Application study on numerical analysis method of onshore launching system design for over-length with large diameter HDPE pipe

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Abstract. Due to High-Density Polyethylene Pipes (HDPE) hold the characteristics of reliable connectivity and service life, good impact resistance, low fluid resistance and excellent corrosion resistance, especially for large diameter HDPE pipes are more economic, they have been applied to drainage projects. The overlength HDPE pipe with large-diameter has the combined characteristics of rigidity and flexibility, namely, rigidity is dominating within small pile length, flexibility will then dominate with the increasing of pipe length, which lead to onshore launching will be under dynamic changing process, hence the slope of launching ramp, the bearing capacity of the pipeline onshore launching system and the linear control will be very critical, which will make onshore launching of over length HDPE with large diameter more difficult. Based on the numerical dynamic analysis and simulation, and based on the JIGCC Project in Saudi Arabia, the onshore launching process of overlength HDPE with large diameter is studied. The results not only state the loading state of HDPE and launching systems during the onshore launching stage, but also provide a theoretical basis for a more reasonable and economic design of the over length HDPE with large diameter onshore launching system.

Introduction

1. Introduction

Generally speaking, the installation of over-length with large diameter HDPE pipe sections is divided into six processes [1], which are onshore transportation (including onshore welding), sea floating, adjustment and positioning, irrigation and sinking, underwater docking and pipe sections sinking. Sit on the bottom. The success of the onshore transportation process directly affects whether the subsequent underwater installation of the pipeline can proceed smoothly, and it is the leading link in the pipeline's underwater installation. As the most important link in the onshore transportation system of the pipe section, the setting of the outbound track directly determines the efficiency and success rate of the onshore transportation of the pipe section. From the perspective of ensuring the safety of the HDPE pipe section and saving production costs, the over-length with large diameter HDPE pipe section outbound track should be composed of a straight section track and multiple sections of continuously changing gradient track. Because the large-diameter and super-long HDPE pipe is composed of multiple short pipe sections which are welded onshore and installed with counterweights. The outgoing track is reasonably set up with straight sections and variable-gradient tracks to meet the requirements for onshore welding of pipe sections. At the same time, it can also meet the power requirements for onshore transportation of the pipe section, which not only improves the utilization efficiency of the construction site, but also ensures the smooth progress of the onshore transportation.
of the pipe section. In addition, the reasonable setting of the variable-gradient track has an important impact on the safety of onshore transportation of HDPE pipelines and the control of production costs.

Due to the combination of rigidity and flexibility of over-length with large diameter HDPE pipes, for variable-gradient tracks, if the track slope is too large, it will cause the pipeline near the variable slope point to hang in the air. The transportation trolley at the slope point is not conducive to ensuring the safety of the pipe section; and the too small slope means that the preparation of the transportation system requires a huge amount of working, and the underwater construction is inconvenient and costly. By rationally setting up multiple sections of ramps that gradually become steeper, the outgoing track is transitioned to the seabed surface, which can ensure the smooth and safe outgoing of the pipe section while also achieving the goal of saving production costs [2][3].

Based on the above considerations, in order to improve the installation efficiency of the HDPE pipe section and ensure the safety of the pipe section, from the perspective of economy and rationality, this paper uses the numerical analysis of the motion state of the over-length with large diameter HDPE pipe to develop and summarize the over-length with large diameter HDPE pipe section. The principles and methods for determining the track line type for onshore transportation, under the premise of ensuring the feasibility of the pipeline for onshore transportation, study the reconciliation between the track line type design and the transportation system configuration, and design an economical and reasonable HDPE pipeline. The delivery system has been successfully applied to the HDPE pipe section installation sub-item of the JIGCC Water Intake and Drainage Project in Jizan, Saudi Arabia, which has important theoretical significance and use value for the subsequent development of similar projects [4].

2. Outbound track design

2.1 Design methodology

When the HDPE pipeline is shipped out, it is the most unfavorable state when the outgoing trolley is at the variable slope point. When the load and stiffness of the HDPE pipeline are constant, the design of the track line type of the water-entering variable-slope section is mainly determined by the angle between adjacent variable-slope sections and the carrying capacity of the trolley. In order to obtain the relationship between the angle between adjacent variable slope sections and the force of the trolley, set the angle between adjacent variable slope sections as $\theta$. Through the analysis of the different distances between the HDPE pipe and the variable slope point, it is determined that when the force of the trolley is the largest, the pipe leaves the distance $\Delta$ of the slope point. According to the same analysis method, analyze the included angle of other adjacent variable slope sections, and then obtain the relationship between the included angle of different adjacent variable slope sections and the maximum force of the trolley. Therefore, the angle between adjacent slope sections and the maximum trolley carrying capacity should be adapted to each other.

According to the above theoretical analysis results, $\theta_{\text{max}}$ is determined as the maximum included angle of the variable slope section, and then according to the characteristics of the actual site, the line type of the outgoing track is determined, and the total length of the outgoing track is set to $L$. Among them, the horizontal section length $L_1$, the sliding section length $L_2$, and the total length of the slope is $L_3$. Through the linear combination of the outgoing track, the elevation of the top of the track's front end is gradually reduced from above the water surface to below the water surface, and the track is transitioned to the seabed surface.

After the track linear type is determined, the finite element software Midas is used to conduct a dynamic numerical analysis of the pipeline's onshore transportation process to verify whether the water-entry variable-slope section track and the selected trolley meet the requirements of on-site construction according to the above-mentioned track design theory analysis.
2.2 Dynamic numerical analysis

2.2.1 Parameter definition
The over-length with large diameter HDPE pipes used for underwater installation are usually composed of HDPE pipe joints, counterweights and blind plates used to block pipe ports. During onshore transportation, hoists and other machinery are used to provide movement force, and the onshore transportation process is completed under suitable water level conditions. In order to facilitate the analysis and description below, the parameters used in the calculation are defined in Table 1.

| No. | Load Type                                           | Parameter | Unit   |
|-----|----------------------------------------------------|-----------|--------|
| 1   | Pipe weight                                        | \( G_p \) | KN/m   |
| 2   | Traction force of the blind plate on the offshore side | \( F_Q \) | KN     |
| 3   | Buoyancy of offshore pipeline                      | \( F_F \) | KN     |
| 4   | Counterweight                                      | \( G_W \) | KN     |

2.2.2 Determination of boundary conditions
In the numerical analysis of the outbound state of over-length with large diameter HDPE pipes, the boundary conditions are mainly determined by the following aspects:

- **Dry boundary.**
  For the slope section of the track, the boundary conditions of the sliding section \( L_2 \) and the variable slope section \( L_3 \) need to be determined. Because the track of the descending section has a single gradient, it is the transition section of the straight section track and the variable-grade section track, so the pipeline unit and the delivery track are always in contact, that is, the interaction between the pipeline unit (including the delivery trolley) and the track always exists. According to this situation, in the Midas calculation program, only the elastic support of the compression node is selected to describe the interaction between the outgoing trolley and the track of the sliding section.
  The pipeline unit located on the slope, due to the continuous change of track slope and the dominant rigidity of the short pipe section, will cause the pipeline units on the adjacent two sections of variable slopes to have a certain degree of suspension, that is, the pipeline unit needs to have a quantitative vertical direction. After the displacement, the pipeline unit (including the transport trolley) will interact with the track. To solve this problem, pressure-only gap elements and general supports are used to describe the interaction between the pipeline unit and the variable-grade track during onshore transportation.

- **Wet boundary.**
  After the front end of the pipeline enters the water, due to the nonlinear relationship between the buoyancy of the pipeline and the ballast block and the depth of the water, in order to accurately simulate the force change during the pipeline entry into the water, the finite element method of thinking is used to measure the buoyancy of the pipeline and ballast block. Discretization simulation. Specifically, a single section of HDPE pipe with a total length of \( L \) is divided into \( \Delta L \) pipeline control units, and each counterweight area serves as a control unit. As shown in Figure 1, the spring model is used to simulate the buoyancy of each control unit.
When projecting to numerical calculation, node elastic support is added to each control unit, and considering that the buoyancy of each control unit changes with the water penetration depth, the node elastic support is set to a polyline type.

\[
F_V = 10.25 \times S \times \Delta L
\]

\[
S = r^2 \arccos \left( \frac{r - h_d}{h_d} \right) - (r - h_d) \sqrt{r^2 - (r - h_d)^2}
\]

Where:
- \( S \) - Pipeline draft area (\( m^2 \));
- \( \Delta L \) - Length of pipeline control unit (\( m \));
- \( r \) - Pipe radius (\( m \));
- \( h_d \) - Pipeline draft (\( m \));

According to formula (1), the buoyancy of the pipeline at different drafts \( h_d \) can be obtained. According to the same calculation method, the buoyancy of the counterweight can be obtained. Input the buoyancy force at the corresponding draft as the spring force into the polyline shape in the Midas software, and start the calculation after inputting the weight of the pipeline and the weight of the counterweight. It should be noted that in the multi-fold linear input parameters of the software, when the pipe draft \( h_d \) exceeds the pipe diameter, it indicates that the pipe has been completely submerged under water. At this time, the spring force should be constant and equal to the buoyancy of the pipeline when \( h_d = 2r \).

2.2.3 Calculation and analysis
Since the pipeline delivery process is a continuous process, as mentioned above, when the pipeline unit and the delivery trolley are located at the slope change point, due to the rigidity of the pipeline unit dominates, some of the pipeline units on the slope change track are suspended. As a result, the weight of the pipeline and counterweight is concentrated on the adjacent outgoing trolley, which may exceed the carrying capacity of the outgoing trolley, which is the most unfavourable working condition. Therefore, the numerical analysis of the moving state of the over-length with large diameter HDPE pipeline mainly focuses on the analysis of the force state of the transport trolley at the variable slope point, which is used as a controlled working condition for research. In order to fully obtain the force state of the pipeline at each position during the transportation process, it is necessary to successively analyze the stress state of the pipeline unit and the transport trolley when the pipeline
control unit with the length of $1^* \Delta L$, $2^* \Delta L$, $3^* \Delta L$...$n^* \Delta L$ ($n = \frac{L}{\Delta L}$) crosses each slope point in turn.

When the front section of the pipeline floats after entering the water, the buoyancy of the pipeline and the counterweight can be used to resist the part gravity of the pipeline to reduce the concentrated load of the transport trolley. When the front section of the pipeline floats smoothly on the sea, the transport trolley has passed Extreme use state, the dynamic numerical analysis process can be ended at this time.

3. Application in engineering

The installation of HDPE pipes in the JIGCC water intake and drainage project in Saudi Arabia includes 6 HDPE pipes with an inner diameter of 3000mm, each of which extends about 2.5km to the sea side. The construction is divided into 7 installation sections of non-equal length, and sectional joints are connected by flanges. The inner diameter of the HDPE pipe is 3m, and the maximum theoretical design length of a single pipe section is 561.92m, which belongs to the category of over-length with large diameter HDPE pipe sections. In this project, the length of a single HDPE pipe section is 5.85m, and the pipe head is a flanged pipe section with a length of 2.1m. The counterweight is arranged at the node of the pipe joint, and the shipping trolley is located under the counterweight as shown in figure 2.

The total length of the track is 635m, divided into horizontal section $L_1 = 250$m, downhill section track slope ratio is 1:70, length $L_2 = 325$m, the slope ratio of variable slope section gradually is 1:45, 1:35, 1:25, 1:18, 1:2, the total length of the variable slope section is $L_3 = 60$m, the top elevation of the track front end is gradually reduced from above the water surface to below the water surface, and then the track is transitioned to the seabed surface from the steep slope of 1:2. This section takes the track line type as an example to illustrate the numerical analysis of the onshore launching state of an over-length with large diameter HDPE pipe.

Using the idea in section 2.1, the analysis shows that the trolley receives the maximum force when the pipeline leaves the variable slope point ($3^* 5.85 + 2.1$) m, as shown in Figure 3. According to this analysis method, analyze the angles of other adjacent variable slope sections. The relationship between the included angle of different adjacent gradient sections and the maximum force of the trolley is obtained, as shown in Figure 4. It can be seen from Figure 5 that the included angle of adjacent variable slope sections is in the range of 0.4°~1.6°, and the included angle of adjacent variable slope sections is approximately proportional to the maximum force of the trolley. In this project, the included angle of the maximum variable slope section of the track is 0.88°, so the maximum trolley load is 731 KN.
After calculating and analyzing each working condition of the pipeline transportation process according to the loads and boundary conditions provided in section 2.2.2 and 2.2.3, due to the many dynamic numerical analysis working conditions of the pipeline transportation process, it will only show when the pipeline transportation tends to be stable (when the front end of the pipeline is floating...
on the water, \((18 \times 5.85 + 2.1) \ m\) pipeline crosses the 1:70 variable slope point working condition), the finite element analysis results of the trolley and the pipeline

Figure 6 shows the force of the outgoing trolley when \(n = 18\) pipeline units cross the 1:70 gradient point. It can be seen from the figure that under this working condition, the force of the trolley is \(478KN < 750KN\), which meets the requirements of use.

Figure 6. Force diagram of the outgoing trolley (unit: \(KN\)).

Figure 7 shows the displacement change of the outgoing trolley when \(n = 18\) pipeline units cross the 1:70 slope point. In this project, the difference between the 0.2m water level at the front end of the pipeline and the bottom edge of the pipeline is 0.099m, that is, when the front section of the pipeline has not entered water, it is located at 0.099m on the water surface. According to Figure 7, when the front end of the pipeline is in a stable floating state, the draft is \(1.433 \times 0.099 = 1.334m\);

Figure 7. Displacement diagram of outgoing trolley (unit: m)

Figure 8 shows the stress distribution of the pipe where \(n = 18\) pipe elements cross the 1:70 slope point. It can be seen from the figure that the pipeline stress is \(2.77 \ MPa\), which is less than the pipeline allowable stress \(12.3 \ MPa\), which meets the design requirements.

Figure 8. Stress diagram (\(MPa\))

By analogy, in accordance with the above calculation process, the rest of the working conditions are analyzed, and the results of the analysis of the force of the shipping trolley and the stress of the pipeline are obtained, as shown in Table 2. It can be seen from Table 2:

- When the HDPE pipeline is onshore launching within the 60m variable slope section, the presence of the slope point causes a large change in the force of the outgoing trolley, but the force of the trolley is less than \(750 \ KN\);
After the HDPE pipeline exceeds the 60 m variable slope section, the force of the trolley in the variable slope section remains basically stable;

The stress level of the HDPE pipeline is relatively low during the onshore launching process;

After the (13*5.85+2.1) m pipeline crosses the 1:70 slope point, the pipeline begins to float.

### Table 2. Outgoing trolley and pipeline stress.

| No. | Distance from slope of 1:70/m | Maximum force of trolley /kN | Maximum combined stress of HDPE pipe /MPa | Draft at the front end of the pipeline /m |
|-----|-------------------------------|-----------------------------|------------------------------------------|-----------------------------------------|
| 1   | 1*5.85+2.1                    | 578                         | 2.52                                     | 0                                       |
| 2   | 2*5.85+2.1                    | 435                         | 2.24                                     | 0                                       |
| 3   | 3*5.85+2.1                    | 427                         | 2.22                                     | 0                                       |
| 4   | 4*5.85+2.1                    | 427                         | 2.22                                     | 0                                       |
| 5   | 5*5.85+2.1                    | 551                         | 2.24                                     | 0                                       |
| 6   | 6*5.85+2.1                    | 432                         | 2.23                                     | 0                                       |
| 7   | 7*5.85+2.1                    | 489                         | 1.71                                     | 0                                       |
| 8   | 8*5.85+2.1                    | 484                         | 2.23                                     | 0.160                                   |
| 9   | 9*5.85+2.1                    | 487                         | 2.23                                     | 0.453                                   |
| 10  | 10*5.85+2.1                   | 485                         | 2.23                                     | 0.811                                   |
| 11  | 11*5.85+2.1                   | 484                         | 2.23                                     | 1.187                                   |
| 12  | 12*5.85+2.1                   | 484                         | 2.23                                     | 1.532                                   |
| 13  | 13*5.85+2.1                   | 489                         | 2.23                                     | 1.568                                   |
| 14  | 14*5.85+2.1                   | 487                         | 2.23                                     | 1.560                                   |
| 15  | 15*5.85+2.1                   | 487                         | 2.23                                     | 1.541                                   |
| 16  | 18*5.85+2.1                   | 487                         | 2.78                                     | 1.334                                   |

Note: Allowable bearing capacity of trolley=750kN, allowable stress of HDPE pipe=12.3MPa

4. Conclusion

In this paper, the finite element method is used to carry out a dynamic numerical analysis of the over-length with large diameter HDPE pipeline offshore installation, onshore launching, and the finite element software Midas is used to carry out the numerical analysis and calculation, and the numerical analysis results of the over-length with large diameter HDPE pipeline offshore installation, onshore launching are successfully applied to the HDPE pipe section installation sub-item of the JIGCC water intake and outtake project in Jizan, Saudi Arabia, is of reference significance for the subsequent development of similar projects.

Within the scope of this paper, the main research results obtained are shown as follows:

- A method to determine the boundary conditions of the numerical analysis of the onshore launching state of an over-length with large diameter HDPE pipe is given, and the idea of simulating the buoyancy of the pipe unit and the counterweight with a spring model is proposed. The research results show that it is feasible to simulate water buoyancy by using the elastic support of multi-fold linear joints.

- Giving the thought and principle of the line design of the outbound track. When the angle between adjacent slope sections is within a certain range, the supporting reaction force of the outgoing trolley is positively correlated with the angle between adjacent slope sections. Economical and reasonable outbound track line system can be designed through the angle between adjacent slope sections.

- Designed the optimal track line system for the HDPE installation of the JIGCC water intake and outtake project in Saudi Arabia. The slope ratio of the downslope section is 1:70, and the slope ratio of the variable slope section is gradually 1:45, 1:35, 1:25, 1:18, 1:2, which ensures the safe and efficient onshore launching of the pipeline, it also reduces the amount of onshore launching working, saving time and economic costs.
References

[1] Yang Lei. Construction technology of large diameter HDPE discharge pipe [J]. Traffic Engineering Construction, 2013(4): 12-16.

[2] Li Li, Shi Yudong. HDPE pipe construction technology in municipal water supply and drainage construction[J]. Heilongjiang Science and Technology Information, 2013(7):260-260.

[3] Ge Yepeng. The application of high-density polyethylene pipes[J]. Shanxi Science and Technology, 2008(3):161-162.

[4] Gao Lixin. Application of HDPE pipe in municipal drainage engineering [J]. Water Supply and Drainage, 2003, 29(4): 69–72.