Outline -- Cable

- Primary Cable Functions
- Foundations of Design
- Cable Types and Families
- Cable Characteristics and Handling
- Cable Qualification
- Cable Manufacture
- New Challenges
Fiber and Cable Go Hand in Hand

Optical Fiber is the **Heart** of the Cable System

Cable **Protects the Fiber** and **Carries Power**
High Level Functionality

**Fibers:** Benign environment for optical fibers

**Strength:** For deployment and recovery

**Electrical:** Power for repeaters and network elements

**Armoring:** Protection against external aggression
Primary Cable Functions

**Protect the Fiber**

Benign Environment against:
- Tensile stress
- Bending (cushion)
- Pressure
- Water diffusion
- Hydrogen penetration

**Carry the Power**

Powering:
- Low electrical resistance conductor
- Insulation from Sea Ground

**Longevity:**
- Abrasion Resistance
- Water penetration resistance (cable cut)
Foundations of Design
Learning from our Forefathers

SD Coaxial Cable

SL Optical Cable Concept
Interlocking Strength Members Resist External Pressure – *Tried-and-True Cable Design*

**SD Cable**
- 0.023” (average) thickness
- 0.330” O.D. inner conductor
- 0.010” thickness outer conductor
- 1.000” O.D. dielectric
- 1.250” O.D. sheath
- 0.290” O.D. strength member (41 wires)

**SL Cable**
- Re-sized first two layers of SD interlocking steel wires
Steel Strand Wire Approach

Interlocking Strength Members Resist External Pressure

Hydrostatic Pressure
Steel Strand Wire Package Analysis

Finite Element Modeling - Compressive Load on Strand Wire Package

Compressive Radial Forces Studied

Strand Package Stability Confirmed
**Functionality Satisfied -- Simply**

<table>
<thead>
<tr>
<th>Loose Tube &amp; Gel:*</th>
<th>Steel Wires:</th>
<th>Copper Sheath:</th>
<th>Polyethylene Jacket:</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Fiber cushion</td>
<td>✓ Tensile strength</td>
<td>✓ Electrical conduction</td>
<td>✓ Electrical insulation</td>
</tr>
<tr>
<td>✓ Prevents axial water penetration (cable cut)</td>
<td>✓ Pressure resistance</td>
<td>✓ Hermetic &amp; $H_2$ barrier</td>
<td>✓ Abrasion protection</td>
</tr>
</tbody>
</table>

* Original SL Cable used extruded tight buffer core that was changed to Loose Tube with $A_{eff} \sim 65\mu m^2$ fibers
Cable Types and Families
LW Cable – Deep Water Use

- Ultra-High Strength Steel Wires (16)
- Ultra-High Strength Steel Wires (8)
- Polyethylene Insulation (MDPE)
- Optical Fibers
- Waterblocking compound in steel interstices
- Loose Tube with Gel
- Power Conductor Sheath (Copper or Aluminum)

LW Cable
Protected Cables

Special Applications Cable (SPA)

Light Wire Armor (LWA) and Single Armor (SA)

Double Armor – High Strength (DA) And Double Armor- High Abrasion (DA-HA)

Rock Armor (RA)

Increasing Level of Protection
# Cable Type Applications

<table>
<thead>
<tr>
<th>Type</th>
<th>Max Depth</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lightweight (LW)</td>
<td>10,000m</td>
<td>Benign, sandy bottom. Deepwater deployment.</td>
</tr>
<tr>
<td>Special Application (SPA)</td>
<td>6,500m</td>
<td>Rough seabed. Risk of moderate abrasion and/or attack by marine life.</td>
</tr>
<tr>
<td>Light-Wire Armor (LWA)</td>
<td>2,000m</td>
<td>Rocky terrain. Some risk of fishing damage. Used for burial in areas of decreased risk of external aggression. Shallow water deployment.</td>
</tr>
<tr>
<td>Single Armor (SA)</td>
<td>1,500m</td>
<td>Rocky terrain. Moderate risk of fishing damage. Shallow water deployment.</td>
</tr>
<tr>
<td>Double Armor (DA)</td>
<td>800m</td>
<td>Very rocky terrain. High risk of fishing damage. Pipeline crossings. Near shore deployment.</td>
</tr>
</tbody>
</table>

Additional cable types are qualified such as DA-HA (High Abrasion), Dynamic Riser Cable for platforms, etc.
Armored Cables for Harsh, Shallow Areas
Cable Families: SL17-A1, SL17 and SL21

14mm OD versions of SL17-A1 and SL17, named SL14-A1 and SL14, are qualified for lower voltage applications
Cable Characteristics and Handling
Cable Mechanical Properties: Tensile Strength Ratings

Industry Standard Cable Tensile Strength Ratings

➢ Breaking Strength (Ultimate Tensile Strength, UTS)
  • Sufficiently larger than NTTS
  • Initial Strength-to-Weight Parameter ➔ Cable Modulus = UTS / Weight in Water

➢ Nominal Transient Tensile Strength (NTTS)
  • Maximum allowable short-term cable tension (cumulative over ~ 1 hour)

➢ Nominal Operating Tensile Strength (NOTS)
  • Maximum allowable average operational tension for repair period (typically 48 hours)

➢ Nominal Permanent Tensile Strength (NPTS)
  • Maximum allowable permanent tension applied to cable on the seabed after installation
## Cable Mechanical Properties: Tensile Strength Ratings

<table>
<thead>
<tr>
<th>Tensile Strength</th>
<th>LW</th>
<th>SPA</th>
<th>LWA</th>
<th>SA</th>
<th>DA</th>
<th>RA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NTTS (kN)</strong></td>
<td>58</td>
<td>81</td>
<td>58</td>
<td>81</td>
<td>200</td>
<td>237</td>
</tr>
<tr>
<td><strong>NOTS (kN)</strong></td>
<td>41</td>
<td>57</td>
<td>41</td>
<td>57</td>
<td>140</td>
<td>168</td>
</tr>
<tr>
<td><strong>NPTS (kN)</strong></td>
<td>19</td>
<td>27</td>
<td>19</td>
<td>27</td>
<td>80</td>
<td>94</td>
</tr>
</tbody>
</table>

**Units:** kN
Critical Angle “alpha” is the entry angle that the cable makes with the surface of the water.

\[ \alpha = \arccos \left( \sqrt{1 + \frac{1}{4} \left( \frac{H \pi}{V_s 180} \right)^4} - \frac{1}{2} \left( \frac{H \pi}{V_s 180} \right)^2 \right) \]

For critical angles less than 30°, alpha can be closely approximated:

\[ \alpha = \frac{H}{V_s} \]
For the same vessel speed...

\[ H = \left( \frac{180}{\pi} \right) \sqrt{\frac{2w}{C_d \rho d}} \]

\[ L = \frac{h}{\sin \alpha} \]

<table>
<thead>
<tr>
<th>LW Cable</th>
<th>H (degree-knots)</th>
<th>( \alpha ) (for 2 knots vessel speed)</th>
<th>L (m) (for 5000m water depth)</th>
<th>Lay Tension at ship (kN) (5000m water depth)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL17</td>
<td>46</td>
<td>23°</td>
<td>12.8</td>
<td>18 (NTTS=58)</td>
</tr>
<tr>
<td>SL21</td>
<td>48</td>
<td>24°</td>
<td>12.3</td>
<td>24 (NTTS=81)</td>
</tr>
</tbody>
</table>
Cable Recovery

Highest cable tension is during recovery (not laying) due to the downward drag force as the cable moves through the water.

\[ V_s = \text{ship speed} \]
\[ \alpha_s = \text{recovery angle} \]
\[ V_c = \text{recovery speed} \]
Recovery Tension

- Proportional to Water Depth and Cable Weight
- Significantly affected by Recovery Conditions - Recovery Speed, Recovery Angle, Sea Conditions

Recovery Tension @ Ship, Ts = wh + T_{bottom} + T_{wave-induced}

(For a surface-laid cable, without a repeater)

From 5000m water depth:

SL17 LW Recovery Tension ~ 46 kN (SL17 LW NTTS = 58 kN)
SL21 LW Recovery Tension ~ 62 kN (SL21 LW NTTS = 81 kN)

(For typical recovery conditions of 1 knot recovery speed, 75 degree lead angle, and 4m sea swell)
Cable Recovery

Recovery Depth Curves

For Maximum Recovery Depth Calculation, NTTS is set equal to Ts.
Cable Mechanical Properties: Tensile Strength Characterization

Tensile Strength:

- Experimentally verified through Tensile Testing
  - Cable Tension vs. Cable Elongation Curve

- Highest Cable Tension levels are typically encountered during Recovery at Maximum Depth
  - Recovery operations aim not to exceed **Nominal Transient Tensile Strength (NTTS)**

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SL17 LW

13200 lbf [59kN] = 0.71% strain
Cable Qualification
## Qualification Test Program

Cable qualification program in conformance with ITU-T Recommendation G.976

<table>
<thead>
<tr>
<th>SubCom Qualification Test</th>
<th>ITU-T G.976 (05/2014)</th>
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<tr>
<td></td>
<td>Reference Paragraph</td>
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<tr>
<td>Cabled Fiber Optical Performance</td>
<td>8.2.1.1; 8.2.1.2</td>
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<tr>
<td>Extended Range Temperature</td>
<td>8.2.1.3</td>
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<tr>
<td>Reverse Flexure with Temperature</td>
<td>8.2.1.3; 8.2.2.5</td>
</tr>
<tr>
<td>Reverse Bend</td>
<td>8.2.2.5</td>
</tr>
<tr>
<td>Tension/Torque/Elongation</td>
<td>8.2.1.2; 8.2.2.1; 8.2.2.2</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension/Torque/Rotation</td>
<td>8.2.1.2; 8.2.2.1; 8.2.2.2</td>
</tr>
<tr>
<td>Stopper Test</td>
<td>8.2.5.2</td>
</tr>
<tr>
<td>Adhesion</td>
<td>8.2.5.1</td>
</tr>
<tr>
<td>Crush &amp; Impact Test</td>
<td>8.2.3.1; 8.2.3.2</td>
</tr>
<tr>
<td>Water Ingress</td>
<td>8.3.4.1</td>
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<tr>
<td>HV &amp; Insulation Resistance</td>
<td>8.3.4.2; 8.2.4.4</td>
</tr>
<tr>
<td>Sea Trial*</td>
<td>8.2.5.3</td>
</tr>
</tbody>
</table>

* Verification test
Qualification Test Program

- Extended Range Temperature

**Sample:** 10-15km long cable on a reel, placed in an environmental temperature chamber

**Test Description:** Sample is subjected to a temperature profile ranging from -20 °C to +60 °C
Qualification Test Program

- Reverse Flexure with Temperature

**Sample:**
A ≥100m-long cable sample, placed in an environmental temperature chamber and subjected to small radius bending.

**Test Description:**
Sample is subjected to flexing while at temperatures ranging from −20°C to +60°C.

Simulates low-tension loading from the cable factory to the ship during very hot or very cold weather conditions.

[Diagram of test equipment with labels such as 'Pivot Arm', 'Die Holder', and 'Flex Arm.']

Back and forth movement of Flex Arm bends cable on sheaves.
Cable Mechanical Properties

Reverse Flexure with Temperature

- Sample holder; Pivots during test
- Flex Arm
- One end of sample captured between bend radii
- 0.5m Bend Radius

Back and forth movement of Flex Arm bends cable on sheaves
Qualification Test Program

- Reverse Bend

**Sample:** 100m-long cable sample in a tensile bed.

**Test Description:**
- The cable is routed through three 3m diameter sheaves attached to a moveable carriage.
- Tension applied up to NTTS.
- Carriage traverses over a portion of the sample and impart cycles of reverse bends at different tension levels.
Cable Mechanical Properties

**REVERSE BEND TEST**

- 3-meter diameter sheaves
- Moveable carriage traverses over a 70m portion of 100m long test specimen
- 100m test specimen
Qualification Test Program

- Tension/Torque/Elongation

**Sample:** 100m long cable sample in a tensile bed.

**Test Description:**
- Cable ends pinned against rotation.
- Tension applied incrementally to NTTS.
- Optical loss monitored, along with tension, torque and elongation.
Qualification Test Program

- Tension/Rotation/Elongation

**Sample:** 100m long cable sample in a tensile bed.

**Test Description:**
- One cable end pinned against rotation, other end free to rotate.
- Tension applied incrementally to NTTS.
- Optical loss monitored, along with tension, rotation and elongation.

![Diagram of Tension/Rotation/Elongation test setup](image)
Qualification Test Program

- Crush

**Sample:** ~5m long cable sample

**Test Description:**
The sample is placed between two flat plates over a 10cm long section of the cable, and then loaded.
Cable Manufacture
Cable Manufacturing -- LW

Loose Tube → Power Conductor → Polyethylene Extrusion
Cable Manufacturing -- Armoring
New Challenges

Next Generation Cable:

• Improved Fiber Cushioning for New Fibers?
• Higher Voltage Capability?
• More Economical & Efficient Power Conduction?
• New Insulating Material?
• Quicker Jointing Process?
• ???

How will you progress Subsea Communications?
Thank You