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Development of *K* and COD Solutions of Non-idealized Circumferential Through-wall Cracks for PARTRIDGE

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1. Introduction

PARTRIDGE (Probabilistic Analysis as a Regulatory Tool for Risk Informed Decision GuidancE) is an international research program, main purposes of which are to enhance PRO-LOCA (PRObabilistic-Loss Of Coolant Accident) code, a research piping probabilistic fracture mechanics code originally developed for USNRC, and to support the development of a new modular probabilistic fracture mechanics code, xLPR(Extremely Low Probability of Rupture).

KINS, KHNP, and KEPCO E&C established a Korea Consortium to take part in the PARTRIDGE and have provided not only financial but also technical contribution to it. As part of the research in-kind contribution, Korea Consortium has developed new Mode I stress intensity factors (K_I) and crack opening displacements (COD, δ) for non-idealized through-wall cracks along with EMC2 (Engineering Mechanics Corporation of Columbus).

In this paper, the results of linear elastic fracture mechanics (LEFM) analysis for non-idealized circumferential through-wall cracks performed by Korea Consortium were provided.

2. *K* and COD of Non-idealized Through-Wall Cracks in Cylinders

Until now, PRO-LOCA and xLPR have utilized the concept of the equivalent area method to depict the moment when a surface crack penetrates the wall thickness. This approach assumes that a surface crack grows into an idealized through-wall crack which has the same area as the surface crack after wall penetration. However, recent research [1] demonstrated that the idealized transition from a surface to a through-wall crack can significantly affect a leak rate calculation and may provide non-conservative results in terms of leak rate, especially for long surface cracks.

As a result of feasibility study of the existing *K* and COD solutions for non-idealized through wall cracks, EMC2 showed that they can more accurately simulate the transition behavior. However, since the existing solutions are limited to a certain number of geometries, additional solutions should be developed.

2.1 Methodology

The non-idealized through-wall crack, also called as a slanted through-wall crack, has a different crack length at the inner and outer surface of a pipe as shown in Fig. 1.

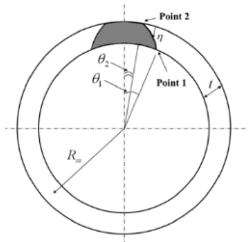

Fig. 1. Schematic illustration of a non-idealized through-wall cracked pipe [2]

Correction factors, *G* and *V* for *K* and COD, respectively, were introduced to correlate the *K* and COD of the idealized through-wall crack with those of the non-idealized one, and were defined as follows[2]:

$$K_I^{Non-idealized} = G_i \cdot K_I^{Idealized} \quad (1)$$

$$\delta^{Non-idealized} = V_i \cdot \frac{4\sigma R_m \theta_1}{E} \quad (2)$$

where σ is the applied load (axial tension or global bending), and subscription 'i' means the specific location along the thickness direction, i.e., 1=inner surface (Point 1), m=middle-thickness, 2=outer surface (Point 2) of a pipe.

Three-dimensional, elastic FE (Finite element) analyses were performed using ABAQUS to obtain *K* and COD for both non-idealized and idealized through-wall cracks. *K* values at the OD and ID surface points were extrapolated using a polynomial fit, then *G* and *V* can be calculated using above equations. FE meshes were generated and provided by EMC2.

2.2 Mesh sensitivity analysis

In order to verify the FE model and to obtain consistency in data processing method used by each member organization of Korea Consortium, sample analyses were performed and compared with the existing solutions [2].

As a result, *G* values at the surface points showed a maximum difference of 50%, meaning possibility of mesh dependence, while *V* values were well agreed. Therefore, mesh sensitivity analyses were performed for the circumferential through-wall cracks existing in cylinders of R_m/t=5, θ_1/π=0.25, and θ_1/θ_2=1, 4 under axial tension or global bending, respectively.

Five models having the different number of elements along the crack front in the thickness direction were considered as in Table 1.

Table 1: Number of elements along the crack front

C2	*C1*	*M*	*F1*	*F2*
15	30	60	120	180

Although *K* values increase with the finer mesh, they seemed to converge as the mesh is refined, as shown in Fig. 2. For this reason, the finer mesh *F2* were chosen for further analyses.

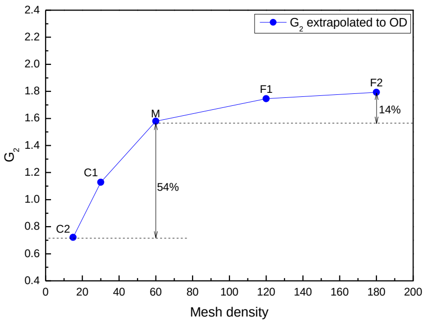

Fig. 2. *G* values at outer surface (G_2) of a through-wall cracked cylinder

2.3 K and COD of Non-idealized through-wall Cracks

A total of 200 cases were analyzed as given in Table 3. The number of nodes and elements in each model are 292,243 and 67,680, respectively. The number of elements along the crack front is 180.

Table 3: Analysis Cases

R_m/t	2, 5, 10, 20
θ_1/π	0.125, 0.25, 0.3, 0.4, 0.5
θ_1/θ_2	1, 1.5, 2, 3, 4
Loading	Axial tension, Global bending

Fig. 3 shows the *G* and *V* factors along the crack front for various crack length ratio (θ_1/θ_2) of the non-idealized through-wall crack with R_m/t=5, θ_1/π=0.125 under the axial tension. The *x*-axis of Fig. 3 represents the normalized distance from the outer surface to the inner surface. Other results, not presented here, also showed similar trend for the *G* and *V* factors.

Generally, the outer surface yields the maximum G_2 values greater than 1 while the inner surface shows the minimum G_1 values less than 1. This implies that the crack would grow mainly at outer surface until it finally grows into an idealized through-wall crack. As the θ_1/θ_2 increases, both *G* and *V* values decrease.

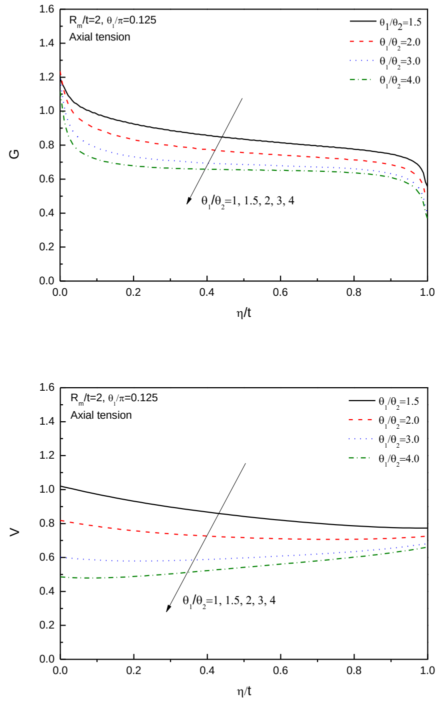

Fig. 3. *G* and *V* values along the crack front of various non-idealized through-wall cracks in a cylinder under axial tension

Korea consortium has provided PARTRIDGE with the tables of *G* and *V* values for the analysis cases of Table 3. These values will be justified by comparing with natural crack growth analyses that will be conducted by EMC2, and then will be incorporated into the crack transition module of PRO-LOCA and xLPR.

3. Conclusions

Korea Consortium, KINS, KHNP, and KEPCO E&C, performs LEFM analyses for non-idealized circumferential through-wall cracks as part of in-kind contribution to the international research program called PARTRIDGE. As a result of analyses, the correction factors, *G* and *V* values, for non-idealized through-wall cracks were provided in the form of table. After justified, they will be incorporated into the crack transition module of the probabilistic fracture mechanics codes, PRO-LOCA and xLPR.

REFERENCES

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