Upper Bounds to Tensile Loads for Inhomogeneous T-Welds

by

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Abstract

The limit loads, along with data on crack length versus web displacement, are needed to find the work required to grow a crack in T-joint fillet weld under tension on the web. For upper bounds to the limit load, the displacement field is taken to be symmetrical about the middle of the T, with each half consisting of three rigid regions separated by two oblique slip planes radiating from the crack tip. As the web of the T is pulled away from the stationary base, the central rigid region is drawn in between the two slip planes. For homogeneous welds of surface angles smaller than 45°, the least such upper bound is found at slip angles of 90° and 0°, with the deformation concentrated in the 90° plane. The limit load obtained corresponds to the shear yield strength along the active plane. For welds with surface angles greater than 45°, the slip planes angles are found to be 90° apart, and at 45° degrees from the weld surface to the crack tip. Calculations considering weld penetration and crack tip positions in the penetration zone gave an upper slip plane of an angle defined from the crack tip to the intersection point between the web and weld surfaces, and a lower slip plane at an angle defined by the crack tip and intersection of the weld and base plate surfaces. A computer program analysis of an inhomogeneous 6 mm weld of structural ship steel, with weld surface angle of 37.5° showed slip planes near 90° and 0°, as expected from the homogeneous weld calculations. Specifically the variation in slip line angles from the homogeneous values was within $\pm$ 0.5° of the solution of the previous iteration when the angles of the find test mesh were 0.43° or 0.44° for two different crack tip positions. Extensions to arcs as slip surfaces and to predict the crack growth are outlined.

Thesis Supervisor: Frank A. McClintock
Title: Professor Emeritus

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I. INTRODUCTION

Traditionally, welded T-joints between the longitudinal stiffener (web) and the hull plating (base plate) of a ship tanker are designed against longitudinal shear. This has proved to be insufficient for accidental loadings such as those occurring during ship groundings, where the bottom plate sometimes is peeled away from the stiffeners (McDonald 1993).

To assure that the weld does not fail in this mode, the weld tearing work per unit length R, must be high enough so the plate must be folded back and crushed rather than peeled off. That is, the plate must become fully plastic before R is reached. This concept is shown with the aid of a plot of plate bending moment M versus curvature κ (Fig.1). For steady state tearing of the weld, it turns out that the total work per unit length as the plate is bent through κ, $M\kappa$, is the sum of the weld tearing work R, and the plate bending work $\int M d\kappa$ (McDonald,1993), Fig. 3a. That is, the weld tearing work R is the complementary plate bending work, $\int^{M_p} \kappa \, dM$. If R is greater than this value, the base plate will become fully plastic and bend back on itself before the weld tears, or else the base plate will buckle. Whether or not this involves tearing of the weld, far higher forces will be required than for simple peeling of the base plate away from the stiffeners. Thus the weld should be sized so that

$$R > \int^{M_p} \kappa \, dM \,. \tag{1}$$

As shown in Fig.1, much of R comes from the falling part of the load-displacement curve for tension applied to the web. For full size welds, this is not obtainable in direct tension, due to the compliance of tensile testing machines (Fig.2). For a stable test, Kirkov

(1994) made a specimen consisting of 1 m bars of 150 mm by 25 mm cross-section, joined end-to-end by a double lap joint with 6 mm leg length fillet welds (Fig.3). The specimen was loaded in bending, which put the bottom of the central bar (web) in tension. An analysis of his tests gives only the total tearing work R, with no distinction between the part due to crack initiation and due to the crack growth.

The work during these stages can be estimated from measurements of sections of specimens partially cracked along the length of the weld. If data are obtained on the displacement between the web and base plate in sections showing different stages of initiation and growth along the weld length, and the corresponding limit loads per unit length of the weld can be estimated from the crack tip position and integrated over both the crack initiation and growth displacements, the total tearing work can be found. A program to calculate these limit loads is the objective of this work.

The limit loads are approximated by upper bounds found from relative sliding of three rigid elements separated by two straight slip lines emanating from the crack tip. Inhomogeneous welds are considered, without restriction to weld angle and penetration depth. The angles of the slip lines are chosen by a computer program to give the least upper bound for the hardness distribution and the current crack tip. The input data includes the crack tips position, weld geometry, and hardness distribution of partially cracked fillet welds. For example, these data can be found by sectioning along the length of the welds tested by Kirkov 1994. From the corresponding limit loads, the force versus displacement curve and the tearing work can be obtained and compared with the tearing work found from the macroscopic analysis of the weld tearing test.

The resulting slip line angles found by the computer program and the given displacements, along with the tractions across the slip line required by equilibrium, give insights for developing a theory of crack growth, extending the work of Kardomateas and McClintock, 1989. The possibility of circular arcs as slip surfaces to better approximate the limit load is also presented as a further possible development.

II. ANALYSIS

An exact solution to the limit load for a rigid-plastic, non-hardening body requires satisfying equations of equilibrium, strain-displacement, yield, and plastic strain-increment versus stress, along with the boundary conditions. The limit load can be bounded by satisfying only some of these requirements at once. To find upper bounds to the limit load it is necessary to have fields of displacement increments $\delta u_i(x_j)$ which satisfy any displacement boundary conditions, give no change in volume anywhere, and give an integral of the plastic work increment throughout the body which is the upper bound load P_{ub} times the corresponding displacement component in the direction of the load δu_P:

$$P\delta u_P \leq P_{ub}\delta u_P = \delta W^p = \int Y \; \delta \bar{\varepsilon}^p dV \; . \tag{2}$$

To find lower bounds to the limit load it is necessary to have stress distributions which satisfy any stress boundary conditions, everywhere satisfy equilibrium of stress gradients, and nowhere violate the yield criterion. For this study, since it is quite impractical to obtain exact or lower bound stress distributions throughout the weld, base plate and web, especially with inhomogeneity, the analysis is based only on the upper bounds to the limit load. With simple approximations of the displacement field by sliding between rigid regions, it is possible to obtain a family of upper bounds to limit loads, of which the least is the most meaningful.

The displacement fields consist of two planes between three rigid regions (Fig. 4). The lower slip plane is in the direction in which a rigid wedge from the weld flows to fill the gap as the web is moved up. The upper slip plane delimits the wedge.

A. Formulation of the upper bounds to the tensile limit load

For a pair of homogeneous fillet welds, with shear strength k, (2) for upper bounds can be expressed in terms of the velocities of each region and the lengths of the slip lines (Chakrabarty 1987), to give:

$$P_{ub}\, \vec{v}_Z = 2kb\, [\, L_{AB} |\vec{v}_A - \vec{v}_B| + L_{BC} |\vec{v}_B - \vec{v}_C|\,] . \qquad (3)$$

From the plot of velocities of various points (hodograph) of Fig.5, the velocity of region (A) relative to region (B), and of region (B) relative to (C), are given in terms of the velocity of region (A) and the angles of the slip lines θ_{AB} and θ_{BC}, by:

$$|\vec{v}_A - \vec{v}_B| = |\vec{v}_A| \frac{|\cos\theta_{BC}|}{\sin(\theta_{AB} - \theta_{BC})} , \qquad (4)$$

$$|\vec{v}_B - \vec{v}_C| = |\vec{v}_B| = |\vec{v}_A| \frac{|\cos\theta_{AB}|}{\sin(\theta_{AB} - \theta_{BC})} , \text{ where } \theta_{AB} \text{ is always greater than } \theta_{BC}. \qquad (5)$$

Substituting (4) and (5) into (3), and canceling out V_A, gives:

$$P_{ub} = 2kb \left[L_{AB} \frac{|\cos\theta_{BC}|}{\sin(\theta_{AB} - \theta_{BC})} + L_{BC} \frac{|\cos\theta_{AB}|}{\sin(\theta_{AB} - \theta_{BC})} \right] . \qquad (6)$$

For 45^o welds with no penetration, the slip line angles are found to be at $\theta_{AB} = 90^o$and $\theta_{BC} = 0^o$, and the minimum limit load per unit length given by (6) is $2kb\sqrt{2}$. The shear yield strength can be defined for non-hardening isotropic metals as $k = TS/\sqrt{3}$, where TS is the tensile strength.

In inhomogeneous welds, the slip lines traverse elements of different hardness, determined experimentally. The local shear yield strength k, is most easily expressed in terms of Knoop hardness HK. From conversion tables TS ~ 0.3HK. This gives $k = 0.3HK/\sqrt{3}$. The length of the slip lines will depend on the path which gives the minimum hardness, as well as on the slip line angle, which is also affected by the weld angle and penetration distance. If it is assumed that the hardness distribution is of a set of cells with constant hardness, the least upper bound to the limit load will be found when the angles of the slip lines limiting regions (A), (B), and (C) are such that the sum of the lengths of slip lines in each cell, multiplied by its hardness, gives the smallest possible value. Then (6) can be expressed for inhomogeneous welds as:

$$P_{ub} = \frac{0.6}{\sqrt{3}} \left[\sum_i (L_{AB_i} HK_{AB_i}) \frac{|\cos\theta_{BC}|}{\sin(\theta_{AB} - \theta_{BC})} + \sum_j (L_{BC_j} HK_{BC_j}) \frac{|\cos\theta_{AB}|}{\sin(\theta_{AB} - \theta_{BC})} \right] . \qquad (7)$$

B. Computer program for the least upper bound to the tensile limit load

A computer program was developed to help in the calculation of a minimum upper bound to the limit load in tension, for inhomogeneous welded T-joints, of arbitrary weld angles and penetrations, as stated in (7). For this study it was assumed that the crack always starts at the tip of the gap left between the web and base plate. If the crack tip is in the web area (Xc < Xw as in Fig.5a), the maximum slip line angle θ_{AB} obtainable is that between the crack tip and the surface of the web at the end of the area under consideration (Fig.6a). If the crack tip lies inside the weld area (Xc > Xw), the maximum angle is limited to the corner where the weld joins with the web (Fig.6b). Similarly, the minimum slip line angle θ_{BC} is limited by the angle between the crack tip and the corner where the weld joins the base plate (Fig.6). This angle could assume negative values.

The hardnesses of the weld, base plate and web are approximated by assigned values to cells in an array. Just one side is considered for the analysis, as symmetry with the other side is assumed. Integer numbers of cells are chosen along the leg and height of the weld. Any cell entirely outside the weld, base plate or web, has a zero hardness value.

The length of the slip line is a function of its angle and the weld angle (Fig.7). For a crack tip in the web area (Xc < Xw) whose slip line angle gives a line ending at the web surface, the slip line length is found from the triangle formed by the slip line, the surface of the web, and a line from the crack tip to the intersection between the weld and web surface:

$$Lsl = \frac{Xw - Xc}{\cos \theta sl} . \quad (8)$$

For a crack tip inside the weld area (Xc > Xw) or inside the web area (Xc < Xw), if the slip line angle gives a line ending on the weld surface, the law of sines gives the following equation for the length:

$$Lsl = \frac{[Xw - Xc - Yc - Yw \cot \theta w1] \sin \theta w1}{\sin (\theta w1 + \theta sl)} . \quad (9)$$

The slip line length is used by the computer program to limit the calculation of the hardness-length product, $\Sigma L_i HK_i$. As each cell is crossed, the program multiplies the length of the slip line in the cell by its hardness until the sum of the lengths is equal to the total slip line length. The logic followed by the program is that for each cell the program moves on the X axis, it calculates the corresponding move on Y according to the angle of the slip line. When the cell height is reached, a new row of Y is considered. When the end of the line is reached, the shortened length in the last cell is esed to complete the $\Sigma L_i HK_i$.

This is done for six pairs of slip line angles (Fig.8), where $\theta_{AB} > \theta_{BC}$. Both the pairs of angles and the corresponding limit loads are used in a matrix to define a polynomial surface for the limit load with the describing equation:

$$a + b\, \theta_{ABk} + c\, \theta_{BCk} + d\, \theta_{ABk}^2 + e\, \theta_{BCk}^2 + f\, \theta_{ABk}\theta_{BCk} = Pub_k \quad (10)$$

The values of the variables a to f are found solving the matrix of six equations (10) by Gauss elimination. These values are used to find θ_{AB} and θ_{BC} by partial differentiation of (10) with respect to θ_{AB} and θ_{BC}:

$$\frac{\partial Pub}{\partial \theta AB} = 0 = b + 2d\theta AB + f\theta BC, \qquad \frac{\partial Pub}{\partial \theta BC} = 0 = c + 2e\theta BC + f\theta AB. \tag{11}$$

Solving (11) for θ_{AB} and θ_{BC} gives:

$$\theta AB = \frac{2eb - cf}{f^2 - 4ed}, \qquad \theta BC = \frac{-b - 2d\theta AB}{f}. \tag{12}$$

These are the slip line angles at which the polynomial gives the least upper bound to the limit load. They are used to define a new closer set of six pairs of angles, and hence a new polynomial surface. Sucessive iterations are run until the result converges to a limit load.

III. CORRELATION OF COMPUTER PROGRAM OUTPUT WITH HOMOGENEOUS WELD THEORY

There are some conditions of the limit load surface as a function of θ_{AB} and θ_{BC} that make the initial guess of angles given to the program important for convergence to a minimum load:

1. From (7), notice that if $\theta_{AB} = 90^o$, only the first summation remaims and that becomes independent of θ_{BC}, so any value of θ_{BC} will give the same limit load. The absolute value signs mean that at $\theta_{AB} = 90^o$, a discontinuity in the function is found.

2. Local minima can be obtain depending on the hardness distribution in the weld.

3. The surface of the function can have some twisting, which may lead the program to look for a maximum, instead of a minimum.

The slip line field defined in this study for homogeneous welds of weld surface angle $\theta_w = 45^o$ and below is probably composed of a fan region of plastically deformed material from the crack tip to the weld surface, as shown on Fig. 9. This field is related to the work of McClintock and Clerico, 1980. For a single slip line, 90^o is obtained. This is corroborated by the computer program output of homogeneous hardness welds with θ_w of 17.1^o, 37.6^o, and 45^o (Appendix C). Convergence is found when the angle of θ_{AB} is 90^o, regardless of θ_{BC} value.

Once the weld surface angle θ_w goes above 45^o, with sufficient crack growth the theoretical upper bound to the limit load of an homogeneous weld is given by a pair of slip planes that are at 45^o from the weld surface coming from the crack tip, and 90^o apart from each other (Fig. 10). This is also shown by the computer program output of a homogeneous hardness weld with $\theta_w = 59^o$. The resultant θ_{AB} and θ_{BC}, are 76^o and -14^o, respectively. (NOTE: The numerical results are comparable to the theoretical ones within the expected round off (the computer works with 6 decimal places on mathematical calculations such as the sum of hardness-length product) and tolerance error (tolerances of 0.005 of the limit load and 0.5^o are compared against the difference between the current values for the limit load and angles, and the values from the previous iteration)).

For homogeneous welds with small penetration and crack tips within the penetration zone (Fig.11), the θ_{AB} is limited to the maximum angle obtainable between the crack tip and the intersection point of the weld surface and the web surface. The least limit load will then be at that θ_{AB} and θ_{BC} some where above the θ_{BC} minimum, given by the angle from the crack tip to the base plate surface and weld surface intersection. If the crack tip position is high enough the least limit load will be at a θ_{BC} at 45^o from the weld surface. For example, the program output for a weld with a penetration of 1.5mm and a 5mm height, and crack tip at the gap tip, is $\theta_{AB} = 73.3^o$ and $\theta_{BC} = 0^o$. For a crack tip 1.25 mm up and

0.75 mm out, the result is θ_{AB} maximum = 75.3° and a θ_{BC} minimum = -3.4°, to the toe of the weld.

The calculations done for an inhomogeneous weld were for the hardness distribution and weld geometry given by Middaugh (1993) of a AWS 36 steel, welded with E7018 rod, and normalized 37 min at 890°C. The weld surface angle was 37.6°, with no penetration. For the hardness distribution, the effect of inhomogeneity found was small. The results are within the homogeneous hardness theoretical value of θ_{AB} = 90°, ±0.5° from the angles given on the previous iteration, and a mesh angle difference of 0.43° or 0.44° depending on the crack tip position. (NOTE: A small deviation of θ_{AB} from 90° will cause a greater deviation of θ_{BC} from 0°, so the convergence value found for θ_{BC} can be more off than that of θ_{AB} form the homogeneous hardness theoretical result.)

A tabulation of all significant program output and the corresponding theoretical homogeneous values is given in the Table of Results.

IV. FURTHER DEVELOPMENTS

A. Consideration of slip arcs to define rigid regions (A), (B), and (C)

Using slip arcs rather than slip lines to define the rigid regions (A), (B), and (C) has the possible advantage of avoiding points of high hardness. This was suggested by the hardness distribution in a fillet weld and the attached base plate and web found by Middaugh, 1993 (Fig.12).

The field of displacement proposed that meets all the requirements of the upper bound theory is shown on Fig. 13a & 13b. A restriction on the arcs is that the same velocity must be found at any point $\bar{x}$ in (B), regardless of whether its motion is described relative to (C) in terms of the center of the arc, $\overline{x_{BC}}$, or to (A), and then to (C) relative to (A). This gives:

$$\omega \times (\overline{X} - \overline{XBC}) = \omega \times (\overline{X} - \overline{XAB}) + VA \text{, so that} \tag{13}$$

$$\omega \times (\overline{XAB} - \overline{XBC}) = \overline{VA} .$$

As a result the field has two arcs of different radii, but with centers on the same horizontal line. The location of this line is given by the angular velocity of region (B) that will produce a vertical displacement of region (A), in the upward direction. The fitting of curvatures for the slip arcs will be determined by the circular path which will give the lowest hardness-length product. If this conditions are incorporated to the analysis, the limit load found will be even closer to the actual value.

Another relaxation to the limitations of the program is that the slip arc does not have to start at the crack tip but at the point on the crack where the least limit load in tension is found. This means that it is possible to find another place in the crack which needs a lower load to grow the crack than at the crack tip, due to the hardness distribution, which may then be the point at which the actual crack will grow (Fig.14).

B. Crack growth consideration

Following Kardomateas and McClintock, 1989, the fully plastic crack growth can be assumed to be a mixture of sliding off along two slip planes and cracking in a possibly third direction. The crack growth is then idealized by assuming cycles of sliding off first on an upper slip line plane, U_{AB}, with the corresponding cracking for that slip, U_{CAB}, in a direction θ_{CAB}, and then on a lower slip line plane, U_{BC}, with the corresponding cracking for that slip, U_{CBC}, in a direction θ_{CBC} (Fig.15). Presumably, the ratio of cracking to sliding off, c/s, and the angle of cracking relative to the slip plane, (θc -θs), together, the cracking on a meso-scopic scale, are set by micromechanisms of fracture as affected by the normal stress and the sign of the shear across the plane:

$$c/s = f_{c/s}\,(\sigma_s/2k), \qquad \theta_c - \theta_s = -sign(\gamma_{r\theta}) f_{\theta cs}(\sigma_s/2k)\,. \tag{14}$$

Here both plastic anisotropy, which affects both slip and cracking, and the more important fracture anisotropy, which affects cracking, are neglected. Even so, finding the functions (14) experimentally or theoretically is a challenge beyond the scope of this paper. However an effort should be encouraged, because if interactions can be neglected, adding together the effects of cracking and sliding off on two slip systems at the crack tip would give the direction and magnitude of crack advance, the angles of the crack flacks, and the decrease of the ligament per unit far-field displacement.

Although the crack displacement and direction are not obtained in this work, the displacements along the final slip planes can be found from the following information. Symmetry requires that the axial extension, U_A, only has a component on the Y axis. U_{AB} and U_{BC} are in θ_{AB} and θ_{BC} direction respectively. θ_{AB} and θ_{BC} are given as part of the computer program output. If the displacements are related to the upward velocity of the web $\overline{V_A}$, the velocity of region (B), and the relative velocity of (B) with respect to (A); canceling the time differentials will give:

$$U_{AB} = U_A\left(\frac{\cos\theta_{BC}}{\sin(\theta_{AB} - \theta_{BC})}\right) \tag{15}$$

$$U_{BC} = U_A\left(\frac{\cos\theta_{AB}}{\sin(\theta_{AB} - \theta_{BC})}\right), \text{ where } U_A \text{ is the web displacement.} \tag{16}$$

These displacements can be found, but to predict the crack growth of a crack in a T-joint weld, the crack displacement and direction must be known. This depends on the hardness of the material and the functions (14) described above.

V. CONCLUSIONS

A computer program was developed to find a least upper bound to the limit load in tension of inhomogeneous welded T-joints.

Although the hardness for AWS 36 plates welded with E7018 rod varied by a factor of 2, its variation in the deformation zone of the weld is only $\pm$ 10%. Therefore the results obtained for a 37^{o} angle weld are within 10% of those found for homogeneous welds.

The program output and a slip plane theory analysis show that the limit load in tension of homogeneous welded T-joints of surface angle greater than 45^{o} is given by a pair of slip lines 90^{o} apart and at 45^{o} to the weld surface starting at the crack tip, provided the lower slip line does reach the toe of the weld.

A plasticity analysis of welded T-joints, using the upper bound theory to the limit load for the tearing, gives the least limit load, for a homogeneous welds of 45^{o} or less, corresponding to the shear yield strength along the active plane. The active slip plane is at 90^{o}, and the inactive slip plane is at 0^{o} (Fig.9). These results were also obtained from the computer program developed, for an inhomogeneous weld of 37.57^{o} weld surface angle and no penetration, within $\pm 0.5^{o}$ from the angles given on the previous iteration, and a mesh angle difference of 0.43^{o} or 0.44^{o} depending on the crack tip position.

This work concentrates on the first step required to find the tearing work needed to fracture T-joint welds, as those used on ship construction, which is the determination of limit loads for various crack tip positions, considering inhomogeneity of the material and the weld surface angle. To help in the calculations a program was developed, based on the upper bound theory of plasticity. The steps to follow are the obtaining of experimental data for hardness distributions, crack tip positions, and corresponding displacements of the web, and the plotting of a curve of load versus displacement of the web. The area underneath the curve is the work done during cracking (Fig15). This work is the total tearing work per unit length needed to tear a T-joint weld.

The purpose of the calculation of the work required to tear a T-joint weld is that it will give valuable insights to specify the dimensions of required for T-joint welds, so they can withstand accidental loadings as those occurred during ship grounding, or so that the bottom plate will crumple rather than peeling off from the stiffeners, which is a less catastrophic situation.

VI. SUGGESTIONS

1. Use the change in angle between the set angles θ_{AB} and θ_{BC} of the actual series of equations, and the solution set of angles θ_{AB} and θ_{BC} found on the previous iteration, to improve convergence.

2. Use a method of minimization capable of distinguishing between maximum or minimum when a twisting occurs in the surface function, and work on the actual computer program to implement it.

3. Use a different method of detecting whether was found is just a local minimum due to the hardness distributions, and work on the actual program to implement the method.

4. With data of weld hardness distribution, crack tips, and corresponding displacements of the web, calculate the upper bounds to the limit loads with the program and graph the limit load against the web displacement, to get the crack growth work, which is the area under the curve.

ACKNOWLEDGMENT

I want to thank Professor Frank A. McClintock for his invaluable help and inspiration, as well as persons who helped me in any aspect of my work as, Heather McDonald, Kirk Kirkov, Gina Middaugh and Zuimdie Guerra. I also want to recognized and thanks the GEM fellowship members, specially my sponsoring company Hewlett-Packard, and the Department of Mechanical Engineering of Massachusetts Institute of Technology for their monetary support.

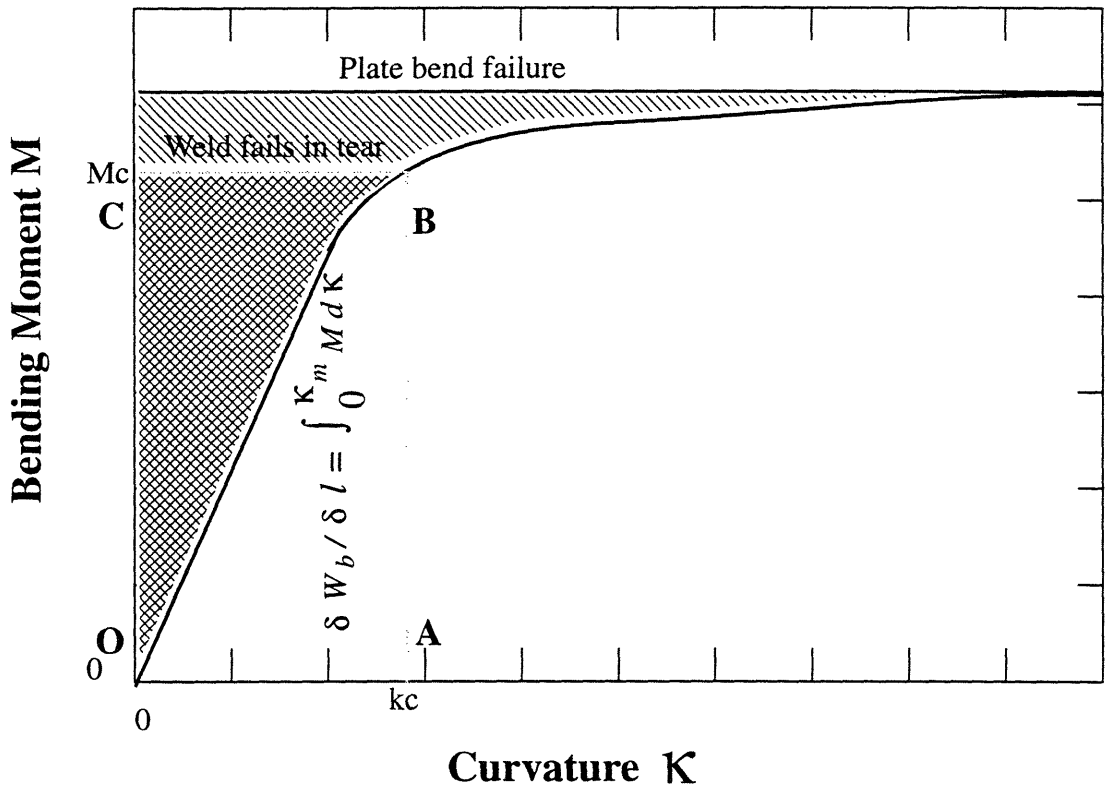

Figure 1. Relation between bending moment and curvature of a plate to determine failure mode.

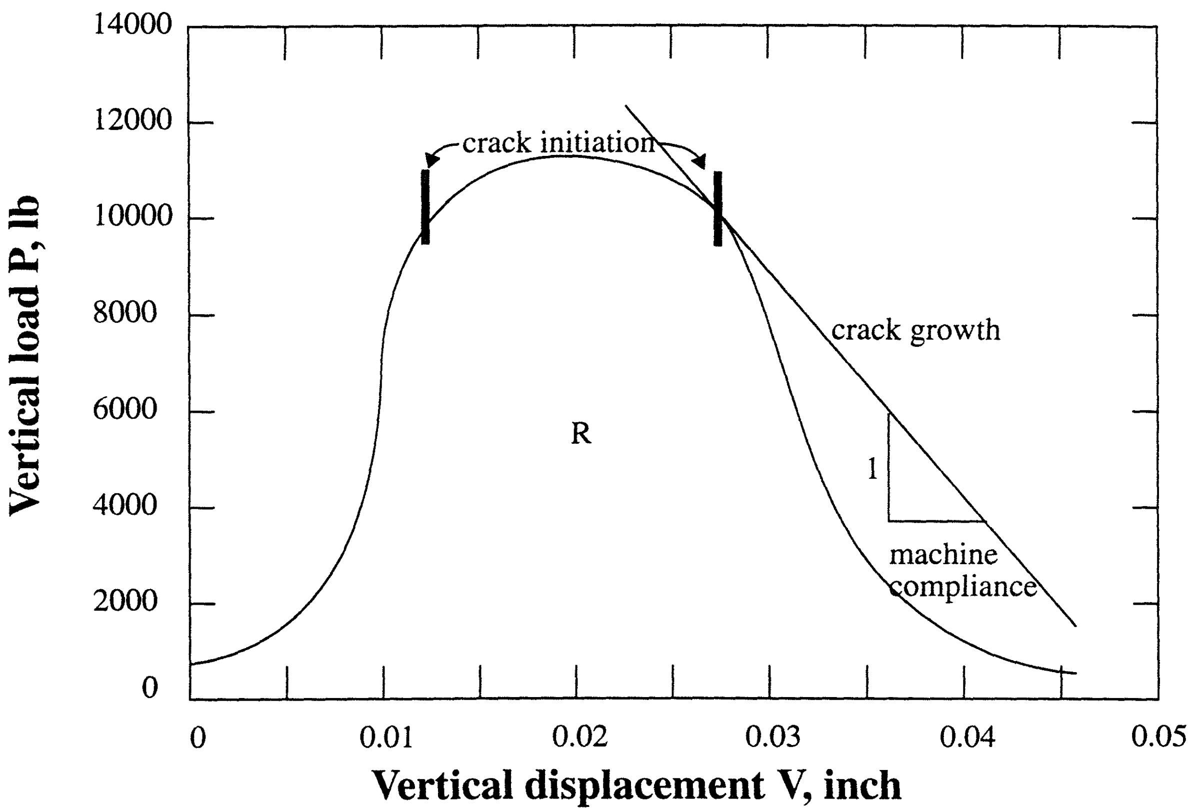

Figure 2. Desired load-displacement curve to get the tearing work.

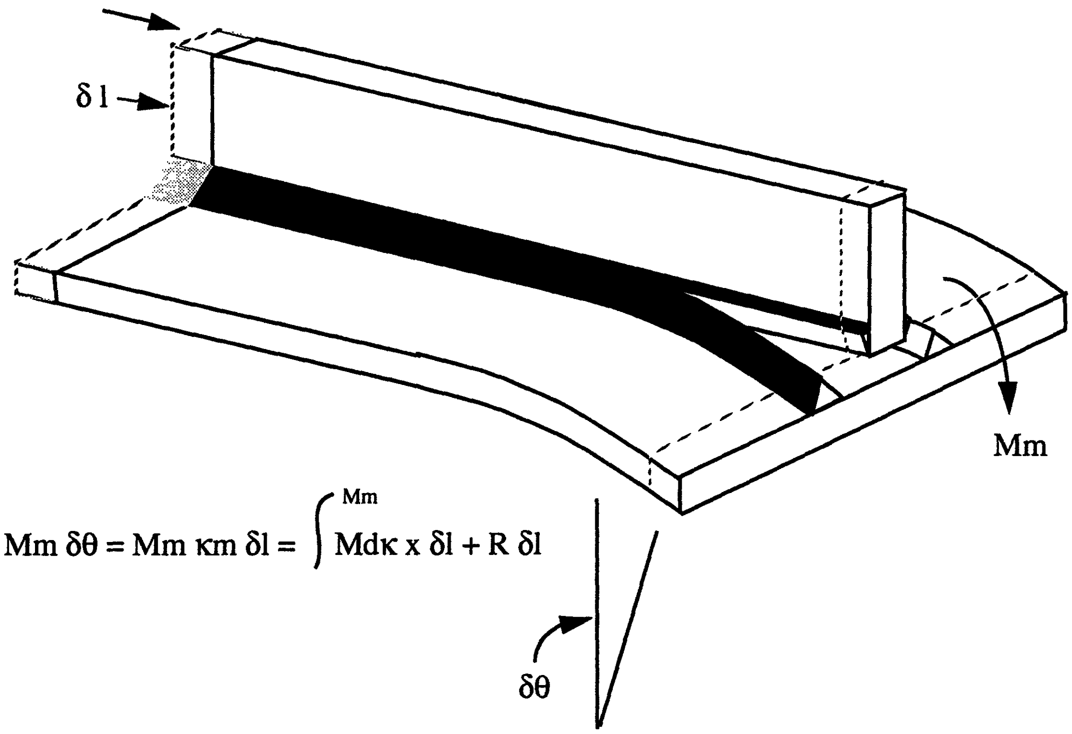

Figure 3 (a). Applied work for peeling fracture of a weld

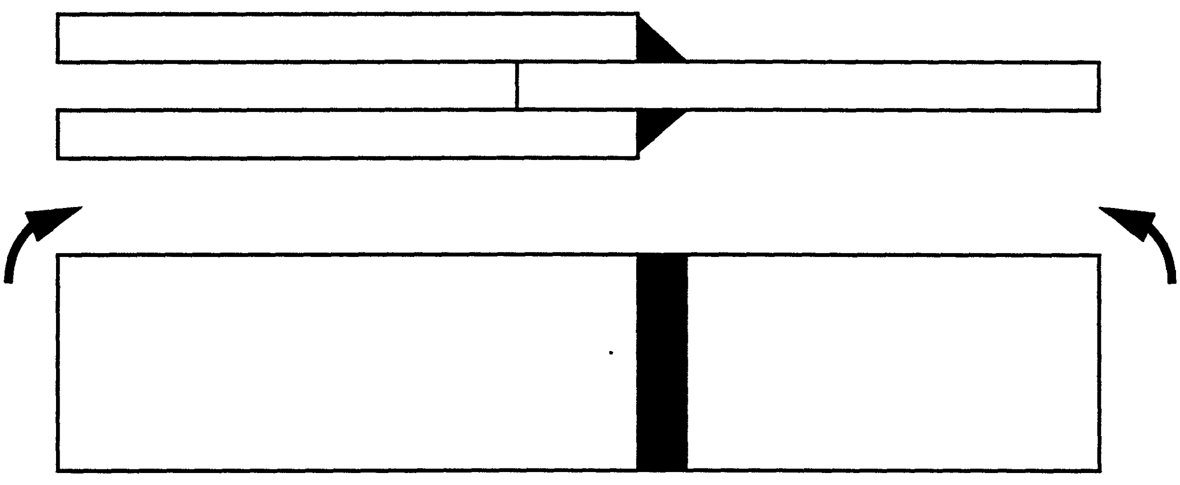

Figure 3 (b). Doble lap welded joint specimen loaded in bending along the longitudinal axis

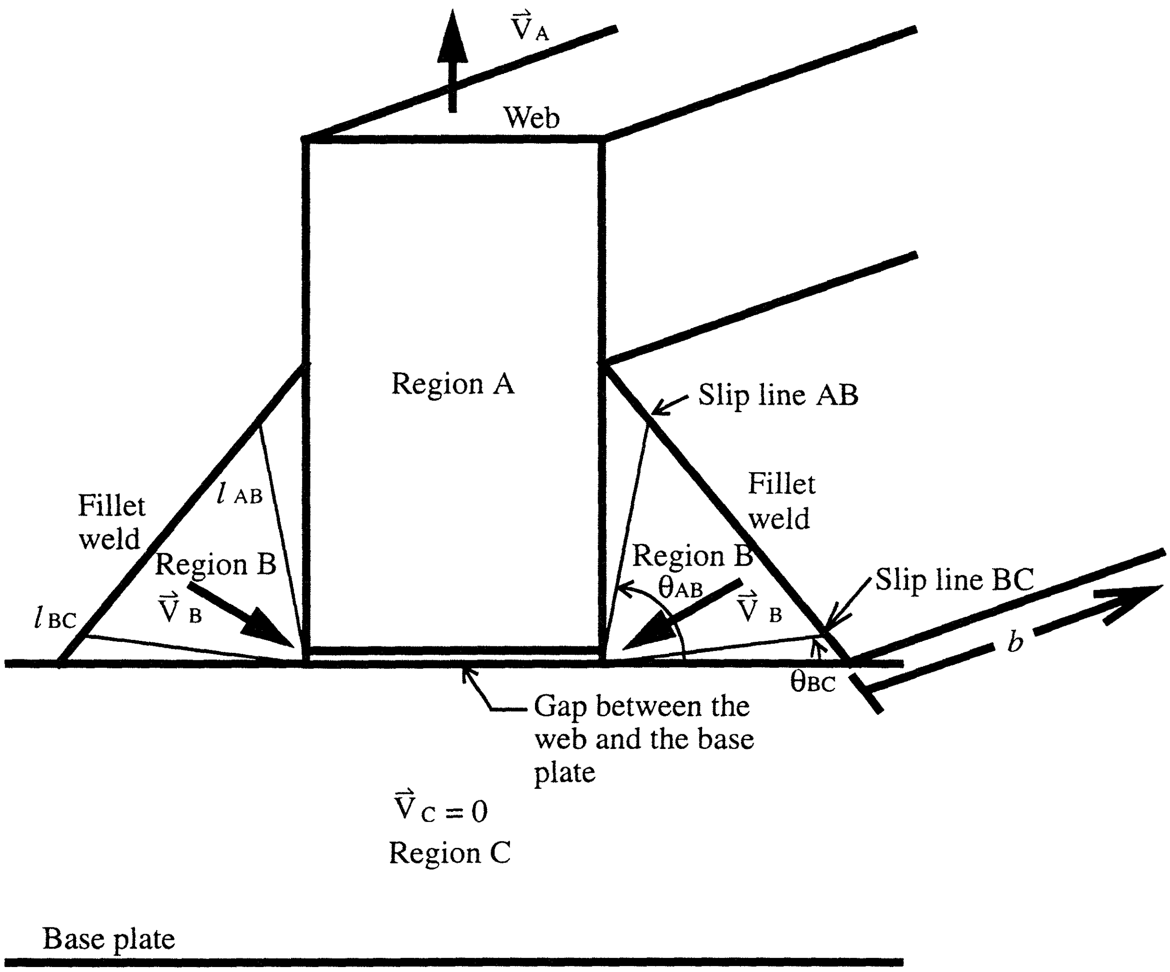

Figure 4. Block-sliding displacement field for tension of a welded T-joint.

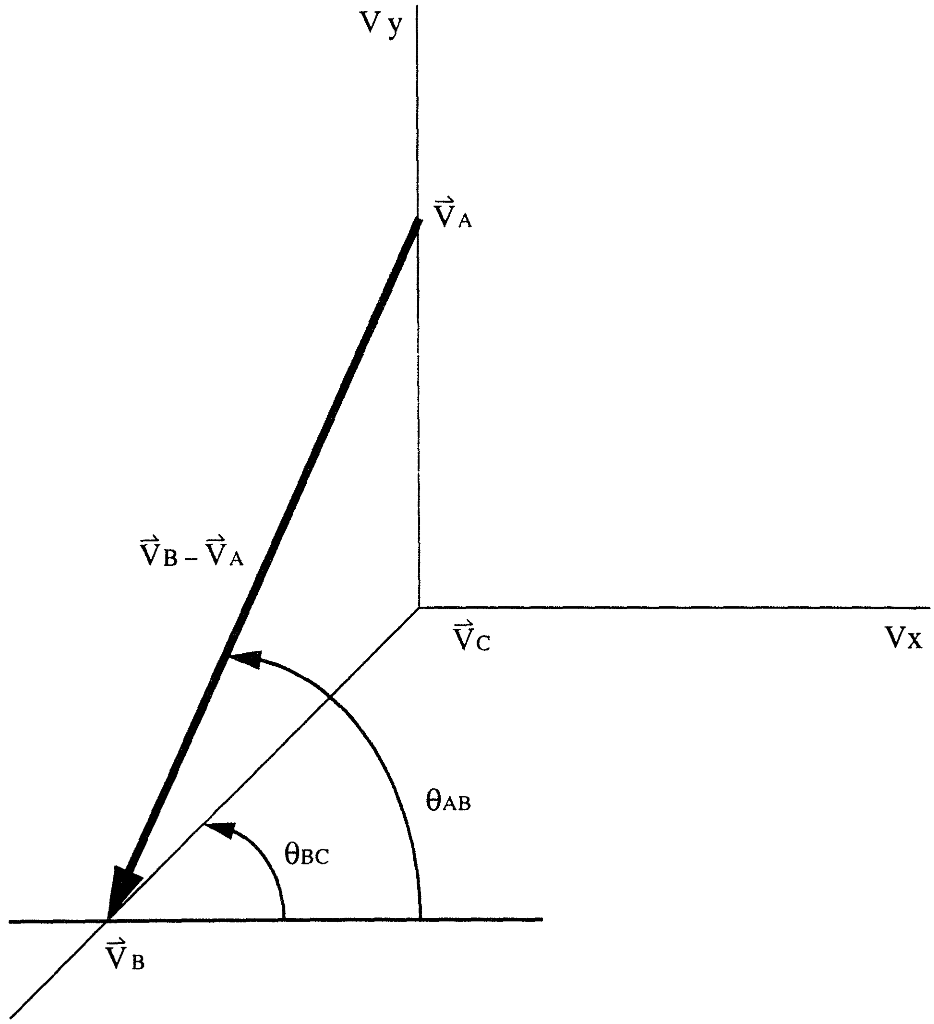

Figure 5. Velocity hodograph.

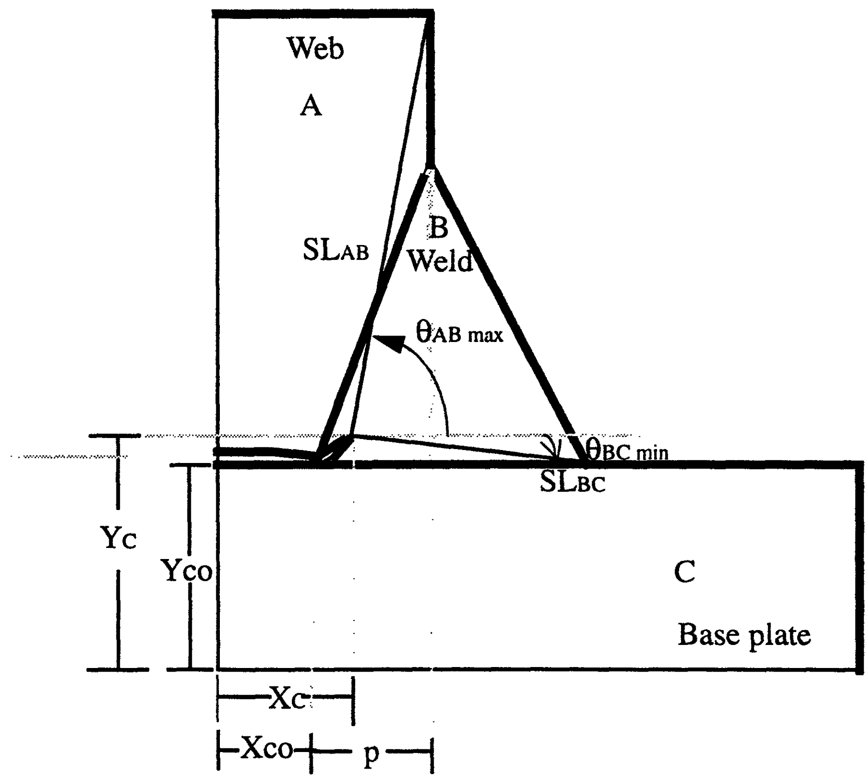

Figure 6 (a). Limits to slip line angles with crack tip penetration area.

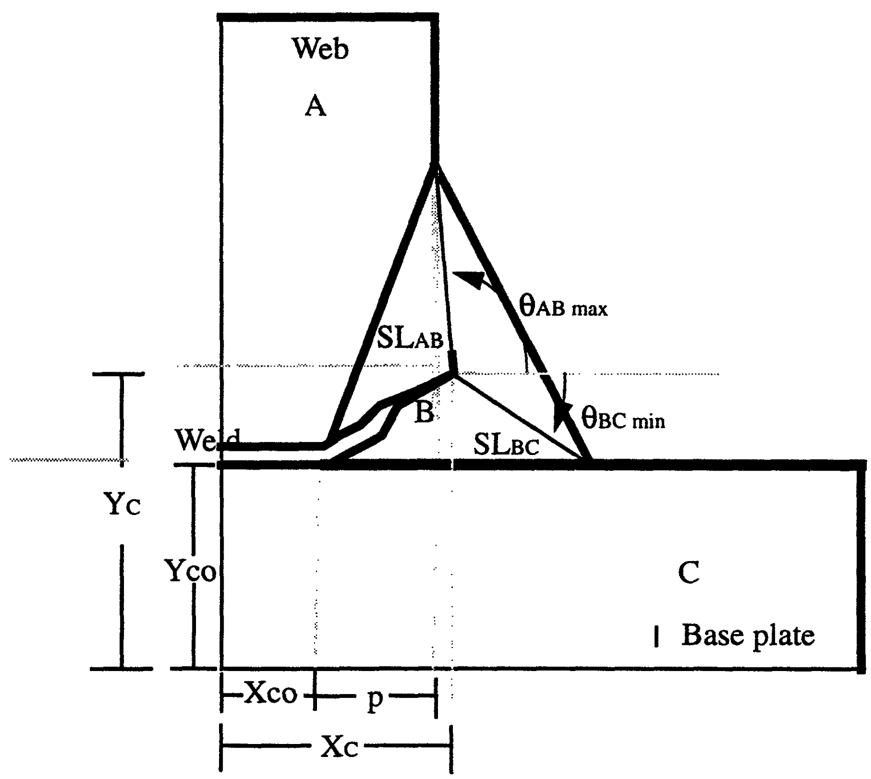

Figure 6 (b). Limits to slip line angles with crack tip in weld area.

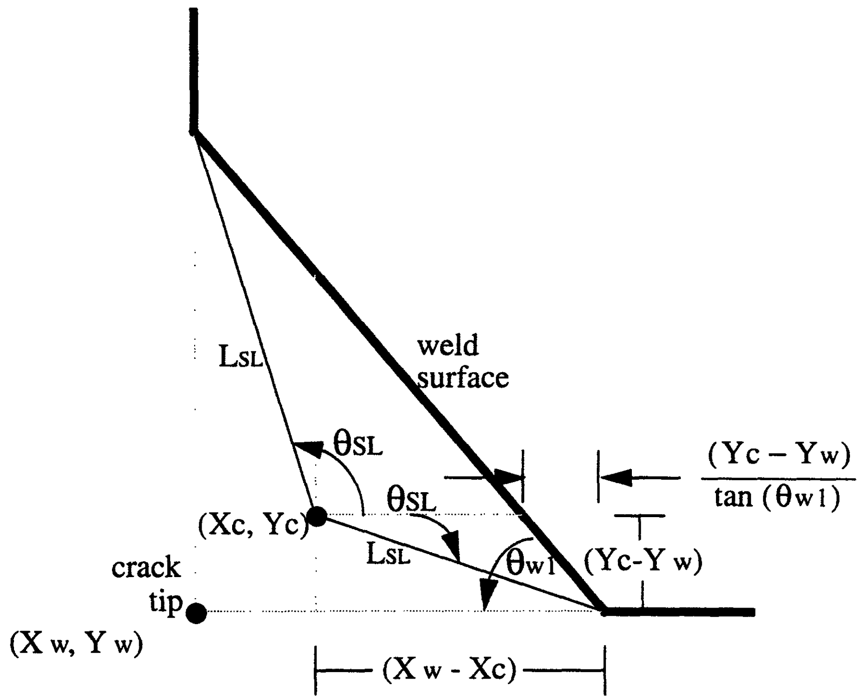

Figure7 (a). Slip line length for angles ending at the weld surface.

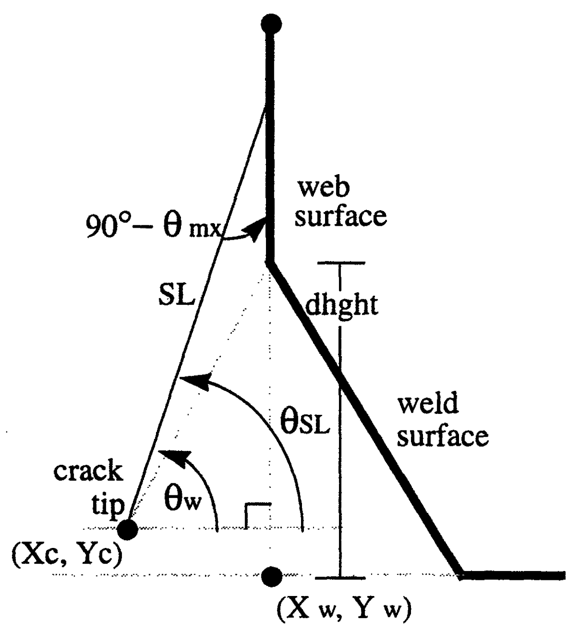

Figure7 (b). Slip line length for angles ending at the web surface.

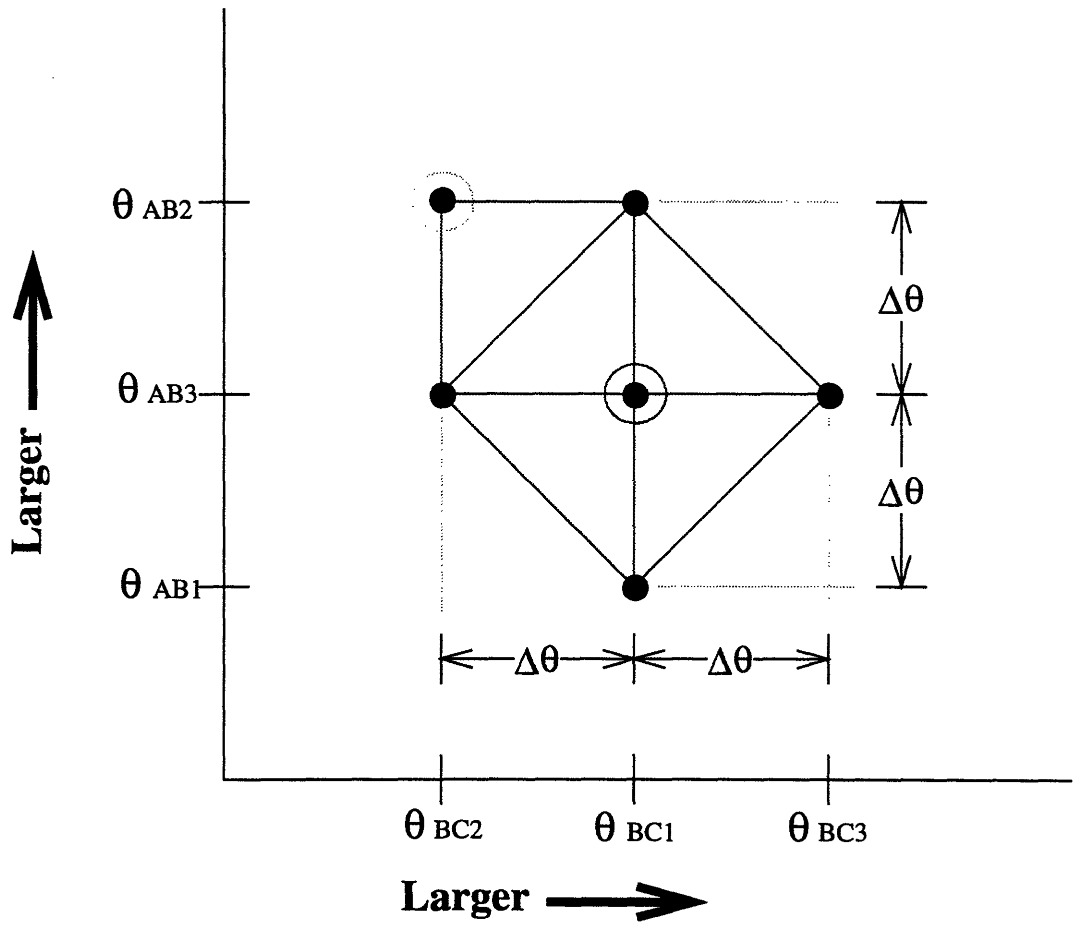

Figure 8. Graphical representation of angles chosen for matrix.

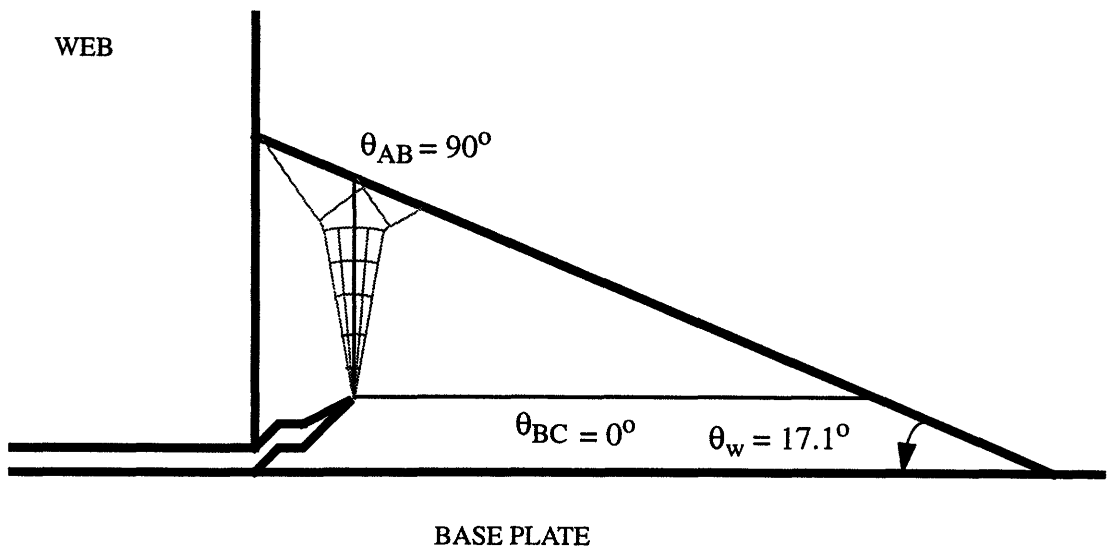

Figure 9. Slip line theory solution for homogeneous welds with surface angles smaller than45°

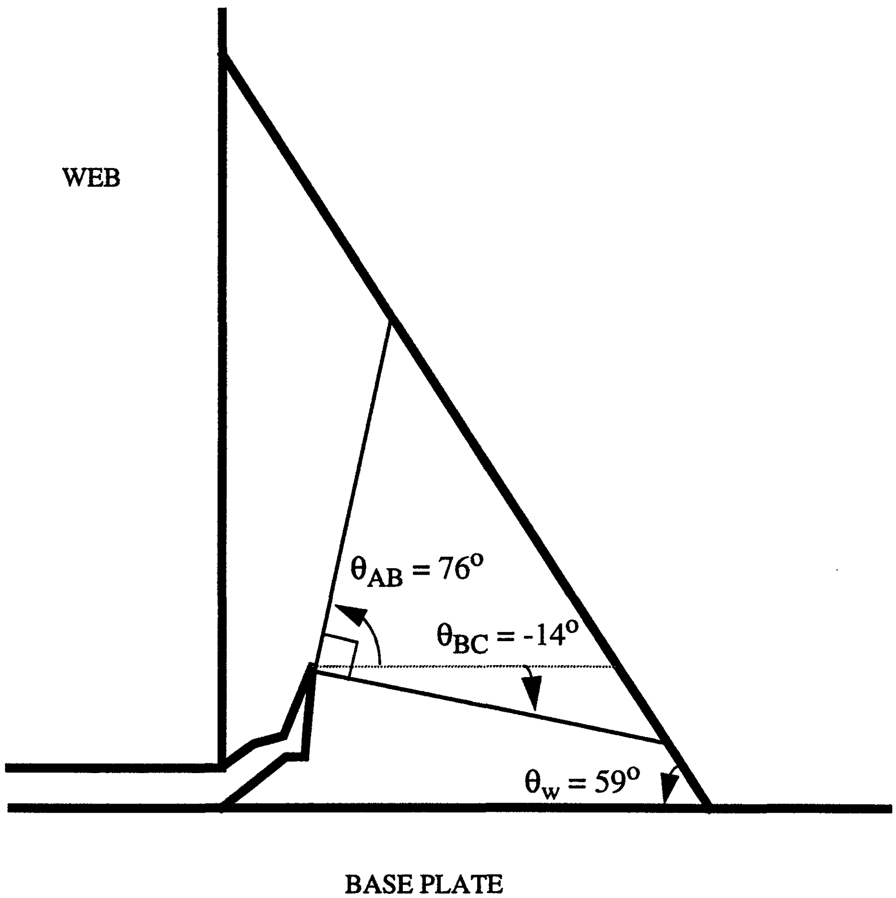

Figure 10. Slip line theory solution for homogeneous welds with surface angles greater than 45^o

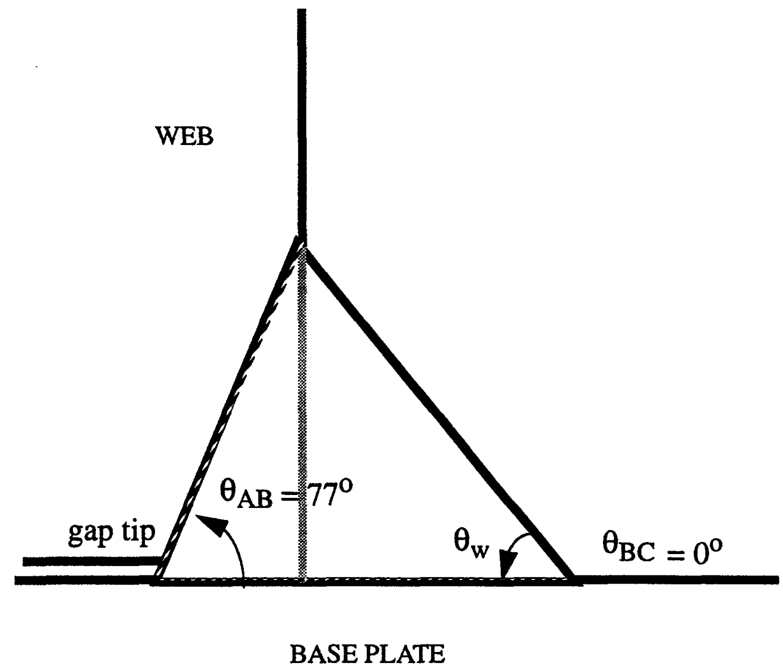

Figure 11 (a). Theoretical slip line plane solution for homogeneous welds with weld penetration

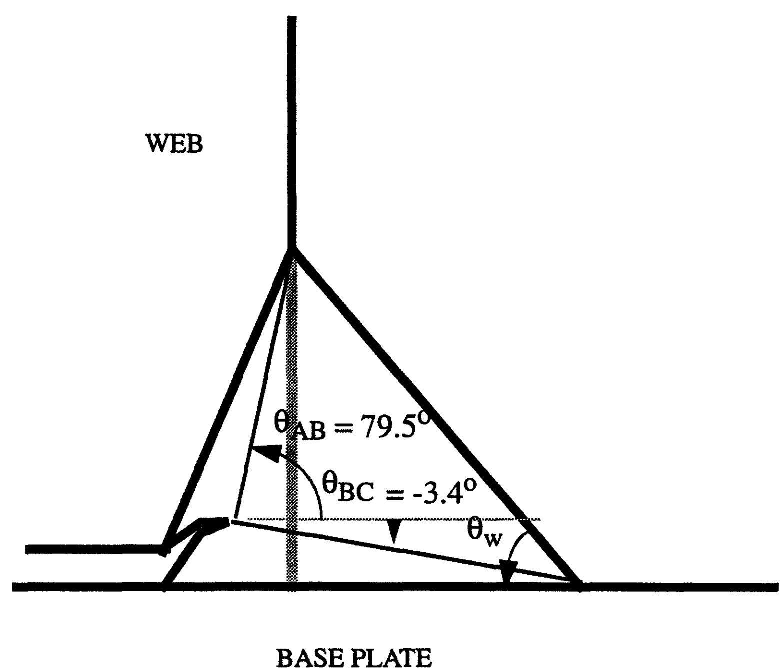

Figure 11 (b). Theoretical slip line plane solution for homogeneous welds with penetration and crack tips above the gap tip, but still in the penetration zone

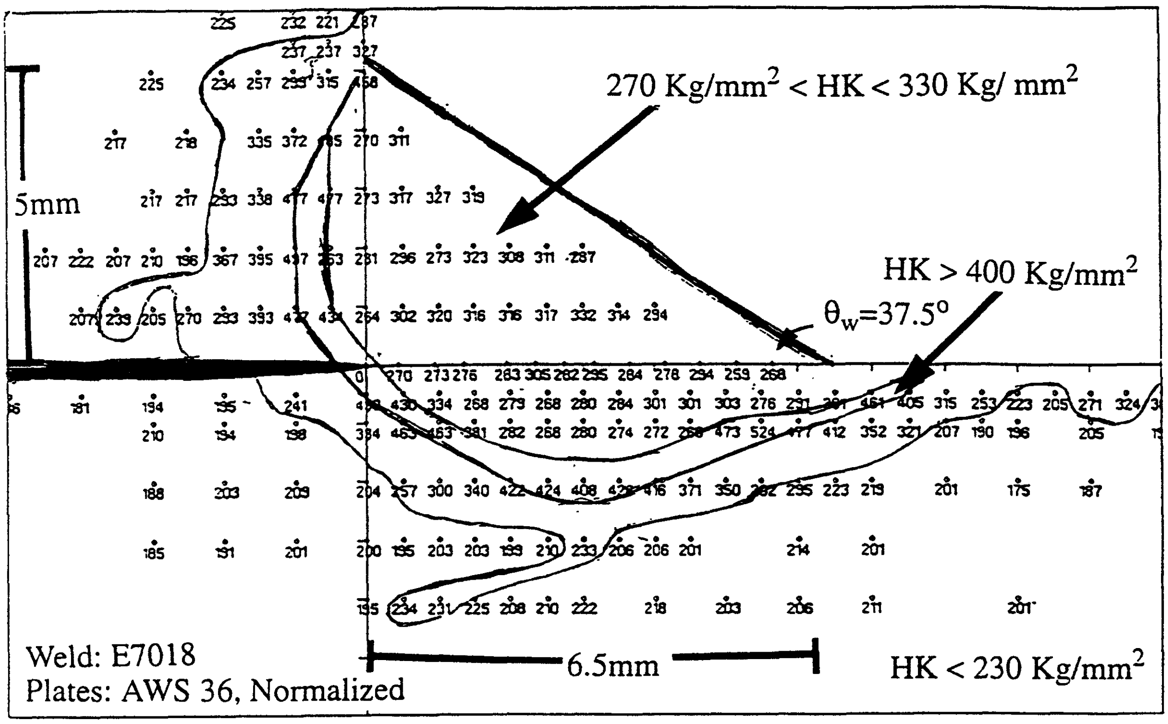

Figure 12. Hardness distribution of an inhomogeneous weld with no penetration and weld surface angle of 37.5°
(source: Gina Middaugh, Nov. 19, 1993)

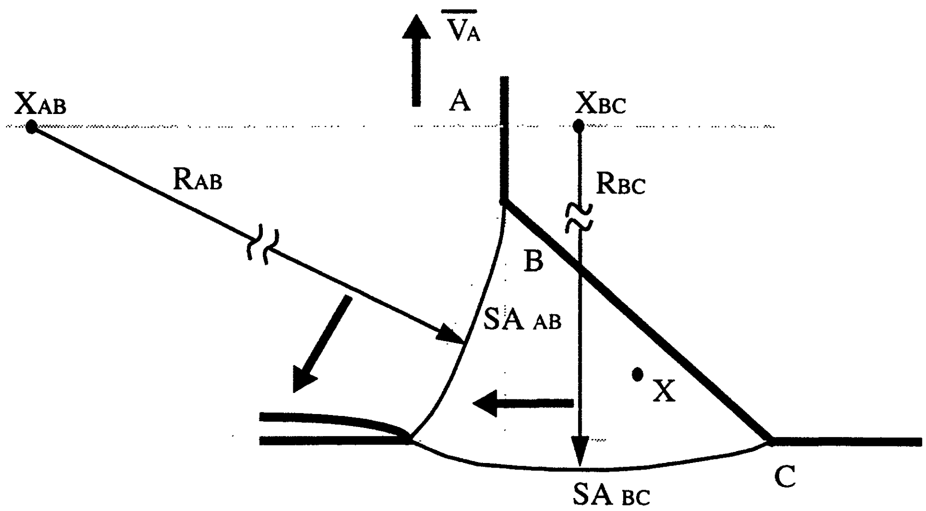

Figure 13 (a). Displacement field with slip arcs in penetration area.

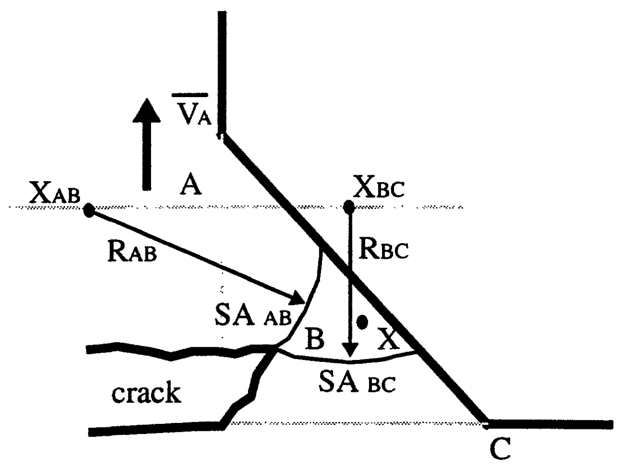

Figure 13 (b). Displacement field with slip arcs in the weld area.

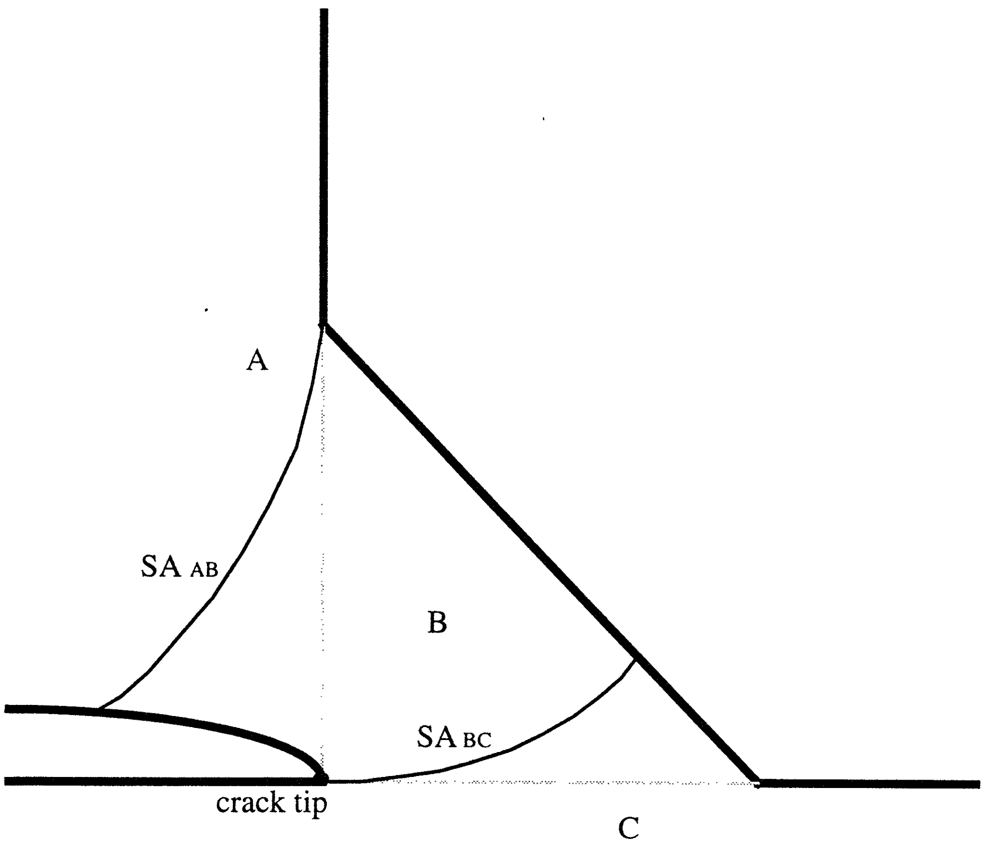

Figure 14. Slip arcs todefine slip wedge.

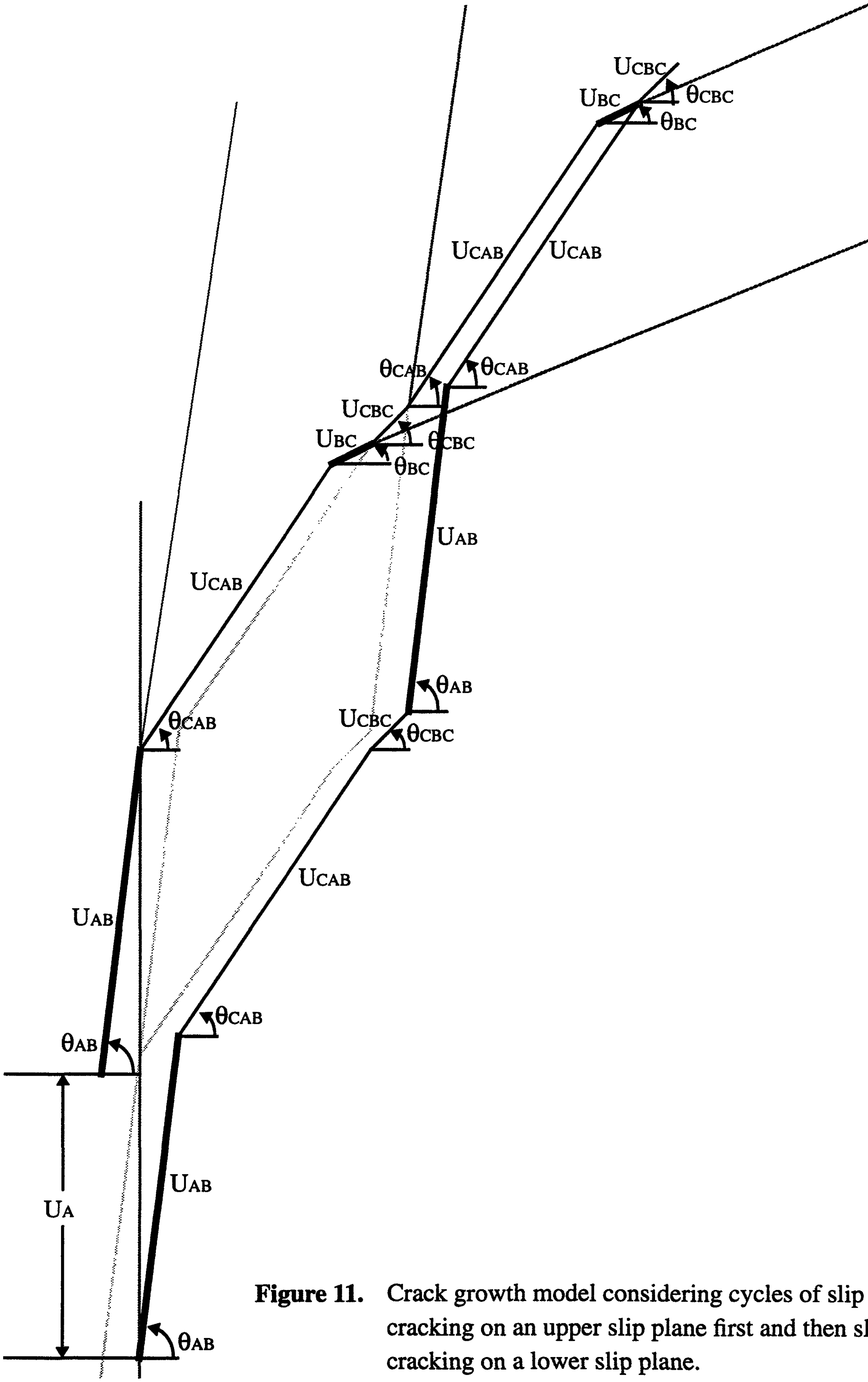

Figure 11. Crack growth model considering cycles of slip and cracking on an upper slip plane first and then slip and cracking on a lower slip plane.

Table of Results

Weld Description	Calculated Values	θ_{AB}	θ_{BC}	P_{ub}
1) Homogeneous weld (HK=325 kg/mm^2) with weld surface angle, θ_w=45°. Crack tip at gap tip,coordinates (0, 0). No initial guess of angles given, i.e. assums θ_{mx}=90°, θ_{mn}=0°.	Program Output	90.00°	0.31°	562.92kg/mm
	Slip Line Theory	90°	0°	562.92kg/mm
2) Homogeneous weld (HK=325 kg/mm^2) with weld surface at θ_w=17.1° . Crack tip at (0.75, 0.25). No initial guess of angles, i.e. assumes θ_{mx}=113.2°, θ_{mn}=−2.5°.	Program Output	90.02°	20.27°	171.12kg/mm
	Slip Line Theory	90°	0°	171.33kg/mm
3) Homogeneous weld (HK=325 kg/mm^2) with weld surface at θ_w=37.5° . Crack tip at (0.75, 1.25). Initial guess of angles is 95°and 30°.	Program Output	90.00°	36.39°	357.26kg/mm
	Slip Line Theory	90°	0°	357.28kg/mm
4) Homogeneous weld (HK=325 kg/mm^2) with weld surface at θ_w=59° . Crack tip at (0.75, 1.25). Initial guess of angles is 76°and -14°.	Program Output	75.55°	− 13.70°	248.20kg/mm
	Slip Line Theory	76°	− 14°	248.38kg/mm
5) Homogeneous weld (HK=325 kg/mm^2) with penetration of 1.5 mm, the weld height is 3.0 mm, therefor the angle of penetration is 77°. Crap tip at (0, 0). Initial guess of angles is 75° and 10°.	Program Output	73.19°	0.00°	765.97kg/mm
	Slip Line Theory	73.3°	0°	766.45kg/mm
6) Homogeneous weld (HK=325 kg/mm^2) with penetration angle of 77° . Crack tip at (0.25, 0.25). Initial guess of angles is 72°and 8°.	Program Output	74.64°	− 3.37°	688.37kg/mm
	Slip Line Theory	75.3°	− 3.37°	689.47kg/mm
7) Inhomogeneous weld with no penetration and weld surface angle of θ_w=37.5°. Crack tip at (0.75, 1.25). Initial guess of angles is 100° and −2°.	Program Output	89.75°	2.83°	338.26kg/mm
	Slip Line Theory - Homogeneous weld	90°	0°	357.28kg/mm
8) Inhomogeneous weld with no penetration and weld surface angle of θ_w=37.5°. Crack tip at (1.75, 2). No initial guess of angles, i.e. assumes θ_{mx}=120.2°, θ_{mn}=−22.8°.	Program Output	89.75°	7.77°	179.45kg/mm
	Slip Line Theory - Homogeneous weld	90°	0°	186.28kg/mm

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APPENDIX A

Supplementary Notes on Program Use

Supplementary Notes on Program Use

A computer program was developed to calculate the least upper bound to the limit load in tension of inhomogeneous welded T-joints. Input is stored in a data file named "inp.dat" shown in Appendix B. The first series of input lines contains information on the date of run, number of sets in the data file, data source, and a description of the weld and its conditions. This information is useful for future references. The next set of input lines has the size and hardness distribution of the weld. Then a set of lines with information about the geometry of the weld follows. It includes the weld leg and height, penetration length, weld surface angle, and the initial gap tip and actual crack tip. The angle given for the weld surface must correspond to the already specified dimensions of weld height and leg. The coordinates of the gap and crack tip are given from the lower left corner of the hardness array. Information on the maximum number of prior iterations to be reported, and the maximum number of iterations allowed before the program stops comes after If the maximum number of prior iterations reported is zero, then the output just gives the convergence value for Pub (upper bound to the limit load) and the slip line angles θ_{AB} and θ_{BC}. The program stops iterating for convergence on the Pub, θ_{AB} and θ_{BC}, when the maximum number of iterations allowed is reached or when the following conditions are met:

1) The difference in Pub between the current and previous iteration is less than the value of Pub found on this iteration multiplied by 0.005.

2) The difference between angles of the previous iteration and the current one is less than 0.5^{o}.

There is an option to initialize the guess angles θ_{AB} and θ_{BC}, and to specify the tolerance values for conversion on the last set of input lines. If the answer to the question for input of initial guess angles is no, the θ_{MX} and θ_{MN} are taken as initial guess angles for

θ_{AB} and θ_{BC}. θ_{MX} is defined as the maximum angle possible for a plane that goes from the crack tip to the intersection between the planes describing the web and that weld surface. θ_{MN} is defined as the minimum angle possible for a plane that goes from the crack tip to the intersection of the planes describing the weld surface and the base plate. The purpose of the initial guess angles is to avoid the programs falling into a local maximum instead of a minimum. If a no is answered to the question of input tolerances for convergence, the values discussed previously are used. If the answer is yes, the first entry is for the multiplication factor for the Pub, and the second entry is the difference in angles allowed.

Other set values for the program that could be changed according to the application are:

1) The weld length "WL", which is taken as one for an unitary length result.

2) The hardness array "Hij" dimensions of (25,25) and of the number of sets of prior iterations in the storing array "Viter" of (10,--), which are arbitrary.

3) The reduction factor of (1.25) of the mesh angle (called "change" in the program) used to generate the polinomial surface.

4) The initial size of the mesh angle, "change", of 10^{o}.

The hardness distribution of Middaugh (1993), shows that the variation in hardness for plates of AWS 36 welded with E7018 is concentrated in a heat affected zone (HAZ) outside the weld material. Therefore on the weld, the change in hardness is more gradual and suitable for fitting by a parabolic surface to find the convergence to a limit load. As a result the values found for inhomogeneous welds fall within 10% of those found for homogeneous welds.

The draw backs of fitting parabolic polynomial surfaces to find the least limit load are first that twisting of the function leads the program to look for a local maximum instead of a minimum, in which case the program will stop and warn the user. Second, since the function studied is not perfectly parabolic, the solution of a given set of angles can throw the next guess in a direction of higher limit loads, or can give non-physical related values for the angles. To help against this wild wandering, the amount of jump in any direction is limited to the size of the surface of that particular iteration. In other words, the size of the jump is the difference between the center point of the set and any other point of the group.

Any iteration can be reported, if it was stated in the input, even if convergence is not achieved. This will be helpful to guess a better initial pair of angles and to look for trends in the function. Program lines for a detailed print out of the iteration steps are left in the program as comment cards to help in any future development or as reference.

Output of the program goes to a file named "out.dat" (Appendix B). It includes an echo printing of the input data file, and the least limit load with its corresponding slip line angles, with warnings at the beginning of the output if something went wrong, that means that the reported limit load is not the least. A warning about the angles found by the iteration being greater or smaller than the limits is also reported at the beginning of the output file, but these do not affect the convergence because the program replaces those values by the limits. If the values for previous iterations were desired, they will follow below.

It is important to mention that the output goes to a file created by the program as new, so if the program is run for a second time, the results of the previous run have to be saved under other name and deleted, so the output can be direct to the assigned file, "out.dat".

Similarly, for the input file, if a new file is to be run, you can save the previous input file under other name and work with the name of "inp.dat" for this one; or change the input file name at the open statement.

APPENDIX B

PUBTJ.F Program Listing

```
C Program to calculate the least upper bound to tensile load of a
C   T-joint with symmetrical fillet welds. It models the deformation in
C   welds as the interaction of three rigid regions bounded by two slip
C   lines. The region above the upper slip line moves up with the web.
C   The region below the lower slip line has zero velocity.  The region
C   between slip lines moves to give pure shear across the slip lines.
C   The hardness of the weld may be considered inhomogeneous.
C
C For analysis, refer to thesis Upper Bound to Tensile Load of T-Joint
C   Fillet Welds, Arlene Guerra 1994.
C
C Date of revision: January 14,1994
C
C Input to the program:
C   a) Date of run, date
C   b) Data set number, nDtSt
C   c) Maximum data set number, mxDtSt
C   d) Source of data (limited to 70 characters or change on
C      line 1), source
C   e) Description of conditions and geometry (limited to 70 characters
C      or change on line 1), data
C   f) Hardness array dimensions (maximum 25x25; or change dimension
C      limits of Hij on line 1 and 101, and format 12), imx,jmx
C   g) Hardness array values in Kg/mm**2 (assign zero to cells out of the
C      weld or plates), Hij
C   h) Number of cells along the weld leg and along the weld height,
C      Ndx,Ndy
C   i) Weld geometry, d(weld leg), p(penetration distance),
C      dhght (weld height), WL(weld length , assume unity or change
C      at line 4), THTw1(angle between weld surface and base plate
C      in degrees)
C   j) Initial crack tip position, Xco,Yco
C   k) Crack tip position, Xc,Yc
C   l) Number of reported slip lines and limit loads iterations, Niter
C      (Niter = 0 reports no iterations values; if Niter is greater
C      than 10, change dimension limit of Viter, on line 1)
C   m) Maximum number of iterations allowed before stop, MNiter
C   n) Initial guess of slip line angles (optional), THTABi, THTBCi
C   o) Tolerances for convergence in iterations; multiplication factor
C      for previous load (TOL = dfact * Pub, program assumes 0.005),
C      angular difference (in degrees)(program assumes 0.5 degress),
C      dfact, dTHT
C
C Ouput of program:
C   a) Echo of input
C   b) Minimum limit load, Pub
C   C) Slip line angles of limit load, THTAB,THTBC
C   d) Slip line angles and limit load for last Niter iterations
C      (Niter = 0 reports no iterations values; if Niter is greater
C      than 10, change dimension limit of Viter, on line 1)
C
C (1) Dimensioning of arrays for weld hardness, trial slip line angles,
C     trial hardness-length product, trial limit load, iterations
C     values of last Niter sets,gauss elimination matrix, and solution
```

```
  1          DIMENSION Hij(25,25),THTslt(6),HLt(6),Pubt(6),Viter(10,12)
             REAL MATRIX(6,7),SOLN(6)
        LOGICAL ERROR
C
C (2) Define as character variables temporary heading,date, source of
C     run, and description of conditions and geometry
  2          CHARACTER HeadTp*50,date*20,source*70,data*70,ANS*50
C
C (3) Read input file (see file inp.dat):
             OPEN (UNIT=33,FILE='inp.dat',STATUS='old')
             OPEN (UNIT=36,FILE='out.dat',STATUS='new')
C     a) Temporary heading, HeadTp
C     b) Date of run, date
  3     READ (33,*)  HeadTp,date
C     c) Data set number, nDtSt
C     d) Maximum data set number, mxDtSt
             READ (33,*) HeadTp,nDtSt,HeadTp,mxDtSt
C     e) Source of data (limited to 70 characters or change on
C        line 1), source
             READ (33,*) HeadTp
        READ (33,*) source
C     f) Description of conditions and geometry (limited to 70
C        characters or change on line 1), data
             READ (33,*) HeadTp
             READ (33,*) data
C     g) Hardness array dimensions (maximum 25x25; or change dimension
C        limits of Hij on line 1 and 101, and format 12), imx,jmx
             READ (33,*) HeadTp,imx,jmx
C    h) Hardness array values in Kg/mm**2 (assign zero to cells out of the
C        weld or plates), Hij
             READ (33,*) HeadTp
             READ (33,*) ((Hij(J,I),J=1,jmx),I=imx,1,-1)
C     i) Units of length and angle
        READ (33,*) HeadTp
C     j) Number of cells along weld leg and along weld height, Edx,Edy
             READ (33,*) HeadTp,Ndx,Ndy
C     k) Weld geometry, d(weld leg),p(penetration distance),
C        dhght (weld height),WL(weld length, assume unity or change
C        at line 4), THTw1(angle between weld surface and base plate
C        in degrees)
             READ (33,*) HeadTp,d,HeadTp,p,HeadTp,dhght
             READ (33,*) HeadTp,THTw1
C     l) Initial crack tip position, Xco,Yco
             READ (33,*) HeadTp,Xco,Yco
C     m) Crack tip position, Xc,Yc
             READ (33,*) HeadTp,Xc,Yc
C     n) Number of reported slip lines & limit loads iterations, Niter
C        (Niter = 0 reports no iterations values; if Niter is greater
C        than 10, change dimension limit of Viter, on line 1)
             READ (33,*) HeadTp,Niter
C     o) Maximum number of iterations allowed before stop, MNiter
             READ (33,*) HeadTp,MNiter
C     p) Initial guess of slip line angles (optional), THTABi, THTBCi
             READ (33,*) HeadTp,HeadTp
```

```
        IF (HeadTp.EQ.'yes'.OR.HeadTp.EQ.'y'.OR.HeadTp.EQ.'YES'.OR.
     +  HeadTp.EQ.'Y') READ (33,*) THTABi,THTBCi
C     q) Tolerances for convergence in iterations;multiplication factor
C        for previous load (TOL = dfact * Pub, program assumes 0.005),
C        angular difference (in degrees)(program assumes 0.5 degress),
C        dfact, dTHT
            READ (33,*) ANS,ANS
        IF (ANS.EQ.'yes'.OR.ANS.EQ.'y'.OR.ANS.EQ.'YES'.OR.ANS.EQ.'Y')
     +  THEN
          READ (33,*) dfact,dTHT
        ELSE
          dfact = 0.005
          dTHT = 0.5
        ENDIF
C
  4         WL = 1.0
C
            Edx = Ndx
            Edy = Ndy
            dx = d/Edx
            dy = dhght/Edy
C
C (4) Convert from degree to radian
            pi = 4.0 * ATAN(1.0)
            THTw1 = THTw1 * (pi/180.0)
C
C (5) Determine maximum slip line angle:
C     (5.1) If the crack tip is out of the weld penetration area
C           the maximum slip line angle is given by the line that
C           connects the crack tip to the intersection of the weld
C           surface and the web.
C
C     (5.2) If the crack tip is inside the weld penetration area
C           the maximum slip line angle is given by the line that
C           connects the crack tip to the farthest point of the web
C           surface.
C
            IF (Xc.GE.(Xco+p)) THEN
               THTmx = ATAN( (Xc-(Xco+p))/((dhght+Yco)-Yc) ) + pi/2.0
            ELSE
               THTmx = pi/2.0 - ATAN( ((p+Xco)-Xc)/(dy*imx-Yc) )
            ENDIF
C
C (6) Determine minimum slip line angle (Fig. 2)
            THTmn = -ATAN( (Yc-Yco)/((Xco+p+d)-Xc) )
            WRITE (36,*) 'THTmx & THTmn',THTmx*180.0/pi,THTmn*180.0/pi
C
C (7) Define initial values for trial slip line angles THTAB, THTBC
C     with 1 degree offset from their limits
        change = 10.0*pi/180.0
            THTslt(2) = THTmx
            THTslt(5) = THTmn
            THTslt(1) = THTslt(2) - 2.0*change
            THTslt(3) = THTslt(2) - change
```

```
            THTslt(4) = THTslt(5) + change
            THTslt(6) = THTslt(5) + 2.0*change
        IF (HeadTp.EQ.'yes'.OR.HeadTp.EQ.'y'.OR.HeadTp.EQ.'YES'.OR.
     +  HeadTp.EQ.'Y') THEN
          delta1 = THTmx - THTABi*pi/180.0
          delta2 = ABS(THTmn - THTBCi*pi/180.0)
          IF (delta1.LT.10.0*pi/180.0.OR.delta2.LT.10.0*pi/180.0) THEN
            IF (delta1.LT.delta2) change = delta1
            IF (delta2.LT.delta1) change = delta2
          ENDIF
          THTslt(3) = THTABi*pi/180.0
          THTslt(4) = THTBCi*pi/180.0
          THTslt(1) = THTslt(3) - change
          THTslt(2) = THTslt(3) + change
          THTslt(5) = THTslt(4) - change
          THTslt(6) = THTslt(4) + change
C
C         WRITE (36,*) 'THTABi & THTBCi', THTABi,THTBCi
C
        ENDIF
C
C (8) Give the hardness-length product HLt of slip lines at THTslt's
        CALL HLPROD (Hij,dx,dy, Xco,Yco,Xc,Yc, THTw1,d,p,dhght, pi,
     +                THTslt, HLt)
C
C (9) Give the limit load Pubt for HLt at given THTslt's
            CALL LOAD (HLt,THTslt,WL, Pubt)
C
C        Do 1116 I = 1,6
C          WRITE (36,*) Pubt(I)
C 1116   CONTINUE
C
C (10) Look for least upper bound to the limit load
C     (10.1) Initialization of variables for iteration
C             (previous slip line angles, THTABp, THTBCp, previous
C             limit load, Pubp, maximum number of iterations reported,
C             MxN, number of iterations, N)
        THTAB = THTslt(2)
        THTBC = THTslt(5)
        Pub = Pubt(4)
        IF (HeadTp.EQ.'yes'.OR.HeadTp.EQ.'y'.OR.HeadTp.EQ.'YES'.OR.
     +  HeadTp.EQ.'Y') THEN
          THTAB = THTslt(3)
          THTBC = THTslt(4)
          Pub = Pubt(3)
        ENDIF
        MxN = 10
        IF (Niter.GT.10) MxN = Niter
        N = -1
C
C     (10.2) Start iteration to find least upper bound limit load
600     N = N + 1
        THTABp = THTAB
        THTBCp = THTBC
```

```
      Pubp = Pub
C
C    (10.3) Use Gauss elimination to get the variables a to f of the
C           equation that describe the polynomial surface of Pub
C           (10.3.1) Read input matrix of equations
      DO 550 I = 1,6
        MATRIX(I,1) = 1.0
        MATRIX(I,7) = Pubt(I)
            SOLN(I) = 0.0
 550  CONTINUE
      KN = 4
      NM = 1
      II = 1
      DO 555 K = 1,3
        DO 560 L = NM,3
          MATRIX(II,2) = THTslt(L)
          MATRIX(II,3) = THTslt(KN)
          MATRIX(II,4) = THTslt(L)*THTslt(L)
          MATRIX(II,5) = THTslt(KN)*THTslt(KN)
          MATRIX(II,6) = THTslt(L)*THTslt(KN)
          II = II + 1
 560    CONTINUE
        NM = NM + 1
        KN = KN + 1
 555  CONTINUE
C
C         WRITE (36,*) 'MATRIX ARRAY'
C      DO 1111 I = 1,6
C        WRITE (36,*) MATRIX(I,1),MATRIX(I,2)*180.0/pi,
C    +          MATRIX(I,3)*180.0/pi,
C    +          MATRIX(I,4)*180.0/pi,MATRIX(I,5)*180.0/pi,
C    +          MATRIX(I,6)*180.0/pi,MATRIX(I,7)
C 1111  CONTINUE
C
C          (10.3.2) Look for the pivot equation and reorder the matrix
      NPIVOT = 1
      ERROR = .FALSE.
 565  IF (NPIVOT.LT.6.AND..NOT.ERROR) THEN
        NROWmx = NPIVOT
        DO 570 NROW = NPIVOT+1,6
          IF (ABS(MATRIX(NROW,NPIVOT)).GT.ABS(MATRIX(NROWmx,NPIVOT)))
     +    NROWmx = NROW
 570    CONTINUE
        IF (ABS(MATRIX(NROWmx,NPIVOT)).LT.1.0E-05) THEN
          ERROR = .TRUE.
        ELSE
          IF (NROWmx.NE.NPIVOT) THEN
            DO 575 K = 1,7
              TempM = MATRIX(NROWmx,K)
              MATRIX(NROWmx,K) = MATRIX(NPIVOT,K)
              MATRIX(NPIVOT,K) = TempM
 575        CONTINUE
          ENDIF
        ENDIF
```

```
C
C           (10.3.3) Elimimation of elements from lower diagonal half
          IF (.NOT.ERROR) THEN
            DO 580 NROW = NPIVOT+1,6
              Factor = MATRIX(NROW,NPIVOT) / MATRIX(NPIVOT,NPIVOT)
              MATRIX(NROW,NPIVOT) = 0.0
              DO 585 NCOLNM = NPIVOT+1,7
                MATRIX(NROW,NCOLNM) = MATRIX(NROW,NCOLNM) -
     +                                MATRIX(NPIVOT,NCOLNM) * Factor
  585         CONTINUE
  580       CONTINUE
            NPIVOT = NPIVOT + 1
          ENDIF
          GOTO 565
        ENDIF
C
C         (10.3.4) Exit program is there is no unique solution
        IF (ERROR) THEN
          WRITE (36,*) 'No unique solution found.'
          GOTO 1114
        ELSE
C
C         (10.3.5) Do back-substitution to deternine the solution
C                  matrix (coefficients of equation that describes Pub)
          DO 590 NROW = 6,1,-1
            DO 595 NCOLMN = 6,NROW+1,-1
              MATRIX(NROW,7) = MATRIX(NROW,7) - SOLN(NCOLMN)*
     +                         MATRIX(NROW,NCOLMN)
  595       CONTINUE
            SOLN(NROW) = MATRIX(NROW,7) / MATRIX(NROW,NROW)
 590      CONTINUE
        ENDIF
C
C        print *,'SOLN ARRAY'
C        DO 1117 J = 1,6
C          WRITE (36,*) SOLN(J)
C 1117   CONTINUE
C
            IF (SOLN(4).GT.0.0.AND.SOLN(5).LT.0.0) THEN
          WRITE (36,*) 'Warning: stoped because program is looking for
     + local maximum, instead of a mimimum. Use a better initial guess
     + of slip line angles.'
          N = N - 1
          GOTO 1114
        ENDIF
            IF (SOLN(4).LT.0.0.AND.SOLN(5).GT.0.0)THEN
          WRITE (36,*) 'Warning: stoped because program is looking for
     + local maximum, instead of a mimimum. Use a better initial guess
     + of slip line angles.'
          N = N - 1
          GOTO 1114
        ENDIF
C      (10.4) Calculate THTAB and THTBC from the partial derivates
C             of the Pub eqn., and compare them to the limits, adjusting
```

```
C             if neccessary
        THTAB = (2.0*SOLN(5)*SOLN(2) - SOLN(3)*SOLN(6))/
     +          (SOLN(6)**2.0 - 4.0*SOLN(5)*SOLN(4))
        THTBC = (-SOLN(2) - 2.0*SOLN(4)*THTAB) / SOLN(6)
C
C        WRITE (36,*) 'THTABp & THTBCp'
C        WRITE (36,*) THTABp*180.0/pi,THTBCp*180.0/pi
C        WRITE (36,*) 'THTAB & THTBC'
C        WRITE (36,*) THTAB*180.0/pi,THTBC*180.0/pi
C
        IF (THTBC.GT.THTAB) THEN
          WRITE (36,*) 'Warning: SOLN THTBC value is greater than THTAB'
          GOTO 1114
        ENDIF
        IF (THTAB.GT.THTmx) THEN
          THTAB = THTmx
          THTBC = (-SOLN(3) - SOLN(6)*THTAB) / (2.0*SOLN(5))
          WRITE (36,*) 'Warning: Soln. THTAB is greater than THTmx'
        ENDIF
        IF (THTBC.LT.THTmn) THEN
          THTBC = THTmn
          THTAB = (-SOLN(2) - SOLN(6)*THTBC) / (2.0*SOLN(4))
          WRITE (36,*) 'Warning: Soln. THTBC is smaller than THTmn'
          IF (THTAB.GT.THTmx) THEN
            THTAB = THTmx - change
            THTBC = (-SOLN(3) - SOLN(6)*THTAB) / (2.0*SOLN(5))
          IF (THTBC.LT.THTmn) THTBC = THTmn + change
          ENDIF
        ENDIF
        IF (ABS(THTAB-THTABp).GT.change) THEN
          IF (THTAB-THTABp.LT.0.0) THEN
            THTAB = THTABp - change
            IF (THTAB+change-change/2.0.GT.THTABp.AND.THTABp.GT.
     +      THTAB+change+change/2.0) change = change * 1.25
          ENDIF
          IF (THTAB-THTABp.GT.0.0) THEN
            THTAB = THTABp + change
            IF (THTAB-change-change/2.0.GT.THTABp.AND.THTABp.GT.
     +      THTAB-change+change/2.0) change = change * 1.25
          ENDIF
          THTBC = (-SOLN(3) - SOLN(6)*THTAB) / (2.0*SOLN(5))
          IF (THTBC.LT.THTmn) THTBC = THTmn
        ENDIF
        IF (ABS(THTBC-THTBCp).GT.change) THEN
          IF (THTBC-THTBCp.LT.0.0) THEN
            THTBC = THTBCp - change
            IF (THTBC+change-change/2.0.GT.THTBCp.AND.THTBCp.GT.
     +      THTBC+change+change/2.0) change = change * 1.25
          ENDIF
          IF (THTBC-THTBCp.GT.0.0) THEN
            THTBC = THTBCp + change
            IF (THTBC-change-change/2.0.GT.THTBCp.AND.THTBCp.GT.
     +      THTBC-change+change/2.0) change = change * 1.25
          ENDIF
```

```
          THTAB = (-SOLN(2) - SOLN(6)*THTBC) / (2.0*SOLN(4))
          IF (THTAB.GT.THTmx) THTAB = THTmx
        ENDIF
C
C        WRITE (36,*) 'THTAB & THTBC II'
C        WRITE (36,*) THTAB*180.0/pi,THTBC*180.0/pi
C
C     (10.5) Storage iterations values for the last Niter iterations
C            if the number is greater than the Niter iterations desired
            IF (N.NE.0) THEN
          IF (N.LE.MxN) Nt = N
          IF (N.GT.MxN) THEN
            Nt = MxN
            DO 650 I = 1,MxN-1
              DO 640 J = 1,12
                Viter(I,J) = Viter(I+1,J)
  640         CONTINUE
 650        CONTINUE
          ENDIF
C
C     (10.6) Storage iteration values if the number of iterations is
C            lest than Niter
          DO 660 J=1,6
            Viter(Nt,J) = THTslt(J)
            Viter(Nt,J+6) = Pubt(J)
 660      CONTINUE
C
C        WRITE (36,*) 'iteration number',Nt
C        WRITE (36,*) 'Viter ARRAY'
C            WRITE (36,*) Viter(Nt,1)*180.0/pi,Viter(Nt,2)*180.0/pi,
C     +          Viter(Nt,3)*180.0/pi,Viter(Nt,4)*180.0/pi,
C     +          Viter(Nt,5)*180.0/pi,Viter(Nt,6)*180.0/pi
C            WRITE (36,*) Viter(Nt,7),Viter(Nt,8),
C     +          Viter(Nt,9),Viter(Nt,10),Viter(Nt,11),Viter(Nt,12)
C
        ENDIF
C
C     (10.7) Define angles for next set of equations
        change = change/1.25
c       If (change.LT.2.0*pi/180.0) change = 5.0*pi/180.0
            IF (THTAB.EQ.THTmx.AND.THTBC.EQ.THTmn) THEN
          THTslt(2) = THTAB
          THTslt(5) = THTBC
          THTslt(3) = THTslt(2) - change
          THTslt(1) = THTslt(2) - 2.0*change
          THTslt(4) = THTslt(5) + change
          THTslt(6) = THTslt(5) + 2.0*change
        ELSE IF (THTAB.EQ.THTmx) THEN
          THTslt(2) = THTAB
          THTslt(4) = THTBC
          THTslt(5) = THTslt(4) - change
          IF (THTslt(5).LT.THTmn) THEN
            change = ABS(THTmn - THTslt(4))
          ENDIF
```

```
          THTslt(5) = THTslt(4) - change
          THTslt(6) = THTslt(4) + change
          THTslt(3) = THTslt(2) - change
          THTslt(1) = THTslt(2) - 2.0*change
        ELSE IF (THTBC.EQ.THTmn) THEN
          THTslt(3) = THTAB
          THTslt(5) = THTBC
          THTslt(2) = THTslt(3) + change
          IF (THTslt(2).GT.THTmx) THEN
            change = THTmx - THTslt(3)
          ENDIF
          THTslt(2) = THTslt(3) + change
          THTslt(1) = THTslt(3) - change
          THTslt(4) = THTslt(5) + change
          THTslt(6) = THTslt(5) + 2.0*change
        ELSE
              THTslt(3) = THTAB
              THTslt(4) = THTBC
              THTslt(2) = THTAB + change
          IF (THTslt(2).GT.THTmx) THEN
            change = THTmx - THTslt(3)
          ENDIF
              THTslt(5) = THTBC - change
 597      IF (THTslt(5).LT.THTmn) THEN
            change = ABS(THTmn - THTslt(4))
          ENDIF
          THTslt(2) = THTAB + change
          THTslt(5) = THTBC - change
              THTslt(1) = THTAB - change
              THTslt(6) = THTBC + change
 598    ENDIF
C
C     (10.8) Calculate hardness-length product of new set of equations
        CALL HLPROD (Hij,dx,dy, Xco,Yco,Xc,Yc, THTw1,d,p,dhght,pi,
     +              THTslt, HLt)
C
C     (10.9) Calculate Limit load for the new set of equations
            CALL LOAD (HLt,THTslt,WL, Pubt)
C
C     (10.10) Limit load of THTAB and THTBC
        IF (THTslt(2).EQ.THTmx.AND.THTslt(5).EQ.THTmn) THEN
          Pub = Pubt(4)
        ELSE IF (THTslt(2).EQ.THTmx) THEN
          Pub = Pubt(2)
        ELSE IF (THTslt(5).EQ.THTmn) THEN
          Pub = Pubt(5)
            ELSE
              Pub = Pubt(3)
        ENDIF
C
C     (10.11) Compare the limit load and slip line angles THTAB and
C             THTBC, with the limit load and angles of the last
C             iteration. If the differences are less than the
C             tolerances, the iteration stops.
```

```
        IF (N.EQ.0) GOTO 600
            TOL = dfact * Pub
        tTHT = dTHT * pi/180.0
            dLOAD = ABS(Pubp - Pub)
        dTHTAB = ABS(THTABp - THTAB)
        dTHTBC = ABS(THTBCp - THTBC)
C
C        WRITE (36,*) 'Pub, TOL, dLOAD , dTHTAB, dTHTBC'
C        WRITE (36,*) Pub,TOL,dLOAD,dTHTAB*180.0/pi,dTHTBC*180.0/pi
C
         IF (N.GT.MNiter-1) THEN
          WRITE (36,*) 'STOP after', MNiter, ' iterations. Use a better
     + initial guess of slip line angles, or allow for more iterations'
          GOTO 1114
            ENDIF
        IF (dLOAD.GT.TOL.OR.dTHTAB.GT.tTHT.OR.dTHTBC.GT.tTHT) GOTO 600
C
C (11) Ouput of program:
C      a) Echo of input
1114   WRITE (36,7)
 7     FORMAT (50X,'INPUT')
       WRITE (36,8) date
 8     FORMAT (1X,'Date of run: ',1X,A)
       WRITE (36,9) nDtSt,mxDtSt
 9     FORMAT (1X,'Data set number: ',I2,' of a maximum data set number
     + of: ',I2)
       WRITE (36,*) 'Source of data: '
       WRITE (36,*) source
       WRITE (36,*) 'Description of conditions and geometry: '
       WRITE (36,*) data
       WRITE (36,11) imx,jmx
 11    FORMAT (1X,'Hardness array dimensions: ',I2,' X ',I2)
       WRITE (36,*) 'Hardness array (unit is kg/mm**2):'
       WRITE (36,12) ((Hij(J,I),J=1,jmx),I=imx,1,-1)
 12    FORMAT (25(25(1X,F5.1)))
       WRITE (36,*) 'Unit of length is mm, of angle is degree.'
       WRITE (36,13) Edx,Edy
 13    FORMAT (1X,'Number of cells on weld leg & height:',F5.2,1X,F5.2)
       WRITE (36,14) d,p
 14    FORMAT (1X,'Weld leg: ',F5.2,'    ','Penetration: ',F5.2)
       WRITE (36,16) dhght
 16    FORMAT (1X,'Weld height: ',F5.2)
       WRITE (36,17) THTw1*180/pi
 17    FORMAT (1X,'Angle between weld surface and base plate: ',F6.2)
       WRITE (36,18) Xco,Yco
 18    FORMAT (1X,'Initial crack tip position: ',F5.2,1X,F5.2)
       WRITE (36,19) Xc,Yc
 19    FORMAT (1X,'Crack tip position: ',F5.2,1X,F5.2)
       WRITE (36,21) Niter
 21    FORMAT (1X,'Number of prior iterations reported: ',I2)
       WRITE (36,28) MNiter
 28    FORMAT (1X,'Maximum number of iterations allowed is: ',I2)
       IF (HeadTp.EQ.'yes'.OR.HeadTp.EQ.'y'.OR.HeadTp.EQ.'YES'.OR.
     + HeadTp.EQ.'Y') THEN
```

```
          WRITE (36,29) THTABi,THTBCi
 29       FORMAT (1X,'Initial guess of slip line angles is:',
     +            1X,F6.2,' , ',F6.2)
        ENDIF
        IF (ANS.EQ.'yes'.OR.ANS.EQ.'y'.OR.ANS.EQ.'YES'.OR.ANS.EQ.'Y')
     + THEN
           WRITE (33,37) dfact,dTHT
 37        FORMAT (1X,'Tolerance for load, multipied by: ',F9.6,
     +            ' Tolerance for change in angle is: ',F6.2)
        ENDIF
C
C       b) Minimum limit load, Pub
C       C) Slip line angles of limit load, THTAB,THTBC
        WRITE (36,22)
 22     FORMAT (50X,'OUTPUT')
        WRITE (36,23) Pub
 23     FORMAT (1X,'Least limit Load is ',F8.2,'Kg/mm')
        WRITE (36,24) THTAB*180.0/pi,THTBC*180.0/pi
 24     FORMAT (1X,'Slip line angles are ',F6.2,' and ',F6.2,' degrees')
        DIFmn = (pi/2.0) - (0.1*pi/180.0)
        DIFmx = (pi/2.0) + (0.1*pi/180.0)
        IF (THTAB.GT.DIFmn.AND.THTAB.LT.DIFmx) WRITE (36,31)
 31     FORMAT (1X,'NOTE: IF THTAB equals 90.0 degrees, the angle THTBC
     + does not affect the result of Pub; therefor THTBC is chosen to
     + be 0 degrees')
C
C       d) Slip line angles and limit load for last Niter iterations
C          (Niter = 0 reports no iterations values; if Niter is greater
C          than 10, change dimension limit of Viter, on line 1)
        IF (Niter.GT.0) THEN
           NC = 0
           NV = Niter
           IF (N.LT.Niter) NV = N
               DO 10 K=NV,1,-1
             M = 1
             NN = 1
                 WRITE (36,26) N-NC
 26          FORMAT (1X,'Iteration ',I3)
                 NC = NC + 1
                 WRITE (36,*) 'Angles(degrees):   THTAB     THTBC',
     +                     '           ','Load(Kg/mm):   Pub'
             DO 15 J=4,6
                DO 20 I=NN,3
                  WRITE (36,27) Viter(K,I)*(180.0/pi),
     +                          Viter(K,J)*(180.0/pi),
     +                          Viter(K,(M+6))
 27               FORMAT (19X,F6.2,4X,F6.2,22X,F8.2)
                      M = M + 1
   20           CONTINUE
                NN = NN + 1
  15          CONTINUE
 10         CONTINUE
         ENDIF
C
```

```
C (12) Loop to read next set of data
            IF (nDtSt.LT.mxDtSt) GOTO 3
C
C (13) End of main program
 30         STOP
            END
C
C
            SUBROUTINE LOAD (HLt,THTslt,WL, Pubt)
C
C (9.1) Input to subroutine:
C       a) Hardness-length products array, HLt
C       b) Temporary slip line angles array, THTslt
C       c) Weld length, WL
C       Output to subroutine:
C       a) Upper bound limit loads array
C
C (9.2) Dimensioning arrays
        DIMENSION HLt(6),THTslt(6),Pubt(6)
C
C (9.3) Find limit load, Pubt, given values of temporary
C       hardness-length products, HLt, and temporary slip
C       line angles, THTslt of six trial sets of angles
      M = 1
      NN = 1
      DO 50 J=4,6
             DO 55 I=NN,3
                AB = ABS(COS(THTslt(J)))/SIN(THTslt(I)-THTslt(J))
                BC = ABS(COS(THTslt(I)))/SIN(THTslt(I)-THTslt(J))
            Pubt(M)= ((0.6*WL)/SQRT(3.0))*((HLt(I)*AB)+(HLt(J)*BC))
            M = M + 1
   55     CONTINUE
          NN = NN + 1
  50  CONTINUE
C
C (9.4) Return to main program
      RETURN
      END
C
            SUBROUTINE HLPROD (Hij,dx,dy, Xco,Yco,Xc,Yc,
THTw1,d,p,dhght,
     +                       pi,  THTslt, HLt)
C
C (8.1) Input to subroutine:
C     a) Array of hardness values, Hij
C     b) Cell dimensions, dx,dy
C     c) Initial crack tip position, Xco,Yco
C     d) Crack tip position, Xc,Yc
C     e) Weld angle, THTw1
C     f) Weld leg, d
C     g) Weld penetration, p
C     h) Weld height, dhght
C     i) value of pi, pi
C     g) Array of temporary slip line angles,THTslt
```

```
C     Output to subroutine:
C     a) Array of temporary hardness-length products, HLt
C
C (8.2) Dimensioning of arrays for hardness, temporary slip line
C     angles, and temporary hardness-length product
 101        DIMENSION Hij(25,25),THTslt(6),HLt(6)
C
        CHARACTER condtn*5
C
C (8.3) Calculate the slip line length-hardness product for each angle
C       of the THTslt array
            DO 500 I=1,6
              condtn = 'start'
C
C     (8.3.1) Determine the cell where the crack tip lies (result is
C             an integer)
              IXc = (Xc/dx) + 1
              IYc = (Yc/dy) + 1
C
C     (8.3.2) Determine position of the crack tip respect to lower left
C             corner
              RXc = INT(Xc/dx)
              RYc = INT(Yc/dy)
              DXc = ((Xc/dx) - RXc)*dx
              DYc = ((Yc/dy) - RYc)*dy
C
C     (8.3.3) Calculate the slip line length
C            (8.3.3.1) Length of the slip line if it ends on the web
C                      surface
          IF (Xc.LT.Xco+p) THEN
            THTW = ATAN((dhght + Yco - Yc)/(Xco + P - Xc))
            IF (THTslt(I).GT.THTW) THEN
              SLT = (Xco + p - Xc) / COS(THTslt(I))
            ELSE
              SLT = ((Xco+p+d-Xc-(Yc-Yco)/TAN(THTw1))*SIN(THTw1))/
     +              SIN(THTw1+THTslt(I))
            ENDIF
C
C            (8.3.3.2) Length of the slip line if it ends on the weld
C                      surface
          ELSE
            SLT = ((Xco+p+d-Xc-(Yc-Yco)/TAN(THTw1))*SIN(THTw1))/
     +            SIN(THTw1+THTslt(I))
          ENDIF
C
C    (8.3.4) Calculate the hardness-length product if the angle is zero
              IF (THTslt(I).EQ.0.0) THEN
C
C          (8.3.4.1) Number of cells on X axis
                SLX = (DXc+SLT)/dx
                ISLX = INT(SLX)
C
C          (8.3.4.2) Slip line length of first cell
                SL = dx - DXc
```

```
C
C         (8.3.4.3) First cell hardness-length product
            IF (SL.LT.SLT) THEN
              HLt(I) = SL * Hij(IXc,IYc)
                ELSE
              HLt(I) = SLT * Hij(IXc,IYc)
                  condtn = 'ended'
            ENDIF
C
C         (8.3.4.4) If the slip line end is reached, then go for the
C                   next line
            IF (condtn.EQ.'ended') GOTO 107
C
C         (8.3.4.5) If next cell is last, go to calculate last cell
C                   hardness-length product
                IF (ISLX.EQ.1) GOTO 105
C
C         (8.3.4.6) Intermidiate cells hardness-length product
                SL = dx
                DO 100 J=1,ISLX-1
                  HLt(I) = HLt(I) + SL*Hij(IXc+J,IYc)
  100       CONTINUE
C
C         (8.3.4.7) Slip line length of last cell
  105       RSLX = ISLX
            SL = (dx-DXc) + (RSLX-1.0)*dx
            SL = SLT - SL
C
C         (8.3.4.8) Last cell hardness-length product
            HLt(I) = HLt(I) + SL*Hij(IXc+ISLX,IYc)
                condtn = 'ended'
 107      ENDIF
C
C         (8.3.4.8) If the slip line end is reached, then go for the
C                   next line
          IF (condtn.EQ.'ended') GOTO 500
C
C    (8.3.5) Calculate the hardness-length product if the angle is 90
          IF (THTslt(I).EQ.pi/2.0) THEN
C
C         (8.3.5.1) Number of cells on Y axis
            SLY = (DYc+SLT) / dy
                ISLY = INT(SLY)
C
C         (8.3.5.2) Slip line length on first cell
                SL = dy - DYc
C
C         (8.3.5.3) First cell hardness-length product
            IF (SL.LT.SLT) THEN
              HLt(I) = SL * Hij(IXc,IYc)
                ELSE
              HLt(I) = SLT * Hij(IXc,IYc)
                  condtn = 'ended'
            ENDIF
```

```
C
C         (8.3.5.4) If the slip line end is reached, then go for the
C                   next line
            IF (condtn.EQ.'ended') GOTO 117
C
C         (8.3.5.5) If next cell is last, go to calculate last cell
C                   hardness-length product
                IF (ISLY.EQ.1) GOTO 115
C
C         (8.3.6.6) Intermidiate cells hardness-length product
                SL = dy
                DO 110 J=1,ISLY-1
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
  110         CONTINUE
C
C         (8.3.5.7) Slip line length of last cell
  115         RSLY = ISLY
              SL = (dy - DYc) + (RSLY-1.0)*dy
              SL = SLT - SL
C
C         (8.3.5.8) Last cell hardness-length product
              HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
                  condtn = 'ended'
  117       ENDIF
C
C         (8.3.5.9) If the slip line end is reached, then go for the
C                   next line
            IF (condtn.EQ.'ended') GOTO 500
C
C    (8.3.6) Calculate the hardness-length product of negative
C            angles
            IF (THTslt(I).LT.0.0) THEN
C
C         (8.3.6.1) Number of cells on X axis
              SLX = (SLT * COS(THTslt(I)) + DXc) / dx
                  ISLX = INT(SLX)
                  RSLX = ISLX
C
C         (8.3.6.2) For a slip line that ends on the first row
                  IF (SLX.LE.1.0) THEN
C
C                (8.3.6.2.1) Calculate number of cells on Y axis
                  SLY = (SLT * SIN(-THTslt(I)) + (dy - DYc)) / dy
                  ISLY = INT(SLY)
C
C                (8.3.6.2.2) If slip line ends on the first cell,
C                            calculate its' hardness-length product
C                            and go to the next slip line
               IF (SLY.LE.1.0) THEN
                         HLt(I) = SLT * Hij(IXc,IYc)
                     condtn = 'ended'
               ENDIF
               IF (condtn.EQ.'ended') GOTO 127
C
```

```
C             (8.3.6.2.3) If slip line does not end on the first
C                         cell, calculate its' hardness-length
C                         product (HLt)
C
C                       (8.3.6.2.3.1) Slip line length of first cell
C                                     on Y axis
         SL = DYc / SIN(-THTslt(I))
C
C                       (8.3.6.2.3.2) HLt of first cell on Y axis
             HLt(I) = SL * Hij(IXc,IYc)
C
C                       (8.3.6.2.3.3) If next cell is last on Y, go
C                                     to calculate last cell length
C                                     and hardness-length product
             IF (ISLY.EQ.1) GOTO 125
C
C                       (8.3.6.2.3.4) HLt of intermidiate cells on Y
             SL = dy / SIN(-THTslt(I))
             DO 120 J=1,ISLY-1
                   HLt(I) = HLt(I) + SL*Hij(IXc,IYc-J)
  120        CONTINUE
C
C                       (8.3.6.2.3.5) If the slip line ended on the
C                                     corner of last cell,get next
C                                     slip line
  125        RSLY = ISLY
             IF (SLY-RSLY.EQ.0.0) GOTO 126
C
C                       (8.3.6.2.3.6) Slip line length of last cell
C                                     on Y axis
             SL = (DYc + (RSLY-1.0)*dy) / SIN(-THTslt(I))
             SL = SLT - SL
C
C                       (8.3.6.2.3.7) HLt of last cell
             HLt(I) = HLt(I) + SL*Hij(IXc,IYc-ISLY)
  126        condtn = 'ended'
 127       ENDIF
C
C                       (8.3.6.2.3.8) If the slip line end is
C                                     reached, then go for the next
           IF (condtn.EQ.'ended') GOTO 180
C
C          (8.3.6.3) For first cell on X axis, if it is not the
C                    last cell
C                 (8.3.6.3.1) Number of cells on Y axis
             SLY = ((dx-DXc) * TAN(-THTslt(I)) + (dy-DYc)) / dy
             ISLY = INT(SLY)
C
C                 (8.3.6.3.2) If the slip line cross just the first Y
C                             cell, calculate its' HLt and go to next
C                             cell on X
           IF (SLY.LE.1.0) THEN
             HLt(I) = (dx-DXc) / COS(THTslt(I)) * Hij(IXc,IYc)
             IF (SLY.EQ.1.0) ISLY = 1
```

```
      ENDIF
      IF (SLY.LE.1.0) GOTO 140
C
C             (8.3.6.3.3) If the slip line cross more that just
C                         the first Y cell, calculate its' HLt
      HLt(I) = DYc / SIN(-THTslt(I)) * Hij(IXc,IYc)
C
C             (8.3.6.3.4) If next cell is the last on Y, go to
C                         last cell calculation of length and HLt
      IF (ISLY.EQ.1) GOTO 135
C
C             (8.3.6.3.5) Calculate HLt of intermidiate cells on
C                         Y axis
        SL = dy / SIN(-THTslt(I))
      DO 130 J=1,ISLY-1
       HLt(I) = HLt(I) + SL*Hij(IXc,IYc-J)
  130 CONTINUE
C
C             (8.3.6.3.6) If the slip line ended on the corner of
C                         last cell, move to the next cell
  135 RSLY = ISLY
      IF (SLY-RSLY.EQ.0.0) GOTO 140
C
C             (8.3.6.3.7) Slip line length of last cell on the
C                         Y axis
        SL = (DYc + (RSLY-1.0)*dy) / SIN(-THTslt(I))
      SL = (dx - DXc) / COS(THTslt(I)) - SL
C
C             (8.3.6.3.8) Calculate HLt of last cell on Y axis of
C                         first row
        HLt(I) = HLt(I) + SL*Hij(IXc,IYc-ISLY)
C
C             (8.3.6.3.9) Define X and Y of next cell
  140 IXc = IXc + 1
      IYc = IYC - ISLY
C
C     (8.3.6.4) If next cell on X is last, go to last cell HLt
C               calculation
      IF (ISLX.EQ.1) GOTO 165
C
C     (8.3.6.5) Calculate HLt of intermidiate cells on X
        DO 150 J=1,ISLX-1
C
C            (8.3.6.5.1) Number of cells on Y axis
         DSLY = SLY - RSLY
         SLY = (dx * TAN(-THTslt(I)) + DSLY*dy) / dy
         ISLY = INT(SLY)
       RSLY = ISLY
C
C            (8.3.6.5.2) If the slip line cross only one cell on
C                        Y, calculate its' HLt, and define and
C                        move to next cell
         IF (SLY.LE.1.0) THEN
            HLt(I) = HLt(I) + dx/COS(THTslt(I)) *
```

```
Hij(IXc,IYc)
                        IXc = IXc + 1
                        IF (SLY.EQ.1.0) IYc = IYc - 1
              ENDIF
                  IF (SLY.LE.1.0) GOTO 150
C
C                 (8.3.6.5.3) If the slip line cross more than one cell
C                           (8.3.6.5.3.1) Calculate slip line length of
C                                         first cell on Y
              SL = (dy - DSLY*dy) / SIN(-THTslt(I))
C
C                           (8.3.6.5.3.2) Calculate HLt of first cell
C                                         on Y
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
C
C                           (8.3.6.5.3.3) If next cell is last on Y, go
C                                         to calculate last cell's HLt
                  IF (ISLY.EQ.1) GOTO 160
C
C                           (8.3.6.5.3.4) Slip line length of intermi-
C                                         diate cells on Y axis
              SL = dy / SIN(-THTslt(I))
C
C                           (8.3.6.5.3.5) HLt of intermidiate cells on
C                                         the Y axis
                  DO 155 K=1,ISLY-1
                        HLt(I) = HLt(I) + SL*Hij(IXc,IYc-K)
  155         CONTINUE
C
C                           (8.3.6.5.3.6) If the slip line ended on the
C                                         corner of last cell, move to
C                                         next cell
  160         IF (SLY-RSLY.EQ.0.0) GOTO 157
C
C                 (8.3.6.5.4) Slip line length of last cell on Y axis
                  SL = (dy - DSLY*dy + (RSLY-1.0)*dy) / SIN(-THTslt(I))
                  SL = dx/COS(THTslt(I)) - SL
C
C                 (8.3.6.5.5) HLt of last cell on Y
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc-ISLY)
C
C                 (8.3.6.5.6) Next cell position
 157          IXc = IXc + 1
              IYc = IYc - ISLY
 150        CONTINUE
C
C                 (8.3.6.5.7) Number of cells on Y axis for last row
 165        DSLX = SLX - RSLX
                DSLY = SLY - RSLY
                SLY = (DSLX * TAN(-THTslt(I)) + DSLY)
                ISLY = INT(SLY)
C
C           (8.3.6.6) For last cell
                IF (SLY.LE.1.0) THEN
```

```
C
C                (8.3.6.6.1) Calculate slip line length and HLT of
C                            last cell
              SL = SLT - ((dx-DXc)+(RSLX-1.0)*dx) / COS(THTslt(I))
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
                  condtn = 'ended'
            ENDIF
C
C                (8.3.6.6.2) If the slip line end is reached, then go
C                            for the next line
            IF (condtn.EQ.'ended') GOTO 180
C
C                (8.3.6.6.3) Calculate slip line length  and HLt of
C                            first cell on Y of last row
                SL = (dy - DSLY*dy) / SIN(-THTslt(I))
                HLt(I) = HLT(I) + SL*Hij(IXc,IYc)
C
C                (8.3.6.6.4) If next cell is last, go to last cell
C                            calculations
                IF (ISLY.EQ.1) GOTO 175
C
C                (8.3.6.6.5) Calculate slip line length and HLt on Y
C                            of intermidiate cells of last row
            SL = dy / SIN(-THTslt(I))
            DO 170 J=1,ISLY-1
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc-J)
 170        CONTINUE
C
C                (8.3.6.6.6)  If the slip line ended on the corner,
C                             get next slip line
 175        RSLY = ISLY
            IF (SLY-RSLY.EQ.0.0) GOTO 177
C
C                (8.3.6.6.7) Slip line length and HLt of last cell
C                            (total HLt of the slip line is found)
               SL = ((RSLX-1.0)*dx + (dx-DXc)) / COS(THTslt(I)) + ((RSLY
     +            - 1.0)*dy + (dy - DSLY*dy)) / SIN(-THTslt(I))
                SL = SLT - SL
            HLt(I) = HLt(I) + SL*Hij(IXc,IYc-ISLY)
  177       condtn = 'ended'
 180      ENDIF
C
C                (8.3.6.6.8) End of the slip line, go to get the next
          IF (condtn.EQ.'ended') GOTO 500
C
C     (8.3.7) Calculate the hardness-length product of angles greater
C             than 90 degrees
          IF (THTslt(I).GT.pi/2.0) THEN
C
C         (8.3.7.1) Number of cells on X axis
            SLX = (SLT * SIN(THTslt(I)-pi/2.0) + (dx - DXc)) / dx
                ISLX = INT(SLX)
                RSLX = ISLX
C
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```
C         (8.3.7.2) For a slip line that ends on the first row
                IF (SLX.LE.1.0) THEN
C
C                 (8.3.7.2.1) Calculate number of cells on Y axis
                  SLY = (SLT * COS(THTslt(I)-pi/2.0) + DYc) / dy
                  ISLY = INT(SLY)
C
C                 (8.3.7.2.2) If slip line ends on the first cell,
C                             calculate its' hardness-length product
C                             and go to the next slip line
              IF (SLY.LE.1.0) THEN
                        HLt(I) = SLT * Hij(IXc,IYc)
                    condtn = 'ended'
              ENDIF
              IF (condtn.EQ.'ended') GOTO 227
C
C                 (8.3.7.2.3) If slip line does not end on the first
C                             cell, calculate its' hardness-length
C                             product (HLt)
C                           (8.3.7.2.3.1) Slip line length of first cell
C                                         on Y axis
              SL = (dy - DYc) / COS(THTslt(I)-pi/2.0)
C
C                           (8.3.7.2.3.2) HLt of first cell on Y axis
                  HLt(I) = SL * Hij(IXc,IYc)
C
C                           (8.3.7.2.3.3) If next cell is last on Y, go
C                                         to calculate last cell length
C                                         and hardness-length product
                  IF (ISLY.EQ.1) GOTO 225
C
C                           (8.3.7.2.3.4) HLt of intermidiate cells on Y
                  SL = dy / COS(THTslt(I)-pi/2.0)
                  DO 220 J=1,ISLY-1
                        HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
  220         CONTINUE
C
C                           (8.3.7.2.3.5) If the slip line ended on the
C                                         corner of last cell,get next
C                                         slip line
  225         RSLY = ISLY
              IF (SLY-RSLY.EQ.0.0) GOTO 226
C
C                           (8.3.7.2.3.6) Slip line length of last cell
C                                         on Y axis
                  SL = (dy-DYc + (RSLY-1.0)*dy) / COS(THTslt(I)-pi/2.0)
                  SL = SLT - SL
C
C                           (8.3.7.2.3.7) HLt of last cell
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
  226         condtn = 'ended'
 227        ENDIF
C
C                           (8.3.7.2.3.8) If the slip line end is
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C                                        reached, then go for the next
         IF (condtn.EQ.'ended') GOTO 280
C
C        (8.3.7.3) For first cell on X axis, if it is not the
C                  last cell
C                (8.3.7.3.1) Number of cells on Y axis
            SLY = (DXc / TAN(THTslt(I)-pi/2.0) + DYc) / dy
            ISLY = INT(SLY)
C
C                (8.3.7.3.2) If the slip line cross just the first Y
C                            cell, calculate its' HLt and go to next
C                            cell on X
         IF (SLY.LE.1.0) THEN
              HLt(I) = DXc / SIN(THTslt(I)-pi/2.0) * Hij(IXc,IYc)
              IF (SLY.EQ.1.0) ISLY = 1
         ENDIF
         IF (SLY.LE.1.0) GOTO 240
C
C                (8.3.7.3.3) If the slip line cross more that just
C                            the first Y cell, calculate its' HLt
         HLt(I) = (dy - DYc) / COS(THTslt(I)-pi/2.0) * Hij(IXc,IYc)
C
C                (8.3.7.3.4) If next cell is the last on Y, go to
C                            last cell calculation of length and HLt
         IF (ISLY.EQ.1) GOTO 235
C
C                (8.3.7.3.5) Calculate HLt of intermidiate cells on
C                            Y axis
            SL = dy / COS(THTslt(I)-pi/2.0)
         DO 230 J=1,ISLY-1
           HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
  230    CONTINUE
C
C                (8.3.7.3.6) If the slip line ended on the corner of
C                            last cell, move to the next cell
  235    RSLY = ISLY
         IF (SLY-RSLY.EQ.0.0) GOTO 240
C
C                (8.3.7.3.7) Slip line length of last cell on the
C                            Y axis
            SL = (dy-DYc + (RSLY-1.0)*dy) / COS(THTslt(I)-pi/2.0)
         SL = DXc / SIN(THTslt(I)-pi/2.0) - SL
C
C                (8.3.7.3.8) Calculate HLt of last cell on Y axis of
C                            first row
            HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
C
C                (8.3.7.3.9) Define X and Y of next cell
  240    IXc = IXc - 1
         IYc = IYC + ISLY
C
C        (8.3.7.4) If next cell on X is last, go to last cell HLt
C                  calculation
         IF (ISLX.EQ.1) GOTO 265
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C
C          (8.3.7.5) Calculate HLt of intermidiate cells on X
              DO 250 J=1,ISLX-1
C
C                 (8.3.7.5.1) Number of cells on Y axis
                DSLY = SLY - RSLY
                SLY = (dx / TAN(THTslt(I)-pi/2.0) + DSLY*dy) / dy
                ISLY = INT(SLY)
            RSLY = ISLY
C
C                 (8.3.7.5.2) If the slip line cross only one cell on
C                             Y, calculate its' HLt, and define and
C                             move to next cell
                IF (SLY.LE.1.0) THEN
                      HLt(I) = HLt(I) + dx/SIN(THTslt(I)-pi/2.0) *
     +                 Hij(IXc,IYc)
                      IXc = IXc - 1
                      IF (SLY.EQ.1.0) IYc = IYc + 1
            ENDIF
                IF (SLY.LE.1.0) GOTO 250
C
C               (8.3.7.5.3) If the slip line cross more than one cell
C                         (8.3.7.5.3.1) Calculate slip line length of
C                                       first cell on Y
            SL = (dy - DSLY*dy) / COS(THTslt(I)-pi/2.0)
C
C                         (8.3.7.5.3.2) Calculate HLt of first cell
C                                       on YY
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
C
C                         (8.3.7.5.3.3) If next cell is last on Y, go
C                                       to calculate last cell's HLt
                IF (ISLY.EQ.1) GOTO 260
C
C                         (8.3.7.5.3.4) Slip line length of intermi-
C                                       diate cells on Y axis
            SL = dy / COS(THTslt(I)-pi/2.0)
C
C                         (8.3.7.5.3.5) HLt of intermidiate cells on
C                                       the Y axis
                DO 255 K=1,ISLY-1
                      HLt(I) = HLt(I) + SL*Hij(IXc,IYc+K)
  255       CONTINUE
C
C                         (8.3.7.5.3.6) If the slip line ended on the
C                                       corner of last cell, move to
C                                       next cell
  260       IF (SLY-RSLY.EQ.0.0) GOTO 257
C
C               (8.3.7.5.4) Slip line length of last cell on Y axis
              SL = (dy-DSLY*dy + (RSLY-1.0)*dy) / COS(THTslt(I)-pi/2.0)
                SL = dx/SIN(THTslt(I)-pi/2.0) - SL
C
C               (8.3.7.5.5) HLt of last cell on Y
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```
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
C
C               (8.3.7.5.6) Next cell position
 257          IXc = IXc - 1
              IYc = IYc + ISLY
 250        CONTINUE
C
C               (8.3.7.5.7) Number of cells on Y axis for last ro
 265        DSLX = SLX - RSLX
              DSLY = SLY - RSLY
              SLY = (DSLX / TAN(THTslt(I)-pi/2.0) + DSLY)
              ISLY = INT(SLY)
C
C           (8.3.7.6) For last cell
              IF (SLY.LE.1.0) THEN
C
C               (8.3.7.6.1) Calculate slip line length and HLT of
C                           last cell
          SL = SLT - (DXc+(RSLX-1.0)*dx) / SIN(THTslt(I)-pi/2.0)
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
                condtn = 'ended'
            ENDIF
C
C               (8.3.7.6.2) If the slip line end is reached, then go
C                           for the next line
            IF (condtn.EQ.'ended') GOTO 280
C
C               (8.3.7.6.3) Calculate slip line length  and HLt of
C                           first cell on Y of last row
              SL = (dy - DSLY*dy) / COS(THTslt(I)-pi/2.0)
              HLt(I) = HLT(I) + SL*Hij(IXc,IYc)
C
C               (8.3.7.6.4) If next cell is last, go to last cell
C                           calculations
              IF (ISLY.EQ.1) GOTO 275
C
C               (8.3.7.6.5) Calculate slip line length and HLt on Y
C                           of intermidiate cells of last row
            SL = dy / COS(THTslt(I)-pi/2.0)
            DO 270 J=1,ISLY-1
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
 270        CONTINUE
C
C               (8.3.7.6.6)  If the slip line ended on the corner,
C                            get next slip line
 275        RSLY = ISLY
            IF (SLY-RSLY.EQ.0.0) GOTO 277
C
C               (8.3.7.6.7) Slip line length and HLt of last cell
C                           (total HLt of the slip line is found)
              SL = ((RSLX-1.0)*dx + DXc) / SIN(THTslt(I)-pi/2.0) +
     +      ((RSLY - 1.0)*dy + (dy - DSLY*dy)) / COS(THTslt(I)-pi/2.0)
              SL = SLT - SL
            HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
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 277       condtn = 'ended'
 280      ENDIF
C
C                (8.3.7.6.8) End of the slip line, go to get the next
          IF (condtn.EQ.'ended') GOTO 500
C
C     (8.3.8) Calculate the hardness-length product of angles between
C             0 and 90 degrees
C         (8.3.8.1) Number of cells on X axis
          SLX = (SLT * COS(THTslt(I)) + DXc) / dx
              ISLX = INT(SLX)
              RSLX = ISLX
C
C         (8.3.8.2) For a slip line that ends on the first row
              IF (SLX.LE.1.0) THEN
C
C                (8.3.8.2.1) Calculate number of cells on Y axis
                SLY = (SLT * SIN(THTslt(I)) + DYc) / dy
                ISLY = INT(SLY)
C
C                (8.3.8.2.2) If slip line ends on the first cell,
C                            calculate its' hardness-length product
C                            and go to the next slip line
            IF (SLY.LE.1.0) THEN
              HLt(I) = SLT * Hij(IXc,IYc)
                  condtn = 'ended'
            ENDIF
            IF (condtn.EQ.'ended') GOTO 327
C
C                (8.3.8.2.3) If slip line does not end on the first
C                            cell, calculate its' hardness-length
C                            product (HLt)
C                          (8.3.6.2.3.1) Slip line length of first cell
C                                        on Y axis
            SL = (dy - DYc) / SIN(THTslt(I))
C
C                          (8.3.8.2.3.2) HLt of first cell on Y axis
                HLt(I) = SL * Hij(IXc,IYc)
C
C                          (8.3.8.2.3.3) If next cell is last on Y, go
C                                        to calculate last cell length
C                                        and hardness-length product
                IF (ISLY.EQ.1) GOTO 325
C
C                          (8.3.8.2.3.4) HLt of intermidiate cells on Y
                SL = dy / SIN(THTslt(I))
                DO 320 J=1,ISLY-1
              HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
 320        CONTINUE
C
C                          (8.3.8.2.3.5) If the slip line ended on the
C                                        corner of last cell,get next
C                                        slip line
 325        RSLY = ISLY
```

```
          IF (SLY-RSLY.EQ.0.0) GOTO 326
C
C                        (8.3.8.2.3.6) Slip line length of last cell
C                                      on Y axis
            SL = (dy - DYc + (RSLY-1.0)*dy) / SIN(THTslt(I))
            SL = SLT - SL
C
C                        (8.3.8.2.3.7) HLt of last cell
            HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
  326     condtn = 'ended'
 327    ENDIF
C
C                        (8.3.8.2.3.8) If the slip line end is
C                                      reached, then go for the next
        IF (condtn.EQ.'ended') GOTO 500
C
C         (8.3.8.3) For first cell on X axis, if it is not the
C                   last cell
C                 (8.3.8.3.1) Number of cells on Y axis
           SLY = ((dx-DXc) * TAN(THTslt(I)) + DYc) / dy
           ISLY = INT(SLY)
C
C                 (8.3.8.3.2) If the slip line cross just the first Y
C                             cell, calculate its' HLt and go to next
C                             cell on X
        IF (SLY.LE.1.0) THEN
            HLt(I) = (dx-DXc) / COS(THTslt(I)) * Hij(IXc,IYc)
            IF (SLY.EQ.1.0) ISLY = 1
        ENDIF
        IF (SLY.LE.1.0) GOTO 340
C
C                 (8.3.8.3.3) If the slip line cross more that just
C                             the first Y cell, calculate its' HLt
        HLt(I) = (dy - DYc) / SIN(THTslt(I)) * Hij(IXc,IYc)
C
C                 (8.3.8.3.4) If next cell is the last on Y, go to
C                             last cell calculation of length and HLt
        IF (ISLY.EQ.1) GOTO 335
C
C                 (8.3.8.3.5) Calculate HLt of intermidiate cells on
C                             Y axis
           SL = dy / SIN(THTslt(I))
        DO 330 J=1,ISLY-1
          HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
  330   CONTINUE
C
C                 (8.3.8.3.6) If the slip line ended on the corner of
C                             last cell, move to the next cell
  335   RSLY = ISLY
        IF (SLY-RSLY.EQ.0.0) GOTO 340
C
C                 (8.3.8.3.7) Slip line length of last cell on the
C                             Y axis
           SL = (dy - DYc + (RSLY-1.0)*dy) / SIN(THTslt(I))
```

```
          SL = (dx - DXc) / COS(THTslt(I)) - SL
C
C                   (8.3.8.3.8) Calculate HLt of last cell on Y axis of
C                               first row
              HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
C
C                   (8.3.8.3.9) Define X and Y of next cell
  340     IXc = IXc + 1
          IYc = IYC + ISLY
C
C           (8.3.8.4) If next cell on X is last, go to last cell HLt
C                     calculation
          IF (ISLX.EQ.1) GOTO 365
C
C           (8.3.8.5) Calculate HLt of intermidiate cells on X
              DO 350 J=1,ISLX-1
C
C                  (8.3.8.5.1) Number of cells on Y axis
                DSLY = SLY - RSLY
                SLY = (dx * TAN(THTslt(I)) + DSLY*dy) / dy
                ISLY = INT(SLY)
            RSLY = ISLY
C
C                  (8.3.8.5.2) If the slip line cross only one cell on
C                              Y, calculate its' HLt, and define and
C                              move to next cell
                IF (SLY.LE.1.0) THEN
                  HLt(I) = HLt(I) + dx/COS(THTslt(I)) * Hij(IXc,IYc)
                  IXc = IXc + 1
                  IF (SLY.EQ.1.0) IYc = IYc + 1
            ENDIF
                IF (SLY.LE.1.0) GOTO 350
C
C                 (8.3.8.5.3) If the slip line cross more than one cell
C                         (8.3.8.5.3.1) Calculate slip line length of
C                                       first cell on Y
            SL = (dy - DSLY*dy) / SIN(THTslt(I))
C
C                         (8.3.8.5.3.2) Calculate HLt of first cell
C                                       on Y
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
C
C                         (8.3.8.5.3.3) If next cell is last on Y, go
C                                       to calculate last cell's HLt
                IF (ISLY.EQ.1) GOTO 360
C
C                         (8.3.8.5.3.4) Slip line length of intermi-
C                                       diate cells on Y axis
            SL = dy / SIN(THTslt(I))
C
C                         (8.3.8.5.3.5) HLt of intermidiate cells on
C                                       the Y axis
                DO 355 K=1,ISLY-1
                  HLt(I) = HLt(I) + SL*Hij(IXc,IYc+K)
```

```
  355         CONTINUE
C
C                           (8.3.8.5.3.6) If the slip line ended on the
C                                         corner of last cell, move to
C                                         next cell
  360         IF (SLY-RSLY.EQ.0.0) GOTO 357
C
C                 (8.3.8.5.4) Slip line length of last cell on Y axis
                SL = (dy - DSLY*dy + (RSLY-1.0)*dy) / SIN(THTslt(I))
                SL = dx/COS(THTslt(I)) - SL
C
C                 (8.3.8.5.5) HLt of last cell on Y
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
C
C                 (8.3.8.5.6) Next cell position
 357          IXc = IXc + 1
              IYc = IYc + ISLY
 350        CONTINUE
C
C                 (8.3.8.5.7) Number of cells on Y axis for last row
 365        DSLX = SLX - RSLX
              DSLY = SLY - RSLY
              SLY = (DSLX * TAN(THTslt(I)) + DSLY)
              ISLY = INT(SLY)
C
C             (8.3.8.6) For last cell
              IF (SLY.LE.1.0) THEN
C
C                 (8.3.8.6.1) Calculate slip line length and HLT of
C                             last cell
            SL = SLT - ((dx-DXc)+(RSLX-1.0)*dx) / COS(THTslt(I))
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc)
                condtn = 'ended'
            ENDIF
C
C                 (8.3.8.6.2) If the slip line end is reached, then go
C                             for the next line
            IF (condtn.EQ.'ended') GOTO 500
C
C                 (8.3.8.6.3) Calculate slip line length  and HLt of
C                             first cell on Y of last row
              SL = (dy - DSLY*dy) / SIN(THTslt(I))
              HLt(I) = HLT(I) + SL*Hij(IXc,IYc)
C
C                 (8.3.8.6.4) If next cell is last, go to last cell
C                             calculations
              IF (ISLY.EQ.1) GOTO 375
C
C                 (8.3.8.6.5) Calculate slip line length and HLt on Y
C                             of intermidiate cells of last row
            SL = dy / SIN(THTslt(I))
            DO 370 J=1,ISLY-1
                HLt(I) = HLt(I) + SL*Hij(IXc,IYc+J)
 370        CONTINUE
```

```
C
C                  (8.3.8.6.6)  If the slip line ended on the corner,
C                               get next slip line
 375      RSLY = ISLY
          IF (SLY-RSLY.EQ.0.0) GOTO 500
C
C                  (8.3.8.6.7) Slip line length and HLt of last cell
C                              (total HLt of the slip line is found)
              SL = ((RSLX-1.0)*dx + (dx-DXc)) / COS(THTslt(I)) + ((RSLY
     +         - 1.0)*dy + (dy - DSLY*dy)) / SIN(THTslt(I))
              SL = SLT - SL
          HLt(I) = HLt(I) + SL*Hij(IXc,IYc+ISLY)
C
 500    CONTINUE
C
C (8.4) Return to main program
            RETURN
        END
```

APPENDIX C

Significant PUBTJ.F Program Input and Output Files

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with no penetration and weld surface at 45 degrees'
'Hardness array imx(row) jmx(col):' 15 18
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 10  10
'Weld leg:' 5 'Penetration:' 0 'Weld height:' 5
'Angle between weld surface & base plate:' 45
'Initial crack tip position:' 2 0.5
'Crack tip position:' 2 0.5
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?','NO'
'Input tolerance for load and change in angle?' 'NO'
```

```
THTmx & THTmn  90.00000000      0.0000000000E+00
Warning: Soln. THTAB is greater than THTmx
Warning: Soln. THTAB is greater than THTmx
Warning: Soln. THTAB is greater than THTmx
Warning: Soln. THTAB is greater than THTmx
Warning: Soln. THTAB is greater than THTmx
                                                  INPUT
Date of run:  Jan. 14/94
Data set number:  1 of a maximum data set number  of:  1
Source of data:
Homogeneous weld, assumed hardness 325 Kg/mm**2
Description of conditions and geometry:
homogeneous weld with no penetration and weld surface at 45 degrees
Hardness array dimensions: 15 X 18
Hardness array (unit is kg/mm**2):
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0
 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0
 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0
 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0    .0
   .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
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   .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
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   .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
Unit of length is mm, of angle is degree.
Number of cells on weld leg & height:10.00 10.00
Weld leg:  5.00   Penetration:   .00
Weld height:  5.00
Angle between weld surface and base plate:  45.00
Initial crack tip position:  2.00   .50
Crack tip position:  2.00   .50
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
                                                  OUTPUT
Least limit Load is   562.92Kg/mm
Slip line angles are  90.00 and    .31 degrees
NOTE: IF THTAB equals 90.0 degrees, the angle THTBC  does not affect the
result of Pub; therefor THTBC is chosen to    be 0 degrees
Iteration   4
Angles(degrees):   THTAB      THTBC          Load(Kg/mm):   Pub
                   88.75        .63                         563.44
```

	90.00	.63		562.92
	89.38	.63		563.05
	90.00	.00		562.92
	89.38	.00		563.05
	89.38	1.25		563.05
Iteration 3				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	87.50	1.25		565.00
	90.00	1.25		562.92
	88.75	1.25		563.45
	90.00	.00		562.92
	88.75	.00		563.44
	88.75	2.50		563.49
Iteration 2				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	85.00	2.50		571.05
	90.00	2.50		562.92
	87.50	2.50		565.07
	90.00	.00		562.92
	87.50	.00		564.97
	87.50	5.00		565.33
Iteration 1				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	80.00	5.00		594.56
	90.00	5.00		562.92
	85.00	5.00		571.60
	90.00	.00		562.92
	85.00	.00		570.84
	85.00	10.00		573.61

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with no penetration and weld surface at 17 degrees'
'Hardness array imx(row) jmx(col):' 6 18
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 13  4
'Weld leg:' 6.5 'Penetration:' 0 'Weld height:' 2
'Angle between weld surface & base plate:' 17.10
'Initial crack tip position:' 2 0.5
'Crack tip position:' 2.75 0.75
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 15
'Input initial guess of slip line angles?','no'
'Input tolerance for load and change in angle?' 'NO'
```

```
 THTmx & THTmn  113.1985931      -2.489552975
 Warning: Soln. THTAB is greater than THTmx
 Warning: Soln. THTAB is greater than THTmx
 Warning: Soln. THTAB is greater than THTmx
                                                  INPUT
 Date of run:  Jan. 14/94
 Data set number:  1 of a maximum data set number  of:  1
 Source of data:
 Homogeneous weld, assumed hardness 325 Kg/mm**2
 Description of conditions and geometry:
 homogeneous weld with no penetration and weld surface at 17 degrees
 Hardness array dimensions:  6 X 18
 Hardness array (unit is kg/mm**2):
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0
.0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0
.0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0    .0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
325.0 325.0 325.0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
 Unit of length is mm, of angle is degree.
 Number of cells on weld leg & height:13.00  4.00
 Weld leg:  6.50   Penetration:   .00
 Weld height:  2.00
 Angle between weld surface and base plate:  17.10
 Initial crack tip position:  2.00   .50
 Crack tip position:  2.75   .75
 Number of prior iterations reported: 10
 Maximum number of iterations allowed is: 15
                                                  OUTPUT
 Least limit Load is   171.12Kg/mm
 Slip line angles are  90.02 and  20.27 degrees
 NOTE: IF THTAB equals 90.0 degrees, the angle THTBC  does not affect the
result of Pub; therefor THTBC is chosen to    be 0 degrees
 Iteration  14
 Angles(degrees):   THTAB     THTBC          Load(Kg/mm):   Pub
                    89.59     20.71                         173.13
                    90.47     20.71                         173.27
                    90.03     20.71                         171.17
                    90.47     20.27                         173.30
                    90.03     20.27                         171.17
                    90.03     21.15                         171.16
 Iteration  13
 Angles(degrees):   THTAB     THTBC          Load(Kg/mm):   Pub
                    89.50     21.26                         173.62
                    90.60     21.26                         173.83
                    90.05     21.26                         171.24
                    90.60     20.71                         173.87
                    90.05     20.71                         171.24
                    90.05     21.81                         171.24
 Iteration  12
 Angles(degrees):   THTAB     THTBC          Load(Kg/mm):   Pub
```

89.39	21.94	174.20
90.76	21.94	174.53
90.08	21.94	171.35
90.76	21.26	174.60
90.08	21.26	171.36
90.08	22.63	171.35

Iteration 11

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	89.52	22.80		173.48
	91.24	22.80		176.62
	90.38	22.80		172.73
	91.24	21.94		176.76
	90.38	21.94		172.77
	90.38	23.66		172.69

Iteration 10

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	88.23	21.73		180.47
	90.37	21.73		172.74
	89.30	21.73		174.67
	90.37	20.66		172.80
	89.30	20.66		174.68
	89.30	22.80		174.66

Iteration 9

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	86.62	21.68		189.60
	89.30	21.68		174.67
	87.96	21.68		181.96
	89.30	20.33		174.68
	87.96	20.33		181.99
	87.96	23.02		181.95

Iteration 8

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	84.60	21.23		201.78
	87.96	21.23		181.96
	86.28	21.23		191.58
	87.96	19.55		182.03
	86.28	19.55		191.67
	86.28	22.90		191.57

Iteration 7

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	82.09	20.50		218.26
	86.28	20.50		191.61
	84.18	20.50		204.45
	86.28	18.40		191.79
	84.18	18.40		204.68
	84.18	22.60		204.43

Iteration 6

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	78.94	19.46		240.99
	84.18	19.46		204.54
	81.56	19.46		221.95
	84.18	16.84		205.01
	81.56	16.84		222.51
	81.56	22.08		221.91

Iteration 5

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	75.01	18.02		273.12
	81.56	18.02		222.18
	78.29	18.02		246.22
	81.56	14.74		223.38
	78.29	14.74		247.60
	78.29	21.29		246.12

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with no penetration and weld surface at 37 degrees'
'Hardness array imx(row) jmx(col):' 15 18
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 13  10
'Weld leg:' 6.5 'Penetration:' 0 'Weld height:' 5
'Angle between weld surface & base plate:' 37.57
'Initial crack tip position:' 2 0.5
'Crack tip position:' 2.75 1.75
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?','YES'
95.0 30.0
'Input tolerance for load and change in angle?' 'NO'
```

THTmx & THTmn 101.3099289   -12.26477337

INPUT

Date of run: Jan. 14/94
Data set number: 1 of a maximum data set number of: 1
Source of data:
Homogeneous weld, assumed hardness 325 Kg/mm**2
Description of conditions and geometry:
homogeneous weld with no penetration and weld surface at 37 degrees
Hardness array dimensions: 15 X 18
Hardness array (unit is kg/mm**2):

```
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0
    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0    .0    .0    .0
    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
 325.0 325.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
    .0    .0    .0    .0 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0
    .0    .0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0
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    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0
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    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
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 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
```

Unit of length is mm, of angle is degree.
Number of cells on weld leg & height:13.00 10.00
Weld leg: 6.50   Penetration: .00
Weld height: 5.00
Angle between weld surface and base plate: 37.57
Initial crack tip position: 2.00   .50
Crack tip position: 2.75 1.75
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
Initial guess of slip line angles is: 95.00 ,   30.00

OUTPUT

Least limit Load is   357.26Kg/mm
Slip line angles are 90.00 and 36.39 degrees
NOTE: IF THTAB equals 90.0 degrees, the angle THTBC does not affect the result of Pub; therefor THTBC is chosen to   be 0 degrees
Iteration   5

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	87.93	36.85		371.35
	92.07	36.85		371.18
	90.00	36.85		357.28
	92.07	34.78		371.71
	90.00	34.78		357.28

	THTAB	THTBC		Pub
	90.00	38.91		357.28
Iteration 4				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	87.41	35.46		374.44
	92.58	35.46		375.19
	90.00	35.46		357.28
	92.58	32.87		376.02
	90.00	32.87		357.28
	90.00	38.04		357.28
Iteration 3				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	86.89	32.23		376.22
	93.35	32.23		382.16
	90.12	32.23		358.10
	93.35	28.99		383.59
	90.12	28.99		358.15
	90.12	35.46		358.05
Iteration 2				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	86.93	36.26		378.57
	95.01	36.26		392.83
	90.97	36.26		363.77
	95.01	32.23		395.46
	90.97	32.23		364.25
	90.97	40.30		363.30
Iteration 1				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	80.88	36.31		436.43
	90.97	36.31		363.76
	85.92	36.31		386.73
	90.97	31.26		364.36
	85.92	31.26		382.27
	85.92	41.36		392.42

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with no penetration and weld surface at 59 degrees'
'Hardness array imx(row) jmx(col):' 15 11
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 0.0 0.0 0.0 0.0
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325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0
325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 6  10
'Weld leg:' 3 'Penetration:' 0 'Weld height:' 5
'Angle between weld surface & base plate:' 59.04
'Initial crack tip position:' 2 0.5
'Crack tip position:' 2.75 1.75
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?','YES'
76.0 -14.0
'Input tolerance for load and change in angle?' 'NO'
```

```
THTmx & THTmn  101.3099289      -29.05460358
                                                    INPUT
Date of run:  Jan. 14/94
Data set number:  1 of a maximum data set number  of:  1
Source of data:
Homogeneous weld, assumed hardness 325 Kg/mm**2
Description of conditions and geometry:
homogeneous weld with no penetration and weld surface at 59 degrees
Hardness array dimensions: 15 X 11
Hardness array (unit is kg/mm**2):
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0
325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
   .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0
   .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0    .0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0
Unit of length is mm, of angle is degree.
Number of cells on weld leg & height: 6.00 10.00
Weld leg:  3.00   Penetration:   .00
Weld height:  5.00
Angle between weld surface and base plate:  59.04
Initial crack tip position:  2.00   .50
Crack tip position:  2.75  1.75
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
Initial guess of slip line angles is:  76.00 , -14.00
                                                    OUTPUT
Least limit Load is   248.20Kg/mm
Slip line angles are  75.55 and -13.70 degrees
Iteration   2
Angles(degrees):   THTAB     THTBC          Load(Kg/mm):   Pub
                   69.12    -13.71                        253.19
                   81.92    -13.71                        253.11
                   75.52    -13.71                        248.20
                   81.92    -20.11                        253.89
                   75.52    -20.11                        249.70
                   75.52     -7.31                        249.68
Iteration   1
Angles(degrees):   THTAB     THTBC          Load(Kg/mm):   Pub
                   66.82    -12.74                        257.41
                   82.82    -12.74                        254.97
                   74.82    -12.74                        248.59
                   82.82    -20.74                        255.64
                   74.82    -20.74                        250.21
                   74.82     -4.74                        251.02
```

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with penetration of 77 and weld surface at 59'
'Hardness array imx(row) jmx(col):' 15 11
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 0.0 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 0.0 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0
325 325 325 325 325 325 325 325 325 0.0 0.0
325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 6  10
'Weld leg:' 3 'Penetration:' 1.5 'Weld height:' 5
'Angle between weld surface & base plate:' 59.04
'Initial crack tip position:' 0.5 0.5
'Crack tip position:' 0.5 0.5
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?','YES'
75.0 10.0
'Input tolerance for load and change in angle?' 'NO'
```

```
THTmx & THTmn  77.90524292      0.0000000000E+00
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
                                                  INPUT
Date of run:  Jan. 14/94
Data set number:  1 of a maximum data set number  of:  1
Source of data:
Homogeneous weld, assumed hardness 325 Kg/mm**2
Description of conditions and geometry:
homogeneous weld with penetration of 77 and weld surface at 59
Hardness array dimensions: 15 X 11
Hardness array (unit is kg/mm**2):
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0
325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
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   .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0
Unit of length is mm, of angle is degree.
Number of cells on weld leg & height: 6.00 10.00
Weld leg:  3.00   Penetration:  1.50
Weld height:  5.00
Angle between weld surface and base plate:  59.04
Initial crack tip position:   .50   .50
Crack tip position:   .50   .50
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
Initial guess of slip line angles is:  75.00 ,  10.00
                                                  OUTPUT
Least limit Load is   765.97Kg/mm
Slip line angles are  73.19 and    .00 degrees
Iteration   5
Angles(degrees):   THTAB     THTBC         Load(Kg/mm):   Pub
                   72.72       .23                      768.13
                   73.19       .23                      766.55
                   72.96       .23                      767.32
                   73.19       .00                      765.97
                   72.96       .00                      766.73
                   72.96       .47                      767.91
Iteration   4
Angles(degrees):   THTAB     THTBC         Load(Kg/mm):   Pub
                   71.06      1.42                      778.50
```

	73.44	1.42		772.46
	72.25	1.42		773.12
	73.44	.23		769.44
	72.25	.23		769.87
	72.25	2.61		776.61

Iteration 3

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	70.82	2.91		784.58
	73.79	2.91		784.93
	72.30	2.91		777.29
	73.79	1.42		780.89
	72.30	1.42		772.91
	72.30	4.40		782.04

Iteration 2

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	69.99	4.77		796.33
	73.71	4.77		788.34
	71.85	4.77		785.55
	73.71	2.91		782.81
	71.85	2.91		779.37
	71.85	6.63		792.34

Iteration 1

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	69.89	7.09		806.77
	74.54	7.09		817.85
	72.22	7.09		792.08
	74.54	4.77		810.36
	72.22	4.77		783.71
	72.22	9.42		801.40

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Homogeneous weld, assumed hardness of 325 Kg/mm**2'
'Description of conditions and geometry:'
'homogeneous weld with penetration of 77 and weld surface at 59'
'Hardness array imx(row) jmx(col):' 15 11
'Hardness array (unit is Kg/mm**2):'
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0 0.0
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325 325 325 325 325 0.0 0.0 0.0 0.0 0.0 0.0
325 325 325 325 325 325 0.0 0.0 0.0 0.0 0.0
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325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 0.0
325 325 325 325 325 325 325 325 325 325 325
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 6  10
'Weld leg:' 3 'Penetration:' 1.5 'Weld height:' 5
'Angle between weld surface & base plate:' 59.04
'Initial crack tip position:' 0.5 0.5
'Crack tip position:' 0.75 0.75
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?','YES'
72.0 8.0
'Input tolerance for load and change in angle?' 'NO'
```

```
THTmx & THTmn  79.50852203      -3.366460562
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
Warning: Soln. THTBC is smaller than THTmn
                                                    INPUT
Date of run:  Jan. 14/94
Data set number:  1 of a maximum data set number  of:  1
Source of data:
Homogeneous weld, assumed hardness of 325 Kg/mm**2
Description of conditions and geometry:
homogeneous weld with penetration of 77 and weld surface at 59
Hardness array dimensions: 15 X 11
Hardness array (unit is kg/mm**2):
 325.0 325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0
325.0 325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0
325.0 325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0
325.0    .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0
  .0    .0    .0    .0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0
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325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0    .0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0    .0 325.0 325.0 325.0 325.0
325.0 325.0 325.0 325.0 325.0 325.0 325.0
Unit of length is mm, of angle is degree.
Number of cells on weld leg & height: 6.00 10.00
Weld leg:  3.00   Penetration:  1.50
Weld height:  5.00
Angle between weld surface and base plate:  59.04
Initial crack tip position:   .50   .50
Crack tip position:   .75   .75
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
Initial guess of slip line angles is:  72.00 ,   8.00
                                                    OUTPUT
Least limit Load is   688.37Kg/mm
Slip line angles are  74.64 and  -3.37 degrees
Iteration   7
Angles(degrees):   THTAB    THTBC        Load(Kg/mm):   Pub
                   74.07    -2.36                       691.06
                   76.09    -2.36                       713.18
                   75.08    -2.36                       689.39
                   76.09    -3.37                       711.58
                   75.08    -3.37                       687.78
                   75.08    -1.34                       691.12
Iteration   6
```

Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
72.55	-2.10	695.32
75.08	-2.10	689.81
73.81	-2.10	692.05
75.08	-3.37	687.78
73.81	-3.37	689.82
73.81	-.84	694.48

Iteration 5
Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
72.75	-1.79	695.38
75.91	-1.79	708.54
74.33	-1.79	691.58
75.91	-3.37	705.99
74.33	-3.37	688.87
74.33	-.21	694.61

Iteration 4
Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
73.22	-1.39	694.86
77.17	-1.39	752.49
75.19	-1.39	690.88
77.17	-3.37	749.22
75.19	-3.37	687.64
75.19	.58	694.58

Iteration 3
Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
70.39	-.90	706.14
75.33	-.90	693.53
72.86	-.90	696.90
75.33	-3.37	689.44
72.86	-3.37	692.05
72.86	1.57	702.63

Iteration 2
Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
70.83	-.28	705.75
77.01	-.28	748.33
73.92	-.28	695.37
77.01	-3.37	743.05
73.92	-3.37	689.61
73.92	2.81	702.39

Iteration 1
Angles(degrees):

THTAB	THTBC	Load(Kg/mm): Pub
66.20	.49	735.00
73.92	.49	697.01
70.06	.49	711.40
73.92	-3.37	689.61
70.06	-3.37	701.79
70.06	4.35	723.62

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Hardness distridution data from Middaugh,1993'
'Description of conditions and geometry:'
'weld with no penetration and weld surface at 37 degrees'
'Hardness array imx(row) jmx(col):' 15 18
'Hardness array (unit is Kg/mm**2):'
225 232 221 225 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
230 237 237 287 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
230 237 237 230 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
257 299 315 327 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
257 299 315 458 458 378 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 372 485 270 311 315 318 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 372 485 270 311 320 320 318 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 477 477 273 317 329 319 315 313 310 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
338 477 477 273 317 327 319 313 312 307 305 0.0 0.0 0.0 0.0 0.0 0.0 0.0
395 437 263 281 296 273 323 308 311 297 298 297 0.0 0.0 0.0 0.0 0.0 0.0
395 477 263 281 296 273 323 308 311 287 300 297 295 293 0.0 0.0 0.0 0.0
393 477 434 264 302 320 316 316 317 332 314 294 293 292 281 0.0 0.0 0.0
393 477 434 264 302 320 316 316 317 332 314 294 287 291 275 273 0.0 0.0
300 400 380 350 270 273 276 283 305 282 295 284 278 294 259 268 240 0.0
194 195 241 350 270 273 276 283 305 282 295 284 278 294 259 268 240 250
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 13  10
'Weld leg:' 6.5 'Penetration:' 0 'Weld height:' 5
'Angle between weld surface & base plate:' 37.57
'Initial crack tip position:' 2 0.5
'Crack tip position:' 2.75 1.75
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 10
'Input initial guess of slip line angles?' 'YES'
100.0 -2.0
'Input tolerance for load and change in angle?' 'NO'
```

THTmx & THTmn 101.3099289 -12.26477337
Warning: Soln. THTAB is greater than THTmx

INPUT

Date of run: Jan. 14/94
Data set number: 1 of a maximum data set number of: 1
Source of data:
Hardness distridution data from Middaugh,1993
Description of conditions and geometry:
weld with no penetration and weld surface at 37 degrees
Hardness array dimensions: 15 X 18
Hardness array (unit is kg/mm**2):

```
 225.0 232.0 221.0 225.0    .0    .0    .0    .0    .0    .0    .0    .0
    .0    .0    .0    .0    .0    .0 230.0 237.0 237.0 287.0    .0    .0    .0
    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0 230.0 237.0
237.0 230.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
    .0    .0    .0    .0 257.0 299.0 315.0 327.0    .0    .0    .0    .0    .0
    .0    .0    .0    .0    .0    .0    .0    .0    .0 257.0 299.0 315.0 458.0
458.0 378.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
    .0    .0 335.0 372.0 485.0 270.0 311.0 315.0 318.0    .0    .0    .0    .0
    .0    .0    .0    .0    .0    .0    .0 335.0 372.0 485.0 270.0 311.0 320.0
320.0 318.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
335.0 477.0 477.0 273.0 317.0 329.0 319.0 315.0 313.0 310.0    .0    .0
    .0    .0    .0    .0    .0    .0 338.0 477.0 477.0 273.0 317.0 327.0 319.0
313.0 312.0 307.0 305.0    .0    .0    .0    .0    .0    .0    .0 395.0
437.0 263.0 281.0 296.0 273.0 323.0 308.0 311.0 297.0 298.0 297.0    .0
    .0    .0    .0    .0    .0 395.0 477.0 263.0 281.0 296.0 273.0 323.0 308.0
311.0 287.0 300.0 297.0 295.0 293.0    .0    .0    .0    .0 393.0 477.0
434.0 264.0 302.0 320.0 316.0 316.0 317.0 332.0 314.0 294.0 293.0 292.0
281.0    .0    .0    .0 393.0 477.0 434.0 264.0 302.0 320.0 316.0 316.0
317.0 332.0 314.0 294.0 287.0 291.0 275.0 273.0    .0    .0 300.0 400.0
380.0 350.0 270.0 273.0 276.0 283.0 305.0 282.0 295.0 284.0 278.0 294.0
259.0 268.0 240.0    .0 194.0 195.0 241.0 350.0 270.0 273.0 276.0 283.0
305.0 282.0 295.0 284.0 278.0 294.0 259.0 268.0 240.0 250.0
```

Unit of length is mm, of angle is degree.
Number of cells on weld leg & height:13.00 10.00
Weld leg: 6.50 Penetration: .00
Weld height: 5.00
Angle between weld surface and base plate: 37.57
Initial crack tip position: 2.00 .50
Crack tip position: 2.75 1.75
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 10
Initial guess of slip line angles is: 100.00 , -2.00

OUTPUT

Least limit Load is 338.26Kg/mm
Slip line angles are 89.75 and 2.83 degrees
Iteration 5

Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	89.31	2.40		339.65
	90.17	2.40		339.52
	89.74	2.40		338.31
	90.17	1.97		339.54
	89.74	1.97		338.31
	89.74	2.83		338.30

Iteration 4

Angles(degrees): THTAB	THTBC	Load(Kg/mm): Pub
89.08	1.87	340.42
90.15	1.87	339.35
89.62	1.87	338.70
90.15	1.33	339.37
89.62	1.33	338.70
89.62	2.40	338.69

Iteration 3

Angles(degrees): THTAB	THTBC	Load(Kg/mm): Pub
89.00	1.20	340.72
90.34	1.20	341.65
89.67	1.20	338.54
90.34	.53	341.71
89.67	.53	338.55
89.67	1.87	338.53

Iteration 2

Angles(degrees): THTAB	THTBC	Load(Kg/mm): Pub
81.24	.36	374.11
82.92	.36	366.35
82.08	.36	370.01
82.92	-.48	366.67
82.08	-.48	370.37
82.08	1.20	369.72

Iteration 1

Angles(degrees): THTAB	THTBC	Load(Kg/mm): Pub
77.79	-.69	396.41
79.88	-.69	381.92
78.84	-.69	388.00
79.88	-1.74	382.57
78.84	-1.74	388.71
78.84	.36	387.42

```
'Date of run:' 'Jan. 14/94'
'Data set number nDtSt:' 1 'out of maximum data set DtStmx:' 1
'Source of data:'
'Hardness distridution data from Middaugh,1993'
'Description of conditions and geometry:'
'weld with no penetration and weld surface at 37 degrees'
'Hardness array imx(row) jmx(col):' 15 18
'Hardness array (unit is Kg/mm**2):'
225 232 221 225 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
230 237 237 287 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
230 237 237 230 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
257 299 315 327 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
257 299 315 458 458 378 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 372 485 270 311 315 318 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 372 485 270 311 320 320 318 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
335 477 477 273 317 329 319 315 313 310 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0
338 477 477 273 317 327 319 313 312 307 305 0.0 0.0 0.0 0.0 0.0 0.0 0.0
395 437 263 281 296 273 323 308 311 297 298 297 0.0 0.0 0.0 0.0 0.0 0.0
395 477 263 281 296 273 323 308 311 287 300 297 295 293 0.0 0.0 0.0 0.0
393 477 434 264 302 320 316 316 317 332 314 294 293 292 281 0.0 0.0 0.0
393 477 434 264 302 320 316 316 317 332 314 294 287 291 275 273 0.0 0.0
300 400 380 350 270 273 276 283 305 282 295 284 278 294 259 268 240 0.0
194 195 241 350 270 273 276 283 305 282 295 284 278 294 259 268 240 250
'(Unit of length is mm; unit of angle is degree)'
'Number of cells on weld leg (Edx) & height(Edy):' 13  10
'Weld leg:' 6.5 'Penetration:' 0 'Weld height:' 5
'Angle between weld surface & base plate:' 37.57
'Initial crack tip position:' 2 0.5
'Crack tip position:' 3.75 2.5
'Number of prior iterations reported:' 10
'Maximum number of iterations allowed before stop:' 20
'Input initial guess of slip line angles?' 'no'
'Input tolerance for load and change in angle?' 'NO'
```

```
THTmx & THTmn  120.2564316      -22.83365250
Warning: Soln. THTBC is smaller than THTmn
                                                     INPUT
Date of run:  Jan. 14/94
Data set number:  1 of a maximum data set number  of:  1
Source of data:
Hardness distridution data from Middaugh,1993
Description of conditions and geometry:
weld with no penetration and weld surface at 37 degrees
Hardness array dimensions: 15 X 18
Hardness array (unit is kg/mm**2):
225.0 232.0 221.0 225.0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0 230.0 237.0 237.0 287.0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0 230.0 237.0
237.0 230.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0    .0    .0 257.0 299.0 315.0 327.0    .0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0    .0    .0 257.0 299.0 315.0 458.0
458.0 378.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
   .0    .0 335.0 372.0 485.0 270.0 311.0 315.0 318.0    .0    .0    .0    .0
   .0    .0    .0    .0    .0    .0    .0 335.0 372.0 485.0 270.0 311.0 320.0
320.0 318.0    .0    .0    .0    .0    .0    .0    .0    .0    .0    .0
335.0 477.0 477.0 273.0 317.0 329.0 319.0 315.0 313.0 310.0    .0    .0
   .0    .0    .0    .0    .0    .0 338.0 477.0 477.0 273.0 317.0 327.0 319.0
313.0 312.0 307.0 305.0    .0    .0    .0    .0    .0    .0    .0 395.0
437.0 263.0 281.0 296.0 273.0 323.0 308.0 311.0 297.0 298.0 297.0    .0
   .0    .0    .0    .0    .0 395.0 477.0 263.0 281.0 296.0 273.0 323.0 308.0
311.0 287.0 300.0 297.0 295.0 293.0    .0    .0    .0    .0 393.0 477.0
434.0 264.0 302.0 320.0 316.0 316.0 317.0 332.0 314.0 294.0 293.0 292.0
281.0    .0    .0    .0 393.0 477.0 434.0 264.0 302.0 320.0 316.0 316.0
317.0 332.0 314.0 294.0 287.0 291.0 275.0 273.0    .0    .0 300.0 400.0
380.0 350.0 270.0 273.0 276.0 283.0 305.0 282.0 295.0 284.0 278.0 294.0
259.0 268.0 240.0    .0 194.0 195.0 241.0 350.0 270.0 273.0 276.0 283.0
305.0 282.0 295.0 284.0 278.0 294.0 259.0 268.0 240.0 250.0
Unit of length is mm, of angle is degree.
Number of cells on weld leg & height:13.00 10.00
Weld leg:  6.50   Penetration:   .00
Weld height:  5.00
Angle between weld surface and base plate:  37.57
Initial crack tip position:  2.00    .50
Crack tip position:  3.75  2.50
Number of prior iterations reported: 10
Maximum number of iterations allowed is: 20
                                                     OUTPUT
Least limit Load is   179.45Kg/mm
Slip line angles are  89.75 and   7.77 degrees
Iteration  14
Angles(degrees):   THTAB      THTBC          Load(Kg/mm):   Pub
                   89.30       8.21                        180.10
                   90.18       8.21                        180.05
                   89.74       8.21                        179.46
                   90.18       7.77                        180.06
                   89.74       7.77                        179.46
                   89.74       8.65                        179.46
Iteration  13
```

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
89.06	7.66	180.47
90.16	7.66	179.95
89.61	7.66	179.64
90.16	7.11	179.96
89.61	7.11	179.64
89.61	8.21	179.64

Iteration 12

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
88.90	8.35	180.73
90.27	8.35	180.55
89.58	8.35	179.68
90.27	7.66	180.57
89.58	7.66	179.68
89.58	9.03	179.68

Iteration 11

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
88.55	7.49	181.29
90.26	7.49	180.53
89.40	7.49	179.94
90.26	6.63	180.56
89.40	6.63	179.94
89.40	8.35	179.95

Iteration 10

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
88.26	8.56	181.77
90.41	8.56	181.29
89.34	8.56	180.05
90.41	7.49	181.34
89.34	7.49	180.04
89.34	9.64	180.06

Iteration 9

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
87.77	7.67	182.62
90.45	7.67	181.56
89.11	7.67	180.39
90.45	6.32	181.63
89.11	6.32	180.38
89.11	9.01	180.40

Iteration 8

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
87.29	8.36	183.51
90.64	8.36	182.57
88.97	8.36	180.62
90.64	6.68	182.68
88.97	6.68	180.61
88.97	10.03	180.64

Iteration 7

Angles(degrees): Load(Kg/mm):

THTAB	THTBC	Pub
86.57	7.48	184.86
90.77	7.48	183.32
88.67	7.48	181.08
90.77	5.38	183.50
88.67	5.38	181.08

	88.67	9.58		181.11
Iteration 6				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	85.86	5.87		186.29
	91.10	5.87		185.38
	88.48	5.87		181.39
	91.10	3.25		185.72
	88.48	3.25		181.42
	88.48	8.49		181.41
Iteration 5				
Angles(degrees):	THTAB	THTBC	Load(Kg/mm):	Pub
	84.58	2.59		189.20
	91.14	2.59		186.05
	87.86	2.59		182.50
	91.14	-.69		186.54
	87.86	-.69		182.63
	87.86	5.87		182.44