Calculation Force to Pull Cables into Pipes

UPDATE THEORY FROM 1953

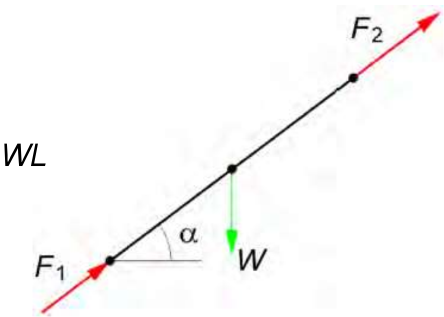
Willem GRIFFIOEN

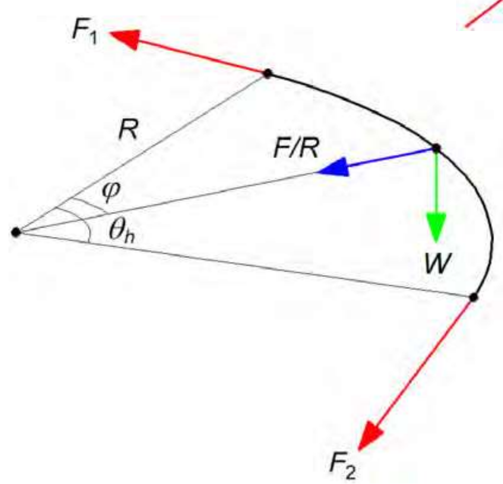
CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

Gravity friction

- Coefficient of friction (COF) f
- Straight section
- Bends
  - Cable tension
    - Sidewall force
    - Capstan effect
    - Exponential formula
  - Together with gravity more complex
    - See next slide

$$F_2 = F_1 + (f\cos\alpha + \sin\alpha)WL$$





$$F_2 = F_1 \exp(f\theta)$$

CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

Rifenburg formulas (1953)

- Horizontal bend $$F_2 = WR\sinh\left[f\theta_h + \sinh^{-1}\left(\frac{F_1}{WR}\right)\right]$$
- Vertical bend

$$F_2 = F_1e^{f\varphi} - \frac{WR}{1+f^2}\left[2f\sin\varphi + \left(1-f^2\right)\left(\cos\varphi - e^{f\varphi}\right)\right] \qquad \text{4a}$$

$$F_2 = F_1e^{f\varphi} - \frac{WR}{1+f^2}\left[2f\left(\cos\varphi - e^{f\varphi}\right) - \left(1-f^2\right)\sin\varphi\right] \qquad \text{4b}$$

$$F_2 = F_1e^{f\varphi} + \frac{WR}{1+f^2}\left[2f\sin\varphi + \left(1-f^2\right)\left(\cos\varphi - e^{f\varphi}\right)\right] \qquad \text{4c}$$

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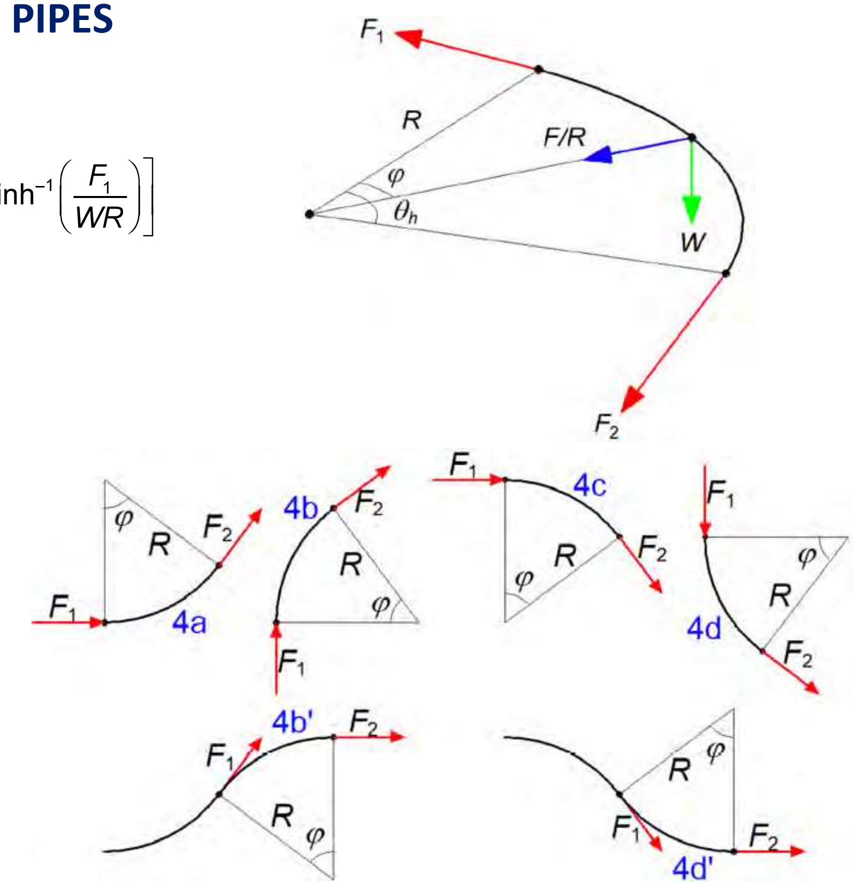


CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

Rifenburg drawbacks for vertical bends (still):

- Formulas given only cover special cases (else formulas get more complex)
- User must define what kind of bend it is
- Does not cover large radius bends, like in horizontal directional drills (HDD)
  - When mass dominant cable follows outside facing pipe wall
- Does not cover pushing at all

Drawbacks taken away with new theory:

- Covers all situations, only α_1 and α_2 needed (vertical bends)
- Also full down to up (or vice versa) bends, covers 2 quadrants

$$F_2 = F_1 e^{\pm f|\alpha_2 - \alpha_1|} \mp \frac{WR}{1+f^2}\left[\psi(\alpha_2) - e^{\pm f|\alpha_2-\alpha_1|}\psi(\alpha_1)\right]$$ with:

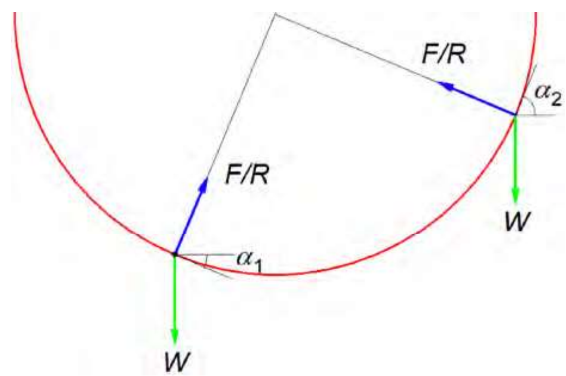
$$\psi(\alpha) = 2f\sin\alpha \pm (1-f^2)\cos\alpha$$ $\alpha_2 > \alpha_1$ (concave)

$$\psi(\alpha) = 2f\sin\alpha \mp (1-f^2)\cos\alpha$$ $\alpha_2 < \alpha_1$ (convex)

$F \gtrless \pm WR\cos\alpha$

$\pm$ Inside facing wall

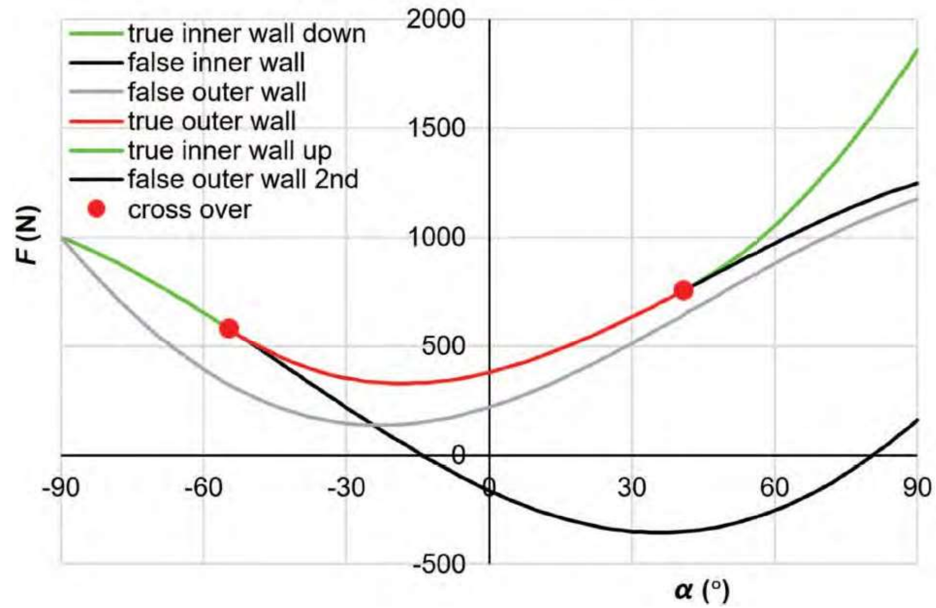
$\mp$ Outside facing wall



CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

Example showing difference with old theory (extreme case)

- Vertical bend starting 90° down, ending 90° up, bend radius 10 m
- Cable with linear weight density 100 N/m
- Coefficient of friction 0.5
- Pulling force before bend 1000 N
- Starts following inside facing pipe wall
  - Like in old theory
- Then crosses over to outside facing wall
  - New theory takes this into account
- Finally crosses back to inside facing wall
  - Like in old theory again
  - But, totally different answer



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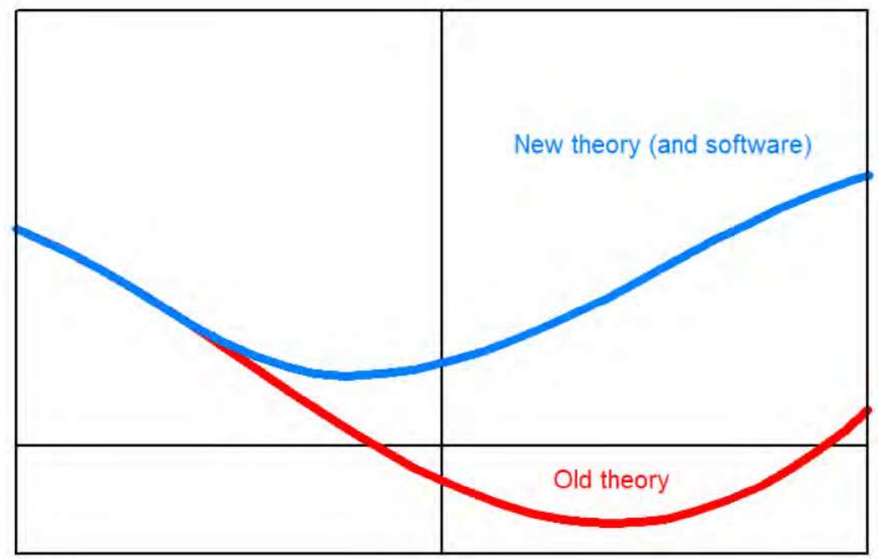
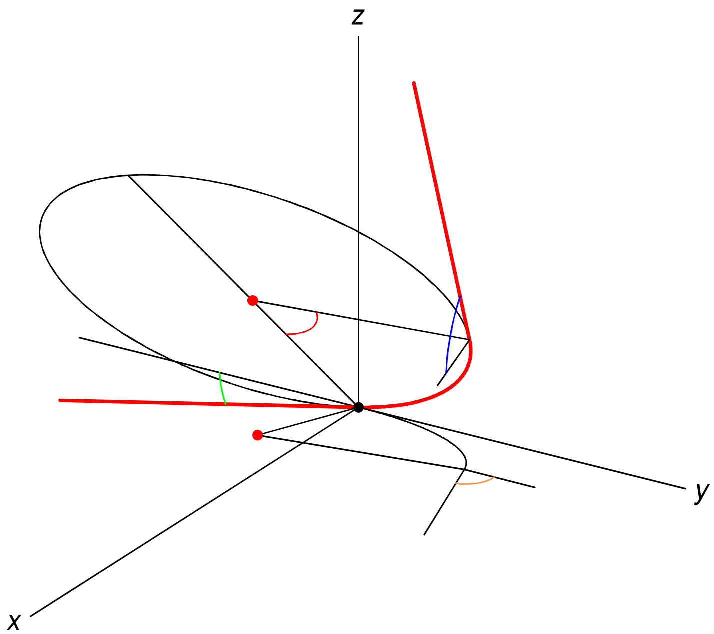


CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

3-Dimensional bends

- Input parameters
  - Slope at entry bend α_1
  - Slope at exit bend α_2
  - Angle of horizontal bend θ_h
- Calculated parameters
  - Help parameter β
  - Total angle 3D bend θ (function of local real angle φ)
  - Local slope along bend α
  - Angle between gravity and capstan force ξ (needed to calculate pulling force)



$$\cos\theta = \cos\alpha_1 \cos\alpha_2 \cos\theta_h + \sin\alpha_1 \sin\alpha_2$$

$$\sin\alpha = \cos\alpha_1 \sin\beta \cos\varphi + \sin\alpha_1 \cos\varphi$$

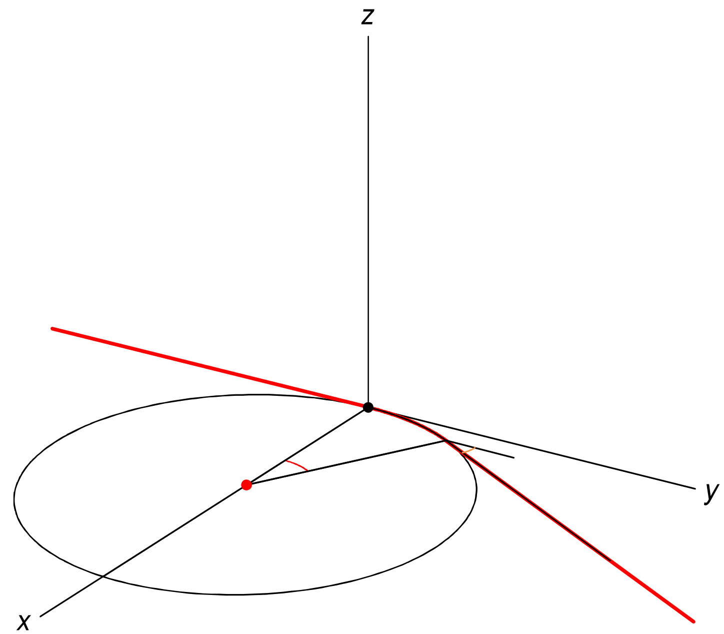
$$\cos\xi = \sin\alpha_1 \sin\varphi - \cos\alpha_1 \sin\beta \cos\varphi$$

$$\tan\beta = \frac{\sin\alpha_2 \cos\alpha_1 - \sin\alpha_1 \cos\alpha_2 \cos\theta_h}{\cos\alpha_2 \sin\theta_h}$$

CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

3-Dimensional bends

- A few configurations α_1 α_2 θ_h θ
- Horizontal



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3-Dimensional bends

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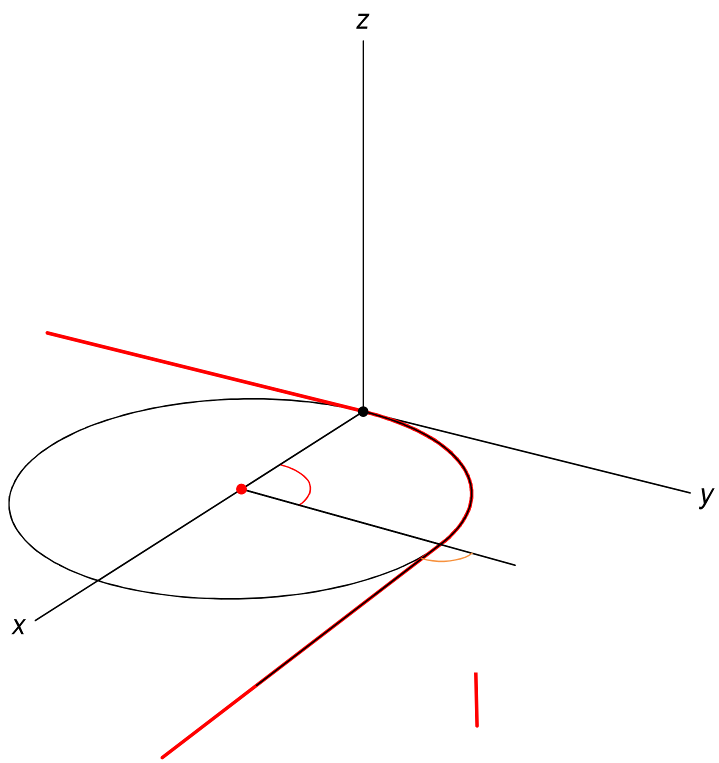
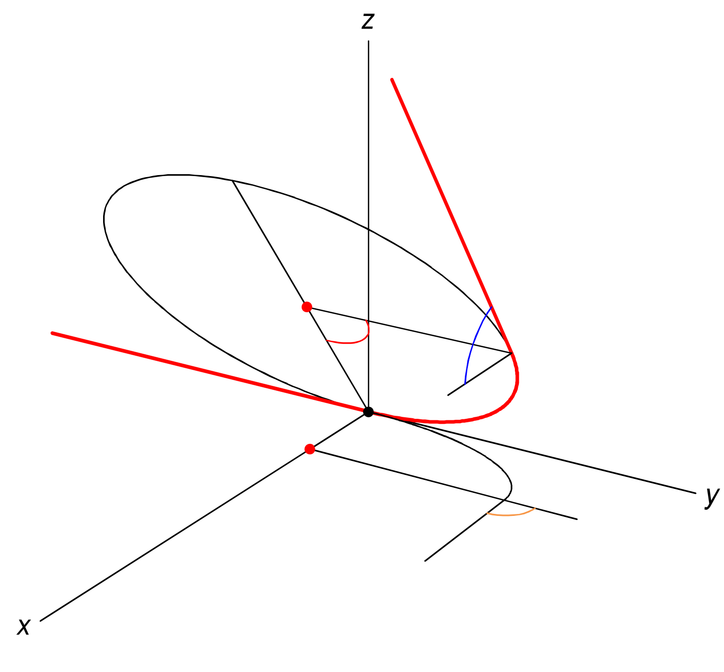


CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

3-Dimensional bends

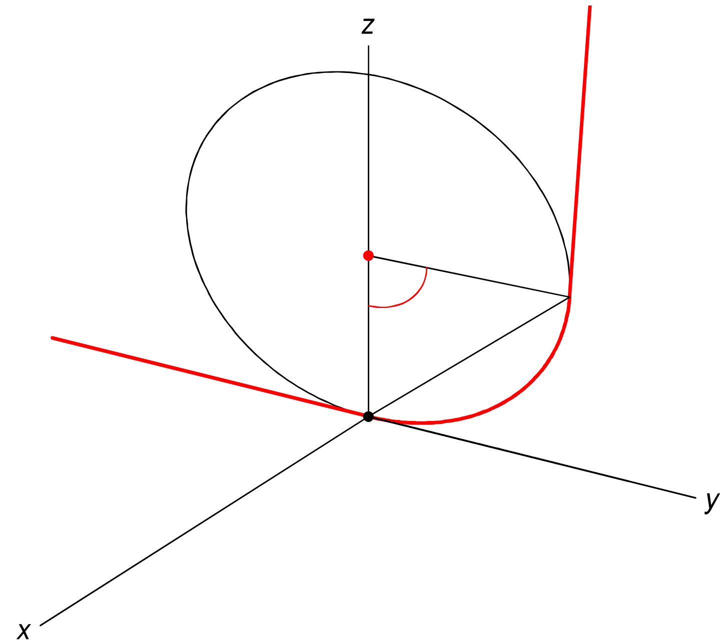
- A few configurations α_1 α_2 θ_h θ
- Horizontal
- Inclined



CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

3-Dimensional bends

- A few configurations α_1 α_2 θ_h θ
- Horizontal
- Inclined
- Vertical



CALCULATION FORCE TO PULL CABLES INTO PIPES
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3-Dimensional bends

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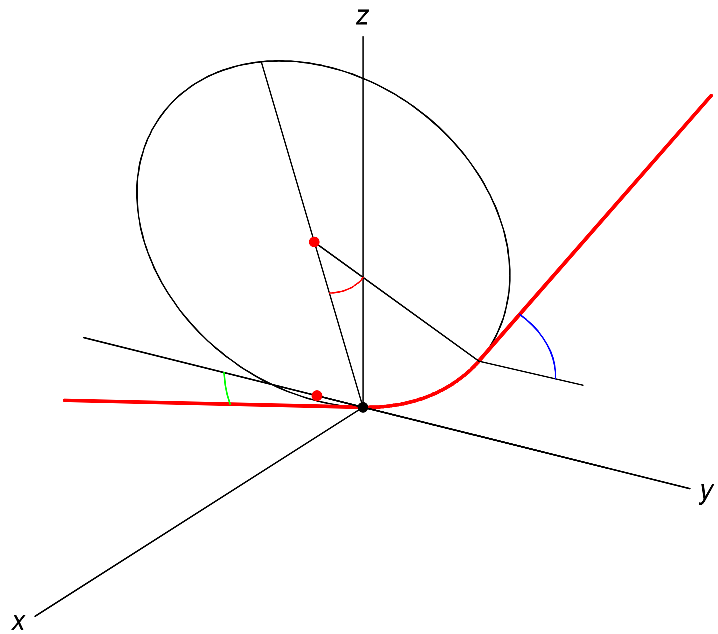
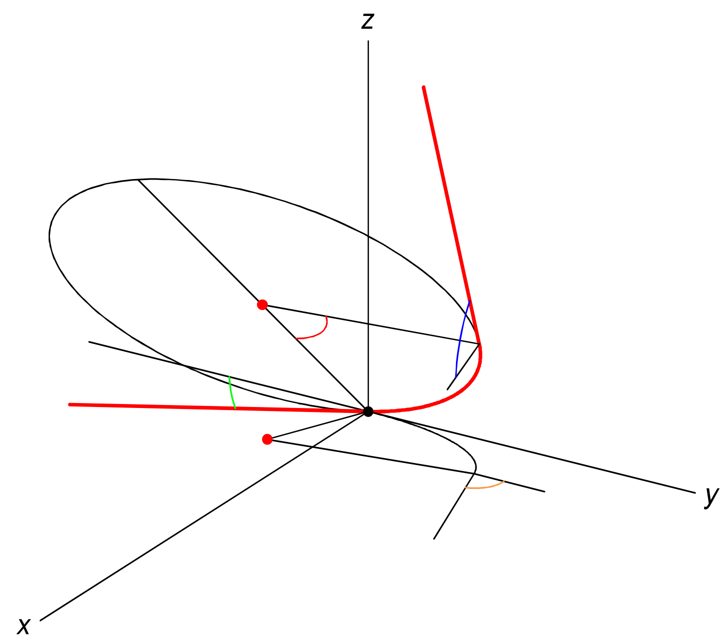


CALCULATION FORCE TO PULL CABLES INTO PIPES
Theory

3-Dimensional bends

- A few configurations α_1 α_2 θ_h θ
- Horizontal
- Inclined
- Vertical
- Arbitrary



CALCULATION FORCE TO PULL CABLES INTO PIPES
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3-Dimensional bends

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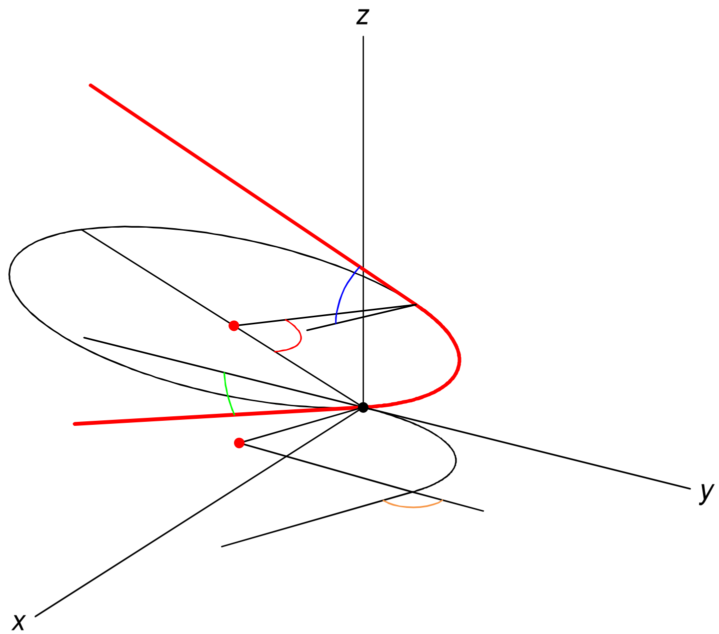


TRAJECTORY INPUT

Sequence of alternating straights and bends which each only 2 parameters

- Straights
  - Length and slope
- Bends
  - Horizontal angle and bend radius

No need to identify type of bends:

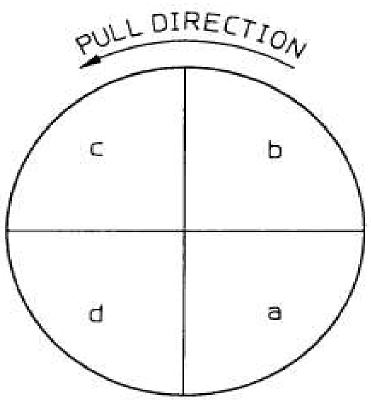
- Whether horizontal or vertical
- Which quadrant for vertical bend

Any entry and exit slope possible

- No need to start or end horizontally or vertically

Possibility to have bends over 2 quadrants

a) Concave up
b) Convex up
c) Convex down
d) Concave down

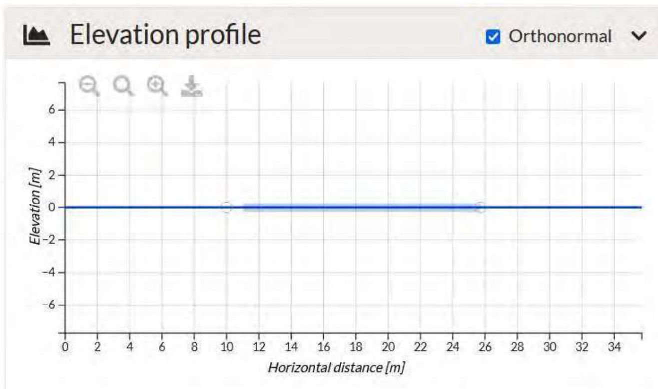


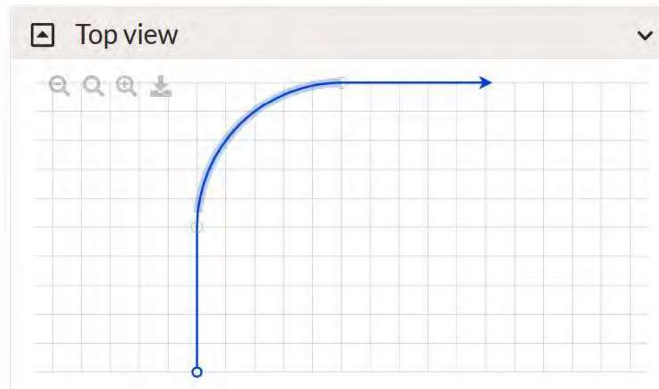
PULLING FORCE CALCULATION SOFTWARE
TRAJECTORY INPUT

Example

1. Horizontal bend

1	Straight	Length	10.00 m	Cumulative length	10.00 m	Altitude at end	0.00 m
		Slope	0.00°				
2	Curve	Length	15.71 m	Cumulative length	25.71 m	Altitude at end	-0.00 m
		Horizontal angle	90.00°	Total angle	90.00°	Bending radius	10.00 m
3	Straight	Length	10.00 m	Cumulative length	35.71 m	Altitude at end	-0.00 m
		Slope	0.00°				

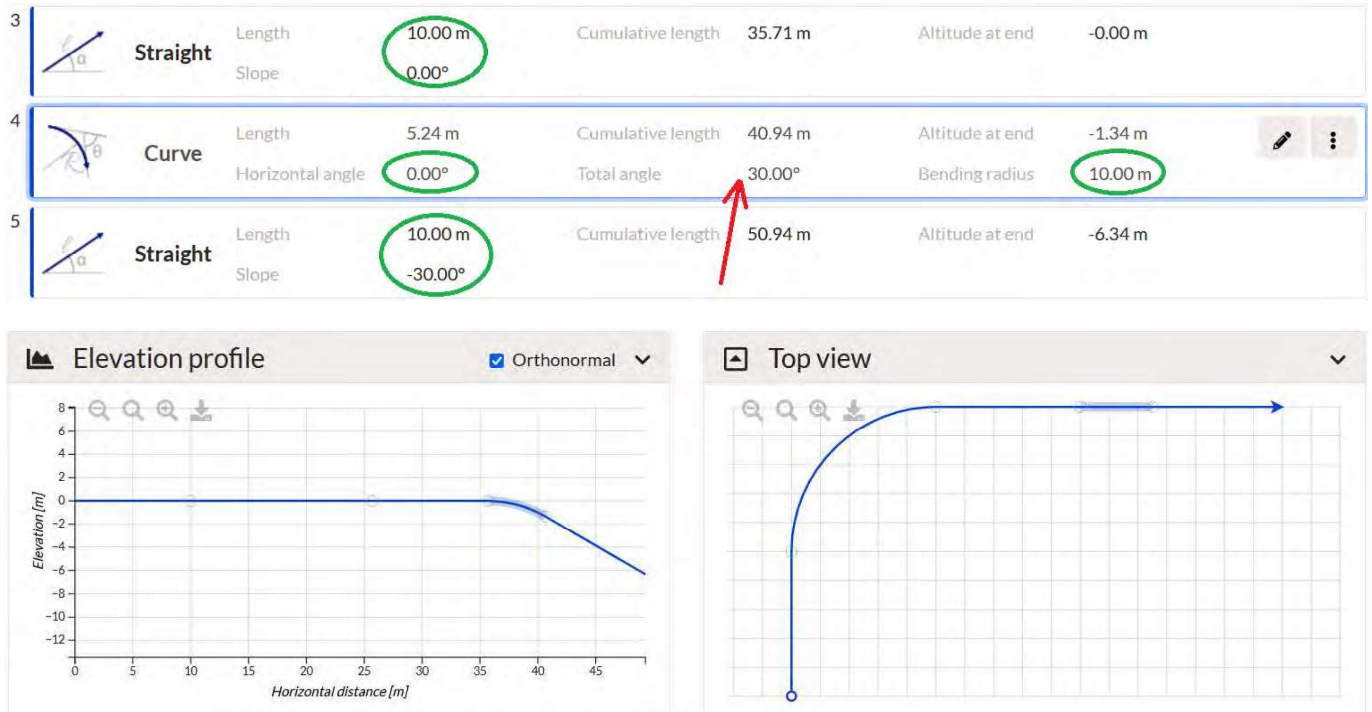




PULLING FORCE CALCULATION SOFTWARE
TRAJECTORY INPUT

Example

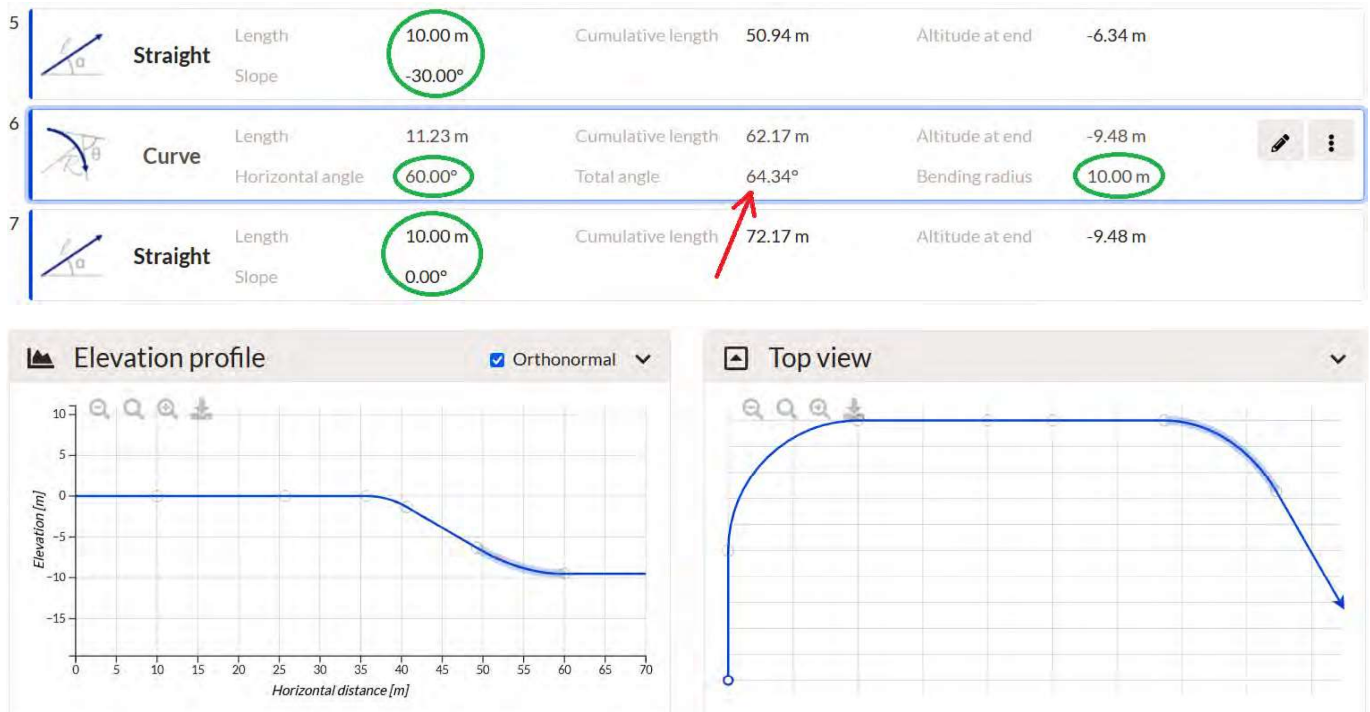
1. Horizontal bend
2. Next vertical bend



PULLING FORCE CALCULATION SOFTWARE
TRAJECTORY INPUT

Example

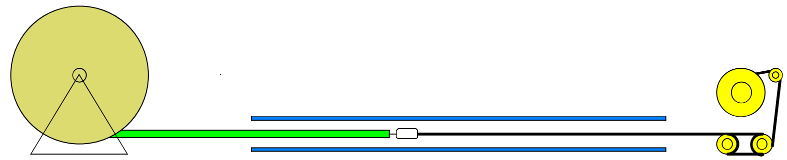
1. Horizontal bend
2. Next vertical bend
3. Next 3D bend



PULLING FORCE CALCULATION SOFTWARE
SIMULATIONS

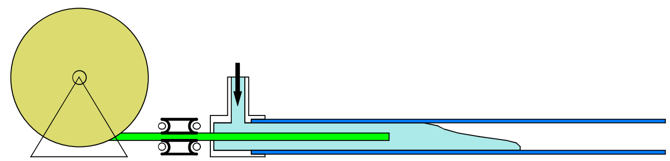
Techniques to install cables into pipes

- Traditional: winch pulling

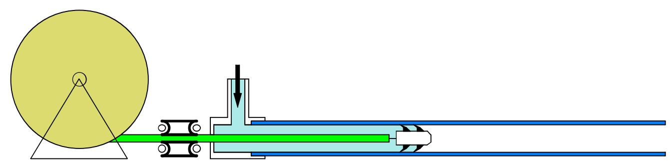


Alternative installation methods

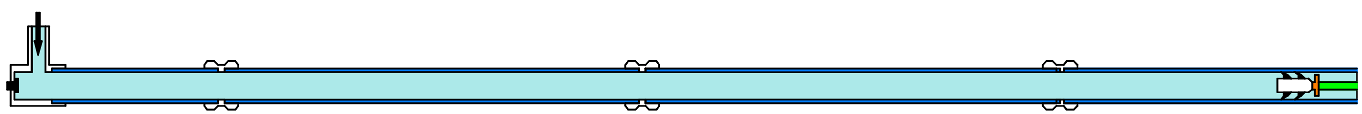
- Floating (pipes ID up to 100 mm)



- WaterPushPulling (unlimited pipe ID)



- FreeFloating (unlimited length!)



SIMULATIONS

Cable parameters

- Mass, diameter, stiffness, max force (pulling, pushing, radial), min bend radius

Pipe parameters

- Outside and inside diameter, max pressure, undulations

Coefficient of friction

Trajectory

- See previous

Installation method

- Pulling, Pushing, Pushpulling, Floating, WaterPushPulling, FreeFloating, Blowing (optical cables)
- This presentation focuses on Pulling (optional with pushing assistance)
- Cable stiffness (not taken into account in other software) important because:
  - High cable stiffness reduces buckling friction loss (on top of capstan effect) during pushing
    - If pushing can be calculated in other software, then buckling friction not taken into account
  - High cable stiffness also increases friction in bends (especially when sharp) and undulations in trajectory

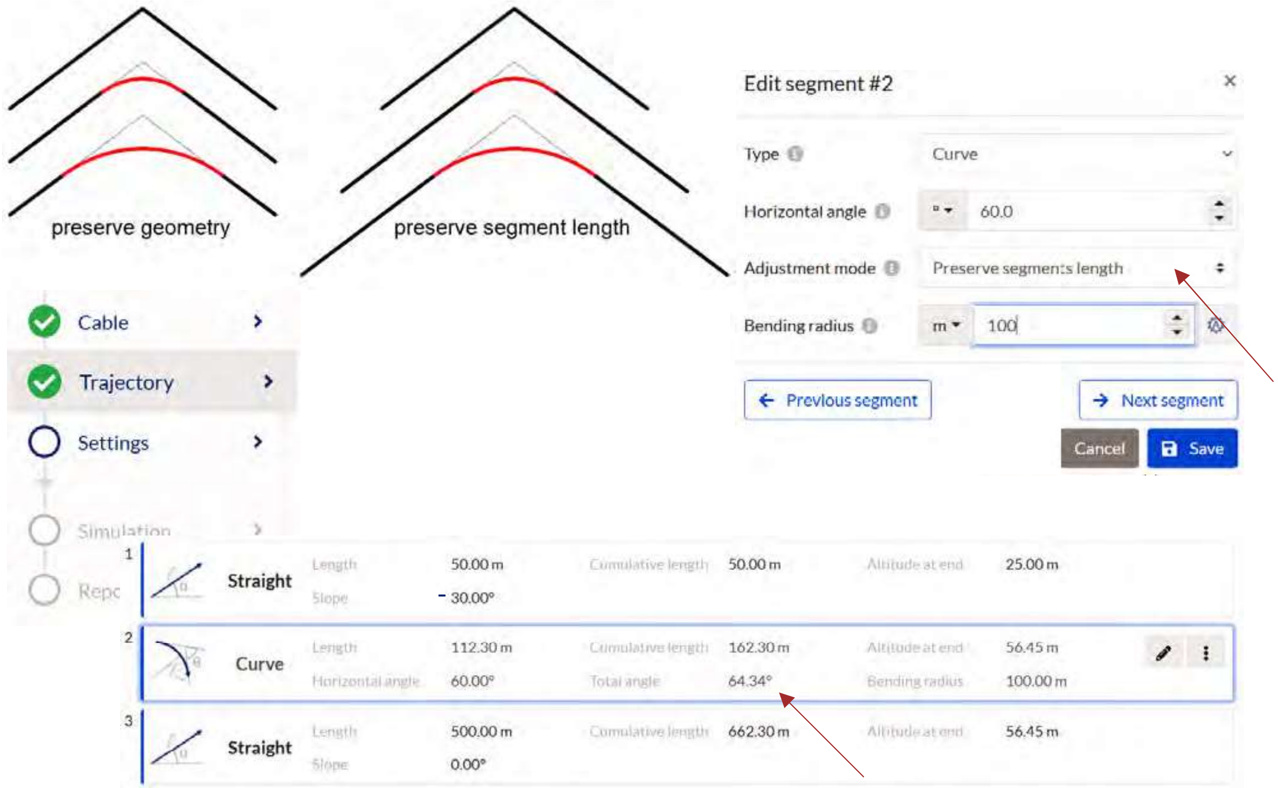
PULLING FORCE CALCULATION SOFTWARE
SIMULATIONS

Cable pulling example

- Start new project
- Method
- Equipment
- Stretches
- Cable parameters
- Trajectory
  - Add segment
  - Add more segments

  Curve between straights

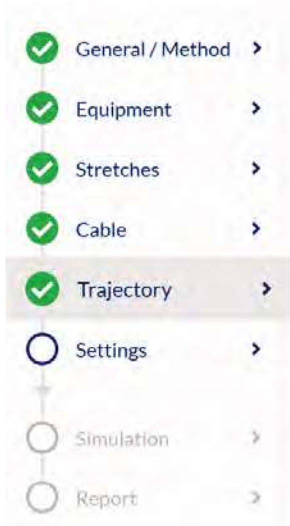
  And straight between curves
  - Note bend 2 (3D)

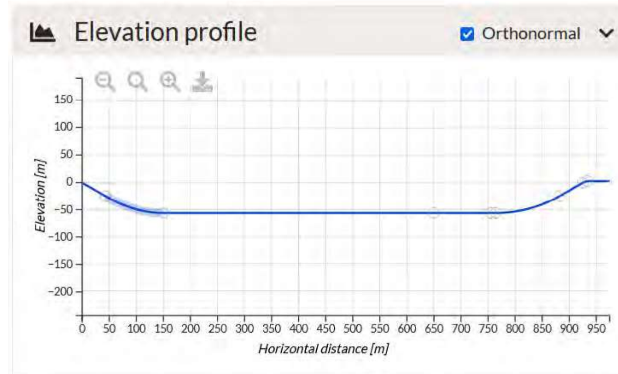


PULLING FORCE CALCULATION SOFTWARE
SIMULATIONS

Cable pulling example

- Start new project
- Method
- Equipment
- Stretches
- Cable parameters
- Trajectory
  - Overview



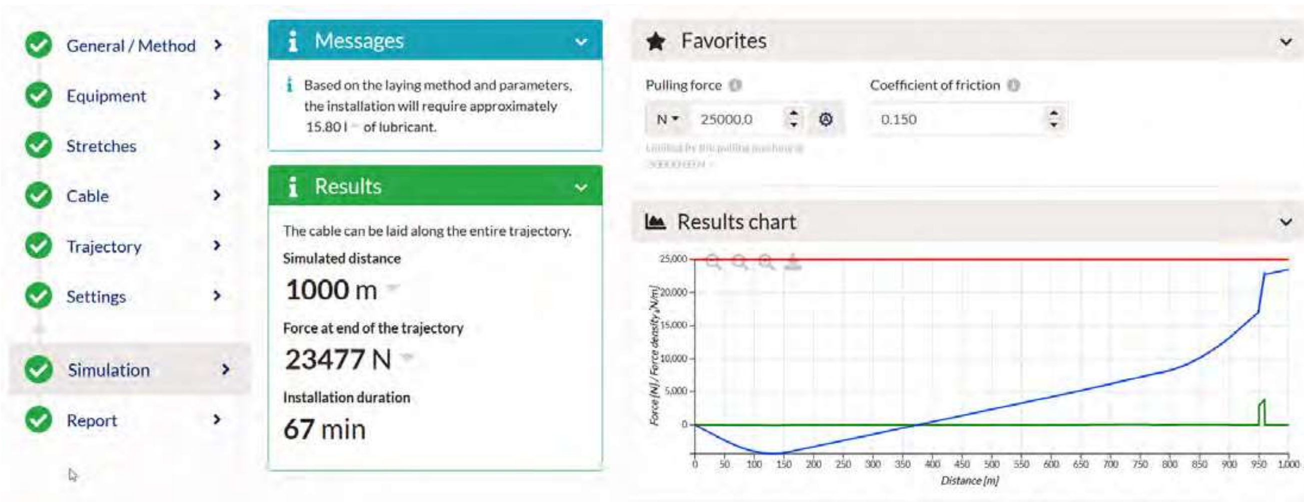


PULLING FORCE CALCULATION SOFTWARE
SIMULATIONS

Cable pulling example

- Start new project
- Method
- Equipment
- Stretches
- Cable parameters
- Trajectory
- Settings
- Simulation
  - Vary favorite
  - Pulling force
  - Or another favorite (coefficient of friction)

Blue line = axial force built up in cable
Red line = potential available axial force
Green line = radial force density



CALCULATION FORCE TO PULL CABLES INTO PIPES
Conclusions

Theory for calculating force to pull cables into pipes (1953)

- Still used today
- Not accurate for large bend radii in pipe (like HDD drills) when force still low
- Also not accurate when pushing cable

Upgrade of theory presented

- Corrected for above inaccuracies
- Recognizes crossing over cable from inside to outside facing pipe wall
- Also includes 3D bends
  - Calculates 3D bend parameters from
    - Straights with lengths and slope
    - Bends with horizontal angle and bend radius
    - Easy programming
  - Takes into account pulling force build-up for 3D bends
- Software presented that does it all, plus more:
  - Other installation techniques, effect of cable stiffness, etcetera

THANK YOU

FOR YOUR ATTENTION

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