OFFSHORE PIPELINE OPERATIONS

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Summary

The topic brings a screening on the many aspects that govern the offshore pipelines design and construction. Through the comments on the main design issues, the intention is to qualify the main physical effects that drive the behavior of offshore pipelines. Both flowlines and risers are mentioned, each one with their technical specific details and their common aspects as well. The work is aimed to give the basics of the design and also the ultimate techniques employed by the industry as well as the technological challenges which are faced by the technical community nowadays.

1. Introduction

The pipelines were drawn into the waters initially with the function of taking sewage to the rivers and oceans. The necessity of oil transportation by means of cargo ships brought the need for loading and offloading terminals by the coast. In order to allow the access to big ships near coastal areas, which were not prepared to serve as harbors, the offloading terminals were placed at some distance from the land. These situations correspond to one of the first usages of offshore pipelines but, at this time they were used to cover a relatively small distance.

A pipeline can be used to link two lands or to cross rivers. What is probably the first initiative to transport oil between two lands is the pipeline installed between England and France during the Second World War. The purpose was to provide the allies with vehicles after the invasion planned to recover the European Continent.

The oil transportation by means of ships brings the flexibility of taking oil from a production center to practically anywhere in the world. The investment is relatively small once the ship, one loading terminal and one offloading terminal, is the required structure. The transportation by means of pipelines requires a bigger initial investment, but once it is installed, the overall efficiency of oil transportation is bigger than the one performed by cargo ships.

By the middle of the 20^{th} century, the oil started to be explored offshore. The discovery of oil provinces under the seabed nearby some countries coasts brought the need for oil transportation from the offshore fields to land. The offshore oil production today is a significant part of the total world oil production.

In an offshore production field, usually a production plant facility, also called offshore platform, is placed nearby the wells used to explore the field. Then many pipelines, called intrafield pipelines are used for the connection between the wells and the production facility, between the wells and subsea equipment, and between two platforms. In general terms, the offshore production platforms are intended to take the multiphase produced flow that contains oil, gas, condensate and water, and separate basically into two products to be exported: oil and gas. Therefore, the output of an offshore platform is usually taken by export pipelines, which are much longer than intrafield lines because they need to carry the production from a production province to the land, often 200 km away or even farther. An exception exists, for the cases where export pipelines are not available: the platform can be planned to store oil and an ocean offloading terminal must be planned in order to periodically transfer oil to cargo ships.

Imagine an oil reservoir located 2 or 3 km below the seabed, and then the wells making the connection between the reservoir and the seabed. The offshore platform can then be located over the wells, and in this case a vertical pipeline placed to carry oil to the sea surface is called riser. When the platform is placed far from the wells, then a certain length of intrafield pipeline is required to cover the distance between the well and the platform. The part of the pipeline which is designed to be laid over the seabed is called flowline, and the part of the pipeline which lifts off the seabed and goes towards the sea surface to connect to the platform is called riser.

In the beginning of offshore field exploration, the gas was burned, but the overall system has evolved to the use of the associated produced gas, which besides adding more energy, is considered to be a “clean energy”, when used to run cars, for domestic use and for industry power supply. It has also the advantage of not causing environmental pollution generated by the direct burning of the gas. The gas transportation by ships is much more complex than oil transportation. Special ships must be used to transport compressed, frozen or liquefied gas in a volume that can compensate the cost of the trip. The use of gas pipelines is cost effective, but has brought the need for bigger diameters than those used for oil transportation.

In the aforementioned intrafield pipelines, besides the function of bringing the produced fluids from the wells, there are also other functions such as the water injection in order to keep the internal pressure and to help pushing the oil from the reservoir. Sometimes gas is injected into the wells and pipelines to increase the flow pressure, when it is needed, to help the multiphase production to reach the sea surface level on the platform.

Between the main offshore provinces, the Gulf of Mexico, North Sea, West Africa and Brazil, are currently the main ones, but the exploration is not restricted to these locations. Many others do exist, but these locations have received more attention because they concentrate the efforts to reach deeper waters and other challenging situations such as uneven seabeds. One of the main challenges in the exploration of offshore fields is to be able to overcome the water depth and the pressures associated to it. The definition of deep water used to be the water depths that correspond to a level beyond the capacity of diver's intervention, which is limited to 300 meters. In the primary phases of oil production, one important feature was that the offshore platforms used to be framed steel structures, called jacket type platforms, installed over the seabed, and made high enough to reach a height of 20 to 30 meters above the sea surface level. With the increase of the water depth, the fixed type structures had to be replaced by floating units. The record nowadays for the operation of a floating production unit is around 3000 meters of water depth.

The offshore pipelines differ from the land pipelines mainly by three factors: the difficulty for the construction and/or installation; the high external pressure as a function of the water column; and the corrosive and relatively cold environment represented by the seawater.

The offshore pipelines must fulfill a number of operational requirements, but among them, the structural integrity is one of the most critical one, because if a mechanical failure occurs, leakage of products causing environmental damage and even the loss of human lives can be reminded as the main risks involved. Considering a pipeline as a structure that needs to withstand operational and accidental loads, one can easily conclude that it is a kind of structure with no redundancies. When, in the framed structure, one part is damaged, it is possible that the applied loads can be redistributed and withstood by the remaining intact parts. For the pipelines, once damage occurs, no redundancy does exist to help carrying out the loads. So, it is a feature of the pipeline engineering activity that makes the design sometimes challenging.

The topic cover many aspects in order to give an idea of the main aspects involved in the pipeline design, not aiming to cover how a design is to be undertaken but to highlight the main physics involved on that. Wherever possible, the technology limits and the newest technologies are pointed out in order to give an idea of the directions being taken by the industry and by the technical community, in order to achieve the production and transportation under the most harsh and risky situations.

2. Installation and Construction

The installation of offshore pipelines is very commonly interconnected to the construction. If one thinks about the most common pipeline construction practices, it consists of several welded steel pipes measuring around 12 meters. By this process, it is possible to achieve any total length required to be covered by a pipeline.

In order to get a string of welded pipes deployed in the ocean, it was realized that specialized naval units would be necessary. Any floating unit needs to be provided with means of keeping its position under the action of environmental effects. In the beginning, the floating units used to get the pipes to the ocean were kept in position by mooring lines and anchors. It means that the movement of the installation vessel was associated to the repositioning of the anchors, as the pipeline installation progressed.

The naval technology then has progressed to the dynamic positioned vessels. These units are equipped with a set of propellers that can be turned on to compensate the tendency of a movement. Each propeller usually covers a certain range of directions. A central system gets the position and the orientation of the vessel on a continuous basis, and automatically activates the thrusters, in terms of power and direction, in order to keep the vessel aligned and in the expected position.

The installation methods considered today by operators for offshore pipeline installation can be named as: Reel-lay, S-lay, J-lay, and Tow method. The first three methods are based on laying the pipeline on the seabed from the vessels on the water surface. The vessel needs to put a certain level of tension to the pipeline in order to avoid high stresses on the pipeline sag bend. The assumed configuration is a catenary, where the higher the tension, the higher will be the departure angle with respect to the vertical direction, and the lower will be the curvature at the touch down point (point that correspond to the first point of the pipeline that reaches the soil when we imagine coming from the sea surface towards the seabed) and at the sag bend, which is the region were the pipeline presents the higher curvature level as it changes angle to be able to achieve the soil level in an asymptotic profile.

The Reel-lay method (Figure 1) consists of welding on land a certain number of pipes achieving lengths of about 1 km or more, called stalks. This fabrication process is performed at an onshore site having a port capable of receiving the installation vessel, which is equipped with reeling drums and positioned nearby the construction facility. One end of the stalk is then pulled to the vessel and connected to the reel drum that rotates and makes the pipes to conform to the drum geometry. In this process, one stalk can be welded to the other, such that the reel drum can be loaded to achieve its total capacity of pipeline length transportation. This capacity is a function of the drum diameter and also a function of pipe diameter. The order of magnitude of a typically reeled length is around 3 km.

The characteristic of the reeling method is that the construction is made onshore and the vessel goes offshore with the only task of laying the pipeline, making the installation process faster. According to the required pipeline length, it is possible that more than one vessel trip is necessary. In this case, the vessel goes back to land to be loaded again. When it is back to the offshore location, one end of a previously installed segment will be pulled from the seabed back to the installation vessel to be welded to the subsequent segment of pipeline. The process can be repeated as many times as it is necessary to fulfill the overall pipeline construction.

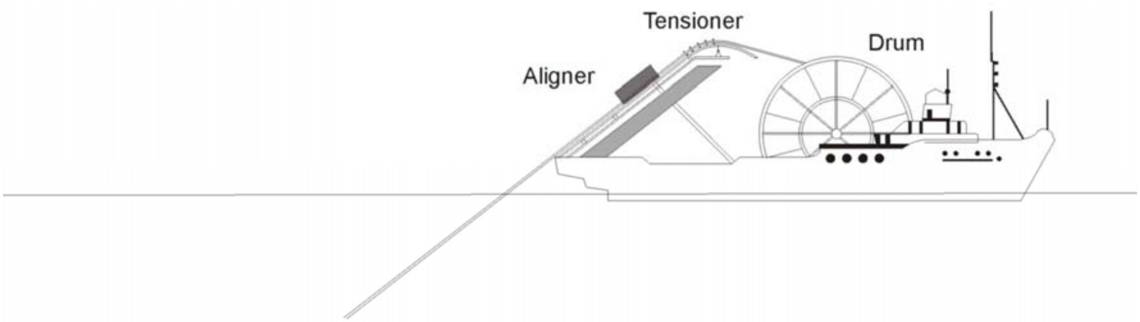

Figure 1 – Reel-lay Method

Another important feature of the reel method is that the pipes must go beyond the elastic limit in the reeling process. The elastic limit corresponds to the point from where the pipe will return to its straight configuration after being bent. After being submitted to permanent deformation (or going beyond elastic limit), a steel pipe will present a curved geometry. The vessel then puts onto the pipes an inverse plastic deformation, before laying it, in order to make the pipes to recover their straight geometry. The application of a plastic deformation brings requirements to the pipe steel and also to the welding. A minimum wall thickness is also required in order to allow pipes to withstand the bend applied without the formation of wrinkles. After the process, the level of ovalisation of the pipe sections is increased.

Today the 18-inch diameter is considered as a limit to the Reel method. One of the concerns regarding the Reel method is that whether severe fatigue damage can be applied to the pipe during the process. Another important point of concern is when the pipeline is planned to operate with fluids containing H_2S. After the reeling-unreeling process the steel would be more susceptible to the process called Sulphide Stress Corrosion. This problem tends to increase the criticality as higher steel grades are considered.

In the S-lay and J-lay methods, individual pipes or pipe sections are transported in the ship and welded offshore. The ship is moved as the pipe sections are welded and a longer pipeline length is made available.

The S-lay is named this way because the pipe is welded in the horizontal position and then it leaves the vessel in a shape similar to the shape that is assumed close to the seabed, thus making an S-shape (Figure 2). In the departure region, in order to protect the pipeline from large bending strains, a framed structure called stinger is used to promote a gradual change in the curvature of the pipeline. To guarantee pipeline integrity, not only the stinger but also a control on the pipeline tension, which is done by the control of vessel position is required. Rollers are installed along the framed structure (stinger) through which the pipe can oscillate and can be installed avoiding the wear of the outer surface.

The J-lay method was meant to be the one used for deeper waters because it requires a lower laying tension. In this case, the pipeline is welded in the vertical position. The departure angle is taken as minimum to assure pipeline integrity in the bottom region where the curvature radius has the minimum values (Figure 3). Here again the vessel position controlling the pipeline lay tension is critical to keep the sag bend region free from plastic strains. For the J-lay method the stinger is also used but usually a smaller length is required concerning what is used in the S-lay method. While in the S-lay method a horizontal long production line is available, in the J-lay method, only a working station is usually available, as the pipeline is run in an almost vertical position. To fasten the method, dual, triple or even quadruple joints are loaded into the vessel. Automated welding process as well as automated welding inspection is also employed with the same objective.

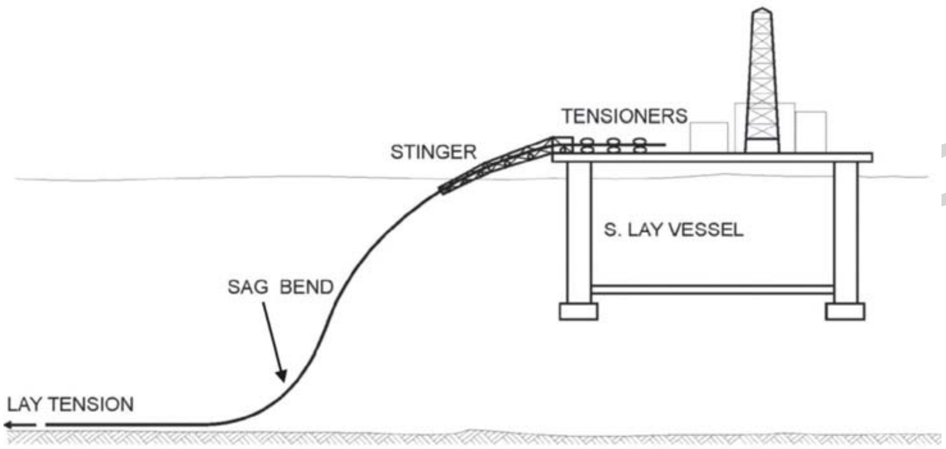

Figure 2 – S-lay Method

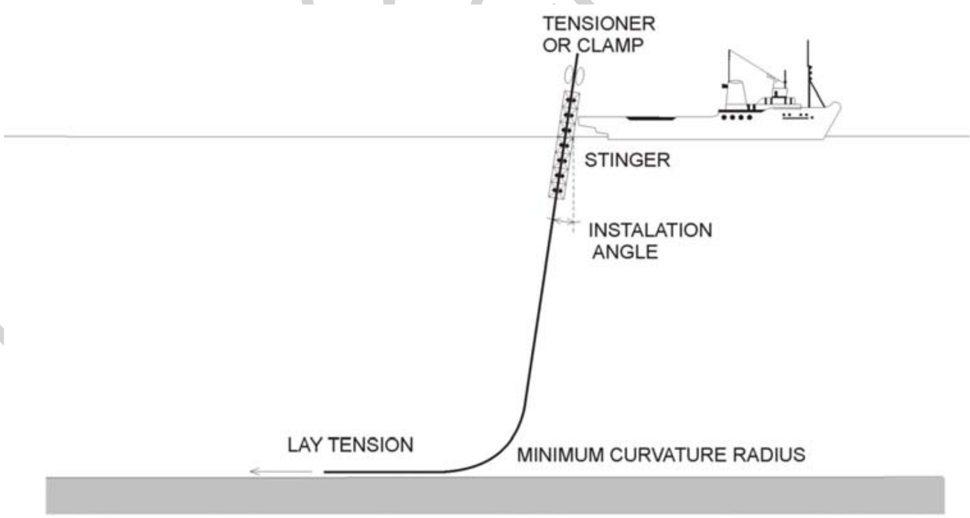

Figure 3 – J-lay Method

The installation speed is a very important parameter, as the laying vessels can have high daily rental rates representing an important percentage of total pipeline cost. Another good reason for performing offshore operations as fast as possible is the weather. The installation of a pipeline needs to be made under a certain limit of weather conditions. For any of the installation methods, the environmental conditions can govern the feasibility of the operation. As waves become higher, the vessel motions will increase and then impose to the pipeline unacceptable deformations. Also the winds and currents can bring difficulties for the installation vessel to keep in position. When planning an offshore installation, the designer needs to establish contingency plans for the extreme situations; which usually includes the pipe abandonment at the seabed for future recovery. This is the extreme measure to avoid damage to the pipeline.

Depending on the world region and time of the year, different weather conditions may exist. In some of the regions offshore installations during winter are avoided. Even in a time of the year when harsh conditions are not expected, cold masses and other nature events might happen, requiring the determination of an operational window during the design phase. The installation of a pipeline is usually a critical path for business of several billions of dollars, making the installation in any part of the year desirable to avoid delays that have high cost impacts. It means that during the operation, the weather conditions and the weather forecast need to be carefully followed. Sometimes the measurement of vessel motions, waves, currents, winds will be implemented in order to assure that the specified conditions required for pipeline integrity are not violated at any moment.

The last installation method is the tow method that has the main advantage in the elimination of the requirement for the use of a specialized pipeline installation vessel. Tugboats can be used to tow a long pipeline length from a beach site to the intended location (Figure 4). Some difficulties appear, though; a proper site must be provided, where a long section is assembled. The other difficulty consists in launching the pipeline into the water and then overcoming the shallow waters. It is not possible to simply drag a long section of pipeline against the beach sea bottom when pulling it from the land. It is then necessary to make the pipeline buoyant and the employment of buoys or floaters are extremely important in this phase of the operation, in order to reduce the friction forces with the soil. After inserting the entire section length into the water and reaching a minimum water depth, the pipeline stalk can be suspended by two vessels, one at each end, and the vessels will then travel with the same speed to the intended offshore location. This method has another advantage, besides using cheaper vessels, which is making the pipeline construction on land. The transportation process however, is sometimes complex and can cause fatigue, damage or excessive strains to the pipeline or riser section if not very well planned and executed.

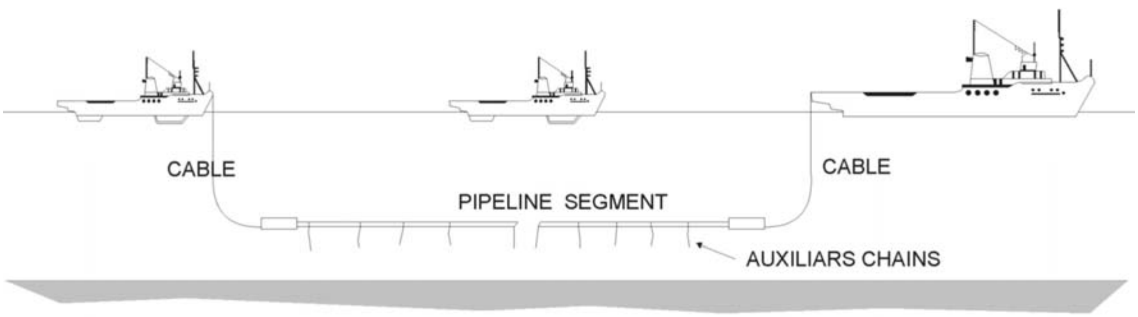

Figure 4 – Tow Method

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