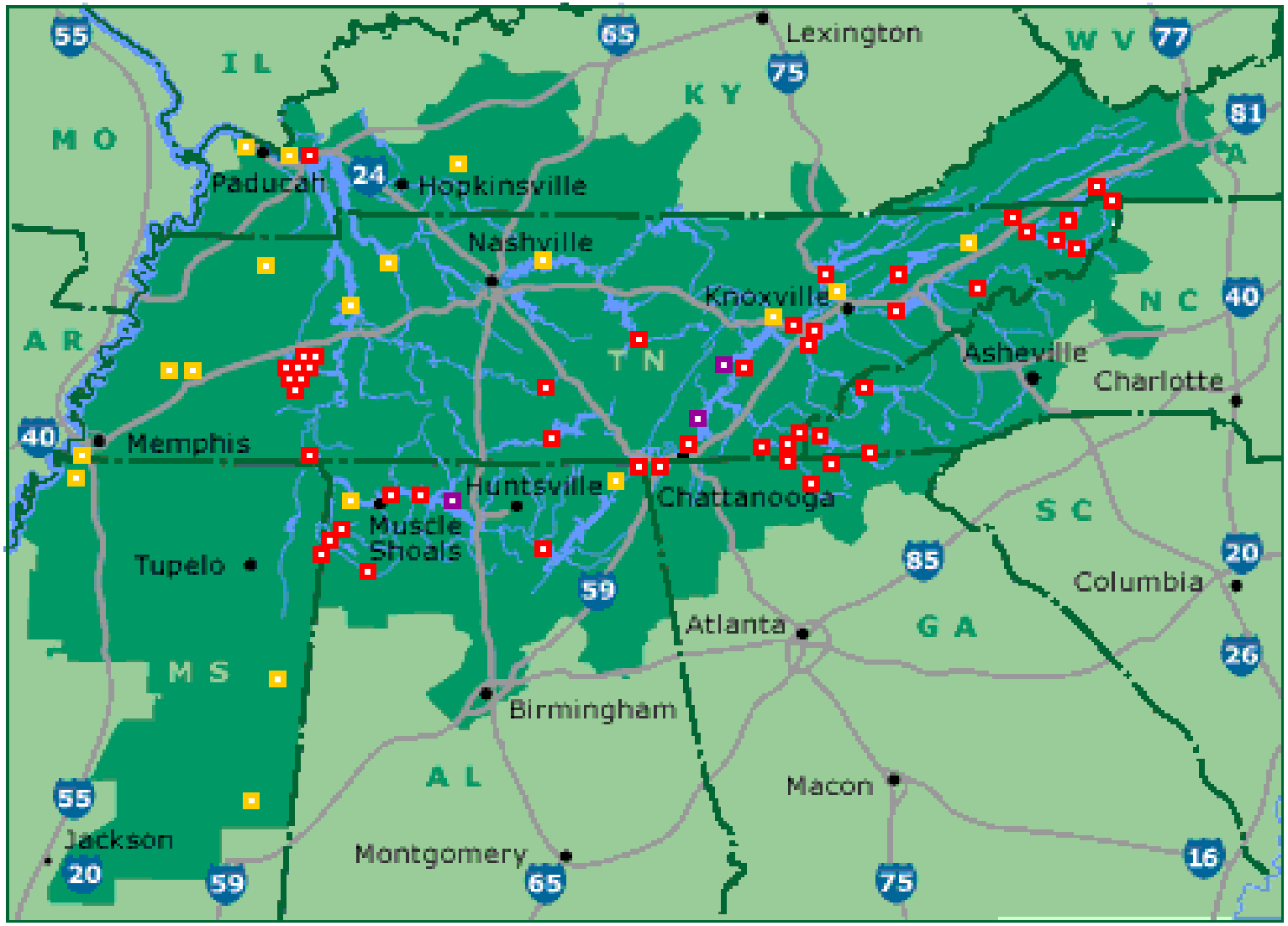
Tennessee Valley Authority

Thermal Assessment of Existing 161kv & 500kv Transmission Lines

TVA Power Service Area



Why are we gathering aerial laser survey & doing thermal assessments?

- **Before 1977; NESC ground clearance requirements @ 120°F (49°C)**
- **1977 NESC code required clearances at <u>maximum operating temperature</u>**
- **Have generally designed new lines for 100°C since 1977**

Transmission Line Assessment and Up-Rate Program

Background

- NESC Code for Lines Built Before 1977 Required Clearance be Maintained for a Conductor Temperature of 49 Degrees C
- 1977 NESC Code Revision Required Clearances be Maintained Based on Actual Operating Temperatures
- Peak Conditions Typically Require Operation between 80 – 100 Degrees C
- Transmission Line Operation and Clearance Requirements are a Matter of NERC Compliance. The scope includes 8,137 Miles of Transmission Line
  - 2,405 Miles of 500-kV Transmission Lines
  - 5,662 Miles of 161-kV Transmission Lines
  - 70 Miles of 46/69-kV Transmission Lines
- Current Asset Condition Could Impact Reputation and Cost
  - Assumed Rating Could Lead to NERC Reportable Flashover Events
  - Increased Risk of Public Contact Events
  - NESC or NERC Violations Receive More Scrutiny Since Blackout of 2003

TVA in-house engineering assessed about 30% of our lines

Burns & McDonnell
Mesa Associates
Sargent & Lundy

Aerotec LLC
Optimal Geomatics
Geodigital
Network Mapping
Terrapoint USA Inc
Tuck Engineering

MESA coupled with Optimal Geomatics
S&L coupled with Geodigital
Burns & Mac and Network Mapping

Vertical clearance of conductors above roads, driveways, parking lots, areas subject to truck traffic, unpaved land subject to cultivating.

	69kV	161kV	230kV	500kV
TVA	22.1	24.1	25.5	29.8
NESC	19.1	21.1	22.5	26.8
delta	3.0	3.0	3.0	3.0
Lidar NESC + 1 ft.	**20.1**	**22.1**	**23.5**	**27.8**

- Buffer is 1ft.
- Need to model as accurate as possible with lidar
- Why?- affects the sag/clearance (long spans could change sag several feet)
- If there is a violation, could be significat cost for modification

Graphical Sag Options

Snap Mode

- (•) Fit to survey point closest to mouse
- ( ) Fit to mouse coordinates

Fit Mode

- ( ) 1) Ruling Span
  Horizontal tension is always the same for all spans in section.
  Sagging tension and condition will be changed. Display condition will be changed.
- ( ) 2) Finite Element Insulators Plumb at Sagging Condition.
  Horizontal tension constant throughout section at sagging condition but may vary at other conditions.
  Sagging tension will be changed. Display condition will be changed.
- ( ) 3) Finite Element Selected Spans Wire Length Adjustment
  Adjust length of wire in selected spans without regard for effects on other spans.
  Wire lengths for selected spans will be changed. Display condition will be changed.
- ( ) 4) Finite Element All Spans Wire Length Adjustment
  Adjust wire length in all spans to fit selected point(s) without changing mid span wire elevation in other spans.
  Wire length for all spans in section will be changed. Display condition will be changed.

  Tip: There can be a delay after each left click while wire is fit to the selected point(s). Use middle clicks or the Enter key to select points without a fit delay. When done selecting points use a left click to perform the fit.
- ( ) 5) Finite Element Manual Length Adjust
  Manually enter change in unstressed wire length for a span.
  Unstressed wire length for selected spans is changed. Display condition will be changed.
- (•) 6) Finite Element Multiple Point Fit
  Calculate catenary constant and required wire & insulator attachment points required to fit through three points in each span.
  May change wire lengths, structure locations and display condition.
  - [ ] Adjust wire length in each span to fit calculated catenary and wire attachment points
  - [ ] Adjust structure stations, height and offset adjustments to match calculated insulator attachment points
  - [ ] Follow up with a Finite Element All Spans Wire Length Adjustment (option 4) after adjustments above
  - [x] Least squares fit to all wire points within specified distance of 3 point catenary curve — Max distance from 3 point (ft) 3.000
  - [x] Generate report showing attachment point locations and tensions
  - [x] Draw markers showing fit results (fit points, catenary curve, attachment points)
  - [x] Create survey points at calculated mid span and wire/insulator attachment points

  Wire attach. feature: 1702 cond mid FE6
  Insulator attach. feature: 1702 cond mid FE6
  Mid span point feature: 1702 cond mid FE6

  Feature code for structure points (may be used to help refine attachment point calculation): 99999 Substation Data

  [x] Automatically select fit points in each span (for fit mode 4 and 6) — Feature code for wire fit: 1701 Conductor (OH)-Transmiss

  - ( ) Use single point closest to current wire position (old way)
  - ( ) Use centroid of all points within 1m of current wire position (tends to err on high side for bundles)
  - ( ) Use center of rectangle encompassing all points within 1m of current wire position (good for bundles but sensitive to outliers)
  - ( ) Use lowest of all points within 1m of current wire position (good for bundles but sensitive to outliers)
  - ( ) Use center of smallest circle enclosing all points within 1 m of current wire (good for bundles but may be sensitive to outliers)
  - (•) Use bundle-aware centroid: centroid of each wire's centroids, using points within 1m of current position (less sensitive to outliers)

    Enter either the bundle diameter : (in) 13.000 or the bundle spacing : (in) 13.000

Show Web technical note "Graphical Sag Options: Making the Wire System Match 'As-Built' Survey Points"

OK Cancel

With lidar

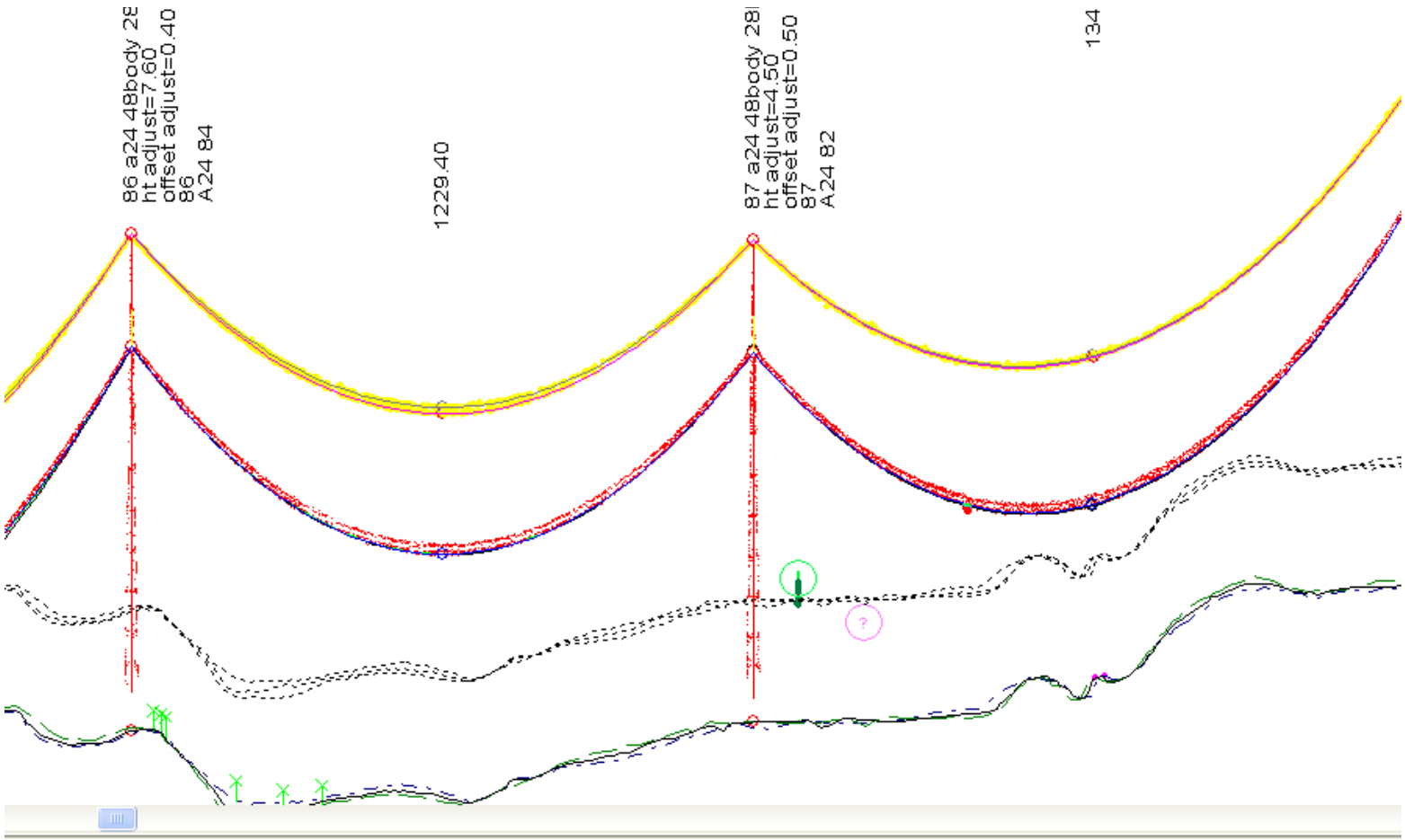
Structure location +- 0.2 ft
Wire tension +- 20 lbs
Ground/obstacles +- 0.2ft

However,

Temperature not directly measured.

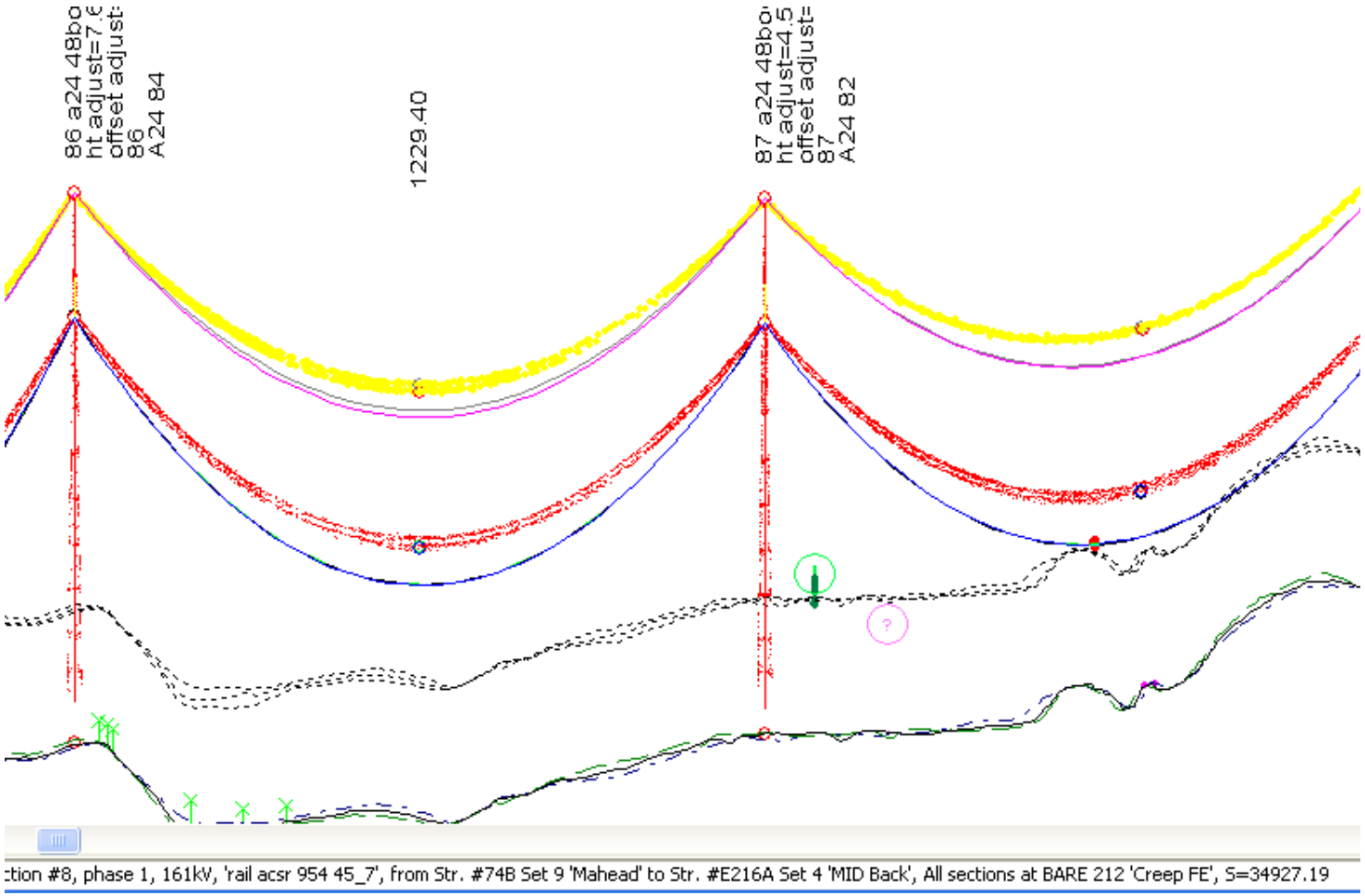
Derived from IEEE 738

As Captured Match Lidar 110.3deg Creep FE



:ion): Section #8, phase 1, 161kV, 'rail acsr 954 45_7', from Str. #74B Set 9 'Mahead' to Str. #E216A Set 4 'MID Back', Section at cond (74B-E216A) 110.3deg 'Creep FE', S=34710.86

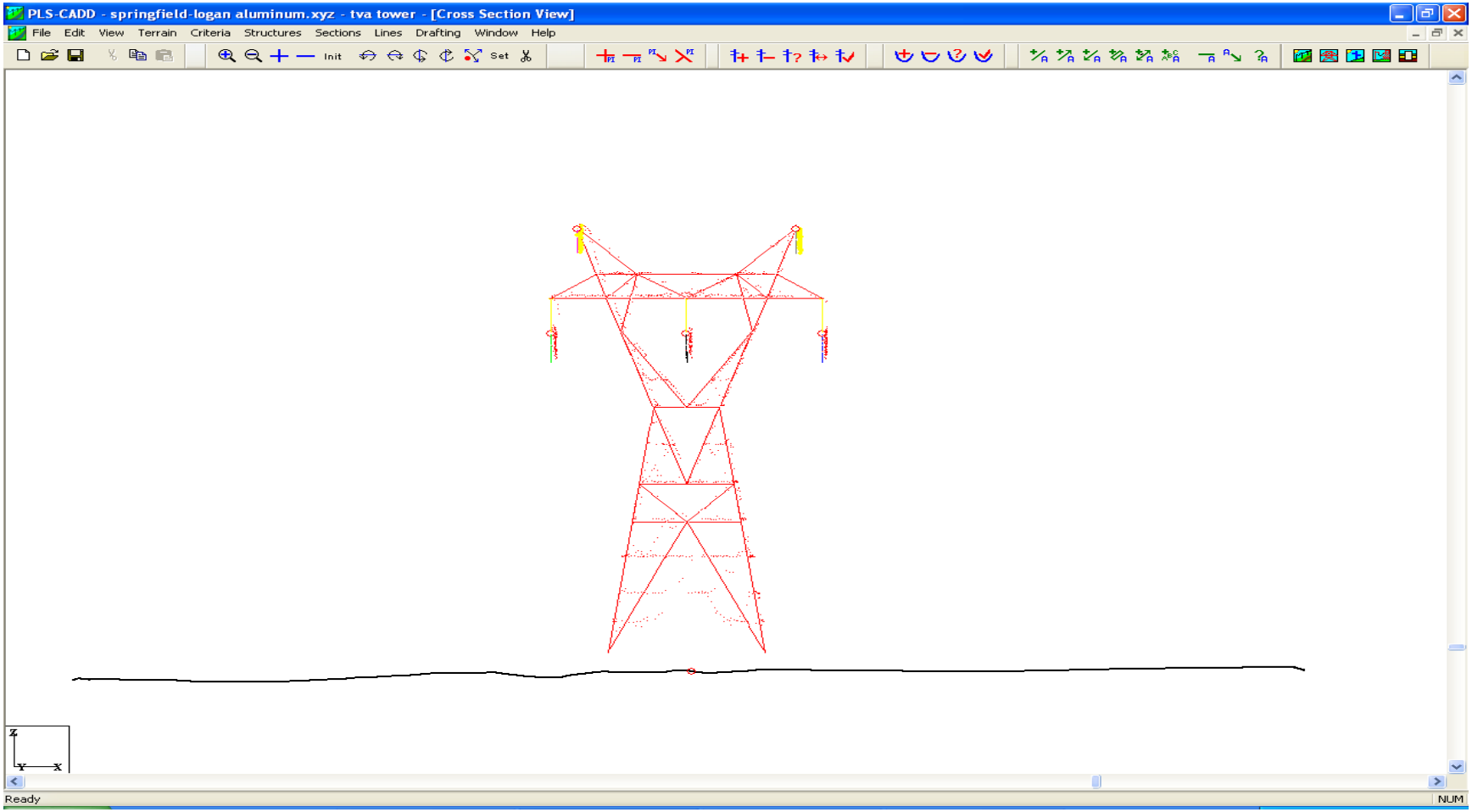
212 deg F creep FE



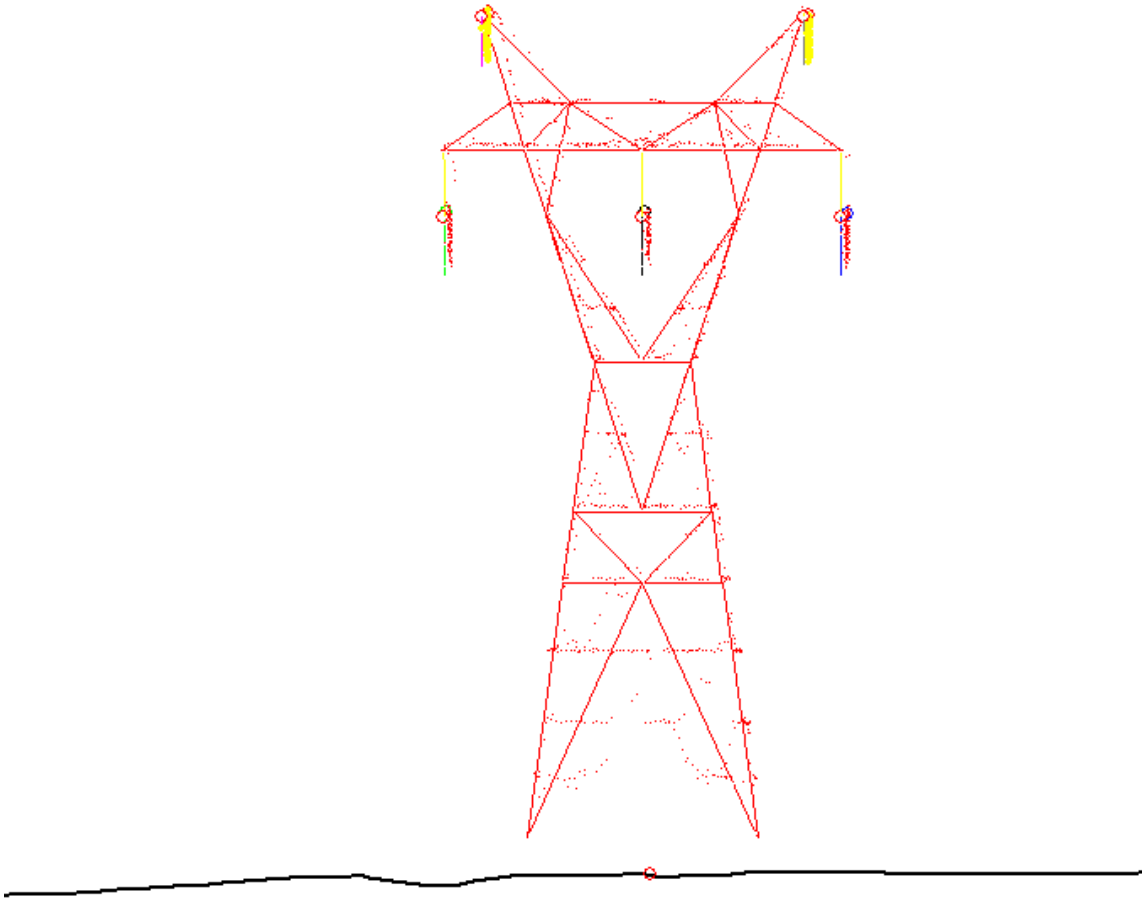
Steps to get FE sag

- Alignment
- Structure locations (station/offset)
- Conductor temperature (weather data)
- Assume sagging temperature (plumb INS)
- As captured least square best fit Tension (FE6) Used to get tension not move structures
- Adjust each span at mid span (non-plumb INS)FE3

First locate structures (cross section view)

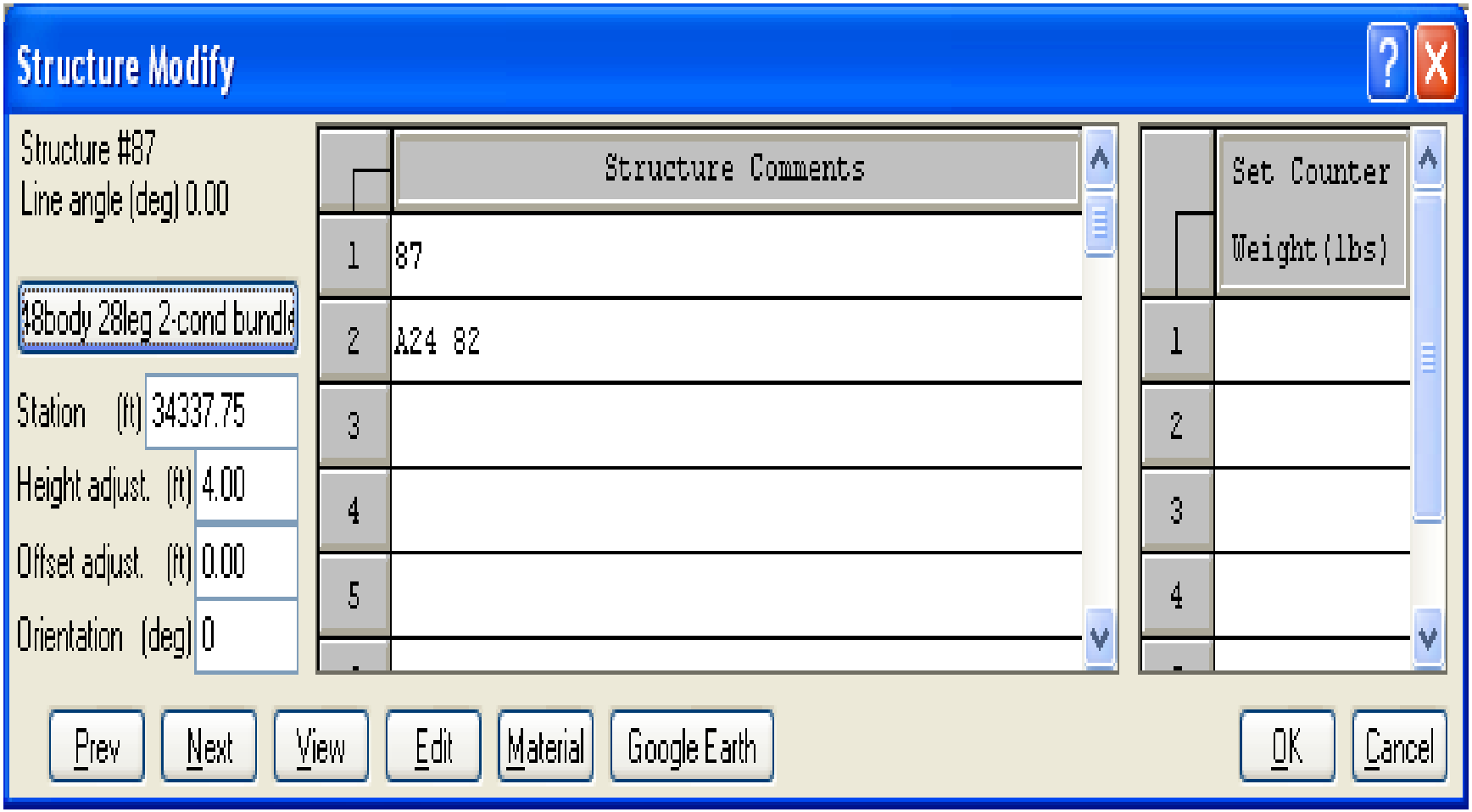


Example of locating structures to match the lidar ghost

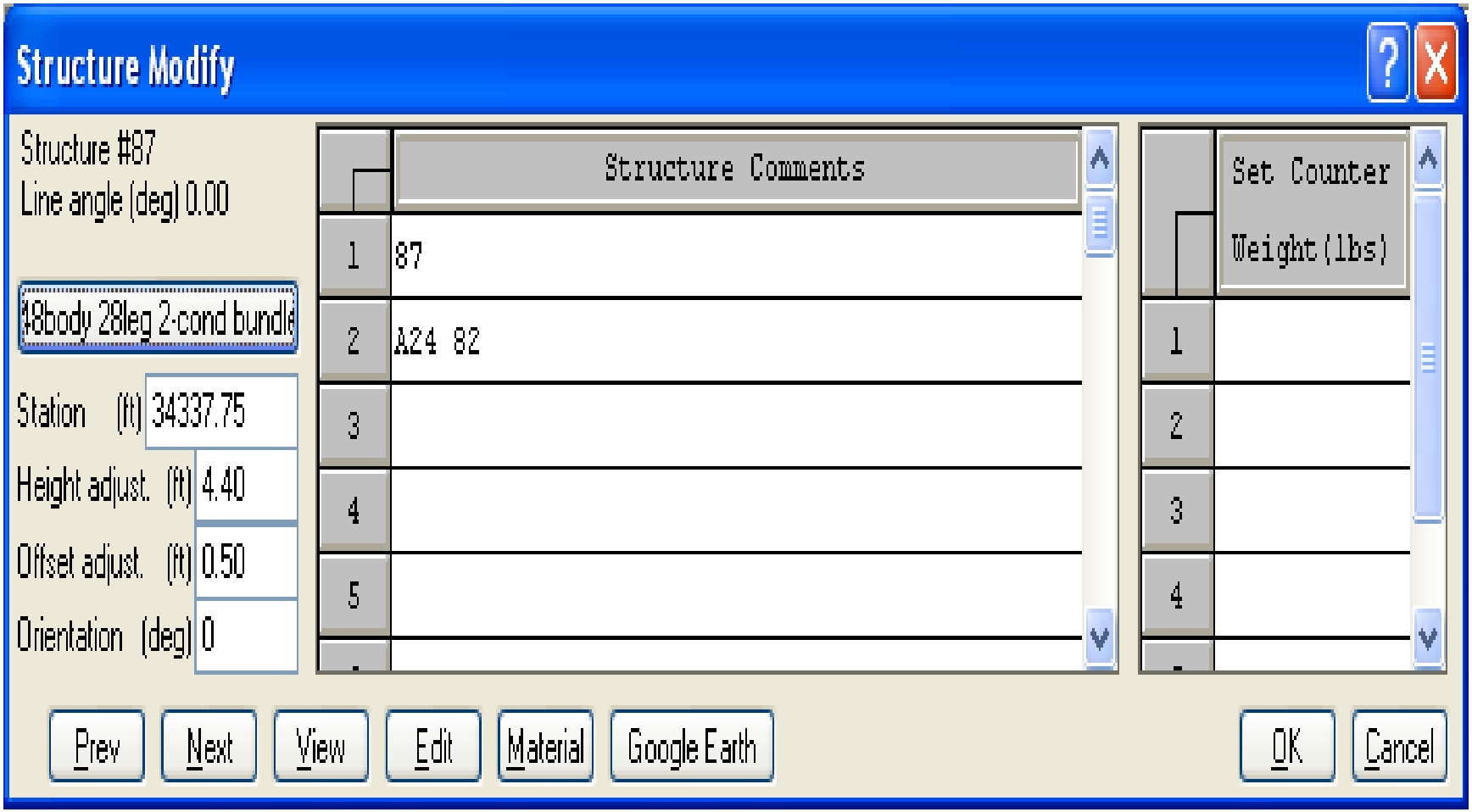


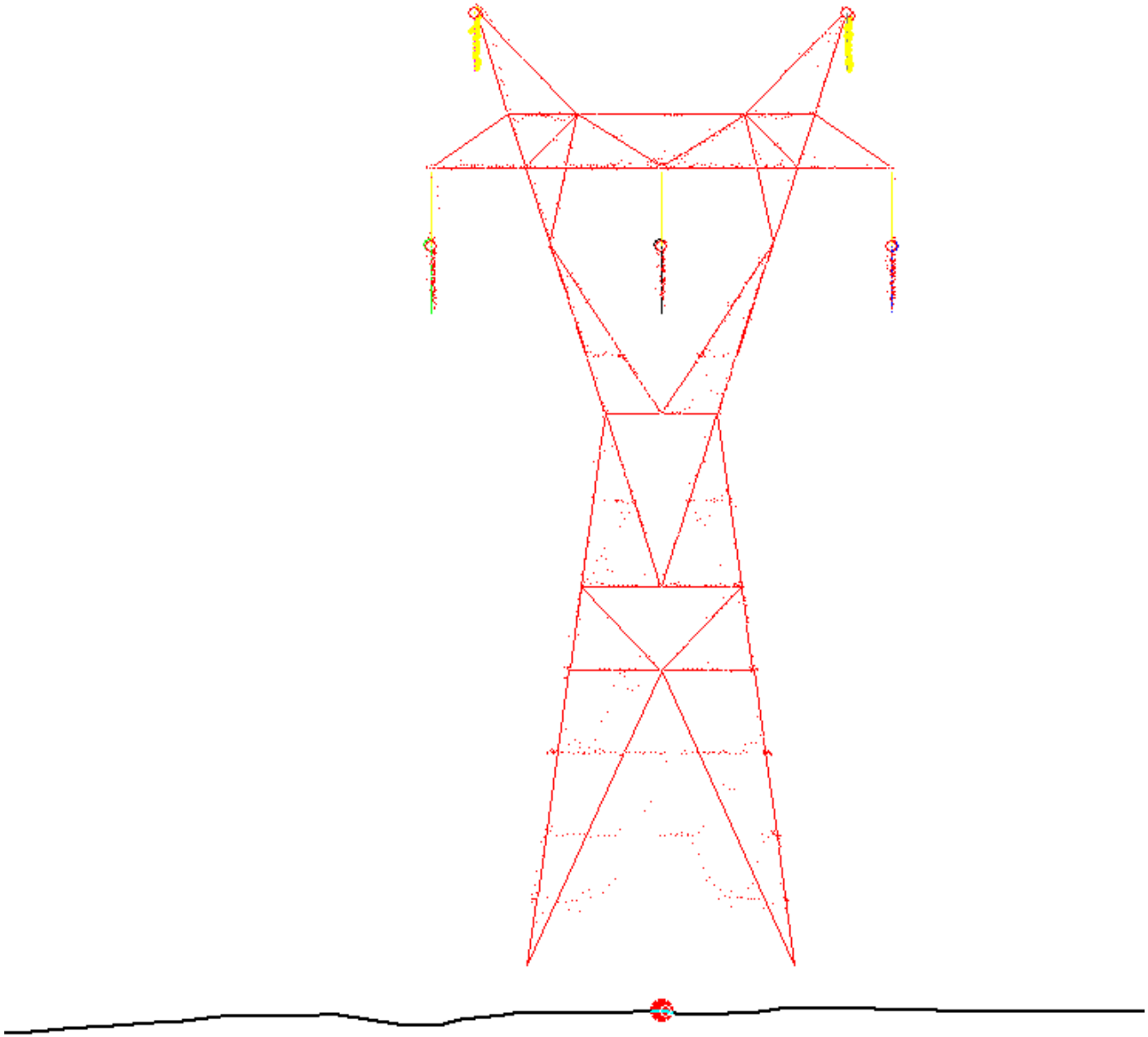
ucture): Struct #87 'g:\common\civil\pls\jld (unchecked)\tower\a24\2-cond bundle\a24 48body 28leg 2-cond bundle.tow' S=34337.75 Strengt

Present Location (hgt=4.0 offset 0.0)

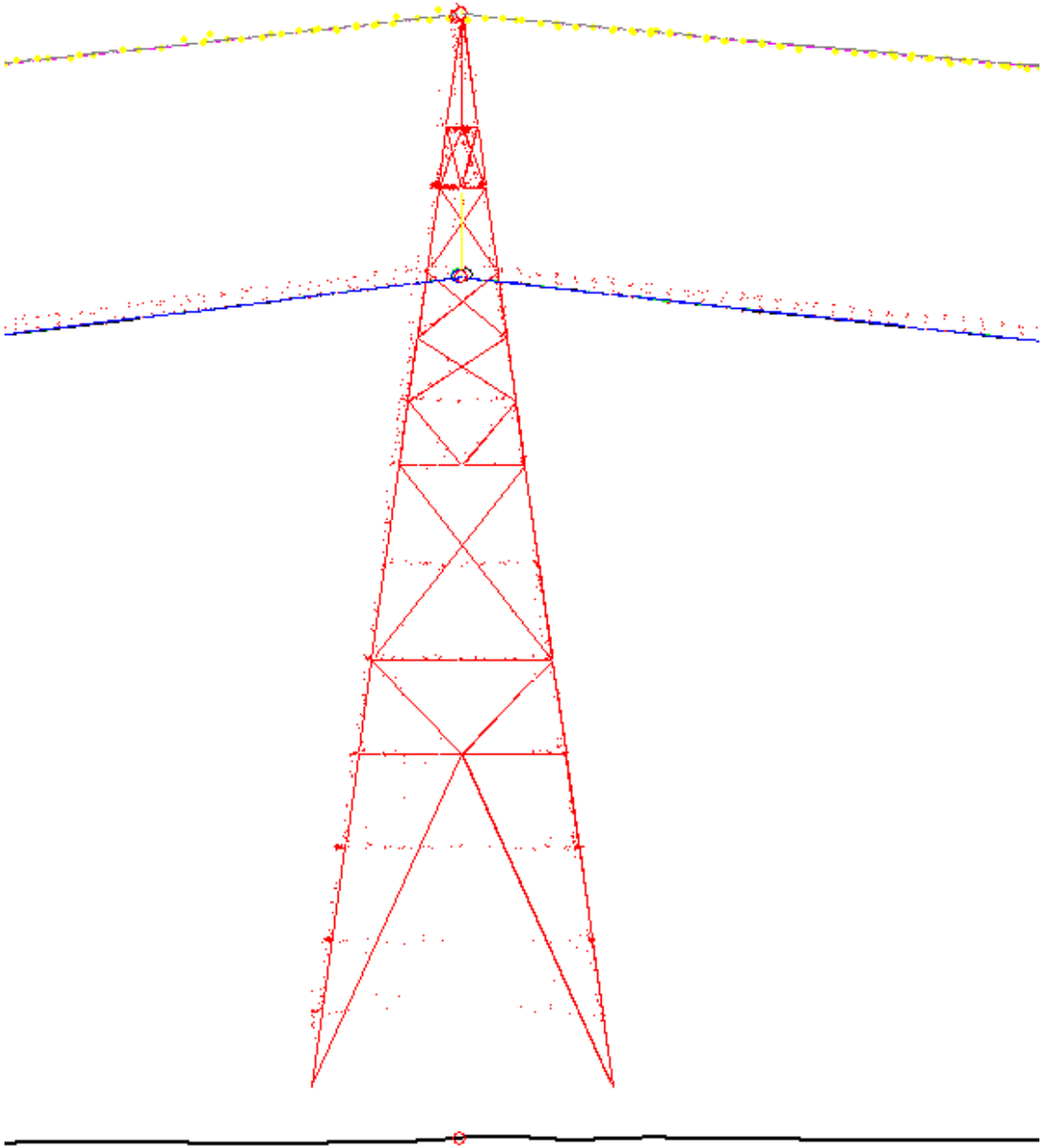


Adjust Height & Offset (hgt=4.4 offset 0.5)

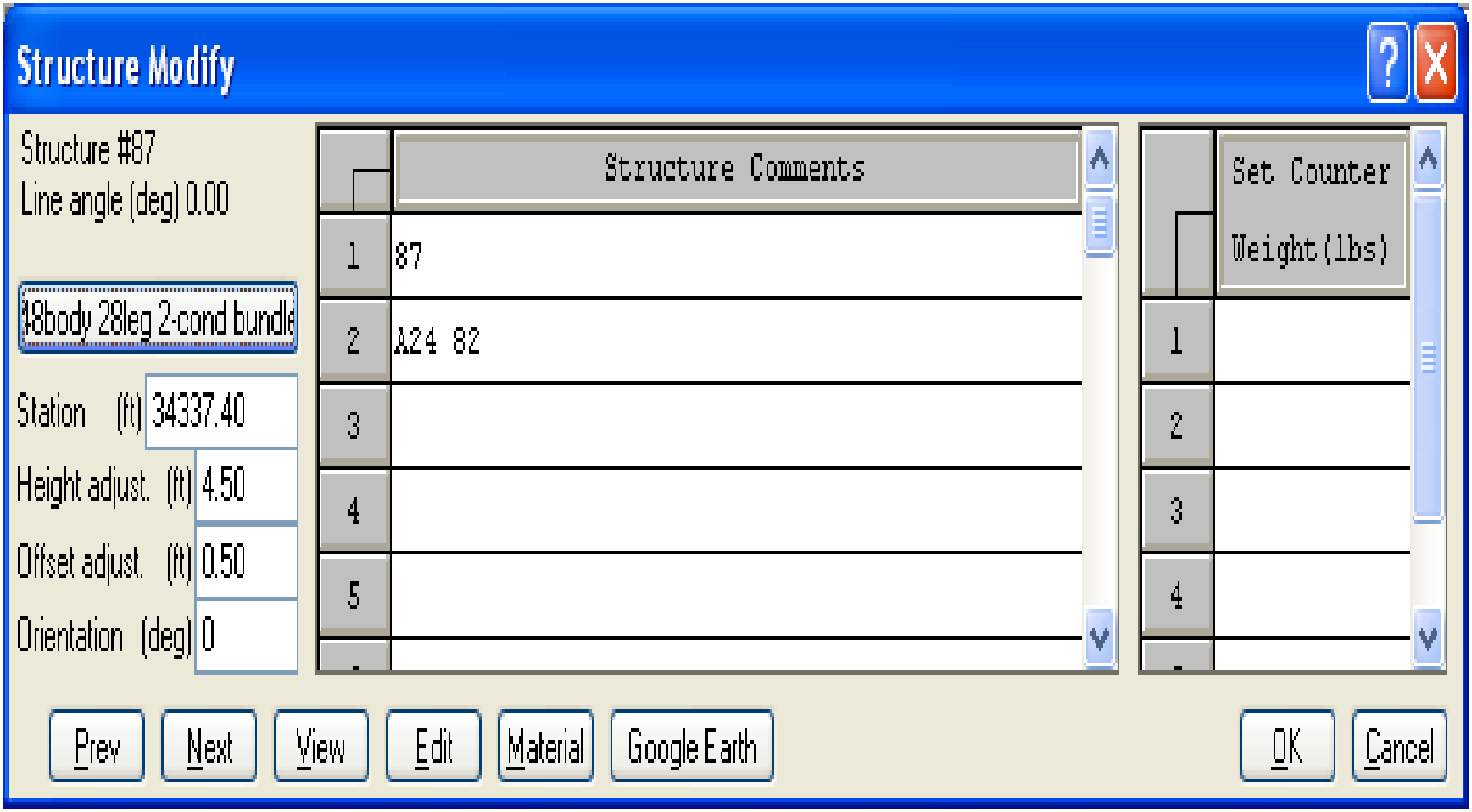


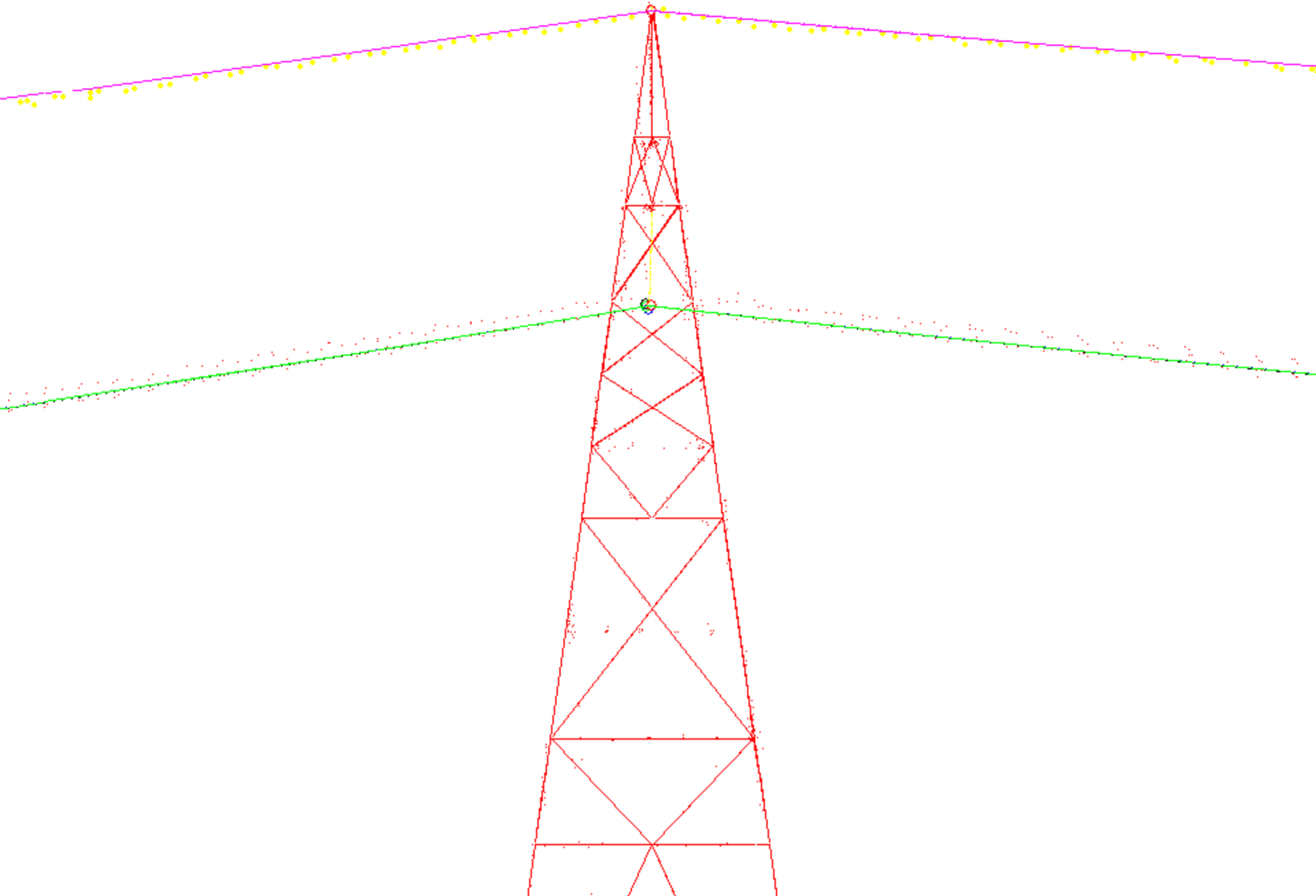


:ructure): Struct #87 'g:\common\civil\pls\jld (unchecked)\tower\a24\2-cond bundle\a24 48body 28leg 2-cond bundle.tow' S=34337.75 Strength=Pending

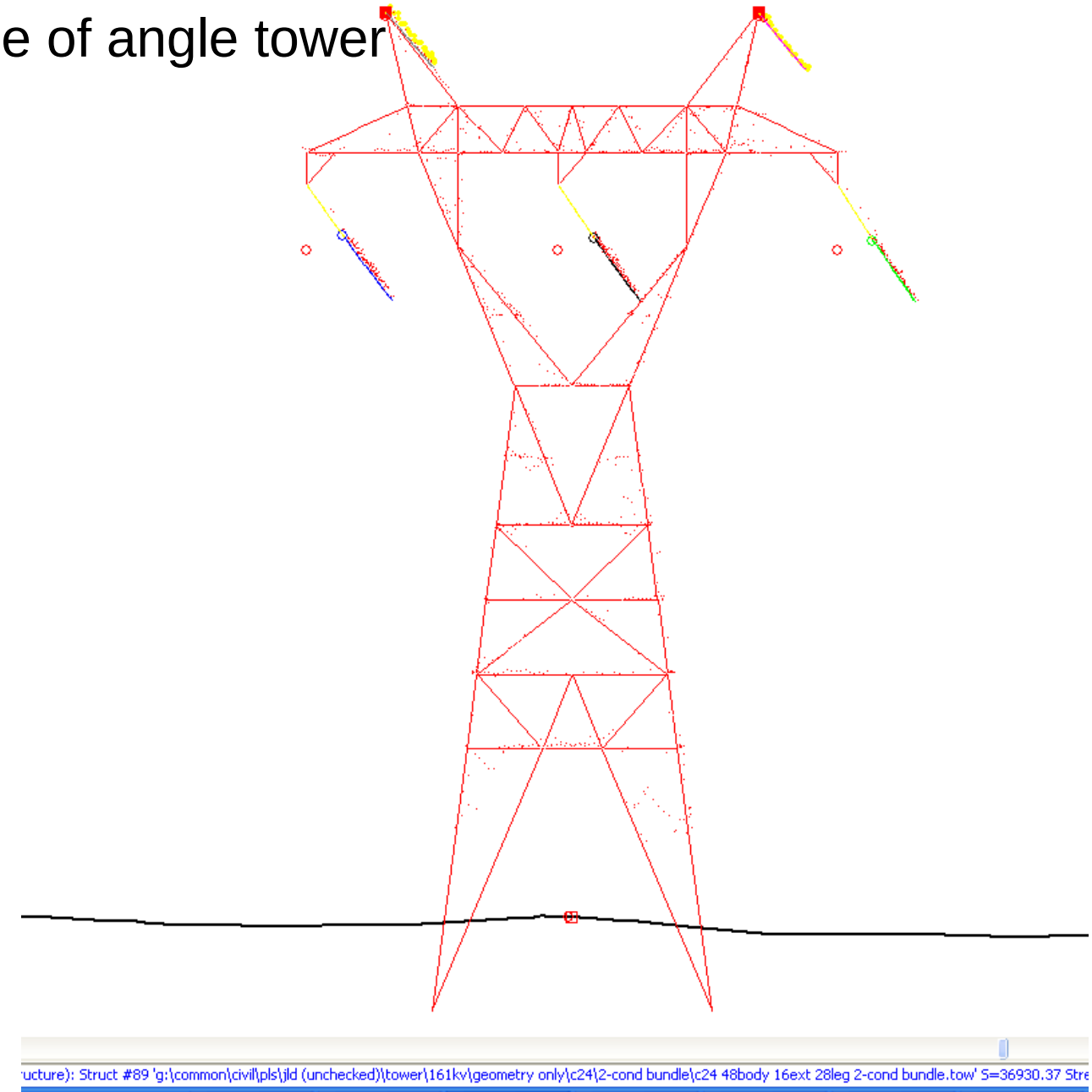


Adjust Station (37337.75 to 37337.4)

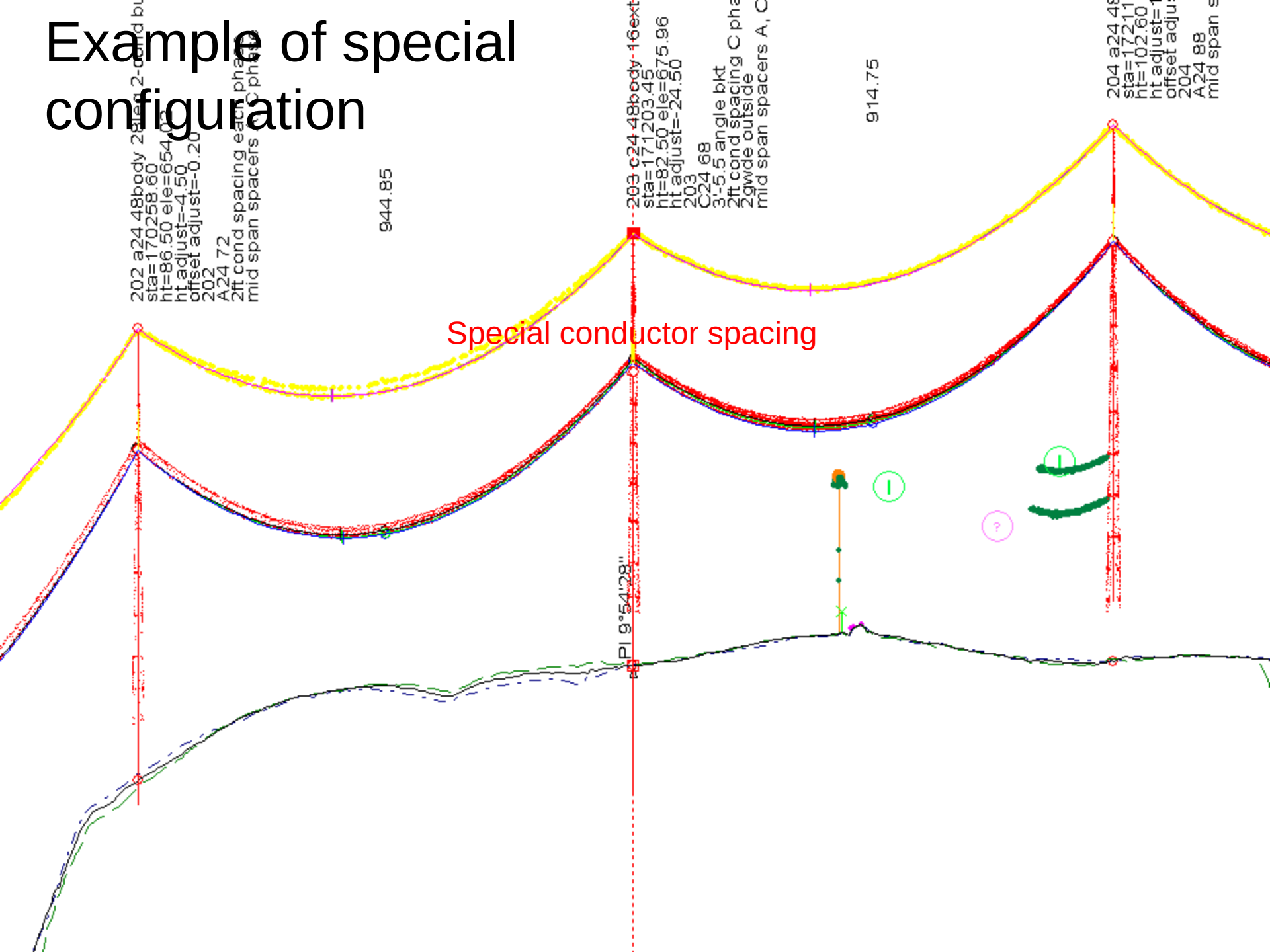




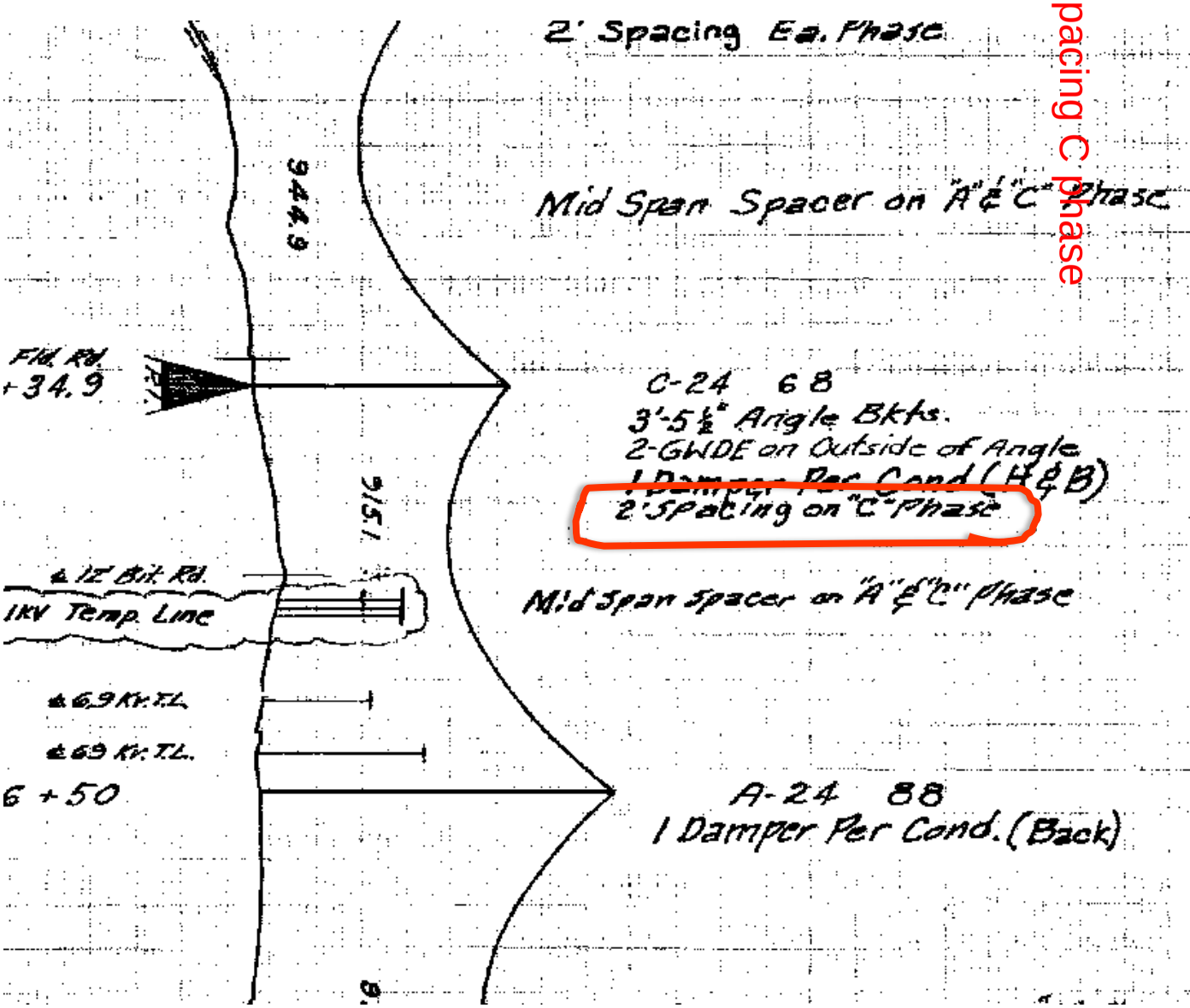
Example of angle tower

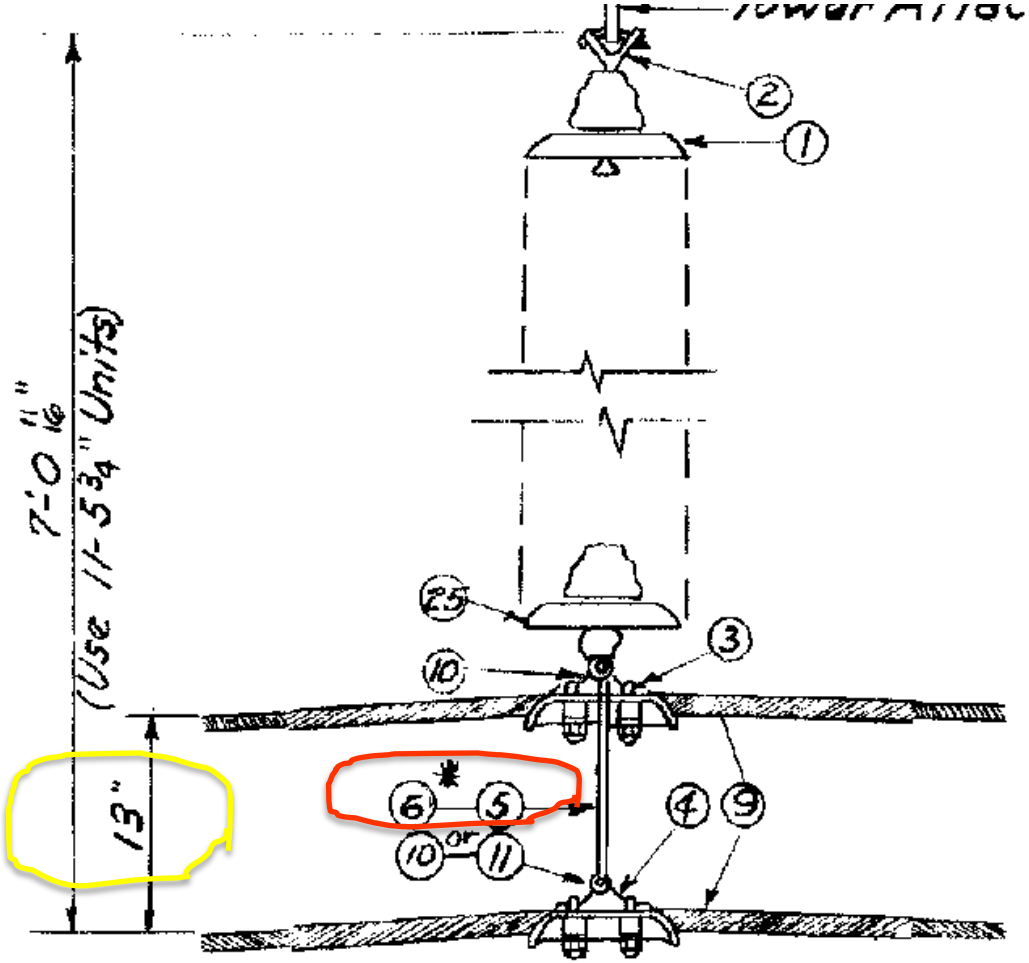


Example of special configuration



2 ft spacing C phase



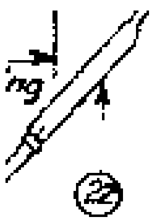


I.D. 599

SING. STRING SUSP. ASSEMBLY

Use on Tang. Bkts., 2 Angle Bkts. & 3-5½" Angle Bkts.

* Use Only When Specified on P&P



BILL OF MATERIAL

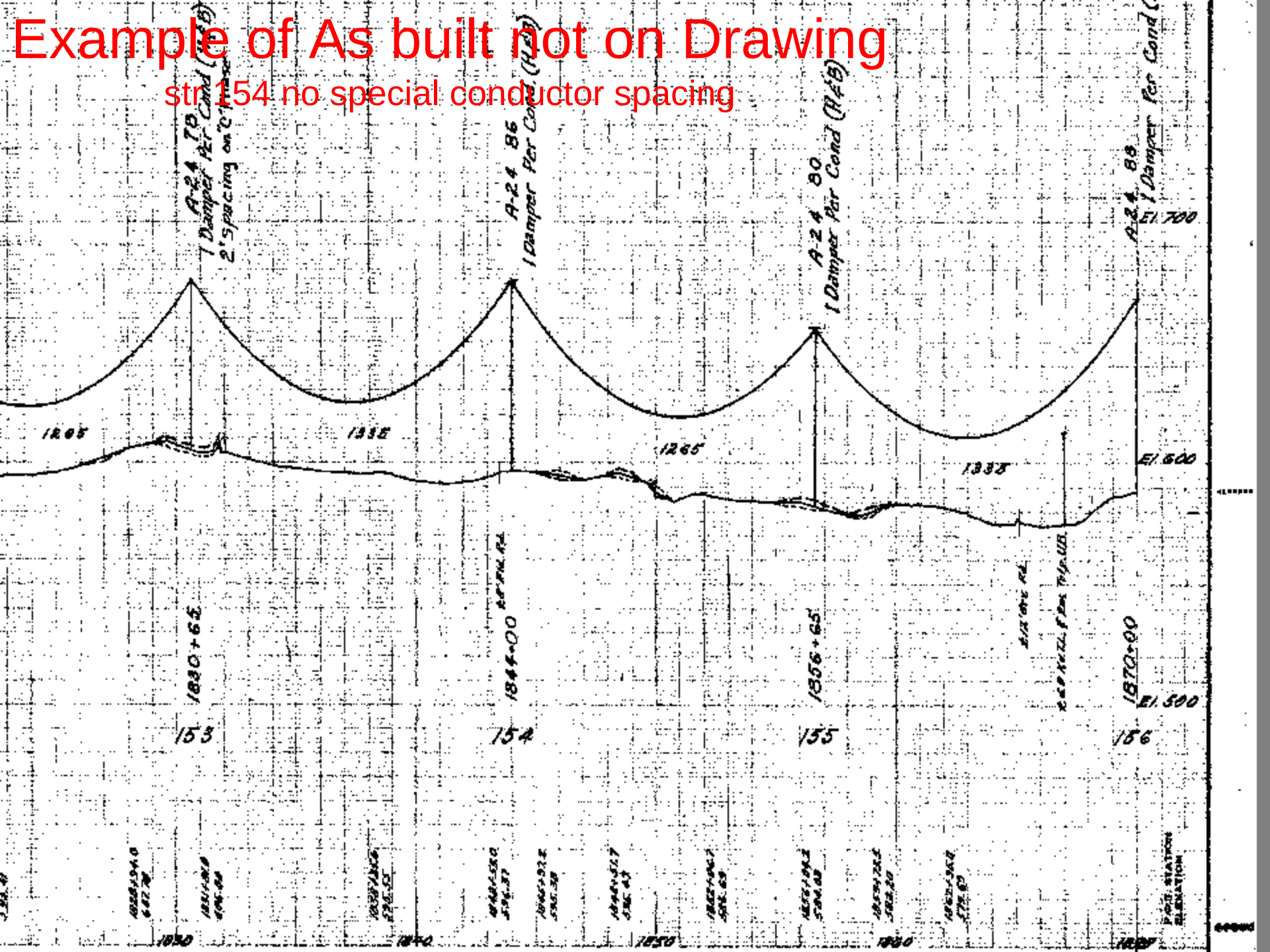
	ITEM NO.	DESCRIPTION		Susp. S.S.	[illegible]	Susp. [illegible]	D.E.
	1	5¾"x10" Disc. Insulator 25,000#	26.015	10	20	22	28
	2	"Y" Type Ball Clevis with (Bolt Nut & Cotter)	54.032-9	1		1	2
**	3	Susp. Clamp with Socket Eye (Special)	BT-9506U	1			
**	4	Susp. Clamp (Special)	BT-9548U	1	2		
	5	⅝" Eye to Eye Extension Rod (13")		2	2		
*	6	⅞" Eye to Eye Extension Rod (24" or 34")		2*	2*		

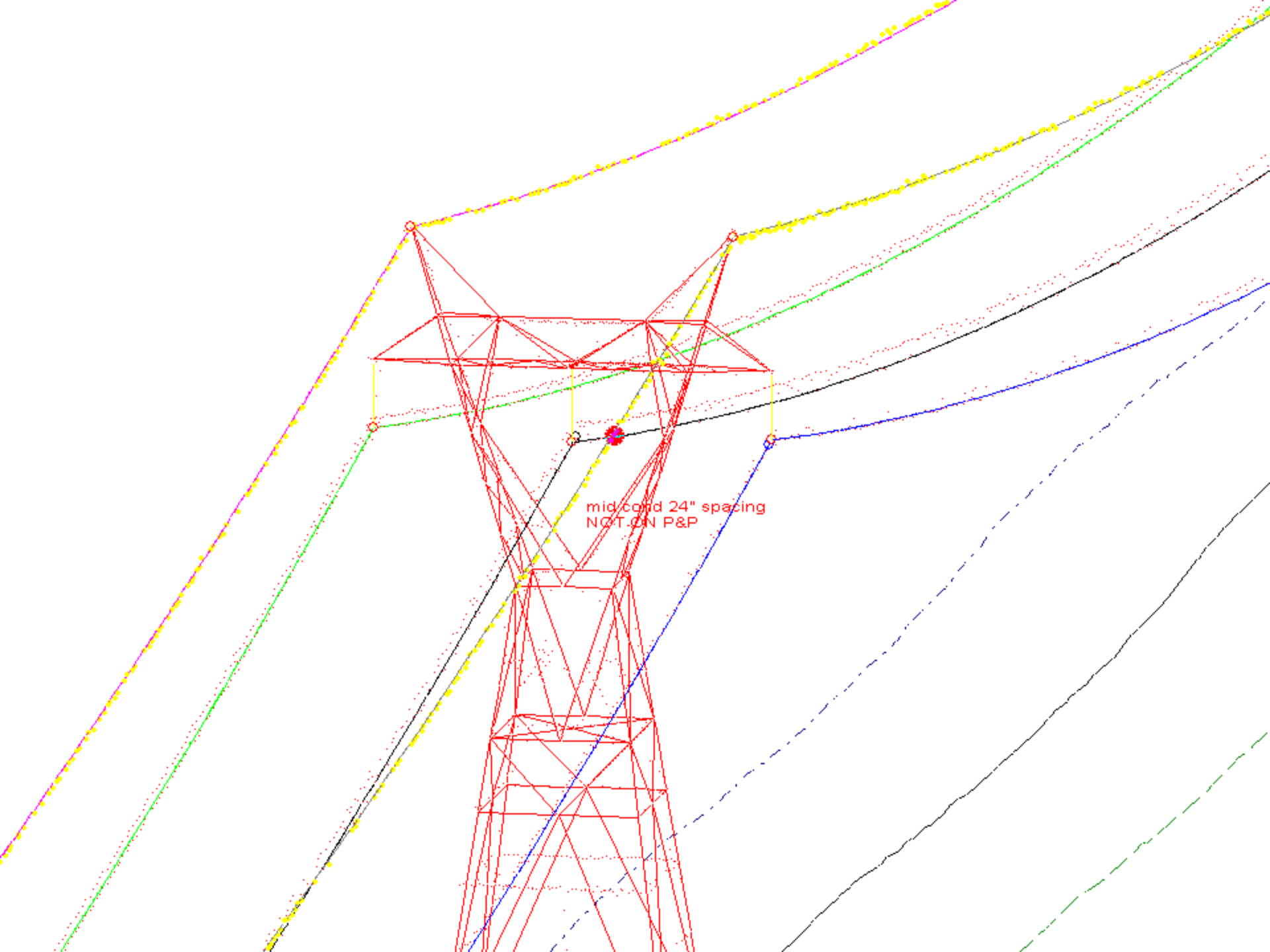

IMG00034.jpg
Type: JPG File
Size: 1.80 MB
Dimension: 2592 x 1944 pixels

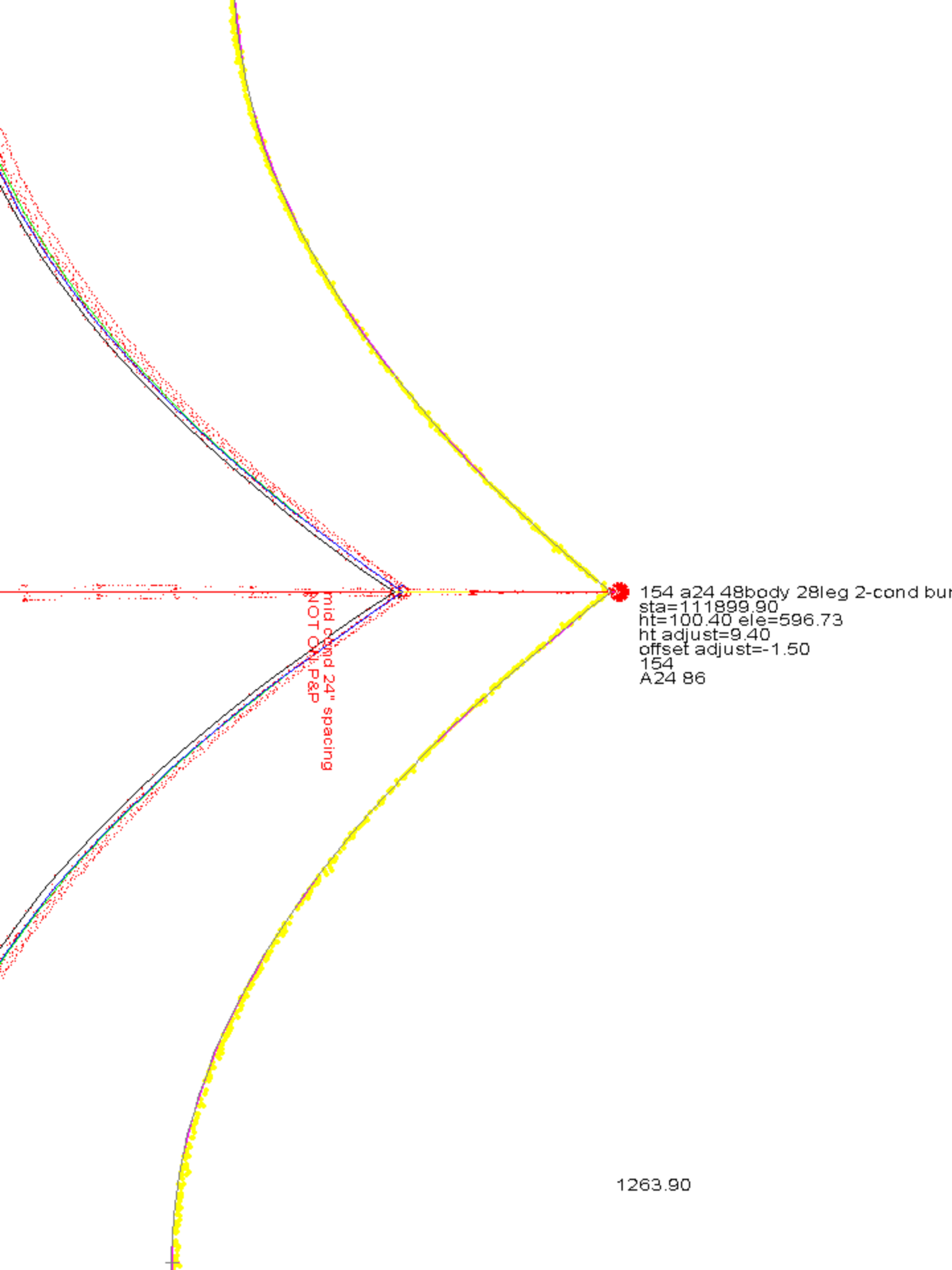
2ft conductor spacing C phase

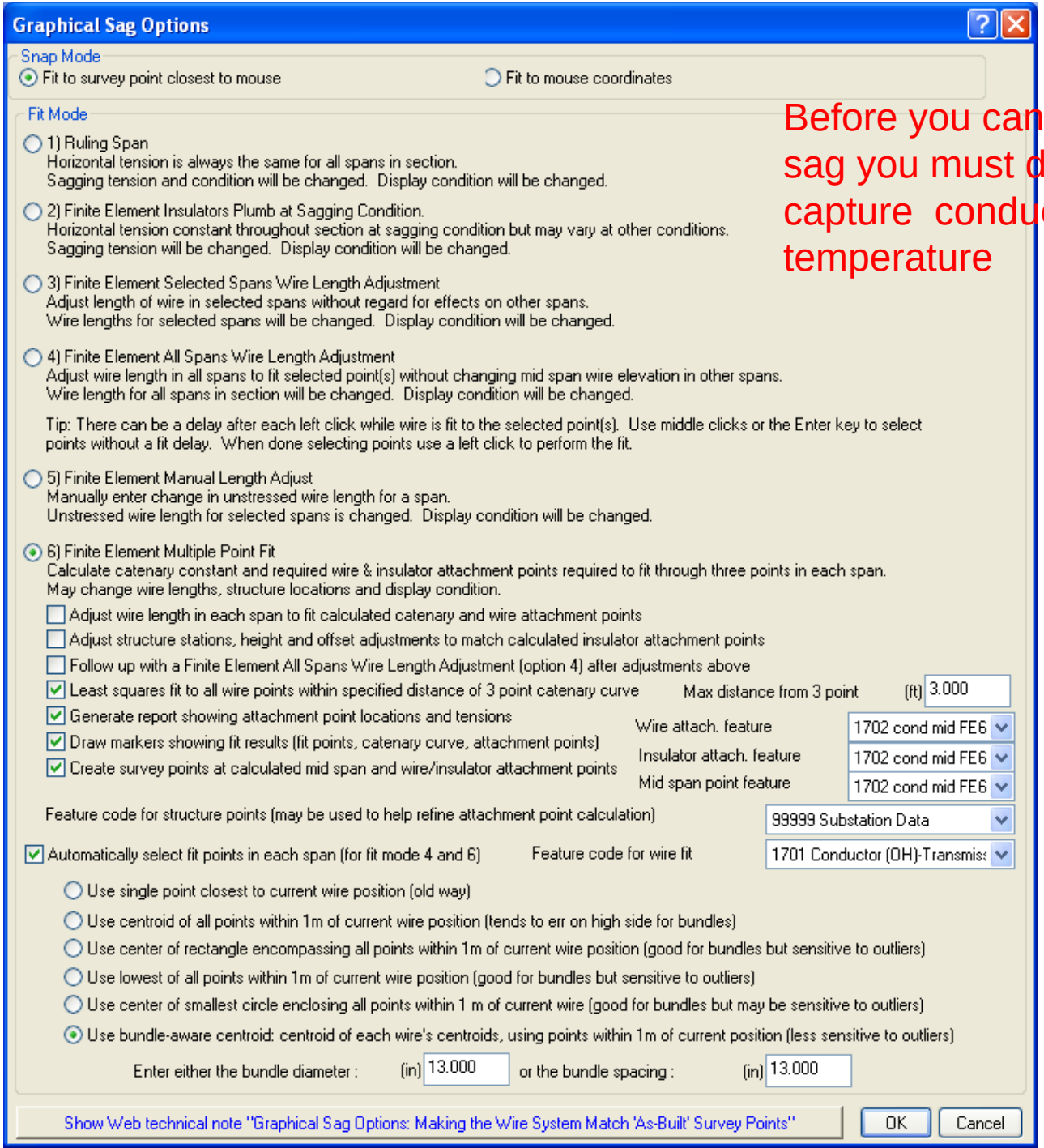
Example of As built not on Drawing

str 154 no special conductor spacing

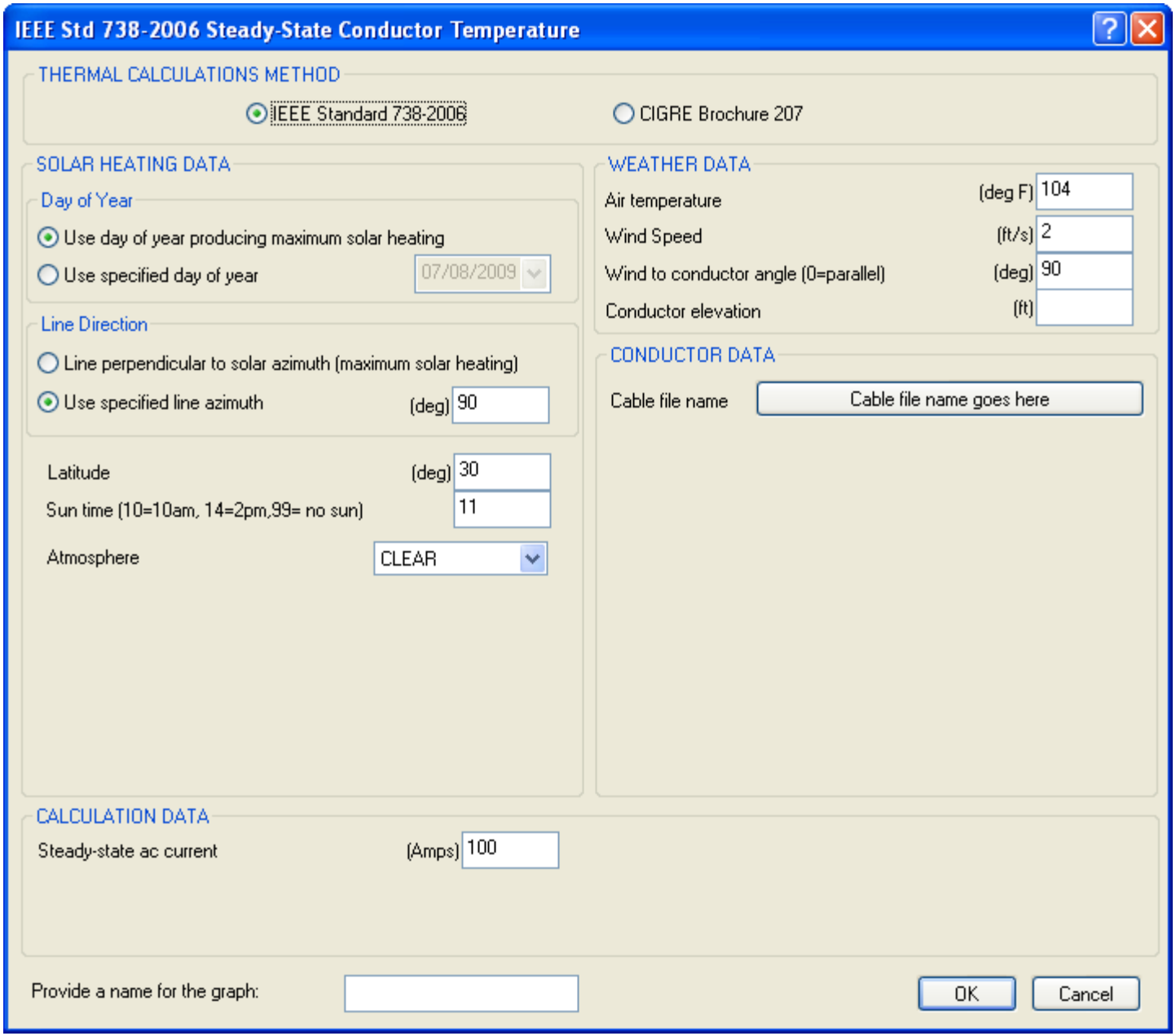



mid cond 24" spacing
NOT ON P&P


154 a24 48body 28leg 2-cond bur
sta=111899.90
ht=100.40 ele=596.73
ht adjust=9.40
offset adjust=-1.50
154
A24 86
mid cond 24" spacing
NOT ON P&P
1263.90

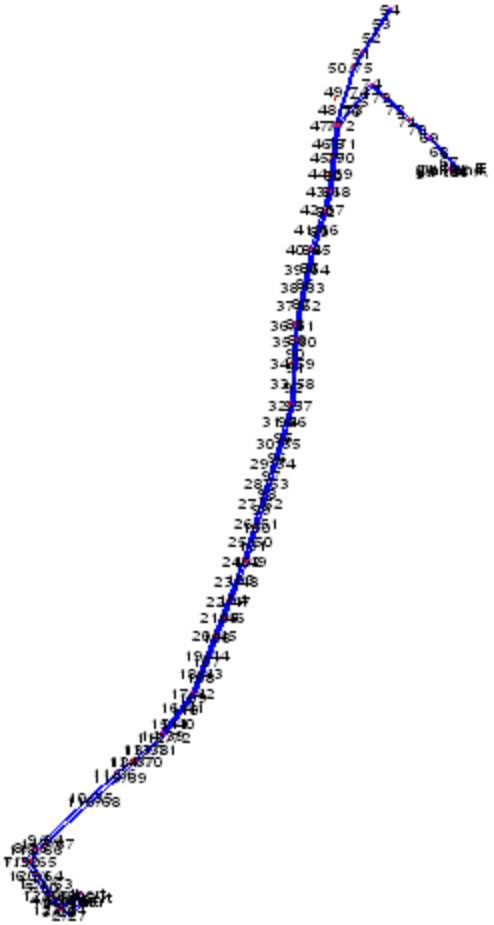


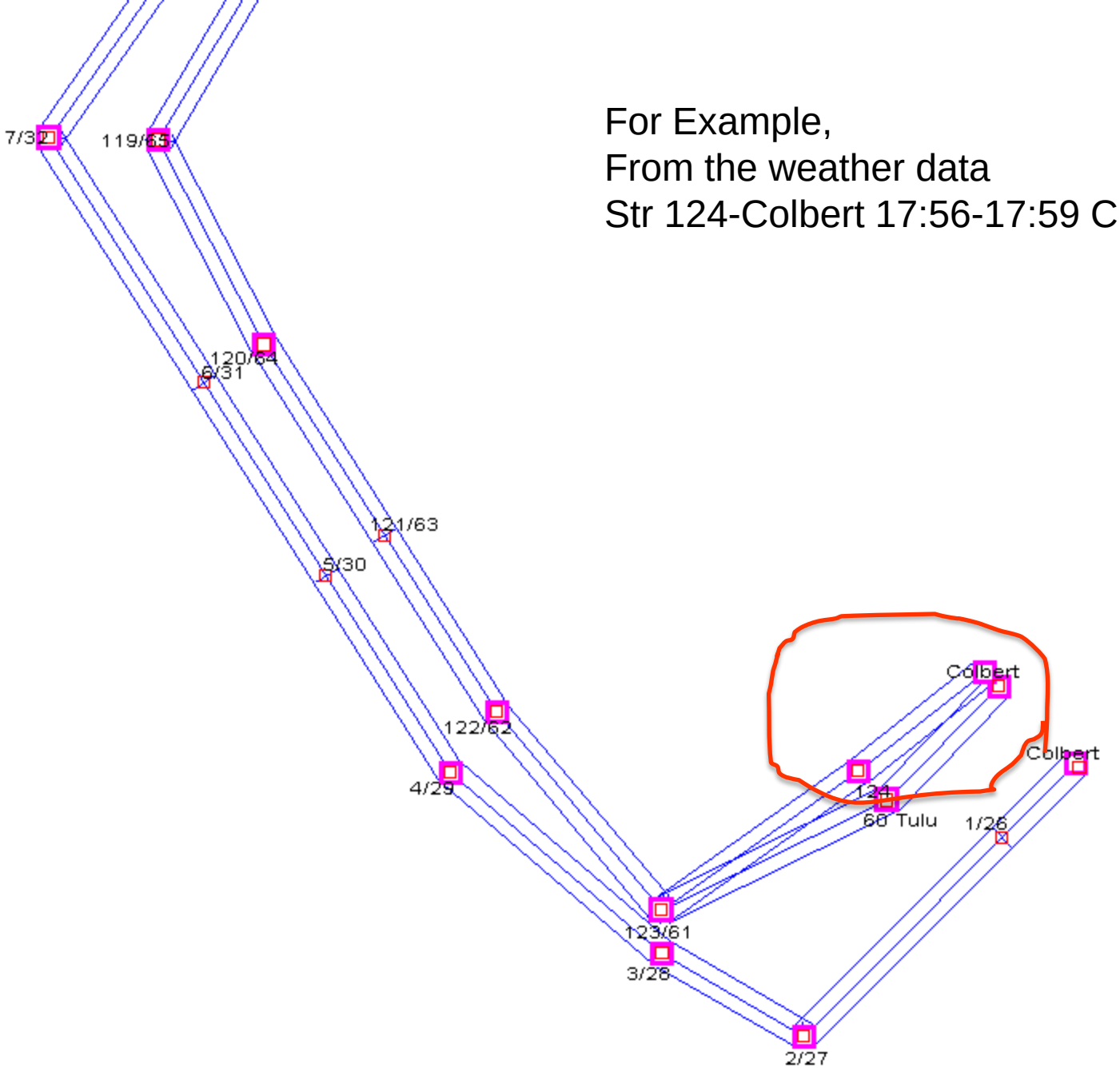
Before you can do graphical sag you must determine as capture conductor temperature


IEEE Std 738-2006 Steady-State Conductor Temperature
THERMAL CALCULATIONS METHOD
IEEE Standard 738-2006
CIGRE Brochure 207
SOLAR HEATING DATA
Day of Year
Use day of year producing maximum solar heating
Use specified day of year
07/08/2009
Line Direction
Line perpendicular to solar azimuth (maximum solar heating)
Use specified line azimuth
(deg) 90
Latitude (deg) 30
Sun time (10=10am, 14=2pm,99= no sun) 11
Atmosphere CLEAR
WEATHER DATA
Air temperature (deg F) 104
Wind Speed (ft/s) 2
Wind to conductor angle (0=parallel) (deg) 90
Conductor elevation (ft)
CONDUCTOR DATA
Cable file name
Cable file name goes here
CALCULATION DATA
Steady-state ac current (Amps) 100
Provide a name for the graph:
OK
Cancel

Tennessee Valley Authority, Project: "colbert-oakland cwa.xyz"
PLS-CADD Version 10.002, 1:39:15 PM Monday, July 06, 2009
Line Title: 'tower'

Flight Time
5/01/2005
17:09CDT-17:59CDT





For Example,
From the weather data
Str 124-Colbert 17:56-17:59 CDT

	GMT	CDT	deg C	m/s			
			Temp	Wind	Wind		
Date	Time		Out	Speed	Dir		
--------	--------		-------	------	------		
01/05/2005	22:51	5:51 PM	18.9	1.3	NNW	337.5	
01/05/2005	22:52	5:52 PM	18.9	0.9	W	270	
01/05/2005	22:53	5:53 PM	18.9	1.3	W	270	
01/05/2005	22:54	5:54 PM	19.1	0.9	W	270	
01/05/2005	22:55	5:55 PM	19.1	1.8	WSW	247.5	
01/05/2005	22:56	5:56 PM	18.9	2.2	WNW	292.5	
01/05/2005	22:57	5:57 PM	18.9	3.1	WNW	292.5	
01/05/2005	22:58	5:58 PM	18.9	1.3	NW	315	
01/05/2005	22:59	5:59 PM	18.9	1.3	NW	315	
01/05/2005	23:00	6:00 PM	18.9	1.8	NNE	382.5	Not use 22.5
01/05/2005	23:01	6:01 PM	18.9	1.3	W	270	
01/05/2005	23:02	6:02 PM	18.9	0.9	N	360	
01/05/2005	23:03	6:03 PM	18.9	2.2	NW	315	
01/05/2005	23:04	6:04 PM	18.9	2.2	WSW	247.5	
			ave	ave			
			18.9	1.61			
			deg F	ft/s		ave	Average about WNW
			66.1	5.27		298.93	
					max	382.5	NNE
						83.57	
Use average for flight time +- 5min							
					min	247.5	WSW
						-51.43	

Temp not variable but wind speed and direction are

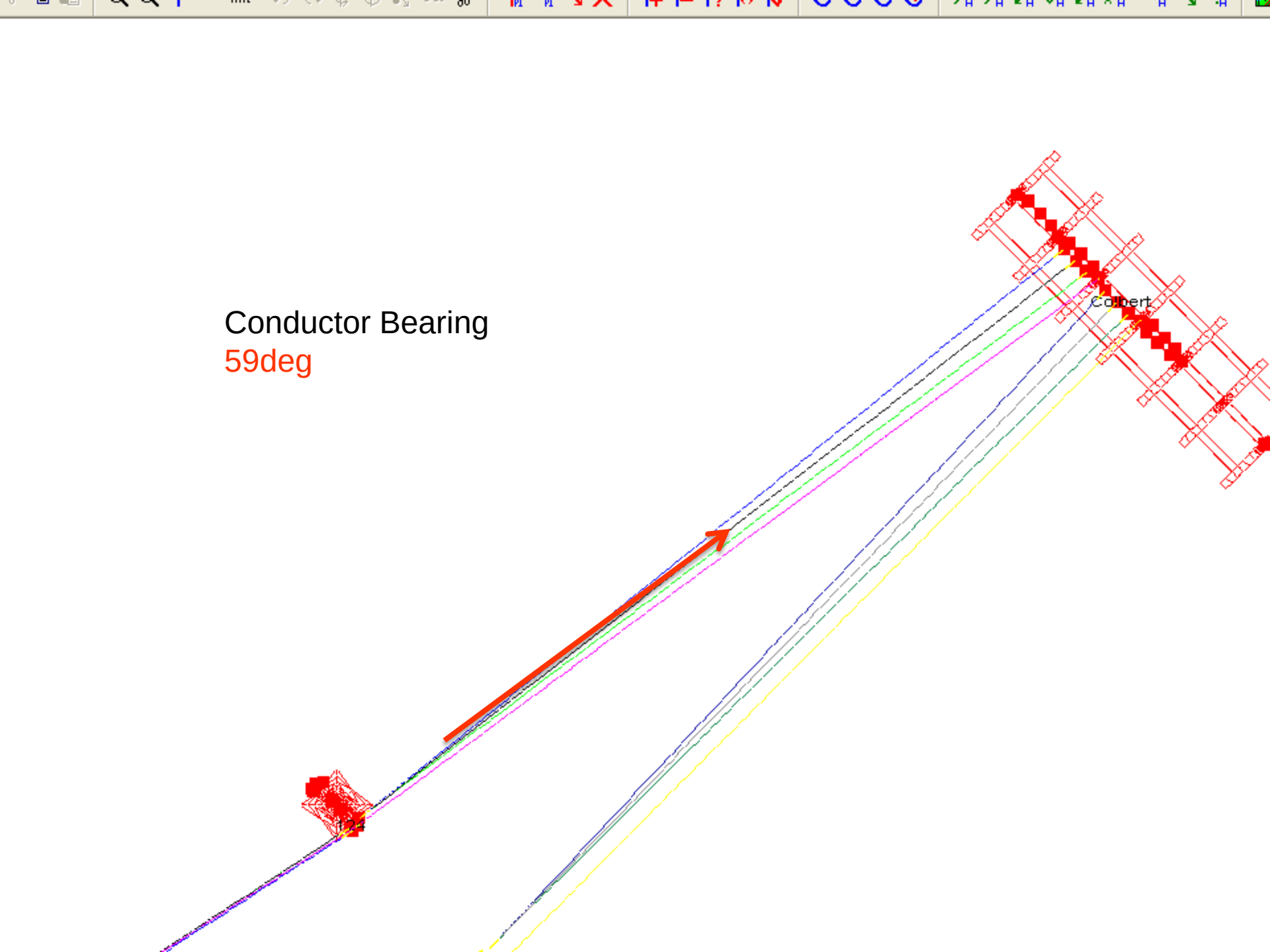
Easting & Northing from PI report gives Azimuth
Convert Flight Time to Sun Time
Using difference between Azimuth and wind direction gives wind angle, for example from str 124 to Colbert AZ=59deg Wind Dir = 298.9deg

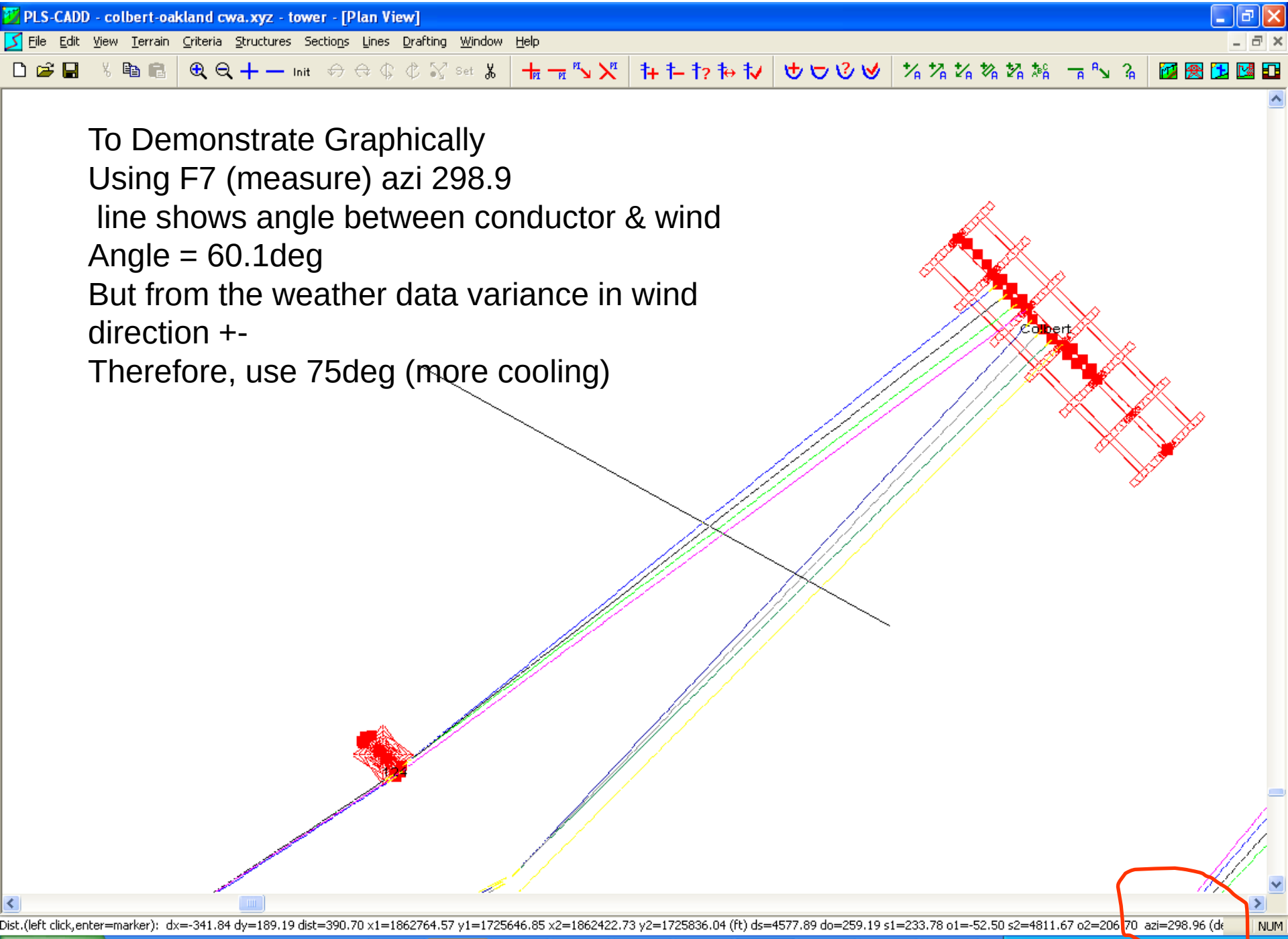
121	05/01/2005											
STR #	STR TYPE	EASTING	NORTHING	FLIGHT TIME	SUN TIME	AVERAGE SUN TIME	AZIMUTH (MATCH) (PLS)	TEMP (°F)	WIND (fps)	WIND DIRECTION (DEG)	WIND ANGLE	USE WIND ANGLE
Oakland	PULL-OFF	1884910.98	1768918.28	17:09CDT	16.3446	16.35	96	66.9	8.67	296.3	19.8	45
66	H20 80	1885455.9	1768856.85	17:10CDT	16.3613	16.42	314	66.7	8.88	303.8	10.7	30
74	H20 56	1880219.14	1773986.5	17:17CDT	16.4780	16.49	220	66.5	8.10	308.1	88.0	90
77	H20 72	1878180.74	1771560.55	17:19CDT	16.5113	16.59	191	66.5	8.26	313.9	57.1	75
89	H20 60	1875709.96	1758881.66	17:29CDT	16.6780	16.70	183	66.4	8.65	308.6	54.3	75
93	G20 68	1875515.79	1754977.75	17:32CDT	16.7280	16.83	199	66.3	8.19	301.3	77.5	90
109	G20 84	1869634.3	1737708.284	17:44CDT	16.9280	16.95	216	66.1	6.56	303.8	87.7	90
112/72	G20 76	1867851.79	1735256.66	17:47CDT	16.9780	16.99	228	66.2	5.93	296.0	68.1	90
115/69	M21 80	1865148.42	1732812.296	17:49CDT	17.0113	17.03	228	66.2	5.70	289.0	61.2	90
118/66	M21 80	1860347.73	1728470.06	17:51CDT	17.0446	17.05	211	66.2	6.53	283.1	72.4	90
119/65	H20 92	1859934.45	1727774.05	17:52CDT	17.0613	17.09	149	66.1	6.21	295.7	33.7	60
122/62	H20 92	1861123.3	1725760.41	17:55CDT	17.1113	17.11	140	66.1	5.40	296.6	23.6	45
123/61	H20 92	1861703.3	1725065.52	17:55CDT	17.1113	17.12	55	66.1	5.30	294.4	59.4	75
124	H20 60	1862397.32	1725552.74	17:56CDT	17.1280	17.15	59	66.1	5.27	298.9	60.1	75
Colbert	Pulloff	1862890.59	1725850.63	17:59CDT	17.1780							

IEEE uses cond elev, Latitude, and Amps
Longitude is used for Sun Time

STR #	STR TYPE	COND ELEVATION	LATITUDE (DEG)	LONGITUDE (DEG)	COND AMPS	COND
Oakland	PULL-OFF	668	34.862053	87.778484	211.6	636 26/7
66	H20 80	627			211.6	636 26/7
74	H20 56	631			211.6	795 26/7
77	H20 72	632			219.8	795 26/7
89	H20 60	577			211.6	795 26/7
93	G20 68	578			221.0	795 26/7
109	G20 84	557			122.5	795 26/7
112/72	G20 76	579			122.5	795 26/7
115/69	M21 80	656			122.5	795 30/19
118/66	M21 80	549			122.5	795 26/7
119/65	H20 92	525			122.5	795 26/7
122/62	H20 92	546			122.5	795 26/7
123/61	H20 92	525			122.5	795 26/7
124	H20 60	506			118.5	795 26/7
Colbert	Pulloff		34.74356	87.85167		
			AVG LAT	AVG LONG		
			34.8028	87.8151		

Conductor Bearing
59deg




PLS-CADD - colbert-oakland cwa.xyz - tower - [Plan View]
File Edit View Terrain Criteria Structures Sections Lines Drafting Window Help
To Demonstrate Graphically
Using F7 (measure) azi 298.9
line shows angle between conductor & wind
Angle = 60.1deg
But from the weather data variance in wind direction +-
Therefore, use 75deg (more cooling)
Colbert
Dist.(left click,enter=marker): dx=-341.84 dy=189.19 dist=390.70 x1=1862764.57 y1=1725646.85 x2=1862422.73 y2=1725836.04 (ft) ds=4577.89 do=259.19 s1=233.78 o1=-52.50 s2=4811.67 o2=206.70 azi=298.96
NUM

Weather instruments:
Multiple Davis Instruments Weather Wizard III portable weather stations with recording equipment in vinyl container and with weather probes mounted on telescopic masts.

Temperature accuracy: +/- 1 degree F

Temperature range: -50 degrees F to 140 degrees F

Wind speed accuracy: +/- 5%

Wind speed range: 2 mph to 150 mph (2.9 ft/sec to 220 ft/sec)
Wind direction accuracy: +/- 7 degrees

$$LST = CT + \left(\frac{1}{15}\right)(L_{std} - L_{loc}) + E - DT \qquad \text{[hr]} \qquad \text{Equation 2}$$

Equation for Sun Time

Where:

LST = Local Solar Time [hr]

CT = Clock Time [hr]

L_{std} = Standard Meridian for the local time zone [degrees west]

L_{loc} = Longitude of actual location [degrees west]

E = Equation of Time [hr]

DT = Daylight Savings Time correction (DT = 0 if not on Daylight Savings Time, otherwise DT is equal to the number of hours that the time is advanced for Daylight Savings Time, usually 1hr)

In using Equation 2, all of the times must first be converted to decimal format from zero to 24, (e.g., a clock time of 3:45 p.m. is expressed as CT = 15.75 hr).

Values of the Equation of Time, E, are calculated by:

$$E = 0.165 \sin 2B - 0.126 \cos B - 0.025 \sin B \qquad \text{[hr]} \qquad \text{Equation 3a}$$

where:

$$B = \frac{360(n - 81)}{364} \qquad \text{[degrees]}$$

and n is the day of the year.

```
=CT+(1/15)*(IF(OR(C8="CST",C8="CDT"),90,IF(OR(C8="EST",C8="EDT"),75,"Check"))-A8)+(0.165*SIN(2*RADIANS(360*(n-81)/364))-0.126*COS(RADIANS(360*(n-81)/364))-0.025*SIN(RADIANS(360*(n-81)/364)))-IF(OR(C8="CST",C8="EST"),0,IF(OR(C8="CDT",C8="EDT"),1,"Check"))
```

Equation in EXCEL

Also, use website

- http://aa.usno.navy.mil

U.S. Naval Observatory
Astronomical Applications Department

Sun and Moon Data for One Day

The following information is provided for Sheffield, Colbert County, Alabama (longitude W87.7, latitude N34.8):

Sunday
1 May 2005 Central Daylight Time

SUN	
Begin civil twilight	5:33 a.m.
Sunrise	6:00 a.m.
Sun transit	12:48 p.m.
Sunset	7:36 p.m.
End civil twilight	8:03 p.m.
MOON	
Moonset	11:26 a.m. on preceding day
Moonrise	2:22 a.m.
Moon transit	7:27 a.m.
Moonset	12:39 p.m.
Moonrise	2:59 a.m. on following day

-48/60 = -0.80 17:59 =17.98 -0.80 = 17.18 (matches spreadsheet)

IEEE Std. 738-2006 method of calculation

Air temperature is 66.10 (deg F)
Wind speed is 5.27 (ft/s)
Angle between wind and conductor is 75 (deg)
Conductor elevation above sea level is 506 (ft)
Conductor bearing is 59 (deg) (user specified bearing, may not be value producing maximum solar heating)
Sun time is 17.15 hours (solar altitude is 19 deg. and solar azimuth is -85 deg.)
Conductor latitude is 34.8 (deg)
Atmosphere is CLEAR
Day of year is 121 (corresponds to May 1 in year 2009) (user specified day, may not be day producing maximum solar heating)

Conductor description: 795 kcmil 26/7 Strands DRAKE ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.108 (in)
Conductor resistance is 0.1166 (Ohm/mile) at 77.0 (deg F)
and 0.1390 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.7 and solar absorptivity is 0.9

Solar heat input is 3.396 (Watt/ft) (corresponds to Global Solar Radiation of **40.865** (Watt/ft^2) - which was calculated)
Radiation cooling is 0.514 (Watt/ft)
Convective cooling is 3.190 (Watt/ft)

Given a constant ac current of 118.5 amperes,
The conductor surface temperature is **74.6 (deg F)**

Surface? Change in PLS 10.002

Range Ambient 66.1 to Only Uncertain Variable No Wind 90.7 previous 74.6

IEEE Std. 738-2006 method of calculation

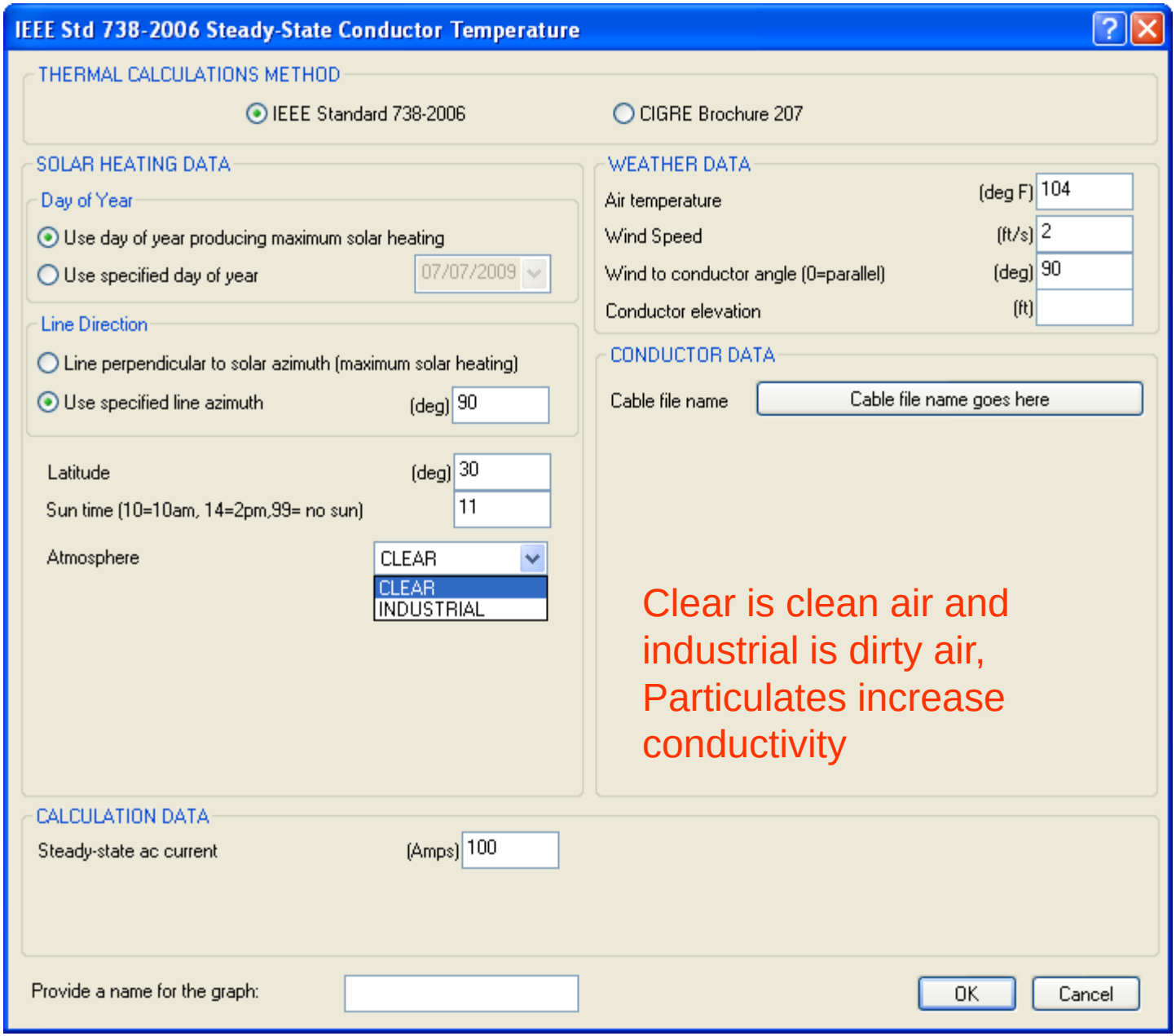
Lower Bound Ambient too Conservative
Upper Bound No wind not realistic 2fps min

Air temperature is 66.10 (deg F)
Wind speed is 0.00 (ft/s)
Angle between wind and conductor is 75 (deg)
Conductor elevation above sea level is 506 (ft)
Conductor bearing is 59 (deg) (user specified bearing, may not be value producing maximum solar heating)
Sun time is 17.15 hours (solar altitude is 19 deg. and solar azimuth is -85 deg.)
Conductor latitude is 34.8 (deg)
Atmosphere is CLEAR
Day of year is 121 (corresponds to May 1 in year 2009) (user specified day, may not be day producing maximum solar heating)

Conductor description: 795 kcmil 26/7 Strands DRAKE ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.108 (in)
Conductor resistance is 0.1166 (Ohm/mile) at 77.0 (deg F)
and 0.1390 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.7 and solar absorptivity is 0.9

Solar heat input is 3.396 (Watt/ft) (corresponds to Global Solar Radiation of 40.865 (Watt/ft^2) - which was calculated)
Radiation cooling is 1.559 (Watt/ft)
Convective cooling is 2.157 (Watt/ft)

Given a constant ac current of 118.5 amperes,
The conductor surface temperature is 90.7 (deg F)


IEEE Std 738-2006 Steady-State Conductor Temperature
THERMAL CALCULATIONS METHOD
IEEE Standard 738-2006
CIGRE Brochure 207
SOLAR HEATING DATA
Day of Year
Use day of year producing maximum solar heating
Use specified day of year
07/07/2009
Line Direction
Line perpendicular to solar azimuth (maximum solar heating)
Use specified line azimuth
(deg) 90
Latitude (deg) 30
Sun time (10=10am, 14=2pm,99= no sun) 11
Atmosphere CLEAR
CLEAR
INDUSTRIAL
WEATHER DATA
Air temperature (deg F) 104
Wind Speed (ft/s) 2
Wind to conductor angle (0=parallel) (deg) 90
Conductor elevation (ft)
CONDUCTOR DATA
Cable file name
Cable file name goes here
Clear is clean air and industrial is dirty air, Particulates increase conductivity
CALCULATION DATA
Steady-state ac current (Amps) 100
Provide a name for the graph:
OK
Cancel

Sky Not Always Clear

History : Weather Underground

Time: (CDT)	Temp.:	DewPoint:	Humidity:	Sea Level: Pressure	Visibility:	WindDir:Wind:Gust Speed	Speed:	Precip:	Events:	Conditions:
8:53 AM	53.1 °F	41.0 °F	64%	30.20 in	10.0 miles	Calm	Calm	-	N/A	Clear
9:53 AM	59.0 °F	37.0 °F	44%	30.21 in	10.0 miles	Calm	Calm	-	N/A	Clear
10:53 AM	61.0 °F	33.1 °F	35%	30.21 in	10.0 miles	WNW	9.2 mph	-	N/A	Clear
11:53 AM	63.0 °F	33.1 °F	33%	30.21 in	10.0 miles	WNW	10.4 mph	16.1 mph	N/A	Clear
12:53 PM	64.0 °F	34.0 °F	33%	30.18 in	10.0 miles	Variable	6.9 mph	-	N/A	Clear
1:53 PM	64.0 °F	35.1 °F	34%	30.17 in	10.0 miles	Variable	4.6 mph	-	N/A	Partly Cloudy
2:53 PM	64.9 °F	37.0 °F	36%	30.16 in	10.0 miles	Variable	4.6 mph	-	N/A	Clear
3:53 PM	66.0 °F	39.0 °F	37%	30.14 in	10.0 miles	WNW	6.9 mph	-	N/A	ScatteredClouds
4:53 PM	66.0 °F	37.0 °F	34%	30.13 in	10.0 miles	WNW	13.8 mph	-	N/A	Partly Cloudy
5:53 PM	6.0 °F	36.0 °F	33%	30.12 in	10.0 miles	NW	10.4 mph	-	N/A	Clear
6:53 PM	63.0 °F	35.1 °F	35%	30.12 in	10.0 miles	NW	6.9 mph	-	N/A	Clear
7:53 PM	55.9 °F	39.9 °F	55%	30.12 in	10.0 miles	Calm	Calm	-	N/A	Clear
8:53 PM	51.1 °F	43.0 °F	74%	30.12 in	10.0 miles	South	3.5 mph	-	N/A	Partly Cloudy
9:53 PM	48.0 °F	43.0 °F	83%	30.13 in	10.0 miles	SSW	3.5 mph	-	N/A	Partly Cloudy
10:53 PM	46.0 °F	41.0 °F	83%	30.14 in	10.0 miles	Calm	Calm	-	N/A	Clear
11:53 PM	45.0 °F	42.1 °F	90%	30.14 in	10.0 miles	Calm	Calm	-	N/A	Clear

	GMT	CDT	deg C	m/s			Watts/m^2	Watts/ft^2		
			Temp	Wind	Wind		Solar		Drake 795 26/7	
Date	Time		Out	Speed	Dir		Rad.		dia	
01/05/2005	22:51	5:51 PM	18.9	1.3	NNW	337.5	275	25.55	1.108	2.359
01/05/2005	22:52	5:52 PM	18.9	0.9	W	270	271	25.18	1.108	2.325
01/05/2005	22:53	5:53 PM	18.9	1.3	W	270	262	24.34	1.108	2.247
01/05/2005	22:54	5:54 PM	19.1	0.9	W	270	243	22.58	1.108	2.084
01/05/2005	22:55	5:55 PM	19.1	1.8	WSW	247.5	257	23.88	1.108	2.205
01/05/2005	22:56	5:56 PM	18.9	2.2	WNW	292.5	251	23.32	1.108	2.153
01/05/2005	22:57	5:57 PM	18.9	3.1	WNW	292.5	250	23.23	1.108	2.145
01/05/2005	22:58	5:58 PM	18.9	1.3	NW	315	248	23.04	1.108	2.127
01/05/2005	22:59	5:59 PM	18.9	1.3	NW	315	245	22.76	1.108	2.102
01/05/2005	23:00	6:00 PM	18.9	1.8	NNE	382.5	243	22.58	1.108	2.084
01/05/2005	23:01	6:01 PM	18.9	1.3	W	270	239	22.20	1.108	2.050
01/05/2005	23:02	6:02 PM	18.9	0.9	N	360	236	21.93	1.108	2.024
01/05/2005	23:03	6:03 PM	18.9	2.2	NW	315	232	21.55	1.108	1.990
01/05/2005	23:04	6:04 PM	18.9	2.2	WSW	247.5	225	20.90	1.108	1.930
			ave	ave				ave		
			18.9	1.61				**23.073**		2.130
			deg F	ft/s		ave				
			66.1	5.27		298.93				
					max	382.5	NNE			
						83.57				
Use average for flight time +- 5min										
					min	247.5	WSW			
						-51.43				

NOT ALL WEATHER DATA REPORTS GAVE SOLAR RADIATION

IEEE Std. 738-2006 method of calculation

Iterate on Sun time to get Watts/ft^2 to match

Air temperature is 66.10 (deg F)
Wind speed is 5.27 (ft/s)
Angle between wind and conductor is 75 (deg)
Conductor elevation above sea level is 506 (ft)
Conductor bearing is 59 (deg) (user specified bearing, may not be value producing maximum solar heating)
Sun time is **18.063** hours (solar altitude is 8 deg. and solar azimuth is -77 deg.)
Conductor latitude is 34.8 (deg)
Atmosphere is CLEAR
Day of year is 121 (corresponds to May 1 in year 2009) (user specified day, may not be day producing maximum solar heating)

Conductor description: 795 kcmil 26/7 Strands DRAKE ACSR - Adapted from 1970's Publicly Available Data
Conductor diameter is 1.108 (in)
Conductor resistance is 0.1166 (Ohm/mile) at 77.0 (deg F)
and 0.1390 (Ohm/mile) at 167.0 (deg F)
Emissivity is 0.7 and solar absorptivity is 0.9

Solar heat input is 1.918 (Watt/ft) (corresponds to Global Solar Radiation of **23.081** (Watt/ft^2) - which was calculated)
Radiation cooling is 0.306 (Watt/ft)
Convective cooling is 1.919 (Watt/ft)

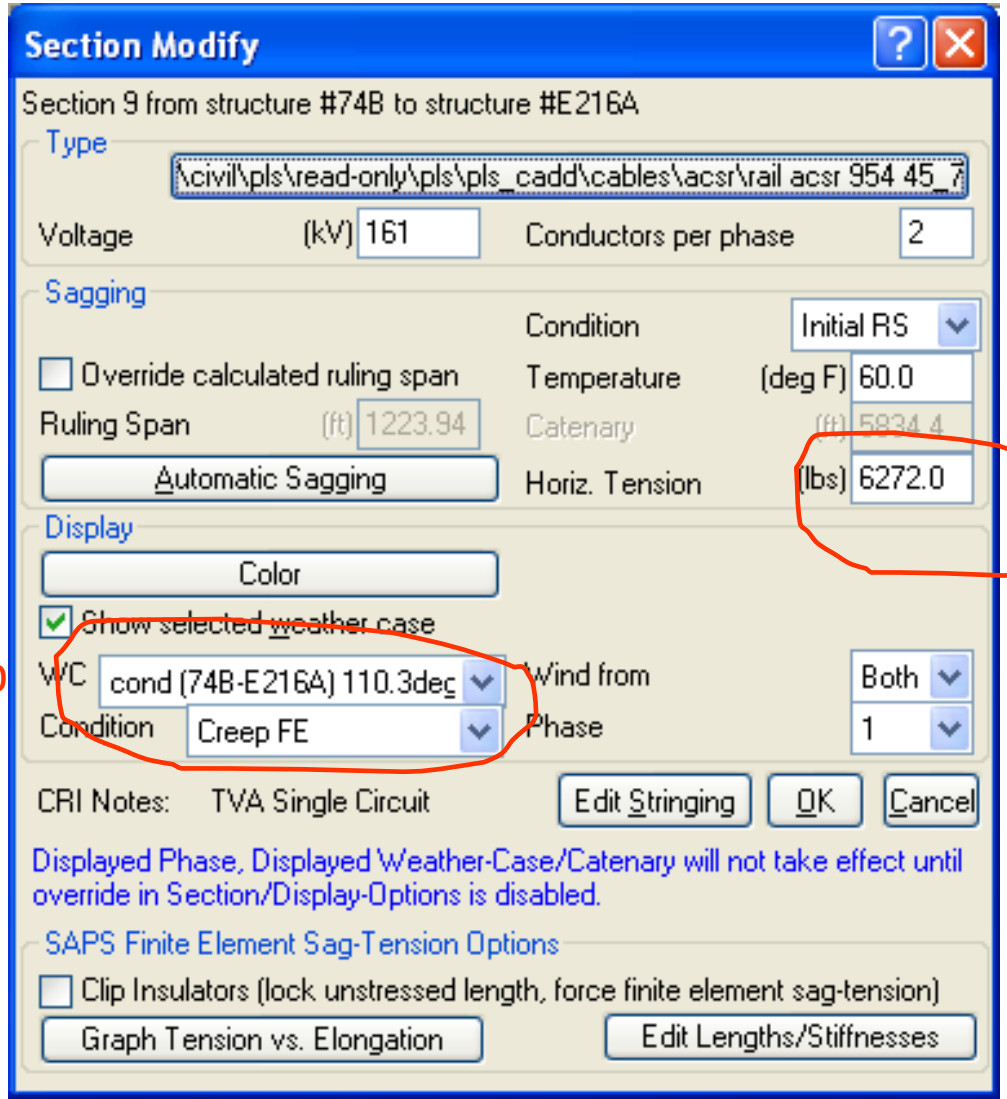
Given a constant ac current of 118.5 amperes,
The conductor surface temperature is 71.2 (deg F)

Changed conductor temp from 74.6 to 71.2 (Very Cloudy would be significant)

Steps to get FE sag

- Alignment
- Structure locations (station/offset)
- Conductor temperature (weather data)
- Assume sagging temperature (plumb INS)
- As captured least square best fit Tension (FE6) Used to get tension not move structures
- Adjust each span at mid span (non-plumb INS)FE3

Assumed stringing condition 60deg Initial insulators plumb

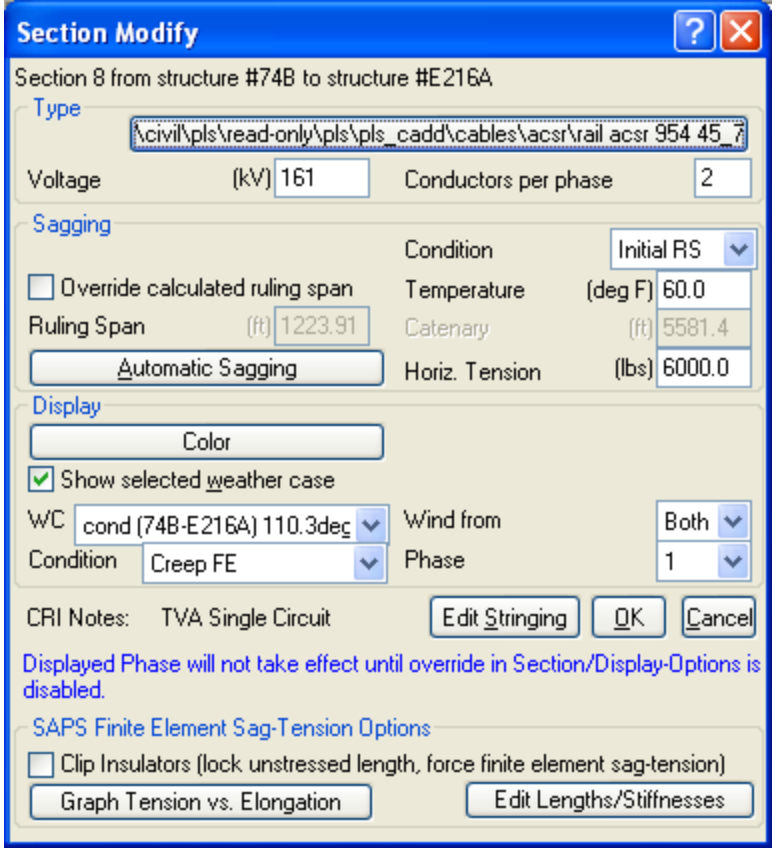


As Captured Temp

Sagging Tension is derived from least square best fit of As Captured

Least Square Best Fit

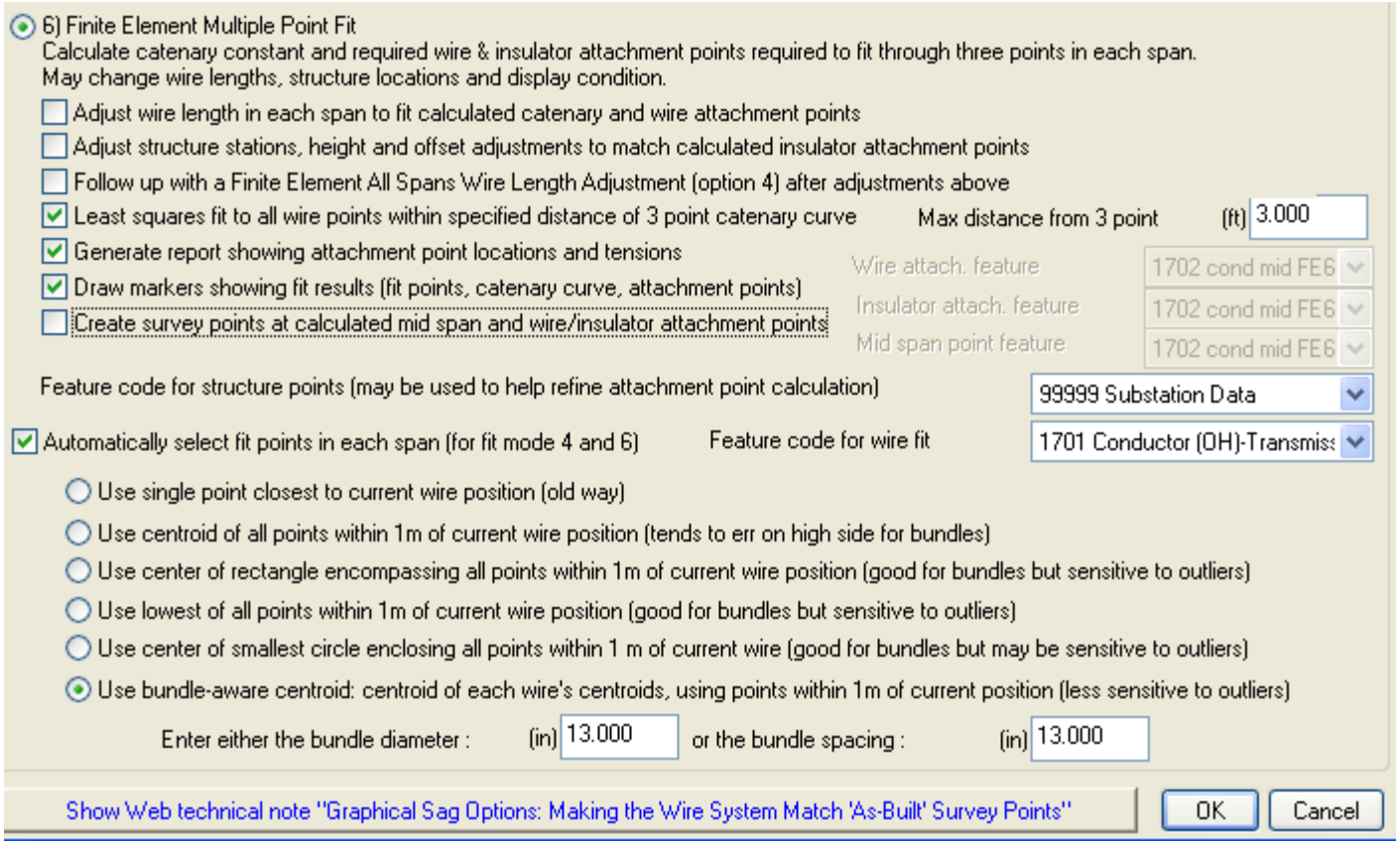
- FE gives a different tension in each span
- FE gives insulator swing at every condition besides Sagging Condition
- Thus, FE gives insulator swings at As Captured Temperature
- Must determine if swing/sag is due to FE or insulator installed out of plumb initially
- Input Sagging condition Tension(60deg Initial) is one value
- Determine outliers (spans that do not match FE tension)



To Illistrate
Using Sagging Tension
= 6000

Note: str are adjusted

Least Square Best Fit



Least Square Answers do not change with Sagging input

Based on lidar points only

Graphical Sag Tension Report

Structure Number	Set Number	Phase No.	Three Point Calc. Tension (lbs)	Least Squares Calc. Tension (lbs)	Number Points Least Squares Fit	Tension Before (lbs)	Tension After (lbs)	Tension Error -Tension Before (lbs)
74B	9	1	2124.17	2991.69	225	4891.16	6005.32	3013.63
75	4	1	4927.85	4907.70	2031	4906.58	6005.56	1097.87
76	4	1	4954.27	4937.14	1826	4887.36	6007.43	1070.29
77	4	1	4970.02	4959.16	1520	4907.58	6004.48	1045.32
78	4	1	4970.25	5007.41	1151	4951.95	6002.76	995.35
79	4	1	4971.11	5024.33	1126	4955.94	6002.20	977.88
80	4	1	4936.19	5041.59	816	5004.34	6002.03	960.44
81	4	1	5102.22	5106.94	1335	5108.82	6002.31	895.38
82	4	1	4859.67	4973.88	865	5030.29	6003.36	1029.48
83	4	1	5017.29	5036.29	1506	4989.98	6005.95	969.66
84	4	1	5039.66	5034.95	1211	4959.21	6006.30	971.34
85	4	1	4966.74	5020.04	986	4956.82	6004.68	984.64
86	4	1	4997.25	5063.62	818	4928.81	6004.25	940.62
87	4	1	5042.49	5017.46	914	4924.90	6004.65	987.18
88	4	1	4969.19	4972.16	901	4887.46	6006.45	1034.30
89	4	1	5035.10	4950.09	1133	4830.23	6007.69	1057.59
90	4	1	4806.83	4861.13	1311	4768.40	6008.11	1146.98
91	4	1	4839.69	4870.14	1057	4743.14	6009.36	1139.22
92	4	1	4770.34	4901.51	780	4724.05	6012.02	1110.51
93	4	1	4838.02	4856.39	820	4700.56	6011.30	1154.91
94	4	1	4768.98	4875.28	822	4699.75	6009.28	1134.00

Row #	Structure Number	Set Number	Phase No.	Three Point Calc. Tension (lbs)	Least Squares Calc. Tension (lbs)	Number Points Least Squares Fit	Tension Before (lbs)	Difference	red > 6%	2%	4%	6%
1	74B	9	1	2124.17	2991.69	225	4891.16	-1899.47	-63.5%			
2	75	4	1	4927.85	4907.7	2031	4906.58	1.12	0.0%	1.12	1.12	1.12
3	76	4	1	4954.27	4937.14	1826	4887.36	49.78	1.0%	49.78	49.78	49.78
4	77	4	1	4970.02	4959.16	1520	4907.58	51.58	1.0%	51.58	51.58	51.58
5	78	4	1	4970.25	5007.41	1151	4951.95	55.46	1.1%	55.46	55.46	55.46
6	79	4	1	4971.11	5024.33	1126	4955.94	68.39	1.4%	68.39	68.39	68.39
7	80	4	1	4936.19	5041.59	816	5004.34	37.25	0.7%	37.25	37.25	37.25
8	81	4	1	5102.22	5106.94	1335	5108.82	-1.88	0.0%	-1.88	-1.88	-1.88
					94.13	687	4813.16	80.97	1.7%	80.97	80.97	80.97
					68.29	571	4799.38	68.91	1.4%	68.91	68.91	68.91
					72.84	593	4811.67	61.17	1.3%	61.17	61.17	61.17
					789.5	633	4736.3	53.2	1.1%	53.2	53.2	53.2
					62.08	745	4751.98	110.1	2.3%		110.1	110.1
					961.2	1077	4762.64	198.56	4.0%			198.56
					072.36	1498	4763.13	309.23	6.1%			
					56.26	1162	4827.89	328.37	6.4%			
					50.98	684	4877.45	273.53	5.3%			273.53
					75.32	747	4961.69	213.63	4.1%			213.63
					963.59	657	4798.04	165.55	3.3%		165.55	165.55
					39.84	521	4771.56	168.28	3.4%		168.28	168.28
					33.26	594	4787.39	345.87	6.7%			
					39.92	618	4826.6	313.32	6.1%			
					41.57	1029	4880.61	260.96	5.1%			260.96
					70.71	1037	4951	219.71	4.2%			219.71
					669.45	399	4827.91	-158.46	-3.4%		-158.46	-158.46
								14537.37		3366.19	11016.04	14827.15
								143		65	121	137
										0.45	**0.85**	**0.96**
								101.65993		51.78754	91.04165	108.2274

Section Modify

Section 8 from structure #74B to structure #E216A

Type: \civil\pls\read-only\pls\pls_cadd\cables\acsr\rail acsr 954 45_7

Voltage (kV) 161 — Conductors per phase 2

Sagging

Condition: Initial RS

Override calculated ruling span — Temperature (deg F) 60.0

Ruling Span (ft) 1223.91 — Catenary (ft) 5581.4

Automatic Sagging — Horiz. Tension (lbs) 6000.0

Display

Color

Show selected weather case

WC: cond (74B-E216A) 110.3deg — Wind from: Both

Condition: Creep FE — Phase: 1

CRI Notes: TVA Single Circuit — Edit Stringing — OK — Cancel

Displayed Phase will not take effect until override in Section/Display-Options is disabled.

SAPS Finite Element Sag-Tension Options

Clip Insulators (lock unstressed length, force finite element sag-tension)

Graph Tension vs. Elongation — Edit Lengths/Stiffnesses

Row #	Structure	Set Number	Phase No.	Three Point Calc. Tension (lbs)	Least Squares Calc. Tension (lbs)	Number Points Least Squares Fit	Tension Before (lbs)	Difference	red > 6%	2%	4%	6%
1	74B	9	1	2124.17	2991.69	225	5010.5	-2018.81	-67.5%			
2	75	4	1	4935.39	4907.7	2031	5026.01	-118.31	-2.4%		-118.31	-118.31
3	76	4	1	4954.27	4937.14	1826	5007.54	-70.4	-1.4%	-70.4	-70.4	-70.4
4	77	4	1	4970.02	4959.16	1520	5028.11	-68.95	-1.4%	-68.95	-68.95	-68.95
5	78	4	1	4970.25	5007.41	1151	5073.33	-65.92	-1.3%	-65.92	-65.92	-65.92
6	79	4	1	5093.06	5024.33	1126	5078.41	-54.08	-1.1%	-54.08	-54.08	-54.08
7	80	4	1	4936.19	5041.59	816	5128.46	-86.87	-1.7%	-86.87	-86.87	-86.87
8	81	4	1	5072.87	5106.94	1335	5235.8	-128.86	-2.5%		-128.86	-128.86
32	105	4	1	4867.77	4894.13	687	4922.5	-28.37	-0.6%	-28.37	-28.37	-28.37
33	106	4	1	4864.78	4868.29	571	4909.3	-41.01	-0.8%	-41.01	-41.01	-41.01
					2.84	593	4922.23	-49.39	-1.0%	-49.39	-49.39	-49.39
					89.5	633	4843.75	-54.25	-1.1%	-54.25	-54.25	-54.25
					2.08	745	4860.05	2.03	0.0%	2.03	2.03	2.03
					61.2	1077	4871.71	89.49	1.8%	89.49	89.49	89.49
					2.36	1498	4873.31	199.05	3.9%		199.05	199.05
					6.26	1162	4939.82	216.44	4.2%			216.44
					0.98	684	4991.43	159.55	3.1%		159.55	159.55
					5.32	747	5078.04	97.28	1.9%	97.28	97.28	97.28
					3.59	657	4911.14	52.45	1.1%	52.45	52.45	52.45
					9.84	521	4884.42	55.42	1.1%	55.42	55.42	55.42
					3.26	594	4900.73	232.53	4.5%			232.53
					9.92	618	4941.22	198.7	3.9%		198.7	198.7
					1.57	1029	4996.46	145.11	2.8%		145.11	145.11
					0.71	1037	5069.7	101.01	2.0%	101.01	101.01	101.01
					9.45	399	4942.17	-272.72	-5.8%			-272.72
								-1754.58		-739.25	287.62	264.23
								143		115	138	142
										0.80	**0.97**	**0.99**
								-12.26979		-6.42826	2.084203	1.860775

Section Modify

Section 8 from structure #74B to structure #E216A

Type: \civil\pls\read-only\pls\pls_cadd\cables\acsr\rail acsr 954 45_7

Voltage (kV) 161 — Conductors per phase 2

Sagging

Override calculated ruling span — Ruling Span (ft) 1223.91 — Automatic Sagging

Condition: Initial BS

Temperature (deg F) 60.0

Catenary (ft) 5785.1

Horiz. Tension (lbs) 6219.0

Display

Color

Show selected weather case

WC: cond (74B-E216A) 110.3deg — Wind from: Both

Condition: Creep FE — Phase: 1

CRI Notes: TVA Single Circuit — Edit Stringing — OK — Cancel

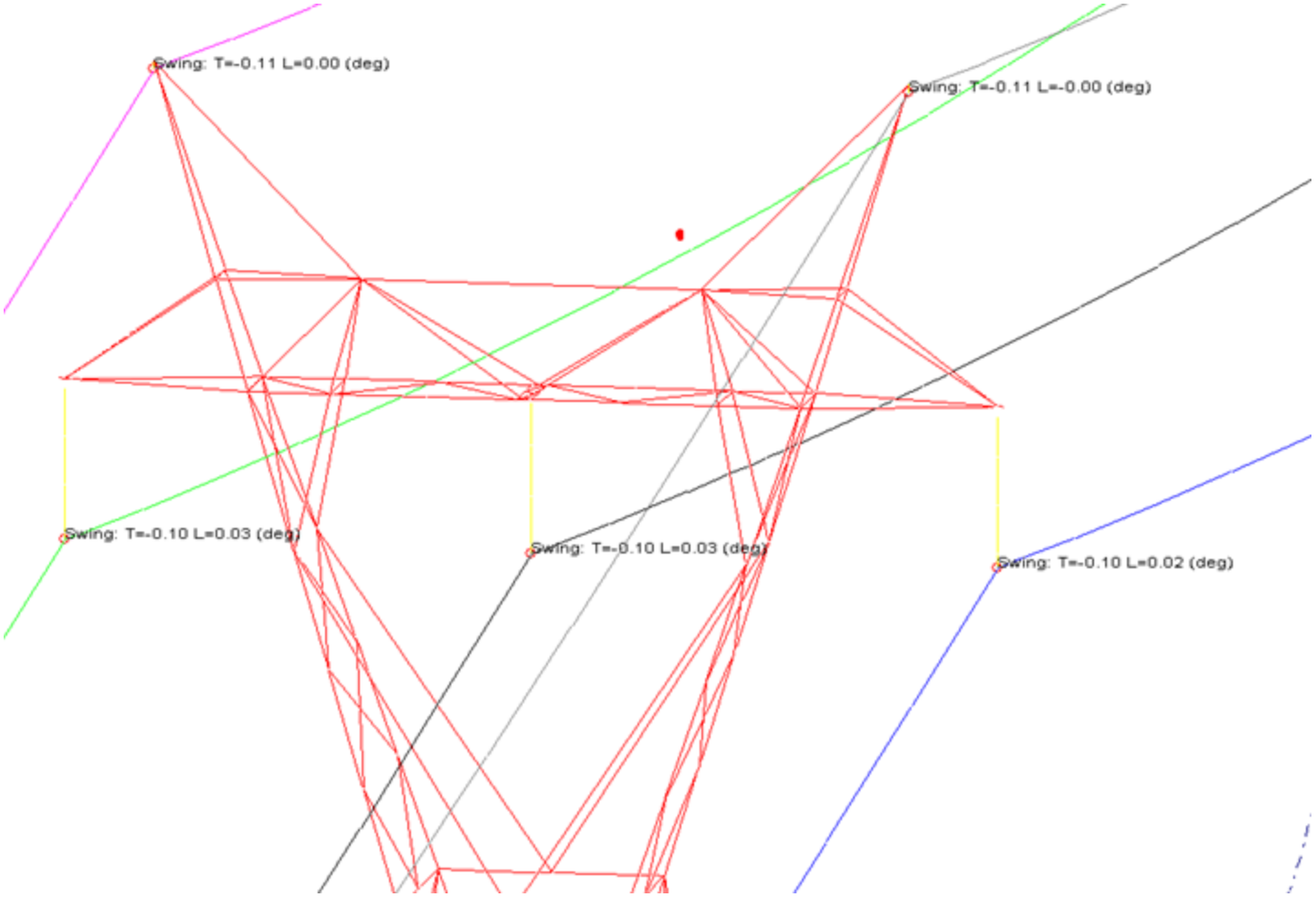
Displayed Phase will not take effect until override in Section/Display-Options is disabled.

SAPS Finite Element Sag-Tension Options

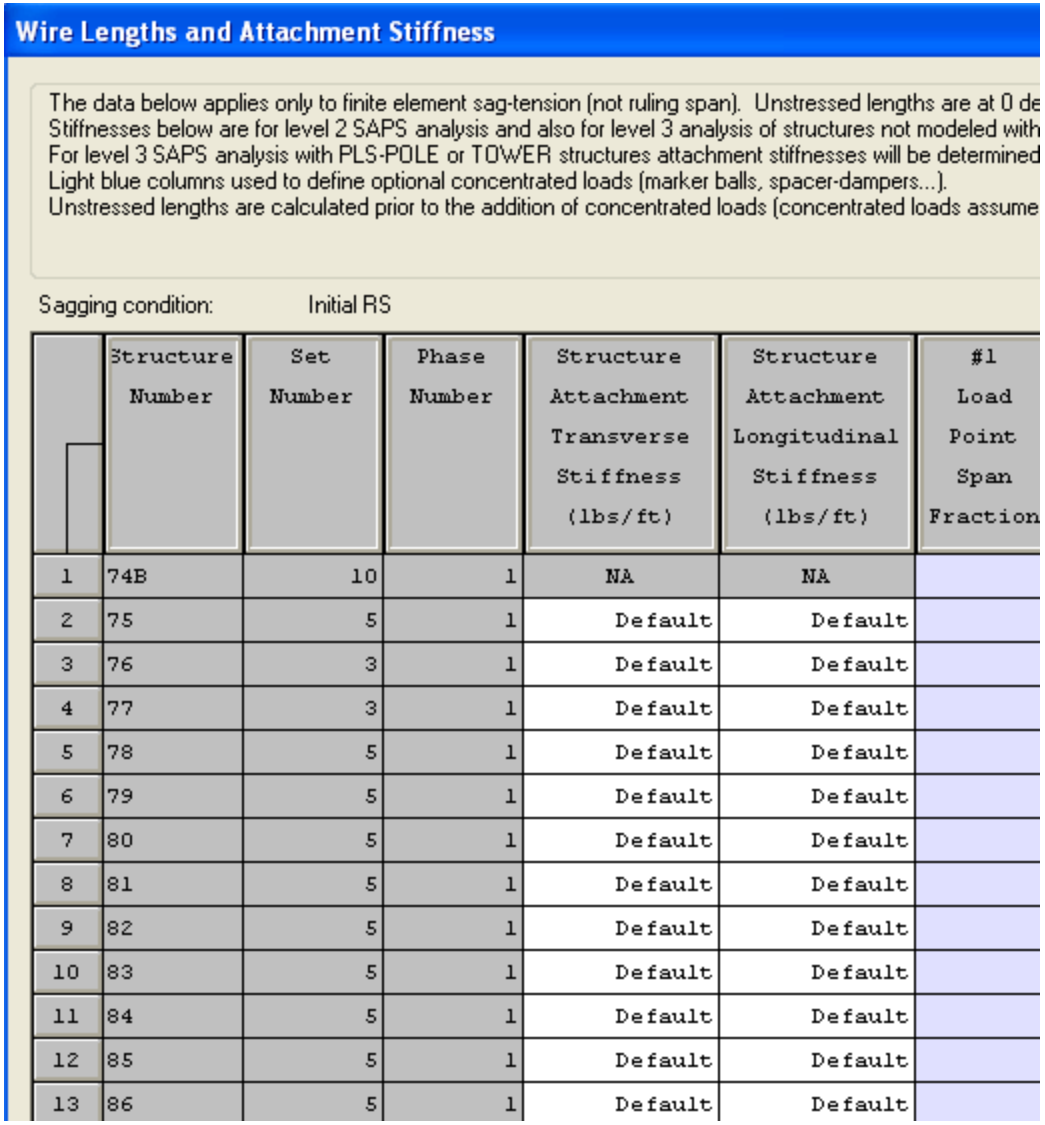
Clip Insulators (lock unstressed length, force finite element sag-tension)

Graph Tension vs. Elongation — Edit Lengths/Stiffnesses

Stringing condition 60deg Initial
Assumed insulators plumb (to be corrected)



Before Adjustments



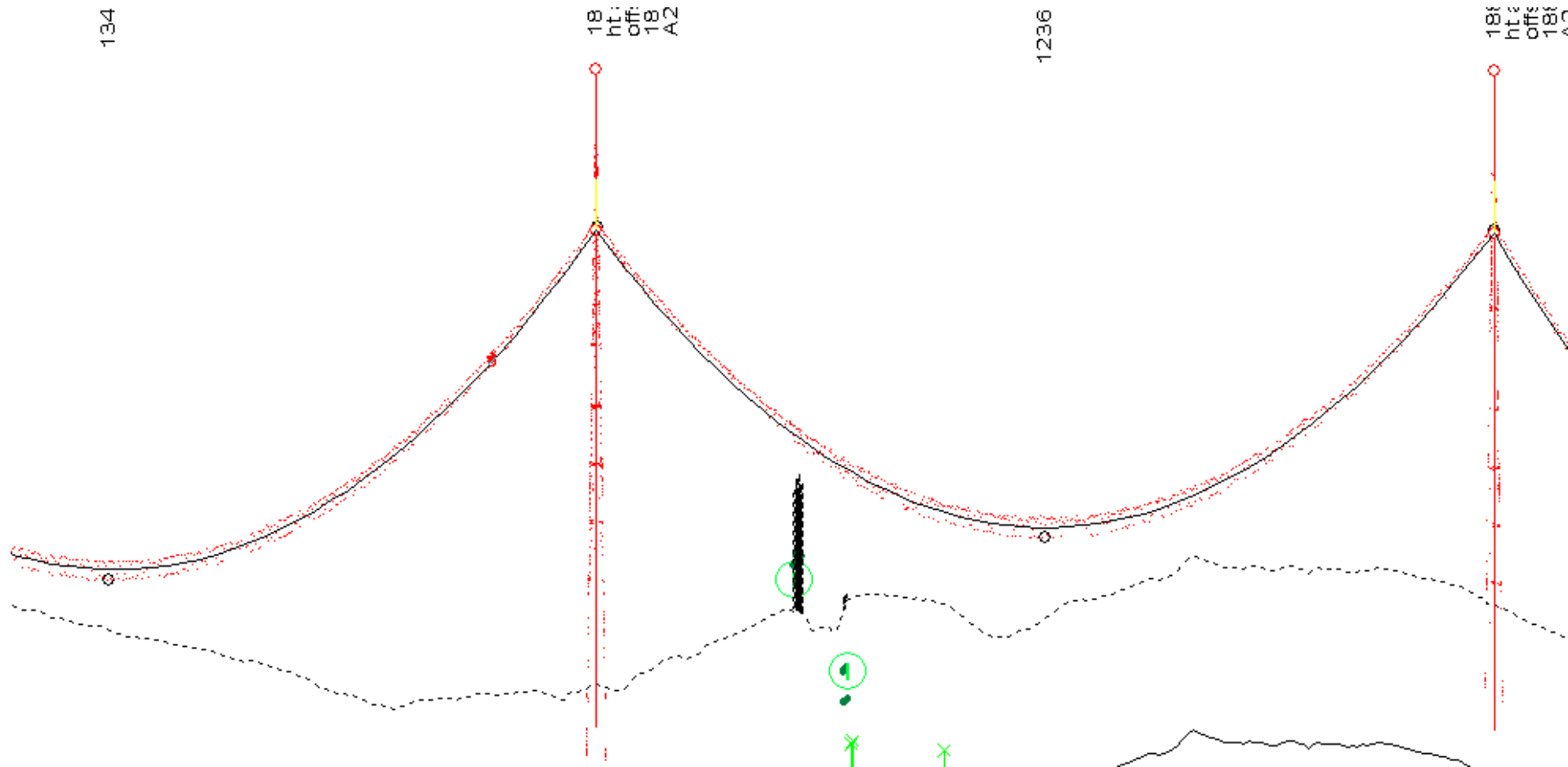
Wire Lengths and Attachment Stiffness

The data below applies only to finite element sag-tension (not ruling span). Unstressed lengths are at 0 de
Stiffnesses below are for level 2 SAPS analysis and also for level 3 analysis of structures not modeled with
For level 3 SAPS analysis with PLS-POLE or TOWER structures attachment stiffnesses will be determined
Light blue columns used to define optional concentrated loads (marker balls, spacer-dampers...).
Unstressed lengths are calculated prior to the addition of concentrated loads (concentrated loads assume

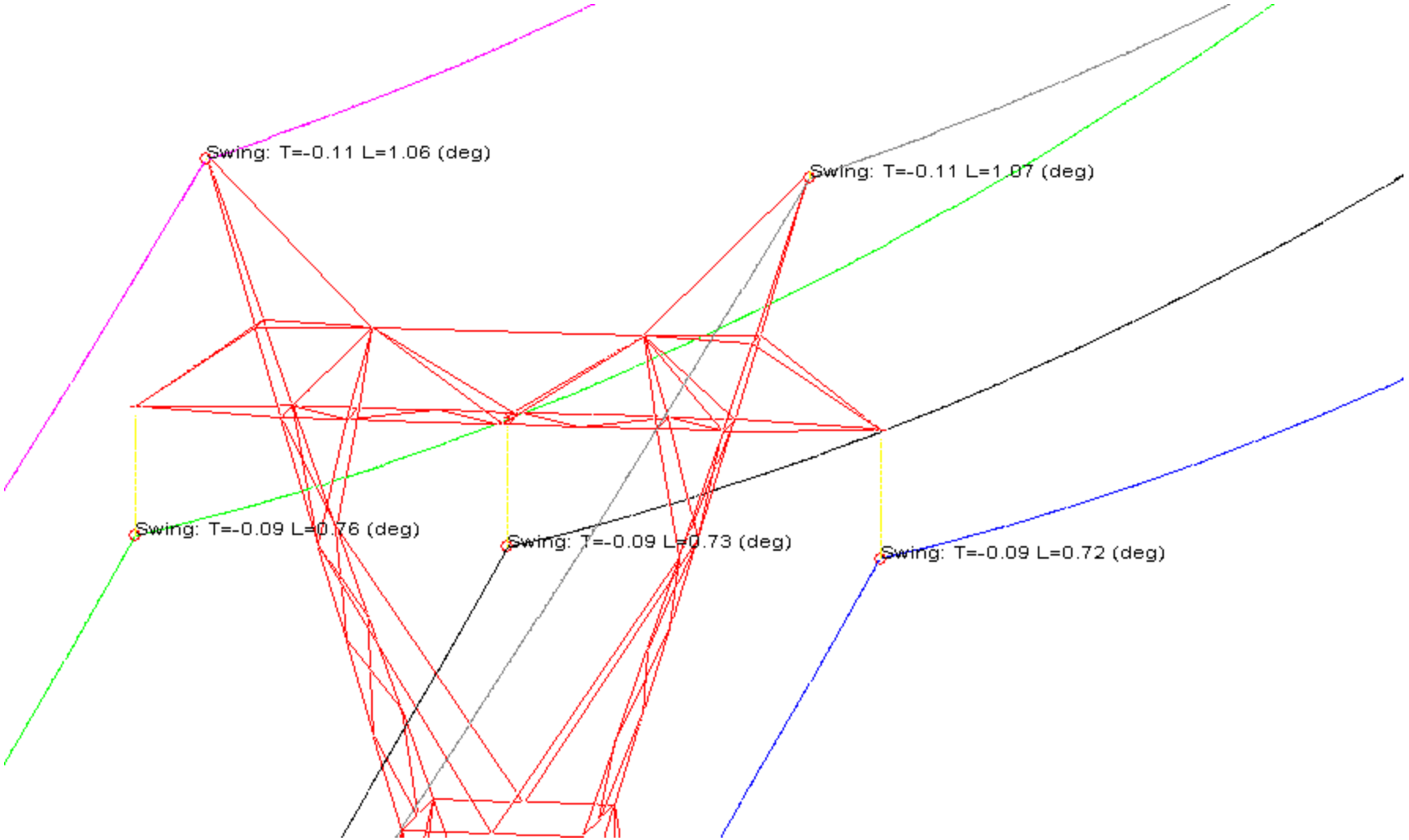
Sagging condition: Initial RS

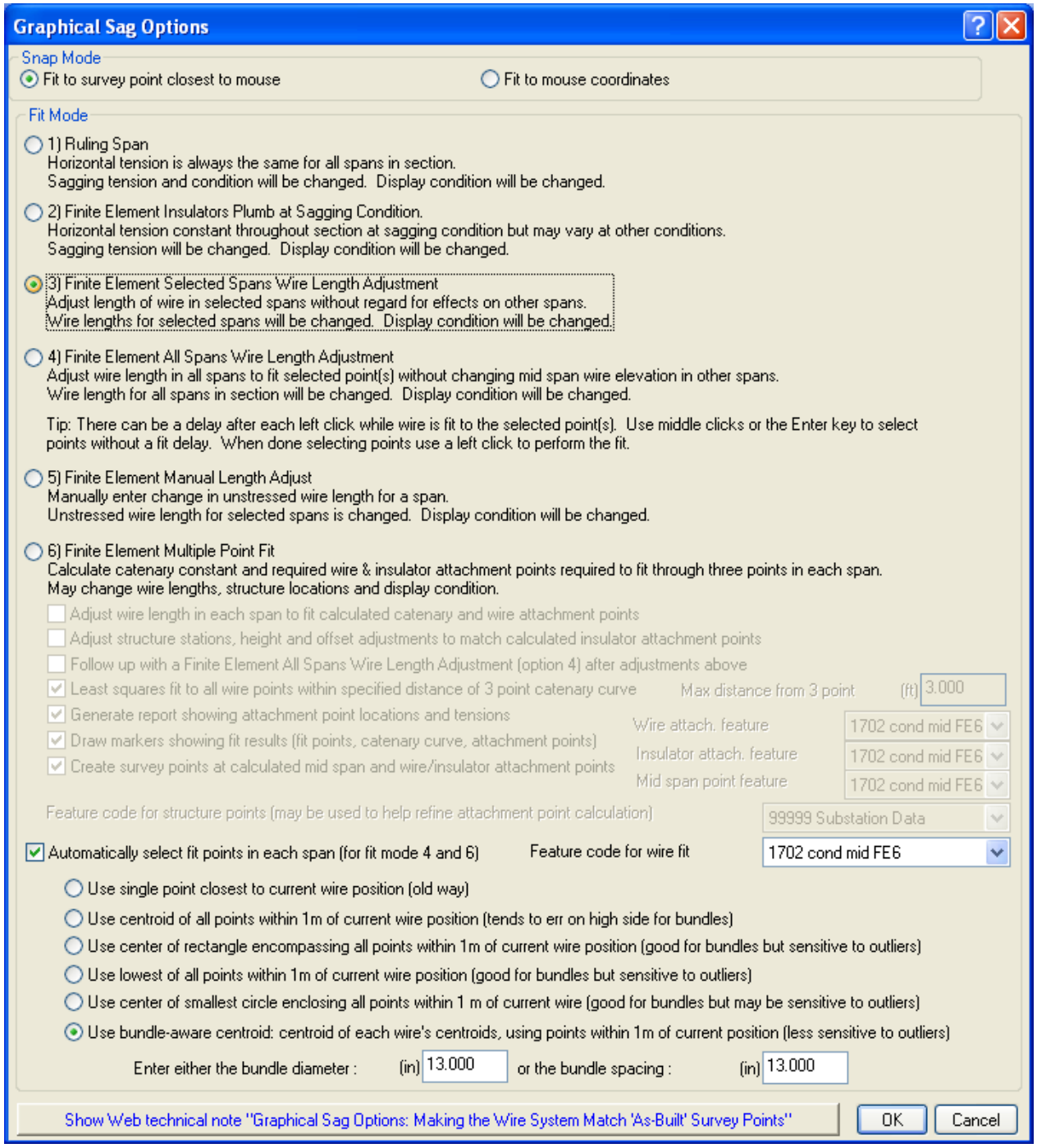
	Structure Number	Set Number	Phase Number	Structure Attachment Transverse Stiffness (lbs/ft)	Structure Attachment Longitudinal Stiffness (lbs/ft)	#1 Load Point Span Fraction
1	74B	10	1	NA	NA	
2	75	5	1	Default	Default	
3	76	3	1	Default	Default	
4	77	3	1	Default	Default	
5	78	5	1	Default	Default	
6	79	5	1	Default	Default	
7	80	5	1	Default	Default	
8	81	5	1	Default	Default	
9	82	5	1	Default	Default	
10	83	5	1	Default	Default	
11	84	5	1	Default	Default	
12	85	5	1	Default	Default	
13	86	5	1	Default	Default	

As captured temperature no adjustment

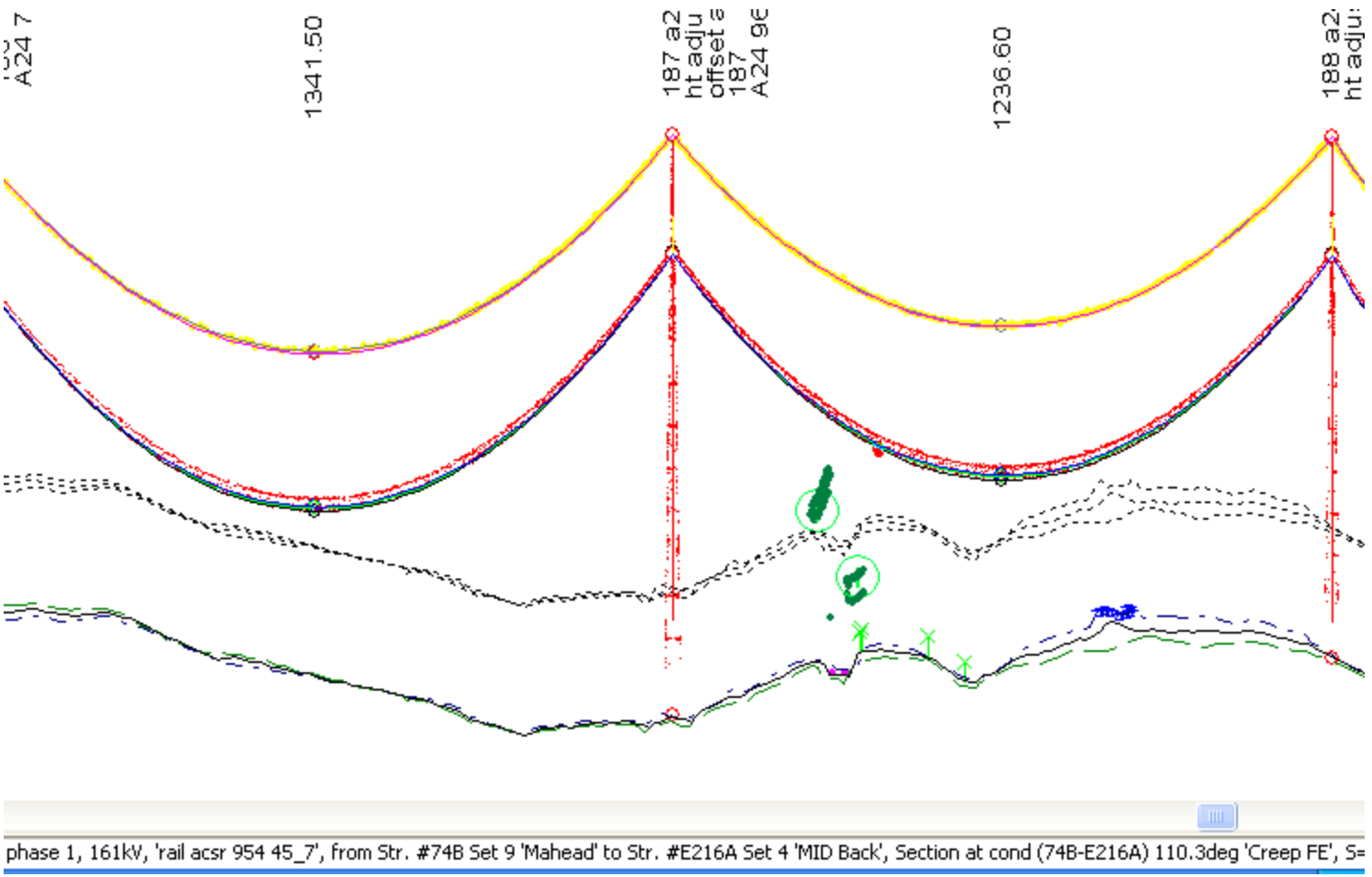


As captured temperature no adjustment

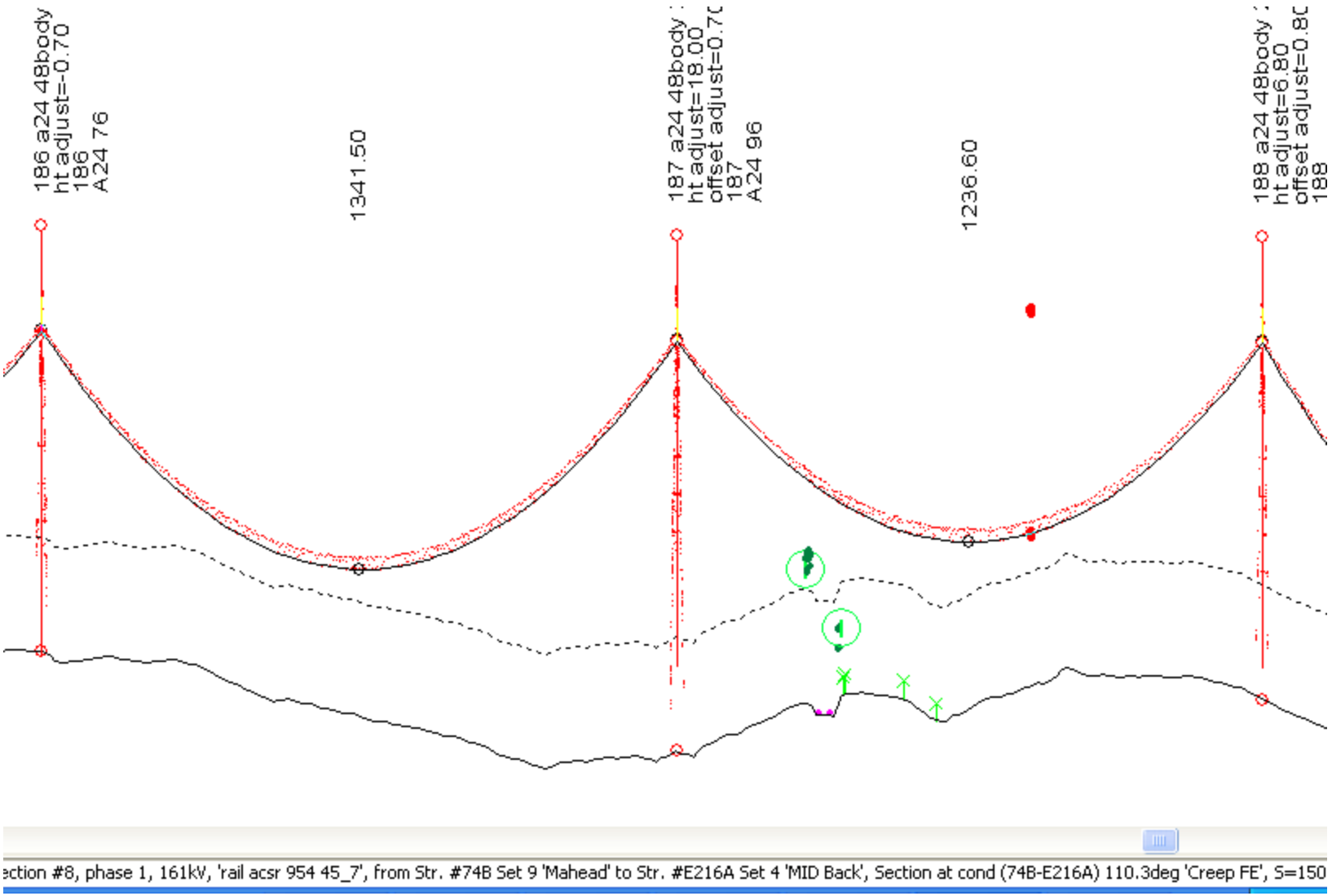



Graphical Sag Options
Snap Mode
Fit to survey point closest to mouse
Fit to mouse coordinates
Fit Mode
1) Ruling Span
Horizontal tension is always the same for all spans in section.
Sagging tension and condition will be changed. Display condition will be changed.
2) Finite Element Insulators Plumb at Sagging Condition.
Horizontal tension constant throughout section at sagging condition but may vary at other conditions.
Sagging tension will be changed. Display condition will be changed.
3) Finite Element Selected Spans Wire Length Adjustment
Adjust length of wire in selected spans without regard for effects on other spans.
Wire lengths for selected spans will be changed. Display condition will be changed.
4) Finite Element All Spans Wire Length Adjustment
Adjust wire length in all spans to fit selected point(s) without changing mid span wire elevation in other spans.
Wire length for all spans in section will be changed. Display condition will be changed.
Tip: There can be a delay after each left click while wire is fit to the selected point(s). Use middle clicks or the Enter key to select points without a fit delay. When done selecting points use a left click to perform the fit.
5) Finite Element Manual Length Adjust
Manually enter change in unstressed wire length for a span.
Unstressed wire length for selected spans is changed. Display condition will be changed.
6) Finite Element Multiple Point Fit
Calculate catenary constant and required wire & insulator attachment points required to fit through three points in each span.
May change wire lengths, structure locations and display condition.
Adjust wire length in each span to fit calculated catenary and wire attachment points
Adjust structure stations, height and offset adjustments to match calculated insulator attachment points
Follow up with a Finite Element All Spans Wire Length Adjustment (option 4) after adjustments above
Least squares fit to all wire points within specified distance of 3 point catenary curve
Max distance from 3 point
(ft)
3.000
Generate report showing attachment point locations and tensions
Draw markers showing fit results (fit points, catenary curve, attachment points)
Create survey points at calculated mid span and wire/insulator attachment points
Wire attach. feature
1702 cond mid FE6
Insulator attach. feature
1702 cond mid FE6
Mid span point feature
1702 cond mid FE6
Feature code for structure points (may be used to help refine attachment point calculation)
99999 Substation Data
Automatically select fit points in each span (for fit mode 4 and 6)
Feature code for wire fit
1702 cond mid FE6
Use single point closest to current wire position (old way)
Use centroid of all points within 1m of current wire position (tends to err on high side for bundles)
Use center of rectangle encompassing all points within 1m of current wire position (good for bundles but sensitive to outliers)
Use lowest of all points within 1m of current wire position (good for bundles but sensitive to outliers)
Use center of smallest circle enclosing all points within 1 m of current wire (good for bundles but may be sensitive to outliers)
Use bundle-aware centroid: centroid of each wire's centroids, using points within 1m of current position (less sensitive to outliers)
Enter either the bundle diameter :
(in)
13.000
or the bundle spacing :
(in)
13.000
Show Web technical note "Graphical Sag Options: Making the Wire System Match 'As-Built' Survey Points"
OK
Cancel

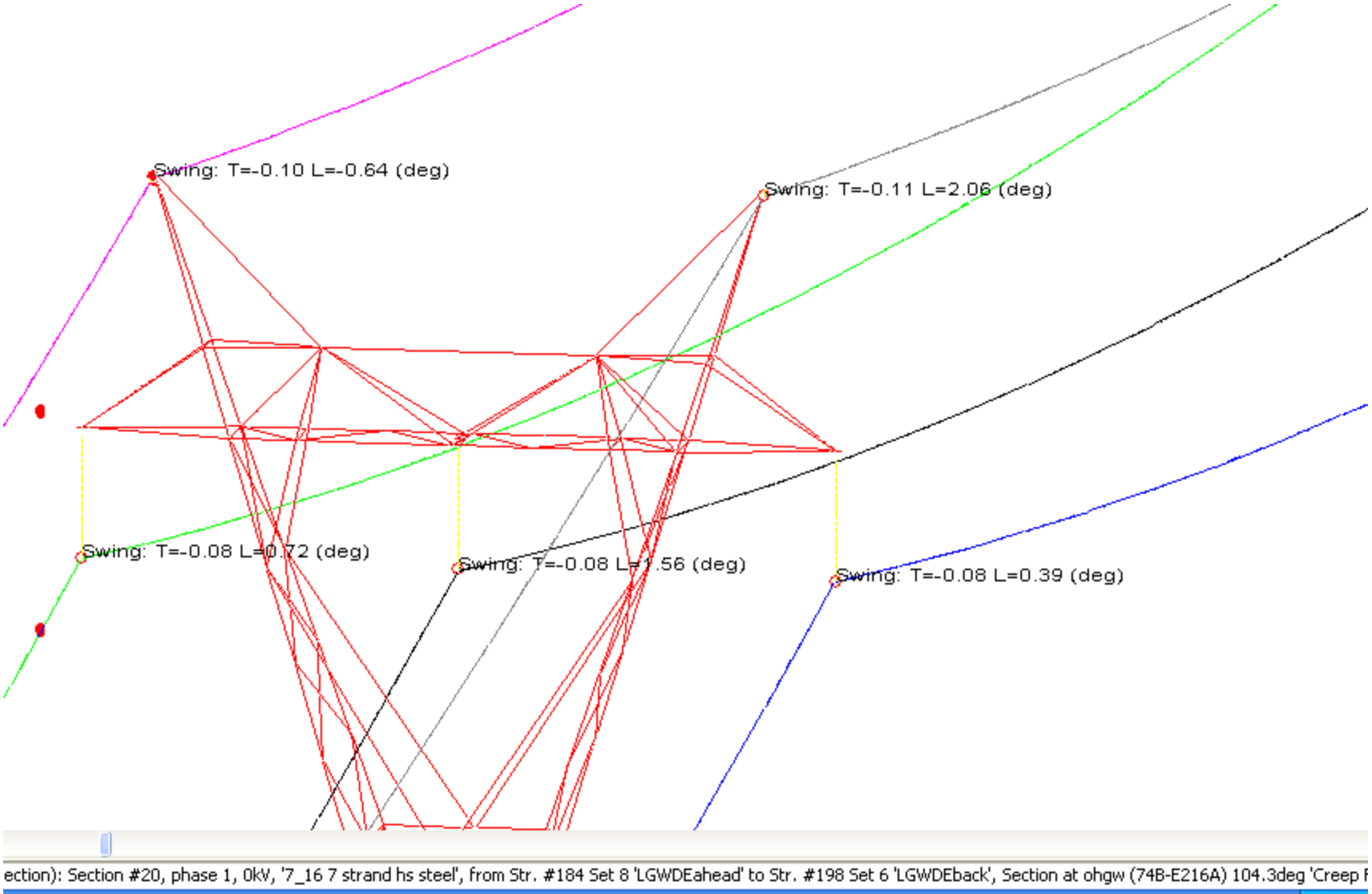
All phases As captured temperature with adjustment



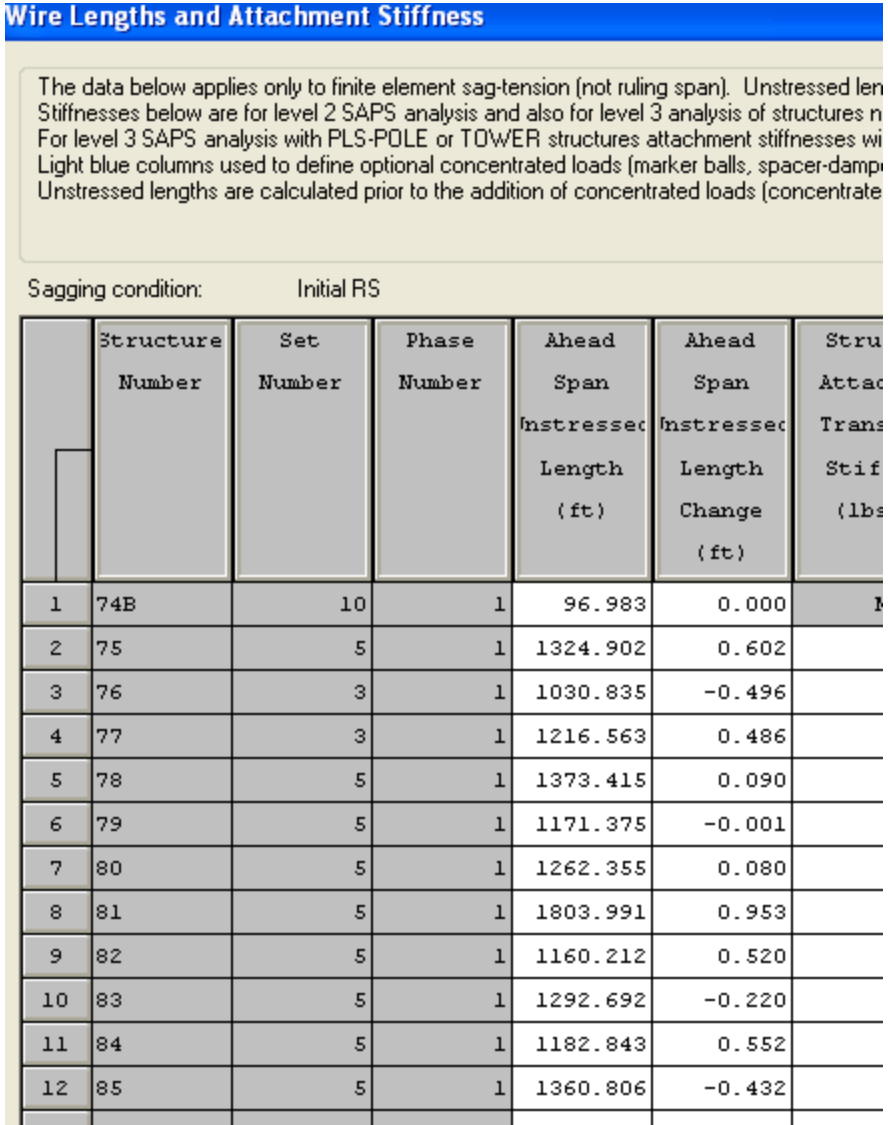
Center phase As captured temperature with adjustment



As captured temperature with adjustment



After Adjustments



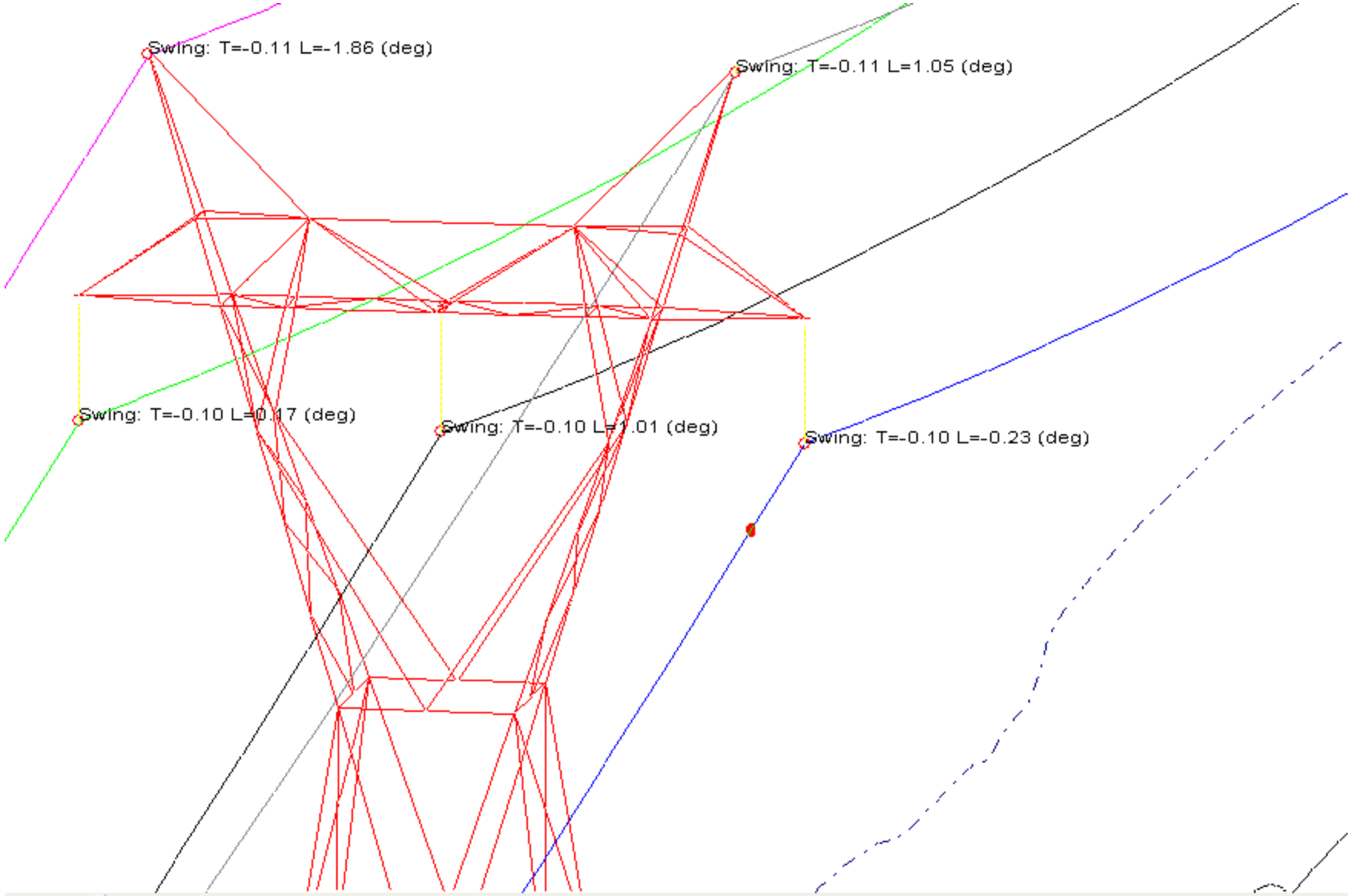
Wire Lengths and Attachment Stiffness

The data below applies only to finite element sag-tension (not ruling span). Unstressed len
Stiffnesses below are for level 2 SAPS analysis and also for level 3 analysis of structures n
For level 3 SAPS analysis with PLS-POLE or TOWER structures attachment stiffnesses wi
Light blue columns used to define optional concentrated loads (marker balls, spacer-dampe
Unstressed lengths are calculated prior to the addition of concentrated loads (concentrate

Sagging condition: Initial RS

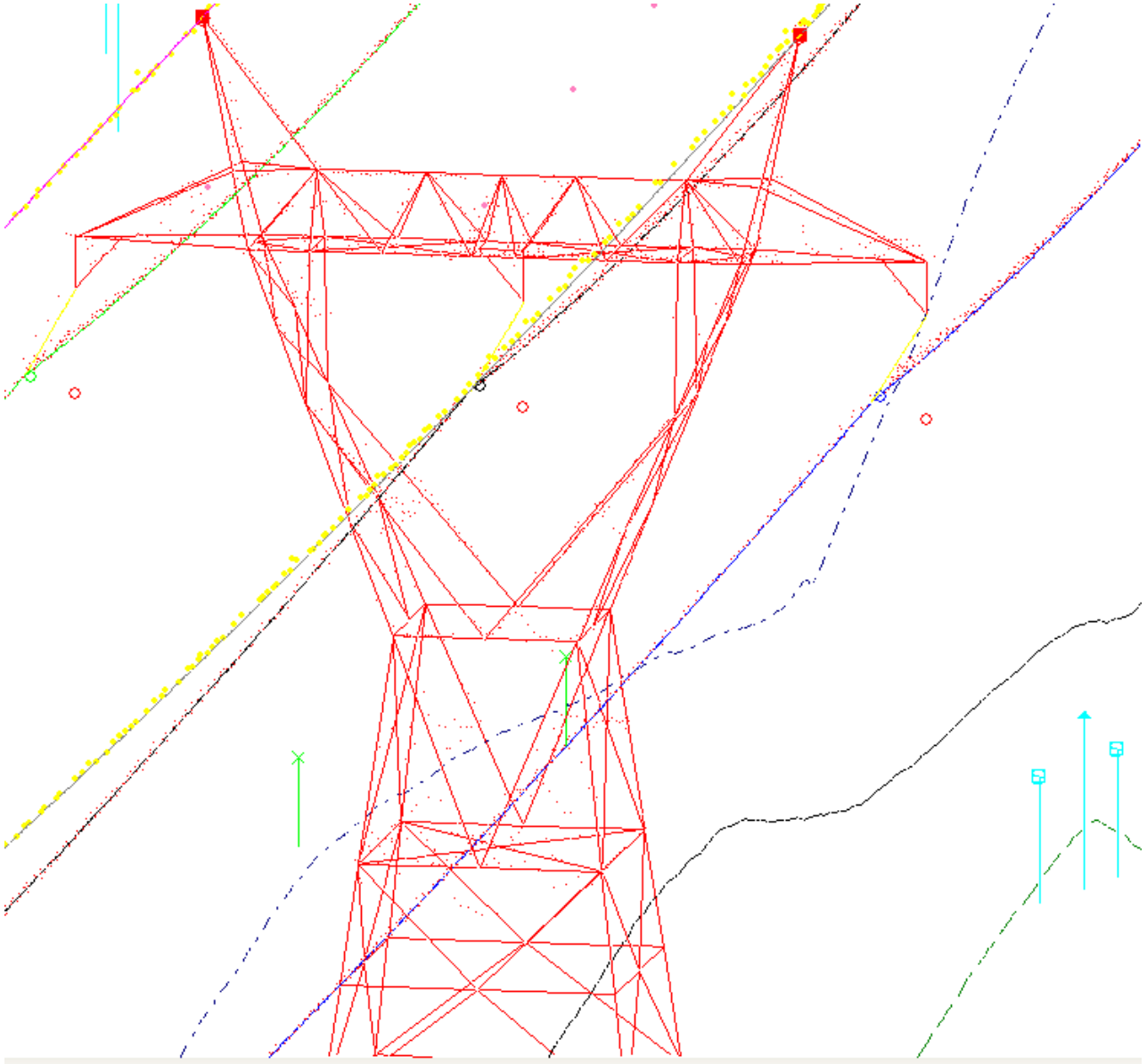
	Structure Number	Set Number	Phase Number	Ahead Span Unstressed Length (ft)	Ahead Span Unstressed Length Change (ft)	Stru Attac Trans Stif (lbs
1	74B	10	1	96.983	0.000	
2	75	5	1	1324.902	0.602	
3	76	3	1	1030.835	-0.496	
4	77	3	1	1216.563	0.486	
5	78	5	1	1373.415	0.090	
6	79	5	1	1171.375	-0.001	
7	80	5	1	1262.355	0.080	
8	81	5	1	1803.991	0.953	
9	82	5	1	1160.212	0.520	
10	83	5	1	1292.692	-0.220	
11	84	5	1	1182.843	0.552	
12	85	5	1	1360.806	-0.432	

Stringing condition 60deg Initial with adjustments (Assumption of plumb Insulator removed)

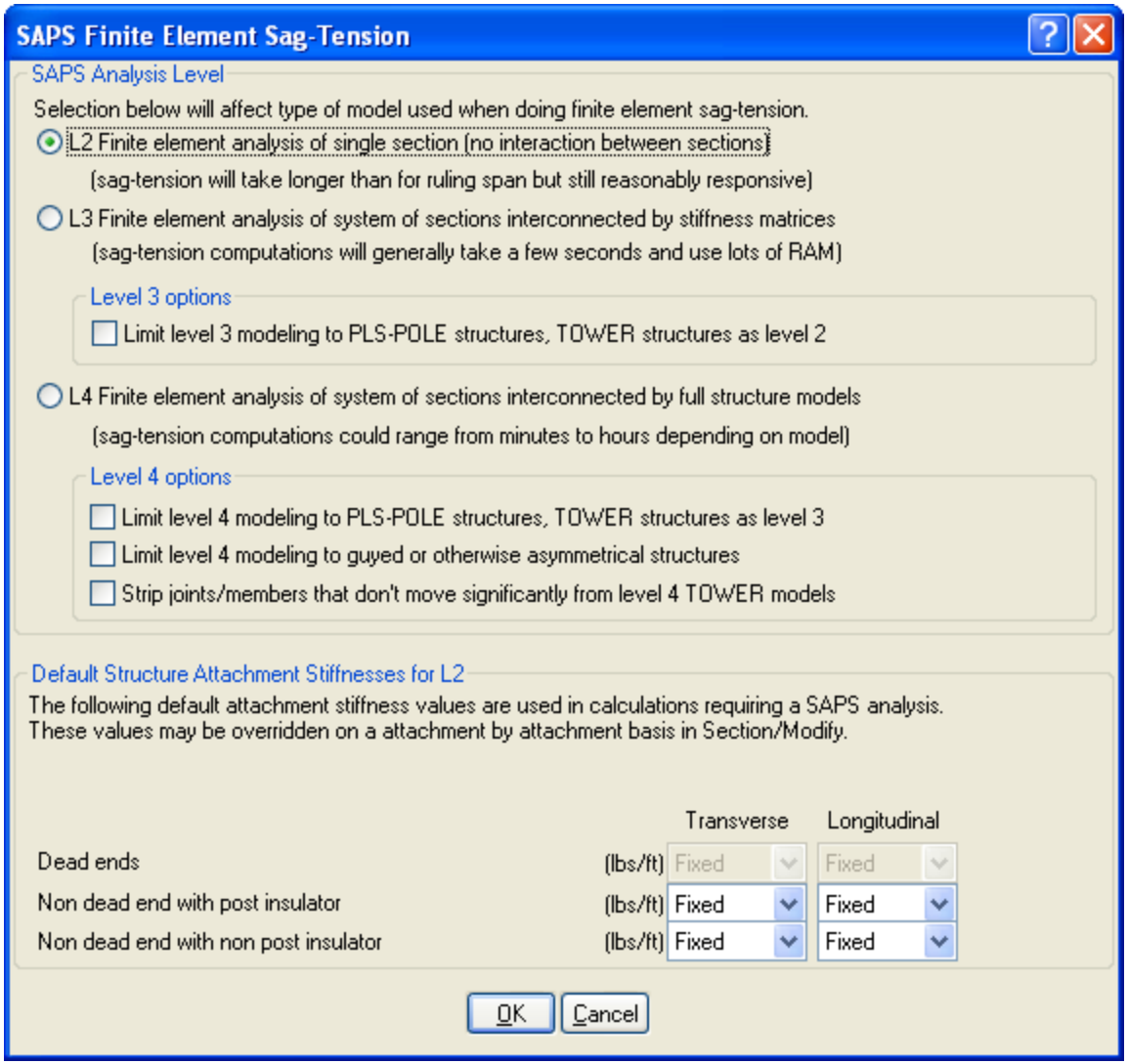


ection): Section #9, phase 1, 161kV, 'rail acsr 954 45_7', from Str. #74B Set 10 'Rahead' to Str. #E216A Set 5 'BOT Back', All sections at BARE 60 'Initial FE', S=151539.84

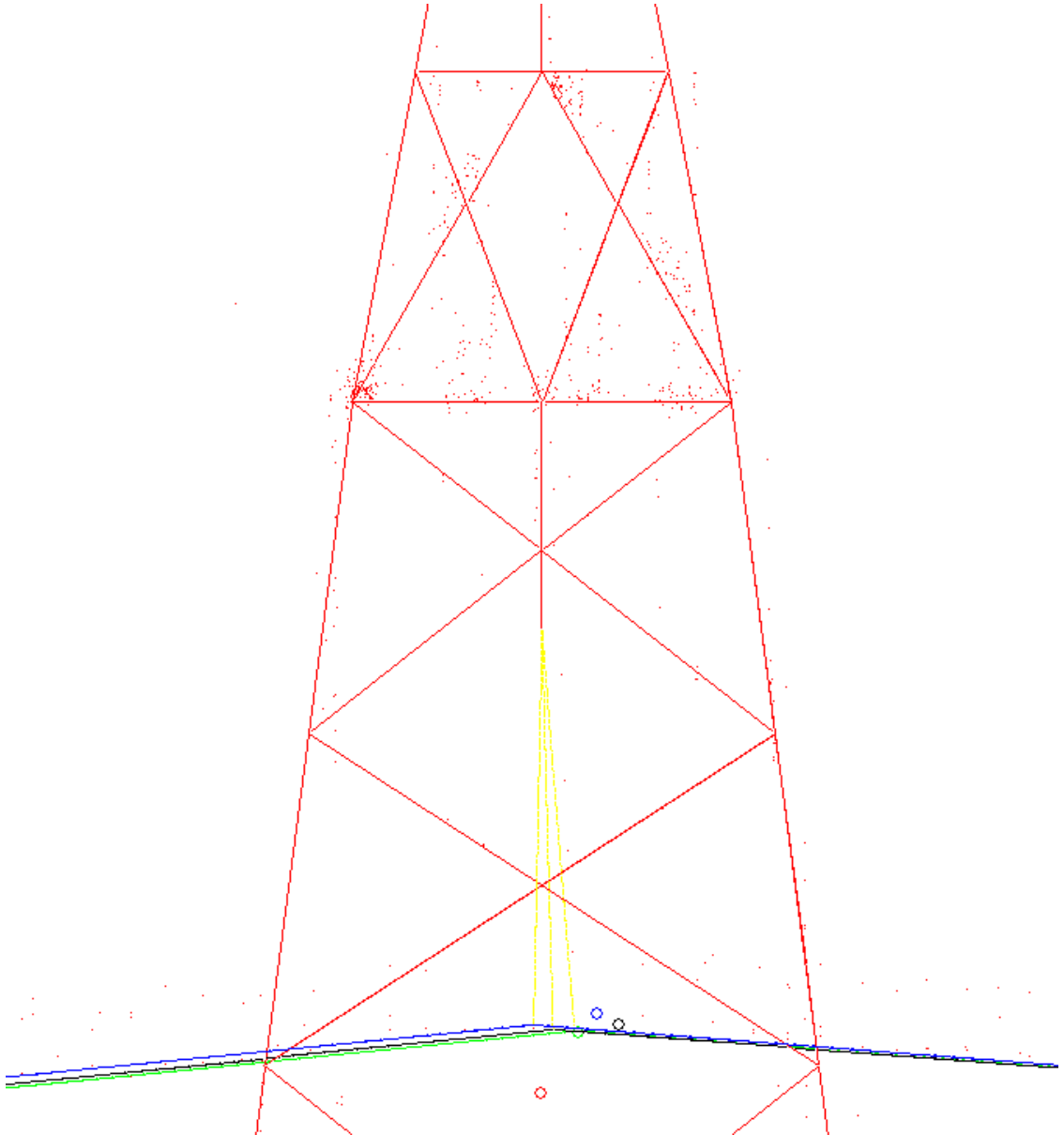
Angle brackets 3’-5”



Brackets do not swing with Level 2

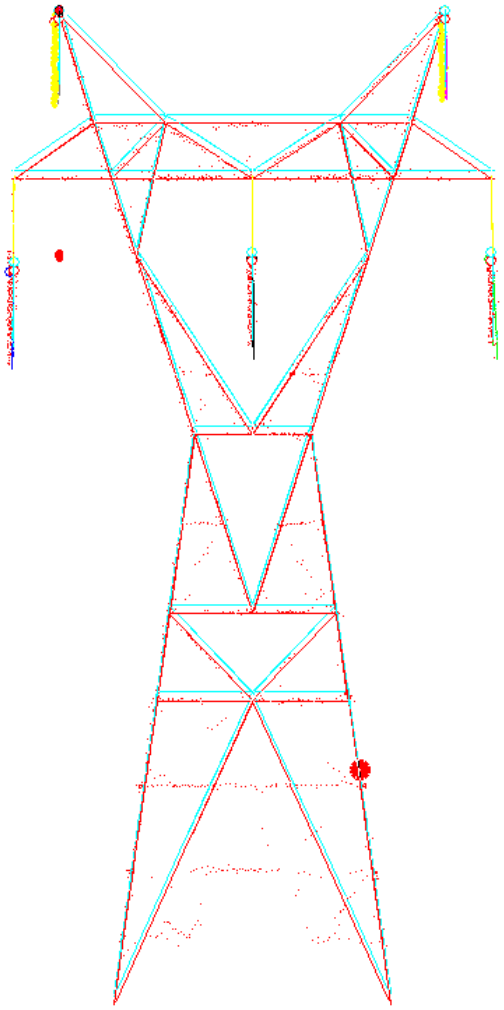


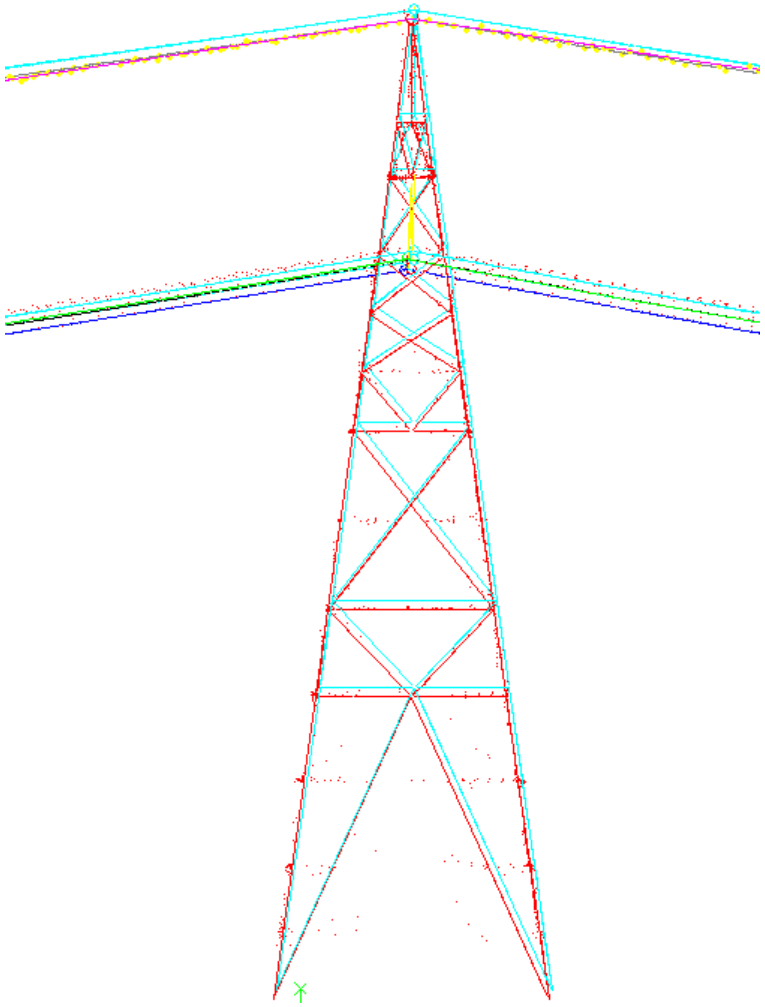
Only Insulators Swing (not brackets)

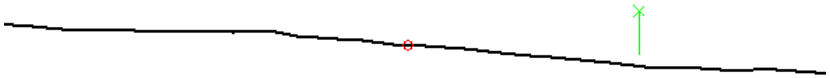


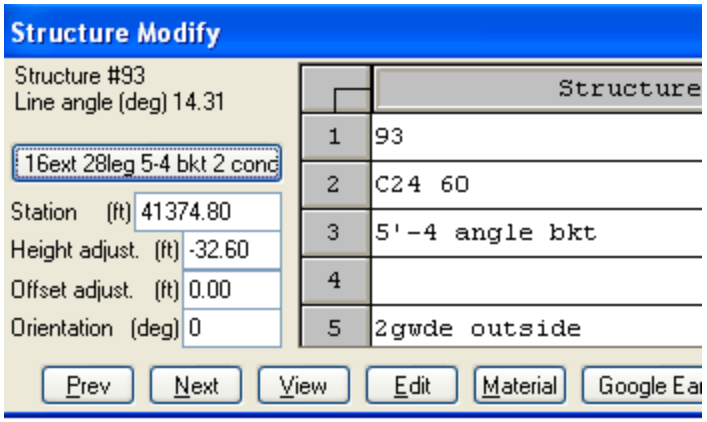
Use all adjustments

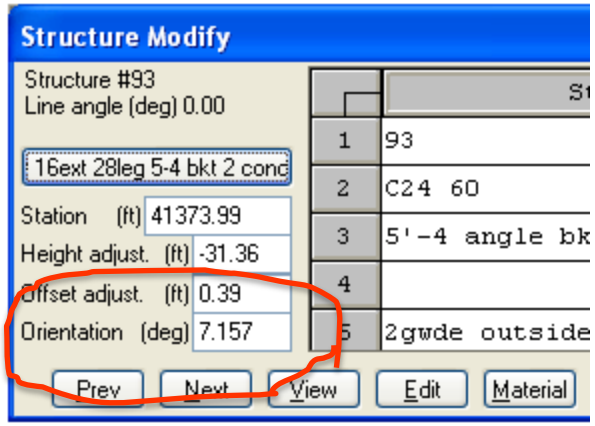
Moved Structure
based on one phase only
bundle conductor located tower to centroid

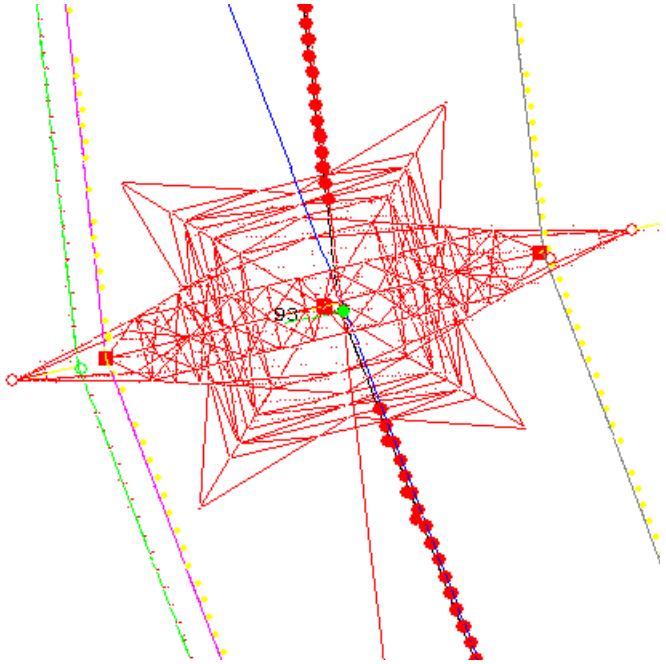


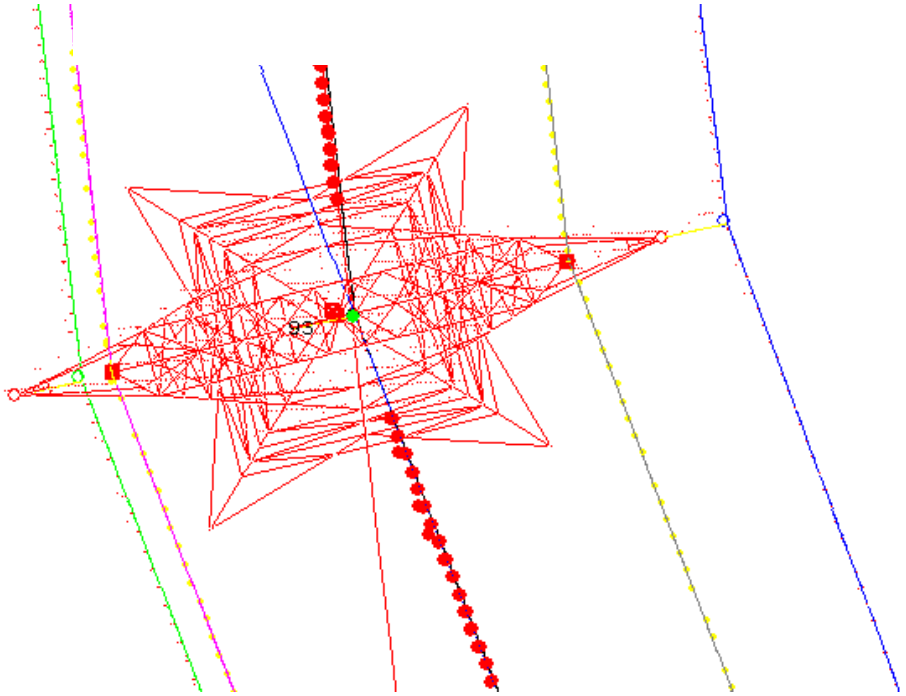






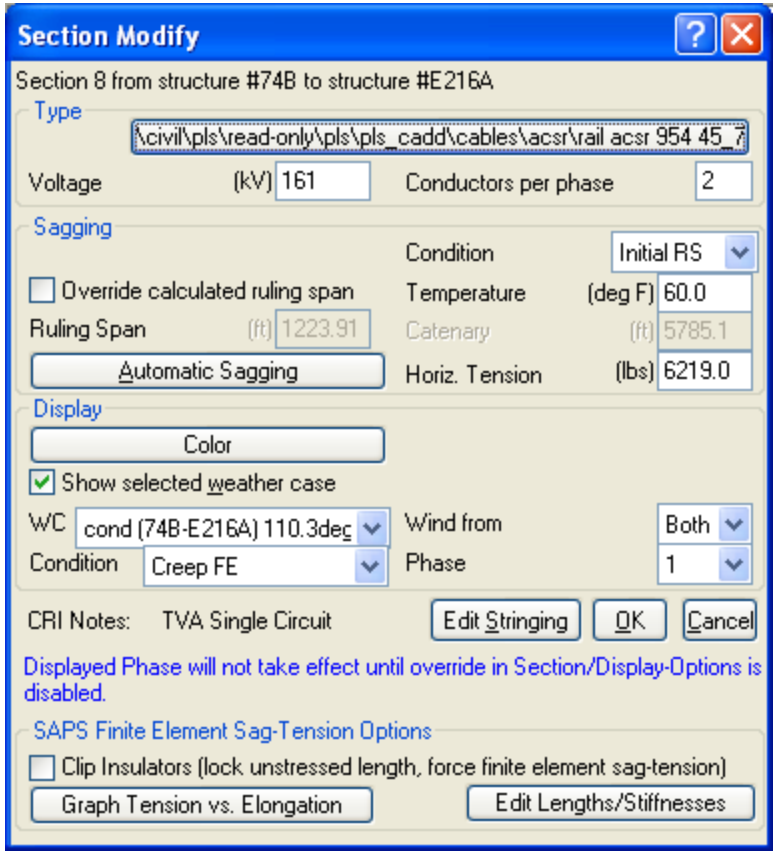




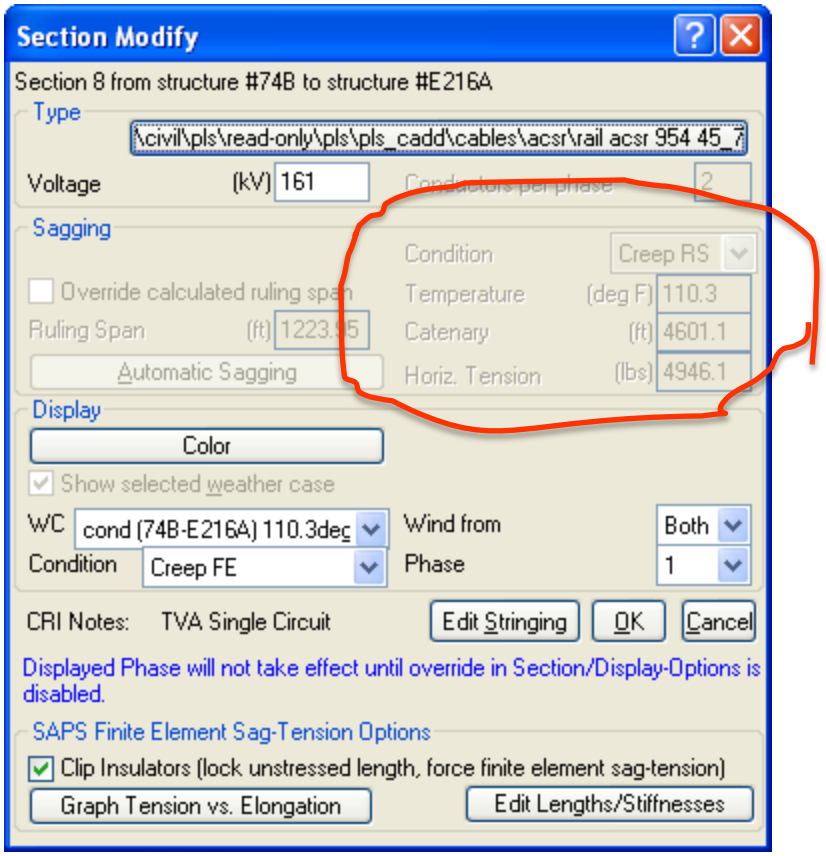


Using FE6 adjust str
moved str of PI

FE6 first three options not selected

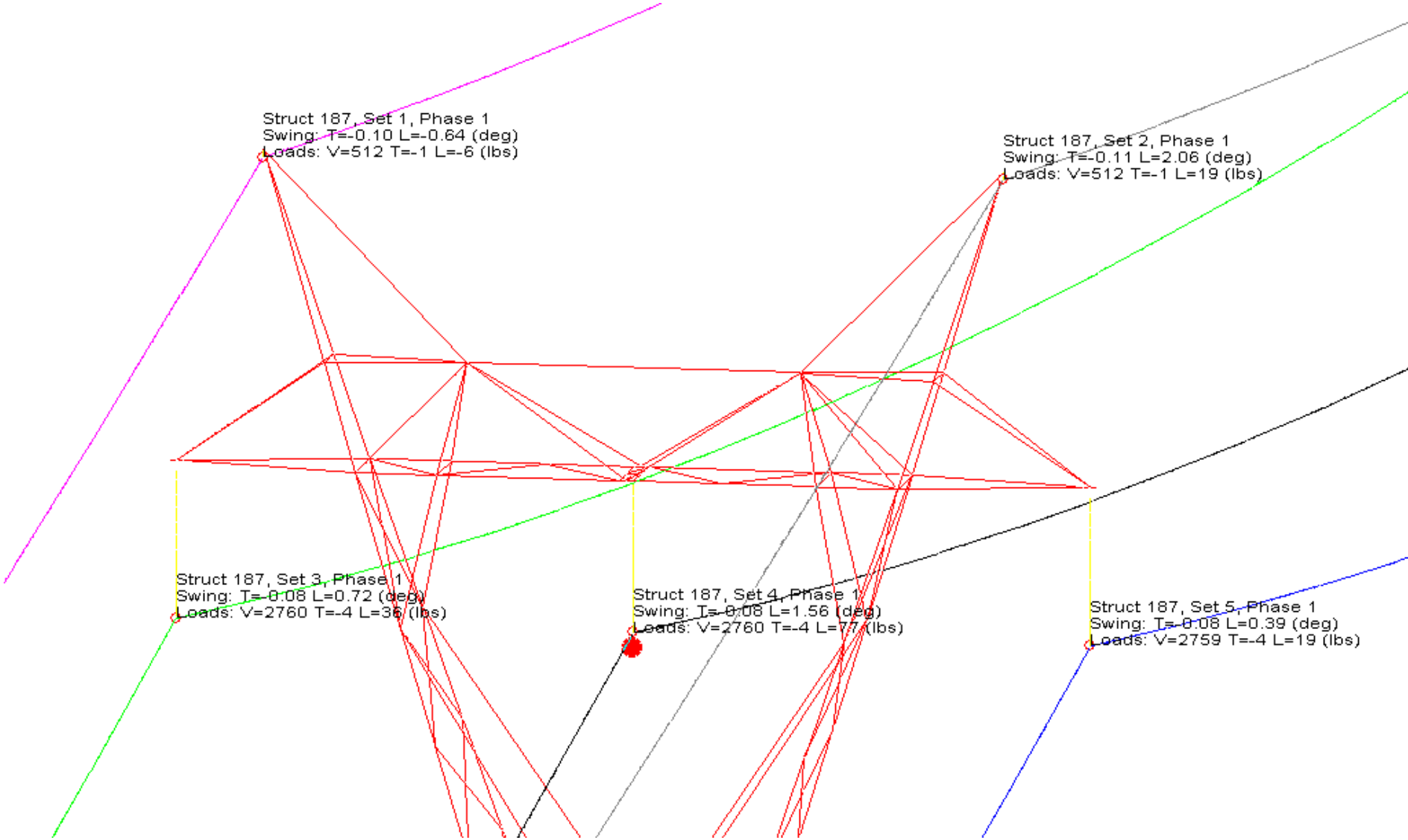


FE6 with first three options selected

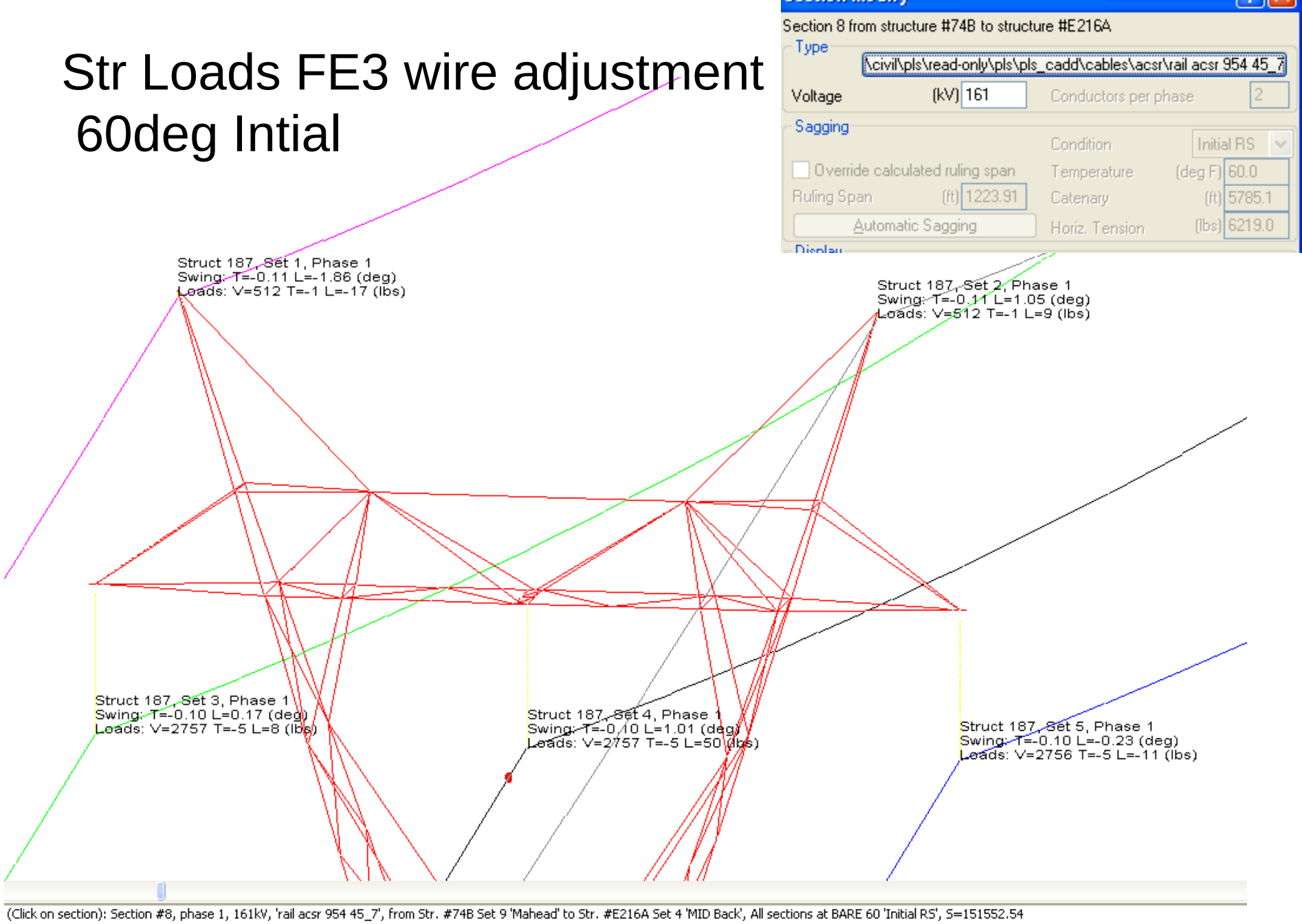


Also
Longitudinal Loads on the structure will be determined from modeled insulator swings at As captured and sagging conditions

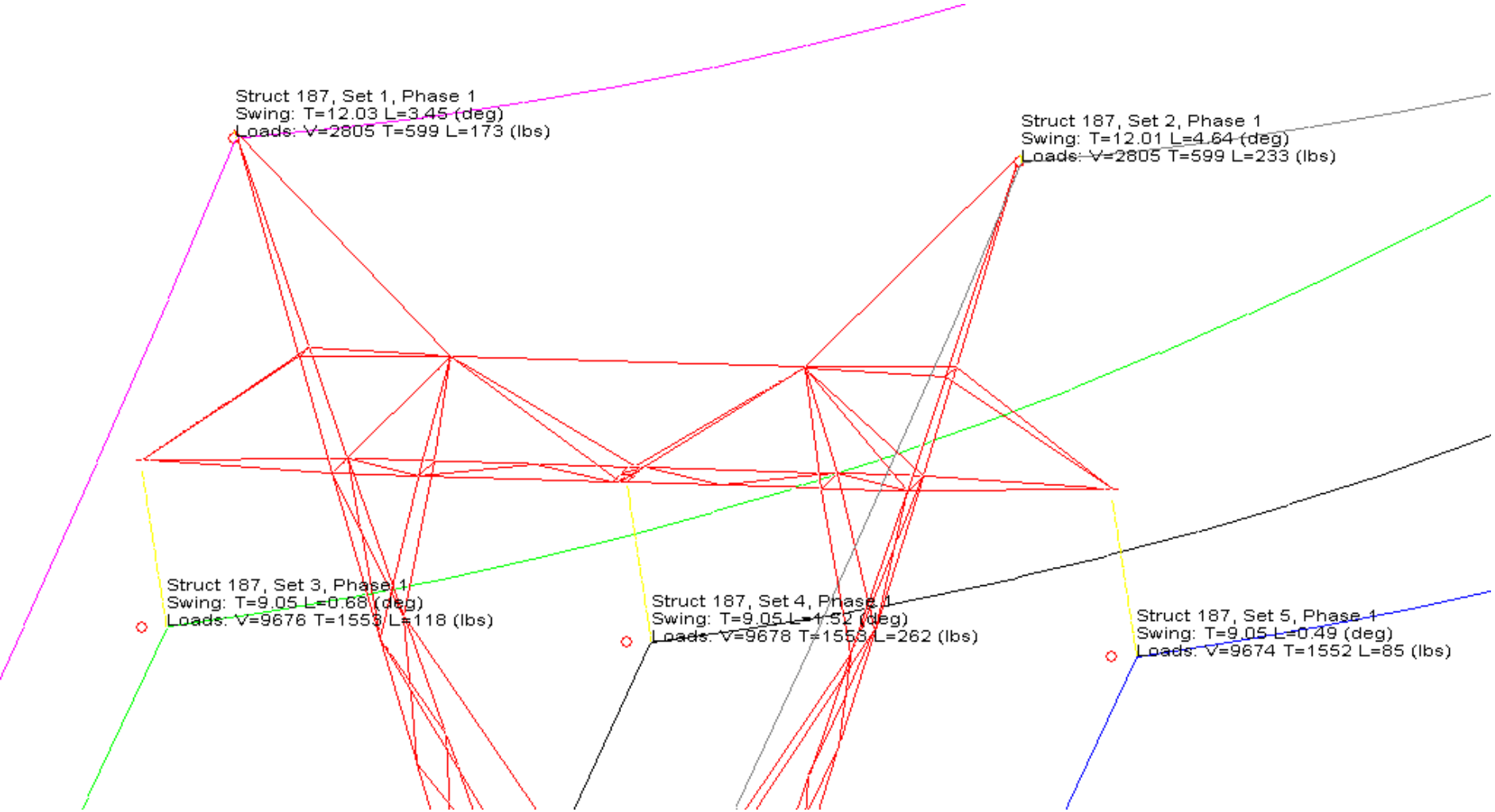
Str Loads FE3 wire adjustment As Capture



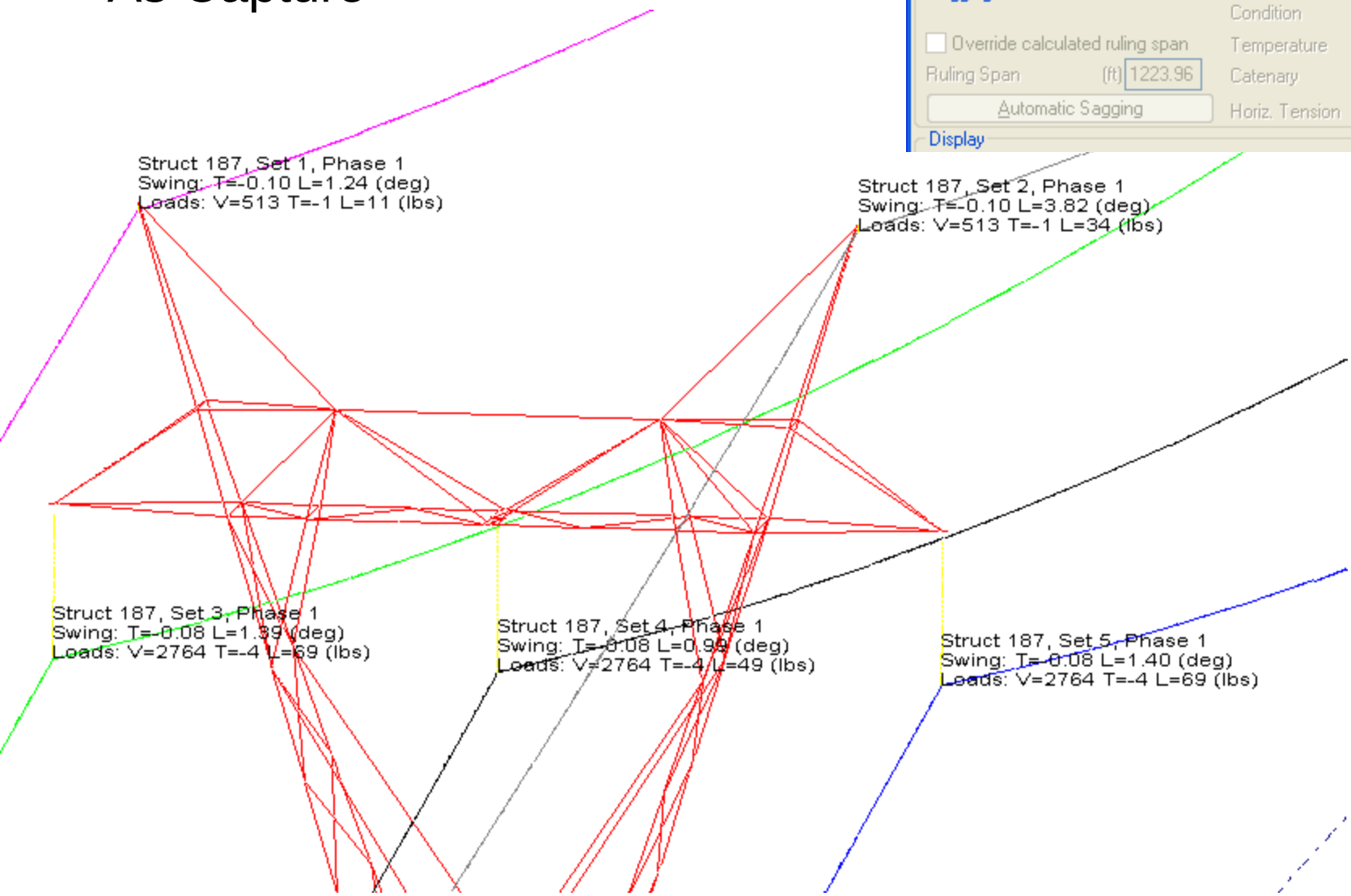
Str Loads FE3 wire adjustment 60deg Intial

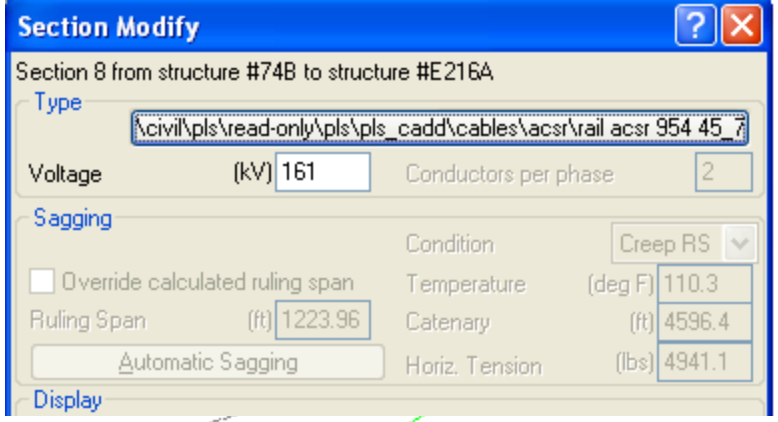


Str Loads FE3 wire adjustment NESC 1” Ice 250D

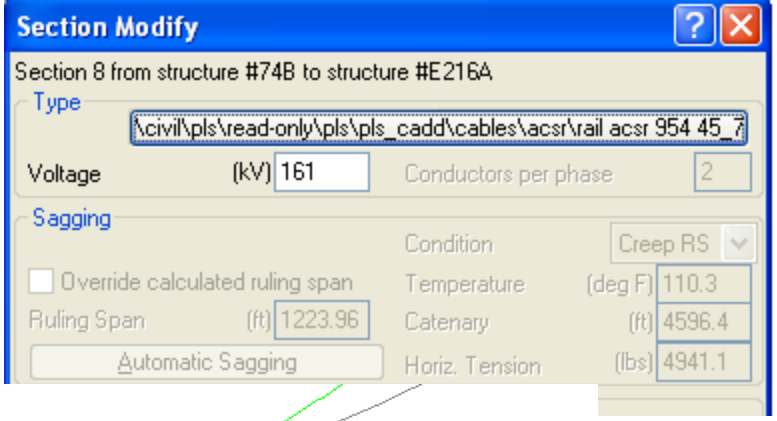


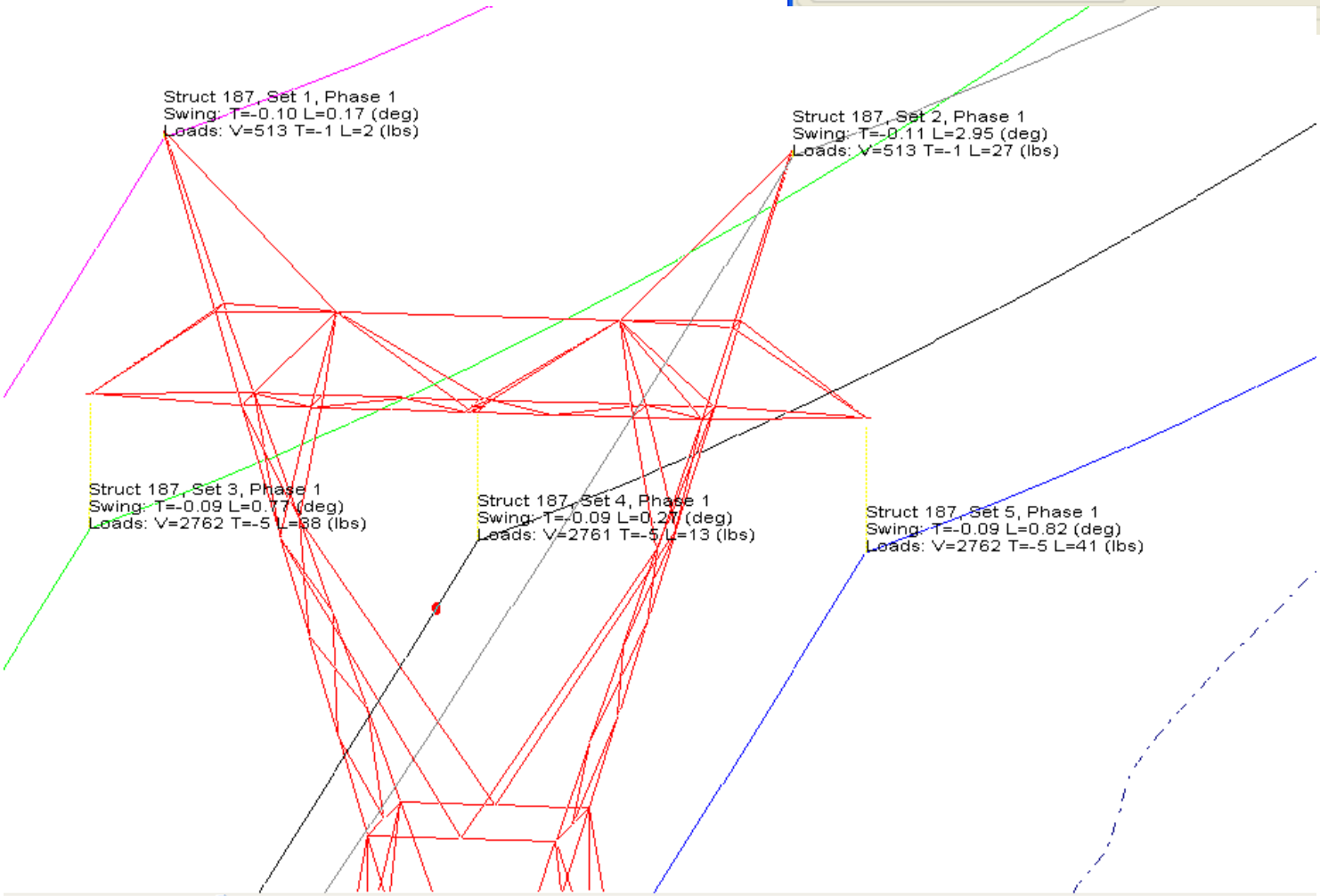
Str Loads FE4 wire adjustment As Capture





Str Loads FE4 wire adjustment 60deg Initial





Structural Loads

- Longitudinal loads will depend on Sagging Conditions FE3 (Initial 60) FE4 (AS Captured Final)
- NESC ICE (250D) loads will be influenced by As Capture Swing
- Additional Longitudinal Load created by Cut/Slide to provide clearances

Conclusion

- Assumption of insulators are plumb is removed by FE3 adjustment with correct sags in each span
- Results are still based on how well derive the conductor Temperature from weather data
- Range Ambient 66.1deg to No Wind 90.7deg
- Using all the weather data including solar radiation gave 71.2deg
- Thermal Rating is impacted approximately an equal temperature from the input conductor temperature
- Cost of additional modifications