

STRESS INTENSITY FACTORS FOR CORNER CRACKS IN LOADED HOLES IN LUGS AND WIDE PLATES (TENTATIVE)

1. INTRODUCTION

This Item presents stress intensity factor solutions for corner cracks emanating from single loaded holes in square ended lugs and wide plates. The Item is designated 'tentative' because of the limitations in the analysis and the resulting uncertainties in the accuracy of the solutions obtained. The solutions are presented in terms of the non dimensional geometric parameter α_θ and have been derived via a finite element analysis. This analysis calculates values of stress intensity factor, around the crack front, for two symmetrical corner cracks emanating from single holes in wide plates subjected to two loading conditions, either remote tension or simulated pin-loading. Using the method of superposition and applying suitable correction factors these solutions have been modified to provide values of α_θ for a limited range of lug and wide plate geometries. Correction factors are also provided so that stress intensity factors can be calculated for lugs and plates containing single cracks.

2. NOTATION

Both SI and British units are quoted.

a	crack length along face of lug or plate (from edge of hole)	m	in
c	distance from centre of hole to end of lug or plate	m	in
d	diameter of hole in lug or plate	m	in
F_p	stress intensity boundary-correction factor for wide plate with simulated pin-loaded hole		
F_t	stress intensity boundary-correction factor for wide plate with open hole, loaded by remote tension		
f_c	correction factor for lug head height ratio, c/W		
f_s	correction factor for lug or plate containing single corner crack		
f_w	finite width correction factor defined by Equation (5.4)		
h	crack length along bore of hole	m	in
$K_{I\theta}$	mode I stress intensity factor at positions around crack front defined by θ	N/m ^{3/2}	lbf/in ^{3/2}
P	load on lug or plate	N	lbf
Q	shape factor for an elliptical crack defined by Equations (5.5) and (5.6)		
S	stress based on gross cross-sectional area, thus $S = P/Wt$	N/m ²	lbf/in ²

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S_p	pin bearing stress, thus $S_p = P/dt$	N/m ²	lbf/in ²
t	thickness of lug or plate	m	in
W	width of lug or plate	m	in
α_θ	geometrical factor* defined as $\alpha_\theta = \frac{K_{I\theta}}{S(\pi a)^{1/2}}$		
$\alpha_{\theta h}$	geometrical factor* defined as $\alpha_{\theta h} = \frac{K_{I\theta}}{S(\pi h)^{1/2}}$		
θ	angle around crack measured from face of lug or plate on inscribed quarter-circle (see Sketch 3.1 and Figures 1 to 3)	rad	rad

Suffixes

c	indicates applies to lug head height
s	indicates applies to single cracks

* For a definition of mode I cracks and notes on α see Data Item No. 80036 "Introduction to the use of linear elastic fracture mechanics in estimating fatigue crack growth rates and residual strength of components".

3. PRESENTATION OF DATA

This Item provides values of the geometrical factor α_θ and $\alpha_{\theta h}$ for square-ended lugs and finite width plates subjected to simulated pin loading in the hole and containing two symmetrical corner cracks, either quarter-elliptical or quarter-circular in shape, see Sketch 3.1. Cracks of equal size are assumed to exist on each side of the pin hole along the line of the transverse diameter and down the bore of the hole, but do not completely penetrate the thickness of the component. The stress intensity factor $K_{I\theta}$ may be presented in terms of the angle θ around the crack front and expressed in terms of the factors α_θ and $\alpha_{\theta h}$ so that

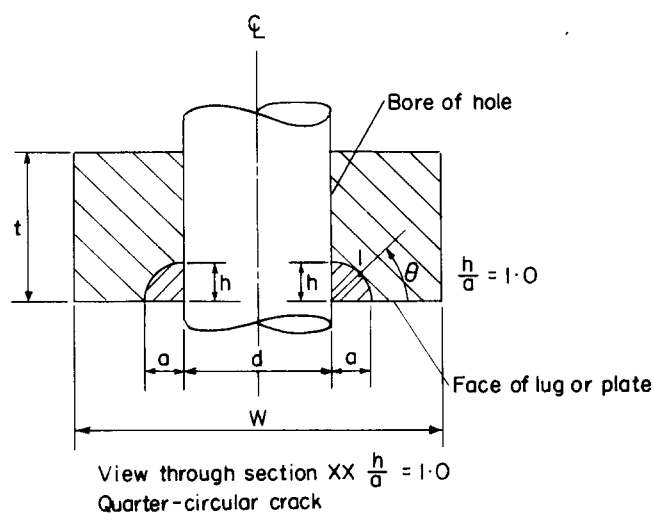
$$K_{I\theta} = S(\pi a)^{1/2} \alpha_\theta, \quad (3.1)$$

in terms of the crack length along the face of the component, and

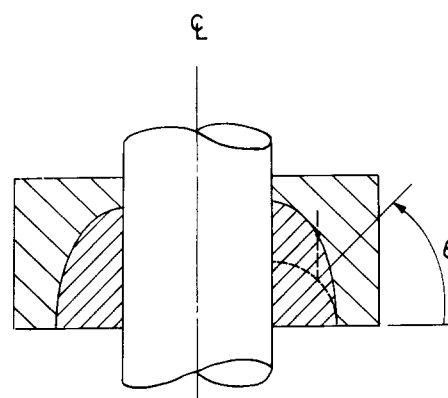
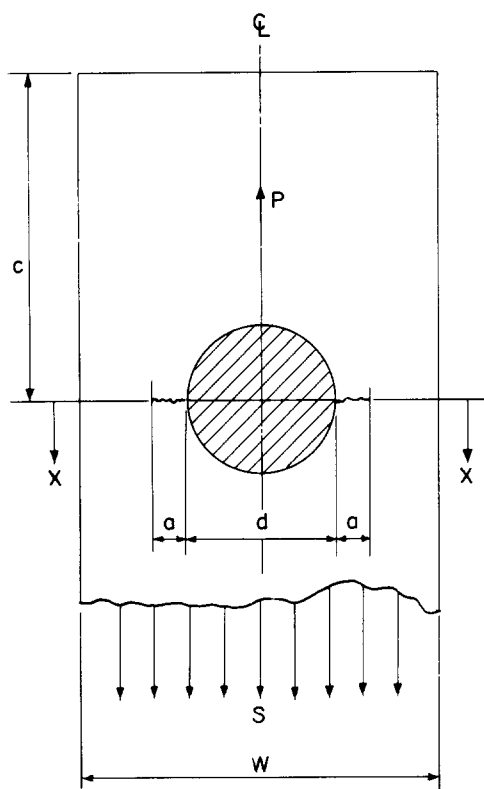
$$K_{I\theta} = S(\pi h)^{1/2} \alpha_{\theta h}, \quad (3.2)$$

in terms of the crack length along the bore of the hole.

The stress intensity factor solution for a lug or finite width plate will be affected by the geometry of the component and the shape and size of the crack. Solutions of α_θ and $\alpha_{\theta h}$ are therefore presented in terms of the geometric parameters shown in Sketch 3.1.



Point I is the position around the crack front at which the values of α_θ are presented in terms of the angle θ , see tabulated data in Section 7.



Sketch 3.1 Showing a typical lug and crack geometry, $\frac{c}{W} = 0.9$, $\frac{W}{d} = 2.5$

Solutions for α_θ and $\alpha_{\theta h}$ pertaining to four lug geometries, the W/d ratios of which range from 2.0 to 4.0, and three plate geometries, with W/d ratios of 5, 10 and 20, are presented in tabular form, see Section 7. For all the geometries considered the lug head height ratio, c/W , is 0.9. In no case does the area of both cracks exceed 50 per cent of the total net area of the lug or plate. Tables 7.1 to 7.18 present values of the factors α_θ and $\alpha_{\theta h}$ as $f(\theta, d/t \text{ and } h/t)$ for various lug and plate geometries, W/d , and crack shapes, h/a , where the angular distance around the crack from the face of the lug or plate to the bore of the hole is presented in terms of the non-dimensional factor $2\theta/\pi$. For each crack shape, values of α_θ and $\alpha_{\theta h}$ are given for the three crack sizes, $h/t = 0.2, 0.5$ and 0.8 , in so far as those crack sizes are within the limitations of the lug or plate geometry.

Figures 1 to 3 present values of α_θ in graphical form for a particular lug ratio, $W/d = 2.5$, for two lug geometries, $d/t = 1.0$ and 2.0 , and for the three crack shapes, two quarter-elliptical, $h/a = 0.2$ and 2.0 , and one quarter-circular, $h/a = 1.0$. Figures 4 and 5 present curves showing how α_θ varies with lug or plate geometry and crack size (W/d , d/t and h/t). Figure 4 presents data for quarter-elliptical cracks, $h/a = 2.0$ at $2\theta/\pi = 0$. Figure 5 presents data for quarter-circular cracks, $h/a = 1.0$ at values of $2\theta/\pi$ of 0.25 and 0.75 . These two figures are used to obtain the theoretical values of α_θ that are presented in terms of $\alpha_{\theta c}$ on Figures 8, 9 and 10.

3.1 Correction Factor for Lugs/Plates Containing a Single Crack

The values of α_θ and $\alpha_{\theta h}$ presented in the tables and on Figures 1 to 5 are for square-ended pin-loaded lugs or plates containing two symmetrical cracks, one on each side of the transverse diameter of the hole. Solutions of α_θ for single cracks can be obtained by multiplying the values of α_θ and $\alpha_{\theta h}$ given in the tables by a correction factor f_s so that

$$\alpha_{\theta s} = \alpha_\theta f_s \quad (3.3)$$

$$\text{and} \quad \alpha_{\theta hs} = \alpha_{\theta h} f_s. \quad (3.4)$$

The following expression for f_s , obtained from Derivation 3, is considered suitable

$$f_s = \sqrt{\frac{d + \pi ah/(4t)}{d + \pi ah/(2t)}}. \quad (3.5)$$

Values of f_s are presented in Figure 6 for the lug or plate geometries and crack sizes covered in this Item.

References 11 and 12 use similar methods to deduce stress intensity factors for single crack configurations.

3.2 Correction Factor for Variations of the Lug Head Height Ratio, c/W

As stated in Section 3 the solutions of α_θ and $\alpha_{\theta h}$ provided in the tables are for one value of the ratio c/W . Variations in this ratio will affect the value of the stress intensity factor, but no data for corner cracks are available. Data Item No. 81029* provides data on the effect of c/W on the stress intensity factor, for through-thickness cracks in round-ended lugs with three different values of c/W , 0.4 , 0.5 and 0.6 . Figure 7 has been derived from these data and provides a correction factor, f_c , which may be applied to the tabulated values of α_θ and $\alpha_{\theta h}$ at $c/W = 0.9$ to correct for the other values of c/W . The assumption is made that the variation of α_θ with c/W for corner cracks in square-ended lugs is similar to that of through-thickness cracks in round-ended lugs so that

$$\alpha_{\theta c} = \alpha_\theta f_c \quad (3.6)$$

$$\text{and} \quad \alpha_{\theta hc} = \alpha_{\theta h} f_c. \quad (3.7)$$

* Item No. 81029 "Stress intensity factors in lugs (through-thickness cracks)".

3.3 Discussion of Figures 1 to 5

It can be seen from Figures 1 to 3 that for the crack shapes $h/a = 0.2$ and $h/a = 1.0$ an increase in the factor $2\theta/\pi$ increases the value of α_θ . For the crack shape $h/a = 2.0$, however, there is a decrease in the value of α_θ as $2\theta/\pi$ increases. The figures also show that lugs with $d/t = 2.0$ have higher values of α_θ than lugs with $d/t = 1.0$. The effect of crack size, h/t , is not consistent and some of the curves cross over, particularly at high and low values of $2\theta/\pi$, but the trend is that the smaller the value of h/t the larger the value of α_θ . Note that, for all lug geometries, there is a decrease in the value of α_θ as the crack intersects the bore of the hole, at $2\theta/\pi = 1.0$. This decrease may not be a physical phenomenon but may be a result of the basic assumptions made in the model of the stress field for three-dimensional cracks. For practical purposes it is suggested that the value of α_θ at $2\theta/\pi = 0.96$ should be used for values of $2\theta/\pi$ in the range $0.96 \leq 2\theta/\pi \leq 1.0$. These values are close to the maximum value of α_θ , depending on the crack shape, see Figures 1, 2 and 3, and are therefore conservative. The values of α_θ at $2\theta/\pi = 0$ given in this Item are considered satisfactory to use at positions close to the intersection of the crack with the face of the lug or plate.

On Figures 4 and 5 a linear relationship between the values of α_θ and W/d is shown in most cases for $W/d \geq 5.0$ (wide plates); below this value of W/d (lug geometries) the curves tend to flatten out although there is a certain amount of overlapping. The reason for the increasing value of α_θ as W/d increases on these figures is that as $(W/d) \rightarrow \infty$ the gross stress $S \rightarrow 0$.

3.4 Comparison with Other Published Data (Figures 8 to 11)

Figures 8 and 9 compare some experimental data* with the solutions of α_θ presented in the tables that have been multiplied by the factor f_c to take into account the effect of the lug head height ratio, c/W . The data show how α_θ and $\alpha_{\theta c}$ vary with the ratio $2a/d$ for lugs for which the W/d , d/t , h/a and c/W ratios are approximately the same. Figure 8 shows that at values of $2a/d > 0.34$ the experimental values of α_θ rise very rapidly to the order of 5 or 6, well above the values of α_θ given in this Item, although a direct comparison cannot be made because this Item does not provide solutions of α_θ for values of $2a/d < 0.2$. Figure 9, on the other hand, shows that the experimental values of α_θ are larger, over the range of $2a/d$ considered, than those presented in this Item. The trends of the curves on the two figures are similar but the differences between the experimental and theoretical values of α_θ are not consistent. The differences are due to the limitations of the finite element analysis, as stated in Section 4, and because of the considerable variations in the test conditions under which the experimental data were obtained. The subsequent analysis of the test results also leads to differences that cannot be quantified.

Figure 10 compares some other published theoretical solutions of α_θ with values presented in this Item for lugs with similar geometries. The table on the figure shows that in most cases the solutions given do not consider the effect of the c/W ratio. The figure shows that the values of α_θ given in this Item are greater than those of the other predictions and are therefore less optimistic. The solutions given in this Item can be as much as 4.5 times greater than some of the earlier published data. For example compare the Data Item solutions with those of Reference 6.

Figure 11 compares some other published finite element solutions of α_θ with values obtained from this Item for wide plates, $W/d = 12$, and in terms of crack shapes, h/a , in the range 0.2 to 2.0. The figure shows that the solutions presented in Reference 8 have similar trends to those given in this Item although only three values of h/a are available. The data of Reference 8 also show a much larger scatter.

* The experimental data presented on these figures have been derived from the results of fatigue crack growth tests on lug specimens. Test values of da/dN for the lugs have been calculated and by the use of $da/dN - \Delta K$ data for the same material values of α have been deduced.

4. LIMITATIONS AND ASSUMPTIONS OF FINITE ELEMENT MODEL

The corner crack that develops from a pin-loaded hole in a lug or plate is a complex three dimensional problem with the crack growing along the face of the component and along the bore of the hole. The finite element model of Derivation 2 therefore makes a number of assumptions and has limitations that are potential sources of error. Hence, when solutions of $K_{I\theta}$ obtained from the theoretical analysis are compared with values obtained from experimental results large differences may occur (as shown in Figures 8 and 9). The assumptions of the model are listed below.

- (i) The simulated pin loading at the hole is assumed to be distributed sinusoidally around the hole. In practice this may not be so. It has been shown that the radial pressure distribution in pin-loaded lugs is an important factor that may influence the value of $K_{I\theta}$, see References 10 and 13.
- (ii) No attempt has been made to model the pin or to take into account pin-fit, pin bending or frictional forces between the lug or plate and pin. References 10 and 13 have shown that the effect of frictional forces on the values of $K_{I\theta}$ is an important factor.
- (iii) The crack shape model assumes a perfect quarter-circle or quarter-ellipse. In reality cracks are only approximately circular or elliptical in shape and where they intersect either the bore of the hole or the face of the component they tend to lag behind the perfect geometric form.
- (iv) As stated previously the model assumes a constant lug head height ratio of $c/W = 0.9$ and applies to square-ended wide plates ($W/d \geq 5.4$)

5. ANALYSIS

Derivation 2 provides solutions of $\alpha_{\theta h}$ for pin-loaded wide plates ($W/d \geq 5.4$) containing three types of corner crack. The expression for $\alpha_{\theta h}$ in Derivation 2 is given by

$$\alpha_{\theta h} = \frac{K_{I\theta}}{S_p \sqrt{\frac{\pi h}{Q}}} = \frac{1}{2} \left(\frac{d}{W} F_t + F_p \right), \quad (5.1)$$

where S_p is the pin bearing stress and Q is a shape factor for an elliptical crack.

The solutions of α_{θ} and $\alpha_{\theta h}$ presented in the tables of this Item have been obtained from modified forms of Equation (5.1). These modifications allow the stress intensity factors to be expressed in terms of the gross stress remote from the cracked area, account for the finite width of the lug or plate and incorporate the shape factor, Q , in the expressions for α_{θ} , so that the form of Equation (3.1) is retained. Equation (5.1) can therefore be rewritten

$$\alpha_{\theta h} = \frac{f_w}{2\sqrt{Q}} \left(F_t + \frac{W}{d} F_p \right). \quad (5.2)$$

An additional modification allows the above solution to be expressed in terms of the crack length, a , so that,

$$\alpha_{\theta} = \frac{f_w}{2\sqrt{Q}} \left(F_t + \frac{W}{d} F_p \right) \sqrt{\frac{h}{a}}. \quad (5.3)$$

Values of F_t and F_p for various values of the angle θ are obtained from tabulated solutions given in Derivations 2 and 5.

The finite width correction factor is expressed by the following equation

$$f_w = \left[\sec\left(\frac{\pi d}{2W}\right) \sec\left\{\frac{\pi}{W}\left(\frac{d}{2} + a\right) \sqrt{\frac{h}{t}}\right\} \right]^{1/2} \quad (5.4)$$

obtained from Derivation 1 and is strictly for an unloaded hole in a finite width plate, but is suitable for use in this Item for the more complex case of the pin-loaded hole in a finite width plate.

The solutions for Q , the shape factor for elliptical cracks, are obtained from the expressions of Derivation 4

$$Q = \left[1 + 1.464 \left(\frac{h}{a} \right)^{1.65} \right] \quad \text{when } \frac{h}{a} \leq 1.0 \quad (5.5)$$

$$\text{and} \quad Q = \left[1 + 1.464 \left(\frac{a}{h} \right)^{1.65} \right] \left(\frac{h}{a} \right)^2 \quad \text{when } \frac{h}{a} > 1.0. \quad (5.6)$$

Equations (5.5) and (5.6) give continuous values of Q over the full range of h/a , from 0 to 2.0 and eliminate the discontinuity of Q suggested by earlier equations (Derivation 1).

6. DERIVATION AND REFERENCES

Derivation

This section lists selected sources that have assisted in the preparation of this Item.

- | | | |
|----|----------------------------|--|
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| 4. | SCHIJVE, J. | Technical Note. Brief note on the stress intensity factor of elliptical cracks. <i>Engng Fract. Mech.</i> , Vol. 18, No. 5, pp. 1067-1069, 1983. |
| 5. | NEWMAN, J.C. | Private communication with Dr J.C. Newman at NASA Langley Research Center, Hampton, Va, USA, July 1983. |

References

This section gives recommended sources of information supplementary to that in this Item.

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7. FUJIMOTO, W.T. Determination of crack growth and fracture toughness parameters for surface flaws emanating from fastener holes. Paper at 17th SDM Meeting of AIAA/ASME/SAE, Valley Forge, Pa, USA, May 1976.
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SMITH, F.W. Part-elliptical cracks emanating from open and loaded holes in plates. *J. Engng Mat. Tech.*, Vol. 101, pp. 12-17, January 1979.
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10. MOON, J.E. Crack growth in pin loaded lugs. Royal Aircraft Establishment, Farnborough, UK, RAE TR 82023, March 1982.
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SCHIJVE, J. Fatigue crack growth of corner cracks in lug specimens. Delft Univ. of Tech., Delft, The Netherlands, Rep. LR-375, January 1983.
13. MOON, J.E. The effect of frictional forces on fatigue crack growth in lugs. Paper presented at the 12th symposium of ICAF, Toulouse, France, May 1983.



7. TABLES

TABLE 7.1

TWO SYMMETRICAL QUARTER CIRCULAR CORNER CRACKS			TWO SYMMETRICAL QUARTER CIRCULAR CORNER CRACKS		
W/d= 2.000 f _w = 1.265	d/t= 1.000 Q= 2.470	h/a= 1.000 h/t= 0.200	W/d= 2.000 f _w = 1.245	d/t= 2.000 Q= 2.470	h/a= 1.000 h/t= 0.200
2θ/π	α _{θh}	α _θ	2θ/π	α _{θh}	α _θ
0.000	1.251	1.251	0.000	1.699	1.699
0.125	1.291	1.291	0.125	1.721	1.721
0.250	1.321	1.321	0.250	1.719	1.719
0.375	1.377	1.377	0.375	1.750	1.750
0.500	1.457	1.457	0.500	1.799	1.799
0.625	1.560	1.560	0.625	1.861	1.861
0.750	1.682	1.682	0.750	1.923	1.923
0.833	1.787	1.787	0.833	1.961	1.961
0.917	1.871	1.871	0.917	1.959	1.959
0.958	1.843	1.843	0.958	1.855	1.855
1.000	1.537	1.537	1.000	1.492	1.492

W/d= 2.000 f _w = 1.450	d/t= 2.000 Q= 2.470	h/a= 1.000 h/t= 0.500
2θ/π	α _{θh}	α _θ
0.000	1.716	1.716
0.125	1.724	1.724
0.250	1.712	1.712
0.375	1.743	1.743
0.500	1.814	1.814
0.625	1.919	1.919
0.750	2.059	2.059
0.833	2.188	2.188
0.917	2.296	2.296
0.958	2.261	2.261
1.000	1.873	1.873

TABLE 7.2

TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS			TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS		
W/d= 2.000 f _w = 1.246	d/t= 1.000 Q= 5.866	h/a= 2.000 h/t= 0.200	W/d= 2.000 f _w = 1.236	d/t= 2.000 Q= 5.866	h/a= 2.000 h/t= 0.200
2θ/π	α _{θh}	α _θ	2θ/π	α _{θh}	α _θ
0.000	1.526	2.159	0.000	1.942	2.747
0.125	1.541	2.179	0.125	1.929	2.728
0.250	1.538	2.175	0.250	1.889	2.672
0.375	1.530	2.164	0.375	1.843	2.607
0.500	1.510	2.136	0.500	1.781	2.518
0.625	1.478	2.090	0.625	1.699	2.403
0.750	1.449	2.049	0.750	1.620	2.291
0.833	1.418	2.005	0.833	1.545	2.185
0.917	1.393	1.969	0.917	1.476	2.088
0.958	1.316	1.861	0.958	1.363	1.928
1.000	1.074	1.518	1.000	1.088	1.538

W/d= 2.000 f _w = 1.450	d/t= 1.000 Q= 5.866	h/a= 2.000 h/t= 0.500	W/d= 2.000 f _w = 1.356	d/t= 2.000 Q= 5.866	h/a= 2.000 h/t= 0.500
2θ/π	α _{θh}	α _θ	2θ/π	α _{θh}	α _θ
0.000	1.413	1.999	0.000	1.829	2.587
0.125	1.425	2.015	0.125	1.820	2.573
0.250	1.416	2.003	0.250	1.782	2.519
0.375	1.408	1.991	0.375	1.747	2.470
0.500	1.402	1.983	0.500	1.710	2.418
0.625	1.402	1.983	0.625	1.668	2.359
0.750	1.428	2.019	0.750	1.641	2.321
0.833	1.457	2.060	0.833	1.615	2.283
0.917	1.509	2.134	0.917	1.603	2.268
0.958	1.491	2.108	0.958	1.528	2.162
1.000	1.280	1.810	1.000	1.254	1.774

W/d= 2.000 f _w = 1.598	d/t= 2.000 Q= 5.866	h/a= 2.000 h/t= 0.800
2θ/π	α _{θh}	α _θ
0.000	1.966	2.780
0.125	1.934	2.735
0.250	1.874	2.650
0.375	1.826	2.582
0.500	1.783	2.521
0.625	1.757	2.485
0.750	1.760	2.489
0.833	1.774	2.509
0.917	1.812	2.563
0.958	1.770	2.503
1.000	1.479	2.091



TABLE 7.3

TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS			TWO SYMMETRICAL QUARTER CIRCULAR CORNER CRACKS		
$W/d= 2.500$ $f_w= 1.209$	$d/t= 2.000$ $r= 1.105$	$h/a= 0.200$ $h/t= 0.200$	$W/d= 2.500$ $f_w= 1.144$	$d/t= 2.000$ $Q= 2.470$	$h/a= 1.000$ $h/t= 0.200$
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
0.000	0.688	0.308	0.000	1.740	1.740
0.125	0.734	0.328	0.125	1.764	1.764
0.250	0.882	0.394	0.250	1.762	1.762
0.375	1.094	0.489	0.375	1.795	1.795
0.500	1.339	0.599	0.500	1.847	1.847
0.625	1.636	0.732	0.625	1.913	1.913
0.750	1.999	0.894	0.750	1.979	1.979
0.833	2.360	1.055	0.833	2.019	2.019
0.917	2.735	1.223	0.917	2.018	2.018
0.958	2.870	1.283	0.958	1.911	1.911
1.000	2.307	1.032	1.000	1.539	1.539
TWO SYMMETRICAL QUARTER CIRCULAR CORNER CRACKS			$W/d= 2.500$ $f_w= 1.254$	$d/t= 2.000$ $Q= 2.470$	$h/a= 1.000$ $h/t= 0.500$
$W/d= 2.500$ $f_w= 1.155$	$d/t= 1.000$ $Q= 2.470$	$h/a= 1.000$ $h/t= 0.200$	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	0.000	1.642	1.642
0.000	1.259	1.259	0.125	1.652	1.652
0.125	1.302	1.302	0.250	1.642	1.642
0.250	1.334	1.334	0.375	1.675	1.675
0.375	1.394	1.394	0.500	1.746	1.746
0.500	1.478	1.478	0.625	1.851	1.851
0.625	1.586	1.586	0.750	1.989	1.989
0.750	1.713	1.713	0.833	2.116	2.116
0.833	1.823	1.823	0.917	2.224	2.224
0.917	1.911	1.911	0.958	2.191	2.191
0.958	1.883	1.883	1.000	1.817	1.817
1.000	1.572	1.572	TWO SYMMETRICAL QUARTER CIRCULAR CORNER CRACKS		
$W/d= 2.500$ $f_w= 1.400$	$d/t= 1.000$ $Q= 2.470$	$h/a= 1.000$ $h/t= 0.500$	$W/d= 2.500$ $f_w= 1.526$	$d/t= 2.000$ $Q= 2.470$	$h/a= 1.000$ $h/t= 0.800$
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	0.000	1.938	1.938
0.000	1.271	1.271	0.125	1.906	1.906
0.125	1.291	1.291	0.250	1.832	1.832
0.250	1.301	1.301	0.375	1.794	1.794
0.375	1.342	1.342	0.500	1.841	1.841
0.500	1.419	1.419	0.625	1.940	1.940
0.625	1.541	1.541	0.750	2.124	2.124
0.750	1.717	1.717	0.833	2.330	2.330
0.833	1.909	1.909	0.917	2.548	2.548
0.917	2.101	2.101	0.958	2.626	2.626
0.958	2.180	2.180	1.000	2.304	2.304
1.000	2.012	2.012			

TABLE 7.4

TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS			TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS		
$W/d= 2.500$ $f_w= 1.145$	$d/t= 1.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.200$	$W/d= 2.500$ $f_w= 1.139$	$d/t= 2.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.200$
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	0.000	2.007	2.838
0.000	1.564	2.212	0.125	1.994	2.820
0.125	1.580	2.234	0.250	1.954	2.763
0.250	1.579	2.233	0.375	1.907	2.697
0.375	1.572	2.224	0.500	1.843	2.606
0.500	1.554	2.198	0.625	1.759	2.488
0.625	1.522	2.152	0.750	1.678	2.374
0.750	1.493	2.112	0.833	1.601	2.264
0.833	1.462	2.068	0.917	1.530	2.164
0.917	1.437	2.032	0.958	1.413	1.999
0.958	1.358	1.921	1.000	1.128	1.595
1.000	1.109	1.568	TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS		
$W/d= 2.500$ $f_w= 1.254$	$d/t= 1.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.500$	$W/d= 2.500$ $f_w= 1.202$	$d/t= 2.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.500$
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	0.000	1.812	2.562
0.000	1.353	1.913	0.125	1.803	2.550
0.125	1.366	1.931	0.250	1.767	2.499
0.250	1.360	1.924	0.375	1.734	2.452
0.375	1.354	1.914	0.500	1.699	2.402
0.500	1.351	1.911	0.625	1.659	2.346
0.625	1.354	1.914	0.750	1.633	2.309
0.750	1.381	1.954	0.833	1.608	2.274
0.833	1.411	1.996	0.917	1.598	2.260
0.917	1.464	2.070	0.958	1.523	2.154
0.958	1.446	2.045	1.000	1.250	1.768
1.000	1.243	1.758	TWO SYMMETRICAL QUARTER ELLIPTICAL CORNER CRACKS		
$W/d= 2.500$ $f_w= 1.526$	$d/t= 1.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.800$	$W/d= 2.500$ $f_w= 1.323$	$d/t= 2.000$ $Q= 5.866$	$h/a= 2.000$ $h/t= 0.800$
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}
$2\theta/\pi$	$\alpha_{\theta h}$	α_{θ}	0.000	1.813	2.564
0.000	1.442	2.040	0.125	1.785	2.524
0.125	1.432	2.025	0.250	1.731	2.448
0.250	1.398	1.978	0.375	1.688	2.387
0.375	1.371	1.939	0.500	1.650	2.334
0.500	1.359	1.922	0.625	1.629	2.304
0.625	1.369	1.936	0.750	1.634	2.310
0.750	1.418	2.005	0.833	1.649	2.332
0.833	1.487	2.103	0.917	1.686	2.384
0.917	1.598	2.260	0.958	1.647	2.329
0.958	1.634	2.310	1.000	1.377	1.947
1.000	1.447	2.046			