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Strain-Based Pipelines: Design Consideration Overview

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ABSTRACT

The need to use strain-based design is growing due to approaching pipeline projects in challenging environments including permafrost, offshore ice hazards, active seismic areas, and in high temperature/high pressure operations. This has stimulated significant research and development efforts in industry, and some of the work is making its way into design codes and industry projects. To ensure pipeline integrity and overall cost effectiveness, a strain-based design approach needs to consider all key interrelated design aspects, including strain demand, design methods, material selection, strain capacity validation, and impact on construction and operation. This paper examines some of these key considerations and recommends practices for engineering and execution of strain-based pipelines. It also includes a discussion of strategies for projects to minimize strain demand, including monitoring and mitigating high strain locations as they develop in the pipeline during operation. The paper highlights ExxonMobil's effort in design, testing, model development, and project applications to advance and enhance the capability of strain-based pipeline applications.

KEY WORDS: Pipeline; strain-based design; strain capacity; seismic; arctic; buckling.

INTRODUCTION

As the world energy demand pushes industry to develop hydrocarbons in more remote areas and deeper waters, pipelines or flowlines that transport hydrocarbons from distant or deepwater producing regions to consumer markets often have to traverse challenging environments. These environments feature hazards such as permafrost, seismic, land slide prone terrains, or require operation with extreme thermal/pressure fluctuations. Large ground movements in these terrains and high temperature/pressure operation can cause longitudinal plastic deformation in the pipeline beyond the strain range permitted by the allowable stress limits in the commonly used industry design codes and standards. Costly measures may be required to satisfy the allowable stress limits if the conventional design methods are used for these pipeline applications. A strain-based design approach, which permits a limited amount of plastic strain, may be more suitable. This is particularly true for applications where the loading is displacement-controlled and the maximum resulting strain is bounded.

Conventional pipeline design uses the Allowable Stress Design (ASD) approach, which limits pipeline stress to a prescribed fraction of its specified minimum yield strength, such as 72% of the yield strength in hoop direction and 90% of the yield strength for combined hoop and longitudinal stresses. The combined stress criterion is intended to limit the longitudinal stress. This criterion, while appropriate for buried pipelines that are fully constrained and not exposed to bending loads, is difficult to satisfy for pipelines that must withstand ground movements induced by the environment or buckling due to operating conditions. Additionally, the ASD approach makes no distinction between load-controlled and displacement-controlled conditions, between stable and unstable failure modes, or between the loss of serviceability and loss of pressure containment.

Recognizing this limitation, more and more industry standards allow application of strain-based design for loading conditions outside those typically considered for more conventional pipelines. Strain-based design is a specific application of a limit state design approach. Instead of applying stress limits, the capacity of the pipeline to withstand longitudinal strain without failure is quantified and compared to the strain expected in service under displacement-controlled conditions. Strain-based design allows a more effective use of the pipeline's longitudinal strain capacity while maintaining the hoop pressure containment capacity as illustrated in Figure 1. Hence it is more suitable to use a strain-based design rather than an allowable stress