HORIZON 2020

ExchangeRisk

EXperimental & Computational Hybrid Assessment of Natural Gas Pipelines Exposed to Seismic Risk

Damage of natural gas pipelines under compression

Grigorios Tsinidis, University of Sannio, Italy
Luigi Di Sarno, University of Sannio, Italy & University of Liverpool, UK

Università degli Studi del Sannio

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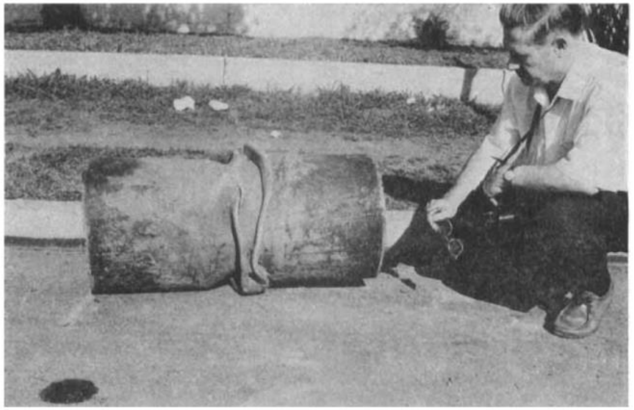
VCE Vienna Consulting Engineers ZT GmbH

Observed seismic behaviour of NG pipelines under compression

- **Excessive earthquake-induced ground movements may cause large compression loadings on pipelines, potentially leading to shell-mode (or local) buckling or beam buckling failures (Yun & Kyriakides, 1990)**

- **Examples of bad behaviour:**
  - **O' Rourke & Liu (1999) reported a local buckling failure of a 406 mm diameter steel gas pipeline during the 1972 San Fernando earthquake**

  - **Mitsuya et al. (2013) reported beam buckling failures of gas pipelines with 114 mm diameter, caused by ground seismic shaking, during the 2007 Niigataken Chuetsu-oki earthquake**



Buckling response of embedded pipelines

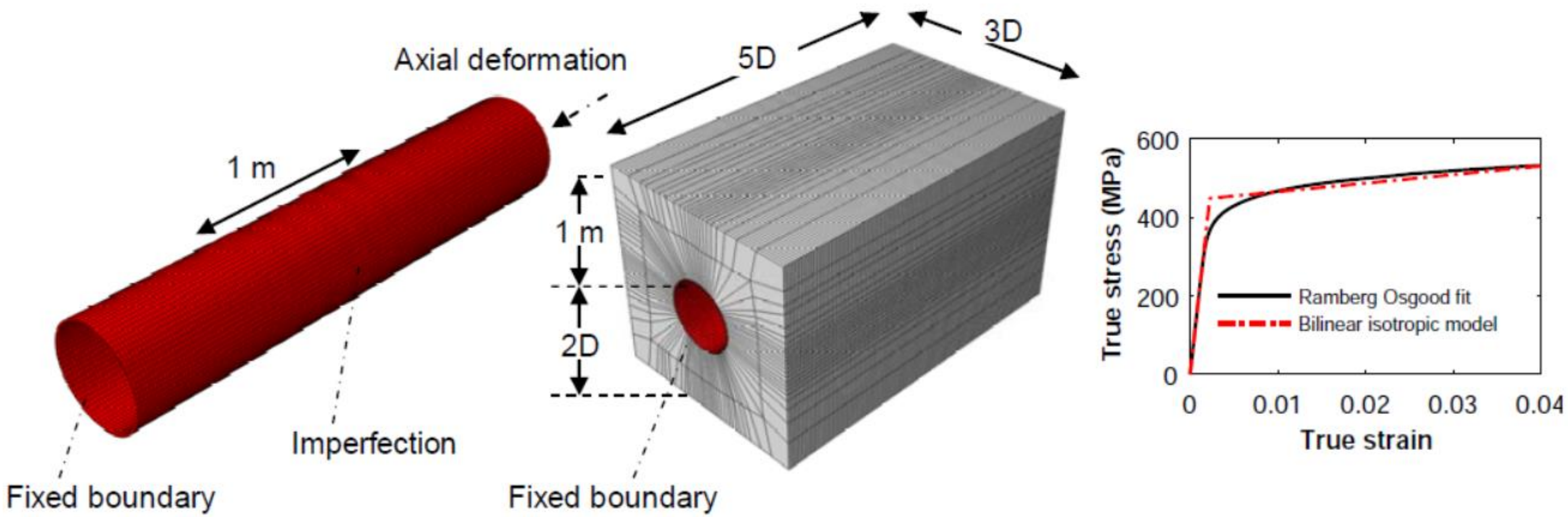
- **For typical radius to thickness (R/t) ratios and steel grades that are commonly used in NG pipeline applications, the shell-mode instabilities are expected in the inelastic regime of response, i.e. plastic buckling phenomena may occur**

- **Previous studies (e.g. Paquette & Kyriakides 2006, Kyriakides & Corona 2007) have demonstrated that the axial response of pressurized pipelines is interacting plastically with the stress caused by the internal pressure**

Numerical study on the response of NG pipelines under compression

- A series of static compression analyses was carried out on segments of embedded and above ground gas pipelines, to better understand the buckling response of this type of structures, as well as the relevant simulation aspects (geometric imperfections, effect of internal pressure etc)

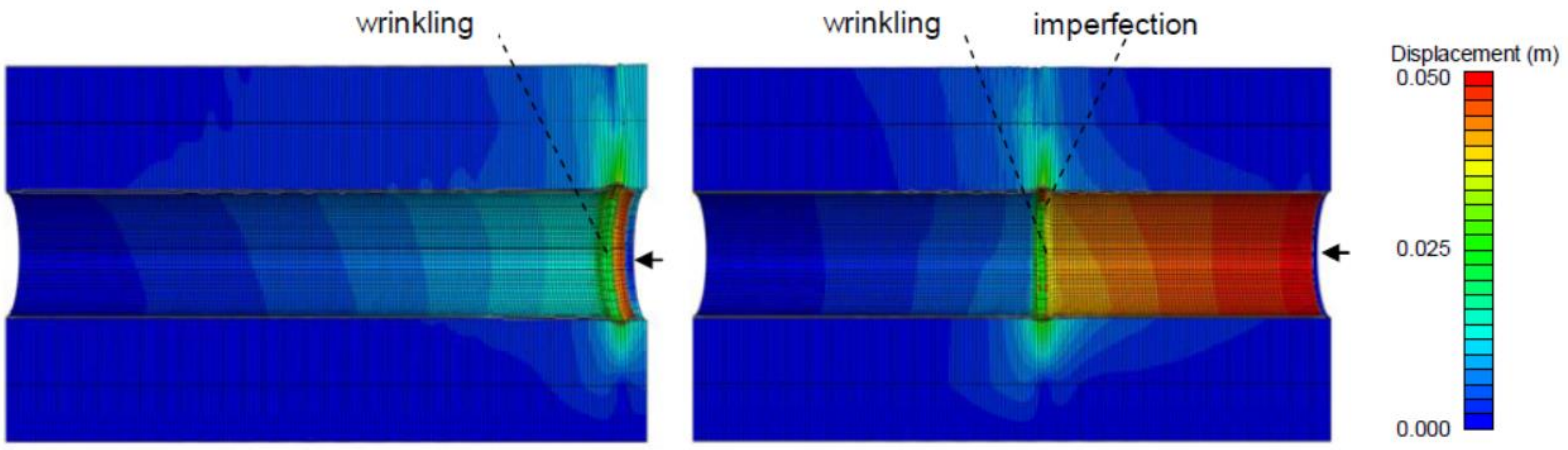
- Analyses of ‘perfect’ segments and segments with initial stress-free geometric imperfection at the middle section



Numerical study on the response of NG pipelines under compression

- **Contour diagrams of resultant displacement on deformed shapes of systems of trench-embedded pipe segments (D = 914.4 mm), computed after critical loading**

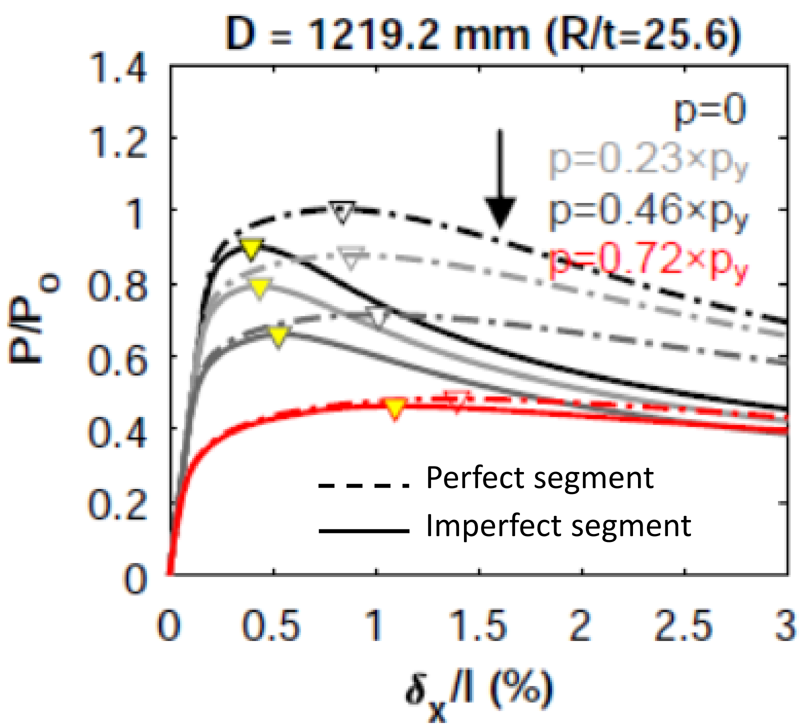
perfect segment | **segment with imperfection (w/t = 0.1)**



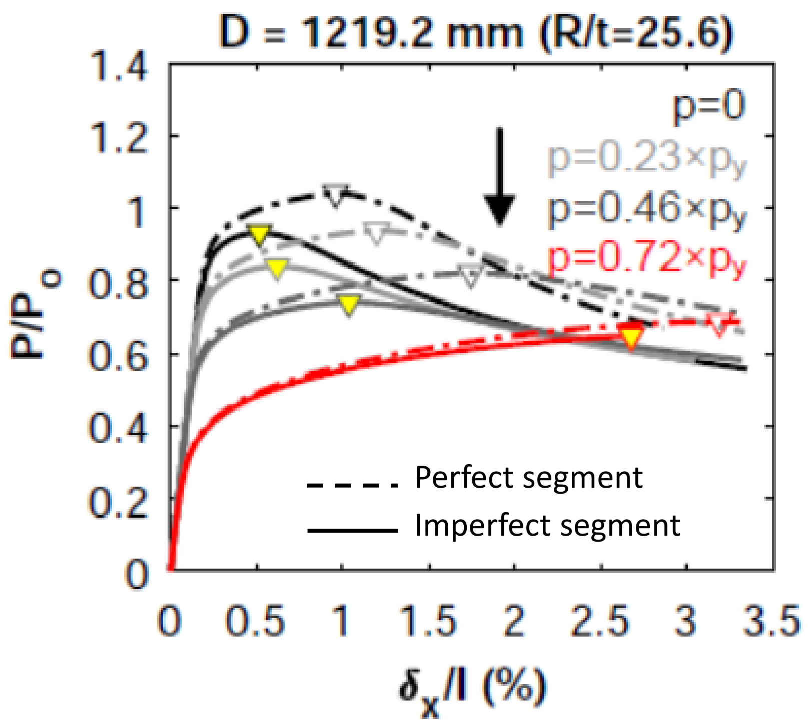
Numerical study on the response of NG pipelines under compression

- Average axial load-deformation paths of pipe segments, computed for various levels of internal pressure

Above ground pipe segments

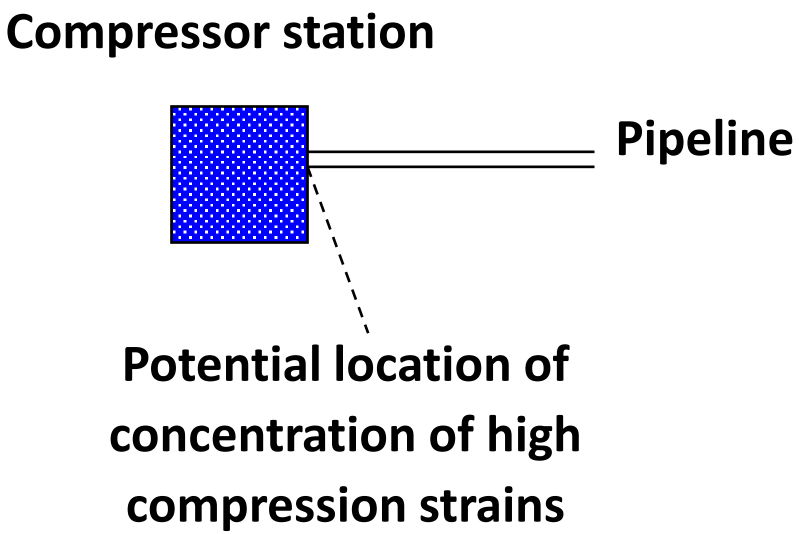


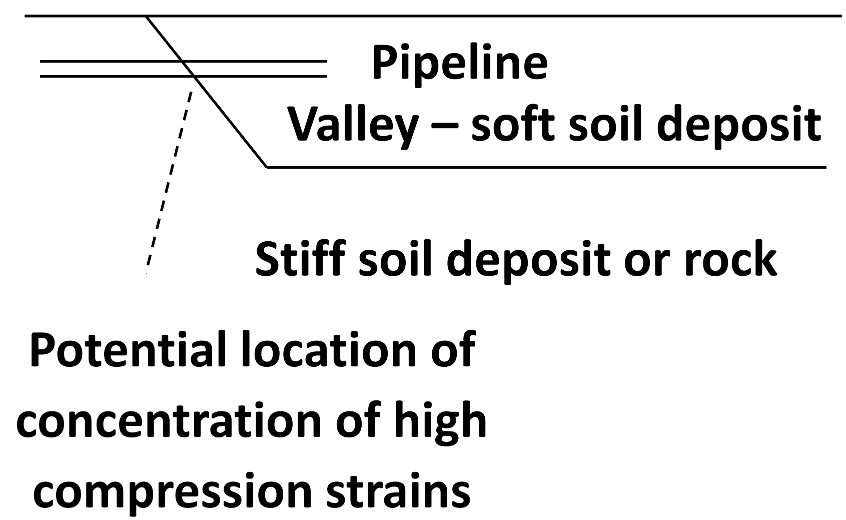
Embedded pipe segments



Compression of NG pipelines due to seismically-induced ground deformations

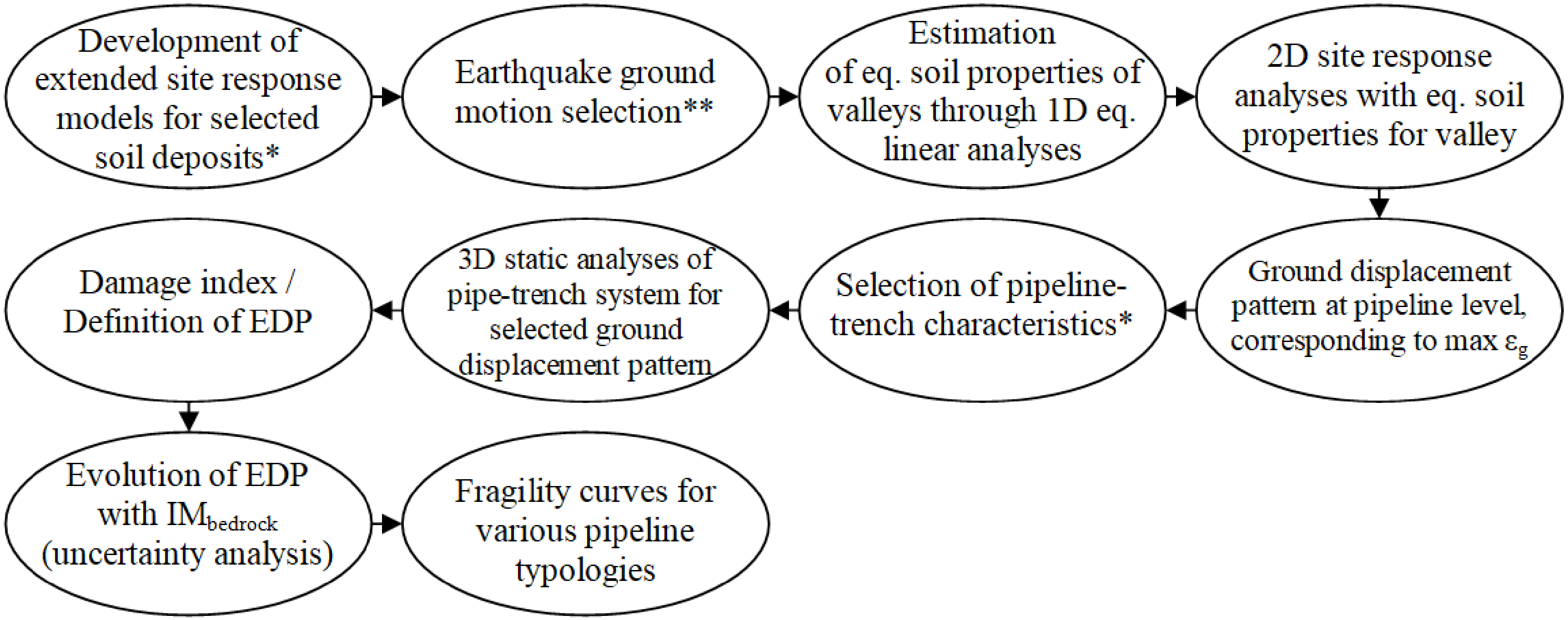
- Significant compression strains on the pipelines are expected at locations where the pipe is restrained, or at locations where the stiffness of the surrounding ground is changed abruptly (e.g. at the interfaces of valleys with stiff soil or rock)





Methodology for the seismic fragility assessment of NG pipelines

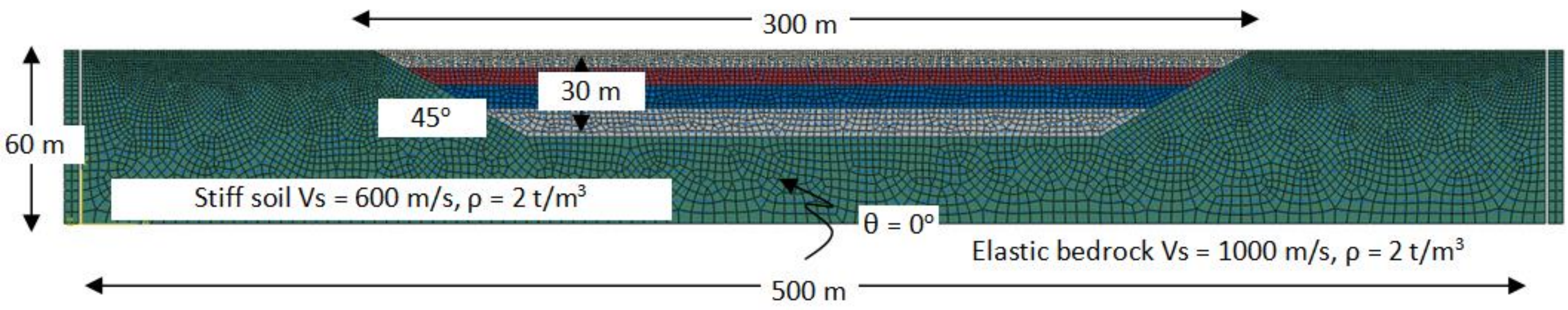
- A methodology to examine the fragility of gas pipelines crossing valleys under earthquake-induced buckling damages is currently being developed
- A propabilistic seismic demand analysis (cloud analysis) is proposed to be implemented in selected pipe-soil configurations, subjected to selected ground seismic motions
- Flowchart of proposed methodology:



Methodology for the seismic fragility assessment of NG pipelines

- Analysis in steps, following Psyrras et al. (2018):

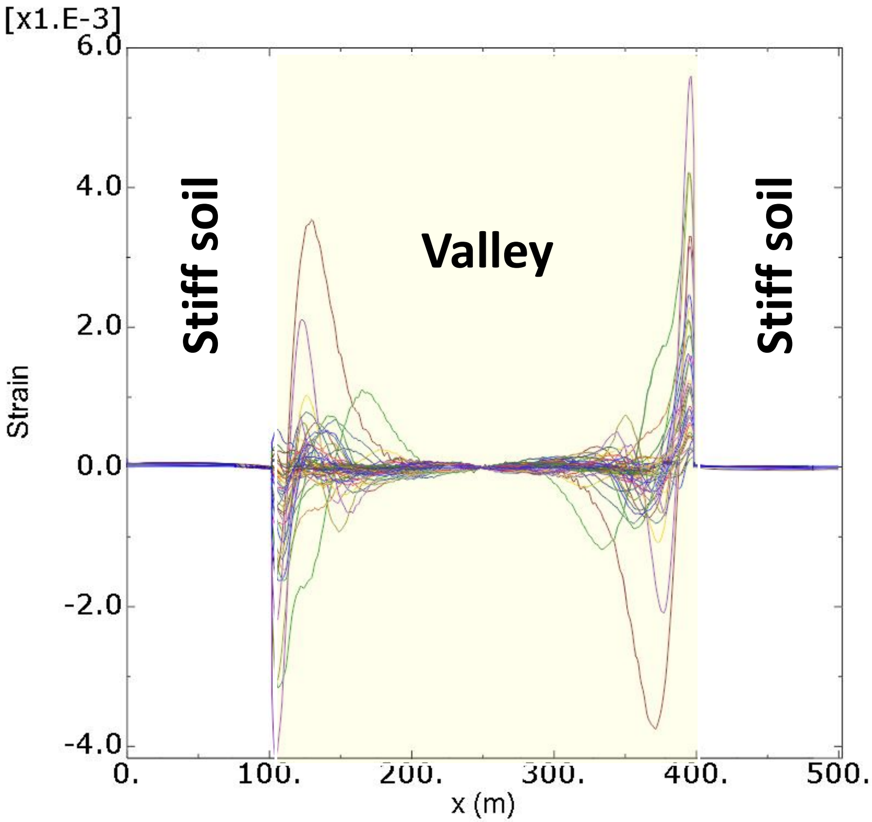
- Step 1 - Evaluation of site ground response: 2D dynamic time history analyses under plane strain conditions, neglecting the presence of pipe



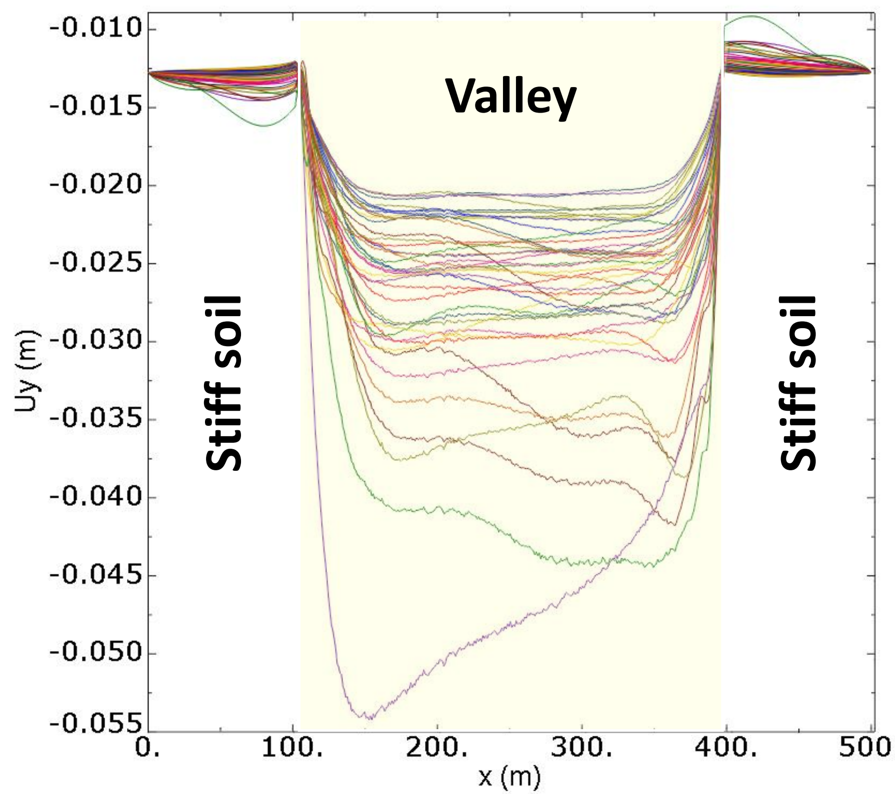
Methodology for the seismic fragility assessment of NG pipelines

- **Step 1 - examples: Distributions of seismically-induced ground strains and ground deformations computed along the axis of pipe for various ground shaking motions**

Ground strains

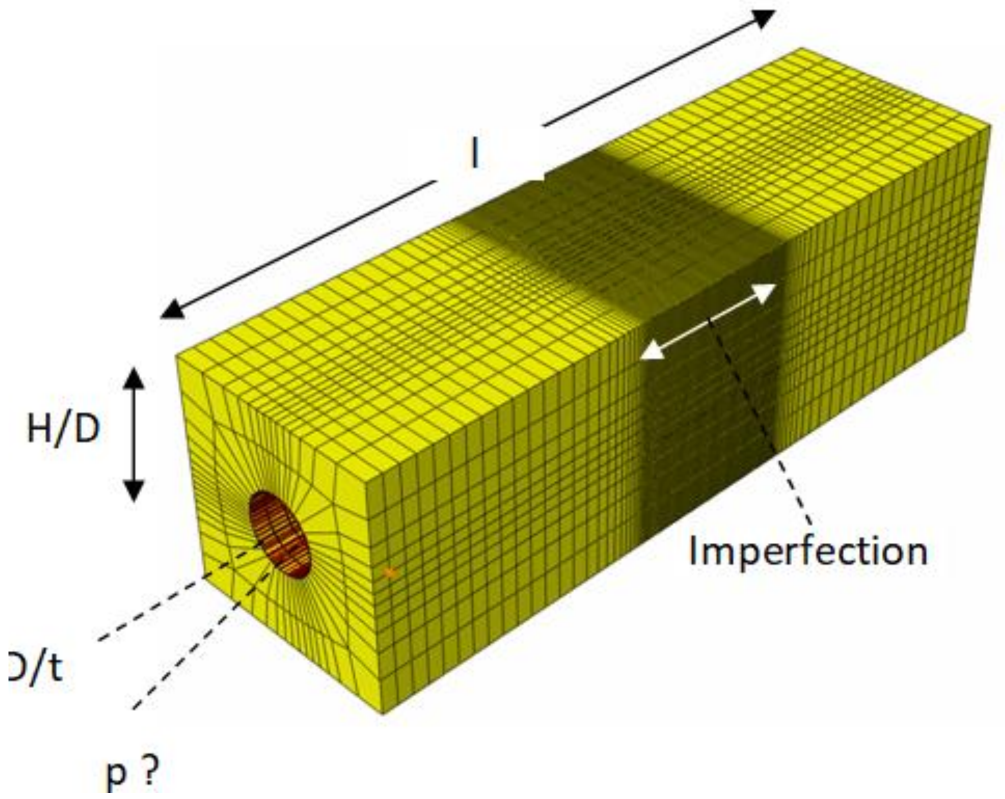


Ground deformations



Methodology for the seismic fragility assessment of NG pipelines

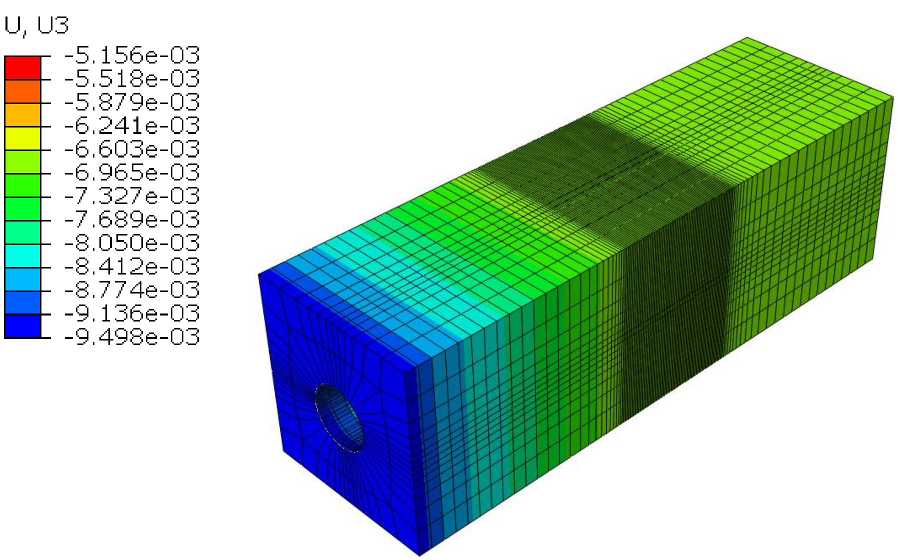
- **Analysis in steps, following Psyrras et al. (2018):**
- **Step 2 - evaluation of pipe response: Static analyses of the selected pipe-trench systems under the ground deformation patterns defined in Step 1, using 3D models of finite (reduced) length at the area of stiff-soil – valley interface and accounting for the effects of the soil-pipe interface characteristics, the internal pressure and the geometrical imperfections**

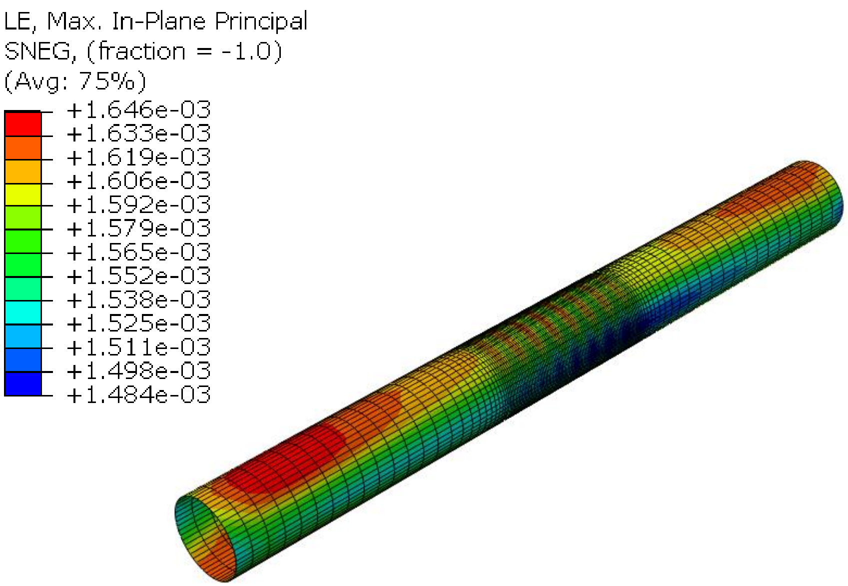


Methodology for the seismic fragility assessment of NG pipelines

- **Step 2 - example: pipe-trench response under a ground deformation pattern defined in Step 1, computed using a reduced length model, i.e. L = 10 D**

- **Reduced length models without proper boundary conditions at the end sides of the pipe were found not capable of reproducing the axial response of the pipe adequately, due to issues related with the proper simulation of the required 'anchorage' length, as well as the extent of the earthquake-induced displacement 'disturbance'**

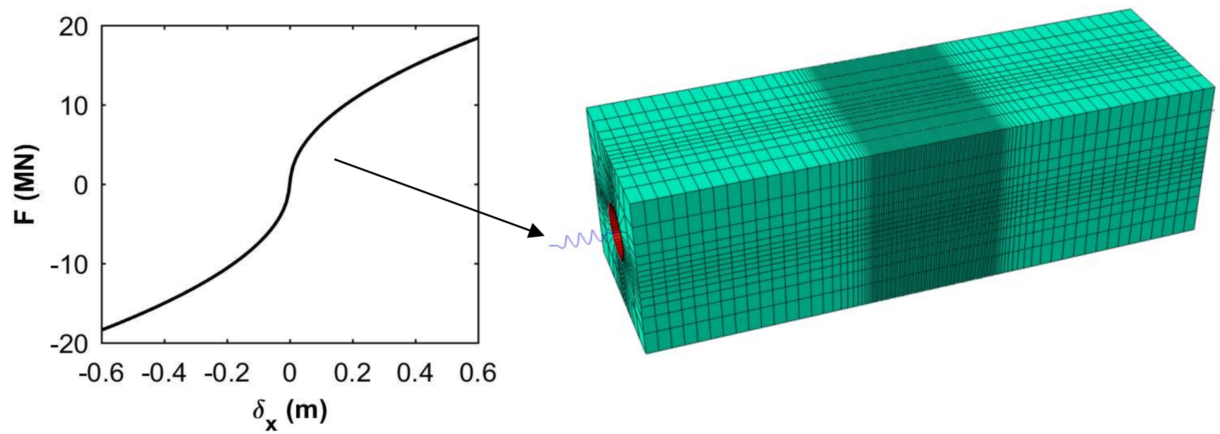




Methodology for the seismic fragility assessment of NG pipelines

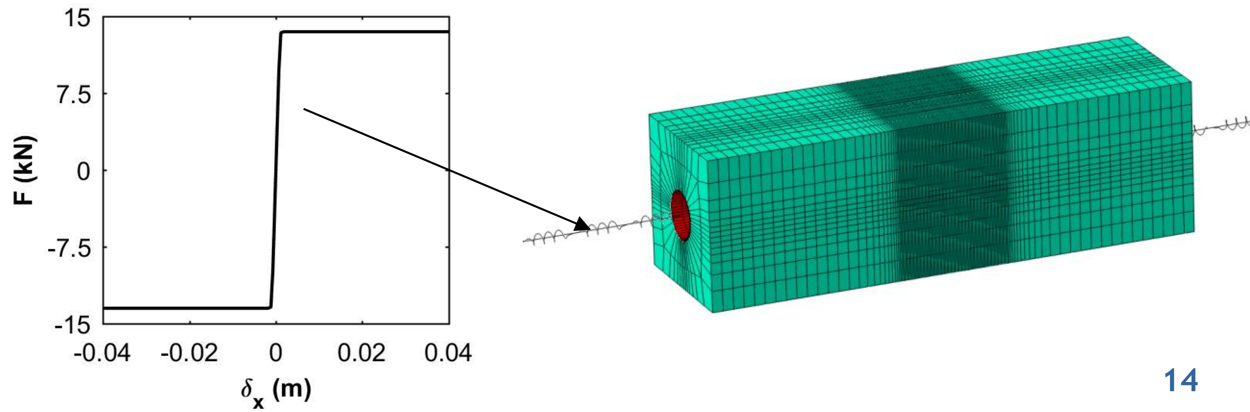
- **Alternative methods to account for the extent of the actual 3D pipe-soil system in a computationally effiecient fashion are examined**

Generalized springs at the end sides of the pipe



$$F_0 = \begin{cases} \lambda E A u_0 & \text{for} \quad u_0 \le \frac{\tau_{max}}{k_s} \\ \lambda E A \frac{\tau_{max}}{k_s} + \frac{\pi D \tau_{max}}{m}\left(\sqrt{\left(\lambda \frac{\tau_{max}}{k_s}\right)^2 + 2m\left(u_0 - \frac{\tau_{max}}{k_s}\right)} - \lambda \frac{\tau_{max}}{k_s}\right) & \text{for} \quad u_0 > \frac{\tau_{max}}{k_s} \end{cases}$$

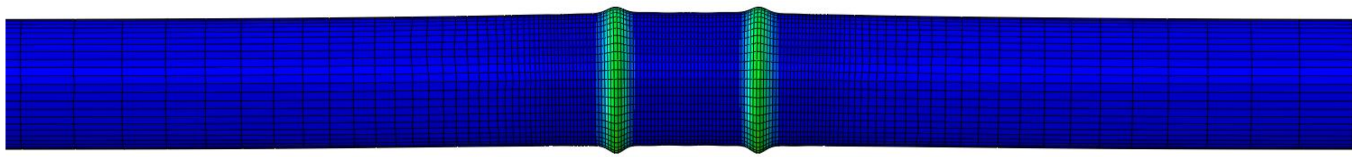
Beam on springs models at the end sides of the pipe



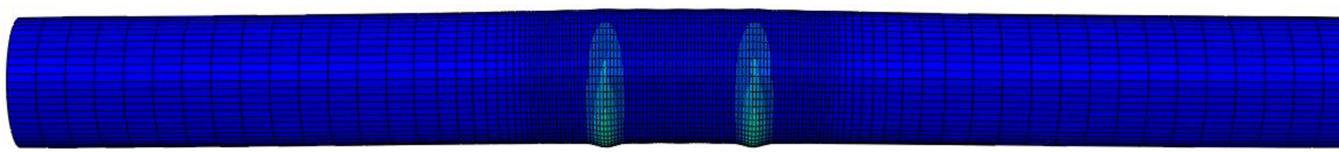
Methodology for the seismic fragility assessment of NG pipelines

- **Comparisons of responses computed by a 'long' 3D model, i.e. L = 100 D and hybrid models of distinct lengths with generalized springs at the end sides**

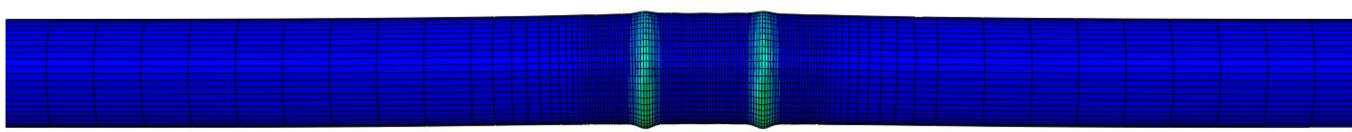
Long model, L = 100D

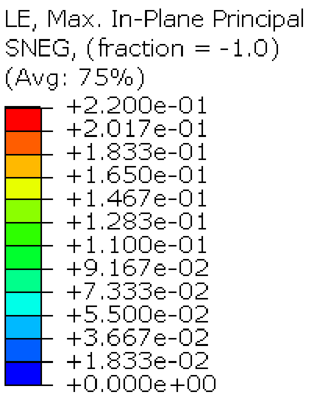


Hybrid model, L = 10 D



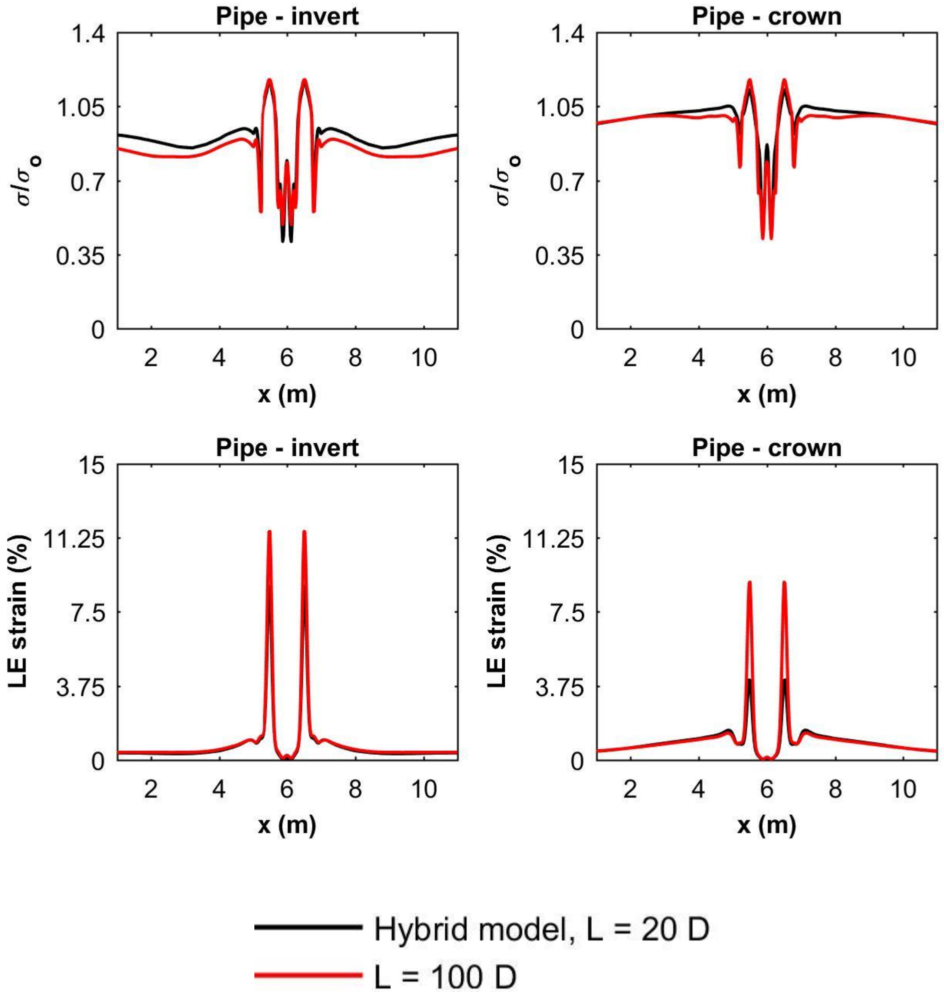
Hybrid model, L = 20 D





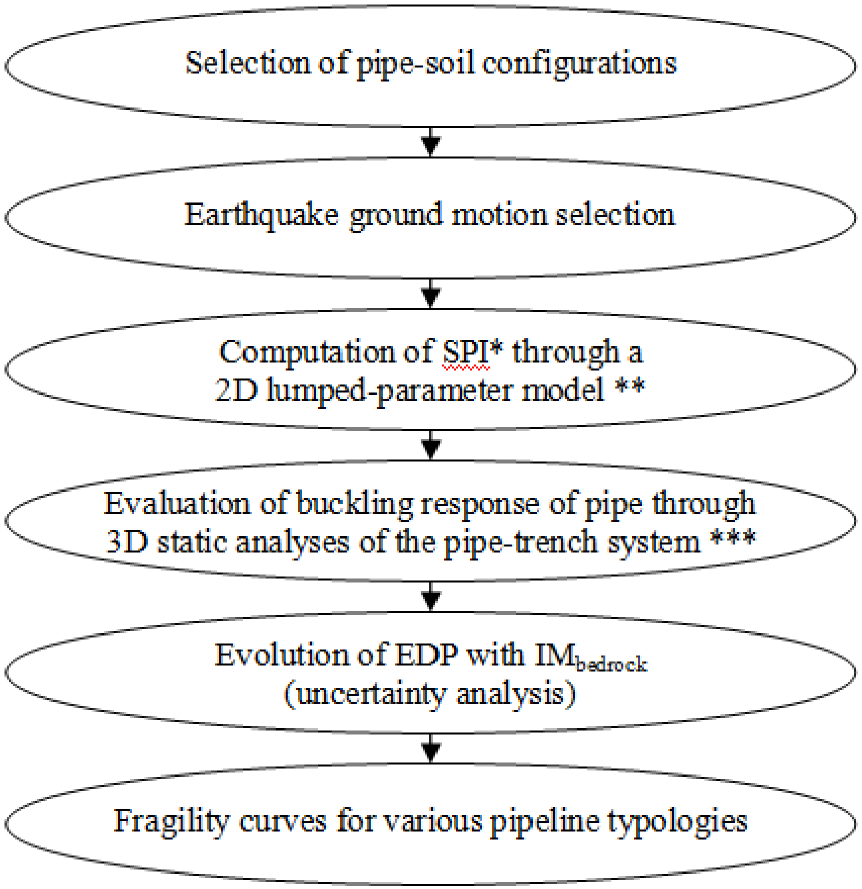
Methodology for the seismic fragility assessment of NG pipelines

- **Comparisons of responses computed by a 'long' 3D model, i.e. L = 100 D and a hybrid model of length L = 20 D with generalized springs at the end sides**



Methodology for the seismic fragility assessment of NG pipelines

- **An alternative potential framework for the fragility assessment is also investigated in collaboration with the University of Bristol (Psyrras & Sextos)**
- **Flowchart of the framework:**



Methodology for the seismic fragility assessment of NG pipelines

- **The main novelty of the new framework is the development of a 2D lumped model for the investigation of the soil-pipe interaction effects, which will account for the frictional phenomena at the soil-pipe interface, as well, resulting in the final deformation loading along the axis of the pipeline**

- **This will allow for the use of fully bonded pipe-soil models, reducing the required length of the 3D pipe-trench models and hence reducing the relevant computational cost**

Conclusions

- **Under certain conditions NG pipelines may be subjected to significant seismically-induced ground deformations potentially, leading to shell-mode or beam buckling failures**

- **A numerical study was conducted to further elaborate on the response of NG pipelines under compression and the relevant simulation aspects. The study highlighted the crucial effects of geometric imperfections, internal pressure and ground confinement on the axial response of NG pipelines**

- **Frameworks for the fragility assessment of NG pipelines under potential buckling failures are under development**