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APPLICATION OF OPTIMIZATION TECHNIQUES TO MINIMIZE THE EFFECTS OF VORTEX-INDUCED VIBRATION (VIV) IN FREE SPANNING PIPELINES

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Abstract. The use of submarine pipelines to transport oil and gas is a common practice. However, one of the main problems associated with the use of this technology is related to the irregularities of the seabed, which creates regions with free spans, propitiating the occurrence of the phenomenon of vortex-induced vibration (VIV). The design of pipelines in regions with free spans involves a thorough evaluation, which allows identifying the VIV and the probable damage due to fatigue, to find out the need to increase the operational life of pipelines. A widely used method for VIV mitigation is the reduction of the effective length of the span installing supports at strategic points of the pipeline, minimizing the fatigue damage. The search for these points can be seen as an optimization problem to identify the position and the adequate amount of supports to minimize the occurrence of VIV. Thus, this work consists of a study on the use of optimization techniques to identify the most suitable configuration for the installation of the supports, assisting in the development of pipelines projects. For that, different situations were analyzed, involving the change of bathymetry and the variation of the effective span length.

Keywords: Optimization, vibration, natural frequencies, pipelines, free spans

1 Introduction

In the offshore system, marine pipelines are responsible for transporting fluids such as oil, gas and water between the well and the platform, between platforms, or between the platform and a location on land. According to Lima [1], marine pipelines can adapt to a wide variety of scenarios, including the most hostile ones, making them one of the most efficient means of fluid transport. According to Vieira [2], a seabed topology makes it difficult to define a viable route for the pipeline. Often the route with accentuated irregularities is inevitable. Thus, the pipe does not fit the geometry of the seabed, resulting in free span regions. For Kristiansen et al. [3], whenever the pipe is exposed to wave or bottom current actions, the free span region is susceptible to the emergence of vortex induced vibrations (VIV), which can cause fatigue failure.

Therefore, the study of the effects of this phenomenon on overall structures is essential, due to the risk that these dynamic efforts have to cause fatigue failure if natural frequency is reached. Therefore, the appropriate study allows the adoption of actions capable of minimizing the effects of vortex shedding on the structures. One of the most commonly used methods for VIV mitigation is the installation of supports at strategic points in the pipe to minimize fatigue damage. Thus, the focus of this work will be on the application of optimization techniques to identify the most appropriate configurations for the installation of supports that increases the useful life of the pipe, contributing to the development of pipeline projects.

2 Methodology

Initially, the model was created in Abaqus^{TM} software, used for finite element analysis. After modeling, optimization methods were used to, by varying the position of the supports along the length of the pipe, find the configurations that resulted in longest services lives. Three cases were analyzed: position variation of 1 support, 2 supports and 3 supports.

2.1 Pipeline and spring properties.

The first step consisted of pipe modeling, serving for subsequent parts of the analysis. The pipeline properties used in this model are described in Table 1. The pipeline length is 28 m, resulting in length of diameter ratio of L/D = 100.

Table 1. Pipeline and spring properties. Source: Author.

Property	Symbol	Value	Unit
External diameter	D_s	0.2731	m
Nominal thickness	t_{steel}	0.0127	m
Modulus of elasticity	E	207	GPa
Steel density	ρ_{steel}	7850	kg/m^3
Coating thickness	$t_{coating}$	0.0027	m
Coating Density	$\rho_{coating}$	923	kg/m^3
Coefficient of temperature expansion	α_E	923	$°C^{-1}$

To simulate the actual operating conditions of the pipe, proper consideration of the values for internal and external pressures, temperature variation, internal content properties, and residual lay tension are required. In this model, only the effects of the bottom current were considered and the current distribution used can be considered severe because it can reach speeds of 1.4 m/s in some directions.

2.2 Creation of the model in Abaqus^{TM}

The analysis of the model was done by the finite element method (FEM), using Abaqus^{TM} software. The three-dimensional model consists of a 28 m long pipe, discretized into 0.25 m elements, restricted on three degrees of freedom for translation at both ends. Still, at the extremities, springs were placed in the same direction of the pipe, with flexural stiffness, to adjust the way the pipeline deflects in these directions. Finally, the supports used were modeled as springs. At the nodes where the supports were placed, two springs were inserted, one in the in-line direction and one in the cross-flow direction. Figure 1 shows how the model was structured.

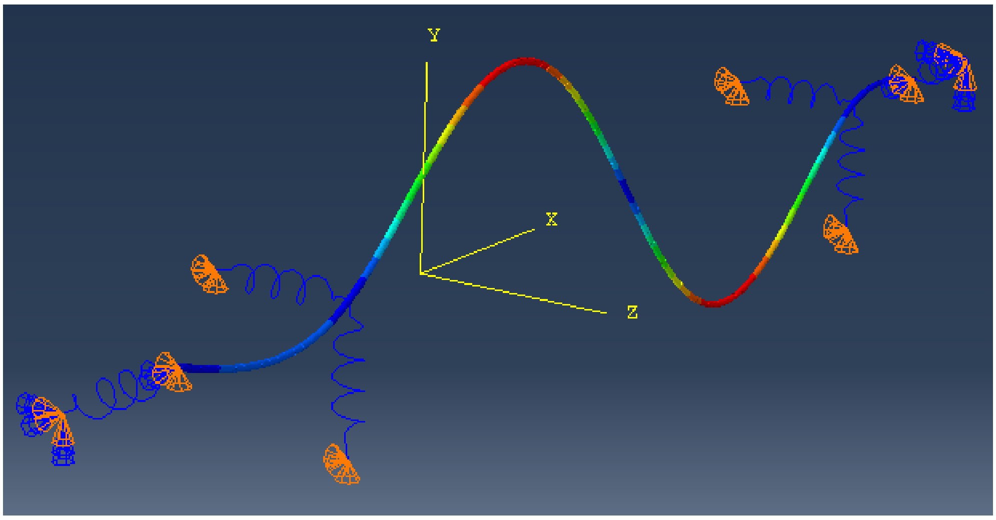

Figure 1. Model used in Abaqus^{TM}.

2.3 Supports and Optimization Techniques

In the optimization process, an Evolutionary Optimization Algorithm (EVOL), based on the works of Rechenberg [4] and Schwefel [5] was used. This was applied in 3 cases: variation of only 1 support, variation of 2 supports and variation of 3 supports. The effect of each position combination of each case was analyzed by the finite element method, using Abaqus^{TM} software. In each analysis, the frequencies and vibration modes of the structure were extracted. Subsequently, the data extracted was used in the formulations adopted by recommend practice DNVGL-RP-F105 2017 [6] (Free spanning pipelines), which allows to evaluate the fatigue caused by VIV, from an empirical relationship between the reduced velocity and the amplitude of the adimensional response, where the reduced velocity is a parameter that takes into account the diameter of the pipe, the natural frequency associated with the free span region and the speed of the current (Fyrileiv and Mork [7]).

3 Results

Figures 2 and 3 show the graphs for the two active vibration modes of the pipe along its length in its unsupported configuration. In the first graph, the placement position of the only support of the first case analyzed was marked with a vertical dashed line. The second graph shows, with a shading, the viable regions for the placement of the case with 2 supports.

After the optimization process, the results were extracted of the three cases analyzed. In the first case, for the configuration with only 1 support, the genetic algorithm required 49 generations to find the complete results and, among all the alternatives analyzed, the best option found was to place the support in the position 14.52 m, which corresponds approximately in the middle of the pipe and resulted in a fatigue life of 1.47 years. Analyzing the graph of Figure 2, it can be seen that this position mainly fights the first vibration mode, which corresponds to the lowest frequency and that most compromises the material life.

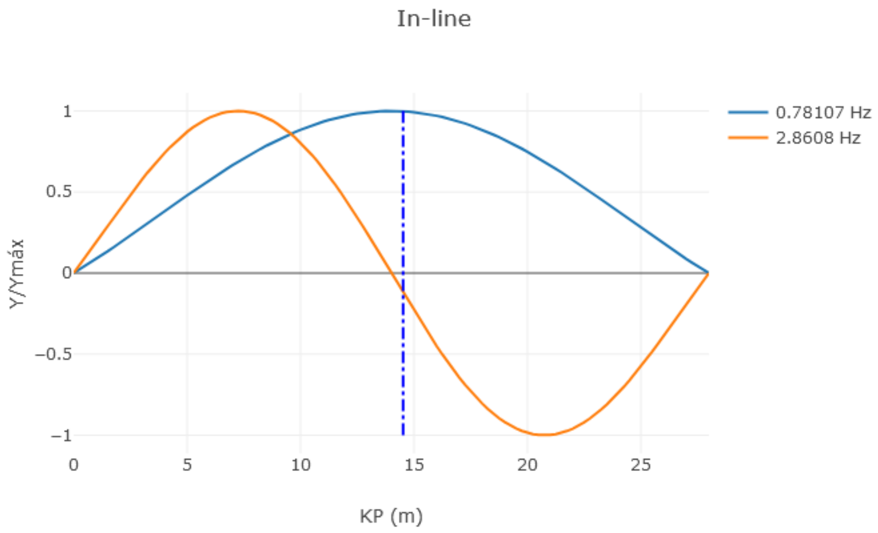

Figure 2. In-line Modes (In unsupported configuration). Positioning of 1 support.

Alternatively, the option of optimizing the positioning of 2 supports was tried. In this case, the algorithm introduced restrictions where the position of one of the supports should always be higher than that of the other. In addition, it took 1000 generations to find the full results. It was noted that in this situation, no specific configuration was found, but a viable region, where the location of the supports in this region could lead to a drastic increase in pipeline fatigue life to 1000000 years (see Figure 3).

Finally, attempts were made to optimize the positioning of 3 supports. A viable region was also obtained, which also increased pipeline life to 1000000 years. Thus, it can be seen that the third support became irrelevant, since with only 2 supports it was possible to obtain the same results for fatigue life.

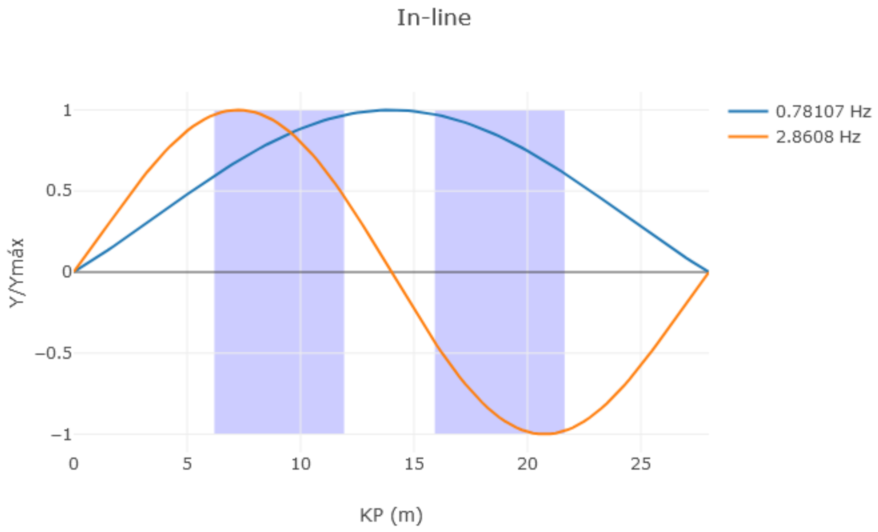

Figure 3. In-line Modes (In unsupported configuration). Viable regions for the position of 2 supports.

4 Conclusion

Based on the results presented, it was noted that the strategy of selecting the positions and quantities of supports by means of optimization algorithms proved to be viable for a simplified model such as this, where it was possible to minimize fatigue damage and, consequently, increase the fatigue life of the pipe. This approach becomes even more relevant in more complex models, where the environment conditions are more hostile and the pipe configurations are such that the number of active vibration modes is higher, making it difficult to properly position the supports. Thus, in future work, this methodology will be applied in more realistic situations, with different current conditions, new bathymetries, and the adoption of new types of support.

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References

[1] Lima, A. J., 2007. AnÁlise de dutos submarinos sujeitos a vibraÇoes induzidas por vÓrtices. Mestrado, Universidade Federal do Rio de Janeiro (UFRJ), Rio de Janeiro - RJ.

[2] Vieira, I. N., 2011. *OTIMIZACÃO MULTI-OBJETIVO DE ROTAS DE DUTOS SUBMARINOS ATRAVÉS DE SISTEMAS IMUNOLÓGICOS ARTIFICIAIS*. Doutorado, Pontíficia Universidade Católica do Rio de Janeiro (PUC), Rio de Janeiro.

[3] Kristiansen, N. , Tørnes, K., Nystrøm, P., & Damsleth, P., 1988. Experiences using dnv-rp-f105 in assessment of free spanning pipelines. *The International Society of Offshore and Polar Engineers*, pp. 24–29.

[4] Rechenberg, I., 1971. *Evolutionsstrategie - Optimierung technischer Systeme nach Prinzipien der biologischen Evolution. Mit einem Nachwort von Manfred Eigen Frommann-Holzboog [Stuttgart-Bad Cannstatt]*. Ph.d. thesis, Verfahrenstechnik TUBerlin.

[5] Schwefel, H. P., 1975. *"Evolutionsstrategie und Numerische Optimierung"*. Phd thesis, Verfahrenstechnik TUBerlin.

[6] DNV, 2017. *DNVGL-RP F105*. DET NORSKE VERITAS.

[7] Fyrileiv, O. & Mork, K., 2002. Structural response of pipeline free spans based on beam theory. *ASME 2002 21st International Conference on Offshore Mechanics and Arctic Engineering*.