LOCAL STRAIN EVALUATION OF LOAD CARRYING CRUCIFORM JOINTS IN LOW AND HIGH CYCLE FATIGUE REGION

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1. INTRODUCTION

Recent survey[1)] revealed that load carrying cruciform joints at the beam to column connection have partial penetration weld joints which can be crack initiation point due to earthquake load or traffic load called low and high cycle fatigue damage. In order to assess the low and high cycle fatigue strength, local strain approach is considered as an effective tool[2)]. However, it is difficult to evaluate local strain from weld root because of sharp crack tip, hence, the concept of effective notch is introduced to avoid the stress singularity. As a result, it is possible to evaluate the local strain at the weld root of load carrying cruciform joints

2. METHODOLOGY

The objective of this research is to bridge the relation between nominal strain and local strain. Since local strain can be used to assess fatigue strength, but it is not easy to obtain local strain directly from large size structural modeling because relatively small size of element is required for determining the local strain, thus, the attempt is made to establish the relation between local strain of elasto-plastic analysis and nominal strain of elastic analysis. The outline of this research is described as following.

1. The assumption of this concept is described in Eq(1)

$$\frac{\varepsilon_{l,ep}}{\varepsilon_{n,e}} = \frac{\varepsilon_{l,ep}}{\varepsilon_{l,e}} \times \frac{\varepsilon_{l,e}}{\varepsilon_{n,e}} = K_\varepsilon \times K_\sigma \qquad \text{--- Eq (1)}$$

Where $\varepsilon_{l,ep}$ = Local strain from elasto-plastic analysis
$\varepsilon_{l,e}$ = Local strain from elastic analysis
$\varepsilon_{n,e}$ = Nominal strain from elastic analysis

2. Create various aspects of analysis models.
3. Elastic analysis was performed by applied same boundary condition to analysis model. Obtains the local and nominal strain. Then, establishing the formulation which can predict analysis results, considering as K_σ
4. Elastic and Elasto-plastic analysis were performed, series of displacement range were applied to both models. Obtain the relation between local strain from elastic and elasto-plastic analysis. Fit these relations with appropriate equation, considering as K_ε .

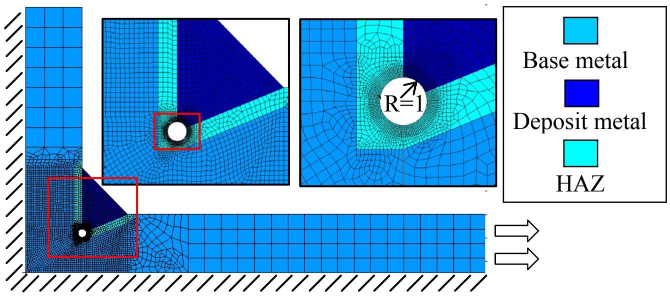
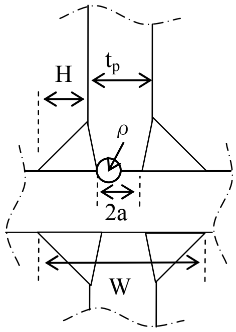


Fig.1 Analysis model

Table 1 Configurations and dimensions of analysis models

Models	H/tp	2a/tp	a/ρ	ρ	tp
1	0.4	0.75	6	1	16
2	0.4	0.75	10.5	1	28
3	0.4	0.75	15	1	40
4	0.6	0.75	10.5	1	28
5	0.2	0.75	10.5	1	28
6	0.4	1	14	1	28
7	0.4	0.5	7	1	28
8	0.4	0.75	21	0.5	28
9	0.4	0.75	7	1.5	28



3. STRAIN CONCENTRATION FACTOR : K_σ

(3.1).Analysis models

Fig.1 presents an example of analysis model and boundary conditions. Two dimensional analyses under plain strain assumption were performed with ABAQUS code. By considering symmetry condition, one-quarter model was created. Geometry of each models were reflected based on **Table 1**.

(3.2) Evaluation of K_σ for linear analysis

By introducing fictitious notch at weld root tip, linear analysis were performed on analysis model as shown in **Fig.1**, the local strain in element along the notch can be calculated from Eq (2). Nominal strain $\sigma_{n,e}$ is defined as load divided by cross section area and young 's modulus.

$$\bar{\varepsilon}_{l,e} = \frac{1}{E}\sqrt{\frac{1}{2}\left[(\sigma_x-\sigma_y)^2+(\sigma_y-\sigma_z)^2+(\sigma_z-\sigma_x)^2+6(\tau_{xy}^2+\tau_{yz}^2+\tau_{zx}^2)\right]} \qquad \text{--- Eq (2)}$$

By considering SIF of load carrying cruciform joint[4)], the SCF for elastic condition can be proposed as following.

$$K_\sigma = \frac{\bar{\varepsilon}_{l,e}}{\varepsilon_{n,e}} = 2\sqrt{\frac{a}{\rho}}\left(A_0 + A_1\frac{a}{w} + A_2\left(\frac{a}{w}\right)^2\right)\sqrt{\sec\frac{\pi a}{w}} \qquad \text{--- Eq (3)}$$

Key Words: load carrying cruciform joint, incomplete penetration, material matching, effective notch, local strain
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(3.3) Verification of K_σ

Fig.2 shows the comparison results between K_σ from analysis and Eq(3), relatively accurate prediction can be achieved.

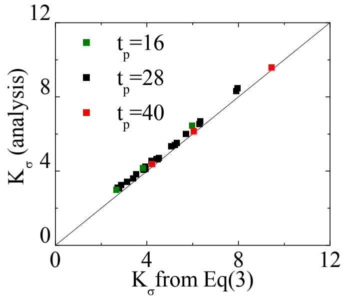

Fig. 2 Accuracy of equation (3)

4. STRAIN CONCENTRATION FACTOR : K_ε

The configurations and dimensions of analysis models were basically same as (3.1). The base metal region (BM), the deposit metal region (DM) and the heat affected zone (HAZ) were divided with different color as shown in Fig.1 The material properties were considered from following Eq.

$$f = \sigma - X - R - \sigma_y \qquad \text{--- Eq (4)}$$

$$R = R_\infty (1 - \exp(-b \cdot \varepsilon_n)) \qquad \text{--- Eq (5)}$$

$$X = X_\infty (1 - \exp(-\gamma \cdot \varepsilon_n)) \qquad \text{--- Eq (6)}$$

Where, R is the isotropic hardening, X is the back stress, σ_y, R_∞, b, X_∞, γ are material parameters, ε_p is plastic strain.

Fig.3-6 show the relation between local strain range of elasto-plastic analysis ($\varepsilon_{l,ep}$), calculated from Eq(7), and local strain range of elastic analysis ($\varepsilon_{l,e}$), calculated from Eq(1) divided by young 's modulus of elasticity. It is obvious that tp, H/tp, 2a/tp and MR, ratio between yield stress of weld deposit and base metal, are influencing parameters.

$$\varepsilon_{l,ep} = \frac{1}{3}\sqrt{2\left[(\varepsilon_x - \varepsilon_y)^2 + (\varepsilon_y - \varepsilon_z)^2 + (\varepsilon_z - \varepsilon_x)^2 + \frac{3}{2}(\gamma_{xy}^2 + \gamma_{yz}^2 + \gamma_{zx}^2)\right]} \qquad \text{--- Eq (7)}$$

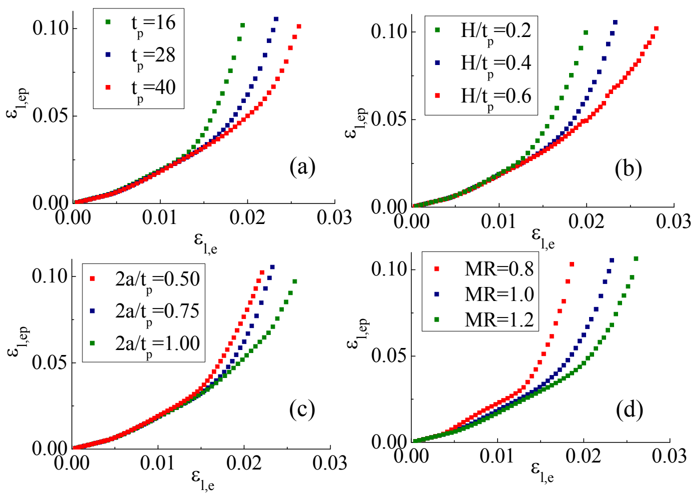

Fig. 3 Effect of plate thickness(a) weld leg(b) incomplete penetration (c) and Material matching (d)

The equation which can fit relation between $\varepsilon_{1,ep}$ and $\varepsilon_{1,e}$ is expressed as shown in Eq(8). By employing the least-squares method, parameter A, B and C can be determined as following.

$$\varepsilon_{l,ep} = A\varepsilon_{l,e} + B\varepsilon_{l,e}^{C} \qquad \text{--- Eq(8)}$$

$$A = 1.829(MR^{-0.401})$$

Where $B = 3.385x10^{12}(M_k{}^{6.592})(\sec(\pi a/w)^{-6.737})(a/R^{-2.438})(H/t_p{}^{-0.492})(a/W^{3.721})$

$$C = 5.207(MR^{0.235})$$

5. ESTIMATION of $\varepsilon_{l,ep}$ FROM $\varepsilon_{n,e}$

Fig.4 presents the accuracy of Eq(8). Vertical axis is $\varepsilon_{l,ep}$ obtained from analysis results. Horizontal axis is $\varepsilon_{l,ep}$ obtained from Eq(8). It is clear that the established equation can be used to calculate local strain of elasto-plastic analysis from nominal strain of elastic analysis with relatively good accurate.

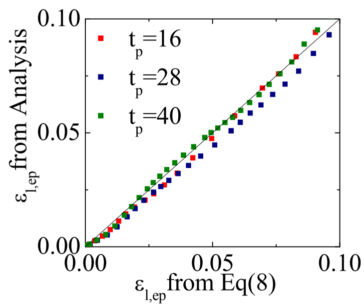

Fig. 4 Accuracy of equation (8)

6. CONCLUSIONS

1.) Stress concentration of load carrying cruciform joints for high and low cycle fatigue region can be proposed.

2.) The concept of effective notch, which originally proposed for high cycle fatigue region, can be extended to low cycle fatigue region.

3.) Strength matching between the weld deposit and the base metal has significant influence on the low cycle fatigue strength, however, it can be negligible in high cycle fatigue region.

7. REFERENCES

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