
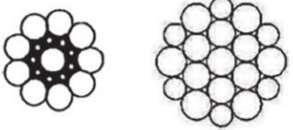


Prestressing Steel - New and Existing Products Overview

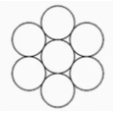
Jon Cornelius, Executive Vice President, Sumiden Wire Products Corporation
September 27, 2019

Types of Prestressing Steel Wire Products

Product	Material	ASTM Specification(s)	Recent Activity
 PC Strand 7-Wire	Steel	ASTM A416	Higher strengths, Larger Diameter
	Steel - Galvanized		New ASTM standard in process
	Steel - Epoxy Coated	ASTM A882	ASTM A882 in process of revision and reinstatement
	Stainless Steel		New product with a new ASTM standard in process
 PC Strand 19-Wire	Steel		
PC Wire	Steel Plain and Indented	ASTM A421 ASTM A881	

9 + 9 + 1

12(6 + 6) + 6 + 1



7-Wire Prestressing Steel Strands (USA) - Uncoated

ASTM A416 – 2018 Sizes & Grades

Diameter (in)	Tensile Strength (ksi)
1/4"	250
0.313	250
3/8"	250, 270
7/16"	250, 270
1/2"	250, 270
1/2" Special (0.52")	270
6/10"	250, 270
0.62"	270
7/10"	270

- Additional details
 - Sizes under 3/8" and 0.62" & 7/10" are available in the US, but typically made-to-order (not inventoried)
 - Tensile Strengths up to 300 ksi are available in the US using Buy-America compliant wire rod.
 - Tensile Strengths above 300 ksi **are not** currently available in the US using Buy-America compliant wire rod.



Higher Strength 7-Wire Prestressing Steel Strands (Global)

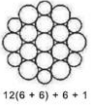
ISO 6934-4 (Current)

Diameter (mm)	Diameter (in)	Tensile Strength (N/mm ²)	Tensile Strength (ksi)
12.7	1/2"	1,860	270
15.2	6/10"	1,860	270

ISO 6934-4 (DRAFT)

Diameter (mm)	Diameter (in)	Tensile Strength (N/mm ²)	Tensile Strength (ksi)
12.7	1/2"	1,860	270
		2,160	313
		2,230	323
		2,360	342
15.2	6/10"	1,860	270
		2,160	313
		2,230	323
		2,360	342

- Higher strength strands (>300 ksi) are available from a limited number of suppliers globally.
- >300 ksi strands **are not** currently available using Buy-America compliant wire rod.



19-Wire Prestressing Steel Strands (Global)

ISO 6934-4 (Current)

Diameter (mm)	Diameter (in)	Tensile Strength (N/mm ²)	Tensile Strength (ksi)
17.8	7/10"	1,860	270
19.3	0.76"	1,860	270
20.3	8/10"	1,810	263
21.8	0.86"	1,810	263

ISO 6934-4 (DRAFT)

Diameter (mm)	Diameter (in)	Tensile Strength (N/mm ²)	Tensile Strength (ksi)
17.8	7/10"	1,860	270
19.3	0.76"	1,860	270
20.3	8/10"	1,810	263
21.8	0.86"	1,810	263
28.6	1.13"	1,780	258

- 19-wire prestressing steel strands **are not** currently produced in the US.
- Most applications for 19-wire strands are post-tensioning
 - Examples: Transverse bridge tendons, underground mine roof bolts, etc.

Corrosion Resistant PC Strand Types

One Example of a Common Corrosion Problem



Steel Strand Deterioration
(Spalling)

I-95 over the Turtle River in Brunswick, GA

Solutions for Corrosion Resistance



Uncoated Strand



Epoxy Coated Strand



Stainless Steel Strand

Corrosion Resistance Solutions!

Material Properties Comparison

	A416 PC Strand	A882 Epoxy Coated PC Strand	Stainless Steel PC Strand
Material	1080 Carbon Steel	1080 Carbon Steel	2205 Duplex Alloy
Diameters	3/8" – 0.7"	3/8" – 0.7"	3/8" – 0.7"*
Tensile Strength(s)	250ksi, 270ksi, 300+ ksi	250ksi, 270ksi, 300+ ksi	240 ksi - 250ksi
Elongation @ UTS	≥3.5%	≥3.5%	≥1.4%
1,000 Hr Relaxation @ 70% GUTS	<2.5%	Normal: <6.5% Low-Relax: <2.5%	<2.5%
Yield @ 1% EUL	90% specified min. breaking load	90% specified min. breaking load	90% specified min. breaking load
Elastic Modulus	28.6 Mpsi	28.6 Mpsi	24.5 Mpsi
Buy-America Compliant	Yes	Yes	Yes
Cost Index (Index: A416 Strand = 1)	1	2.5 – 3	8 - 9

* As of 09/2019, only 1/2" and 0.6" has been produced using 2205 duplex alloy stainless steel.

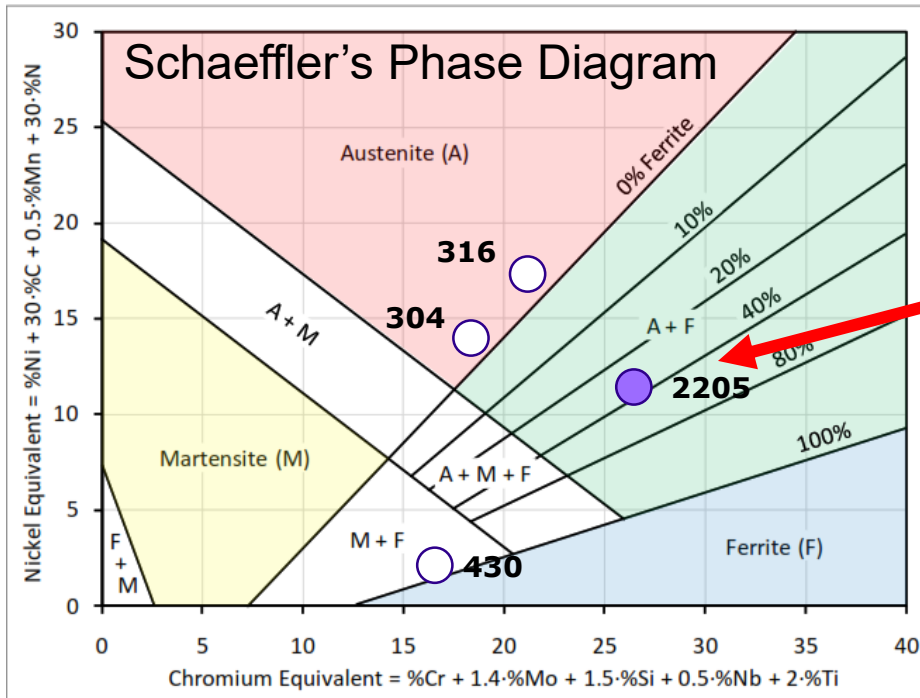
2205 Alloy Stainless Steel PC Strand

Stainless Alloy Selection (Georgia Tech Research Team)

Alloy	Structure	Composition (%)				PREN	Relative Cost*
		Cr	Ni	Mo	Other		
304	Austenitic	18.2	8.1	-	-	19.2	6.9
316	Austenitic	17	11	2.8	-	27.2	9.6
2101	Duplex	21.5	1.5	-	5Mn, 0.2N	29.1	5.0
2205	Duplex	22	5.5	3	0.17N	37.0	8.8
2304	Duplex	23	4.8	0.3	0.10N	27.0	6.4
17-7PH	Martensitic	17	7	-	1Al, 1Si	17.0	8.2

Alloys Considered by Georgia Tech Team

- These (left) stainless alloys were considered by the Georgia Tech team.
- 2205 was selected because it provided both the **highest strength** and **best corrosion resistance** among the alloys evaluated.

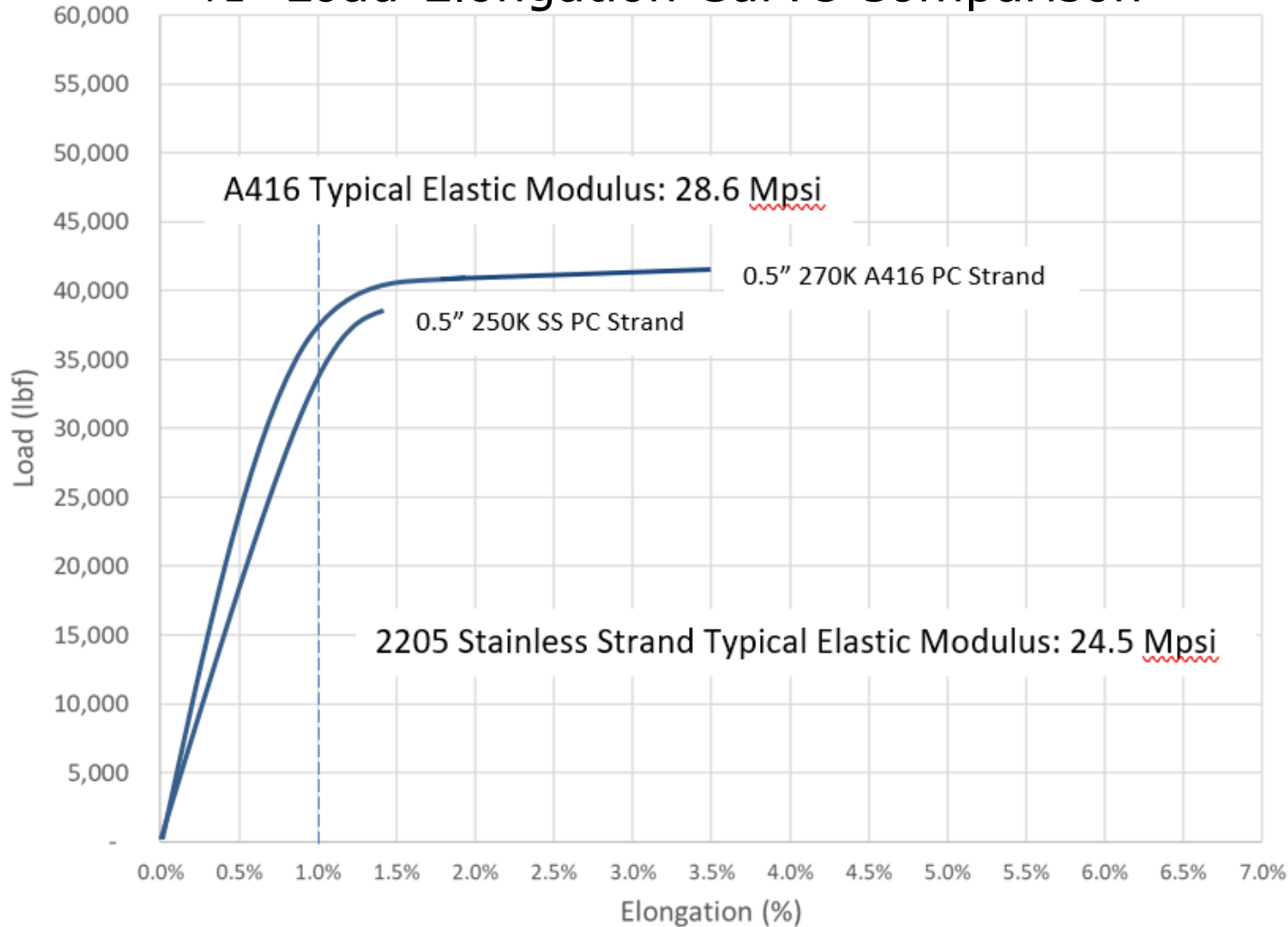


2205 Alloy Overview

- Duplex alloy (Near equal % of austenite and ferrite)
- 2205 is not a commonly known alloy
- Much more resistant to stress corrosion cracking than 304 & 316 stainless steels

Comparison A416 270K Strand vs. Stainless Steel Strand

1/2" Load-Elongation Curve Comparison



	A416 PC Strand	Stainless Steel PC Strand
Material	1080 Carbon Steel	2205 Duplex Alloy
Diameters	3/8" - 0.7"	3/8" - 0.7"*
Tensile Strength(s)	250ksi, 270ksi, 300+ksi	240ksi - 250ksi
Elongation @ UTS	≥3.5%	≥1.4%
1,000 Hr Relaxation @ 70% GUTS	<2.5%	<2.5%
Yield @ 1% EUL	90% specified min. breaking load	90% specified min. breaking load
Elastic Modulus	28.6 Mpsi	24.5 Mpsi
Buy America Compliant	Yes	Yes
Cost Index (Index: A416 Strand = 1)	1	8 - 9

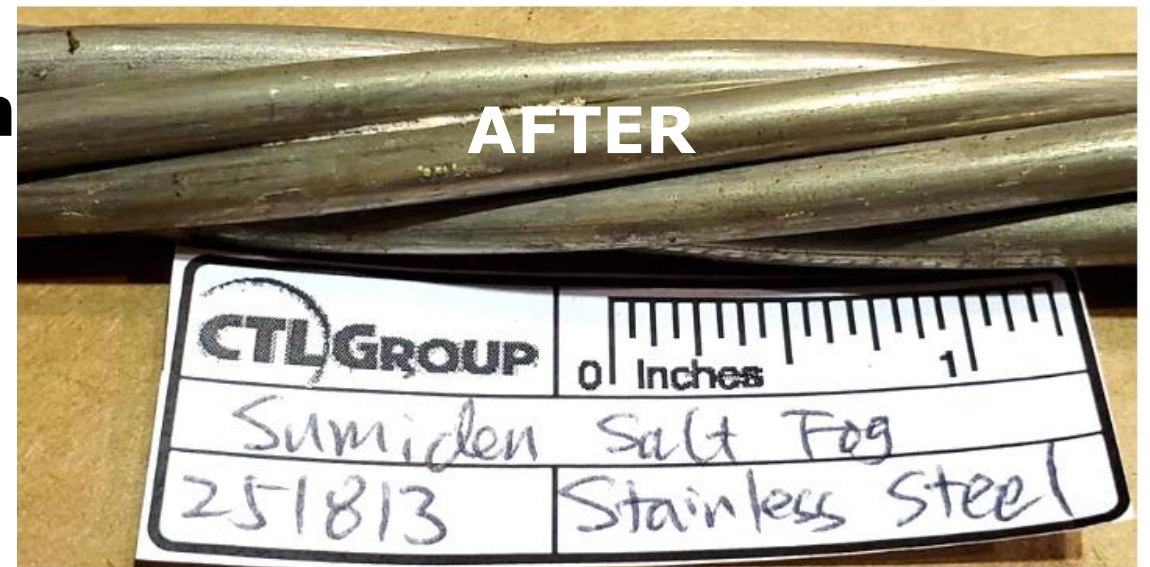
2205 Stainless PC Strand 3,000 Hour Salt Fog Test @ 70% GUTS

3,000 Hour Salt Fog Test

- Testing Conditions
 - Strand stressed 70% GUTS
 - 3,000 hour salt fog
- Test Results
 - **No loss of tensile strength**
 - **No corrosion**



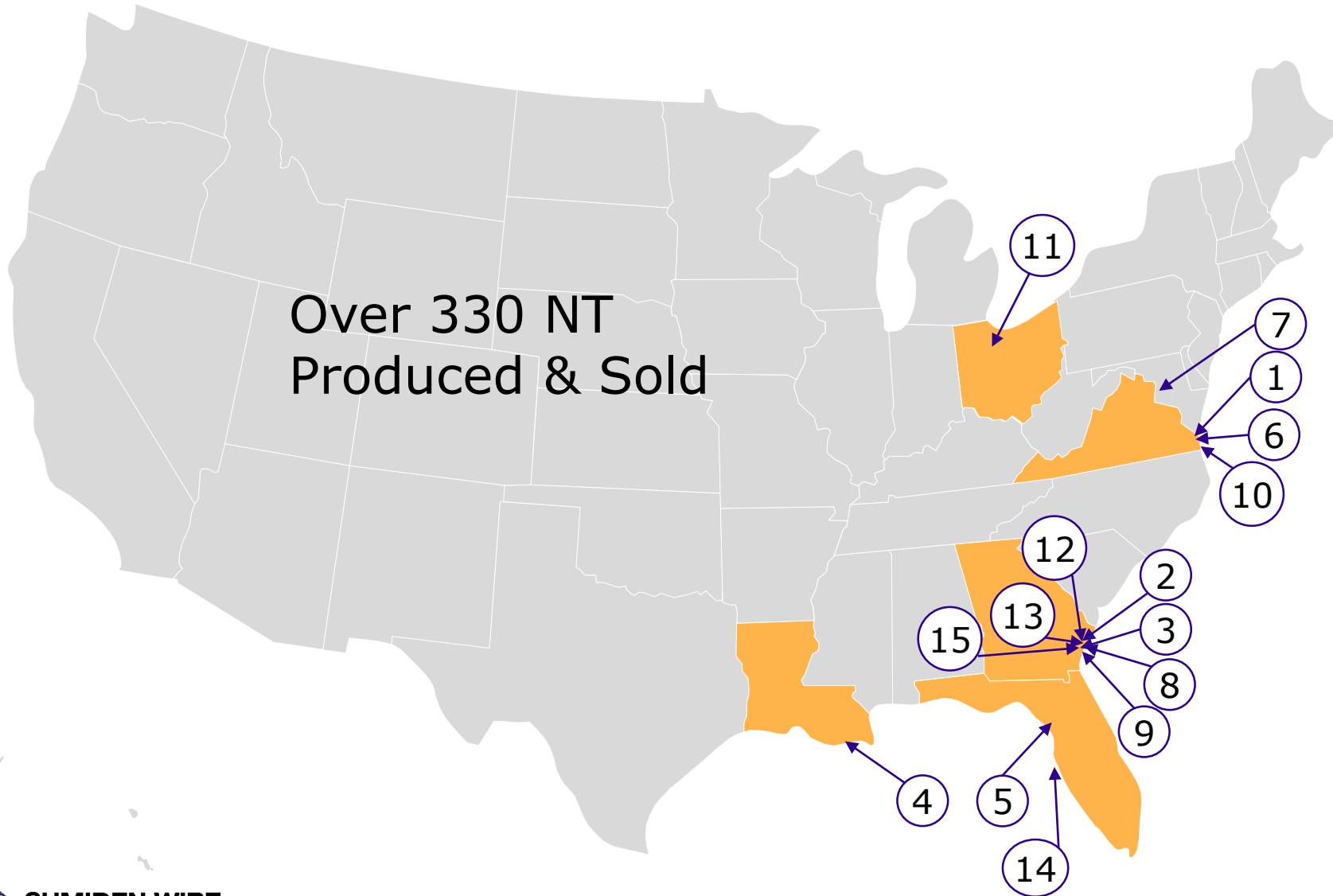
Figure 1 Specimen Surface Conditions prior to the Salt Fog Test



(b)

Figure 5 Strand Condition after 3000 Hours Exposure

2205 Stainless Steel Strand Past & Current Projects



#	Project Name - Owner	Year (Application)
1	Nimmo Parkway - VDOT	2013 (piling)
2	Riceboro Creek - GDOT	2016 (piling)
3	Satilla River - GDOT	2016 (piling)
4	LA 1 Grand Isle - LADOT	2017 (piling)
5	Cedar Key Bridge - FDOT	2018 (piling)
6	High Rise Bridge - VDOT	2018-2019 (piling)
7	Arlington Bridge - EFL	2018-2019 (deck panels)
8	Wilmington River Bridge- GDOT	2018-2019 (piling)
9	Jimmy Delouch Parkway - GDOT	2018-2019
10	Queens Creek - VDOT	2019 (piling)
11	Seneca 19 - ODOT	2019 (box beams)
12	Sterling Creek Bridge - GDOT	2019 (piling)
13	Pipemakers Canal - GDOT	2019 (piling)
14	Skyway Bridge 19025 - FDOT	2019 (sheetpile)
15	Island Parkway - GDOT	2019 (piling)

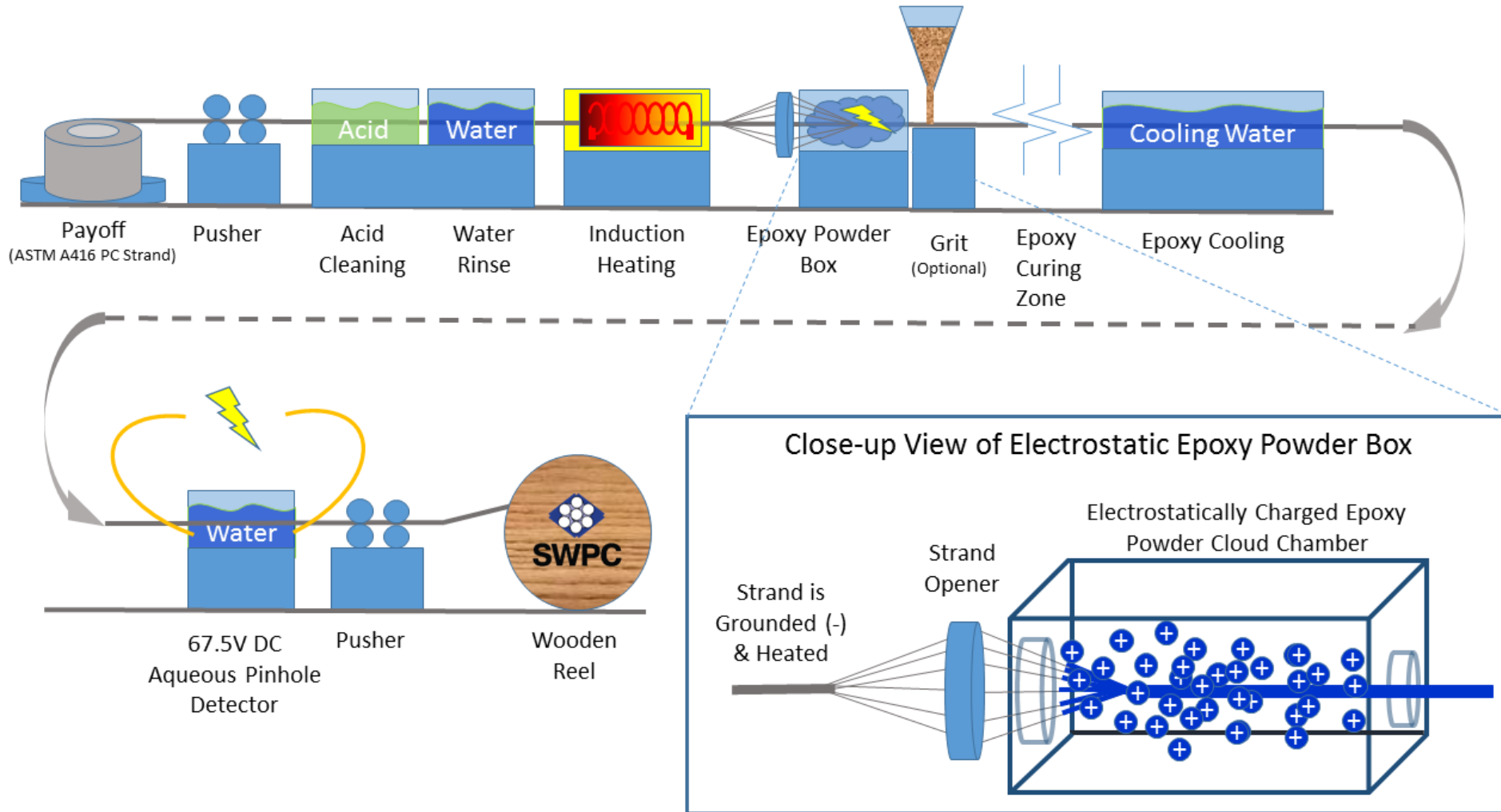
ASTM A882 Epoxy Coated PC Strand

Types of Epoxy Surface Finish

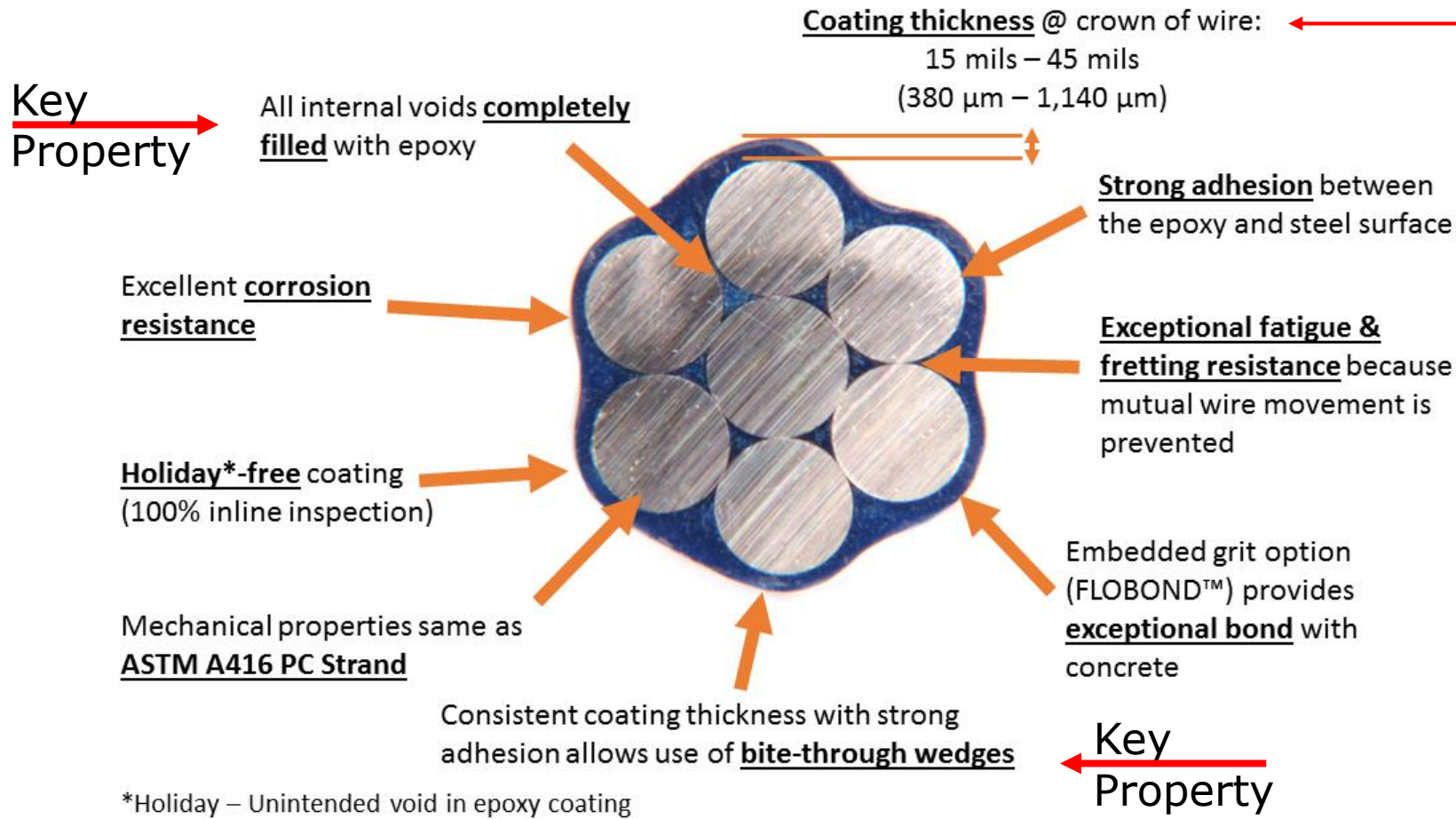


- **Flo-Gard®**
 - No Grit
- **Flo-Bond® (Coarse Grit)**
 - Coarse grit (90 grit silica) particles imbedded on epoxy surface
 - Very high bond with concrete
- **Flo-Bond® (Fine Grit)**
 - Fine grit (aluminum oxide) particles imbedded on epoxy surface
 - Similar bond as bare strand with concrete
- **Available Strengths**
 - 270K
 - 300K

Epoxy Coating Process



Key Properties of ASTM A882 Epoxy Coated PC Strand



- ### Coating Thickness
- A882 Epoxy Coated Strand coating thickness:
 - 15 mils – 45 mils
 - 3-4 mils* epoxy thickness is enough to protect steel from chloride attack
 - Comparison: ASTM A775 epoxy coated rebar specified thickness
 - 7 – 16 mils.

*Reference: FHWA-RD-74-18

Epoxy Coated Strand Anti-Corrosive Property

After 1,000 hour salt spray test, epoxy coated strand **outperforms** all other forms of protection

Bare Strand



Galvanized Strand



Epoxy Coated Strand



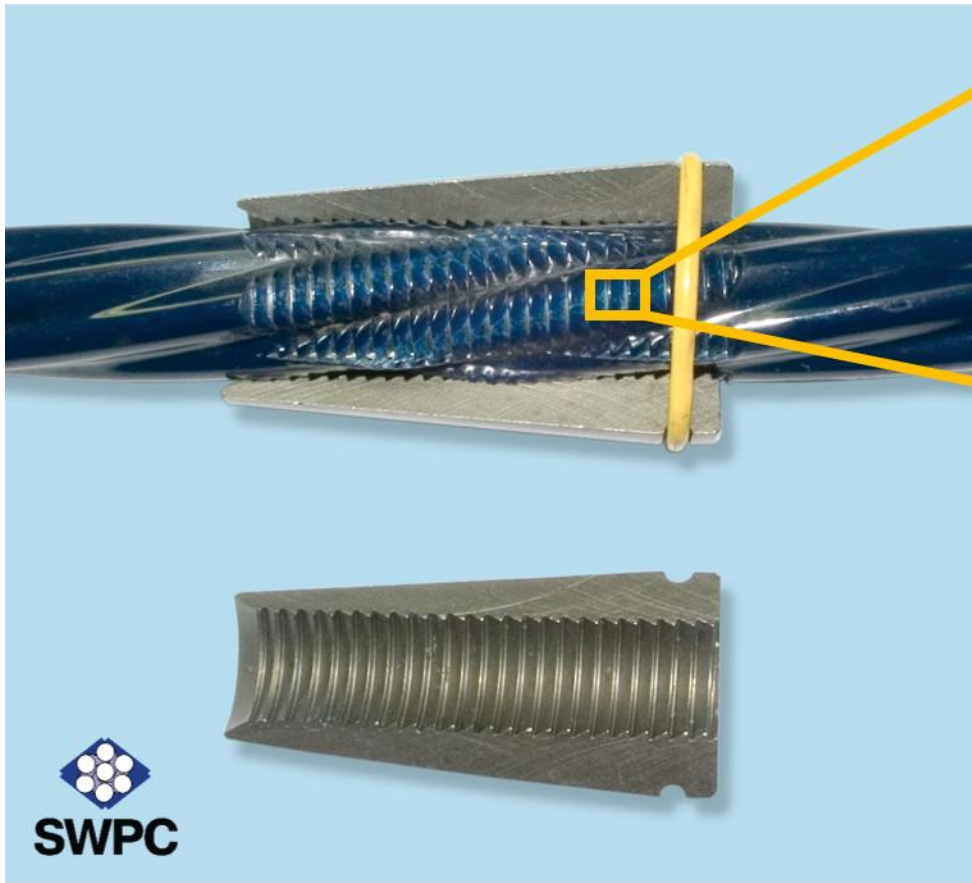
Epoxy Coated Strand Anti-Corrosive Property

3,000 Hour Salt Fog Test

- Testing Conditions
 - 3,000 hour salt fog
 - Strand stressed 70% GUTS
 - 2 Strand Types
 - As produced
 - Intentional Damage
- Test Results (Both Samples)
 - No loss of tensile strength
 - **No corrosion** on wire except on the exposed wire surface.
 - **No corrosion migration** nor loss of epoxy adhesion

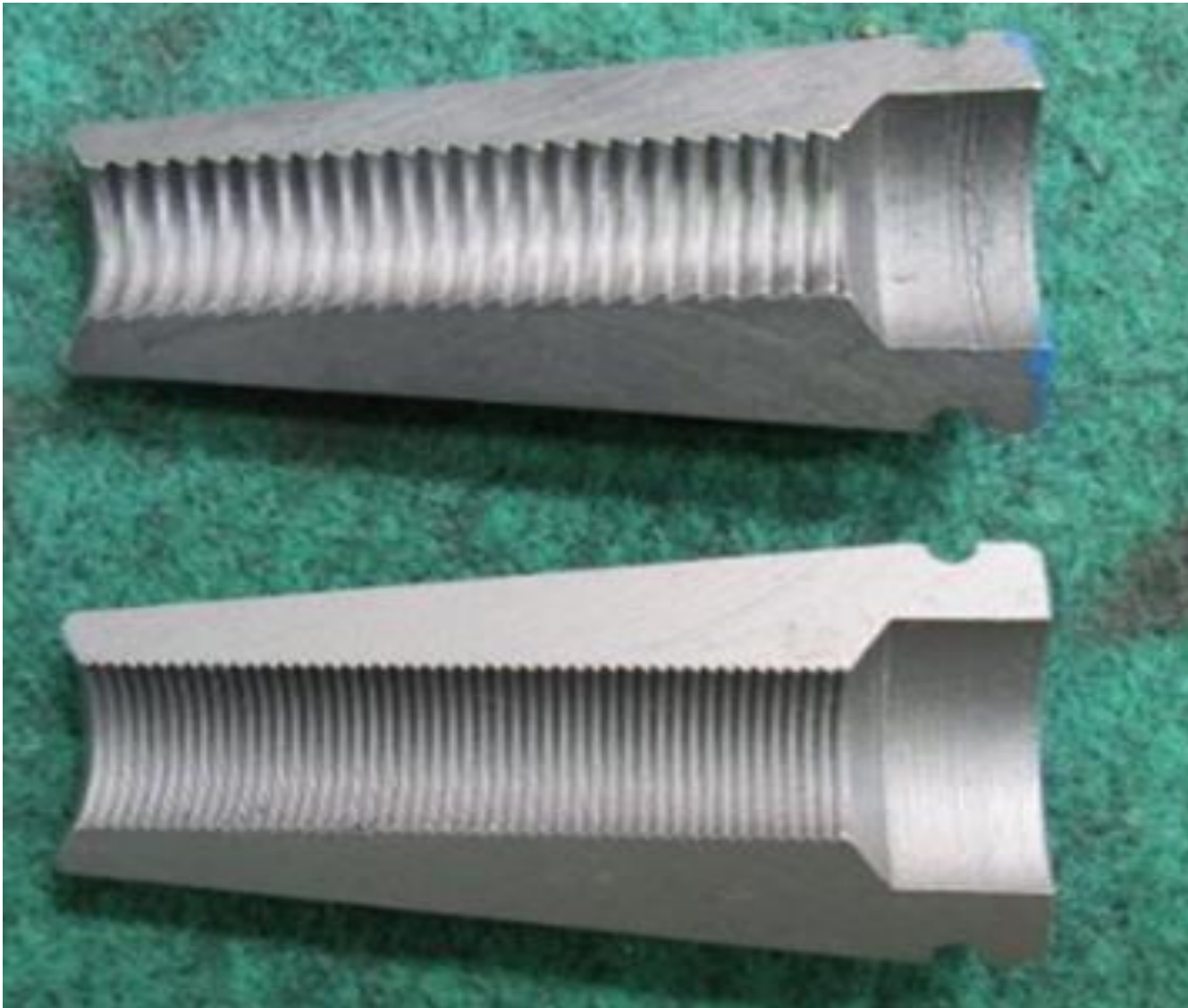


Epoxy Coated Strand - Bite-Through Wedge



Strand anchoring without removing the epoxy coating is common with Sumiden Wire's epoxy coated strand due to the uniform coating thickness and excellent adhesion. Specially designed wedges with deeper teeth and wider teeth spacing ensures penetration through the epoxy layer into the steel wires.

Bite-Through Wedge vs. Standard Wedge

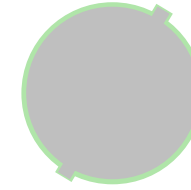


Bite-Through Epoxy
Coated PC Strand Wedge

Standard PC Strand Wedge

Epoxy Coating Comparison: PC Strand & Rebar

Epoxy Coating Comparison: PC Strand & Rebar



	ASTM A882 Epoxy Coated PC Strand		ASTM A775 Epoxy Coated Rebar	
Epoxy Thickness	15 mils – 45 mils (380 μm – 1,140 μm)		#3 - #5 rebar	7mils – 12 mils (175 μm – 300μm)
			#6 - #18 rebar	7mils – 16 mils (175 μm – 400μm)
Surface Preparation	Chemical Cleaned		Blast Cleaned	
Pinhole Inspection	1 st Check	67V Aqueous	Wet Sponge @ 67 V	
	2 nd Check	3000V Dry Spark		
Allowed Pinhole Frequency	No pinholes allowed		Maximum 1 pinhole per linear foot	

Epoxy coated PC strand has a thicker coating, better surface preparation and fewer pinholes allowed than epoxy coated rebar.

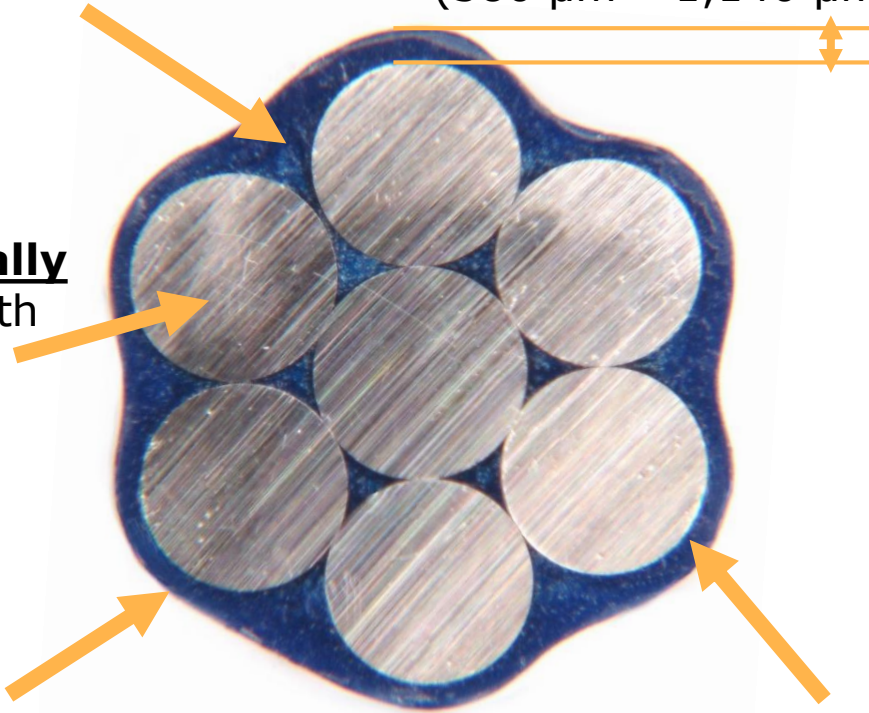
Epoxy Coating Comparison: PC Strand & Rebar

Coating thickness @
crown of wire:
15 mils – 45 mils
(380 μm – 1,140 μm)

Coating thickness @
7 mils – 16 mils
(175 μm – 400 μm)

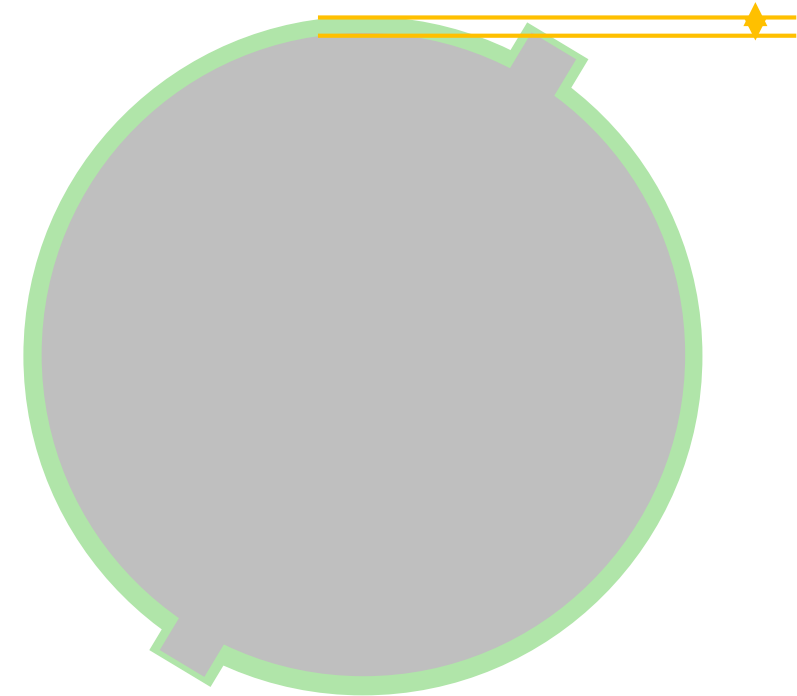
All internal voids
completely filled with
epoxy

Each wire
individually
coated with
epoxy



Pinhole-free coating
(100% inline inspection)

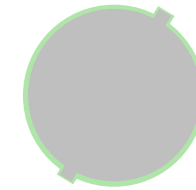
Strong adhesion between
the epoxy and steel surface



Epoxy Coating Comparison: PC Strand & Rebar

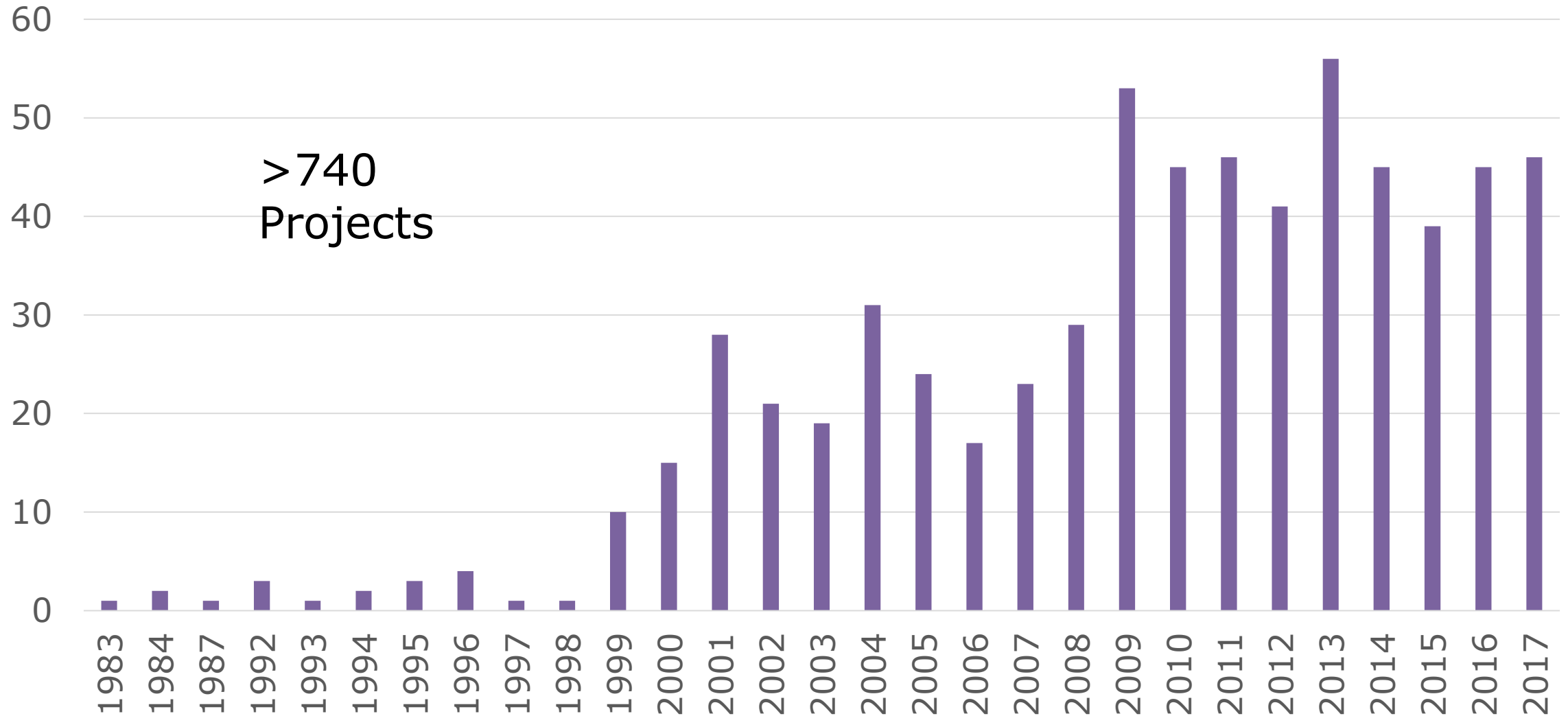


Epoxy coated strand is shipped and handled in the field using protective wooden spools.



Epoxy coated rebar is shipped and handled in the field with many points of contact during handling, storage and installation

Partial List of ASTM A882 Epoxy Coated PC Strand Global Projects Since 1983 by Year

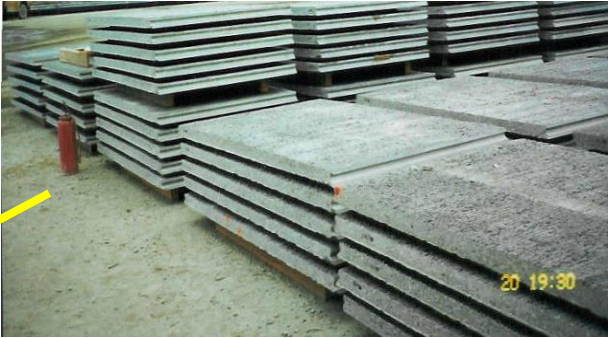


Partial List of ASTM A882 Epoxy Coated PC Strand Global Projects Since 1983 (by Type)

Application	# of Projects
Extradosed/Stay Cable	100
Ground Anchor	20
External Tendon	370
Internal Tendon	90
Pre-Tensioned Piling, Girders, Etc.*	12
Transverse Tendon	23
Other	133
Total	748

*NOTE: The Pre-Tensioned list is significantly understated. Epoxy coated strand is typically sold to pre-tensioned concrete producers without disclosure of the project. Sumiden is only typically aware of the larger projects. Examples of Pre-tension applications are piling, bridge deck panels, sound wall supports, etc.

Epoxy Coated PC Strand – Pretensioned Application



Decking



Girders



Pile

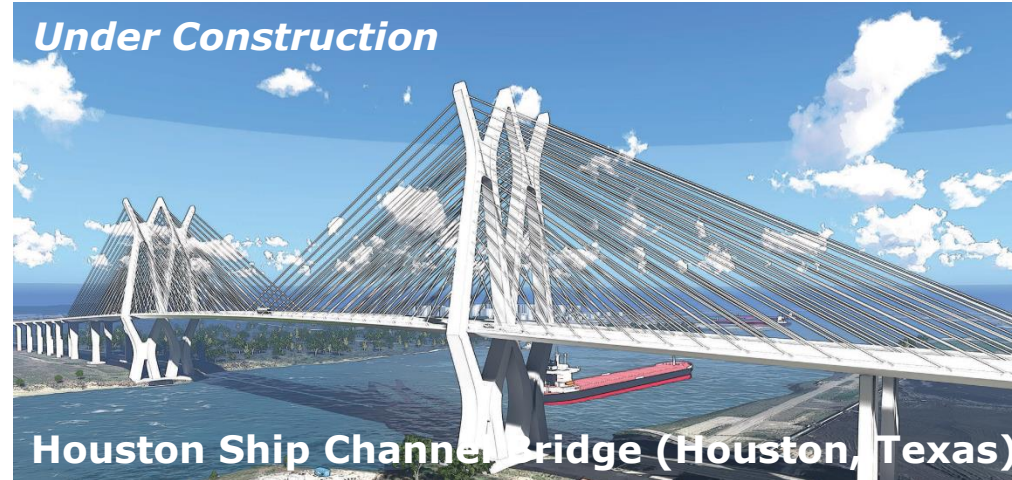
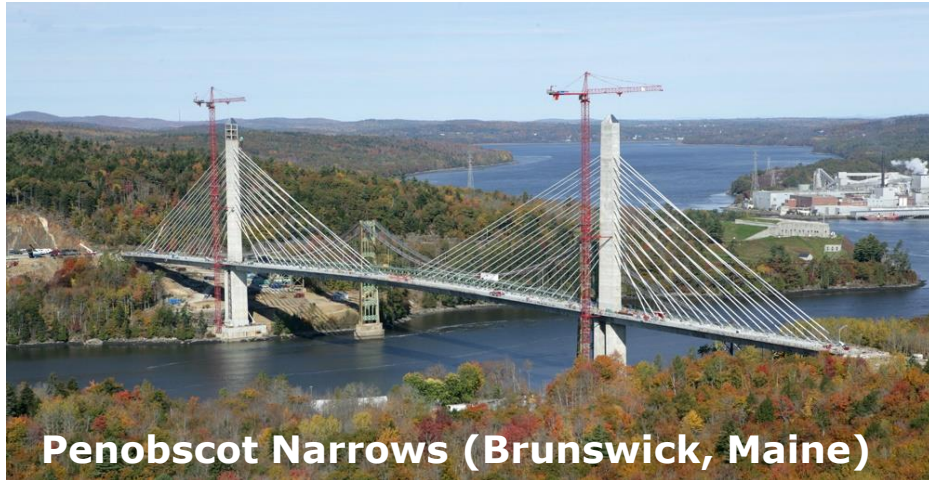


Epoxy Coated PC Strand – Post-Tensioned External Tendons



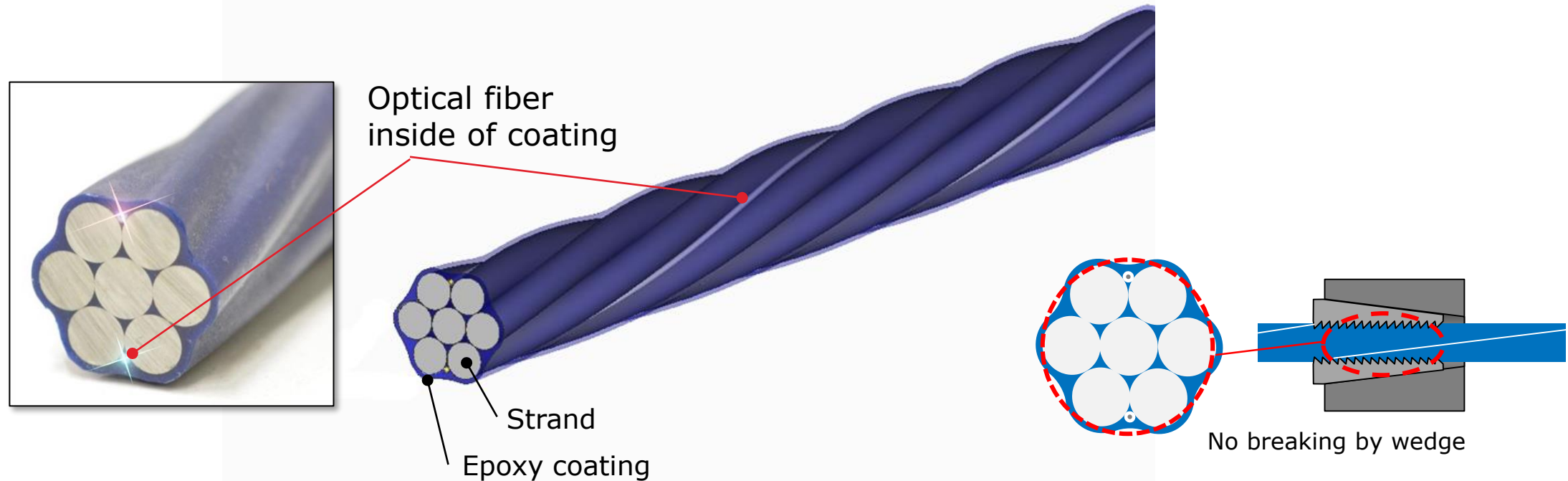
Akabuchigawa Bridge (Japan)

Epoxy Coated Strand - Stay Cable Bridges



Fiber Optic Stress and Strain Measurement for PC Strand

Epoxy Coated PC Strand with Fiber Optic Monitoring

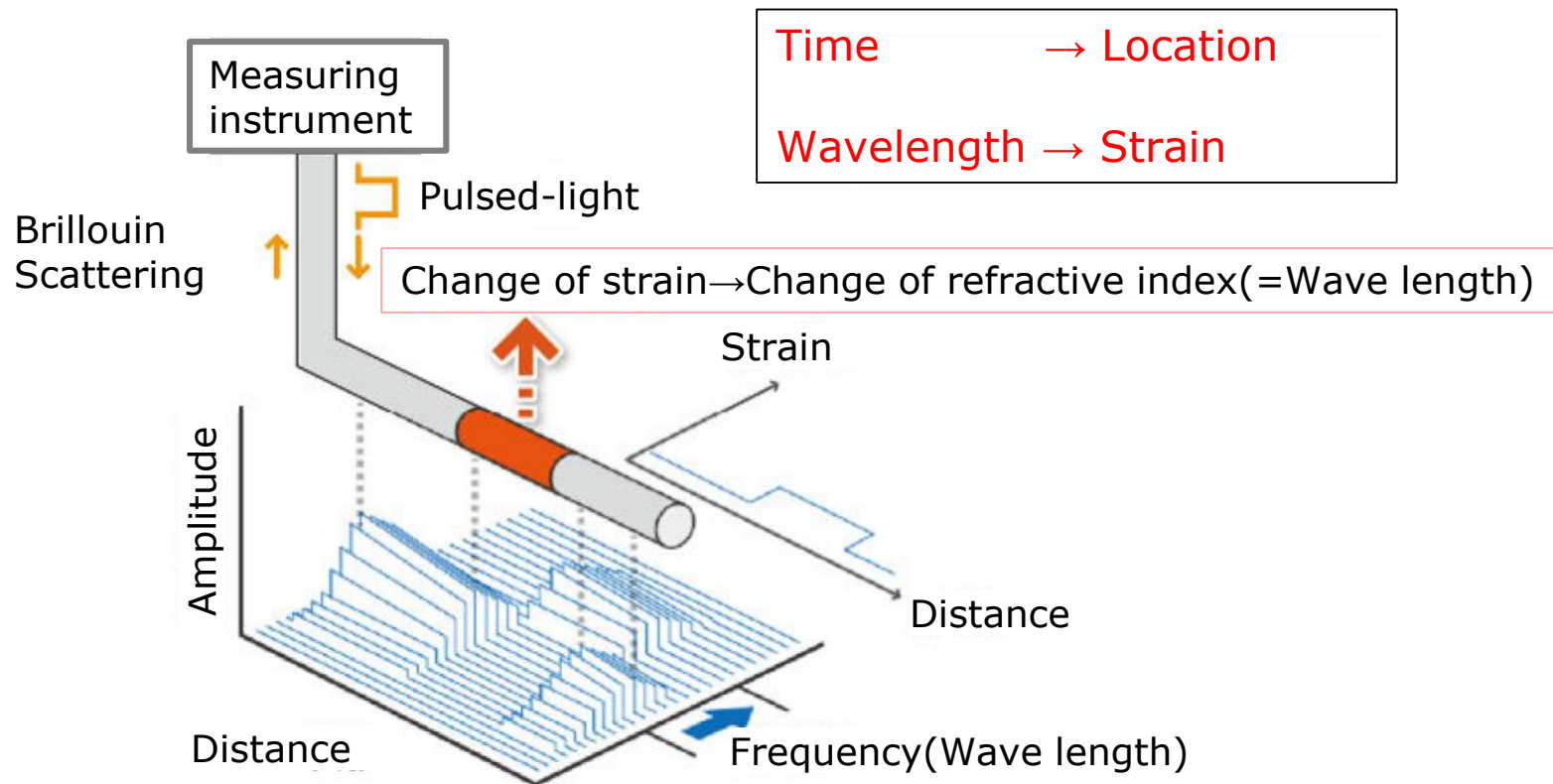


- 1) This cable provides strain data for itself when it is stressed, together with superior durability of cable.
- 2) Strain data are able to be converted to tensile stress of cable according to its young's modulus.
- 3) Strain at any section along the strand length can be detected.

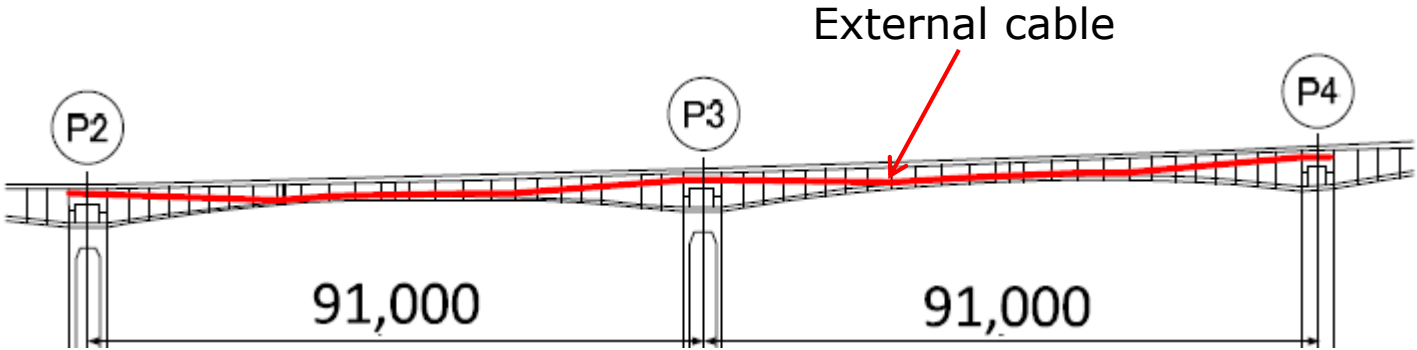
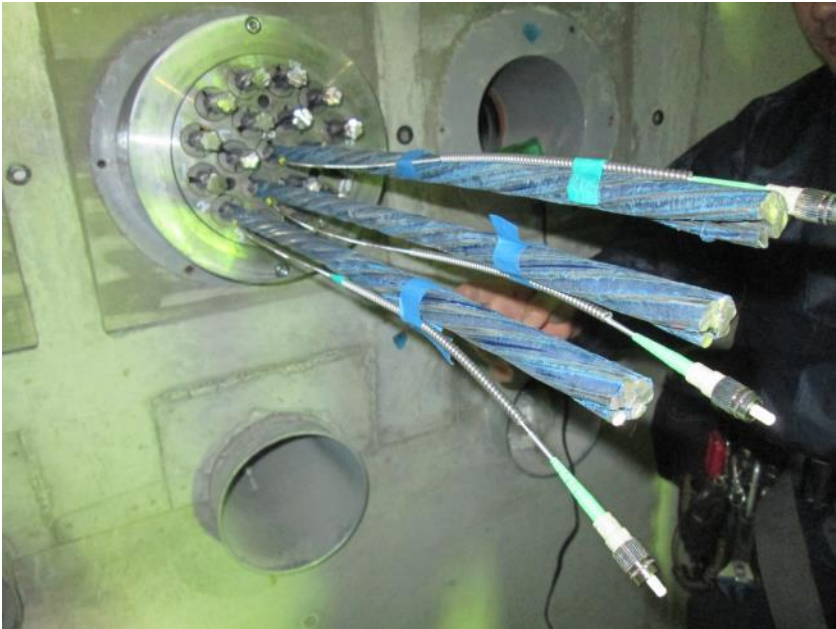
Measurement Principle

BOTDR (Brillouin Optical Time Domain Reflectometer)
= Strain measurement using Brillouin scattering

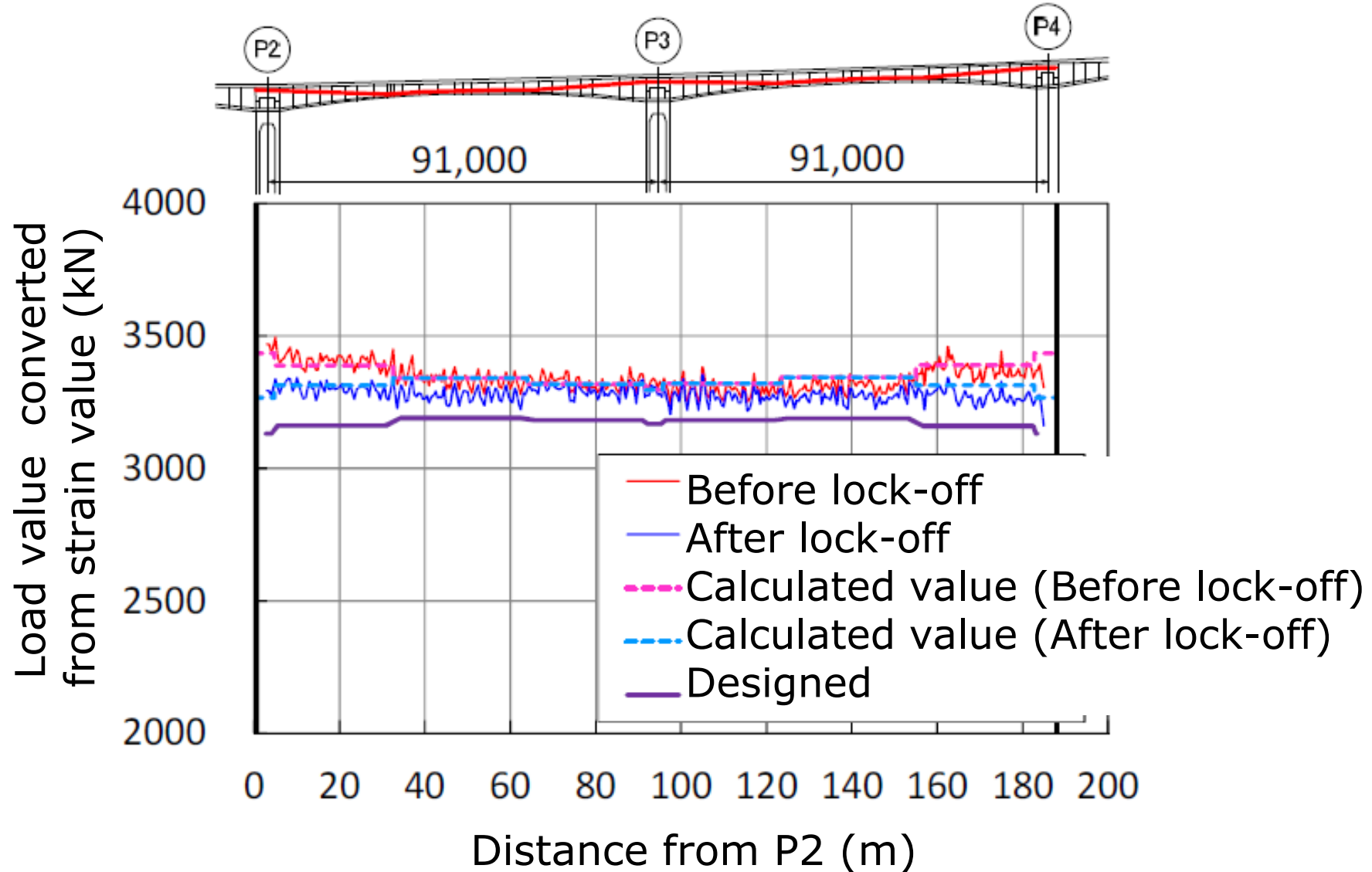
'Time' and 'Wavelength' is extracted from scattered light.



Demonstration Project - Tsukidate bridge (Highway Bridge)



Monitoring Result from the Stressing Operation



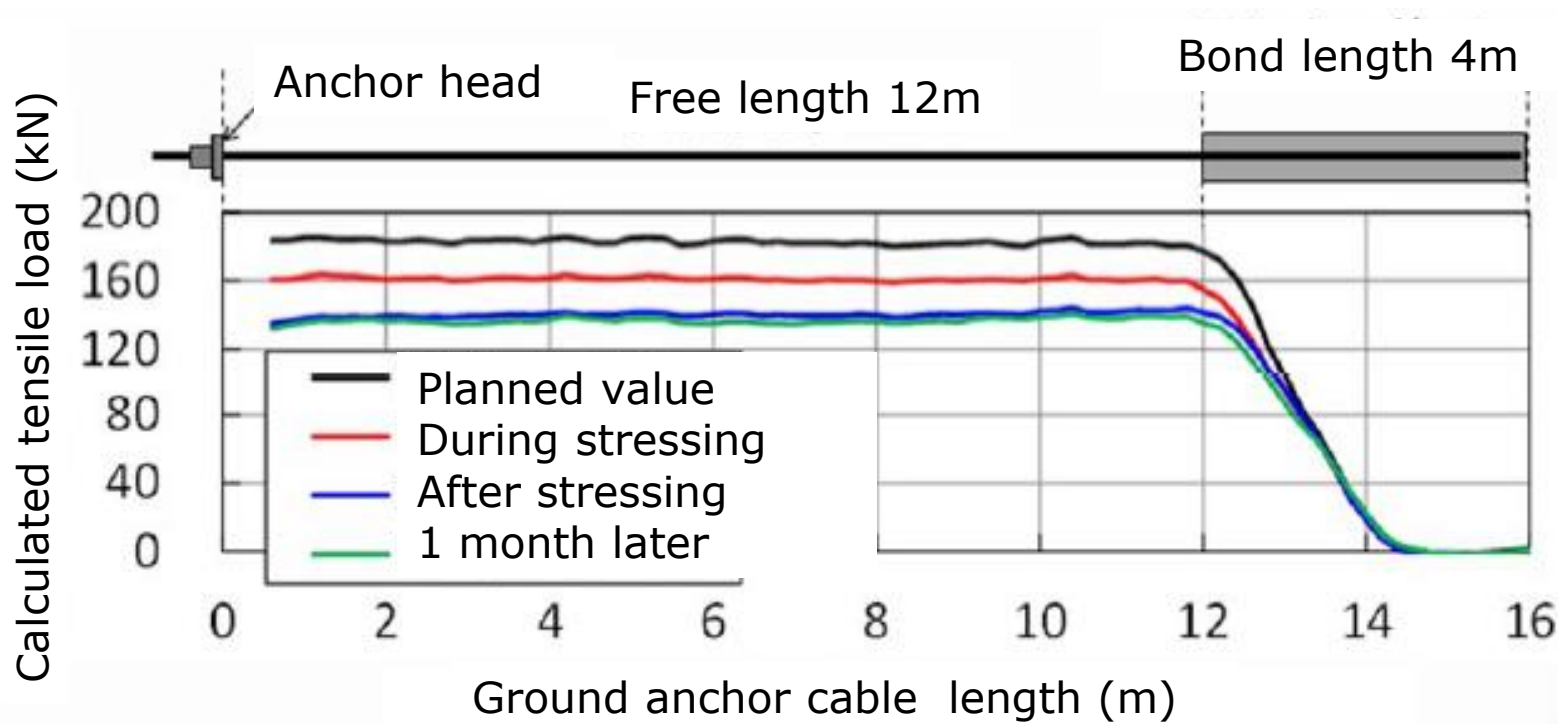
Demonstration Project – Ground Anchor

Tensile test was conducted using ground anchor system with optical fiber built-in ECF strand.



- 1 Install ground anchor cable and set anchorage parts
- 2 Install Jack and Pump
- 3 Take out optical fiber after removing Epoxy coating
- 4 Connect optical fiber with measurement machine (BOTDR)

Monitoring Result from the Stressing Operation

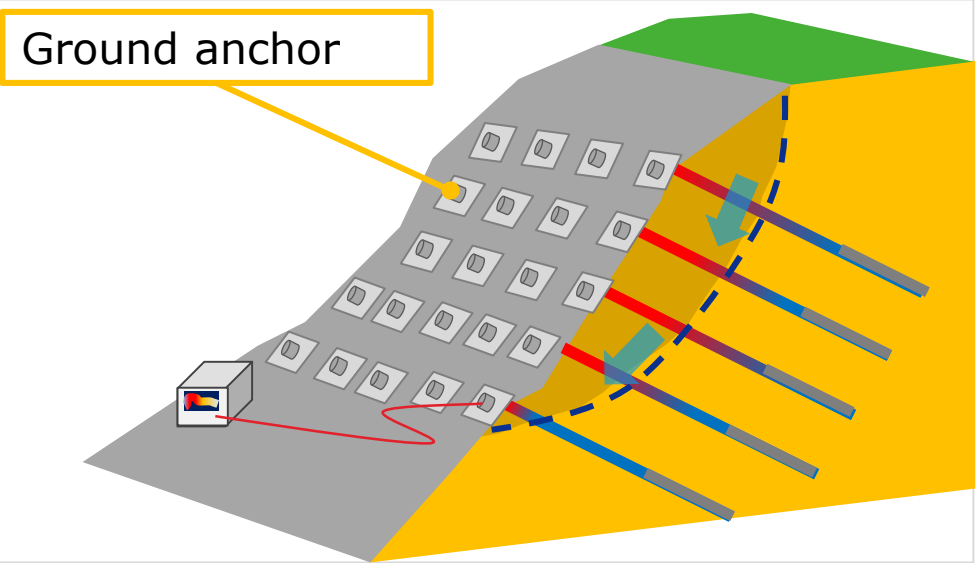
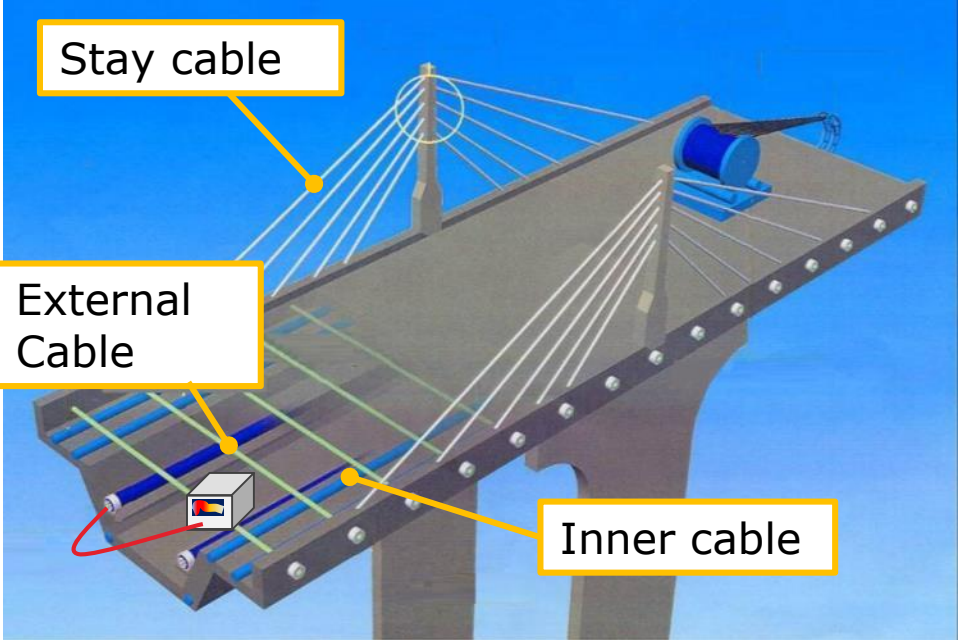
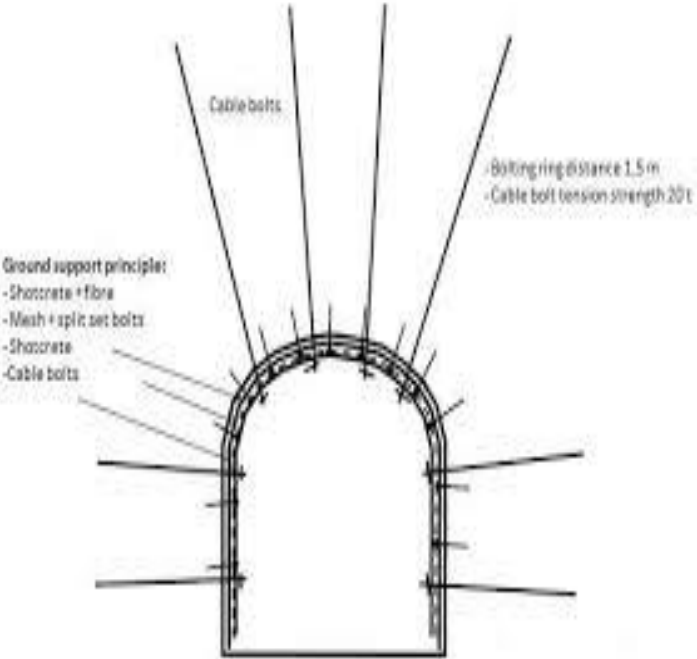


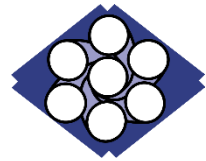
- The load over the free length is constant.
- The load over the bond length is reduced to 0 at the bottom of the anchor.
- One (1) month later, the load is maintained.

The distribution of the load on a ground anchor tendon can be measured using optical fiber built-in ECF strand.

Possible Applications for Fiber Optic PC Strand

Underground Mining





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