NTNU
Norwegian University of Science and Technology

Norwegian Centre of Excellence

Flexible Risers with Slug Flow

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Retirement of Prof. Carl M. Larsen

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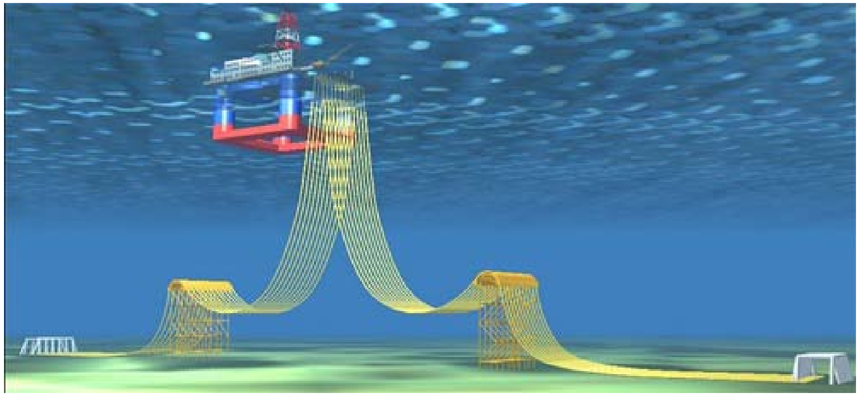
Flexible Risers with Slug Flow

Objective:

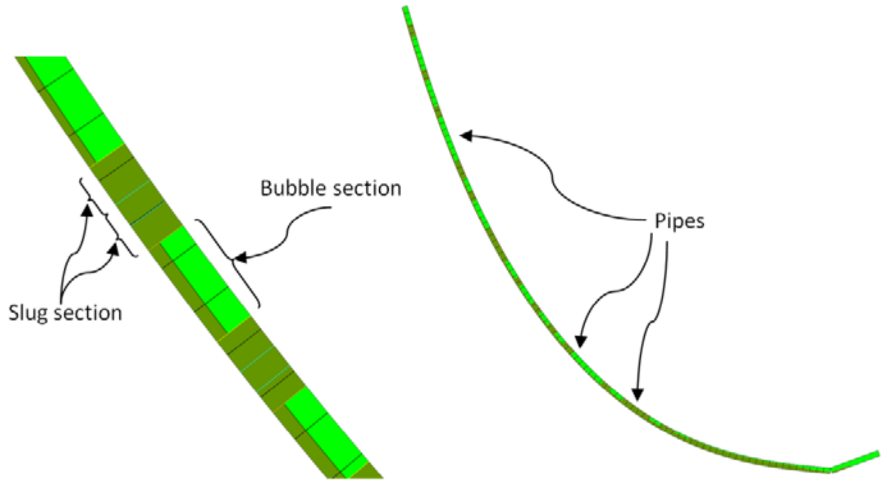
1. Influence of slug flow in dynamic response of flexible risers.
2. Influence of the dynamic riser configuration in development of slug flow.
3. Build a computational tool for simulation of the fluid-structure interaction.



Flexible Risers with Slug Flow

Slug Flow Program:

- Program for simulation of unsteady slug flow in pipes and risers.
- *In-house* code.
- OOP, written C++.
- Based on a Lagrangian Slug Tracking Model.



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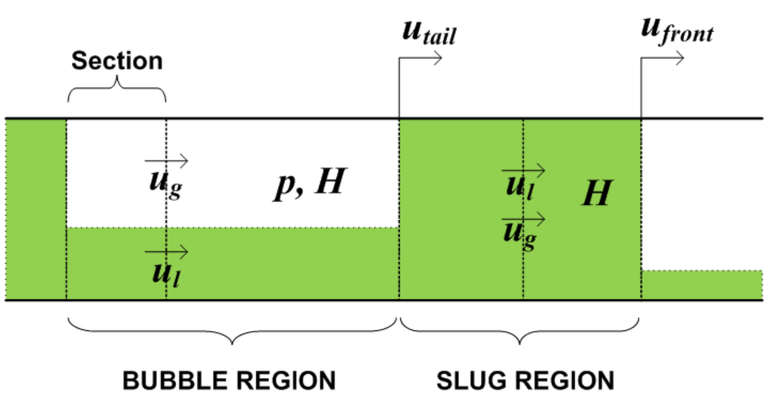
Slug Flow Program:

- Slugs and bubbles are considered as objects.
- Objects have characteristic data (holdup, velocities, and pressure)
- Fluid conservations equations are balanced into each object.
- Similarly slugs and bubbles are linked by mass and momentum balances



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Riser Analysis Program:

- Program for GRA of flexible risers.
- *In-house* code.
- Modular programming written in Fortran.
- Static and dynamic analysis.
- Lazy-wave, catenary and other arbitrary riser configurations.
- Simulate forces from waves and internal single/two-phase flow.
- Based in a non-linear FEM.

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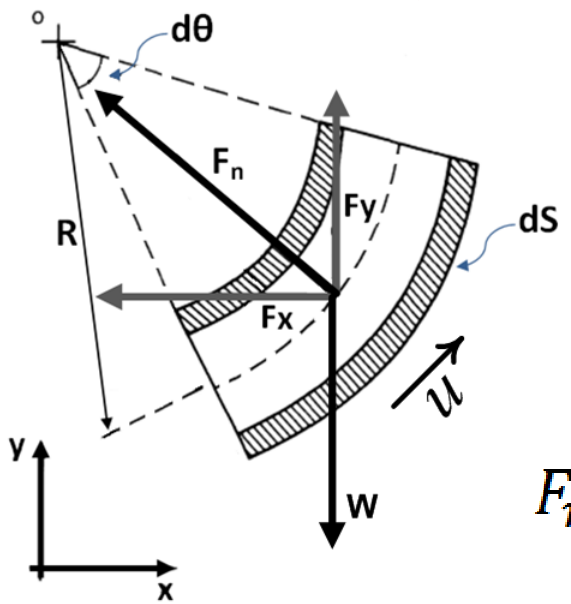
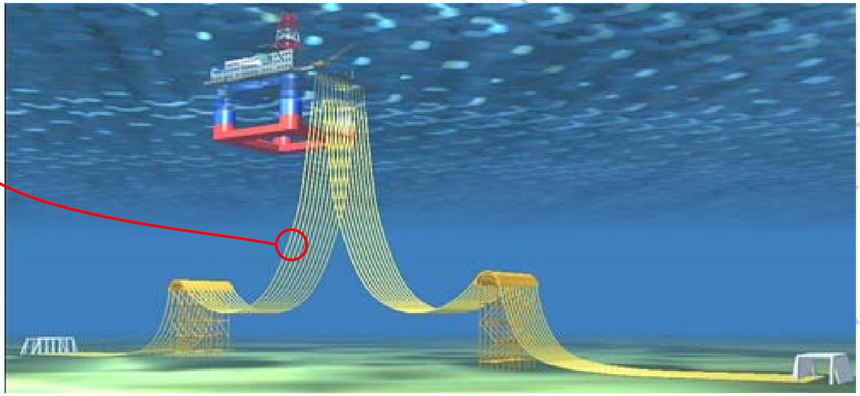
A fluid particle traveling along a riser:





F_n : *normal equivalent force / centripetal force*

- From the conservation equations:

$$F_n = \rho_{\substack{fluid\\particle}} A U_{\substack{fluid\\particle}}^{\ 2} \frac{dS}{R}$$

- For two-phase flow:

$$F_n = F_{n_l} + F_{n_g} \qquad F_{n_k} = M_k \frac{{U_k}^2}{R}$$

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Incremental formulation of Dynamic Equilibrium Equation:

$$M^{*}\Delta\ddot{r} + C\Delta\dot{r} + K\Delta r = F^{e^{*}} - F^{i^{*}}$$

* Variation due to two-phase flow:

$$M^{*} = M_{pipe} + M_{added} + M_{l} + M_{g}$$ mass matrix

$$\vec{F}^{e*} = \sum \vec{F}^{e} + M_{l}\left(\vec{a}_{c_l} + \vec{g}\right) + M_{g}\left(\vec{a}_{c_g} + \vec{g}\right)$$ external force vector

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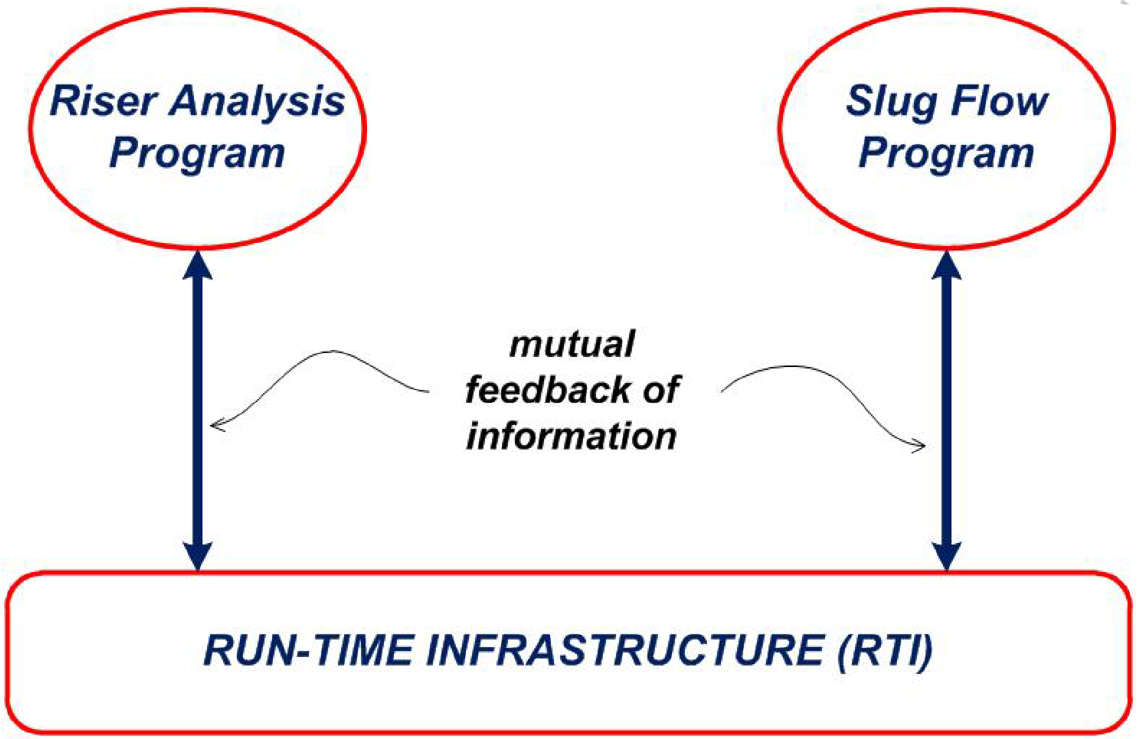
Communication Interface:

Independent but Interconnected Systems.



High Level Architecture (HLA)

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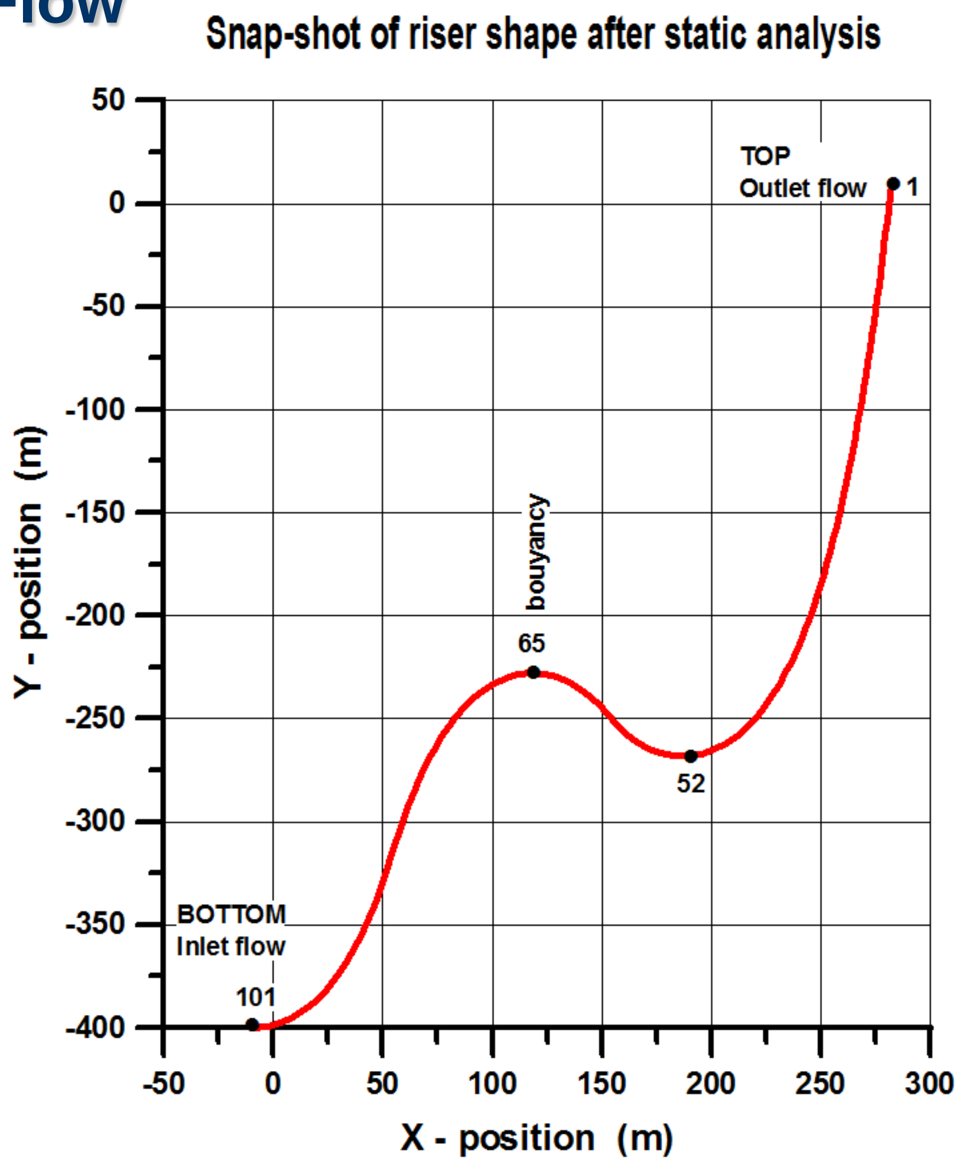
Case Base 1:

- Lazy-wave configuration.
- Water depth: 400 m
- Riser length: 620 m
- External diameter: 0.4 m
- Discretization: 100 elements
- Inlet liquid flow rate: 300 kg/s
- Inlet gas flow rate: 8 kg/s
- Outlet pressure: 1 atm.
- Hydrodynamic slugging.



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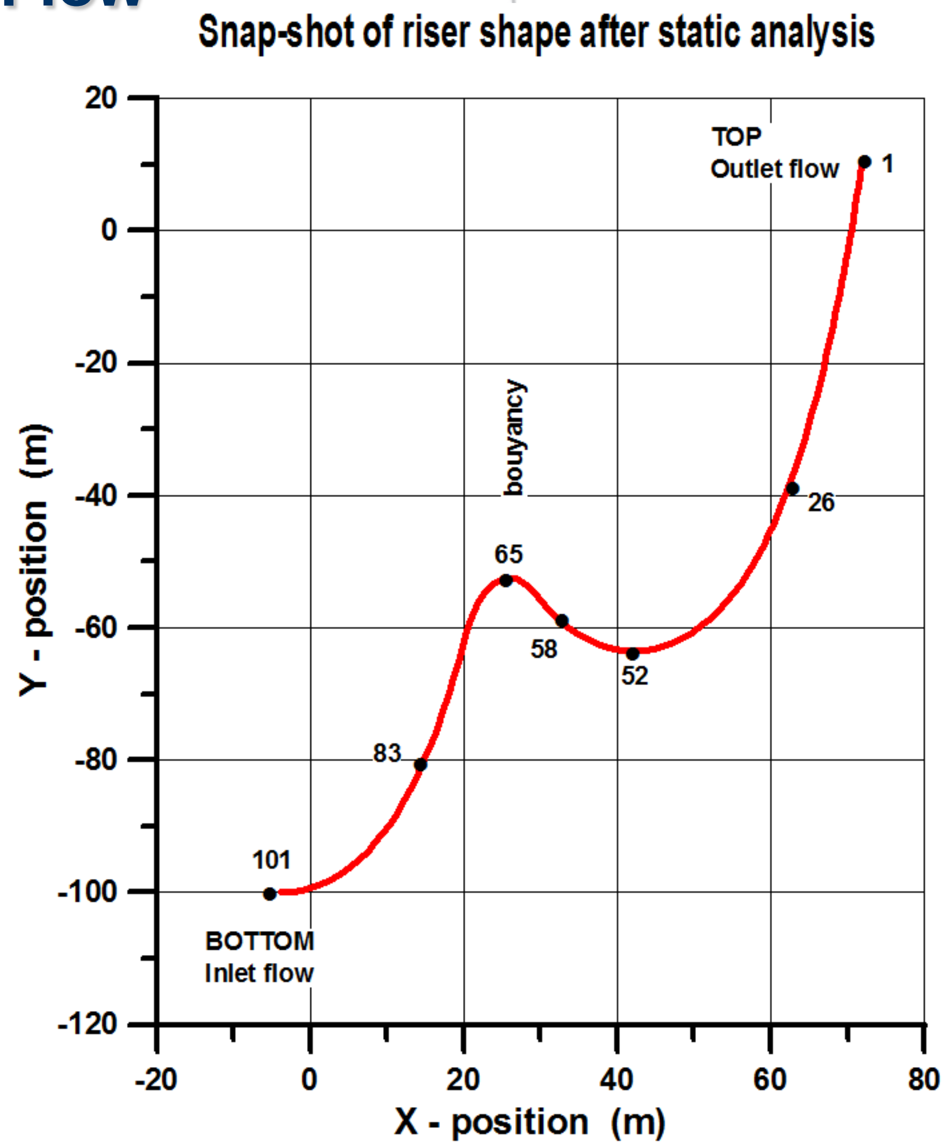
Case Base 2:

- Lazy-wave configuration.
- Water depth: 100 m
- Riser length: 160 m
- Internal diameter: 6 in
- Discretization: 100 elements
- Inlet liquid flow rate: 9 kg/s
- Inlet gas flow rate: 0.25 kg/s
- Outlet pressure: 1 atm.
- Severe slugging.



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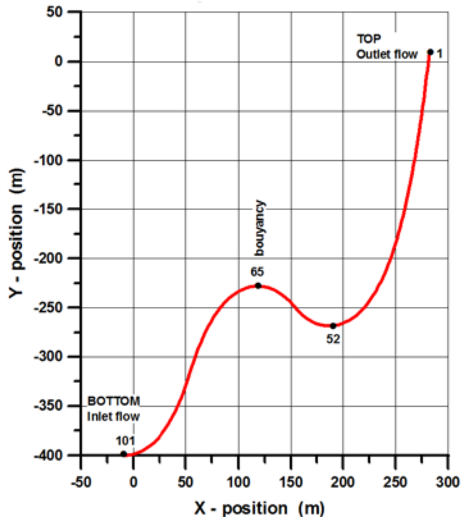
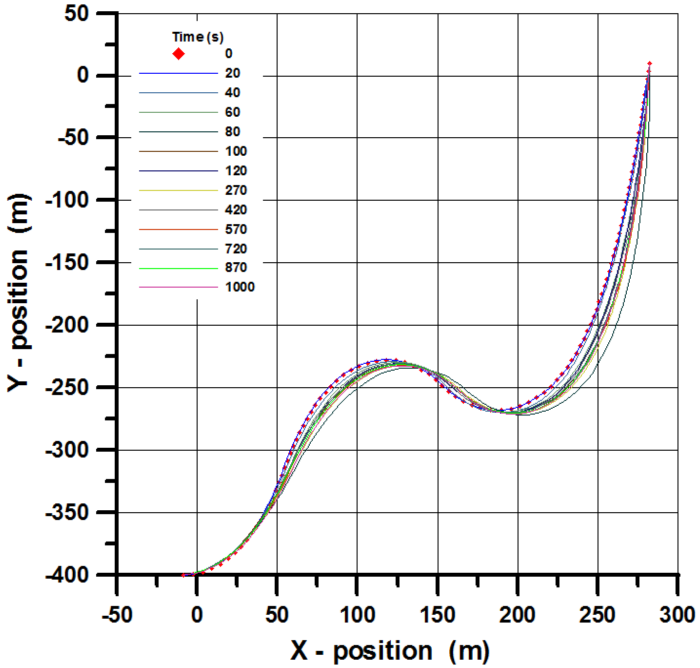
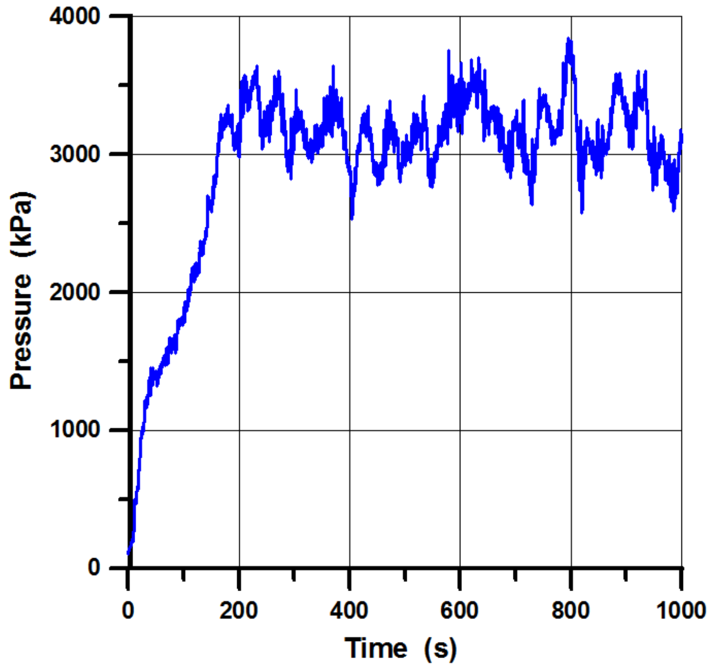




Snap-shots of riser shapes during time integration



Time history of slug flow inlet pressure

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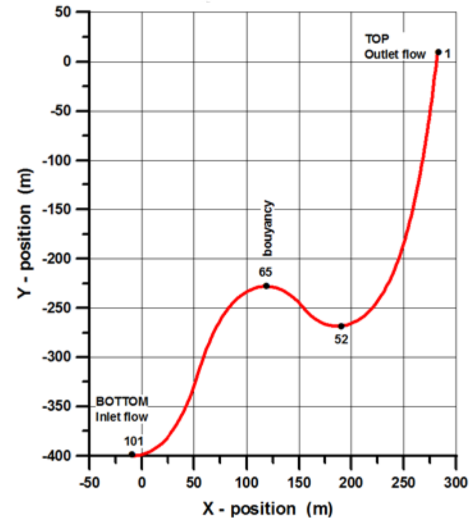
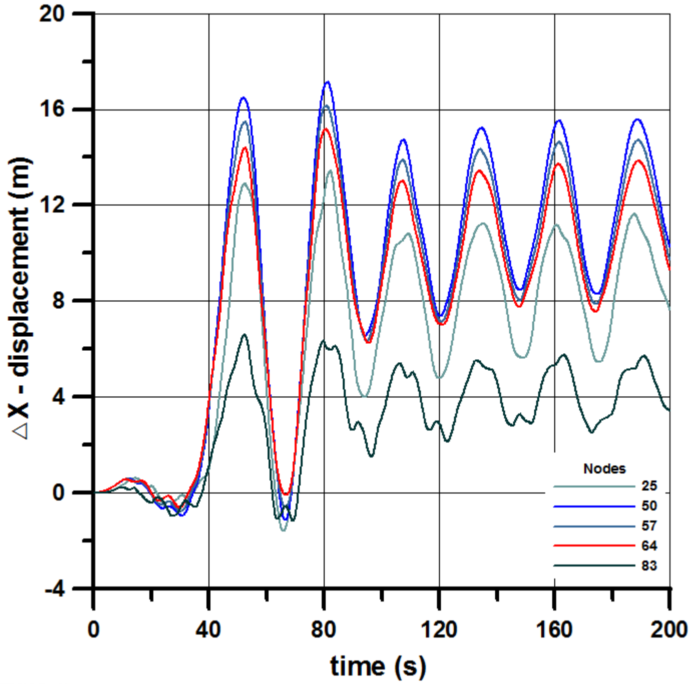
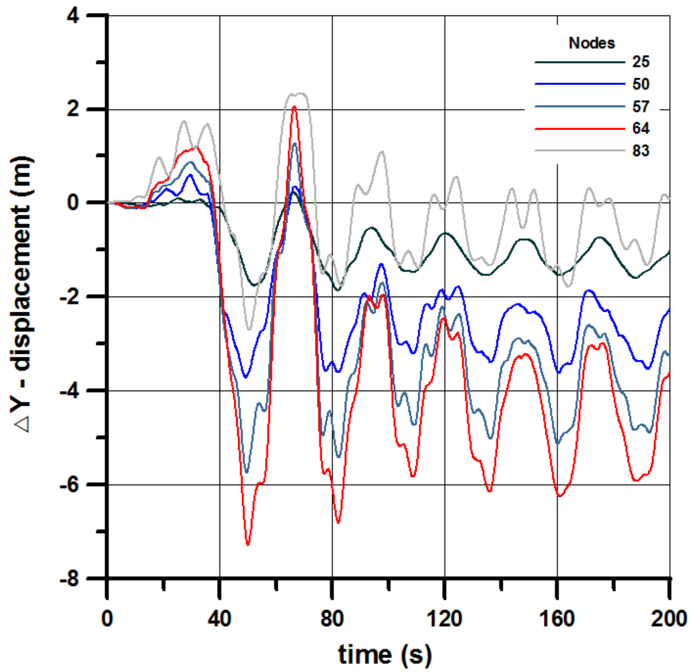


Time history of displacements



Time history of ΔX displacements



Time history of ΔY displacements

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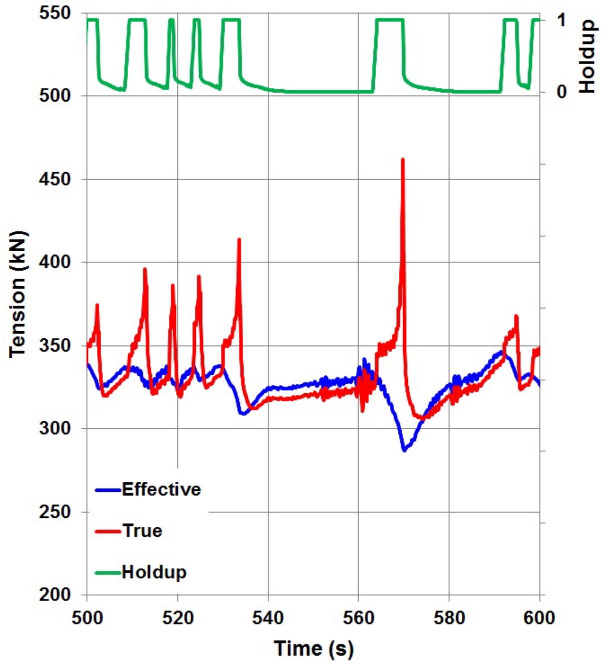
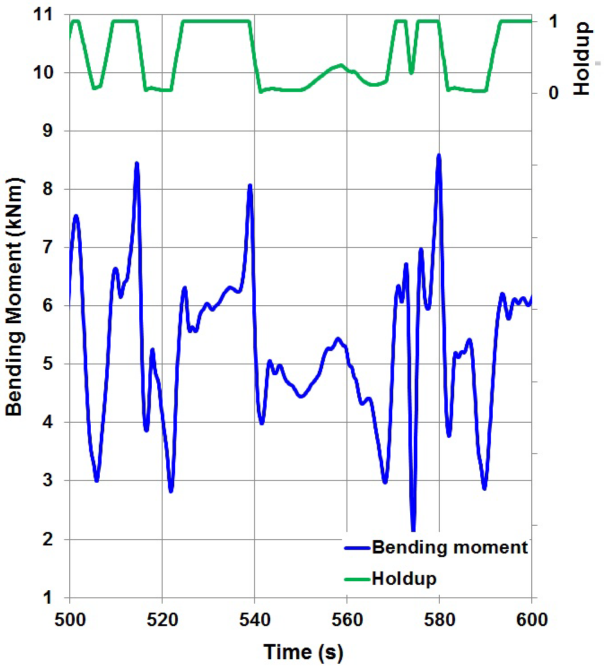
Time Series



Time history of top tension



Time history of bending moment at node 29

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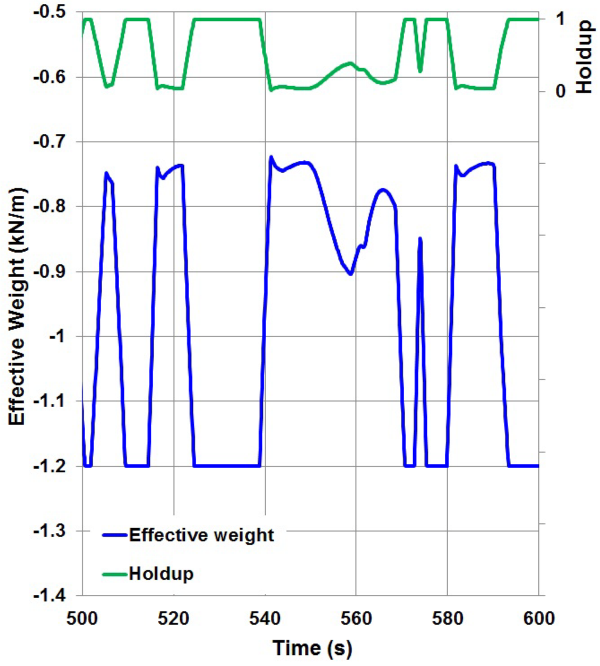
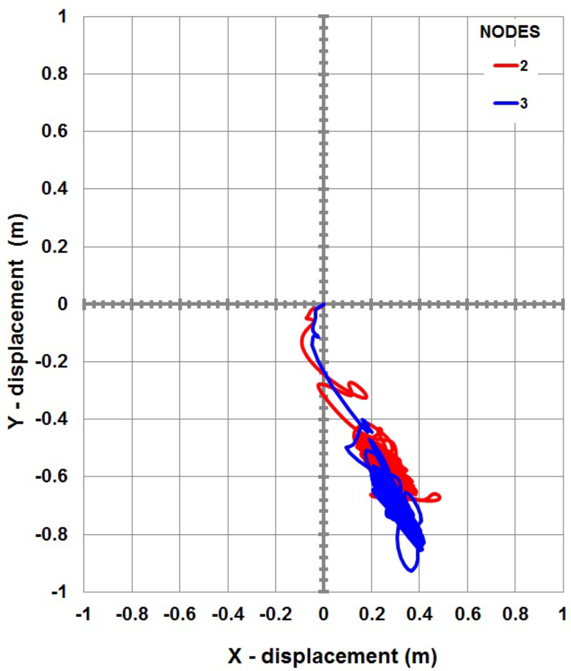
Time Series



Time history of effective weight at node 29



In-plane displacement

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Final Remarks:

- A computational tool for analyzing of the interaction fluid-structure has been built.
- *In-house* codes worked as independent, interconnected by information feedback.
- Lazy-wave riser configurations.
- Undergoing a hydrodynamic and severe slugging.
- Riser response influenced in the behavior of slug flow.
- Slug flow generated displacements, moments and tensions variations.

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Thank you very much !!!