NON-LINEAR TIME DOMAIN ANALYSIS OF VORTEX INDUCED VIBRATIONS

Author: Jan Vidar Ulveseter

Supervisors: Carl Martin Larsen, Mats Jørgen Thorsen

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Department of Marine Technology - NTNU

Scope

In this study, effects of nonlinear soil contact for free spanning pipelines experiencing VIV, are to be investigated. The purpose of the present work is to combine Thorsen's hydrodynamic force model for prediction of VIV (Thorsen et al., 2014), with a nonlinear finite element model. The results obtained will be compared to results from other VIV prediction tools. The following objectives are to be fulfilled:

- Make a simple MATLAB code for analysis of a free spanning pipeline with non-linear springs and dampers at the shoulders
- Combine this model with Thorsen's time domain model for VIV
- Compare new method to traditional frequency domain models

Introduction

Pipelines are frequently used by the offshore industry for transportation of oil and gas to land terminals (Larsen et al., 2004). When laid on an uneven seabed, these pipelines will have several free spans, as is the case for the Ormen Lange field in the North Sea. When facing a current, the free spans will be subjected to an oscillating excitation force, due to the vortex shedding process (see Figure 1). If the structural characteristics of the free spanning pipe, the seabed profile and the current condition is such that the frequency of the excitation force is close to an eigenfrequency of free spanning pipe, we get VIV. The resulting stresses can cause fatigue damage. It is thus important to be able to make fairly accurate predictions of VIV, to make sure the estimated lifetime of the pipeline is acceptable.

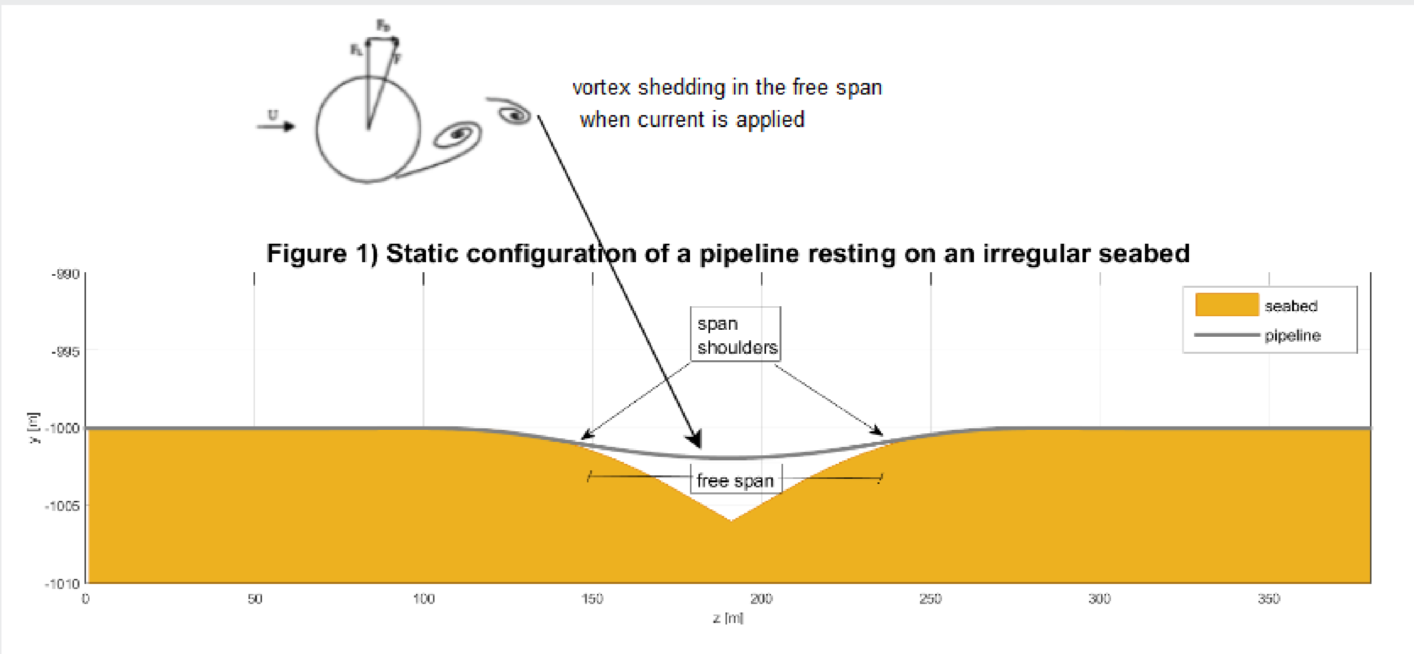


Figure 1) Static configuration of a pipeline resting on an irregular seabed

Results

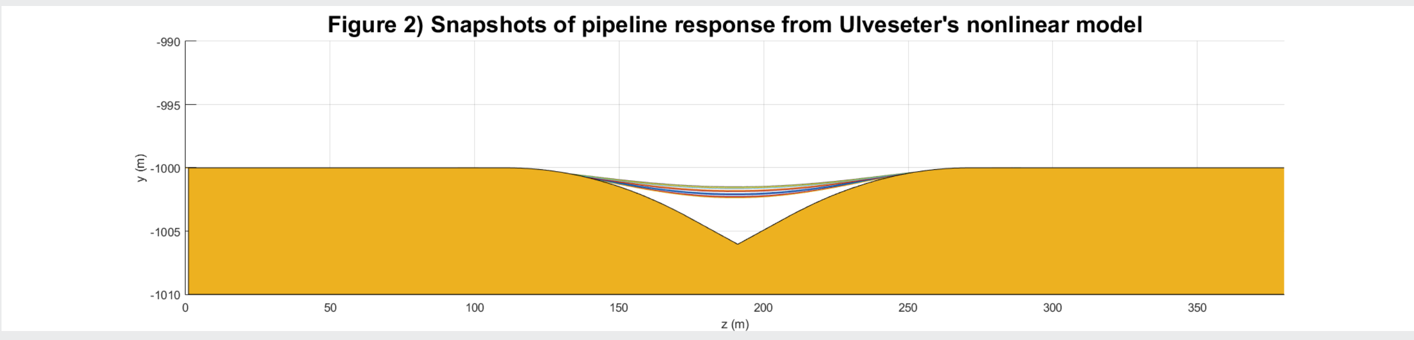


Figure 2) Snapshots of pipeline response from Ulveseter's nonlinear model

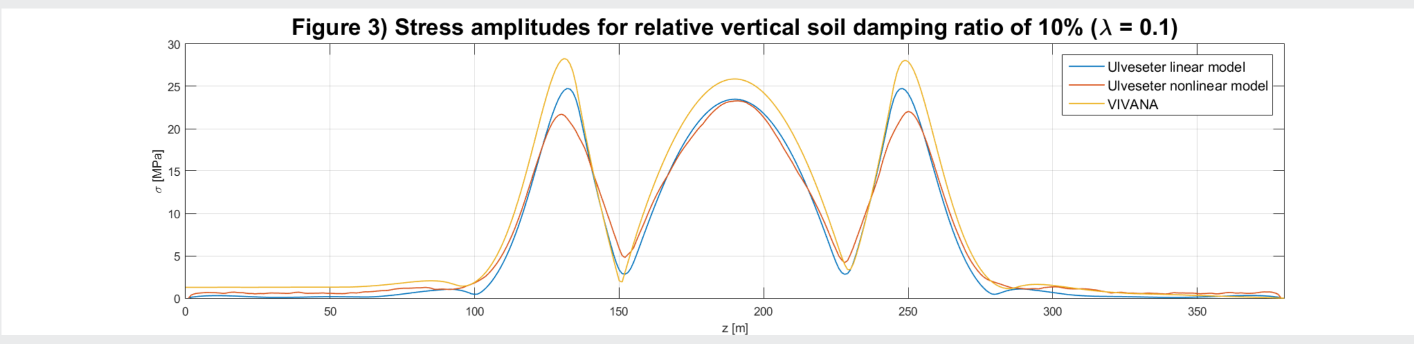


Figure 3) Stress amplitudes for relative vertical soil damping ratio of 10% (λ = 0.1)

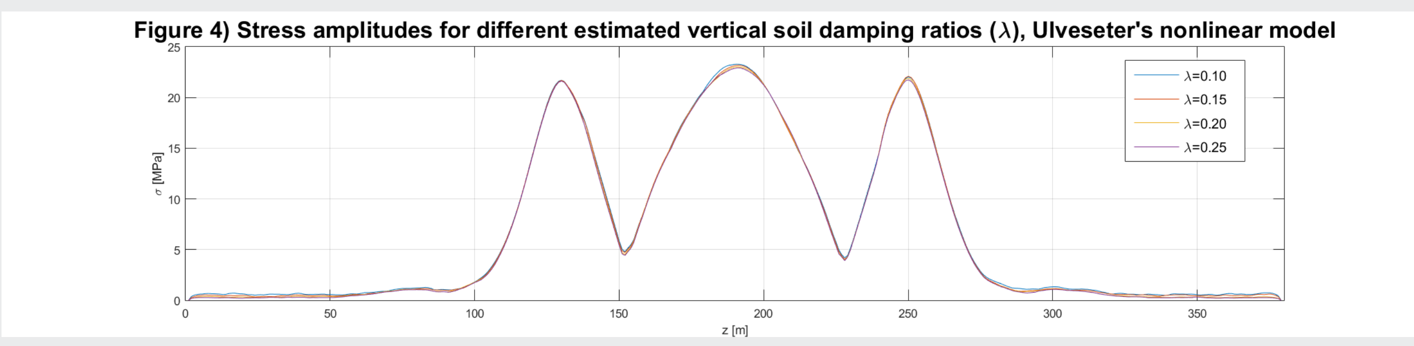


Figure 4) Stress amplitudes for different estimated vertical soil damping ratios (λ), Ulveseter's nonlinear model

Conclusion

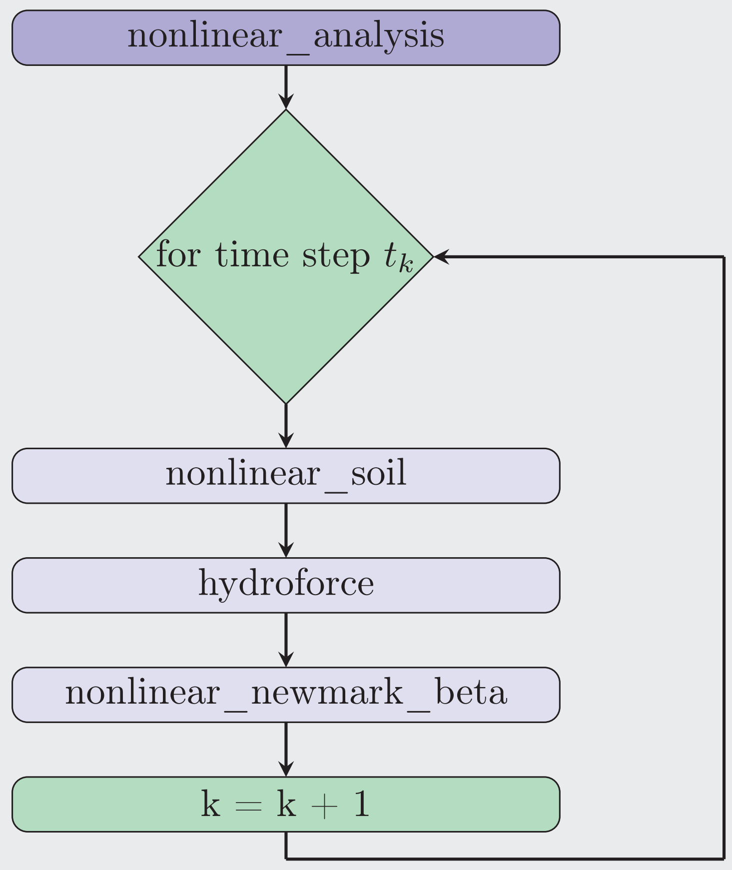
- From Figure 3, the developed MATLAB program, referred to as Ulveseter's model, predicts stress amplitudes somehow smaller than VIVANA. This can be a result of the different solution methods (frequency domain and time domain), and that the theoretical basis is not the same for the two programs. However, the difference between the two prediction models is not significant, indicating that Ulveseter's model gives realistic results.
- The nonlinear soil contact reduces the stress amplitude at the pipe shoulders. This is as physically expected because the nonlinear springs allow the pipeline to lift off from the seabed, so that the curvature at the shoulders is reduced.
- In Figure 4, the soil damping plays a small role for the pipeline response. The soil damping influence will be a function of pipeline data, the seabed profile, and the ocean current as discussed in my Master Thesis. Even though this case study indicates that soil damping can be neglected, other cases may provide different results.

Modelling

The challenge is how to solve the dynamic equilibrium equation (1), and how to include the nonlinear soil contact in the stiffness matrix **K**, and damping matrix **C**.

$$\mathbf{M}\ddot{\mathbf{r}}(t) + \mathbf{C}\dot{\mathbf{r}}(t) + \mathbf{K}\mathbf{r}(t) = \mathbf{F}(t) \tag{1}$$

M is the consistent mass matrix, including added mass, $\mathbf{r}(t)$ is the response amplitude vector and $\mathbf{F}(t)$ is the VIV force vector from Thorsen's work.



The nonlinear analysis requires that the stiffness matrix and damping matrix are calculated for every time step of the time integration. This is done in the function nonlinear_soil.m. At every time step this function uses the information about the seabed position and the response of the pipe to check if the pipe is in contact with the soil. If there is contact, the input value of the soil stiffness and soil damping are added to the vertical translation dofs where we have pipe-soil contact. If there is no contact, nonlinear_soil.m will check the next node along the pipeline without adding a stiffness and damping term.

The hydrodynamic force is calculated in hydroforce.m for time step t_{k+1}. The algorithm for nonlinear Newmark-β time integration, as outlined in (Langen and Sigbjörnsson, 1979), solves the dynamic equilibrium equation (1) incrementally. The output is response, velocity and acceleration for time step t_{k+1}. We then look at the next time step and apply the same procedure over and over again until the simulation time is reached.

For comparison, a MATLAB code for linear time domain analysis is also created, based on Thorsen's hydrodynamic force model. It is based on the same solution method as the nonlinear solution, but the stiffness and damping matrices are constant, in agreement with linear theory. The stiffness and damping matrices are established for the static configuration.

Simulation

The developed MATLAB code is compared to results from VIVANA, which is a MARINTEK program calculating VIV in frequency domain. The VIV analysis is a cross-flow analysis only, and the pipeline is facing a constant current. The case data is given in the table below.

Name	Symbol	Size	Dimension
Length	L	380	m
Diameter	D	0.55	m
Bending stiffness	EI	$2.9 * 10^8$	Nm^2
Mass per unit length (air)	m	315	kg/m
End tension	T	$450 * 10^3$	N
Current velocity	U	0.7	m/s
Soil stiffness	k_s	$40 * 10^3$	N/m^2

References

Langen, I. and Sigbjörnsson, R. (1979) *Dynamisk Analyse av Konstruksjoner*, Tapir

Larsen, C. M., Baarholm, G. S., Passano, E., and Koushan, K. (2004). Non-linear time domain analysis vortex induced vibrations for free spanning pipelines. In *Proceedings of OMAE04: 23rd International Conference on Offshore Mechanics and Arctic Engineering.*

Thorsen M., Sævik, S., and Larsen, C. (2014). A simplified method for time domain simulation of cross-flow vortex-induced vibrations. *Journal of Fluids and Structures*

NTNU – Trondheim

Norwegian University of Science and Technology