OPGW Sag and Tension Calculations (and more!)

Mike Riddle
President

June 20, 2024

RCEP COMPLIANT

- Incab America has met the standards and requirements of the Registered Continuing Education Program.
- Credit earned on completion of this program will be reported to RCEP.net.
- Certificates of Completion will be issued to all participants via the RCEP.net online system.
- As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP
REGISTERED CONTINUING EDUCATION PROGRAM

PURPOSE AND LEARNING OBJECTIVES

This course will teach you how to perform sag and tension calculations and will guide you through everything you need to know to ensure you project goes smoothly.

After this class, you will be able to:

1. Perform sag and tension calculations for OPGW using the two most used software platforms in our industry: Power Line® Systems' PLS-CADD and Southwire®'s Sag10®.
2. Explain the meaning and importance of a OPGW's Maximum Rated Design Tension (MRDT) and how it should be used in sag and tension calculations.
3. Explain the importance of reel lengths in the OPGW procurement process.
4. Determine suitable splice point locations and use them to calculate your project's required reel lengths.
5. Explain to a purchasing agent what basic information needs to be on the purchase order plus what important additional information should also be included because it will help ensure that your project's logistics proceed smoothly.

Incab University “School of Excellence in Fiber Optics”
Agenda

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

Recall that OPGW…

A Multi-Purpose Cable

- Optical Ground Wire or «OPGW»
  - Per IEEE 1138-2021 (USA and some countries)
  - Per IEC 60794-4-10 (Many other countries)

- Primary function of OPGW is to be a shield wire for a transmission line:
  - **To protect the phase conductors from lightning**
  - To provide a path for fault current

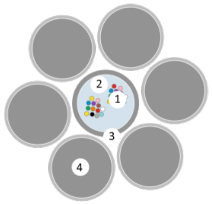
- Secondary function: housing optical fiber for data and communications

- In use since the late 1980's

OPGW – Quick Review of 3 Design Types

1. Center Tube Type – has two variants

A. Plain Stainless-Steel Tube (SSLT)

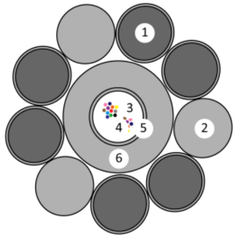


OPGW C

CONSTRUCTION:

1. Optical fiber Corning SMF-28 Ultra
2. Water-blocking gel
3. Stainless Steel Loose Tube (SSLT)
4. Aluminum-Clad Steel Wire (ACS)

B. SSLT with aluminum-cladding or in aluminum pipe

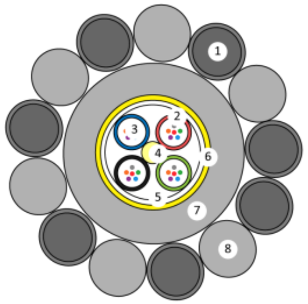


OPGW C

CONSTRUCTION:

1. Aluminum-Clad Steel Wire 20SA
2. Aluminum alloy wire
3. Water-blocking gel
4. Optical fiber Corning SMF-28 Ultra
5. Stainless Steel Loose Tube (SSLT)
6. Aluminum jacket

2. Aluminum Pipe Type (stranded plastic tubes)

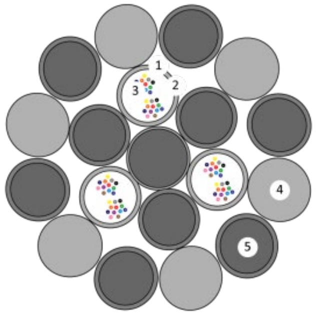


OPGW AP

CONSTRUCTION:

1. Aluminum-Clad Steel Wire 20SA
2. Gel filled loose tube
3. Optical fiber Corning SMF-28 Ultra
4. Central strength member FRP
5. Water-swellable tape
6. Thermal barrier
7. Aluminum pipe
8. Aluminum alloy wire

3. Stranded Stainless-Steel Tube (SSLT) Type



OPGW S

CONSTRUCTION:

1. Stainless Steel Loose Tube (SSLT)
2. Water-blocking gel
3. Optical fiber Corning SMF-28 Ultra
4. Aluminum alloy wire
5. Aluminum-Clad Steel Wire 20SA

OPGW as a Structural Element

OPGW is also a structural element on your transmission line, so…

- It contributes load to your structures
- It has sag
- Its tension and its sag will vary with environmental conditions
- Clearances must be checked

➔To do these things, you must perform sag and tension calculations

➔Our purpose today is to learn how to do such calculations

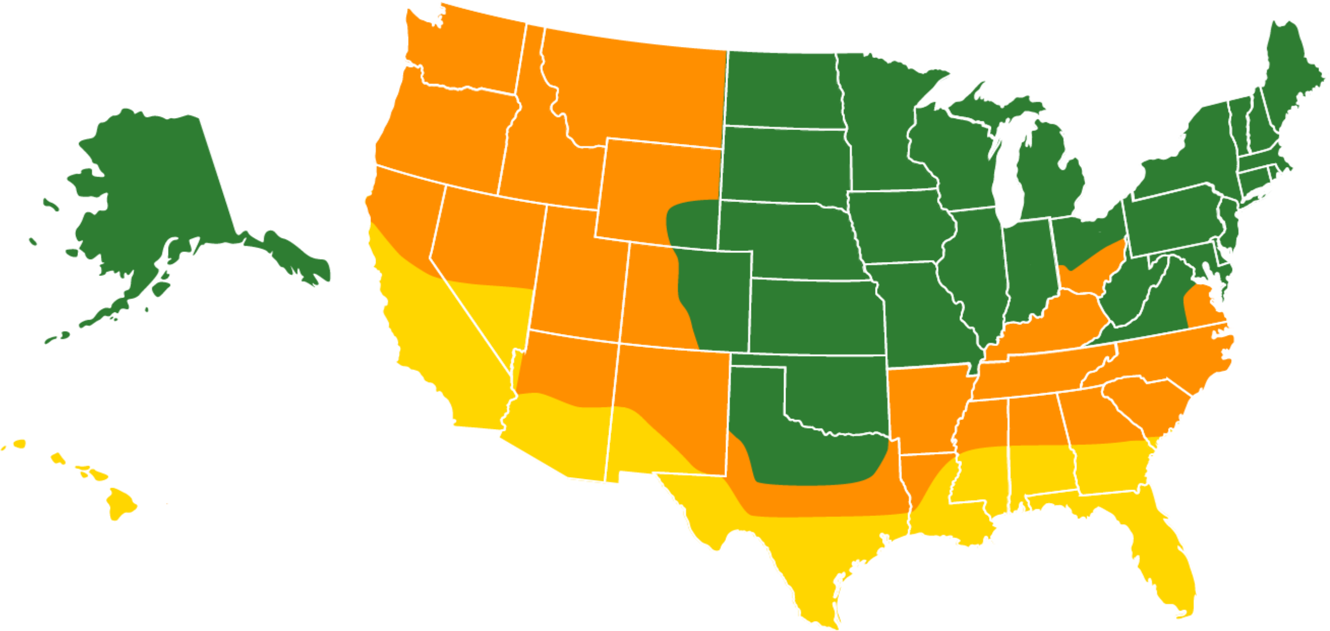
OPGW Sag and Tension Calculations

- Five step process
  1. Review your loading criteria
  2. Get the specifications for the cable you're using
     - Basic data plus MRDT and ZFSM (we'll define these soon)
  3. Set up your modeling software
     - For PLS-CADD – You must have a .WIR file ("wire file")
     - For Sag10 – You need a "coefficient chart number"
  4. Generate the data
  5. Check the data

Sag and Tension Data Generation

Step 1: Review Your Loading Criteria

- Determine your base loading criteria
  - NESC Rule 250B loading zone
  - Alternate for your state or country
- Do you also have "extreme ice" or "concurrent wind and ice" conditions?
  - NESC Rule 250C and D
  - Additional criteria for your state or country
- Criteria unique to your utility or project?
  - Tension limits?
  - Sag limits?



Sag and Tension Data Generation

Step 2a: Get the Basic Specifications for the Cable You're Using

- The two commonly used programs for making sag and tension calculations in the USA are Power Line System®'s PLS-CADD and Southwire®'s Sag10®

    ➔ Both programs need the following basic cable specifications:

    1. Cross-sectional area (square inches or mm^2)
    2. Outside diameter (inches or mm)
    3. Unit weight (lb/ft or kg/km)
    4. Rated Breaking Strength (lb or kN)
    5. Stress-strain coefficients (usually a Sag10 chart number)

- You will find such basic data on the cable datasheet (always)

Sag and Tension Data Generation

Step 2b: Get the MRDT and ZFSM for the Cable You're Using

- Very important! You must have the cable's "Maximum Rated Design Tension" (MRDT)!
  - Defined in IEEE 1138
    - Same meaning as "Maximum Rated Cable Load" (MRCL) which is used for ADSS
  - MRDT is the tension that the cable should NEVER, EVER exceed under any loading condition!
- You should also get the cable's "Zero Fiber Strain Margin" (ZFSM)
  - ZFSM is the point in %RBS where the fibers begin to experience tension
  - It is important for optical reliability that the ZFSM > the "everyday" (unloaded) tension
- **Notice**: Many suppliers omit one or both of these values on their datasheets, so you must ask them for the values!

Sag and Tension Data Generation

Step 3:

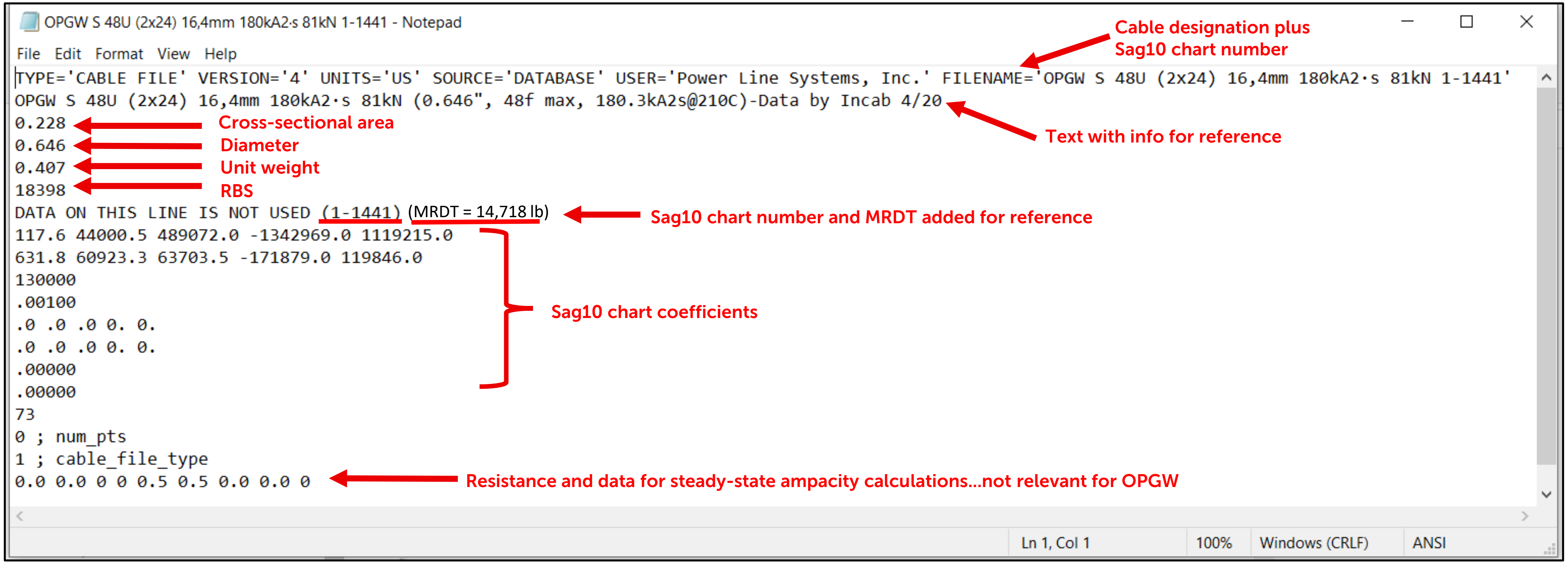
If Using PLS-CADD, Set-up Your .WIR File

- Hint: It's good to know how to do this procedure and to understand what's in a .WIR file, but...
  - It's easier if you just ask for a .WIR file from the cable manufacturer
  - You can find a library of .WIR files by cable manufacturer at www.powline.com/files/cables
  - Consequently, we will talk about this process very generally and very quickly

Sag and Tension Data Generation

Step 3A – Setting up a .WIR File

- It's best to start with a "donor" .WIR file using the same chart number as the cable you are using. Example:




```
TYPE='CABLE FILE' VERSION='4' UNITS='US' SOURCE='DATABASE' USER='Power Line Systems, Inc.' FILENAME='OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN 1-1441'
OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN (0.646", 48f max, 180.3kA2s@210C)-Data by Incab 4/20
0.228
0.646
0.407
18398
DATA ON THIS LINE IS NOT USED (1-1441)
117.6 44000.5 489072.0 -1342969.0 1119215.0
631.8 60923.3 63703.5 -171879.0 119846.0
130000
.00100
.0 .0 .0 0. 0.
.0 .0 .0 0. 0.
.00000
.00000
73
0 ; num_pts
1 ; cable_file_type
0.0 0.0 0 0 0.5 0.5 0.0 0.0 0
```

Sag and Tension Data Generation

Step 3A – How to Find the Sag10 Chart Number?

- Find the Sag10 chart number on the cable datasheet:

Technical Specifications		
Mechanical	**Metric**	**Customary**
Cable diameter	12.8 mm	0.504 in
Cable unit weight	566 kg/km	0.380 lb/ft
Rated breaking strength (RBS) (without SSLT's)	95.1 kN	21,376 lb
Maximum rated design tension (MRDT) (50% RBS)	47.6 kN	10,692 lb
Cross-sectional area of ACS wire	74.5 mm²	0.115 in²
Cross-sectional area of AY wire	22.5 mm²	0.035 in²
Cable total cross-sectional area	97.0 mm²	0.150 in²
Modulus of Elasticity, initial	102.9 kN/mm²	14,927 ksi
Modulus of Elasticity, final	131.4 kN/mm²	19,061 ksi
Temperature coefficient of linear expansion	13.71 E^{-6}/°C	7.61 E^{-6}/°F
Southwire Sag10™ coefficient chart number	1-1441	-
Lay direction of outer layer	Left	-

Note: This one is ours, but for other suppliers the chart number will be somewhere on their datasheet. If not, they're not experienced in the US market, and you'll have to ask.

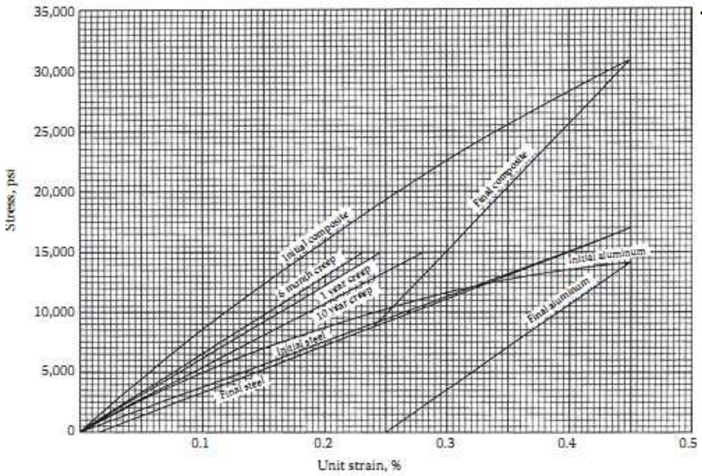
Sag and Tension Data Generation

Step 3A – What Are These Coefficients?

- Here's what those coefficients in a chart mean:

DATA ON THIS LINE IS NOT USED (Chart 1-1455) (MRDT = x lb.) <===< Use Maximum rated design load from datasheet
-1114.5 137270.3 -16623.3 -113531.0 78251.0 <===< (a0) Stress-Strain polynomial coefficients (composite or aluminum if separate steel values below)
709.2 78505.3 59189.0 -132936.0 73913.0 (a1) <===< Creep polynomial coefficients (composite or aluminum if separate steel values below)

124000 <===< (a2) Modulus (in ksi x 10)
.00088 <===< (a3) Coefficient of thermal expansion (per deg F x 100)
0.0 0.0 0.0 0.0 0.0 <===< (if present, steel core stress-strain)
0.0 0.0 0.0 0.0 0.0 <===< (if present, steel core creep)
.00000 <===< (if present, steel core modulus)
.00000 <===< (if present, steel core coefficient of thermal expansion)
70 <===< Test temperature



Equations for curves (X = unit strain in %; Y = stress in psi):

Initial composite: $X = 4.07 \times 10^{-5} + (1.28 \times 10^{-5})Y - (1.18 \times 10^{-10})Y^2 + (5.64 \times 10^{-15})Y^3$
$Y = -512 + (8.617 \times 10^4)X - (1.18 \times 10^4)X^2 - (5.76 \times 10^{-4})X^3$
Initial steel: $Y = (37.15 \times 10^3)X$
Initial aluminum: $Y = -512 = (4.902 \times 10^4)X - (1.18 \times 10^4)X^2 - (5.76 \times 10^4)X^3$
Final composite: $Y = (107.55X - 17.65) \times 10^3$
Final Steel: $Y = (38.60X - 0.65) \times 10^3$
Final aluminum: $Y = (68.95X - 17.00) \times 10^3$
6 month creep: $Y = (68.75 \times 10^3)X$
1 year creep: $Y = (60.60 \times 10^3)X$
10 year creep: $Y = (53.45 \times 10^3)X$

Test temperature 70°F–75°F

Typical Set of Stress-Strain and Creep Curves

- Those coefficients are for a 4th order polynomial equation that:
  - Approximates the cable's stress-strain curve
  - Approximates the cable's creep curve

Sag and Tension Data Generation

Step 3A – Friends Tell Friends to Use a Donor File

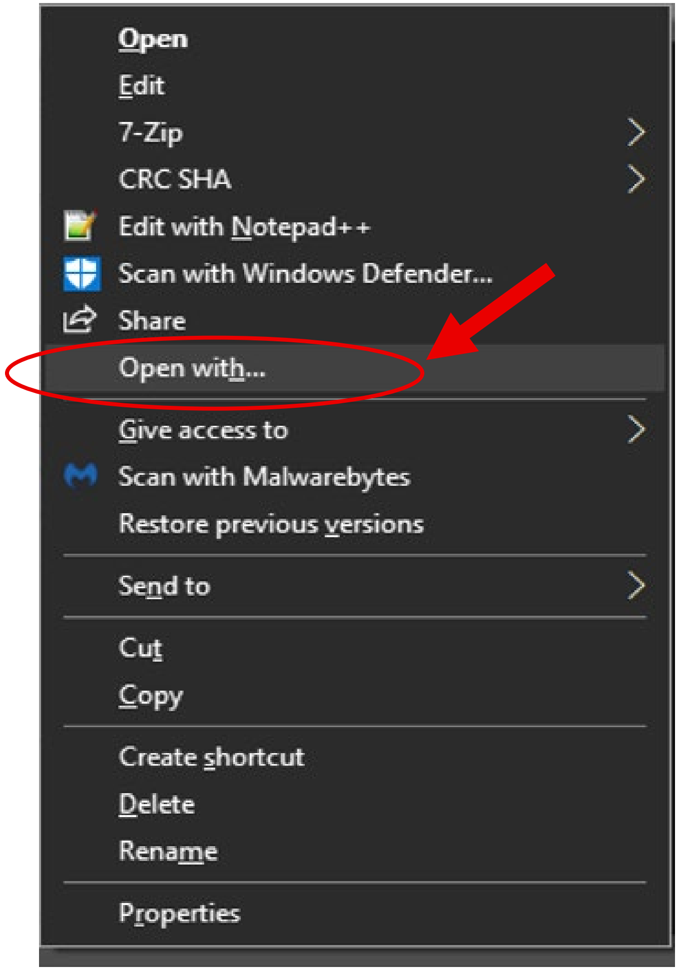
- If you don't use a donor file, then you will have to type in all this data by hand! (Yikes!)
    - Tedious and fraught with risk of error!

Sag and Tension Data Generation

Step 3A – Editing a Donor .WIR File

- You can open a .WIR file by right-clicking on it, selecting "Open With", and then selecting "Notepad".

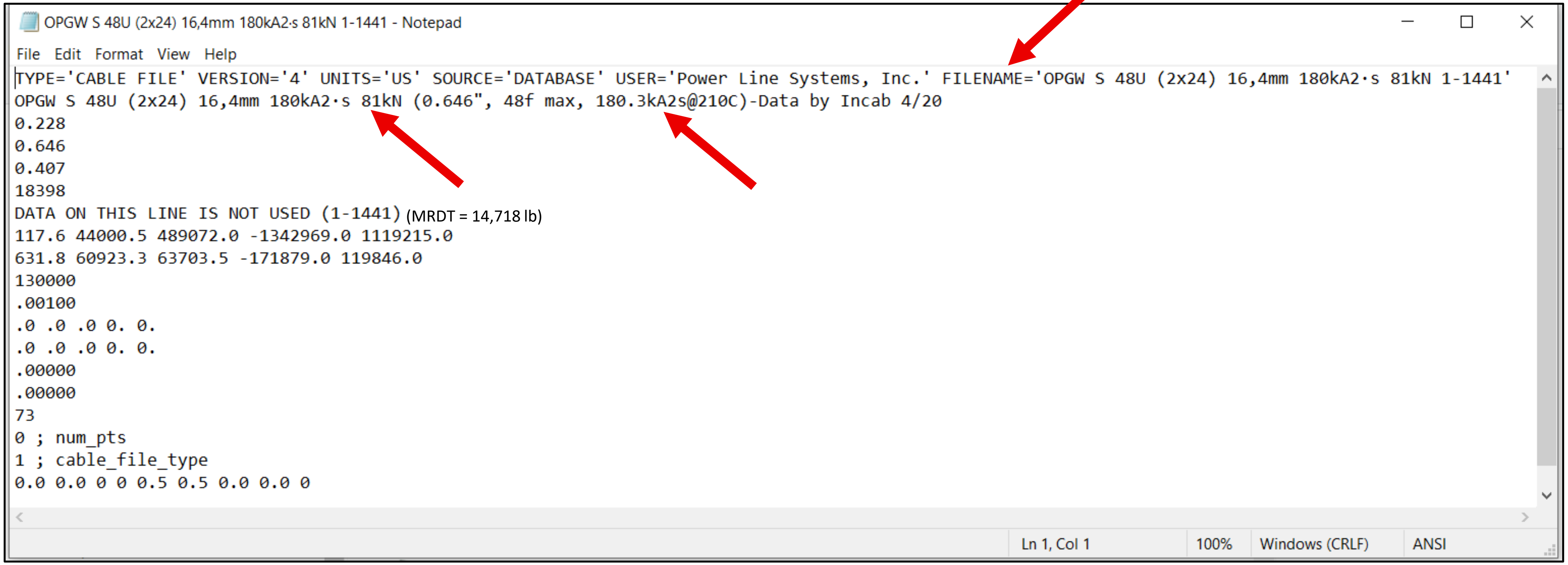
- It is a text file, so Notepad works best.



Sag and Tension Data Generation

Step 3B – What to Edit in the Donor .WIR File

- Update the file name and header information



OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN 1-1441 - Notepad

File Edit Format View Help

```
TYPE='CABLE FILE' VERSION='4' UNITS='US' SOURCE='DATABASE' USER='Power Line Systems, Inc.' FILENAME='OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN 1-1441'
OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN (0.646", 48f max, 180.3kA2s@210C)-Data by Incab 4/20
0.228
0.646
0.407
18398
DATA ON THIS LINE IS NOT USED (1-1441) (MRDT = 14,718 lb)
117.6 44000.5 489072.0 -1342969.0 1119215.0
631.8 60923.3 63703.5 -171879.0 119846.0
130000
.00100
.0 .0 .0 0. 0.
.0 .0 .0 0. 0.
.00000
.00000
73
0 ; num_pts
1 ; cable_file_type
0.0 0.0 0 0 0.5 0.5 0.0 0.0 0
```

Ln 1, Col 1 | 100% | Windows (CRLF) | ANSI

Sag and Tension Data Generation

Step 3C – More Editing That's Required

- Update the cable specifications

"Donor file"

Remember: Should have updated header info first

OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN 1-1441 - Notepad

File Edit Format View Help

```
TYPE='CABLE FILE' VERSION='4' UNITS='US' SOURCE='DATABASE' USER='Power Line Systems, Inc.' FILENAME='OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN 1-1441'
OPGW S 48U (2x24) 16,4mm 180kA2·s 81kN (0.646", 48f max, 180.3kA2s@210C)-Data by Incab 4/20
0.228
0.646
0.407
18398
DATA ON THIS LINE IS NOT USED (1-1441)
117.6 44000.5 489072.0 -1342969.0 1119215.0
631.8 60923.3 63703.5 -171879.0 119846.0
130000
.00100
.0 .0 .0 0. 0.
.0 .0 .0 0. 0.
.00000
.00000
73
0 ; num_pts
1 ; cable_file_type
0.0 0.0 0 0 0.5 0.5 0.0 0.0 0
```

A
B
C
D
(MRDT = 14,718 lb)
E

Technical Specifications

Mechanical	Metric	Customary	
Cable diameter	12.8 mm	0.504 in	B
Cable unit weight	566 kg/km	0.380 lb/ft	C
Rated breaking strength (RBS) (without SSLT's)	95.1 kN	21,376 lb	D
Maximum rated design tension (MRDT) (50% RBS)	47.6 kN	10,692 lb	E
Cross-sectional area of ACS wire	74.5 mm²	0.115 in²	
Cross-sectional area of AY wire	22.5 mm²	0.035 in²	
Cable total cross-sectional area	97.0 mm²	0.150 in²	A
Modulus of Elasticity, initial	102.9 kN/mm²	14,927 ksi	
Modulus of Elasticity, final	131.4 kN/mm²	19,061 ksi	
Temperature coefficient of linear expansion	13.71 E⁻⁶/°C	7.61 E⁻⁶/°F	
Southwire Sag10™ coefficient chart number	1-1441	-	
Lay direction of outer layer	Left	-	

Note: This is our datasheet, but these values will be found on other manufacturers' datasheets too, or you can ask for them

Sag and Tension Data Generation

Step 3D – Save and Continue

- Save the new .WIR file
- Load the new .WIR file into PLS-CADD, complete your problem file, and let the program compute the sag and tensions for you

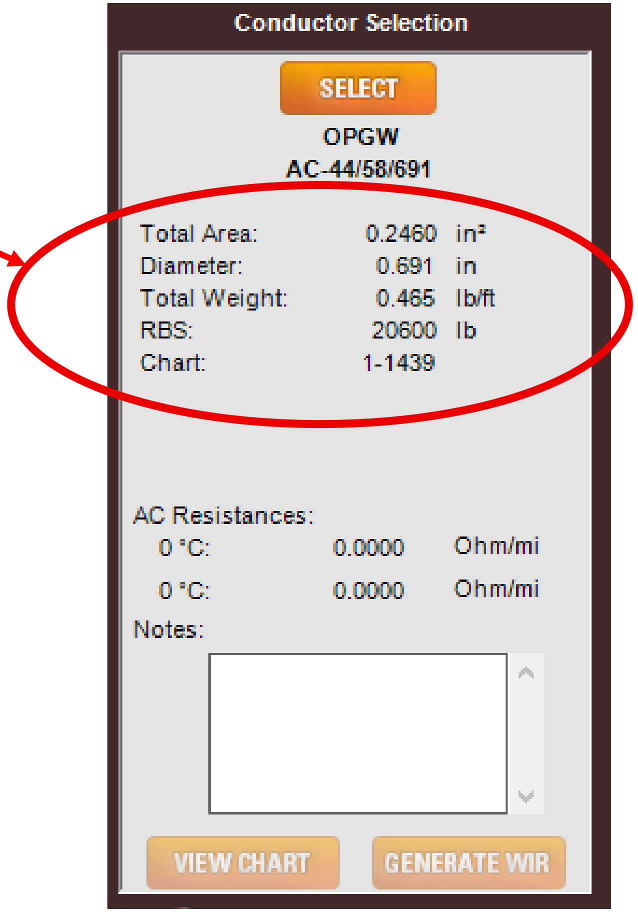
The previous eight (8) slides have described the process for PLS-CADD

➔ What about the process for Sag10?

Sag and Tension Data Generation

Step 3: If Using Southwire SAG10, Set-up a Problem File

- Cable data entry
  - ➔ The five basic cable specifications



Sag and Tension Data Generation

Step 3: If Using Southwire SAG10, Set-up a Problem File

- What if the program does not have the chart you need?
- Get the chart coefficients from the cable manufacturer and set-up the chart in Sag10

Sag and Tension Data Generation

Important Tip: Check ZFSM!

- To ensure long-term optical reliability, it is also good to check to make sure that under "everyday" conditions (no wind or ice loading) the tension on the cable is less than the cable's ZFSM
    - Unfortunately, neither PLS-CADD nor Sag10 do this automatically for you, so you have to check it manually yourself
- Ask the cable manufacturer to confirm their ZFSM value if it is not on their datasheet.

Sag and Tension Data Generation

Important Tip: Help Limit Aeolian Vibration

Issue: Some loading conditions—notably NESC rule 250B Light– can yield a final tension at 60°F (16°C) unloaded ("everyday") greater than 20% RBS

- If so, then you are guaranteed to have aeolian vibration problems and need extra vibration dampers!
- To mitigate this problem, keep the tension under 20% RBS
  - PLS-CADD includes this limit already (check to make sure it is there, just in case)
  - In Sag10, you must add this yourself as a separate condition
- This will NOT eliminate the need for dampers!
  - Think of dampers as cheap insurance against damage

Sag and Tension Data Generation

Important Tip: Limit Sustained High Tension!

- For <u>any</u> metallic cable, the maximum sustained tension should not exceed 80% RBS
    - This is incorporated in NESC Rule 250 C & D limits
    - Already included in PLS-CADD
    - Must be added in Sag10

Sag and Tension Data Generation

Critical Final Step – Verifying MRDT Maintained!

Remember the cable's MRDT? It's critical!

- You must manually check in both PLS-CADD and Sag10 that tension never, ever exceeds the cable's MRDT!
  - If it does, you risk optical problems (short and/or long term)!
  - If it does, you risk a voided warranty!
- Repeat: The tension under any and all conditions must never, ever exceed the cable's MRDT!

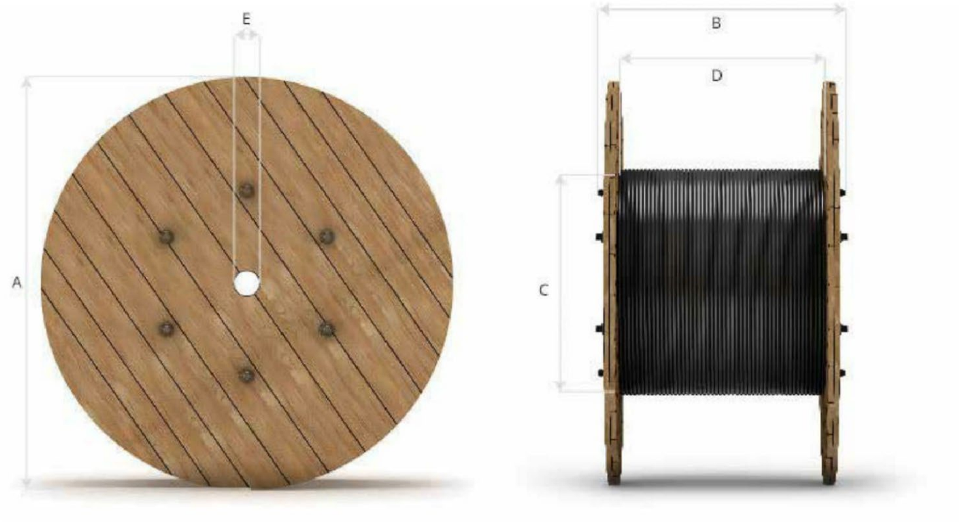
Important

OPGW Specific Issues

Reel Lengths are Essential!

- For two reasons:
  - **Manufacturing can't actually begin without reel lengths**
    - ASC wire and buffer tubes are ordered/made to specific lengths

Important



- **You must plan your splice points**
  - When a reel runs out, you have to splice the fibers in it to the next reel in order to keep going.

1. You cannot use compression splices as you can for conventional shield wire or conductor
2. Therefore, you must plan **splice points** where one reel will be joined to another

IMPORTANT: Quoted lead time is almost always based upon order <u>AND</u> reel lengths!

OPGW Specific Issues

Reel Length Solutions

"Master" or "Standard" reel lengths

- All reels are the same length, typically 18,000 – 25,000 ft

Advantages:

- No engineering time required, so production can start immediately
- Reels can't get mixed up in the field

Disadvantage:

- More scrap

"Specific" or "Point-to-point" reel lengths

- A specific reel length is determined from one splice point to the next

Advantage:

- Much less scrap

Disadvantages:

- Requires engineering time which can delay start of production
- Reels can get mixed up in the field

OPGW Specific Issues

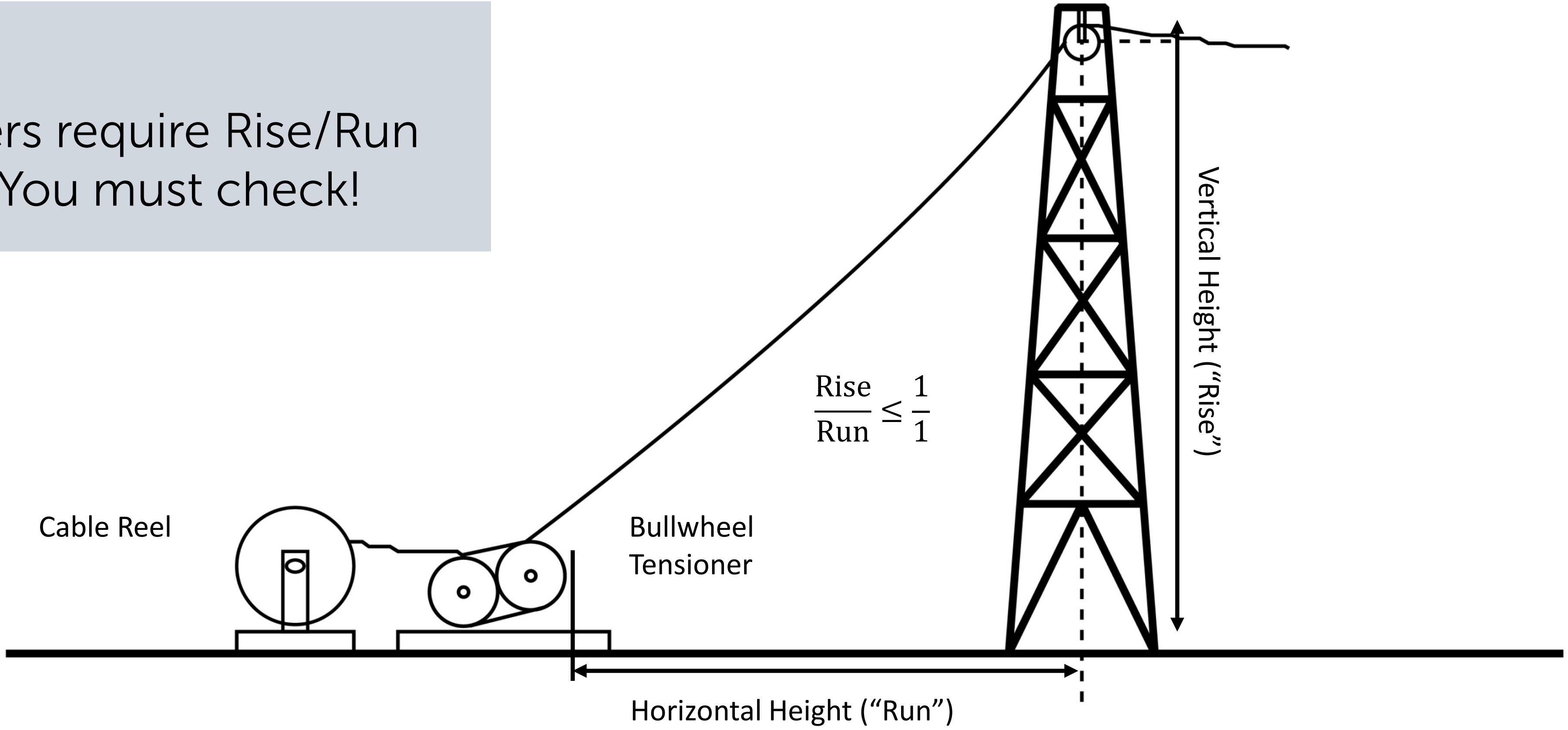
Splice Point Considerations

- **General guidelines**
  - Must determine possible pull locations
  - Good access and satisfactory bearing for equipment
  - Maintain the manufacturer's Horizontal-to-Vertical distance ratio (illustrated on next slide)

OPGW Specific Issues

Pull Set Up

Caution!
Some suppliers require Rise/Run of 1/3 or 1/4. You must check!



OPGW Specific Issues

Splice Point Considerations

- **General considerations**
  - **Which structures can be used as splice locations?**
    - A tangent for the phase conductors can still be good as a splice point for the OPGW
    - Take advantage of large angles
  - **What is the standard maximum reel length available?**
    - Function of wire size, bobbin capacity, and reel capacity
    - Limit can be volume or weight
    - Both machine bobbins and reels have volume and weight limits
- **The maximum reel length is provided by the cable manufacturer**
  - Often shown on their datasheet, or you can ask

OPGW Specific Issues

Splice Point Considerations

- **Added guidelines:**
  - Maximum pulling tension
    - Quality cable will be good for up to 20% RBS

Note: Greater than this is not needed because the concern is permanent elongation messing up sagging, not cable damage.

Caution! The maximum available reel length <u>can exceed</u> the maximum safe pulling tension or pulling conditions! **Important**

➔ You should check, especially for reels > 20,000 ft (6 km)

OPGW Specific Issues

Splice Point Considerations

- **More added guidelines:**
  - Check the estimated pulling tension (reference: IEEE 524)

    Step 1. $T_{\text{Payoff}} \approx \frac{1}{2}$ Design tension, 60°F Initial, unloaded

    Step 2. $T_{Max\ (Pulling\ end)} \approx \frac{T_{\text{Payoff}}}{0.98^N}$ where N = number of structures

  - Example:
    - 19,500 ft pull through 30 structures. Cable RBS = 20,000 lb. Design tension is 3,000 lb.
    - 20% RBS = 4,000 lb.
    - Estimated tension at payoff = 1,500 lb.
    - Estimated maximum tension = 1.8 * 1,500 = 2,700 lb.
    - 2,700 lb < 4,000 lb ➔ OK!

OPGW Specific Issues

Splice Point Considerations

- **Yet more guidelines:**
  - Verify the maximum amount of horizontal line angle change that is allowed
    Incab guidelines are:
    - Types C (plain center SSLT), CA (aluminum-clad center SSLT) and AP (aluminum pipe): $\leq$ 270° total, 1 $\geq$ 90°
    - Type S (stranded SSLT): $\leq$ 360° total, 2 $\geq$ 90°
  - Notes:
    - Ignore angles $\leq$ 5°
    - These are guidelines only, *not* laws.
  - Other suppliers could be more or less restrictive ➔ You must check!
  - Check with the cable manufacturer if you have a problem situation

OPGW Specific Issues

Computing Your Reel Lengths to Order

- **Once pulling/splicing locations are determined:**

1. Sum horizontal span lengths
2. Add the attachment height for both the first and the last structure
   (Example: Attachment height at tensioner end is 100 ft; at puller end is 60 ft. Additional amount is 100 + 60 = 160 ft)
3. Allow additional length for sag (generally, 1.5% is plenty)
4. Determine additional length for storage coil and fiber inside splice case
   (100 ft at each end = 200 ft total is good)
5. Add 100 ft for reeving the bullwheels

To compute the reel length, add values for 1-5 above

Remember to instruct the stringing crew how much tail you need left at the pole!

Typically, this formula works out to 3 - 5% over the linear distance

OPGW Specific Issues

Tips for the Purchase Order

- Remember to include and verify the part number, quantity, and price
- **Reel lengths**
  - Order can be placed but recall that manufacturing cannot really begin without these lengths!
- **QC Reports**
  - Original attached to each reel
  - Ask for an email copy too
- **Shipping information**
  - Location (GPS coordinates OK), POC name and phone number
  - Flat bed truck
  - Notification required
- **Delivery date required — factor in a cushion if possible**
  - 10 – 12 weeks ARO and reel lengths is standard, but…

Recap

Today we have:

1. Learned how to do sag and tension calculations for OPGW using PLS-CADD and Sag10®
2. Reviewed the meaning and importance of an OPGW's Maximum Rated Design Tension (MRDT) and learned how it must be checked as part of doing sag and tension calculations
3. Seen the importance of reel lengths in the OPGW procurement process
4. Learned how to determine suitable splice point locations and use them to calculate point-to-point reel lengths
5. Learned what information should be on a PO for OPGW to help your project go smoothly

Incab

Thank you!
Questions?

INCABAMERICA.COM