해저지역 파이프라인 설계시 고려되야할 주요 문제점 연구

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A Study on the Main Considerations for Designing Marine Pipeline Systems

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1. Introduction

According to the economic globalization, the trend of international cooperation accelerates to efficiently develop world's marginal energy reserves and to deliver them cost-effectively to end-user around the world. Hence the transport becomes more important than ever before. Among many transportation methods (such like by trucks, ships, rails, and pipelines) pipelines become one of the most efficient methods to transport oil, oil products, and gas from where they are produced to where they are consumed.

As current projects are going to be transcontinental scale, pipeline should go through huge regions with different environment conditions. For the pipeline system to be well operated, it should be designed for the given environment in which it is layed. Especially in marginal deep marine fields, special considerations are required for pipeline design.

Here, we describe typical environment characteristics of marine areas and summarize the techniques for designing pipelines to overcome the constraints due to environment characteristics.

2. Major Considerations for Marine Pipeline Design

Typical main characteristics of the marine environment are deep water, current movement, buoyancy force, unconsolidated seabed, frequent seismic event, ice burg or ice cover in the arctic area, and so on. These characteristics can make it difficult the design of pipeline systems in marine environment. Special considerations for designing pipelines in the offshore are the followings.

- Special pipe laying techniques

- Pipeline deformation due to instability of seabed
- Collapse or buckling due to high pressure
- Short open-water season (in arctic area)
- Protection from damage by moving ice masses that contact the seabed (in arctic area)
- Gas hydrate or condensate flow in pipeline

Among the above factors, collapse/buckling, instability of seabed, buoyant force, and ice cover/ice burg are critical problems for designing pipeline system in the marine area.

Collapse or Buckling

An important consideration in designing and installing offshore pipelines, especially in deep water, is the prevention of collapse or buckling. Buckling can be caused by longitudinal bending of the pipe during installation. The danger of collapse or buckling increases with greater water depths and larger pipe. Factors affecting the tendency for buckling and collapse include pipe out-of-roundness, ratio of diameter to wall thickness, yield strength, and stress/strain behavior of the pipe steel.

In conventional pipelaying methods, the pressure inside the pipe during installation is atmospheric, and the external hydrostatic pressure can cause severe stresses. In some pipelaying methods today, pipe has been pressurized internally to offset the hydrostatic pressure. The seriousness of pipe buckling depends on the next external pressure on the pipe relative to the buckle initiation pressure and the buckle propagation pressure. The initiation pressure is higher than the propagation pressure.

Collapse of a submarine pipeline may be local only or it may propagate itself along the pipeline, damaging a significant length. The greatest danger of collapse is during installation, when the pipe is subjected to laying stresses. However, it can also occur after the pipe is installed if, for example, there is no internal pressure on the line. To avoid collapse and buckling requires careful design, control of curvature of the pipe during installation to stay within design criteria, and quality control of the pipe to avoid lengths with excessive out-of-roundness or other imperfections.

Pipe buckling can be expensive to repair. A dry buckle may take several days to repair; a wet buckle where the pipe is flooded with water can take weeks to repair. Repairs must normally be done with the pipelay barge on location, and lay barge rental can run as high as several hundred thousand dollars per day. In addition to design and quality control, equipment is available to use during construction to detect buckles and to halt the propagation of a buckle. Even though a properly designed, carefully installed pipeline is not likely to buckle, the severe consequences of a buckle make it common to install buckle arrestors when installing pipelines in deep water.

There are three types of buckle arrestors: the free-ring aresstor, heavy-walled cylinder or integral arrestor, and the welded ring arrestor. The free-ring arrestor is a steel sleeve of larger-diameter pipe that is slipped over the pipe joint. The integral arrestor is of heavier wall thickness than the pipe but usually has the same inside diameter and is welded into the pipeline. The welded ring arrestor is similar to the free-ring arrestor but is welded to the pipe.

Instability of Seabed

Offshore pipelines are often anchored to the seabed to prevent movement due to current, seismic effect and other external forces. One mechanical anchoring method involves screwing auger-like anchors into the seabed that hold a bracket down over the pipe, pinning the pipe to the ocean floor. Auger-type anchors must be used in a soil that offers sufficient resistance to the anchor in order to be effective. Other types of anchors that depend on weight (gravity anchors) have been used. They can be either set on the pipeline or bolted to the pipeline and are typically made of concrete.

Various techniques have developed for installing pipeline anchors. The type of anchor and installation method must be designed for each specific location. Soil conditions, particularly soil resistance, and the seabed profile are key factors in choosing the proper type of anchor, the placement method, and the location where anchors will be needed.

Buoyant Force

Offshore pipelines are coated with concrete in addition to the corrosion coating to provide negative buoyancy (a weight greater than the buoyant force of the water) to the pipeline. This added weight is necessary to sink the pipeline to the ocean floor and remain in position on the seabed. To be effective, a concrete coating must resist damage during installation and after it is in place. In addition to providing needed weight, the concrete coating protects the corrosion coating.

Design of the concrete coating is critical if it is to withstand laying stresses and resist damage from anchors, fishing gear, and other hazards during operation. Considerable research has been aimed at the improvement of concrete coatings and application methods, based in part on the performance of early concrete-coated pipelines. One of the most critical considerations in concrete coating design is the overbend area where the pipe leaves the lay barges pipe ramp during installation. If laying stresses are not properly calculated and maintained within design limits, concrete coating can crack during installation.

Application of the concrete coating is critical to its performance. Several application methods have been used: forming, guniting, extrusion, and impingement. Concrete coatings must be designed to withstand impact and stresses even though they will be trenched after installation on the seabed. Trenching is often not completely successful, and portions of the pipeline remain exposed. In addition, the line may be on the seafloor for some time before trenching can begin; during this time shipping and fishing activity can pose a hazard. Concrete coating is used in some cases to weight pipelines that cross streams.

Ice Cover or Ice Burg

Many construction techniques in arctic offshore areas are similar to those used in more moderate offshore locations. However, there are some differences required to cope with ice and with short open-water periods. For instance, a conventional lay barge may be costly due to the short work periods. Bottom-tow methods have advantages because much of the work can be done in winter and the lines placed during the open-water season. Laying pipe with a reel barge could also offer advantages in arctic waters.

On-ice construction methods are also possible. A pipeline may be laid in very shallow waters by cutting a trench through the ice and into the soil, much as in conventional land pipeline construction. In deeper water, the pipe can be welded together on the ice and lowered to the seabed through a slot in the ice. Modifications of the bottom-pull method can also be used in ice-covered areas.

Pipe in arctic waters must also be protected from damage by moving ice masses that may gouge the ocean floor. If the depth that these masses penetrate the seafloor is known, one approach is to trench the pipe below that depth. The trenching method used-jetting, dredging, plowing-depends on the type soil encountered. Those trenching methods with higher rates are the most desirable because of the short open-water season, provided the method used is able to trench in the type of soil that exists along the pipeline route.

Typical main characteristics of marine regions and special technologies for solving them are summarized in **Table 1**.

3. Field Example

In the future, production facilities and the pipelines for the transportation of oil and gas in the off-shore region will be installed in ever deeper waters. Hence, the collapse behavior of the linepipe due to the external hydrostatic pressure becomes a very important issue. Requirement for high collapse strength implies pipes with a large ratio of wall thickness to diameter, that is, heavy wall thickness pipelines.

Here is an offshore pipeline project from Oman to India. The planed project has a length of 1,200 km and a water depth up to 3,500 m, which is 4 times deeper than the deepest pipeline today. **Fig. 1** shows one of the possible routes from Oman to India through the Arabian Sea. To prevent collapse of the pipeline under an ambient external pressure of about 350 bar, the linepipe to be used has to meet severe requirements. The most important requirements for this project are shown in the **Table 2**. The key point to cover this requirement is to produce a high grade heavy wall pipeline.

Special chemical component and alloying process have to be adopted to produce and manufacture these pipelines. Metallurgically, the yield and tensile strengths of the material can be increased by increasing the alloy content. carbon, manganese and the microalloying elements such as niobium and vanadium play an important role in this connection.

For sour service linepipe, carbon and manganese contents are restricted because of high HIC resistance needed. Hence, vanadium and niobium additions are made to these materials to increase the strength. **Table 3** shows the alloy system that is used to meet such requirements as a high external hydrostatic pressure in this project.

Acknowledgment

We thank KOGAS for sponsoring the project "Case Studies related to the Design, Maintenance and Repair of Subsea and Arctic Natural Gas Pipeline,"1999. This paper is the part of the project report.

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Table 1. Typical main characteristics of marine region and problem solving techniques.

Typical main characteristics	Problems or concerns	Solving methods
Low temperature marine(arctic)	Ice cover/ice burg	New laying and tie-in method
Current movement	Gas hydrate/condensate	Pigging
Buoyant force	Instability seabed	Concrete coating
Unconsolidated seabed	Deformation	Proper route selection
Seismic effect	Collapse/bucking	Buckling arrestor
Water depth	Accessibility	Heavy wall pipe selection

Table 2. Oman-India gas pipeline requirements.

Requirement	Value
Length of submarine line	1,200 km
Max. water depth	3,500 m
Max. pipe dimension	610 mm dia. x 41 mm W.T.
Material	X70 non-sour
Yield strength	482~586 Mpa
Tensile strength	530~793 Mpa
CVN base at -10C	200/150 J
CVN weld at 10C	100/75 J
DWTT at -10C	min. 85% SA
CTOD weld at 10C	min. 0.15 mm
Out of roundness	4 mm

Table 3. Chemical answers to the requirements for heavy wall pipes.

Demand	Grade	Chemical composition (max.) (weight %)				CEQ max (%)	Notched bar Impact bend test		DWT	
		C	Mn	Nb	V		Temp. (°C)	Av (J)	Temp. (°C)	SA (%)
28"x 41 mm	X70 sweet	0.09	0.70	0.055	0.08	0.21	-10	200 (ASTM)	-10	85

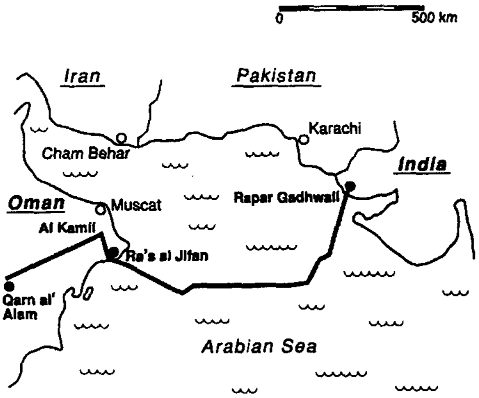

Fig. 1 Oman-India gas pipeline possible route.