FRACTURE CONTROL OF ENGINEERING STRUCTURES – ECF 6

WEIGHT FUNCTIONS FOR THE NON-SYMMETRIC PROBLEM OF AN INCLINED CRACK IN A STRIP

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Few results have been published on dissymmetrically cracked bodies.
Weight functions are calculated for non symmetrically cracked strips. Comparison with solutions of symmetrical problems are presented.

INTRODUCTION

It is well known that a symmetric load on a dissymmetrically cracked body results in mixed modes. However very few solutions have been published for non symmetrical problems.
In this paper the Bueckner's weight functions are calculated for strips with an inclined crack. Dissymmetry results in four weight functions for which curves and polynomial expressions are presented.

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I - Definition and calculation of the weight functions

1.1 - Bueckner's weight functions [1] are here defined as the stress intensity factor resulting from a unit force per unit thickness applied on the crack sides (fig. 1) at the point x

$$G_{ij}(x,a) = \sqrt{\frac{\pi}{2}}\ \frac{K_{ij}(x,a)}{F_j}$$

$$i = I,\ II \qquad\qquad j = N,\ T$$

The singularity of G_{IN} and G_{IIT} at the front makes it advisable to define non dimensional and non singular functions

$$m_{ij}(x,a) = G_{ij}(x,a)\ \sqrt{a-x} \qquad (1)$$

At the crack front x=a the direct functions are [1]

$$m_{IN}(a,a) = m_{IIT}(a,a) = 1 \qquad (2\text{-}a)$$

while the crossed functions resulting from geometric dissymmetry are

$$m_{IIN}(a,a) = m_{IT}(a,a) = 0 \qquad (2\text{-}b)$$

The stress intensity factors are

$$K_I = \sqrt{\frac{2}{\pi}} \int_{-a}^{a} \frac{N(x)\, m_{IN}(x,a) + T(x)\, m_{IT}(x,a)}{\sqrt{a-x}}\, dx = K_{IN} + K_{IT}$$

$$K_{II} = \sqrt{\frac{2}{\pi}} \int_{-a}^{a} \frac{N(x)\, m_{IIN}(x,a) + T(x)\, m_{IIT}(x,a)}{\sqrt{a-x}}\, dx = K_{IIN} + K_{IIT} \qquad (3)$$

The sign convention for K_{II} is as usual $K_{II} > 0$ for $u_x^+ > 0$

1.2 - A normal force N at the point x on the crack sides results in displacements at abscissa t on the crack sides $u_{yN}(x,a,t)$ and $u_{xN}(x,a,t)$ with near the front, $r = a-t$

$$u_{yN}^+ - u_{yN}^- = \frac{4}{E'}\, K_{IN}(a,x) \sqrt{\frac{2r}{\pi}} + B_y r^{3/2} + 0(r^{5/2})$$

$$u_{xN}^+ - u_{xN}^- = \frac{4}{E'}\, K_{IIN}(a,x) \sqrt{\frac{2r}{\pi}} + B_x r^{3/2} + 0(r^{5/2})$$

$E' = E/(1-\nu^2)$ plane strain $\quad E' = E$ plane stress

The stress intensity factors are calculated the ordinary way

$$K_{IN}(a,x) = \frac{E'}{4}\sqrt{\frac{\pi}{2}} \lim_{r \to 0} \frac{u^+_{yN} - u^-_{yN}}{\sqrt{r}}$$

$$K_{IIN}(a,x) = \frac{E'}{4}\sqrt{\frac{\pi}{2}} \lim_{r \to 0} \frac{u^+_{xN} - u^-_{xN}}{\sqrt{r}} \qquad (4)$$

and the corresponding non dimensional weight functions are

$$m_{IN}(x,a) = \frac{K_{IN}(a,x)}{N} \sqrt{\frac{\pi(a-x)}{2}}$$

$$m_{IIN}(x,a) = \frac{K_{IIN}(a,x)}{N} \sqrt{\frac{\pi(a-x)}{2}} \qquad (5)$$

and similarly $m_{IT}(x,a)$ and $m_{IIT}(x,a)$ using $K_{IT}(x,a)/T$ and $K_{IIT}(x,a)/T$.

II - Numerical calculation by finite elements

2.1 - Calculations were performed using the finite element code TITUS, for five inclinations (fig. 2).

β = 90°, 75°, 60°, 45°, 30°

and three crack length ratios

$\alpha = \frac{a \sin \beta}{b}$ = 0,25 - 0,50 - 0,75

The strip was long enough for the results at the front not being influenced by the ends, even for β = 30° and α = 0,75 (fig. 1) L/b = 4.

Dissymmetry makes it necessary to model the whole strip, not only one half.

Around the crack fronts the grid is composed of 8 quarter point elements of 45° each. This angle was judged sufficiently refined, after a comparison with 24 elements on strips subjected to a uniform traction. The size of the crack tip element is less than 2 % of the crack length (fig. 2).

The code and the grid were checked by calculating the well known solution for the symmetric problem (β = 90°) with a uniform traction.

This is an easy method which can be duplicated by anybody who can use a finite element two dimensional code.

2.2 - As mentioned in Sect. I, normal and tangential forces N and T were applied in 30 to 84 nodes, depending on the length, on both sides of the crack. In one computer run the displacements for all the positions of N and T were computed. It was then easy to calculate the $K_{ij}(a,x)$ by the displacements near the front (4), and the four non dimensional weight functions (5).

The displacements were not accurate near the points of application of the forces N and T, where they have a logarithmic singularity. This did not matter for remote points, but resulted in inaccuracy for the points of application near the front. This did not influence the results since according to (2), at the crack front the direct functions m_{IN} and m_{IIT} are one, while the crossed functions m_{IIN} and m_{IT} are zero.

III - Results for the symmetric problem $\beta = 90°$

3.1 - For this problem (fig. 3) symmetry results in

$$\frac{K_{IN}}{N} = \frac{K_{IIT}}{T}$$

and

$$m_{IN}(x,a) = m_{IIT}(x,a) = m(x,a)$$

$$m_{IIN} = m_{IT} = 0 \qquad (6)$$

In an infinite plane, from handbooks and [2]

$$m_{\infty}(x,a) = \sqrt{\frac{1}{2}\left(1 + \frac{x}{a}\right)} \qquad (7)$$

The results are presented with reference to the infinite plane in the form

$$m(x,a) = \sqrt{\frac{1}{2}\left(1 + \frac{x}{a}\right)}\; P\left(\frac{x}{b},\frac{a}{b}\right)$$

or with $\alpha = \frac{a}{b}$ $\quad \xi = \frac{x}{b}$

$$m(\xi,\alpha) = \sqrt{\frac{1}{2}\left(1+\frac{\xi}{\alpha}\right)}\; P(\xi,\alpha) \qquad (8)$$

where $P(\xi,\alpha)$ is a polynomial of ξ, with coefficients functions of α

$$P(\xi,\alpha) = A_0(\alpha) + A_1(\alpha)\left(\frac{\xi}{\alpha}\right) + A_2(\alpha)\left(\frac{\xi}{\alpha}\right)^2 + A_3(\alpha)\left(\frac{\xi}{\alpha}\right)^3 \qquad (9)$$

The results for $\alpha = 0{,}25 - 0{,}50 - 0{,}75$ are presented on fig. 5, with the coefficients $A_i(\alpha)$ in Appendix.

The difference with m_{∞} is very little for $\alpha = 0{,}25$; not negligible, 30% for $\alpha = 0{,}50$; important, 100% for $\alpha = 0{,}75$

3.2 - Comparison with Tada's formula.
In [2] Tada gives the equation

$$\frac{K_I}{N} = \frac{1}{\sqrt{2b}} \left[1+0,297 \sqrt{1-\left(\frac{x}{a}\right)^2} \left(1-\cos\frac{\pi a}{2b}\right)\right] F_{III}\left(\frac{x}{a},\frac{a}{b}\right) \qquad (10)$$

$F_{III}\left(\frac{x}{a},\frac{a}{b}\right)$ is the algebraic solution for a strip in mode III. It results from the addition of two symmetric distributions of forces of period 4b on a periodic array of cracks of period 2b ; this sum yields zero shear stresses on the lines $x = \pm b$, and is the solution for a strip. It yields the following non dimensional weight function

$$m_{III}\left(\frac{x}{a},\frac{a}{b}\right) = \frac{1}{2}\sqrt{\frac{\pi}{b}\,\mathrm{tg}\,\frac{\pi a}{2b}}\;\frac{1+\dfrac{\sin\frac{\pi x}{2b}}{\sin\frac{\pi a}{2b}}}{\sqrt{1-\left(\dfrac{\cos\frac{\pi a}{2b}}{\cos\frac{\pi x}{2b}}\right)^2}}\;\sqrt{a-x} \qquad (11)$$

As it is not very easy to handle this $m_{III}\left(\frac{a}{b},\frac{x}{b}\right)$ the reference to the infinite plane rather than to the strip in mode III has been chosen for the expressions (8) of $m(\xi, \alpha)$.

The ratio $m\left(\frac{x}{a},\frac{a}{b}\right) / m_{III}\left(\frac{x}{a},\frac{a}{b}\right)$ has been found in agreement for $x = \pm a$, $x = 0$, but not for the intermediate values of x.
For agreement it should not be 1 everywhere, but it should be Tada's correcting factor III to I between [ ] in equation (10).

The difference with (11) increases with the length of the crack. The difference of stress intensity factors for a uniform traction is not very important, but it could be more important for tractions varying on the crack.

IV - Results for inclined cracks

4.1 - The four non dimensional weight functions $m_{ij}(x,a)$ or $m_{ij}(\xi,\alpha)$ ($i = I, II$; $j = N, T$) defined by eq (1) were calculated for twelve cases

crack lengths $\alpha = \frac{a \sin\beta}{b} = 0{,}25 - 0{,}50 - 0{,}75$

angle $\beta = 75 - 60 - 45 - 30°$

Abscissa $\xi = \frac{x \sin\beta}{b}$

Constant α means a constant ratio of the crack length to the inclined section of the strip, not a constant crack length.

The results are given by three sets, for α fixed, of four diagrams (fig.6,7,8), the scale varies with the page.

4.2 - The diagrams evidence the following features

- short cracks ($\alpha = 0{,}25$) at small inclinations ($\beta = 75°-60°$) have m_{IN}, m_{IIT} very near m_∞, with m_{IIN}, m_{IT} near zero ; this could easily be foreseen
- for a given α, m_{IN} increases with the inclination (β decreasing), rapidly for large α, while m_{IIT} is little sensitive to inclination
- the crossed functions m_{IIN} and m_{IT} are small compared to the direct ones, except for long cracks and large inclinations ($\alpha = 0{,}75$ - $\beta = 30°$)
- m_{IIN} and m_{IT} are most often negative ; however m_{IIN} is positive for small β, and for larger β gets positive for long cracks.

4.3 - Small values of m_{IIN} and m_{IT} explain that most often geometric dissymmetry alone does not result in important mixed modes.
Some authors have applied the equations for $\beta = 90°$ to problems with $a^* = a \sin\beta = 0{,}20$ b and $\beta = 45° - 60°$. Fig. 6 a) b) c) show the error could be negligible for $\beta = 75°$, but not for $\beta = 45$ or $60°$.

Negative values of m_{IT} can be explained on long cracks (fig. 1) by the different rigidities of the regions each side of the crack ; on the figure (1b) the crack is opened by a normal traction N, and a superimposed traction T results in $u^-_{yT} > u^+_{yT} > 0$ and $K_{IT} < 0$.

Similarly in (1c) normal traction N yields $u^+_{xN} < 0$, $u^-_{xN} > |u^+_{xN}| > 0$ and $K_{IIN} < 0$.

4.4 - Polynomials $P_{ij}(\xi,\alpha,\beta)$ defined by $m_{ij}(\xi,\alpha,\beta) = P_{ij}(\xi,\alpha,\beta)\ m_\infty = P_{ij}(\xi,\alpha,\beta)\sqrt{\frac{1}{2}\left(1+\frac{\xi}{\alpha}\right)}$ are presented in Appendix.

4.5 - For a uniform traction σ_o on the strip the stress intensity factors were calculated using the weight functions, and directly applying the traction, for $\beta = 30°$ and $\alpha = 0,25 - 0,50 - 0,75$ (fig. 4).

$$K_I = K_{IN} + K_{IT} = \sqrt{\frac{2a}{\pi\alpha}}\ \sigma_o \int_{-\alpha}^{\alpha} \frac{m_{IN}\sin^2\beta + m_{IT}\sin\beta\cos\beta}{\sqrt{\alpha - \xi}}\, d\xi$$

$$K_{II} = K_{IIN} + K_{IIT} = \sqrt{\frac{2a}{\pi\alpha}}\ \sigma_o \int_{-\alpha}^{\alpha} \frac{m_{IIN}\sin^2\beta + m_{IIT}\sin\beta\cos\beta}{\sqrt{\alpha - \xi}}\, d\xi$$

while for the infinite plane

$$K_{I\infty} = \sigma_o \sqrt{\pi a}\ \sin^2\beta$$

$$K_{II\infty} = \sigma_o \sqrt{\pi a}\ \sin\beta\cos\beta$$

The results are ($\beta = 30°$)

	α	0,25	0,50	0,75
$K_I/K_{I\infty}$	w.f	1,22	1,81	2,96
	direct	1,24	1,83	2,99
$K_{II}/K_{II\infty}$	w.f	1,11	1,37	1,91
	direct	1,11	1,38	1,91

The calculated weight functions seem therefore reliable It is sure that for small β, $K_{II} > K_I$ on account of the different orders of magnitude of $\sin\beta\cos\beta$ and $\sin^2\beta$. This reversal takes place for $\beta < 30°$.

The importance of the crossed terms is also evidenced ($\beta = 30°$).

	α	0,25	0,50	0,75
$100\ K_{IT}/K_I$		-3,03	-17,6	-45,9
$100\ K_{IIN}/K_{II}$		0,09	4,15	15,74

The relative importance of K_{IT} compared to K_{IIN} results from $\sin\beta\cos\beta = \sqrt{3}/4$ and $\sin^2\beta = 1/4$ for $\beta = 30°$

4.6 - A similar calculation in bending yields a comparison with the infinite plane.
Let the applied stress on the strip be (fig. 4)

$$\sigma_B\ (\xi) = \sigma_B \frac{x}{a} = \sigma_B \frac{\xi}{\alpha}$$

(σ_B = bending stress at the front).

In the infinite plane

$$K^B_{I\infty} = \sqrt{\frac{2}{\pi}}\ \sigma_B \sin^2\beta \int_{-a}^{a} \frac{x}{a} \sqrt{\frac{1}{2}\,\frac{1+\frac{x}{a}}{a-x}}\ dx$$

$$K^B_{I\infty} = \frac{\sigma_B}{2}\sqrt{\pi a}\ \sin^2\beta$$

$$K^B_{II\infty} = \frac{\sigma_B}{2}\sqrt{\pi a}\ \sin\beta\ \cos\beta$$

and in the strip

$$K^B_I = K^B_{IN} + K^B_{IT} = \sqrt{\frac{2a}{\pi\alpha}}\ \sigma_B \int_{-\alpha}^{\alpha} \frac{\xi}{\alpha}\,\frac{m_{IN}\sin^2\beta + m_{IT}\sin\beta\cos\beta}{\sqrt{\alpha-\xi}}\ d\xi$$

$$K^B_{II} = K^B_{IIN} + K^B_{IIT} = \sqrt{\frac{2a}{\pi\alpha}}\ \sigma_B \int_{-\alpha}^{\alpha} \frac{\xi}{\alpha}\,\frac{m_{IIN}\sin^2\beta + m_{IIT}\sin\beta\cos\beta}{\sqrt{\alpha-\xi}}\ d\xi$$

The results are ($\beta = 30°$)

	α	0,25	0,50	0,75
$K^B_I\ /\ K^B_{I\infty}$		1,008	1,172	1,627
$K^B_{II}\ /\ K^B_{II\infty}$		1,008	1,100	1,421
$100\ K^B_{IT}\ /\ K^B_I$		-0,47	-6,88	-26,94
$100\ K^B_{IIN}\ /\ K^B_{II}$		negligible	1,39	10,94

The crossed terms are rather important for long cracks.

V - Conclusion

Weight functions for dissymmetrically cracked strips have been calculated.
Very long cracks have not been studied. The limit for this problem would be an infinite notch leaving a neck in a semi infinite plane, on which indications can be found in [1, 2].
Few results have been previously published on non symmetric bodies. This study confirms that geometric dissymmetry results only in weakly mixed modes if the load is symmetric and the crack rather short. But dissymmetry must be taken into account when the crack is moderately long compared to the dimensions of the body.

Polynomial expressions have been presented for $\beta \geqslant 30°$; they might be rather different for smaller angles.

REFERENCES

1 - H.F. Bueckner - Field singularities and related integral representations - ch. V of Mechanics of Fracture I - Edited by G.C.SIH - Noordhoff - 1973.

2 - H.Tada, P. Paris and G. Irwin - The Stress Analysis of Cracks Handbook - Del Research Corporation - Saint Louis - 1973.

3 - H.M. Westergaard - Bearing pressures and cracks - Journal of Applied Mechanics - June 1939, p. 49.

APPENDIX

Polynomial representations

A - Symmetric problems $\beta = 90°$ $\qquad \alpha \leqslant 0,75$

$$P(\xi,\alpha) = A_0(\alpha) + \left(\frac{\xi}{\alpha}\right) A_1(\alpha) + \left(\frac{\xi}{\alpha}\right)^2 A_2(\alpha) + \left(\frac{\xi}{\alpha}\right)^3 A_3(\alpha)$$

$$A_0(\alpha) = 0,99237 + 0,30295\,\alpha - 1,0130\,\alpha^2 + 3,6281\,\alpha^3$$

$$A_1(\alpha) = -0,00155 - 0,13768\,\alpha - 1,0127\,\alpha^2 + 0,46172\,\alpha^3$$

$$A_2(\alpha) = 0,00572 - 0,43261\,\alpha + 2,4685\,\alpha^2 - 4,0458\,\alpha^3$$

$$A_3(\alpha) = 0,00272 + 0,25455\,\alpha - 0,44225\,\alpha^2 - 0,01897\,\alpha^3$$

These coefficients result from 7 values of α, and are pretty sure in the limit $\alpha \leqslant 0,75$.

B – Dissymmetric problems $\beta = 75 - 60 - 45 - 30°$
$\alpha = 0{,}25 - 0{,}50 - 0{,}75$

For each angle β, polynomials are defined

$$P_{ij}(\xi,\alpha,\beta) = \sum_{k=0}^{5} \left(\frac{\xi}{\alpha}\right)^k B_k(\alpha)$$

$$B_k(\alpha) = \sum_{l=0}^{3} B_{kl}\ \alpha^l$$

$i = I,\ II \qquad j = N,\ T$

For α very near zero, whatever β is, the solution is that of the infinite plane. Therefore

$P_{IN} = P_{IIT} = 1 \quad B_{oo} = 1 \quad B_{ok} = 0 \quad k \neq 0$

$P_{IT} = P_{IIN} = 0 \quad$ all $B_{ok} = 0$

The following tables of coefficients could not be checked for other β, α than those mentioned. They are sure for these values ; interpolation for $\alpha = 0{,}125 - 0{,}375 - 0{,}625$ is questionable. Other calculations would be useful.

– $\beta = 75°$ – Values of coefficients B_{kl}

	l \ k	0	1	2	3	4	5
P_{IN}	0	1	0	0	0	0	0
	1	0,23420	0,17728	-0,08813	-0,81588	-0,25314	0,75192
	2	-0,60560	-1,9853	1,0050	1,6628	1,1532	-1,1999
	3	3,5840	1,0138	-2,2980	-1,2916	-1,6752	0,60201
P_{IIT}	0	1	0	0	0	0	0
	1	0,28080	-0,03518	0,09632	-0,74078	-0,25541	0,64907
	2	-0,50080	-0,73352	-0,80117	2,6412	1,4784	-2,0516
	3	3,0848	-1,1651	0,80730	-2,5126	-1,9355	1,6651
P_{IT}	0	0	0	0	0	0	0
	1	-0,12188	0,03538	0,01993	0,08817	0,03314	-0,05296
	2	0,49480	0,05346	-0,17133	-0,52937	-0,20056	0,34333
	3	-1,3727	0,55726	0,48318	0,58624	0,24389	-0,48507
P_{IIN}	0	0	0	0	0	0	0
	1	-0,00269	0,09373	-0,16073	-0,01083	0,08627	-0,00742
	2	-0,30302	-0,27033	1,0041	0,10073	-0,52586	0,00410
	3	0,01188	0,79492	-1,5551	-0,01087	0,82864	-0,08502

- $\beta = 60°$ - Values of coefficients B_{kl}

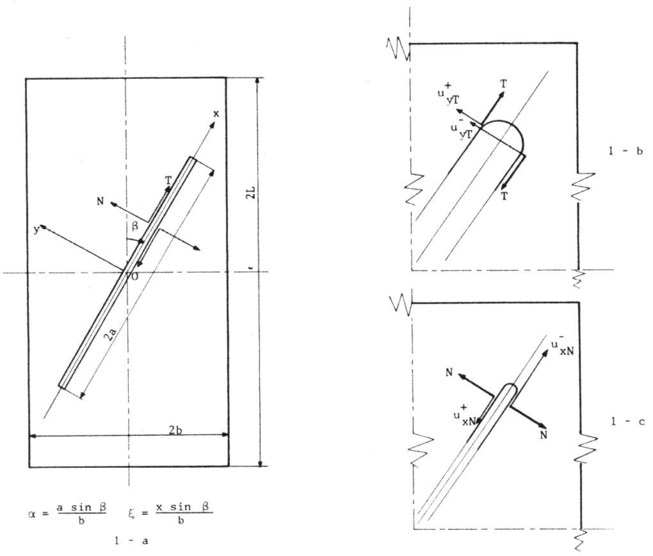
	l \ k	0	1	2	3	4	5
P_{IN}	0	1	0	0	0	0	0
	1	0,62833	-0,10445	-0,14047	-0,22072	-0,15846	-0,00830
	2	-1,9736	-1,4611	1,4887	-0,92234	0,61610	2,3543
	3	6,2251	-0,05856	-3,0883	0,97856	-1,6669	-2,5267
P_{IIT}	0	1	0	0	0	0	0
	1	0,17567	-0,12920	0,28720	-0,13108	-0,25059	0,05799
	2	0,25200	-0,68996	-1,7654	0,66700	1,6156	-0,13386
	3	2,1333	-0,67792	1,5999	-0,86087	-2,2407	0,08918
P_{IT}	0	0	0	0	0	0	0
	1	-0,26817	0,06111	0,02719	0,23937	0,09166	-0,14445
	2	1,2369	0,09414	-0,33596	-1,3971	-0,51670	0,88060
	3	-3,0531	0,96216	1,2552	1,5156	0,56129	-1,1931
P_{IIN}	0	0	0	0	0	0	0
	1	0,01014	0,23965	-0,27013	-0,20708	0,09287	0,12928
	2	-0,62588	-0,93750	1,7929	1,2396	-0,67273	-0,76505
	3	0,29744	1,8614	-3,0646	-1,1651	1,3831	0,64368

- $\beta = 45°$ - Values of coefficients B_{kl}

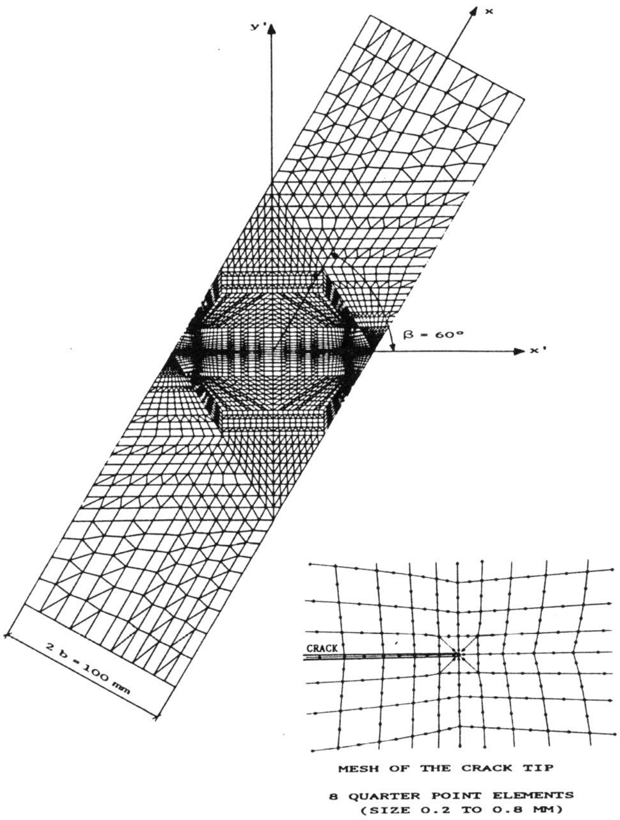
	l \ k	0	1	2	3	4	5
P_{IN}	0	1	0	0	0	0	0
	1	0,48500	-0,22710	1,1316	-0,95061	-1,3927	0,99126
	2	0,33600	-2,5150	-5,2523	2,3836	7,2683	-2,3143
	3	6,5888	0,01520	2,8773	-2,2328	-9,6985	2,4915
P_{IIT}	0	1	0	0	0	0	0
	1	0,12280	-0,35683	0,44282	0,28684	-0,27239	-0,21191
	2	1,1616	-0,16206	-2,9710	-1,4894	2,0469	1,3575
	3	0,82560	-0,45416	2,8600	1,4534	-3,0764	-1,5720
P_{IT}	0	0	0	0	0	0	0
	1	-0,28908	0,00670	-0,15776	0,34946	0,29829	-0,19299
	2	1,5312	0,45772	0,46470	-2,1578	-1,6167	1,2317
	3	-4,4198	0,70288	1,6541	2,4007	1,5547	-1,7701
P_{IIN}	0	0	0	0	0	0	0
	1	0,03975	0,43319	-0,40938	-0,23506	0,19274	-0,03476
	2	-0,93006	-2,1560	2,8662	1,6575	-1,3683	0,01363
	3	1,2679	3,3085	-5,4173	-1,8967	2,6642	-0,04213

- $\beta = 30°$ - Values of coefficients B_{kl}

	l \ k	0	1	2	3	4	5
P_{IN}	0	1	0	0	0	0	0
	1	1,1325	-1,4919	3,1577	-1,4597	-3,1683	1,8889
	2	1,2552	0,46180	-17,933	4,7154	17,987	-6,6785
	3	11,452	-4,6408	13,741	-4,0558	-24,378	7,9832
P_{IIT}	0	1	0	0	0	0	0
	1	0,36087	-1,1171	0,82720	0,68046	-0,36369	-0,34482
	2	2,5240	2,1001	-6,2876	-3,7311	2,7156	2,4449
	3	-1,5531	-1,6325	6,7692	4,0774	-4,2958	-3,1287
P_{IT}	0	0	0	0	0	0	0
	1	-0,20498	0,20075	-1,0136	-0,01459	1,0874	0,00776
	2	1,3758	-0,54976	5,1828	-0,59557	-6,0296	0,23352
	3	-5,5845	1,3171	-1,0197	0,82271	5,7977	-0,80721
P_{IIN}	0	0	0	0	0	0	0
	1	0,08507	0,59025	0,10555	-0,25095	-0,44093	-0,15426
	2	-1,2558	-3,7241	0,41428	2,2714	2,1035	0,58509
	3	4,4148	4,8681	-5,7693	-3,3807	-0,46567	-0,19678

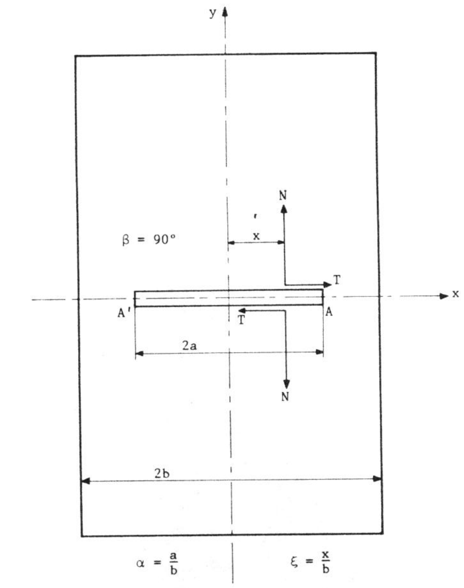


- FIGURE 1 -

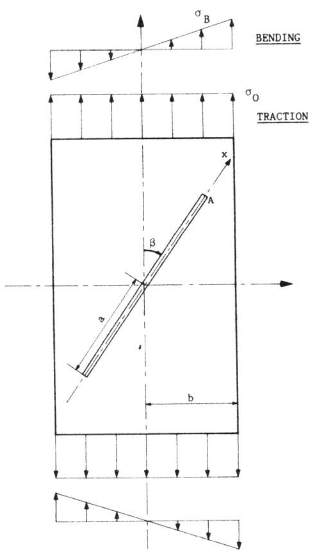


α = 0.75 * β = 60 * 18750 D.O.F.

- FIGURE 2 -



- FIGURE 3 -



- FIGURE 4 -

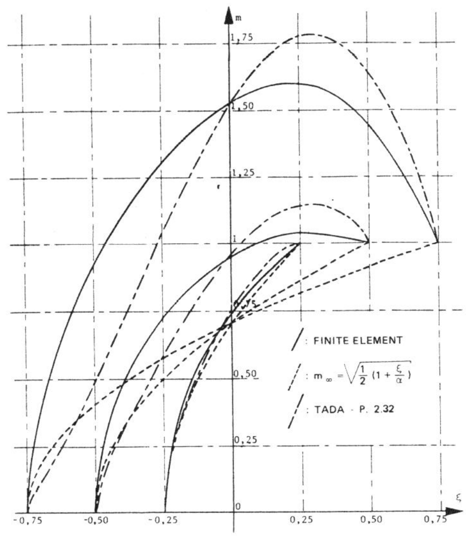
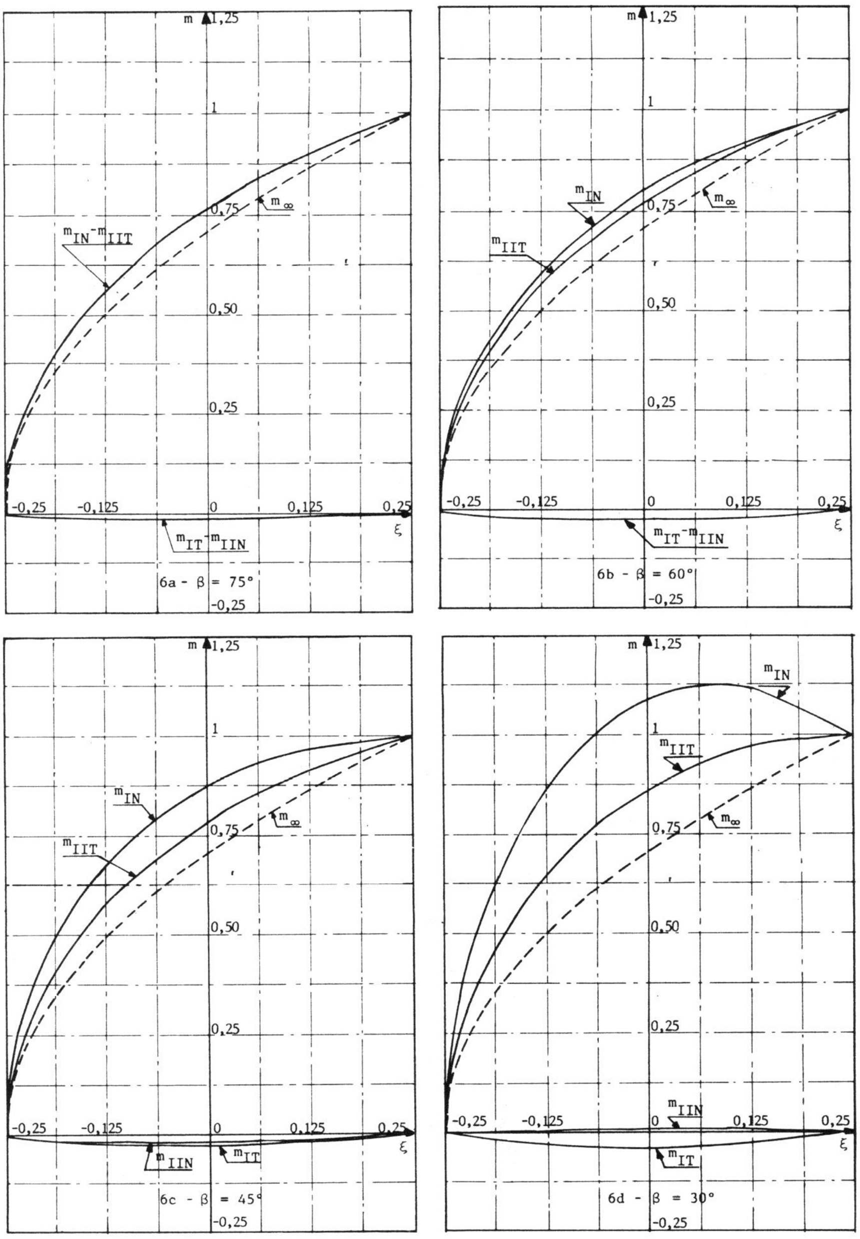
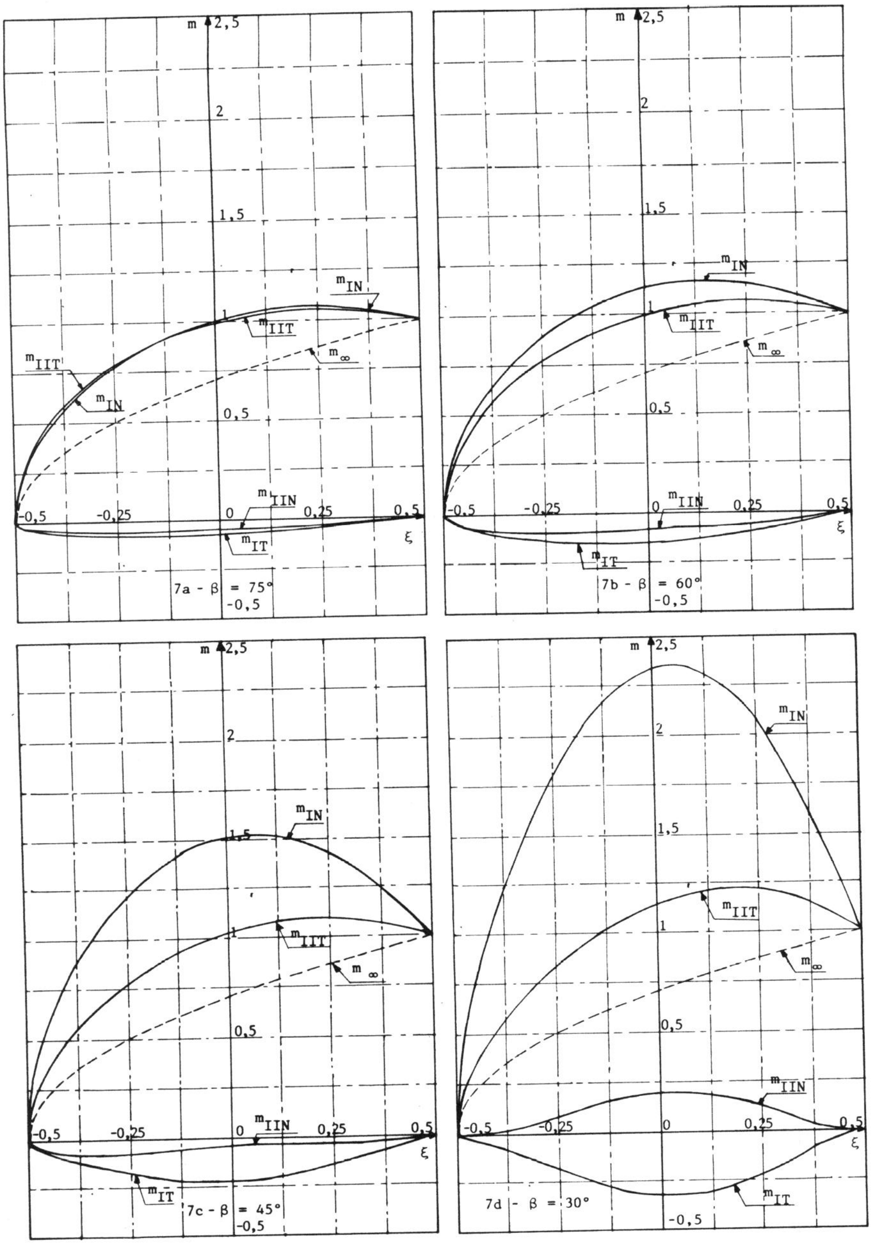


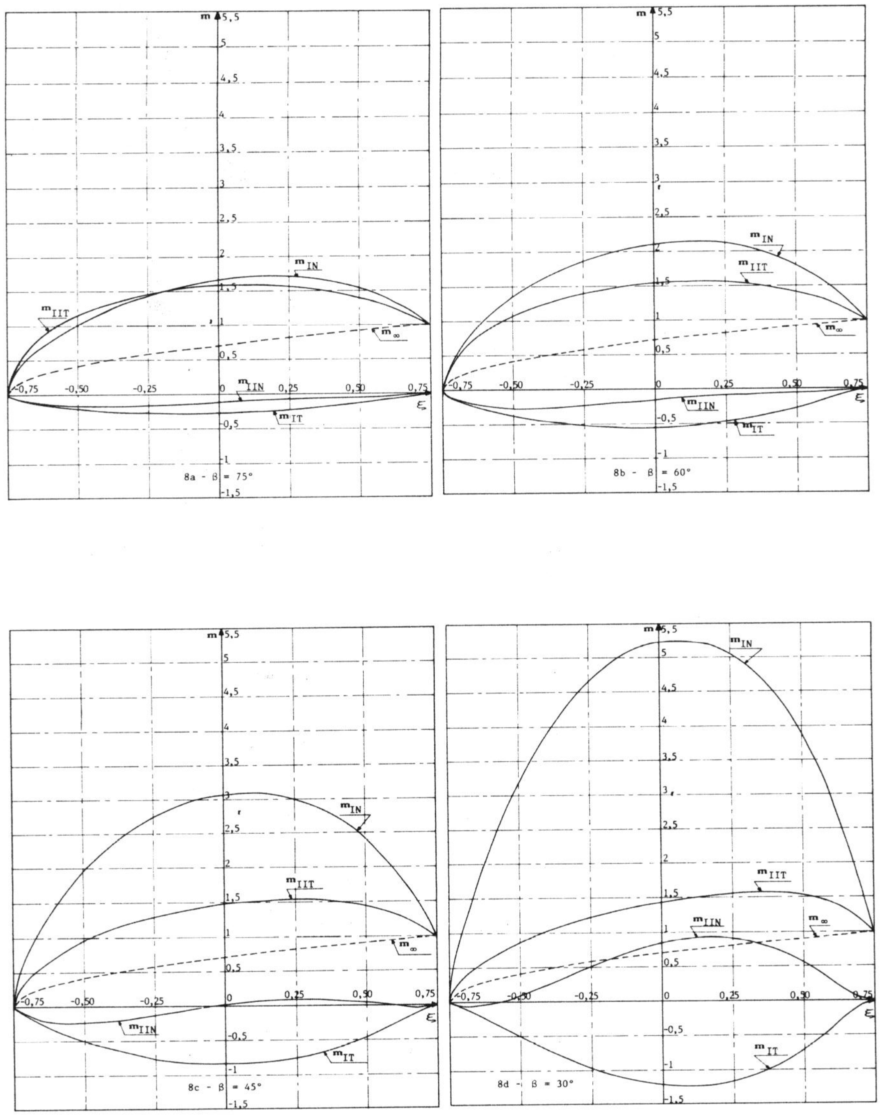
FIGURE 5 - SYMMETRICALLY CRACKED STRIP - β = 90° -
(α = 0,25 - 0,50 - 0,75)



- FIGURE 6 - α = 0,25



- FIGURE 7 - α = 0,50



- FIGURE 8 - α = 0,75