Development of a web tool for analysis of fatigue life of free span pipelines

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Abstract. Throughout the last decades, with the discovery of oil and gas fields in offshore zones, more extensive pipeline systems are needed and, consequently, more prone to the occurrence of free spans, caused by seabed irregularities. Pipes in this situation are exposed to the Vortex-Induced Vibrations (VIV) phenomenon, which can cause damage, mainly related to fatigue. In this way, several recommended practices provide formulations that can be implemented in electronic spreadsheets to assist in academic and professional projects. The problem with the approach of spreadsheets is the difficulty in using their implementations for the coupling with other software. In this sense, the objective of this work is to develop a web tool for the analysis of rigid free-spanning pipelines in VIV, using modern web programming resources and enabling its reuse in the development of other applications.

Keywords: VIV, Free span, Pipeline, Fatigue life

1 Introduction

The oil and gas industry has demonstrated that the use of subsea pipeline systems is the most economical and reliable way to transport hydrocarbons, whether between the oil well and the platform, between platforms or between the platform and shore. With advances in research and the discovery of fields in offshore regions, there has been a demand for more extensive pipelines capable of adapting to hostile environments, such as deep waters with a very irregular seabed (Lima [1]).

According to Santos [2], determining the pipeline guideline in these scenarios, it is sometimes impossible to ensure that the pipeline does not have sections that are not fully supported due to the irregularities of the seabed (free-spanning pipelines), which is a problem related to structural integrity, because oscillatory loads may arise naturally due to the action of sea currents and waves, causing vibrations. In regions with free-spans, the main loads are caused by the phenomenon known as Vortex-Induced Vibrations (VIV) which can lead to pipeline rupture, mainly due to fatigue.

Given the problem, there are several standards and recommended practices that discuss free-spanning pipelines, such as DNVGL-RP-F105 (DNV GL [3]), which presents design criteria and guidelines for free spans subjected to combined loads of waves and currents and presents an analytical formulation used to estimate parameters related to the VIV phenomenon.

The exposure of simplified analytical formulations in standards and recommended practices allows the implementation of calculations in electronic spreadsheets and the FatFree® (DNV GL [4]) tool is frequently used by designers because it is based on DNVGL-RP-F105 and implemented in the Visual Basic for Applications® language.

However, the approach of spreadsheets as FatFree® hinders the development of new tools, as well as the coupling with other software considering the current programming practices.

Therefore, this work aims to contribute to the design of pipelines subjected to the VIV phenomenon through the development of a web tool with a graphical interface based on the DNVGL-RP-F105 recommended practice.

2 Methodology

Client-side programming was done using HTML (HyperText Markup Language), CSS (Cascading Style Sheets), and JavaScript, with the help of the React library and the Bootstrap framework in the implementation and styling of the interface's visual components.

In addition to the mentioned tools, the React Router library was used to implement the application's routes, and the Context API was used to facilitate communication between the application's components.

The Python programming language (Van Rossum and Drake Jr [5]) was used for server-side programming, using the Flask framework. JSON (JavaScript Object Notation) file type was used in the tool's requests and responses.

The calculations involving the free span were implemented taking the DNVGL-RP-F105 (DNV GL [3]) recommended practice as a basis, while the calculations related to the soil parameters were based on DNVGL-RP-F114 (DNV GL [6]), which deals with pipe-soil interaction for submarine pipelines.

To illustrate its use and validate the tool, the calculations performed by the FatFree® spreadsheet presented in the work of Valença [7] were reproduced in the application. The main tab of the spreadsheet can be seen in Fig. 1.

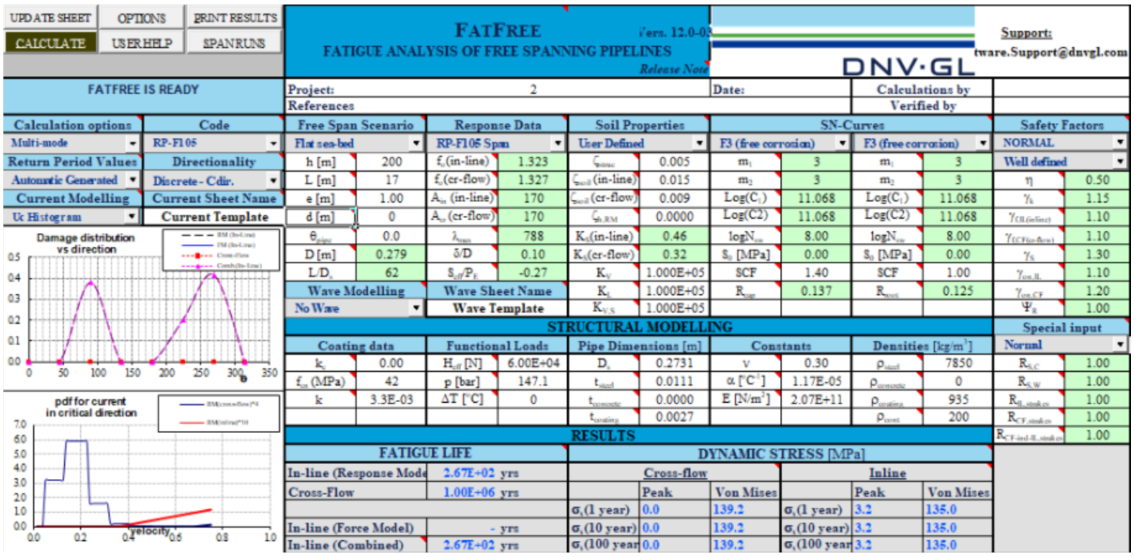

Figure 1. Main tab of the evaluated example

3 Results and Discussion

The tool's input tab with the filled-in data can be seen in Fig. 2.

The results tab of the tool for the evaluated example can be seen in Fig. 3.

To compare results, the values of fundamental natural frequencies and maximum unit diameter stress amplitudes obtained were analyzed. The fundamental natural frequency and maximum unit diameter stress amplitude may be approximated by eq. (1) and eq. (2) respectively.

$$f_1 = C_1 \cdot \sqrt{1 + CSF} \cdot \sqrt{\frac{E \cdot I}{m_e \cdot L_{eff}^4}} \cdot \left(1 + \frac{S_{eff}}{P_{cr}} + C_3 \cdot \left(\frac{\delta}{D}\right)^2\right), \tag{1}$$

$$A_{IL/CF,1}^{max} = 2 \cdot C_4 \cdot (1 + CSF) \cdot \frac{D \cdot E \cdot r}{L_{eff}^2}, \tag{2}$$

where C_1, C_3 and C_4 are boundary conditions coefficients, E is young modulus for steel, I is moment of inertia for steel, CSF is concrete stiffness enhancement factor, L_{eff} is effective span length, m_e is effective mass, D is

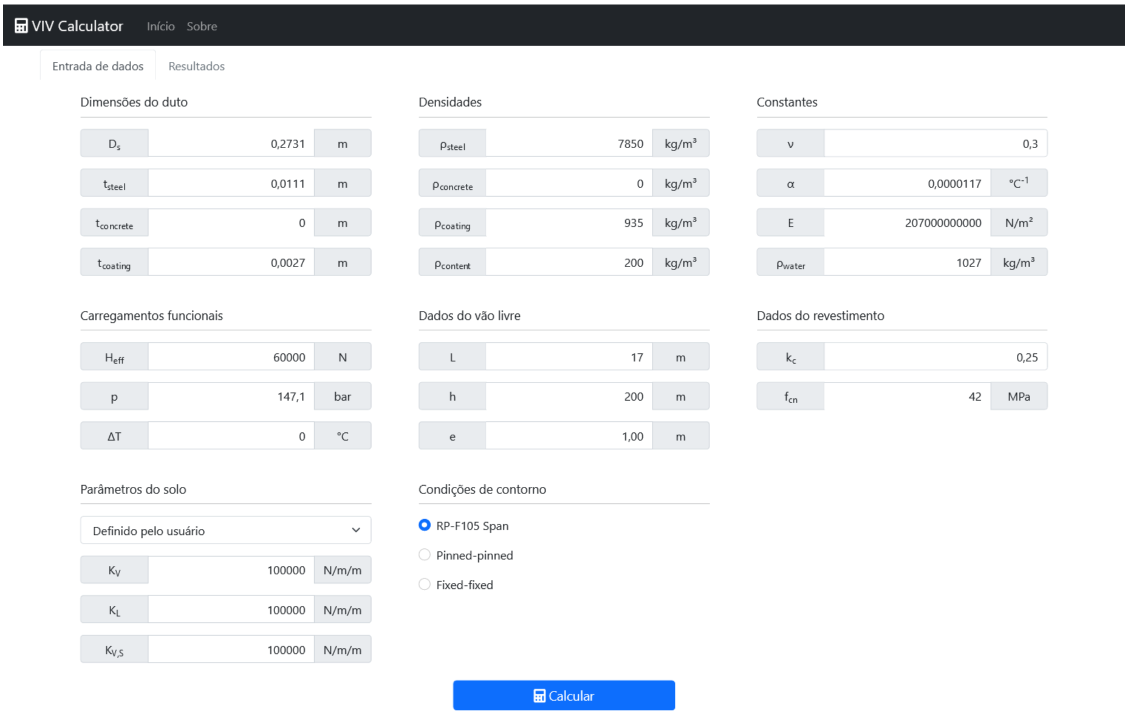

Figure 2. Input tab of the tool with filled-in data

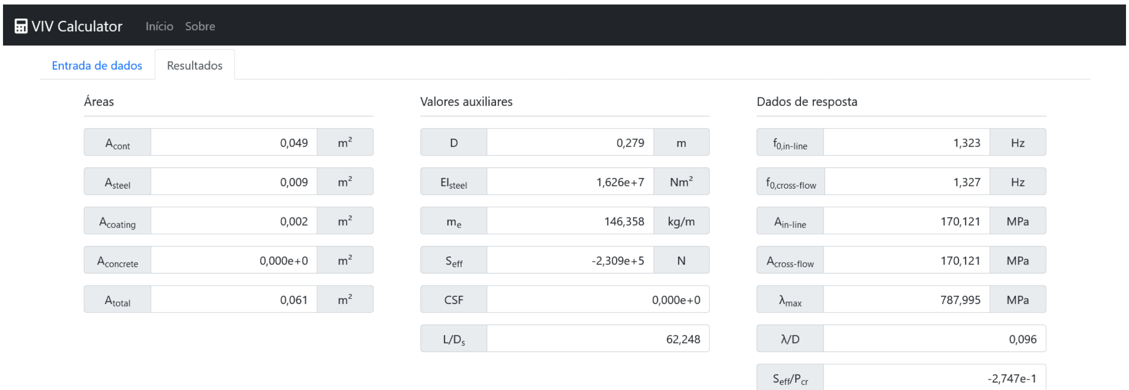

Figure 3. Result tab of the tool

outer diameter of pipe, P_{cr} is critical buckling load, δ is static deflection, S_{eff} is effective axial force and r is radial coordinate of the pipe cross section.

A comparative analysis of results is shown in Table 1. The values obtained by the web tool have been compared with those obtained by FatFree® from the work of Valença [7].

Table 1. Comparative analysis between results of the tool and those obtained by Valença [7]

Parameter	Results - Work of Valença [7]	Results - Web tool	Percent error
$f_{1,\text{in-line}}$ (Hz)	1.323	1.323	0.000%
$f_{1,\text{cross-flow}}$ (Hz)	1.327	1.327	0.000%
$A_{\text{IL},1}^{\text{max}}$ (MPa)	170.000	170.121	0.071%
$A_{\text{CF},1}^{\text{max}}$ (MPa)	170.000	170.121	0.071%

It has been observed that the percent errors were very small, which was expected because both the application and the FatFree® spreadsheet are based on DNVGL-RP-F105 recommended practice (DNV GL [3]). Differences obtained can be due to the errors propagation in the used rounding procedures.

4 Conclusions

Because all the above, it was noted that the web tool developed proved to be useful and produced valid results when subjected to a comparative analysis of the results obtained by a widely used spreadsheet among submarine pipeline designers.

Furthermore, because it is implemented using modern programming resources, the tool's functionalities can be coupled with other software which avoids rework and increases efficiency in the development of similar and complementary applications.

Therefore, the implementation of the web tool contributed to the knowledge about free-spanning pipelines, since the theoretical basis was thoroughly consulted during all phases of its development.

Future work should take advantage of the implementation already developed and couple it in the development of new tools, such as the inclusion of environmental data to estimate the fatigue life of pipelines subjected to VIV and other known spreadsheet functionalities.

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