching the anchorage.

b. Protection Against Corrosion. Extend the two complementary internal corrosion-protection barriers, defined for the stay strand, continuously through the free length of the stay and entire anchorage transition zones, including the saddles.
If the external anti-corrosion barrier is replaced by a local casing in the anchorage, inject it with an appropriate blocking medium. Ensure this blocking medium is a flexible material.

Protect the anchor assemblies and components at all times against corrosion, particularly the wedge and wedge holes. Show corrosion protection measures on the shop drawings. At the end of the stay cable, close the outer casing with a watertight cap attached to the anchorage head and cover at least the entire area of the strand terminations. Ensure this cap is removable for inspection of the strand terminations and is injected with a corrosion protective material that does not induce hydrogen embrittlement. Protect the strand tails and the exposed threaded area of the anchor with the corrosion protective material. Heavily coat the threaded area exposed inside the bearing plate/guide pipe with a corrosion inhibiting material. Obtain approval of the Engineer for the corrosion protective material.

Ensure this integrity and continuity of the waterproofing is consistent with the other functions of the anchorage and maintain under all service conditions (vibration, movement, aging, temperature variations, etc.). The water tightness at the entrance of the strand into the anchorage is a key factor.

c. Protection Against Wear. To prevent fretting corrosion and fatigue, do not allow steel to steel contact between the strand and the parts of the transition zone.

Take steps to prevent fretting corrosion and fatigue at critical points: at each deviation of the strand, where the strand enters the anchorage head, etc.

In order to avoid an accumulation of causes of fatigue (axial and flexural action effects) at the anchorage head, take steps to guide lateral displacement of strands.

2. Stay Anchor/Guide Pipe & Bearing Plate. Conform the stay anchor pipe and guide pipe attached to the longitudinal box girders at deck level for the anchorage assembly to the requirements of ASTM A500, Grade C with a minimum thickness shown on the Plans. Fabricate bearing plates from ASTM A709, Grade 50 with a minimum thickness as shown on the Plans.

Hot-dip galvanize the anchor/guide pipes (inside and out) and bearing plates after fabrication per ASTM A123. After galvanizing, shop paint exposed portions of anchor/guide pipes and bearing plate in accordance with Item 446 of the Standard Specifications. Paint color for the appearance coat as shown on the Plans. Include as incidental to the price bid for Stay Cables the payment for galvanizing and painting the pipes and outer surfaces of the stay components.

F. Cable Stay Saddles. Design saddles to provide continuity of the strands through the pylon and individually anchor each strand. Make the strand load transfer capacity across the saddle sufficient to prevent strand slipping under any load case.
Submit shop drawings to the Engineer for approval showing all dimensions, materials and operations for fabrication of the stay saddle assembly. Sign and seal all shop drawings by a Professional Engineer registered in the state of Texas.

1. **Protection Against Corrosion.** Maintain an internal corrosion-protection barrier of the strands through the entire saddle zone to provide protection against corrosion and keep water out of the free length of the stay cable. If the stay cable supplier’s patented saddle system allows the HDPE sheathing to be continuous through the pylons in saddles, use an alternative filler material other than petroleum wax to enable force transfer from the strand through the internal corrosion barrier and into the saddle. In such cases respect the specified properties in these Special Specifications pertaining to the complete filling of the interstices between the wires with a stable and flexible medium. In addition, demonstrate through testing the ability to transfer the shear and compressive loads from the strand to the saddle to be sufficient to avoid sliding of the strand relative to the saddle, to avoid movement/creep of the strand relative to the internal corrosion barrier and without damaging the internal corrosion barrier. For satisfactory bond transfer, use a filler compound with the capacity to transfer a minimum shear strength of 4 MPa (0.6 ksi) at 20°C between the surface of the steel 7-wire strand and the extruded HDPE sheath.

Removal of the interior barrier (HDPE sheathing) and/or its substitution in the saddle area by another means is allowed if required by the cable system supplier’s patented saddle system, provided adequate corrosion protection of the strand within the saddle area is demonstrated, to the satisfaction of the Engineer. Similar to the requirements for the stay cable free length, provide the strand within the saddle area with redundant protection against corrosion of the strands, by means of two complementary, nested barriers.

2. **Protection Against Wear.** To prevent fretting corrosion and fretting fatigue, do not allow steel to steel contact between the strand wires and any part of the saddle.

3. **Filtering Out Angular Deviations.** Incorporate a cable guide system in the saddle at each end to prevent high bending stress concentrations resulting from angular deviations of the strand at the saddle entrance and exit points.

Take into account in the design of the cable guide system the deviations resulting from: pylon rotation under live loads; inaccuracy of saddle placing; and permanent angle deviation due to the fanning out of the strand bundle.

Make the saddle capable of independently handling the following combination of deviation angles, as a minimum, without damaging the cable:

- +/- 20 milliradians static angle or the installation tolerances, whichever is greater;
- +/- 10 milliradians dynamic angle.

Document the efficiency of such means to reach the following criteria: the bending stresses in each strand less than 250 MPa (36 ksi) in the transition zone at the entrance/exit of the saddle under a deviation of 30 Mrad and a load of 45% GUTS.

3. **Qualification and Testing**

   A. **Individually Sheathed Polyethylene Strand.**

   1. **Performance Tests.** Furnish to the Engineer, a test report prepared by an independent laboratory documenting compliance with items a through f below. Ensure HDPE sheathed strand meet the following requirements:

      a. **Chemical resistance test** – Evaluate the chemical resistance of the sheathing in accordance with ASTM G20 “Standard Test Method for Chemical Resistance of Pipeline Coatings,” by immersing coated strands in each of the following: a 3M (Molar) aqueous solution of CaCl₂, a 3M (Molar) aqueous solution of NaOH, and a solution saturated with Ca(OH)₂. In addition, to simulate cementitious grout, utilize an aqueous solution of potassium hydroxide and an aqueous solution of sodium hydroxide for this test. Perform tests at 24±2°C with specimens without damage to the sheathing and specimens with intentional 6 mm diameter holes drilled through the sheathing. Perform the test for a minimum of 45 days. Verify the polyethylene is not soft, cracked, or visually deteriorated.

      b. **Chloride permeability test** – Measure, using the methods outlined in FHWA-RD-74-018, “Non-metallic coatings for Reinforcing Bars,” the chloride permeability characteristics of the films of cured coating having the minimum thickness as proposed for use. Perform the test at 24±2°C for 45 days. Verify the accumulative concentration of chloride ion permeating through the film is less than 1 x 10⁻⁴M.

      c. **Impact test** – Determine the resistance of a strand sheathing to mechanical damage by using the falling weight test. Use a test apparatus similar to that described in ASTM G14 “Standard Test Method for Impact Resistance of Pipeline Coatings (Falling Weight Test),” along with a 1.8kg tup. Ensure impact occurs on the crown areas on the sheathed strand. Perform the test at room temperature. With an impact of 9 N-m, ensure no shattering or cracking, of the sheathing occurs except at the impact area, that is, the area permanently deformed by the tup.

      d. **Abrasion resistance test** – Determine the resistance of the strand sheathing to abrasion by using the falling sand method of ASTM D968 “Standard Test Method for Abrasion Resistance of Organic Coatings by Falling Abrasive” adopted for testing sheathed strand. Do not exceed net loss of sheathing by 0.25 mm per 1,000 L of abrasive.

      e. **Salt spray (fog) test** – Tension sheathed strand specimens to 70 percent of the minimum ultimate tensile strength and expose to salt fog for 3,000 hours in accordance with ASTM B117. Take care to protect the end anchorage used from salt fog or corrosion so as not to influence the test results.
Make observations for signs of corrosion and record every 250 hours. After 3,000 hours of exposure, ensure no evidence of corrosion is present, and the specimen is holiday free. After the salt spray (fog) test is completed, perform a tensile test on the specimen in conformance with ASTM A416. Do not allow any cracks visible to the unaided eye in the HDPE or HDPP up to an elongation of 1 percent (yield point).

f. Water tightness test – Propose a water tightness test for the approval of the Engineer. Carry out one test of the void filling manufacturing process of the sheathed strand as per the approved test procedure per production run or portion thereof.

2. Quality Control Tests. Furnish test reports to the Engineer for each inspection unit of strand documenting compliance of the material properties in Section 3.2.2.1 of the PTI “Recommendations for Stay Cable Design, Testing and Installation”, 5th edition. Include in the inspection unit for sampling, the unit of production composed of coated products (wires or seven-wire strands) coming from the same factory and of the same grade and nominal diameter, manufactured according to the same process. Define this unit either by cast or by batch, the mass of each inspection unit being no more than 20 tons. Take three samples when the number of coils in an inspection unit is lower than 3. Take one sample per coil when the number of coils in an inspection unit is greater than 3. The maximum number of samples is limited to 12.

a. Standard Properties. On each sample, complete one series of tests to document compliance with the following:
   - Minimum ultimate tensile stress;
   - Minimum yield stress;
   - Elastic modulus.

b. Particular Properties. Carry out the following tests on one sample per inspection unit or fraction thereof:
   - One-Pin Test for ductility;
   - Fatigue strength.

Perform tests as outlined in Section 3.2.2.1 of the PTI “Recommendations for Stay Cable Design, Testing and Installation”, 5th edition. Select 3 samples for each test. If the test on the first sample fails, carry out two more tests. If either of the two additional tests fails, reject the quantity of strands represented by the three samples.

B. HDPE Stay Pipe. Furnish a certificate of analysis to the Engineer for each shipment of pipe stating the material supplied meets this Special Specification and showing the results of the tests performed by an approved independent laboratory.
C. **Anchorage Assembly and Fully Assembled Stay Cable.** Qualification and acceptance testing of the stay cable system based on fatigue and ultimate strength tests of the stay system and leak tests of the anchorage assembly in accordance with Sections 4.2 and 4.1.6, respectively, of the PTI “Recommendations for Stay Cable Design, Testing and Installation”, 5th edition, is not required. Submit evidence of previous tests conducted for previous projects on specimens similar in stay size, design, and details to those proposed for this project to the Engineer for acceptance. Only stay cable systems having previously passed such testing witnessed by a third party are qualified. Perform quality control tests outlined above for the sheathed strand to establish that the prestressing steel supplied for this project has fatigue characteristics comparable to the prestressing steel used in the acceptance tests of the stay cable specimens in the previous project. Demonstrate with shop drawings that the stay anchorage hardware proposed is the same as in the previous tests.

D. **Cable Stay Saddles.**

1. **Friction.** Provide evidence of the adopted friction coefficient value through previous tests performed on the proposed saddle system, with radiuses and deviations relevant for this project. Provide evidence of any evolution due to fatigue loading through documented tests. Submit results of previous friction tests to the Engineer for approval.

   Make the friction coefficient of the cable equal to or greater than 0.4 (based upon proven test results, before applying safety factors) with the permanent corrosion protection details as applicable for the cable.

   Make the friction coefficient of the cable equal to or greater than 0.5 (based upon proven test results, before applying safety factors) during construction before application of permanent corrosion protection details as applicable for patented saddle system supplied (with temporary corrosion protection details).

2. **Fatigue Resistance.** Demonstrate the fatigue resistance of the proposed saddle system through previous fatigue tests. Demonstrate a minimal resistance of 2 million cycles, 159 MPa (23 ksi) stress range and 45 % GUTS maximum stress on a radius equal or lower than 2.00 m (6.56 ft).

   When each strand is individually deviated and guided through the proposed saddle, monostrand testing will be considered representative. Submit the results of previous tests to the Engineer for approval.

   Qualify the durability of the internal barrier, after completion of the 2 million cycles, 159 MPa (23 ksi) stress range, 45 % GUTS maximal stress on a radius equal or less than the minimum project actual radii but in no case less than 2.00 m (6.56 ft). Subject the remaining internal strand sheath to corrosion barrier qualification testing in accordance with Section 4.1.4.1 of the PTI “Recommendations for Stay Cable Design, Testing and Installation”, 5th edition, except the specimen may have been tested without application of an axial load.
3. **Corrosion Protection.** Qualify corrosion protection systems for the saddles in accordance with Section 4.1 of the PTI “Recommendations for Stay Cable Design, Testing and Installation”, 5th edition. Conduct corrosion protection system qualification for all saddle details, beginning with the transition or coupling to the saddle, and continuing through the saddle. Submit to the Engineer for approval the results of previous tests to qualify corrosion barriers for all saddles details and for strand extending through the saddle zone.

4. **Construction.**

   A. **Construction Analyses.** Submit detailed step-by-step construction analyses consistent with actual loads, sequences, schedules, material properties, cable forces, and all aspects of construction of the bridge. Prepare and sign/seal all computations by a Professional Engineer registered in the state of Texas, with demonstrated experience in the design and construction of steel edge girder cable-stayed bridges.

   B. **Installation.** Install stay cables in accordance with the procedures prescribed by the stay cable supplier. Submit to the Engineer for review and approval, a method statement which describes the installation operations, including a description of the main items of the equipment required, as well as an engineered cable installation program that prescribes the cable force and elongation of each stay cable.

      Stay cable procedure will be compatible with the bridge construction sequence with cables generally erected in-situ. Prefabrication may be considered provided specific procedures are developed to ensure the strands remain parallel, equally stressed and that no damage to any elements of the system is permitted.

   C. **Handling.** Develop procedures to assure that stay cable components will not be damaged during handling.

      Protect stay cable components from corrosion, heat, abrasion and other harmful effects throughout the fabrication, shipping, delivery, storage and installation.

      The minimum bending diameter for the HDPE outer casing is 50 times its outside diameter during fabrication, transport, storage or erection of stay cables.

      Evaluate and remedy all damage to stay cables or components thereof prior to installation of the stays. Replace any damaged strand. Repair damage to non load-carrying components to the Engineer's satisfaction prior to the installation of the stays.

   D. **Strand-by-Strand Erection.** Take appropriate measures to prevent the leading end of the strand from damaging the stay pipe or the sheaths of the strands installed previously.

      Fit all the special features of the stay cable (anchorages, guidance systems, etc.) with protection to avoid damaging the individual protection of strands.

      Ensure the strands are parallel throughout their length and that they pass through matching holes in the two anchorage heads.
E. **Stressing.** Calibrate jacks and gauges for stay cable installation with reference to a standard pressure gauge or load cell within one month prior to the beginning of the cable installation, and every 6 months thereafter, or for 500 strands, for the duration of cable installation.

The standard gauge should have a relative accuracy of at least 0.5% and should itself be gauged by an appropriate laboratory at least once per year.

In-situ erected parallel strand stay cables may be tensioned one-by-one provided that it can be demonstrated, to the satisfaction of the Engineer, that the final tension and elongation of each strand is equalized within a range of +/-1.25% GUTS.

Record all stressing automatically with a computer system connected to load cells.

In case of length measurement of all the strands before erection, place in a straight, confined and covered area, at a controlled temperature and protected from any damage.

Use stay cables that are capable of being tensioned, de-tensioned and re-tensioned more than once during the construction of the structure. These operations may be carried out either by full jacking of the live anchorage and adjusting the ring nut setting, or strand by strand. If de-tensioning cables strand by strand in such way that the "gripping" zone is incorporated in the stressed portion of the stay, do not leave a "gripped" zone permanently on the stressed portion of the stay.

F. **Corrosion Protection During Erection.** If the strand corrosion protection system is not put in place at the time the cable is installed on the structure, apply an appropriate temporary corrosion-protection system.

G. **Monitoring & Adjustment.** Monitor strands extending through the cable stay saddles for any possible slippage during construction and adjust if needed in accordance with procedures prescribed by the stay cable supplier.

At some intermediate stage of superstructure erection, which the Engineer will designate depending on the approved construction sequence, check the tension in each stay cable with a full head lift off to ensure it is within the anticipated range. Adjust any stay cable as required at this stage using approved stressing procedures.

Adjust stay cables in the final dead load condition such that each individual cable does not deviate from the stay cable dead load force values shown on the Plans by +/-5%. Perform force verification with full head lift off tests. It is possible that one individual cable may have to be adjusted to lesser tolerances to prevent stress in other cables from exceeding the +/-5% tolerance.

H. **Finishing.** After the final cable tension adjustment has been completed, and subjected to the Engineer's approval, carry out the finishing of the anchorage and transition zones (permanent corrosion protection, installation of dampers, etc.).

Submit a detailed procedure for these operations for the approval of the Engineer.
5. **Measurement.** Measure Stay Cables, complete in place and accepted, by the lump sum. Make partial payment based on the percentage of work completed as determined by the Engineer.

6. **Payment.** Pay for the work performed and materials furnished in accordance with this Item and measure as provided under “Measurement” at the unit price bid for “Stay Cables”. This price is full compensation for furnishing, fabricating, transporting, installation, and stressing of stay cables, and for all materials, labor, tools, equipment and incidentals.