National
Technical
University of
Athens

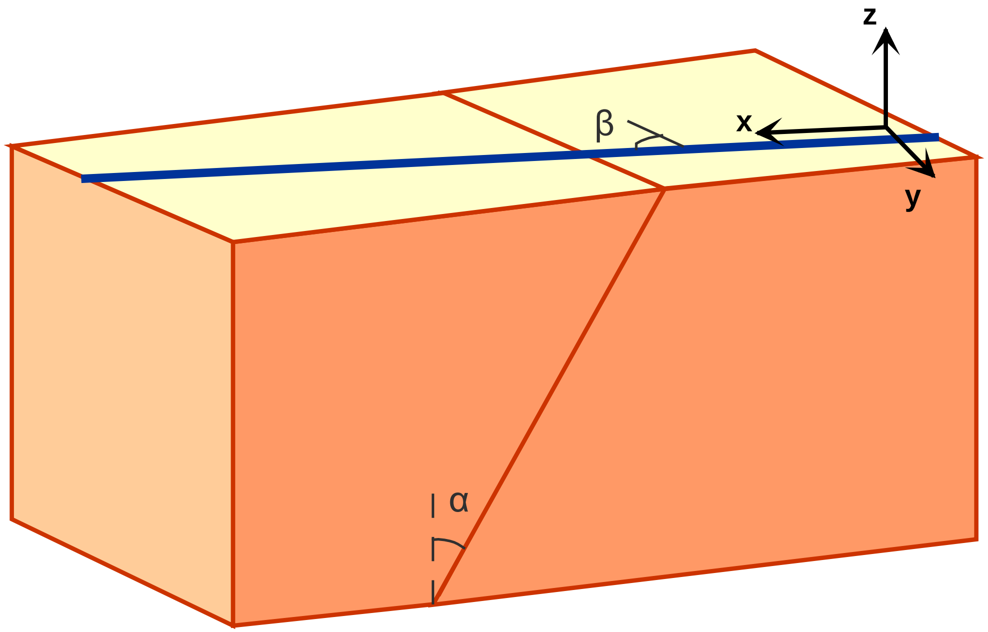
Design of Buried Pipelines against Permanent Ground Displacements

Dr Dimitris Karamitros

Lecturer in Civil Engineering

Problem Description

Seismic Fault Crossings



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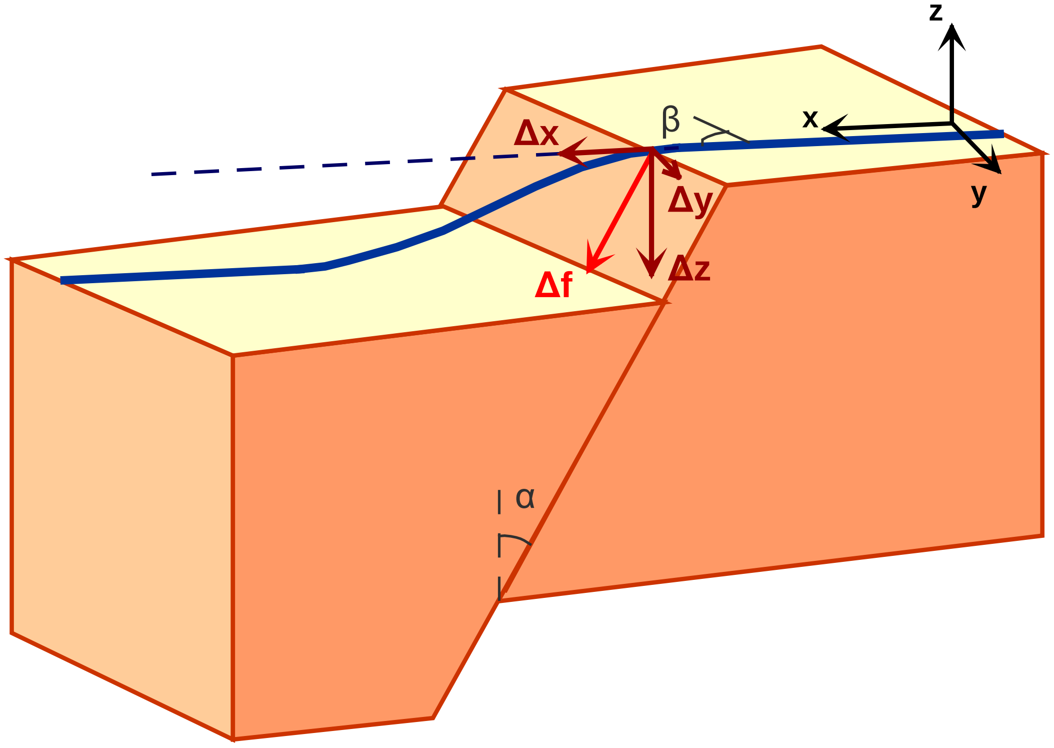

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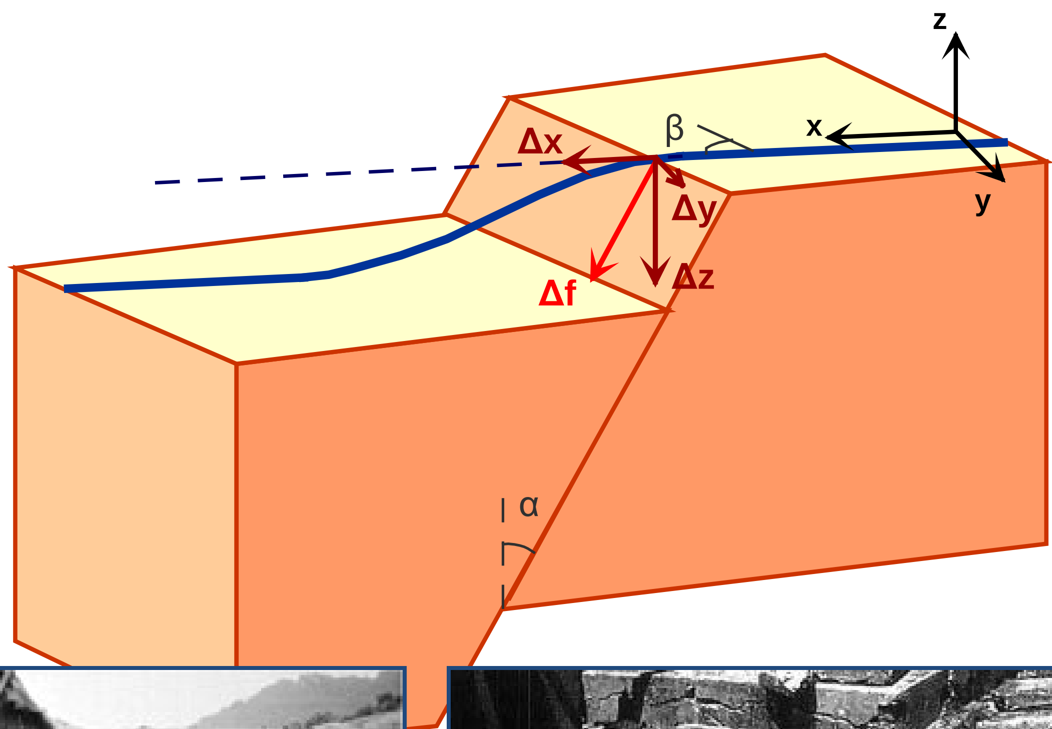
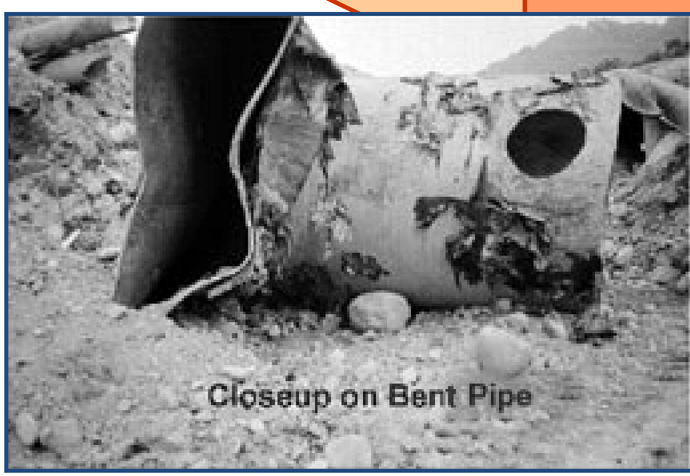




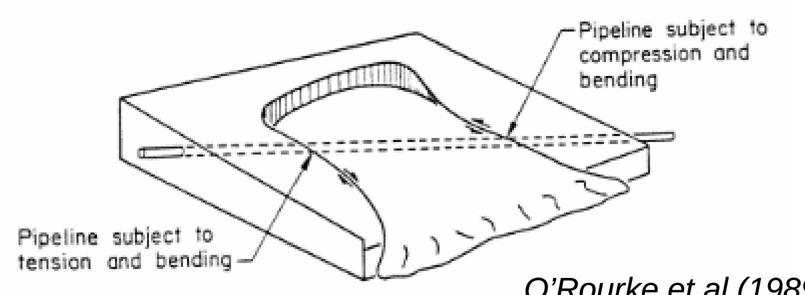
Kocaeli, Turkey (1999)

Chi-Chi, Taiwan (1999)

Problem Description

Other types of Permanent Ground Displacements

- Slope failures



O'Rourke et al (1989)

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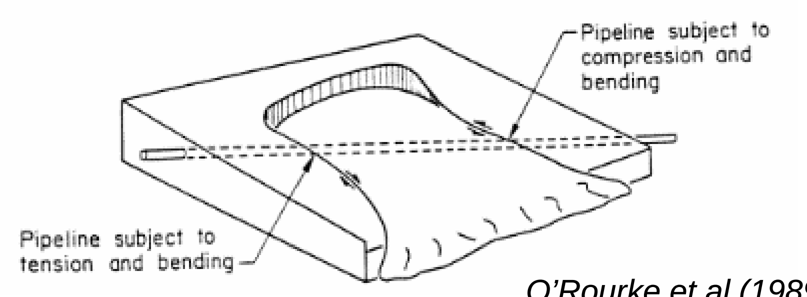
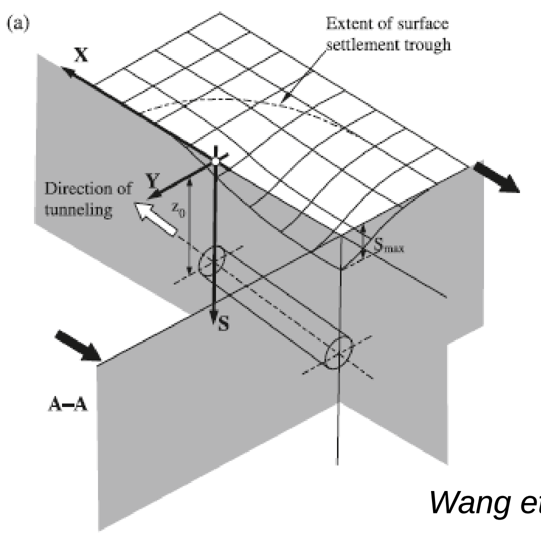


O'Rourke et al (1989)

- Underground works (e.g. tunneling)



Wang et al (2011)

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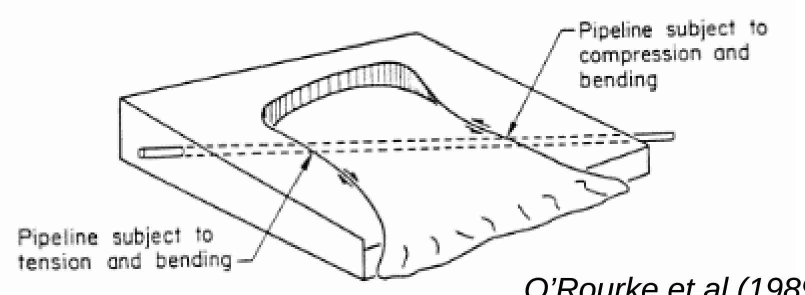
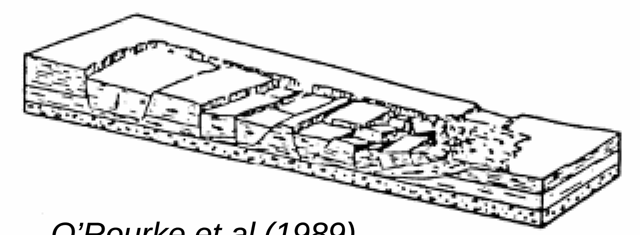


O'Rourke et al (1989)

- Lateral-spreading (liquefaction)



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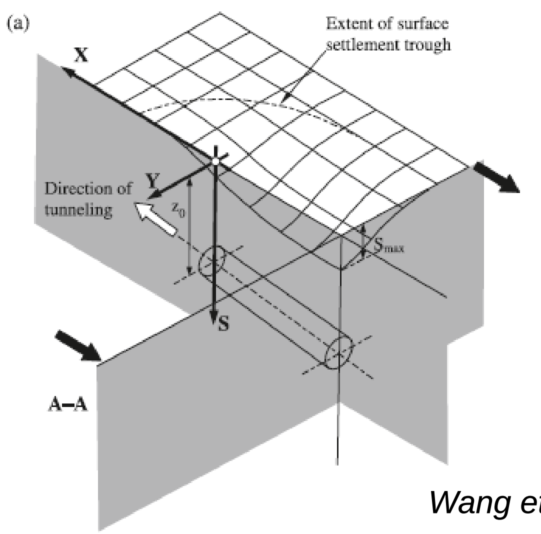

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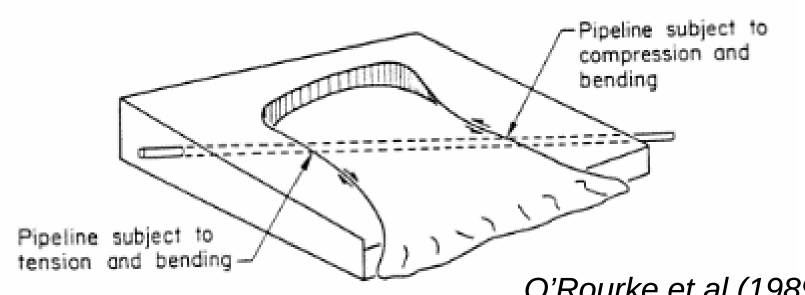

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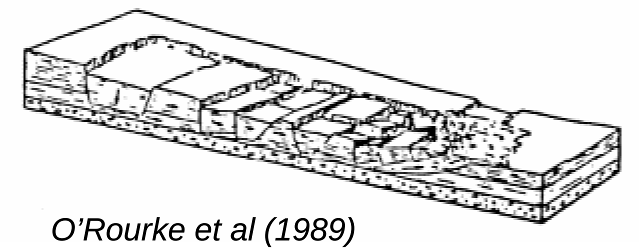

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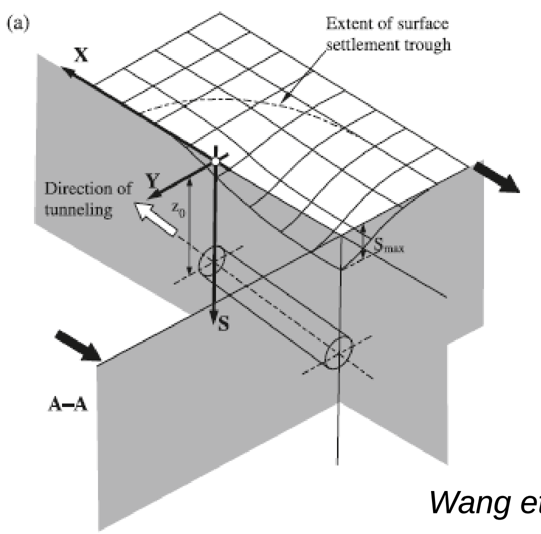
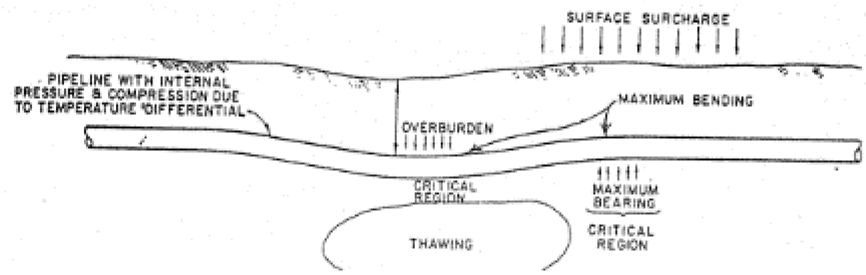


Wang et al (2011)

- Differential settlement / heave

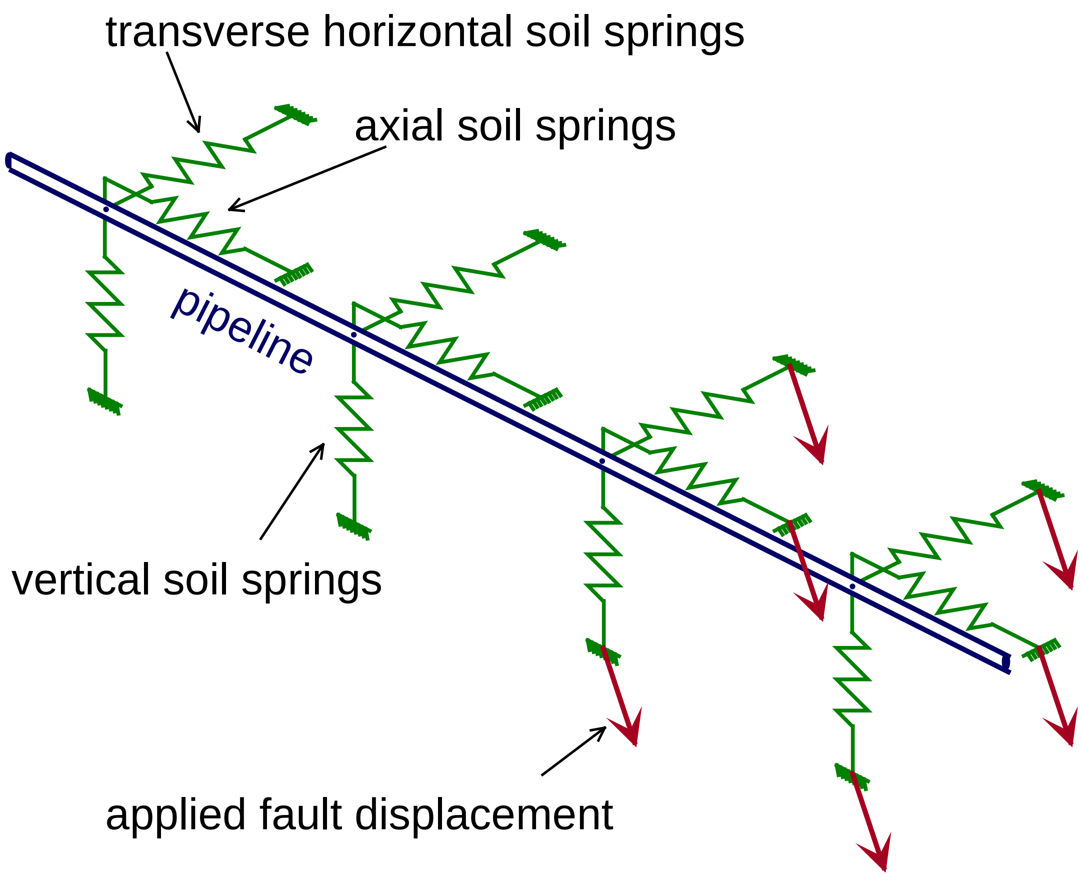


ALA-ASCE (2005)

- …and others…

Current Design Practice

3-D Finite Element Analyses



American Lifelines Alliance
ASCE (2005)

Current Design Practice

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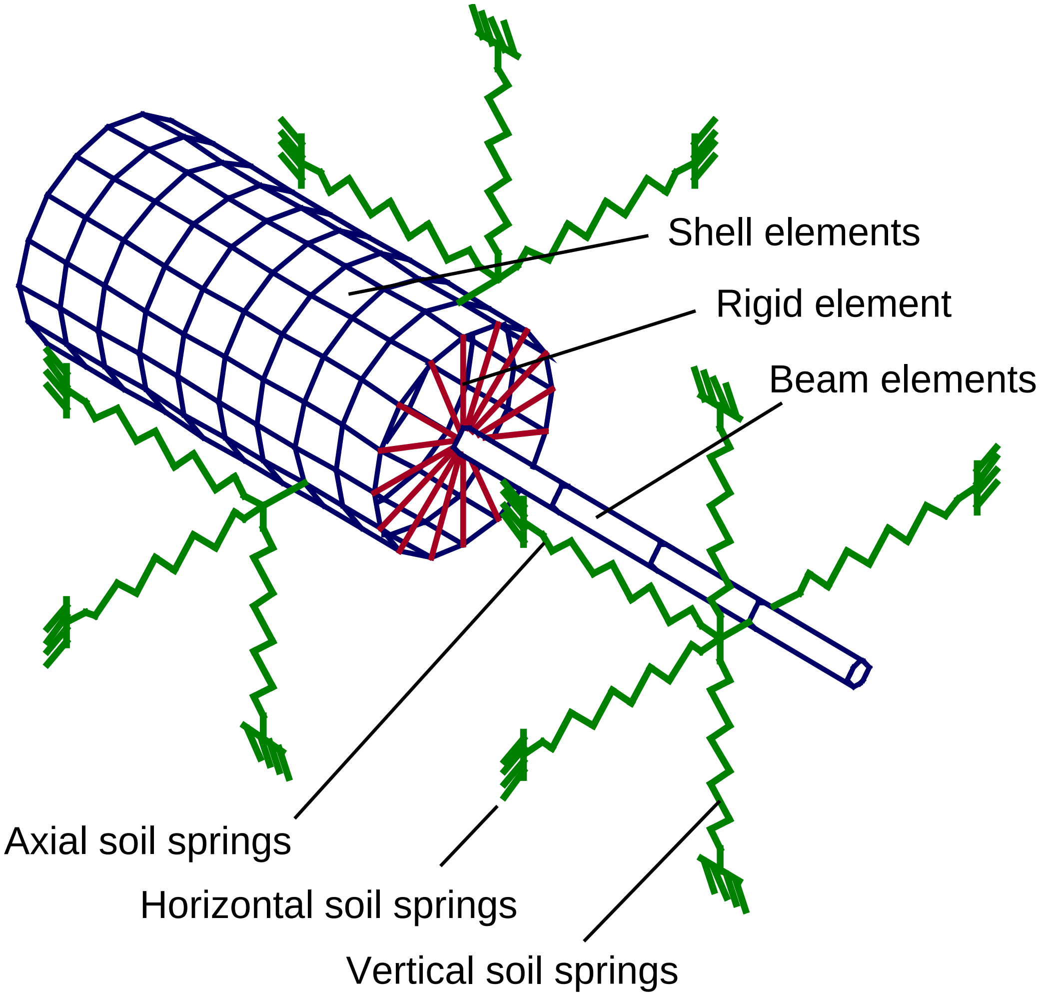

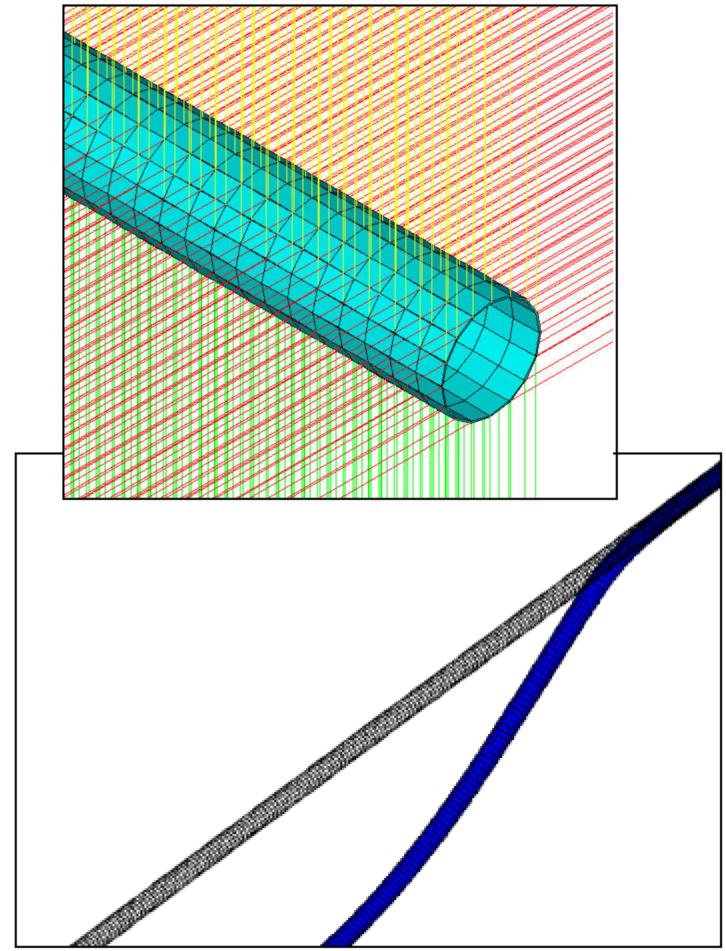

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ASCE (2005)

Current Design Practice

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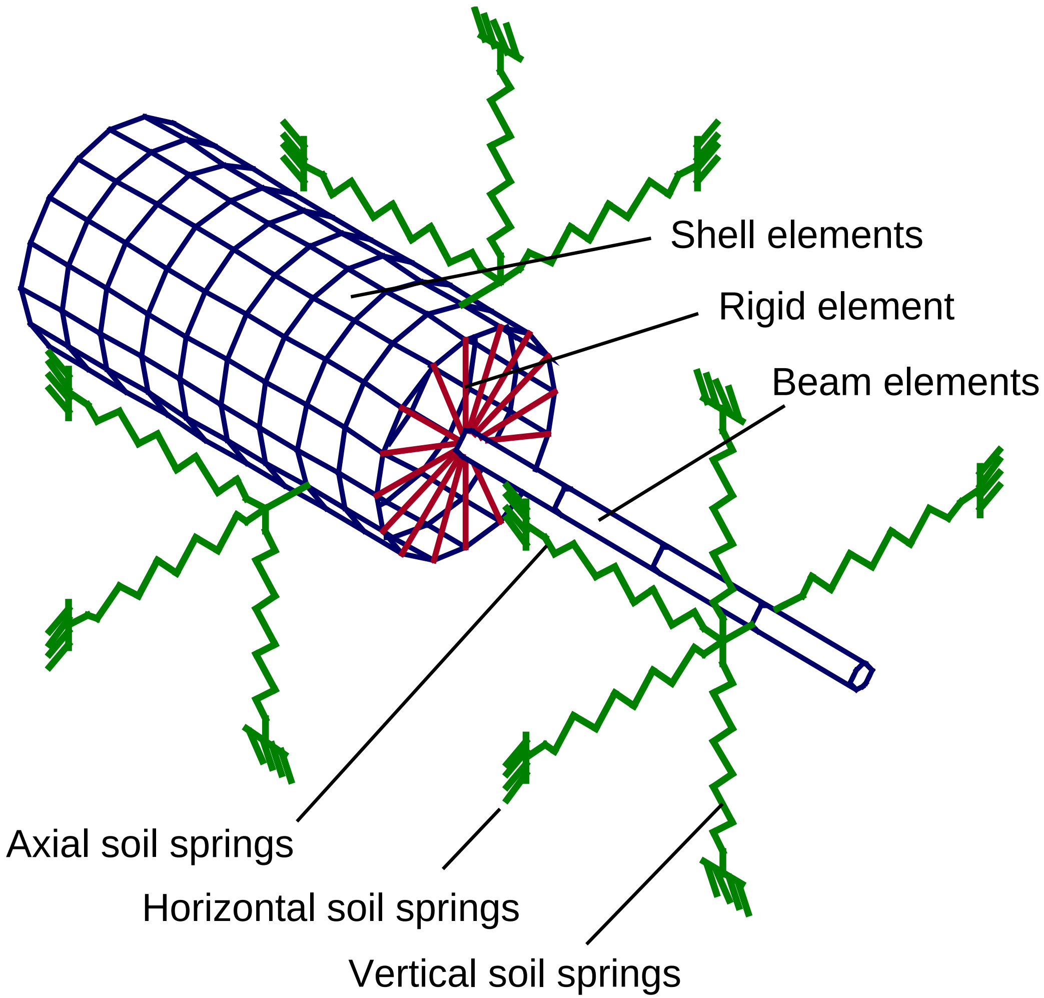
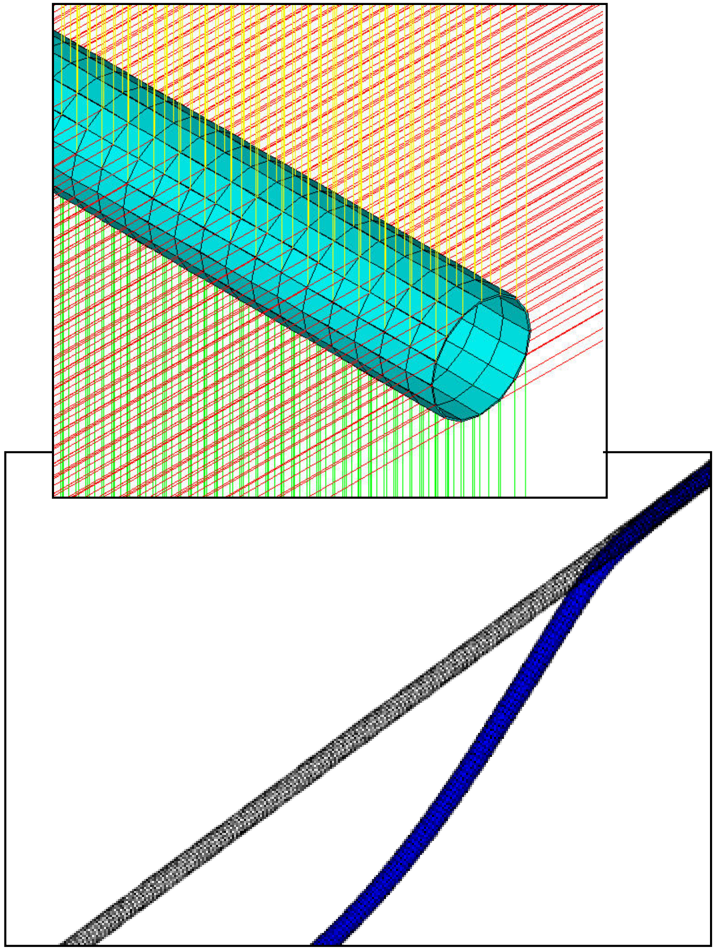


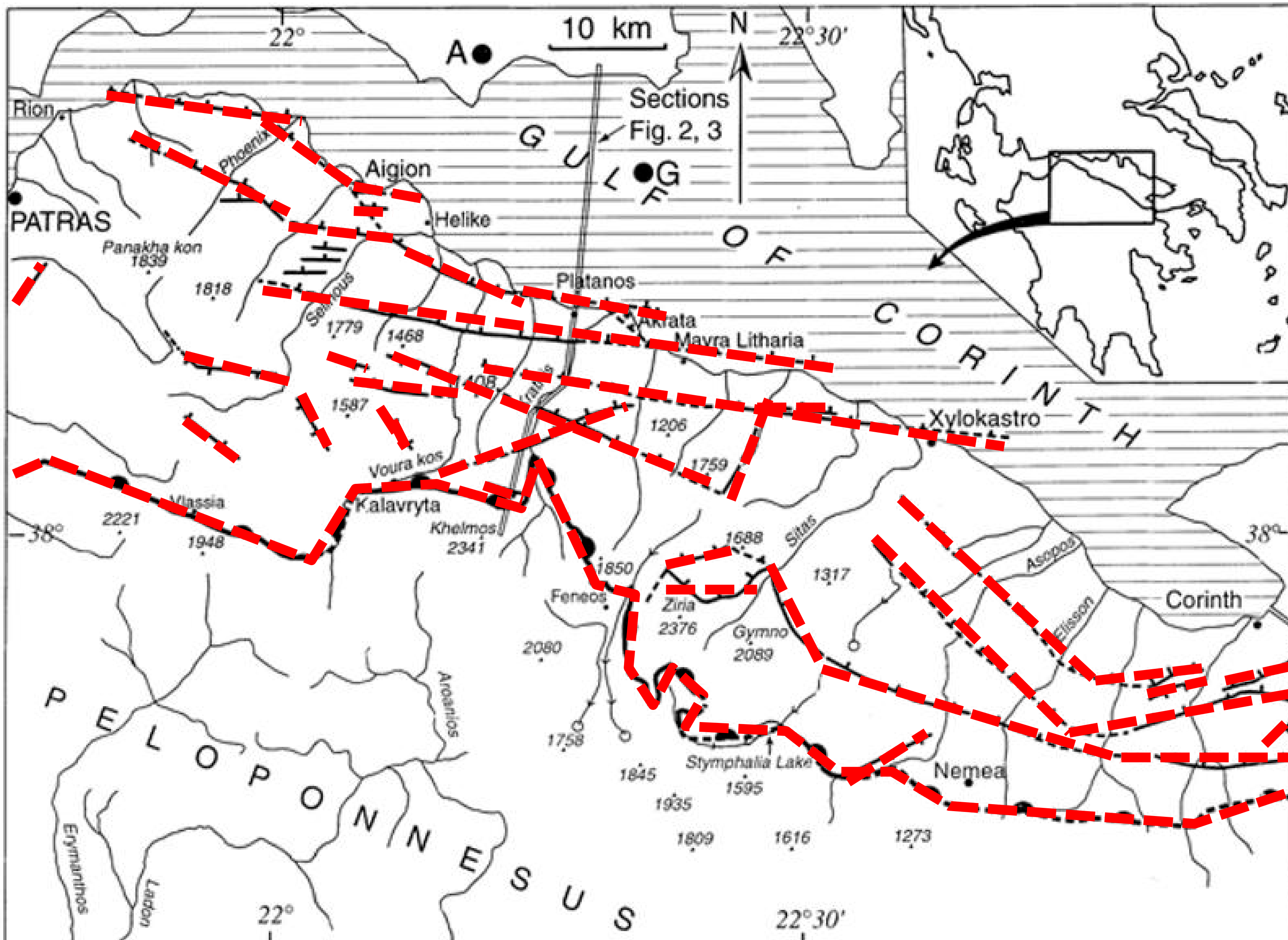


American Lifelines Alliance
ASCE (2005)

- ✓ Non-linear behavior of pipeline steel
- ✓ Elasto-plastic soil springs
- ✓ Second-order effects

Current Design Practice

Typical Example



Current Design Practice

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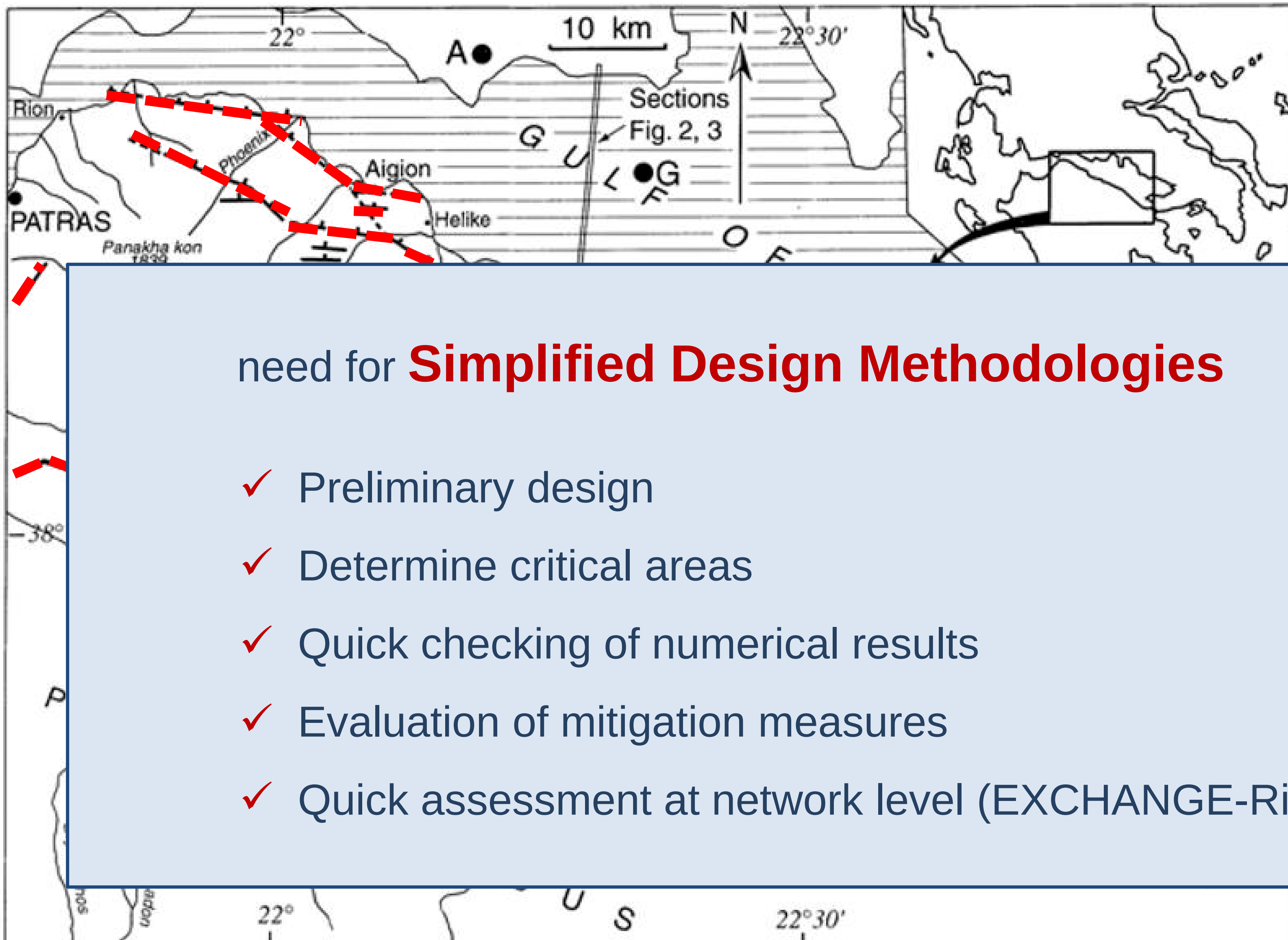


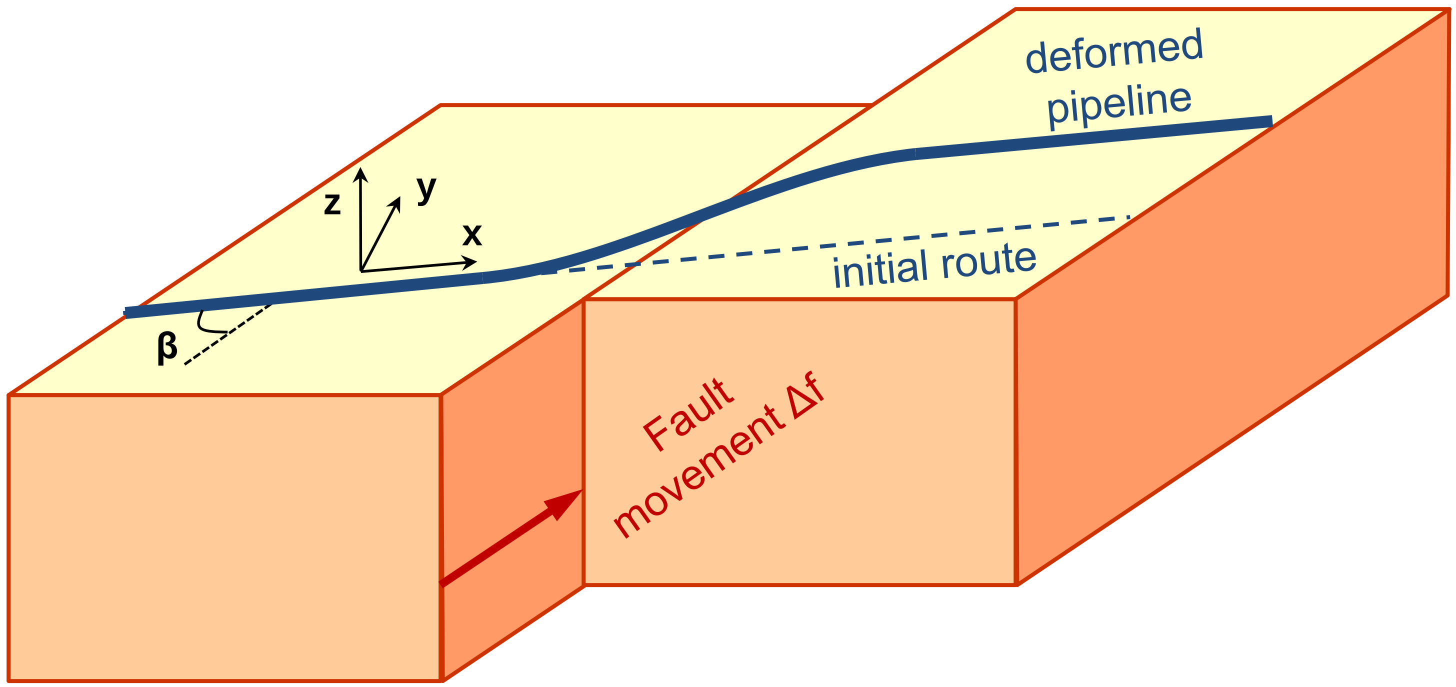
need for **Simplified Design Methodologies**

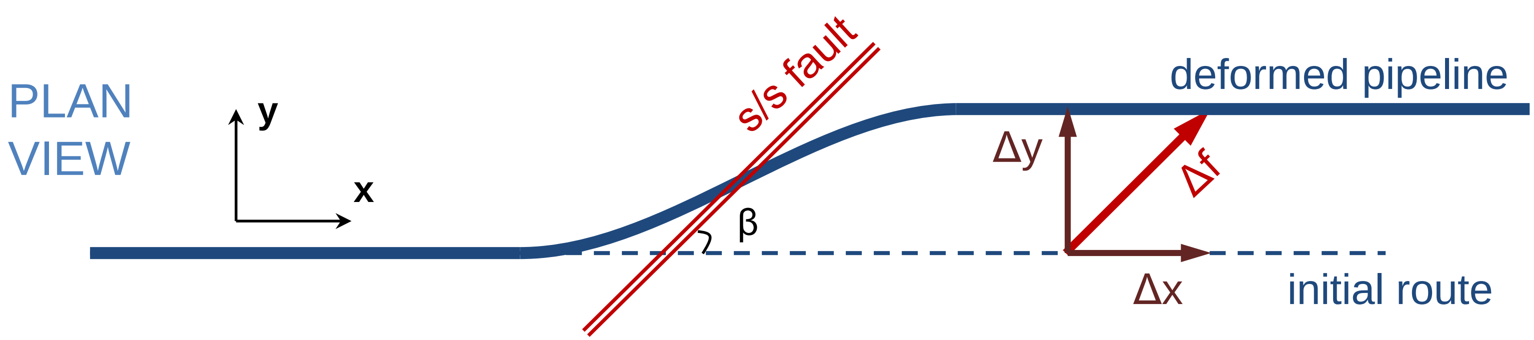
- ✓ Preliminary design
- ✓ Determine critical areas
- ✓ Quick checking of numerical results
- ✓ Evaluation of mitigation measures
- ✓ Quick assessment at network level (EXCHANGE-Risk)

University of BRISTOL

Analytical Methodology

Strike-slip fault crossings

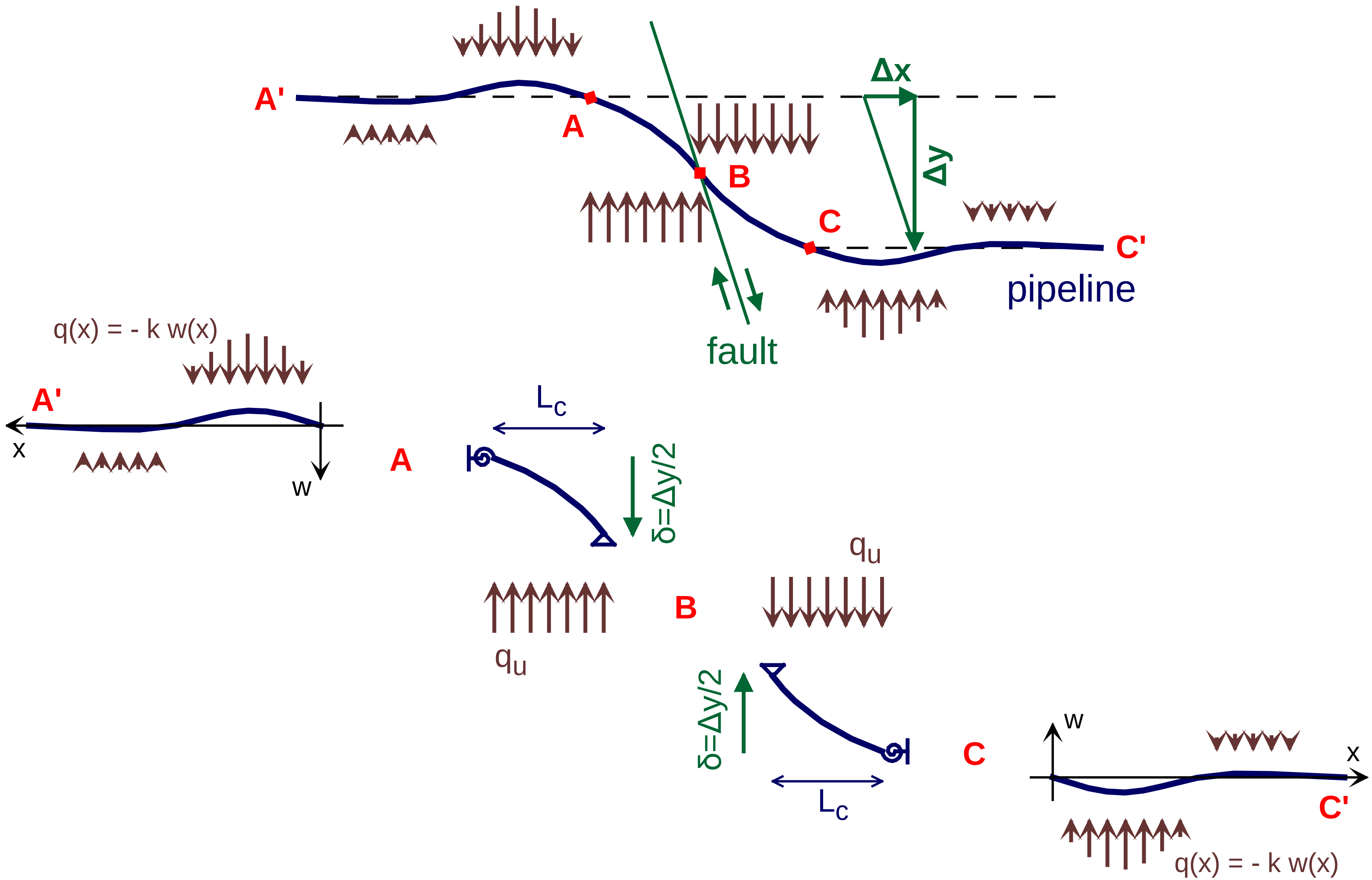




Analytical Methodology

Karamitros et al (2007) – Strike-Slip Fault Crossings

Basic Principle: Partitioning of the pipeline into 4 segments



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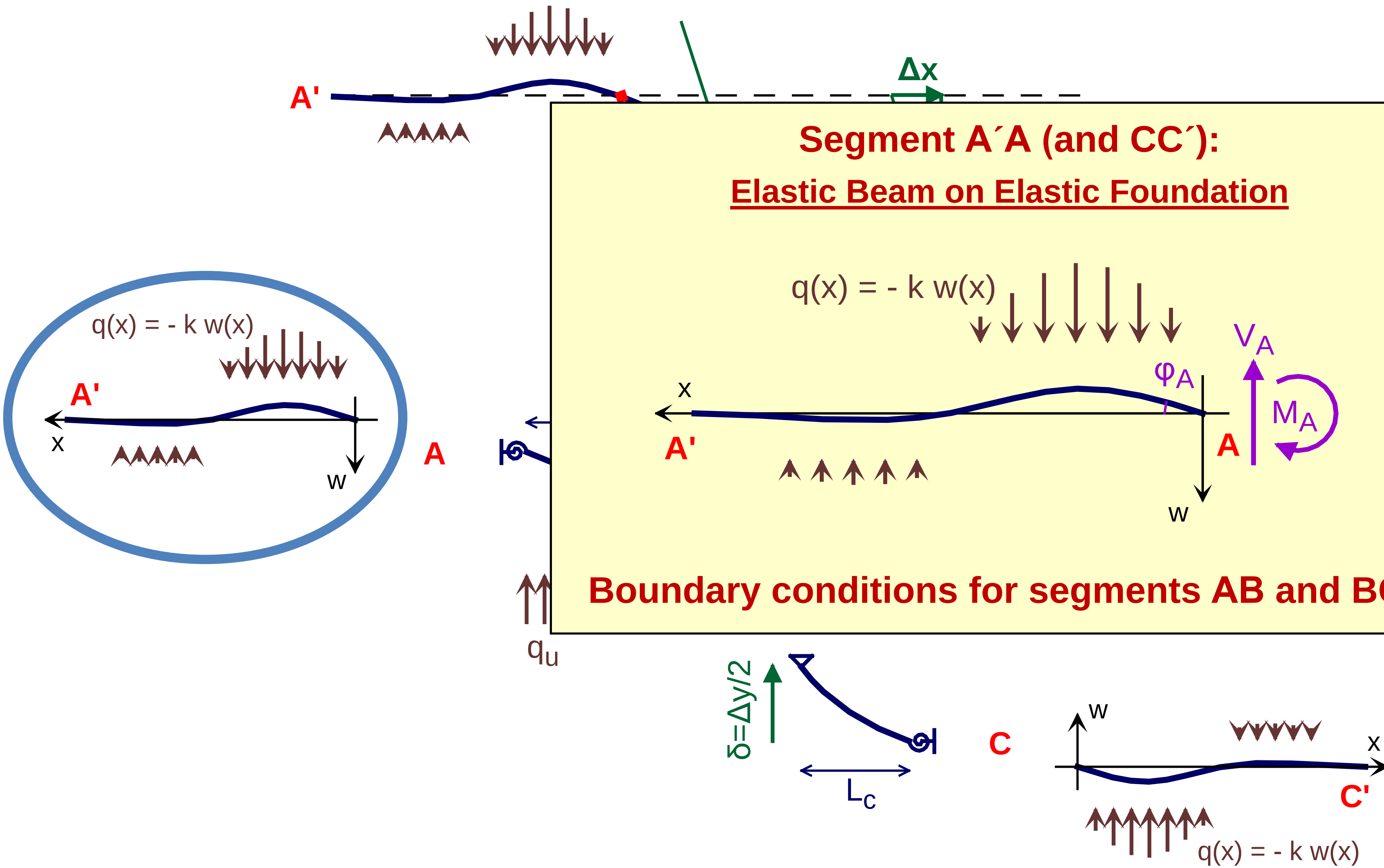

Segment A´A (and CC´):

Elastic Beam on Elastic Foundation

Boundary conditions for segments AB and BC

Analytical Methodology

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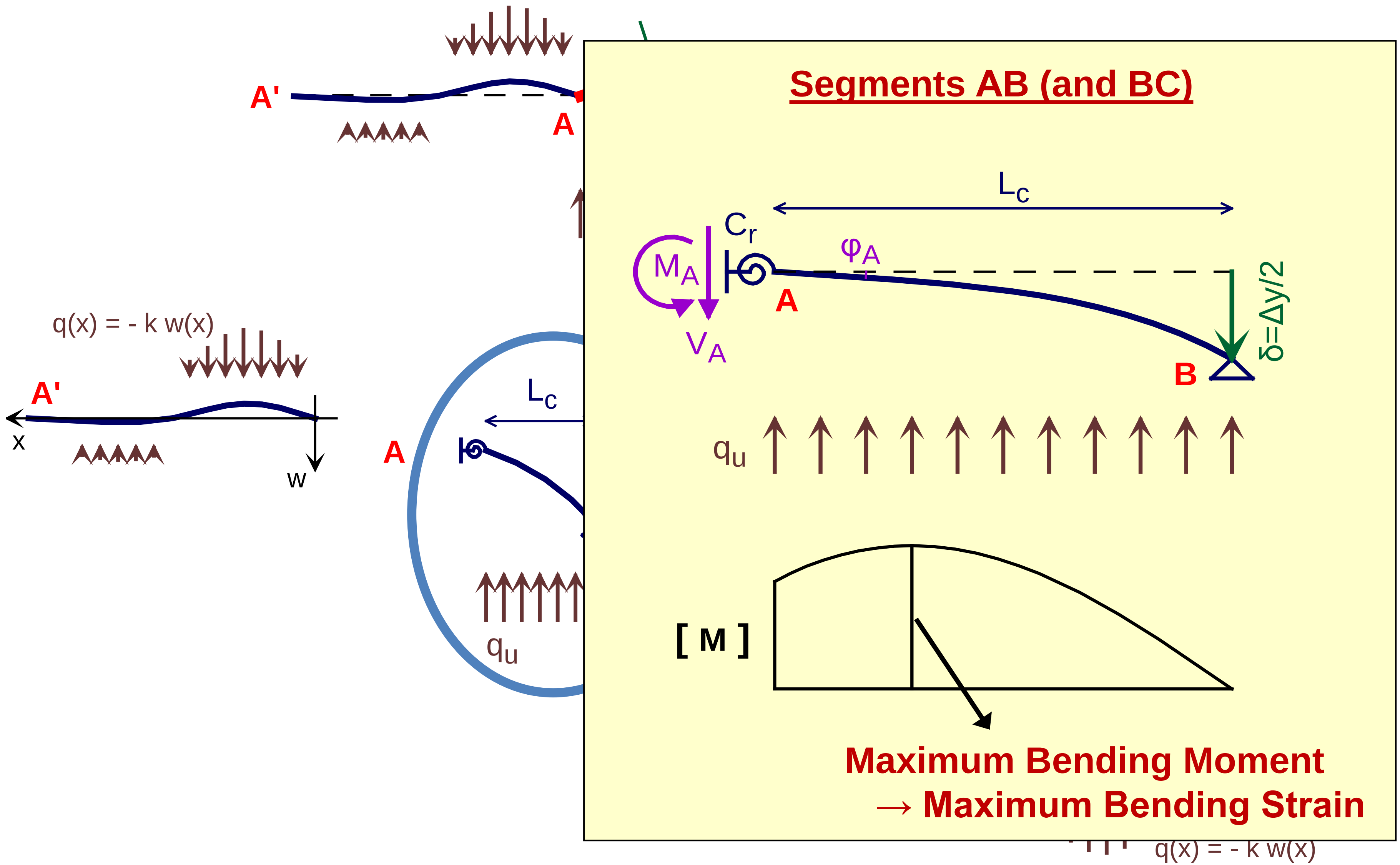
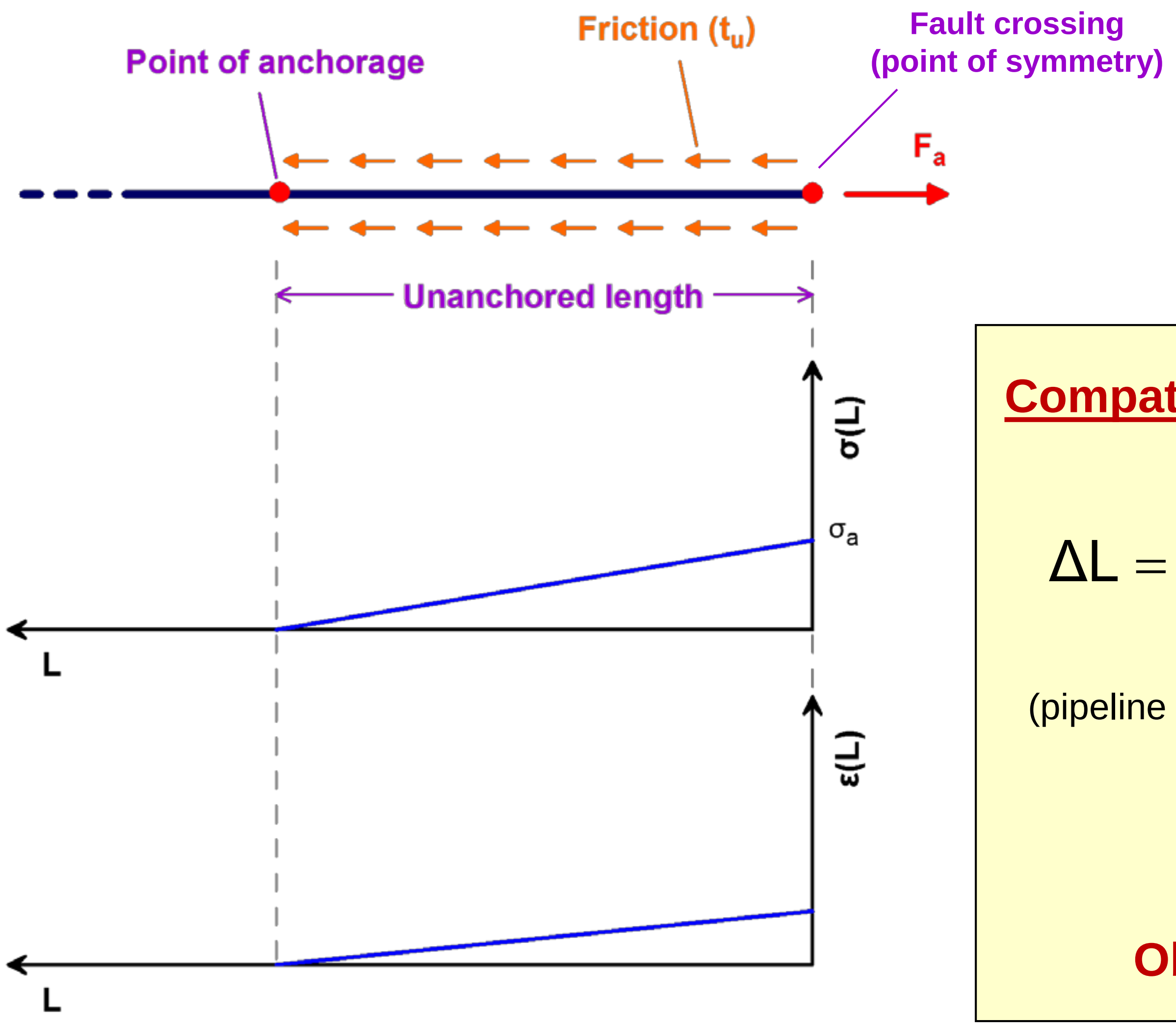


Analytical Methodology

Karamitros et al (2007) – Strike-Slip Fault Crossings

Simplified computation of axial strains



Compatibility of displacements:

$$\Delta L = 2 \cdot \int_{0}^{L_{anch}} \varepsilon(L) \cdot dL = \Delta x$$

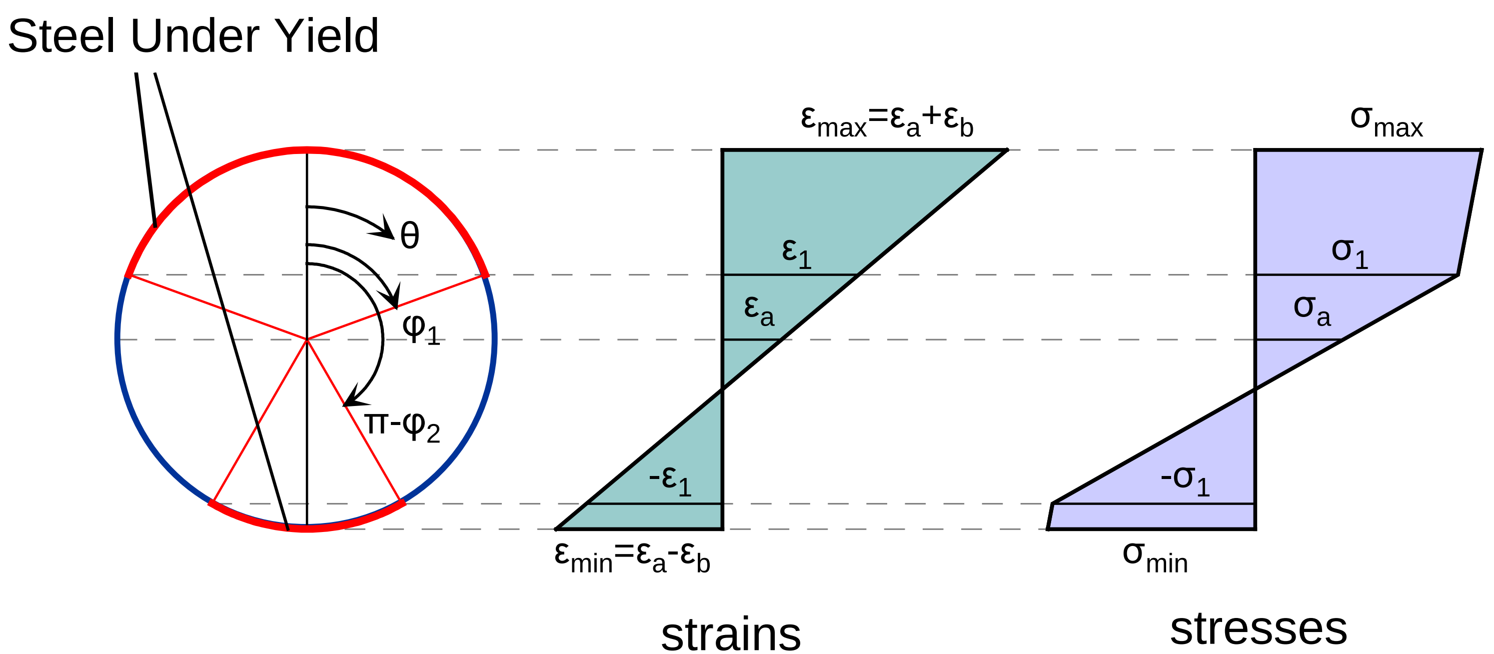
(pipeline elongation = fault displacement)

Obtain axial force F_a

Analytical Methodology

Karamitros et al (2007) – Strike-Slip Fault Crossings

Equivalent linear solution (iterative), using secant modulus:

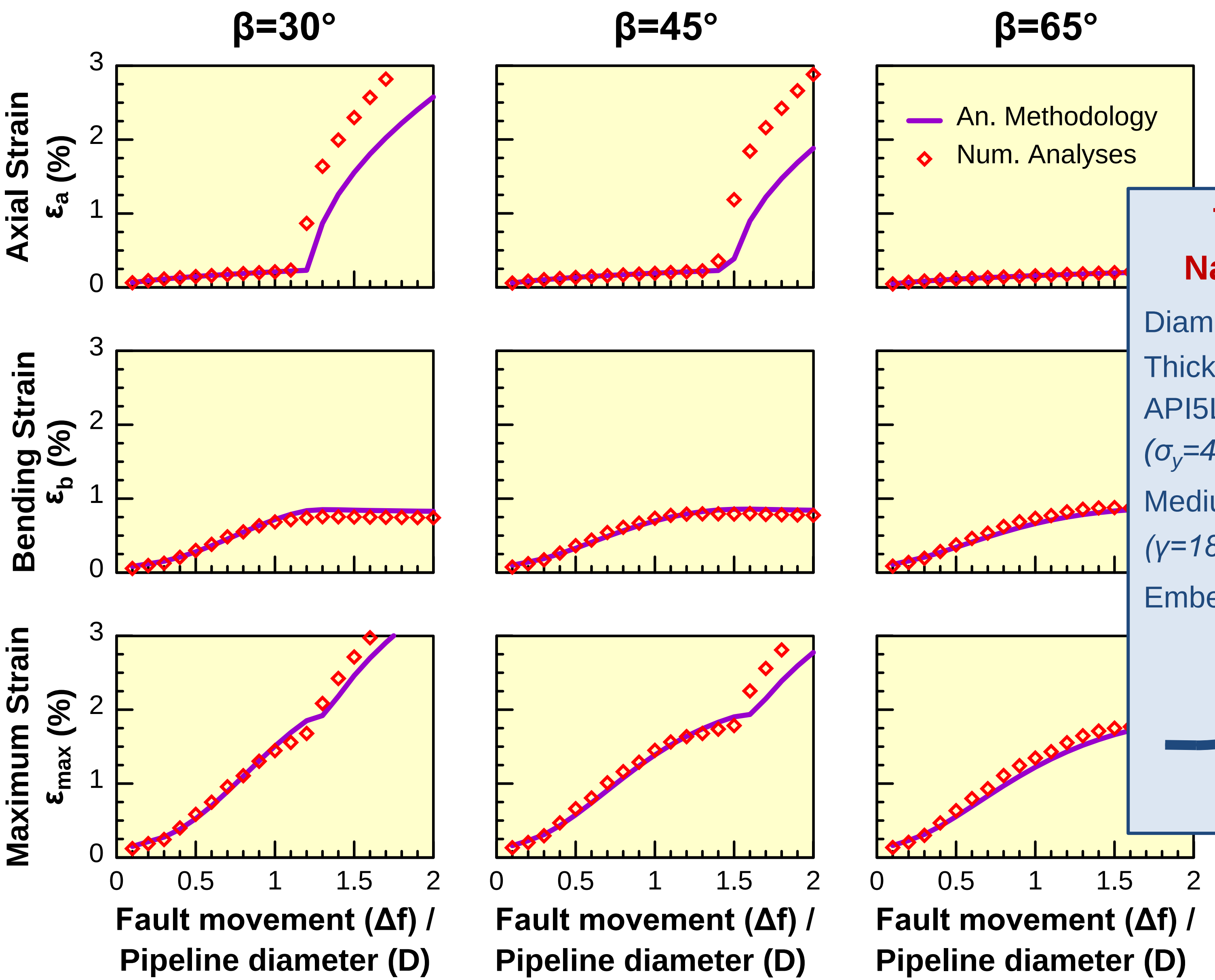


Obtain **maximum bending strain ε_b** and **maximum axial force F_a** from elastic solution

➪ Readjust **secant Young's modulus** $E' = \frac{M_{max} \cdot D}{2 \cdot I \cdot \varepsilon_b}$

Analytical Methodology

Karamitros et al (2007) – Strike-Slip Fault Crossings



Typical HPTS Natural Gas Pipe

Diameter D=0.9144 m

Thickenss t=0.0119 m

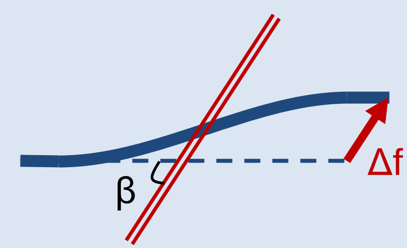
API5L-X65 steel

(σ_y=490MPa)

Medium dense sand

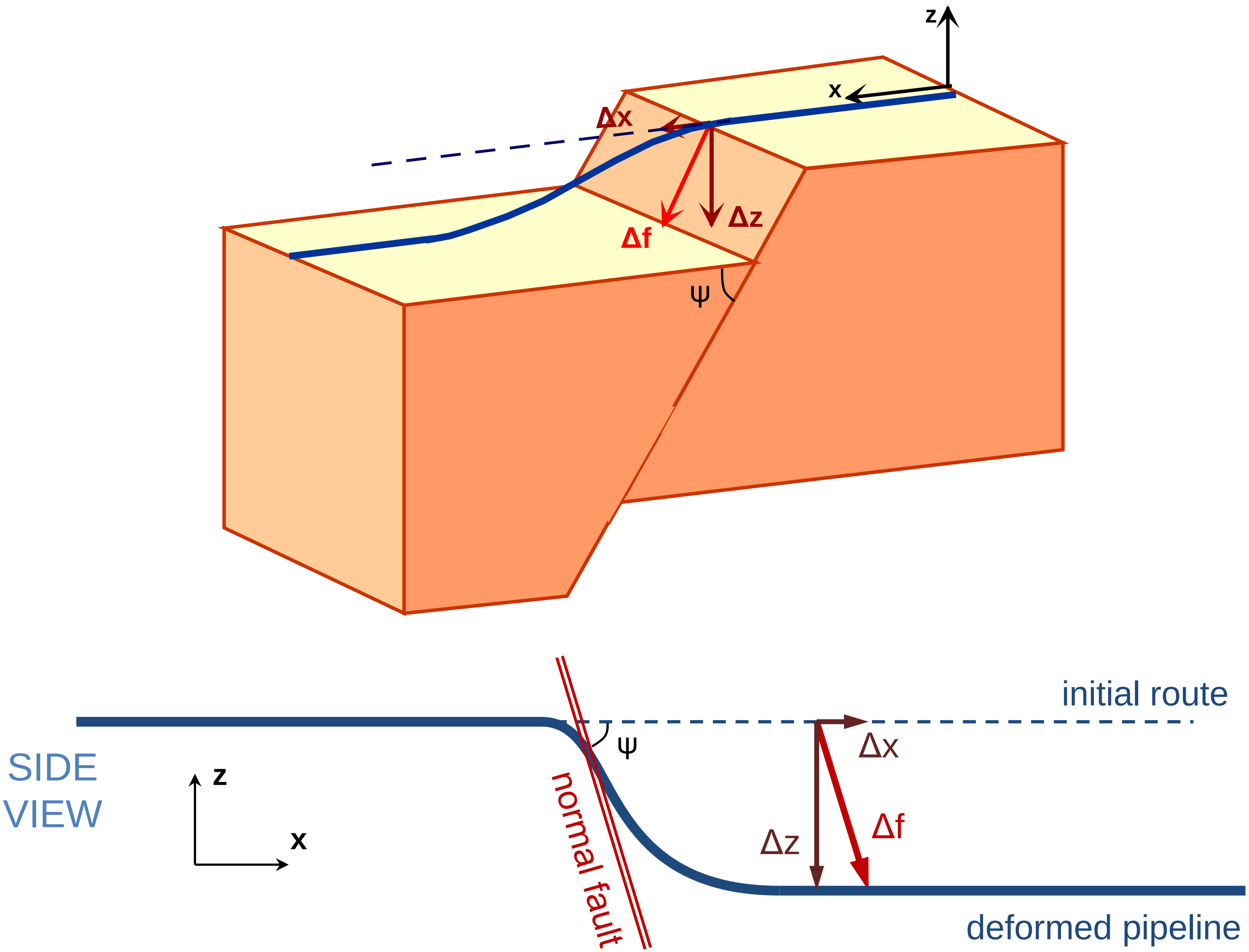
(γ=18KN/m^3 , φ=36°)

Embedment H=1.30m



Analytical Methodology

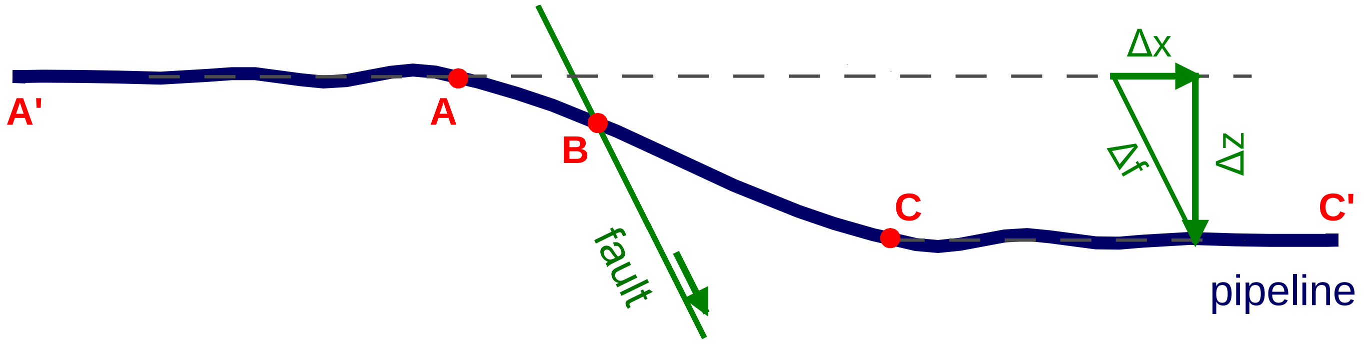
Karamitros et al (2011) – Normal Fault Crossings

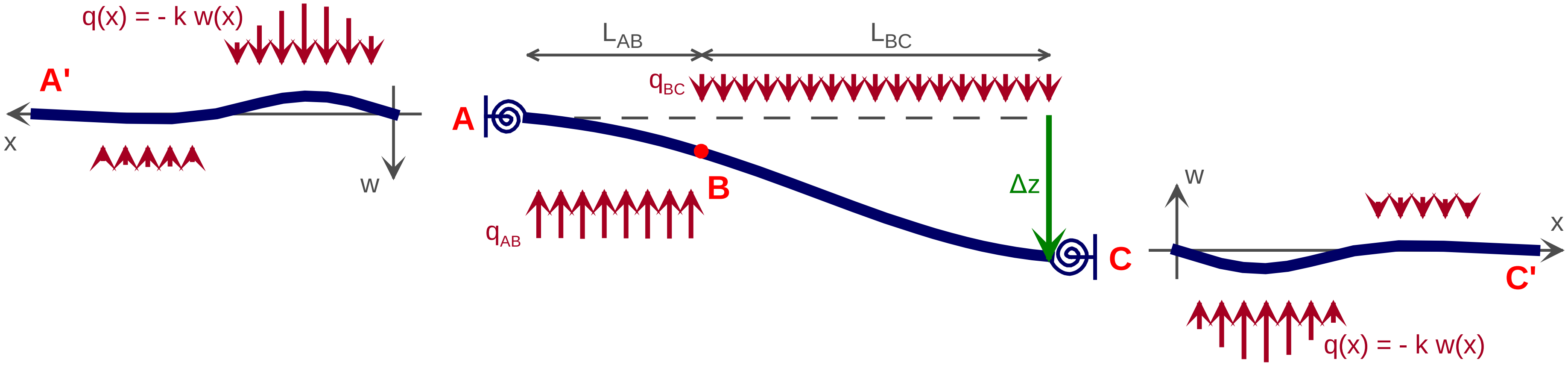


Analytical Methodology

Karamitros et al (2011) – Normal Fault Crossings

Pipeline discretized in 3 segments:





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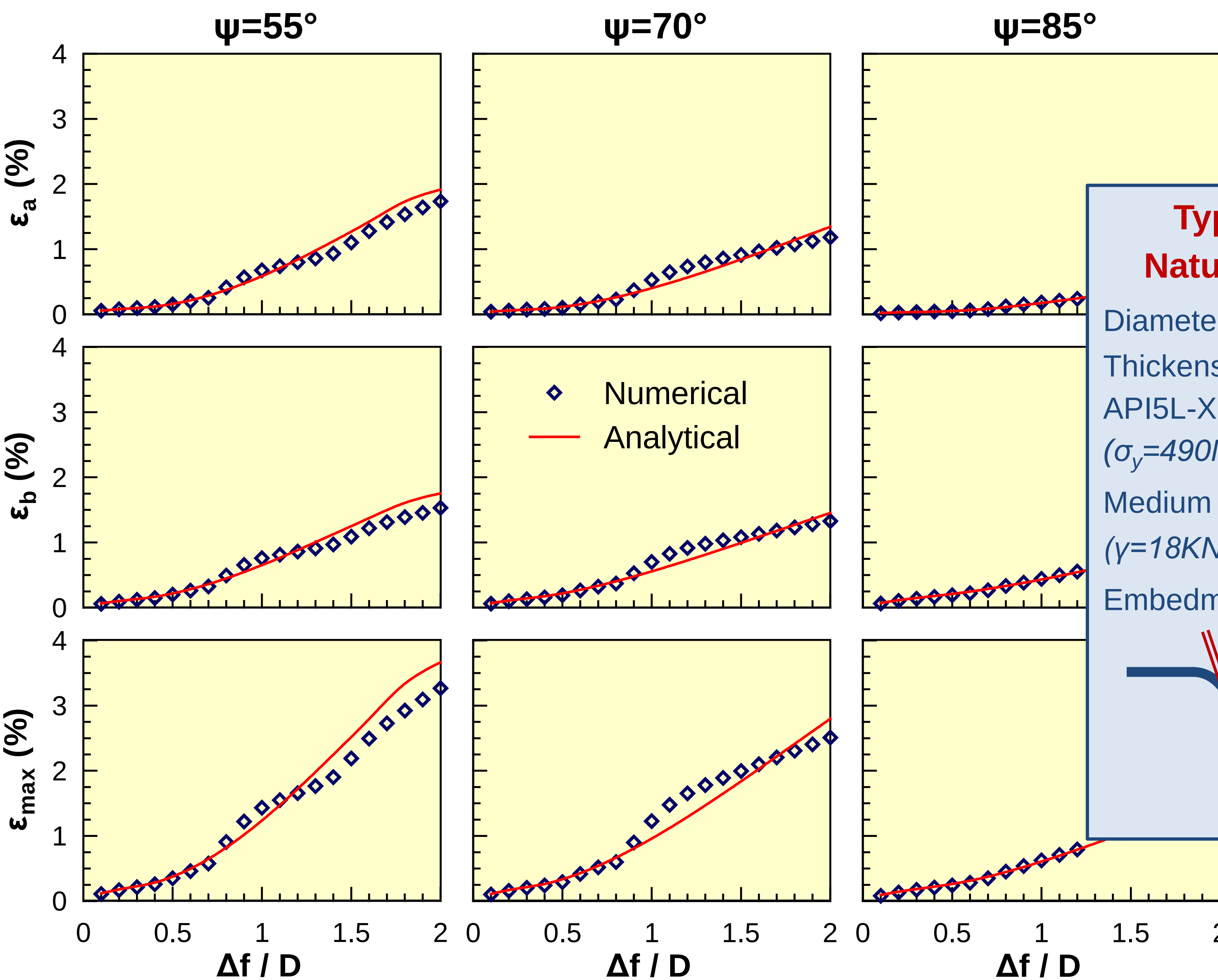

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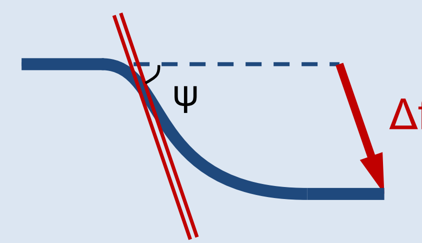
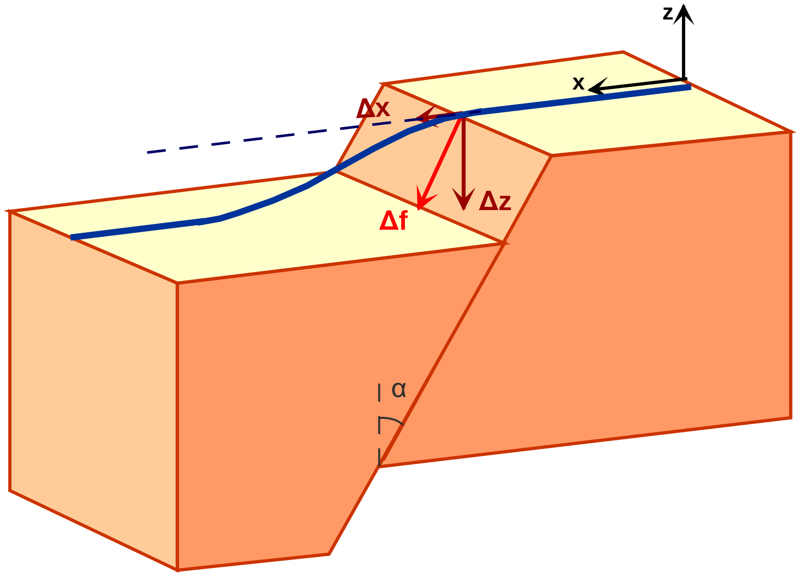


Oblique Fault Crossings



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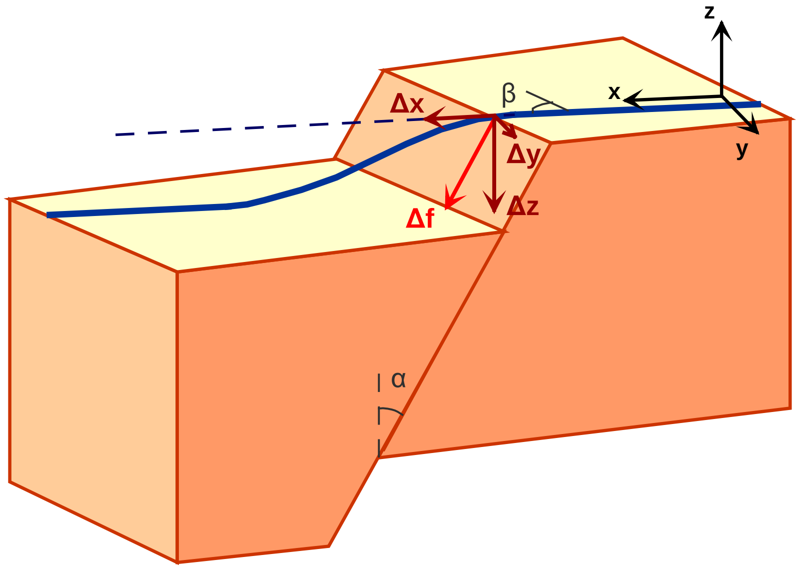

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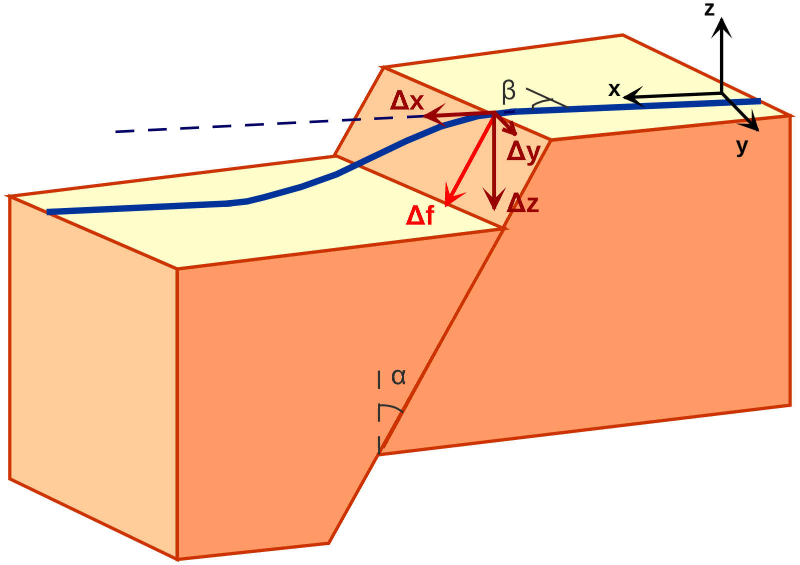
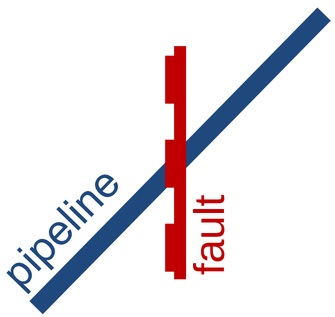
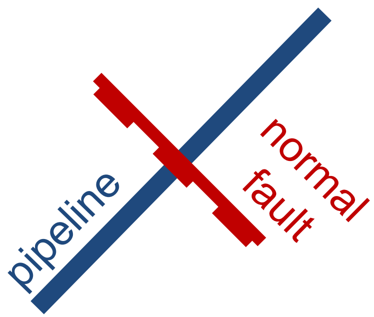




Oblique Crossing

Δx, Δy, Δz

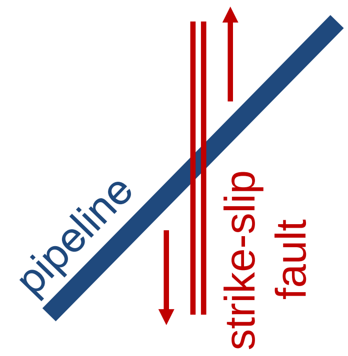
=



Normal Fault Crossing

Δx, Δz *(Δy=0)*

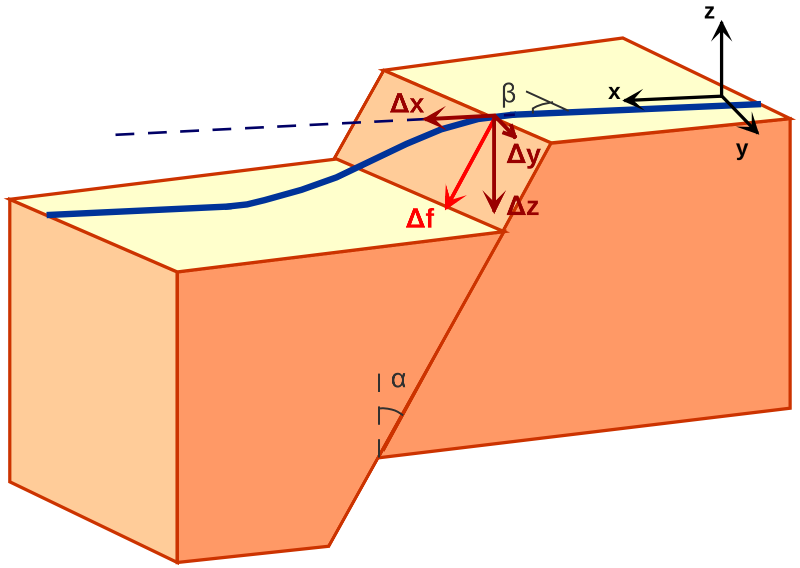
+



Strike-Slip Fault Crossing

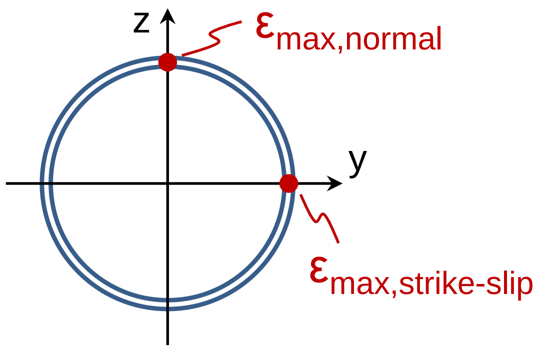
Δx, Δy *(Δz=0)*

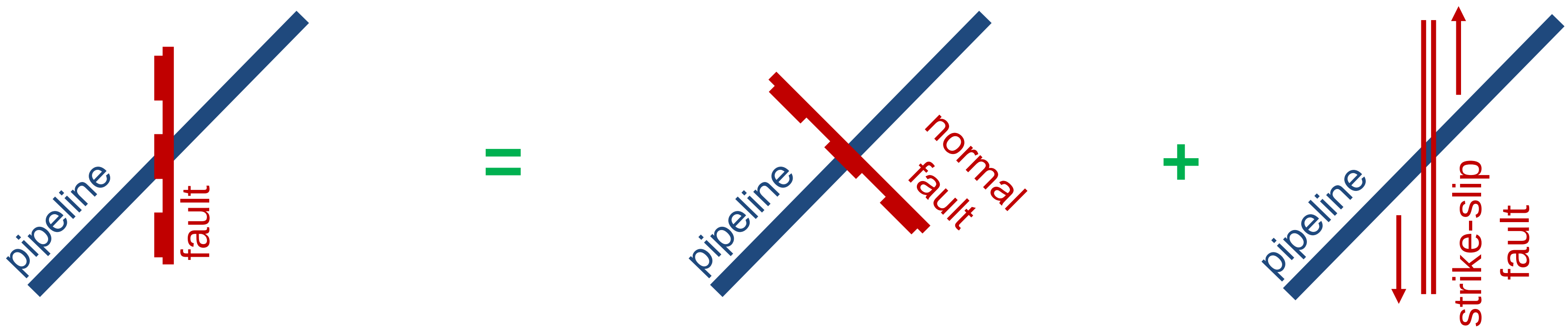
Oblique Fault Crossings



Maximum strains occur at:

- different locations along the pipeline
- different positions on the cross-section





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Strike-Slip Fault Crossing

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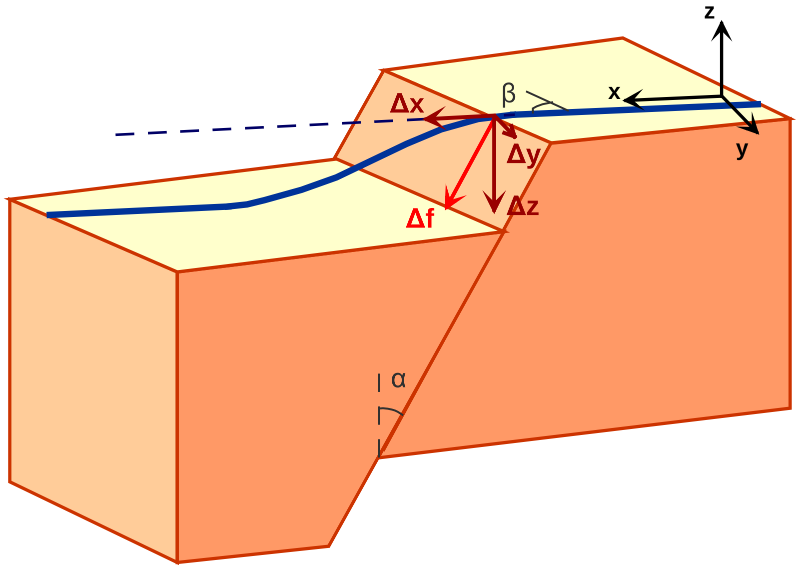

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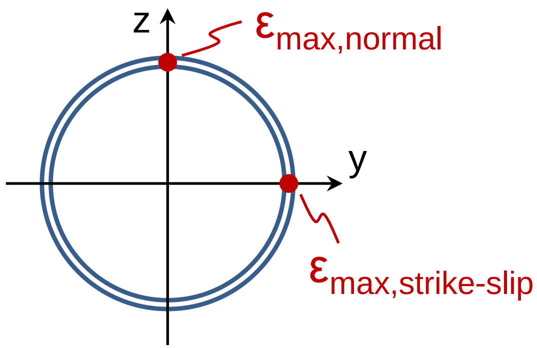

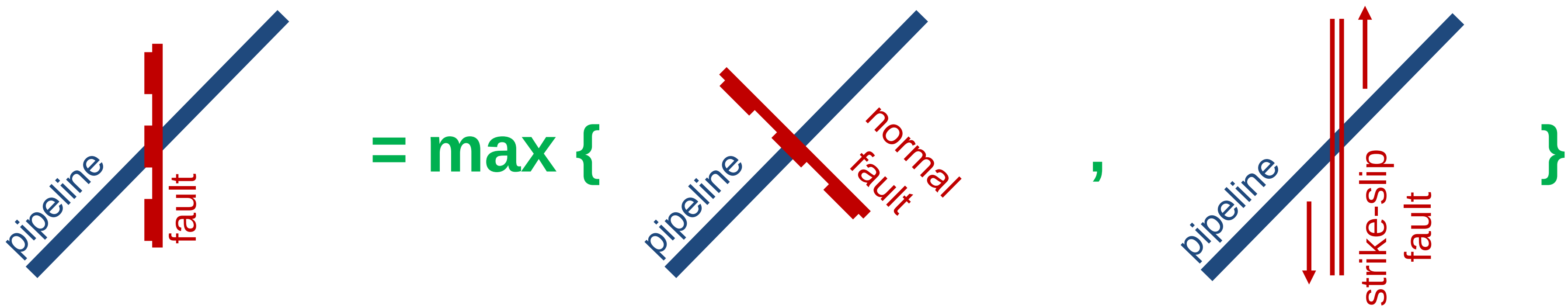

Oblique Crossing

Δx, Δy, Δz

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Δx, Δy *(Δz=0)*

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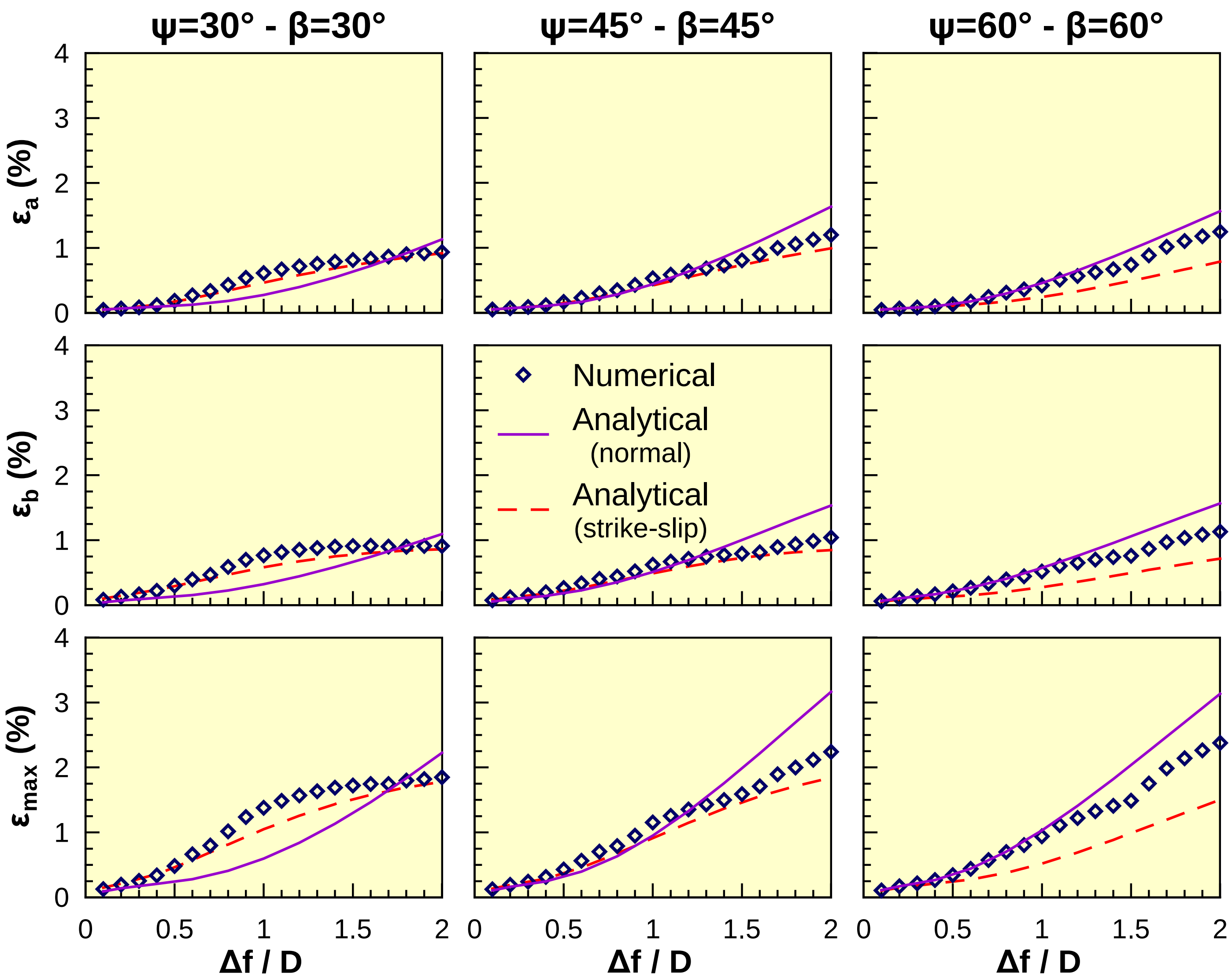
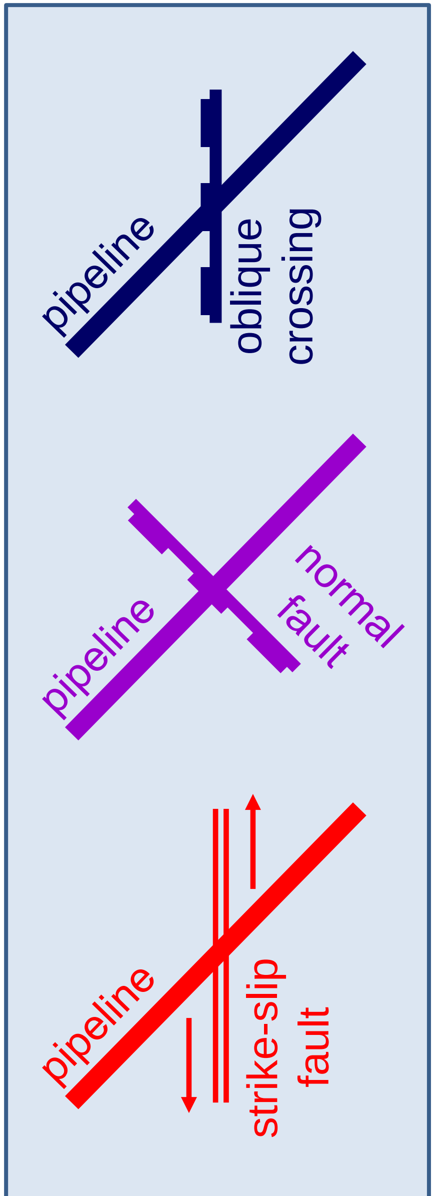
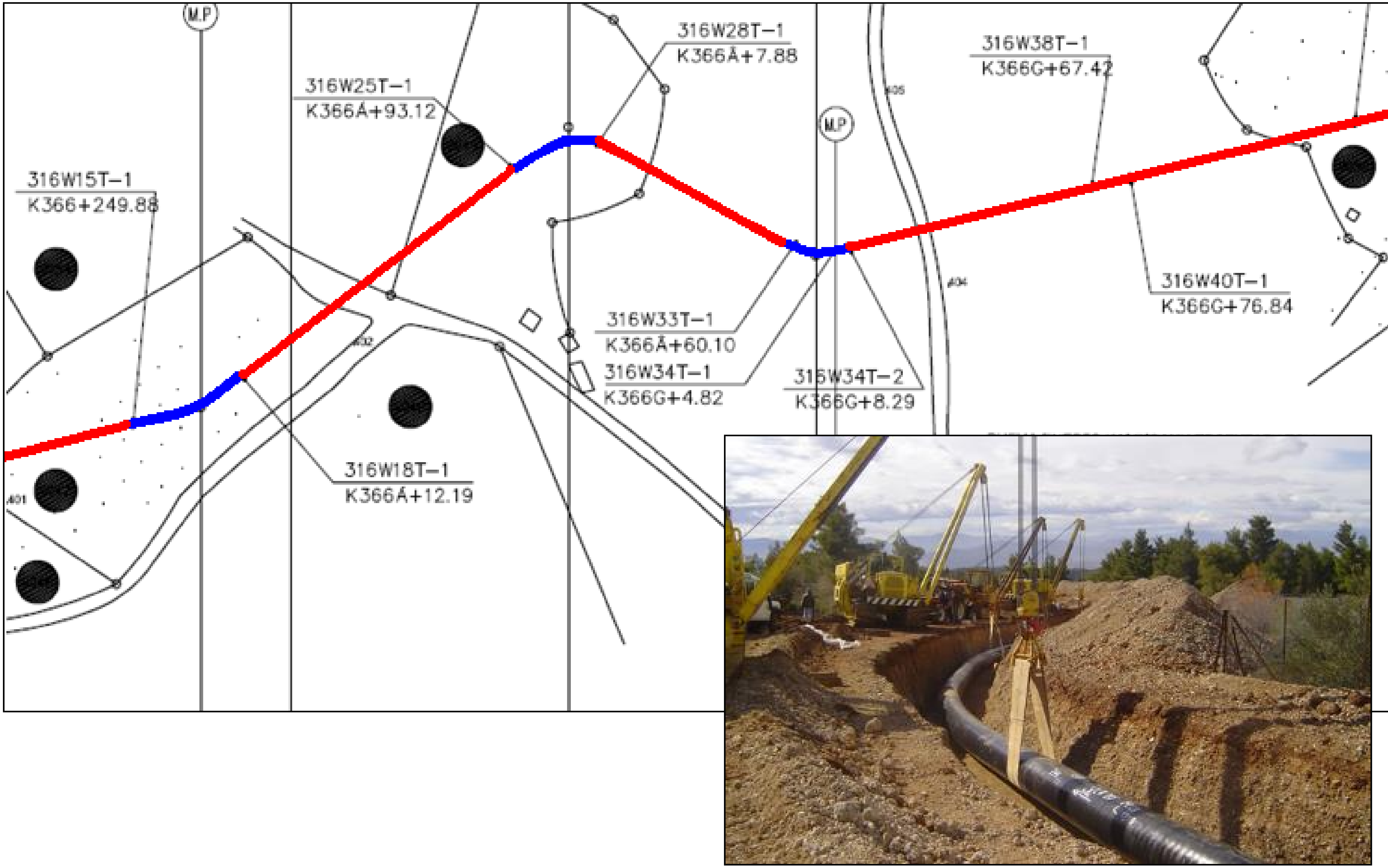




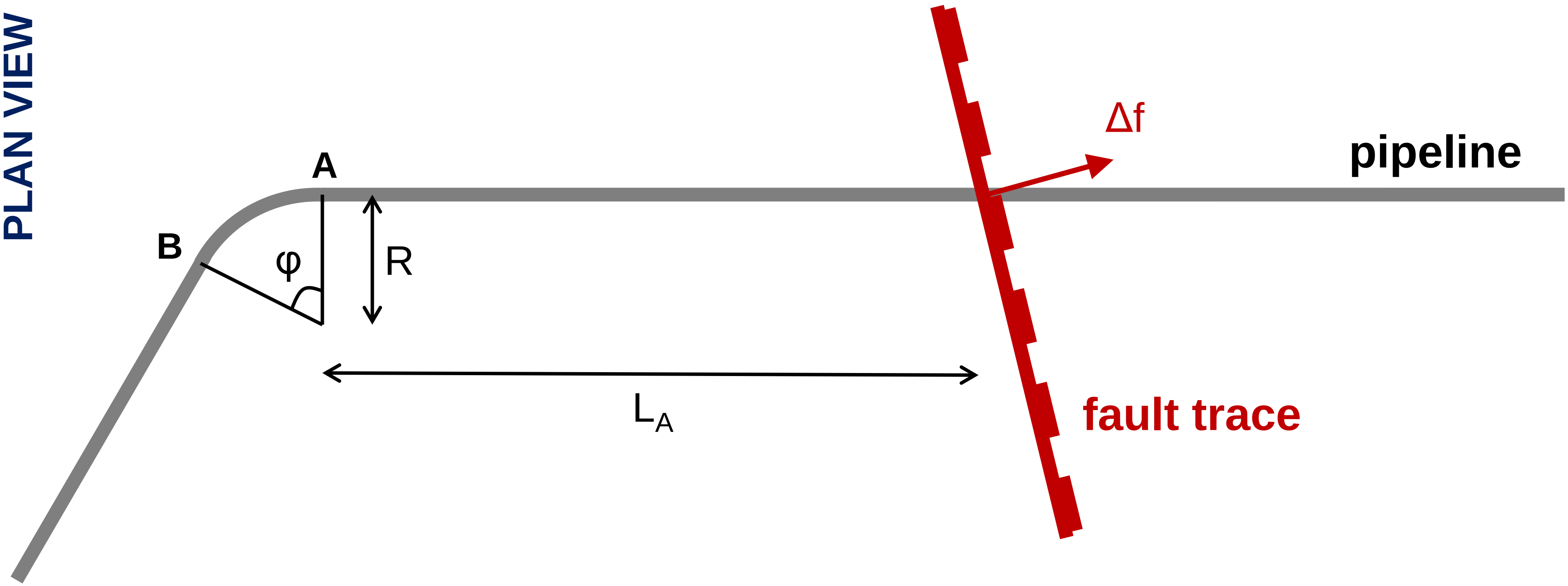
Typical Pipeline Layout in Practice



Analytical Methodology

Karamitros et al (2016) – Pipelines with Bends

PLAN VIEW



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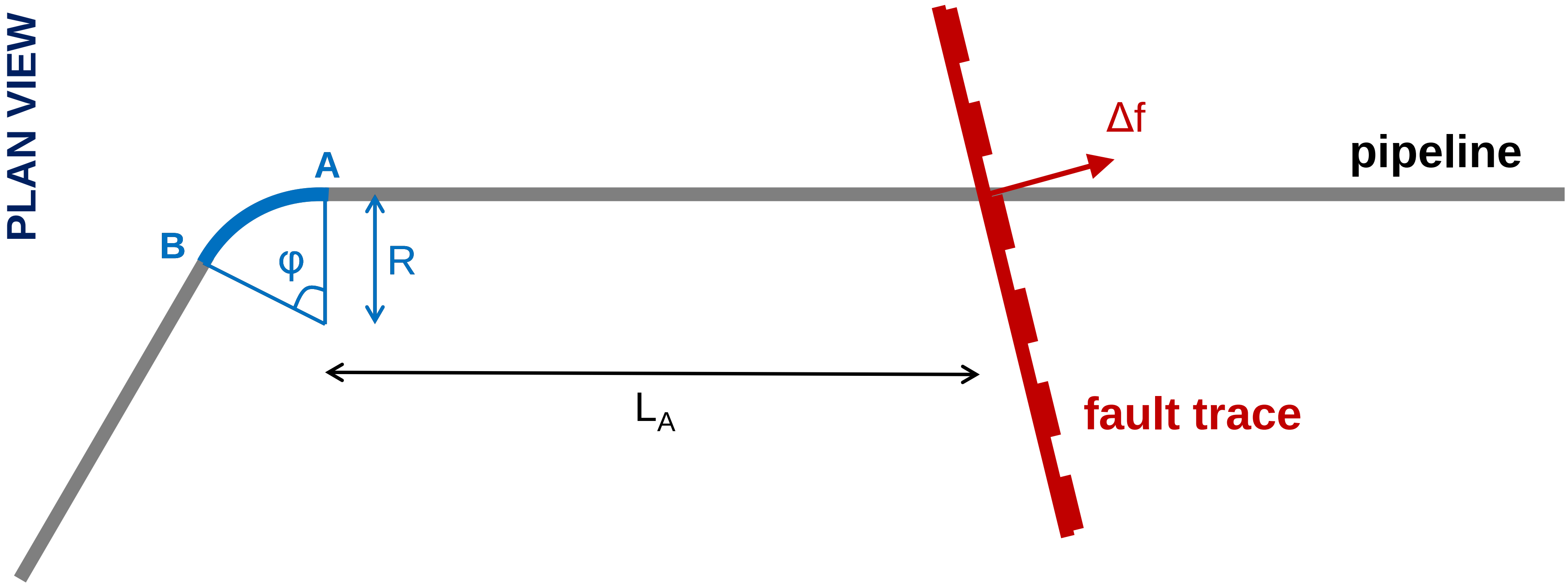
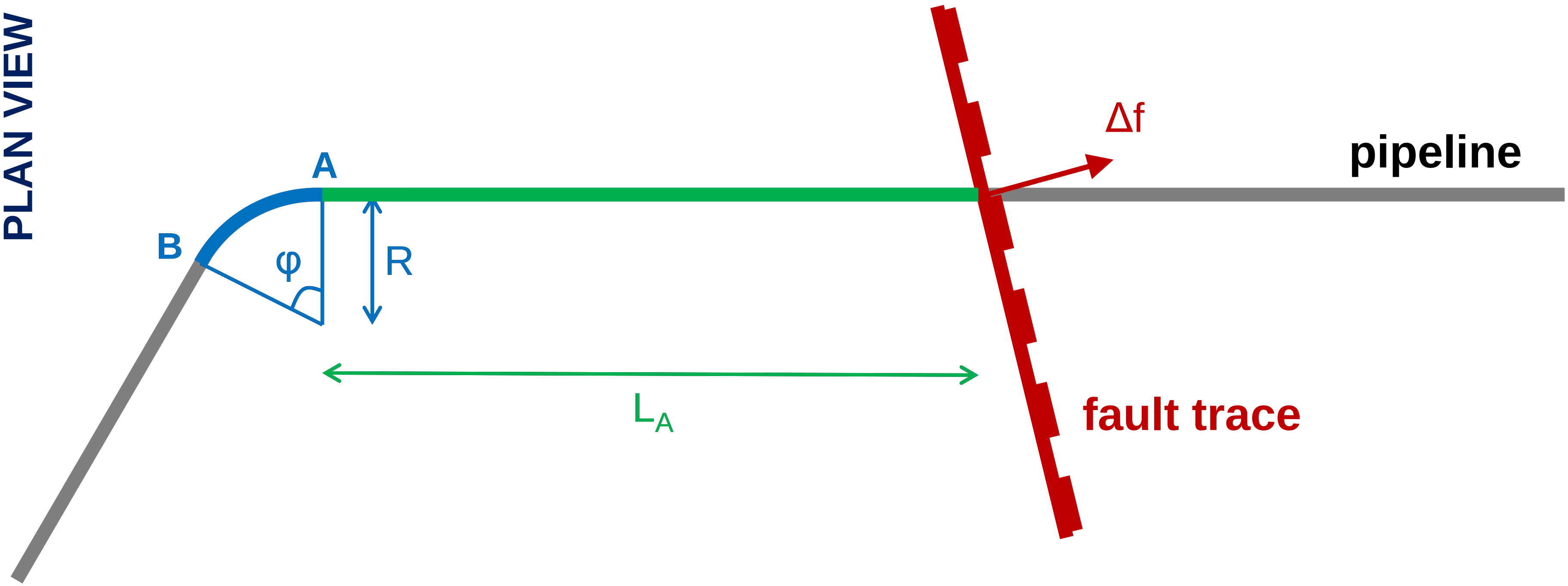


Step 1: Analyze the pipeline close to the bend

Analytical Methodology

Karamitros et al (2016) – Pipelines with Bends

PLAN VIEW

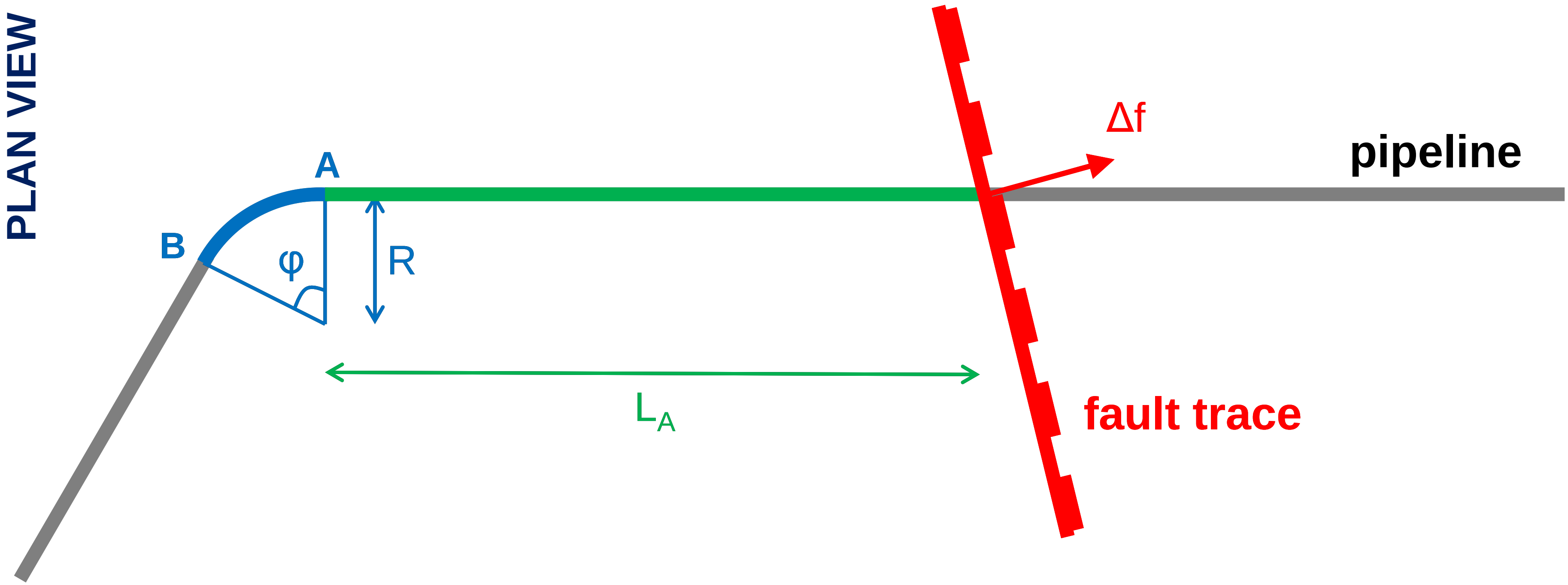


Step 1: Analyze the pipeline close to the bend

Step 2: Fault – bend interaction

Analytical Methodology

Karamitros et al (2016) – Pipelines with Bends

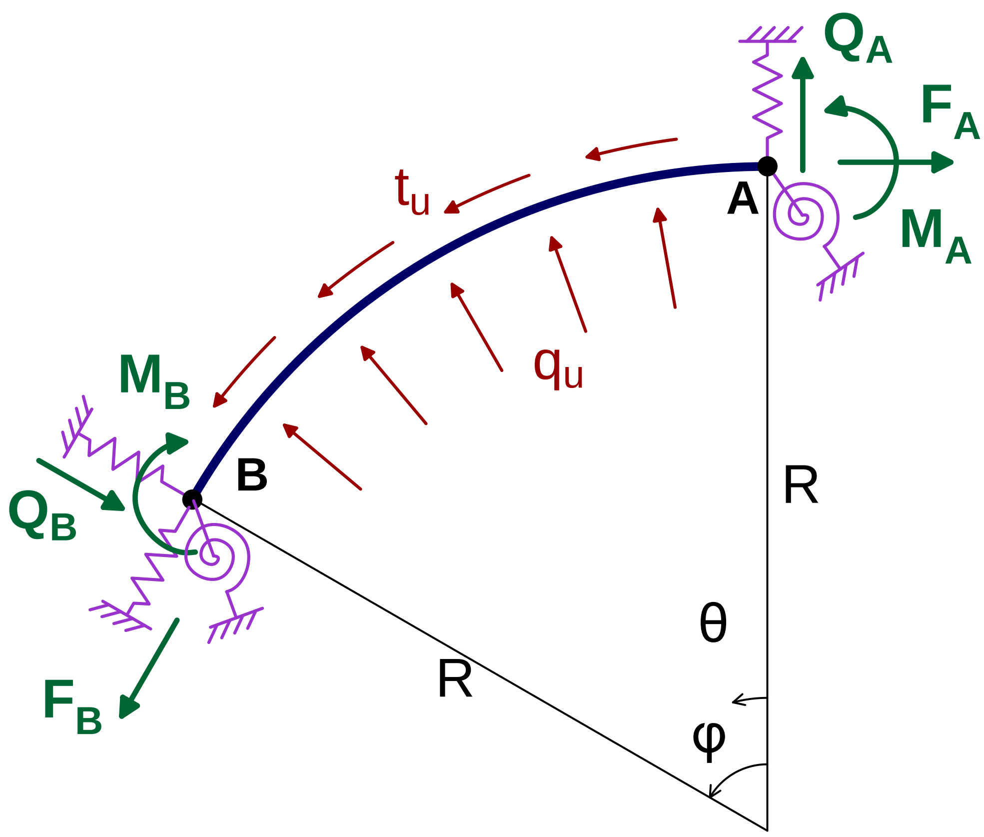


Step 1: Analyze the pipeline close to the bend

Step 2: Fault – bend interaction

Step 3: Analyze the pipe at the fault crossing

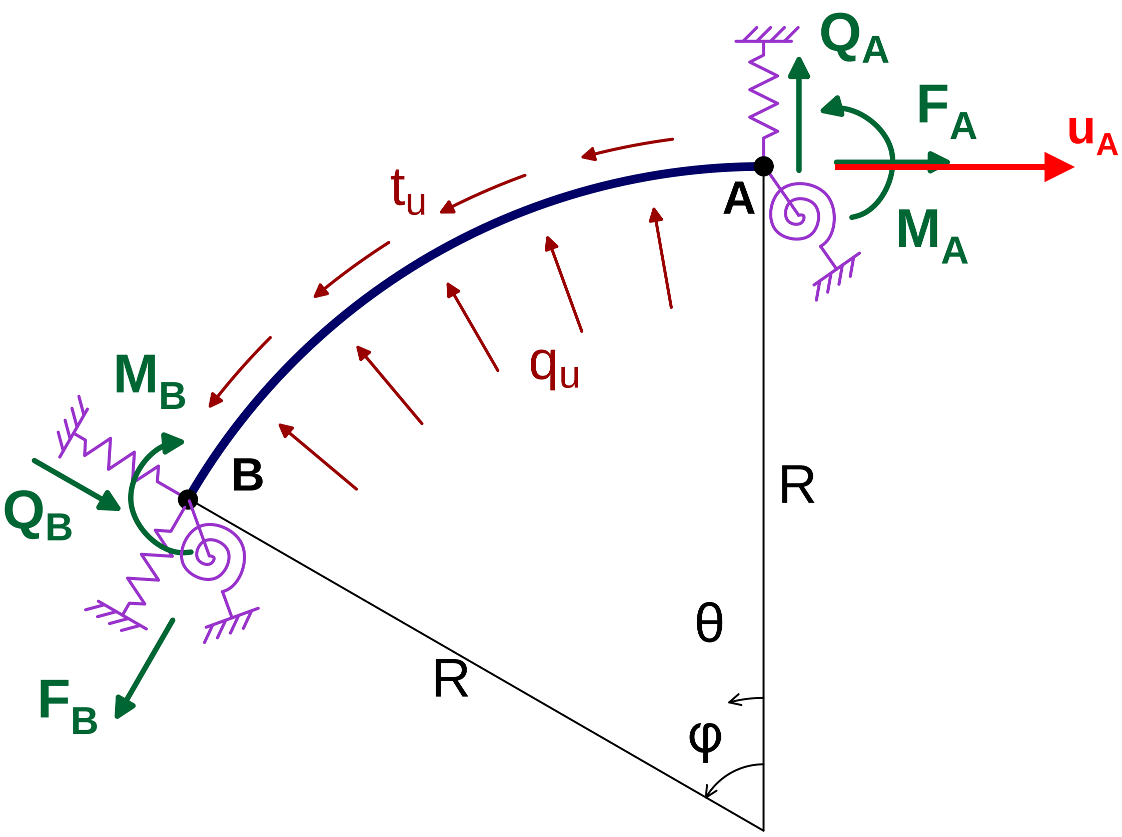
Step 1: Analysis of the Bend



Analysis using the Direct Stiffness Method:

$$\{P\} - \{P_L\} = \left([K] + \left\lfloor K_{spr} \right\rfloor\right)\{u\}$$

Step 1: Analysis of the Bend



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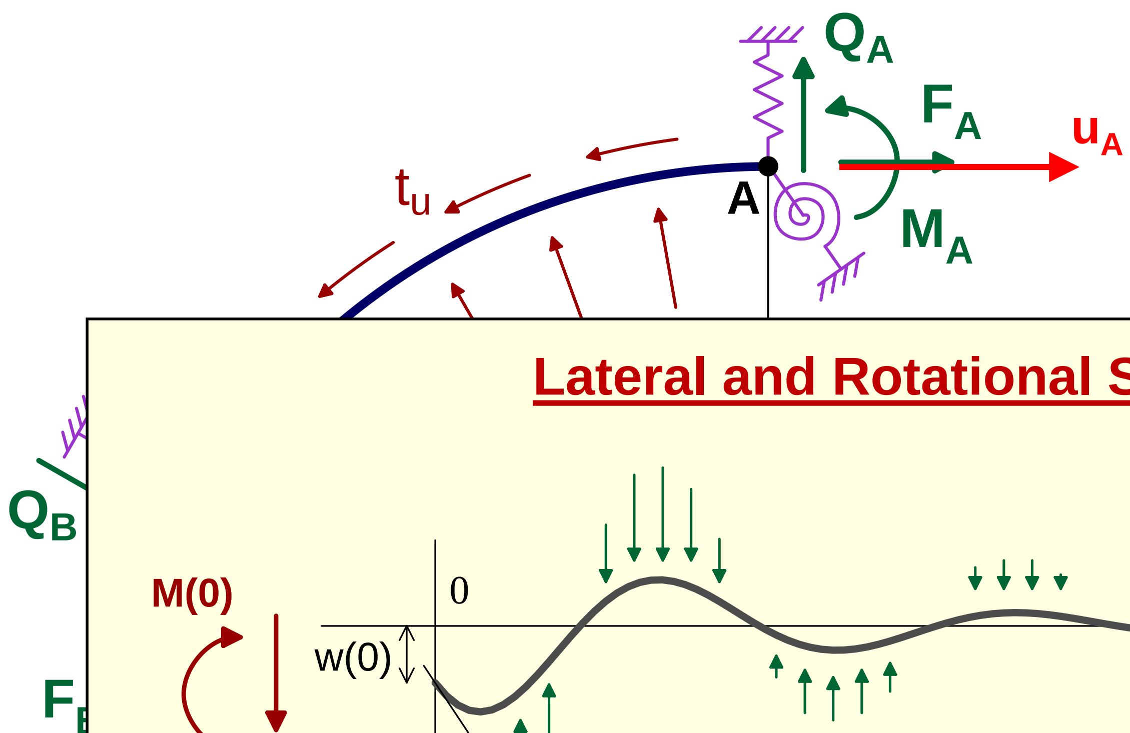
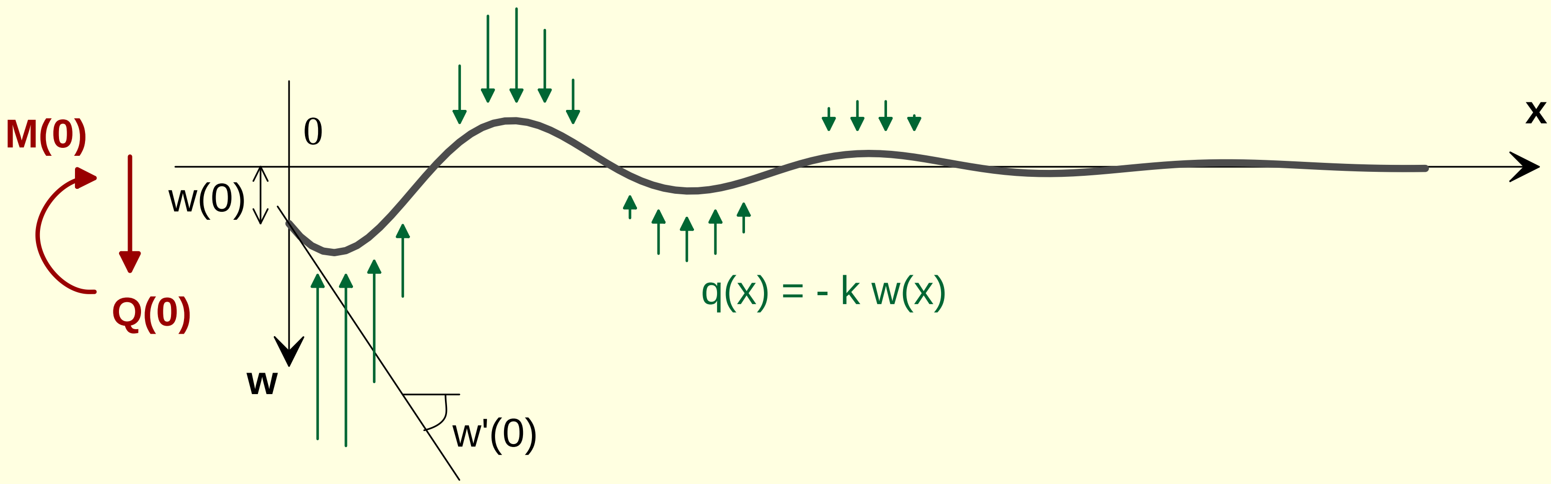


Analy

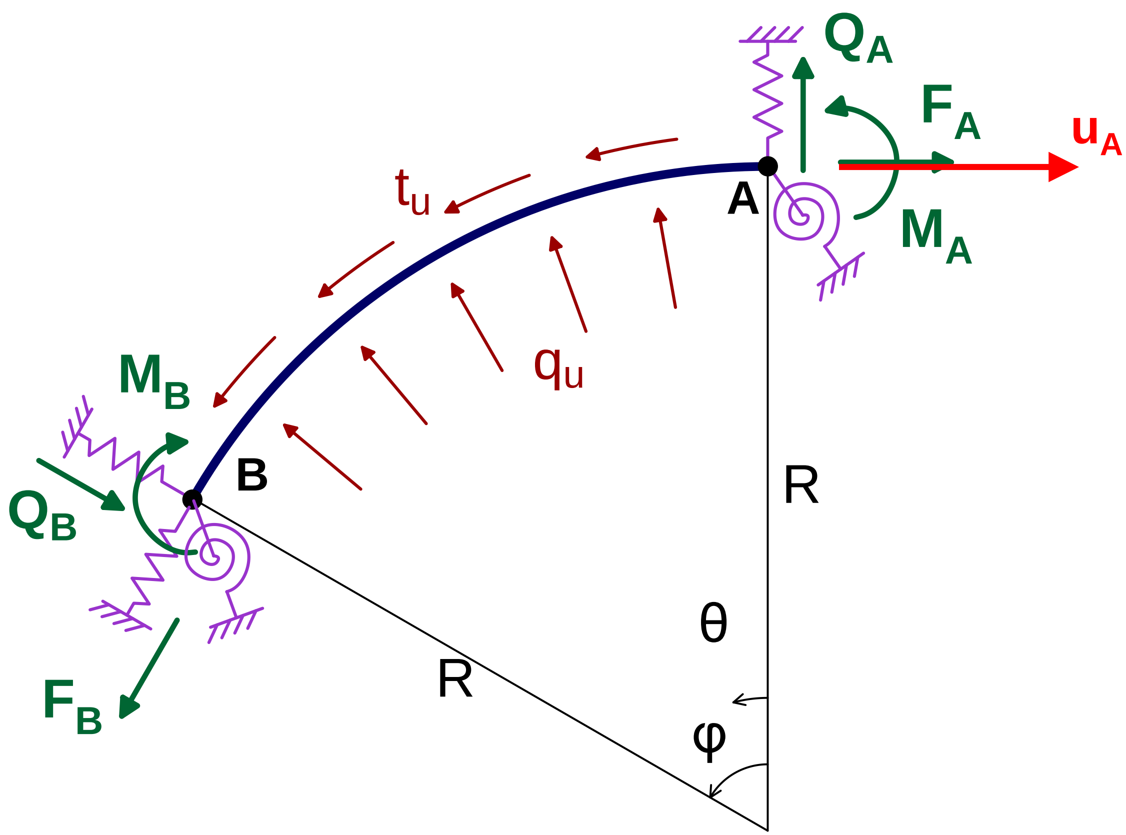
Lateral and Rotational Springs



Elastic beam on elastic foundation

➪ Obtain relations between **M(0)**, **Q(0)** and **w´(0)**, **w(0)**

Step 1: Analysis of the Bend



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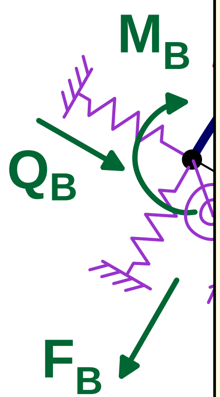
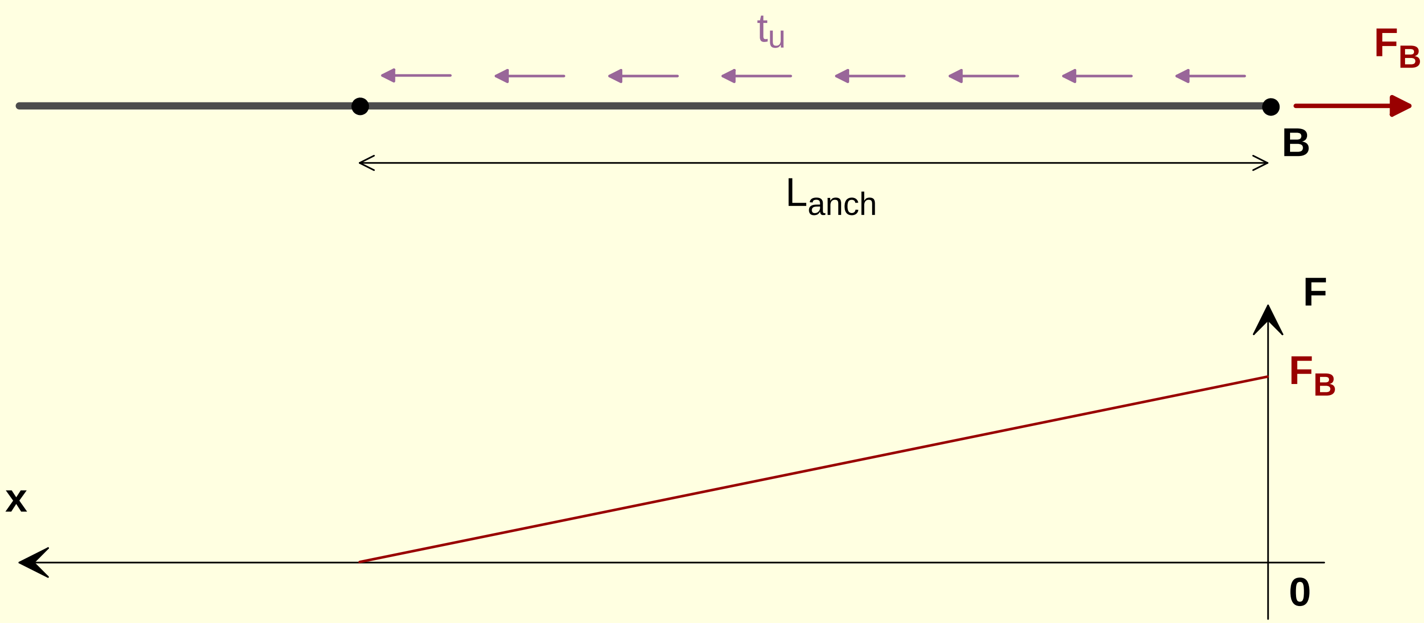
Step 1: Analysis of the Bend



Axial Spring at end B



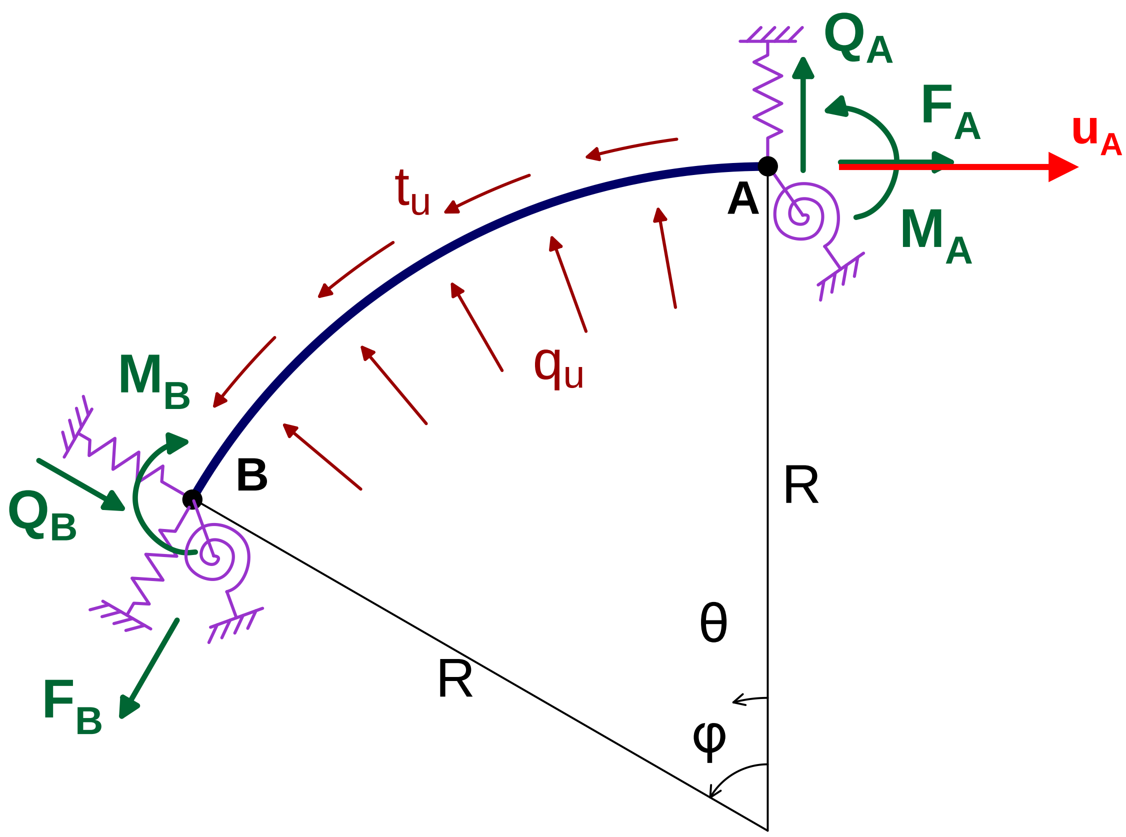
Axial force (and strain) distribution along the pipeline

⇨ Obtain relation between $\mathbf{F_B}$ and $\mathbf{u_B}$

Analysis using the Direct Stiffness Method:

$$\{P\} - \{P_L\} = \left([K] + \left|K_{spr}\right|\right)\{u\}$$

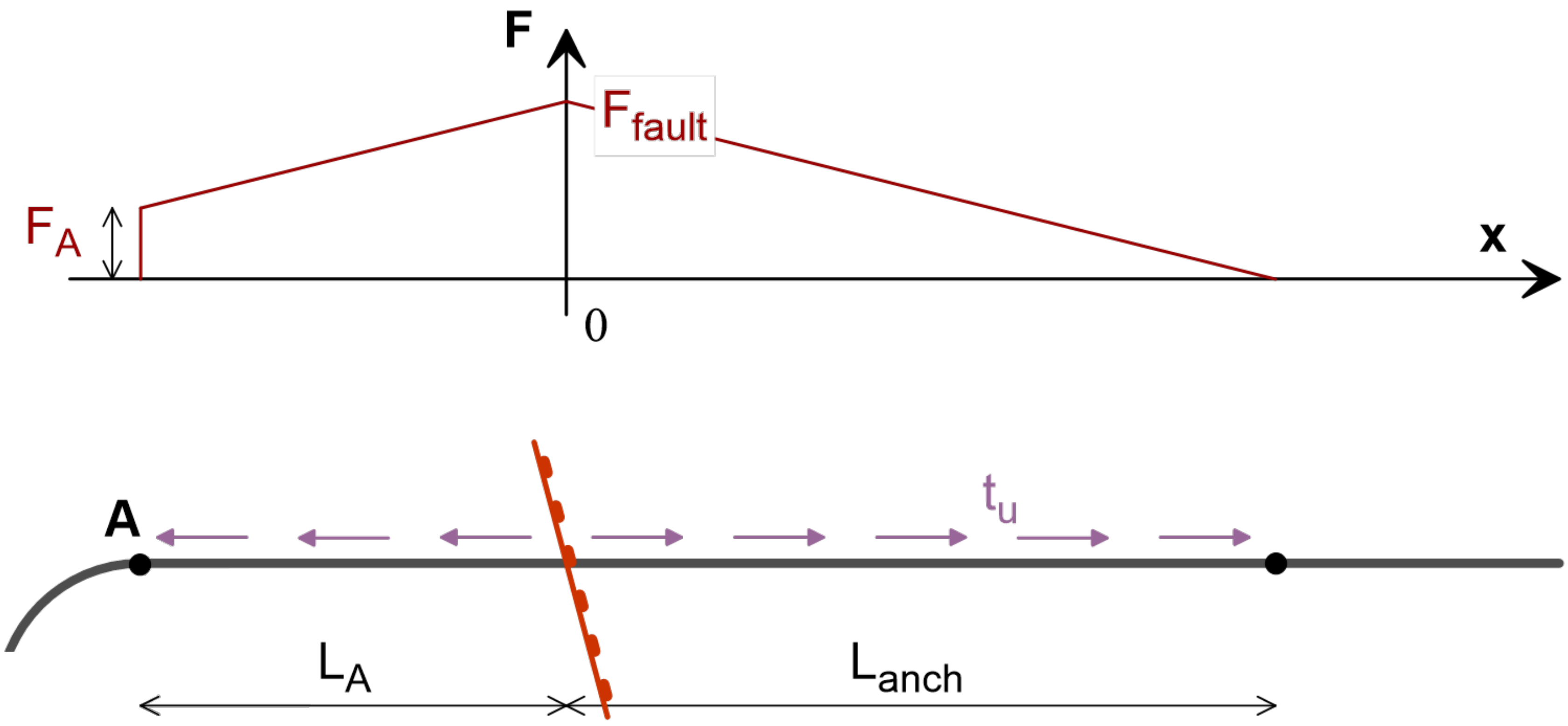
Step 1: Analysis of the Bend



Analysis using the Direct Stiffness Method:

$$\{\boldsymbol{P}\} - \{\boldsymbol{P_L}\} = \left([\boldsymbol{K}] + \left[\boldsymbol{K_{spr}}\right]\right)\{\boldsymbol{u}\}$$

Step 2: Fault-Bend Interaction



Axial component of Fault movement **=** Axial displacement at bend u_A **+** Integral of strains along the pipeline

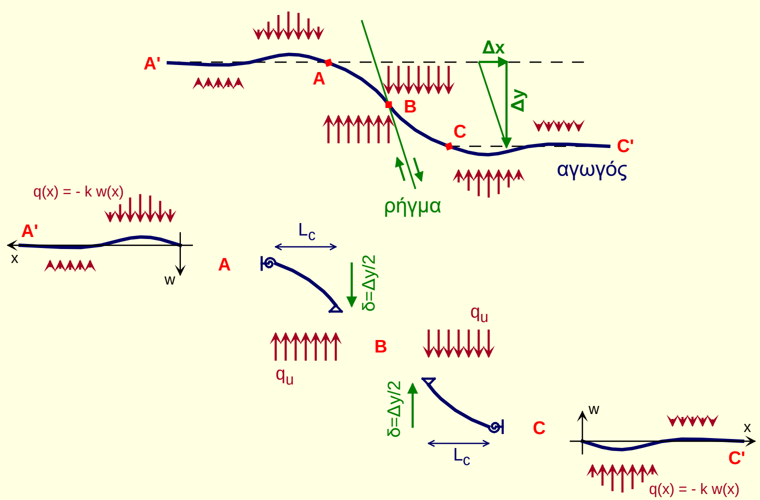
Step 3: Verification at Fault Crossing

Calculate axial force F_{fault} at the position of the fault

and employ one of the existing analytical methodologies:

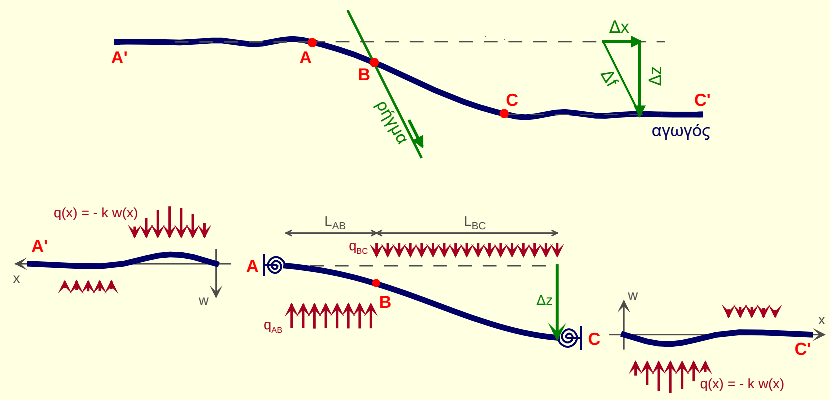
Analytical Methodology for strike-slip fault crossings

Karamitros et al (2007)



Analytical Methodology for normal fault crossings

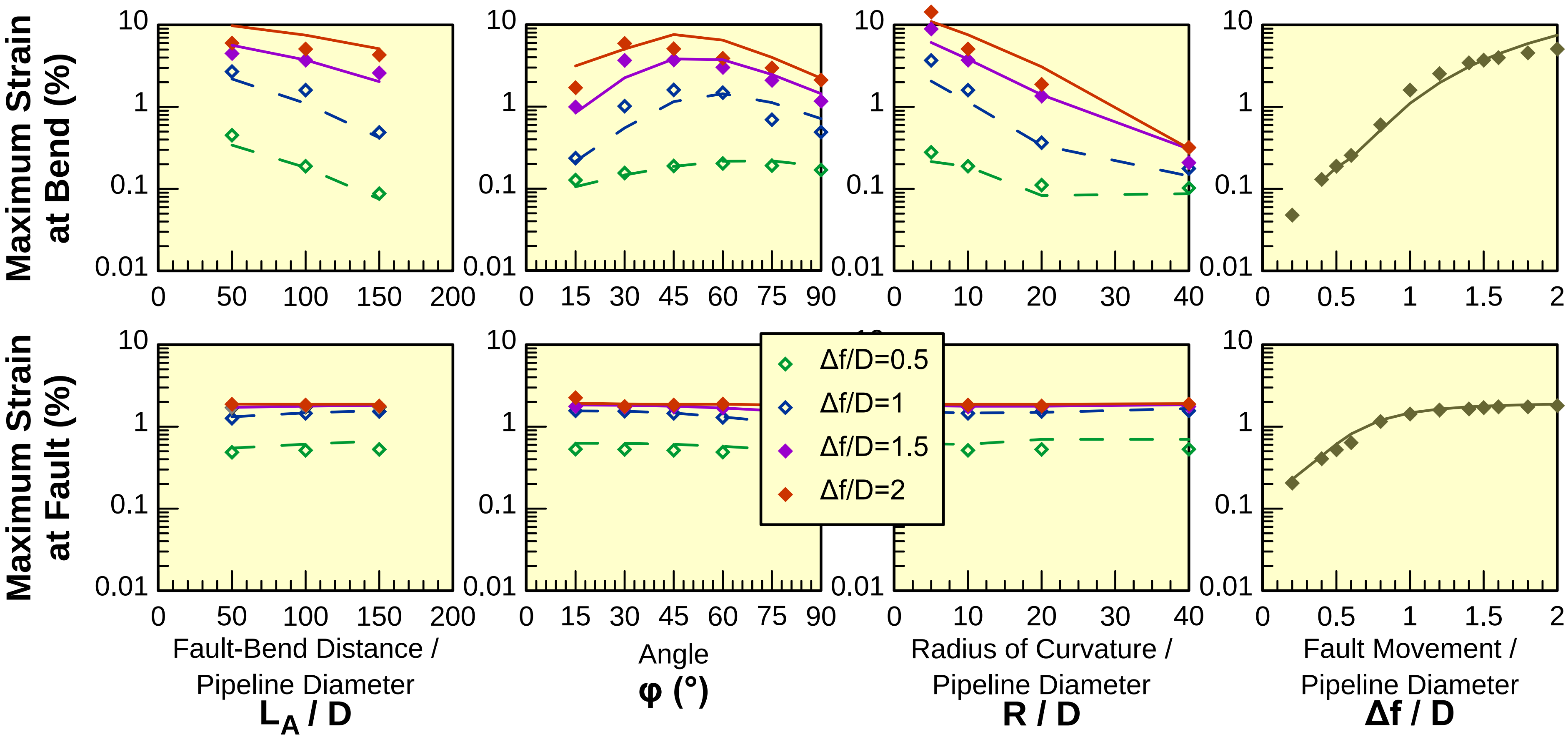
Karamitros et al (2011)



…or their newer versions, e.g. Trifonov & Cherniy (2010)

New Analytical Methodology

Karamitros et al (2016) – Pipelines with Bends



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Thank you for your attention!

Karamitros D.K., Bouckovalas G.D., Kouretzis G.P. (2007): *"Stress Analysis of Buried Steel Pipelines at Strike-slip Fault Crossings"*, Soil Dynamics and Earthquake Engineering, vol. 27, pp. 200–211.

Karamitros D.K., Bouckovalas G.D., Kouretzis G.P., Gkesouli V. (2011): *"An Analytical Method for Strength Verification of Buried Steel Pipelines at Normal Fault Crossings"*, Soil Dynamics and Earthquake Engineering, vol. 31(11), pp. 1452-1464.

Kouretzis G.P., Karamitros D.K., Sloan S.W. (2015): *"Analysis of buried pipelines subjected to ground surface settlement and heave"*, Canadian Geotechnical Journal, vol. 52(8), pp. 1058-1071.

Karamitros D.K., Bouckovalas G.D., Zoupantis C. (2016): *"Buried Pipelines with bends: Analytical verification against permanent ground displacements"*, Canadian Geotechnical Journal, 10.1139.

Calculation spreadsheets available at: **www.dimitriskaramitros.com**