Dynamic analysis of a subsea pipeline installation on seabed

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Nowadays a subsea pipeline technology is successfully applied in the offshore engineering activities. Computational models and analysis methods for analysis are reflected by the standards published by classification societies (API, DNV, etc.). Most popular computational models are based on FE (finite element) formulations, addressing different phases of the project [1]. Pipeline installation often takes place at rough seas, where dynamic environmental conditions (such as wind, waves, current) impose additional loads to the system. The deployment vessel undergoes wave-generated motions and the pipe is additionally loaded, which could cause damage. Quite a few various aspects in the numerical model have to be taken into consideration, such as large deflections with potentially plastic deformations (non-linear materials), contact, fluid-structure interaction, pipe-soil interaction, coupled vibrations of the pipe with laying equipment, stability, high excessive dynamic forces and other. In the current work, the rigid finite element method (RFEM) [2] is adopted in order to include the above phenomena. It allows the flexibility of the pipeline to be taken into account.

![Figure 1: Offshore (reeled) pipe laying using the J-loop method](image)

The vessel motion on the sea waves is simulated according to the following function:

\[
q(V) = f(t, H, T_z, S(\omega), RAO(\omega))
\]

where \( q(V) = [x(V) y(V) \psi(V)]^T \), \( x(V) \) is the surge, \( y(V) \) is the heave and \( \psi(V) \) is the vessel pitch angle, \( S(\omega) \)
is the assumed wave spectrum (Pierson-Moskowitz, JONSWAP, etc.), $H$ is the significant wave height, $T_z$ is the wave period, $\text{RAO}(\omega)$ is the Response Amplitude Operator vector of the vessel used.

![Figure 2: Generalised coordinates of the $RFE_i$]

Rigid finite element method is used in order to discretize the pipeline. Each pipe finite element has three degrees of freedom, in the motion with respect to the base element (the vessel), Figure 2. The element $RFE_0$ is coupled with the lay ramp by constraints reactions, while the last element $RFE_n$ can have flexible or rigid connection to the seabed. The equations of motion of the pipe with constraints can be presented in the form:

$$
\begin{align*}
A\ddot{q} - DR &= F \\
-D^T\dot{q} &= W
\end{align*}
$$

where $A = \text{diag}\{A_1, \ldots, A_n\}$, $A_i = \text{diag}\{m_i, I_i\}$, $m_i, I_i$ are mass and mass moment of inertia of the $i$th $RFE$. $q = \begin{bmatrix} q_{(0)}^T, \ldots, q_{(n)}^T \end{bmatrix}^T$, $\dot{q}_{(i)} = \begin{bmatrix} x_{(i)}^{(V)}, y_{(i)}^{(V)}, \psi_{(i)}^{(V)} \end{bmatrix}$, $x_{(i)}^{(V)}$, $y_{(i)}^{(V)}$ and $\psi_{(i)}^{(V)}$ are the generalised coordinates of the $RFE_i$ (Figure 2). $R = \begin{bmatrix} R_x^{(0)}, R_y^{(0)}, M^{(0)} \end{bmatrix}^T$, $R_x^{(0)}$, $R_y^{(0)}$, and $M^{(0)}$ are unknown reaction forces and moment acting on $RFE_0$, $R_x^{(n)}$, $R_y^{(n)}$ are reaction forces in constrained point on the seabed, $D$, $W$ are matrices with constraint coefficients, $n$ is the number of elements in the system and $F = F(t, q, \dot{q}, \ddot{q}, q^{(V)})$ is the vector of generalised forces and moments arising from external loads, fluid and soil interaction with pipe elements, gyroscopic and Coriolis forces.

Before any dynamic problem can be analysed, a static solution has to be determined. A set of non-linear equations is solved by the Newton method. Initial pipe configuration is a large deformed structure (with respect to an unstressed shape), defining the J-loop or S-loop. Wave build-up process follows next, and at fully developed waves the system simulates pipe stresses, deformations, forces acting on the vessel structure.

The mathematical model of a pipeline installation will be presented at the Conference, as well as the simulation results obtained from the computer programme worked out.

References