Incab

Understanding The Loose Tube Design Concept

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ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

PURPOSE STATEMENT / COURSE DESCRIPTION

Registered continuing education program

- In this webinar we will discuss why the loose tube design concept is the go-to solution for aerial fiber optic cable systems. In so doing, we will learn the importance of excess fiber length (EFL), and as we do so, we also will learn about its sources and the effect of period and phase.

- We will also gain insight into the expected range of EFL in modern fiber optic cables and explore alternative design concepts, weighing their advantages and disadvantages for specific applications.

LEARNING OBJECTIVES

After this class, you will be able to:

1. State the primary benefit of the loose tube design concept for fiber optic cables.
2. Explain why the loose tube design concept is the way to go for aerial fiber optic cable systems.
3. Explain what "excess fiber length" or "EFL" is and how it contributes to the loose tube design concept.
4. State the two potential sources of EFL in a fiber optic cable.
5. Explain the importance of period and phase as related to EFL.
6. State the range of EFL that should be expected in today's fiber optic cables.
7. State the three alternatives to loose tube design, their relative advantages/disadvantages, and when these alternatives are good solutions for use in a fiber optic cable.

Incab University "School of Excellence in Fiber Optics"
Agenda

- Introduction
- Course Description
- Learning Objectives
- Presentation
- Q&A (Technical questions only)
- Let's start!

Background

Aerial Cables Have a Hard Life

- All aerial cables have it rough because they are exposed to the elements 24/7/365 for their entire operational life which can be
  - 20 – 25 years for dielectric fiber optic cables such as ADSS
  - 40 – 80 years for metallic cables fiber optic cables such as OPGW
    - Most utilities expect at least 40
    - One utility has studied this and concluded that 70 is realistic for well-designed, well-made cables

Background

Aerial Cables Have a Hard Life

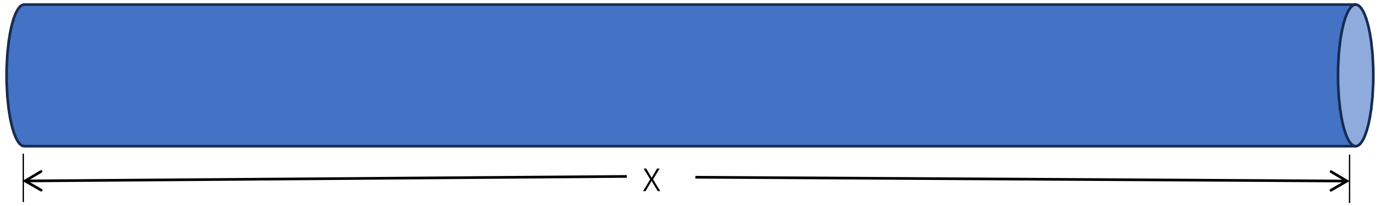
- During that exposure, environmental conditions are constantly changing
    - Temperature changes – Both ambient and direct solar heat input on the cable
    - Wind speed changes
    - Snow/ice load changes
- No surprise, these changes cause changes in tension and elongation in the cable

➡ But how would such changes affect the fiber?

Let's think about it...

Changes in Cable Elongation

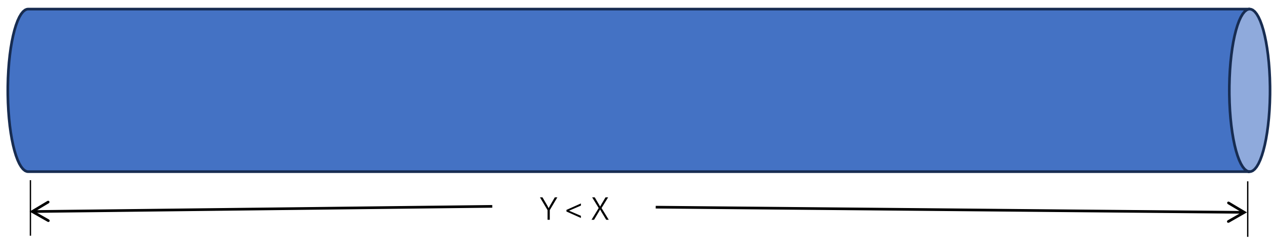
- Let's imagine an aerial "cable" with just one element
  - Let's keep it simple, and just look at a short unit length of it



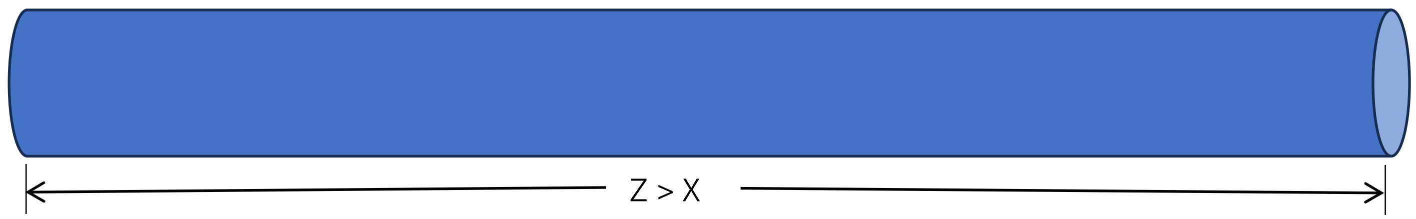
- This length will change in response to environmental changes…

Changes in Cable Elongation

- A lower temperature will cause the cable to shrink back:



- A higher temperature or increased wind or ice loading will cause the cable to stretch:



Changes in Cable Elongation

- These changes happen regardless of the material used in the cable, but…

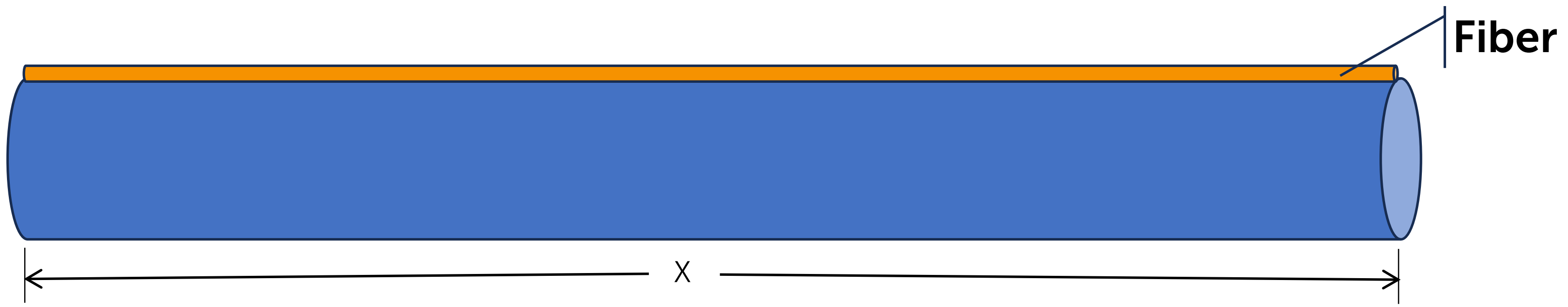
  - In dielectric (plastic) cables, *relative* to metallic cables
    - the change in length due to changes in temperature is small
    - the change in length due to loading changes (wind and ice) is large

  - In metallic cables, *relative* to dielectric cables
    - the change in length due to changes in temperature is large
    - the change in length due to loading changes is small

- These differences are the result of the differences between the basic properties of these two types of material

Changes in Cable Elongation

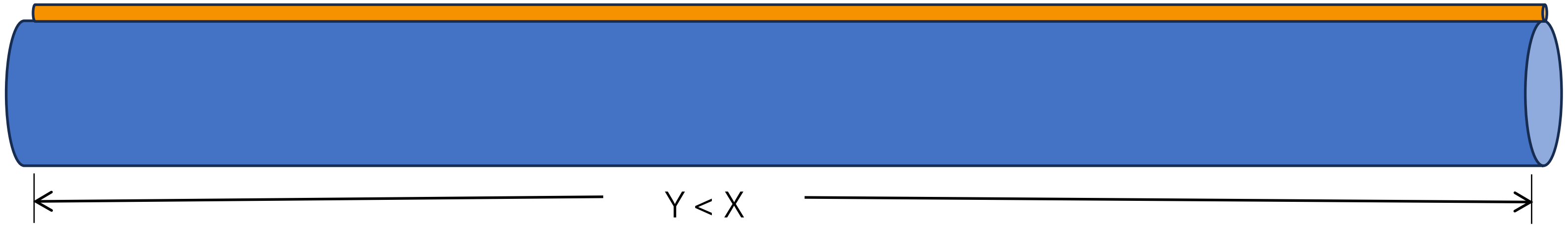
- Now, let's add a fiber to our cable
- Let's keep it simple, and just glue the fiber on top



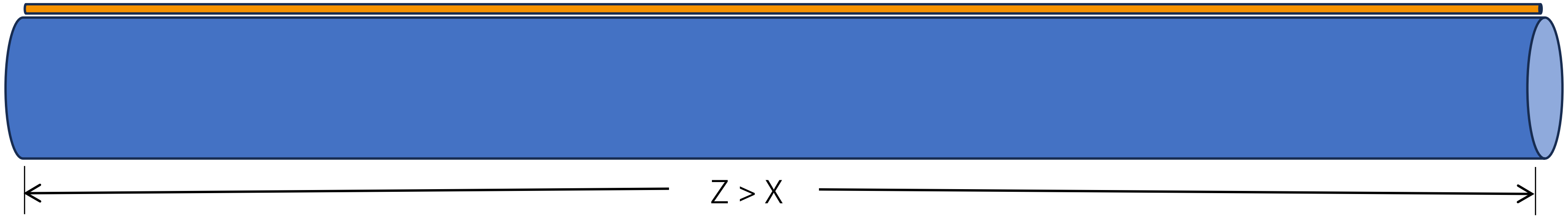
- Now what happens with changes in temperature and loading?

Changes in Cable Elongation

- **Answer: The same things tend to happen**
- A lower temperature will cause the cable and fiber to shrink back:



A higher temperature or increased wind or ice loading will cause the cable and fiber to stretch:



Changes in Cable Elongation

- *But*, the fiber has its own material properties, so its responses to the changes will differ from those of the cable itself, and so…

The fiber will tend to resist the changes

- Consequently…
  - When the cable is shrinking, the fiber could "buckle" (perhaps breaking the bond)
  - When the cable is stretching, the fiber will be forced to stretch, too (or maybe it will break itself or the bond)

Changes in Cable Elongation

- So, if the fiber and the cable do not naturally work together in peace, love, and harmony, what does this mean?

  More specifically:

  - How would this condition likely affect the fiber's operation and service life?

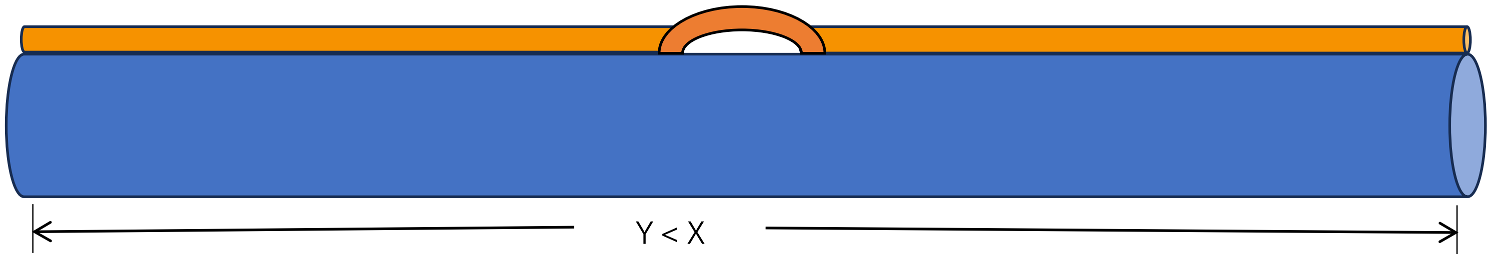
  - If the answers to (1) are negative in nature, can we find a way to add the fiber to our cable and avoid those negative ramifications?

- Let's look at each question...

Changes in Cable Elongation

- Question 1 – If the fiber and the cable do not work together, how will this likely affect the fiber's operation and service life?

  - Case 1 - When the cable is shrinking, we said the fiber could "buckle"



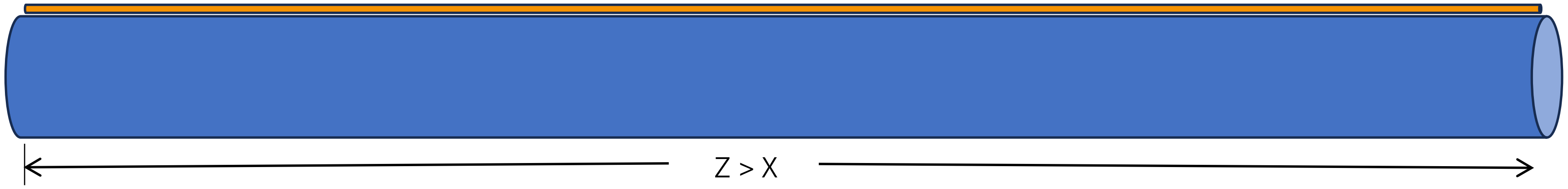
  - Operational Effect - "Macrobending" which could lead to increased attenuation
    Note: Today's "bend insensitive fiber" (per G.657) tolerate macrobending better

  - Service Life Effect – None likely

Changes in Cable Elongation

- Question 1 – If the fiber and the cable do not work together, how will this likely affect the fiber's operation and service life?

- Case 2 - When the cable is stretching, we said the fiber must stretch too (or break itself or the bond)



  - Operational Effect – Likely none, unless the fiber breaks, of course

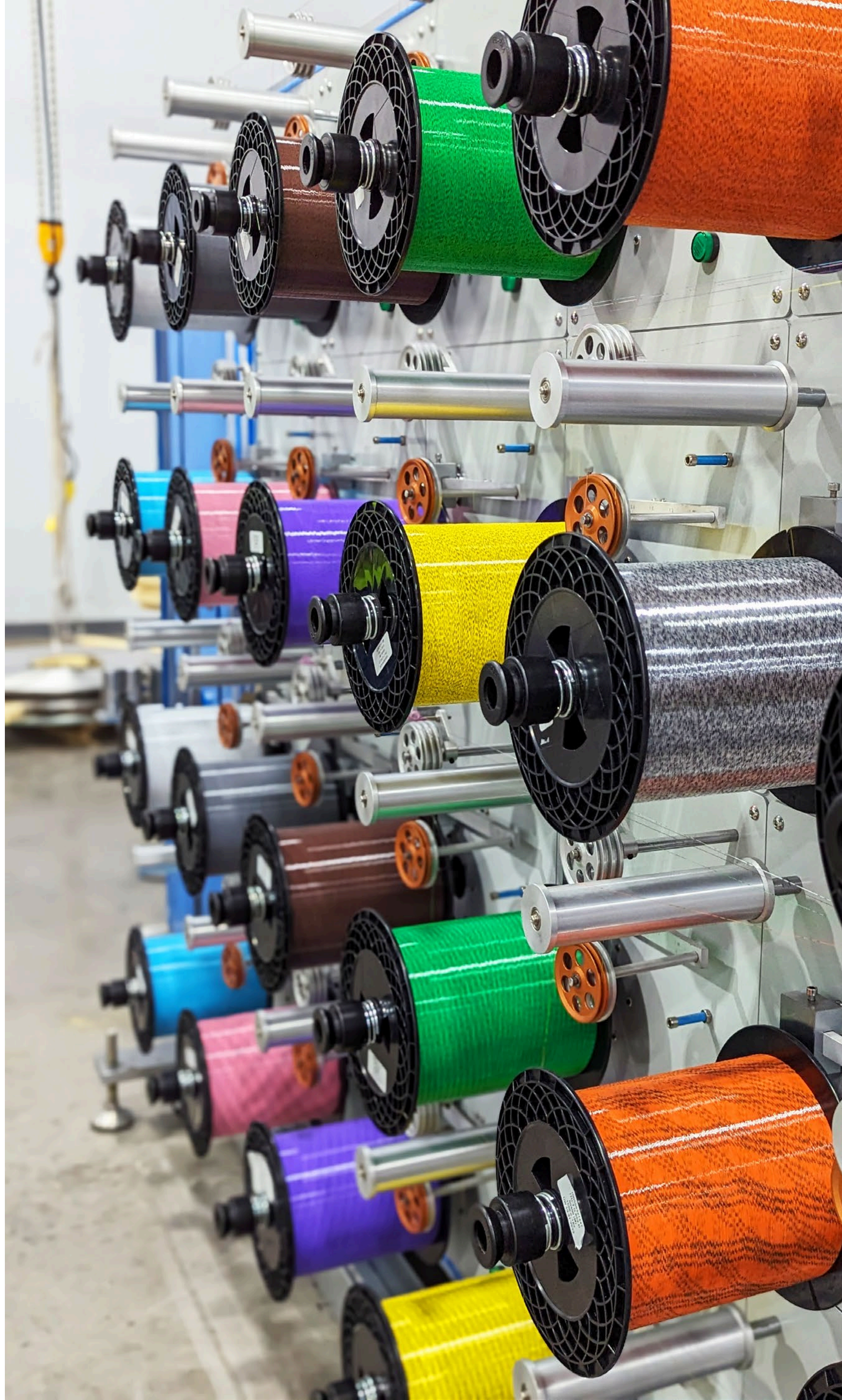
  - Service Life Effect – If the stretching ("strain") exceeds a safe limit, then there likely will be an adverse effect on service life(!)

Changes in Cable Elongation

- That's a key point on that last slide! Let's repeat it and then investigate:
    - If the stretching ("**strain**") exceeds a **safe limit**, then there likely will be an adverse effect on service life(!)
- This begs two questions:
    - What's a "**safe limit**"?
    - Can we quantify the degree of "adverse effect"?
- Fortunately, Corning has done research to answer both these questions

Effects of Fiber Strain

- Corning's research on the effects of fiber strain summarized:
  - 40-year life = Fiber strain ≤ 0.20%
  - 4-hour life = Fiber strain ≤ 0.33%
  - 1-second life = Fiber strain ≤ 0.50%
- These are "**expected life**" calculations, not "**guaranteed life**" (or death) calculations!
  - There is still a “low” risk of fiber breaks
    - Probability < 0.005 breaks/million fiber-km/year
  - There is *not* 100% probability of a break after these times
- Other fiber manufacturers have similar data/guidelines



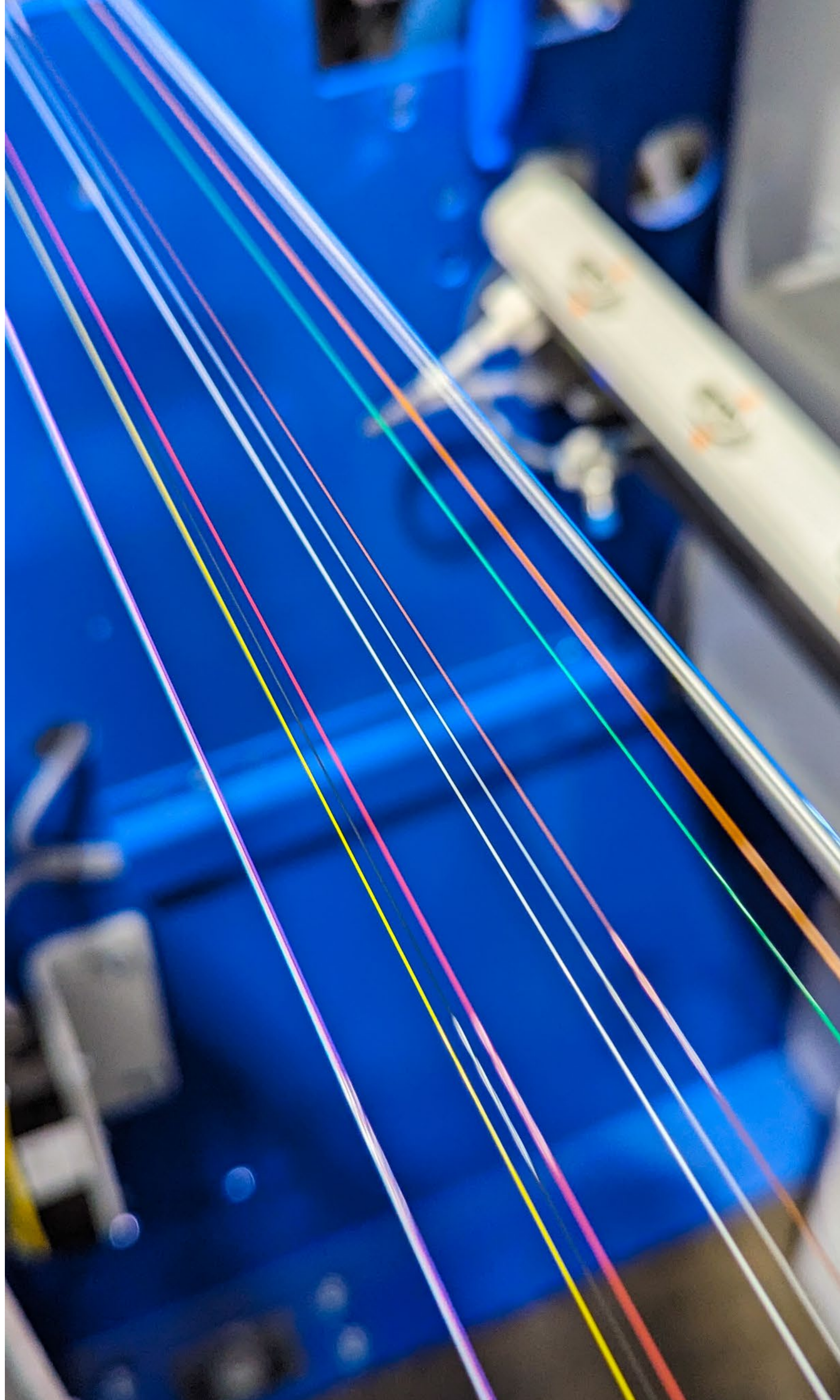
Effects of Fiber Strain

Recall we had two questions about the effect of strain on our fiber:

A. What's a "**safe limit**" for the **strain**?

   Answer:
   Assuming we want a service life of 40 years or more, then 0.20% is our safe limit

   Note: If one wants a lower life, one can use this data to interpolate the safe limit for the desired life expectancy



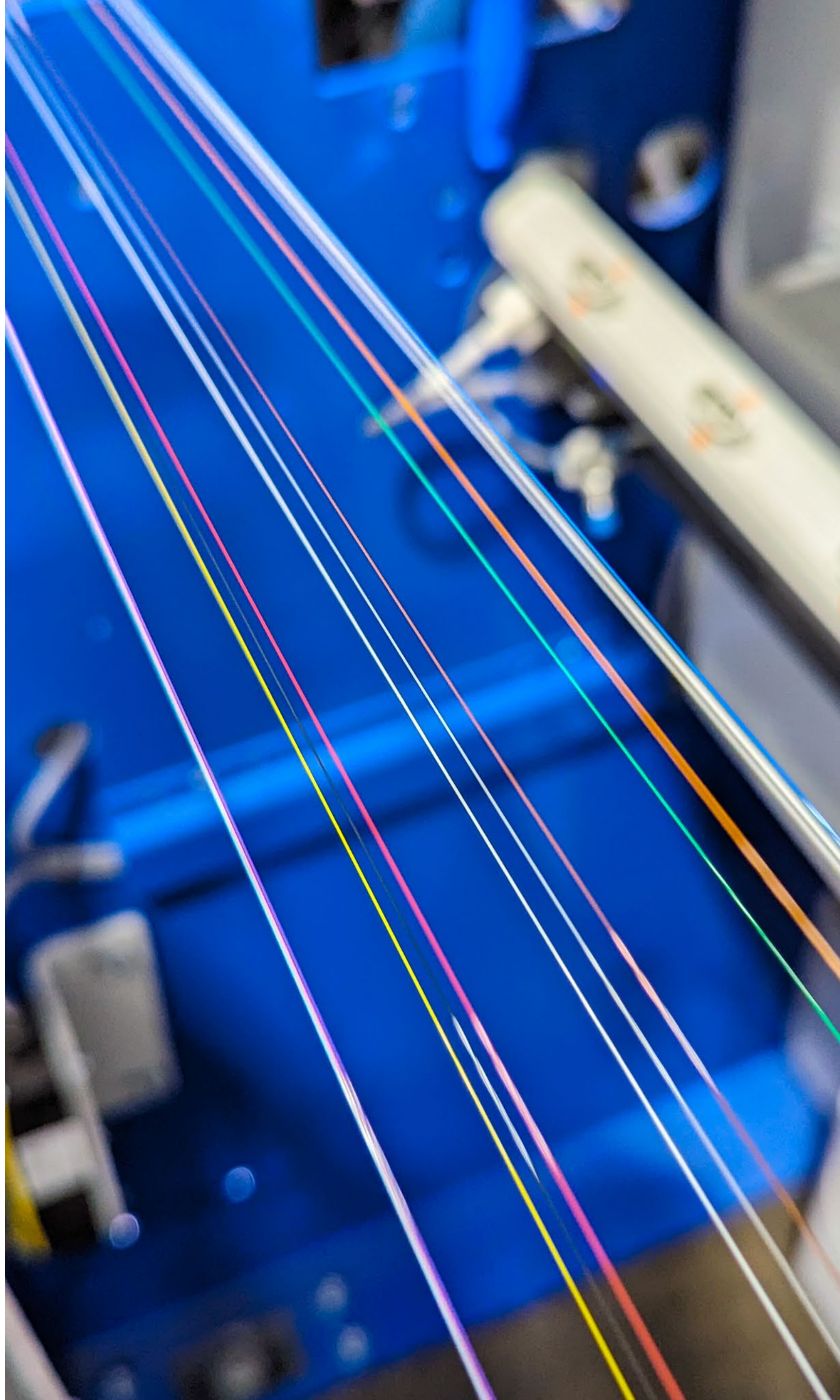
Effects of Fiber Strain

Here's the second question...

B. Can we quantify the degree of "adverse effect"?

Answer:
Yes, we can predict the expected reduction in service life for any level of strain on a fiber that is above 0.20%

- Plus, if one can translate cable strain to fiber strain, then one can also predict the loss of optical service life(!)



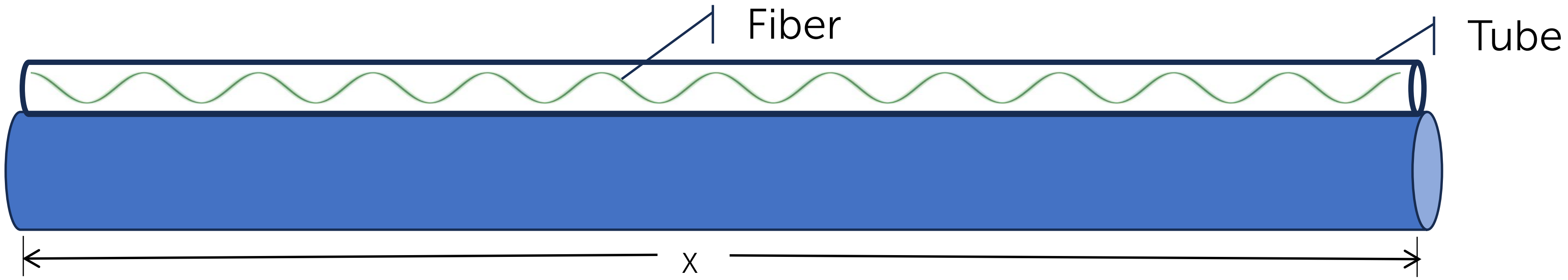
Changes in Cable Elongation

- And now, reach far back in your memory to recall this question:
  - "If the answers to (1) [the effects of tension or compression on the fiber] are negative in nature, can we find a way to add the fiber to our cable and avoid those negative ramifications?"
  - The answer is a resounding "Yes, we can!"
- How, you ask?
  - Through the miracle of the Loose Tube Design Concept!
    - We will see that its primary benefit will be that it will protect our fiber from strain
- Let's see how this works...

Loose Tube Design

- Let's go back to our simple cable

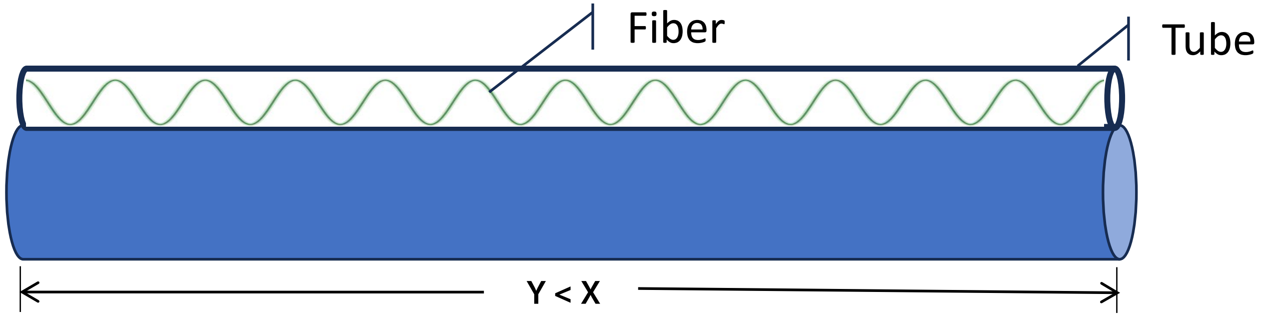
- Let's again add a fiber, but instead of gluing it to top of our cable, let's put it inside a tube in a sinusoidal shape, and then let's glue the tube to our cable



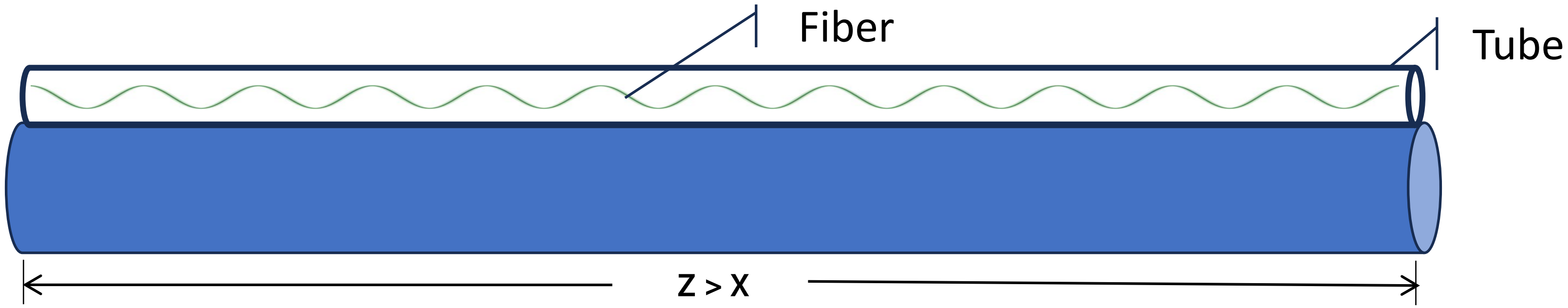
- We will call this a "loose tube design"

Loose Tube Design

- Now watch what happens when we shrink or stretch the cable



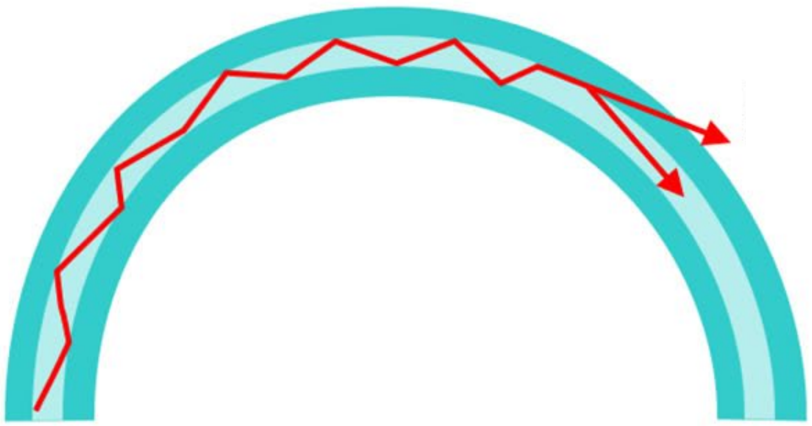
- Shrinking – The fiber period shortens, and the fibers "bunch up"

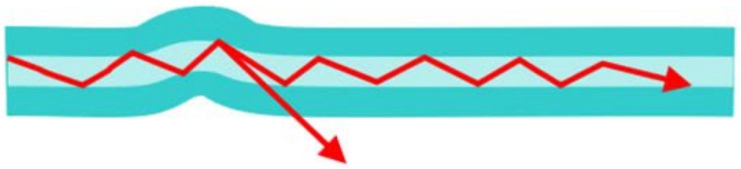


- Stretching – The fiber period lengthens, and the fibers flatten out

Loose Tube Design

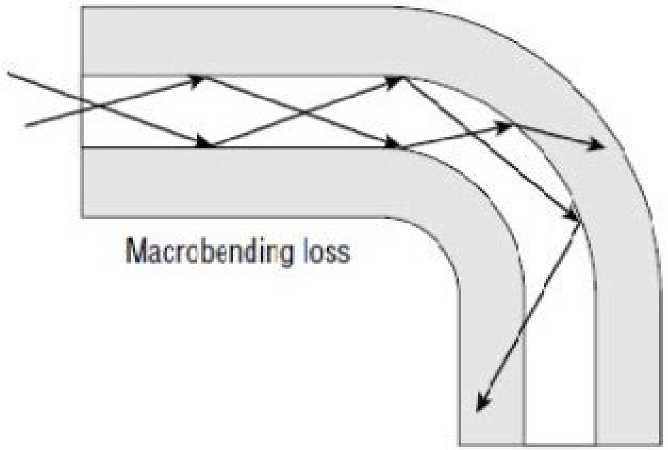
- Interesting…but, how does this help us with our problem?
- Before answering, we need to define two terms:
  - Macrobending
  - Microbending





Loose Tube Design

- "Macrobending" is signal loss from too much bending
  - The fiber's minimum bending radius exceeded
  - Consequently, "total internal reflection" (See note) stops working properly

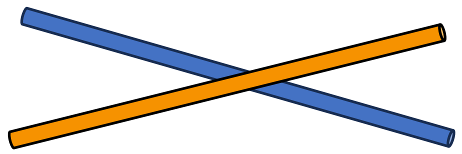


Light is not being reflected internally; it is "escaping" which equates to signal loss

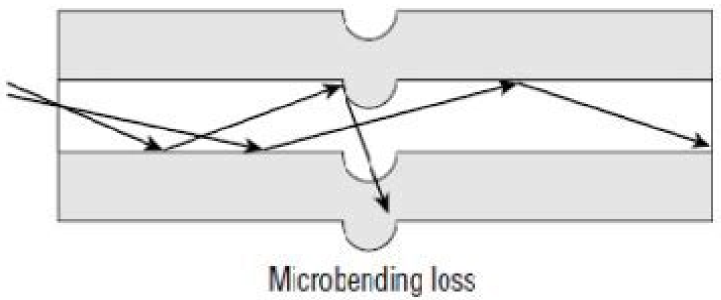
Note: Total Internal Reflection is explained in our "Fiber Optics 101" webinar

Loose Tube Design

- "Microbending" is single loss caused by two or more fibers crossing over each other
  - The crossover creates a pressure point which creates a microscopic indentation
  - Consequently, "total internal reflection" (Reference Fiber Optics 101) fails to work properly



Two fibers cross over each other



Resulting indentation impedes light transmission in both fibers

Loose Tube Design

- Now, back to how our tube with a fiber in a sinusoidal shape helps us with our problem…

- Shrinkage – We would expect a problem with our fiber only when the temperature gets so low that the shrinkage has caused the fibers to bunch up so much that "macrobending" causes attenuation to increase

    - Plus: Our simple cable has only one fiber, so…

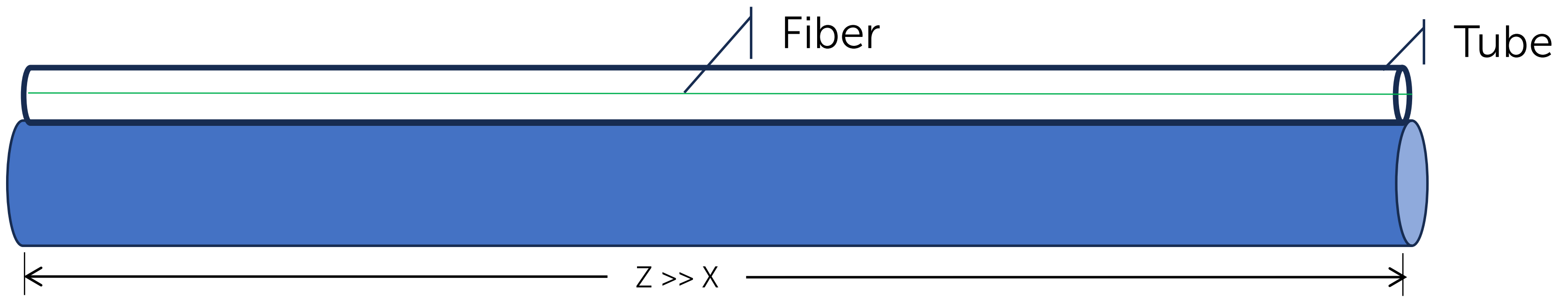
        - If we add even one more fiber, we then add the possibility of having a "microbending" problem too

- Today's cables typically are designed such that these problems do not occur until -40°C (-40°F)
    - Cables can be designed for even lower temperatures

Loose Tube Design

- Our bigger concern is the stretching ("elongation") because this can result in fiber strain which we know can be bad (break the fiber or reduce its expected life)

- Stretching – We would expect a problem only after the elongation has been enough to completely flatten the fiber



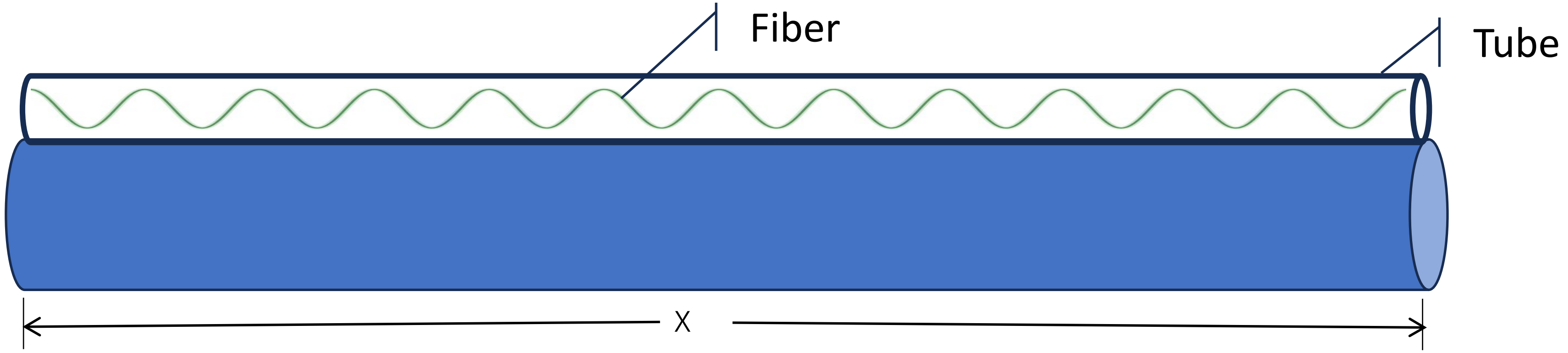
Loose Tube Design

- This degree of elongation is not going to occur from temperature changes alone
- There must be tension changes too, and these can only come from wind and ice loading changes
- *But*, we can see that this Loose Tube Design can protect the fiber to at least some (significant) amount of tension
    - Let's make some inferences from what we have seen so far and define a couple more terms too...

Loose Tube Design

Inference 1

- If the fiber in the "loose tube" is in a sinusoidal shape, then the length of the fiber must be greater than the length of the tube



That is: $L_{fiber} > L_{tube}$

- I would have called this "extra length of fiber" (ELF), but I was not consulted, so instead it is called:
  - **"Excess Fiber Length"** or **EFL**

Loose Tube Design

Inference 2

- If $L_{fiber} > L_{tube}$ then the ratio of L_{fiber} to L_{tube} must be greater than 1

That is: $\frac{L_{fiber}}{L_{tube}} > 1$

- In today's cable manufacturing, best practice is for there to be about 0.25 – 0.30% more fiber than tube

- So, the fiber-tube ratio or EFL is typically 1.0025 – 1.0030
  - EFL < 0.25% usually means a poorly designed or made tube (some exceptions)
  - EFL might be "juiced" up to ≈ 0.40% for some center-tube type cable designs

- Generally, higher EFL is better

Loose Tube Design

Inference 3

- If the fiber does not experience tension until it has flattened out completely ($\frac{L_{fiber}}{L_{tube}}$ = 1), then there is a “gap” between when tension on the cable is first applied and when the fiber first begins to experience tension

- We call this gap the “zero fiber strain margin” (ZFSM)

    - ZFSM = The difference between when the cable experiences strain and when the fibers do

    - Expressed as % rated breaking strength (%RBS) or % rated tensile strength (%RTS) (same thing; just different terms)

- Cables will have different ZFSM depending upon how they are designed
    - We’ll give guidelines later

Loose Tube Design

Inference 4

- For the fiber to have a “good” sinusoidal shape, the tube must be “big enough”
- If we put more than one fiber in a tube, then there must be sufficient room for all of them to have “good” sinusoidal shape
- So, we say that there is an acceptable maximum “fill factor” for a given (internal) size of tube
    - If the safe fill factor is exceeded, then a tube has been “overfilled”
    - ZFSM will be lowered (not good)
    - The fibers will be susceptible to macro and microbending (not good)

Loose Tube Design

- Our inferences lead us to questions:

1. 0.25% EFL does not sound like a lot
   - Is it enough in the real world?
   - Can we do better?

2. What happens if we put more than one fiber in a tube, but the sinusoids are not the same?

3. What happens if we need more than 12 fibers in a tube?

Let's answer each…

Loose Tube Design

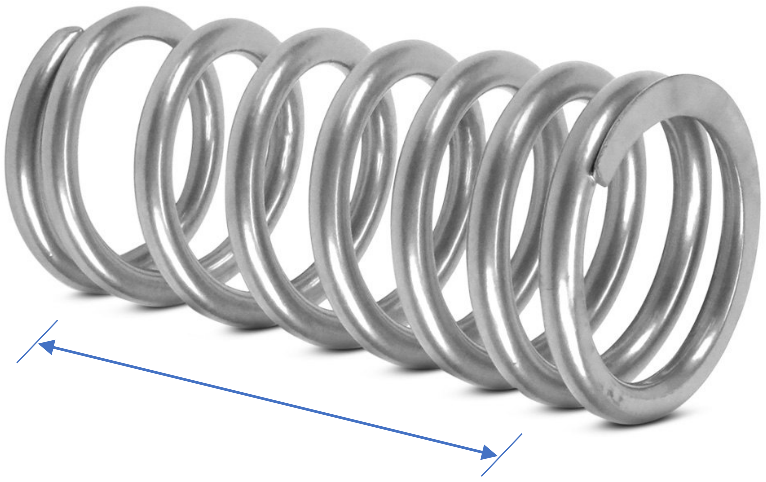
- Question 1 - 0.25% EFL does not sound like a lot
  - Is it enough in the real world?
    Answer: It depends on the cable type and application
    - OK for a dielectric cable with a center tube when the cable is not experiencing a lot of tension changes – such as a cable in a duct
    - Not OK for an aerial all-dielectric self-supporting (ADSS) cable with a center tube
    - Maybe OK for a dielectric cable with a center tube if lashed
    - OK for a metallic aerial cable with a center tube such as Type C or CA OPGW if you understand and accept the performance limitations (we'll describe these later)

  - Can we do better? Answer: Yes! We can strand the tube!

    Let's look at the effect of stranding the tube…

Effect of Stranding

- To understand the effect of stranding a tube, consider this spring

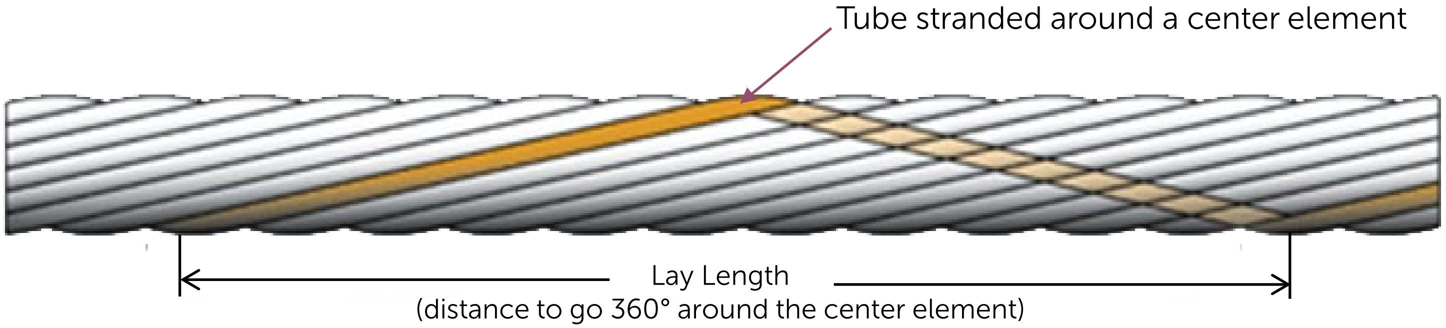


- You can see that the length of the wire used to make this spring is much greater than the length of the spring itself
  - The shape of the wire in the spring is a helix

- So, if this was a tube with fibers, and we wrapped ("stranded") it around something (a center element), our EFL will greatly increase!

Effect of Stranding

- So, in a cable, we get something like this:



- Now we have EFL resulting from the helical shape of the stranded tube
  - We can typically get about 2.5% EFL (≈ 10x the EFL in the tube!)

- Plus, we still have EFL in the tube itself

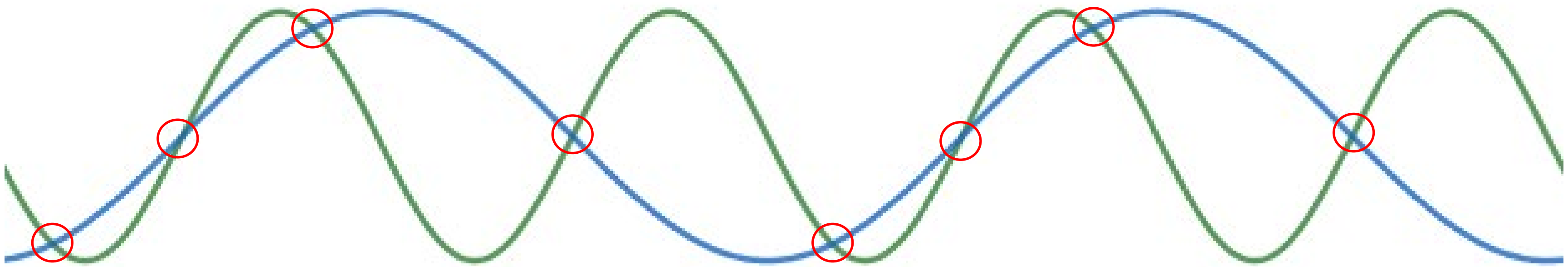
- The two sources work together to boost the ZFSM of the cable
  - So, now we should refer to $\frac{L_{fiber}}{L_{cable}}$, not just the tube
  - And total EFL should be ≈ 1.025 🡐 Often called the cable's "helix factor"

Back to Our Questions

Picking Up Where We Left Off

2. What happens if we put more than one fiber in a tube, but the sinusoids are not the same?

Answer: You get something like this with just two fibers:



Note the crossovers – each one is a potential microbend

Therefore: It's essential that the fibers have:

- Consistent EFL. Each fiber has the same amount
- Well-coordinated EFL. All fibers have the same period and phase

Back to Our Questions

Continuing

3. What happens if we need more than 12 fibers in a tube?

   Answer: You have two possibilities

Option 1. Ring or band marking – Repeat the 12 standard colors with black marks in a pattern such as:

- Fibers 1 – 12 = standard colors
- Fibers 13 – 24 = standard colors + 1 ring mark
- Fibers 25 – 36 = standard colors + 2 ring marks
- Fibers 37 – 48 = standard colors + 3 ring marks

Notes:

a. The black fiber (#8, #20, #32, and #44) is left "natural" (not colored; just the ring marks)
b. This band marking system breaks down above 48 fibers

Back to Our Questions

Yet More Continuing

3. What happens if we need more than 12 fibers in a tube? (cont’d)

Option 2. “Bundle” the fibers into groups of 12 with a bundling (a.k.a binding) thread such as:

- Fibers 1 – 12 bundled with blue bundling thread
- Fibers 13 – 24 bundled with orange bundling thread
- Fibers 25 – 36 bundled with green bundling thread
- Fibers 37 – 48 bundled with brown bundling thread

Notes:

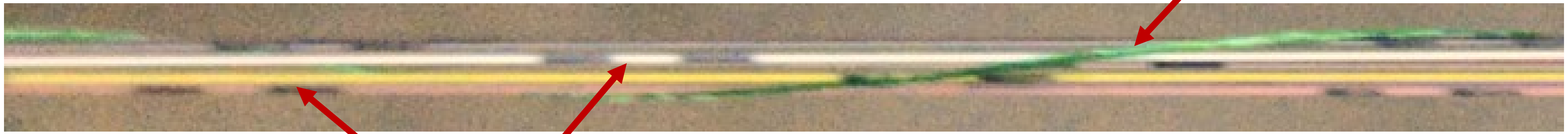
a. The two can be used together (“belt and suspenders”)
   - Band marks give a good back-up in case you lose track of the bundling thread during splice prep

b. The bundling thread system works well up to 144 fibers, but there is one consideration…

Back to Our Questions

Bundling Illustration

Green bundling thread, so these are fibers 25 - 36

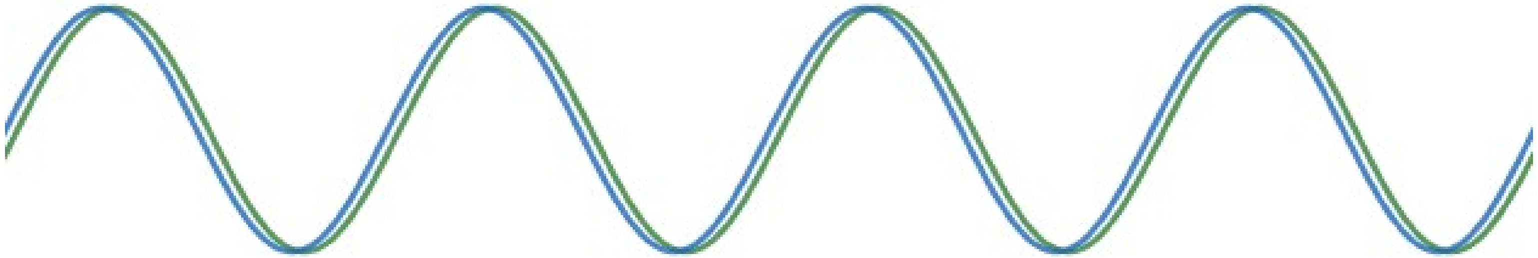


Notice the double band marks, too

Back to Our Questions

- Won't bundling threads restrict the ability of the fibers to move freely?

Answer: Yes, but consider that today's EFL control during tubing yields:



- Consistent EFL. Each fiber has the same amount
- Well-coordinated EFL. All fibers have the same period and phase

Consequently, while there is some restriction in movement, the bundles themselves move as a unit, so the system works well

- It does significantly speed up splice prep, too
  (and I'm not known for being sympathetic to splice prep techs)

Specifying Your Cable

Check Your Fiber Strain!

- By now you might be wondering:
    - "Do I have to worry about including such details as the amount of EFL, the tube fill factor, the lay length, etc. in my specifications?"
- **Answer:** No.

➔ But, you do need to pay attention to the ZFSM and MRDT or MRCL of your aerial cable

- - Plus, you ought to require these values be shown on the cable datasheets

You should have fiber strain limits in your specs!

Specifying Your Cable

Check Your Fiber Strain!

- Recommendations for MRCL = MRDT limits, but first a quick review:
    - "MRCL" = "Maximum Rated Cable Load" = The term used for the maximum tension ADSS cable will experience under the highest wind and ice loading conditions
        - MRCL is the term used in IEEE 1222
    - "MRDT" = "Maximum Rated Design Tension" = The term used for the maximum tension OPGW cable will experience under highest wind and ice loading conditions
        - MRDT is the term used in IEEE 1138
    - The terms mean the same thing: The highest tension that you design to
        - Mother Nature might subject your cable to higher wind or ice loads, but that's not under your control

Specifying Your Cable

Check Your Fiber Strain!

- Recommendations for ZFSM limits
  - ADSS – Should have zero fiber strain at "everyday" condition (no ice, no wind = unloaded)
  - OPGW – ZFSM will vary by design type:
    - Center stainless steel loose tube (Types C and CA) – At least 30% RBS, which as with ADSS will ensure no fiber strain at everyday/unloaded conditions
    - Aluminum pipe with plastic buffer tubes (Type AP) – At least 50% RBS
    - Stranded stainless steel loose tube (Type S) – At least 80% RBS

You should have a ZFSM requirement in your spec

Specifying Your Cable

Check Your Fiber Strain!

- Recommendations for MRCL limits for ADSS
  - ADSS - “Best Practice” is **zero fiber strain to** MRCL = No strain even under fully loaded design conditions (“No strain = No problems”)
    - Acceptable alternates (low risk, but not zero!) might be:
      - OK, ≤ 0.2% (remember, this is our 40-year safe limit in theory)
      - Not too bad, ≤ 0.3% (if you plan for 20 – 25-year service life)
      - Risky, ≤ 0.4% 🡐 Greater than this is just plain crazy!

You should have a fiber strain limit in your specs

Specifying Your Cable

Check Your Fiber Strain!

- Recommendations for MRDT limits for OPGW
  - OPGW - "Best Practice" varies by design type
    - Center stainless steel loose tube (Types C and CA) –
      - Strain ≤ 0.20% at 60% RBS (traditional NESC 250B conditions)
    - Aluminum pipe with plastic buffer tubes (Type AP) –
      - Ideal: strain = 0.0% at 60% RBS
      - Acceptable: strain ≤ 0.20% at 60% RBS
    - Stranded stainless steel loose tube (Type S) – At least 80% RBS
      - Strain = 0.0% at 80% RBS (NESC 250C or D conditions)

You should have a fiber strain limit in your specs

Loose Tube Alternatives

What Else Is Available?

- **Tight Buffer -** Each fiber has its own jacket (900 μm)
  - Good: Very flexible and easy to add connectors
  - Bad: Low to no ZFSM

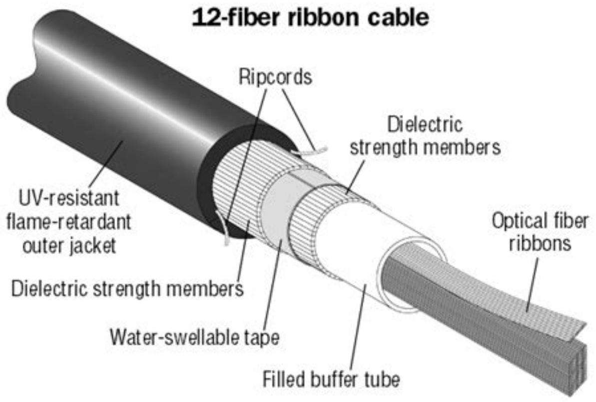
  ➔ Great for indoor cables/Terrible for aerial applications

Loose Tube Alternatives

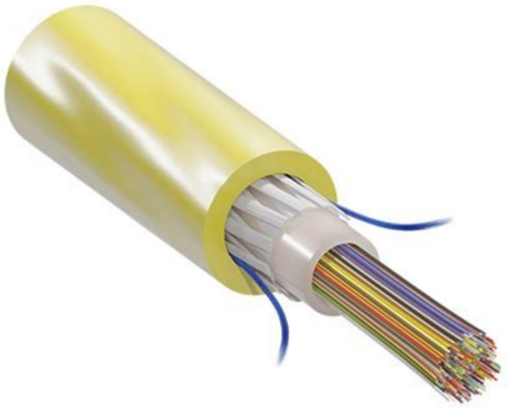
What Else Is Available?

- **Ribbon -** Two versions: (1) "Stack" (traditional), or (2) "Rollable" (newer)
  - Good: Excellent "fiber density" and allows for "mass fusion splicing" to reduce splicing time
  - Bad:
    - Lower ZFSM for rollable version
    - Low to no ZFSM for stack version
    - Increased splice loss for stack version, possibly for rollable, too (or more time)
    - Rollable version hated by splice techs

➔ Used in data centers and where very high fiber density is a must



(1) Cable with ribbons stacked



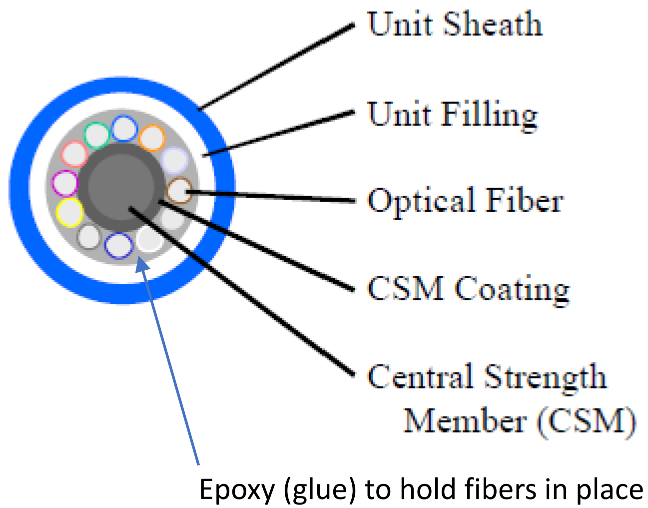
(2) Cable with rollable ribbons

Loose Tube Alternatives

What Else Is Available?

- **Tight Structure –** Fibers stranded around a center element and glued into place
  - Good: None (ouch!)
  - Bad:
    - Low to no ZFSM (= field problems over time)
    - Low fiber density
    - Difficult to splice prep

  ➔ Defunct



Recap

Now you know…

- The why and how of the Loose Tube Design Concept
- The link between fiber strain and optical service life
- The importance of zero fiber strain margin
  - Plus, guidelines to what ZFSM you should specify
- The importance of MRCL and MRDT
  - Plus, guidelines to what you should specify
- Alternatives to the loose tube design concept and when they might be the preferred solution

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Thank you

Questions?

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