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# Influence of ring-stiffeners on buckling behavior of pipelines under hydrostatic pressure

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ABSTRACT

Submarine pipelines are important and influential structures in marine engineering because they transport important, useful, and common fuels around the world. The pipeline structure is affected by different environmental forces from the surrounding conditions such as the external uniform hydrostatic pressure, hydrodynamic pressure, seismic forces, installation forces, free span forces, and forces scouring the pipeline. These conditions cause the pipeline to express complicated behavior.

Local buckling and buckling propagation along the pipeline are common examples of collapses under these conditions and loadings, which can destroy thousands of meters of pipeline. These post-buckling phenomena cause great damage and losses to the oil and gas industries and to the environment; the imposed costs for the repair and protection of pipelines and mitigation of environmental problems are high. The use of ring-stiffeners is one way of increasing the buckling capacity of a pipeline in order to prevent and control the buckling propagation in pipelines.

In this study, the buckling and post-buckling behaviors of ring-stiffened pipelines were investigated at a small scale through experiments and the finite element method (FEM). Two different ring-stiffeners were attached to the specimens. Only the uniform hydrostatic pressure was considered as the main loading; the axial stress was neglected in this study. The buckling modes, lateral displacement of the pipeline, ring tilt, formation of yielding lines, and torsion of yielding lines were examined. The results indicated that increasing the number of ring-stiffeners greatly increases the buckling capacity and lateral displacement of the pipeline. The buckling modes were changed, the post-buckling region was shortened, and torsion in the yielding lines and tilting in the ring-stiffeners clearly appeared in the tests. The results of this study were compared with those of recent research and reliable guidelines and standards.



## 1. Introduction

The uniform external hydrostatic pressure is the main constant load that affects subsea pipelines. When it combined with an external or internal factor such as bending during installation, a drill collar [1,2], or corrosion on the pipeline wall [3–6], raising the hydrostatic pressure to the buckling pressure $P_{cr}$ will cause the pipeline to buckle locally from a small cavity in the pipeline wall.

After the initial buckling, the buckling propagates if the pressure on the pipeline is higher than the propagation pressure $P_P$ [7]. This is a post-buckling phenomenon that causes a progressive structural failure. This occurrence causes the pipeline to flatten in a dog-bone shape (Fig. 1). There is a transition zone between the buckled and unbuckled regions (Fig. 1). After the initial buckling, the propagation reaches a steady state. In this situation, the external hydrostatic pressure is constant. The buckling propagation only stops when the external hydrostatic pressure becomes less than the propagation pressure or the bending rigidity of the pipe is suddenly increased by a buckle arrestor [8]. After the initial buckling, the arrestors limit the spreading damage, which may destroy hundreds of meters of pipeline [9].

The potential for buckling propagation and the limited availability of repair tools have encouraged designers to use conservative pipeline design approaches based on the propagation pressure instead of the collapse pressure. For this reason, pipelines are designed with 1.5–2 times the thickness needed to resist the collapse of intact pipes [7]. Accurately predicting the propagation pressure for deep-water pipelines will help lead to less conservative design recommendations. A preferable alternative is to design the pipeline based on the collapse pressure and install buckling arrestors at regular intervals along the pipeline.

In other words, the buckling and collapse due to external pressure are important issues that determine the design of subsea pipelines. Another important concern is controlling the propagation of the initial buckling in a pipeline. The elastic stability theory and its applications can be divided into the categories of pre- and post-buckling [10]. Kyriakedes et al. [11,12] indicated that a pipeline deforms by following a stable pre-buckling path before the buckling load. Increasing the

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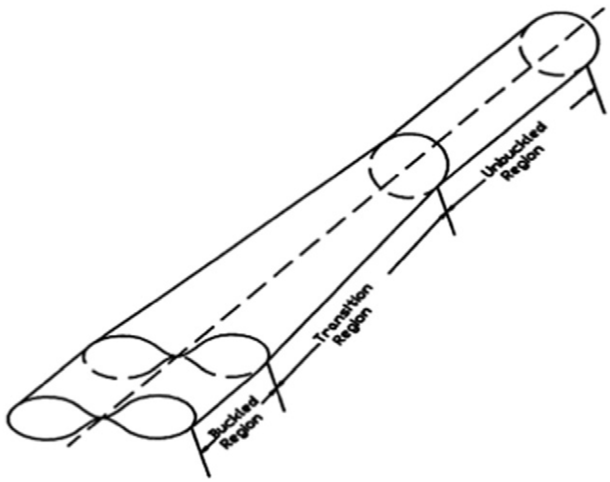


Fig. 1. Steady-state buckling propagation in pipeline.

pressure causes plastic hinges to form on the pipeline section, and the section crumples, respectively. In this step and before buckling, the pressure increases rapidly. Along this stable pre-buckling path, the pipeline experiences a contraction in the radial direction. When the external pressure reaches a critical value (i.e., the buckling load $P_{cr}$), buckling occurs. After this, the post-buckling path begins (Figs. 2 and 3). Fig. 2 shows the deformation of pipeline section along buckling, and Fig. 3 shows a plan view of pipeline wall deformation as well as stages of yielding lines formation along buckling. For elasto-plastic materials, the post-buckling behavior is highly unstable [13]. A slight increase in pressure produces ovalization until yielding occurs along the pipeline wall. Yielding lines appear during this step on the pipeline walls. After yielding, the load-carrying capacity of the pipeline drastically falls.

Buckling starts in this manner; first, a local collapse begins at a weak point on the pipeline wall [14,15]. This collapse forms a circular cavity on the pipeline wall owing to increasing external pressure. The number of these circular cavities on the pipeline wall then increases with the external pressure. Their spread leads to ovalization on the pipeline wall. As these oval cavities spread and reach each other, yielding lines appear on the pipeline wall. The propagation pressure is found to depend on the diameter-to-thickness ratio of the pipeline geometry and the yielding stress and tangent modulus of the pipeline material.

Research on pipelines under external pressure started from the mid-nineteenth century [16]. The pipe length and ratio of the diameter to the wall thickness were found to be important parameters that determine the buckling pressure. Bresse [17] used the small deflection theory to study the stability of a pipeline under hydrostatic pressure and proposed the following formula to estimate the buckling pressure $P_{cr}$:

$$P_{cr} = \frac{3E_t I}{R^3} \quad (1)$$

where R is the pipeline radius, $E_t$ is the tangent modulus of the pipeline material and I is the moment of inertia of the pipeline cross-section.

Bryan [18] formulated an expression similar to Eq. (1) for a free-standing long pipeline under hydrostatic pressure. His equation differs in terms of ($E_t$), which is replaced with $E_t/(1-\upsilon^2)$ to account for the buckling pressure under the plane strain condition of the infinitely

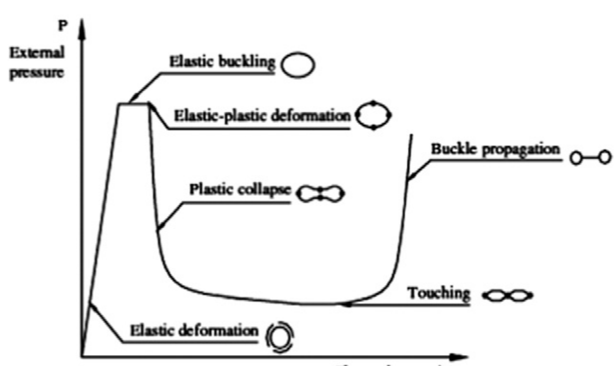


Fig. 2. Stages of buckling and post-buckling behavior on cross-section of pipeline.

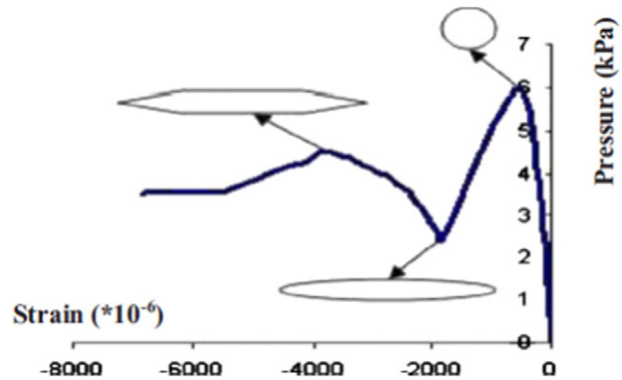


Fig. 3. Buckling propagation in post-buckling stage along pipeline wall, between arrestors.

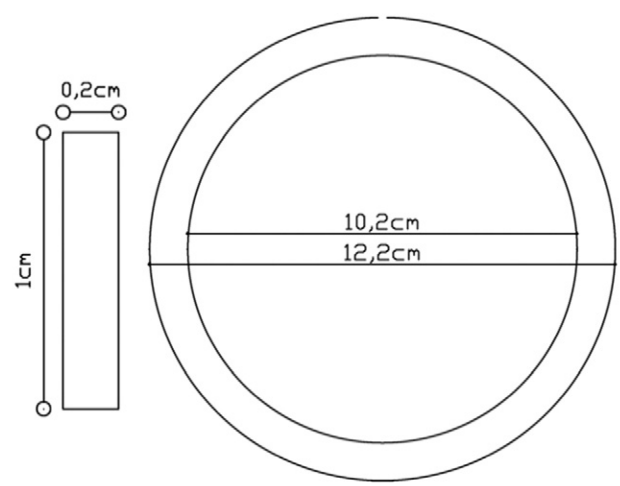


Fig. 4. Shape and section of ring a.

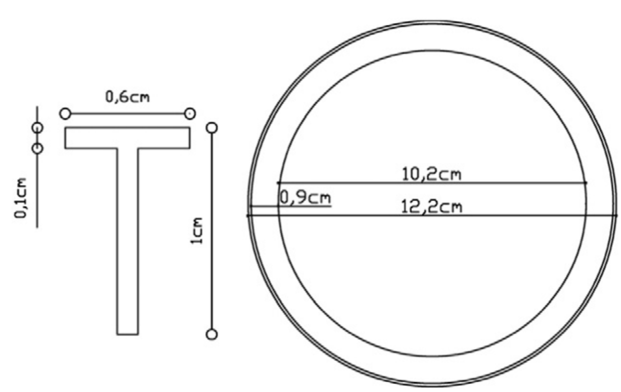


Fig. 5. Shape and section of ring b.