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Considerations of the Initial Crack Damage Effect on the Advanced Idealized Plate Unit

by

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초기균열 손상효과를 고려한 개선된 이상화 판요소

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Abstract

This paper attempts to incorporate the initial crack damage effect into the existing idealized plate unit. For this purpose, a new concept which indicates the equivalent, reduced material properties due to initial cracks at the structural unit level, not at the microscopic aspect, is suggested, and a simplified mechanical plate model for the initially cracked plate in axial tension is formulated as a function of initial crack length, based on the finite-element solutions obtained by crack propagation analysis.

요 약

본 논문은 기존의 이상화 판요소에 초기균열 손상의 효과를 고려하여 개선된 이상화 판요소의 개발에 관한 것이다. 초기균열이 구조물의 거동에 미치는 효과를 규명하기 위해서 인장하중을 받는 판부재가 초기균열의 크기에 따른 거동을 유한요소법으로 해석하여, 그 결과를 바탕으로 기존의 이상화 판요소에 초기균열로 고려할 수 있도록 보완하였다.

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1. Introduction

Under the action of fatigue loading, local cracks may be initiated in the hot spot of the structure. Initial defects or cracks will also be formed in the structure by inappropriate fabrication. These initial cracks will propagate under applied stresses, which eventually may create a very hazardous condition. In the safety assessment of an overall structure, it is, therefore very important to take into account the initial crack effect.

The treatment of this problem may be classified into two groups: one under extreme applied loading and the other under fatigue loading. In this study, attention is paid to the initially cracked plate under monotonically increasing tensile load.

The idealized structural unit method (ISUM)[1] has been developed for analyzing the collapse strength of a ship's hull, and several idealized structural units have been formulated taking into account the combined loading effect, the initial imperfection effect, etc.

The present study attempts to include the initial crack damage effect within the existing idealized plate unit [2][3][4]. For this purpose, a new concept of equivalent, reduced material properties is suggested. A series of crack propagation analysis for an initially cracked plate under tension is performed with variation in the initial crack size, using the finite element technique. Based on the finite element results obtained here, the equivalent, reduced material characteristics, namely the effective elastic modulus, the effective yield stress and the effective critical rupture strain are defined as functions of the inital crack size. Using these effective parameters, the existing idealized plate unit is re-formulated. A verification example for an initially cracked plate under tension is demonstrated.

2. Idealization of Initially Cracked Plate Behavior under Tension

In this study, an initially cracked plate under tension which is applied in the direction perpendicular to the crack line is considered and its behavior is idealized based on finite element solutions. On the other hand, when the axial compression is applied, it is assumed that the behavior of the cracked plate is the same as that of the uncracked one.

2.1 New Concept of Effective Material Property Due to Initial Cracks

When an initially cracked plate is subjected to axial tension, the crack will propagate, and the material characteristic values, namely the elastic modulus, the yield stress, and the critical rupture strain, at the level of the whole plate, will decrease. Here we attempt to define this equivalent, reduced value due to initial cracks at the structural unit level, not just at the microscopic material level as the effective material property, for which the characteristic value will be calculated from the numerical results of crack propagation analysis, using the same technique as for the usual tensile test of the material.

2.2 Method of Crack Propagation FE Analysis

In order to define the effective material property due to initial cracks, a series of crack propagation analysis should be performed. For this analysis, the finite element technique is employed. Since the details of the theory are found in previous papers [5][6], only a brief description is made here.

Two kinds of three-dimensional isoparametric solid elements, one a 6-noded wedge element and the other an 8-noded brick element are used. In principle, the formulation for these elements regarding elasto-plastic behavior is the same as the conventional finite element theory taking into account the strain-hardening effect, but handles the crack propagation behavior differently

In actuality, when the tensile strain reaches the critical rupture strain which is usually greater then the strain at the ultimate tensile strength of the material, the crack will propagate. In this study, however, it is assumed that when the principal tensile stress at the crack tip exceeds the ultimate tensile stress of the material, the crack tip will open with propagation of the crack, these boundary conditions at the newly opended crack tips which have been restrained thus far should be free in the direction of loading. As a result, it is necessary to release the reaction forces which have accumulated at the newly opened nodes. The release of the accumulated reaction force should be made in several steps because unloading in the yielded element may occur in this process. The accuracy of this method has been verified through comparisons with experimental results for initially cracked plates under bending [5][6].

Table 1 Results of propagation analysis by FEM

Properties	Normalized Initial Crack Length, c/b				
	0.0	0.05	0.1	0.3	0.5
E(kg/mm²)	21,000	21,000	21,000	21,000	21,000
σ_0(kg/mm²)	30.0	23.4	22.35	13.25	10.0
ε_{fcr}(%)	18.75	2.908	1.749	0.980	0.697

Note: E = Young's modulus
σ_0 = yield stress
ε_{fcr} = critical rupture strain

2.3 Parametric Analysis and Formulation of Effective Material Property

An initially cracked square plate in tension, as shown in Fig.1, is considered. The crack is through the full thickness and it is located at the center of the plate. Geometric and material properties of the plate are assumed to be :

length a = 1,000 mm
breadth b = 1,000 mm
thickness t = 10 mm
Young's modulus E = 21,000 kg/mm²
Poisson ratio ν = 0.3
yield stress σ_0 = 30 kg/mm²
ultimate tensile stress σ_T = 50kg/mm²($\cong \sigma_0$ /0.6)
strain-hardening coefficient H = 0.01E

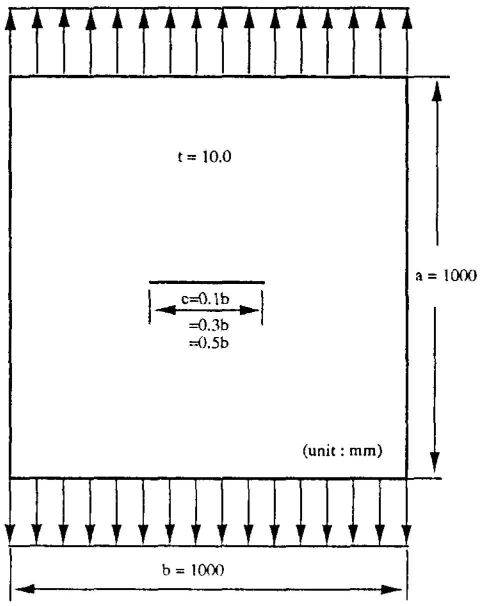

Fig.1 An initially cracked plate under axial tension

Because of symmetry, a quarter of the plate is modelled using the 6-noded wedge elements and the 8-noded brick elements, and small sized elements are used in the vicinity of the initial crack, as shown in Fig.2, in which the minimum size of the elements is 5 x 5 x 5 (mm³). With variation in the crack length, a series of propagation analysis were performed using the super computer CRAY-2S, in which the computing time required for each case was about 50,000 seconds.

Fig.3 shows the average tensile stress-average tensile strain curves of the plate as a function of the crack length. Fig.4 and Table 1 indicate the numerical results of the effective material properties. It is observed that increasing the length of the initial crack does not change the Young's modulus but the yield stress and the critical rupture strain decrease remarkably. In particular, reduction of the critical rupture strain unitl the whole plate is separated into two parts is very rapid. These results may be approximated by the simple formulae, namely

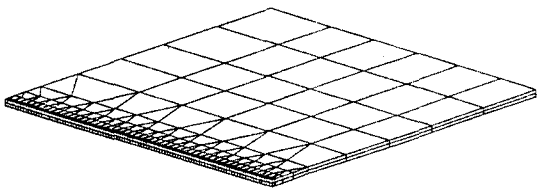

Fig.2 Finite element model for the crack propagation analysis

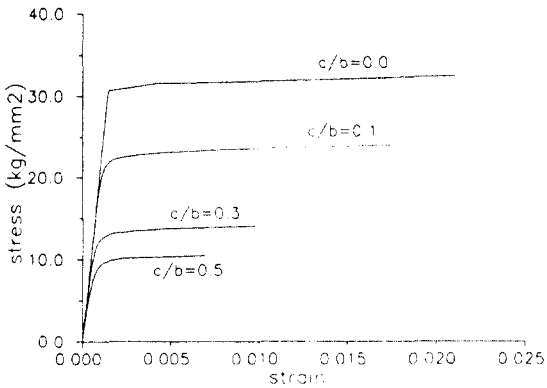

Fig.3 Stress-strain curve for the initially cracked plate

$E_c/E = 1.0$

$\sigma_{oc}/\sigma_o = -5.167(c/b)^4 - 2.600(c/b)^3 + 3.082(c/b)^2 - 2.879(c/b) + 1.0 \quad$ for $c/b \leq 0.5$

$\varepsilon_{tcrc}/\varepsilon_{tcr} = -0.169(c/b) + 0.122 \quad$ for $0.01 < c/b \leq 0.5$

where E_c = effective elastic modulus

E = original elastic modulus (Young's modulus)

σ_{oc} = effective yield stress

σ_o = original yield stress

ε_{tcrc} = effective critical rupture strain (for the uncracked plate)

ε_{tcr} = original critical rupture strain

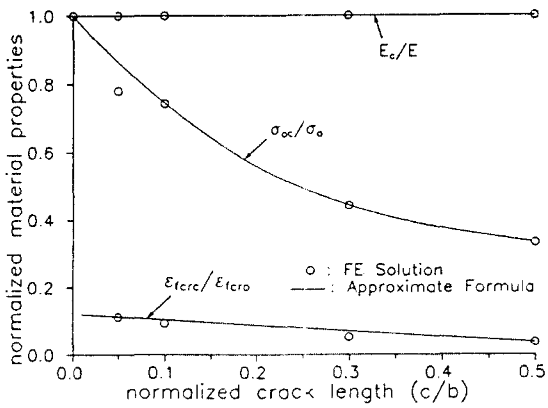

Fig.4 Variance of the effective material properties due to the initial crack length

c = length of the initial crack

d = plate breadth

2.4 Formulation of the Idealized Plate Unit

For an initially cracked plate subjected to an axial tension, the existing idealized plate unit[2][3][4] is re-formulated by replacing the original material parameters with the effective ones defined in the previous section.

3. Verification Example

Using the advanced idealized plate unit, behavior of the initially cracked plate under tension treated in section 2.3 is re-analyzed here. A comparison between the ISUM solutions and the FE results is made in Fig.5. It is observed that the solution by the idealized plate unit agrees well with the FE results.

4. Concluding Remarks

In the structural safety assessment of a ship's hull, initial cracks in local members may play an important role. Almost all research work concerned with this topic has focused on the fatigue strength or on the local

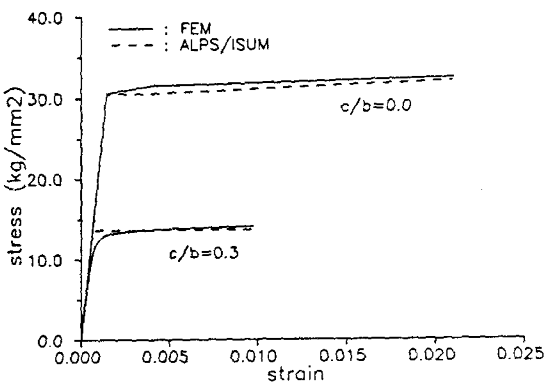

Fig. 5 Accuracy of the idealized plate unit

effects of the initial crack, not on the overall collapse behavior of the structure.

This study aims to treat the initial crack damage affecting the collapse behavior at the overall level of a structure. For this purpose, a new concept of the effective material property due to initial cracks is suggested, and a simplified mechanical model at the structural unit level is formulated based on the numerical solutions by crack propagation FE analysis.

It is observed that the present method provides a reasonable solution, even though idealization of the behavior of an initially cracked plate under tension has been made very simply and approximately.

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