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Evaluation of postulated cross sections with ovality and thinning for 90° pipe bends with circumferential throughwall cracks subjected to in-plane closing bending

S. Sumesh*, AR. Veerappan, S. Shanmugam

Department of Mechanical Engineering, National Institute of Technology, Tiruchirappalli 620 015, Tamilnadu, India

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ABSTRACT

A comparative study of postulated cross sections for failure analysis of 90° structurally deformed pipe bends with critical circumferential throughwall cracks was performed. Elliptical and semi-oval cross sections were assumed to determine the collapse loads under in-plane closing bending moment. Finite element analysis was conducted based on elastic-perfectly-plastic material considering geometric nonlinearity and twice-elastic-slope method was used to obtain collapse loads for each model. The influence of pipe ratio and bend radius in the presence of ovality and thinning were also investigated for the postulated cross sections. The results indicated a pronounced effect of ovality on collapse loads of throughwall circumferentially cracked pipe bends, primarily with elliptic cross sections whereas the thinning effect is significantly lower for both the cross sections. The present study provided a better estimation of the plastic loads and elliptic cross sections were found to be ideal in the analysis of cracked pipe bends for the present geometries and across the boundary conditions considered.

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1. Introduction

Pipe bends are manufactured from straight pipes by standard bending methods as a result of which the cross section of the pipe bend distorts becoming non-circular with variable thickness [1]. The deviation of cross section from circularity is termed as ovality while the variation in thickness is termed as thinning/thickening. The acceptability of a pipe bend depends on the magnitude of these shape imperfections [2]. The published studies on failure analysis using numerical and experimental methods to determine collapse moment and fatigue resistance of uncracked elbows under bending load have evaluated the effects of local wall-thinning. Reference [3] compared the limit (based on small displacement analysis) and collapse loads (based on large displacement analysis) of pipe bends with ovality and thinning under combined internal pressure and in-plane closing moment and concluded that determination of collapse load is suitable rather than limit load when ovality is present in pipe bends.

In the failure analysis of cracked pipe bends, the geometry of the bend cross section is one of the important parameter that determines the accuracy of the collapse load. With regard to the assessment of plastic loads of pipe bends, most of the reported works [4,5] except in the work by Kim et al. [6], assumed circular cross section at the bend with uniform wall thickness. Kim et al. presented a method to determine plastic loads for elbows with non-uniform thicknesses. In the analysis of uncracked pipe bends,

* Corresponding author.

E-mail addresses: sumesh4sai@gmail.com (S. Sumesh), aveer@nitt.edu (A.R. Veerappan), shunt@nitt.edu (S. Shanmugam).

Nomenclature

C_o	percent ovality
C_t	percent thinning
D	pipe outside diameter, mm
D_{max}	maximum outside pipe diameter, mm
D_{min}	minimum outside pipe diameter, mm
t	nominal thickness of pipe bend, mm
t_{max}	maximum pipe thickness, mm
t_{min}	minimum pipe thickness, mm
R	bend radius to neutral axis, mm
r	mean radius of pipe, mm
r_{min}	minimum radius in semi-oval cross section, mm
r_o	nominal outside radius of pipe, mm
σ_0	yield stress of an elastic-perfectly plastic material, MPa
M_O	collapse moment of cracked elbow with ovality, kN-m
M_T	collapse moment of cracked elbow with thinning, kNm
M_R	collapse moment of cracked elbow with circular cross section, kN-m
θ	semi-circumferential crack angle

when ovality is incorporated in the finite element model, the presumed cross sections at the bend have been elliptic [2,3,7] and semi-oval [7,8]. Under a given set of boundary conditions, the pipe bend behavior in the presence of a critical crack can be examined for selecting the most appropriate cross section geometry. Hence, inclusion of these structural distortions and selecting appropriate loading conditions in the analysis of cracked pipe bends is pertinent for a better understanding of the elastic-plastic behavior of these critical components used in piping systems.

Crack-like defects develop on pipe bends not only during various stages during manufacturing and installation, but can also occur with cyclic loading and material deterioration as a result of continued operation [9]. Large throughwall circumferential crack could significantly reduce the load carrying capacity of elbows [10]. The existing theoretical solutions however, have not

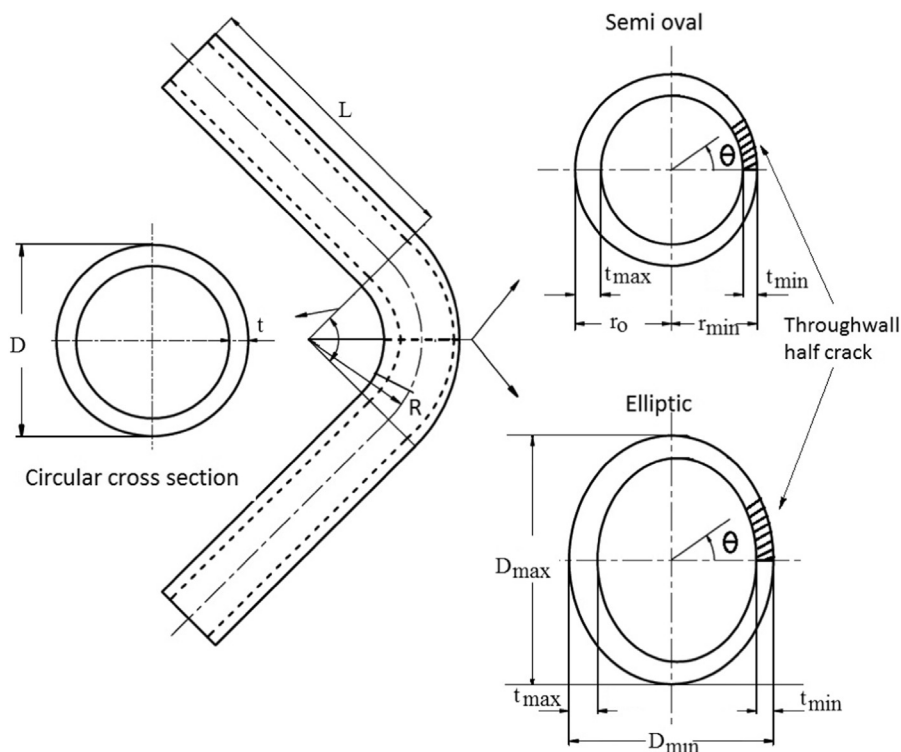


Fig. 1. 90° Pipe bend with attached straight pipe showing elliptic and semi-oval cross sections with circumferential throughwall crack.

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