# An Interactive Software for the Design of Welded Joints

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**ABSTRACT.** The interactive software package that is being introduced here may assist in the analysis of existing welds or the design of new weldments. With a few clicks of the mouse, the user can specify his objective and then select the appropriate *weld geometry* from among many available designs. He can specify a special weld design if he so wishes.

The user proceeds to the specification of applicable *forces*, their directions and their points of application, as well as any existing *couples.* Next comes the selection of an electrode or the *material of the welding rod*. The user is entitled, at this time, to specify a *coefficient of welding*, as well as the declaration of the *type of loading* static, pulsating or alternating. He can even dictate a coefficient for reduction in strength due to *fatigue.* Clicking on the *Solve* command, initializes a string of lengthy computations like the ones indicated above, after which the *results* are declared.

## 1. Introduction

Currently there is considerable research interest in welding, especially in the welding of dissimilar metals. Of particular interest is friction welding, although TIG, laser and electron beam welding also receive attention. Research topics include residual stresses, modeling and testing of weldments, joint efficiency, fatigue strength and crack propagation, stress intensity factors, creep, and acceptable weld defects. Below we present a synopsis of current research on welding.

A new type of 6 multiplied by 6 parallel platform mechanism - designated a `rigid platform'- characterized by very high stiffness and a high degree of accuracy was described by Portman et al [1] . Two new structural concepts were proposed for obtaining high stiffness and accuracy. 1) The joints between the changeable links and the platform and between the changeable links and the base are designed as welded joints. 2) Microactuators for controlled elongation of the legs use controlled longitudinal elastic deformations of the legs. Four possible approaches for analysis of the kinematics of this mechanism were described: infinitesimal kinematics of a classical platform and of a modified classical platform, the finite-elements method, and an identification procedure. Experimental investigations of a pilot setup of the proposed platform confirmed the predictions concerning the accuracy and stiffness of the proposed device.

Kohyama et al [2] noted that, in fission and fusion reactor applications, properties of welds and welded joints are key factors that limit component service conditions including their lifetime. Therefore, the availability of reliable repair welding techniques is strongly required in order to reduce the cost of electricity. One of the most difficult and unique characteristics, which repair welding has to overcome, is the radiation damaged microstructure including nuclear transformed gaseous atoms, such as helium from the (n, alpha ) and hydrogen from the (n, p) reaction. There have been many attempts to investigate weldability of heavily neutron-damaged materials for establishing criteria for the repair welding process. The authors conducted research to clarify the mechanisms of weld cracking, especially for heat affected zone cracking in heavily neutron irradiated stainless steels.

In a related study Asano et al [3] observed that recent welding tests using either neutron irradiated or tritium charged material have shown that there is a good chance of success when there is no repeated heat cycle during welding, e.g., stringer bead welding, single pass laser welding, etc. However, the replacement/repair of the actual load carrying components often requires thick plate welding which can only be realized with multi-layer welding. The authors reported on a study in which 20-mm-thick grooved plate of type 304 stainless steel was irradiated and then butt-welded by multi-layer welding. The weld heat input used was 1.0 and 2.0 MJ/m, which required 28 and 14 passes to fill up the groove. The samples were irradiated to 2.5 multiplied by 10 super 2 super 1 to approximately 1.8 multiplied by 10 super 2 super 3 n/m super 2 (E greater than 1 MeV), which resulted in 0.1 to approximately 1.6 appm of helium being produced. A conventional gas tungsten arc welding procedure was employed. The welded joints were subjected to the tensile test, side bend test, root bend test and cross-sectional metallography. The samples containing as much as 0.14 appm of helium passed all the tests; the mechanical properties fulfilled the standard requirement for the unirradiated base metal. At 0.6 appmHe and 1.0 MJ/m heat input, the welded joint showed sufficient strength, however, tiny intergranular cracking was observed in the HAZ where repetitive thermal cycles operated.

El-Banna [4] studied the effect of preheat temperature on the microstructure obtained in the heat-affected zone (HAZ) and the carbide zone in the weld metal adjacent to HAZ in multipass welds for the as-cast and ferritic ductile cast irons. The welding was carried out with manual shielded metal arc welding using ENiFe-CI filler metal. Ultrasonic, microhardness distribution, tensile and impact tests were conducted to evaluate the quality of welded joints.

Zumelzu et al [5] studied the mechanical behaviour of welded joints of AISI 316 L considering the effect of the amount of ferrite, phase changes and chemical heterogeneity. The base materials were standard coupons of 316 L SS weldment prepared using welding procedures SMAW and GMAW, electrodes type E 308 L-16 and E 316 L-16, and type ER 316 L continuous weld metal, respectively. The authors suggested that this study can be a practical guide in the selection of materials in order to determine the most adequate welding procedures and to anticipate the functionality of welded joints.

Dynamic design and vibro-acoustic modelling issues for automotive structures were illustrated by Singh [6] via two case studies. The first case examined the role and performance of passive and adaptive hydraulic engine mounts. In the second, the importance of welded joints and adhesives in vehicle bodies and chassis structures was highlighted via generic 'T' and 'L' beam assemblies. In each case, analytical and experimental results were presented.

Mochizuki et al [7] presented a new and simplified method of estimating residual stress in welded structures by using inherent strain. The method makes use of elastic analysis by means of the finite element method and is used to calculate the residual stress in complicated three-dimensional structures efficiently. The inherent strain distribution in a welded joint of a small-diameter pipe penetrating a pressure vessel was assumed to be a simple distribution, and the residual stress was calculated. Inherent strain distributions were inferred from those of welded joints with simple shapes. The estimated residual stress using these inferred inherent strains agrees well with the measurements of a mock-up specimen. The authors suggested that the proposed method is a simple way to estimate welding residual stress in three-dimensional structures of complicated shapes.

The influences of mechanical and thermal treatments on the macro- and microstresses in two-phase materials were investigated by Behnken and Hauk [8]. On samples of an austenitic-ferritic duplex steel the alterations of micro-residual stresses caused by different parameters of material treatments, e.g. deformation rate, deformation temperature, tempering, cooling rates were studied. The friction welding procedure is an example of the combination of all these mechanical and thermal parameters. Its effects on macro- and microstresses were investigated on friction welded joints of a quenched and tempered low alloyed steel, of a duplex steel and on joints between both steels. The distributions of macro- and micro-residual stresses were determined versus the distance from the welding zone and from the surface using X-ray and neutron diffraction. Strain measurements on the compact specimens and on thin plates as well as measurements on both phases allow to separate between macro- and microstresses. Both kinds showed pronounced profiles. The results revealed that microstresses should not be neglected in the assessments of X-ray results.

Berry et al [9] stressed that the behavior of thin cylindrical shells under axial compression is very sensitive to imperfections in the initial geometry. Local axisymmetric imperfections are among the most detrimental and have been shown to be a regular feature of circumferentially welded joints in civil engineering shell structures such as steel silos and tanks. Many of the experiments on which current design rules are based were performed on elastic Mylar, copper, or aluminum specimens, which have some very different characteristics to those of steel shells. Furthermore, very few laboratory tests have ever examined the consequences of fabrication processes on shell buckling strength, although these strongly influence the amplitudes and forms of geometric imperfections. The authors presented the findings of a careful experimental program on large steel cylinders fabricated with a fully welded circumferential joint. Thorough measurements were made of the initial imperfections and their transformation into a buckling mode. The results are compared with elastic-plastic finite-element predictions and the most recent design standard.

Wilkinson and Hancock [10] described tests on various types of knee joints for steel portal frames constructed from cold-formed rectangular hollow sections (RHS) to examine the ability of the connections to form plastic hinges. Welded stiffened and unstiffened knee joints, bolted knee joints with end plates, and connections with a fabricated internal sleeve were included in the experimental investigation. Most connections tested under opening moment failed by fracture in the heat-affected zone of the RHS near the weld. The connections tested under closing moment failed by web local buckling, which occurred near the connection. While the stiffened and unstiffened welded connections satisfied the strength interaction requirements in the available design guides, the connections did not maintain the plastic moment for sufficiently large rotations to be considered suitable for a plastic hinge location. The unstiffened welded joints were not able to reach the plastic moment. The use of an internal sleeve moved the plastic hinge in the connection away from the connection center-line and reduced the stress on the weld between the legs of the connection. It was found that sleeve connections were capable of sustaining the plastic moment for large rotations considered suitable for plastic design

In steel construction, sometimes bolts and welds must be combined in a single joint. Manuel and Kulak (2000) observed that provisions for the design of these combination joints can be found in existing specifications, but the design rules generally have not been verified by physical tests. An experimental study using full-scale tension lap splices that combined high-strength bolts and fillet welds was carried out in order to develop a better understanding of combination joints. The results showed that the orientation of the welds and the bearing condition of the bolts are two key factors that must be considered when determining the extent of load sharing in combination joints. The welding software that is introduced below is part of a larger educational software package (Bogis, et. al., [12], [13], [14], [15]) that is being developed by the authors.

## 2. THE WELDED CONNECTIONS PACKAGE

Figure (1) shows the icon of *Welded Connections*. When this icon is clicked, the user accesses the main screen (Fig. 2) of the software which enables the analysis and design of welded connections.

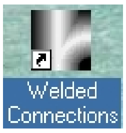


Fig. (1) : The icon of *Welded Connections*.

Lined horizontally at the top of the mainscreen are the prompts *Objective, Geometry, Loads, Materials, Solve, Report, About* and *Exit*. All of these are repeated in a contact-sensitive format as separate buttons lined vertically down the left side of the screen. The only exception is the *About* prompt, which contains information on the authors.

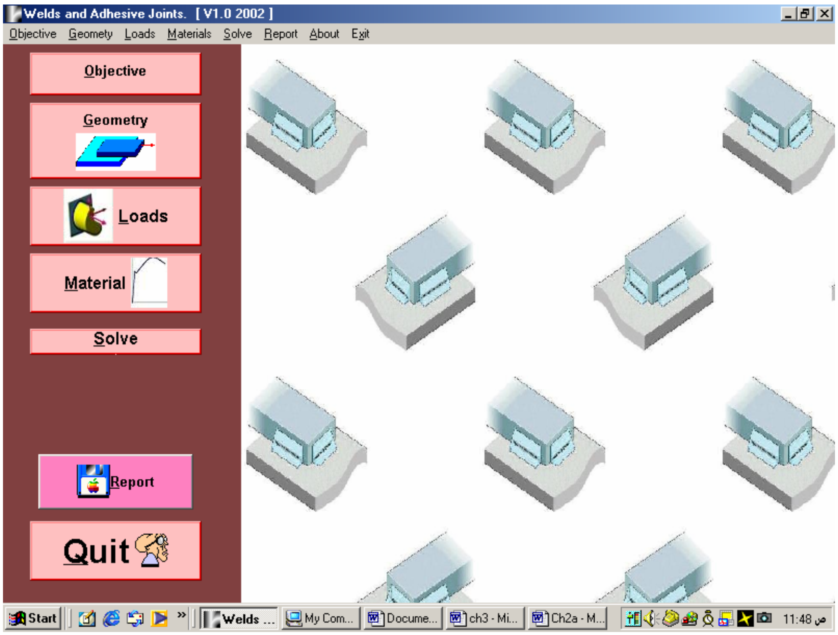
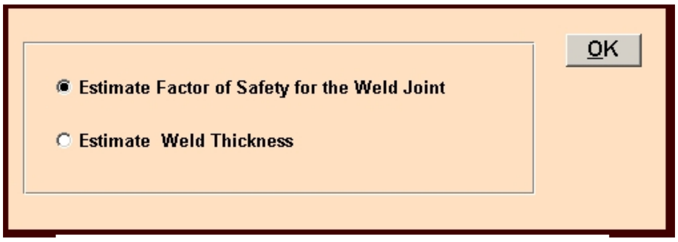


Fig. (2) : The main screen of *Welded Connections*.

When either the *Objective* prompt or the *Objective button* is clicked, the screen of Fig. 3 pops up, whereby the user opts either to find the *Safety Factor* for an existing weld joint, or to find the *Weld Thickness* in a new design.

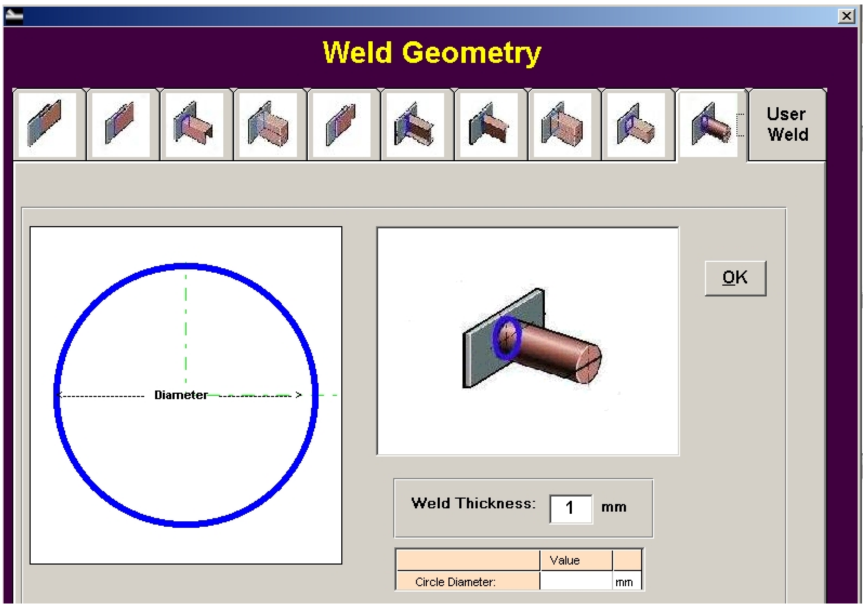


● Estimate Factor of Safety for the Weld Joint

○ Estimate  Weld Thickness

Fig. (3) :  Selection of the *objective*.

Once the *objective* is defined, the next logical step would be to define the *weld geometry*. Thus selection of the *Geometry* task causes the screen of Fig. 4 to appear where welding arrangements of ten common shapes are displayed in the form of buttons at the top of the screen.  An eleventh button is available for the user to define his own structural shape and weld geometry.  The horizontal and vertical broken lines in Fig. 4 and in subsequent figures indicate the x and y axes, respectively.



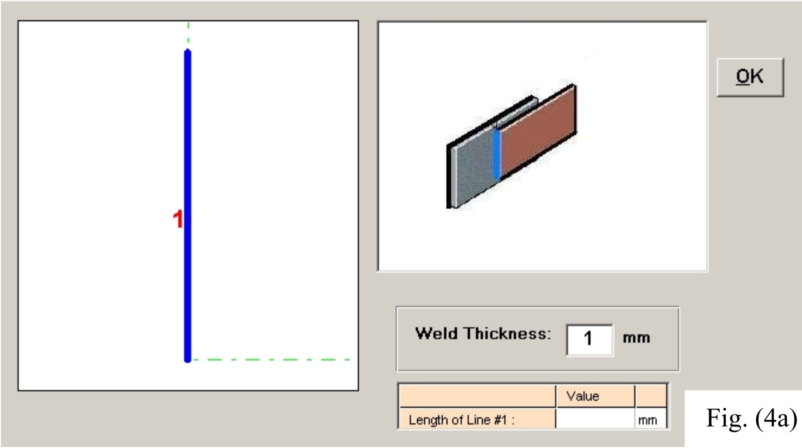
Weld Geometry

Weld Thickness: 1 mm

|  | Value |  |
|---|---|---|
| Circle Diameter: |  | mm |

Fig. (4) :  Configuring of the *weld geometry*.

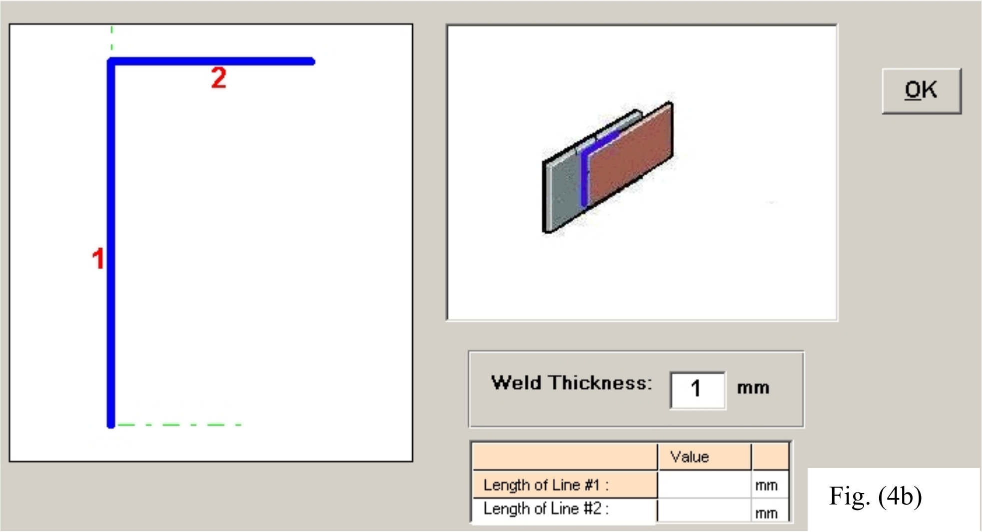
The remaining part of Fig. 4 shows the *weld geometry* in blue, along with boxes for inputting information regarding the geometry of the weld.  The case of Fig. 4 belongs to the tenth button.  Figures 4a to 4i illustrate the displays for the first to the 9th button, respectively.



Weld Thickness: 1 mm

|  | Value |  |
|---|---|---|
| Length of Line #1 : |  | mm |

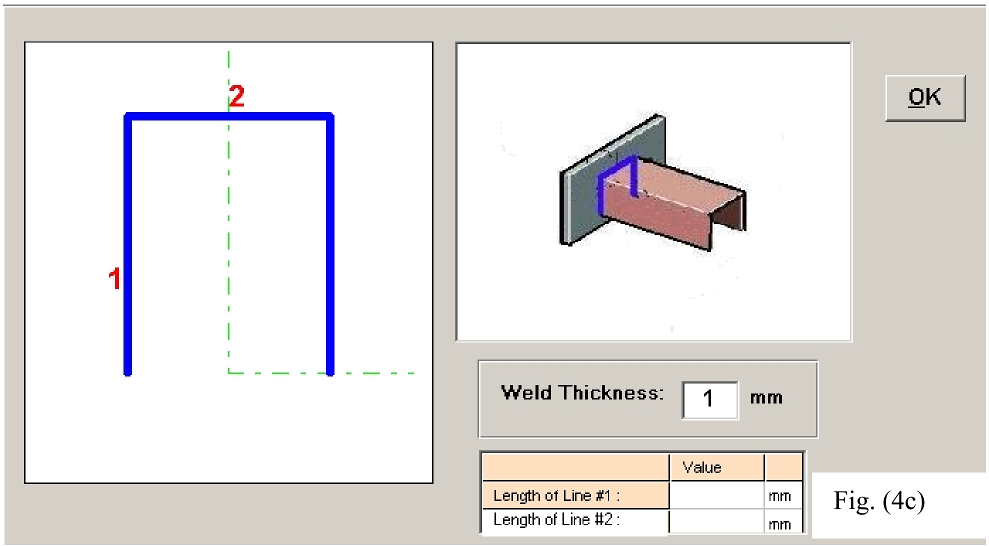
Fig. (4a)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Length of Line #2 : | | mm |

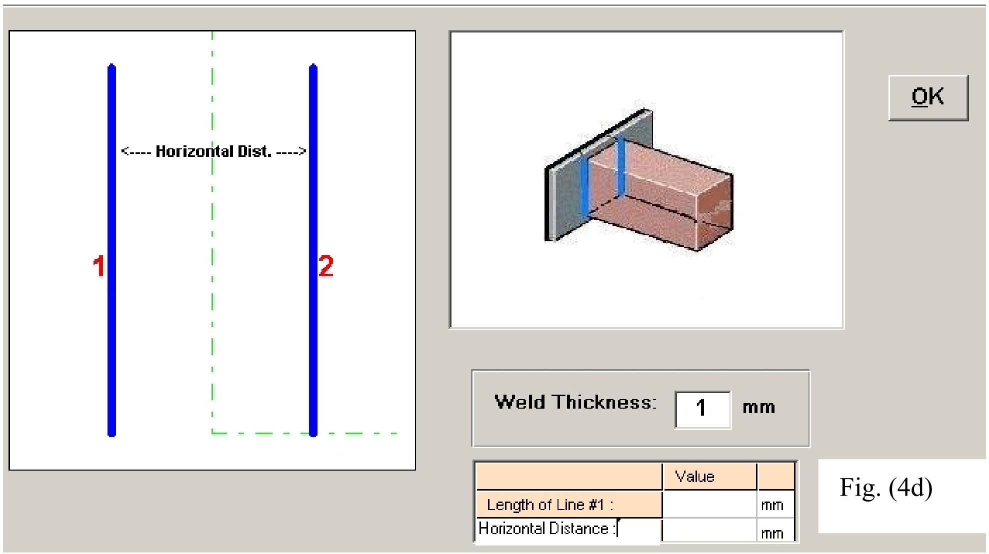
Fig. (4b)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Length of Line #2 : | | mm |

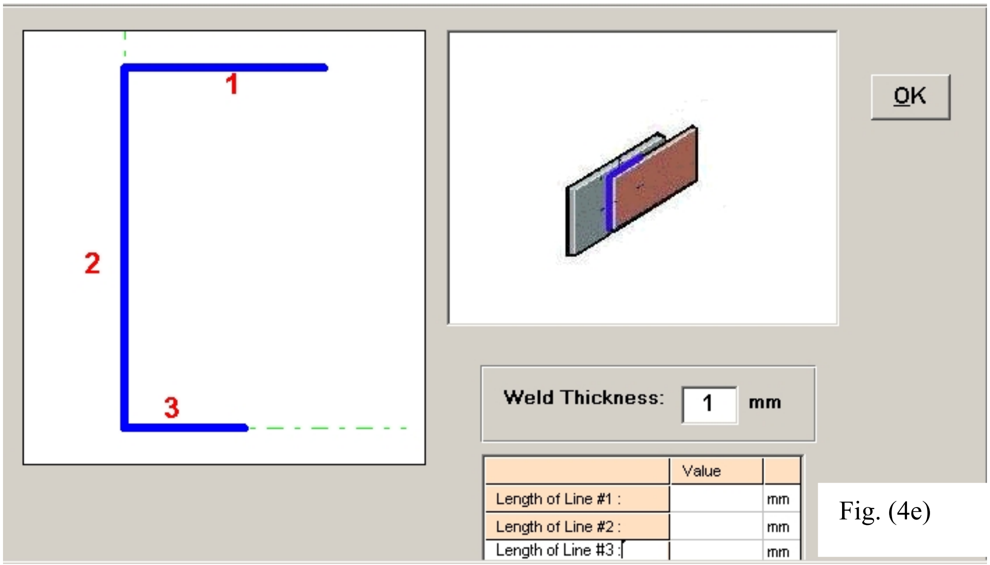
Fig. (4c)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Horizontal Distance : | | mm |

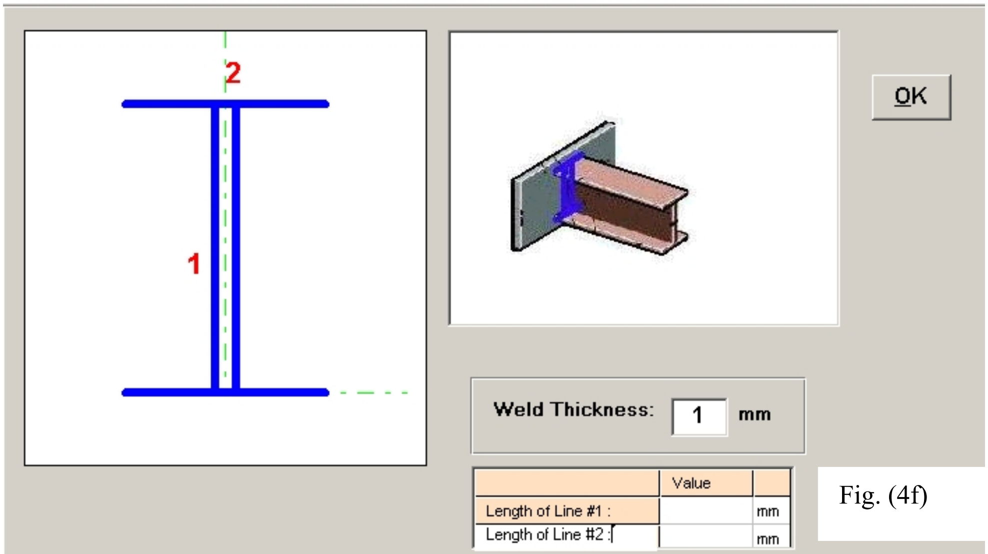
Fig. (4d)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Length of Line #2 : | | mm |
| Length of Line #3 : | | mm |

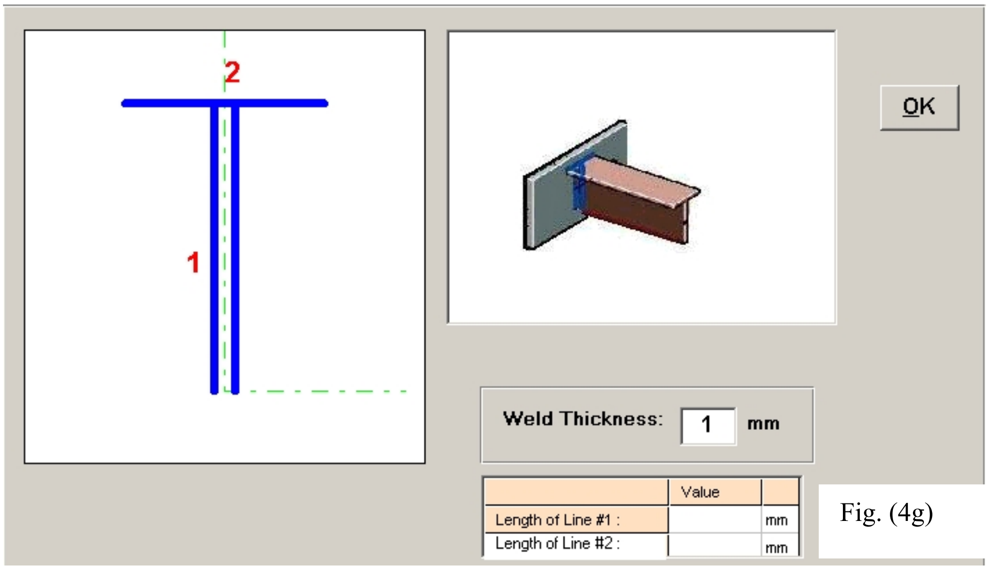
Fig. (4e)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Length of Line #2 : | | mm |

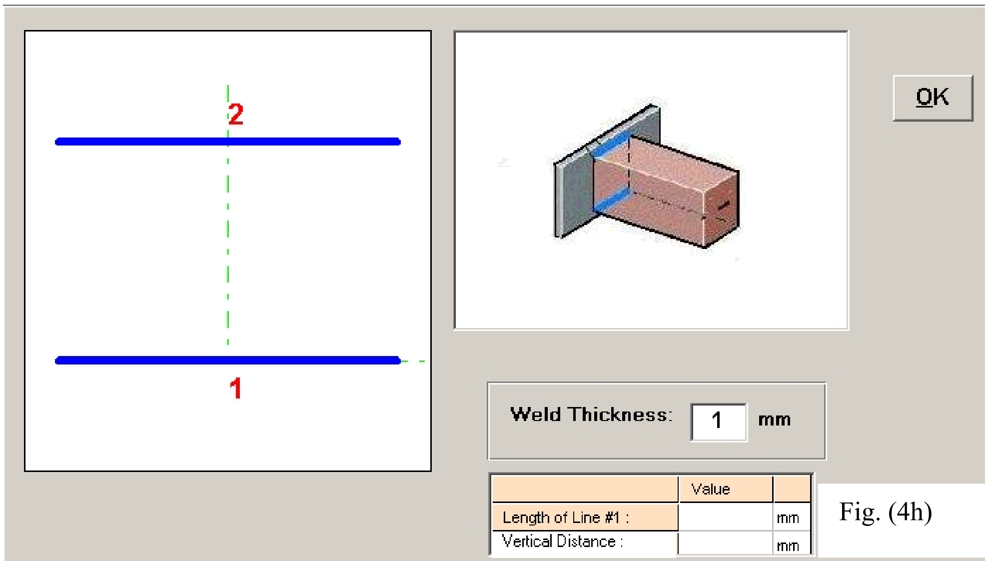
Fig. (4f)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Length of Line #2 : | | mm |

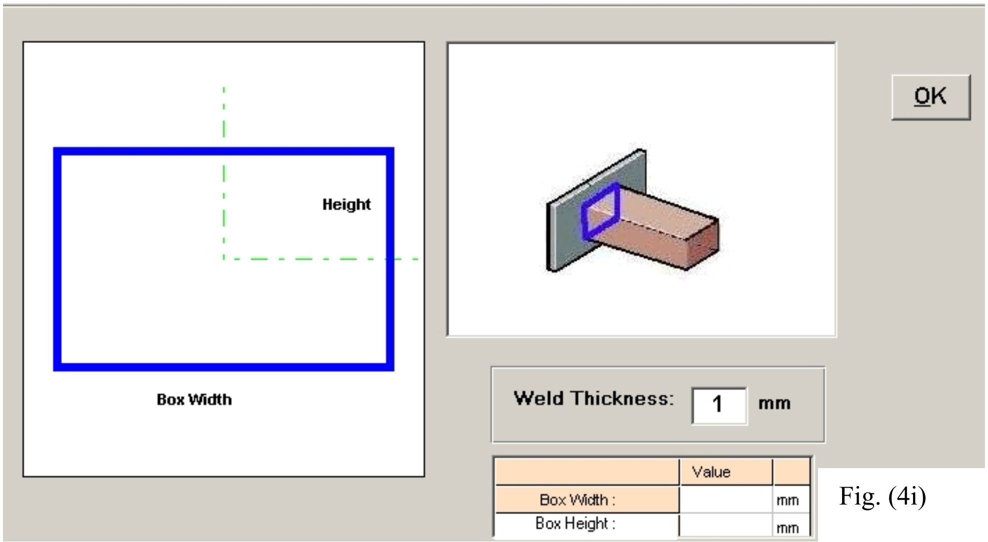
Fig. (4g)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Length of Line #1 : | | mm |
| Vertical Distance : | | mm |

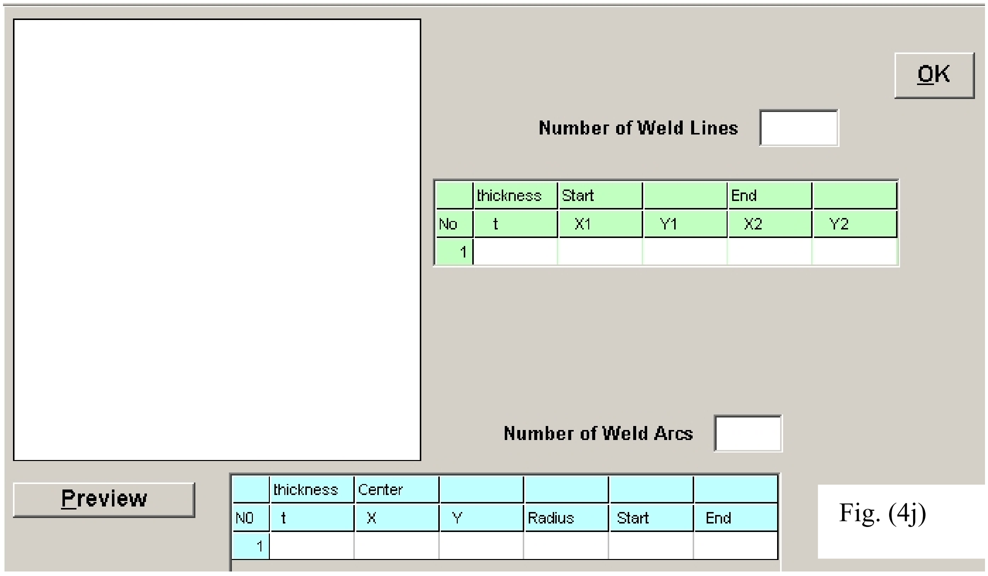
Fig. (4h)



Weld Thickness: 1 mm

| | Value | |
|---|---|---|
| Box Width : | | mm |
| Box Height : | | mm |

Fig. (4i)



Number of Weld Lines

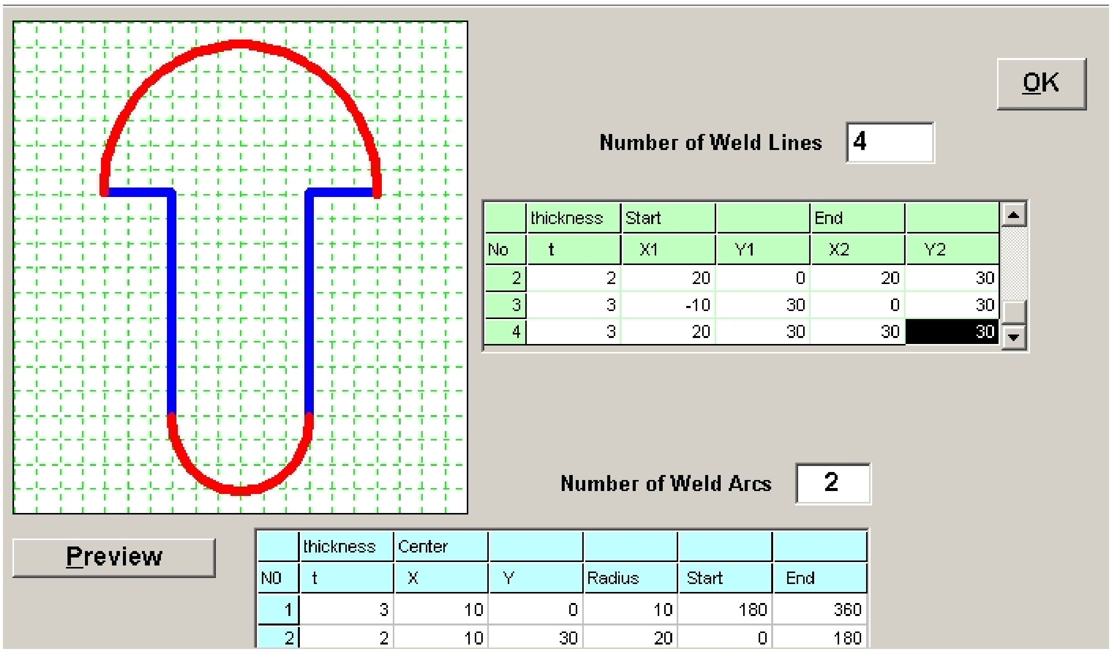
| | thickness | Start | | End | |
|---|---|---|---|---|---|
| No | t | X1 | Y1 | X2 | Y2 |
| 1 | | | | | |

Number of Weld Arcs

| | thickness | Center | | | | |
|---|---|---|---|---|---|---|
| NO | t | X | Y | Radius | Start | End |
| 1 | | | | | | |

Fig. (4j)

When the eleventh, the *User Weld button* is invoked, the screen of Fig. 4j pops up, whereby the number of weld lines, number of arcs, and the particulars of each can be specified. A separate *preview button* enables the displaying of a preview of the geometry of the weld design specified by the user. Figure 4k shows the specification of a weld joint comprising two circular arcs and and four straight lines.



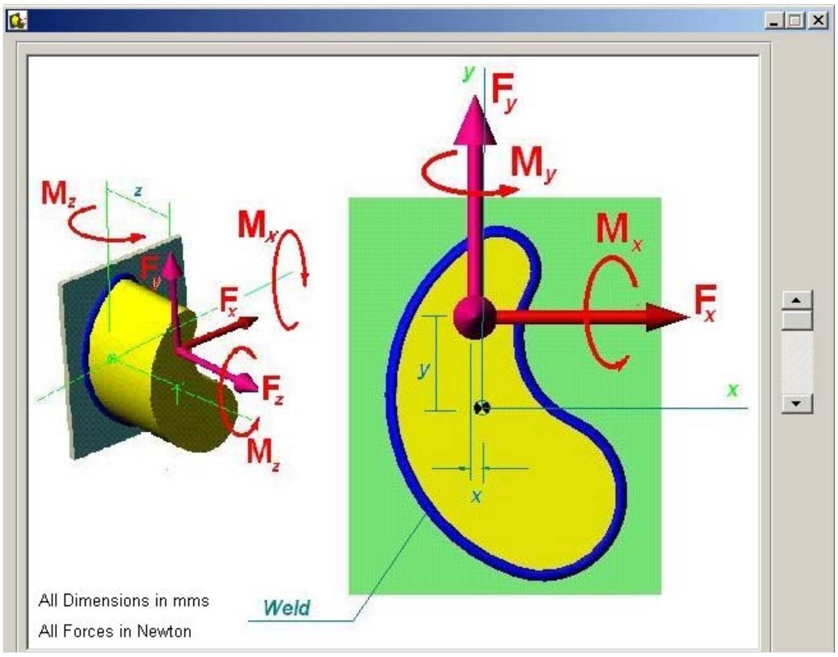
Number of Weld Lines 4

|  | thickness | Start |  | End |  |
|---|---|---|---|---|---|
| No | t | X1 | Y1 | X2 | Y2 |
| 2 | 2 | 20 | 0 | 20 | 30 |
| 3 | 3 | -10 | 30 | 0 | 30 |
| 4 | 3 | 20 | 30 | 30 | 30 |

Number of Weld Arcs 2

|  | thickness | Center |  |  |  |  |
|---|---|---|---|---|---|---|
| NO | t | X | Y | Radius | Start | End |
| 1 | 3 | 10 | 0 | 10 | 180 | 360 |
| 2 | 2 | 10 | 30 | 20 | 0 | 180 |

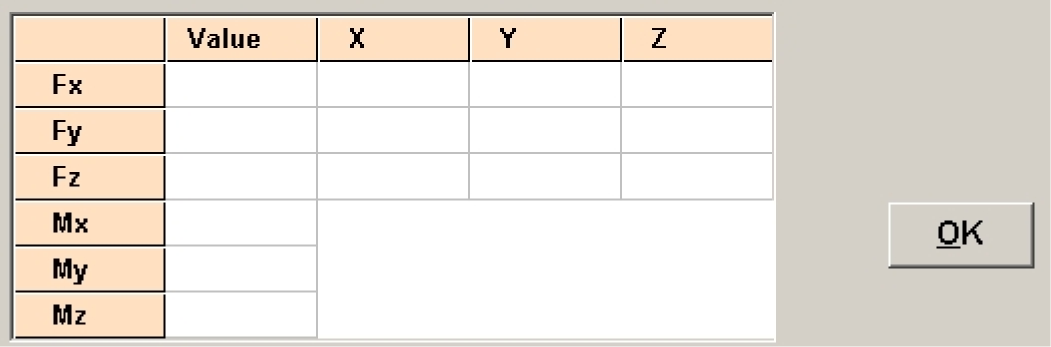
Fig. (4k) : Specification of a *user-defined weld*.



All Dimensions in mms

All Forces in Newton

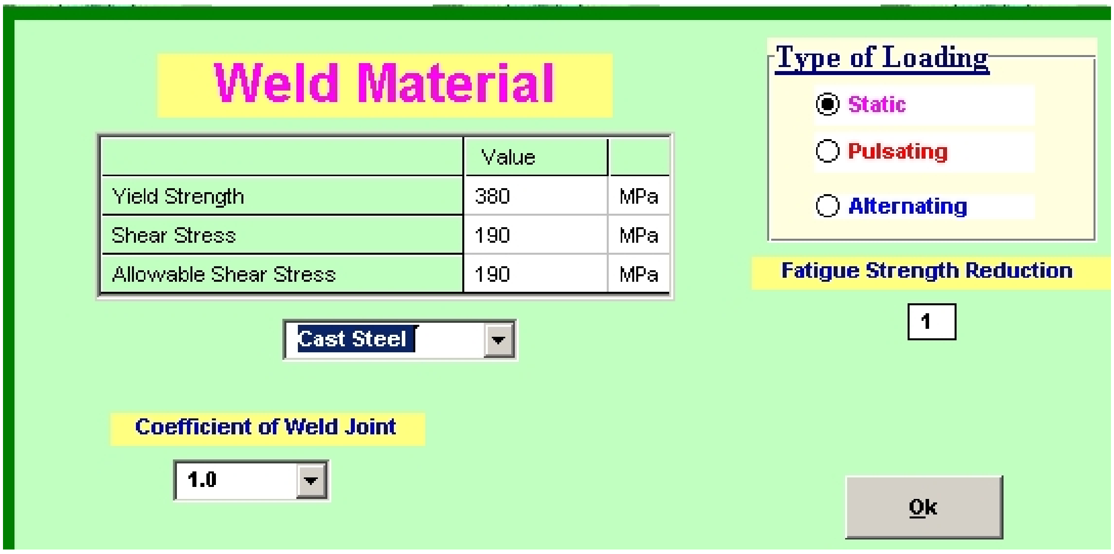
Fig. (5) : Specification of *loads*.



| | Value | X | Y | Z |
|---|---|---|---|---|
| Fx | | | | |
| Fy | | | | |
| Fz | | | | |
| Mx | | | | |
| My | | | | |
| Mz | | | | |

Fig. (5a) : Specification of applied *forces and couples*.

Invoking next the *Loads* button in Fig. 2, the screens of Fig. 5 and 5a are obtained. The coordinates to be specified in Figs. 5 and 5a are relative to the coordinate system indicated in Figs. 4 to 4j or relative to a user-defined coordinate system in the case of the *User Weld* option. The software subsequently computes a centroid for the system for further internal computations.



Weld Material

| | Value | |
|---|---|---|
| Yield Strength | 380 | MPa |
| Shear Stress | 190 | MPa |
| Allowable Shear Stress | 190 | MPa |

Cast Steel

Coefficient of Weld Joint: 1.0

Type of Loading
● Static
○ Pulsating
○ Alternating

Fatigue Strength Reduction: 1

Fig. (6) : Specification of *weld material* or electrode.

Figure 6 shows the screen that appears when the *Material button* on Fig. 2 is invoked. Selecting a particular material (Fig. 6a) reflects on the table of shear and yield stresses. The user has the freedom to specify his own material and its characteristics. At this point a *coefficient* ranging from 0.5 to 1 can be selected for the *welded joint*. The *type of loading* also can be specified as *static, pulsating* in the same direction, or *alternating*. Moreover, the reduction in weld strength due to *fatigue* can be specified by the user. The choice of the *type of loading* affects the values in the table of yield and shear stresses as well as the magnitudes of coefficients.

Fig. (6a)

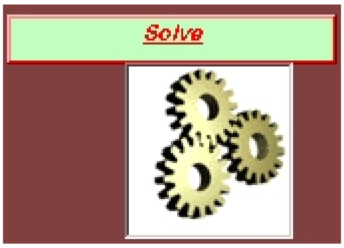
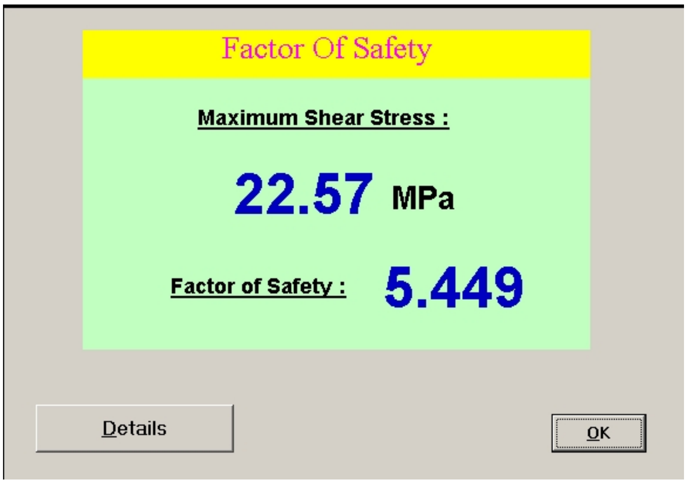


Fig. (7) : The *Solve* button.

After specifying all of the above data, the user next invokes the *Solve button* (Fig. 7) that is found in Fig. 2. Figure 8 is an example of the *output form* when the objective is set as finding the *factor of safety*. Figure 8a shows an output form when the objective is to find the *weld thickness*. Figure 9 depicts an *output report* which results when the *Details button* in Fig. 8 is clicked or the *Report button* in Fig. 2 is invoked.



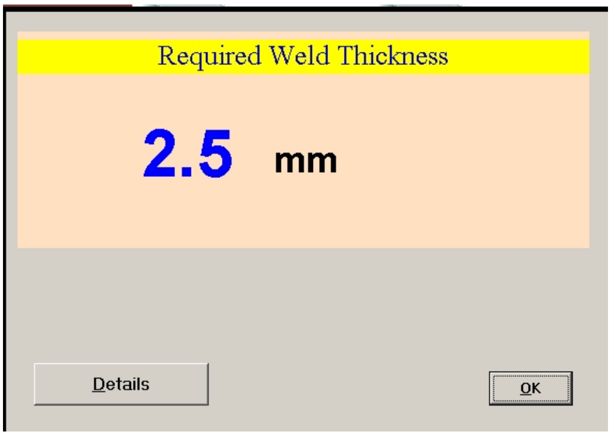
Factor Of Safety

**Maximum Shear Stress :**

22.57 MPa

**Factor of Safety :** 5.449

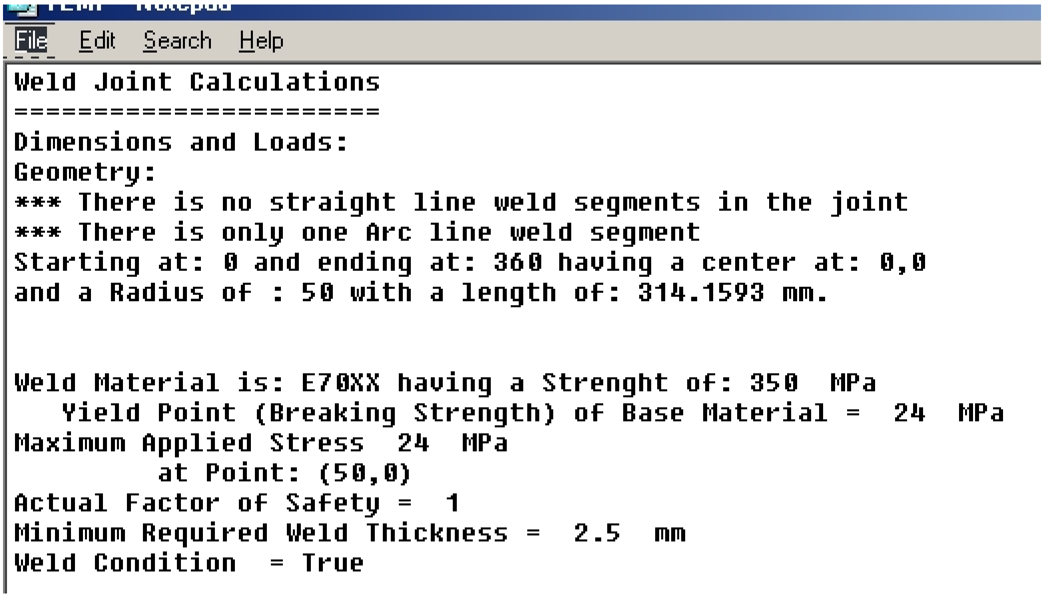
Fig. (8) : The *output form* for factor of safety.



Required Weld Thickness

2.5 mm

Fig. (8a) : The *output form* for weld thickness.



```
Weld Joint Calculations
=======================
Dimensions and Loads:
Geometry:
*** There is no straight line weld segments in the joint
*** There is only one Arc line weld segment
Starting at: 0 and ending at: 360 having a center at: 0,0
and a Radius of : 50 with a length of: 314.1593 mm.


Weld Material is: E70XX having a Strenght of: 350  MPa
   Yield Point (Breaking Strength) of Base Material =  24  MPa
Maximum Applied Stress  24  MPa
         at Point: (50,0)
Actual Factor of Safety =  1
Minimum Required Weld Thickness =  2.5  mm
Weld Condition  = True
```

Fig. (9) : *Summary form* for input and output information.

## 3. Concluding Remarks

Engineers have been using fasteners for thousands of years. The use of rivets and screwed fasteners has a longer history than that of welding, and the entry of adhesive bonding as a method of fastening is relatively recent. One would expect that the first three modes of fastening are mature and saturated, and hence there would not be much current research on screwed fasteners, rivets and welding, although there could be some research activity on bonding. It is interesting to note that this is not the case. It is true that there is research activity, in fact intense current research activity, in the area of bonding. Contrary to expectations, the area of welding however, is not stagnant at all. In fact the research activity is so intense that the authors of the current study were forced to limit the review on welded joints to only a small part of the last one year of research.

Because of lower initial cost, many structural parts of machinery formerly made by casting are now fabricated by welding. The components can be sheared or flame cut from hot-rolled steel plate and then welded together. Sometimes the intricate portion of the body can be cast or stamped. The flat areas, made of plates, then can be attached by welding.

Welded assemblies usually provide greater strength at a reduction in weight - an important advantage for moving parts of machines and transport equipment. In a welded design it is usually necessary to do a smaller amount of machining than for an equivalent casting. The design must provide accessibility to the welds so they can be properly made and inspected.

When the load on a welded joint is applied eccentrically, the effect of the torque or moment must be taken into account as well as the direct load. The state of stress in such a joint is complicated, and simplifying assumptions are generally made during design and analysis. In other circumstances, a welded joint may consist of a number of welds. In such cases it is customary to assume that the moment stress at any point is proportional to the distance from the center of gravity of the group of welds.

The operation of finding this center of gravity is not always straight forward. It may be necessary to use integrals, the parallel axis equation, and polar moments of inertia for finding the maximum torsional stress. The stress resulting from the direct load must be added vectorially to the moment stress in order to obtain the resultant stress. For static loads, it is usual practice to assume that the direct stress in a weld is uniformly distributed throughout its area. For pulsating and vibrating type of loadings, fatigue considerations must be taken into account.

The present software package may be hailed as a source of major relief for the design engineer in terms of the *analysis* of existing welds or the *design* of new weldments. With a few clicks of the mouse, he can specify his *objective* and then select the appropriate *weld geometry* from among many available designs. He can specify a special weld design if he so wishes.

He then proceeds to the specification of applicable *forces*, their directions and their points of application as well as any existing *couples*. Next comes the selection of an *electrode* or the *material of the welding rod*. He is entitled, at this time, to specify a *coefficient of welding*, as well as the declaration of the *type of loading* – static, pulsating or alternating. He can even dictate a coefficient for reduction in strength due to *fatigue*.

Clicking on the *Solve* command initializes a string of lengthy computations like the ones indicated above, after which the *results* are declared. The user can then demand a *summary sheet* containing his *input information* as well as a summary of the *results of computations*.

**Acknowledgement**: This work was sponsored by King Abdulaziz University, Jeddah, Saudi Arabia under contract no. 102/422.

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# تصميم وصلات اللحام بالحاسوب

**هيثم عبدالله بوقس ، على أبوالعز ، عبدالملك علي الجنيدي ، مهمت أكيورت**

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**المستخلص.** برنامج تفاعلي مع المستخدم يساعد في تحليل وتصميم وصلات اللحام. بنقرات قليلة بالفأرة يستطيع المستخدم تحديد هدفه، سواء تحليل أو تصميم وصلة جديدة. إذ أن البرنامج يمكّن من توصيف أبعاد وصلة اللحام لسهولة اختيارها من بين العديد من الوصلات المعدّة في البرنامج أو تحديد أوصافها إذا رغب في ذلك.

يقوم المستخدم أيضاً بتحديد الأحمال كالقوى واتجاهها وأماكن تأثيرها وكذا العزوم المؤثرة على الوصلة، بالإضافة إلي اختيار مادة اللحام أو قضيب اللحام المستخدم. ويمكن البرنامج من اختيار نوعية التحميل الاستاتيكية أو الأحمال المتغيرة.

وباستدعاء أيقونة الحل، فإن سلسلة الحل تتوصل في نهايتها إلى تقرير يشتمل على أبعاد الوصلة الهندسية والسمك المناسب للحام، بالإضافة إلى عامل الأمان في تصميمها.