

Analysis of a Crack at a Nozzle Corner

S. Bhandari, B. Percie du Sert

NOVATOME,
20 av. E. Herriot, F-92350 Le Plessis Robinson, France

B. Barrachin

Commissariat à l'Energie Atomique, D.S.N.,
B.P. No. 6, F-92260 Fontenay-aux-Roses, France

J.-M. Boissenot

Creusot-Loire, 15 rue Pasquier,
F-75383 Paris Cedex 8, France

In a previous paper, a semi-analytical procedure was developed to treat part-circular cracks at various openings under complex loading conditions. The methodology was applied to treat certain problems whose solutions were available in the literature. The comparison showed in general good agreement between the results obtained through the semi-analytical procedure and other methods like the finite-elements and the analytical techniques. In this paper, we present the results of analysis of a hypothetical semi-circular crack at a Nozzle-Corner in the crotch region at the junction between the piping and the pressure vessel. This analysis was carried out through the semi-analytical procedure mentioned above as well as a numerical technique based on the Boundary-Integral-Equations (BIE) method. The results are presented for two loading conditions :

- (a) A moment applied to the nozzle at the edge of the pipe with no pressure in the vessel and
- (b) A moment applied to the nozzle with the vessel pressurized.

After comparing the results and to show the efficiency and the simplicity of the analytical procedure, we go on to present results for nine different crack-sizes at the nozzle-corner for the two types of loadings considered.

1. Introduction

The 3-D problem of part-through cracks initiated at various openings in structural components subjected to various loading conditions is of great practical interest. Due to the general nature of the problem, analytical solutions are extremely difficult and resort is often made to numerical and experimental techniques which finally give solution for one particular geometry under one particular loading at quite a laborious effort and cost. Several attempts have been made to give simple semi-empirical procedures ; the works of Kobayashi, Shah and their colleagues are fundamental to such studies, while numerous results obtained by Smith, Brockhoven and their colleagues provide an insight to various solutions (see [1,2] and references listed there).

In an earlier paper [3], we developed a semi-analytical procedure to treat part-circular cracks at various openings under general loading conditions. It was shown that this problem can be reduced to the resolution of three independent problems :

1. Analysis of the three dimensional uncracked structure with the given opening shape and given loading conditions.
2. Analysis of a two dimensional solid with the given opening shape and a line crack under the given loading conditions.
3. Analysis of a semi-infinite solid with the given crack shape under uniform stress.

The above methodology was applied to treat certain problems whose solutions were available in the literature.

In this paper, we shall present the results of analysis of a hypothetical semi-circular crack at a PWR-nozzle corner in the crotch region at the junction between the piping and the pressure vessel. The analysis was carried out through the semi-analytical procedure mentioned above as well as a numerical method based on the Boundary-Integral-Equations method. The results will be presented for two loading conditions :

- (a) A moment applied to the nozzle at the edge of the pipe with no pressure in the vessel,
- (b) A moment applied to the nozzle along with the vessel pressurized.

After comparing these results and to show the efficiency and the simplicity of the analytical procedure, we go on to present results for nine different crack-sizes at the nozzle corner for the two types of loadings considered.

2. Brief Recall of the Previous Results

We shall enunciate the result obtained in [3] and applicable to the present investigation :

The mode-I stress-intensity factor at a point θ at the tip of a quarter circular crack defined by its radius a , initiating at the edge of a circular opening of radius A under external planer loading conditions is given by :

$$K_I(\theta) = \frac{1}{\pi \sqrt{\pi a}} * C_q(2\theta/\pi) \iint_S \sigma_{mq}^* * G(r, \phi, \theta) r dr d\phi$$

where $C_q(2\theta/r)$ is the crack shape factor for the quarter circular crack ,

$$\sigma_{mq}^* = \sigma_{mq} * g_1 * g_2$$

σ_{mq} being the stress in the uncracked structure in the region of the prospective crack, g_1, g_2 are functions which take into account the effects of the hole and the free edge on the stress distribution σ_{mq} and G is the Green's function for a circular crack in an infinite medium [4].

The integration is to be carried out on the entire crack area S .

The factor C_q and the functions g_1 and g_2 have already been established in reference [3] and illustrated through the use of some examples.

3. Analysis of a Crack at a Nozzle Corner

Fig. (1) shows the general view of the junction between the piping and the pressure vessel. We shall note the following geometrical parameters :

Internal diameter of nozzle : 750 mm
External diameter of nozzle : 1250 mm
Internal diameter of vessel : 4000 mm
Thickness of the vessel : 230 mm
Crack radius used : 128 mm

The structure was subjected to the following two types of loading :

- Load Case n° 1 : A moment $M = 0,36 * 10^9$ daN-mm applied to the nozzle at the edge of the pipe around axis-1, with no pressure in the vessel.
- Load Case n° 2 : consists of Load Case n° 1 applied to a vessel pressurized to 100 bars.

The material is supposed to be linear elastic with

Young's modulus $E = 21000$ daN/mm²
Poisson's ratio $\nu = 0.3$

3.1 Numerical analysis of the Nozzle Crack

A high performance Boundary-Integral-Equations method was used for this analysis. In order to reduce the computational cost, one quarter of the structure was used. Fig. 1 (a) shows the general view of the mesh. The model consists of 369 elements and 470 nodes.

In the first place and for use in the semi-analytical method, a computational run was made for the uncracked structure. The stress distribution was determined at seven radial planes issuing through the crotch region (figs. 2 and 3).

Finally, the analysis was carried out introducing a quarter circular crack of radius 128 mm and the SIF was computed along the edge of the crack using the method of extrapolation of the crack-displacement field. Figs. (4) and (5) show the results as a function of angle defined in the figs. These results are also summarized in Table I.

3.2 Analysis of the corner crack through the semi-analytical procedure

The objective here is to define the SIF along the Crack front through the numerical integration of equation (1) making use of the stresses in the uncracked structure. The other parameters used are defined in ref. (3).

The results obtained are indicated on figs. (4) and (5) where these can be compared with results obtained through the Boundary-Integral-Equations method.

3.3 Discussion of Results

From Table I or Figs. (4) and (5) one can remark that the agreement between the BIE method and the semi-analytical procedure is in general quite good. The maximum difference of results is of the order of 16 % in load Case 1 (Moment) and 17 % in load Case 2 (Moment + Pressure). Some of the divergences in these results can be traced back in the formulation of the simplified procedure in ref. [3], one of the important ones being the conservative linear representation of the real stress profile in the crack region.

4. Parametric Analysis of Cracks at the Nozzle

After verification of the semi-analytical model and to show its simplicity and efficiency in handling a parametric study, we have analysed 9 cracks of radii varying from 10 mm to 125 mm. Figs. (6) and (7) present these results for the two loading cases considered previously.

5. Conclusion

In this investigation, we have applied a previously developed model to analyse a quarter circular crack in the crotch region of a nozzle in a pressure vessel. The results have been compared with those obtained by a Boundary-Integral-Equations method. The maximum difference between the two results is of the order of 17 %. In view of the simplicity of its application and extremely reduced cost of analysis (227 sec CPA on an IBM 6400 computer for the nozzle crack analysis), we feel that the procedure provides us with a powerful tool for a first-approximation analysis. The method has been further used to conduct a parametric study of cracks at the nozzle corner.

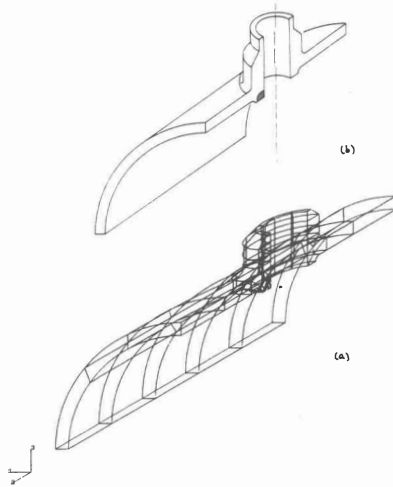


Fig. 1 General view of the junction between Piping and Pressure Vessel

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$\theta = 2/\pi$ Load Case	0.	0.2	0.4	0.6	0.8	1.0
1	15,3 (16,1)	13,50 (13,2)	12,10 (10,7)	11,2 (9,6)	11,5 (10,0)	12,6 (12,5)
2	103,5 (107,2)	94,5 (90,8)	93,0 (83,5)	94,5 (87,4)	99,0 (103,7)	112,5 (131,7)

T A B L E I

Values of K (MPa \sqrt{m}) along the Contour of the Crack
obtained through the use of BIE-method
values in brackets correspond to the proposed method

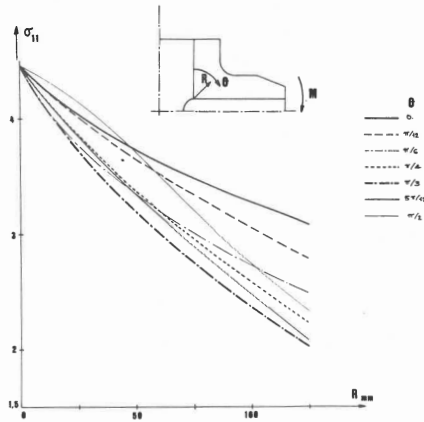


Fig. 2 Stress normal to the Crack Plane in the Uncracked Structure (Load Case 1 : Moment)

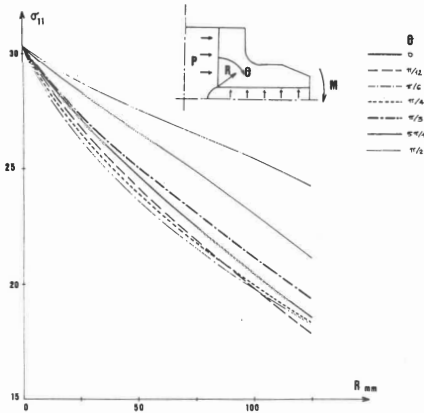


Fig. 3 Stress normal to the Crack Plane in the Uncracked Structure (Load Case 2 : Moment + Pressure)

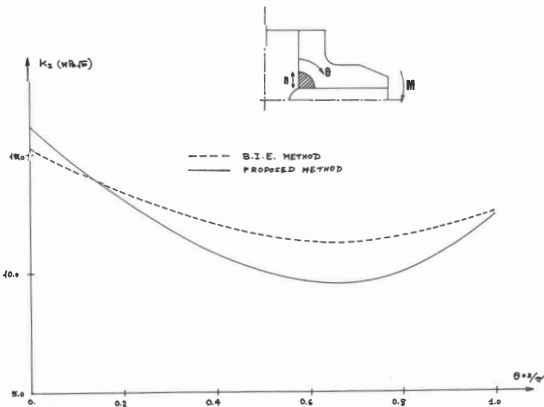


Fig. 4 Comparison between BIE and proposed solutions (Load Case 1 : Moment)

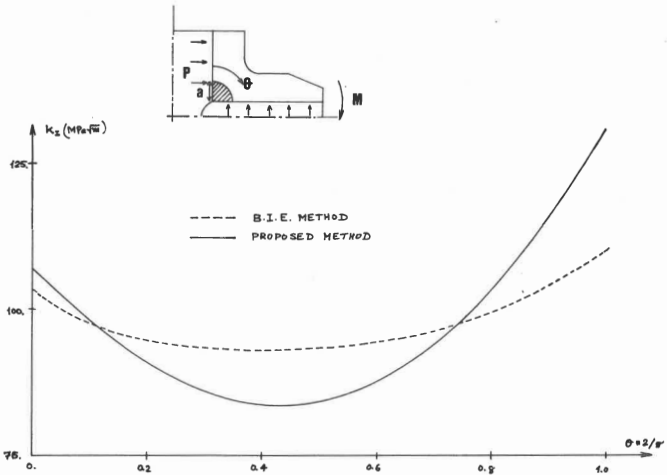


Fig. 5 Comparison between BIE and proposed solutions (Load Case 2 : Moment + Pressure)

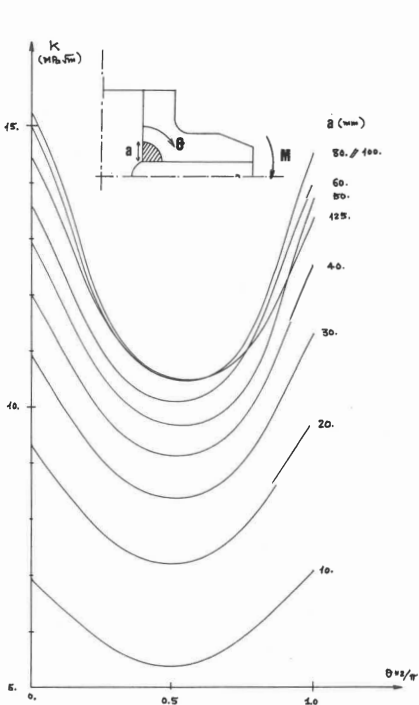


Fig. 6 Parametric study of quarter circular cracks at the Nozzle Corner (Load Case 1 : Moment)

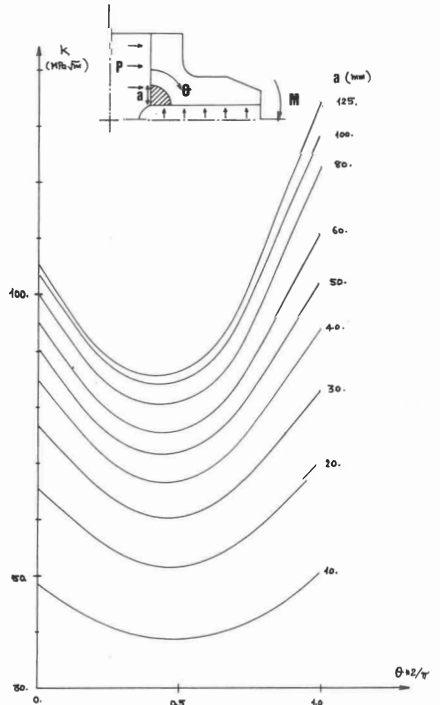


Fig. 7 Parametric study of quarter circular cracks at the Nozzle Corner (Load Case 2 : Moment + Pressure)

