TMR 4585 Specialization Course UWT
Free span design

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Trondheim, 2019

Contents

- **Free spans – major design challenges**
- **The Simla program system**
- **Stages of analyses**
- **Examples**

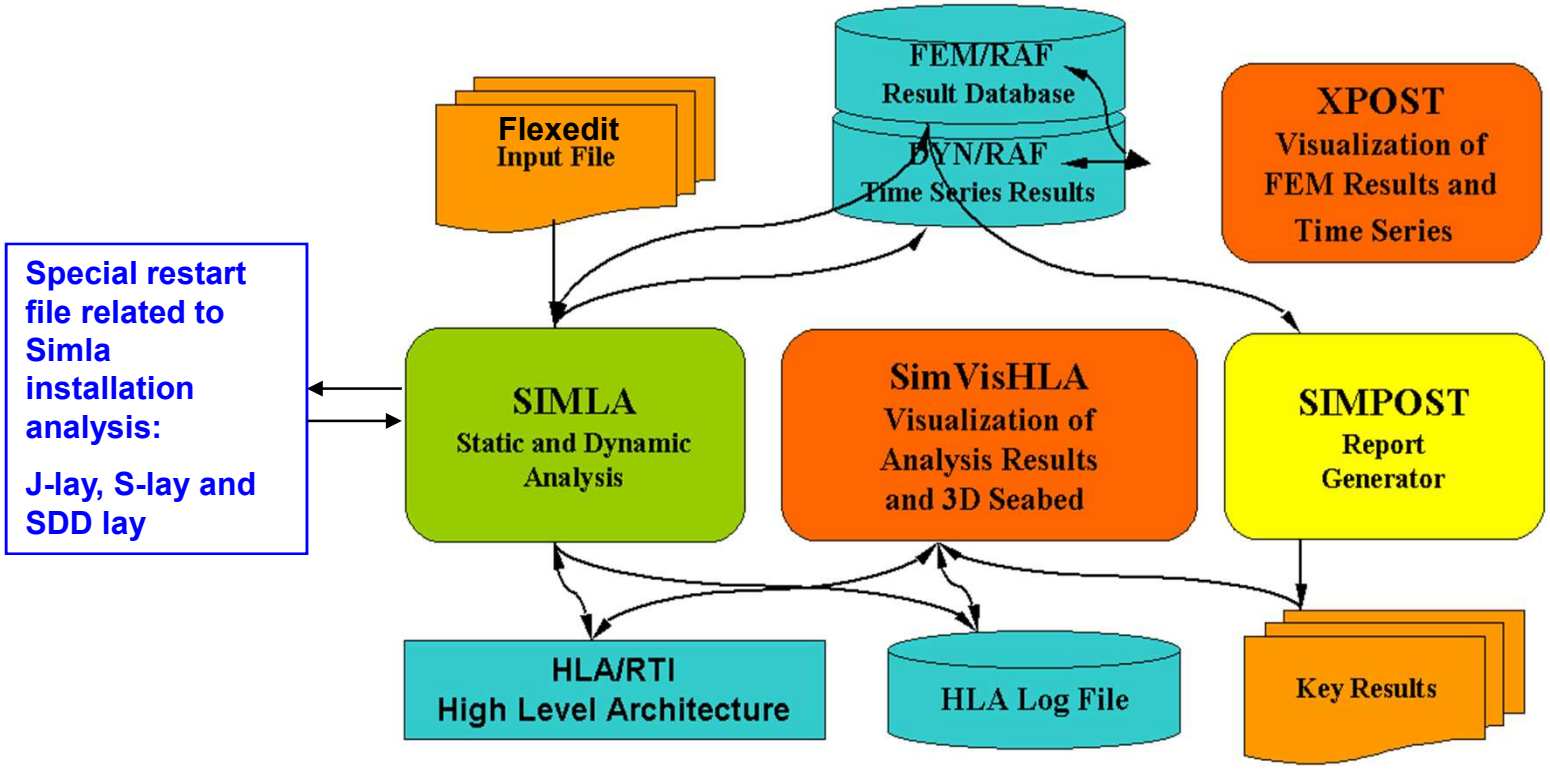
FREE SPAN - MAJOR DESIGN CHALLENGES

- **ROUTING, FREE SPANS**
  - CHECK INSTALLATION
  - SCREENING ON ALLOWABLE SPANS
- **SPAN LENGTH**
  - FATIGUE - CROSS FLOW AND INLINE RESPONSES
  - LOCAL BUCKLING
- **EXPANSION CONTROL**
  - BUCKLING ANALYSIS, AS BASIS FOR ROCK DUMPING
- **TRAWLING**
  - DENTING, BENDING MOMENT CAPACITY

The Simla Program System

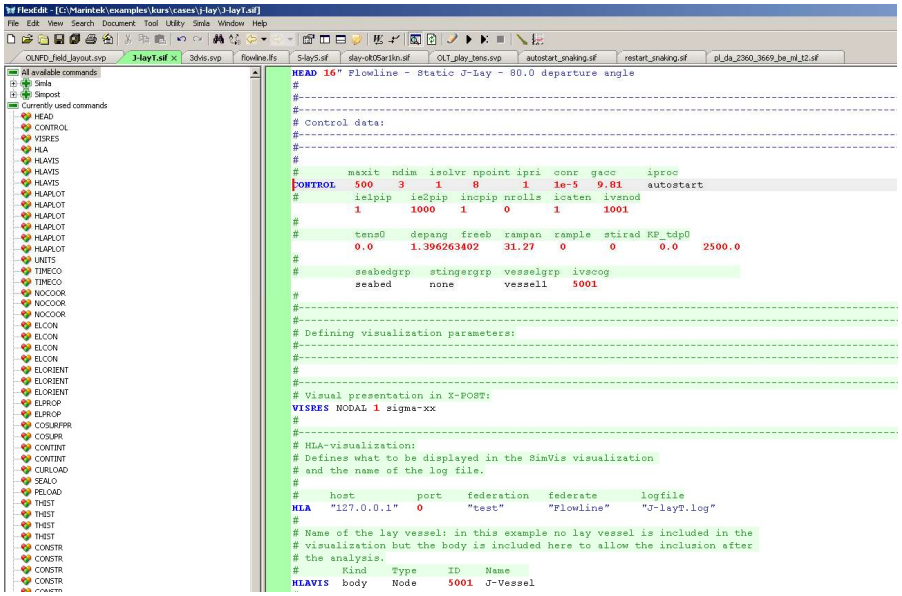
- **Developed by Marintek Structural Engineering 2001-**
- **To meet the challenges related to the Ormen Lange development**
  - Deep water
  - Extremely uneven seabed

SIMLA – System Architecture



Simla

Simla input file .bif use Flexedit text editor with ”built in” user manual



Run Simla.exe

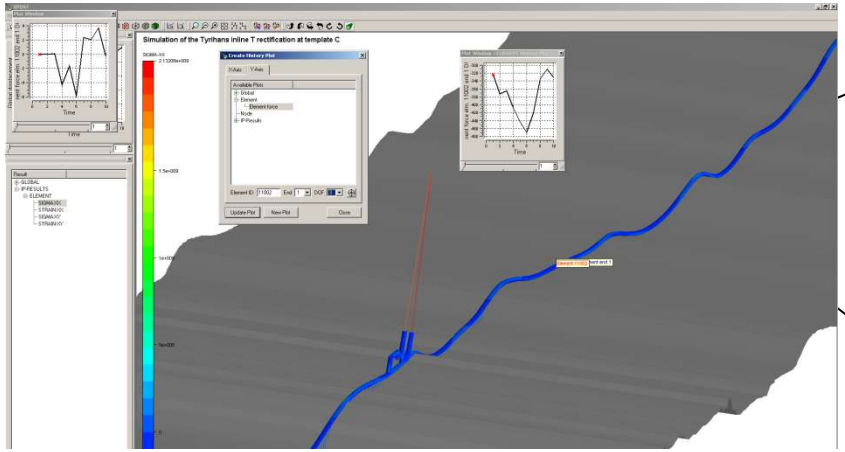
.raf file containing FEM results for stored load steps and for postprocessing by SimPost and XPost

.log file containing results for postprocessing in SimVis

Xpost

.raf files containing FEM results for stored load steps and for postprocessing by SimPost and XPost

Start Xpost and open the .raf file



Create animations that can be imported into powerpoint (by exporting .vtf files, Requires GlviewPlugin)

Create history plots of force/moment versus time/history and stress versus time/history

Simpost

.bpi simpost input file defing which raf file to be opened and which plot types and plot files to be made

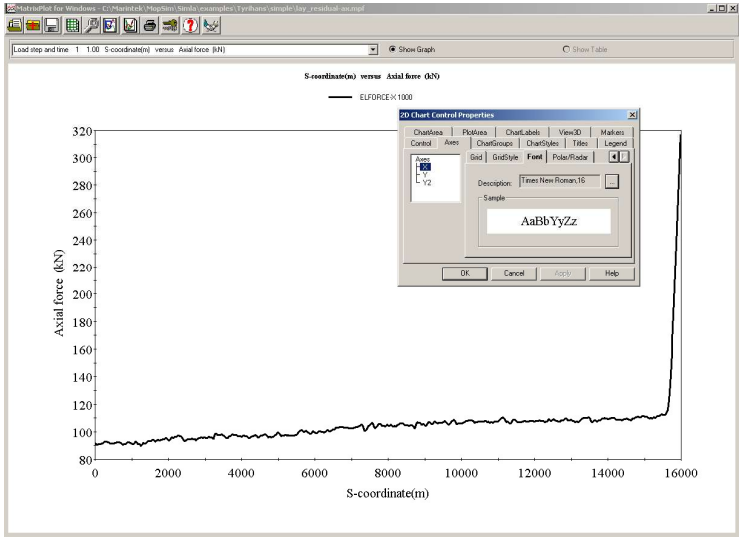
.raf files containing FEM results for stored load steps and for postprocessing by SimPost and XPost

Run simpost.exe

User defined xy-plots of node and element results stored on .mpf files

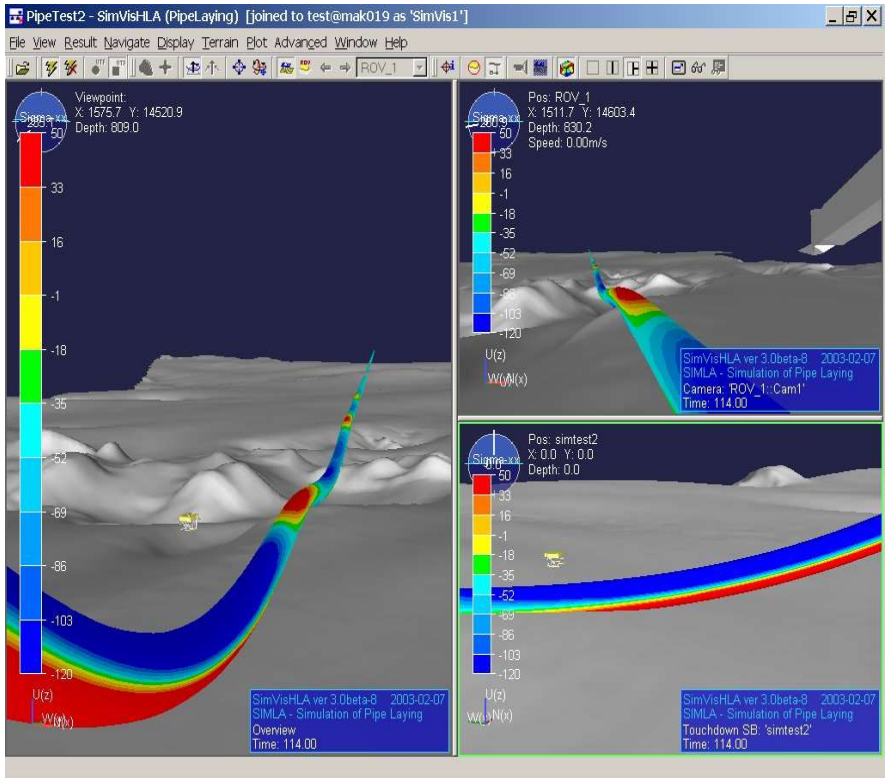
Also including eigenmodes and frequencies at selected load steps and number of modes

Start MatrixPlot and import .mpf and create plot



SimVis

- *Visualization of pipeline installation along a predefined route*
- *Visualization of numerical model including stress response*
- *Visualization of 3D terrain data as the simulation moves along the route*
- *Visualization of existing infrastructure*
- *Pipeline route design*
- *Free span evaluation*
- *Export of route information from 3D terrain model to route.txt file as input to Simla: a file containing a list of x,y,z coordinates of the route profile*

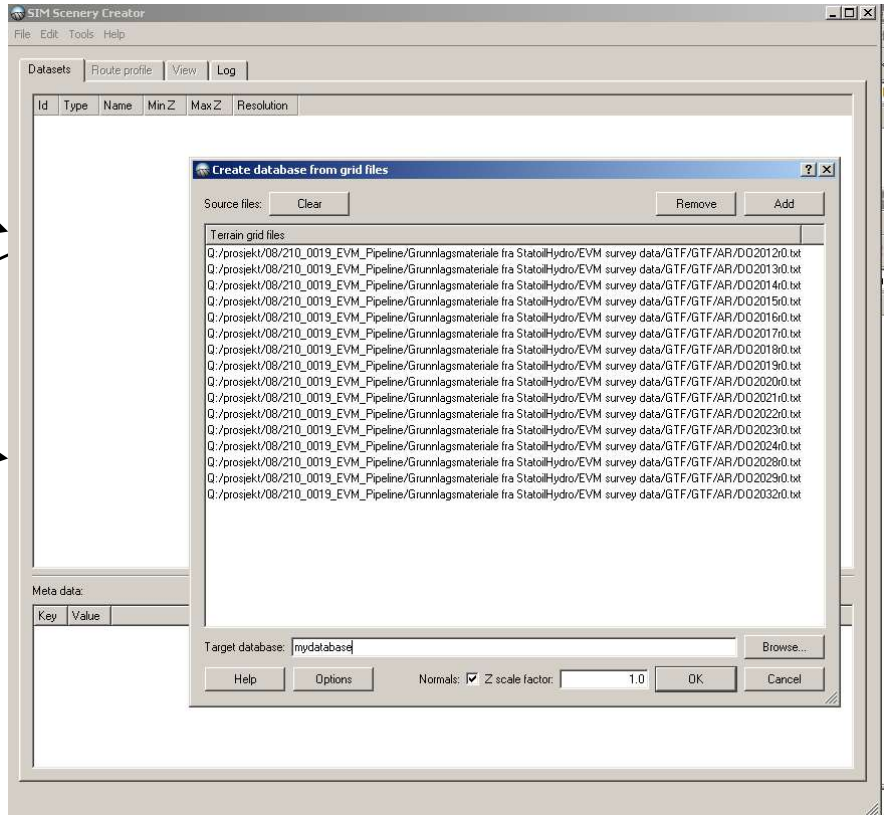


Creator

A set of .xyz, .txt or .dat files representing the xyz coordinates of the seabed terrain.

Create mydatabase

Merge data resulting in mydatabase.1, .2 … .n files



SimVis

Create your .log files containing structural results animation of stress and soil reactions and info regarding which bodies to be visualized by running Simla

↓

Create your field infrastructure drawings and convert them to .vtf format

↓

Create your 3D terrain database by converting .xyz or .dat files using Creator

↓

Create routes .txt files

↓

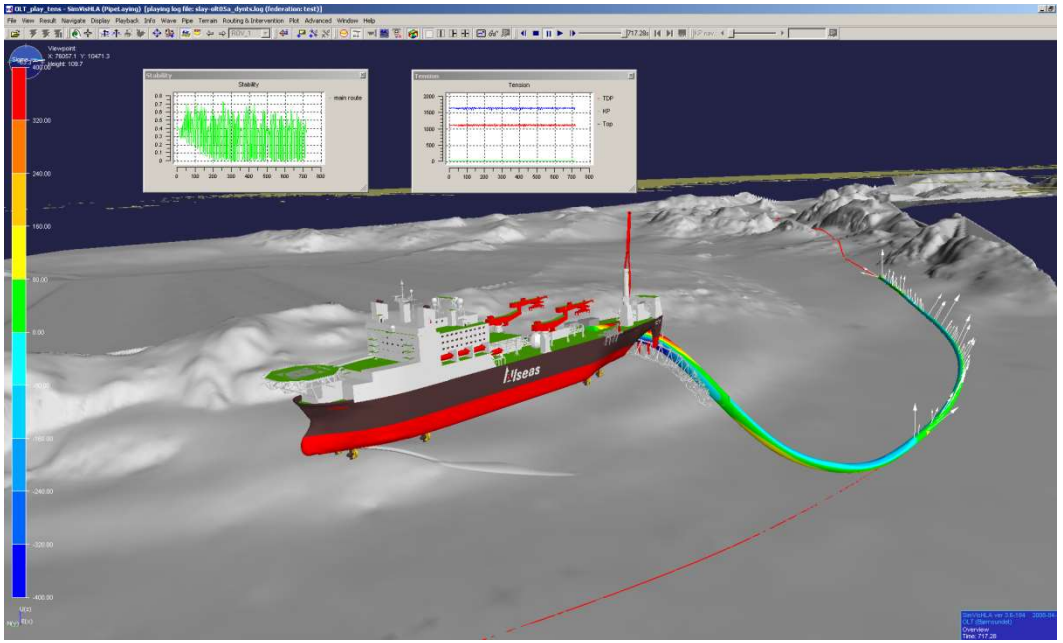
Create a project .svp file

Defining the file links + project specific information

→

Start SimVis and open .svp file

↑



Key functionality – Simla numerical engine

- **Non-linear static and dynamic analysis of pipe and cable structures**
- **Elements: PIPE, CABLE, ROLLER-, PIPE IN PIPE-, SEABED-CONTACT, COATING, BODY**
- **Linear and non-linear material properties**
- **User defined Constraints**
- **Element eccentricity**
- **Gravity, external and internal pressure, temperature, initial strains, current loads**
- **Prescribed displacement, feeding and spooling**
- **Restart with change in boundary conditions and element properties**
- **Export of restart info to other programs**
- **Nonlinear time-domain analysis HHT-α method**
  - vessel motion by RAO
  - Regular wave loading
  - Irregular wave loading
  - User defined load history
  - Harmoninc loading

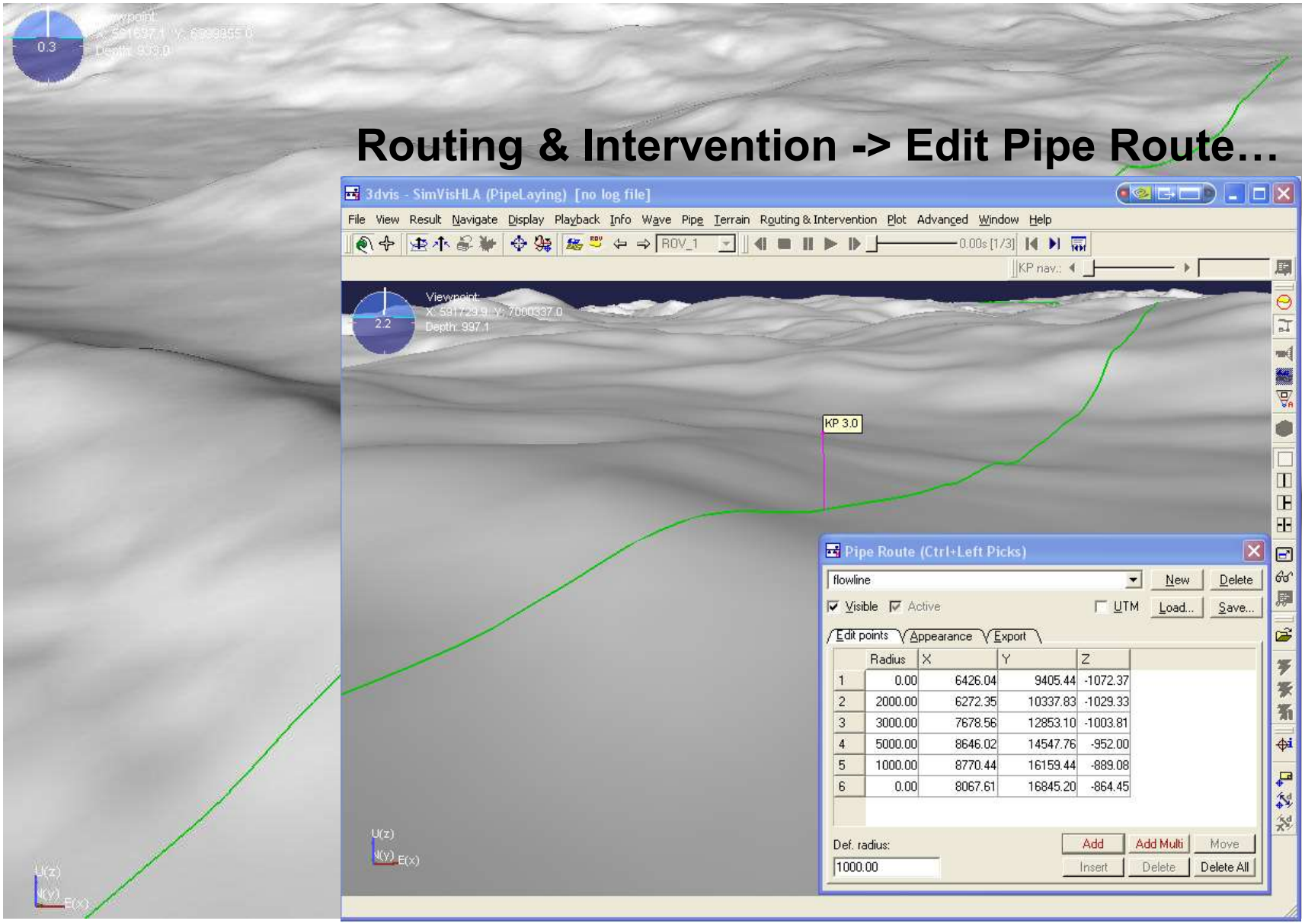
- **User controlled mix of analysis domain**
- **Post processing with 3D graphics and user defined plots on ASCII format**
- **Eigen mode analysis at selected steps – link to FATFREE**

STAGES OF ANALYSES

The analyses and the design checks shall cover the following pipeline conditions:

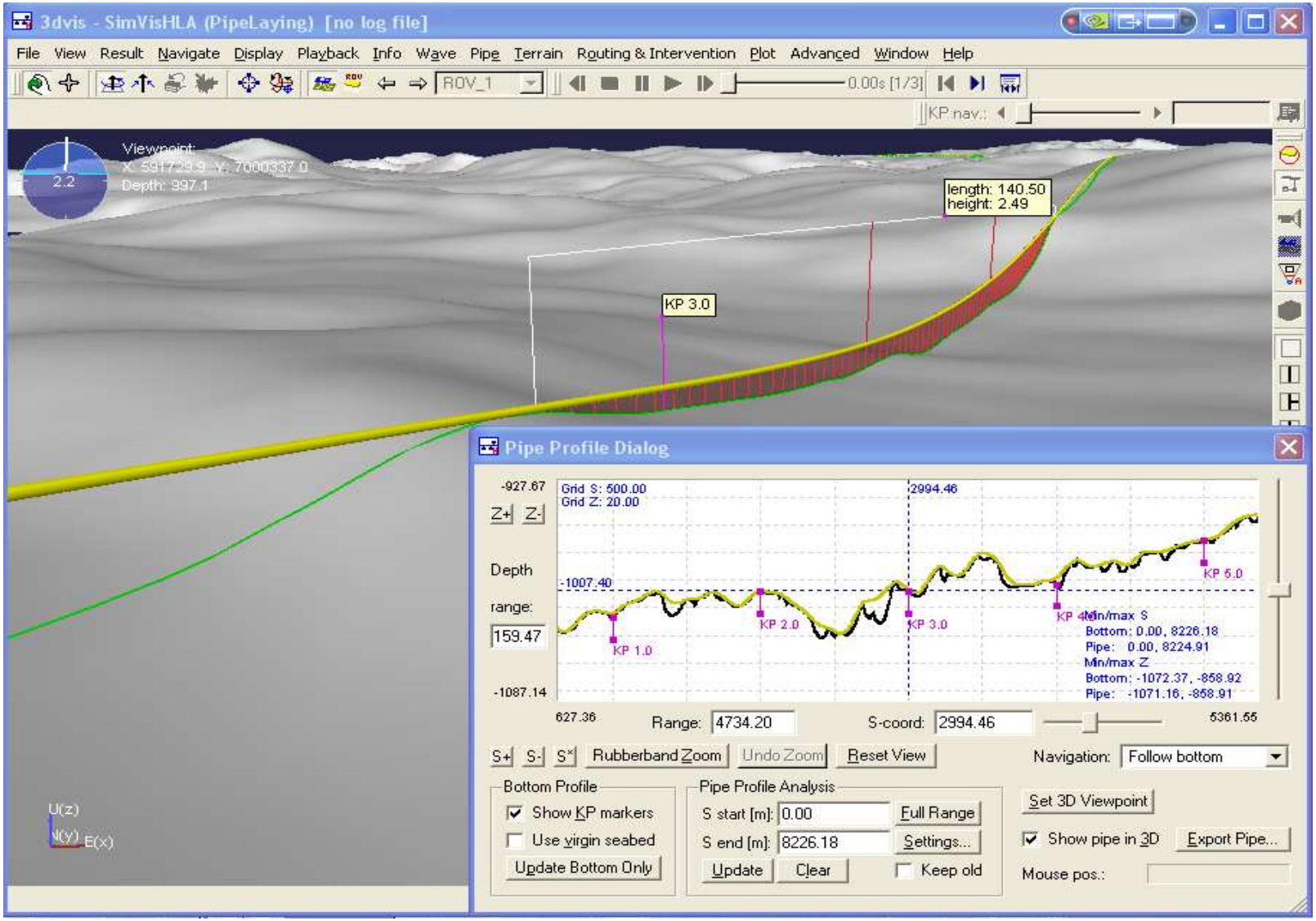
- **As laid (local buckling and fatigue)**
- **Water filled (local buckling and fatigue)**
- **Pressure testing (local buckling)**
- **Operation incl. design pressure and temperature (local buckling and fatigue)**
- **Trawl load (ALS criterion leakage)**
- **Residual damaged (operation)**

Create a Pipe Route in Simvis



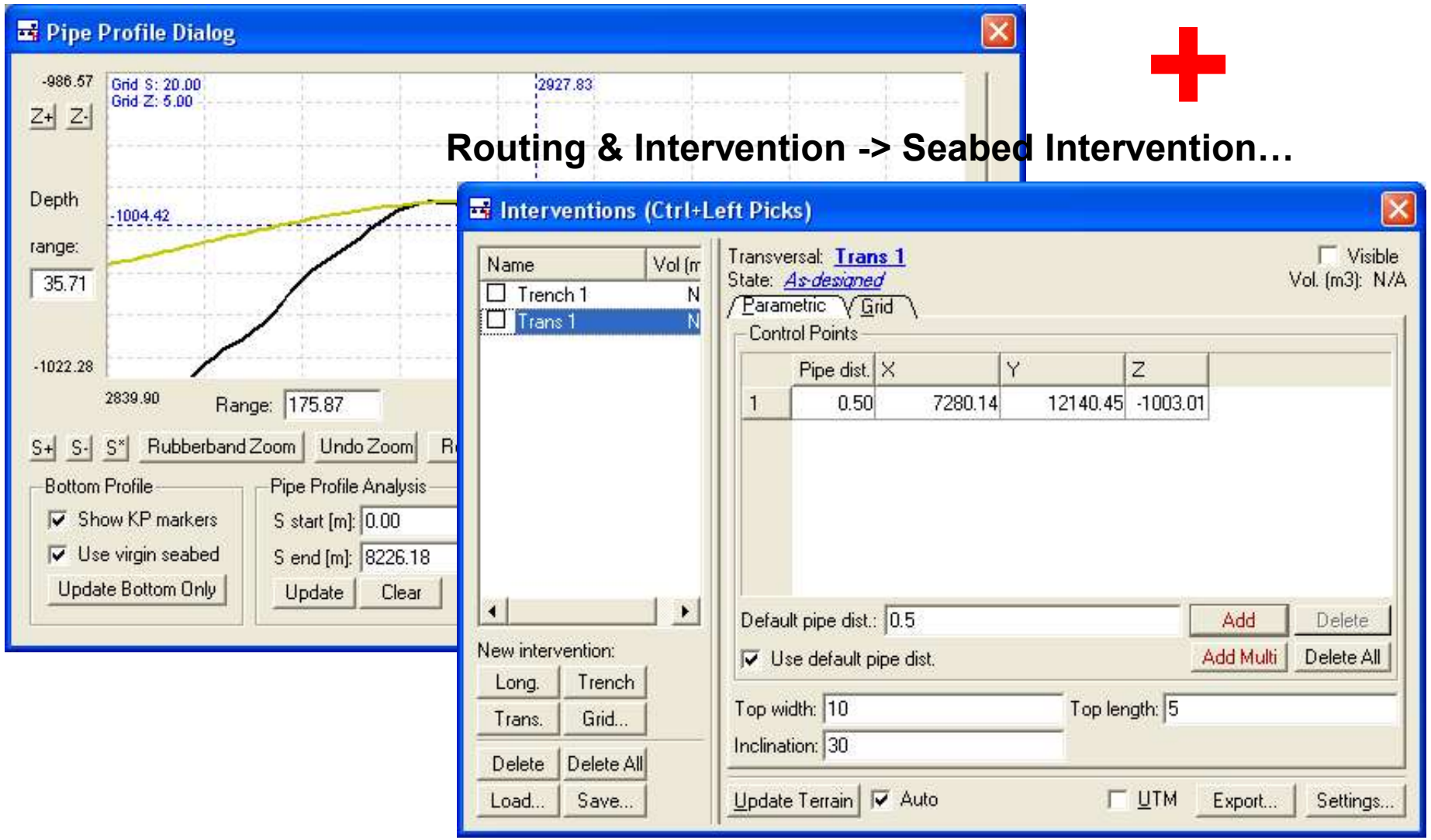
Make a Simplified 2D FE Analysis

Routing & Intervention -> Pipe Route Profile…

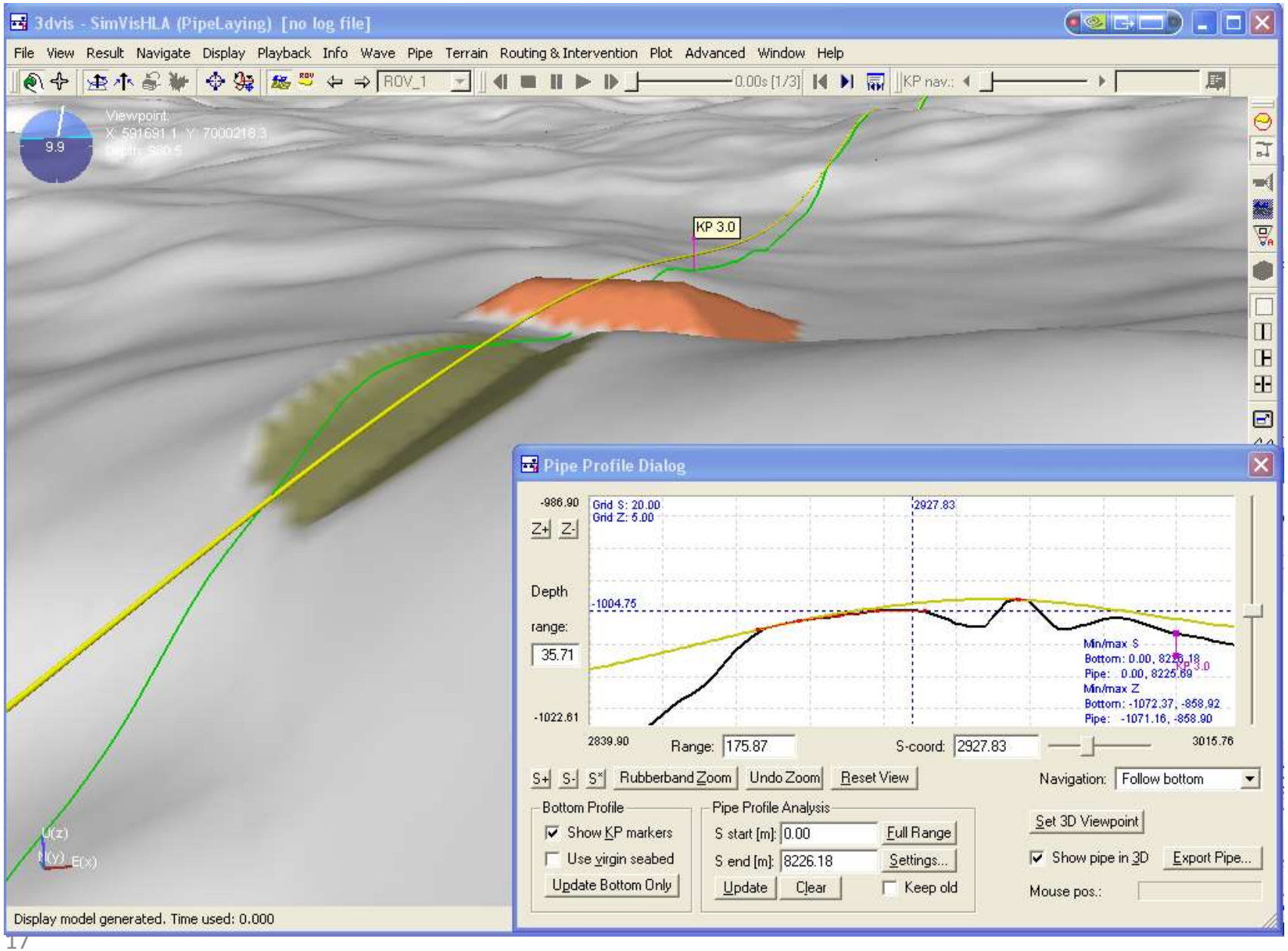


Add Seabed Interventions (1/2)

Routing & Intervention -> Pipe Route Profile…

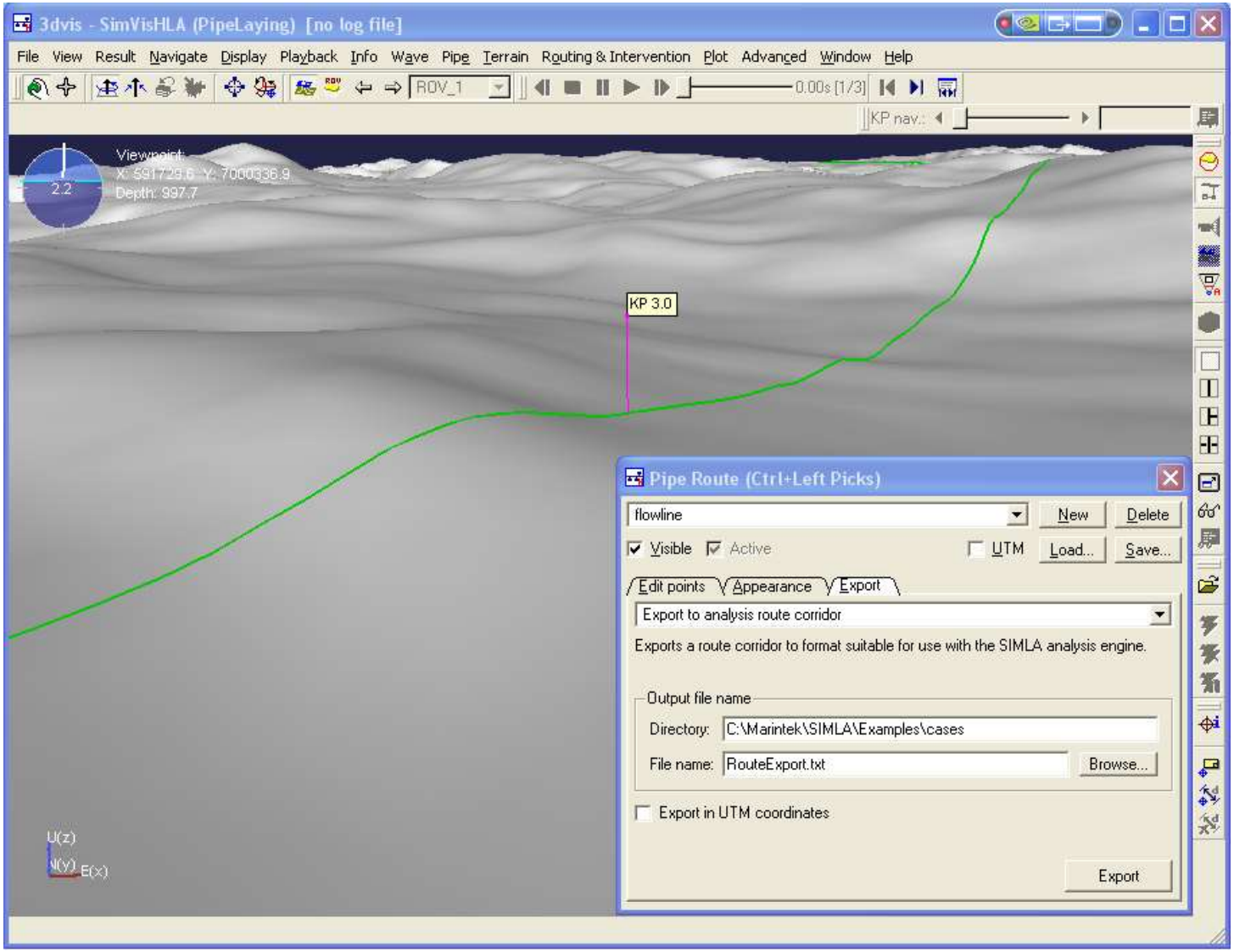


Add Seabed Interventions (2/2)



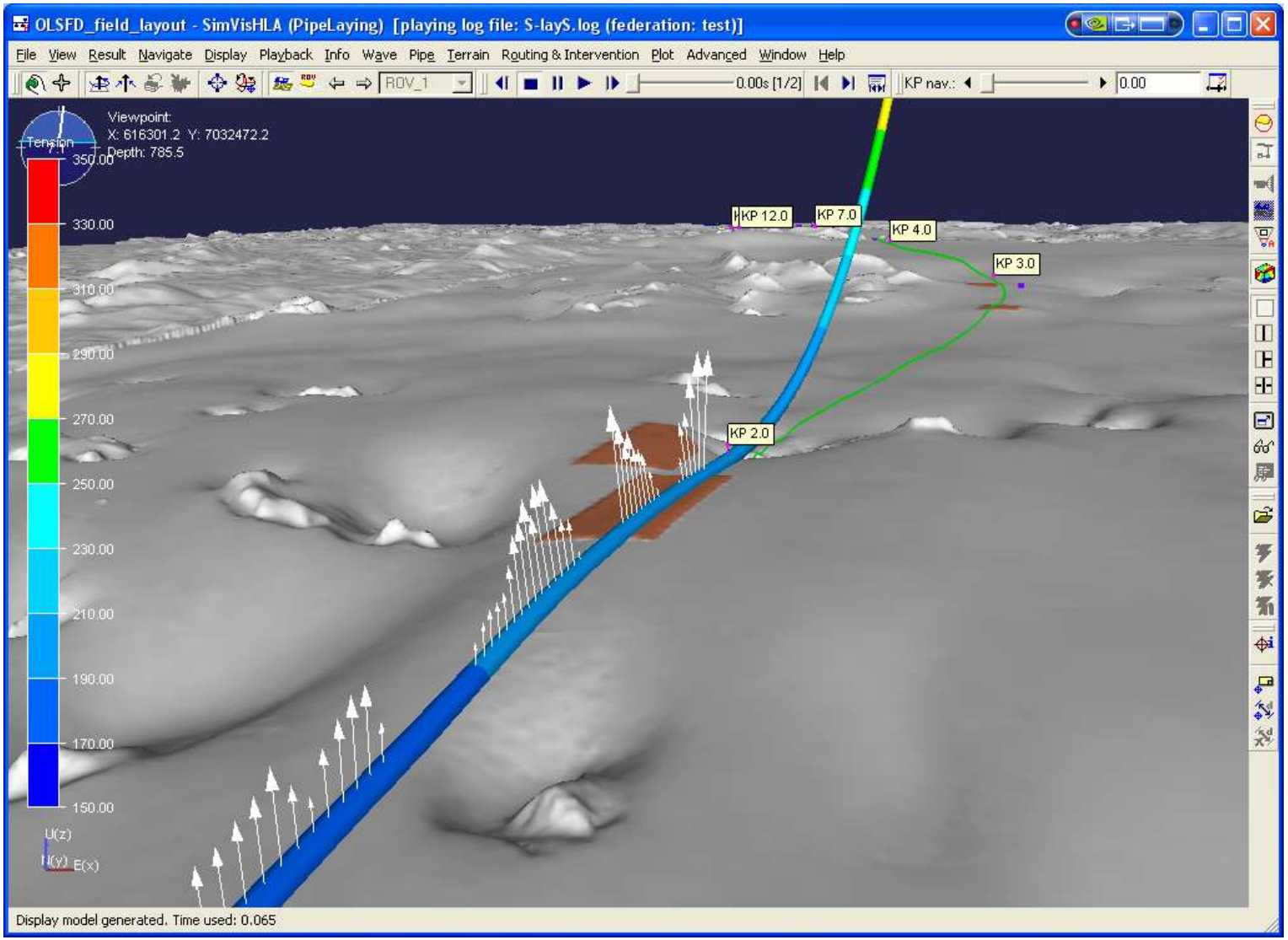
Export a SIMLA Numerical Route

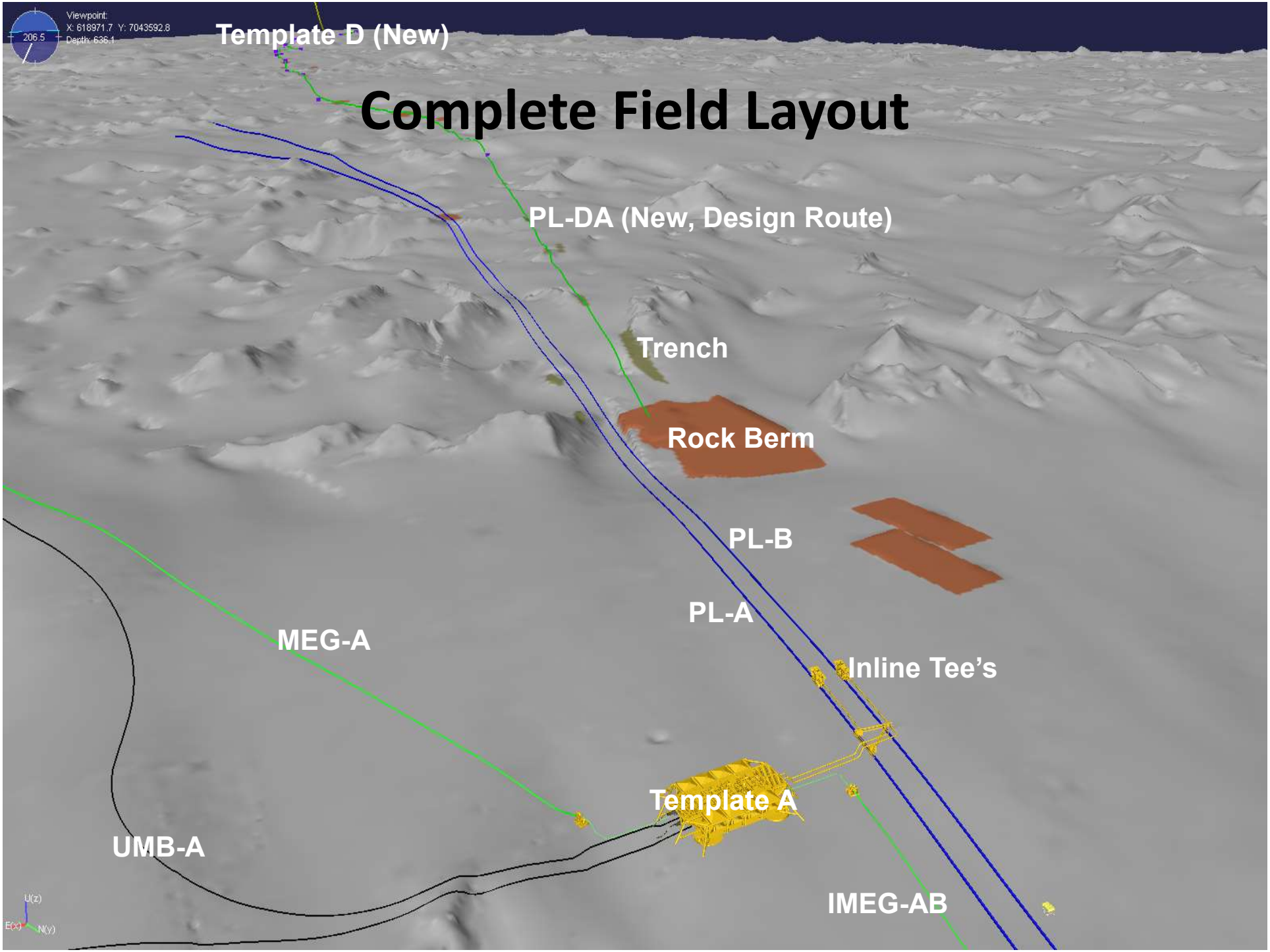
Routing & Intervention -> Edit Pipe Route…



Installation check - 3D FE Analysis (1/2)

Result -> Select Scalar… / Select Vector…

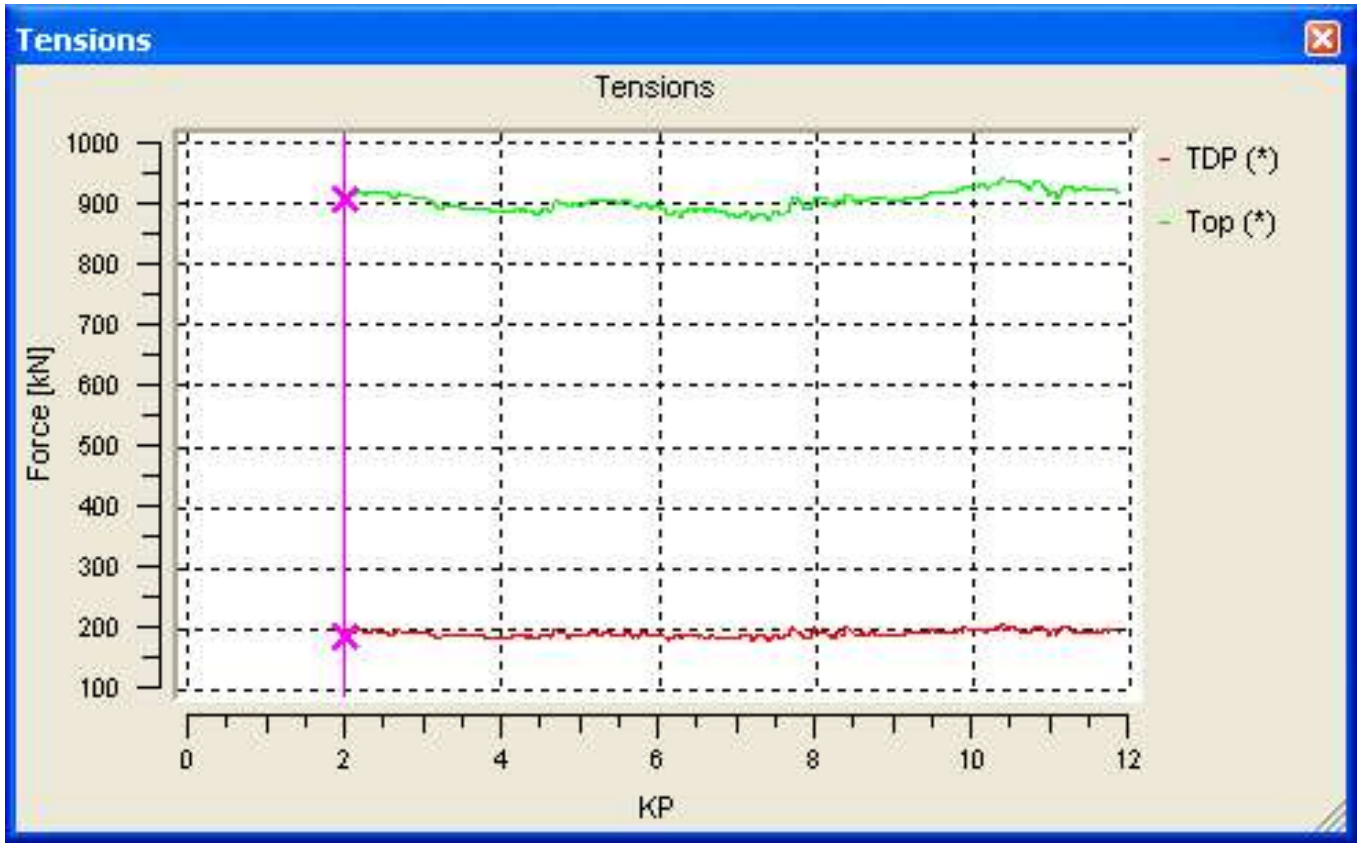



Viewpoint:
X: 618971.7 Y: 7043592.8
206.5
Depth: 636.1
Template D (New)
Complete Field Layout
PL-DA (New, Design Route)
Trench
Rock Berm
PL-B
PL-A
MEG-A
Inline Tee's
Template A
UMB-A
IMEG-AB
U(z)
E(x)
N(y)

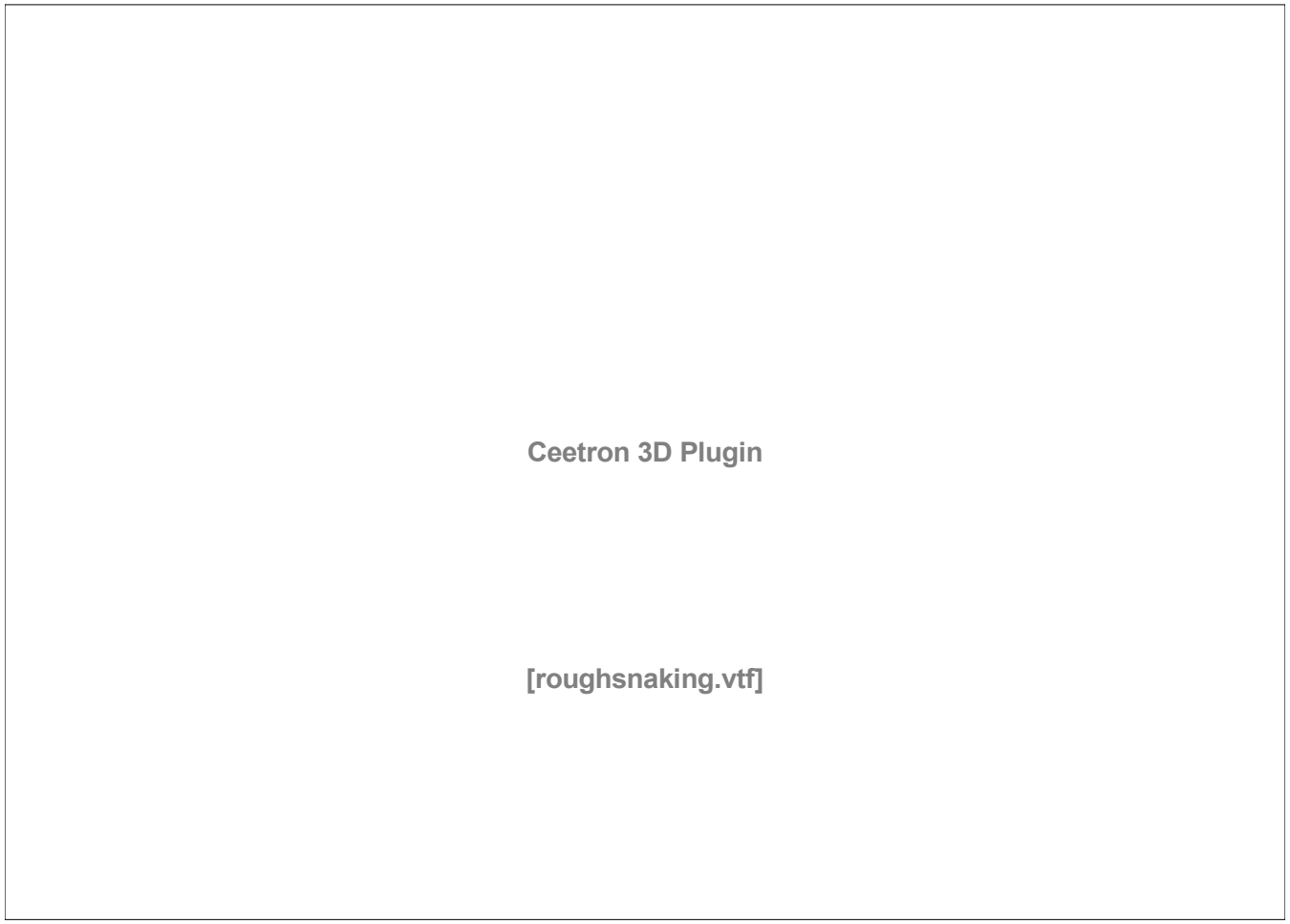
Installation check - 3D FE Analysis (2/2)

Plot -> Show Plots…

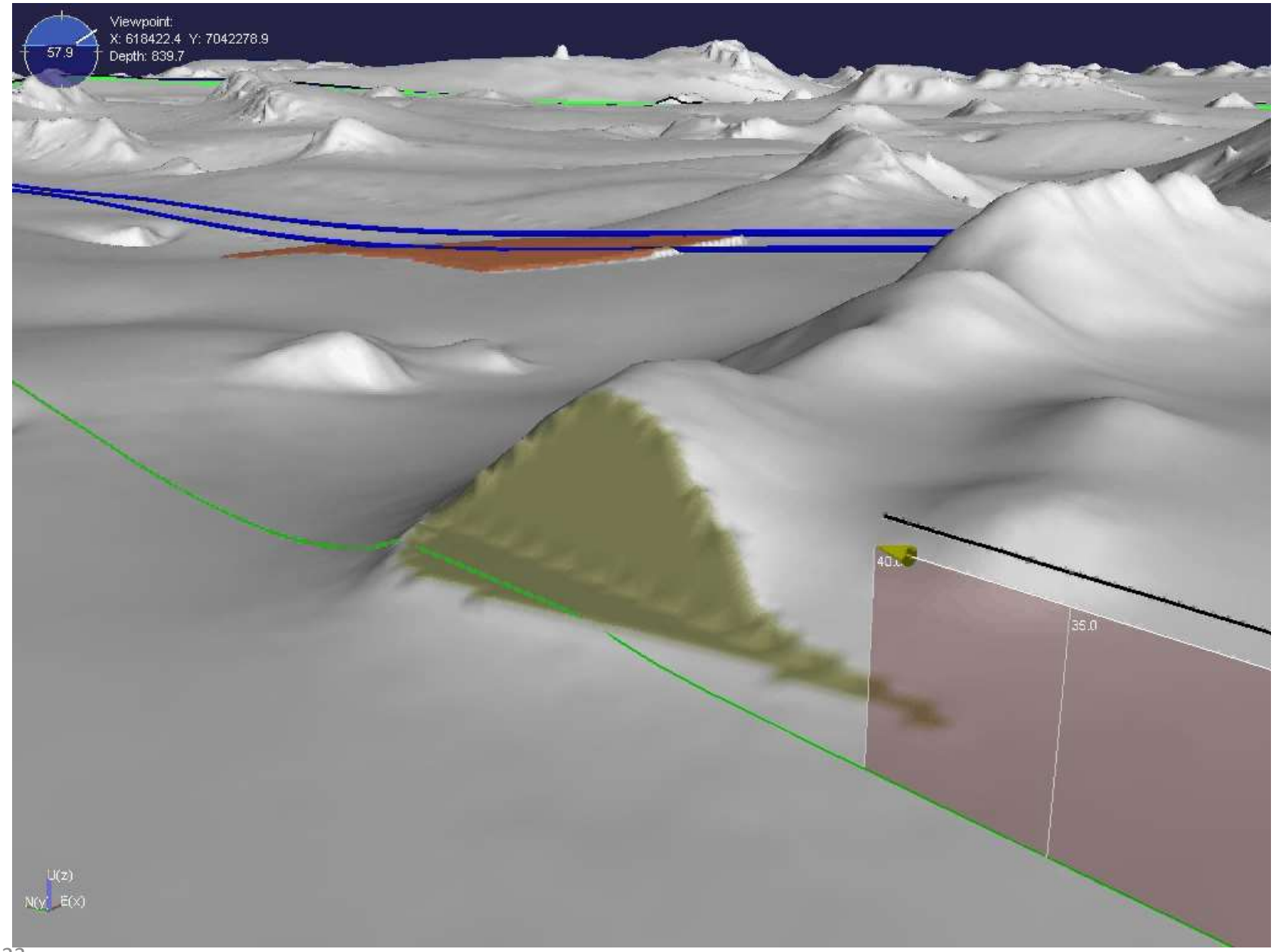
…Tensions



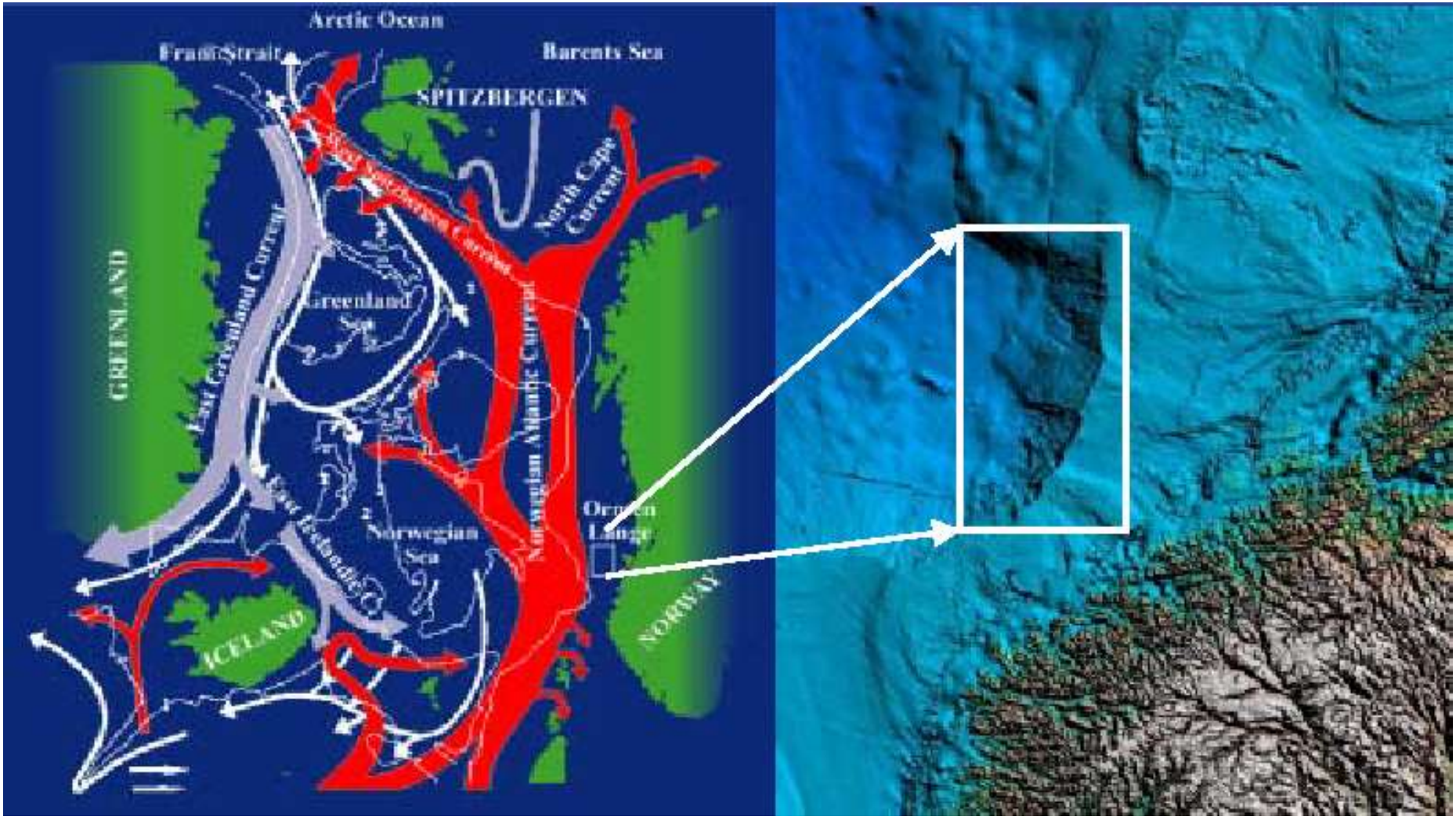
Pipeline global buckling- by FEM



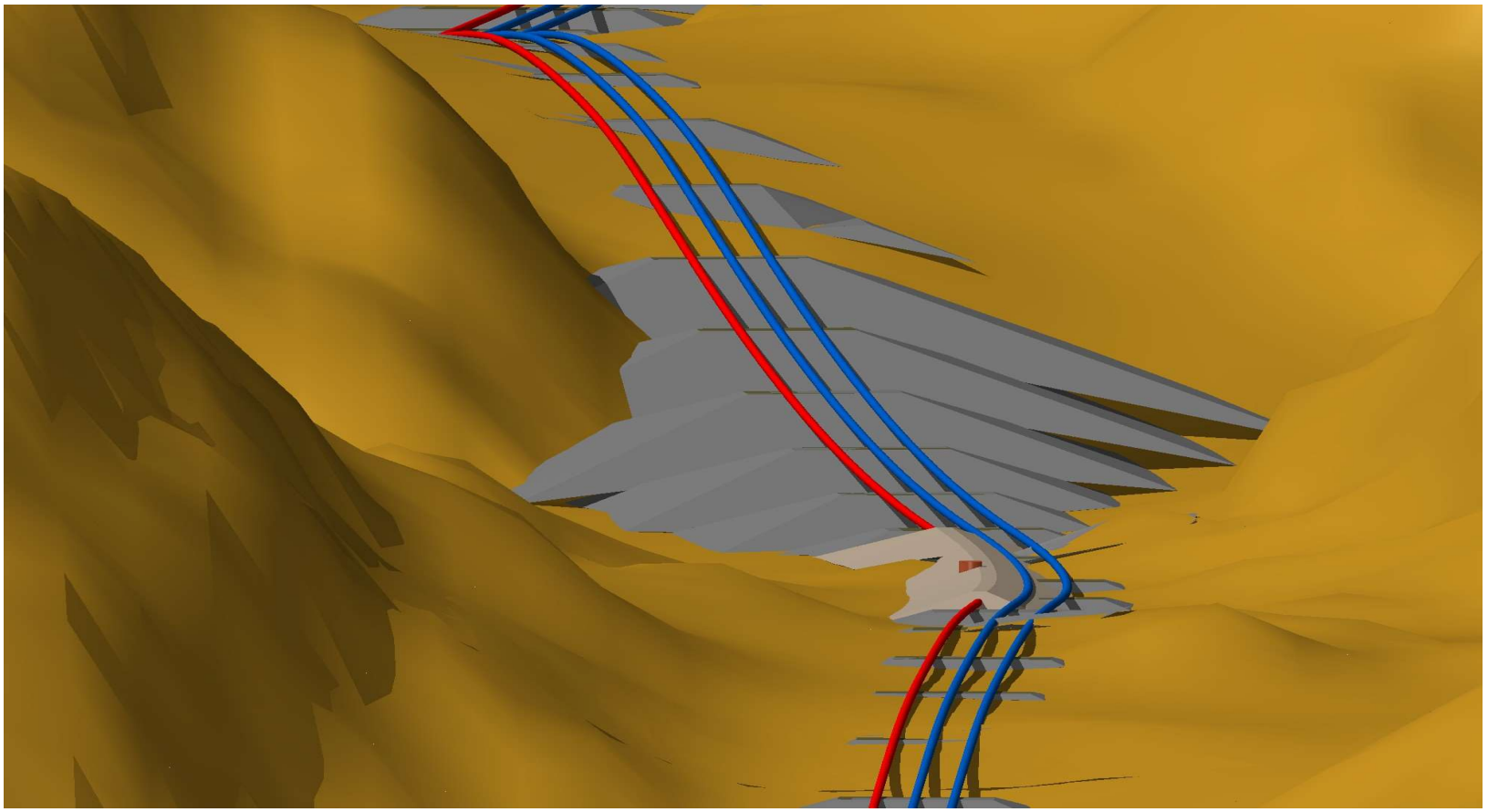
Online 3D Visualization



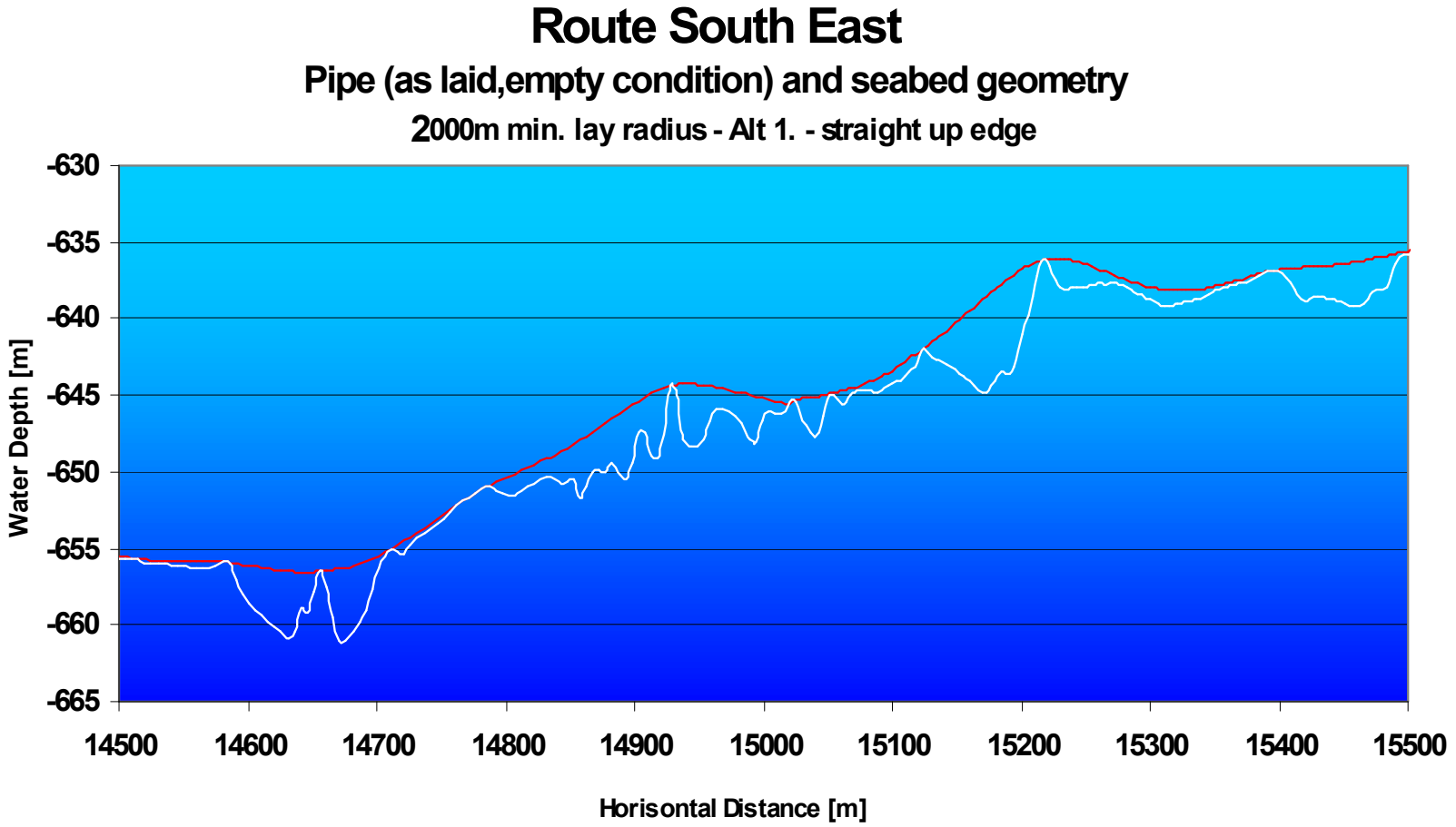
GLOBAL CURRENT PROFILE – Ormen Lange



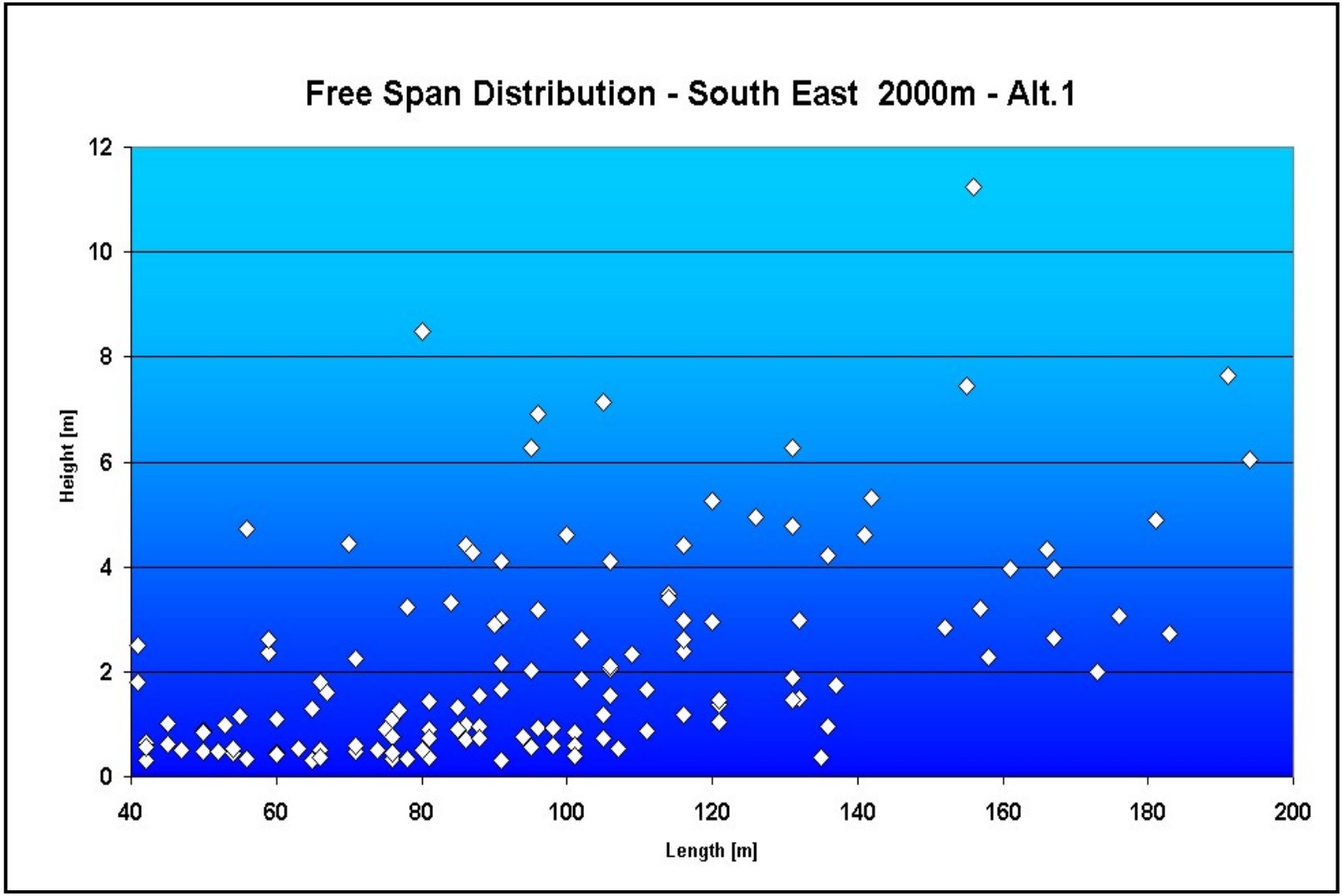
PIPELINE INTERVENTION THROUGH NARROW PART OF BJØRNSUNDET



FREE SPANS - Ormen Lange Deep Water Area

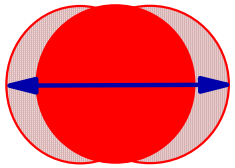


FREE SPAN DISTRIBUTION – Ormen Lange

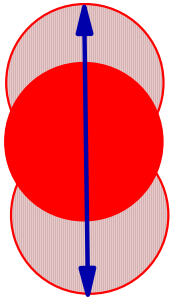


FREE SPAN VIV RESPONSE MODELS

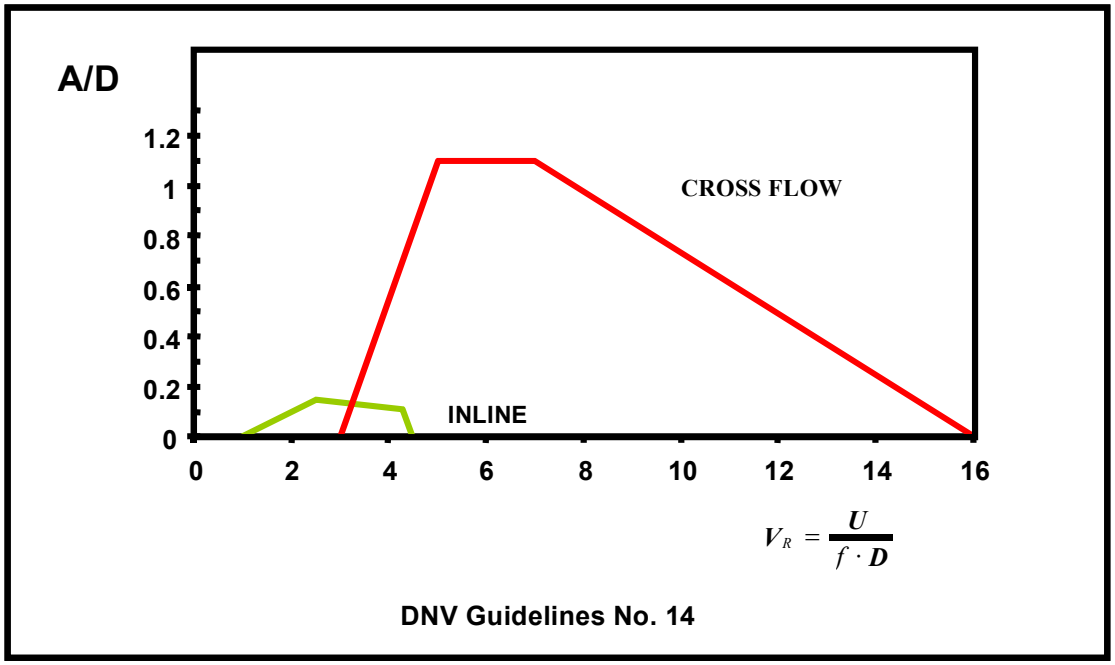
VIV = Vortex Induced Vibrations



Inline vibrations

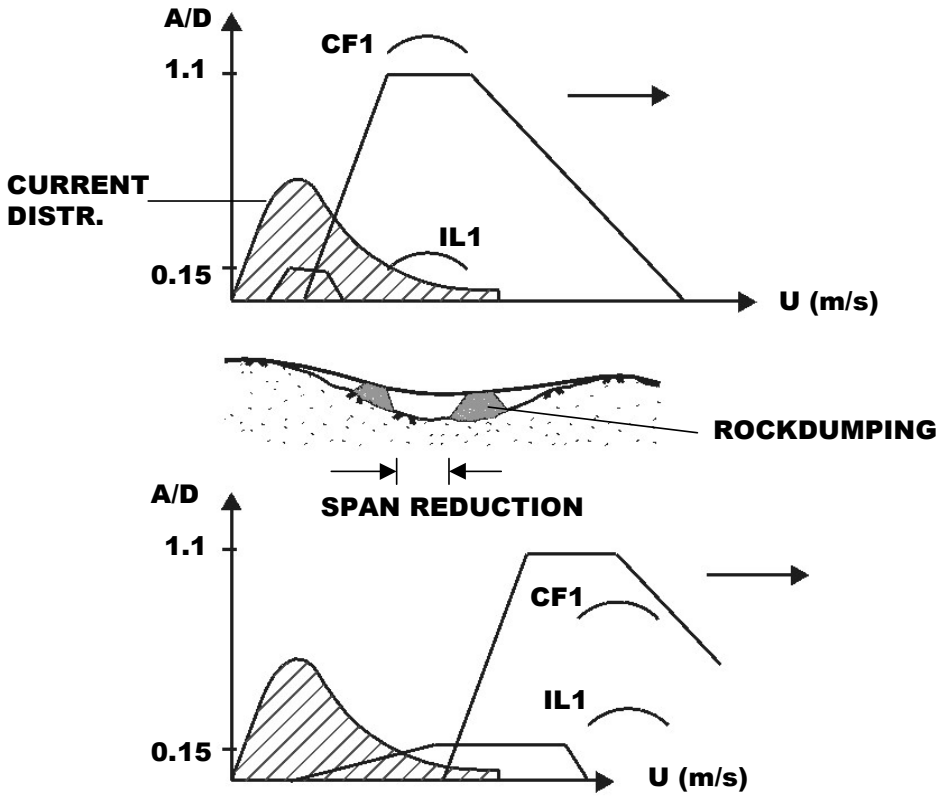


Crossflow vibrations

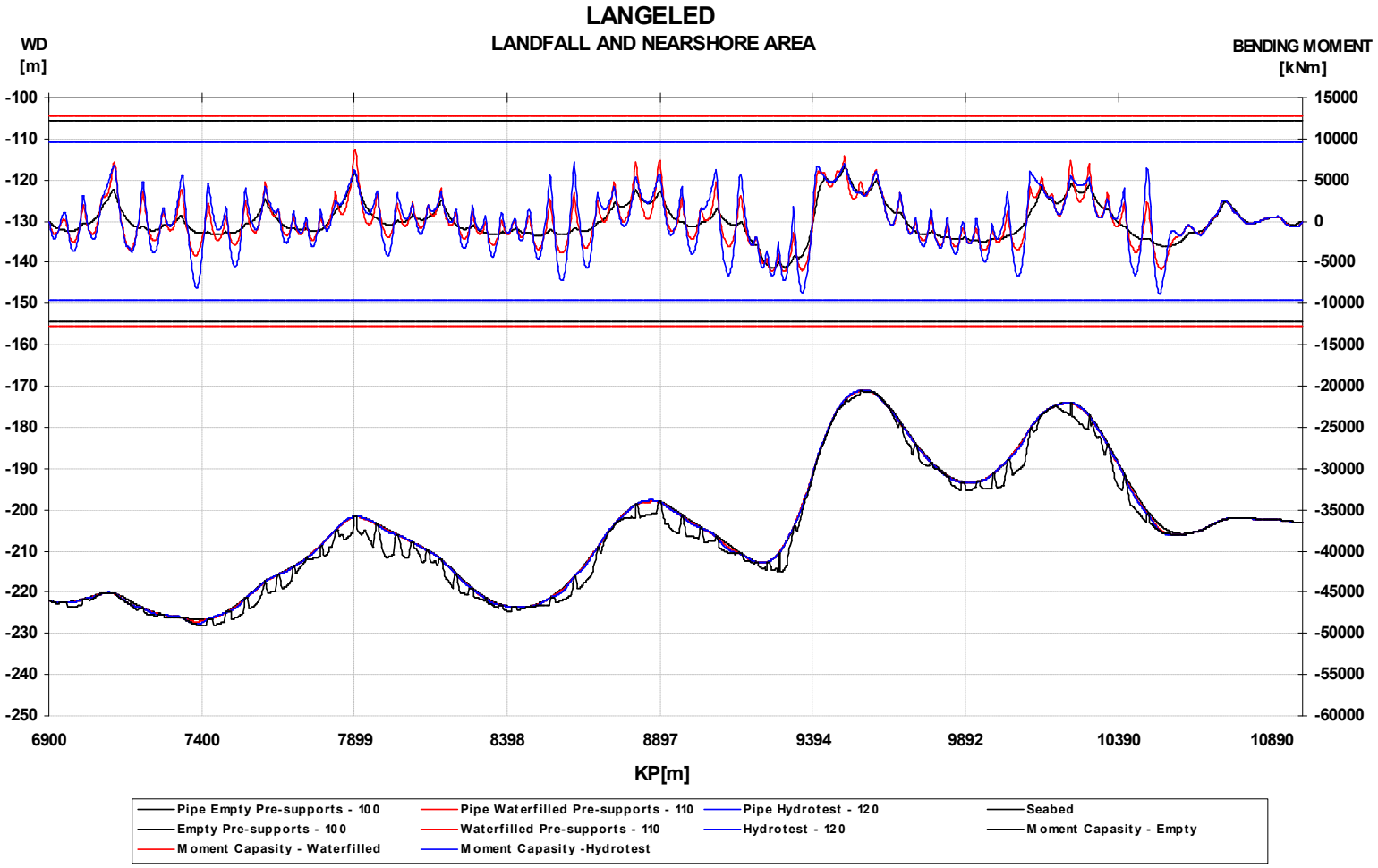


DNV Guidelines No. 14

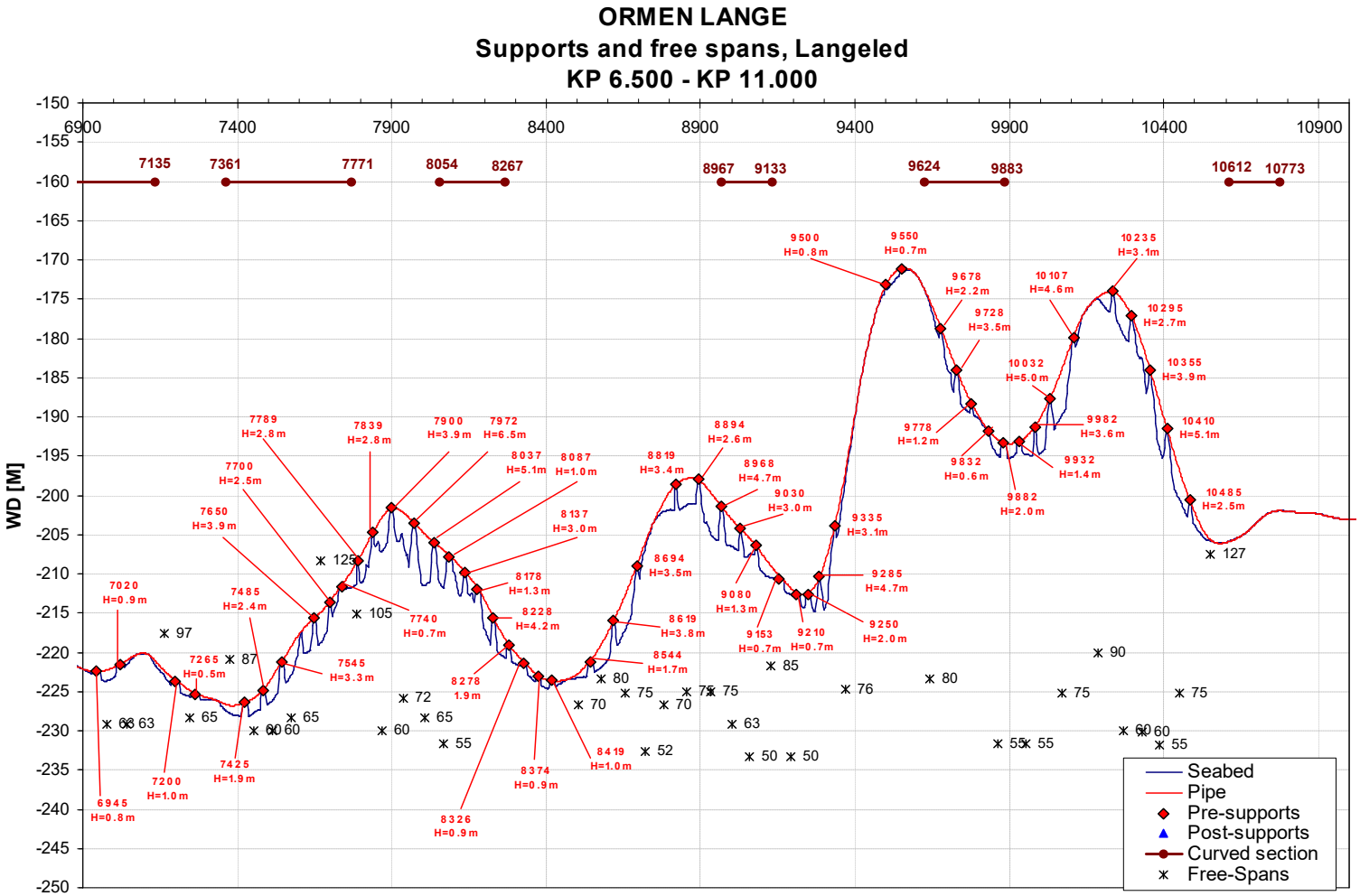
CONVENTIONAL FREE SPAN DESIGN



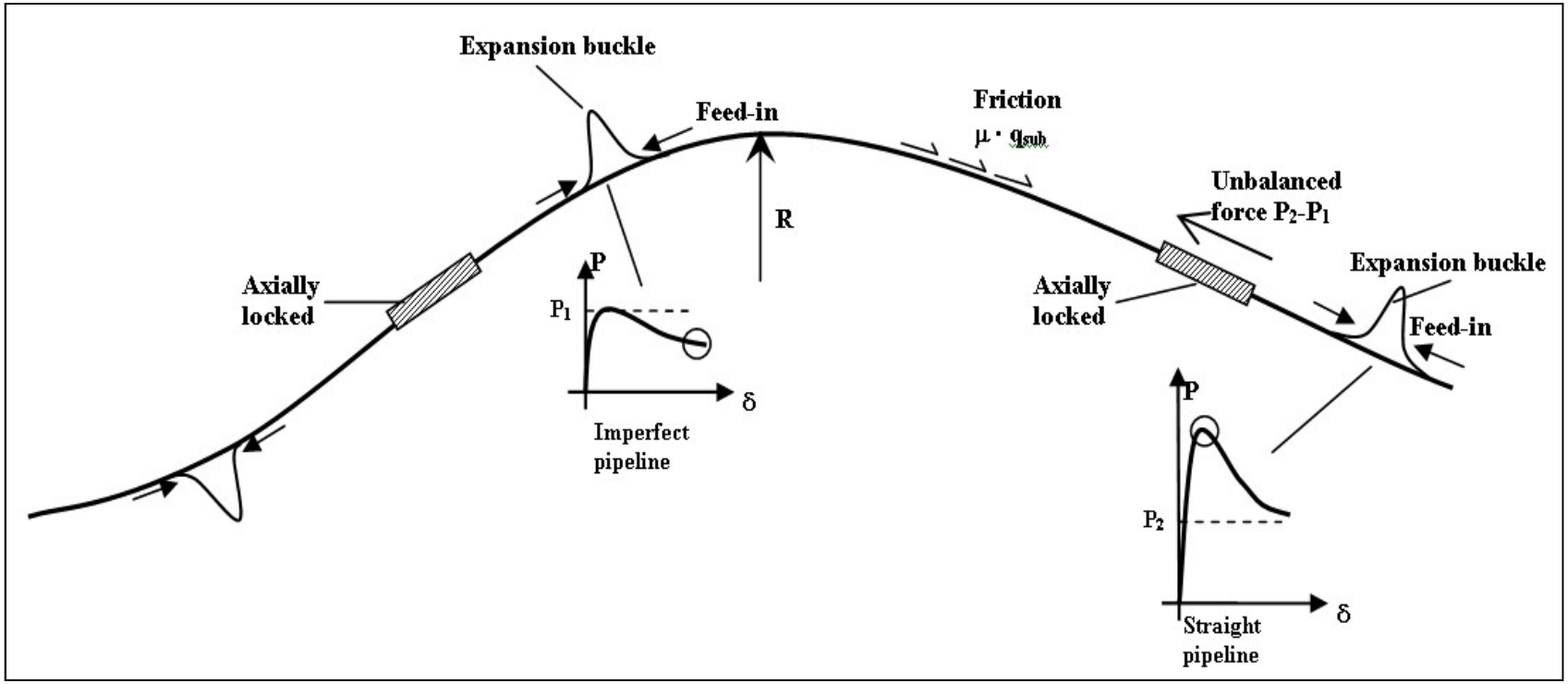
FREE SPAN RESULTS – Simla freespan analysis



PIPELINE SUPPORT DESIGN – Ormen Lange

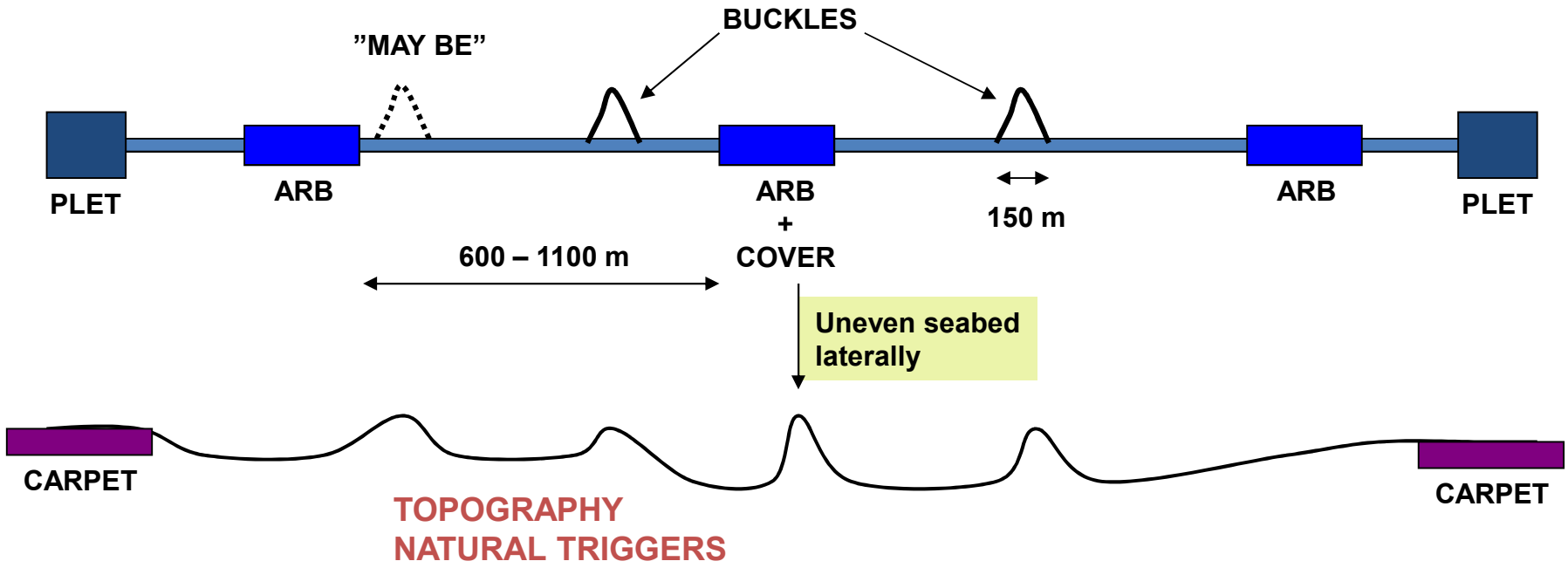


EXPANSION DESIGN PHILOSOPHY



EXPANSION DESIGN CONCEPT

ARBs: KEY ELEMENTS FOR SECTIONING



TOPOGRAPHY
NATURAL TRIGGERS

BUCKLING DESIGN STRATEGY

- **MINIMUM UNBALANCED FORCES IN SYSTEM**

  Reduce built in axial force by triggering buckles.

  Relevant safety level for buckle formation.

  Check seabed at buckle locations.

  Avoid lateral buckling in free spans.

- **UTILIZE UNEVEN SEABED**

  Identify locations with tendency to lift off along the route.

  Check lift off length for lateral buckling.

  Amplify natural imperfections by triggers (snaked laying, trigger berm, buoyancy).

- **COMBINE IMPERFECTIONS**

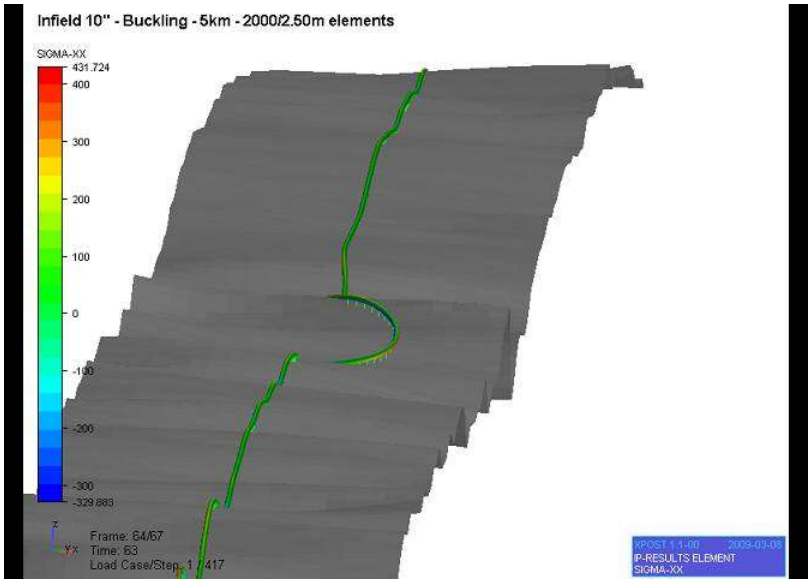
  The combination of vertical and horizontal imperfections gives ”softest” buckling behaviour and minimum unbalanced forces.

  Lateral imperfections are present after first operation/shut-down cycle.

SIMLA EXPANSION ANALYSES

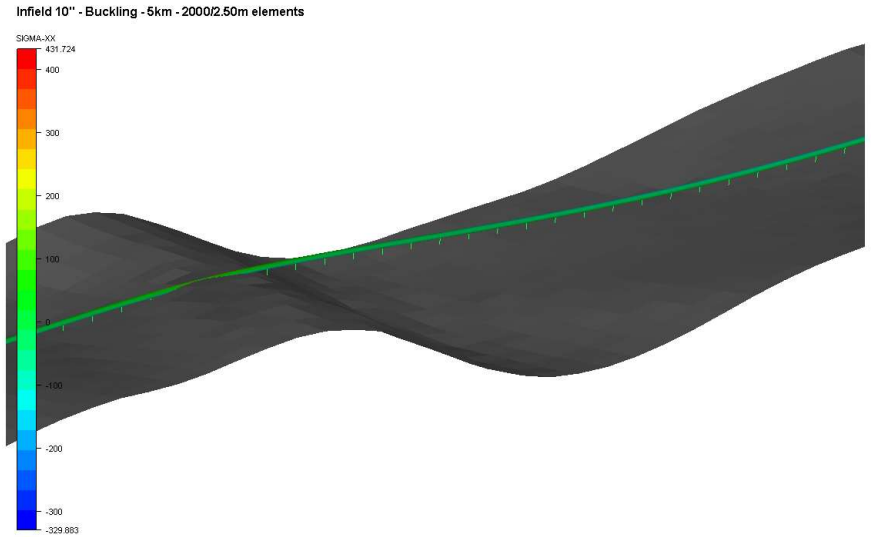
Challenges

- Interaction with 3D terrain
- Soil pipe interaction
- Free-span reduction/increase in cyclic operation-shutdown phases



3D SIMLA analysis

EXPANSION DESIGN - SIMLA Analyses

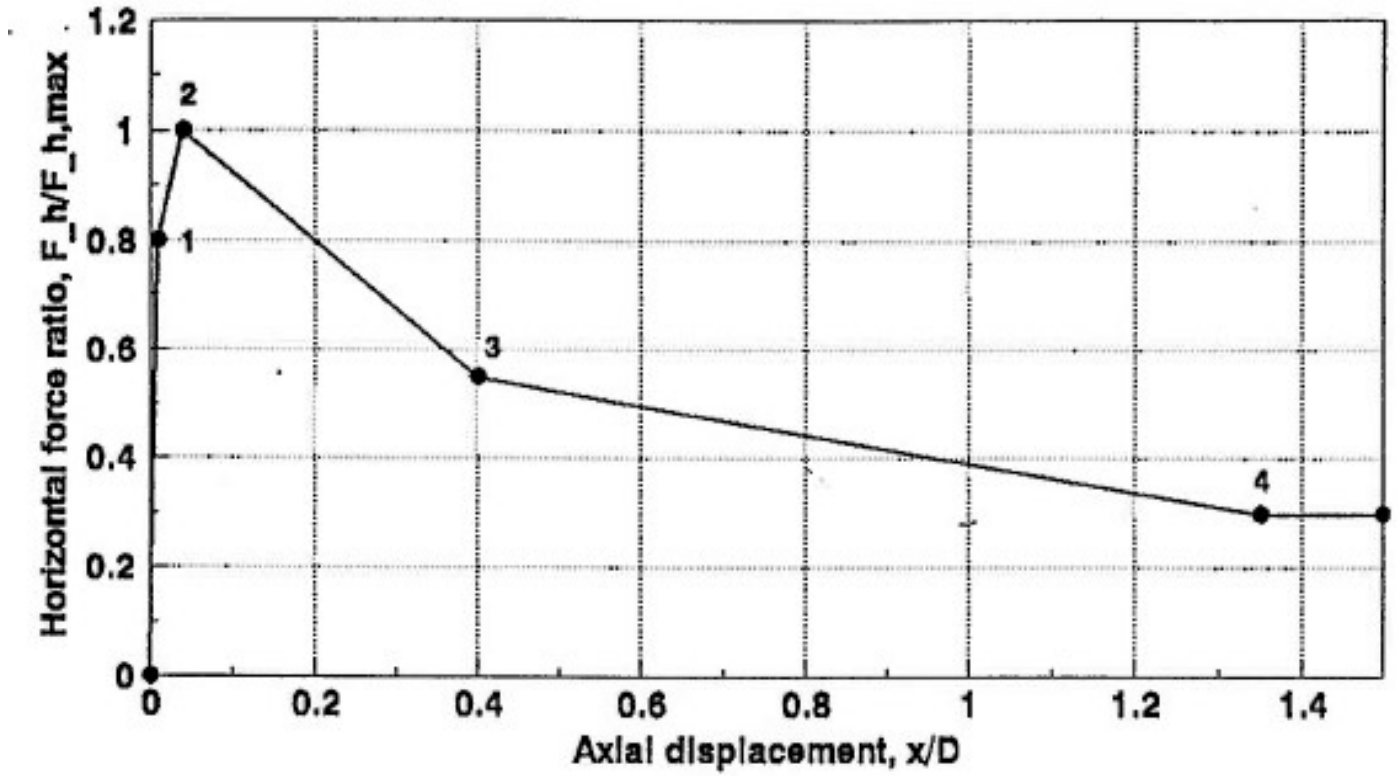


Analysis model with pipeline on seabed

Model segment, for illustration of pipe-seabed interaction

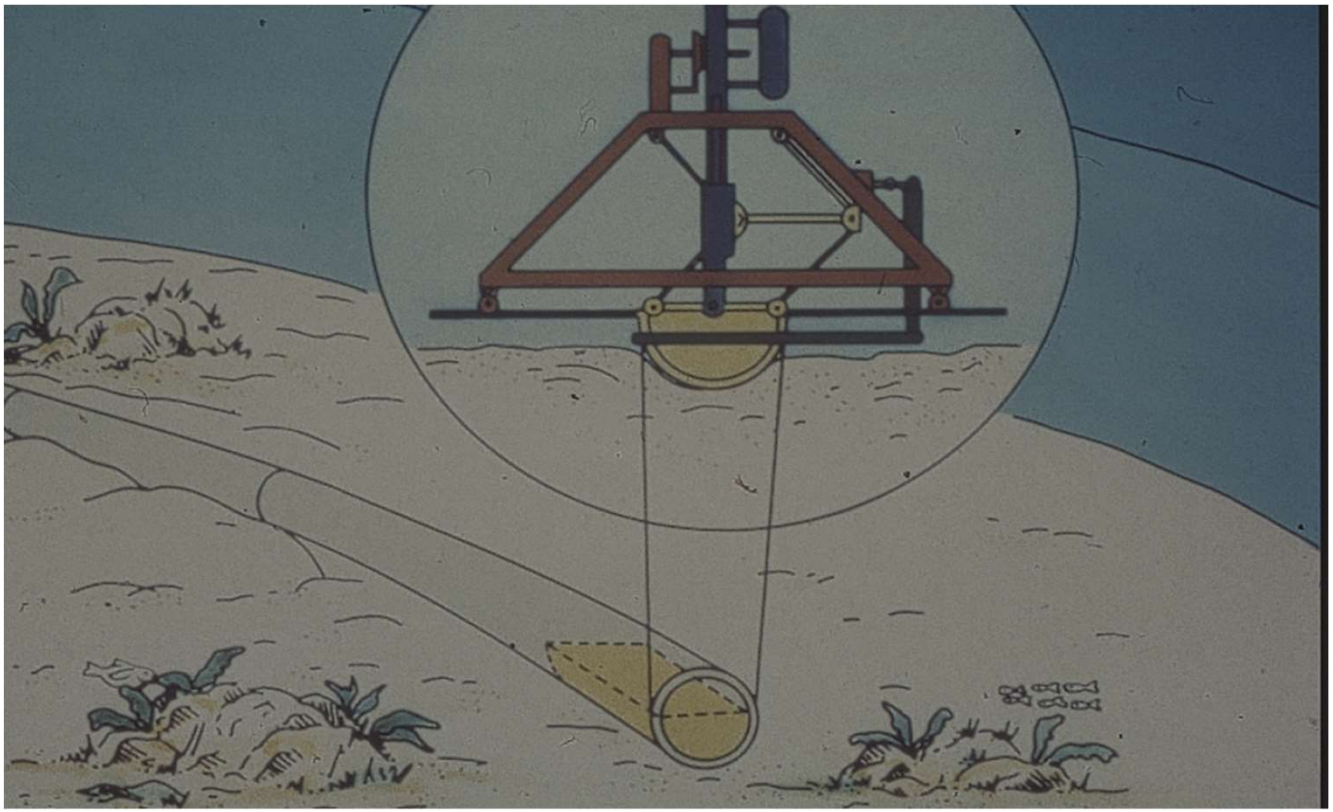
DETAILED 3D ANALYSES
On-bottom axial pipe-soil resistance on clay

- Non-dimensional force-displacement description

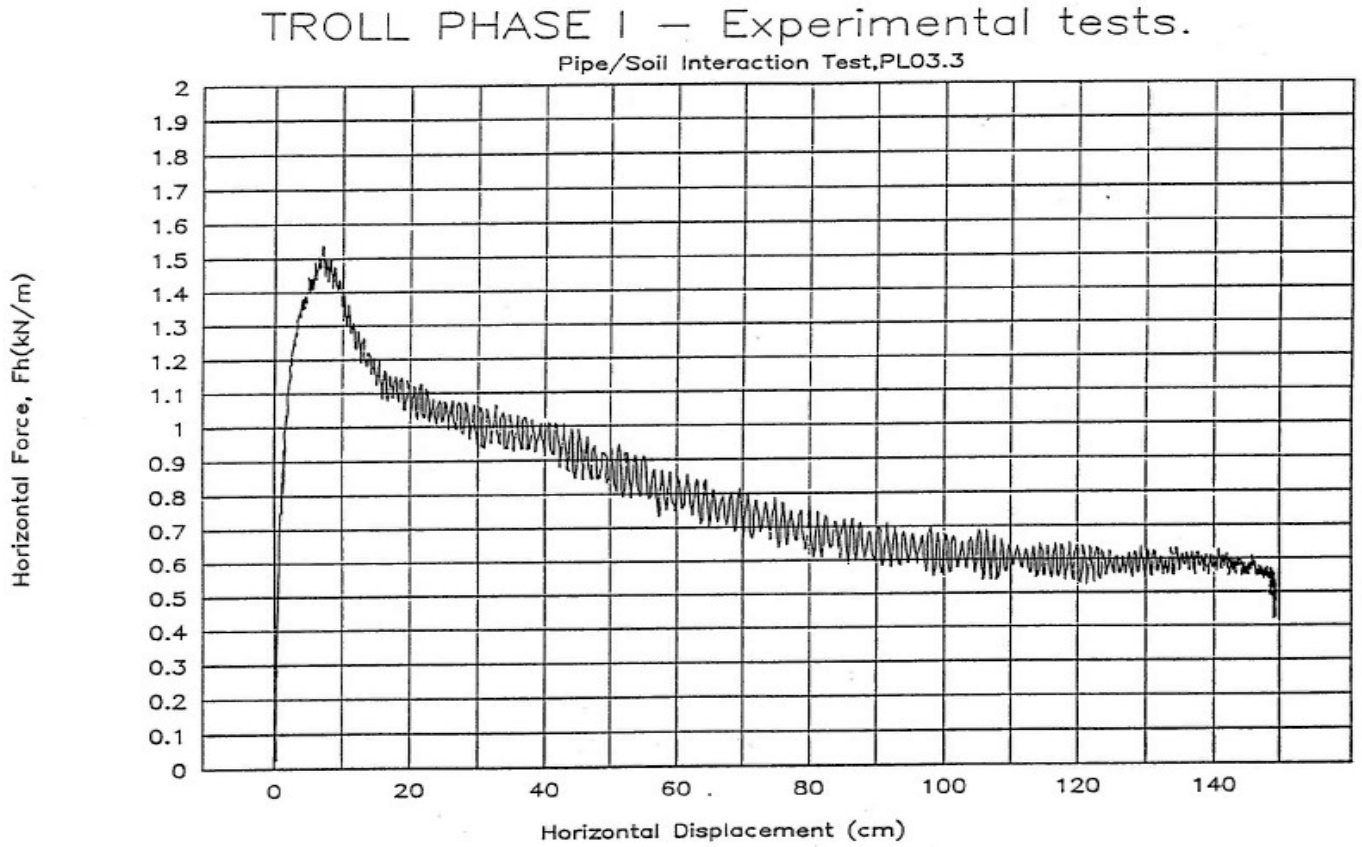


PIPE RESISTANCE TESTS

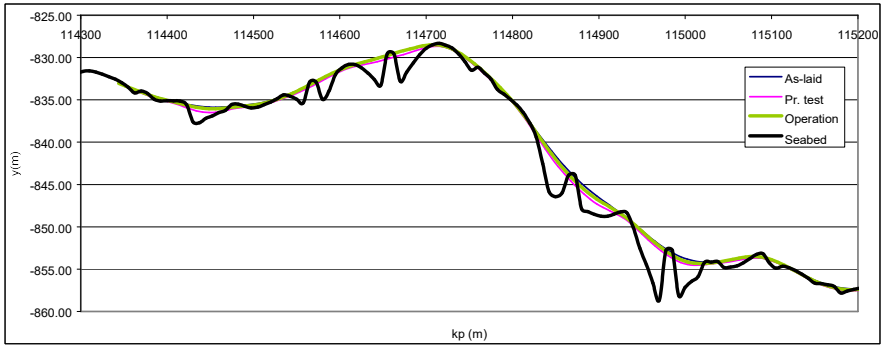
- **LARGER SCALE MODEL TESTING**



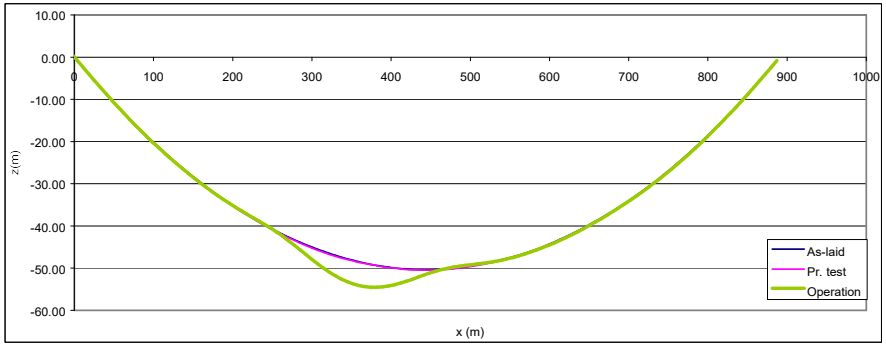
LATERAL RESISTANCE TESTS ON CLAY



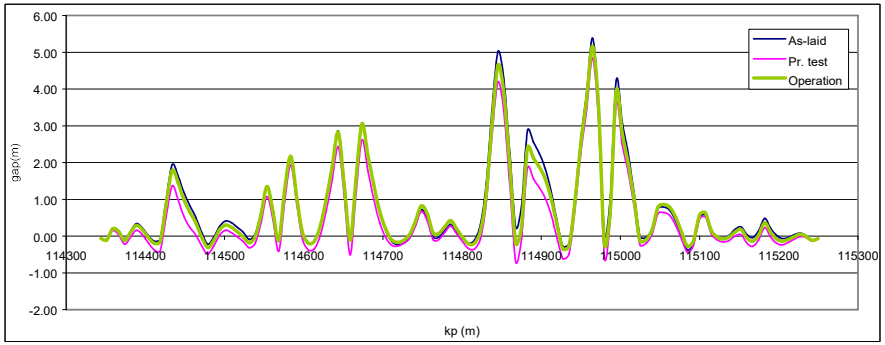
EXPANSION ANALYSIS RESULTS



VERTICAL PROFILE

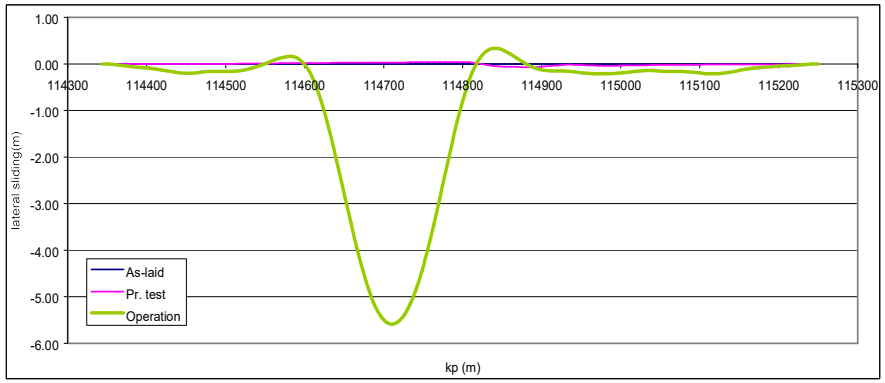


LATERAL MOTION

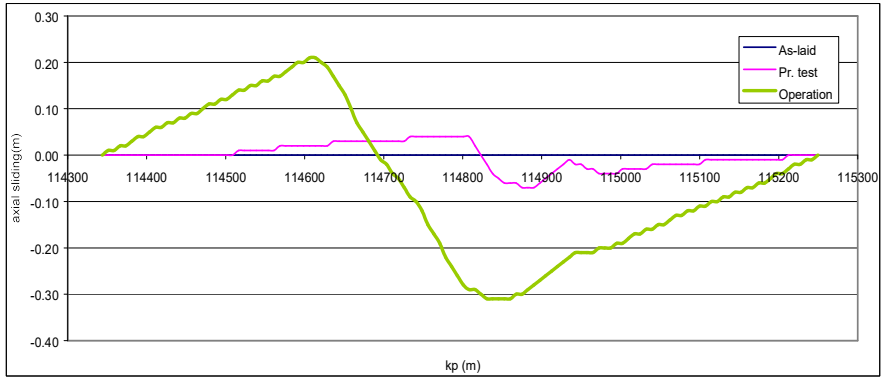


SPAN CLEARANCE

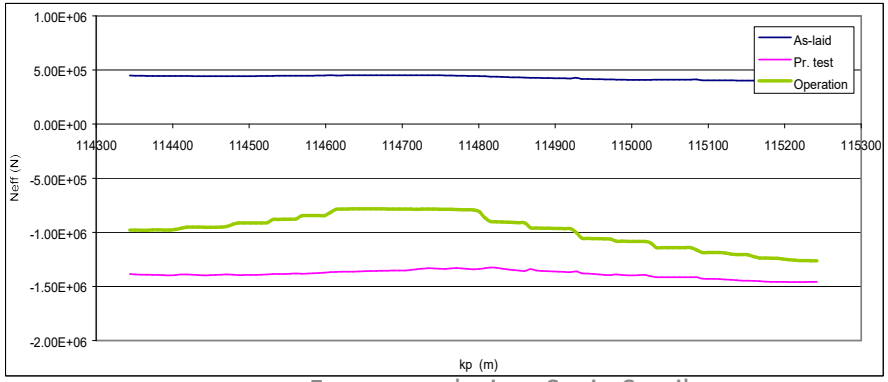
EXPANSION ANALYSIS



LATERAL PROFILE



AXIAL FEED-IN



EFFECTIVE FORCE

CAPACITY CONTROL IN APEX - DNV OS-F101

Local buckling limit state – DNV OS-F101

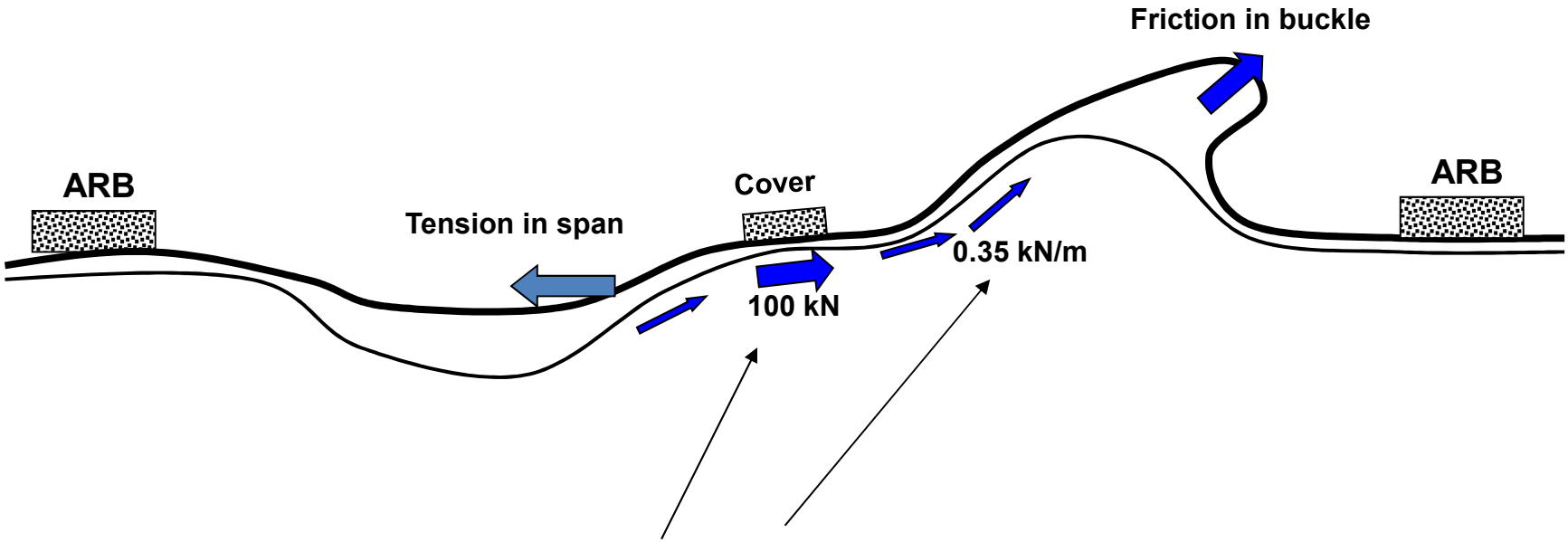
Load controlled condition – Combined loading with internal overpressure

$$\gamma_{sc}\gamma_m\left(\frac{S_d}{\alpha_c S_P}\right)^2+\gamma_{SC}\gamma_m\left(\frac{M_d}{\alpha_c M_p}\sqrt{1-\left(\frac{\Delta p_d}{\alpha_c p_b}\right)^2}\right)+\left(\frac{\Delta p_d}{\alpha_c p_b}\right)^2\le 1$$

where:

M_d: Design bending moment
S_d: Design effective axial force
Δp_d: Design differential overpressure
M_p: Plastic moment resistance
Sp: Characteristic plastic axial force resistance
p_b: Burst pressure
α_c: Flow stress parameter

SHUT DOWN RETRACTION MECHANISM

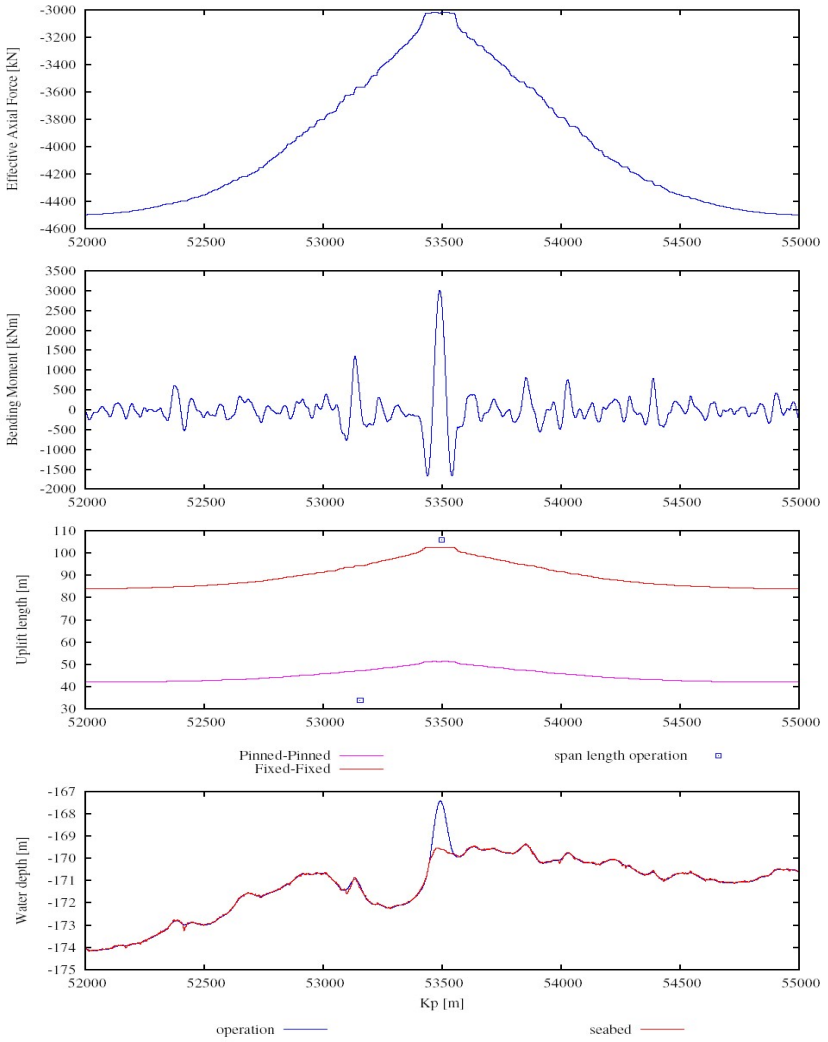


One cover corresponds to 300 m exposed pipe.

IDENTIFICATION OF NATURAL TRIGGERS

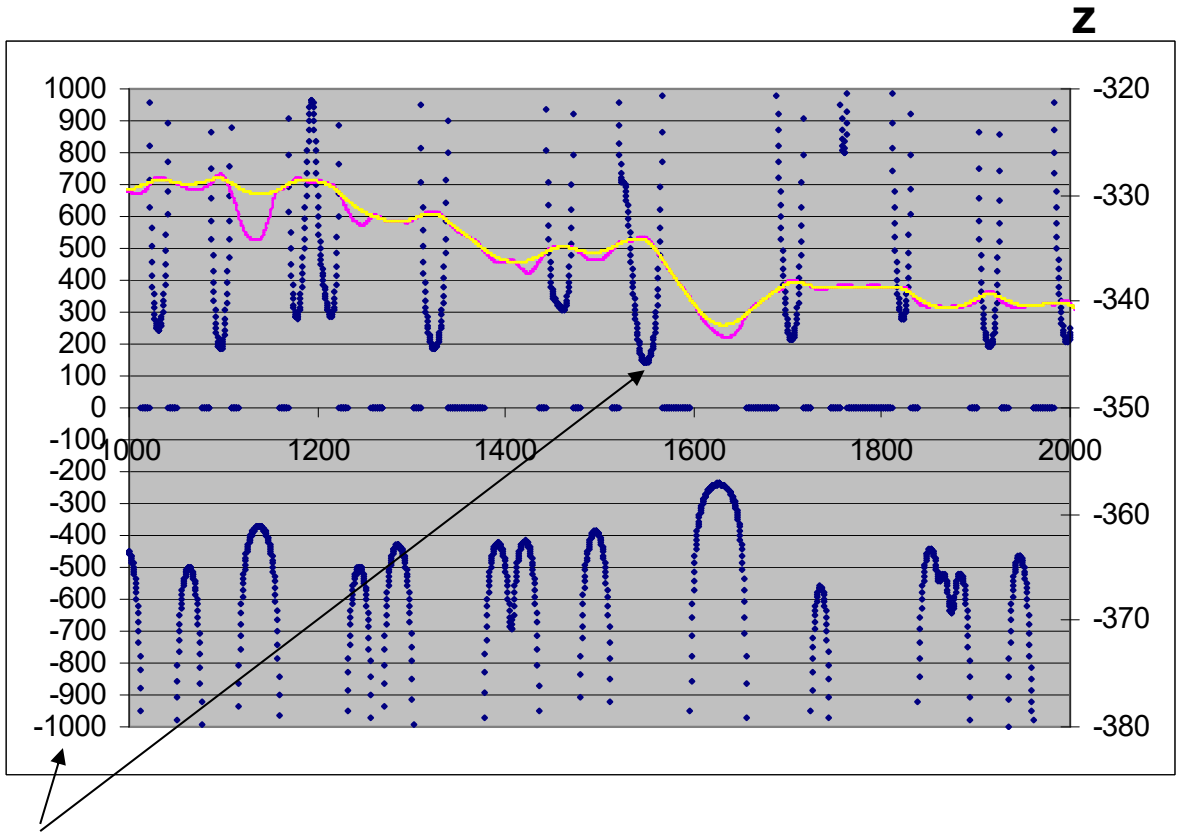
SIMLA - 3D

Early stage analyses to identify natural buckling locations



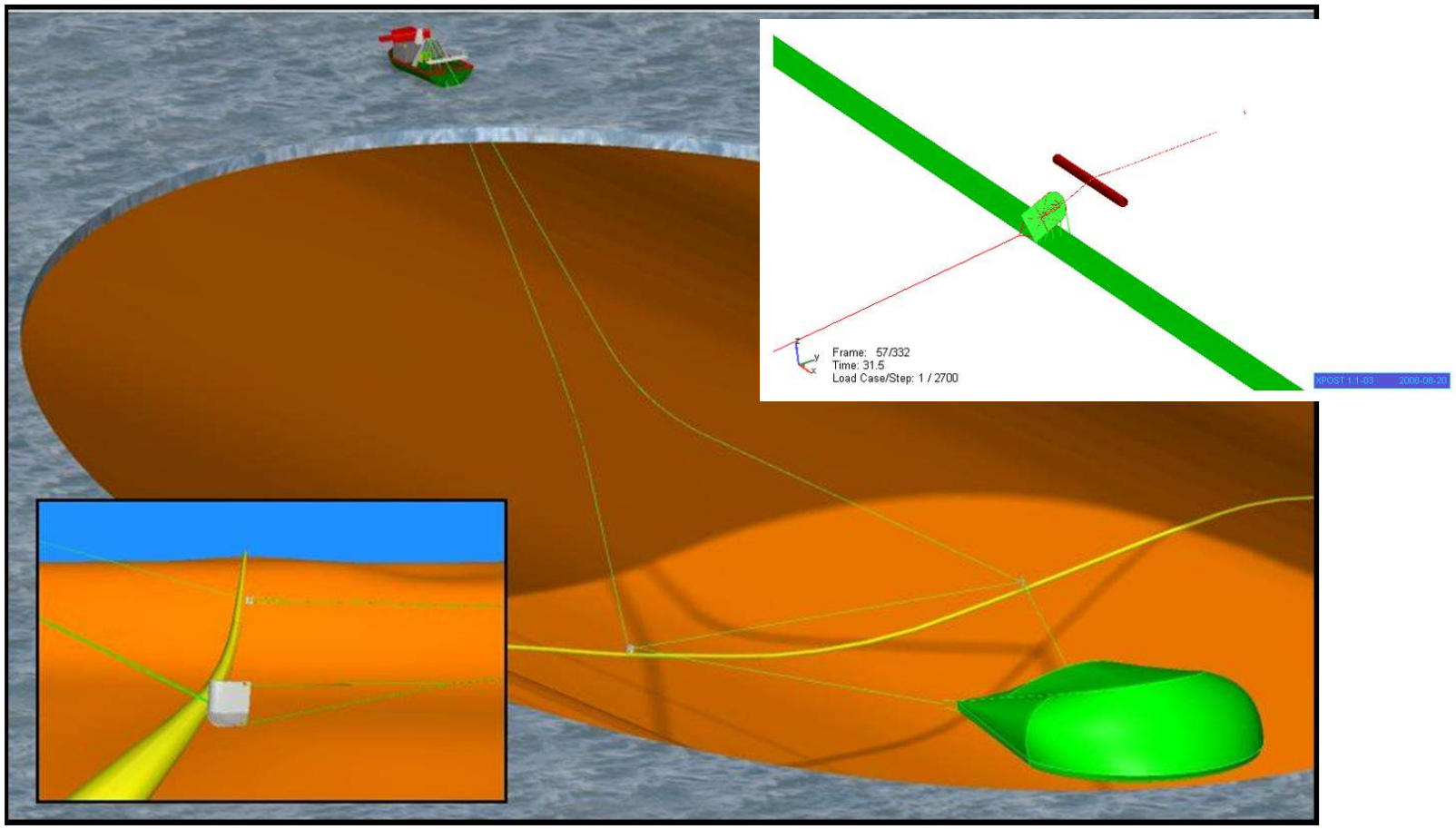
BUCKLE LOCATIONS

- Triggers
- Free-spans
- Seabed intervention
- Suitable buckle locations



r = EI/M (curve radius – bottom roughness analysis)

TRAWLING OVER PIPELINES



Åsgard pipeline expansion analysis

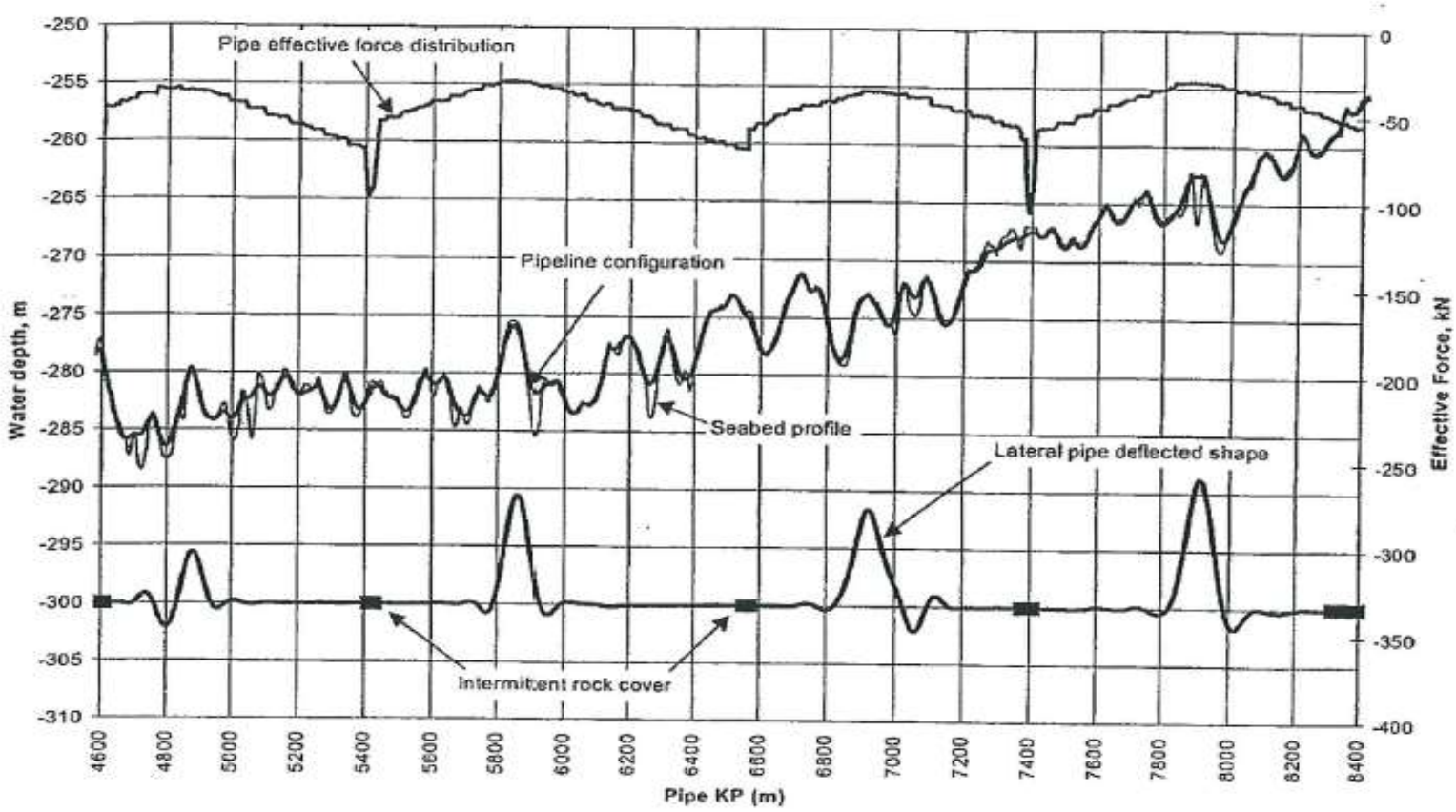


Figure 3: Global Buckling Behaviour of the Operating Pipeline on Uneven Seabed

Design aims

The seabed intervention design aims to:

- Limit the global buckle amplitude with respect to pipe stresses and strains
- Avoid global buckles occurring over pipe free spans

The goal is to achieve an optimum cost for seabed intervention whilst maintaining the integrity of the flowlines within adequate safety margins. For a flowline buckling globally

Design aim

the global buckling behaviour of the flowline. Hence, the strategic placement of the rock cover will lead to the global buckle occurring as intended, within reasonable limits based on the soil friction and seabed imperfection. Therefore the global buckling of the pipe over a free span section can be avoided by adjusting the location of the intermittent rock cover.

Buckling during operation.
Mismatch design/practice

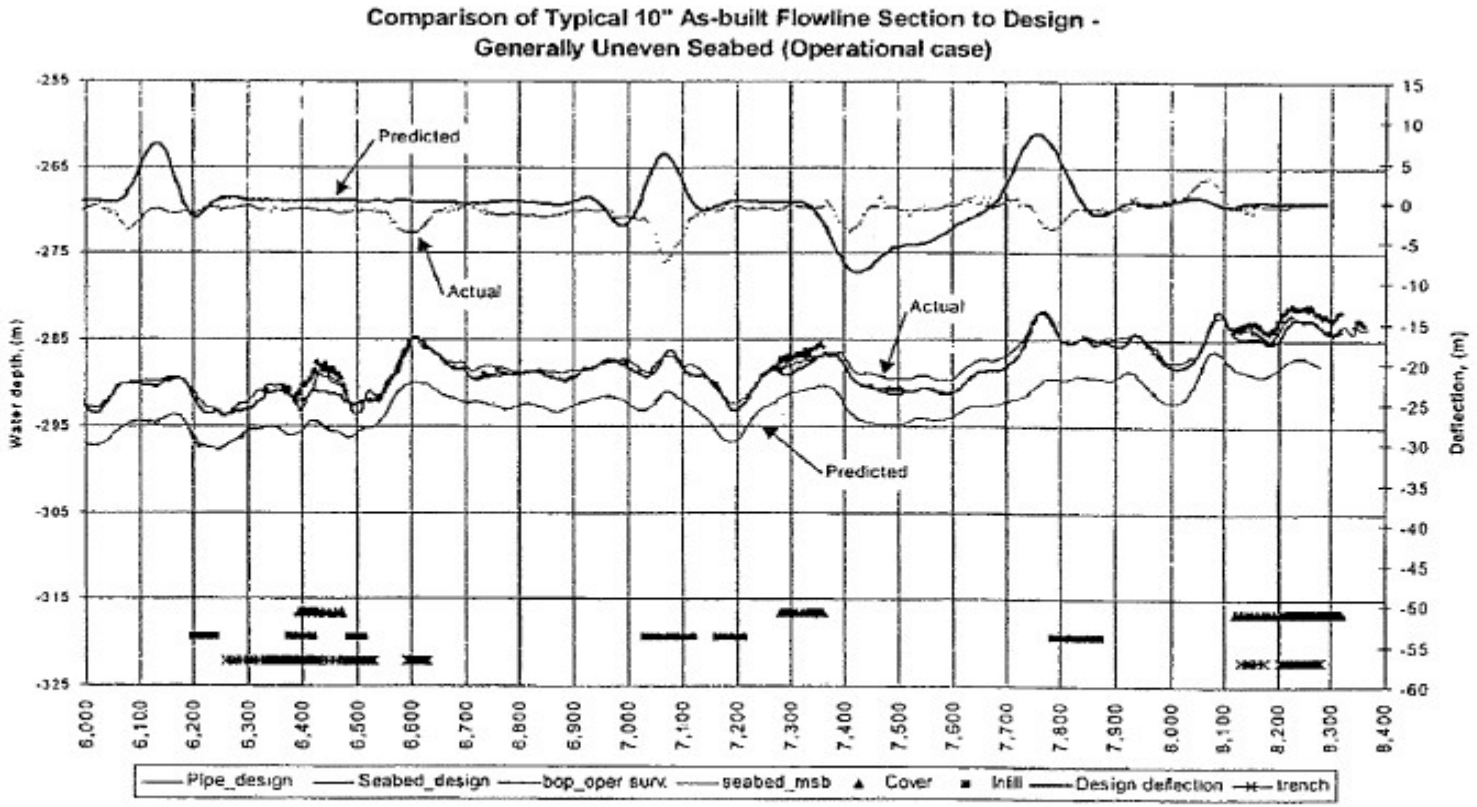


Figure 5 (b): Assessment of Flowline on Uneven Seabed

EXPANSION ANALYSIS - SUMMARY

- **EXPANSION CONTROL IS BASED ON NONLINEAR SOIL-PIPE ANALYSES. SENSITIVITY STUDIES AS BASIS FOR SAFETY FACTORS IN DESIGN.**

- **IN ORDER TO OBTAIN A RATIONAL DESIGN, BASIC CONTINUUM MECHANICS KNOWLEDGE IN PARALLEL WITH NUMERICAL TOOLS IS NEEDED. ANALYTICAL VERIFICATION TOOL.**

- **COMPUTATIONAL MECHANICS KNOWLEDGE HAS TO BE SUPPLIED BY UNDERSTANDING OF PRACTICAL OPERATIONAL PROCEDURES IN ORDER TO COME UP WITH RELEVANT NUMERICAL MODELS.**

INTERVENTION METHODS

INTERVENTION METHOD	PURPOSE	IMPLEMENTATION
Prelay Rock Support	Reduce free spans	In front of PLETs. Part of PLET support.
Anchoring Rock Berm (ARB)	Sectioning of pipeline assuring buckle sharing as well as feed-in control.	Fully implemented as the major capacity and robustness action. Strict sectioning of the pipelines prevents progressive development of pipeline walking.
Rock Cover	Preventing lift at unwanted locations, or protection against dropped objects.	Minimizing use of rock cover due to increased friction and triggering new buckles. Puts also higher requirements on ARB capacity.
Postlay Rock Infill	Filling up free spans to assure no VIV during operation for production lines and eliminate gap in spans for trawling both for production and gas injection lines.	Implemented as the major seabed intervention work.
Trenching	Reduce triggers at unwanted buckle locations as well as eliminating free spans and need for infill.	Not implemented in basic design. Optimization.