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Evaluation of Methods for Optimizing Structural Design Parameters in Oil Wells

Christiano A. F. Várady Filho[1], Aline V. Esteves[1], Joyce K. F. Tenório[1], Beatriz R. Barboza[1], João P. L. Santos[1], Eduardo T. Lima Junior[1], Rafael Dias[2], Fábio S. Cutrim[2], Bruno Sérgio Pimentel de Souza[2].

[1]*Laboratório de Computação Científica e Visualização, Universidade Federal de Alagoas*
Maceió, 57072-970, Alagoas, Brasil
christiano_varady@lccv.ufal.br,alineesteves@lccv.ufal.br,joyce.tenorio@lccv.ufal.br,beatriz@lccv.ufal.br, jpls@lccv.ufal.br, limajunior@lccv.ufal.br
[2]*Petrobras*
Rio de Janeiro, 21941-915, Rio de Janeiro, Brasil
rafael_dias@petrobras.com.br, fabiosawada@petrobras.com.br

Abstract. Present work focuses on the optimization of the conductor casing length and sensitivity analysis of the cement top of surface casings ensuring that global structural design criteria are met. These criteria include: 1) bearing capacity of the conductor casing, 2) displacement of the wellhead system, and 3) surface casing triaxial factor of safety. The implementation uses several optimization techniques to evaluate the performance and accuracy of the parameters while minimizing the criteria. Assessment of the mechanical behavior of the soil-well coupling is done using finite element software and it serves as a data source for the optimization techniques. The implemented software is treated as a “black box” and global criteria are evaluated based on the simulation results. The finite element software is used by an oil company, which also gave specific data about well design as case studies. The case studies are used to evaluate which optimization method provided the best results and processing time for each case. This kind of study on optimization techniques aims to support the decision-making process on well casing design to evaluate the integrity of structural casings. Previous results show consistent accuracy among casing length and cement column parameters for the employed methods.

Keywords: optimization, oil well, casings.

1 Introduction

Among several aspects, the oil and gas industry aims for the best structural integrity possible while keeping the cost budget at an affordable level. Also, environmental and human safety are important premises that are addressed in many normative codes. In the matter of well structural integrity, analysis of the soil-casing coupling is significantly important for conductor and surface casings, as they serve as the foundation to the whole system, supporting severe loads throughout its entire life cycle.

Casings costs can range up to 15% of a well’s total cost [1]. Usual design practice involves repeatedly altering the conductor’s length or cement top of the surface casing and verifying if the global structure design criteria are met. We developed a methodology and implemented a routine in Python to automatize this process.

Optimization studies in this paper involve the determination of the minimum length of the conductor casing and cement top of the surface casing ensuring that the global design criteria for cemented conductors are met:

1. Axial bearing capacity of the conductor casing must be larger than the maximum load (considering a Factor of Safety, FS, equal to 1);
2. The modulus of the displacement of the wellhead system must be smaller than 0.5 m (considering FS=1.5)
3. Triaxial factor of safety of the surface casing must be larger than 1.25.

For the optimization of the conductor casing length, the 3 criteria above are evaluated. For the sensibility analysis of the cement top, only criteria 2 and 3 are considered.

2 Methodology

The steps of the optimization code are shown in Figure 1. The process begins by importing a JSON file with the parameters to be optimized (length of the conductor casing and cement top of the surface casing). With the JSON data as initial estimates of the iterative process, the company's finite element software is called upon to obtain the variables related to the mechanical behavior of the soil-well coupling (bearing capacity, critical load, axial displacement, and triaxial factor of safety of the surface casing).

This software performs a variety of analyses for each phase of an oil well and includes aspects of reliability-based design. In this paper, the software was used as a "black box" to obtain the needed variables to evaluate the global design criteria.

With the target variables, criteria verification is pursued. If the criteria are met, the length of the conductor or the cement top is altered, depending on the objective of the analysis. This process is repeated until one of the criteria is not attained. When that happens, the code is interrupted and returns the last valid design configuration, with the minimum length of the conductor casing or the minimum cement top of the surface casing.

We analyzed several optimization techniques to evaluate their performance and parameter accuracy while minimizing the criteria. Root-finding algorithms greatly improve the performance of the code to obtain the minimum values required and the three criteria were reorganized as expressions where the optimized values are in the zero neighborhood. A case study was developed to verify which optimization method provides the best results with the fewest iterations.

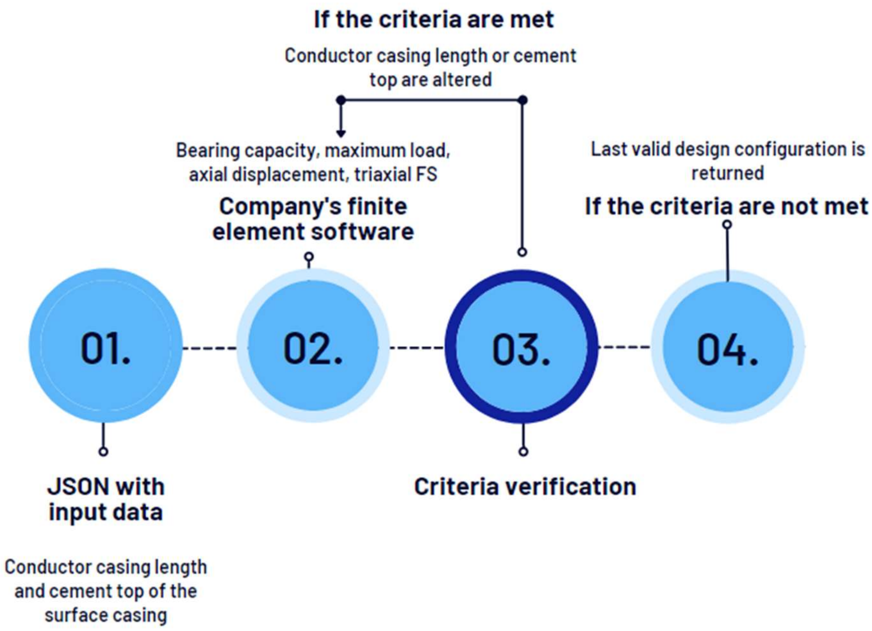

Figure 1. Parameter optimization process

In the conception of the code, we considered that the root of the function is the minimum value of the analyzed parameter that meets the design criteria. A finite interval $[a, b]$ containing the root is specified. The methods aim to refine this range until an approximate value of the root that meets the defined tolerance is reached. The methods are based on a corollary of the Intermediate Value Theorem: $f(x)$ is a continuous function in the interval $[a, b]$. If $f(a) \cdot f(b) < 0$, then $f(x)$ has at least one real root within that interval. The root-finding methods analyzed are presented below:

1. Bisection Method

It is a simple and robust method that guarantees convergence. Root determination can be slow, due to its linear convergence rate. It consists of repeatedly dividing the interval $[a, b]$ in half, verifying the signs of the function until the root is determined. It can be used to obtain a rough approximation of a solution to serve as an initial estimate of a faster convergence method.

2. Brent's classic method and with hyperbolic extrapolation

Brent's classic Method [2] combines root grouping (refinement of the interval [a,b] in which the root is), bisection, and inverse quadratic interpolation. It employs a second-degree Lagrangian interpolating polynomial. The hyperbolic Brent Method applies hyperbolic extrapolation instead of inverse quadratic interpolation [3].

3. Ridder's Method

Ridder's Method [4] associates the false position method (*regula falsi*) with an exponential function to obtain an approximate root value. The method is considered faster than bisection, but not as fast as Brent's methods.

4. 748 Algorithm

The method known as the 748 Algorithm [5] employs a combination of cubic, quadratic, and linear interpolations to find the root of the function. It is considered more efficient than Brent's classic method.

3 Results

The methodology was applied to data from an oil well in an offshore Brazilian basin. The conductor length is equal to 100 m and the cement top of the surface casing is 200 m.

- 1st analysis - Variable conductor length and cement top equal to 200 m;
- 2nd analysis - Conductor length equal to 100 m and variable cement top;
- 3rd analysis - Conductor length equal to the optimal value obtained in the 1st analysis and variable cement top.

Results from the 1st analysis (Table 1) show an optimal value of 89 m for the conductor casing length, obtained by 4 out of 5 root-finding methods evaluated. Brent's methods presented the best results, considering the optimal value obtained and the number of iterations necessary. The routine is quite fast, so the time required per iteration is not a decisive factor in choosing a method.

Table 1. Root-finding methods applied to the optimization of the conductor casing's length

Method	Number of iterations	Casing length (m)	Cement top (m)
Bisection	7	91	200
Brent	7	89	200
Brent + hyperbolic	7	89	200
Ridder	12	89	200
748 Algorithm	11	89	200

Results from the 2nd analysis (Table 2) suggest 133 m as the optimal value of the cement top associated with a casing length of 100 m. The best results were obtained with Ridder's method.

Table 2. Root-finding methods applied to the optimization of the cement top

Method	Number of iterations	Casing length (m)	Cement top (m)
Bisection	7	100	137
Brent	7	100	140
Brent + hyperbolic	7	100	140
Ridder	12	100	133
748 Algorithm	13	100	133

Setting the length of the conductor casing to the optimal value obtained in the 1st analysis (89 m), a minimum value of 173 m of cement top was obtained (3rd Analysis - Table 3). Among the methods, Algorithm 748 led to the best result.

Table 3. 3rd analysis – optimal conductor length and variable cement top

Method	Number of iterations	Casing length (m)	Cement top (m)
Bisection	7	89	175
Brent	7	89	189
Brent + hyperbolic	7	89	189
Ridder	12	89	173
748 Algorithm	11	89	173

A significant difference was noted in the sensitivity of changing the parameters. A unit variation in the length of the conductor casing influences the result much more than the same variation in the cement top.

4 Conclusions

According to our analyses, the optimization methodology discussed in this paper can support oil well designers by significantly reducing the time required for this task with the implemented automatization. The implemented routine returns the optimal configuration of casing length and cement top in a couple of minutes, at most.

Based on the results, Ridder's method and 748 Algorithm provided the best results considering the reduction in the dimensions of the conductor casing and cement top. Improvements can be made to this code, including additional design criteria, for example. Another useful addition is to combine the results with an automated economic analysis to verify which solution is more viable.

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