

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

Abstract

Subsea pipelines play a critical role in the offshore oil and gas industry. The industry is recognized as a vital transportation framework. This literature review investigates the efficacy of flexible pads in safeguarding submarine pipelines from anchor impacts. The objective of the study is to evaluate the safety implications of anchor drops on submarine pipelines and to offer insights into the use of flexible pads as a protective solution. The review addresses the difficulties encountered in shielding underwater pipelines from anchor-related damage and contrasts the use of the Articulated Concrete Block mattress technique in experimental tests. Furthermore, it outlines findings regarding how dimensions and material makeup affect the protection of underwater pipelines. The review concludes by highlighting the necessity for quantitative evaluations and mitigation strategies to prevent pipeline failures due to anchor falls, minimize economic repercussions, and secure the safety of vessels in waterways. In summary, this review delivers important perspectives on the concepts, applications, and challenges involved in protecting submarine pipelines, especially concerning anchor impacts.

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1. Introduction

In the activities of exploration and production, a tool is necessary to channel the distribution of oil and gas from one location to another. Pipes effectively transport oil and gas to consumers in the context of exploration and production. Subsea pipelines are installations designed to transport fluids (water, oil, gas) through pipes situated on the seabed. This underwater piping system allows for the transfer of fluids from one site to another, whether it's from a production unit to another, from a storage unit to a processing facility, or from a processing unit to a storage unit. For the offshore oil and gas industry, subsea pipelines are a vital piece of transportation infrastructure. The construction of ports around coastlines and the expanding undersea pipeline networks have led to several situations where the landing portions of these pipelines intersect shipping routes.

Subsea pipeline installations are placed on the ocean floor with specific safety systems to prevent the pipes from moving due to wave forces, tidal currents, and ground shifts. These underwater pipes, following the contours of the seabed and stretching tens of kilometers, regularly transport feed intake and various processing materials. Therefore, the presence of these underwater pipelines is crucial.

Underwater pipelines encounter difficulties such as shifting and kinking damage, ship anchor impact, and displacement by ship anchors, which can result in breakage and destruction. Subsea pipelines located close to docks or in marine industries are particularly vulnerable to the effects of falling anchors. One of the most dangerous situations in the oil and gas industry is dropping an anchor onto a pipeline. Inadequate risk assessment could have serious negative effects on the environment and the economy.

Ship anchoring is a significant contributing cause to the more than 50% of subsea oil and gas pipeline ruptures worldwide that are ascribed to third-party operations. The DNVGL-RP-F107 code has been used to analyze the danger that falling anchors cause to pipelines. Accident-related pipe damage has a huge financial impact and can seriously contaminate saltwater, which can cause disruptions and stop business activities.

Considering that the impact of an anchor drop on a pipeline has direct consequences for the integrity of the pipe structure and the configuration of its protective coating, this study concentrates on quantifying and analyzing the force applied to the pipe when an anchor is released. Simultaneously, it examines the pipeline's safety across different protective strategies and intends to propose the most efficient safeguarding approach. To avert harm to pipelines from anchor impacts or emergency anchor descents, minimize financial repercussions, and guarantee the safety of vessels in navigable waters, a quantitative evaluation of the effects of ship anchor drops on submerged pipelines is essential. Therefore, protective strategies must be established to prevent failures. The central objective of this research is to assess how the size and material characteristics profoundly affect the safeguarding of underwater pipelines.

2. Test Set Up And Methodology

The approach utilized for this study is library research, focusing on works available in libraries. These literary sources include scientific journals, books, and various articles. In this investigation, the author intends to contrast the use of the Articulated Concrete Block Mattress (ACBM) technique across two experimental trials.

Articulated Concrete Block Mattresses (ACBM) are man-made rectangular concrete blocks that are systematically placed over underwater pipes (SPL), with polypropylene ropes connecting each block to the next. ACBMs are commonly employed for protection against scour in numerous engineering projects. The ropes linking the concrete blocks create a flexible network that enables the ACBM to modify its shape to align with the structure and accommodate variations in the riverbed or seabed, such as those caused by scouring. Originally designed in the nineteenth century, ACBs were used to safeguard riverbanks from the effects of flood erosion. They are also frequently applied in offshore engineering for scour mitigation and secondary stabilization efforts. For each of these various applications, the mattress must be engineered to maintain its hydrodynamic stability under specific design conditions, which necessitates an understanding of the hydrodynamic forces acting upon it.

In their research, Qiu et al. (2015) utilized a blend of discrete element method (DEM) and finite element method (FEM) to examine the dynamic responses of pipes subjected to loading conditions, with a particular emphasis on the energy dissipation properties of rock protection embankments. Their results concerning energy absorption with gravel align with the standards specified in the DNVGL-RP-F107 code. Matahari et al. (2018) analyzed how factors such as the type of seabed material, burial thickness, water depth, and drop height impact the tension experienced at the upper surface of a subsea pipeline. Shin et al. (2020) performed experimental and finite element analyses to investigate the interactions between soil, pipe, and rock, assessing how seabed soil properties, anchor weight, drop height, burial depth, and rock embankment height

influence pipe strain. Li et al. (2021) examined the effects of different buried foundation materials, including clay, sand, and rock, as well as burial depth, on the depression depth and equivalent residual pressure experienced by a buried pipe when struck by a falling spherical object. Their findings indicated that employing a layered burial technique with various foundation materials can significantly enhance the impact resistance of elevated pipes.

This study examined the dynamic reaction of a pipe network using different protective measures when impacted by falling anchors through a series of conversations about physical model testing. The efficiency of one protective strategy is examined, and strain and deformation evaluations are performed. This study is organized as follows: Part 1 provides an introduction; Section 2 describes the test setup and methodology; Section 3 discusses the experimental results and findings; and Section 4 presents the findings.

1. Background of the Testing

A port intends to improve its berths in order to increase the access channel's capacity for navigation. The waterway needs a lot of dredging. As a result, the cover layer becomes thinner and repaving is required to keep the pipe safe. This study investigates the safety of the pipe beneath the channel in the conditions caused by sinking anchors following the channel's enlargement. For channel expansion projects, the load distribution on top of the submerged pipe under anchoring conditions can be used as baseline data.

2. Explanation of the Protection Technique and Size of the Prototype

a. Experiment 1

In this research, pipes positioned on the sandy seabed were enveloped in a protective layer totaling 2.0 m in thickness. Utilizing a combination of a flexible pad and rock composition, the pipes are shielded by layers of the flexible pad, which is then topped with a layer of rock. Each flexible compound pad layer measures 0.75 m in thickness. The primary materials for this protective approach consist of bitumen and gravel reinforced with geogrid, while the outer layer is finished with geotextile. The manufacturer has provided specifications for the compound flexible pads. In this research, two layers of the compound flexible pads were implemented, each having a thickness of 1.5 m [6]. Subsequently, the flexible pad compound is topped with stones measuring 0.5 m in thickness. A diagram illustrating the protection method is presented in Figure 1.

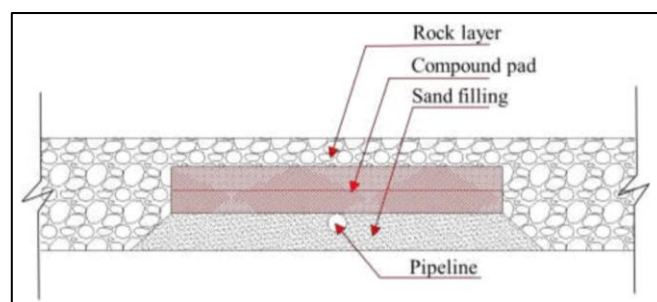


Figure 1. Sketsa compound flexible pad + rock

In this study, a scale model with a ratio of 1:15.4 was utilized, taking into account the dimensions of the flume, water depth, and measurement capabilities. The thickness of the protective layer and the external diameter of the pipe are preserved in geometric similarity, while the rigidity of the pipe is based on an elastic similarity principle, using a PVC pipe with a diameter of 40.2 mm. The model pipe measures 2.0 m in length, matching the width of the drainage pipe. The recorded density of the PVC material is 1360 kg/m^3 , while the model pipe is filled with sand iron, resulting in a total density of 3010 kg/m^3 once achieving heavy equilibrium. The elastic modulus for PVC was measured at $E = 2.3 \times 10^8 \text{ N/m}^2$. The moment of inertia was calculated as $I = 6.8 \times 10^{-8} \text{ m}^4$, leading to a bending stiffness of $EI = 1.56 \times 10^2 \text{ N}\cdot\text{m}^2$ for the pipe model.

Throughout the experiment, the protective layer thickness was diminished from the initial design depicted in Figure 1, arriving at a total thickness of 130 mm. A Hall-type anchor, weighing 4.39 kg, was utilized to replicate a prototype anchor that weighs 16.0 t. [6]

A fiber Bragg grating (FBG) sensor (Micron Optics Int., Atlanta, GA, USA) will be utilized to evaluate the strain exerted on the pipe from falling anchors after analyzing the results and confirming the protective layer's effectiveness. To collect data on the surface tension at the top (T), bottom (B), and sides (S), the FBG sensor strings are arranged at 90-degree intervals around the pipe's axis. Each of the seven measurement points along the FBG sensor string is spaced 250 mm apart. A summary of the testing environment is illustrated in Figure 2. [6]

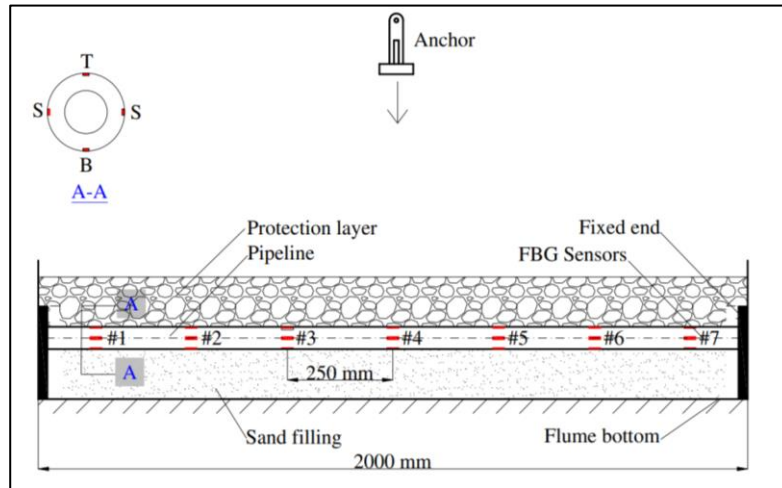


Figure 2. Test sketch

The model anchor is positioned to precisely match the FBG sensor point 4, which is located in the middle of the pipe channel, and is suspended vertically above the pipe. Two anchor drop heights— $h = 1.0$ m and 1.5 m above the protective layer—were investigated in this study. Before the anchor is removed, its orientation is kept at a right angle to the pipe. The experiment was carried out ten times for each height due to the variance in falling spots along the pipe. Before conducting the test again, the protective layer around the drop location is restored to eliminate any plastic strains from the prior test and to allow adequate time for the pipe to return to its original condition. Subsequently, the strain offset is reset to zero. Below is an image of the test, as depicted in Figure 3.



Figure 3. Testing on flexible pad + rock compound

b. Testing 2

The model anchor applied in this study is based on the geometric similarity scale of the Hall anchor used in laboratory experimentation. Due to the limitations of the test tank, the scale ratio for the design test is established at 1:15.39. This experiment aims to evaluate the speed at which the anchor reaches the seabed and the depth of the hole formed upon impact with the seabed. The anchor's weight plays a significant role in its descent behavior, necessitating adjustments to its weight according to the gravity similarity criterion. This research adopts a 300,000-ton oil tanker as the reference model, and based on pertinent vessel specifications, the weight of the prototype equipped with a Hall anchor is calculated to be 16 tons; therefore, according to the model scale, the weight of the anchor model is determined to be 4.39 kg.

In this analysis, the simulated descent of the anchor through the overburden at the average water level is conducted. The characteristics of the overburden layer are identified using analogous geometric scale factors and navigation flow. The draft of a 300,000-ton tanker is 31.5 meters, and when fully loaded, it has a measurement of 22.5 meters, as indicated by the relevant data. Additionally, considering wave effects, Figure 4 illustrates that the pipe is positioned at a depth of -19.0m, the bottom elevation near the engineering site is -17.0m (resulting in a true depth of 18.0m), the experimental water level is noted as +10.0m, and the height of the anchor's drop is marked as +10.0m. [8]



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

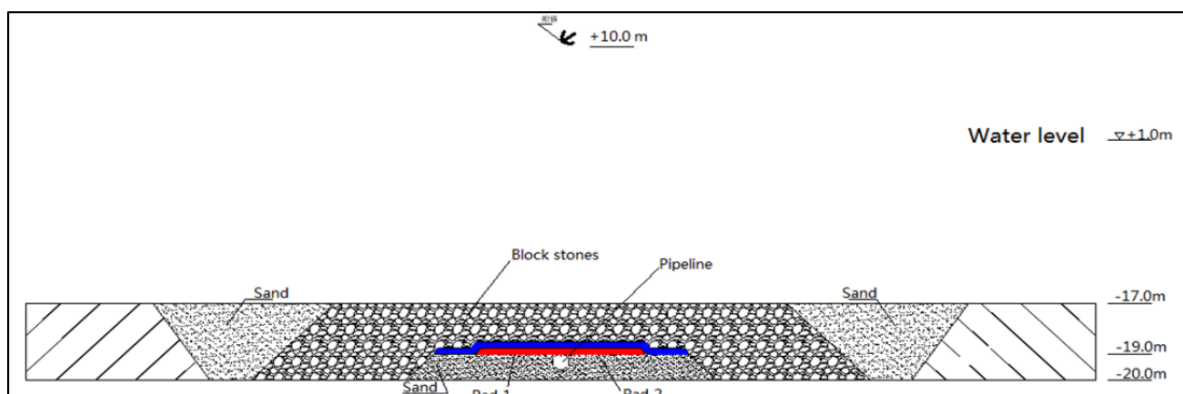


Figure 5. Anchor drop test scheme on the protection layer

In this investigation, the model anchor was situated just above the site for the drop anchor experiment; taking into account its height of suspension, the simulated drop anchor was established at 10 meters above the water surface, while the actual measured depth of the water was 18 meters. An interrupted layer exists within the pipe. The comparative findings presented in Table 1 indicated that the distinctions between the two data sets were not sufficiently pronounced. This suggests that under the given experimental conditions, although the anchor may

experience non-linear effects like liquid splashing when entering the water, the primary factors influencing the anchor's descent velocity continue to be gravity, buoyancy, and water resistance, all of which are incorporated into Eq. (2). Based on the height of the anchor and the water depth under the defined conditions, Eq. (8) establishes that the rate at which the anchor base falls from a height of 10 m is 8.25 m/s, leading to an 18.8% error when contrasted with the observed speed of 9.8 m/s recorded in the experiment. This discrepancy might be linked to possible inaccuracies in the construction of the anchor model. The anchor's smooth surface produces more bubbles as it descends, which diminishes the drag force acting on it and thereby increases its sinking speed.

Table 1. Table comparing measured data with simulated results

Anchor mass (t)	Elevation above water (m)	Water depth (m)	Grounding speed (m/s)	Calculated speed (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

In this research, a flexible protective pad is placed over an underwater pipeline. The base has a thickness of 0.25 meters and a width of 2 meters, with a top layer measuring 9.0 meters in length and a bottom layer measuring 6.0 meters in length. This suggests that the study investigated two operational conditions: single-layer and double-layer protective bearings for a comparative assessment. Stone blocks are positioned on top of a protective cushion that has a thickness of 1.5 meters.

Standard flexible protection pads from Maccaferri, which are frequently used in engineering applications, are the ones that were employed. The Maccaferri company offers a testing approach that ensures consistency in order to guarantee high accuracy in testing. A three-component force sensor is positioned underneath the pipe during the test to measure the impact force produced when the anchor is lowered; Figure 6 illustrates how the pipe is modeled as a semicircle with a constant diameter. Additionally, the pipe is equipped with a three-component force sensor [8]. Figure 6 shows the identification numbers of the 11 sensors that are positioned strategically close to the anchor points.

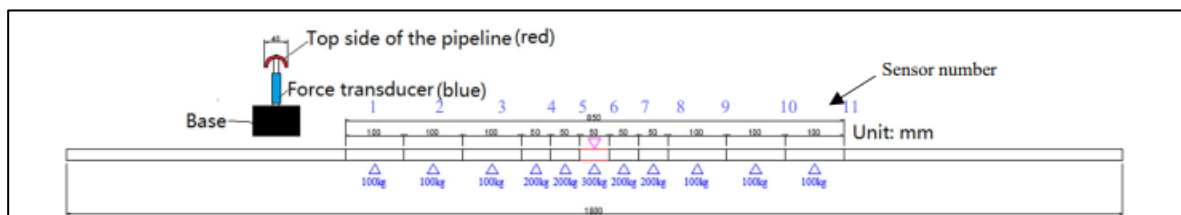


Figure 6. Sensor installation plan

3. Results And Discussion

a. Experiment 1

Figure 7 depicts how strain is distributed along the pipe after it falls from a height of 1.5 m. A comparison is made between the maximum and average strain measurements recorded on the top, bottom, and side surfaces. At the point of impact ($x = 0$ m), the tension reaches its peak, then decreases towards the ends of the pipe. Generally, the absolute strain values on the top and bottom surfaces follow a similar trend but reflect opposite values. The strain readings at the midpoint display contrasting values because of local upper bending at that location. The average strain measurements show a trend consistent with the maximum values. Furthermore, the strain detected on the pipe's surface is notably lower than that observed on both the upper and lower surfaces. The strain at the midpoint is positive, indicating that the pipe is being compressed vertically into an oblate shape due to the anchor, causing the side surface in the middle of the pipe to stretch. Figure 8 shows the strain values for the pipe at a drop height of 1.0 m, which are all lower than those recorded at 1.5 m due to the lesser impact energy from the anchor.

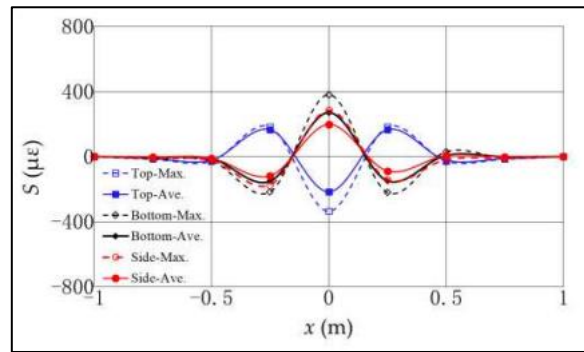


Figure 4. Strain distribution measured at a height of 1.5 m when the anchor drops.

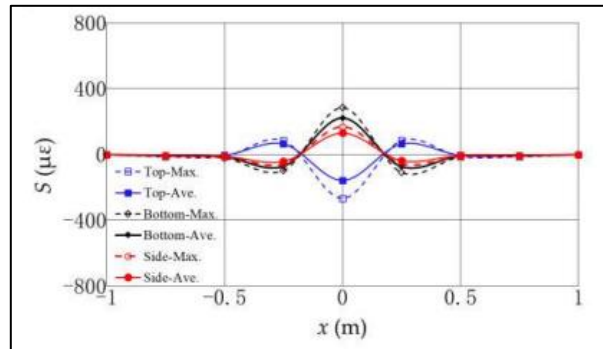


Figure 8. Strain distribution at a height of 1 meter when the anchor drops.

b. Experiment 2

In this portion of the test, a total force sensor is utilized to evaluate the overall force subjected to the pipe at different drop heights and with various protective measures. Figure 8 presents the total force curve for an anchor dropped from a height of 10 meters and the force from the rock protection layer at a height of 1.5 meters. It is clear that the maximum force during the descent of the anchor is recorded at the center (Sensor 6), while the force gradually decreases on both sides as one moves away from the center. As time advances, a more distinct pulse is observed when the drop happens. By analyzing the different protective methods, the peak values for each outcome during the falling process are documented, as shown in Figure 9.

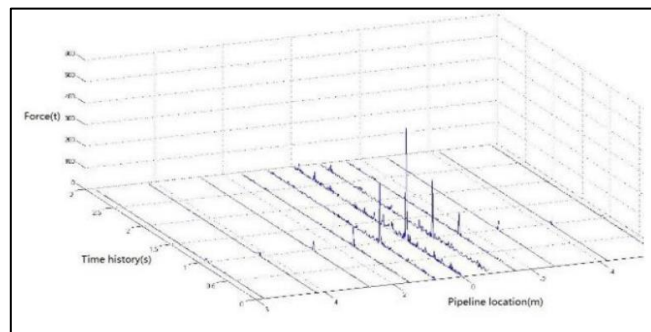


Figure 9. Force process curve when the anchor descends from a height of 10 meters to 1.5 meters of rock layers.

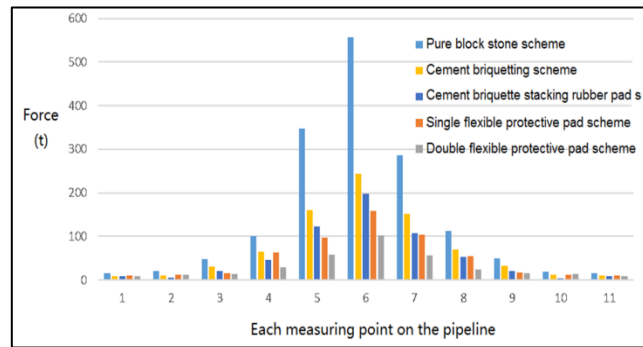


Figure 10. Optimal force allocation at the subsea pipeline when the anchor descends into the seabed.

The y-axis in the total force process graph indicates the number of sampling points. The actual sampling interval for the model is established at 5 ms. During the total force process, the duration of the anchor's falling force is roughly equivalent to one sampling interval, resulting in a significant impact. With a drop height of 10 m and a rock protection layer thickness of only 1.5 m, the peak force can reach up to 34.5 times the anchor's weight. As the thickness of the pad layer increases and different types of protective pads are used, the impact force decreases. Using two layers of flexible protective pads results in the lowest impact force, approximately one-fifth of the previous maximum; the next most effective option involves a rubber pad combined with cement pressure. While incorporating a bearing layer leads to a minor reduction in impact force, it remains comparable to the impact observed with cement briquettes and bricks alone. This suggests that when the protective layer consists of a collection of particles, the impact force exerted by the anchor on the pipe is more significant. In contrast, a notable reduction in impact force is observed when using an embedded continuous medium-type protective bearing. The results from both experiments indicate that employing flexible pads as a protective layer for underwater pipes is very effective, resulting in minimal impact on these pipes if anchors or other heavy objects are dropped. Figures 4 and 5 demonstrate that a 2 m long pipe exhibits a strain distribution that does not exceed 0.5 m, leading to a relatively low impact force.

4. Conclusion

Based on the reviewed literature, it can be inferred that utilizing flexible pads as a protective measure for subsea pipelines against anchor drops is a vital and pertinent subject in the oil and gas sector. This review of literature emphasizes the necessity of performing thorough risk evaluations regarding potential damage to subsea pipelines caused by anchor falls while highlighting the importance of mitigation strategies to minimize economic impacts and safeguard vessels in navigable waters. Additionally, the literature points out the critical need for measuring and assessing the forces exerted on pipelines during anchor deployment, as well as the importance of devising optimal protection strategies for subsea pipelines. Nonetheless, there is a requirement for further investigation to assess the effectiveness of this protective approach in practical scenarios and to establish actionable guidelines for the industry to adopt appropriate protection strategies. This conclusion indicates that the literature review offers significant insights into the concepts, applications, and obstacles associated with safeguarding subsea pipelines, especially concerning anchor falls.

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