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Closed-form plastic collapse loads of pipe bends under combined pressure and in-plane bending

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Abstract

Based on three-dimensional (3-D) FE limit analyses, this paper provides plastic limit, collapse and instability load solutions for pipe bends under combined pressure and in-plane bending. The plastic limit loads are determined from FE limit analyses based on elastic–perfectly-plastic materials using the small geometry change option, and the FE limit analyses using the large geometry change option provide plastic collapse loads (using the twice-elastic-slope method) and instability loads. For the bending mode, both closing bending and opening bending are considered, and a wide range of parameters related to the bend geometry is considered. Based on the FE results, closed-form approximations of plastic limit and collapse load solutions for pipe bends under combined pressure and bending are proposed.

Keywords: Combined pressure and in-plane bending; Collapse load; Finite element limit analysis; Instability load; Large geometry change; Limit load; Small geometry change; Pipe bend

1. Introduction

For design and defect assessment of pipe bends, estimation of maximum load-carrying capacities is required, and thus information on plastic limit, collapse and instability loads is important. Despite its importance of pipe bends in plant components, relevant solutions for pipe bends are still limited. Miller [1,2] summarized existing limit load solutions for pipe bends, but also noted that these solutions are lower bounds and should be used with caution. Although numerical and experimental works on plastic limit analyses of pipe bends can be found recently in the literature (see for instance Refs. [3–8]), it is believed that systematic investigation is still missing, probably due to complexity associated with plastic limit analysis of pipe bends. For instance, pipe bends have more geometric variables, such as the bend radius and angle, compared to straight pipes. More importantly, the large geometry change effect could significantly influence plastic behaviours of pipe bends.

Based on detailed three-dimensional finite element (FE) limit analyses, this paper provides plastic limit and collapse load solutions of pipe bends subject to combined pressure and in-plane bending. For a wide range of

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Nomenclature

E	Young's modulus
M	in-plane bending moment
M_0	limit/collapse in-plane moment of a pipe bend
M_0^s	limit in-plane moment of a straight pipe ($=4\sigma_0 r^2 t$)
P	internal pressure
P_0	limit pressure of a pipe bend
P_0^s	limit pressure of a straight pipe $\left(=\frac{2}{\sqrt{3}}\sigma_0\frac{t}{r}\right)$
R	bend radius
r	mean pipe radius
t	thickness of pipe
λ	bend characteristic, $=Rt/r^2$
v	Possion's ratio
σ_0	limit stress of an elastic–perfectly-plastic material

the geometry for a 90° pipe bend, FE limit analyses are performed based on elastic–perfectly-plastic materials with both small and large geometry change options. Based on FE solutions, closed-form approximations of plastic limit and collapse loads are given. Section 2 describes the FE limit analysis performed in the present work. The plastic limit load solutions together with closed-form approximations for pipe bends under the small geometry change option are given in Section 3. The corresponding plastic collapse and instability solutions under the large geometry change option are given in Section 4. This paper is concluded in Section 5.

2. Finite element limit analyses

Fig. 1a depicts a 90° pipe bend, considered in the present work. The mean radius and thickness of the pipe are denoted by r and t, respectively, and the bend radius by R. Important non-dimensional variables related to the bend geometry are R/r and r/t. The following non-dimensional variable (the bend characteristic) should be noted:

$$\lambda = \frac{Rt}{r^2} = \frac{(R/r)}{(r/t)} \tag{1}$$

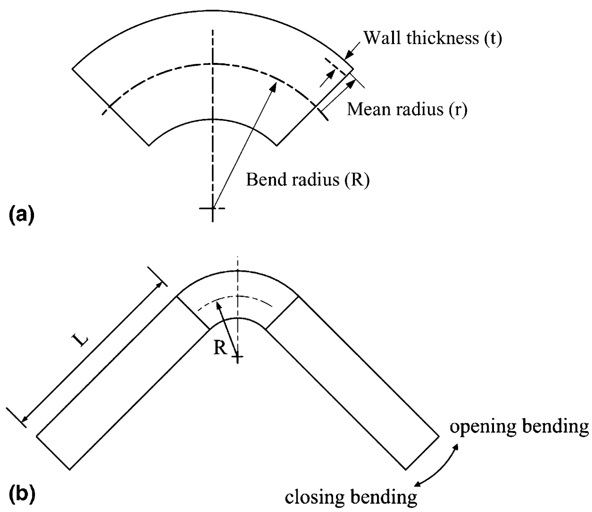

Fig. 1. Schematic illustrations of 90° pipe bends, considered in the present work: (a) without a straight pipe attachment and (b) with the attachment.