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Dynamic Analysis of a J-lay pipeline

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Abstract

Oil and gas reserves are moving towards deeper waters day by day and it has become increasingly important to construct structures and subsea pipelines in deeper waters to transport the hydrocarbons for the users. The J-lay technique has become a better alternative to the conventional S-lay technique for installing subsea pipelines in deep waters. Here the pipeline leaves the vessel in a near vertical position rather than the horizontal position and acquires the J-shape as it reaches the seabed. This method offers several advantages over the conventional S-lay method such as minimal bending and reduced suspended length of pipeline leading to reduced tension and reduced thruster power requirement, precise pipeline positioning and better vessel control.This paper considers a simplified J-lay pipeline numerical modelanalysed using ORCAFLEX. The model consists of 0.6 m diameter steel pipeline being laid at a water depth of 2000 m. Dynamic responses namely effective tension, bending moment and maximum von-Mises stress of the pipeline are studied under the action of waves with and without vessel interaction and under the combined action of waves and currents with vessel interaction. Vessel interaction and presence of currents induces additional stresses in the pipeline being laid and the increase in the maximum values of effective tension, bending moment and maximum von-Mises stress due to the dynamic effects is observed as 36%, 64% and 47.7% respectively.

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Keywords: J-lay technique; pipeline;numerical model; vessel interaction; current.

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1. Introduction

The ever increasing global energy needs have pushed farther the boundaries of the quest for newer oil & gas resource fields into the deeper waters than ever before. The hydrocarbon resources extracted offshore need to be transported to onshore for further processing and utilisation. Among the various methods available for transport

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of hydrocarbons, subsea pipelines are the most widely used as they offer the most efficient and economical mode of transport for hydrocarbons among other alternatives.

The deeper waters pose a great challenge to the design, construction and operation of the subsea pipelines. The subsea pipelines are subjected to complex loading from a wide range of sources such as wave & current in different directions, vessel motions, pipeline seabed interaction, etc. during installation in deep waters. The advancement of innovative technology and knowledge about the deep water domain has enabled us to overcome the challenges in developing subsea pipeline networks in such deep waters. One such technological advancement is the J-lay technique for the installation of subsea pipelines in deep waters.

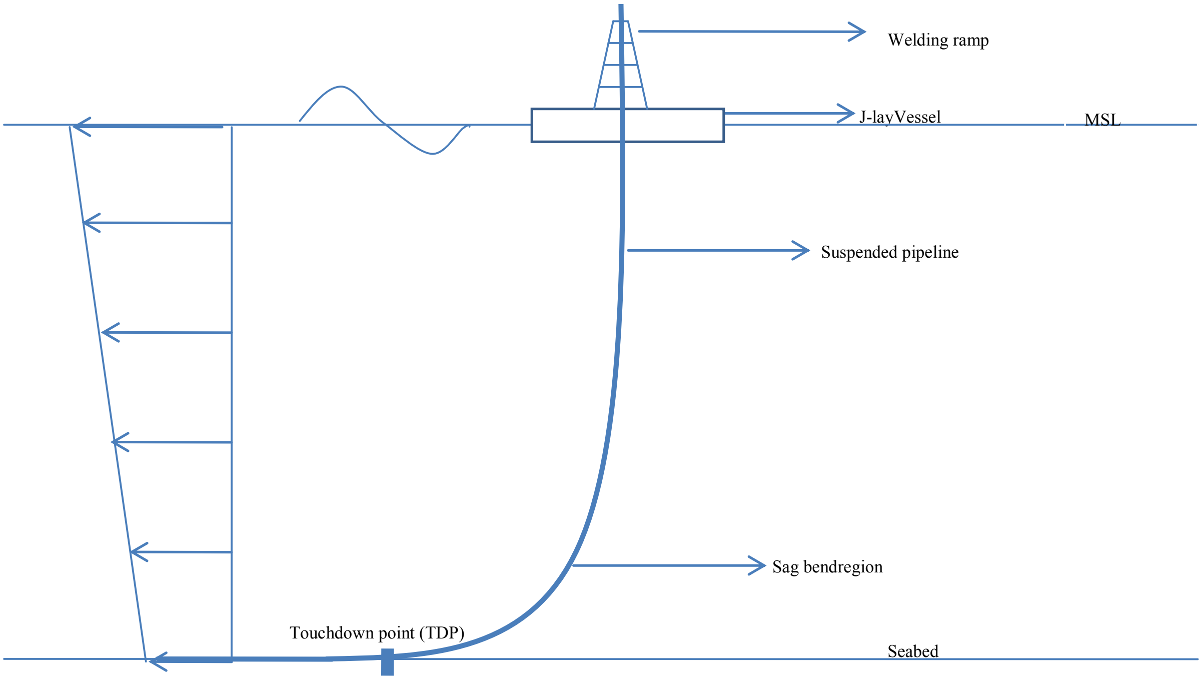

Fig. 1. Schematic diagram of J-lay pipeline

The schematic diagram of J-lay technique is shown in Fig. 1. This technique uses a near vertical welding ramp in contrast to the horizontal firing line system used in conventionalS-lay methods. This ramp being in line with the pipe catenary causes reduction in the suspended span of pipeline as well as minimises the bending of pipeline occurring in the sag bend region resulting in numerous benefits in the pipe laying operation such as reduced tension requirement, reduction in thruster power requirement, precise positioning of pipeline and better vessel control. Hence this technique has obtained prominence in the installation of rigid and fatigue sensitive pipelines in deep waters.

Clauss et al. (1992) reviewed offshore pipe laying operations and studied the significance of dynamic contributions to static stresses and axial forces in the suspended pipe span due to waves and vessel motions. Cowan and Andris (1977) presented about prediction of dynamic responses of pipe laying system undergoing excitations from high sea states. Springmann and Hebert (1994) described a J-Lay pipe lay system utilized to install the deep water portions of a specific pipeline.Lenci and Callegari (2005) developed analytical models to analyse J-lay pipe based on enriched catenary theory.Wang et al. (2010) presented a flexible pipeline model based on the semi empirical Morison’s equation and beam on Winkler foundation model for the static analysis of a J-lay pipeline and calculated the internal forces in the pipeline and deflection profile. Gong et al (2014) studied the dynamic behaviour of deepwater S-lay pipeline using commercial software ORCAFLEX, which demonstrated the sound capability of ORCAFLEX to predict the dynamic behaviour of pipelines being laid in deepwaters. In this paper, the analysis ofa numerical model of a simplified J-lay pipelinein deepwaterusingORCAFLEX is presented.

2. Numerical Model

A 0.6 m diameter freely flooded steel pipeline in J-lay configuration having 1” wall thickness is modelled and analysed in a water depth of 2000 m as shown in Fig.2. The pipeline welding ramp is inclined at an angle of 80^o from the horizontal and the other parameters of the pipeline are as specified in Table 1. The seabed is modelledusing a non-linear soil model suggested by Randolph andQuiggin (2009). The ultimate penetration resistance $P_u(z)$ and the penetration z are related as,

$$P_u(z) = N_c(z/D)\,S_u(z)\,D$$

$$N_c(z/D) = a\,(z/D)^b$$

where$N_c(z/D)$ is the bearing factor, $S_u(z)$ is the undrained shear strength, D is the diameter of the pipeline and a and b are non-dimensional penetration resistance parameters. The non-dimensional parameters are taken as a = 6 and b = 0.25 as suggested by Randolph and White (2008b). The soil has zero shear strength at mudline and the shear strength gradient is assumed to be1.5 kPa/m. The saturated soil density is taken as 1500 kg/m^3 and the other soil model parameters such as the suction resistance, cyclic uplift and repenetration are taken as default values in ORCAFLEX (Orcina 2015). The default values are adopted from the numerical model of Randolph and Quiggin (2009). The effect of wind is not considered for simplicity. A value of 1.2 for normal drag coefficient, 0.024 for axial drag coefficient(Wilson, 1960; Berteaux, 1976) and 1.0 for added mass coefficient is considered for the analysis. The current profile is assumed to be linear with maximum velocity at the sea surface and zero at the seabed as shown in Fig. 3. Generally, subsea pipelines are installed during calm sea states. The random sea state is modelled using JONSWAP spectrum with parameters as given in Table 2. The default vessel in ORCAFLEX having length between perpendiculars (LBP) of 103 m is used to study the effects of vessel interaction during the installation of pipeline whose parameters are listed in Table 3. Its motion is governed by first order wave effects only. The higher order wave forces such as the wave drift force and the other low frequency motions of the vessel whose magnitudes are low have not been included in the analysis.

Table 1.Pipeline parameters.

Parameter	Value
Elastic modulus, E	2.1 x 10^5 MPa
Density of water, ρ_w	1030 kg/m^3
Density of pipeline material, ρ_p	7850 kg/m^3
Outer diameter of pipeline, D_o	0.6 m
Inner diameter of pipeline, D_i	0.55 m
Water depth, d	2000 m
Welding ramp inclination with horizontal, β	80^o

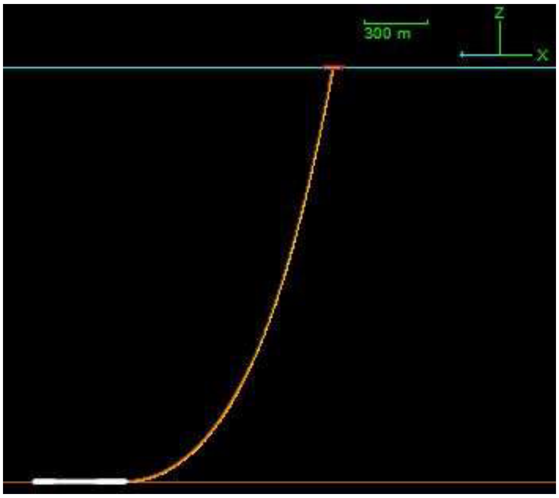

Fig.2.J-lay pipeline model in ORCAFLEX

Table 2.Wave and JONSWAP spectrum parameters.

Parameter	Value
Wave heading angle, θ	270
Significant wave height,H_s	1.77m
Peak period,T_p	8.5s
Mean zero crossing period, T_z	6.61s
Peak frequency, f_m	0.1176Hz
Peak enhancement factor, γ	3.3
Spectral energy parameter, α	0.002
Spectral width parameters, σ_1&σ_2	0.07& 0.09

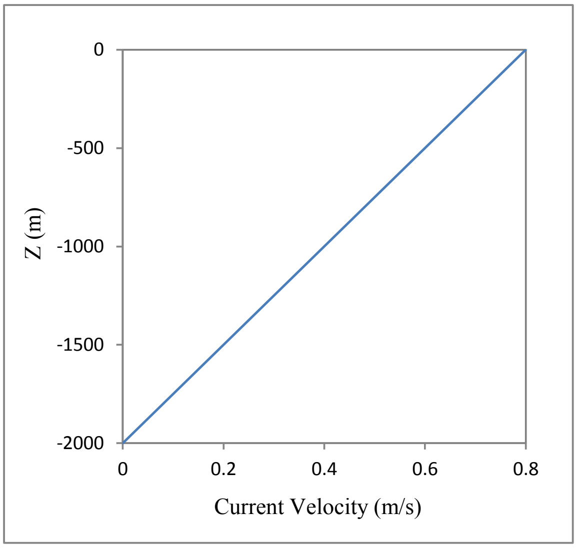

Fig. 3.Current profile

Table 3.Vessel parameters.

LBP (m)	Breadth (m)	Draft (m)	Mass (kg)	Transverse GM (m)	Longitudinal GM (m)	Block Coefficient
103	15.95	6.66	9017950	1.84	114	0.804

3. Static Analysis

The static analysis of the pipeline provides useful insights about the magnitude and nature of the stresses experienced by the pipeline due to its configuration alone without the influence of waves, current and vessel interaction. The primary components of the internalloads causing these stresses in the pipeline are effective tension, bending moment and hydrostatic pressure. Study of these load components gives us a better understanding about the behaviour of the pipelines.

The plots of the overall configuration and the internal load components along the length of the pipeline (X) such as the effective tension, bending moment of the numerical model in static state are compared with those of Lenci and Callegari (2005) and shown in Figures 4 (a), 4 (b) and 5 (a). It is observed that both the plotsare in good agreement validating the numerical model. The effective tension is maximum at the top of the catenary where the total weight of the suspended span of the pipeline is supported and reduces along the suspended span while the bending moment increases along the suspended span due to increase in curvature and reduces as the pipe is laid on seabed.The von-Mises stress is the equivalent stress due to all types of loading on the pipe section. The maximum von-Mises stress is an estimate of the maximum value of the von-Mises stress over the cross-section and its variation along the pipeline is shown in Fig. 5 (b).

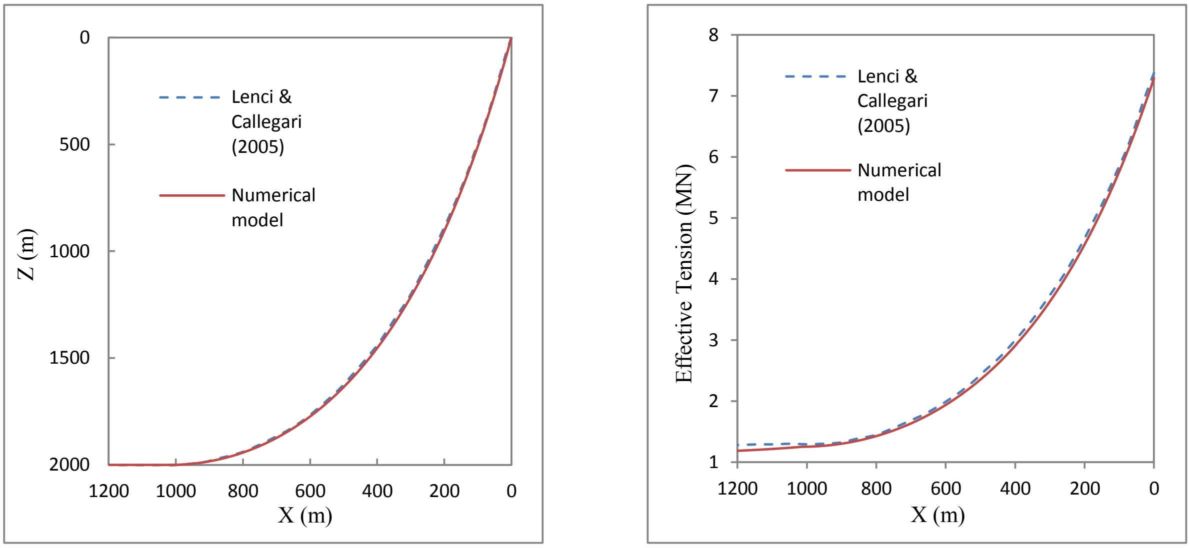

Fig. 4. (a) Configuration of overall pipeline; (b) Effective tension

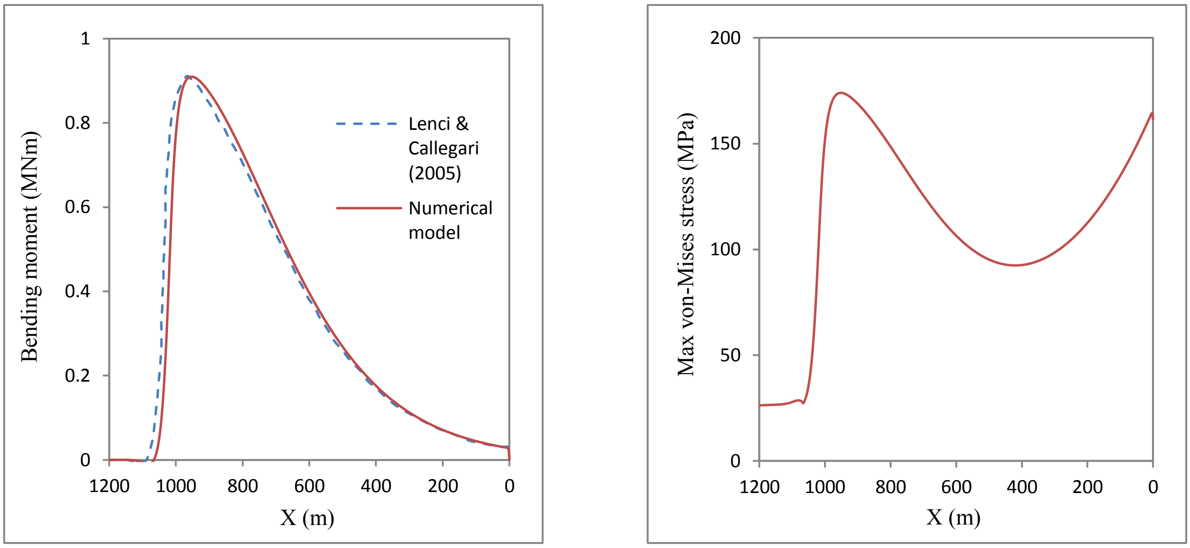

Fig. 5. (a) Bending moment; (b) Maximum von-Mises stress

The von-Mises stress near the top of the catenary region is governed by the effective tension where the effects of the bending moment and hydrostatic pressure are negligible and it gradually reduces along the suspended span with reduction in the effective tension and again increases when the increase in bending moment and hydrostatic pressure become significant when compared with the reduction of effective tension along the suspended pipe span.The von-Mises stress near the TDP region is governed by the bending moment and hydrostatic pressure and it peaks slightly before the TDPwhere the combined effect of effective tension, bending moment, hydrostatic pressure maximises.

4. Dynamic analysis

The stresses in the pipeline during the installation process get magnified due to the dynamic effects of waves and vessel motions. The dynamic amplification of the stresses in the pipeline can be of potential threat to the safety of the pipeline during the installation process. To ascertain the dynamic effects of waves, current and vessel motion, the dynamicbehaviour of the pipeline was studied under the following cases,

- Under wave excitation alone.
- Under wave excitation with vessel interaction.
- Under wave and current excitation with vessel interaction.

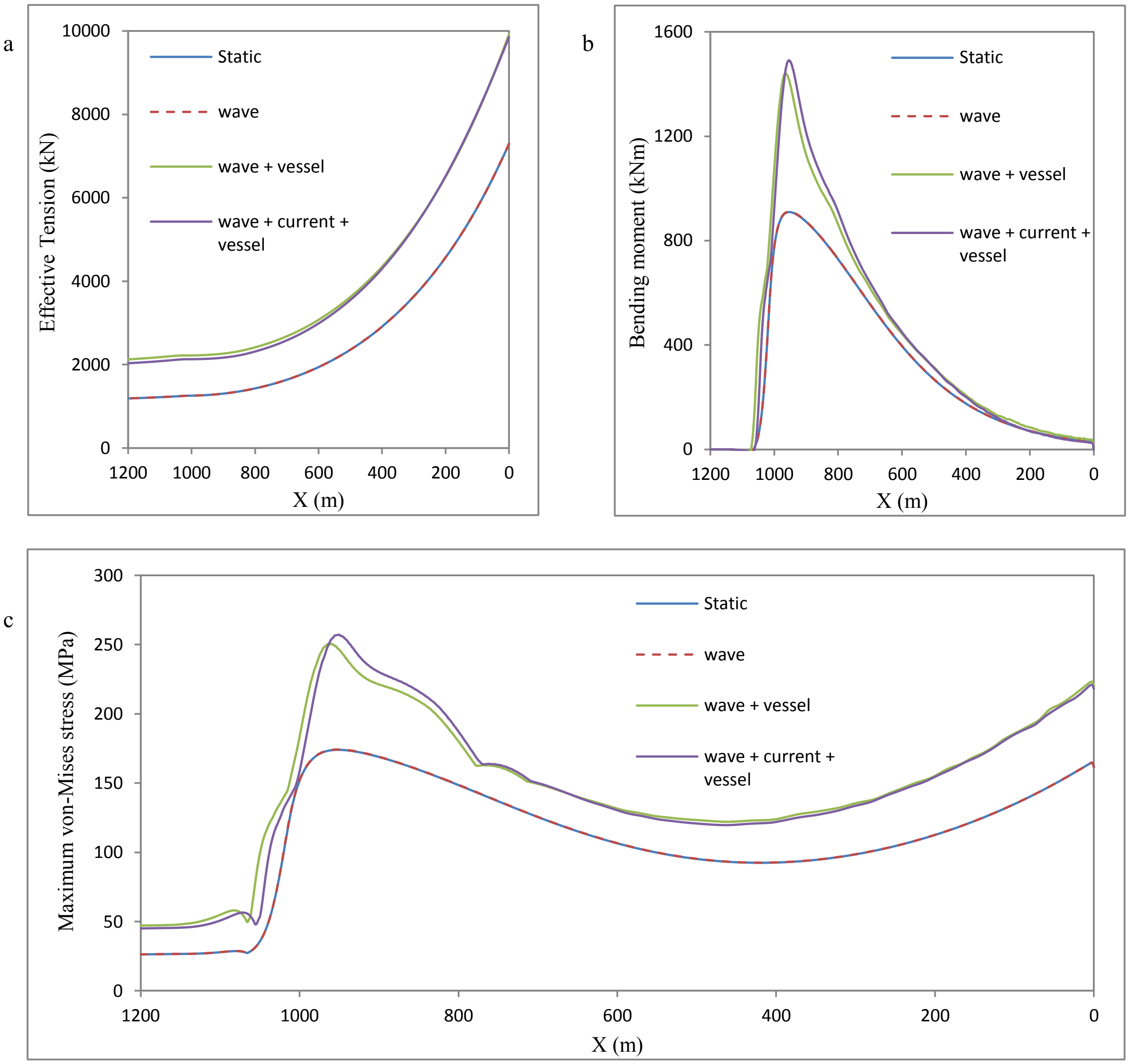

Fig. 6. Dynamic responses of pipeline (a) Effective tension(b) Bending moment (c) Max von-Mises stress

The variation of effective tension, bending moment and maximum von-Mises stress for all the cases along the length of the pipeline (X) are plotted in Fig. 6. The influence of wave loading without vessel interaction on the pipeline is insignificant as observed from these graphs. This may be attributed to the fact that the pipeline is too small to attract significant loading from the wave. When the pipeline is subjected to wave loading with vessel interaction, the dynamic increment in the internal loads and equivalent stress becomes highly significant. This may be due to the fact that the vessel is set into random oscillations due to wave loading on the vessel and this random oscillation of the vessel is transferred to the pipeline which is being paid out from the vessel. The percentage increase of the maximum effective tension during this condition is 36% (see Fig. 6a). This indicates the importance of the vessel interaction towards the dynamic contribution to the internal loads and stresses in the pipeline.This increase in the effective tension assumes importance because the tensioner in the pipe lay vessel must be designed to have sufficient capacity to accommodate these surges. The presence of currents during the pipeline installation alters the internal loads and the stresses in the pipeline depending upon the direction relative to that of the lay direction. Here the current direction is assumed to be opposite the lay direction so as to maximise the bending moment and the equivalent stress near the TDP region which are the peak values. The percentage increase in the maximum bending moment and the maximum of maximum von-Mises stress of 64% (see Fig. 6 b) and 47.7% (see Fig. 6 c) respectively occurs during this condition. However, there is a slight reduction in the peak effective tension during this condition as the current causes reduction in the layback and thereby reduction in the suspended pipe span. The maximum values of effective tension, bending moment and maximum von-Mises stress in static and dynamic analyses are summarised in Table 4.

Table 4.Comparison between static and dynamic results.

Results	Static analysis	Dynamic analysis	Increment (%)
Maximumeffective tension (kN)	7292	9920	36
Maximumbending moment (kNm)	909	1491	64
Maximum of maximum von-Mises stress (MPa)	174	257	47.7

5. Conclusion

Dynamic analysis of a J-lay pipeline in 2000 m water depth is carried out using ORCAFLEX. Following are the salient conclusions from the study,

i. The percentage increase of maximumeffective tension in the pipeline is 36% when compared to the static state and occurs during wave excitation with vessel interaction condition.

ii. The percentage increase of maximum bending moment in the pipeline is 64% when compared to the static state and occurs during wave and current excitation with vessel interaction condition.

iii. The percentage increase of maximum of maximum von-Mises stress in the pipeline is 47.7% when compared to the static state and occurs during wave and current excitation with vessel interaction condition.

It is evident from the study that the dynamic effects due to the action of waves, current and vessel interaction amplify the internal loads inducing additional stresses in the pipeline apart from the static stresses. Such increase in the internal loads and stresses must be accounted for in the design of the pipelines to ensure safe installation of the pipeline.

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