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Denting the oil pipelines by a rigid cylindrical indenter with conical nose by the numerical and experimental analyses

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ABSTRACT

The present research discusses indentation process on the oil pipelines using a rigid indenter in the quasi-static condition by the experimental and numerical analyses. This article investigates influences of internal pressure, diameter and wall thickness of pipes and geometrical characteristics of rigid cylindrical indenters with conical nose such as cone angle, conical nose diameter and cylindrical part diameter on mechanical behavior of the circular steel pipes under concentrated lateral loading (denting). In the experimental part, some specimens made from the steel API5L L245 were prepared and they laterally compressed by a rigid cylindrical indenter with the conical nose to perform the indentation process on them. In the numerical part, some finite element models were prepared and indentation process was simulated on different models with various tube and indenter geometries in different conditions of internal pressure. By comparing the numerical and experimental results, precision and accuracy of the simulations were affirmed. The discussed results show that when tube diameter increases, bending moment arm of the concentrated applied load around the formed plastic hinge lines enhances; therefore, lower lateral load can create a certain plastic deformations in the tube wall; and also, total absorbed energy by the tube enhances. Results demonstrate that when a conical projectile with a certain mass and initial velocity laterally compresses a circular tube, increment of tube diameter causes reduction of probability of the tube failure. The results show that when cone angle of conical indenter decreases and reaches to a certain value that called critical angle, the penetration occurs during the indentation process. Furthermore, it is found that by increasing the diameter of cylindrical part of the indenter, lateral indentation load increases; and when applied internal pressure on the tube increases, ultimate lateral displacement of the indenter decreases; but, the maximum load for the tube wall fracture enhances.

1. Introduction

The explosive character of gas and oil provides a high demand for structural integrity and economical and environmental considerations require assessment of safety. Therefore, reliability and safety of oil and gas pipelines under various service conditions and different mechanical damages should be evaluated [1]. Local distortions on pipeline wall in the form of dents or buckles may constitute a threat for the structural integrity of the steel pipeline [2]. Their mechanical damages occur due to the contact from excavators, graders, ditchers, plows, directional drillers, and just about any other sort of equipment used to penetrate or move soil. General excavation is the most common source of damage, but everything from roadwork to farming has caused incidents, including the pipeline operator or his contractors hitting his own line. Offshore, encroachment damage arises from contact by ship keels and anchors [3]. Ground movement can also be a cause of failure of pipelines. By considering good quality materials and good quality welds, the most common defects in pipelines are corrosion defects and mechanical damages due to external interferences. In Europe, however, a report mentioned that the major causes of transmission pipelines are external interferences: they cause approximately the half of failures. These types of damage can be classified into gouges, dents and combined gouges and dents [1].

A dent in a pipeline is a permanent plastic deformation of the circular cross-section of the pipe. A dent is a gross distortion of the pipe cross-section. Dent depth is defined as the maximum reduction in the diameter of the pipe, comparing with the original diameter [4]. Plain dent is a smooth dent that contains no wall thickness reductions (such as a gouge or a crack) or other defects or imperfections (such as a girth or seam weld). A dent causes a local stress and strain concentration and a local reduction in the pipe diameter. The dent depth is the most significant factor affecting the burst strength and the fatigue life of a

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plain dent [4]. Dents in a pipeline can also present operational problems even though they may not be significant in a structural sense. Consequently, any dent remaining in a pipeline should be checked to ensure that it does not significantly reduce flow rates or obstruct the passage of standard, or intelligent, pigs [4].

In 1976, Thomas et al. [5] considered behavior of simply supported circular tubes under the action of the transverse loading of a wedge-shaped indenter up to the point of maximum load. In 1981, Ghosh et al. [6] considered deformation behavior of mild steel rings and short tubes of various diameters, thicknesses and lengths loaded centrally by opposed conically-headed cylindrical punches. Ong et al. [7] studied the problem of a local dent on a pressurized pipe. Shen and Shu [8] performed a theoretical quasi-static analysis to predict the response and the onset of failure for pipelines. The maximum strain criterion, the effect of strain rate and an empirical formula for estimating the length of a plastic hinge employed in the analysis. Their theoretical study allowed the local or denting deformation to continue during the global deformation phase. Ng and Shen [9] presented the dynamic inelastic response and failure prediction of pipelines under lateral mass impact at the mid-span position. They found that the influences of the internal pressure and the foundation on the critical initial impact energy are significant. Jones and Shen [10] developed a theoretical rigid-plastic in order to predict the quasi-static response of a ductile pipeline which was fully clamped across a span and struck laterally by a rigid mass. This theoretical study presented the local or denting deformations to continue during the global deformation phase which has been considered only semi-empirically in previous work. In addition, it was valid for a mass striking at any position on the span, except very close to a support. Lu [11] checked out behavior of mild steel open tubes loaded centrally by two opposed wedge-shaped indenters. The load-deflection curves were recorded and simple empirical formulae were obtained for them. Jing and Barton [12] reported on two thicknesses of square hollow cross-section mild steel tubes under lateral quasi-static and dynamic loadings at two spans and under fully-clamped and simply-supported end conditions [12]. Wierzbicki and Suh [13] discussed large plastic deformations of tubes subjected. Force-deflection characteristics of tubes were shown to depend strongly on the magnitude of the bending moment and/or axial force applied to the tube ends [13]. Zeinoddini et al. [14] performed experimental studies on axially preloaded tubes under lateral dynamic impact loads. Ruggieri and Ferrari [15] presented an experimental and numerical investigation of structural behavior of a dented tubular member under lateral load which was applicable to marine risers. The load was applied to the center of the pipe using a rigid tube shaped indenter. Brooker [16] modeled denting behavior under knife-edge indenter using the finite element (FE) method. Liu and Francis [17] presented a quasi-static analysis for in-service pressurized pipelines subjected to an external impact. Based on the assumed simple rigid-perfectly plastic deformation model, a simple relationship was obtained between external denting force and the maximum dent depth.

Iflefel et al. [18] modeled the denting process with hemispherical indenter and internal pressure. Results were presented from an FE numerical study of the capacity of a dented pipe to withstand combined pressure and moment loading. Hyde et al. [19] investigated force–deflection behavior of pressurized pipes, due to radial indentation loading (hemispherical indenter), using FE and analytical methods. Karamanos and Andreadakis [20] examined structural response of tubular members subjected to lateral quasi-static loading, imposed by wedge shaped denting devices, in the presence of internal pressure.

Lu et al. [21] presented some principal observations made from a series of experiments in which three-span pipe beams were subjected to central impact by indenters with three different nose shapes, consist of blunt-nose, hemispherical nose and a 90 deg conical-nose. Blachut and Iflefel [22] discussed occurred collapse by the bending moment of mild steel pipes containing plain or gouged dents. Specimens were dented with a rigid, hemispherical indenter. Dented pipes were collapsed by moment loading whilst subjected to constant internal pressure [22].

Gresnigt et al. [23] investigated denting response of internally pressurized steel pipes subjected to lateral quasi-static wedge denting loads, using experimental data, numerical simulation, and a simplified analytical model [23]. Baek et al. [24] studied effects of dent magnitude on collapse behavior of a dented pipe subjected to a combined internal pressure and in-plane bending. Firouzsalari and Showkati [25] performed an experimental study and investigated deformation behavior of pre-compression free-spanned steel tubular members under lateral loads due to a wedge indenter. Jones and Birch [26] studied on steel pipelines which have been struck by a relatively large rigid wedge-shaped mass traveling up to 10.4 m/s [26]. Lu [27] conducted numerical simulations of impact cases of liquid-filled tube impacted by missiles with a commercial finite element code LS-DYNA [27]. Zeinoddini et al. [28] investigated transverse impact problem in continuously supported offshore pipelines in the presence of internal pressure. Quasi-static lateral impacts on tubular members were numerically simulated. Transverse loads were applied through a wedge-shaped indenter. Niknejad and Tadrisi Javan [29] studied indentation process on circular metal tubes during lateral compression process between a V-shape indenter and a rigid platen by experimental and theoretical methods [29]. Akbari Alashti et al. [30] investigated effects of ductile damage on the behavior of a dented steel pipe subjected to internal pressure by experimental and numerical methods. Pinheiro at al. [31] evaluated microstructural mechanisms associated with the initiation of fatigue damage of used steel pipes in the petroleum industry [31]. Recently, Niknejad et al. [32] and Saadatfard et al. [33] investigated effects of applied lateral compression load by a solid cylindrical indenter on quadrangular metal columns and composite tubes in the quasi-static condition. They analyzed indentation process on quadrangular column by both of the theoretical and experimental methods; and studied the corresponding process on composite circular tubes, experimentally.

Overall, pipelines are widely used in the industry to carry and transport oil or pressurized gas. Having a dent defect in a pipeline introduces strain and stress concentrations that must be examined in order to determine the structural integrity and safety of the pipeline [34]. This article investigates indentation process on the oil pipelines using a rigid indenter in the quasi-static condition by the experimental and numerical analyses. The present research work discusses influences of internal pressure, diameter and wall thickness of pipes and geometrical characteristics of rigid cylindrical indenters with conical nose such as cone angle, conical nose diameter and cylindrical part diameter on mechanical behavior and plastic deformation of the circular steel pipes under concentrated lateral loading.

2. Experiments

In the experimental part of the present research work, some steel pipes, typically used in the oil and gas pipeline industry, were selected and used in the indentation process. Four different groups of pipes with different wall thicknesses and diameters, but, with the same material type were used in the experiments. All the pipe specimens have been made from the API 5L L245 steel pipe (based on API 2012). Table 1 reports material properties of the tubes. First group of the initial pipe specimens was prepared using the pipes with 58.8 mm outer diameter and 4.0 mm wall thickness. Second group of the initial samples was made of the steel pipes with 91.7 mm outer diameter and 6.3 mm wall

Table 1
Material properties of the tubes.

Elasticity modulus (MPa)	Yield stress (MPa)	Ultimate stress (MPa)	Density (kg/m^3)	Poisson ratio
200	411	615	7800	0.3

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