Practical calibration of design data to technical capabilities of horizontal directional drilling rig

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Abstract. In order to design more accurately trenchless pipeline passages, a technique has been developed for calculating the passage profile, based on specific parameters of the horizontal directional drilling rig, including the range of possible drilling angles and a list of compatible drill pipe sets. The algorithm for calculating the parameters of the trenchless passage profile is shown in the paper. This algorithm is based on taking into account the features of HDD technology, namely, three different stages of production. The authors take into account that the passage profile is formed at the first stage of passage construction, that is, when drilling a pilot well. The algorithm involves calculating the profile by taking into account parameters of the drill pipes used and angles of their deviation relative to each other during the pilot drilling. This approach allows us to unambiguously calibrate the designed profile for the HDD rig capabilities and the auxiliary and navigation equipment used in the construction process.

1. Introduction

One of the criteria for choosing a drilling rig for constructing a pipeline passage by the method of horizontal directional drilling is the effort necessary to pull a pipeline of a given diameter, taking into account the properties of pipe material [1]. Therefore, in order to minimize energy costs for the construction of the passage, it is necessary to investigate the value of the effect of all factors affecting the pipeline pulling process and the ability to control the pulling process [2].

For practical application of the results of the study of the dependence of the amount of force needed to pull the pipeline on process parameters, it is necessary to calibrate the design data for the technical capabilities of the drilling rig.

In real construction conditions, the characteristics of the HDD rig, by means of which the construction of the pipeline passage is performed, can sufficiently restrict the design possibilities and cause certain difficulties in the implementation of the technical project in full-scale conditions [3, 4]. These parameters generally include not only the power of the rig, but also the possible range of drilling angles, as well as the properties of the drill pipes that can be used with this HDD rig.

The solution of the problem of calibrating theoretical design data to the characteristics of the rig itself can greatly increase the accuracy of work and maximally approximate the working draft to the data of the executive documentation for the facility [5].

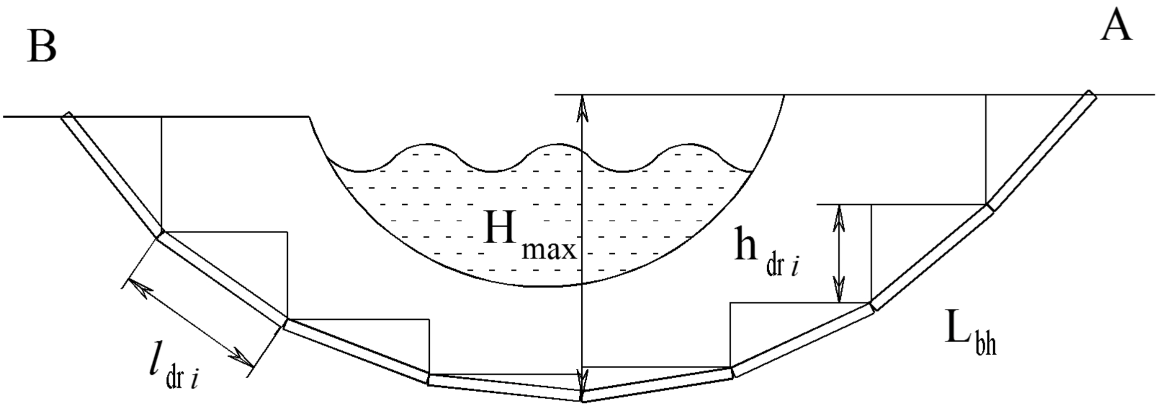

Figure 1. Well profile diagram: *A* – spudding point; *B* – point of entry of the pulled pipeline into the well; L_{bh} - borehole length; l_{dri} - length of the i-th drill pipe; H_{max} - depth of the lower point of the passage profile; h_{dri} - burial depth per one pipe.

From the point of view of practical application, calculation of the well profile must be carried out based on the geometric parameters of the drill pipes used, i.e. the length and angle of deviation of two adjacent drill pipes relative to each other [6]. Since the length of the drill pipe is known and constant, and the deflection angles can be measured or specified at the design stage, the calculation made on the basis of these parameters seems most appropriate [7].

2. Materials and methods

Figure 1 shows a well profile schematically divided into sections equal in length to the drill pipes used in HDD rigs.

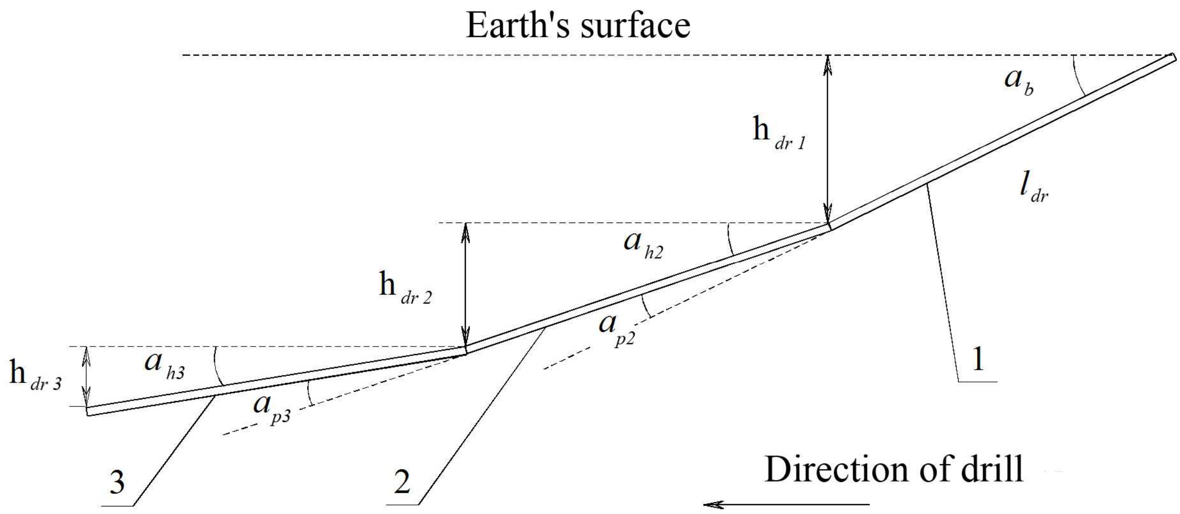

Figure 2. A fragment of the well profile: *1, 2, 3* – drill pipes; a_b – angle of spudding; a_{h2}, a_{h3} - angles of deviation of drill pipes *2* and *3* from the horizontal; a_{p2}, a_{p3} - angles of deviation of drill pipes *2* and *3* relative to the previous one; l_{dr} - drill pipe length, h_{dr1}, h_{dr2}, h_{dr3} - vertical burial depth of the drill pipe.

The maximum burial depth to the well axis is denoted by H_{max}. The axis of the well is taken as the trajectory of the pipe movement.

A section equal in length to one drill pipe is denoted by $\boldsymbol{l_{dr}}$. The depth per one current drill pipe is denoted by $\boldsymbol{h_{dr\,i}}$. The total well length is $\boldsymbol{L_{bh}}$.

In accordance with the design scheme, drilling is performed from right to left, and pulling, respectively, is done in the opposite direction.

Figure 2 shows a fragment of the well profile performed during the construction of an underground passage. Due to deviation of current drill pipe *2* relative to previous drill pipe *1* by angle a_{p2}, drill pipe *2*, after completely entering the ground, will be buried at h_{dr2} relative to drill pipe *1*, and so on.

Since the process of passage construction begins with pilot drilling, let us calculate the geometric parameters of the profile in a sequence from the point of spudding [8].

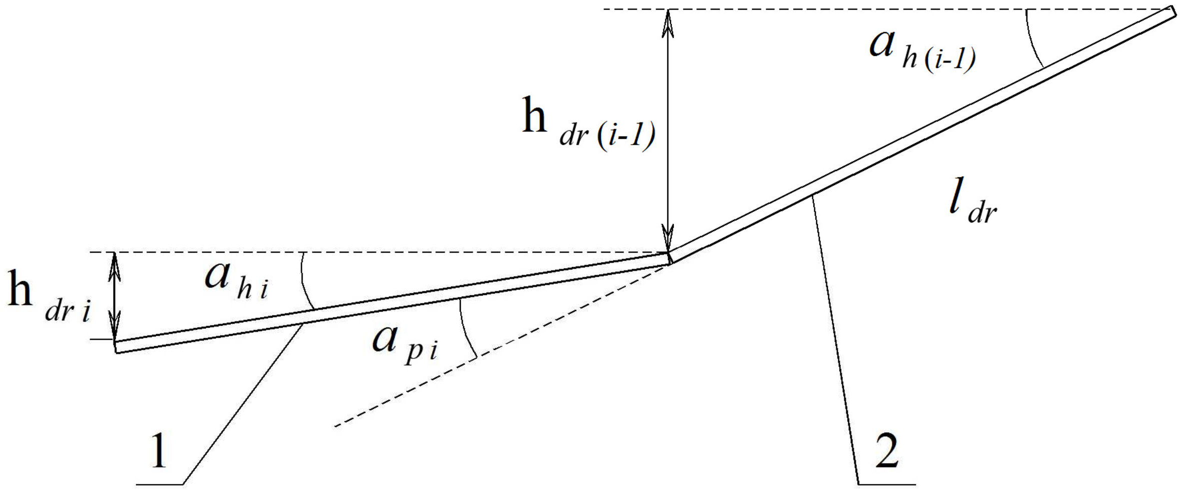

Figure 3. A fragment of the descending section of the borehole profile: *1* – current drill pipe; *2* – previous drill pipe.

There can be three cases in the sequential calculation of the burial depth of drill pipes [9]:

1. Both the current and previous drill pipes are in the descending section of the profile (see Figure 3).
2. Profile passing through the lowest point (see Figure 4).
3. Both current and previous drill pipes are in the ascending section of the profile after passing the lowest point (see Figure 5).

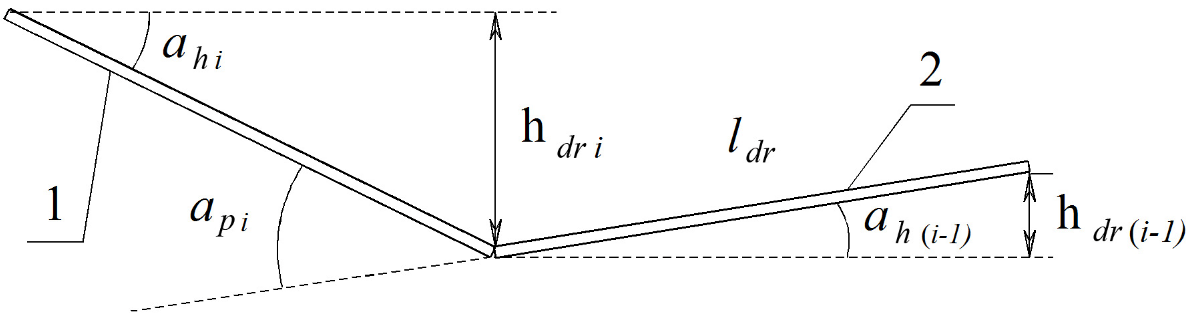

Figure 4. Fragment of the well profile at the lowest point.

Thus, for the first drill pipe:

$$\alpha_{h(1)} = \alpha_b \tag{1}$$

where $a_{h(1)}$ - angle of deviation of the first drill pipe relative to the horizon;
a_b - angle of deviation of the drill mount from the horizon (angle of spudding).
And burial depth $h_{dr\,i}$ for the first drill pipe will be equal to:

$$h_{dr1} = l_{dr} \cdot \sin\alpha_b \tag{2}$$

where l_{dr} – one drill pipe length.

For subsequent drill pipes, the burial depth for current drill pipe $h_{dr\,i}$ relative to the previous one is found:

In the first case:

$$h_{dri} = l_{dr} \cdot \sin \alpha_{hi} \tag{3}$$

where a_{hi} - angle of deviation of the current drill pipe relative to the horizon.

In the second and third cases:

$$h_{dri} = -l_{dr} \cdot \sin \alpha_{hi} \tag{4}$$

The minus sign in the formula indicates that the well profile bends in the second and third cases toward the earth's surface, i.e. depth reduction.

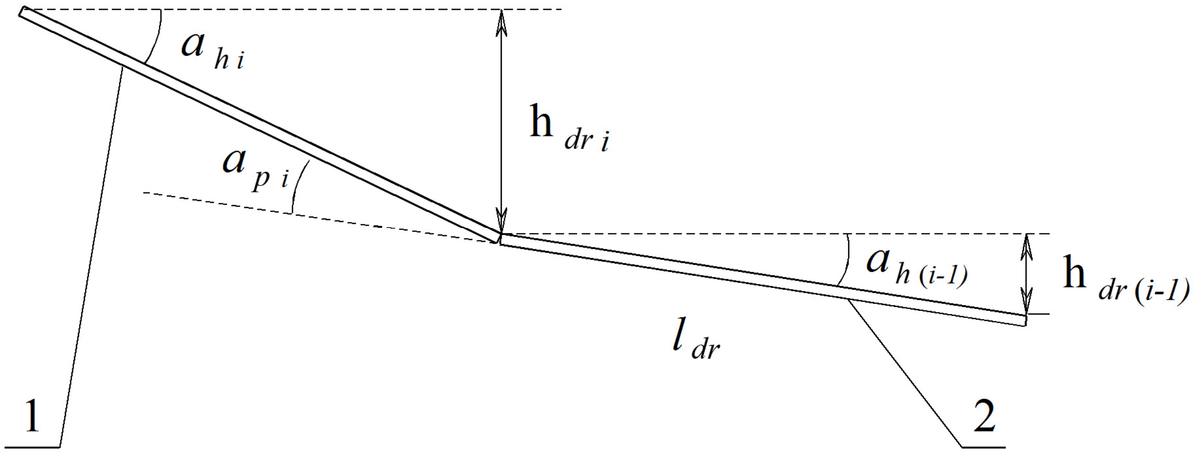

Figure 5. A fragment of the ascending section of the borehole profile.

Angle a_{hi} in the three cases above can be found in different ways.

In the first case:

$$\alpha_{hi} = \alpha_{h(i-1)} - \alpha_{p_i}. \tag{5}$$

In the second case:

$$\alpha_{hi} = \alpha_{p_i} - \alpha_{h(i-1)}. \tag{6}$$

In the third case:

$$\alpha_{hi} = \alpha_{h(i-1)} + \alpha_{p_i}. \tag{7}$$

Then the difference of elevation marks between the drilling point and the current profile point will be equal to:

$$\Delta H = \sum_{i=1}^{n} h_{dr\,i} \tag{8}$$

where n - number of drill pipes in the string.

During summation, the value of ΔH will increase until the value of H_{max} is reached, and then it will gradually decrease and at the point of exit to the surface it will take a value that is equal to the difference in the elevation marks of drilling point A and the exit point to surface B (see Fig.1).

To calculate pulling parameters, it is necessary to use the obtained values of ΔH in the reverse order with reference to the corresponding drill pipes [10].

In case the well profile is given by a constant-radius curve, which may be convenient, values of the borehole bottom burial depth relative to the earth's surface depending on the current well profile can be calculated as follows.

The maximum burial depth of the well profile is determined as:

$$H_{\max} = R_c \cdot \left(1 - \sin\left(\frac{\pi}{2} - \alpha_b\right)\right) \quad (9)$$

where R_c - radius of curvature of the well profile.

In case of curvature with a constant radius, the well profile will be described by the equation (see Figure 6):

$$x^2 + (\Delta H - H_{\max} + R_c)^2 = R_c^2 \quad (10)$$

where x - horizontal coordinate.

For the convenience of calculations, let us assume that the burial depth of the profile is indicated by an increase in ΔH, and the exit to the day surface is indicated by a decrease in ΔH.

The center of the imaginary circle describing the well profile is placed at point $O(0;H_{max} - R_c)$.

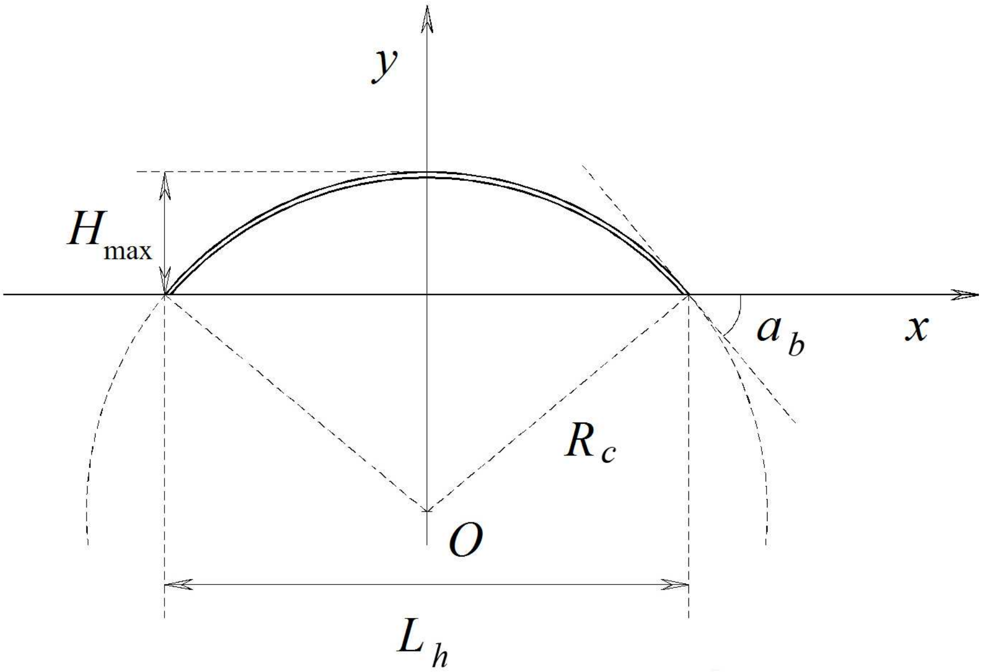

Figure 6. A scheme for calculating the curve profile of a well with a constant radius: O – center of the imaginary circle of the radius R_c; L_h – horizontal well profile length.

Then the burial depth to the current point of the profile will be equal to:

$$\Delta H = \sqrt{R_c^2 - x^2} + H_{\max} - R_c. \quad (11)$$

This will be the burial depth of the current drill pipe at this stage of the pilot well drilling [11].

3. Results and Discussion

If it is required to design a well profile of required horizontal length L_h and maximum burial depth H_{max}, then by selecting the angle of spudding from a range of possible values for a particular rig, it is possible to calculate the radius of curvature of the borehole profile at these parameters:

$$R_c = \frac{L_h}{2\cos\left(\frac{\pi}{2} - \alpha_b\right)} \quad (12)$$

where L_h - horizontal well profile length.

In (10), the current horizontal coordinate is denoted by x. To find the current coordinate along the curved well profile, let us determine the angle of the corresponding section of the profile:

$$\alpha_x = \arcsin\left(\frac{L_h}{2R_c}\right) - \arcsin\left(\frac{\frac{L_h}{2} - x}{R_c}\right). \tag{13}$$

Current coordinate L along the well profile will be equal to:

$$L = R_c \alpha_x . \tag{14}$$

Thus, the current coordinate of the well profile and the length of the drilling site along the day surface were linked.

4. Conclusion

Studying the process of pipeline pulling into the well cannot be done without taking into account the features of the technology [12]. The technology of directional drilling involves a cyclic movement of the pipeline in the well due to the need to consistently untwist drill pipes that come to the surface when the drill string is pulled out by the rig [13].

Therefore, the entire technological process of pulling is expediently divided into cycles. One cycle is the movement of the pipeline and the drill string to the length of one drill pipe [14, 15].

The paper shows a practical method for increasing the accuracy of designing a profile of a curved well for a particular drilling rig with a specific set of equipment and drill pipes.

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