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Plastic limit loads for cracked large bore branch junction

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ABSTRACT

This paper reports plastic limit loads for a cracked large bore branch junction, based on three-dimensional finite element limit analyses using elastic-perfectly plastic materials. Part-through surface and through-wall cracks are postulated in the intersection. For loading conditions, internal pressure and (in-plane and out-of-plane) bending to the branch pipe and to the run pipe are considered. The effect of the crack on limit loads is found to be significant for internal pressure and bending to the branch pipe, but not for bending to the run pipe. The large geometry change effect for bending to the branch pipe is briefly discussed.

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1. Introduction

As branch junctions are widely used in industrial plants, information on plastic limit loads of branch components is important in design and structural integrity assessment. Such information is a direct input to estimate the maximum load-carrying capacity of piping components [1,2]. Furthermore, based on the reference stress approach [3], it can be used to estimate creep rupture and non-linear fracture mechanics parameters (see for instance Refs. [4–9]).

For un-cracked branch components, numerous works have been reported on plastic limit loads [10–23]. Closed-form limit load solutions, proposed recently by Xuan and co-workers [17–19] and the current authors and co-workers [20–23], are worth noting. Xuan et al. [17,19] proposed limit load solutions for branch junctions under internal pressure and under bending to the branch pipe, based on a semi-analytical approach. Based on extensive FE limit analyses, the current authors refined the solutions proposed by Xuan and co-workers, and further extended their solutions to wider ranges of branch geometries. They also developed limit load solutions for branch junctions under bending to the run pipe.

Compared to those for un-cracked branch junctions, works on plastic limit loads for cracked branch junctions are quite limited. Yahiaoui et al. [24] reported experimental and numerical data for surface and through-wall cracked forged branch junctions. Lynch et al. [25] performed FE limit analysis for through-wall cracked welded branch junctions under pressure, out-of-plane bending and combined pressure and out-of-plane bending. Xuan et al. [26] proposed an approximate limit pressure solution for cracked equal-diameter branches and compared with FE results. Literature review shows that, although existing works provide valuable information on the effect of the crack on plastic limit loads, the cases considered are still limited, in terms of branch geometries and loading conditions. More results would be needed to draw general conclusions on the effect of the crack on plastic limit loads for branch junctions.

This work presents plastic limit loads for a cracked large bore branch junction, as used in some UK power plant steam pipework systems, based on 3-D FE limit analyses using elastic-perfectly plastic materials. Part-through surface and

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Nomenclature

a	crack depth
M	bending moment
M_o, M_L	limit moment of an un-cracked and cracked branch junction, respectively
P	internal pressure
P_o, P_L	limit pressure of an un-cracked and cracked branch junction, respectively
R, r	mean radius of the run (main) pipe and the branch for branch junctions
T, t	thickness of the run (main) pipe and the branch for branch junctions
σ_o	limiting strength of an elastic-perfectly plastic material
α, θ	half crack angle for the flank crack and crotch crack, respectively

through-wall cracks are postulated in the intersection, and all types of loading modes are considered. Section 2 describes the FE limit analysis employed in the present work. Limit load results are presented in Section 3 for internal pressure. Results for bending are presented in Sections 4 and 5. The large geometry change effect on plastic limit loads is discussed in Section 6, and the present work is concluded in Section 7.

2. Finite element (FE) limit analysis

2.1. Geometry and loading

To investigate the effect of the crack on plastic limit loads for branch junctions, a large bore welded branch component [8,9,27] was chosen. 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. The branch vessel considered in the present work is depicted in Fig. 1, including details of the welded intersection region. Relevant dimensions are summarized in Table 1.

Either a through-wall or part-through crack is postulated in the branch intersection. Regarding location, the crack is assumed to be located either in the crotch or in the flank, as schematically shown in Fig. 2a. Furthermore it is located either in the upper weld toe or in the lower weld toe, as shown in Fig. 2b. The profile of the crack is defined by the surface projected normally onto the inner surface of the run pipe (Fig. 3). For the through-wall crack, its length is characterized by its half angle, θ, for the crack in the crotch and, α, for the crack in the flank. Five different values of θ/π or α/π were considered in this work, θ/π (α/π) = 0, 0.125, 0.25, 0.44 and 0.5. The part-through surface crack is assumed to be constant-depth a, having a straight crack front, and the relative crack depth (either a/t or a/T) was varied from 0 to 1.0.

The branch is assumed to be subject to various mechanical loadings, such as internal pressure, in-plane bending to the branch pipe or to the run pipe, and out-of-plane bending to the branch pipe or to the run pipe.

2.2. FE limit analysis

Three-dimensional (3-D) elastic-perfectly plastic FE limit analyses were performed to determine plastic limit loads of cracked branch junctions using ABAQUS [28]. Materials were assumed to be elastic-perfectly plastic, and non-hardening J_2 flow theory was used. For efficient computations, symmetry conditions were fully utilized and thus a half model was used

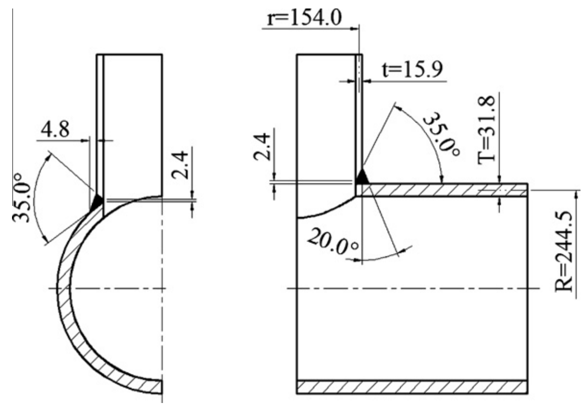

Fig. 1. Schematic diagram of a large bore branch with weld details (dimensions in mm).

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