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Finite element analysis and experimental study on a bellows joint

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ABSTRACT

Bellows joint is a critical part of an underground pipeline system, which can undergo severe damage such as breaking, crushing, and bending under a strong earthquake. In our research work, finite element analysis (FEA) of the bellows joint was studied using LS-DYNA. Single convolution and multi-convolution bellows joints applied with different loadings were investigated. Force – displacement curve, plastic strain distribution and bending moment – angular displacement curve were obtained. Furthermore, low frequency cyclic experiment on 4-convolution bellows joints was conducted and the results from the experiment were compared with the results from FEA. The load capacity of the multi-convolution bellows joint was almost the same as the single convolution bellows joint, and the energy absorption increased with the number of the convolution linearly.

1. Introduction

The underground pipeline system often suffers from severe damage under the action of earthquake. Strong ground motion may cause the interruption of the pipeline, oil or gas leaking, serious waste of resources and environmental pollution. Data from Michoacan earthquake (Mexico, 1985) and Kobe earthquake (Japan, 1995) showed that underground pipeline systems, such as gas, water supply and sewage system, were damaged heavily [1,2]. The joint connecting pipelines was the main damage after earthquakes, and the axial tension damage accounted for about 75%. The seismic response of the pipeline and joint has attracted great attention of many researchers. Earthquake response analysis of a buried pipeline was performed by the nonlinear time-history analysis [1,3]. Numerical simulations using FE method were conducted to determine pipe-soil system response under live load application [4]. Compression performance of steel pipelines with welded slip joints was obtained by experimental measurements and FEM calculations [5,6]. The behavior of socket joint under high operating pressures was studied by numerical and experimental investigation [7].

Nowadays, bellows joints are widely used as compensating elements for thermal expansion and relative movement in pipelines, containers and machines [8]. Axial, angular and lateral expansion joints are the three basic types of the bellows joint. The axial bellows joint absorbs movement in an axial direction and it is often equipped with a guiding tube on the inside of the metal bellows, which reduces the flow resistance and prevents damage caused by direct contact with the flowing medium [8]. A new type bellows and the conventional bellows were compared under cyclic axial loading test, internal pressure test and torsion test [9]. Li et al. investigated the formulae of the maximum meridional stress of the longitudinal line per convolution when a bellows joint is subjected to an axial movement, lateral defection and angular rotation [10]. The low-cycle fatigue life of bellows using elastic-plastic analysis was predicted by Hamada and Tanka [11]. The failure of bellows expansion joint of 304 stainless steel was analyzed by Guan et al. and they found that the stress corrosion cracking caused by the flowing medium was responsible for the failure [12]. A number of cracks were also found originating from weld fusion lines [13].

However, a comprehensive FEA on metal bellows joints subjected to different loadings has not been investigated systematically. This paper investigated the load capacity, deformation behavior and energy dissipation capacity of the single and multi-convolution bellows joint under different loadings. Axial compression, axial tension, one step cyclic loading, multi-step cyclic loading and bending load were considered. The low frequency cyclic loading experiment on the 4-convolution bellows joints was conducted to validate the FEA.

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2. FEA

2.1. Bellows joint

Standard connectors of the axial bellows joint are welded ends, fixed flanges and loose flanges which are connected to the main pipe line to absorb expansions or contractions [8]. The schematic diagram of a bellows joint is shown in Fig. 1(a). The geometric parameters are shown in Fig. 1(b): nominal diameter D_0; wall thickness t; pitch q, distance between the corresponding points of any two adjacent convolutions; convolution height h; convolution radius R; the length of the straight-line segment h_0 and convolutions number n. The convolution radius R was set as a quarter of the pitch q, and the convolution height h can be expressed as $h = 2R + h_0$.

2.2. FEA

Satoshi [9] carried out tests on bellows under axial cyclic loading. The thickness of the bellows was 1.15 mm, and the cyclic loads were controlled by the cyclic displacement with increasing amplitudes of 3.6 mm, 9.1 mm, 18.2 mm, 36 mm, 41.0 mm and 54.6 mm. The strains between the neighboring convolutions at the crest were measured. The bellows joint was made of 304 stainless steel and a simplified bilinear stress-strain relationship with strain hardening was assumed as shown in Fig. 2(a). The yield stress σ_s, young modulus E, plastic tangent modulus E_p, and failure strain are also displayed in Fig. 2(a). The material was defined as a kinematic hardening material (see Fig. 2(a)).

FEA was conducted using LS-DYNA and the element type was fully integrated shell element. The mesh size was 6 mm and the

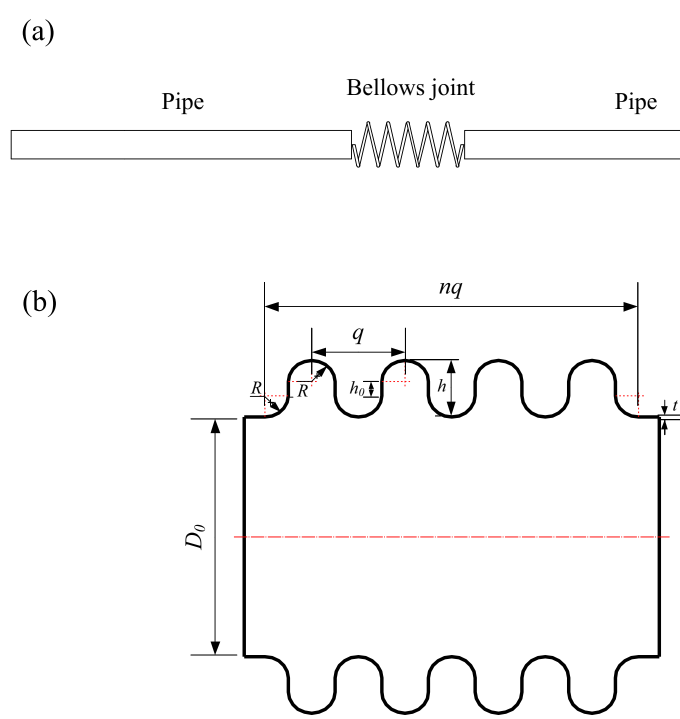

Fig. 1. (a) The schematic diagram; (b) geometric parameters of a bellows joint.

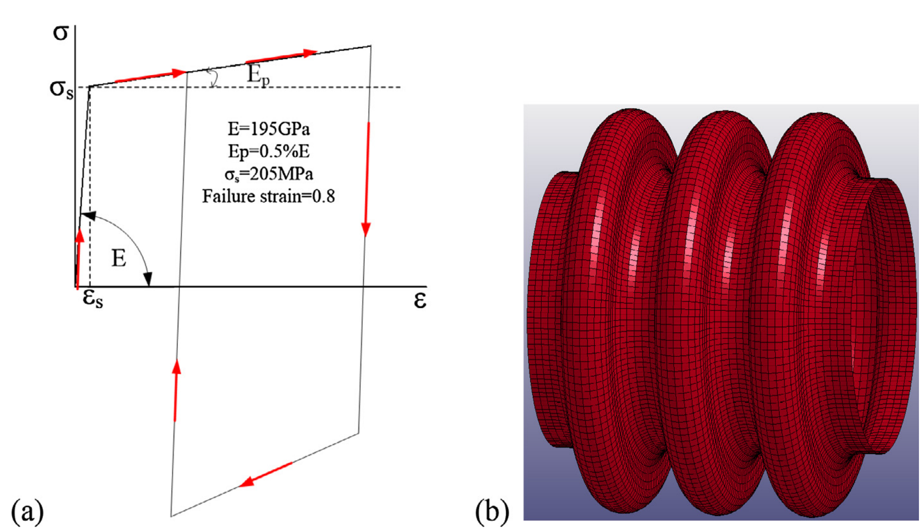

Fig. 2. (a) Stress-strain curve in FEA; (b) a meshed 3-convolution bellows model.