Optical Fiber Cable Design & Reliability

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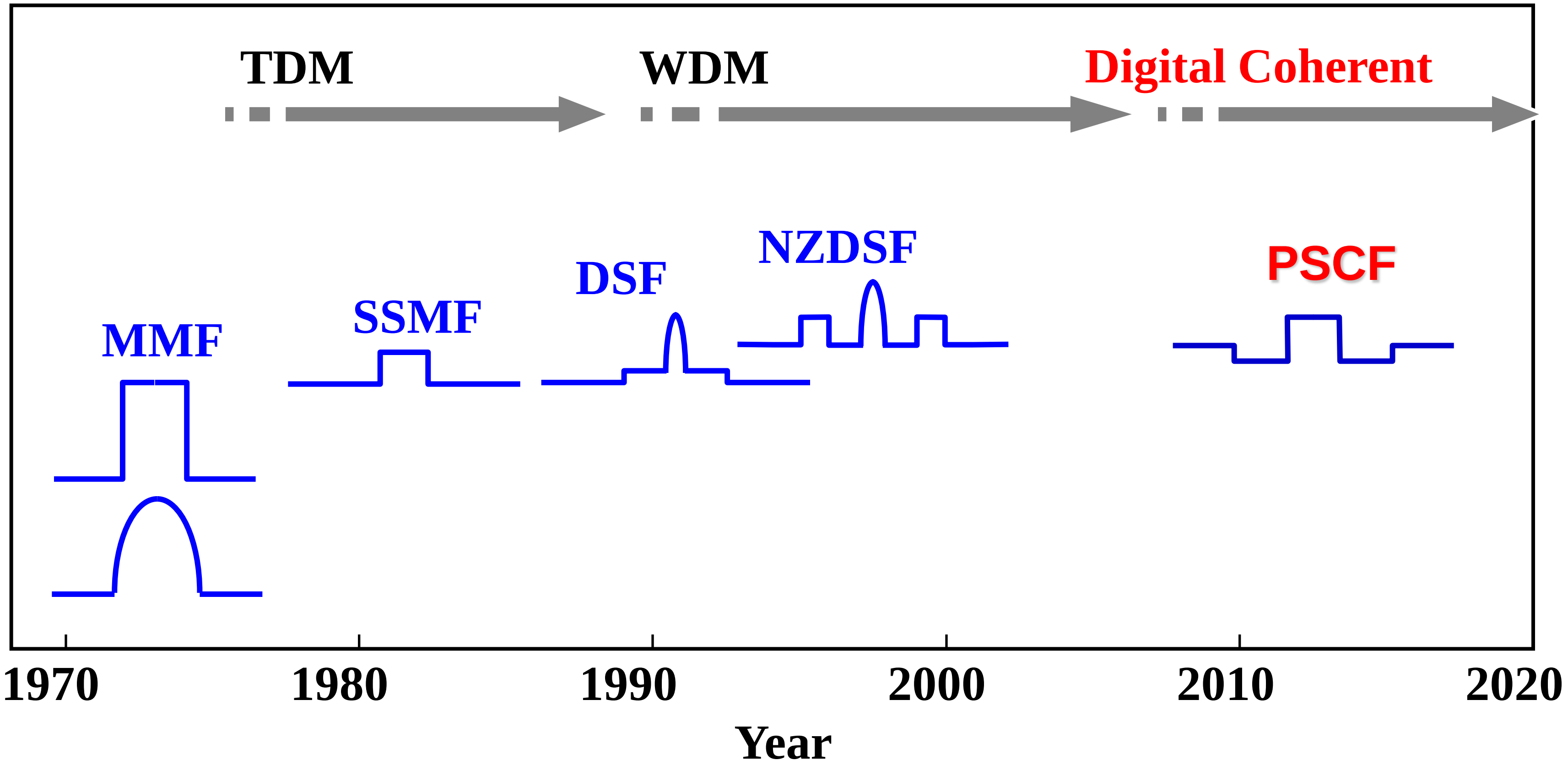
Outline

- Fiber & Cable Design
- Fiber & Cable Reliability
  - Causes & Likelihood of Failure
  - Fiber Reliability
    - Optical
    - Mechanical
  - Cable Standards
  - Cable Reliability
    - Mechanical Damage
    - Environmental Damage
  - Hardware
    - P-Clamps
- Summary

SUMITOMO ELECTRIC LIGHTWAVE

Fiber Design History

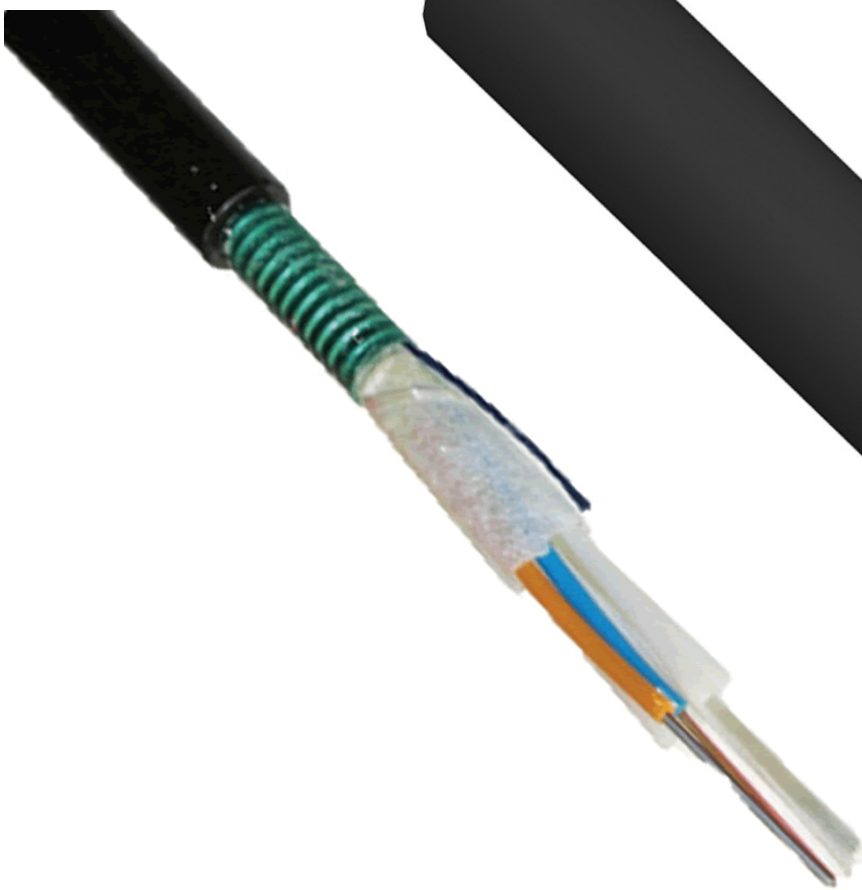
- Fiber design and transmission technology have collaboratively evolved to increase bandwidth.

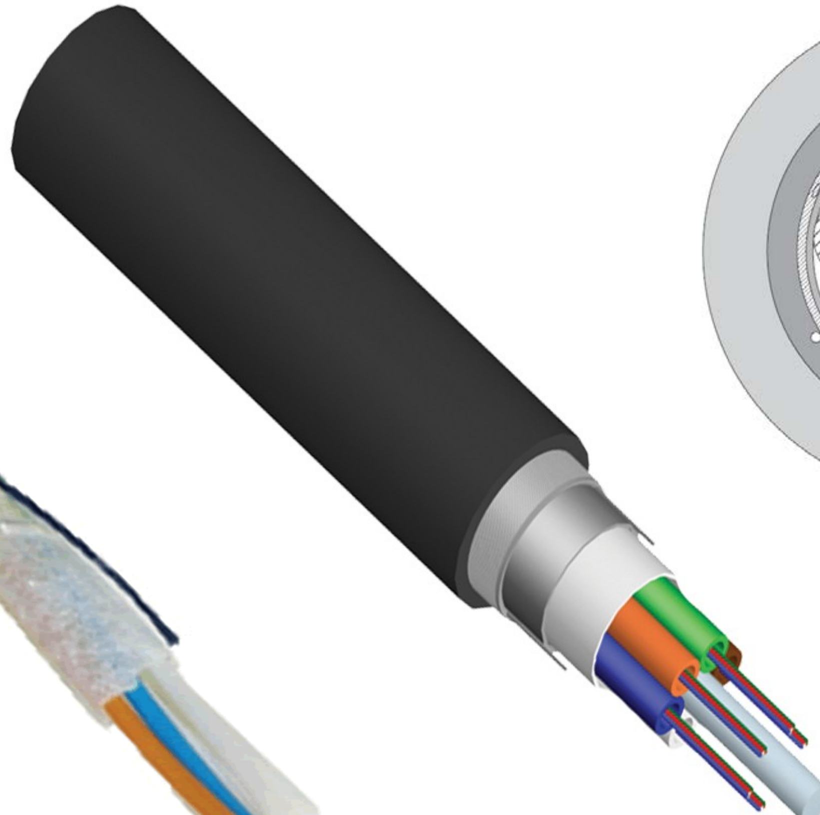


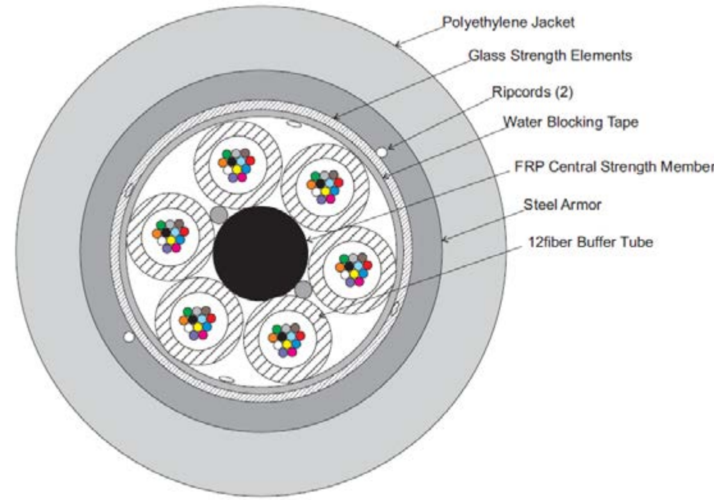
Fiber by Application

Application	Fiber	Standard
Indoor	MM	ISO/IEC OM3/4
Campus		ITU G.657
Metro	SM	ITU G.652
Long Haul (10G/40G)		ITU G.655 ITU G.656
Long Haul (100G/400G)		ITU G.654

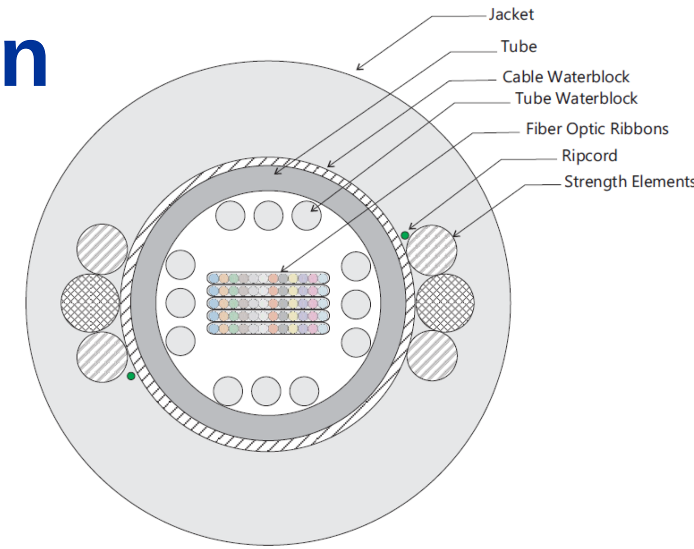
Typical Loose Tube Cable Design

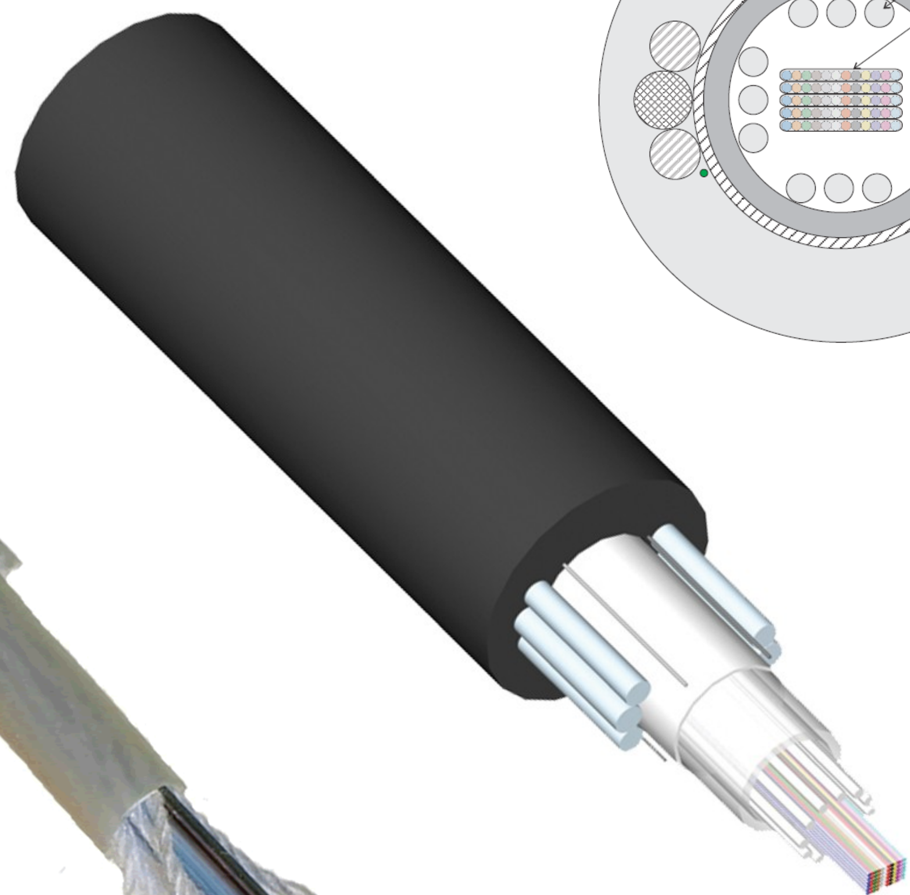


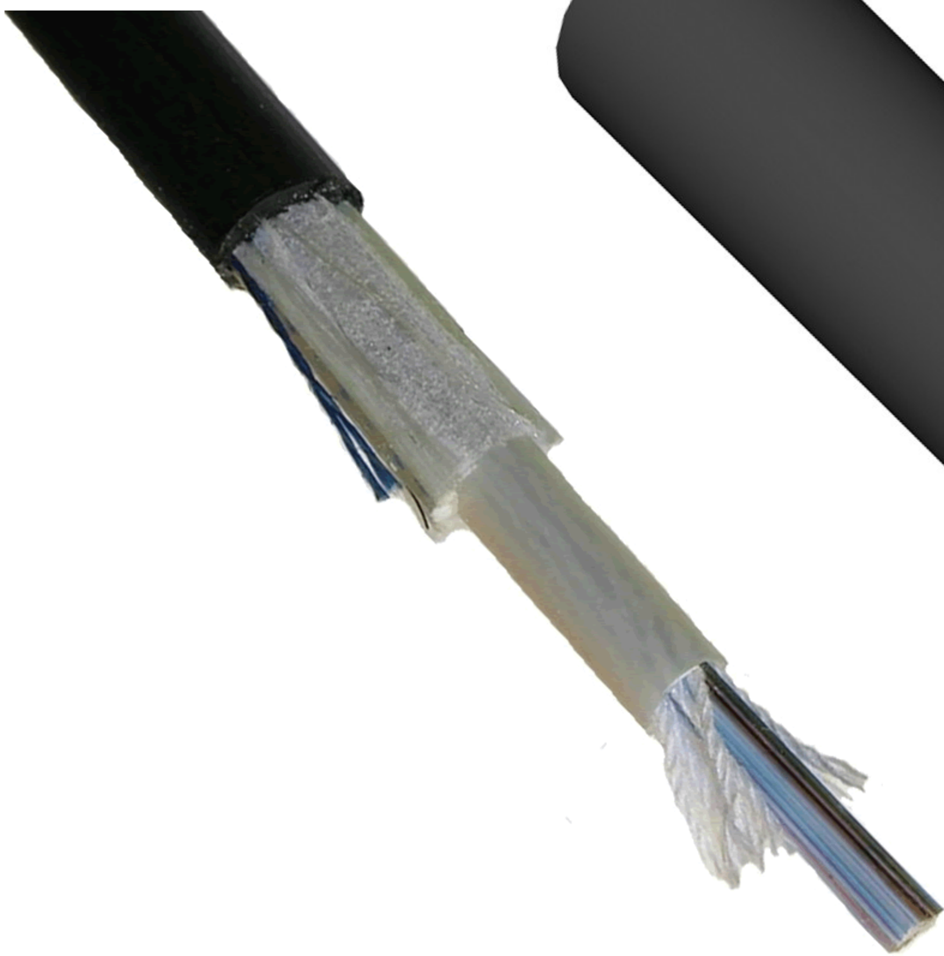




Typical Ribbon Cable Design

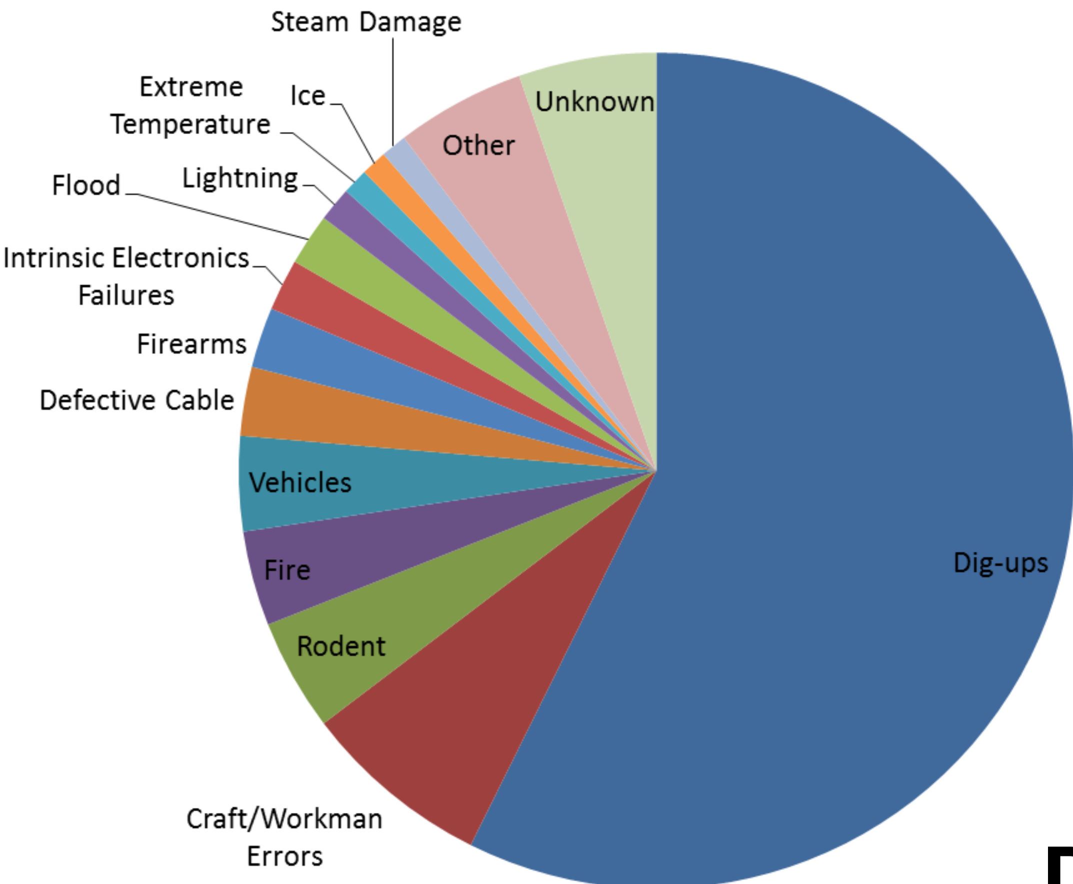






Fiber & Cable Failure

Studies of Historical Cable/Fiber Failure



Causes	Reported Failures	%
Dig-ups	172	57%
Craft/Workman Errors	22	7%
Rodent	13	4%
Fire	11	4%
Vehicles	11	4%
Defective Cable	8	3%
Firearms	7	2%
Intrinsic Electronics Failures	6	2%
Flood	6	2%
Lightning	4	1%
Extreme Temperature	3	1%
Ice	3	1%
Steam Damage	3	1%
Other	15	5%
Unknown	16	5%
	300	100%

Dig-ups dominate!

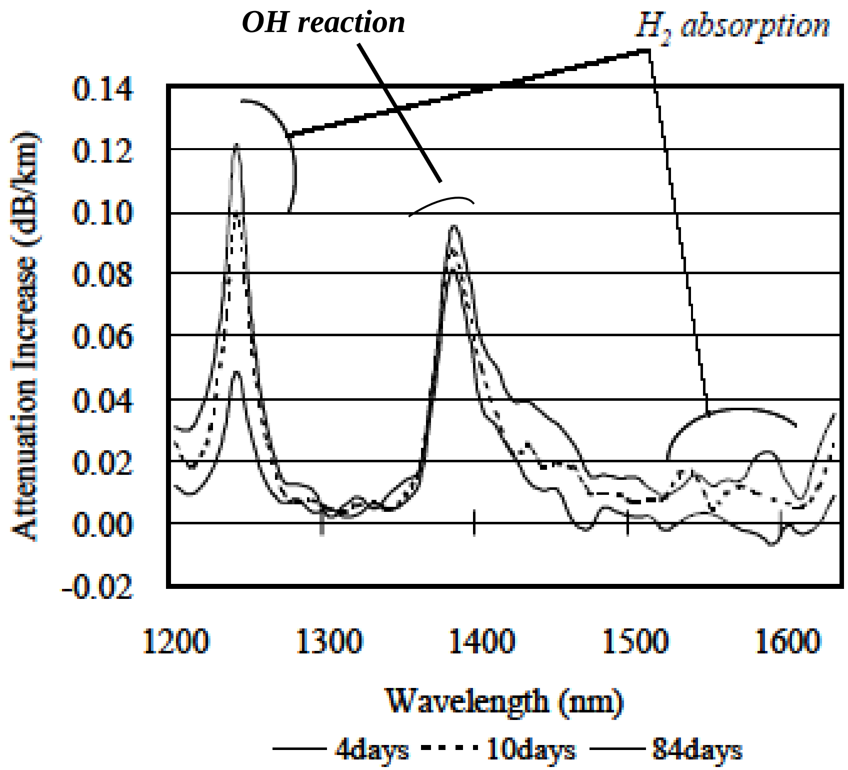
Ref: V. Hou, "Update on Interim Results of Fiber Optic System Field Failure Analysis", *NFOEC Proceedings* Vol. 1, p. 539-545, (1991)

Intrinsic Cable Failure

- Cablers have very little influence on the majority of causes of cable field failures.
- While a small percentage, we can examine the “intrinsic” cable failures and what is done to prevent them.
- Some questions about intrinsic failures:
    - Does the glass inside the cable degrade? Break?
    - What are the cables expected to withstand through their lifecycle?
    - What standards are applicable for cable and fiber?
    - What tests are done to ensure the cable design is robust?

Fiber Lifetime - Optical

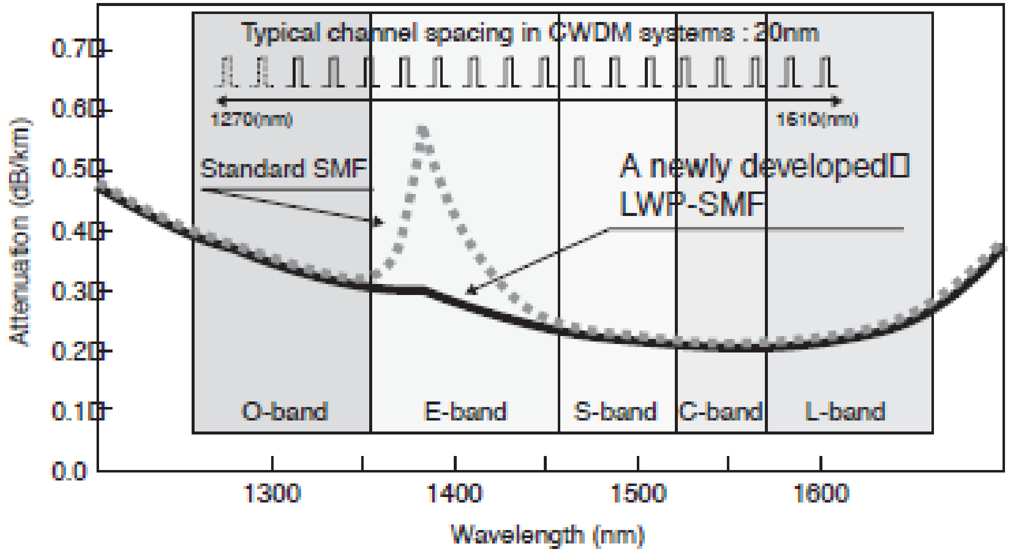
- Early fibers (ITU G.652 A/B) were susceptible to increased losses due to Hydrogen.
- The Hydrogen could come from the atmosphere or evolve out of materials in the cable.
- The losses at 1240nm, 1590nm and other wavelengths were due to interstitial Hydrogen (H_2) and were reversible.
- The losses at 1383nm were permanent and due to a reaction between the Hydrogen and defect sites in the glass forming OH.
- This lead to the introduction of "low water peak" fiber (ITU G.652 C/D).

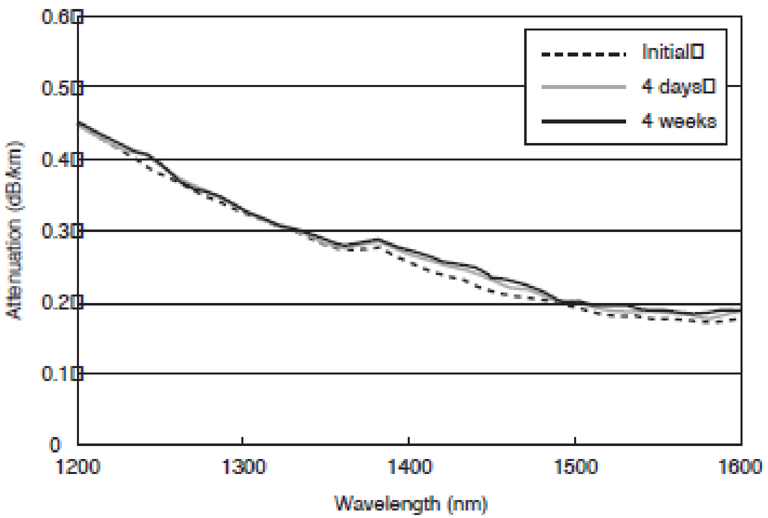


Ref: M. Shimizu et. al, "Hydrogen Aging Tests for Optical Fibers", *IWCS Proceedings*, p. 219-223, (2001)

Fiber Lifetime - Optical

- “Low water peak” fiber (ITU G.652 C/D) is designed to prevent Hydrogen induced loss.
- Fiber is tested to IEC 60793-2-50 C.3.1 which ensures that fiber has both low attenuation initially, but also is resistant to Hydrogen aging.
- This is important for CWDM systems that use wavelengths at or near 1383nm.
- The specification calls for 1383nm attenuation to remain equal to or below the attenuation from 1310nm to 1625nm.

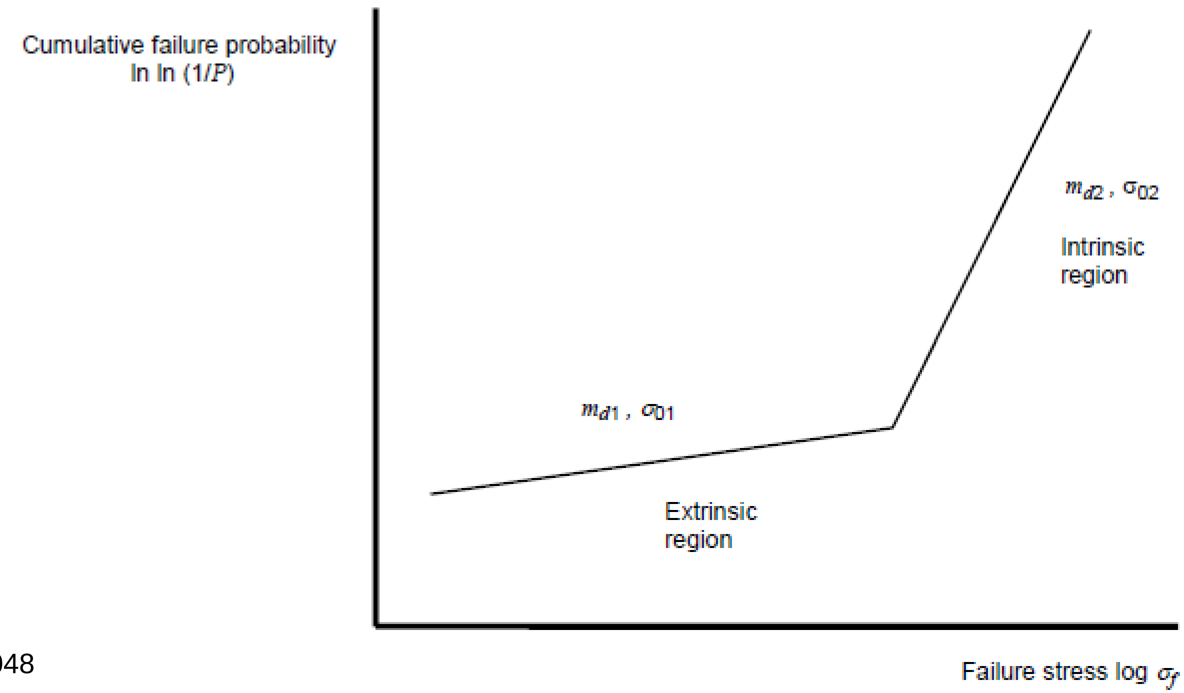




Ref: F. Ohkubo et. al, “Low Water Peak Single-Mode Optical Fiber "PureBand" for Metro and Access Area Networks”, *SEI Whitepaper*, (2001)

Fiber Lifetime - Mechanical

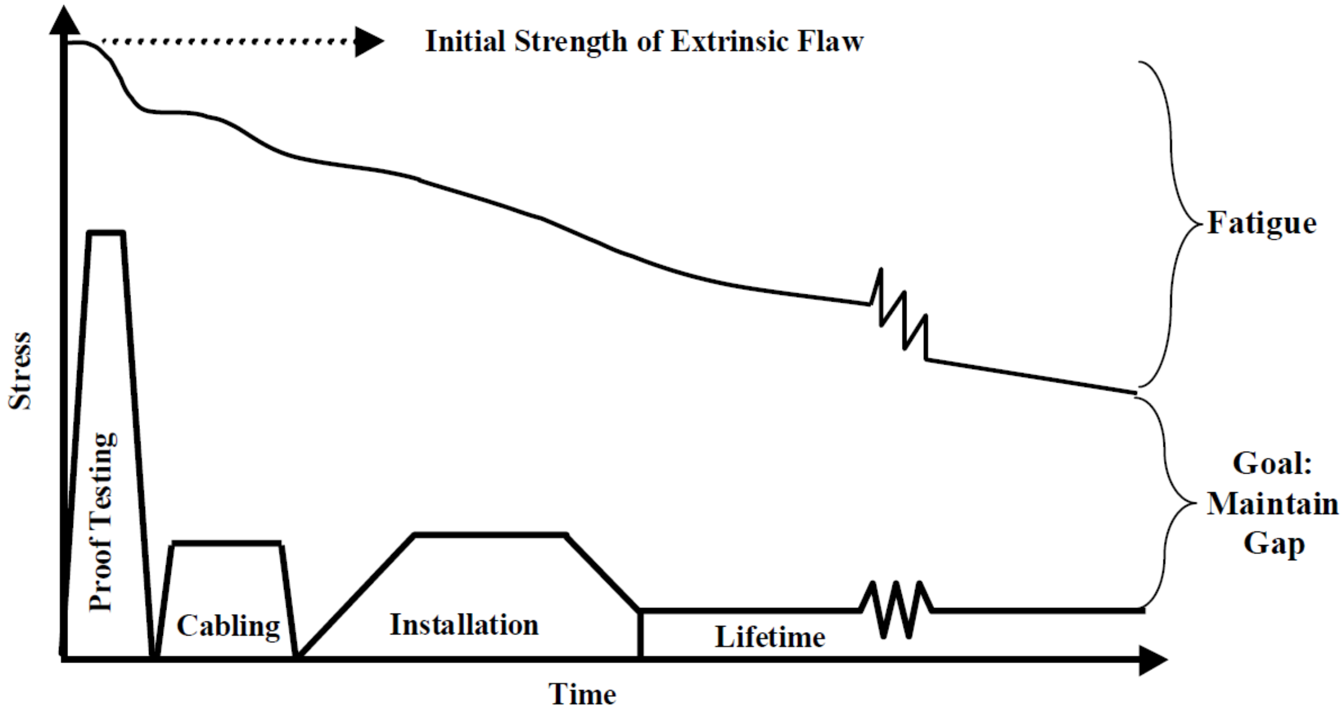
- Glass fiber's strength and reliability has been researched thoroughly.
- The causes of mechanical failure of glass can be broadly separated into two categories:
  - Extrinsic (flaws in the glass due to the manufacturing process, handling during installation, fiber stripping for connectorization, etc.)
  - Intrinsic (the strength of the glass itself absent of large flaws or defects)



Ref: IEC TR62048

Fiber Lifetime - Mechanical

- Fiber is proof tested at manufacture to “weed out” flaws in the extrinsic region.
- Install stress and long term stress of the glass is limited by standards to ensure the fiber lifetime.



Ref: R. Castilone, et. al, “Extrinsic Strength Measurements and Associated Mechanical Reliability Modeling of Optical Fiber,” *NFOEC*, (2000)

Fiber Lifetime – Stress Corrosion

IEC TR62048 – Power Law Theory

"Reliability is expressed as an expected lifetime or as an expected failure rate. The results **cannot be used for specifications** or for the comparison of the quality of different fibres."

$$t_f = \left\{ \left[\frac{\beta^{m_s}}{L} \ln\frac{1}{P} + \left(\sigma_p^n t_p\right)^{m_s} \right]^{\frac{1}{m_s}} - \sigma_p^n t_p \right\} \sigma_a^{-n}$$

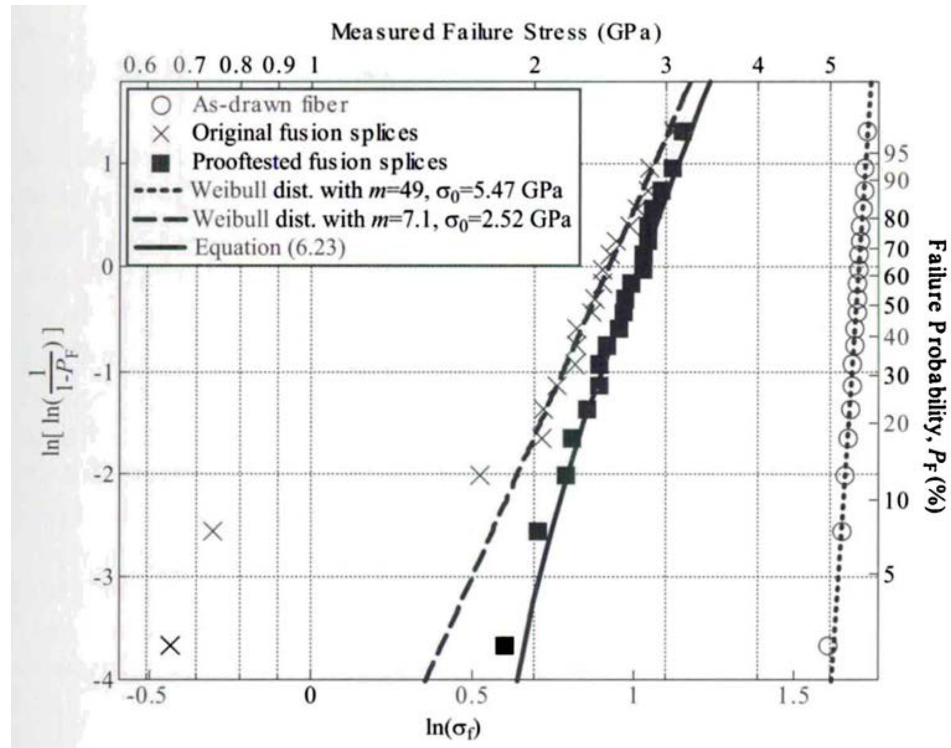
The standards dictate a low long term stress to ensure a long lifetime at an acceptable failure probability.

Applied stress as a % of proof test stress	Failure probability			
	10^{-3}	10^{-4}	10^{-5}	10^{-6}
10	$2{,}56 \times 10^{11}$	$2{,}14 \times 10^{10}$	$2{,}10 \times 10^{9}$	$2{,}10 \times 10^{8}$
15	$7{,}70 \times 10^{7}$	$6{,}43 \times 10^{6}$	$6{,}31 \times 10^{5}$	$6{,}30 \times 10^{4}$
20	$2{,}44 \times 10^{5}$	$2{,}04 \times 10^{4}$	$2{,}00 \times 10^{3}$	$2{,}00 \times 10^{2}$
25	$2{,}82 \times 10^{3}$	$2{,}35 \times 10^{2}$	$2{,}31 \times 10^{1}$	$2{,}30 \times 10^{0}$
30	$7{,}35 \times 10^{1}$	$6{,}13 \times 10^{0}$	$6{,}02 \times 10^{-1}$	$6{,}01 \times 10^{-2}$

Ref: IEC TR62048

Fiber Lifetime - Splices

- UNPROTECTED spliced fiber does have a lower strength than unspliced fiber.
- The splice acts as a flaw in the fiber.
- The strength of the spliced fiber is still high and is additionally protected by a splice sleeve to restore the strength of the splice.



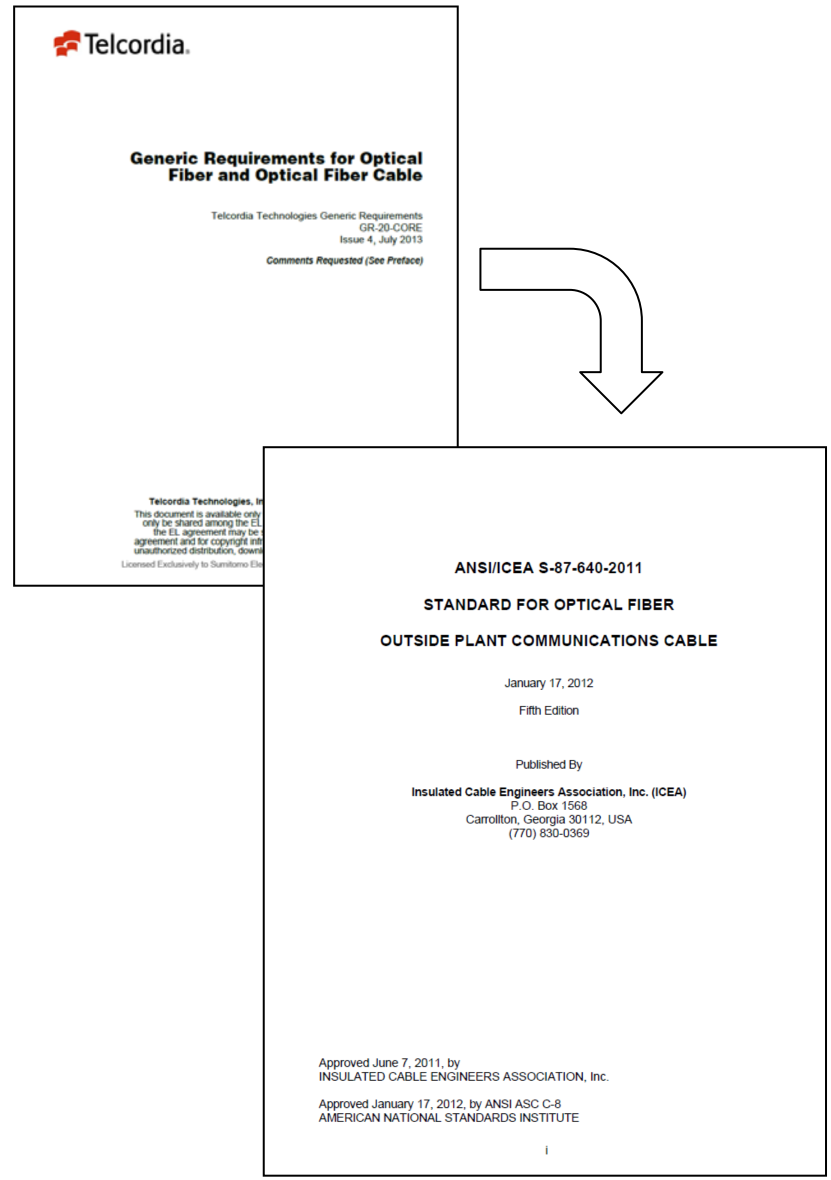
Ref: A.D. Yablon, *Optical Fiber Fusion Splicing*, *Springer*, p. 187, (2005)

Fiber (not Cable) Reliability Interpretation?

- The failure of the glass itself is probabilistic.
- The standards bodies explicitly state this **cannot** be a specified value because it's statistical.
- The statistics indicate that if installed correctly and under acceptable long term load the lifetime of the fiber is very long (>40 years).
- Where to focus next?
  - Cable standards
  - Cable design
  - Cable testing to ensure robust performance against field incidents
  - Hardware reliability

Cable Standards

- Historically Bellcore/Telcordia specifications, mainly influenced by the RBOCs, were the governing standards. (GR20)
- Telcordia GR20 in most cases now defers to the relevant industry specification (not its own specs). For cable this is ANSI/ICEA-640.
- RUS/RDUP has taken a similar approach, PE-90 now defers to ICEA 640.


Telcordia.

Generic Requirements for Optical Fiber and Optical Fiber Cable

Telcordia Technologies Generic Requirements
GR-20-CORE
Issue 4, July 2013

Comments Requested (See Preface)

ANSI/ICEA S-87-640-2011

STANDARD FOR OPTICAL FIBER

OUTSIDE PLANT COMMUNICATIONS CABLE

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Typical Cable Specifications

Install and Long Term Load specified to ensure fiber lifetime

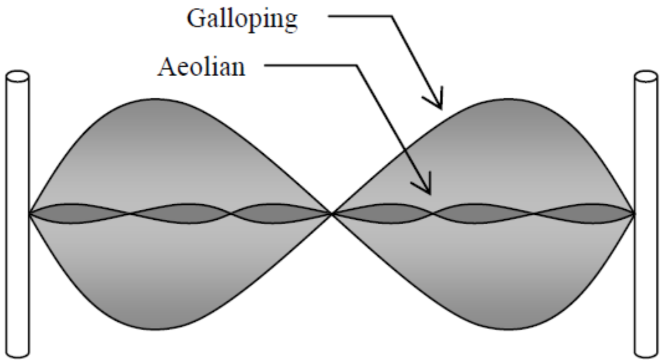
Test Item	ICEA640/GR20 Requirement
Temperature Cycling	-40°C / +70°C (2 cycles)
Cable Aging (Accelerated)	+85°C / 7 days (2 TC cycles)
Tensile Strength	600lb install / 180lb residual
Compressive Strength	2.2 kN
Impact Resistance	4.4 N-m, 2 impacts, 3 locations
Cable Cycling Flexing	20x Cable OD / 25 Cycles
Cable Twist	±180° , 10 Cycles
Low/High Temperature Bend	20x Cable OD / Installation Temps
Water Penetration	1m water head / 1m cable

Cable & Hardware Reliability Tests

- Cable
  - Mechanical Damage
    - Wind Loading
    - High Tensile Installation
    - Dig-ups
  - Environmental Damage
    - Water Penetration
    - Freezing
- Hardware
  - P-Clamps

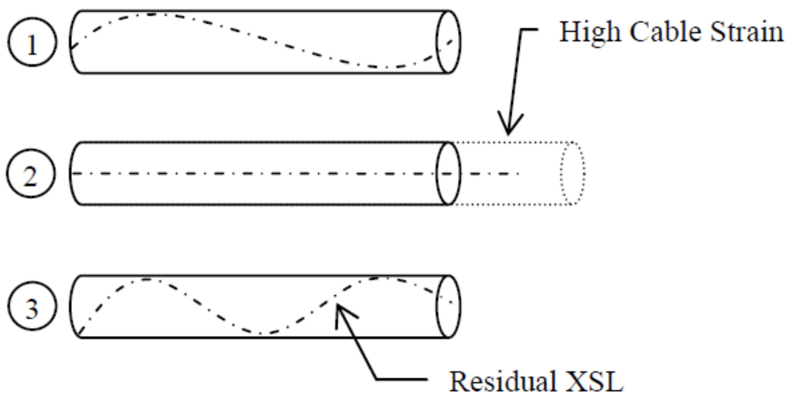
DriTube Ribbon Design

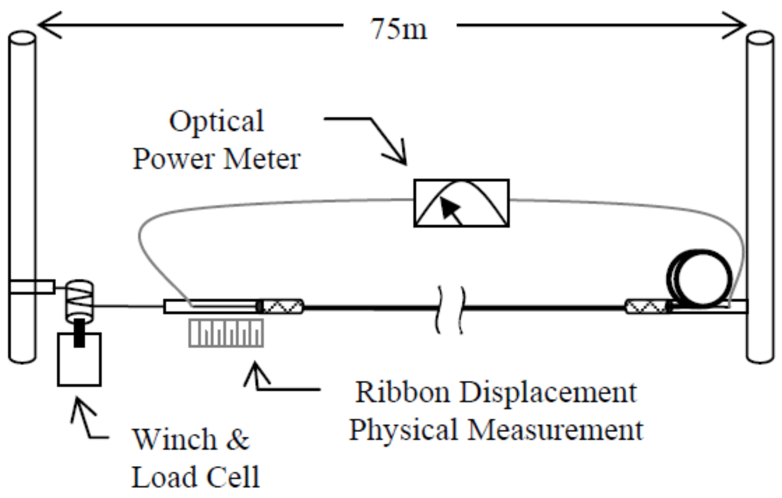
- Aeolian & Galloping Vibration (IEEE 1222)



High Strain Installation

- In addition to standard tensile testing, internal testing examines how robust the cables are at extremes.
- No cable design can protect against all installation conditions (lack of 600lb limiting swivel, pulled in with a truck, etc.)



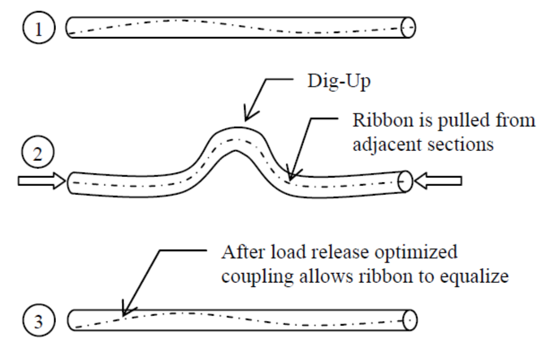


Ref: P. Van Vickle, et. al, “Central Tube Cable Ribbon Coupling”, *IWCS Proceedings*, p. 498-503, (2003)

Cable Dig-Up

Ref: http://blog.level3.com

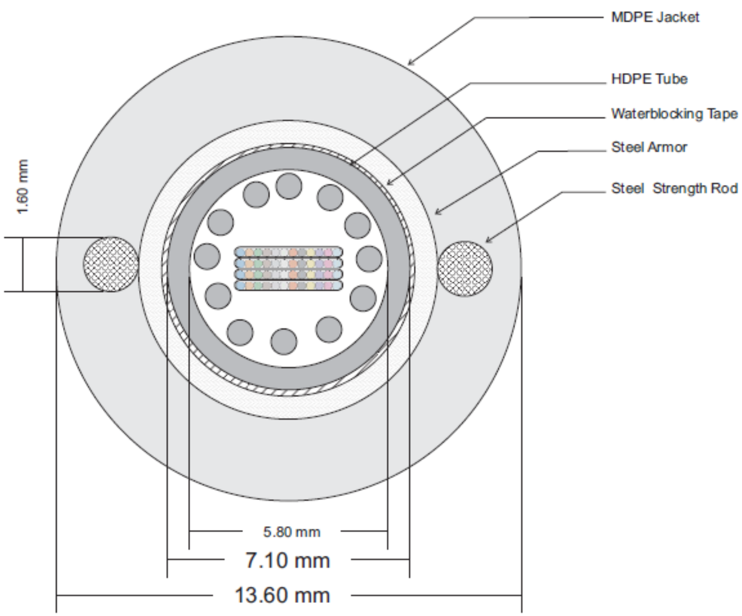
Ref: http://www.pagosadailypost.com/news/5022/Bad_Day_at_the_Piedra_Intersection/

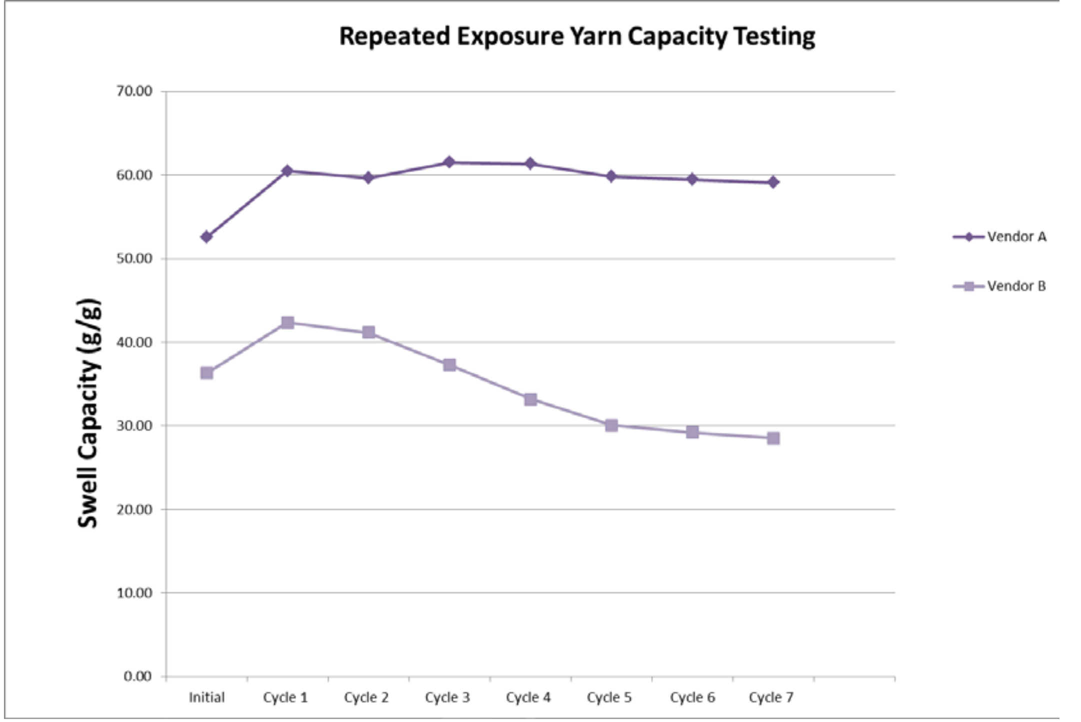


Ref: P. Van Vickle, et. al, “Central Tube Cable Ribbon Coupling”, *IWCS Proceedings*, p. 177-181, (2008)

Dry Cable Water Penetration

- Many open questions about water blocking methods, we first investigated:
  - Tapes – too slow, very poor repeated swell capacity
  - Powders – can wash down the tube, results in poor repeated swell capacity
  - Yarns – very fast, depending on vendor can have very good long term results

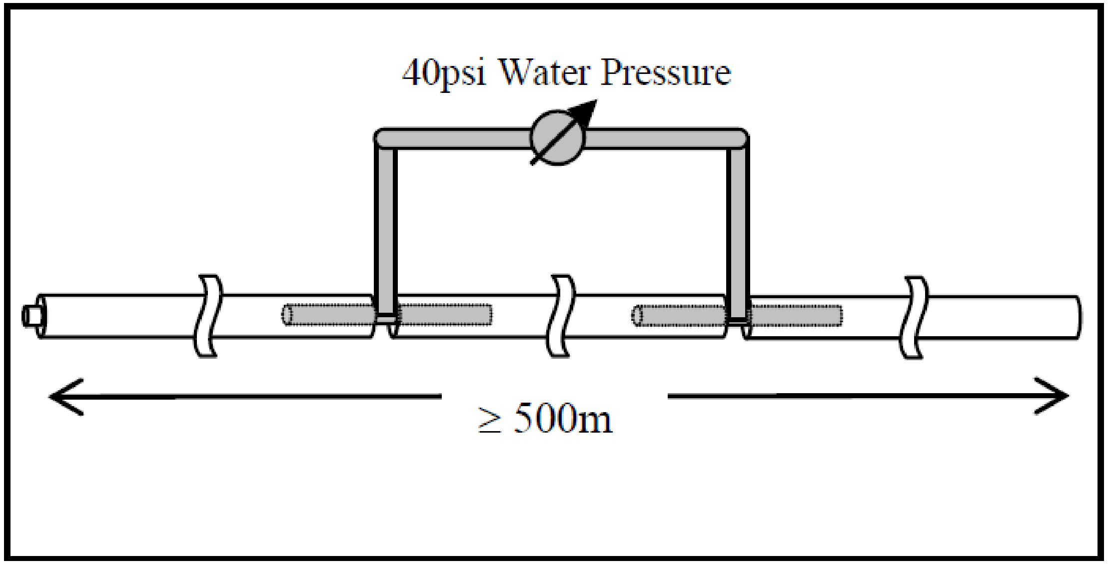




Ref: P. Van Vickle, “Innovative Dry Buffer tube Design for Central Tube ribbon Cable”, *NFOEC*, p. 154-161, (2001)

High Pressure Water Resistance

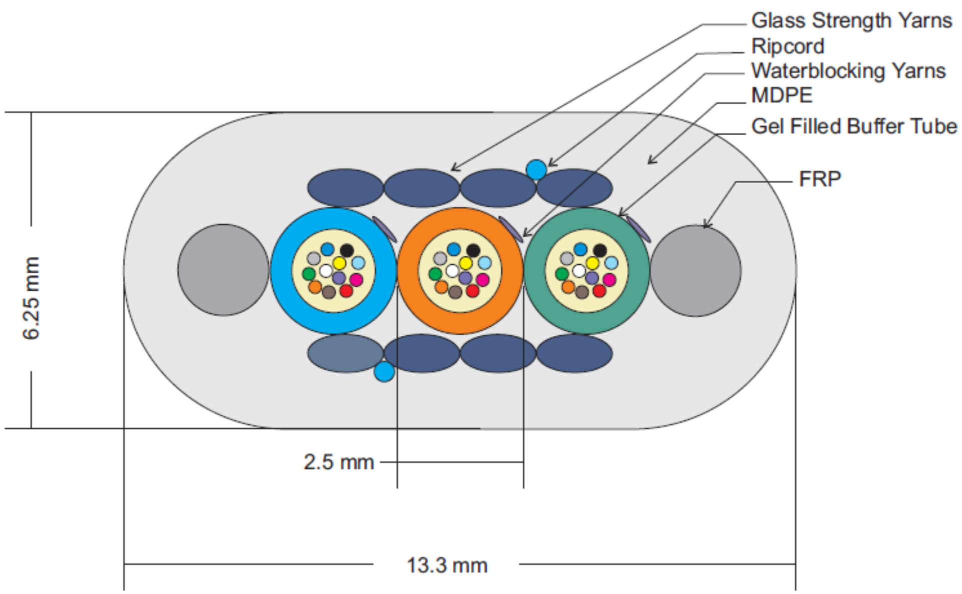
- High pressure water penetration, two locations, then -40°C / +70°C temperature cycling.
- Ensures if water does breach the jacket, the fiber is protected and functional.

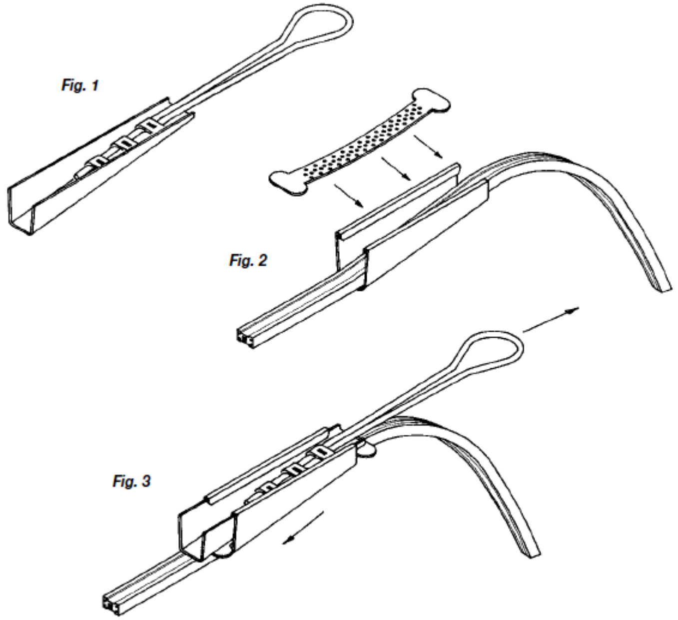


Ref: P. Van Vickle, et. al, "Robust High-Count Dry Central Tube Ribbon Cables", *IWCS Proceedings*, p. 498-503, (2003)

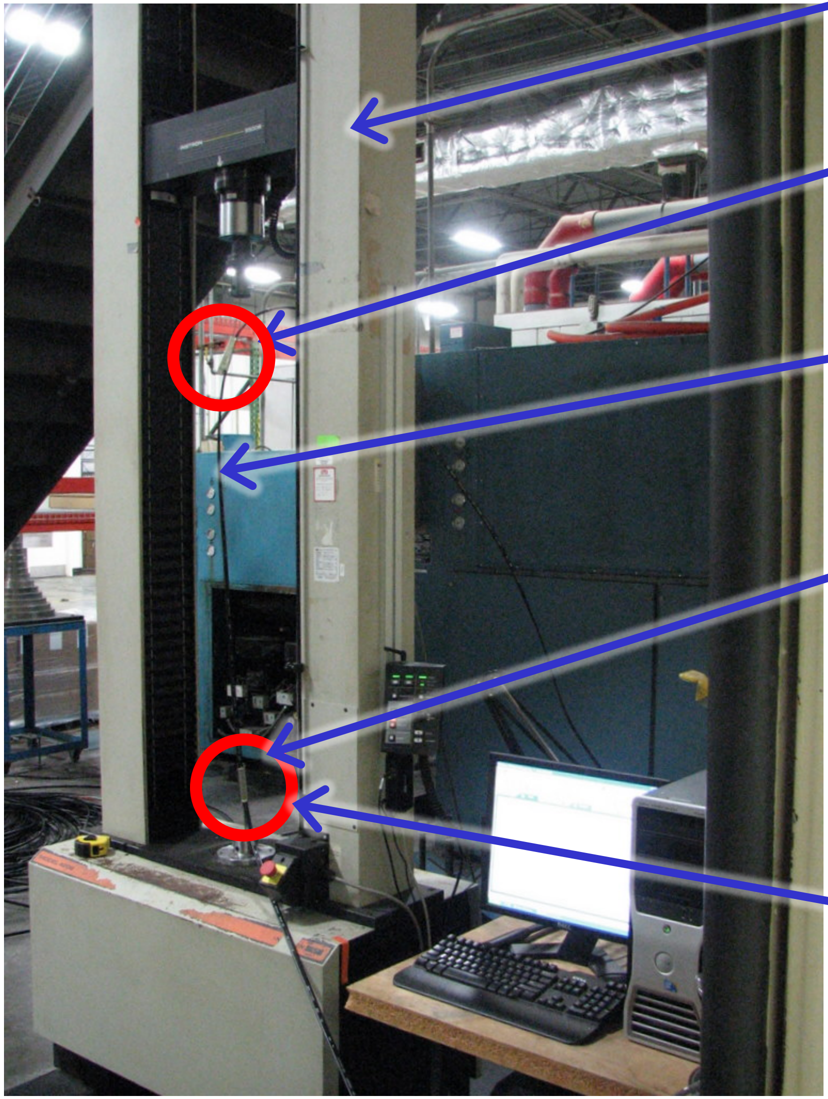
Hardware Reliability

- High reliability drop cable design
  - 36 fiber
  - 250 ft span
  - NESC Heavy ice load each year, 20 years
  - Compatible with conventional copper drop hardware





Clamp Testing



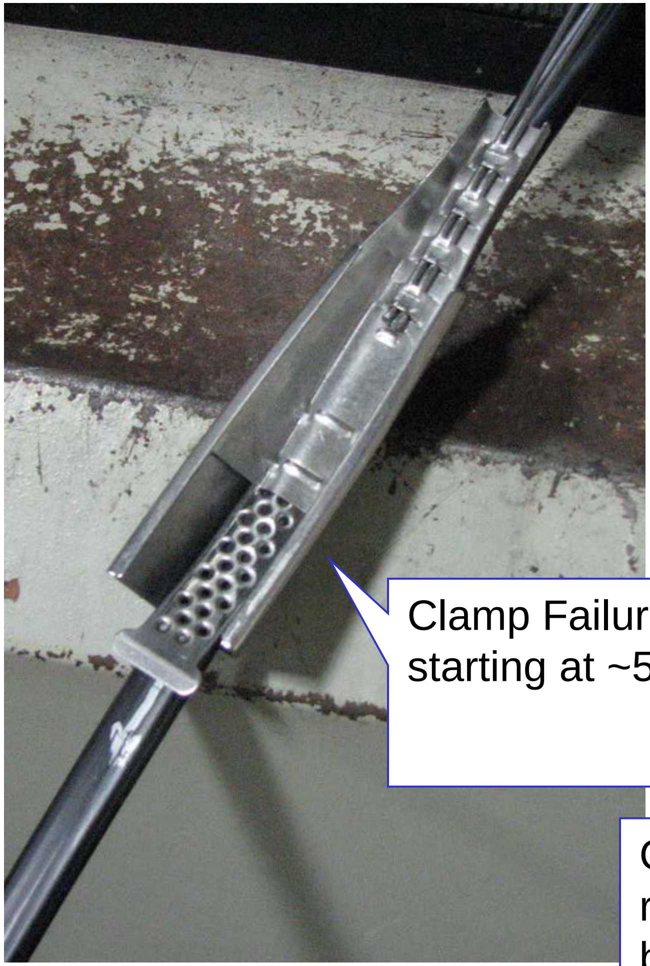
Instron Tensile Testing Machine

P-Clamp

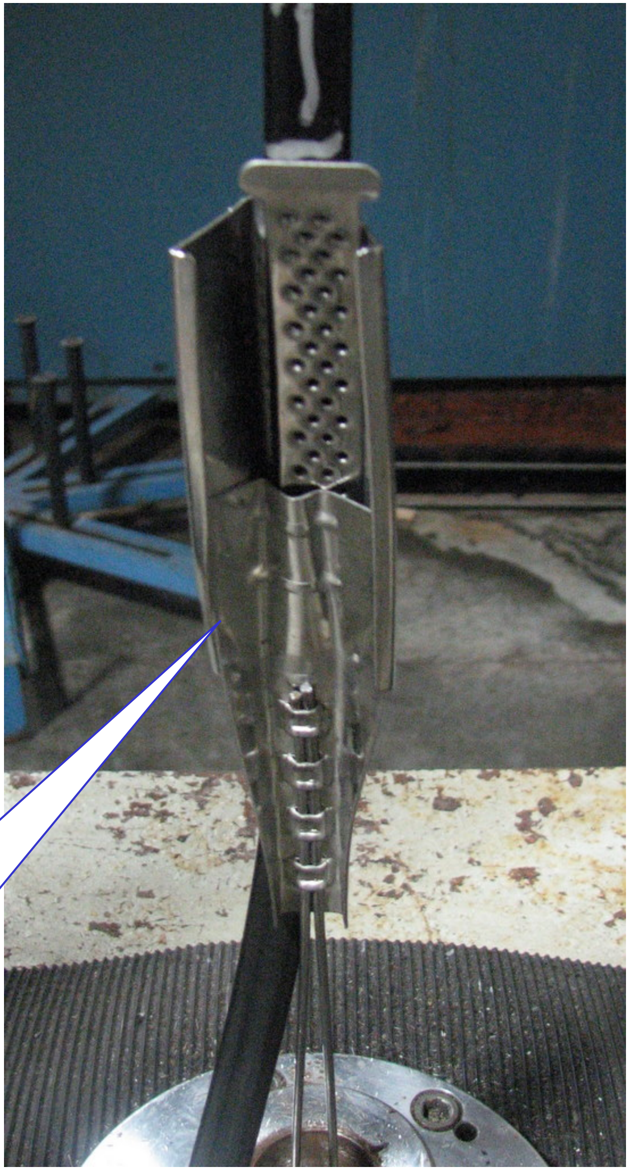
36f Drop Sample (1m) –
Mechanically & Optically
Monitored

P-Clamp

Hardware Evaluation



Clamp Failure starting at ~530lb



Clamp Failure repeatable between 530lb and 650lb

Summary

- Fiber reliability is well established.
- Fiber and cable have long lifetimes if the install and service environment are nominal.
- Backhoes, lightning, rodents, car collisions with poles, etc. will govern the service life of cables.