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Literature Review

Literature Study Of The Effectiveness Of Flexible Pads As Submarine Pipeline Protection Due To Anchor Falls

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ABSTRACT

Subsea pipelines are critical transportation infrastructure for the offshore oil and gas industry. With the increasing construction of undersea pipeline networks and the construction of ports on coastlines, cases often occur where the landing sections of undersea pipelines intersect shipping lanes. Some of the problems faced in underwater pipes include damage to underwater pipes due to shifting and kinking, pipes hitting ship anchors, and pipes being dragged by ship anchors so that they are damaged and broken. Subsea pipelines located in shipping areas or near docks are vulnerable to the effects of falling anchors. Dropping an anchor on a pipe is one of the most severe accidents in the oil and gas industry. Considering that the impact of the anchor drop on the pipe directly affects the safety of the pipe vessel and the cover layer design, this test mainly measures and analyzes the force on the pipe when the anchor is dropped. The main objective of this study is to determine how dimensions and material composition have a significant influence on the protection of underwater pipelines. In this research, a series of discussions were carried out regarding physical model testing to study the dynamic response of a pipe network with various protection methods affected by falling anchors. The results of the two tests show that using flexible pads as a layer to protect underwater pipes is very effective and has minimal impact on underwater pipes if anchors or other heavy objects fall. Applying flexible stone pads can provide the best protection with the lowest strain and length that affects the pipe.

Keywords: Flexible Pads, Protection, Submarine Pipeline.

1. Introduction

In exploration and production activities, a tool is needed to distribute the flow of oil and gas from one point to another. Pipes are suitable for distributing oil and gas to consumers regarding exploration production.[1] Subsea pipelines are piping installations that aim to convey fluids (water, oil, gas) through piping installations located on the sea bed (seabed). Using this underwater pipe installation, fluid can be transferred from one place to another, from a production unit to another, from a storage unit to a processing unit, and from a processing unit transferred to a storage unit.[2] Subsea pipelines are critical transportation infrastructure for the offshore oil and gas industry. With the increasing construction of undersea pipeline networks and the construction of ports on coastlines, cases often occur where the landing sections of undersea pipelines intersect shipping lanes [3].

Subsea pipe installations are installed on the seabed with a particular security system so that the pipes will not shift from their location due to wave pressure, tidal currents and ground movements. The underwater pipes that follow the seabed's contour with an installed length of tens of kilometres routinely carry feed intake and other process materials. Hence, the existence of this underwater pipe is essential [4].

Some of the problems faced in underwater pipes include damage to underwater pipes due to shifting and kinking, pipes hitting ship anchors, and pipes being dragged by ship anchors so that they are damaged and broken. Subsea pipelines located in shipping areas or near docks are vulnerable to the effects of falling anchors. Dropping an anchor on a pipe is one of the most severe accidents in the oil and gas industry. The environmental and economic consequences could be substantial if the risk is not assessed carefully [5].

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More than 50 per cent of global undersea oil and gas pipeline rupture failures have been caused by third parties, and ship anchoring operations are one of the most important causes. The risk assessment of pipelines caused by falling anchors has been assessed in the code DNVGL-RP-F107.[6] Once an accident causes damage to the pipe, the economic loss is enormous, and the seawater pollution is also severe. This incident resulted in disruption and cessation of company operations.

Considering that the impact of the anchor drop on the pipe directly affects the safety of the pipe vessel and the cover layer design, this test mainly measures and analyzes the force on the pipe when the anchor is dropped. At the same time, assess the pipeline's safety under various protective measures and provide the most optimal protection plan. In order to prevent pipeline damage caused by anchor drop or emergency anchor drop, reduce economic losses, and ensure the safety of ships in the waterway, quantitative assessment of the impact of ship anchor drop on pipeline submarines becomes very important. Therefore, mitigation is needed as an effort to avoid failure. The main objective of this study is to determine how dimensions and material composition have a significant influence on the protection of underwater pipelines.

2. Test Set Up And Methodology

The methodology applied for this research is library research, where the research object is library works. The literary work is in scientific journals, books, and articles. In this research, the author will compare the application of the Articulated Concrete Block mattress method in two experimental trials.

Articulated Concrete Block Mattresses (ACBM) are artificial concrete blocks in a rectangular shape which will be installed regularly on underwater pipes (SPL) and between one block and another concrete block connected with polypropylene ropes. ACM is frequently used for scour protection purposes in various engineering applications. The ropes connecting the concrete blocks ensure a flexible network of blocks that allows the ACM to adjust its geometry to suit the structure and adapt to undulations in the river/seabed (e.g. due to scouring). In the nineteenth century, ACMs were initially designed and used to protect river banks from flood erosion. ACM is also routinely used in offshore engineering for scour protection and secondary stabilization measures. For each of these different applications, the mattress must be designed to maintain its hydrodynamic stability under design conditions, requiring knowledge of the hydrodynamic forces acting on it [7].

To estimate the energy dissipation capacity of rock protection embankments, Qiu et al. (2015) combined the discrete element method (DEM) and the finite element method (FEM) to analyze the dynamic response of pipes impacted by loads. The calculation results of energy absorption by gravel are those recommended by the DNVGL-RP-F107 code. Matahari et al. (2018) analyzed the influence of seabed material, burial thickness, water depth, and fall height on a subsea pipeline's upper surface tension history. Shin et al. (2020) conducted an experimental and limited element analysis of soil-pipe-rock interactions to quantify the effects of seabed soil properties, anchor weight, drop height, buried depth, and rock embankment height on pipe strain. Li et al. (2021) studied the effects of buried foundation materials (including clay, sand, and rock) and buried depth on the depression depth and equivalent residual pressure of a buried pipe impacted by a falling spherical object. It has been found that the layered burial method of multi-layer foundation materials can effectively increase the impact resistance of high-rise pipes [7].

In this research, a series of discussions were carried out regarding physical model testing to study the dynamic response of a pipe network with various protection methods affected by falling anchors. One protection method is tested, and the strain and deformation are analyzed to investigate the effectiveness of the protection method. This study consists of the following parts: introduction stated in Part 1; test setup and methodology are given in Section 2; experimental results and discussion are presented in Section 3; and conclusions in Section 4.

2.1. Testing Background

A port needs to renovate its berths to increase the navigation capacity of the access channel. The channel needs to be dredged deeply. As a result, the depth of the cover layer becomes smaller, and it needs to be repaved to ensure the safety of the pipe. In this study, the safety of the pipe under the channel after expansion of the channel under sinking anchor conditions is studied. The load distribution at the top of the submerged pipe under anchoring conditions is obtained, which can provide base load data for channel expansion projects.

2.2. Description of Protection Method and Prototype Size

a. Experiment 1

In this study, pipes placed on the sandy seabed were covered with a protective layer with a total thickness of 2.0

m. With a compound flexible pad + rock composition, the pipe is protected by layers of compound flexible pad and then covered with rock on top. Each layer of the flexible compound pad is 0.75 m thick. The core materials of this protection method are bitumen and gravel with geogrid, and the outer layer is covered with geotextile. The manufacturer provides details of compound flexible pads. In this study, two layers of compound flexible pads were used, each with a thickness of 1.5 m.[6] Then, the flexible pad compound is covered with stones with a thickness of 0.5 m. A sketch of the protection method is shown in Figure 1.

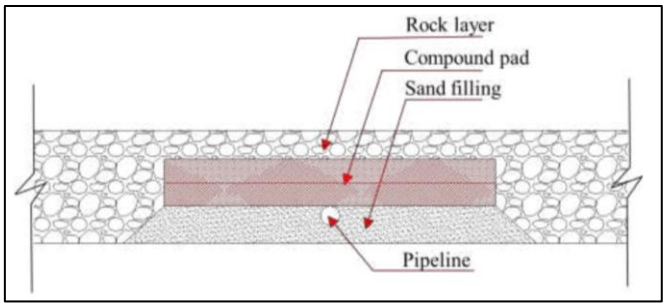


Figure 1. Sketsa compound flexible pad + rock

Based on the flume size, water depth, and measuring range, a 1:15.4 scale model was adopted in this study. The thickness of the protective layer and the outer diameter of the pipe satisfy geometric similarity, and the stiffness of the pipe is designed based on an elastic similarity model pipe with PVC pipe with an outer diameter of 40.2 mm. The length of the pipe model is 2.0 m, which is the same as the width of the drain pipe. The density of PVC material is 1360 kg/m3, and the pipe model is filled with sand iron with a total density of 3010 kg/m3 after heavy balance. The modulus of elasticity of PVC is measured at E = 2.3 × 108 N/m2. The moment of inertia is I = 6.8 × 10−8 m4, which results in a bending stiffness of the pipe model EI = 1.56 × 102 N·m2. In the experiment, the protective layer was reduced from the sketch shown in Figure 1, with a total thickness of the protective layer reaching 130 mm. A Hall-type anchor weighing 4.39 kg was used to represent a prototype anchor weighing 16.0 t [6].

In this study, the sensor used to measure pipe strain caused by falling anchors will use a fibre Bragg grating (FBG) sensor (Micron Optics Int., Atlanta, GA, USA) after obtaining the results and evaluating the protective layer's effectiveness. FBG sensor strings are arranged along the pipe axis at 90-degree circular intervals to collect top (T), bottom (B), and side (S) surface tension data. On the FGB sensor string, seven measuring points are arranged so that the distance between each point is 250 mm. The following is an overview of the test setup shown in Figure 2 [6].

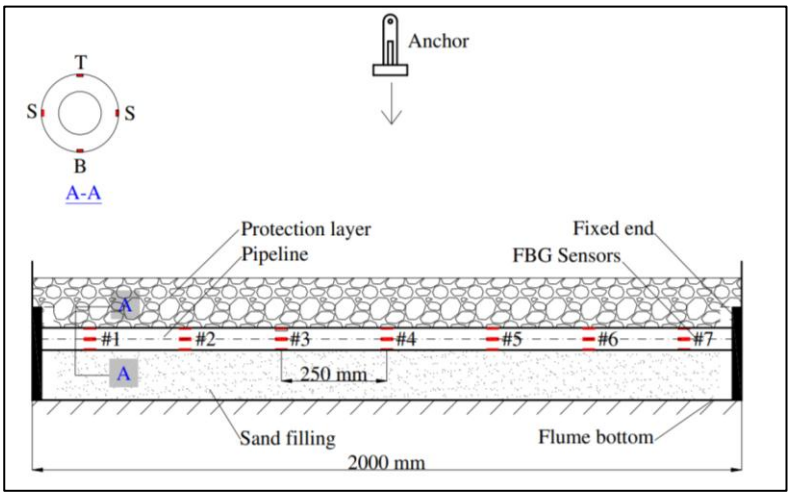


Figure 2. Test sketch

The model anchor is hung vertically above the pipe, and its position is adjusted to fall precisely at the FBG sensor point 4, namely in the middle of the pipe channel. This study tested two anchor drop heights, namely h = 1.0 m and 1.5 m above the protective layer. The orientation of the anchor is kept perpendicular to the pipe before it is removed. Due to the scattering of falling points on the pipe, the test was repeated ten times for each test. Before repeating the test, the protective layer around the drop point will be reconstructed to eliminate plastic strains left by the previous test and allow sufficient time for the pipe to recover its original state. Then, the strain offset is reset to zero. The following is a test image shown in Figure 3.



Figure 3. Testing on flexible pad + rock compound

b. Experiment 2

The anchor model used in this study is based on the geometric similarity scale of the laboratory Hall anchor. Due to the limitations of the test tank, the design test scale ratio is 1:15.39. In this experiment, the speed of the anchor falling to the seabed and the depth of the hole when the anchor touches the seabed will be measured. During the anchor fall, the gravity of the anchor plays a significant role, so the anchor's weight is scaled according to the gravity similarity criterion. This study uses a 300,000-ton oil tanker as a prototype, and looking up the relevant ship information, the prototype's weight with Hall anchor is 16 tons; according to the model scale, the weight of the anchor model is 4.39 kg [8].

This study simulates the anchor falling into the overburden at the average water level. The overburden layer design is obtained according to the navigation flow and similar geometric scale scales. Based on consultation of relevant data, the depth of a 300,000-ton tanker is 31.5m, and the fully loaded draft is 22.5m. Meanwhile, considering the wave impact, the anchor drop height is taken to be +10.0m, the experimental water level is +10.0m, the bottom elevation near the engineering is -17.0m (so the actual depth is 18.0m), and the pipe is laid at a level of - 19.0m, which can be shown in Figure 4 [8].



Figure 4. Image of the anchor falling on the protection layer

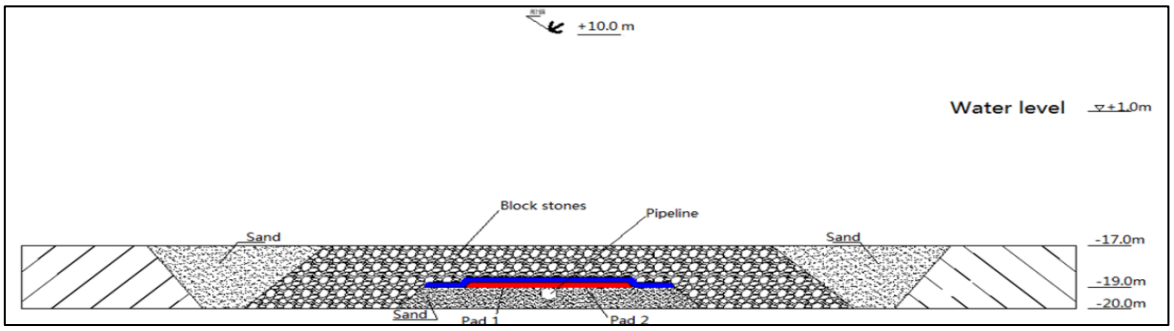


Figure 5. Anchor drop test scheme on the protection layer

In this study, the model anchor was suspended directly above the drop anchor test point; according to the height of the suspension position, the simulated drop anchor height was 10 m on the water surface, and the simulated actual water depth was 18 m. There is a broken layer in the pipe. The comparison results shown in Table 1 showed that the difference between the two data needed to be more significant. This shows that under experimental conditions, although the anchor will have non-linear effects such as liquid splashing when entering the water surface, the main factors that still influence the anchor's falling speed are gravity, buoyancy and water resistance, which are considered in Eq. (2). According to the anchor height and water depth under these conditions. According to Eq. (8), it is calculated that the speed of the anchor base falling at a height of 10 m is 8,25 m/s, which is an error of 18.8% of the 9.8 m/s measured in the test. This may be because the anchor model was not made correctly. The smoothness of the anchor causes more bubbles to be produced during the fall of the anchor, which reduces the anchor's drag force and increases the grounding speed of the anchor.

Table 1. Comparison table of measurement data and simulation results

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

The scheme used in this research is a flexible protective pad: placing a flexible pad on top of the underwater pipe. The base thickness is 0,25 m, the width of the base is 2m, the length of the top layer is 9.0m, and the length of the bottom layer is 6.0m. This shows that the study considered two working conditions of single-layer and double-layer protective bearings for comparison. The stone blocks are placed on a protective cushion with a thickness of 1.5 m.

Flexible protective pads are Maccaferri flexible protective pads standard in engineering. Considering the accuracy of the test as much as possible, in this test, the flexible protective pad Maccaferri manufacturer directly provides a test model to ensure the similarity of the model. In the test, 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 6. In addition, a three-component force sensor is arranged along the length of the pipe. [8] A total of 11 sensors are distributed near the anchor points, and the sensor numbers are shown in Figure 6.

3. Results And Discussion

a. Experiment 1

Figure 7. shows the strain distribution along the pipe at a fall height of 1.5 m. The maximum and average strain values on the top, bottom, and side surfaces are compared. The tension at the middle point of the pipe (that is, the impact point, x = 0 m) has the most significant value, and then the absolute value of the strain decreases from the middle of the two ends of the pipe. Generally, the absolute strain values on the top and bottom surfaces are in the same order but have opposite values. The strain values at points close to the midpoint are opposite to those due to local upper bending at the midpoint. The average strain value also has the same trend as the maximum value.

Meanwhile, the strain on the surface of the pipe has a relatively small value compared to those above and below the surface. The strain at the midpoint of the pipe has a positive value, indicating that the pipe is compressed vertically into an oblate shape by the anchor; thus, the side surface in the middle of the pipe is stretched. Figure 8. shows the pipe strain value at a fall height of 1.0 m. The strain values are all smaller than the fall height of 1.5 m because the anchor impact energy is more minor.

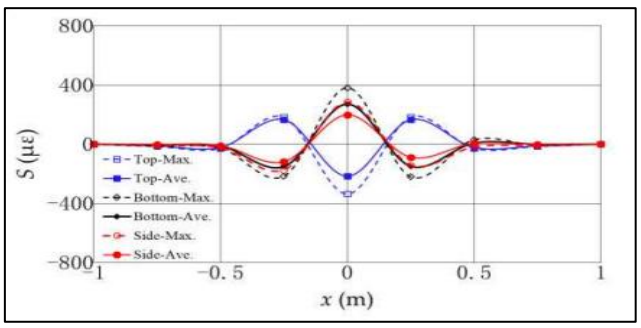


Figure 6. Strain distribution at a height of 1.5 m when the anchor falls

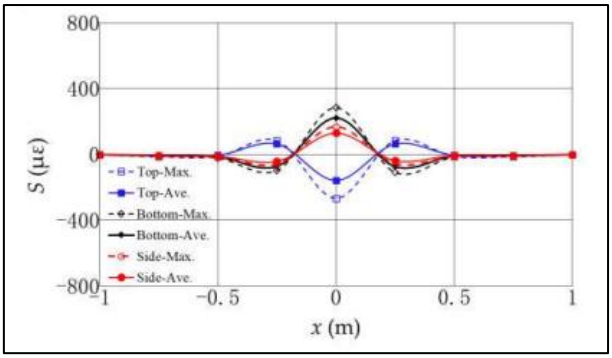


Figure 7. Strain distribution at a height of 1 m when the anchor falls

b. Experiment 2

In this part of the test, a total force sensor is used to measure the total force of the pipe under different fall heights and different protection schemes. Figure 8 shows the total force curve of the anchor drop at 10m and the total force of the rock protection layer at 1.5m. It can be seen that the maximum anchor drop point when the anchor falls is the centre (Sensor 6), and the two sides of the maximum force gradually decrease as they separate from the centre. With time going on, there will be a larger pulse at the drop. Comparing different protection schemes, obtain the maximum value of each result in the fall process, as shown in Figure 9.

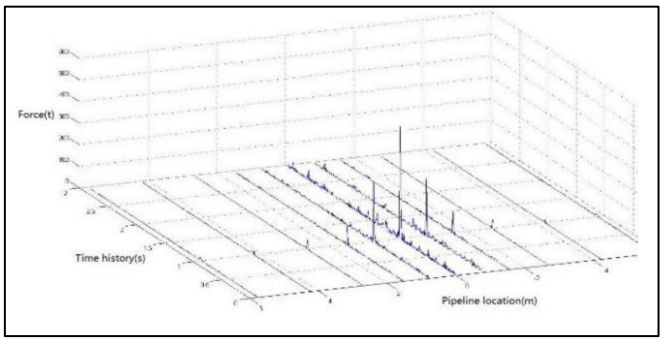


Figure 8. Force process curve when the anchor falls from a height of 10m to 1.5m rock layers.

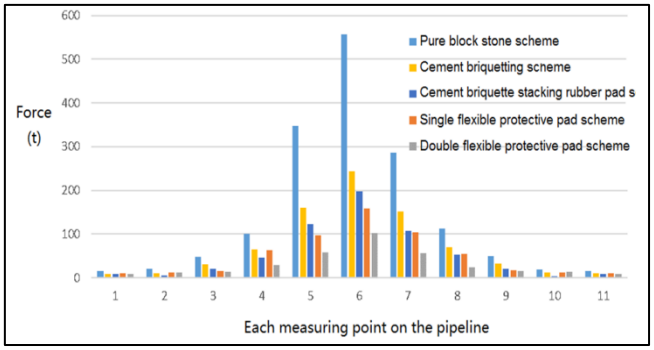


Figure 9. Maximum force distribution at subsea pipeline when the anchor falls into seabed

The number of sampling points is the y coordinate in the total force process graph. The actual sampling interval of the model is 5ms. From the total force process, the time of the anchor falling force is only about one sampling interval, so the impact is relatively significant. When the anchor drop height is 10 m and the rock protection layer is only 1.5m, the maximum force can reach 34.5 times the anchor's weight. As the pad layer's thickness increases and the protective pad type changes, the impact force decreases. When there are two layers of flexible protective pads, the impact force is the smallest, about 1/5 of the previous maximum; the second is an embedded rubber pad and cement pressure. In the case of the bearing layer, the impact force is slightly reduced but not much different from the case of cement briquettes and bricks alone. This shows that the impact force of the anchor on the pipe is more significant when the protective layer is a pile of particles. However, the impact force is significantly reduced when the continuous medium-type protective bearing is embedded. The results of the two tests show that using flexible pads as a layer to protect

underwater pipes is very effective and has minimal impact on underwater pipes if anchors or other heavy objects fall. Figure 4 and Figure 5 show that a pipe with a length of 2 m results in a strain distribution that does not reach 0.5 m., and the resulting impact force is relatively small.

4. Conclusions

In the test, the anchor is dropped from a certain height and strikes at the centre point of the pipe. The peak values and distribution of impacts along the pipeline route are analyzed. The experimental results show that the maximum strain in the pipe is located at the drop point and then decreases along the pipe axis to the two sides. The length of the drop anchor that affects the pipe can be up to 30 ~ 40 times the pipe diameter. The strain's absolute value on the pipe's top surface is almost the same as that on the bottom, which can be treated as pure bending behaviour. The strain on the top surface at the middle point of the pipe has a maximum negative value and a positive value at other points.In contrast, the strain on the bottom surface at the midpoint has positive values and other points on the bottom surface have negative values. This shows that the bending of the pipe at the point of impact is downward, while the bending of the pipe at other points is upward due to support from the surrounding soil. Applying flexible stone pads can provide the best protection with the lowest and longest stretches that affect the pipe.

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