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Deformation behavior and limit state of high-grade induction bend pipes subjected to large ground deformation

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ABSTRACT

For installing high-grade line pipes in a seismic area concerned about soil liquefaction, it is essential to ensure that the deformation of the pipeline does not surpass their limit. In this study, the bending experiments of the API 5L X80 induction bend pipes were performed to clarify the deformation behavior and limit for leakage of the pipes. The large deformation behaviors of these experiments were simulated by a high precision Finite Element (FE) analysis. Based on this analysis, we were able to estimate the leakage of the bend pipes, and the precision of this method was verified by other bending experiments. In combination with the existing deformation analysis for buried pipelines, an evaluation method of bend pipes subjected to a large ground deformation was presented. For instance, by simulating the deformation behavior of the buried pipeline in the case of the lateral ground deformation caused by soil liquefaction, it was demonstrated that the deformation of the pipelines would not surpass their limit state obtained in this study for a pipeline with an outer diameter of 614.4 mm and wall thickness of 14.5 mm.

KEY WORDS: Induction bend pipes, API 5L X80, Large deformation behavior, Soil liquefaction, Lateral ground deformation, Finite Element (FE) analysis.

INTRODUCTION

For the design of gas pipelines, high-grade (high yield stress) line pipes, such as API 5L X80, are now being used. The objective is to reduce the welding time and reduce the material costs caused by the reduced wall thickness. However, the deformability of high-grade pipes could be inferior to conventional pipes, such as API 5L X65, because there is a tendency that the yield ratio (yield stress over tensile stress) of the high-grade line pipes is higher than that of conventional pipes. Therefore, for installing these high-grade line pipes in a seismic area in which the occurrence of soil liquefaction is a concern, it is essential to ensure that the deformation does not surpass their limit state in the case of a large lateral ground deformation caused by soil liquefaction.

Based on this idea, the major problems for installing high-grade line pipes have been solved. Yatabe et al. (2003) studied the leakage limit of a straight line pipe on bending deformation and clarified that the limit condition depends on the design factor. A leakage would occur at compression side under low design factor with large deformation as it is known. On the contrary, it was clarified that it would occur at tension side under high design factor without large deformation. With regard to the welding of pipelines, over matching assures the performance being more than equal to the base material. Motohashi et al. (2005) studied the performance of the girth weld of a pipeline. However, an insufficient study of the leakage limit of a high-grade bend pipe was conducted for installing in a seismic are concerned about soil liquefaction and an overpopulated area. Considering the geometry of the buried pipeline, deformation may concentrate at the bend pipes and damage to bend pipe in fact been reported.

In this study, an evaluation method of bend pipes subjected to large ground deformation was presented on the basis of research on the deformation behavior and limit state of high-grade induction bend pipes. The word “limit state” means the leakage limit of the line pipe in this study.

The bending experiments of the API 5L X80 induction bend pipes were performed to clarify the deformation behavior and limit state of the pipes. The outer diameter of the pipes was 614.4 mm and their center angles were 45 and 90 degrees. With the use of Finite Element (FE) analyses, it was possible to simulate with a high precision the large deformation behaviors of these experiments. The load-displacement relationship and the strain distribution obtained in the simulation agreed with the experimental results until just before the leakage.

Based on this simulation of the bending experiments, bending angles at the limit state were calculated for the bend pipes with various center angles. The limit state was provided by equivalent plastic strain based on the similarity of the stress condition such as the principal stresses. This evaluation method of the bending angle at the limit state was verified by other experimental bending results.

For the design of a buried pipeline in a seismic area, it is essential to ensure that the deformation of the pipelines does not surpass their limit state. In a simulation of a buried pipeline subjected to lateral ground deformation, the actual material properties and dimensions such as wall thickness of each line pipe are unknown in the design phase. Therefore, it is inevitable to use nominal material properties and dimensions as the input conditions. The bending deformation behavior was simulated not using actual values, but using nominal values. As a