International Journal of Architecture and Urbanism Vol. 07, No. 02 (2023) 262 – 278

International Journal of Architecture and Urbanism

Journal homepage: https://talenta.usu.ac.id/ijau

Determination of Size Factor Influencing on Evaluation of F atigue Life of Steel Member

Kum Hyok Choe*[1], Hui Gyun Ri[1]

[1] *Faculty of Civil Engineering, Pyongyang University of Architecture, Pyongyang DPR Korea*

*Corresponding Author: shypinguo202124@126.com

ARTICLE INFO

Article history:
Received 01-05-2023
Revised 26-05-02023
Accepted 07-07-2023
Available online 31-08-2023

E-ISSN: 2622-1640
P-ISSN: 2622-0008

How to cite:
Choe K.H., Ri H.G. Space Contestation in the Tri-Dharma Religious Building (Buddhism, Confucianism, Taoism) in Indonesia. International Journal of Architecture and Urbanism. 2023. 7(2):262-278.

ABSTRACT

Irrational elements inside of structure become greater with the increase of size so this results in higher probability of fatigue failure. Especially, cracks easily occur in the sections with comparatively high stress. Since ordinary tensile and compressive fatigue experiment can't provide clear size effect for smooth specimen, it can cause great error in correction of the fatigue strength of a structural member. This paper analyzed size factors of geometrically similar notched specimen based on finite element method and Theory of critical distance (TCD). First, simple formula was presented to calculate size factor of notched specimen by gradient effect, and introduced it to an example to get size factor. Calculation results show it is reasonable to apply size factor to the notched specimen and it is better to reflect size effect under tension and compression. Under the assumption that the life of notched plane mainly depend on the formation of cracks life span formula for steel materials was prepared. And empirical formula for fatigue strength of notched specimen with local feature variable is presented. These formulas and empirical extrapolation were used as the base to determine the formula for size factor of notched specimen. Fatigue simulation and law of approximation were applied to produce a model of skip structure in mine and formula of size factor was used to calculate size factor of member.

Keywords: factor, fatigue, effect, notched specimen

1 Introduction

Reference [5, 6, 15] clarified that size of a member or specimen directly influences on fatigue feature through the fatigue experiment. With the increase of size fatigue features (fatigue strength and life) is reduced and this is called size effect. The bigger the member is, the clearer the reduction occurs. As already known, size of standard specimen, characterizing main fatigue feature curve, is 6-10mm. It is very small compared with real specimen. If it is used directly, it can cause great error much different from real values. This phenomenon is clearer under the tension cycle. Under the repeated tension notched speciemen has clear size effect while standard specimen has no size effect at all.

In practice size effect occurs variously in standard specimen and notched specimen under tension. Therefore it is essential to study on size effect of notched specimen to clarify theimportance of fatigue analysis on structural members in practice. This study aims to determine fatigue properties of notched member and clarify influence on notched specimen [16].

Generally it is difficult to conduct real fatigue experiment for the structural member. So fatigue is usually simulated by micro model or local stress field model. In a fatigue simulation local maximum stress and real member are preserved but stress gradient and high stressed part differ from simulation member due to the size error. Thus the result can't show fatigue properties of structural member [14, 18].

Principles of crack initiation and its propagation in notched speciemen are same as the crack of bigger structure. So size factor in notched specimen can substitute the one of specimen without damage in section so that fatigue analysis become possible.

Creation of micro model of structural member for determination of size factor

Most of fatigue failures are caused by fatigue crack in locally stressed part. Fatigue failure has locality. Accordingly, stress gradient effect by stress concentration in stage of crack initiation allows crack to enlarge on the notches surface to a certain degree. Maximum stress and surrounding stress field regulates the forming state of crack. Stress concentration factor KT equivalent to it is the main adjusting variable in stage of crack initiation. Main adjustable variable in stage of crack propagation is stress strength factor [11]. Figure 1 shows main adjustable factors according to life span stage.

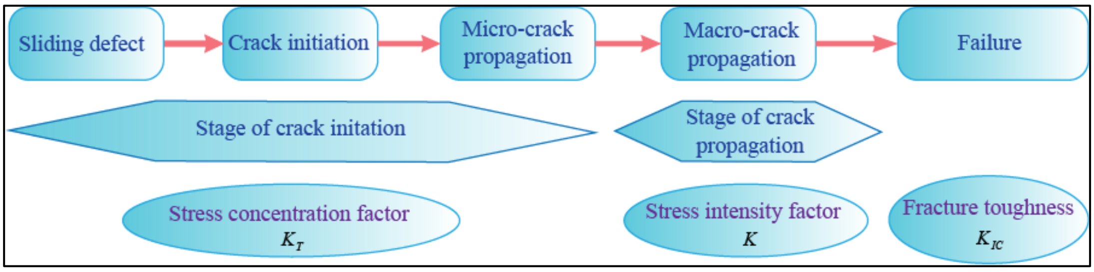


Figure 1 Correlation factor according to life span stage

The main problem is theoretical stress concentration factor KT in the stage of crack initiation. In the structural member with obtuse notched specimen, life span by crack in notched part is dominating.

So K_T is a main adusting variable.

Generally stress distribution in notched part is approximate and it is usually determined by theoretical stress concentration factor K_T and radius of the notched part R. Several experiments prove that in spite of different shape S-N, curve is generally same in notched part with the same K_T. In other words, form of the notched part is not so influential. It is feature value of specimen with K_T.

Fatigue life of obtuse notched member is also mainly determined by two variables [6, 7] those are K_T K_T and $\Delta\sigma$.

Micro model proportional to the structural member can be designed based on the simulation principle, and the stress concentration factors K_T are equal to each other.

Appearance of the member can be also simplified, which is shown in Figure 2.

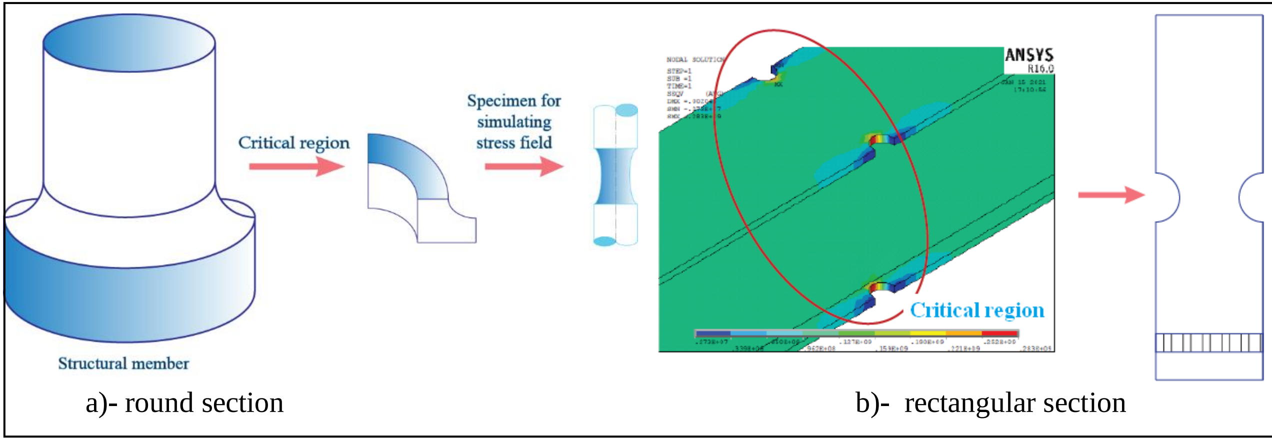


Figure 2 Proportional micro model for simulation

Proportional micro model can be defined as a standard notched specimen during the determination of fatigue life. Structure and experiment condition should satisfy the following conditions to reflect the main characteristics of structural member and preserve the simulation level of small notched specimen.

1. Quality, texture, process technique and surface of the mode must be same with the original member.
2. Cross section type of model and original member must be same.
3. Form and direction of load must be same.
4. Theoretical stress concentration factor must be same. Notched shape in specimen and original member must be same or similar.
5. Stress ratio and working condition of model and original member should be same.

Local proportional micro model is reasonable for high frequency fatigue mainly for crack initiation life. This model has same theoretical stress concentration factor, quality, texture, load bearing type and environment condition with the original member, but the specimen has smaller size and relative big size error with the original member.

Relative size error results in different local size and stress gradient in critical region of specimen. Big specimen also has many cracks in it so its fatigue strength becomes less than of small one. Correction of the size factor can ensure the reflection of practical condition in local micro model.

This paper aims to take size factor on notched specimen to determine formula for size factor by experimental study.

Determination of size factors for notched specimens using gradient effect

As we can see from above, gradient effect is one of the main factors to determine the size effect of notched specimen.

To clarify that the size effect of notched specimen is distinct, finite element method and TCD theory were used to determine the calculation method of size effect for a notched plane specimen in the session of this paper.

1. Approximate calculation of size factor for notched specimens

   To identify the size factor from the one mentioned in the references, ε_n was used to describe the size factor of notched specimen. As we can see from the research results about TCD theory stress curve in notches and length parameters are essential data. Linear or point method could be used to determine the stress curves [19, 20]. Distribution characteristics in notches are displayed in figure 3.

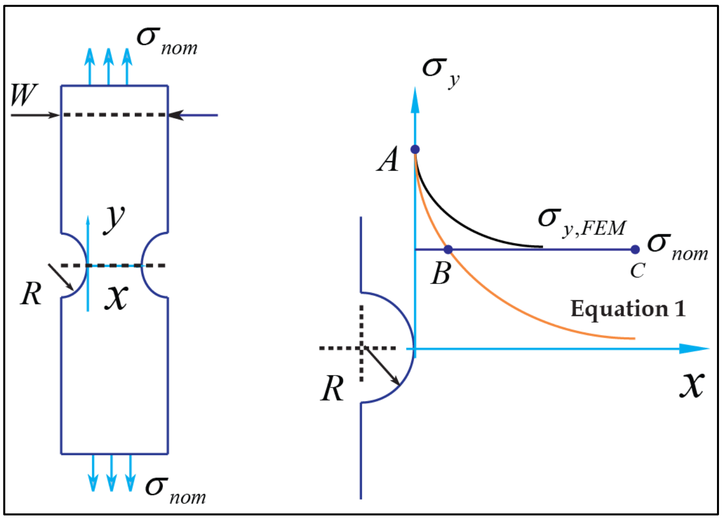


Figure 3 Notch model and stress field

Finite element method is one of the most effective ways and has a relatively high accuracy. In reference [8, 9, 10], approximate expression of stress field in notches using equation 1, 2 and 3 was mentioned. But the results from these equations don't coincide with calculation results from finite elemet method.

$$\sigma_y = \frac{\sigma_{\max}}{3}\left[1+\frac{1}{2}\left(1+\frac{x}{R}\right)^{-2}+\frac{3}{2}\left(1+\frac{x}{R}\right)^{-4}\right] \tag{1}$$

$$\sigma_y = \sigma_{\max}\left[\left(1+\frac{2x}{R}\right)^{-1/2}+\left(1+\frac{2x}{R}\right)^{-3/2}\right] \tag{2}$$

$$\sigma_y = \sigma_{\max}\left[1-2.33\left(\frac{x}{R}\right)+2.59\left(\frac{x}{R}\right)^{1.5}-0.907\left(\frac{x}{R}\right)^{2}+0.037\left(\frac{x}{R}\right)^{3}\right] \tag{3}$$

To obtain more accurate equation about stress field in notches, relatively rational function was gained by combining point method and equation 1.

$$\sigma_y = \sigma_{\max}\left[a''+b''\left(\frac{R}{R+x}\right)+c''\left(\frac{R}{R+x}\right)^{2}+d''\left(\frac{R}{R+x}\right)^{3}+e''\left(\frac{R}{R+x}\right)^{4}\right] \tag{4}$$

In equation 4

R- radius of notches, m

x- distance from notch, m

σ_y - y-dimensional stress, MPa

a'', b'', c'', d'', e'' are simulation factors which are determined from the curve shape of stress changes for stress fields of notches.

Equation 4 is modified into equation 5 by point method based on the TCD theory.

$$\sigma_r = \sigma_{rN}K_T\left[a''+b''\left(\frac{R}{R+L_0/2}\right)+c''\left(\frac{R}{R+L_0/2}\right)^{2}+d''\left(\frac{R}{R+L_0/2}\right)^{3}+e''\left(\frac{R}{R+L_0/2}\right)^{4}\right] \tag{5}$$

σ_r, σ_{rN} in eqauation 5 are fatigue limit of material and notched specimen with the same values of stress ratios.

So equation for fatigue limit of notched specimen can be regarded as equation 6.

$$\sigma_{rN} = \frac{\sigma_r}{K_T}\left[a'' + b''\left(\frac{R}{R+L_0/2}\right) + c''\left(\frac{R}{R+L_0/2}\right)^2 + d''\left(\frac{R}{R+L_0/2}\right)^3 + e''\left(\frac{R}{R+L_0/2}\right)^4\right]^{-1} \quad (6)$$

Since equation 6 contains only one parameter R (change of proportion model) its calculation is comparably simple. Fatigue limit of specimens with different stress concentration factors K_T can be calculated as following. If we name the fatigue limit of a specimen with standard notches σ_{0r}, equation 6 can be described as equation 7.

$$\sigma_{0r} = \frac{\sigma_r}{K_T}\left[f(R_0)^{-1}\right] \quad (7)$$

In equation 7, R_0 is a notch radius of the specimen with standard notches.

From the definition of size factor [6, 17], equation 6 and 7, size factor of notched specimens can be determined as equation 8.

$$\varepsilon_n = \frac{a_0'' + b_0''\left(\frac{R_0}{R_0+L_0/2}\right) + c_0''\left(\frac{R_0}{R_0+L_0/2}\right)^2 + d_0''\left(\frac{R_0}{R_0+L_0/2}\right)^3 + e_0''\left(\frac{R_0}{R_0+L_0/2}\right)^4}{a'' + b''\left(\frac{R}{R+L_0/2}\right) + c''\left(\frac{R}{R+L_0/2}\right)^2 + d''\left(\frac{R}{R+L_0/2}\right)^3 + e''\left(\frac{R}{R+L_0/2}\right)^4} \quad (8)$$

$a_0'', a'', b'', b_0'', c'', c_0'', d'', d_0'', e'', e_0''$ in equation 8 are calculated from stress curve.

Material factor L_0 is gained from design rule or reference [1].

With this equation we can get size factors of notched specimen easily and simplify many experimental stages. As a result this can be regarded as a relatively rational method to determine the size factor affecting the evaluation of fatigue life.

2. Cases for the calculation of size factors

To explain the determination method of size factors for notched specimen by equation 8 in detail, calculation was done for simple cases. Model for the specimen with used standard notches is represented in figure 4.

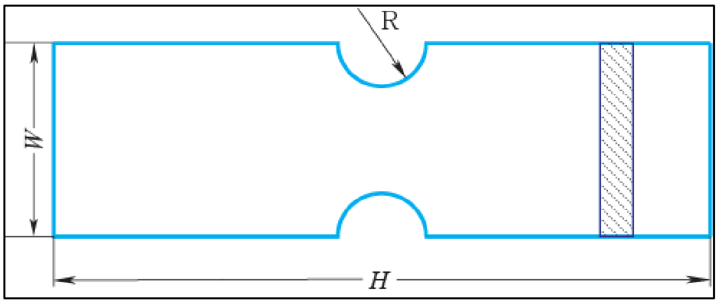


Figure 4 Model of notched specimen

Specimen was plane and there were semicircular notches at two edges. Radii of the notches were 1mm, width and height of a plane was 10mm, 100mm respectively, and had a thickness of 1mm and tensile stress was 10N/mm^2. Material for the specimen was Q235. So we can notice that theoretical stress concentration factor is K_T=2.28 [1, 2]

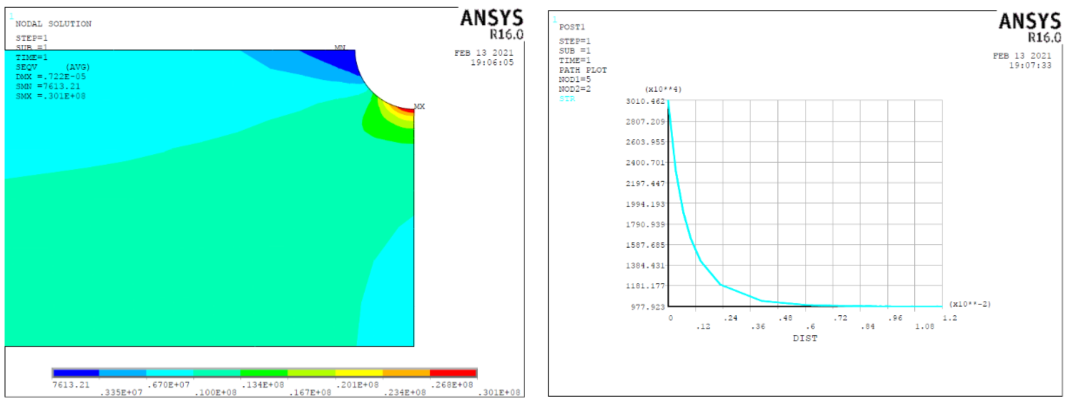
Main properties of the material are monitored in table 1.

Table 1 Properties of the material

Material	σ_s, MPa	σ_b, MPa	σ_r, MPa	R	ΔK_{th}, $MPa \cdot m^{1/2}$	L_0, mm
Q235	235	441	190	-1	6.36	0.08

As the specimen was symmetric we performed finite element analysis by selecting additional a quarter. Under the tensile stress, y-axis stress is regarded as a maximum main stress. In other words stress was calculated along y axis. Analysis on the linear elastic stress was performed prior to the decision of characteristics of stress field and stress distribution.

Changing status of stress field and stress distribution for the specimen with a width of w=300mm, height of h=30mm and diameter of notch R=3mm are represented in figure 5.



a)-stress distribution b)-curve for changes of stress field

Figure 5 Changing of stress field and stress distribution for notched specimen(R=3mm)

We can get factors a'', b'', c'', d'', e'' in equation 4 to 5 by the curve fitting of the calculation results of stresses as displayed in figure 5. It can be regarded as a solution of monomial equation with five variables so the variables were calculated as 0.372, -0.455, 1.405, -1.731 and 1.408 in MATLAB.

From the geometrical similarity we could get corresponding factors a'', b'', c'', d'', e'' by applying finite element method and fitting of stress curve to the geometrically similar specimen again. The results of size factors, calculated from equation 8, are represented in table 2.

Table 2 Size factor (K_T=2.28)

Proportion factor	1:1	2:1	3:1	4:1	5:1	6:1	10:1
Radius of notch R	1mm	2mm	3mm	4mm	5mm	6mm	10mm
Size factor ε_n	1	0.955	0.94	0.932	0.928	0.926	0.92

In the analysis progresses described above, analysis on plane stress was done without considering the influence of the thickness of plane on stress. So previous progress was repeatedly calculated changing the radii of notches of standard specimens.

In the case of stress concentration factor of K_T=2.28, K_T=1.75, K_T=2.64, the changing trend of size factors are represented in figure 6.

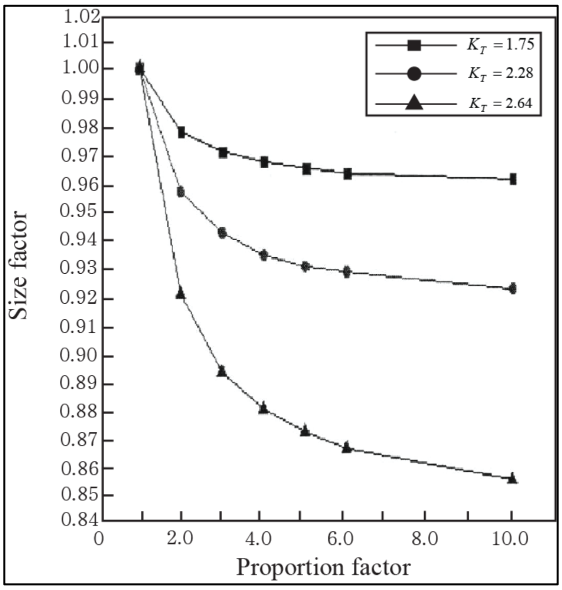


Figure 6 Size factors for different stress concentration factors

As represented in figure 6, the size factor of a notched specimen depends on the changing status of the proportion factor and stress concentration factor.

If the stress concentration factors do not correspond to each other the difference in size factors is huge.

In case of low stress concentration factor the minor change occurs in size factor. This means that it is less affected by size factors and it almost agrees with the size factor of the standard specimen. In other words, it is almost similar to 1.

However, size factor rapidly decreases with the increase of stress concentration factor showing that the influence of size factor is big. As we can see in figure 6 the larger the dimensions of a specimen the slower the gradient of size factor curve. These results agree well with the changes of a size factor of standard cyclider.

These results show that we can accept size factors of a notched specimen calculated with equation 9. Size factors calculated with equation 9 only covers the elastic limit so size curve for entire range of stress concentration factor K_T can be obtained by using interpolate method. We can use equation 10 in case of using interpolate method.

$$\varepsilon_n = \varepsilon_{n1} + (\varepsilon_{n2} - \varepsilon_{n1})(K_T - K_{T1})/(K_{T2} - K_{T1}) \tag{9}$$

$\varepsilon_n, \varepsilon_{n1}, \varepsilon_{n2}$ in equation 9 are size factors corresponding to K_T, K_{T1}, K_{T2}.

As we can notice from the calculation results of cases for the determination of size factors, this method can result correct values in case of thin planes. This method is relatively simple but we must determine its material factor as well as analyzing linear elasticity.

3. Comparison analysis and determination of size factors of notched specimens by experimental method.

Size factor of a notched specimen, which was determined with the finite element method, explains that the size effect of a notched specimen obviously exists. This method can be suitable to apply to thin planes and relatively big error occurs in case of thick planes because it only considers the effect of stress gradient $\vec{G}$. In reference [12, 13], influence of changing status of a specimen on the fatigue life of a specimen, during the fatigue experiment on notched specimens, was analyzed.

So this paper aimed to perform a comparison analysis between the results from experimental method and analytic method, which was already mentioned, so that we can identify the validity of the determination method, suggested in this paper, and to propose a new determination method of the size factors. Moreover this paper covers the changing status of the size factors affecting the fatigue characters of notched specimen with a function displayed as $L/\overline{G}$.

a. Experimental data for the determination of size factors
Experimental situations are following.
The number of vibration was 50Hz, stress ratio was r=0.1, the temperature was 20℃, and the load used was tensile load. Since the influence of a stress concentration factor on the size factor is divergent, Q235 was selected as a material and fatigue experiments were done for cases of stress concentration factors of K_T=2, K_T=3. Chemical composition and mechanical properties of the material are represented in table 3.

Table 3 Chemical composition and mechanical properties [4]

Material	**chemical composition**, %					**mechanical properties**		
	C	Si	Mn	S	P	σ_b / MPa	σ_s / MPa	δ_s(%)
Q235	≤ 0.22	≤ 0.35	≤ 1.4	≤ 0.5	≤ 0.045	441	235	16

Model of the notched specimen used in experiment is represented in figure 7.

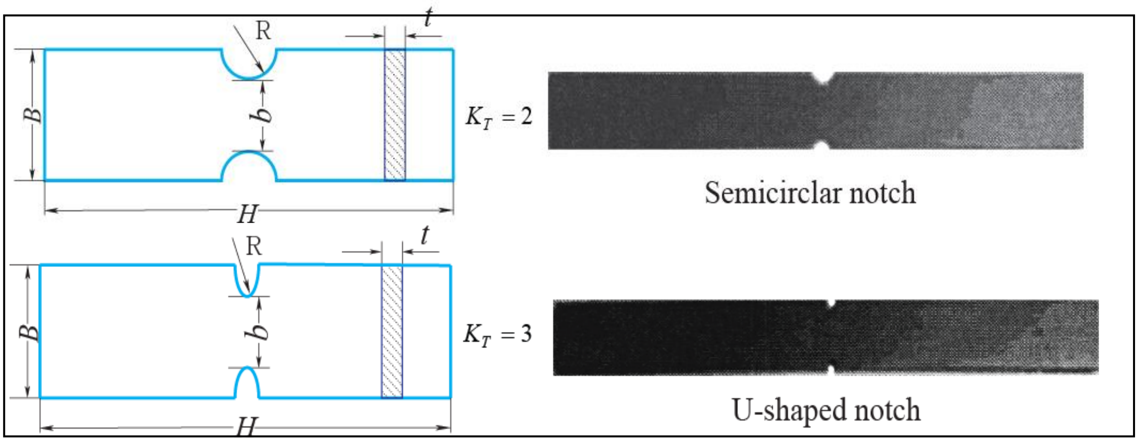


Figure 7 Model of notched specimen

Main dimensions of a specimen with semicircular notches, used in the experiments, are following.

$R = 1.43mm$, $B = 8.4mm$, $b = 6mm$, $t = 1.5mm$

Main dimensions of a specimen with U-shaped notches, used in the experiments, are following.

$R = 0.5mm$, $B = 8.4mm$, $b = 6mm$, $t = 1.5mm$

All the lengthes of both specimens were 120mm [4].

These two specimens described above were prepared as proportional medel specimens having the proportions of 2:1, 3:1, 4:1, 5:1, 8:1, 10:1. In other words all the lengths of specimens were 120mm and the surfaces were smooth.

Specimens used in experiments are represented in figure 8.

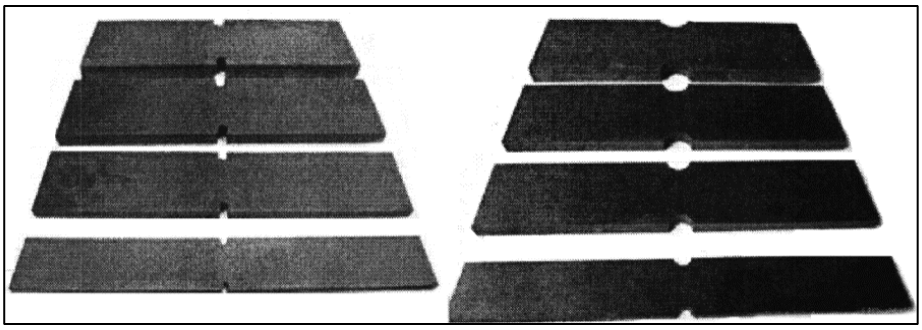


Figure 8 Specimens used in experiments

b. Comparison analysis between the experimental results and the results from the practical formula for calculation of size factors and from equation 9

Prediction results of a fatigue life from the experiments are represented in table 4 and 5.

Table 4 Average life (K_T=2.0) of notched specimen (Q235)

$L/\overline{G}$	Fatigue life $\overline{N}$, cycle			
	380MPa	340MPa	300MPa	280MPa
2.15(1:1)	60 500	102 000	205 000	308 000
8.58(2:1)	52 500	87 800	175 000	260 000
19.31(3:1)	46 500	77 000	150 000	225 000
34.32(4:1)	44 000	72 000	135 000	195 000
53.63(5:1)	41 500	68 000	125 000	180 000
137.28(8:1)	40 000	66 000	120 000	172 000
214.5(10:1)	38 500	63 500	115 000	166 000

Table 5 Average life (K_T=3.0) of notched specimen (Q235)

$L/\overline{G}$	Fatigue life $\overline{N}$, cycle			
	380MPa	340MPa	300MPa	280MPa
0.75(1:1)	26 100	53 000	121 550	203 600
3.00(2:1)	18 650	36 000	84 800	132 500
6.75(3:1)	15 500	28 500	63 500	95 500
12.00(4:1)	13 500	25 800	55 800	84 800
18.75(5:1)	12 500	23 800	51 500	77 000
48.00(8:1)	11 800	22 500	47 600	72 500
75.00(10:1)	11 200	21 200	45 000	69 100

As represented in table 4 and 5, the bigger the proportion factor of notched specimens, the smaller the changing level of prediction results for fatigue life. This is mainly because the bigger notches raised susceptibily level resulting in the approach of fatigue notch factor to theoretical stress concentration factor.

We can get the fatigue strength σ_{nr} of a specimen with the corresponding geometrical similarity by inserting results from table 4 and 5 into equation 11. The results are represented in table 6.

S-N curve equation, mainly used to evaluate the medium or long life, is following.

$$(\sigma_a - \sigma_r)^m N = C \text{ or } \lg N = C - m\lg(\sigma_a - \sigma_r) \quad (10)$$

Fatigue limit of a notched specimen σ_r with a proportional relation can be optained by equation 10. However, as we already got the results of fatigue life at four stress levels, we can use equation 11 for the calculation.

$$\frac{\lg \frac{N_2}{N_1}}{\lg \frac{N_4}{N_3}} = \frac{\lg \frac{\sigma_1 - \sigma_r}{\sigma_2 - \sigma_r}}{\lg \frac{\sigma_3 - \sigma_r}{\sigma_4 - \sigma_r}} \quad (11)$$

Table 6 Calculation results of fatigue strength [σ_{nr}] of notched specimens (Q235)

$L/\overline{G}$	σ_{nr} (**K_T=2.0**)	$L/\overline{G}$	σ_{nr} (**K_T=3.0**)
2.15	195.13	0.75	155.38
8.58	187.93	3.00	142.00
19.31	181.13	6.75	131.30
34.32	172.91	12.00	128.24
53.63	169.25	18.75)	125.67
137.28	167.85	48.00	122.40
214.5	164.72	75.00	121.20

$\sigma_{nr} - L/\overline{G}$ curve drawn out from the fatigue strength results in table 6 is represented in figure 9.

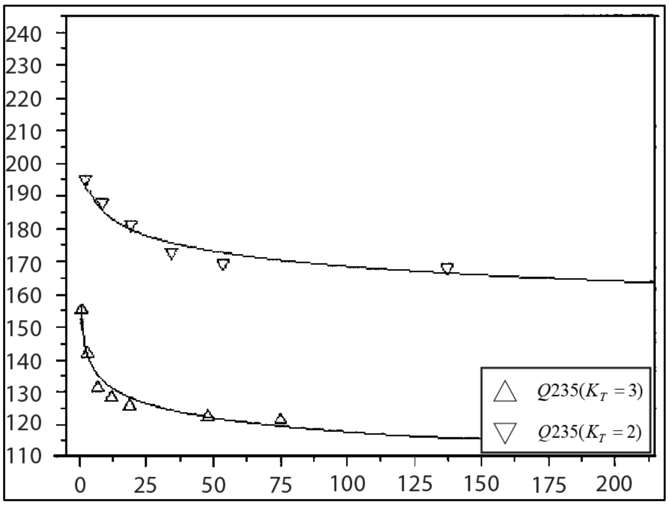


Figure 9 Simulation curve for $\sigma_{nr} - L/\overline{G}$

In this paper, square function simulation for the curve in figure 9 was performed and the result is equation 12. The simulation results were relatively good and the correlation factor was 0.996.

From the results, we can calculate the fatigue strength of specimens with geometrical similarity from equation 12.

$$\begin{aligned} \sigma_{nr} &= 199.71\left(L/\overline{G}\right)^{-0.039} \quad (Q\,235,\, K_T = 2.0) \\ \sigma_{nr} &= 150.54\left(L/\overline{G}\right)^{-0.052} \quad (Q\,235,\, K_T = 3.0) \end{aligned} \tag{12}$$

As we can notice from different factors in right side of equation 12, these factors are divergent with the change of a material of specimen and stress concentration factor for notches.

This shows that we can obtain general determination equation for fatigue strength according to the changing status of stress concentration factors in notches as a shape of equation 13.

$$\sigma_{nr} = \lambda_0\left(\alpha_0 L/\overline{G}\right)^{-\lambda} \tag{13}$$

In equation 13

σ_{nr} - fatigue limit of the specimens with geometrical similarity

λ_0, λ - parameter depending on the type of a material and stress concentration factor

α_0 - calculation factor

In the case of standard notched specimens (1:1 model), as represented in figure 7, size factor for big specimen ε_n can be got by equation 13.

$$\varepsilon_n = \frac{\left(L_L/\overline{G}_L\right)^{-\lambda}}{\left(L_S/\overline{G}_S\right)^{-\lambda}} \tag{14}$$

In equation 14

ε_n - size factor of big specimen

$L_S, \overline{G}_S$ - specific length and relative gradient of a small specimen and standard specimen

$L_L, \overline{G}_L$ - specific length and relative gradient of a long specimen or member.

In this paper, size factor of specimen with a geometrical similarity mentioned in reference [4] was calculated by equation 14.

Comparison results between the analysis results and prediction results are represented in table 7.

Table 7 Comparison results between calculation results by equation 14 and measurement results

$L/\overline{G}$	ε_n (K_T=2.0)			$L/\overline{G}$	ε_n (K_T=3.0)		
	Equation	**Measurement**	**Error**		**Equation**	**Measurement**	**Error(%)**
2.15	1.000	1.000	0	0.75	1.000	1.000	0
8.58	0.948	0.963	1.56	3.00	0.931	0.914	1.86
19.31	0.918	0.928	1.08	6.75	0.89	0.848	4.97
34.32	0.898	0.887	1.25	12.00	0.866	0.826	4.85

$L/\overline{G}$	ε_n (K_T=2.0)			$L/\overline{G}$	ε_n (K_T=3.0)		
	Equation	**Measurement**	**Error**		**Equation**	**Measurement**	**Error(%)**
53.63	0.883	0.868	1.73	18.75	0.846	0.809	4.58
137.28	0.851	0.861	0.6	48.00	0.81	0.788	2.8
214.50	0.836	0.845	1.07	75.00	0.79	0.781	1.16

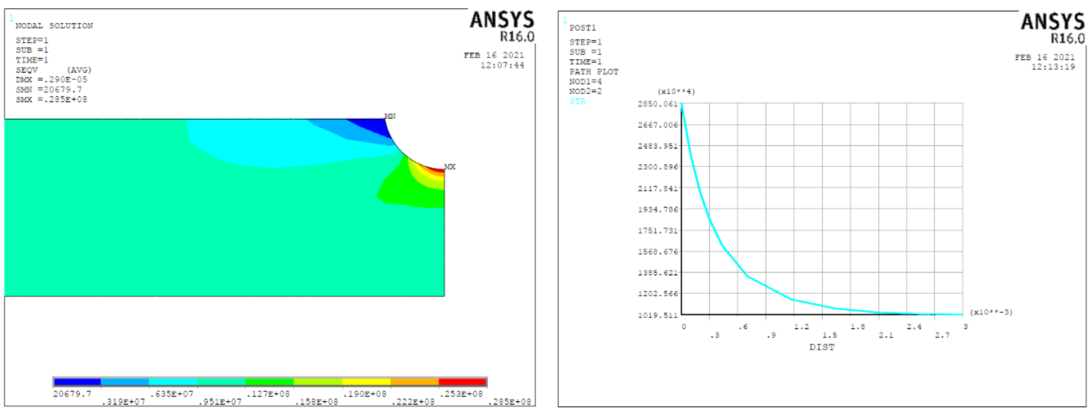
As we can see in table 7, difference between measurement result and values from equation 14 is less than 5% so they are very close. Size factor decreased with the increase of dimensions of specimens and the decrease rate became lower with the increase of dimensions. These results almost agree with the results of undamaged specimens, which are usually used in fatigue design recently, displaying that the reliability of a calculation formula proposed in the thesis is relatively high.

c. Comparison analysis on the results calculated by equation 8 and 14 and from the measurement.

In this paper, finite element method was applied to specimens used in experiment and equation 8 was used to determine the size factor, and then compared it with the results by equation 14.

Semicircular notched specimen with a dimension of $R = 1.43mm$, $B = 8.4mm$, $b = 6mm$, $t = 1.5mm$ and $R = 0.5mm$, $B = 8.4mm$, $b = 6mm$, $t = 1.5mm$ were used as standard specimen and the size factor was determined by appling finite element method to models with proportions of 2:1, 3:1, 4:1, 5:1, 8:1, and 10:1. Here the stress concentration factors were K_T=2.0, K_T=3.0 respectively.

Finite element analysis results for 1/4 model of semicircular notched standard specimens used in the experiment are represented in figure 10.



a- distribution of stress b- curve for changes of stress field

Figure 10 Results of finite element method for the standard semicircular notched specimen (1:1) used in the experiment

a'', b'', c'', d'', e'' for the semicircular notched specimens were determined by b) of figure 10 and equation 5, the results are 0.2737, -0.0000, 1.0911, -2.0631, 1.6983 respectively. Next size factors of proportional specimens were calculated by equation 8. Size factor in case of proportion factor of 2 is following.

$$\varepsilon_2 = \frac{a_0'' + b_0''\left(\frac{R_0}{R_0 + L_0/2}\right) + c_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^2 + d_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^3 + e_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^4}{a'' + b''\left(\frac{R}{R + L_0/2}\right) + c''\left(\frac{R}{R + L_0/2}\right)^2 + d''\left(\frac{R}{R + L_0/2}\right)^3 + e''\left(\frac{R}{R + L_0/2}\right)^4} = 0.964$$

Size factors for other proportional specimens were determined as described above.

Results of finite element method for 1/4 model with U-shaped notches used in the experiment are represented in figure 11.

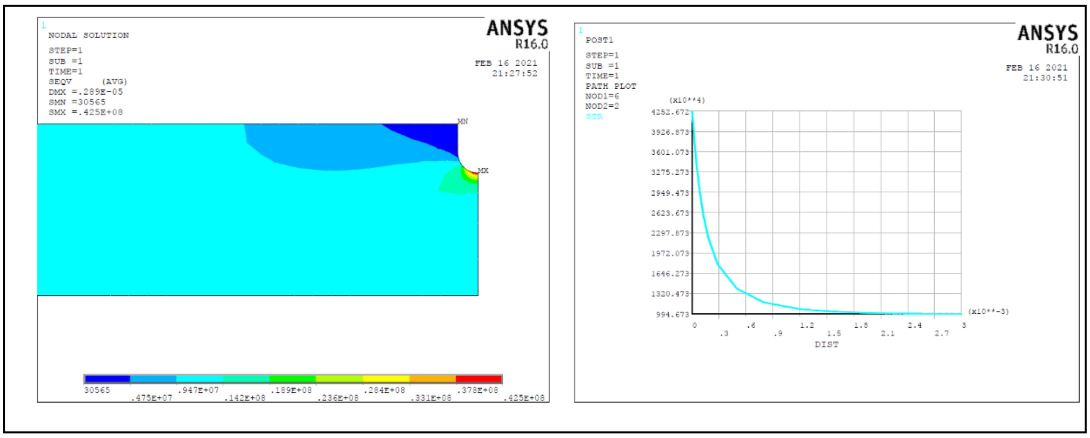


Figure 11 Results of finite element method for 1/4 model of standard specimen (1:1) with U-shaped notches used in the experiment

a'', b'', c'', d'', e'' for semicircular notched specimens were determined by b) of figure 11 and equation 4, the results are 0.2151, -0.0479, 0.8379, -1.0861, 1.0811 respectively. Next size factors of proportional specimens were calculated by equation 8. Size factor in case of proportion factor of 3 is following.

$$\varepsilon_2 = \frac{a_0'' + b_0''\left(\frac{R_0}{R_0 + L_0/2}\right) + c_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^2 + d_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^3 + e_0''\left(\frac{R_0}{R_0 + L_0/2}\right)^4}{a'' + b''\left(\frac{R}{R + L_0/2}\right) + c''\left(\frac{R}{R + L_0/2}\right)^2 + d''\left(\frac{R}{R + L_0/2}\right)^3 + e''\left(\frac{R}{R + L_0/2}\right)^4} = 0.8808$$

Size factors for other proportional specimens were determined as described above.

Comparison results for the size factors determined by equation 8 and 14 are represented in table 8.

Table 8 Comparison results between size factors

$L/\overline{G}$	ε_n (K_T=1.65)			$L/\overline{G}$	ε_n (K_T=2.15)		
	Equation 14	Equation 8	Error(%)		Equation 14	Equation 8	Error(%)
2.15	1.000	1.000	0	0.75	1.000	1.000	0
8.58	0.948	0.964	1.65	3.00	0.931	0.9105	2.25
19.31	0.918	0.952	3.5	6.75	0.893	0.8808	1.38
34.32	0.898	0.946	5.07	12.00	0.866	0.8659	0.01
53.63	0.883	0.943	6.26	18.75	0.846	0.857	1.28
137.28	0.851	0.937	9.17	48.00	0.81	0.8437	3.99
214.50	0.836	0.935	10	75.00	0.79	0.839	5.85

As we can see in table 8, difference between measurement result and values from equation 8 and 14 are less than 10% so they are very close. This means that the accuracy of equation 8, which was determined in the previous part of the paper, is relatively high and that it can be applied to practice. Changing status of size factors by the changes of $L/\overline{G}$ is getting slower with the increase of proportion of a specimen as monitored before.

As represented in table, results from equation 14 were closer to the measurements in the previous method. In other words, error between the results from equation 14 and the measurements was smaller than the error between the result from equation 8 and the measurements. Moreover calculation by equation 14 is simpler than the one by equation 8.

Therefore equation 14 is relatively practical calculation formula to get the size factor of notched specimens. Nevertheless λ in the equation is determined from the experiment or reference review, otherwise, we should determine the power functions by using repeatedly eqation 6 to get fatigue limit of specimens.

So determination of size factors was achieved from equation 8 and 14.

2. Result and Discussion

In this paper size factors for structural member of skip in mine are determined.

2.1 Creation of simulation proportional miniatures

Geometrical dimensions of the standard specimen for bottom member are represented in figure 12.

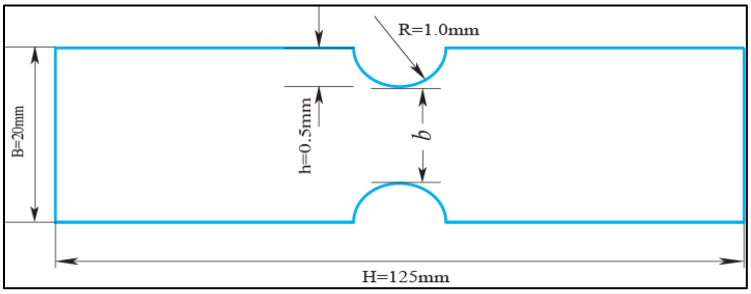
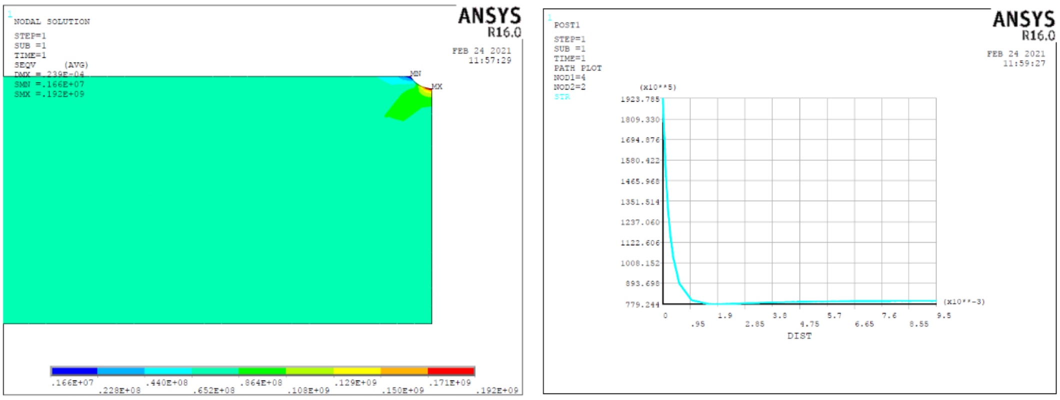


Figure 12 Dimensions and geometrical shape of standard specimen (bottom member, K_T=2.3625)

Standard specimen represented in figure 12 is a geometrically similar specimen having dimensions of 1/40 of bottom member. Calculation for models having the proportions of 1:2, 1:3, 1:4, 1:5, 1:8, 1:10, 1:12, 1:15, 1:20, 1:30, 1:40 are performed using this.

2.2 Determination of stress field using finite element method

Results of finite element method for the 1/4 model of standard bottom member specimen are represented in figure 13.



a-stress distribution b-curve for changes of stress field by distance

Figure 13 Results of finite element analysis for standard specimen (bottom member, K_T=2.3625)

Specific parameters a'', b'', c'', d'', e'' determined by equation 4 and b of figure 13 were 0.4236, -0.0862, 0.4398, -1.2532, 1.4759 respectively.

2.3 Determination of fatigue limit of notched specimens

Fatigue limits determined for geometrically similar specimens by equation 6 are represented in table 9.

Table 9 Fatigue limits of geometrically similar specimens according to proportional factors (bottom member)

$L/\overline{G}$	0.5(1:1)	2(2:1)	4.5(3:1)	8(4:1)	12.5(5:1)	32(8:1)
σ_{nr}, MPa	89.873	85.158	83.582	82.794	82.322	81.612
$L/\overline{G}$	50(10:1)	72(12:1)	112.5(15:1)	200(20:1)	450(30:1)	800(40:1)
σ_{nr}, MPa	81.376	81.219	81.061	80.903	80.746	80.667

2.4 Determination of size factors

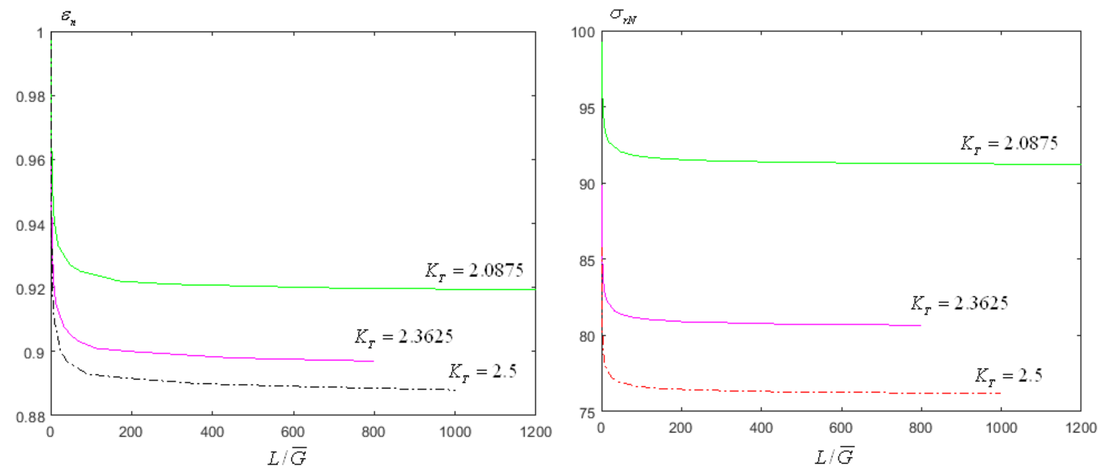
Fatigue limits determined for geometrically similar specimens by equation 8 are represented in table 10.

Table 10 Determination of fatigue limits for geometrically similar specimens according to proportional factors (bottom member)

$L/\overline{G}$	0.5(1:1)	2(2:1)	4.5(3:1)	8(4:1)	12.5(5:1)	32(8:1)
ε_n	1	0.947	0.93	0.921	0.915	0.908
$L/\overline{G}$	50(10:1)	72(12:1)	112.5(15:1)	200(20:1)	450(30:1)	800(40:1)
ε_n	0.905	0.903	0.901	0.9	0.898	0.897

As a result a bottom member has a size factor of $\varepsilon_n = 0.897$ in case of stress concentration factor of $K_T = 2.3625$

As we can notice from table 9 and 10 size factors are decreased with the increase of proportional factor and the reduction level gets slower with the increase of proportional factor. In a case above, $L/\overline{G}$ and changing status of size factor and fatigue limit are represented in figure 14.



a)-changing status of size factor b)-changing status of fatigue limit

Figure 14 Curve for changes of size factor and fatigue limit according to $L/\overline{G}$ (bottom member)

As represented in figure above size factor and fatigue limit of notched specimens are decreased with the increase of stress concentration factor.

Furthermore it slowly decreases rapidly and then slowly by the characteristic parameter. This shows that we must consider the influence of size factor in assessing the fatigue life.

3. Conclusion

In this paper size factors of notched specimen and structural members were determined, then proposed the formula used to calculate the size factor of present structural members followed by its accuracy check with the treatment of experimental data and comparison analysis. From the progress we can notice that error between experimental results and results from calculation equations of size factors suggested in this paper is less than 5%, this means that the accuracy of the equation is guaranteed enough so we can use this equation to get the size factor of structural skip members in mines.

4. Acknowledgement

The author greatly appreciate several critics who gave valuable opinions for the improvement of the thesis.

References

[1] Pietro D'Antuono, Analytical Models for Fatigue Life Prediction of Metals in the Stress-Life Approach, 1-144, A thesis submitted in partial fulfilment of the requirements of Politecnico di Bari,for the award of Doctor of Philosophy in Mechanical Engineering, 2019.

[2] Anders Wormsen, A Fatigue Assessment Methodology for Notched Components Containing Defects, 5-120, Thesis for the degree philosophiae doctor, 2007.

[3] Amir Alipour Ghasabi, Fatigue Pre-Cracking Life Estimation for Fracture Toughness Test Specimens, 5-110, Thesis Submitted To The Graduate School of Natrual and Applied Sciences of Middle East Technical University, 2018.

[4] Tung X YWang DJ，Xu H．Inverstingation of cyclic hysteresis energy in fatigue failure problems [J]. Int．J．Fatigue，1989，11 (5):355-359．

[5] DavidB．Lanninga, Theodore Nicholasb，Anthony Palazotto．The effect of notch geometry on critical distance high cycle fatigue predictions [J]. Int J Fatigue，2005，27：1 623-1 627．

[6] Stamoulis K，Giannakopoulos AE. Size effects on strength. Toughness and fatigue crack growth of gradient elastic solids [J]. International Journal of Solids and Structures，2008，45：492 1-493 5．

[7] BUCH．Verification of Fatigue Life Prediction results for notched specimens with short crack propagation phase [J]. Materials Science and Engineering Technology，1981，12 (8):：272-281．

[8] S．Filippi，P．Lazzarin，R．Tovo．Developments of some explicit formulas useful to describe elastic stress fields ahead of notches in plates [J]. International Journal of Solids and Structures，2002，39：4543-4565．

[9] D．Kujawski，C．S．Shin．On the elastic longitudinal stress estimation in the neighbourhood of notches [J]. Engineering Fracture Mechanics，1997，55 (1):137．138．

[10] Glinka G，Newport A．Universal features ofelastic notch-tip stress fields [J]. Int J Fatigue，1987，9 (3):143-50．

[11] Yves Verreman，Nathalie Limodin．Fatigue notch factor and short crack propagation [J]. Engineering Fracture Mechanics，2008，75：1320-1335．

[12] Langelaan J W，Livne E．Analytic sensitivities and design oriented structural analysis for airplane fuselage shape synthesis [J]. Comppputers&Structures，1 997，62 (3):505-519．

[13] Hakan Ersoy．Design sensitivity analysis of structures based upon the singular value decomposition [J]. Comput Methods Appl．Mech Engrg，2002，19 1：3459．3476．

[14] Makkonen M．Notch size effects in the fatigue limit of steel[J]．Int J Fatigue，2003，25：17-26

[15] M．Makkonen．Statistical size effect in the fatigue limit of steel [J]. Int J Fatigue，2001，23：395-402．

[16] David B．Lanning，Theodore Nicholas，Anthony Palazotto．HCF notch predictions based on weakest—link failure models [J]. Int J Fatigue，2003，25：35．41．

[17] Makkonen M．Notch size effects in the fatigue limit of steel [J]. Int J Fatigue，2003，25：17-26．

[18] Adib-Ramezani H，Jeong J．Advanced volumetric method for fatigue life prediction using stress gradient effects at notch roots叨．Computational Materials Science，2007，39：649-663．

[19] Luca Susmel．The theory of critical distances：a review of its applications in fatigue [J]. Engineering Fracture Mechanics，2008，75：1 706-1 724．

[20] Toshio Hattori，Naoya Nishimura, Minoru Yamashita．Standardization of strength evaluation methods using critical distance stress [J]. Engineering Fracture Mechanics，2008，75：1725-1735．