A research for the safety influence of dropping anchor on the submarine pipeline

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Abstract. The oil submarine pipeline would transfer the gas from the oil well offshore to the land. Considering the wharf may be located nearby area and the pipeline would pass through under the ship channel. There would be danger to the pipeline when the dropping anchor at the emergency situation. In this research, the process of the anchor dropping is introduced. Firstly, the speed of the anchor was obtained by experimental method when the anchor falling to the seabed above the pipeline. Meanwhile, the maximum impact force of the dropping anchor at different protective layer situation was also tested. This research would be instructive to the design of pipeline protection.

1. Introduction
In some bay and harbors, there are many submarine pipelines lay on the seabed. Due to the intensive shipping in our country’s offshore areas, the frequency of dropping anchor would be higher. When a ship needs to brake by falling the anchor because of an emergency, especially the anchor falls near or above the submarine pipeline, it will cause a greater impact on the pipeline. Once the oil pipeline was damaged, it would bring on extremely expensive maintenance costs and environmental pollution problems. Therefore, the anchoring problems should be pay attention to research. More and more researches have focused on the damage and protection of the submarine oil pipeline recently. Wang[1] used energy analysis method to establish a mathematical model of impact damage for submarine pipeline anchoring operations. By using this numerical model, the influence of the anchoring impact on the depression depth and the thicknesses of the concrete protection layer is analyzed in the Bohai Bay. In order to evaluate the risk of submarine pipeline, Tan[2], Wang[3] and Liu[4] discussed the probability of the ship anchoring on the pipeline and the damage degree of the pipeline, based on the Det Norske Veritas Industrial Standard (DNV-RP-F107)][5]. Yu[6] researched the effect of the slope ratio on the protection layer stability. Chen[7] used the numerical method to study the influence of soil situation on the soil piercing depth by anchor falling. Lei[8] aimed at the rockfill protection method of submarine pipelines, the stress state of submarine pipelines during anchoring operation is...
studied through simulation experiments, and the damage analysis of submarine pipelines with different
buried depths is carried out by using energy calculation methods. Li[9] conducted force and distance
analysis on the impact of ship anchoring and towing, and put forward protective measures and
suggestions on the safety protection of submarine oil pipelines in offshore oil exploration and
development. Based on the method of theoretical analysis, which is adopted from the perspective of
energy, Zhang[10] studied the case of emergency anchoring, the speed and penetration depth of the
dropping anchor as well as the depth of the anchor in the bottom of the seabed under the condition of
towing the anchor. To study the impact and protection capabilities of rockfill on ship anchors. However,
in the above research, the impact velocity of the anchor drop test is mostly estimated by empirical
formulas, and there are fewer types of proposals for pipeline protection, therefore, this paper conducts
in-depth research from these two perspectives.

Considering that the impact of the anchor dropped on the pipeline directly affects the safety of the
pipeline and the design of the covering layer, this test mainly measures and analyzes the force on the
pipeline when the anchor is dropped. At the same time, judging the pipeline safety under various
protective measures, and the most optimized protection plan is given. In order to prevent pipeline
damage caused by anchor drop or emergency anchor drop, reduce economic losses, and ensure the safety
of ships on the waterway, quantitative assessment of the impact of ship anchor drop on submarine
pipelines becomes particularly important.

2. Experimental setup

2.1 Test background
A port needs to renovate the berths in order to increase the navigation capacity of the access channel, so
the channel needs to be dredged deeply. As a result, the depth of the covering layer becomes smaller
and needs to be repaved to ensure safety of the pipeline. In this paper, the safety of the pipeline at the
bottom of the channel after the channel expansion under the condition of anchor sinking is studied. The
load distribution on the top of the immersed pipe under the condition of anchoring is obtained, which
could provide basic load data for the channel expansion project.

2.2 Research Content
The ship falls the anchor freely from the fairlead when pass directly above the pipeline. The anchor
entry into the water and hit the covering layer above the pipeline, when different protection layers are
laid above the pipeline, measure the impact force change after the impact, and study the protection of
the pipeline by different covering layers.

2.3 Test model introduction
The anchor model used in this paper is based on the geometrical similarity scaling of the Hall anchor in
the laboratory. Due to the limitation of the test tank, the scale ratio of the design test is 1:15.39. There
are many factors affecting anchor penetration depth, such as anchor type, anchor weight, wave-current
conditions, anchor drop height and anchor drop method, etc. However, the anchor weight, drop anchor
height and water depth are the most important factors[10]. Considering that there will be a certain
difference between the anchor drop speed of the prototype and the experimental conditions, in this paper,
based on the previous research results of the anchor drop in Nakayama[11], the study of the drop of the
anchor is carried out. In this experiment, the speed of the anchor falling to the bottom of the sea and the
depth of the pit when the anchor hits the bottom of the sea are measured. During the anchor falling, the
gravity of the anchor is playing a leading role, so the weight of the anchor is scaled according to the
gravity similarity criterion. This paper uses a 300,000-ton oil tanker as a prototype, and looking up
relevant ship information, the weight of the prototype with the Hall anchor is 16 tons, according to the
model scale, the weight of the anchor model is 4.39 kg, which is shown in Figure 1.
Besides, there are two markers on each side of the Hall anchor, in order to help to measure the speed of the anchor sink into the bottom of the sea, which is shown in Figure 2.

In this paper, the process of the anchor falling into covering layer at the mean water level is simulated. The design of the overburden layer is obtained according to the actual navigation channel and the similar scale of the geometric scale. On the base of consulting relevant data, the depth of the 300,000-ton tanker is 31.5m, and the fully loaded draft is 22.5m. Meanwhile, considering the impact of waves, the drop anchor height is taken as +10.0m, the experimental water level is +10.0m, bottom elevation near the engineering is -17.0m (so the actual depth is 18.0m), and the pipeline is laid on the level of -19.0m, which can be shown in Figure 3.

3. Anchor dropping test

3.1 Velocity measurement of anchor grounding moment

During the whole process of the anchor dropping, the main factors affecting the anchor drop speed are gravity and buoyancy. Based on gravity similarity criterion, this paper studies the influence of water resistance at different heights on anchor dropping speed. In the research of this part, the anchor model is hung directly above the drop anchor test point, according to adjust the height of the suspension position, the simulated drop anchor height is 10m on the water surface, and the actual water depth simulated is 18m. There is a crushed stone layer on the pipeline. During the test, the anchor dropping process was recorded by a high-speed camera, and the speed of anchor landing moment could be calculated by frame-by-frame playback. The anchor landing moment is shown in Figure 4. Through the test, it is found that the instantaneous speed of the falling anchor is 9.8m/s.

Limited by the test conditions, there is no way to test the drop of the full-scale prototype anchor under the same conditions, so prototype verification cannot be performed. However, in order to compare the test results of this paper, this paper will calculate according to the method introduced in [11]. In this paper, a numerical method is introduced to calculate the landing speed of the anchor, and the actual landing speed of the prototype anchor is compared with the calculated results.

Through the comparison results shown in Table 1, it is found that the difference between the two data is not big. This indicates that under the conditions of the experiment, although the anchor will have non-linear effects such as liquid splash when entering the water surface, the main factors affecting the anchor drop speed are still the gravity, buoyancy and water resistance considered in Eq. (2). According to the anchor height and water depth in this condition. According to Eq. (8), it is calculated that the
grounding speed of the anchor falling at a height of 10m is 8.25m/s, which is 18.8% error from the 9.8m/s measured in the test. This may be due to that the anchor model was not truthfully made. The smoothness of the anchor causes more bubbles to be generated during the fall of the anchor, which reduces the drag force of the anchor and increases the grounding speed of the anchor.

Table 1. The comparison between the measured data and simulation results [11].

| Anchor weight(t) | Height in the air(m) | Water depth(m) | Grounding velocity(m/s) | Calculating velocity (m/s) |
|------------------|----------------------|---------------|-------------------------|---------------------------|
| 16.1             | 5.0                  | 17.2          | 7.6                     | 8.21                      |
| 16.1             | 2.5                  | 17.2          | 7.2                     | 8.20                      |
| 16.1             | 0                    | 17.2          | 6.9                     | 8.18                      |

3.2 Impact test of anchor drop on the protective layer of pipeline

In order to compare the protective effect of the protective cushion above the pipe on the pipe when the anchor is dropped, five protective measures are selected for comparison in this section. According to the design of the channel and the oil pipe, the thickness of the upper protective layer of the oil pipe after the deepening is 2.0m. Five schemes are proposed in this test, which are "pure block stone", "cement briquetting", "cement briquetting plus rubber pad" and "flexible protective pad". Each scheme is described as follows:

- Pure block stone scheme: using blocks of the same weight range above the submarine pipe, the block stone layer thickness is 1.5m, and the block stone weight is selected according to 100~200kg. The model scale according to similar criteria to obtain the model block stone;
- Cement briquetting scheme: putting a layer of cement briquettes above the submarine pipeline, the size of the protective pad is provided by the designer: briquette thickness is 0.3m, overall length L=10m, width H=23.1m. The block is a cube cement block with a side length of 30cm, each cement block is spaced 5cm apart, and the cement blocks are connected with a 28mm diameter high-strength nylon rope. As shown in Figure 5, the block stone is laid on the top of the compact layer, and the thickness of the block stone layer is 1.5m;
- Cement briquette stacking rubber pad scheme: in the above cement briquetting scheme, a layer of rubber pad with a thickness of 0.2m is placed on the cement briquette layer;
- Flexible protective pad scheme: laying flexible protective pads above the submarine pipeline. The thickness of the pad is 0.25m, the width of the pad is 2m, the length of the upper layer is 9.0m, and the length of the lower layer is 6.0m, which are shown in Figure 6. It shows that in the study, two working conditions of single-layer and double-layer protective pads were considered for comparison. The block stones are laid on the protective pads with a thickness of 1.5m.

The flexible protective pad is a common Maccaferrer flexible protective pad in engineering. Considering the accuracy of the test as much as possible, in this test, the manufacturer of the Maccaferrer flexible protective pad directly provided the test model to ensure the similarity of the model.

In the test, in order to measure the impact force of the pipe when the anchor is dropped, a three-component force sensor is arranged under the pipe, and the pipe is simulated using a semicircle of the same diameter, as shown in Figure 7. In addition, the three-component force sensors are arranged along the length of the pipeline. A total of 11 sensors are distributed near the anchor point, and the sensor numbers are shown in Figure 7.

In this part of the test, the total force sensor is used to measure the total force of the pipeline under different drop heights and different protection schemes. Figure 8 shows the curve of the total force of the anchor drop at 10m and the total force of the 1.5m stone protection layer. It can be seen that the maximum impact point of the anchor drop at the moment of anchor drop is the middle (Sensor 6), and the two sides of the maximum force are gradually decreased while apart from the middle. With the time going, there will be a larger pulse at moment of the drop. Comparing different protection schemes, get the maximum value of each result in the falling process, as shown in Figure 9.
Figure 6. The internal parts diagram of flexible protective pad. (Explanation: 1. Red part denotes two occluding metal mesh covers. The position of the cover is at the thickness of the cushion h, with length and width of a and B, respectively. The length of the overlap of the two cover plates is $2a/3$; 2. Green part denotes two occlude metal net cover plate, with Length L, width B, thickness h, which h is about 0.8H; 3. Asphalt sand rubber mixture is poured on the cover.)

Figure 7. The layout of force sensors.

Figure 8. The process curve of force when the anchor falling from 10m high to 1.5m rock layer.

Figure 9. The maximum force distribution on the submarine pipe when the anchor falling to the seabed.

The y-coordinate in the total force process graph is the number of sampling points. The actual sampling interval of the model is 5ms. From the total force process, it can be seen that the time of the falling anchor force is only about 1 sampling interval, so the impact is relatively large. When the anchor drop height is 10m and only 1.5m stone protective layer, the maximum force can reach 34.5 times of the anchor weight. As the thickness of the cushion layer increases and the type of protective cushion changes, the impact force decreases. When there are two layers of flexible protective cushions, the impact force is the smallest, which is about 1/5 of the previous maximum; the second is the embedded rubber cushion and cement pressure. In the case of cushion layer, the impact force is slightly reduced but not much different from the case of only cement briquettes and block stones. It shows that the impact force of the anchor on the pipeline is greater when the protective layer is in the form of a particle pile, but the impact force is significantly reduced when the continuous medium type protective pad is embedded.
4. Conclusion

Based on the emergency anchor drop problem that may occur when the ship is traveling in the channel, this work focuses on the effect of several commonly used protection schemes from the perspective of pipeline safety and protection. In the experiment, considering the limitation of conditions, a drop anchor test under laboratory conditions was carried out to determine the grounding speed of the drop anchor. By comparing with previous related numerical methods, it is concluded that there is an error of less than 20% between the anchor dropping speed in the test and the previous results. In the future, the damage of the protective layer under different anchor dropping speeds still needs to be studied in depth.

To compare the protection schemes, the test results of the pipeline protection schemes under different protections is obtained. According to the measurement results of the impact force of the dropped anchor on the pipeline, it can be seen that under different protective layer settings, comparing the maximum impact force, it can be seen that the scheme of the impact force for the pipeline from small to large is: two-layer flexible protective pad scheme, one layer of flexible protective pad scheme, cement briquette and rubber pad scheme, cement briquette scheme, and pure block stone scheme. The results indicate that the two-layer flexible protective pad has the best protection effect among these several protection schemes. In actual projects, it can be based on the required protection effect to make the selection of the plan. In the future, to get a more accurate grounding speed of the anchor drop and the impact of the pipeline, it is recommended to carry out a prototype test.

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