Global buckling analysis of subsea pipelines A study on different soil models

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Introduction

Pipeline is devised to carry a fluid from one to another point. As a transportation method, underwater pipelines are widely used in oil and gas industry nowadays. An issue is that vulnerable hydrocarbon is exposed to high temperature and pressure under the deep sea.[1] In order to operate the oil and gas transportation safely, therefore, pipelines eventually face challenges. Many researchers have previously discussed about pipe-soil interaction, and proposed soil force-displacement models such as Mohr-Coulomb model, DNV model, PONDUS model, and SAFEBUCK model. The scope of this paper is to analyse the global buckling response from different interaction models along with parametric studies.

Materials and Methods

In order to simulate realistic seabed environments a rough seabed profile from one of major oil fields in Norway called Ormen Lange is employed. This uneven seabed geological area includes numerous shallow and deep free spans. 5km long pipeline is laid on the irregular sea floor.

The model is analysed by the finite element method program SIMLA which is a specialized program for underwater pipelines and risers. The theories behind the program are based on virtual work weak form equations for each elements. With virtual displacements reaction forces are balanced in the total equilibrium equation in a local element level. Then local element stiffness can be found.

$$\int_V (\rho\ddot{u} - f)\delta u dV + \int_V \sigma : \delta\epsilon dV - \int_S t\delta u dS = 0$$

By adapting transformation matrix, global stiffness matrices in element level can be found from the local element stiffness matrices. Then all global stiffness matrices in a element level is assembled to find a global stiffness for the entire structure, K_T. Here, non-linearity takes into account on the total global stiffness matrix term. The total matrix includes material and geometric non-linearity

With the total global stiffness matrix , expected displacement Δr from force-displacement equilibrium equation $\Delta R = K_T \Delta r$ is found. To satisfy the equilibrium equation $\Delta R = R_{ext} - R_{int} \approx 0$, implicit time integration with Newton-Raphson iteration at each load steps are solved. Here, external force, R_{ext}, is temperature and pressure loads, and internal force,R_{int},is obtained from resultants of entire structure's reactions.

References

[1] Roger A. King Andrew C. Palmer. *Subsea Pepieline Engineering*. PennWell, 2007.

[2] Y. Tian D.J. White, Z. J. Westgate. Pipeline lateral buckling: Realistic modelling of geotechnical variability and uncertainty. *Offshore Technology Conference*, 2014.

Modeling

• **Rock berms** It is assumed that the pipelines are laying on the irregular sea floor with several rock berms. As a practical view of projects building rock berms is a necessary process to prevent serious fatigue issue and to have cost effectiveness. In this thesis, rock berms are idealized containing great resistance. This assumption neglects interactions between rock berms and pipelines.

• **Contact element** In the finite element program, pipeline element is defined as PIPE33 which describes 3D beam constant axial strain and torsion. This 3D 2-noded beam element consists of thin walled tubular cross-sections with constant radius and thickness along each element. Seabed and rock berms elements employ 1-noded element. For sea floor elements, material curves in the x, y and z directions are introduced with torsion while rock berms allows the user to specify linear springs properties.

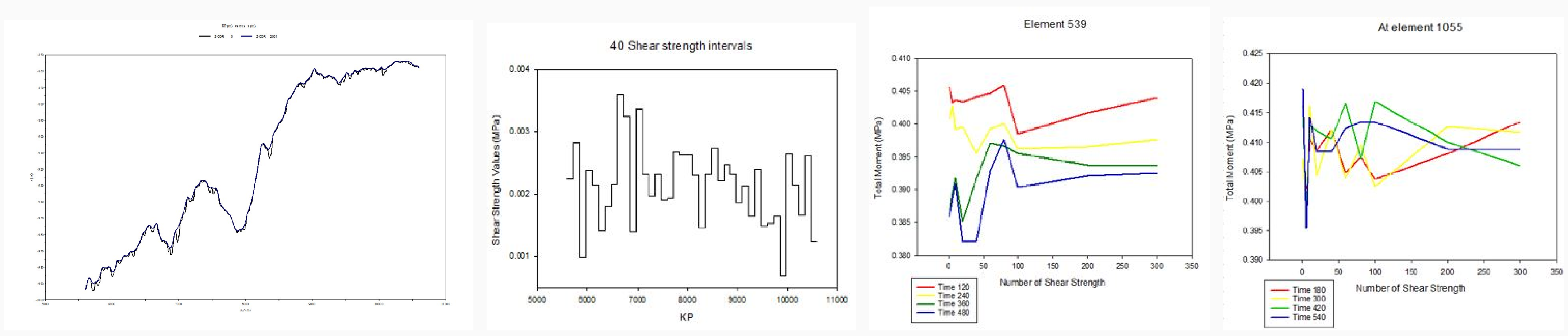
• **Uncertainty of soil properties** Underwater soft soil characteristics such as shear strength are major sources of uncertainty in a design, and the geotechnical inputs influence on response of pipelines[2]. Data in North Sea obtained from MARINTEK shows that shear strength follows normal distribution with average shear strength 2KPa and standard deviation 0.2. Thus, shear strength can be generated by Monte-Carlo method based on the normal distribution.

• **Soil response model** Typical soil response models are Mohr-Coulomb, PONDUS, DNV, SAFEBUCK models. Among those Mohr-Coulomb model is widely used as a industry standard due to its simplicity. DNV model and PONDUS model are adopted for hydrostatic tests. In this report, global buckling responses of Coulomb model and DNV model combined with soil berm formation from SAFEBUCK are compared.

• **Load history** The load model includes a hydro-pressure test after laying the pipelines. During cyclic loads, pressure loads decrease and increase faster than temperature because of a character that thermal conduction works slowly.

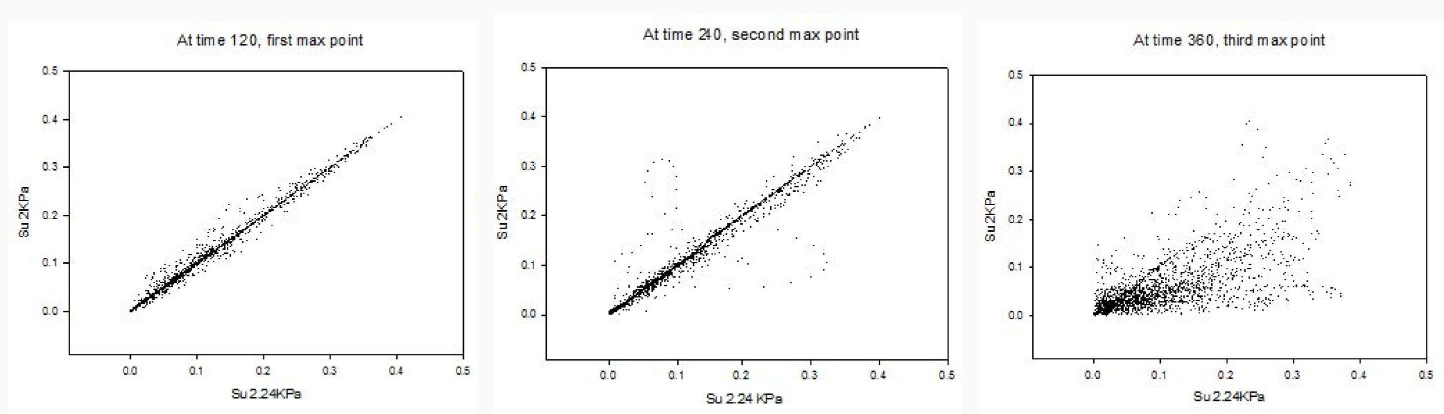
Case Study

• **Impact of shear strength distribution** Parametric study of shear strength 'Su' has conducted. In order to find influence of shear strength on global buckling the route is subdivided into different numbers from one to 300.



Where total global moment is square root of z moment and y moment. Element 539 is a element point where maximum total moment appears while Element 1055 is a point where minimum total moment occurs regardless of number of intervals and cycles. Total moment converges at high cycles by number of shear strength intervals. It is also shown that locations where maximum and minimum moment occurs are influenced by geographic parameters such as depth of free spans and slope of seabed than shear strength distribution. Distribution of shear strength is not strongly connected with total moment distribution. However, it is found that higher Su with big shear strength intervals than average contributes to develop extra moment maximum point. It proves that in reality pipelines do not have extra maximum points by shear strength because Su interval in pipelines is small.

• **Uncertainty sensibility test** In this case study to find sensitiveness of magnitude of shear strength, newly generated Monte-Carlo data has applied on the same number of shear strength intervals.



Total moment distributions (MPa) with shear strength 2KPa and 2.24KPa for the entire pipeline on the same seabed profile have compared. After berm formation(cycle 3) significant difference in moment distributions is observed.

Conclusion

In this work, soil-pipe interactions of submarine pipelines on the uneven seabed profile have investigated using 3D finite element method program SIMLA.
First, in order to discover impact of shear strength distribution, various analytical buckling models with different distributions and FEMs results are compared. Then, it is found that maximum global buckling moment of a pipeline under high pressure and temperature load on the uneven soil profile depends mainly on geographic parameters. Then the result from uncertainty sensibility test exhibits that maximum moment is also affected by value of shear strength in a certain degree.