Simulation of fluid-structure interaction to estimate fatigue life of subsea pipeline spans

Juan P. Pontaza

Shell Projects & Technology
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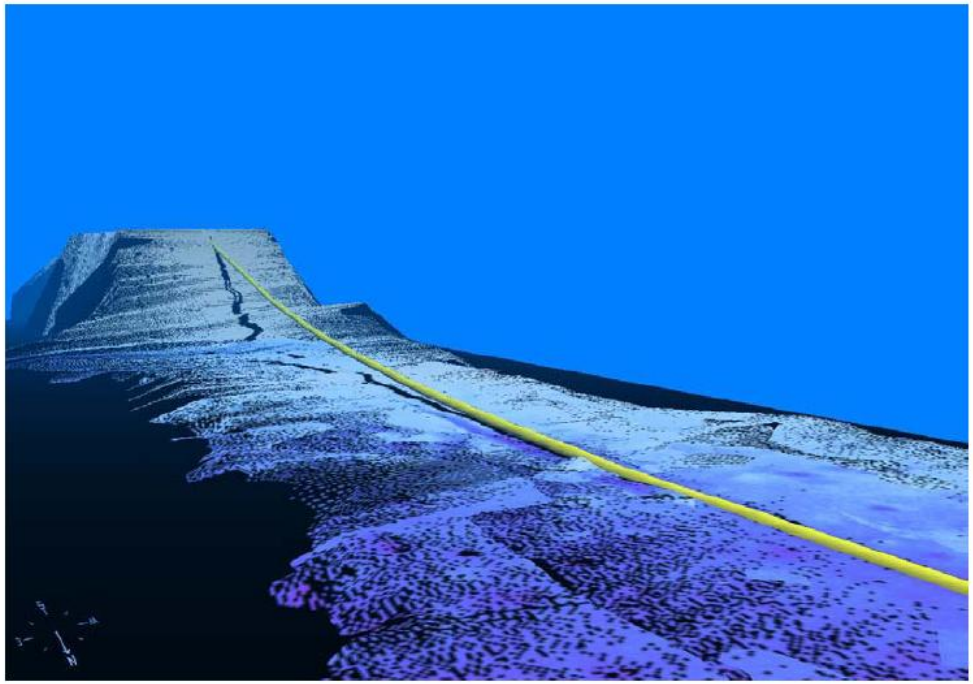
OUTLINE

- Background
  - Vortex-Induced Vibrations (VIV) of subsea pipeline spans
  - Motivation / Numerical Methods / Scope
- Modeling Fluid-Structure Interaction (FSI)
- Field application: A crossing pipeline span
- Concluding Remarks

BACKGROUND: VIV of Pipeline Spans

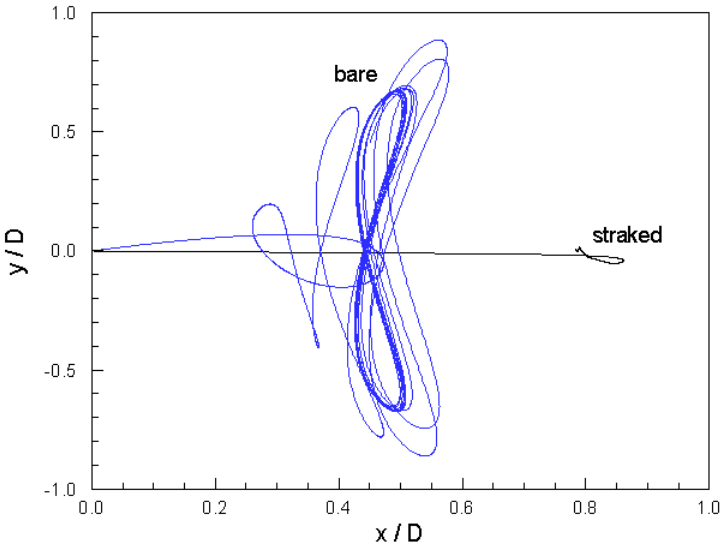
- Vortex-Induced Vibrations
  - External flow about offshore structures
    - Frequency synchronization (lock-in)
    - Fatigue damage
  - Integrity of subsea pipelines

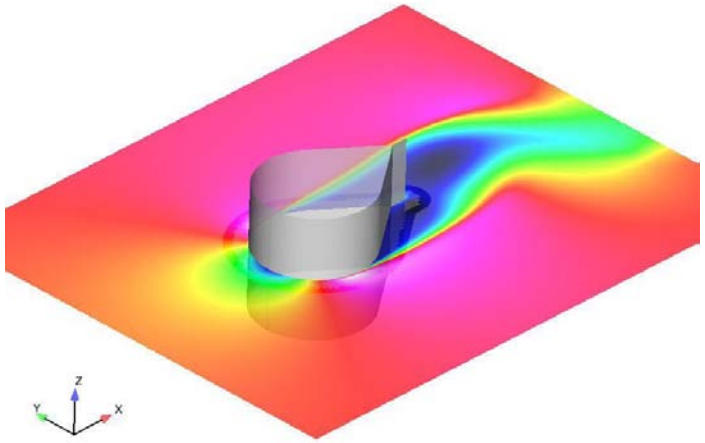


TLP image credit: atlantia.com

BACKGROUND: VIV of Pipeline Spans

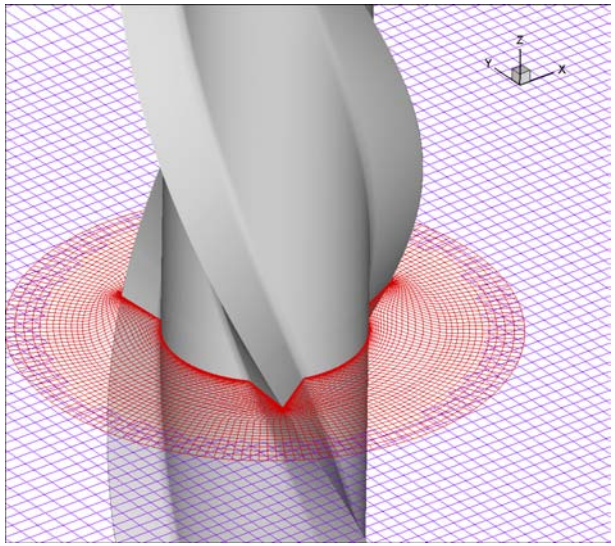
- Widespread solutions to suppress VIV
  - Helical strakes
    - Prevents near-wake interaction of shear-layers
    - Spanwise de-correlation of vortices
    - Some fixed separation points
    - Increased drag coefficient
  - Fairings
    - Flow streamlining
    - Free to weathervane
    - Low drag coefficient
    - Unstable for certain Chord/D





BACKGROUND

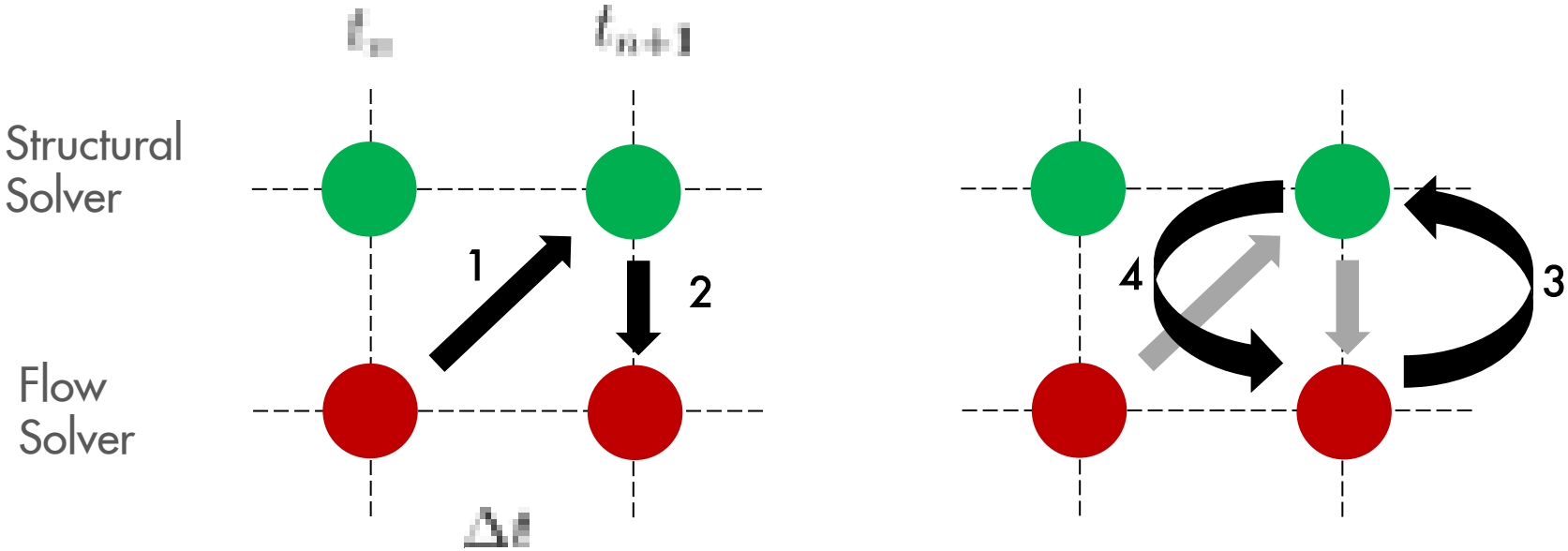
- Motivation
  - Numerical simulation → Prediction → Better assessment of risk
- Numerical methods
  - Block-structured grids / Overset grids
  - Incompressible flow
  - Finite difference / Finite volume hybrid scheme
  - Discretization in (ξ,η,ζ)
  - LES & URANS turbulence models
  - Level-set methods for two-phase flows



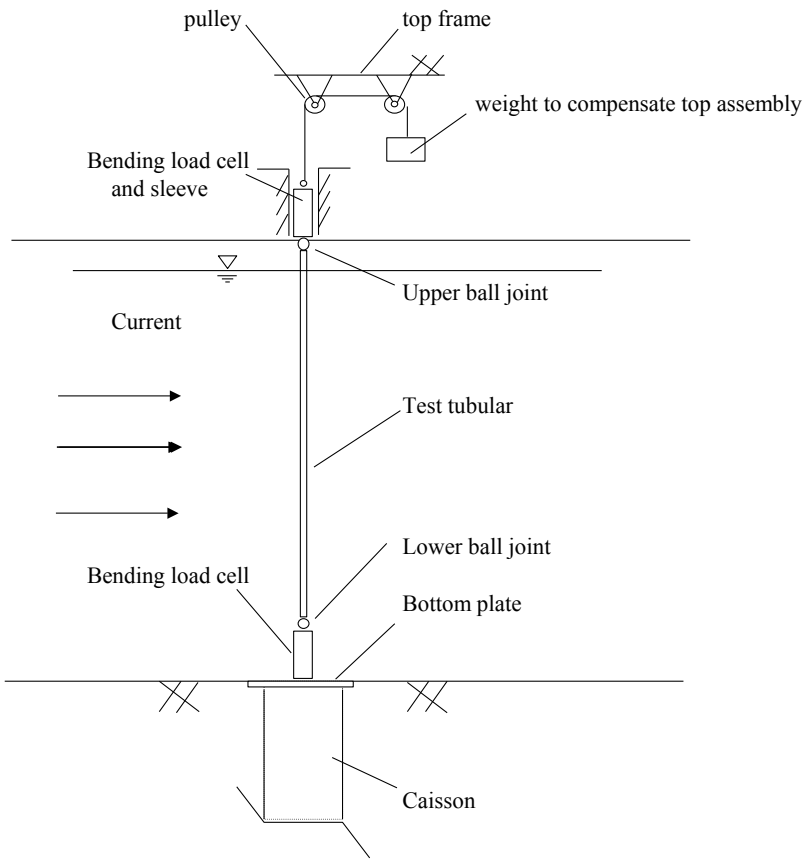
- Scope
  - Asset / Pipeline structural integrity in the presence of fluid flow

MODELLING FSI

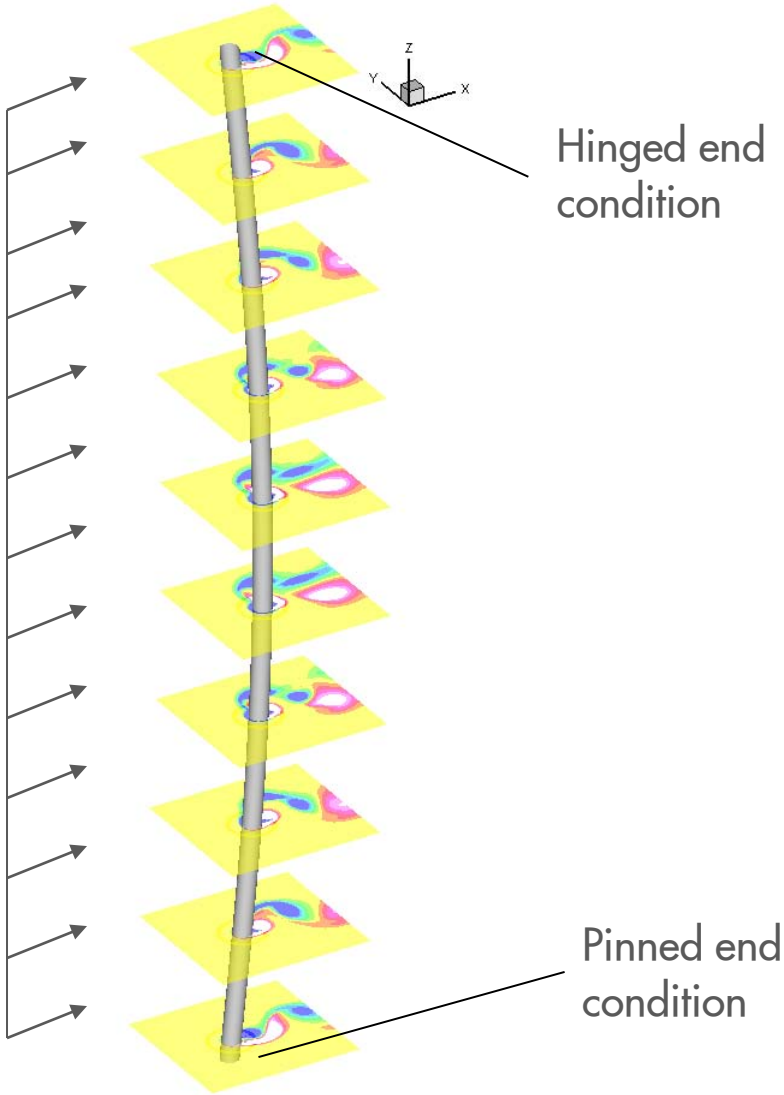
- Fluid & Structure coupling
  - Flow solver/Structural solver/Hole cutter
  - Structural solver receives instantaneous flow-induced loading
  - Flow solver receives instantaneous displacement
  - CSS vs. SLIK



MODELLING FSI: Validation (1/3)



Experimental setup



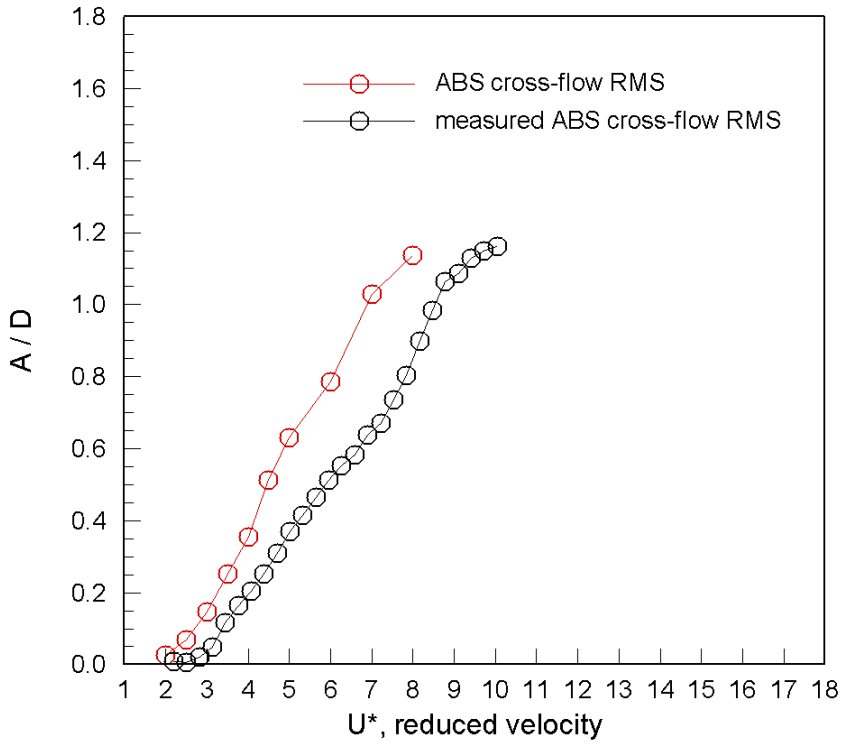
Numerical model

JP Pontaza, RG Menon. OMAE Conference Proceedings. OMAE2009-79150.

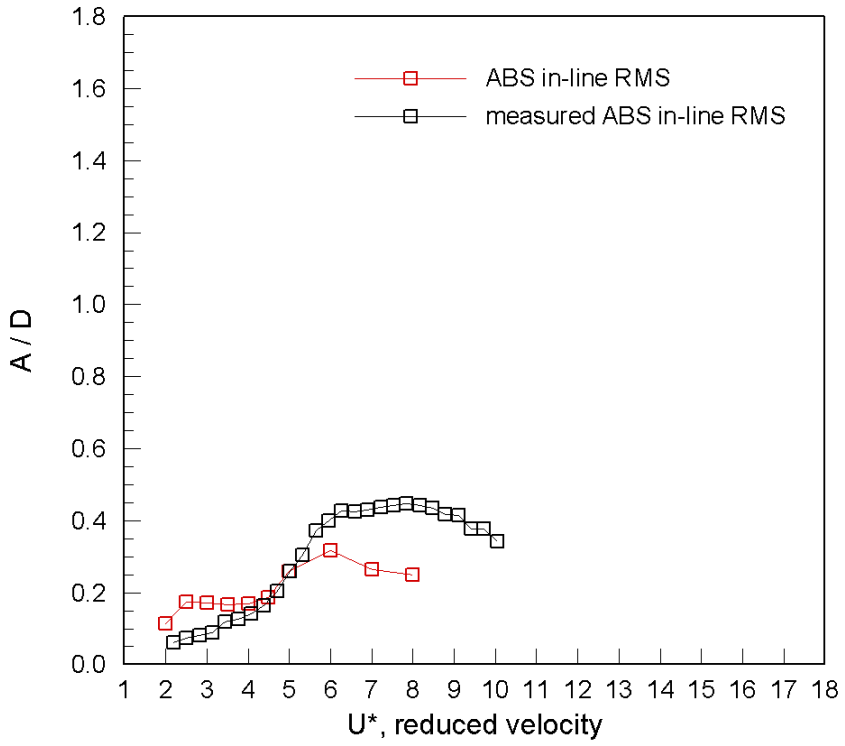
MODELLING FSI: Validation (2/3)

- Comparison with experimental measurements

RMS of cross-flow motion



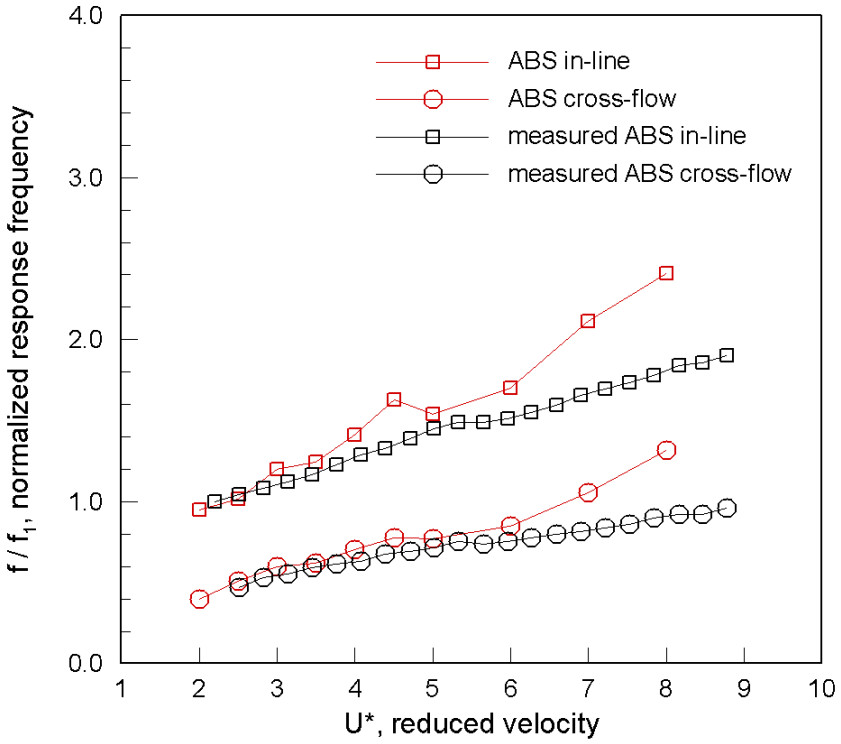
RMS of in-line motion

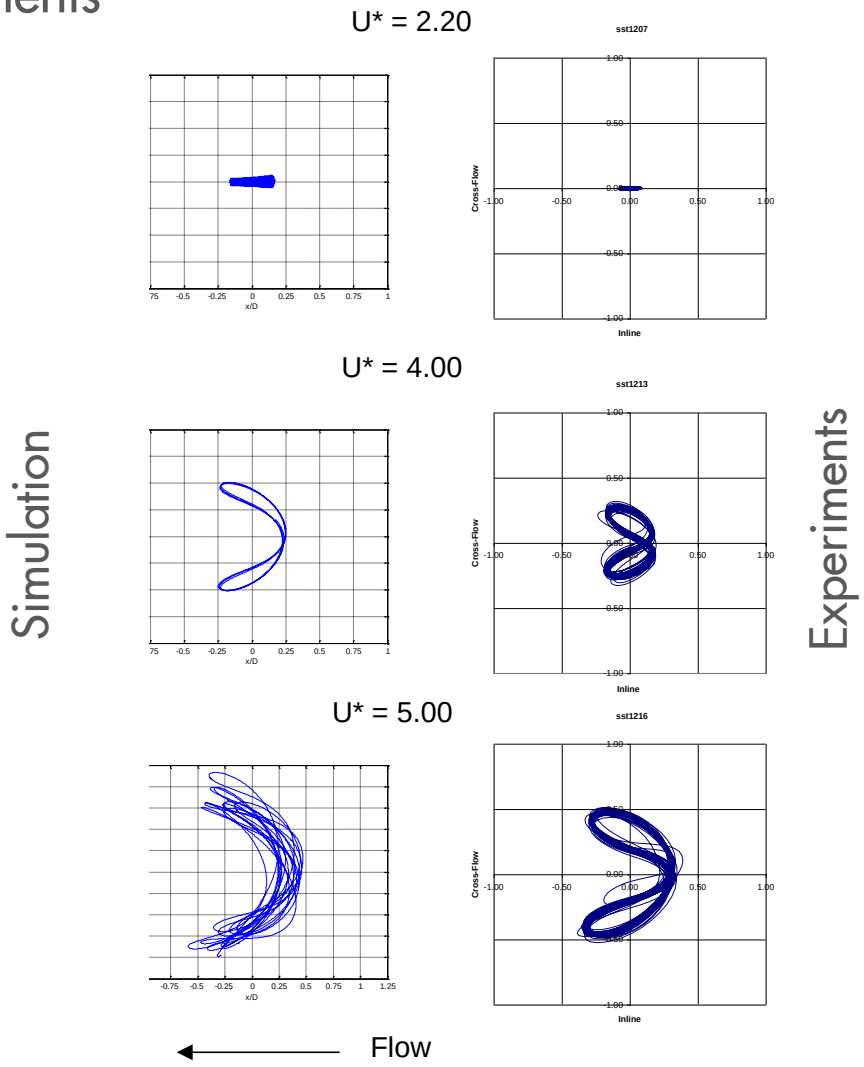


MODELLING FSI: Validation (3/3)

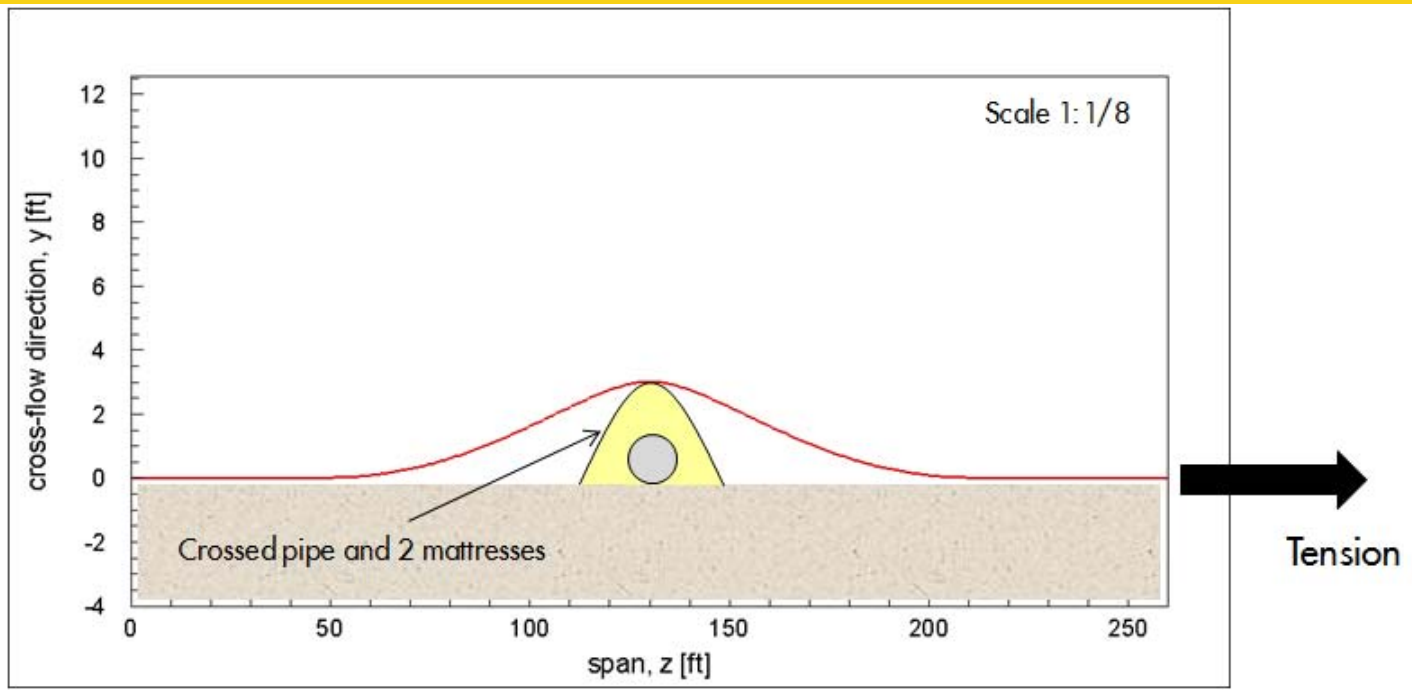
- Comparison with experimental measurements

Response frequency



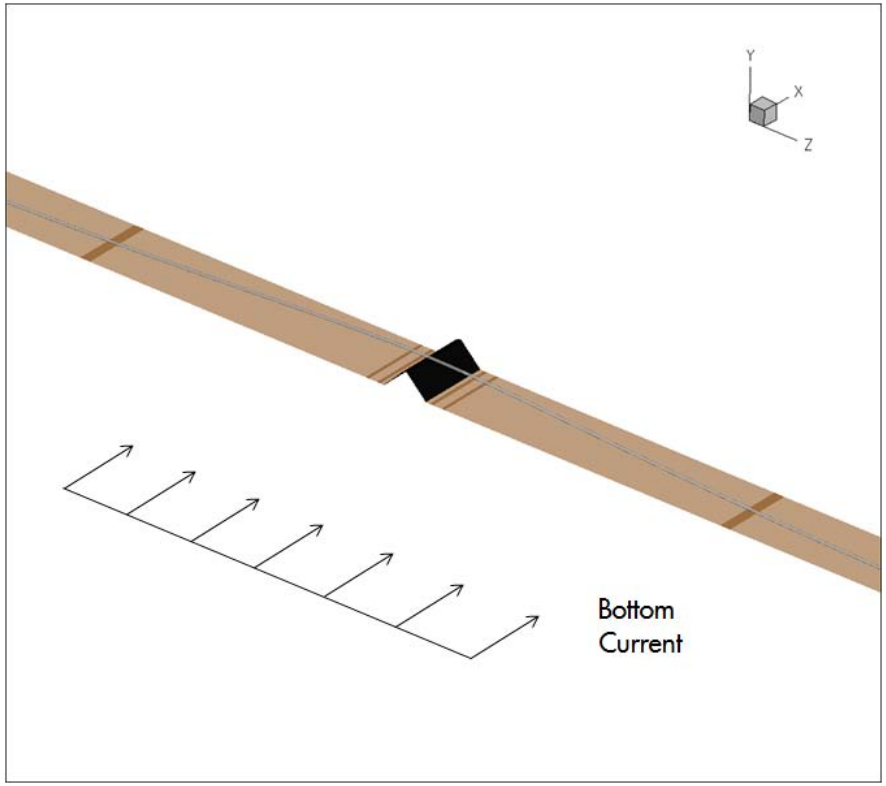


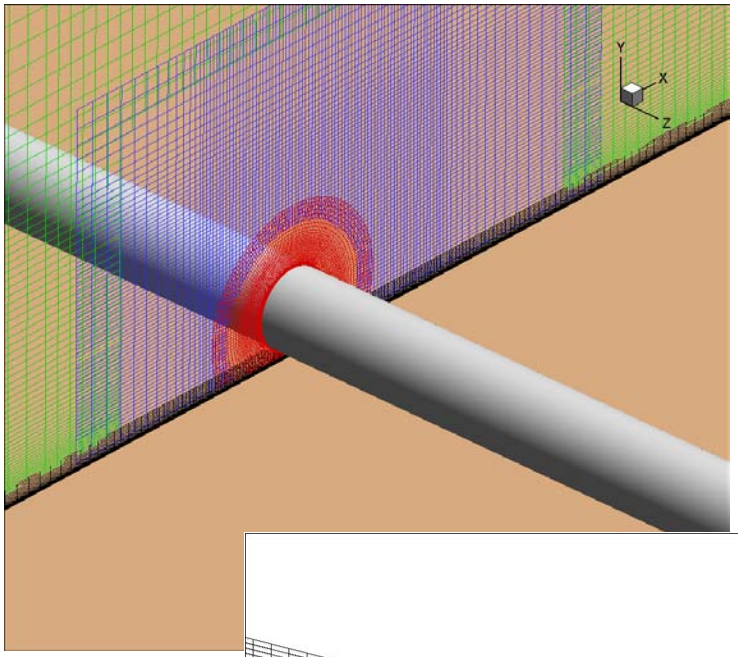
CROSSING SPAN: Structural Model

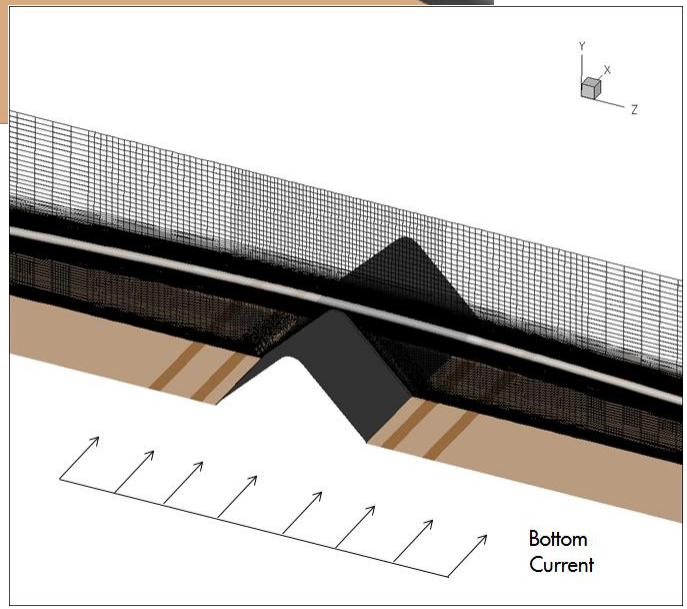


- Pipe is modeled as a beam subject to unsteady three-dimensional flow-induced loads
- Nonlinear strain measures: Coupling of in-line, cross-flow, and axial degrees-of-freedom
- Soil is modeled as an elastic foundation, with stiffness values from field measurements

CROSSING SPAN: Fluid Flow Model (1/2)



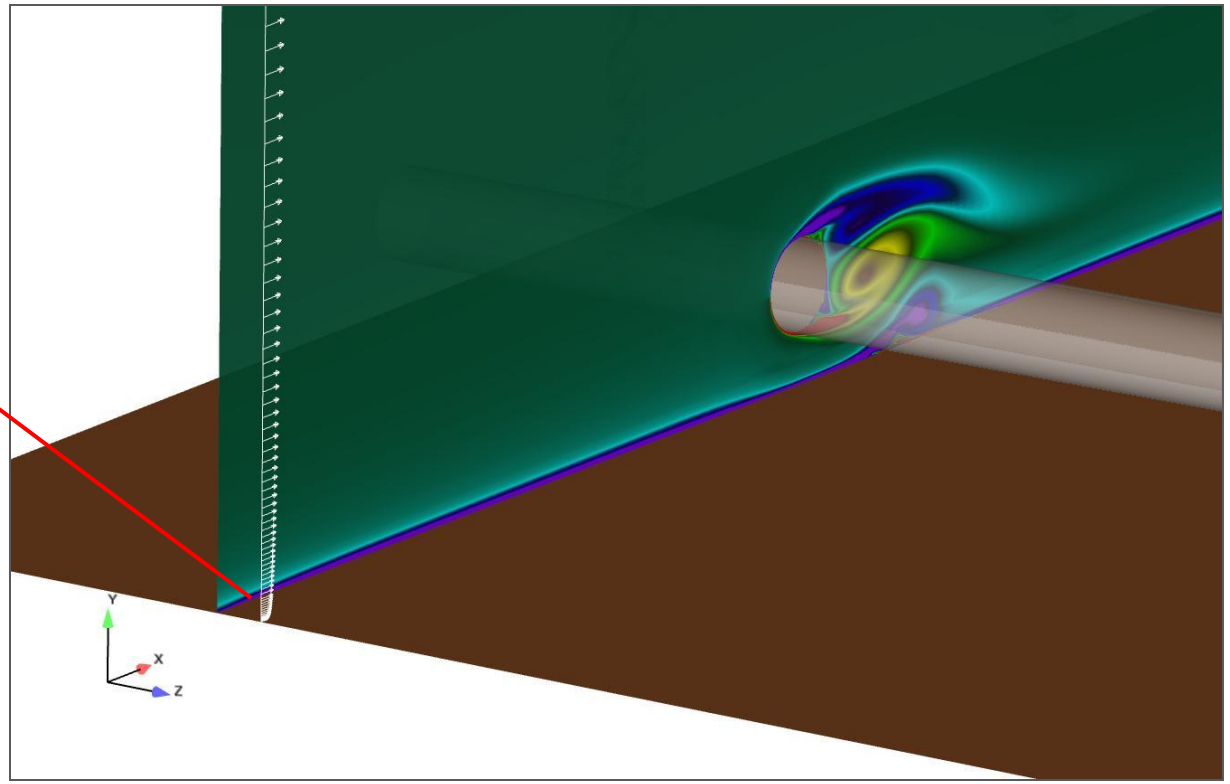




- Near-wall spacing of $\Delta s/D = 10^{-5}$ at all no slip surfaces (seabed & pipe)
- 180 cells around the circumference of the pipe
- Large Eddy Simulation (LES), 17 MM grid points

CROSSING SPAN: Fluid Flow Model (2/2)

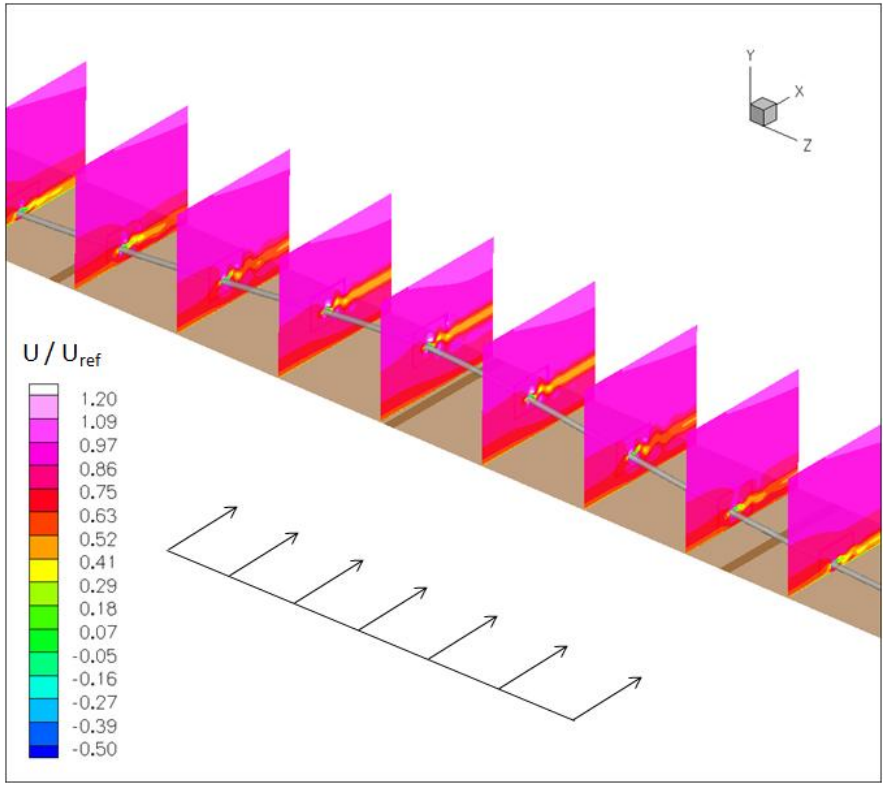
$$\frac{U(y)}{U_{\text{ref}}} = \left(\frac{y}{y_{\text{ref}}}\right)^{\frac{1}{7}}$$

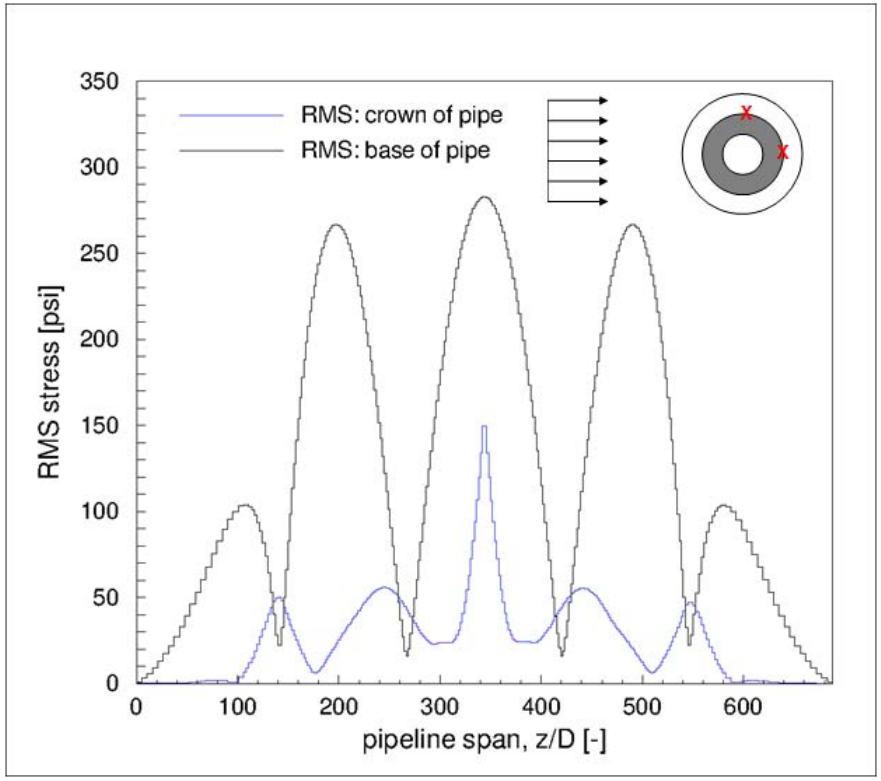


- U_{ref} based on metocean data for extreme sea bottom current event
- Reynolds number, $Re = 4.94 \times 10^4$
- Reduced velocity, $U^* = U_{ref}\, f/D = 3.1$

CROSSING SPAN: Ignoring flow blockage

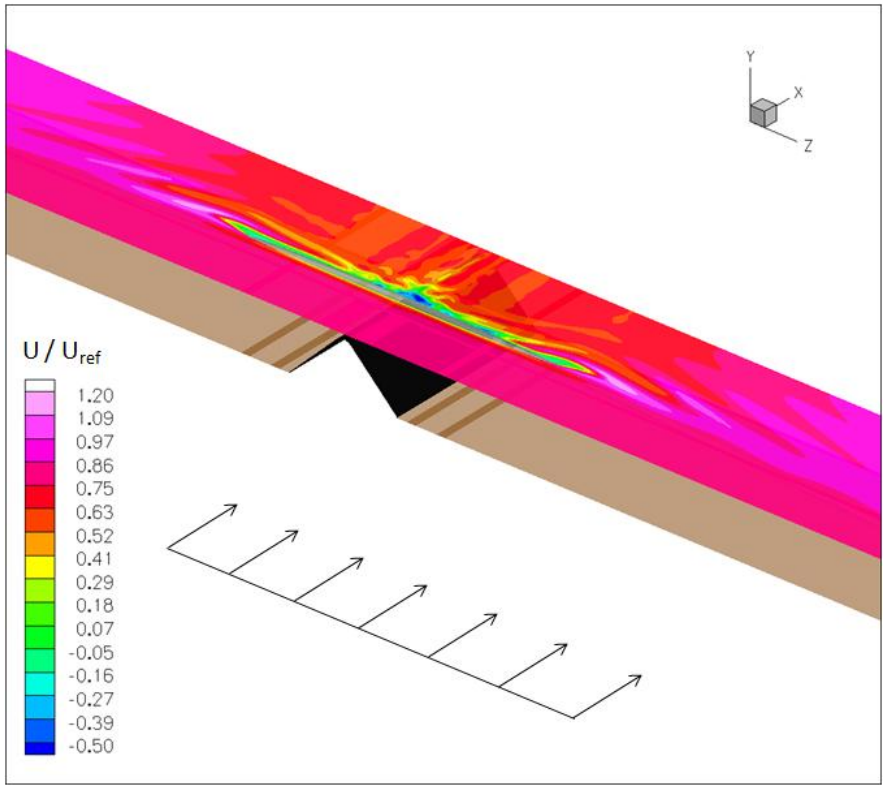
- Idealized scenario where flow blockage is ignored
  - As expected, in-line VIV is significant and dominates the fatigue life

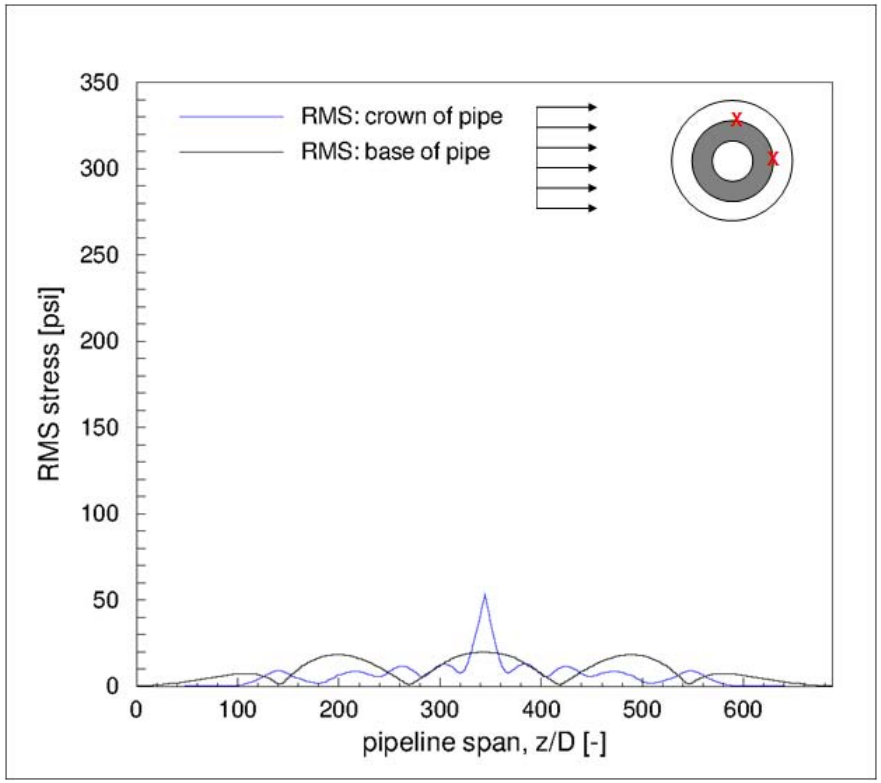




CROSSING SPAN

- Flow blockage effects
  - A localized gap effect at the crossing is present





CONCLUDING REMARKS