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ScienceDirect
International Journal of Pressure Vessels and Piping 85 (2008) 360–367
INTERNATIONAL JOURNAL OF Pressure Vessels and Piping
www.elsevier.com/locate/ijpvp

Limit loads for piping branch junctions under internal pressure and in-plane bending—Extended solutions

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Abstract

The authors have previously proposed plastic limit load solutions for thin-walled branch junctions under internal pressure and in-plane bending, based on finite element (FE) limit loads resulting from three-dimensional (3-D) FE limit analyses using elastic–perfectly plastic materials [Kim YJ, Lee KH, Park CY. Limit loads for thin-walled piping branch junctions under internal pressure and in-plane bending. Int J Press Vessels Piping 2006;83:645–53]. The solutions are valid for ratios of the branch-to-run pipe radius and thickness from 0.4 to 1.0, and for the mean radius-to-thickness ratio of the run pipe from 10.0 to 20.0. Moreover, the solutions considered the case of in-plane bending only on the branch pipe. This paper extends the previous solutions in two aspects. Firstly, plastic limit load solutions are given also for in-plane bending on the run pipe. Secondly, the validity of the proposed solutions is extended to ratios of the branch-to-run pipe radius and thickness from 0.0 to 1.0, and the mean radius-to-thickness ratio of the run pipe from 5.0 to 20.0. Comparisons with FE results show good agreement.

Keywords: Finite element analysis; Branch junction; Internal pressure; In-plane bending; Limit load

1. Introduction

Recently the authors presented finite element (FE)-based limit loads for piping branch junctions under internal pressure and in-plane bending, via three-dimensional (3-D), small-strain FE limit analyses using elastic–perfectly plastic materials [1]. The resulting FE limit loads for branch junctions under internal pressure and in-plane bending were compared with existing limit load solutions [2–4], and new approximate limit load solutions, improving the accuracy, were proposed based on the FE results. Two points are worth noting for the proposed solutions. The first point is that the application of the proposed solutions was limited in terms of geometrical variables. For instance, they can be applied only for ratios of the branch-to-run pipe radius and thickness from 0.4 to 1.0, and for the mean radius-to-thickness ratio of the run pipe from 10.0 to 20.0. It was argued that the main target of the work was to provide a baseline solution for limit load analysis for branch junctions with local wall thinning in pressurized water reactor nuclear power plants, where geometric variables of pipe fittings are covered by the above ranges. On the other hand, wall thinning in thick-walled piping branch junctions is also of interest, for instance, for other types of power plants including nuclear ones. Thus, development of limit load solutions that are applicable not only to thin-walled branch junctions but also to thick-walled ones is desirable. The other point is the loading condition. In our previous work, both internal pressure and in-plane bending were considered. However, for in-plane bending, only bending loading on the branch pipe was considered, not on the run pipe. As wall thinning can also occur in the run pipe, limit load solutions for branch junctions under in-plane bending on the run pipe are needed, which are difficult to find in the literature.

The objective of this paper is to extend the previous limit load solutions in [1] to the above two cases. Section 2 explains the geometry considered in the present work and the FE limit analyses. Sections 3 and 4 present extended limit load solutions for branch junctions under internal pressure and under in-plane bending on the branch pipe.

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0308-0161/$ - see front matter
doi:10.1016/j.ijpvp.2007.11.007

Nomenclature

A	$= r/R$
B	$= 2R/T$
C	$= t/T$
L, ℓ	length of a run pipe and a branch pipe, respectively
M_L	in-plane limit moment of a branch junction
P_L	limit pressure of a branch junction
R, r	mean radius of a run (main) pipe and a branch for branch junctions, respectively
T, t	thickness of a run (main) pipe and a branch for branch junctions, respectively
σ_o	limiting strength of an elastic–perfectly plastic material

Limit load solutions for in-plane bending on the run pipe are presented in Section 5. The work is concluded in Section 6.

2. Geometry and FE limit analyses

2.1. Geometry

Fig. 1 depicts the geometry of the branch junction, considered in the present work. The branch junction is assumed to have no weld or reinforcement around the intersection. The mean radius of the run pipe is denoted by R, and that for the branch pipe by r. Thicknesses of the run and branch pipes are denoted as T and t, respectively. Regarding the axial length, the half-length of the run pipe is denoted as L and the length of the branch pipe as ℓ. Note that in the previous work [1], the geometric variables (R, T, r, t, L, ℓ) were systematically varied within the ranges $0.4 \leqslant (r/R,\ t/T) \leqslant 1.0$ and $10.0 \leqslant R/T \leqslant 20.0$. In this work, such ranges are extended to $0 \leqslant (r/R,\ t/T) \leqslant 1.0$ and $5.0 \leqslant R/T \leqslant 20.0$ for more general applications.

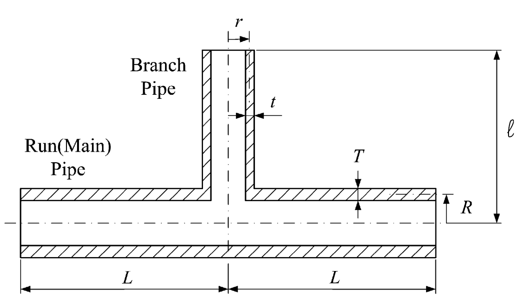

Fig. 1. Schematic of branch junctions with relevant geometric variables.

2.2. FE mesh and limit analysis

3-D, elastic–perfectly plastic FE analyses of the branch junction (Fig. 1) were performed using ABAQUS [5]. Materials were assumed to be elastic–perfectly plastic, and the non-hardening J_2 flow theory was used using a small geometry change continuum FE model. Symmetry conditions were fully utilized in FE models to reduce the computing time. To avoid problems associated with incompressibility, reduced integration elements (element type C3D20R within ABAQUS) were used. Typical FE meshes are shown in Fig. 2. For all cases, three elements are used through the thickness, and the resulting number of elements and nodes in typical FE meshes ranges from 3949 elements/20,598 nodes to 4914 elements/25,649 nodes, which are sufficiently fine to ensure convergence of the FE results for the present study.

2.3. Loading and boundary conditions

Two types of loading conditions were considered in the present work: internal pressure and in-plane bending. For in-plane bending, two cases are further considered. One case is when in-plane bending is applied to the branch pipe. Note that such a case was covered in the previous work [1]. The other case is when bending is applied to the run pipe,

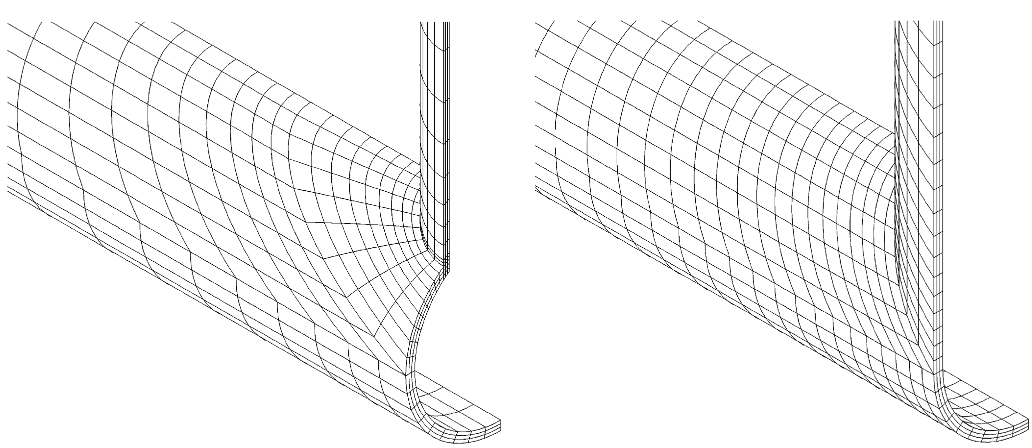

Fig. 2. Finite element meshes for branch junctions.