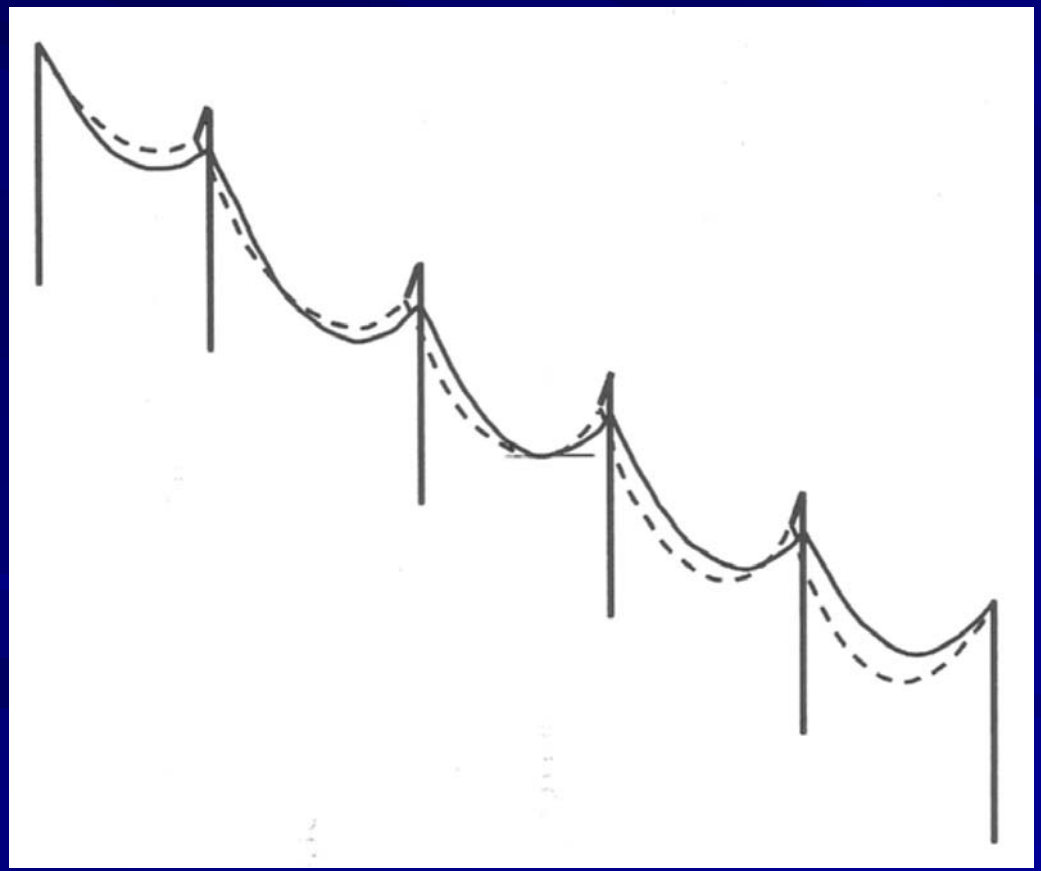
Sag Corrections and Clipping Offsets



Introduction and Basic Concepts

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Scope and Goals of Tutorial

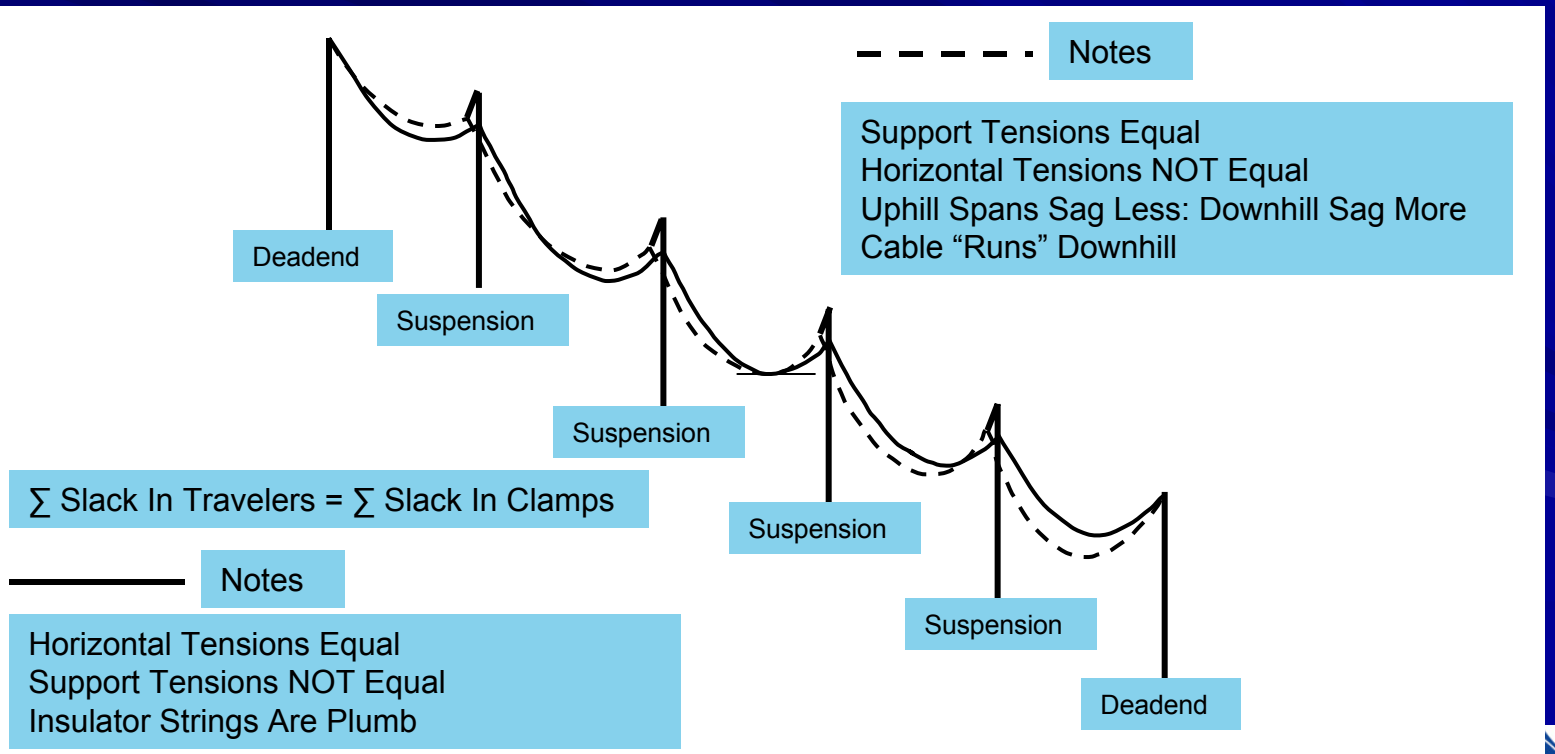
- What are Sag Corrections and Clipping Offsets
- Why bother and when are they needed
- How to apply in the sagging and clipping process
- Also Include …
  - Basic Catenary Equations Useful to Process
  - Brief Description of Physics and Geometry
  - Basic calculation strategy
  - Limitations and Critical Concepts and Mis-concepts
  - General Guidance and Tutorial Take-aways

Sag Corrections and Offsets

- Useful;
  - Sagging a series of suspension spans
  - Hilly terrain – attachments elevations vary by 3% or more
  - Ensure insulators are plumb after clipping complete
- Not Useful;
  - Deadend spans will not use this process
  - Extremely flat terrain – however, process will indicate whether the corrections and offsets are useful
  - Not concerned insulators are plumb after clipping

Basic Concern and Challenge

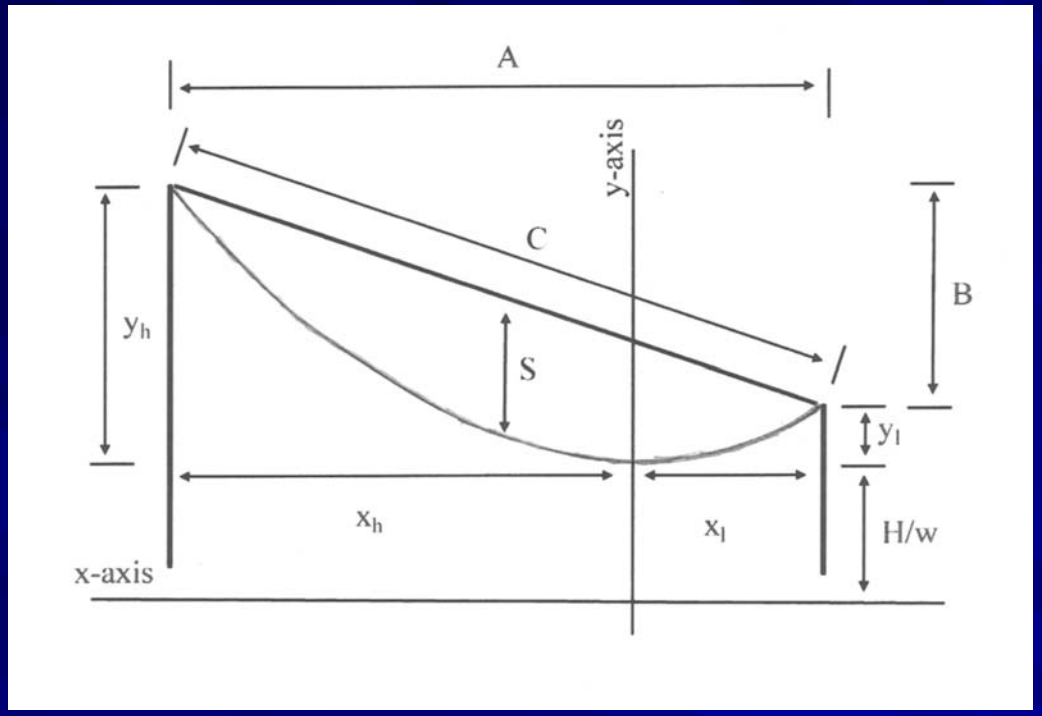
- In travelers cable on dotted line – in clamps cable on solid line.
- How to put cable on proper sag and locate clamps to move from dotted to solid line?



Fundamental Observations

- Slack in travelers is equal to slack in clamps
- In travelers;
  - At each structure support tension ahead and back is equal – otherwise sheave would roll
  - Horizontal tension not equal between spans
  - Uphill spans sag less and downhill spans sag more
- In clamps;
  - Horizontal tension is equal in all spans
  - At each structure support tension is not equal
  - All spans will be in solid line with insulators plumb

Important Catenary Equations



- Vertical distance above low point

$$y_{l,h} = \frac{H}{w}\left(\cosh\left[\frac{x_{l,h}}{H/w}\right] - 1\right)$$

Important Catenary Equations

- Cable Length and Slack

$$L_{l,h} = \frac{H}{w}\sinh\left[\frac{x_{l,h}}{H/w}\right]$$

$$Slack = L_l + L_h - C$$

- Support Tension

$$T_{l,h} = H\cosh\left[\frac{x_{l,h}}{H/w}\right] = H + H\cosh\left[\frac{x_{l,h}}{H/w}\right] - H$$

$$T_{l,h} = H + w \cdot y_{l,h}$$

Cable In Travelers

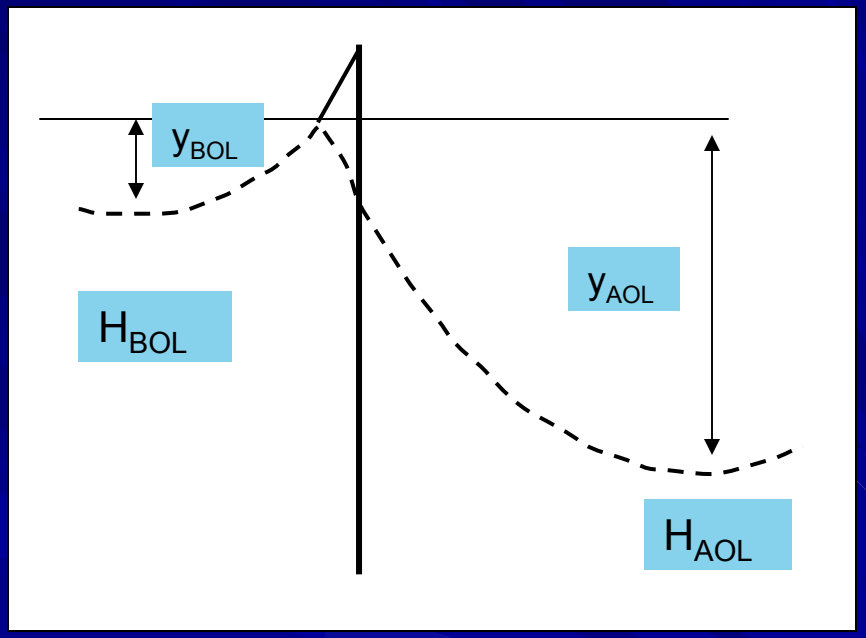
- Traveler swings uphill

$$T_{AOL} = T_{BOL}$$

$$H_{AOL} + w \cdot y_{AOL} = H_{BOL} + w \cdot y_{BOL}$$

$$y_{BOL} < y_{AOL}$$

$$H_{BOL} > H_{AOL}$$



- Slack runs downhill

$$H_1 > H_2 > H_3 \ \ldots$$

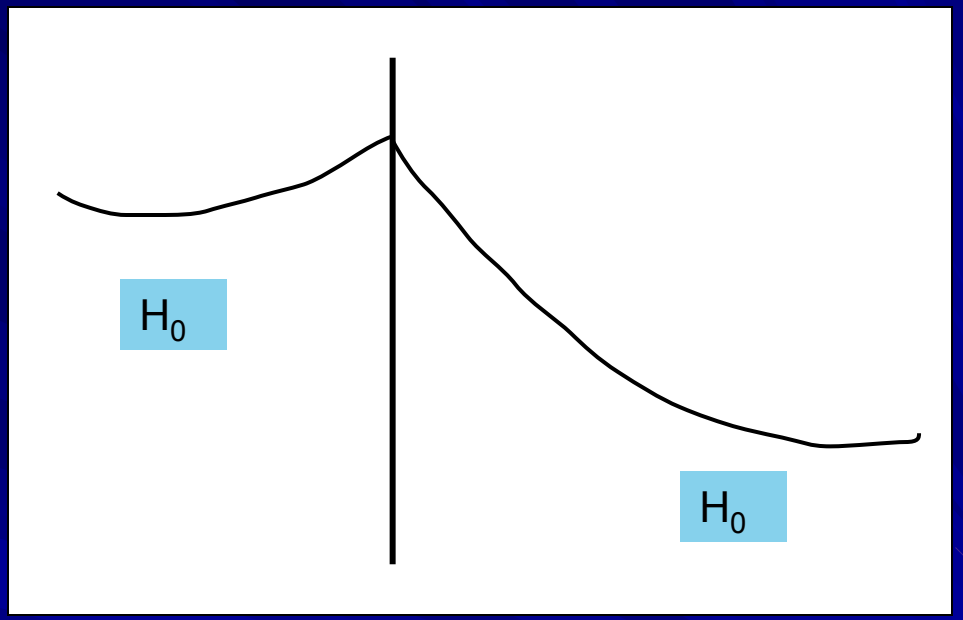
Cable in Clamps

- Insulators plumb

$$H_{AOL} = H_{BOL}$$

$$H_1 = H_2 = H_3 \ldots$$

$$T_{AOL} > T_{BOL}$$



- Slack correct in spans

$$\sum Slack_{Travelers} = \sum Slack_{Clamps}$$

Sagging and Clipping Cable

- Sagging cable puts the correct amount of slack in a sag section to put all spans in section on specified sag when clipped.
- Clipping cable firmly attaches the cable to all its supports in the sag section, restricting slack transfer.

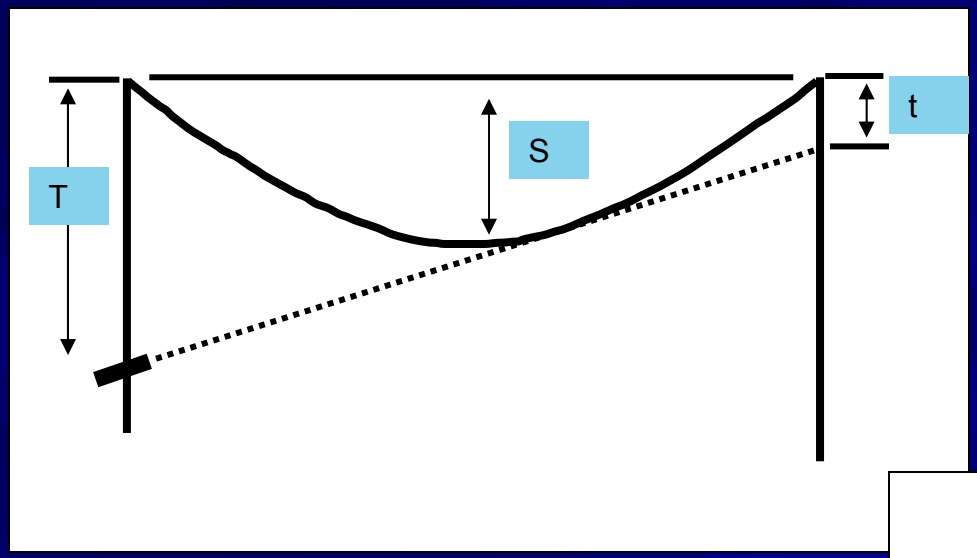
Sag Section and Zero Structure

- Select a sag section to facilitate sagging process
- Usually 20 spans or less
- Zero structure at ends of sag section
  - Holds attachment rigid with “zero” slack transfer
  - Deadends are automatically zero structures
  - Suspensions typically have cables “snubbed” to create zero strucutre
- Sag corrections and clipping offsets highly dependent on sag section geometry

Sagging Cable

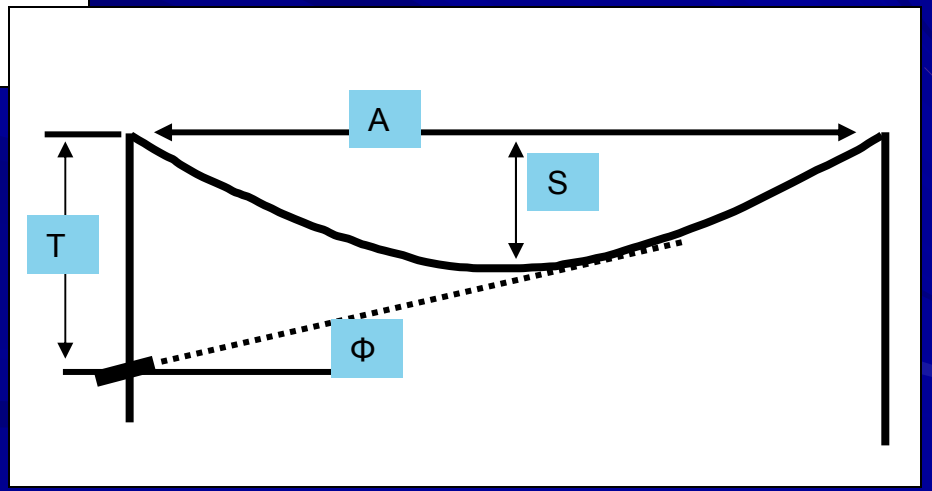
- Preparing for Sagging
  - Select sag section for sagging – zero structures
  - Select control span(s) to measure sag for section
- Select Sagging Method
  - Target Sagging
  - Angle Sagging
  - Other Methods
    - Traveling Wave (Stop Watch)
    - Survey Benches
    - Tension Measurement (Dynos)

Target or Angle Sagging



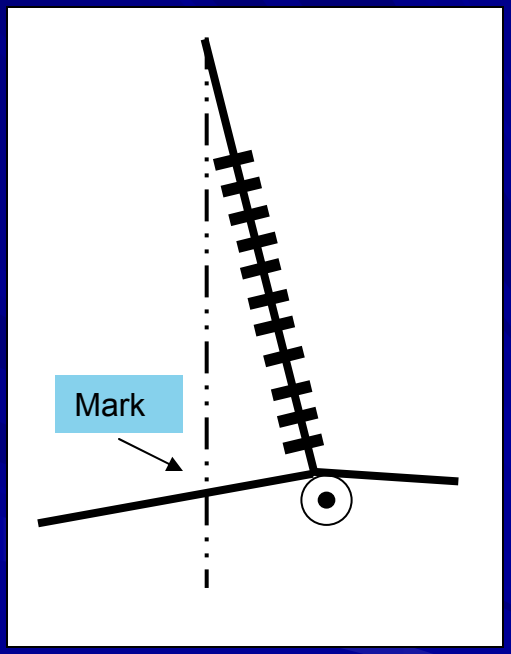
$$\tan\phi = \frac{T - \left(2\sqrt{S} - \sqrt{T}\right)^2}{A}$$

$$t = \left(2\sqrt{S} - \sqrt{T}\right)^2$$



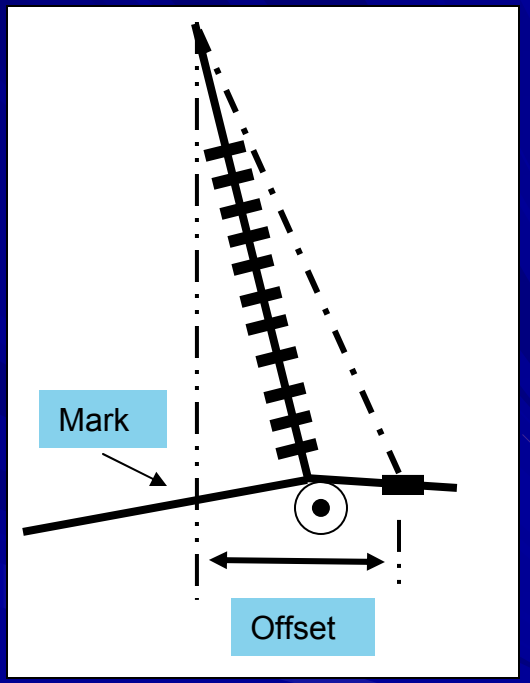
Sagging Cable

- Install Cable On Sag
  - Calculate targets or angles using the spans geometry, design sag (in clamps), and sag correction
  - Place cable on calculated sag in each control span
  - Mark the cable directly below attachment at all structures



Clipping Cable

- Install Cable In Clamps Using Clipping Offsets
  - Attach clamp to cable offset from sagging mark by the specified clipping offset
  - Attach clamp to supporting hardware (insulators)
  - Clipping can commence in any order
  - The supporting hardware will not be plumb until all clipping is complete

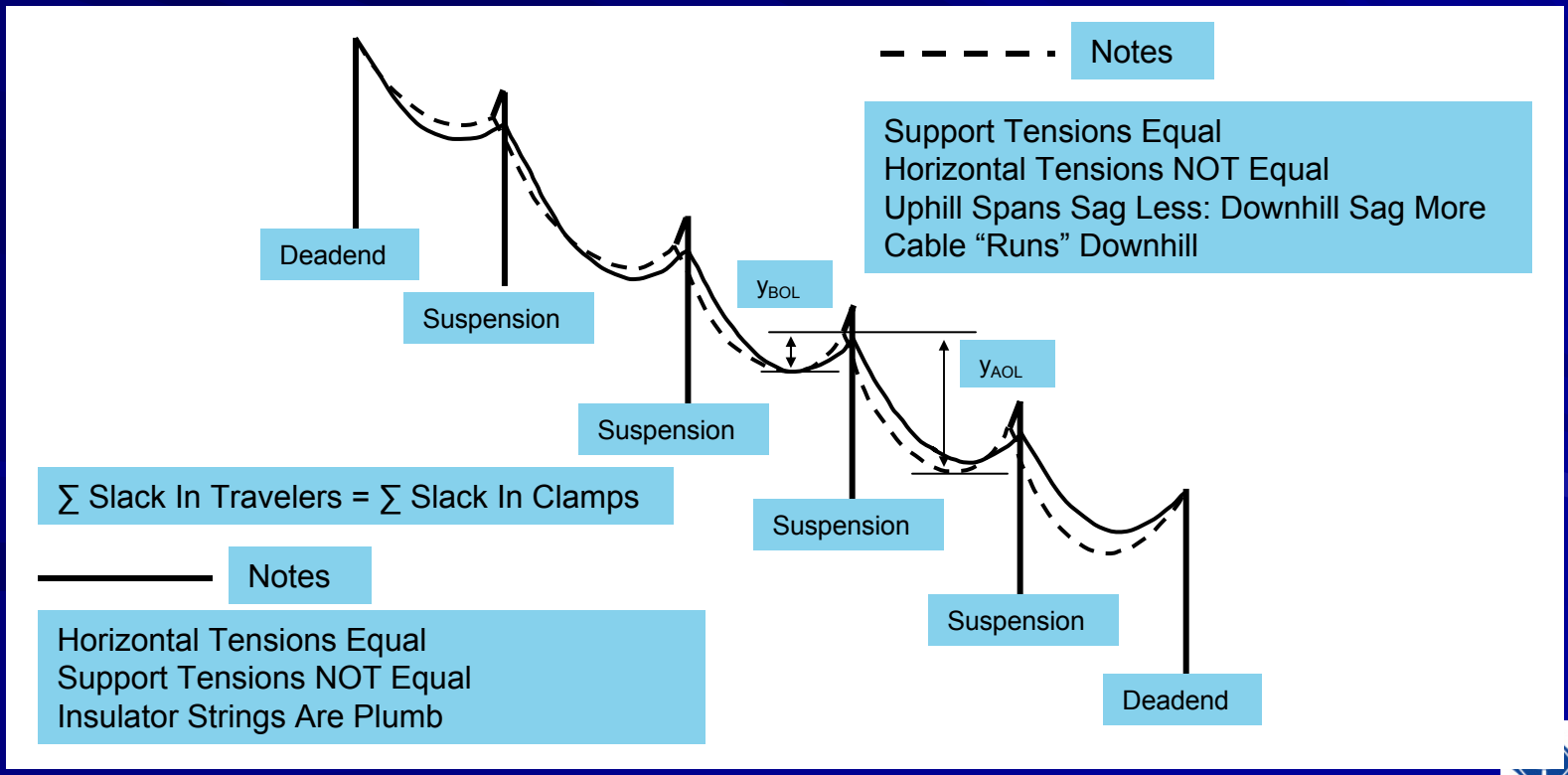


Calculation Process

- Process described is based on: "Sag-Tension Computations and Field Measurements of Bonneville Power Administration" by Paul Winkleman, AIEE Transactions 1959
- Other techniques are available, but perform essentially the same analysis
- Process lends itself to spreadsheets or simple computer coding

Calculation Process - Clamps

- Using design sagging tension (H_0, "solid line")
  - Calculate sags in clipped position for all spans
  - Calculate slack in clipped position for all spans
  - Sum slack in clipped position for sag section



Calculation Process - Travelers

- Using assumed horizontal tension at zero structure (no slack transfer)

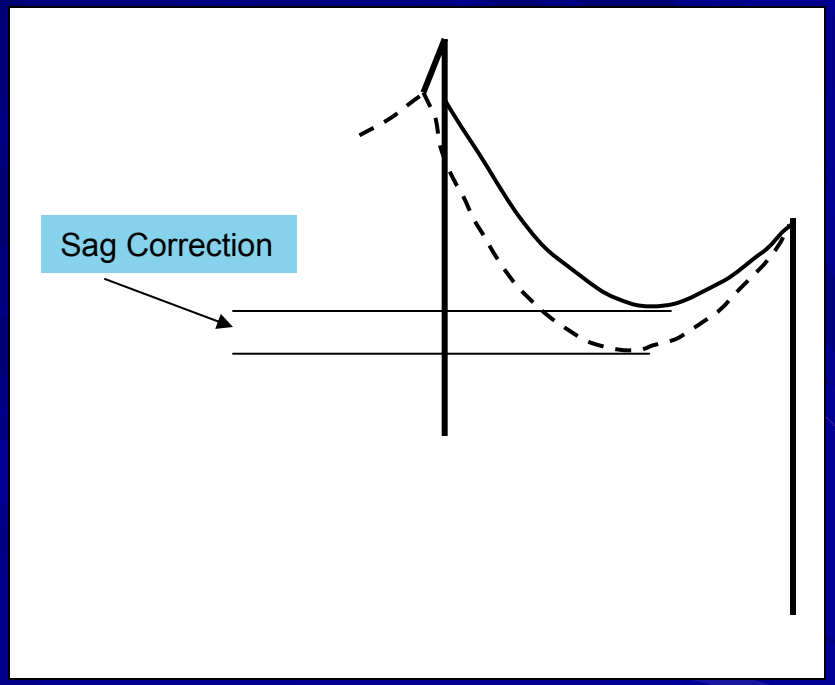
$$H_{BOL} + w \cdot y_{BOL} = H_{AOL} + w \cdot y_{AOL}$$

$$y_{AOL} = \frac{H_{AOL}}{w}\left(\cosh\left[\frac{x_{AOL}}{H_{AOL}/w}\right] - 1\right)$$

  - Adjust H_{AOL} until solution found to satisfy equations
  - Cascade calculation process through sag section
  - Calculate and sum slack for sag section
  - Adjust assumed horizontal tension until slack in travelers equals slack in clamps – dotted line

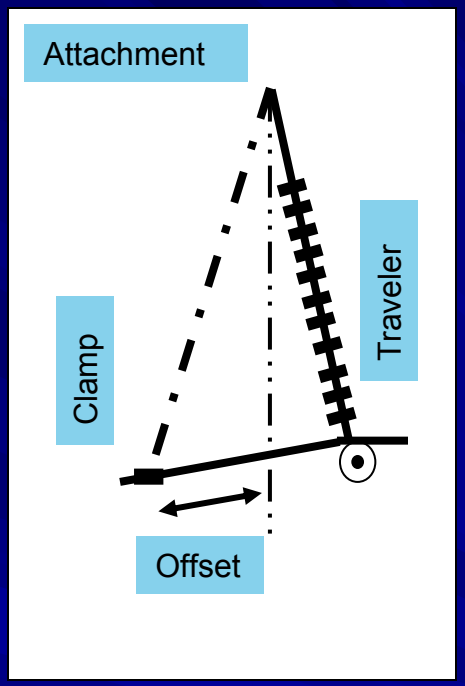
Calculation Process – Sag Corrections

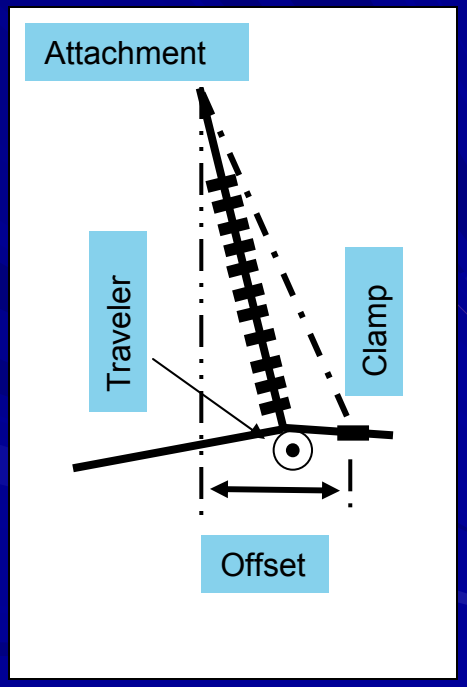
- Difference of sag in travelers and clamps is the sag correction
- Sagging places the right amount of cable and slack in sag section, but not properly distributed between spans



Calculation Process – Clipping Offsets

- Clipping offsets places the right amount of slack in each span for the sag section
- Offsets are from reference mark Ah/Bk
- All marking must be completed before any clipping begins





Calculation Process

- Calculation factors and considerations:
  - Sag section geometry critical to calculations
  - Tension changes between spans in travelers should include consideration for elastic stretch – Hooke's law
  - Cable temperature can be a factor, but nominal value of 60 F usually adequate
- BPA Sag Corrections and Clipping Offsets
  - Analysis utility running on MS Excel platform
  - Uses span specific geometry and design tensions
  - Performs analysis and generates report for specs
  - Uses assumed zero structures – adjust during construction based on Saggers needs

Tutorial Take-Aways

- For rolling or mountainous terrain sag corrections and clipping offsets are required to place cable on design sag when clipped
- Geometry critical for proper values, hence if a zero structure is moved the calculation must be repeated with new geometry
- Sag corrections are specific to each span and can be either negative (less sag) or positive (more sag)

Tutorial Take-Aways

- Marking is directly below structure attachment point and must be completed before any clipping begins
- Clipping can commence in any order, hence careful selection of sequence can facilitate the effort
- Sagging and clipping should be completed in 48 hours to minimize adverse effects of creep due to tension imbalance

Thank You

Q/A