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Design check against the construction code (DNV 2012) of an offshore pipeline using numerical methods

L C Stan , I Călimănescu and D D Velcea
Constanta Maritime University, Department of Engineering Sciences in the Mechanical Field and Environment, 104 Mircea cel Batran Street, 900663, Constanta, Romania

E-mail: liviustan14@yahoo.com

Abstract. The production of oil and gas from offshore oil fields is, nowadays, more and more important. As a result of the increasing demand of oil, and being the shallow water reserves not enough, the industry is pushed forward to develop and exploit more difficult fields in deeper waters. In this paper, there will be deployed the new design code DNV 2012 in terms of checking an offshore pipeline as compliance with the requests of this new construction code, using the Bentley Autopipe V8i. The August 2012 revision of DNV offshore standard, DNV-OS-F101, Submarine Pipeline Systems is supported by AutoPIPE version 9.6. This paper provides a quick walk through for entering input data, analyzing and generating code compliance reports for a model with piping code selected as DNV Offshore 2012. As seen in the present paper, the simulations comprise geometrically complex pipeline subjected to various and variable loading conditions. At the end of the designing process the Engineer has to answer to a simple question: is that pipeline safe or not? The pipeline set as an example, has some sections that are not complying in terms of size and strength with the code DNV 2012 offshore pipelines. Obviously those sections have to be redesigned in a manner to meet those conditions.

1. Introduction

The production of oil and gas from offshore oil fields is, nowadays, more and more important. As a result of the increasing demand of oil, and being the shallow water reserves not enough, the industry is pushed forward to develop and exploit more difficult fields in deeper waters [1].

Deepwater pipelines are used to carry oil and gas from wellheads and manifolds to platforms or to shore. Figure 1 shows a simple representation of a deep-water installation, with the flow lines on the seabed and the risers, a section of pipeline from the seabed to platforms or ships.

As a consequence of the extremely severe work conditions, the constructors of deep-water pipelines need tubular products with enhanced resistance to withstand all the loads that will be applied to the pipeline, both during its construction and in operation; among them: internal and external pressure, bending, fatigue, tension, compression, concentrated loads, impact and thermal loads, impact and thermal load.

If a pipeline is not stable then it will move under the actions of waves and currents. This is a problem since the movement will cause bending stresses in the pipeline, which may then cause the pipe to fatigue and fail. Alternatively, it may cause damage to pipeline coatings, such as cracking of concrete [2].

Submarine pipeline stability is governed by the fundamental balance of forces between loads and resistances.

This approach to stability design of pipelines was incorporated into DNV's Rules for Submarine Pipeline Systems issued in 1976 and was the basis of design for many pipelines around the world [3].

It was known from experimental research that the hydrodynamic loads on a pipeline could be very much higher than in the DNV '76 model. In 1981, DNV's revised rules incorporated a much more realistic hydrodynamic model.

This created an anomaly - the new approach suggested many of the existing pipelines designed to DNV '76 were unstable. However, annual surveys showed no evidence of a wide-spread problem. The explanation lay in the lateral resistance of a pipeline to movement also being very much higher than predicted by the simple model. It was shown experimentally that during a storm a pipeline undergoes small displacements under the action of wave forces, gradually digging itself into the seabed. The pipeline therefore had small soil berms either side, providing increased resistance to movement and greater hydrodynamic shielding. The results of this research were incorporated into AGA's suite of stability design software, providing a state of the art approach. The first pass approach to pipeline stability is a simple force balance model in 2 dimensions. It is the basis of the design methodology used in:

- DNV '76 + '81
- AGA Level 1 stability software

In this paper, we will deploy the new design code DNV 2012 in terms of checking an offshore pipeline as compliance with the requests of this new construction code, using the Bentley Autopipe V8i. The August 2012 revision of DNV offshore standard, DNV-OS-F101, Submarine Pipeline Systems is supported by AutoPIPE version 9.6. This paper provides a quick walk through for entering input data, analyzing and generating code compliance reports for a model with piping code selected as DNV Offshore 2012.

2. Materials and methods

2.1. Structure geometry selection

In order to input the geometry of the offshore pipeline, the Bentley Autopipe V8i software will be used. Structure geometry shall be selected based on various requirements such as routing, sizing of the pipeline considering various process parameter, thermal design etc. The pipeline is part of an offshore field development, as seen in the figure 1 below [4]:

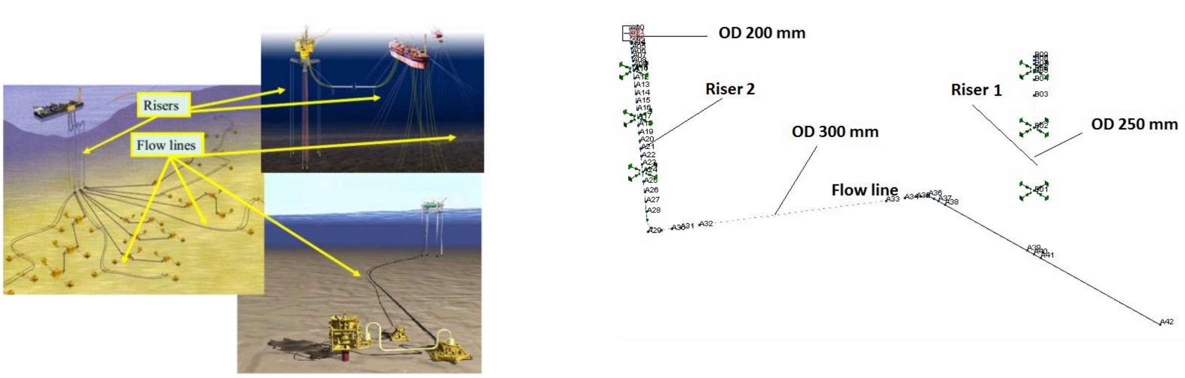


Figure 1. The offshore pipeline field development.

The model contains a pipeline with two vertical legs and a buried horizontal pipe representing pipeline resting on sea bed.

The pipe has three segments, one of the end of the second Riser2 (Nominal Diameter 200 mm), second is the Raiser 2 and the rest of the flow line with the ND=300 mm. The Raiser 1 pipe has the ND=250 mm. The material of the pipes is CMN-415 steel (as per DNV 2012).

The load cases are as per the construction code as follows:

- Operating Pressure and Temperature data for 3 'T' cases
- Earthquake loading cases: E1 and E2
- Wind loading cases: W1 and W2
- Wave loading cases: Wave2 and Wave 3 (One case for accidental)
- User loads: U1 and U2 (Interference loads, may be from trawling)
- Soil Properties: SND11A

2.2. Pressures and temperatures

The depth of the water is taken as 70 m and the external pressure exerted upon the pipe calculated as a consequence. The fluid circulating inside the pipe will follow three distinct cases:

Case 1-Pressure 0 MPa (r) and temperature 200C corresponding to the pipeline at rest with no fluid circulating inside.

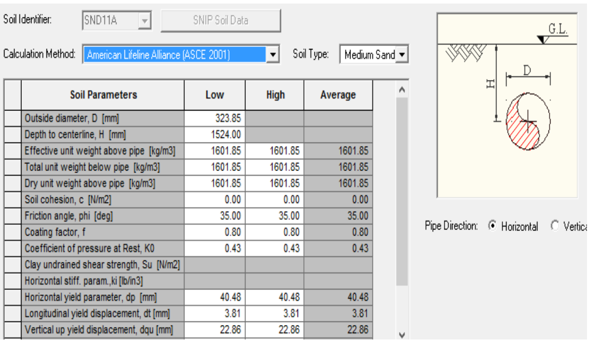
Case 2-Pressure 1.379 MPa (r) and temperature 600C corresponding to the normal operation of the pipeline.

Case 3-Pressure 2.7579 MPa (r) and temperature 900C corresponding to the upset operation condition of the pipeline.

2.3. Soil properties

The model of soil is the SND11A which is a sandy type of soil (figure 2). The process of defining a buried piping system is a combination of user defined piping points, and internally generated (by AutoPIPE) soil points. The user only needs to define piping points for identifying the following critical parts of a buried piping system:

- As required by changes in the system geometry.
- For specification of piping components (e.g. valves, reducers, flanges, anchors, etc.).
- Where soil properties change.
- Where the maximum spacing (between the internally generated soil points) defined for the current soil identifier is to be changed.
-



Soil Parameters	Low	High	Average
Outside diameter, D [mm]	323.85		
Depth to centerline, H [mm]	1524.00		
Effective unit weight above pipe [kg/m3]	1601.85	1601.85	1601.85
Total unit weight below pipe [kg/m3]	1601.85	1601.85	1601.85
Dry unit weight above pipe [kg/m3]	1601.85	1601.85	1601.85
Soil cohesion, c [N/m2]	0.00	0.00	0.00
Friction angle, phi [deg]	35.00	35.00	35.00
Coating factor, f	0.80	0.80	0.80
Coefficient of pressure at Rest, K0	0.43	0.43	0.43
Clay undrained shear strength, Su [N/m2]			
Horizontal stiff. param.,ki [lb/in3]			
Horizontal yield parameter, dp [mm]	40.48	40.48	40.48
Longitudinal yield displacement, dt [mm]	3.81	3.81	3.81
Vertical up yield displacement, dqu [mm]	22.86	22.86	22.86

Figure 2. Soil properties.

2.4. Earthquake load cases

AutoPIPE can define a series of forces action on a structure to represent the effect of earthquake ground motion. This method assumes that the structure responds in its fundamental mode. For this to be true, the structure must be low-rise and must not twist significantly when the ground moves. The acceleration is typically calculated from the natural period of the structure, and applied to the mass of structure to obtain a force.

Static seismic loads are given in factors of gravity, g. As an example, if a static seismic acceleration of 0.5 g's is applied on the x-axis, a force equal to half the systems weight is turned into a uniform load in the x-direction.

AutoPIPE supports the custom creation of these accelerations in the X-, Y- and Z-axes, or can generate accelerations automatically using for instance ASCE 2010 code (figure 3):

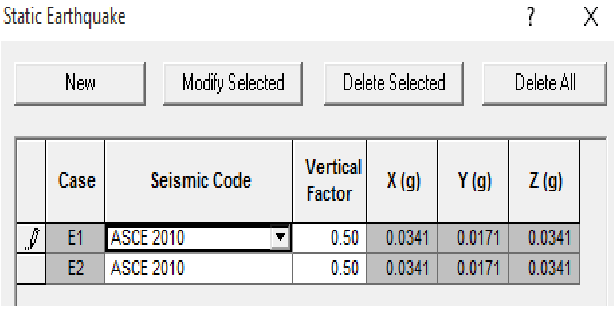


Figure 3. Seismic cases.

2.5. Wind load cases

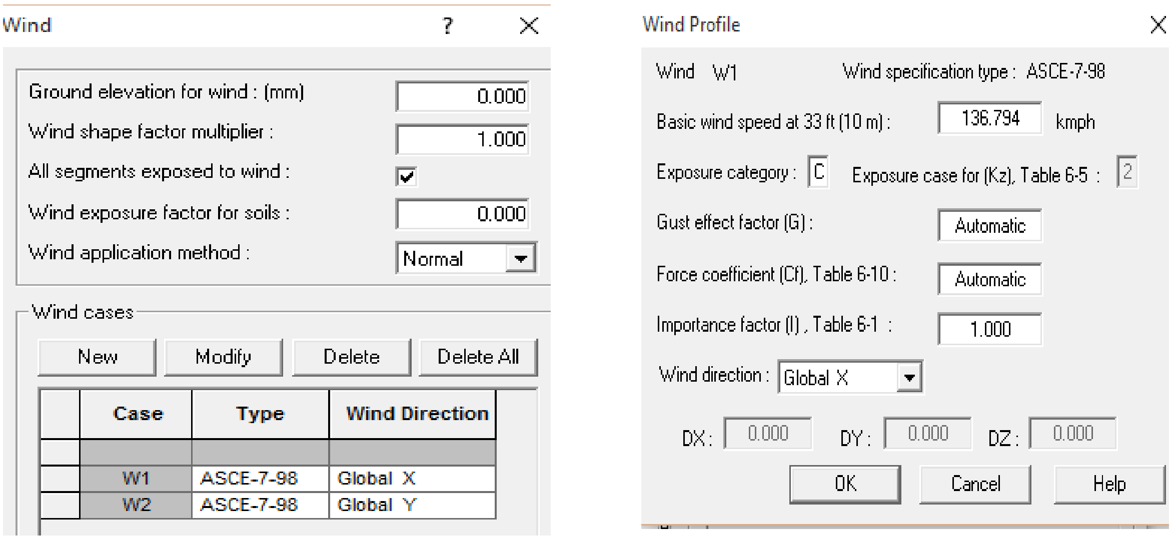


Figure 4. Wind load cases.

The wind loads cases are based on ASCE-7-98 code and for instance the Wind load case W1 has the speed of the wind of 136.7 km/h on the OX direction (figure 4).

2.6. Wave loads

The Load/Wave is defined inside the simulation to model the effect of ocean waves impacting a partially submerged piping system.

The following fields/parameters are provided in the Wave Load dialog: Wave data name, Wave type, Load case, Water - Elev. , Water Depth , Water density , Phase , Wave - Height and Period , Coeff. - Drag and Inertia, Direction - DX, DY, DZ, Depth Fields.

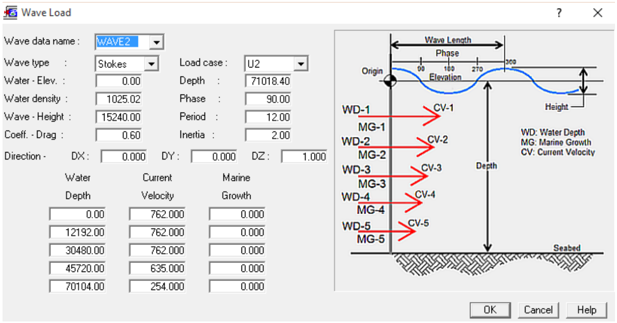


Figure 5. Wave load cases.

The load cases will be Wave 2 and Wave 3. For instance Wave 2 deploys Stokes wave theory, with the wave height of 15 m (under storm conditions), period 12 sec. and the wave current velocity varying from 0.7 m/sec at 12 m depth to 0.25 m/sec at 70 m depth (figure 5).

2.7. Buoyancy loads

The Load Buoyancy command enables us to model the piping system as partially or fully submerged in a fluid (usually sea water) by defining a height of fluid (and related properties) in which the piping system is partially or fully submerged. The buoyant force applies an upward pressure on the system, effectively reducing the weight of the submerged piping. AutoPIPE includes the buoyancy load in the gravity load case (GR) for analysis.

3. Results and discussion

The goal of all the calculations is to identify whether or not there are sections of the offshore pipeline with a poor behaviour under the load combinations set by the design standard.

3.1. The stress inside pipeline sections

The axial stresses act normal on the member section being by all means a normal stress. For our calculated platform these maximum stresses are shown in the figure below:

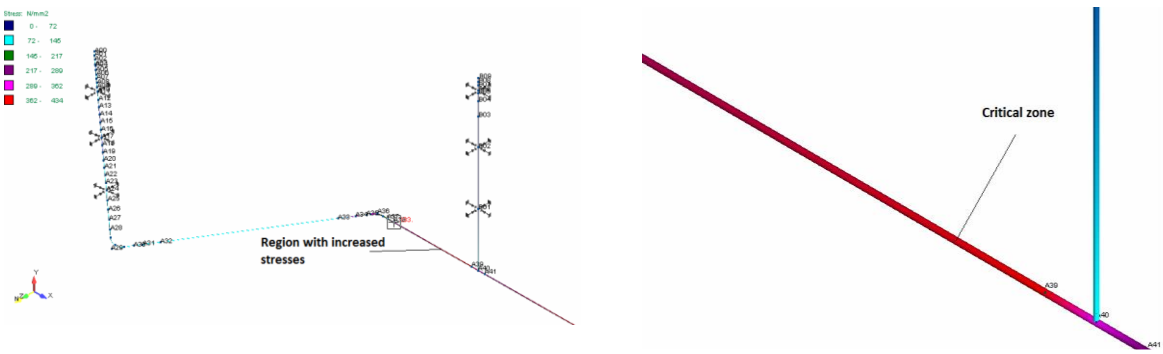


Figure 6. Stresses inside the pipeline.

The maximum values are within the range of 400 MPa, far above of the allowable stresses imposed by the code (figure 6).

3.2. The displacements

The calculated displacements are following the load cases considered in the simulation.

For instance for the Thermal loading case 3 with the upset conditions the displacements are given in the figure 7 below:

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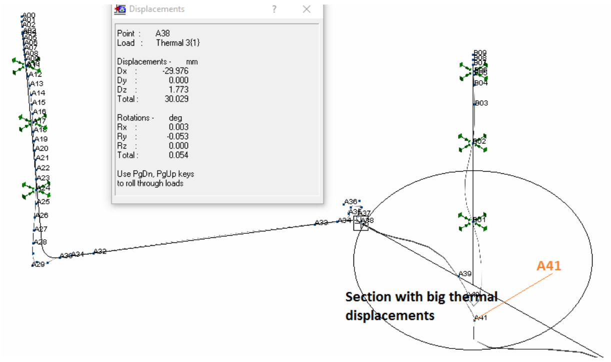

Figure 7. Thermal displacements for Case 3.

For the point A41 for instance the displacement in OX direction is 14 mm and in OY direction is 73 mm.

3.3. Mode shapes
The pipeline structure has its own natural frequencies and mode shapes. For instance the first natural frequency is 1.23 Hz and the mode shape is given in the figure 8 below:

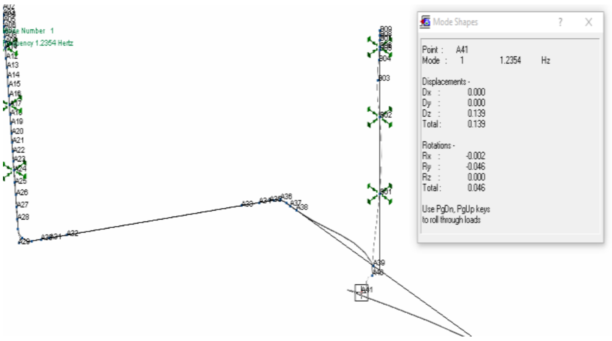

Figure 8. The mode shape for the first natural frequency.

3.4. Soil reactions
During various loads acting upon the pipeline the soil will oppose different reactions mainly in the Anchor points. For example for the anchor point A32 near the critical zone, the maximum reaction is 9587 N/mm in longitudinal direction as seen in the figure 9 below:

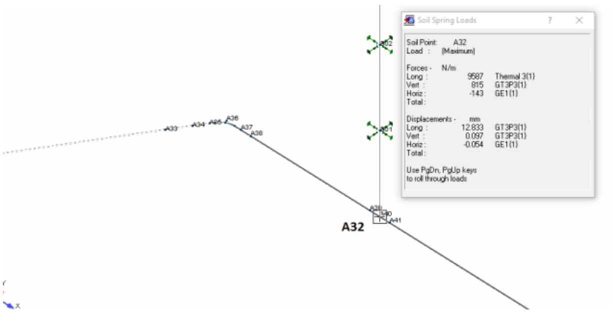

Figure 9. Soil reaction.

4. Conclusions
The offshore pipelines designing is an intricate enterprise following very demanding designing codes since at stake is the integrity of multi-million dollars investments in offshore oil and gas exploitation facilities. The rupture of a live oil pipeline can have disastrous effects over the environment and sea biota with serious penalties coming from the regulatory.

As seen in the present paper, the simulations comprise geometrically complex pipeline subjected to various and variable loading conditions.

At the end of the designing process, the engineer has to answer to a simple question: is that pipeline safe or not?

The pipeline set as an example, has some sections that are not complying in terms of size and strength with the code DNV 2012 offshore pipelines. Obviously those sections have to be redesigned in a manner to meet those conditions.

References

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