Implementation of spring support conditions in linear generalized beam theory (GBT) to model support-pipe interaction

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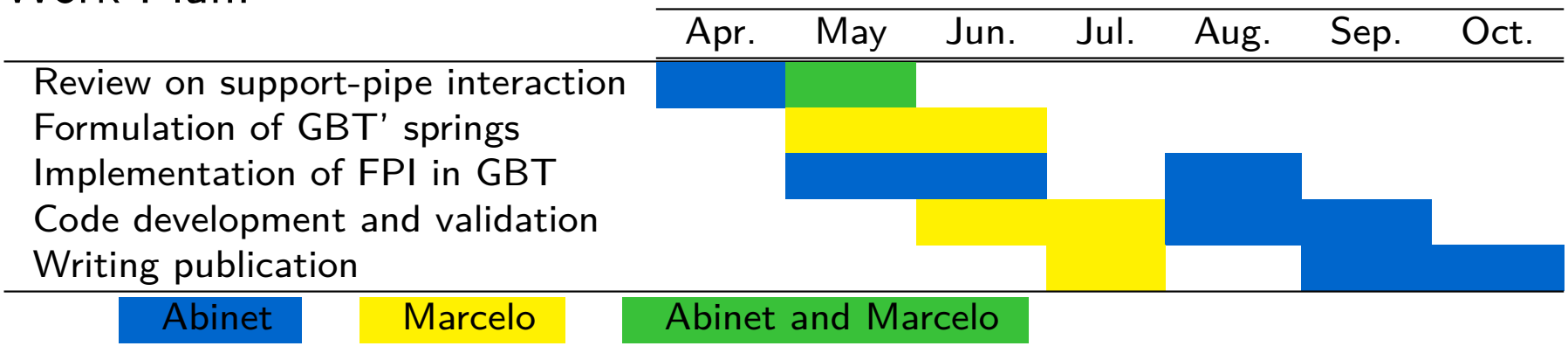
Introduction

- Above ground pipelines
  - Soil-foundation-pipe interaction
  - The effect of the ground motion can be reduced by using special support conditions between foundation and pipe
  - Spring support condition at the supports in GBT pipeline model
- Buried pipelines
  - Soil-pipe interaction
  - Seismic response is largely dependent on the surrounding soil
  - Continuous spring support condition in GBT pipeline model

Secondment Objective

- Focus on above ground pipelines
- Implementation of Foundation-Pipe Interaction(FPI) model in GBT
- Case study: Trans-Alaska Pipeline System(TAPS)
  - Denali fault zone
  - Denali earthquake in 2002, magnitude 7.9
- Work Plan:



- Conference publication or journal publication (based on the results of the research)

Above Ground Pipelines

- Pros:
  - Leakage can be easily detected and repaired
  - Subsoil is permanently frozen
- Cons:
  - The land cannot be used

Support Condition

Can be designed to allow:

- Temperature expansion
- Base isolation in earthquake prone area

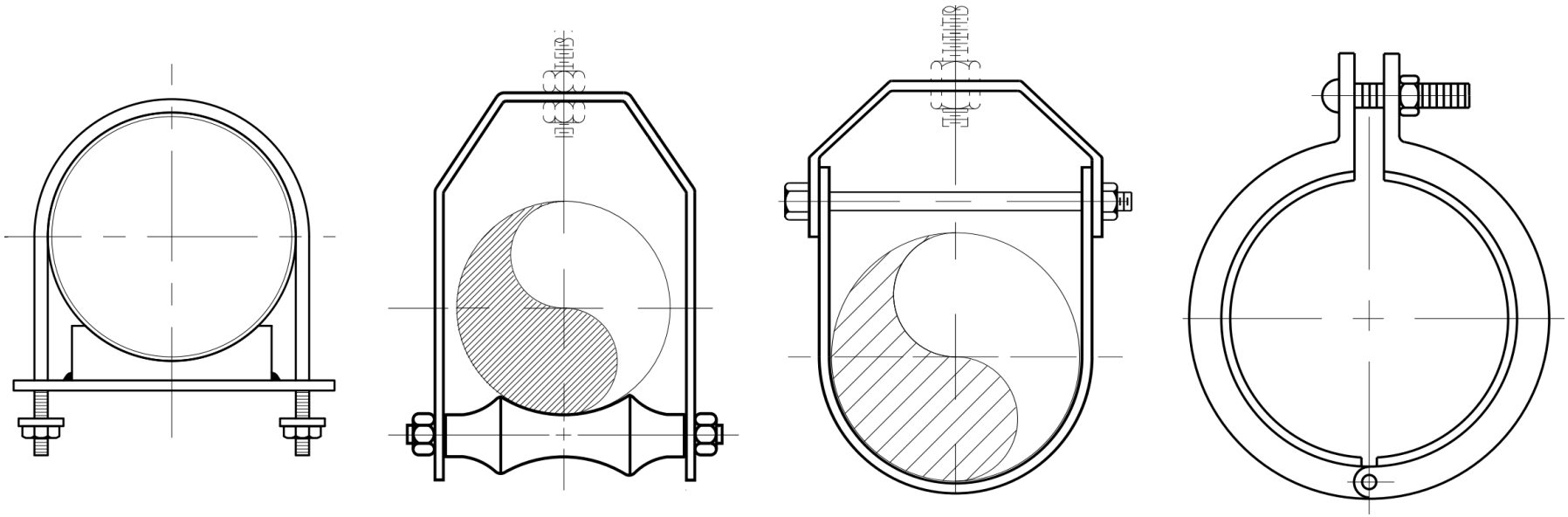


Figure: Support allowing axial expansion[1].

[1] http://www.pipesupports.com

Support Condition

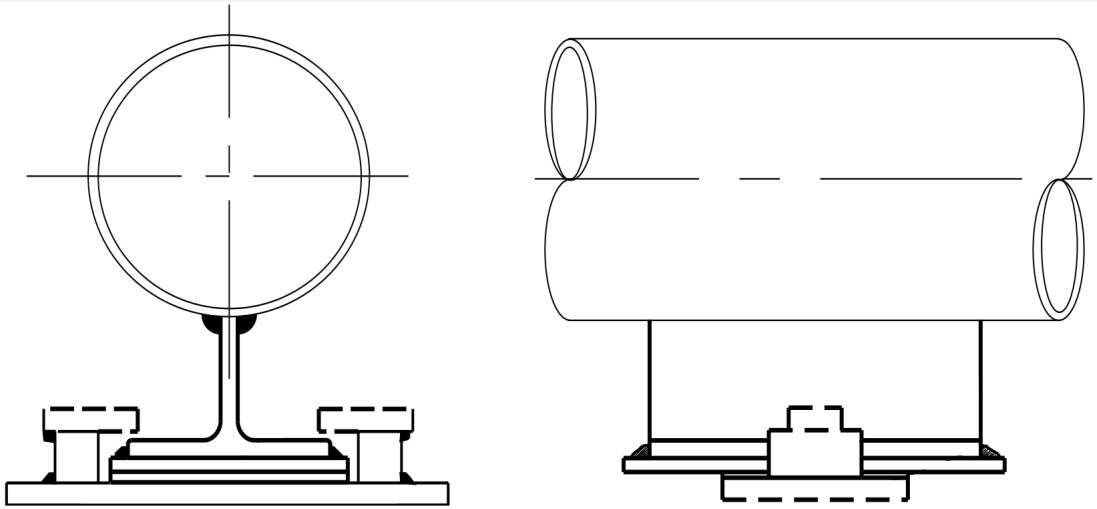


Figure: Support allowing axial expansion[1].

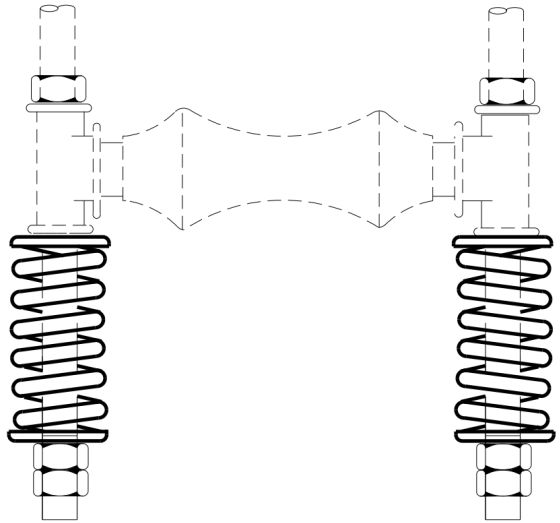


Figure: Support allowing axial expansion and vertical damping[1].

[1] http://www.pipesupports.com

Trans-Alaska Pipeline System

- 1287km long and over one-half of the pipeline (676m) is above ground
- Support bents spaced at 18m
- Diameter 1.219m and thickness 11.7mm

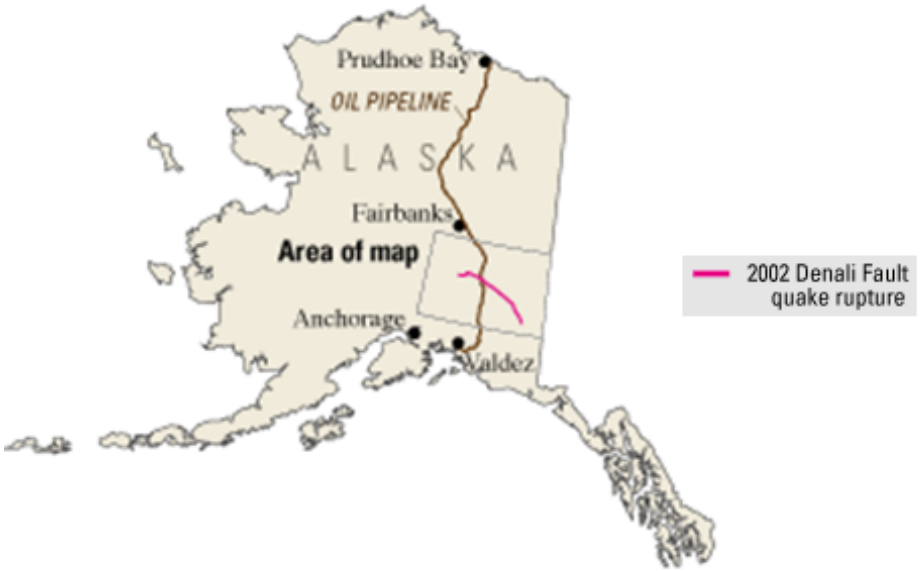


Figure: TAPS Map[2].

[2]https://pubs.usgs.gov

Support Bents

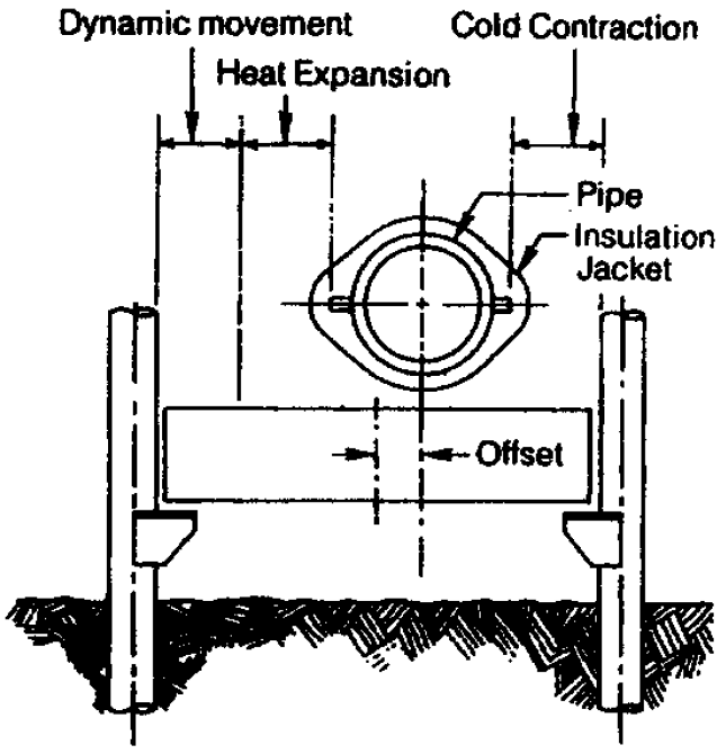


Figure: Cross section of intermediate support[4].

Figure: Support bent [3]

[3] http://www.walwol.ch/39204/trans-alaska-pipeline/

[4] Sorensen, Steve P., et al. Response of the Above-Ground Trans-Alaska Pipeline to the Magnitude 7.9 Denali Fault Earthquake. Advancing Mitigation Technologies and Disaster Response for Lifeline Systems. 2003. 556-565.

Zigzag Configuration

Figure: Trapezoidal or Zigzag above ground configuration[3].

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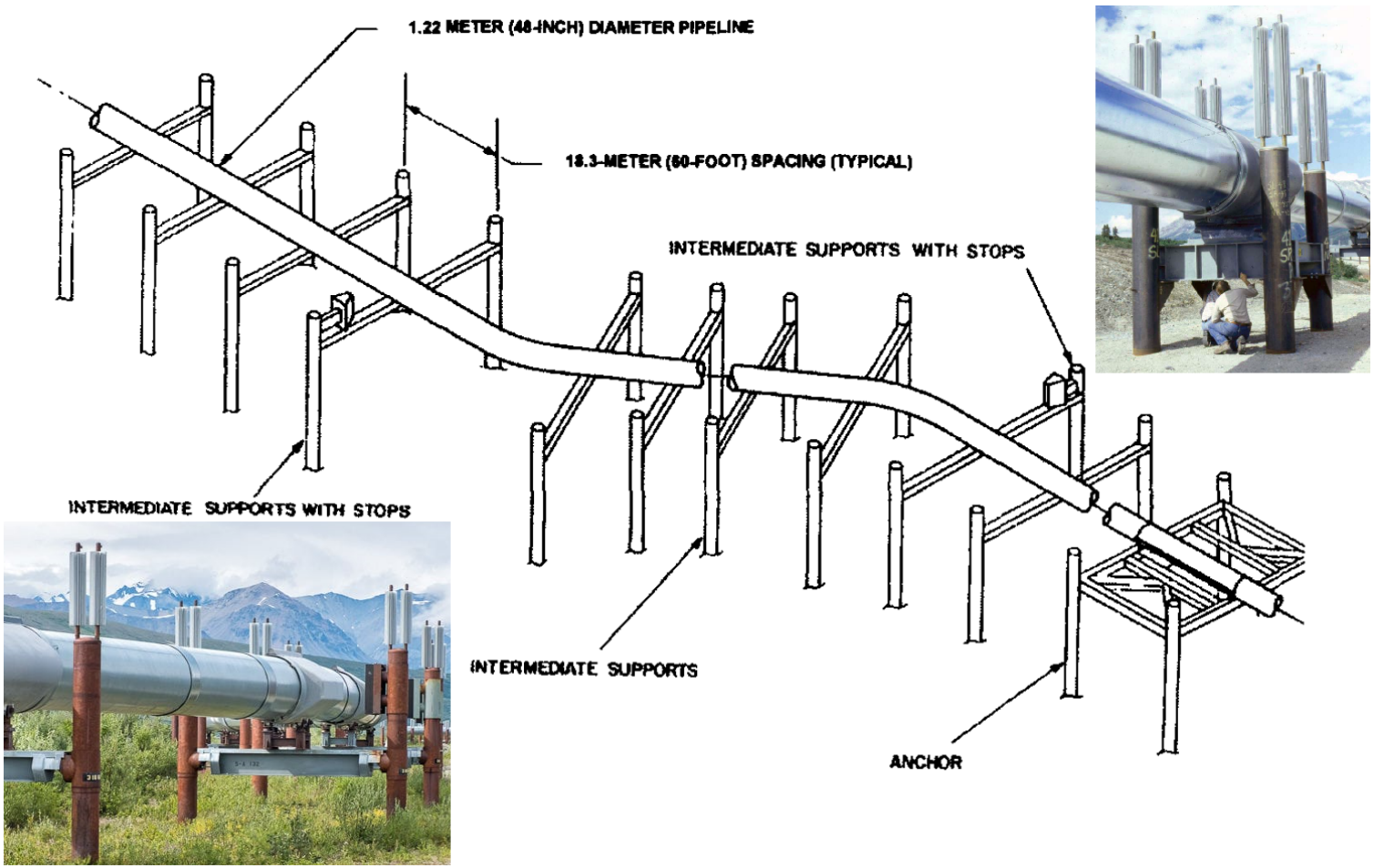

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Denali Fault Zone[5]

- 579m long
- 33 steel box beam or concert beams set on-grade
- Cross beam surface coefficient of friction is 0.1 static and 0.05 dynamic
- Design to accommodate a lateral strike slip of 6m and vertical slip 1.5m

Figure: Support system at the fault zone (looking south)

[5]Hall, William J., et al. Performance of the Trans-Alaska pipeline in the november 3, 2002 denali fault earthquake. Advancing Mitigation Technologies and Disaster Response for Lifeline Systems. 2003. 522-534.

Denali earthquake in 2002

- Magnitude 7.9
- 90km west of the pipeline
- Denali fault ruptured over 336km
- 5.5m near the pipeline and maximum of 9m at 120km east of the pipeline

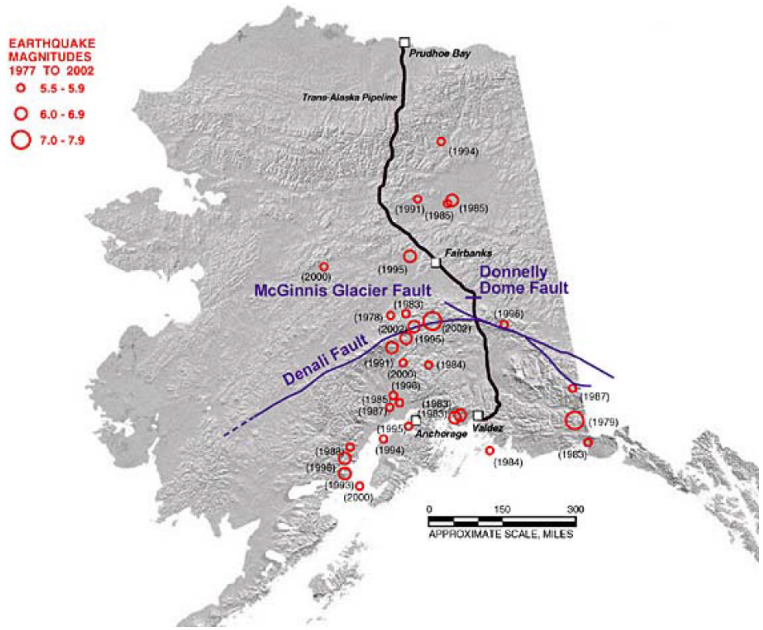


Figure: Location of faults and major earthquakes near TAPS [6]

[6] Donald G. Kinney. Trans-Alaska Pipeline System (TAPS) Seismic Design Criteria and Performance in the 2002 Denali Fault Earthquake. 2009.

Pre and Post Earthquake

Figure: Before the earthquake[7].

Figure: After the earthquake [7]

[7] Hall, Douglas J. Nyman1 William J., and Vincent Szymkowiak. Trans-Alaska pipeline seismic engineering legacy. (2014).

Pre and Post Earthquake

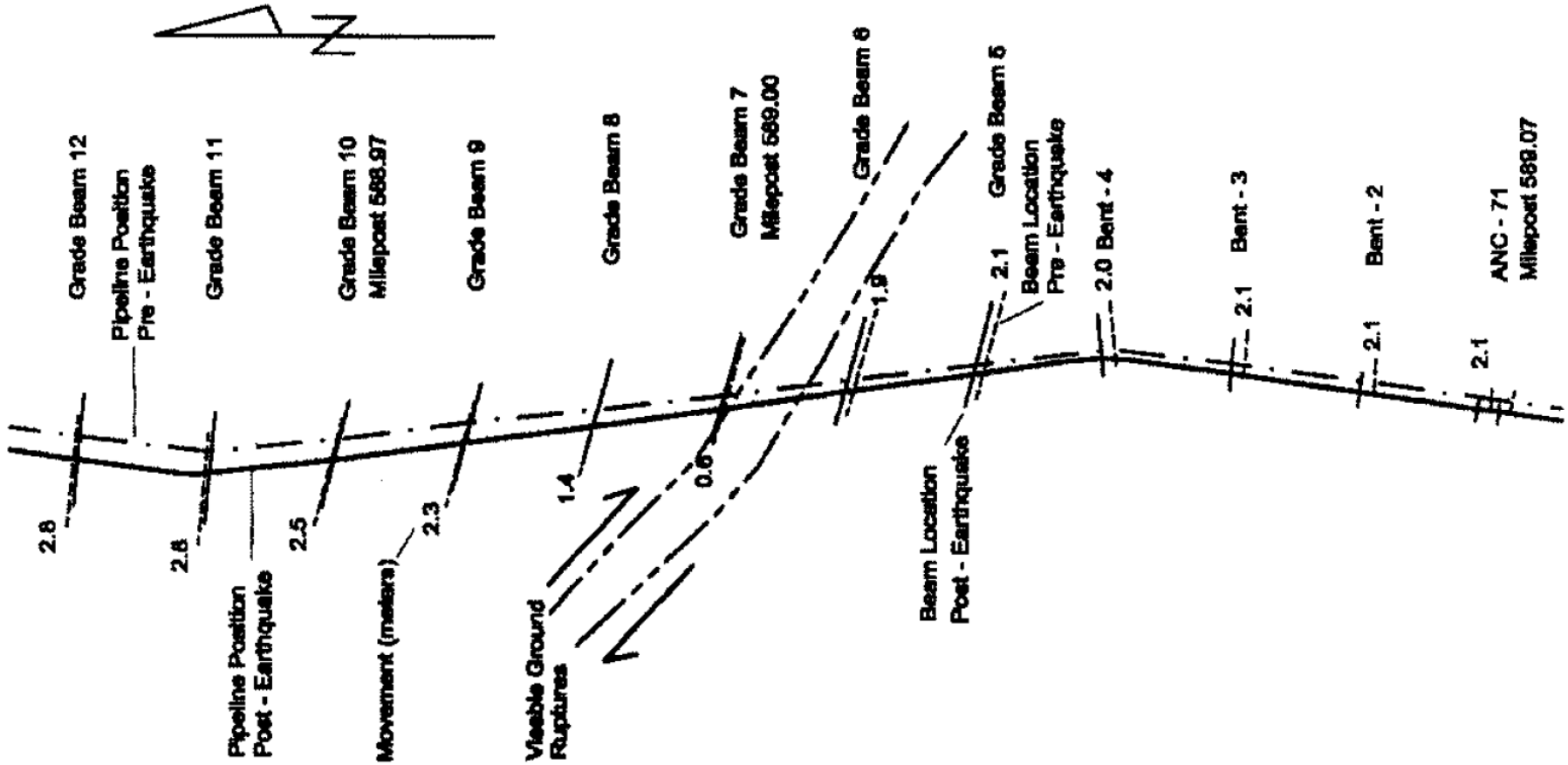


Figure: Denali fault pipeline crossing schematics [8].

[8] Sorensen, Steve P., and Keith J. Meyer. Effect of the Denali fault rupture on the Trans-Alaska pipeline. Advancing Mitigation Technologies and Disaster Response for Lifeline Systems. 2003. 547-555.

Example of linear GBT analysis

- Diameter $1.2m$ and thickness $11.7mm$
- Friction sliding supports spaced at $18m$
- Higher frictional resistance and axial expansion constraint applied at the anchor points.

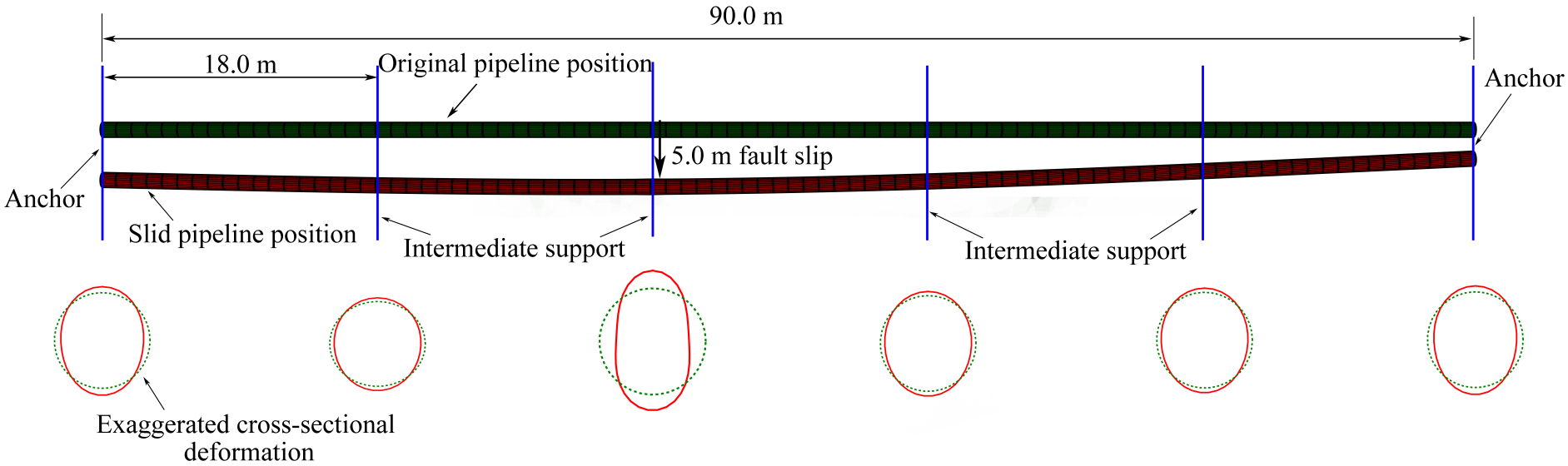


Figure: Example of cross-sectional deformation of TAPS section under slippage of the friction support.

Post Earthquake

Figure: Loss of two adjacent support [6]

[6] Donald G. Kinney. Trans-Alaska Pipeline System (TAPS) Seismic Design Criteria and Performance in the 2002 Denali Fault Earthquake. 2009.

Post Earthquake

Figure: Local pipeline damage due to side-way impact with the vertical supports during earthquake [6]

[6] Donald G. Kinney. Trans-Alaska Pipeline System (TAPS) Seismic Design Criteria and Performance in the 2002 Denali Fault Earthquake. 2009.

Support Spring Formulation in GBT

- The GBT's spring formulation for a pipe cross-section can be divided in two parts:
  - A modal cross-section participation, which the support stiffness around the pipe's perimeter is decomposed in a modal deformation based on Fourier-Series;

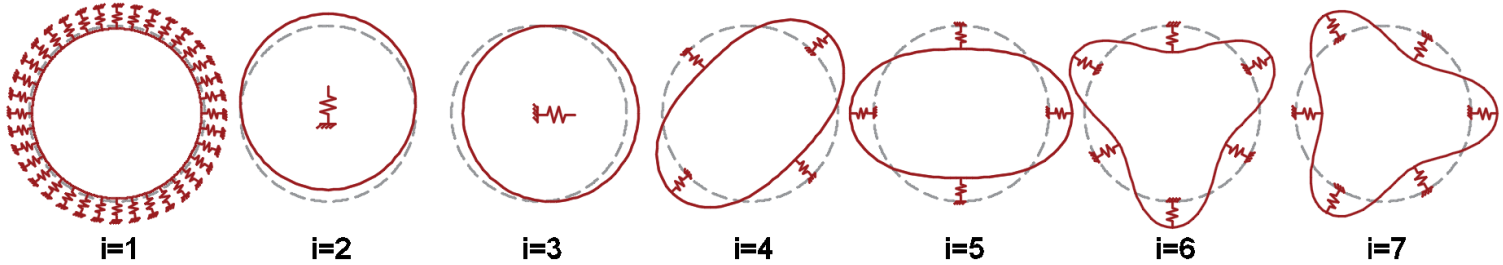


Figure: Transversal deformation shapes according to GBT

  - And a longitudinal amplification V(x), which can be understood as a generalized function of the transversal displacement of the cross-section;

Spring's modal transversal decomposition

- The spring's stiffness is converted in a polar representation, which is decomposed in Fourier-Series. For instance, the case of partial-constant support condition:

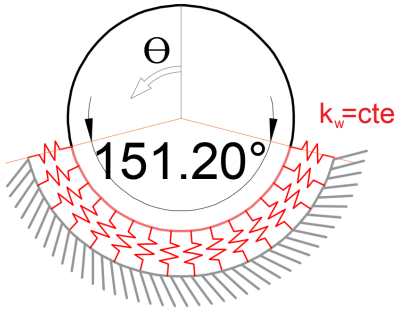


Figure: Radial constant spring support

Requires around 12 deformation modes to be represented:

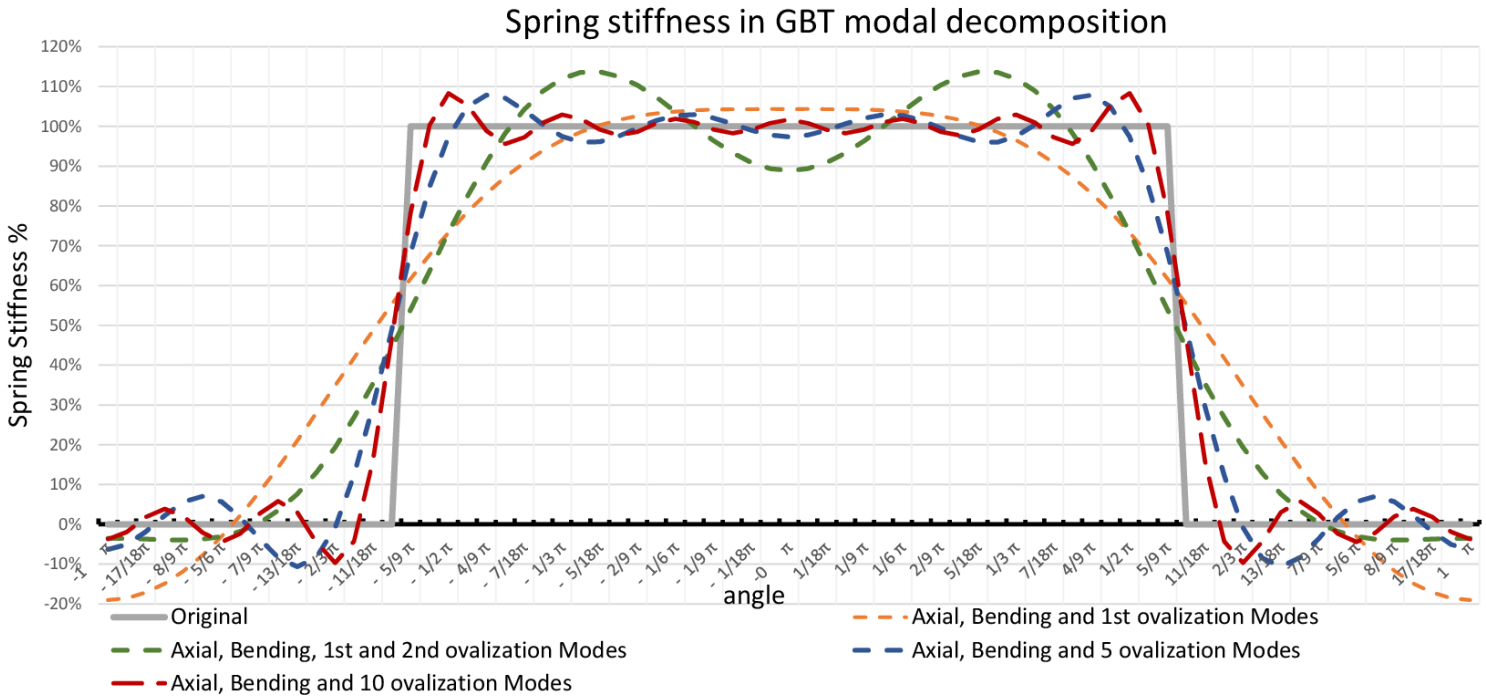


Figure: Fourier decompositon of the radial constant spring support

Spring's longitudinal amplification function: V(x)

- For above ground pipelines, the modal spring's stiffness is added directly into respective generalized degree of freedom:

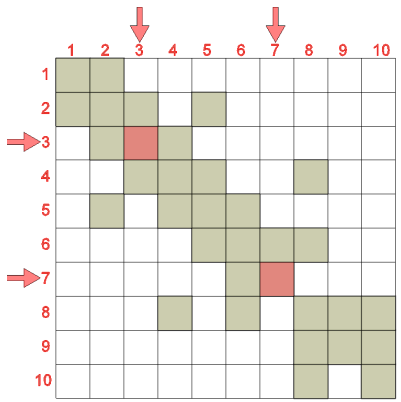


Figure: Modal stiffness addition of modal spring

For buried pipeline, the spring stiffness in longitudinal direction is multiply by the amplification function V(x), which is easily introduced into GBT's ordinary differential equation, similar to a foundation beam:

$$E^i I^i V'''' (x) - G^i{}^i D^i V'' (x) + \left({}^i K + {}^i B\right) {}^i V(x) = {}^i q(s)\, F_x(x) \qquad (1)$$

Example - Nodal Spring

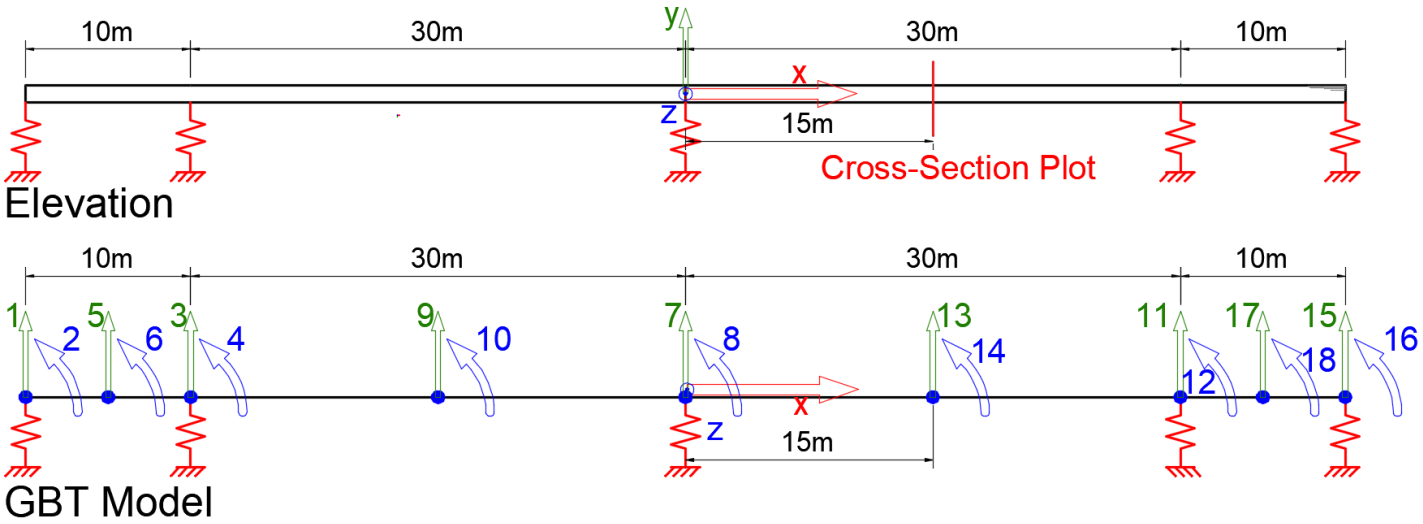
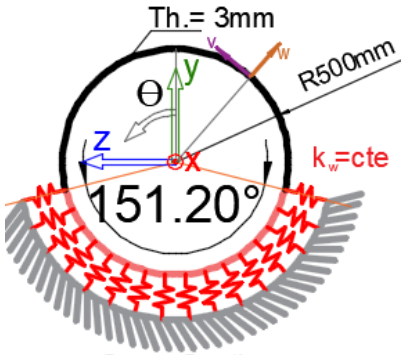
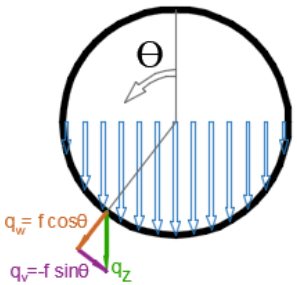


Figure: Example in nodal spring





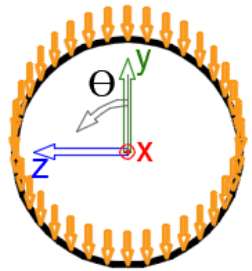


Figure: Cross Section Geometry and loads

- Material: E=205GPa;

Item	Ansys	GBT
elements	200,000	4
Degrees of freedom	360,630	53
Shape function	Quadratic	Hyperbolic

Example - Nodal Spring

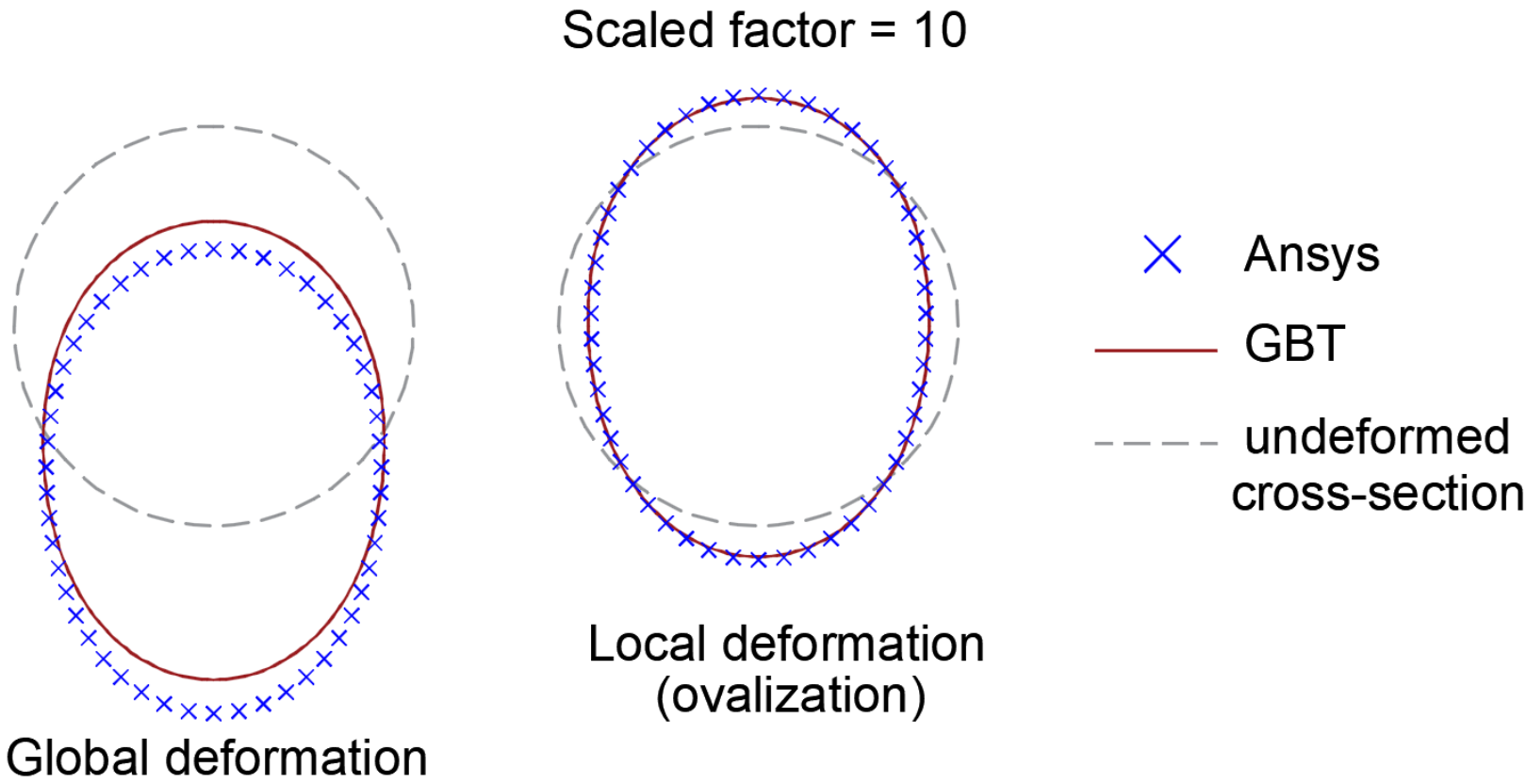


Figure: Comparison between displacement fields

- Major difference is from shear deformation (Timoshenko assumption need to be implemented);
- Average difference in ovalization is 9% (it is necessary to include more modes of ovalization).