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COMPUTER AIDED DESIGN AND ANALYSIS

OF

COLD FORMED SECTIONS

by

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Summary

The work reported in this thesis is concerned with the improvement and expansion of the assistance given to the designer by the computer in the design of cold formed sections. The main contributions have been in four areas, which have consequently led to the fifth, the development of a methodology to optimise designs. This methodology can be considered an " Expert Design System" for cold formed sections.

A different method of determining section properties of profiles was introduced, using the properties of line and circular elements. Graphics were introduced to show the outline of the profile on screen.

The analysis of beam loading has been expanded to beam loading conditions where the number of supports, point loads, and uniform distributive loads can be specified by the designer. The profile can then be checked for suitability for the specified type of loading.

Artificial Intelligence concepts have been introduced to give the designer decision support from the computer, in combination with the computer aided design facilities. The more complex decision support was adopted through the use of production rules. All the support was based on the British standards.

A method has been introduced, by which the appropriate use of stiffeners can be determined and consequently designed by the designer.

Finally, the methodology by which the designer is given assistance from the computer, without constraining the designer, was developed. This methodology gives advice to the designer on possible methods of improving the design, but allows the designer to reject that option, and analysis the profile accordingly. The methodology enables optimisation to be achieved by the designer, designing variety of profiles for a particular loading, and determining which one is best suited.

KEY WORDS: Computer Aided Design,   Cold Formed Sections,
              Artificial Intelligence,   Decision Support Systems,
              Expert Design Systems.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Over the last forty years, since computers were first available to a few elite scientists, the developments of computers have increased exponentially.

The advances of interactive computer graphics, and of now relatively inexpensive 'minis' and 'micros' have prompted the escalation of applications for computers during this period [1,2]. In the designing of a product, computers help by serving as an extension to the memory of the designer, enhancing the analytical and logical power of the designer, and relieving the designer from routine repetitious tasks. In the manufacture they help by directing machines, keeping stock of items, process planning, etc. In Artificial Intelligence, computers are being used to try and understand the nature of human intelligence through the construction of computer programs that imitate intelligent behaviour[3].

Although many computer applications are well established, many are still the subject of lively research work and everyday new applications are being found or being improved. One such area where active research in computer applications is taking place, is that of cold rolled sections.

Cold rolled sections are an important economical proposition for

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the construction industry [4,5]. Over the last thirty years the technology of the design and analysis of thin walled structures has grown at a similar pace to that of computers. The cost of raw materials and the need to utilize the maximum strength of materials have hastened the use of these sections, but the analysis of these sections for different applications is very complex. This has meant that sections were being inefficiently and improperly used [6].

Research in optimal design of Cold Formed Sections has taken place since 1968 [7,8,9], after the publication of the A.I.S.I. Specifications for the Design of Cold Formed Steel Structural Members [10]. These methods are limited to specific sections or simple profiles, and simple structural cases. The complexity of the designing process is such that, even with the use of standards or specifications in conjunction with computer aided design, the time period from requirements to design can take up to two years.

Consequentially in collaboration with a leading West Midlands Company, the department of Mechanical and Production Engineering of Aston University had made possible this research to develop a computerized system by which the optimal design of general profiles could be achieved. The system requiring a wide range of structural loading, where in some cases the loading constraints can be varied. This involved the investigation into the existing methods by which designing was carried out, and generating ways of improving the present procedures.

The following work was undertaken :-

1. Modification of the technique determining the structural properties and the introduction of graphics on screen to show the profile outline.

2. Introduction of a new computer technique for complex loading analysis on continuous beams.

3. Introduction of Artificial Intelligence concepts for Decision Support.

4. Introduction of the suitable use and design of stiffeners.

5. Introduction of an overall method for the designing process with a view to optimization.

CHAPTER 2

COLD FORMED SECTIONS

COLD FORMED SECTIONS

2.1. TYPES

Cold formed sections are made from strip or sheet metal. The sheet or strip is shaped into a variety of shapes [4,5]. These shapes can be seen in diagram 2.1. It can be seen from the diversity that an almost unlimited number of shapes can be produced. This variety has led to a great number of applications for these sections.
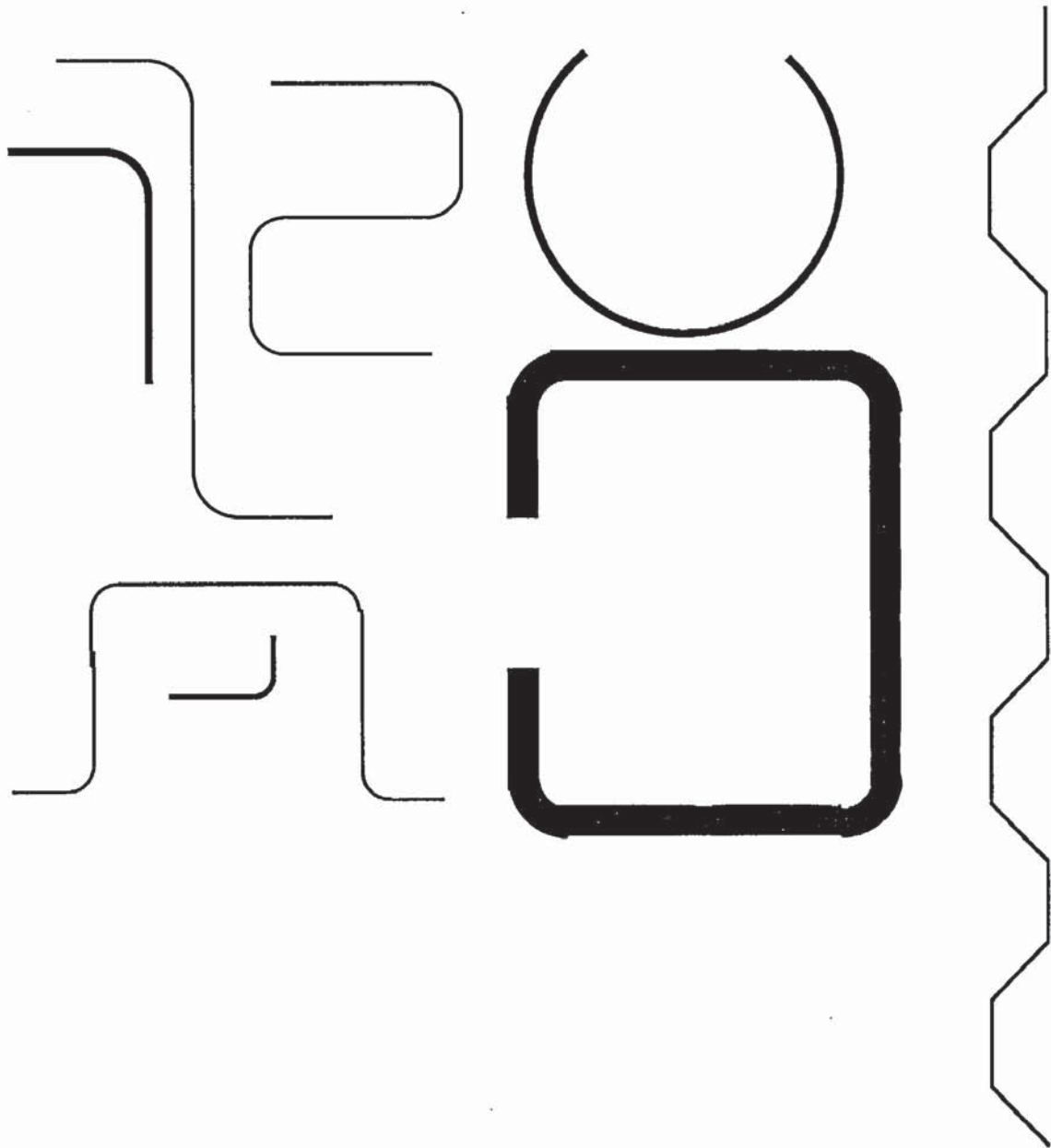
Diagram 2.1: Showing Examples Of Cold Formed Sections

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2.2. APPLICATIONS

Cold formed sections have a high strength to weight ratio and hence are widely used in the construction industry [4,5]. In the building industry the number of applications has continually grown, and among the most popular are:- roof purlins; insulation support sections; cladding and decking sheets; open web joists; and columns.

In the production of transport components cold formed sections are used for:- chassis members; body frames; decorative and functional trim; etc. In domestic goods cold formed sections are used for frames, panels, trims, etc. These applications are illustrated in Diagram 2.2 and 2.3. Cold rolled sections are to be found in almost every enterprise in some form or other.

Roof cladding.

Insulation
support
section.

Cable
channels.

Roof
purlin.

Beam
section.
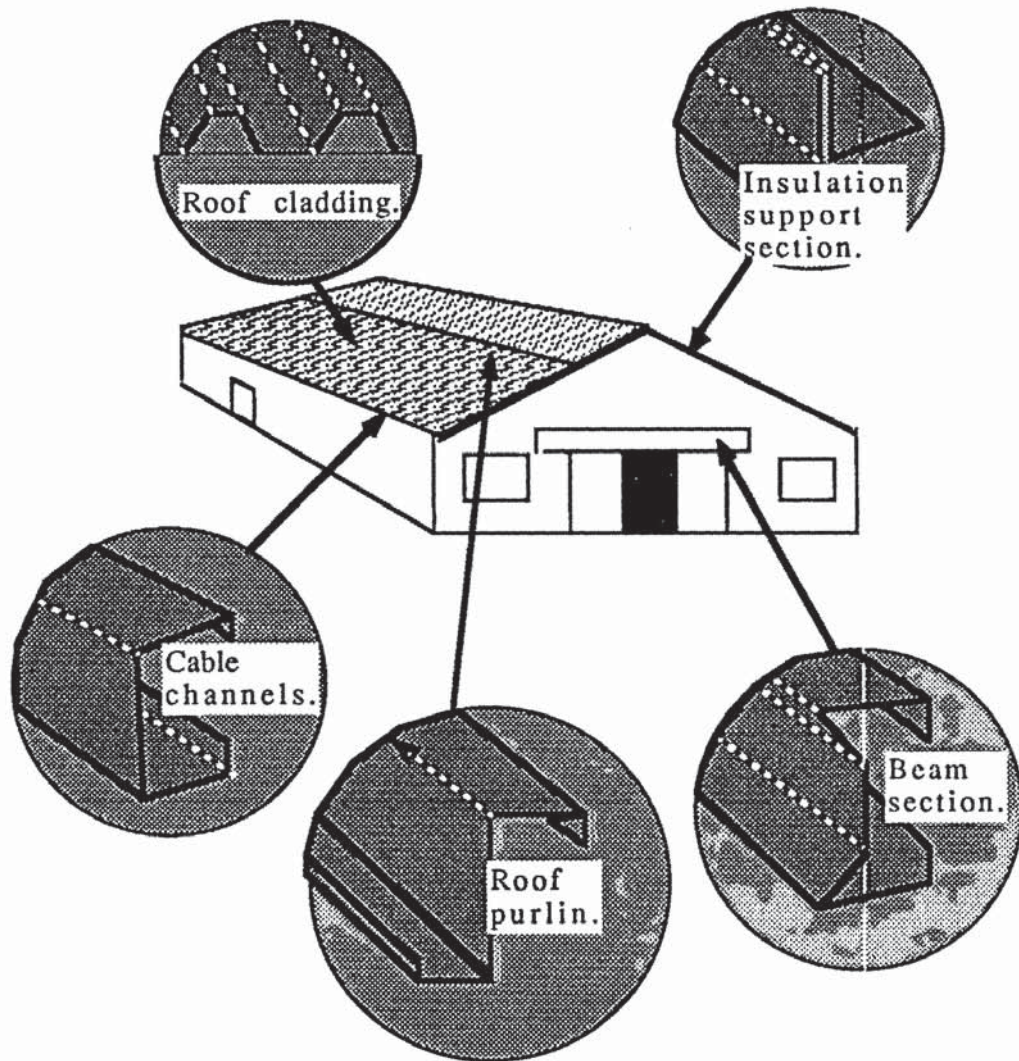
Digram 2.2. : Showing some of the applications of cold formed sections
in building components.
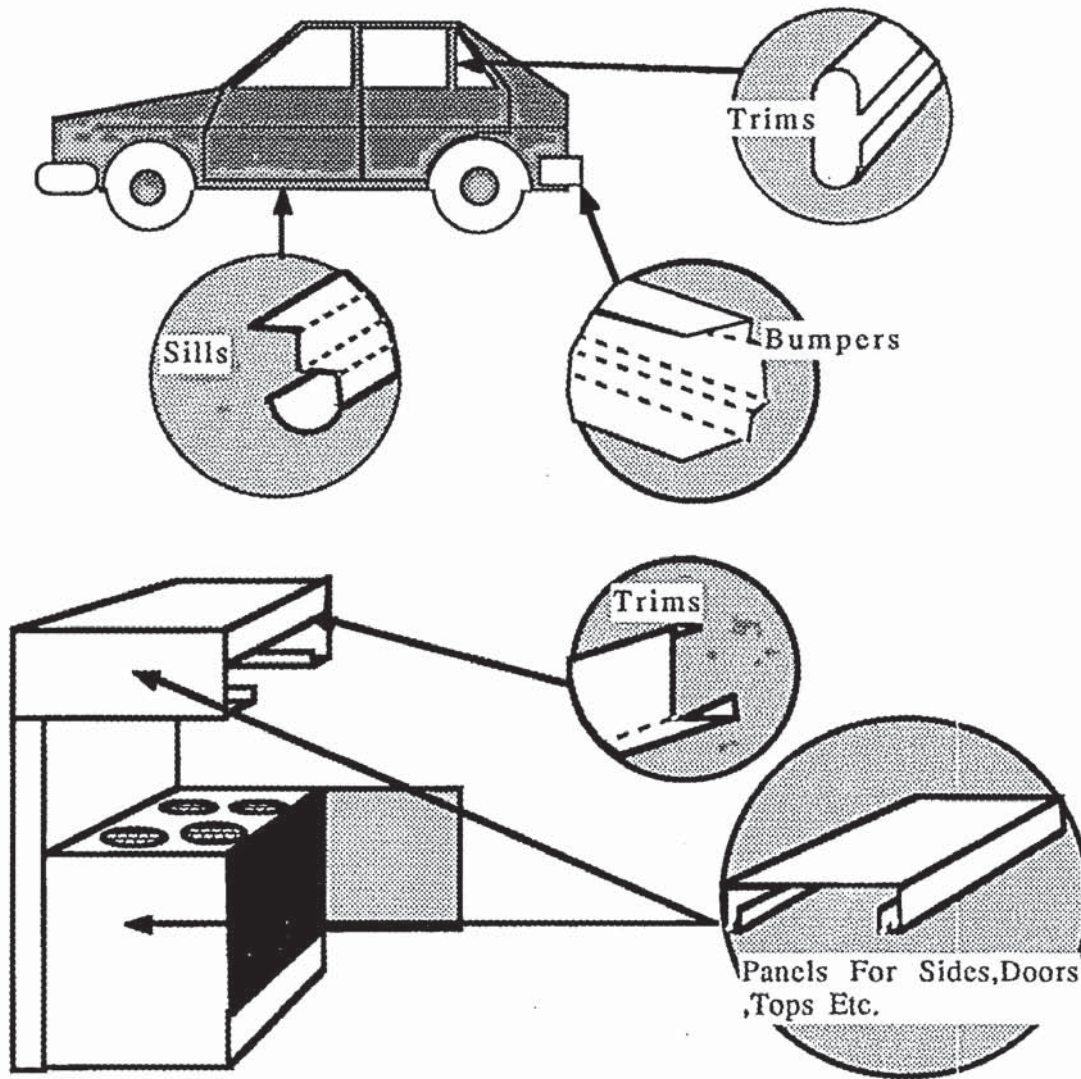
Diagram 2.3. : Ilustrating Some Of The Various Other Applications
Of Cold Formed Sections

2.3. FABRICATION

There are two main methods of producing cold formed sections:-

    1. Cold roll forming

    2. Press Brake

Both processes are widely used and it is usually the economics of the processes which determine the one that is adopted .

2.3.1. Cold Roll Forming

This is a process by which the strip is fed continuously through successive sets of rolls. Each set of rolls progressively forms the strip or sheet until the desired profile has been achieved (this process is illustrated in diagram 2.4.). A set consists of between two and four rolls, mainly the top and bottom roll and optionally side rolls [11].
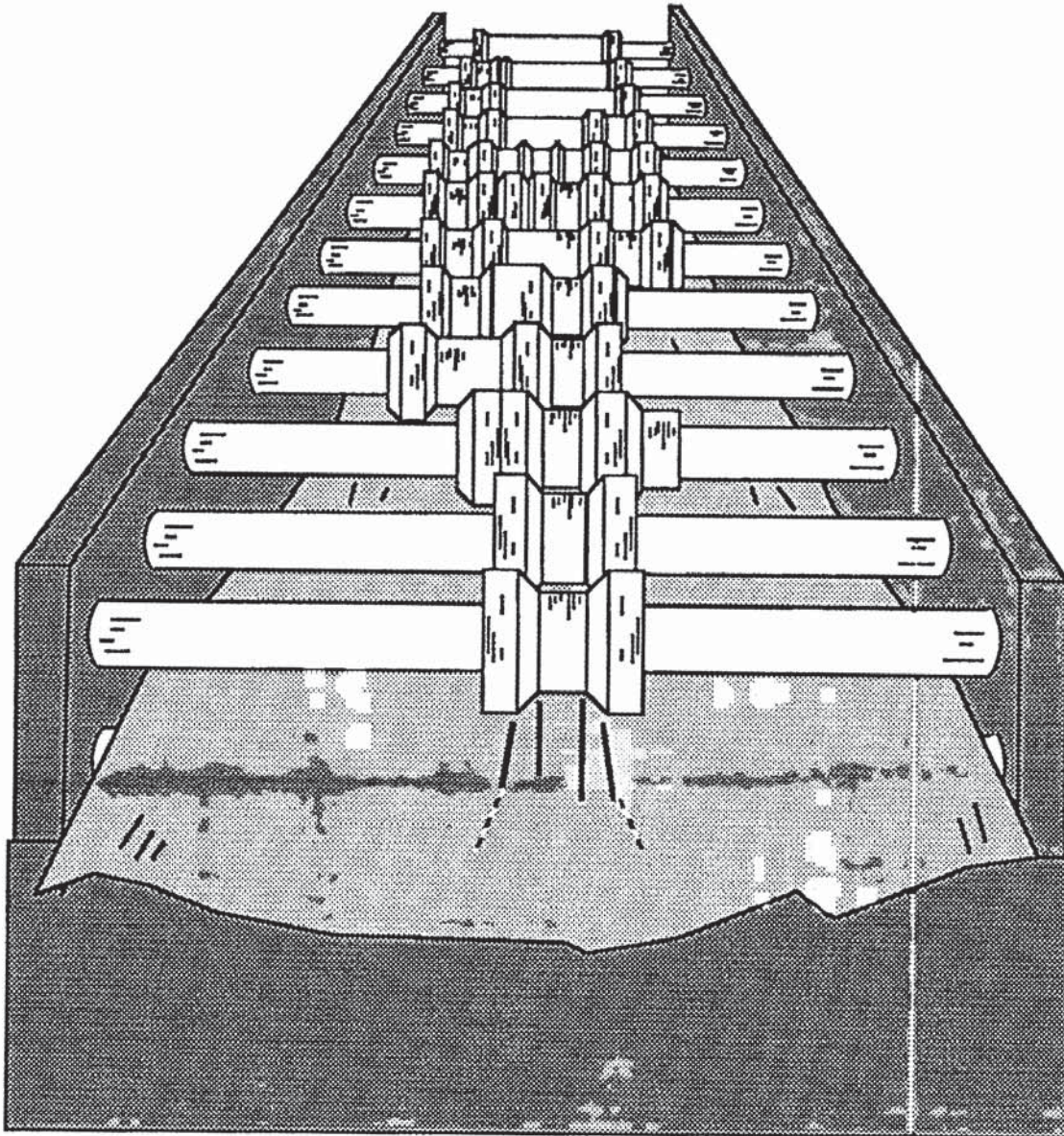
Diagram 2.4. : Rolling Mill For Cold Formed Sections.

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A few of the advantages of cold roll forming are:-

1.   The process is considerably more flexible than other
      processes. Almost any profile of constant thickness can be
      produced, including many which are complex.

2.   The only restriction on the length of sections for this
      method of fabrication is that imposed by transport and
      handling problems.

3.   This can be a highly economic process, especially when
      large quantities of a particular section are required.

4.   It is possible to produce exact lengths thus reducing
      wastage.

5.   Profiles produced have a more aesthetically pleasing
      appearance. This is because the metal largely retains its
      initial surface conditions since it is formed at low
      temperatures and the forming method is a smooth process.

2.3.2. Press Brake

Press braking is a process by which short lengths of strip are fed
into the press brake machine and pressed around shaped dies to form the

required shape (diagram 2.5 illustrates this).
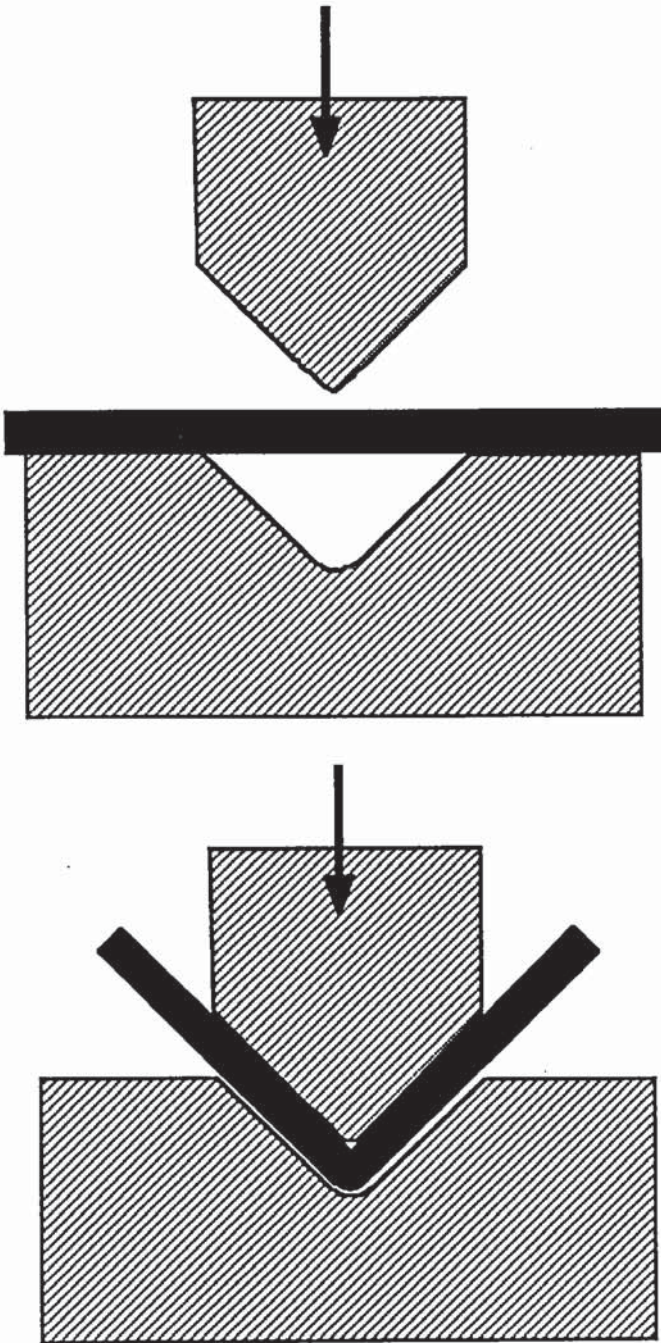
1

Diagram 2.5: Illustrating the action of a press brake machine for shaping of sections.

The length of the shape is limited to the size of the machine, and the shape complexity is limited by the simple tooling [4,5]. The cost of tooling is low in comparison with cold roll forming, hence this method is economical for short simple sections, with short product cycles.

2.3.3. Work Hardening

One of the features for selection of the process to use for the production of clod formed sections is work hardening. Work hardening is produced on both processes of fabrication as the metal is cold worked into shape. But the type and extent of work hardening varies according to the method of fabrication chosen. Using the cold roll forming process not only increases the yield at the formed bends but also along the flat parts of the section, this is due to the smooth method of roll forming as compared to the violent method of the press brake. This does not occur when the press brake fabrication method is used [12]. This can make a difference in the economical design of the profile.

CHAPTER 3

ECONOMIC DESIGN

ECONOMIC DESIGN

In trying to achieve economic design of cold rolled sections, there are certain factors which should be considered. These factors are not apparent at first glance, and are particular to these sections. This is because cold rolled sections are thin and present additional problems to the designer. If these factors are overlooked, they will result in failure of the structure during its period of service[6].

3.1. SPECIAL PROBLEMS OF DESIGN

The following is a brief summary of the problems faced by designers of cold rolled sections.

3.1.1. Local Bucking

Because these sections are thin, their elemental widths are much larger than their thickness, consequentially these thin element will buckle at stress levels much lower than the yield point of the material if they are subject to compression, shear loading or direct loading. Hence in designing, the problem of local buckling is of great importance.
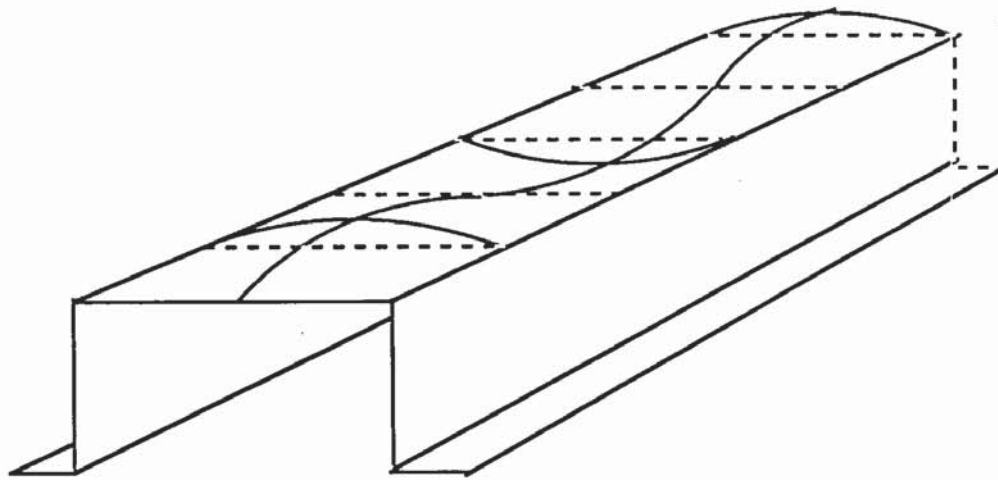
(a)
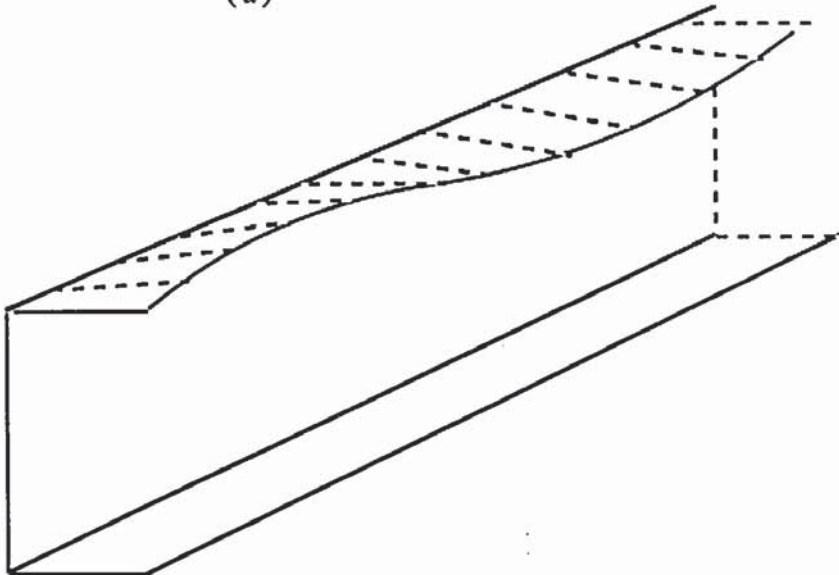
(b)

Diagram 3.1: Showing Local Buckling on

(a) Hat Section

(b) Unstiffened Channel Section

Local buckling does not mean the immediate failure of the section, but reduces the stiffness of the section causing collapse at a lower load than if this problem was not present. The section will

continue to carry higher loads in excess of the first local buckling, this effect is called the post buckling strength. It can be utilized in the design of cold formed sections.

3.1.2. Web Crushing
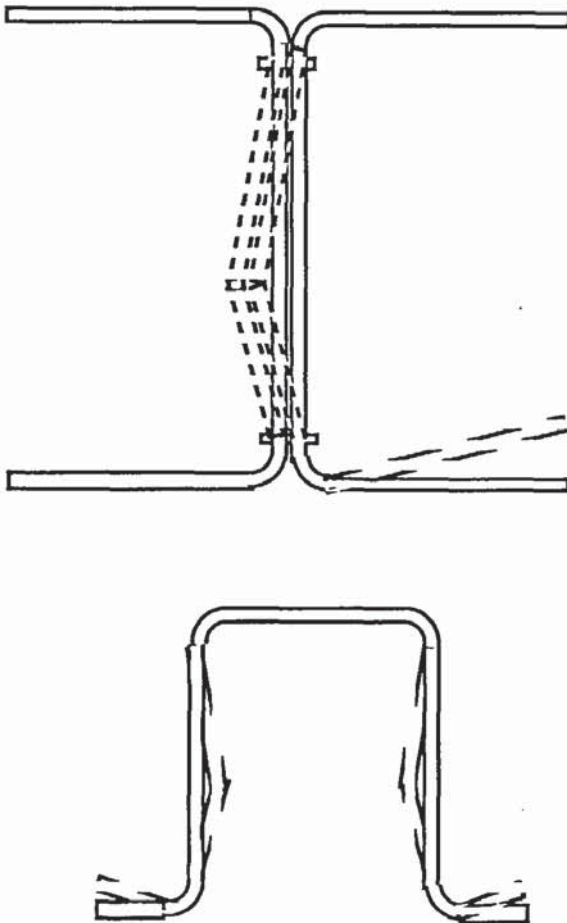
<u>Diagram 3.2:</u> <u>Showing failure of sections due to web crushing.</u>

This is caused by the reactions of the supports and concentrated loads on a section used as a beam. These forces cause local stresses on the web which lead to failure.

3.1.3. Torsional Stiffness
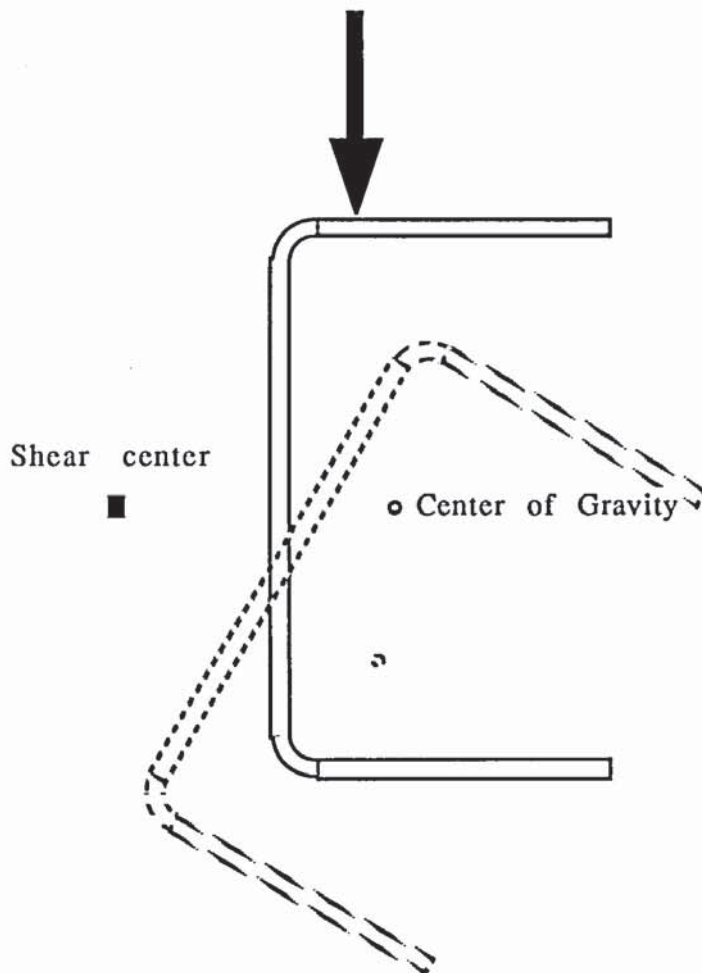
Diagram 3.3:   Showing Torsional Buckling when load not applied about Shear Center.

As the torsional rigidity of an open section is proportional to the cube of its thickness, cold formed sections have very little torsional rigidity. These section may twist when subject to deflection. Therefore in

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many sections where the centroid of the section and its shear center do not coincide, torsional-flexural buckling is a critical factor in failure.

3.1.4. Lateral Buckling

This may occur when bending is taking place about the major axis of the profile cross-section when subject to deflection. Again this is a critical factor if sufficient bracing against this is not provided.
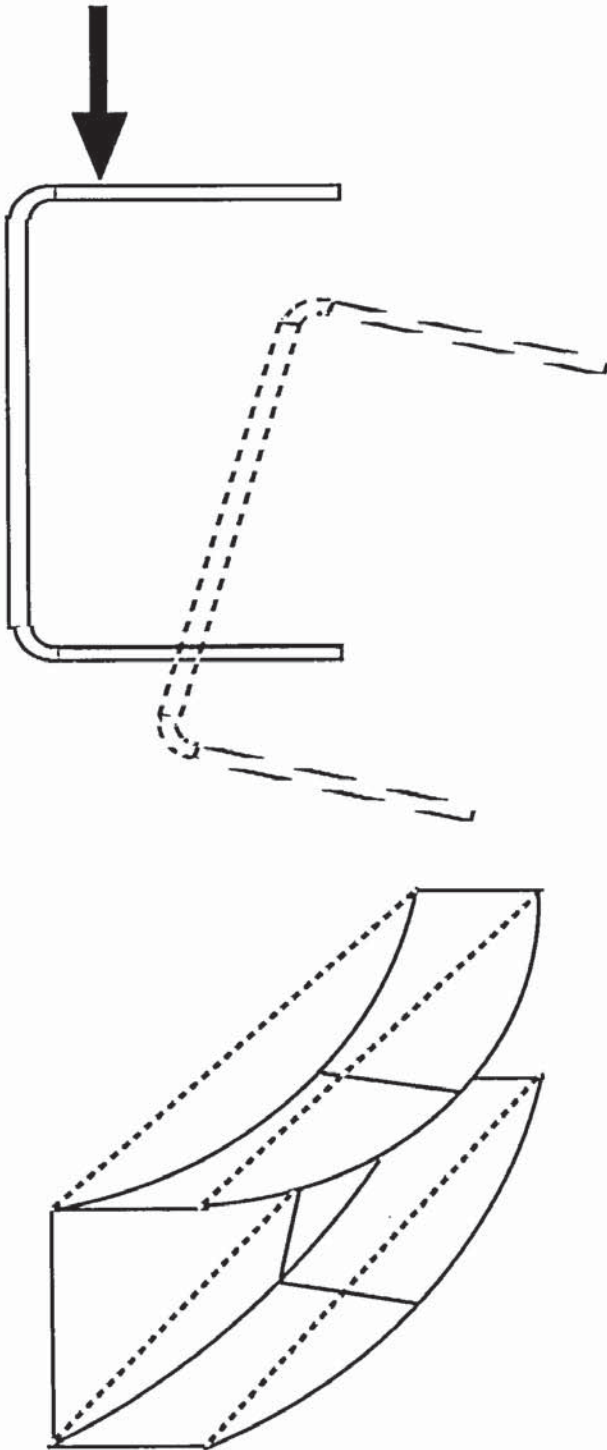
Diagram 3.4: Showing Torsional-Flexural buckling due to Twisting and Lateral buckling.

3.2 WORK HARDENING

In designing cold formed sections the working hardening taken place should be accounted for if the method of fabrication used is to be cold roll forming. There are certain conditions which apply when this can be taken into account. In the present method of practical designing the is totally ignored. This means that some designs are inefficient failing in this objective of optimum design.

3.3. STIFFENERS

In the designing of sections the importance of stiffeners is sometimes not understood. This is because the designer cannot tell, when a profile is stiffened, if that stiffening will result in the improvement of the load carrying capacity. The use of stiffeners is to counter the effects of local buckling. Therefore it is very important to know when to use stiffeners for the optimal design of the profile.

3.4. BACKGROUND

Research into optimal design of cold formed section has taken place since 1968, after the publication of the A.I.S.I. specification for the design of cold formed steel structural members, 1968 edition. All the

techniques that have been developed have had limited use.

The work done by Seaburg and Salmon[7] involved two similar techniques to determine the minimum thickness for the section known as the 'hat-shaped'. Although the techniques were designed to conform with the requirements of the 1968 Specification. They failed take into account the critical factors of torsional-flexural buckling, and the effects of work hardening on these sections. These two factors are very important in the design of economic sections.

Changes in the design like the addition of stiffeners and lips could not be catered for immediately. A new program had to be written for every section and type of loading. Therefore the results were painstakingly slow but competitive designs were established.

Another optimising technique was developed by R. Douty[8], this being the technique of Parametric Bandwidth Constriction. The process of Parametric Bandwith Constriction is based on a man-machine relationship, where the man determines from experience two or three main criteria which may have the optimising effect.

Although the process obtains a design which is competitive but not certain if the design is the optimum. The technique is based on the 1968 Specification and the programs have to be individually written for each case. Changes in the design cannot be easily incorporated and

hence this method is a lengthy process. Also when a designer is working in a new design, the factors which are selected may not be applicable.

A series of programs were developed by Station d'Etudes et de Recherches pour la Construction Metallique (SERCOM)[9], to optimise the dimensions of a cold formed section. The programs can be applied to a variety of sections but is limited by the memory of the computers used. The actual techniques used in the programs have not been reported hence the method used is not known.

The programs are restricted to shapes having only a limited number of stiffeners and corners. Only one type of loading condition is considered, therefore the shapes are only optimal for that particular type of loading. In the calculations of the properties of only the flat parts are considered.

3.5 COMPUTER AIDED DESIGN OF COLD ROLLED SECTIONS

The design technology of cold formed sections is relatively new. Research work on cold rolled sections has been an on-going process, this work has mainly been on the computer aided design and manufacture of form rolls. As a consequence of this work it was found that more complex shapes could be produced and the methods for designing the profile needed to be updated to the same extent.

The basic problem of economic design is to try and achieve the least expensive section which satisfies all the design requirements (i.e. its condition of service). One of the ways in which this can be accomplished is by designing the profile outline for maximum efficiency. In cold rolling this can be done because of the almost unlimited shape that can be made. Major projects were completed by both M.Sc. and final year B.Sc. students in an attempt to obtain economic design of cold rolled sections[13,14]. The use of computer aided design has helped in enabling designs to be produced quickly but as yet they cannot be considered as optimal.

The system which is currently in use is where the computer executes the tasks of reading and interpreting section data to determine basic properties of that section (such as moment of inertia) and analyzing the profile over limited loading cases.

This technique is found to be inadequate as the information entered about the section can not be easily verified. The methods employed do not take into account many of the complex features of the design problem. This is left to the designer. As the designers are uncertain about the analysis, large safety factors are employed to make sure the design is satisfactory.

The loading cases which are considered, are not sufficient for the increasing use of these sections in different applications. Although most

of the standard loading conditions are analysed, it is difficult to determine the behavior of the section when designed for a specific type of loading. In some cases the designers know through experience that the addition of stiffeners can improve the profile but the analysis using the present system does not show this.

CHAPTER 4

SECTION

PROPERTIES

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SECTION PROPERTIES

4.1 INTRODUCTION

The technique used for determining section properties was found to be inadequate as the information entered about the section could not be verified. One of the prime and quick methods of verifying if the data entered is correct is by illustrating the profile on screen. Secondly, the type of data entered to the system had to be more specific to facilitate decision support. The additional requirements of the computer were found to be difficult to facilitate using the present system. A completely new method has been devised to enable the computer to have this facility.

4.2 NEW METHOD

4.2.1 Data Representation

Before the computer can calculate the section properties of the profile, it must 'understand' the information presented to it. This is done when information is entered into the computer in terms of numerical data, representing linear and circular elements of the profile. These linear and circular elements are interpreted as a continuous connecting chain of elements, starting at one end of the profile, and terminating at

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the other.

Element No.	Type	Length/Radius(mm)	Angle
1	1	10	0
2	2	3	90.0

TABLE 4.1: Example of data presentation

Table 4.1 shows how the information is entered to the computer. Element 1 is a linear element (type 1) of length 10 millimeters. Element 2 is a circular element (type 2) with an internal radius of 3 millimeters and a bend of 90 degrees clockwise (a negative sign before the 90.0 constitutes an anti-clockwise bend). Element 2 is attached to the end of element 1 as shown in diagram 4.1.
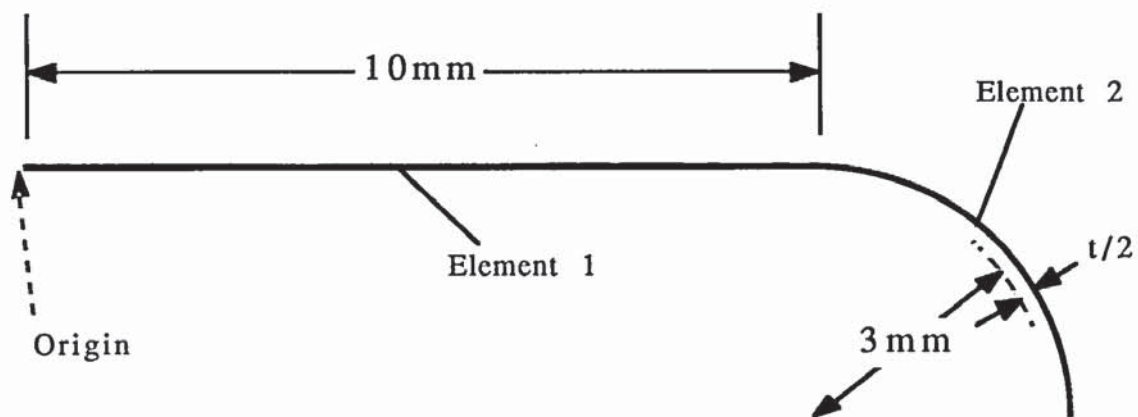
t - Thickness of material

Diagram 4.1 : Showing how profile is built up of elements.

4.2.2   Line Elements

The method for calculating properties of thin walled sections is determined by considering the material to be concentrated along the centerline of the profile. The area elements are considered as if replaced by straight or circular " line elements "[10]. The thickness dimension is introduced after the linear computations have been completed. Although there is some error in the calculations using this approach, it is very small and the values, of section properties obtained, are, if anything, slightly conservative. The use of this method is justified by the fact that these sections are thin, hence very close to line elements, as well as the technique being quick and easy to implement.
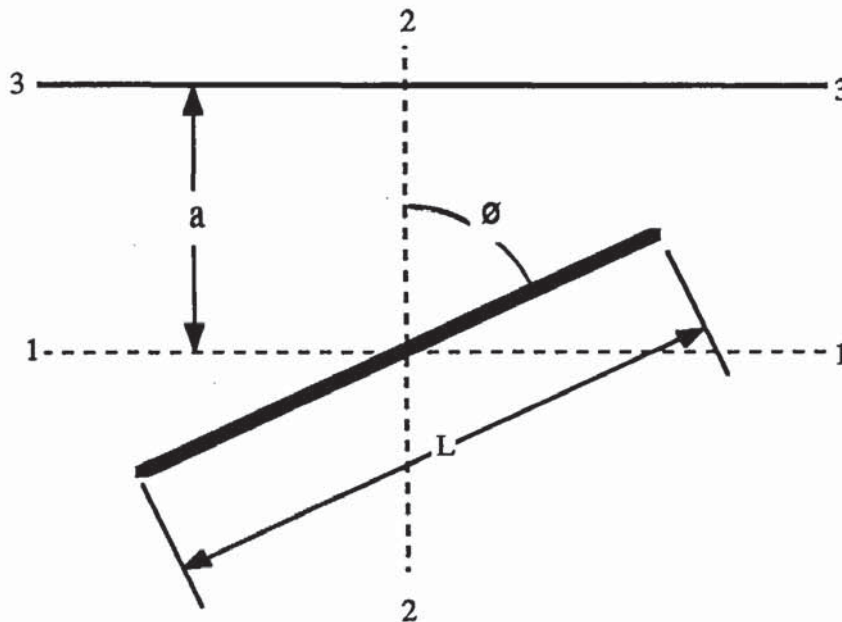
Figure 4.2 :   A flat element length L.

From diagram 4.3 the line properties are given by :

$$I_1 = L^3 * \cos^2 \phi / 12 * t$$

$$I_2 = L^3 * \sin^2 \phi / 12 * t$$

$$I_{12} = L^3 * \cos \phi * \sin \phi * t / 12$$

$$I_3 = [L * a^2 + L^3 * \cos^2 \phi / 12] * t$$

Where   .

I_1, I_2, I_3 -   are the area moment of inertia about the 1-1, 2-2, 3-3 axis respectively.

I_{12} -   is the product of inertia at point of intersection of 1-1 axis and 2-2 axis.
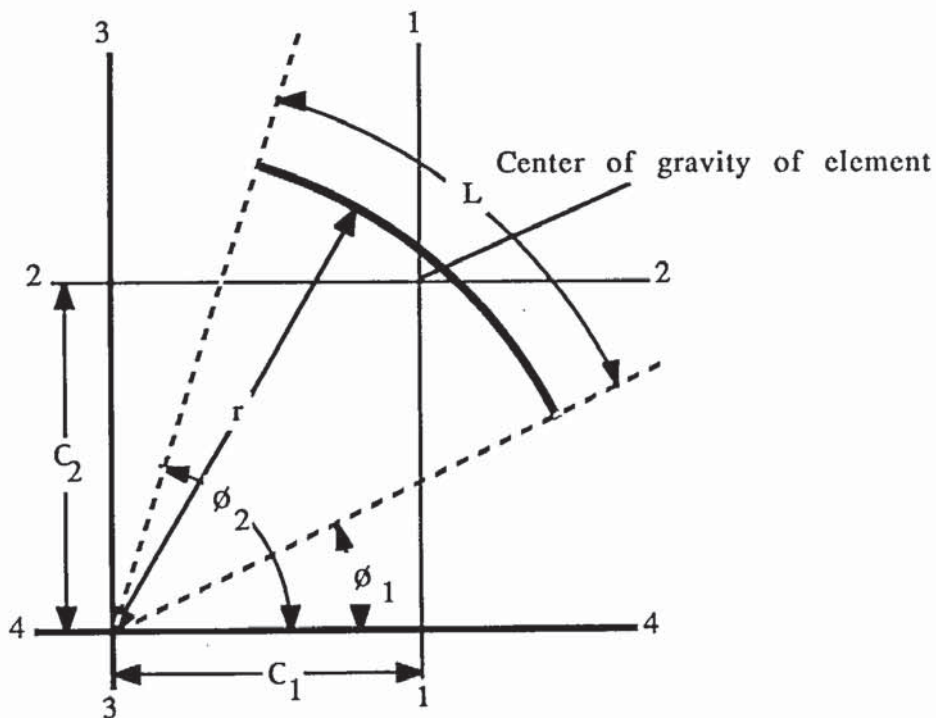
Figure 4.3 :   A curved element length L, radius r

In diagram 4.4 given that ϕ is expressed in radians, $L = (\phi_2 - \phi_1) * r$,

$$C_1 = r_* \frac{(\sin\phi_2 - \sin\phi_1)}{(\phi_2 - \phi_1)}, \quad \text{and} \quad C_2 = r_* \frac{(\cos\phi_1 - \cos\phi_2)}{(\phi_2 - \phi_1)}$$

The line properties are given by :

$$I_1 = \left\{ \frac{(\phi_2 - \phi_1 + \sin\phi_2 * \cos\phi_2 - \sin\phi_1 * \cos\phi_1)}{2} - \frac{(\sin\phi_2 - \sin\phi_1)^2}{(\phi_2 - \phi_1)} \right\} * r^3 * t$$

$$I_2 = \left\{ \frac{(\phi_2 - \phi_1 - \sin\phi_2 * \cos\phi_2 + \sin\phi_1 * \cos\phi_1)}{2} - \frac{(\cos\phi_1 - \cos\phi_2)^2}{(\phi_2 - \phi_1)} \right\} * r^3 * t$$

$$I_{12} = \left\{ \frac{(\sin^2\phi_2 - \sin^2\phi_1)}{2} + \frac{(\sin\phi_2 - \sin\phi_1) * (\cos\phi_2 - \cos\phi_1)}{(\phi_2 - \phi_1)} \right\} * r^3 * t$$

$$I_3 = \left\{ \frac{(\phi_2 - \phi_1 + \sin\phi_2 * \cos\phi_2 - \sin\phi_1 * \cos\phi_1)}{2} \right\} * r^3 * t$$

$$I_4 = \left\{ \frac{(\phi_2 - \phi_1 - \sin\phi_2 * \cos\phi_2 + \sin\phi_1 * \cos\phi_1)}{2} \right\} * r^3 * t$$

$$I_{34} = \left\{ \frac{(\sin^2\phi_2 - \sin^2\phi_1)}{2} \right\} * r^3 * t$$

Where

I_1, I_2, I_3, I_4 - Area moment of inertias. $\quad I_{12}, I_{34}$ - Product of inertias.

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4.2.3   Data Interpretation

The computer interprets the section data into an internal two dimensional coordinate system. The starting position of the profile is taken as the origin and the position of the start and finish points of each element are computed relative to this. The centroid of each element is initially determined from equations of line properties. The relative position of each centroid is calculated and stored in memory.

For straight elements the relative position of its centroid is easily determined. But for the circular elements careful interpretation has to considered. In each of these cases the problem is to determine the relative position of the centre of curvature for the circular element. Then the equations provided for circular elements are used to determine the relative position of the centroid of the circular element. In the co-ordinate system used for this interpretation clockwise input of the circular element is given as a positive angle (figure 4.6-a) and anti-clockwise is given as negative (figure 4.6-b).

4.2.4   Calculations

To illustrate how the calculations are carried out to determine the right interpretation consider the figures 4.6-a and 4.6-b. Let ϕ (-ve in both figures) be the start angle for the flat element from the origin [0,0] in radians, and the length of the flat element be L_1 mm.

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For the flat element :-

the end position [a,b] of the flat element is given by :-

$$a = L_1 * \cos \phi ;$$

$$b = L_1 * \sin \phi .$$

Then the centroid of the flat element from the origin is given by :-   [a/2,b/2].

For circular element, let :-

the radius be R mm. ;

the angle be ß radians;

Then

$$X = R * \sin \phi ;$$

$$Y = R * \cos \phi ;$$

$$C_1 = (\sin (\phi+ß) - \sin \phi) * R / ß ;$$

$$C_2 = (\cos \phi - \cos (\phi+ß)) * R / ß.$$

Then the length of circular element L_2 , equals the positive value of the expression :- R*ß.

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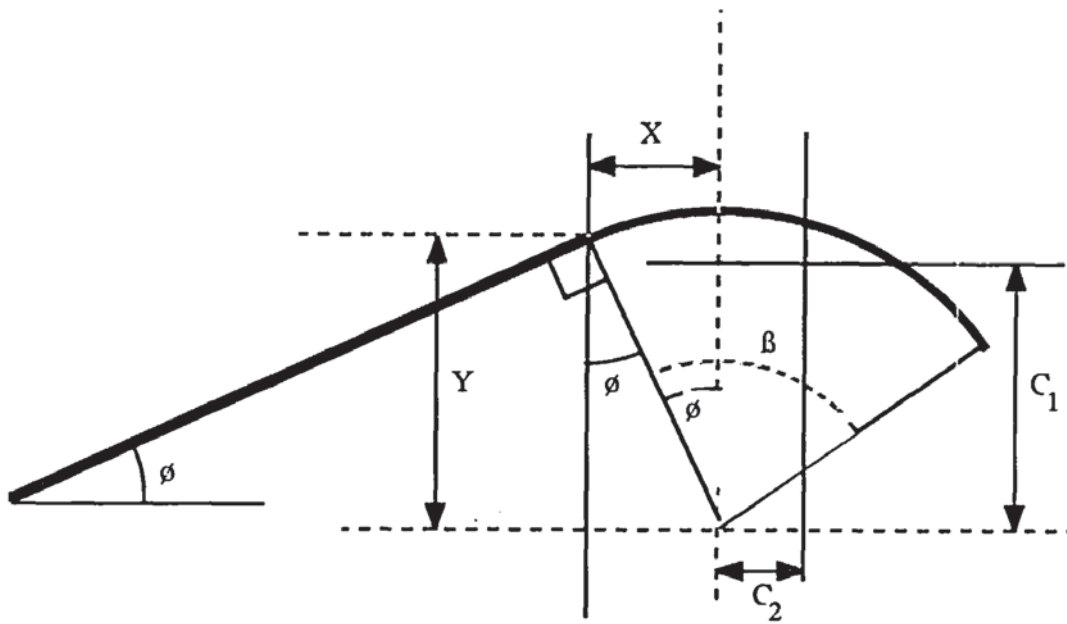
Figure 4.4 :   Illustrating flat and (ß-positive) circular line elements

If ß is positive:

The end position [c,d] of the circular element relative to position[a,b] , the start of circular element is given by the following equations :-

$$c = R * (\sin (\emptyset+ß) - \sin \emptyset) ;$$

$$d = R * (\cos \emptyset - \cos (\emptyset+ß)).$$

The centroid [cx,cy] of the element relative to [a,b] is given by :

$$cx = C_2 - X ;$$

$$cy = Y - C_1.$$

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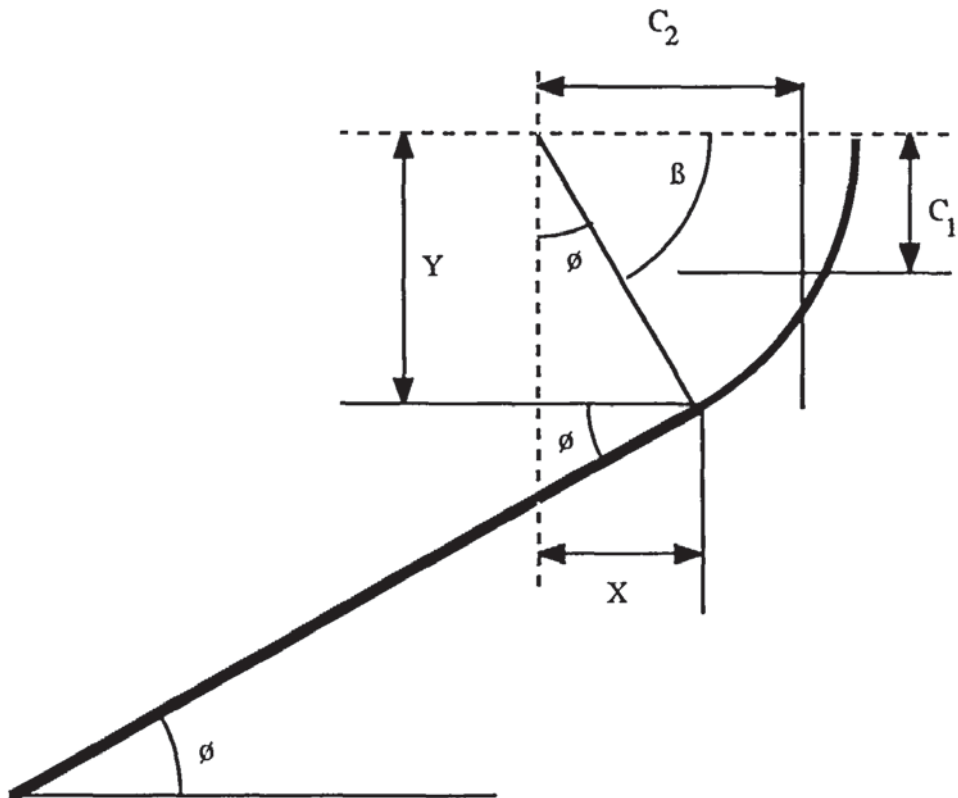
Figure 4.5: Illustrating flat and (ß-negative) circular line elements

If ß is negative :-

The end position [c,d] of the circular element relative to position [a,b], the start of circular element, is given by the equations:-

$$c = R * (\sin \phi - \sin (\phi+ß)) ;$$

$$d = R * (\cos (\phi+ß) - \cos \phi).$$

The centroid [cx,cy] of the element relative to [a,b] is given by :

$$cx = X - C_2 \; ;$$

$$cy = C_1 - Y.$$

Once the relative position of the elements to the origin has been worked out then, the centroid of the section is worked out by taking first moments of each element about the origin (eqn. 1).
i.e.

$$x_i = \frac{(a_{i-1} * x_{i-1} + a_{ci} * x_{ci})}{(a_{i-1} + a_{ei})}$$

$$a_i = a_{i-1} + a_{ei}$$

a_{ei} Length of the i th element.

x_{ei} Position of the centroid of element i relative to the origin.

x_i Position of the centroid of profile (so far having i elements) relative to the origin.

a_i Sum length of profile outline with i elements

a_{i-1} Sum length of profile outline with i-1 elements

x_{i-1} Position of the centroid of profile (so far having i-1 elements) relative to the origin.

By translating this coordinate system on to the screen of the computer terminal, and scaling the profile shape to fit, the outline diagram of the profile can be sketched. Once the centroid of the profile has been established , the area moment of inertias of each element about both x and y imaginary axis through the centroid of the profile, are calculated. This is done by using the equations of flat and circular line element properties in conjunction with the parallel axis theorem[15].

The equations from the line elements give the · individual area moment of inertias for the flat and circular elements about each centroid of each element. Using the parallel axis theorem, the area moment of inertia of each of the elements is determined about the centroid and then added together to give the area moment of inertia of the whole profile. Similarly the product of inertia is calculated.

4.2.5 Dummy Elements

Dummy elements are flat elements which are considered ineffective in the calculation of the section properties. There are two types of dummy elements, the first type is representative of hole or slits in the profile to reduce the weight of the profile. This type is shown in the profile sketch as a gap between two elements and is introduced to the system as data. The second type is an ineffective element, which is considered as such because of local buckling (chapter 3). The ineffective elements are determined by the system using Artificial Intelligence

concepts.

The dummy elements are treated as not existing when calculating the centroid, the area moment of inertias and the product of inertia, but are taken into account for the calculation of the cross-section area of the profile for the purpose of optimization.

CHAPTER 5

LOADING

ANALYSIS

LOADING ANALYSIS

5.1 INTRODUCTION

The loading conditions of the original computer program[13] which were analysed were limited to specific set conditions. The problem with this limitation is that should a profile be required for a particular type of loading which the set cases do not cover, then it would be very difficult to determine if the designed profile is suitable for that use. Beams can be subjected to a large variation of loading and can have more than two supports. As such limitations set by selected cases can lead to inefficient designs.

In order to overcome this difficulty three types of beam loading design were introduced to the new " Expert " design system. This new computerized analysis was developed to enable the designer using the system to check a designed section to specified beam loading. The loading being specified by the designer.

These types are :-

(1)   Simply supported beams with any number of point loads and any number of uniform distributive

loads.

(2)   Continuous beams with any number of supports,
        point loads, and uniform distributive loads where
        the uniform distributive loads completely cover
        individual spans. Uniform distributive loads
        partially covering spans cannot be analysed using
        this technique.

(3)   Continuous beams with any number of supports,
        point loads, and uniform distributive loads. This
        technique can approximately analyse uniform
        distributive loads which partially cover spans.

The difference between each of these techniques is the method
for determining the reactions.

5.2 SIMPLY SUPPORTED BEAMS

The reactions at the supports are determined using the normal
equations of static equilibrium. The main problem was to get the
computer to correctly identify the effect of the loading on the beam and
obtain the correct reactions. The effect of point loads are easily
identified from information presented to the computer. The effect of

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uniform distributive loads require some interpretation.

In the analysis the technique used to interpret the moment effect about a position when dealing with uniform distributive loads is similar to the one used in macaulay's method[16]. In this case the position is where the support is placed.

Consider a partial uniform distributive load of U newtons per metre starting at distance a and ending at distance b with a support at distance r. Taking moments about the support.

When a < r and b < r   (see diagram 5.1)

The effect of this uniform distributive load is interpreted as if the uniform distribution was from a to r and a reverse compensating load is applied of the same value starting at b and ending at r.

i.e, :-

Moment effect of uniform distributive load from left hand side of support

$$= U.[r-a]^2/2 \quad - \quad U.[r-b]^2/2$$
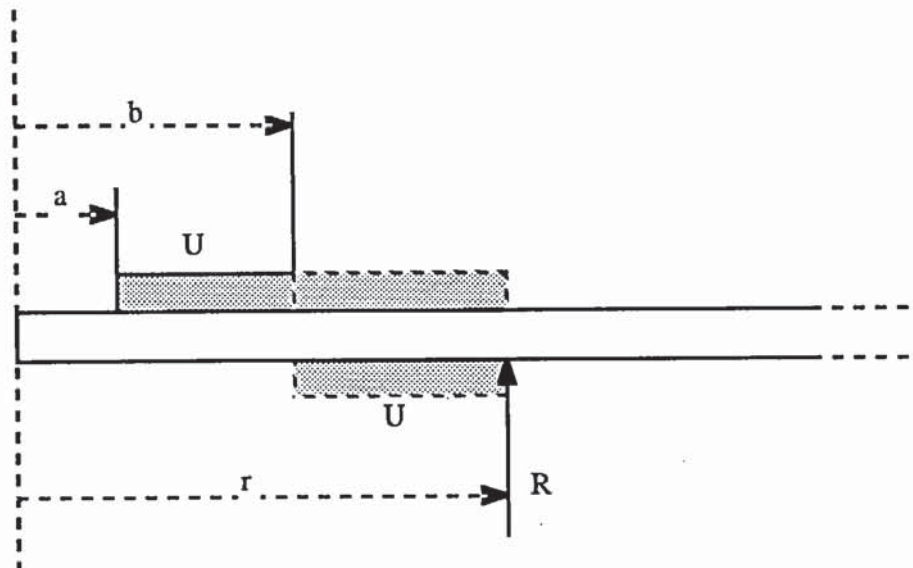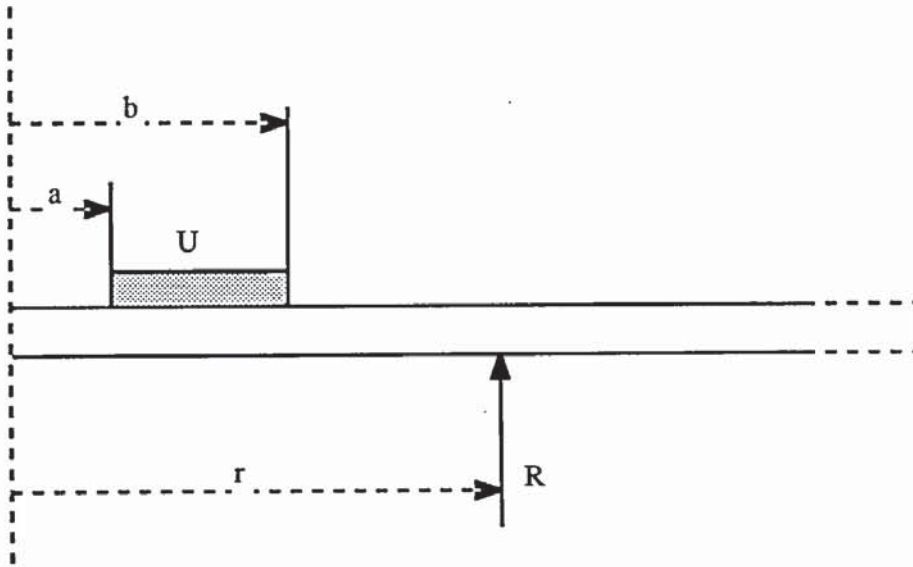
Diagram 5.1 : Top: Showing a partial uniform distributive load at the left of support in the actual loading condition.

Bottom: Showing the computer interpretation of the loading using the compensation method.

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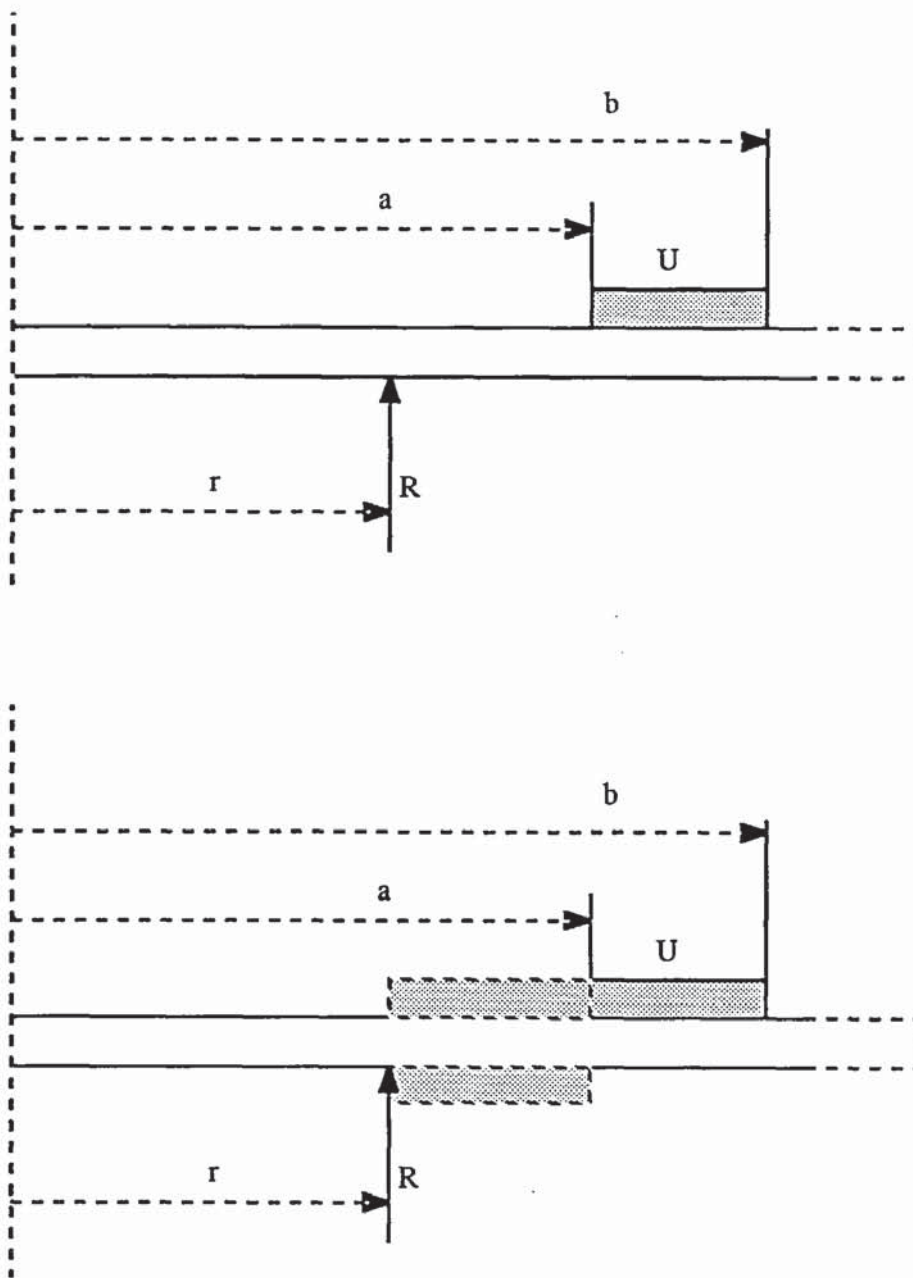
Diagram 5.2 : Top: Showing a partial uniform distributive load at the right of support in the actual loading condition.

Bottom: Showing the computer interpretation of the loading using the compensation method.

When a > r and b > r   (diagram 5.2)

The effect of this uniform distributive load is interpreted as if the uniform distribution was from r to b and a reverse compensating load is applied of the same value starting at r and ending at a.

i.e, :-

Moment effect of uniform distributive load from right hand side of support

$$= U.[b-r]^2/2 \ - \ U.[a-r]^2/2$$

When a < r and b > r   (diagram 5.3)

The effect of this uniform distributive load is interpreted as if the uniform distribution was from a to r and r to b.

i.e, :-

Moment effect of uniform distributive load from left hand side of support

$$= U.[r-a]^2/2$$

Moment effect of uniform distributive load from right hand side of support

$$= U.[b-r]^2/2$$
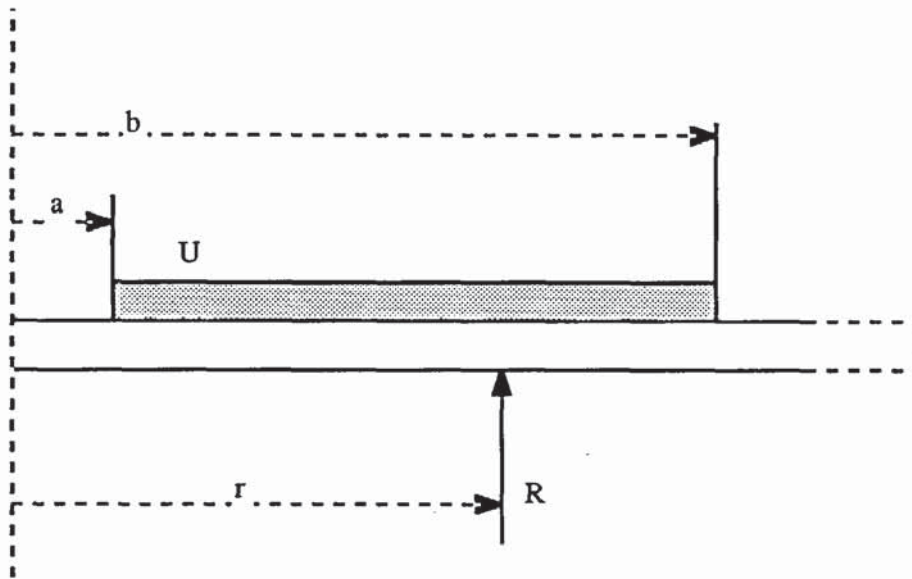
Diagram 5.3 : Showing a partial uniform distributive load across support, no compensation required.

Diagram 5.4 shows a simply supported beam with a n point loads and m uniform distributive loads, which are placed along the beam. Using the equations of static equilibrium, the reaction at the second support can be determined by taking moments about the first support, and the reaction at the first support can be determined by taking moments about the second support. This requires the computer to know the moment effect of each individual type of load.
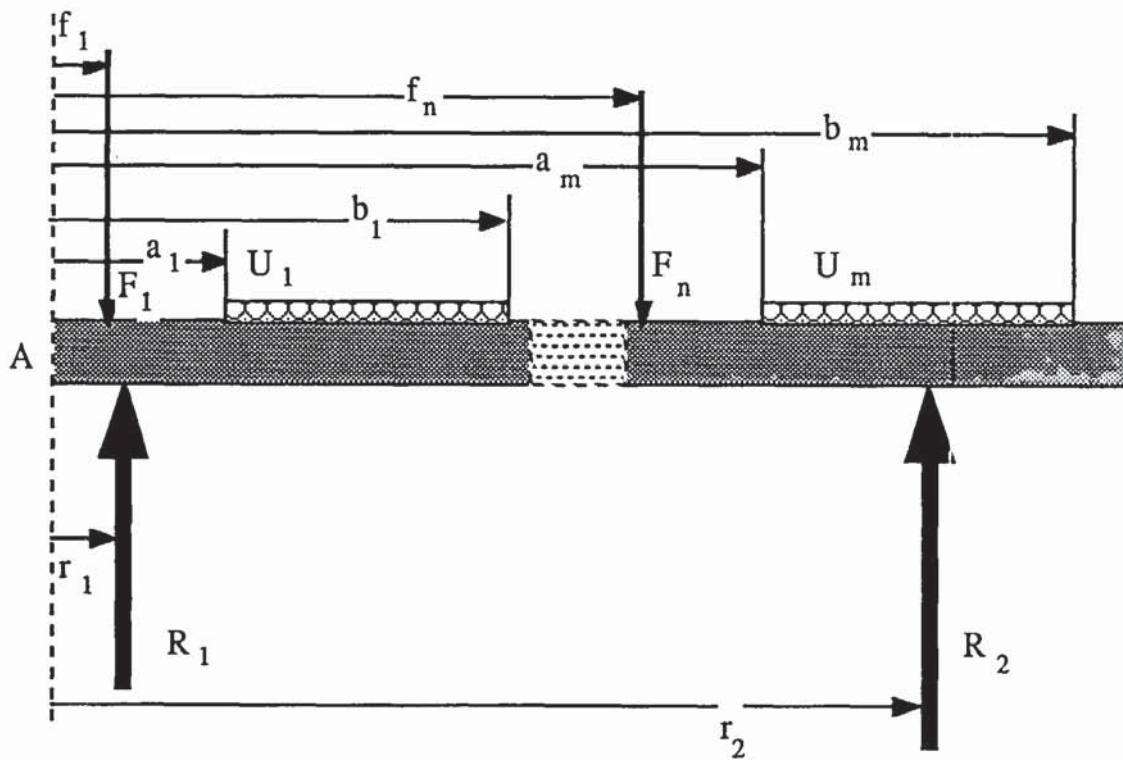
Diagram 5.4 : A Simple Beam With Complex Loading.

Where,

R$_1$, R$_2$ - Reactions at the supports at distance r$_1$, r$_2$ respectively from A.

F$_i$ - Force of ith point load at distance f$_i$ from A.

U$_i$ - Force per metre of ith uniform distributive load staring at distance a$_i$ and ending at distance b$_i$ from A.

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Consider taking moments about the first support at r_1 from A.

From equilibrium the sum of moments on the left hand side of support equals the sum of moments on the right hand side of the support.

i.e,

$$_{i=1}\Sigma^n F_i.[r_1 - f_i] + _{j=1}\Sigma^m U_i.[r_1 - a_j]^2/2 - _{k=1}\Sigma^m U_i.[r_1 - b_k]^2/2$$

$$= _{i=1}\Sigma^n F_i.[f_i - r_1] - _{j=1}\Sigma^m U_i.[a_j - r_1]^2/2 +$$

$$_{k=1}\Sigma^m U_i.[b_k - r_1]^2/2 - R_2.(r_2 - r_1) \quad ....(5.1)$$

Provided the term in the square brackets are only applied if they are positive when evaluated.

To explain this consider the term :-

$$_{i=1}\Sigma^n F_i.[r_1 - f_i]$$

This term means :-

$$F_1.[r_1 - f_1] + F_2.[r_1 - f_2] + F_3.[r_1 - f_3] + ... + F_n.[r_1 - f_n]$$

If only f_1 and f_2 are each less than r_1 (i.e. $[r_1 - f_1]$ and $[r_1 - f_2]$ are positive) then the result would be evaluated as :-

$$F_1.[r_1 - f_1] + F_2.[r_1 - f_2]$$

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Rearranging equation 5.1, the reaction on the second support , R_2 is given by :

$$\left(1/(r2 - r1)\right) \cdot \left\{ \; \sum_{i=1}^{n} F_i \cdot [f_i - r_1] \quad - \quad \sum_{j=1}^{m} U_i \cdot [a_j - r_1]^2/2 \; + \right.$$

$$\sum_{k=1}^{m} U_i \cdot [b_k - r_1]^2/2 \quad - \quad \sum_{i=1}^{n} F_i \cdot [r_1 - f_i] \; -$$

$$\left. \sum_{j=1}^{m} U_i \cdot [r_1 - a_j]^2/2 \quad + \quad \sum_{k=1}^{m} U_i \cdot [r_1 - b_k]^2/2 \; \right\}$$

Similar the reaction on the·first support , R_1 is given by :

$$\left(1/(r1 - r2)\right) \cdot \left\{ \; \sum_{i=1}^{n} F_i \cdot [f_i - r_2] \quad - \quad \sum_{j=1}^{m} U_i \cdot [a_j - r_2]^2/2 \; + \right.$$

$$\sum_{k=1}^{m} U_i \cdot [b_k - r_2]^2/2 \quad - \quad \sum_{i=1}^{n} F_i \cdot [r_2 - f_i] \; -$$

$$\left. \sum_{j=1}^{m} U_i \cdot [r_2 - a_j]^2/2 \quad + \quad \sum_{k=1}^{m} U_i \cdot [r_2 - b_k]^2/2 \; \right\}$$

5.3 CONTINUOUS BEAMS

5.3.1   Clapeyron's "three-moment" Equation

In continuous beams it is not possible to directly determine the reactions by normal equations of static equilibrium since there are too many unknowns. Clapeyron's three-moment equation is a relationship between the bending moments at the supports which is derived from an extension of Morh's area-momemt method[16].
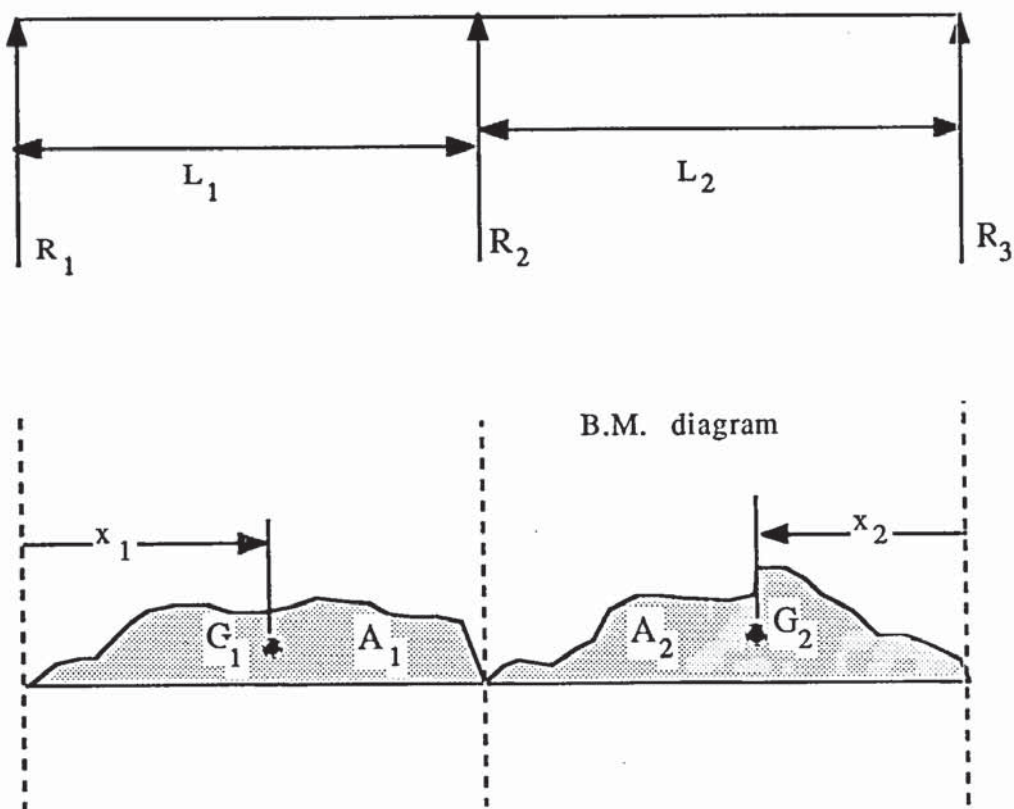
Diagram 5.5: Continuous beam over three supports showing "free" moment diagrams.

Consider the beam shown in diagram 5.5, the areas A_1 and A_2 are the "free" bending moments diagrams, treating the beam as simply supported over two separate spans L_1 and L_2. The bending moments at the three supports will have some values M_1, M_2 and M_3 (in general these moments will not be zero as the diagram suggests). If the beam is uniform and the supports are on the same level, then Clapeyron's three moment equation is as given below :-

$$- M_1L_1 - 2M_2 \{ L_1 + L_2 \} - M_3L_2 = 6 \{ (A_1x_1/ L_1) + (A_2x_2/ L_2) \} \quad ....(5.2)$$

By using this equation repeatedly across a continuous beam we can determine the moment at each of the supports, and consequently their reactions.

5.3.2 Evaluation of 6Ax/L

There are two types of standard loading where the evaluation of 6Ax/L can be done by simple equations[16].

These are:-

(1) Concentrated loads (diagram 5.6)

Where,

$$6Ax/L = Na(L^2 - a^2)/L$$
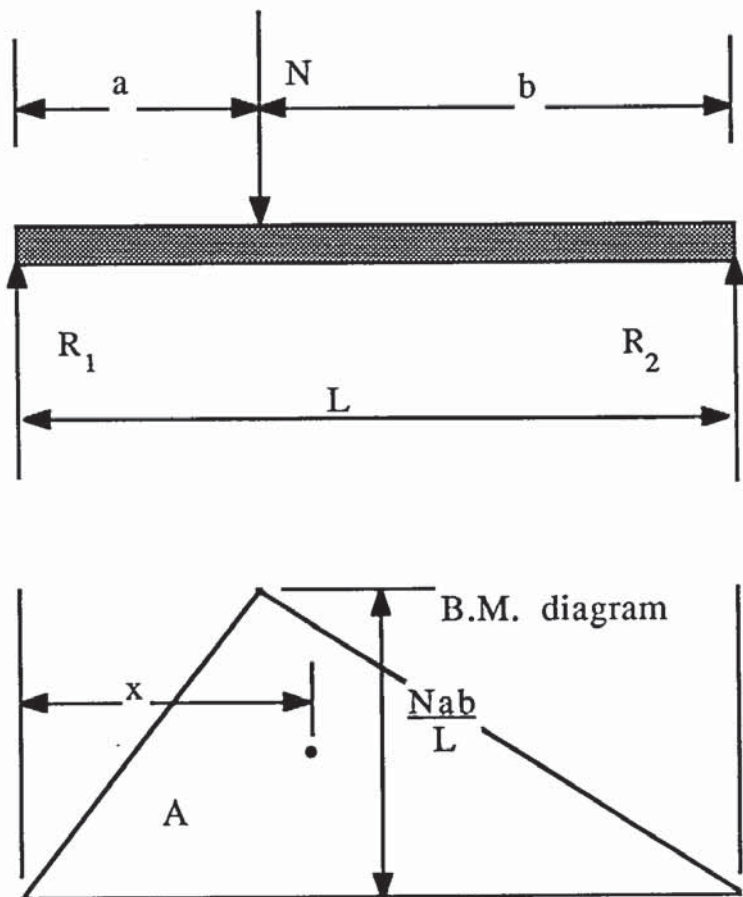
Diagram 5.6: Showing a point load N on a single span and its "free moment" diagram.

(2) Uniform distributive loads across whole span(diagram 5.7)

Where,

$$6Ax/L = UL^3/4$$

U
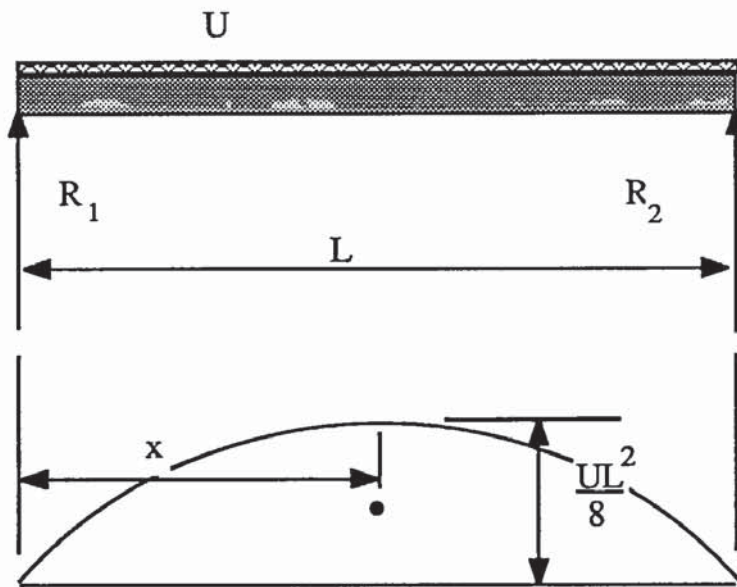
Diagram 5.7: Showing a uniform distributive load U across a whole span and its "free moment" diagram.

In determining the value of 6Ax/L for a partial uniform distributive load on a span, it is no longer possible to use simple equations. An approximate method has been developed based on the fact that the span is considered, a simple beam, for this evaluation.

Consider diagram 5.8, where, R_1 and R_2 are the reaction values due to the partial uniform distributive load when the span is considered a simple beam on two supports.

Then $R_2 = U\ (e+b)\ (e-b)/2L$

and $R_1 = U\ (e-b)\ \{1 - (e+b)/2L\}$
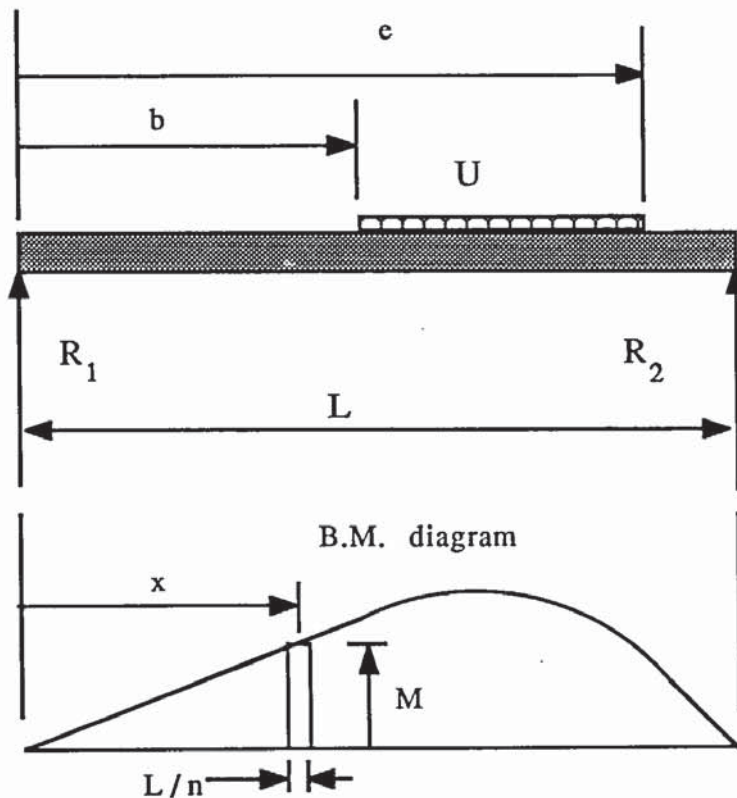
Diagram 5.8: Showing a uniform distributive load U partially across a span and its "free moment" diagram.

Using Macauly's method, the bending moment, M at x is given by:-

$$M = R_1x - U[x-b]^2/2 + U[x-e]^2$$

Where the terms in the square brackets only apply when positive.

The value of Ax can be approximated by dividing the span into n equal parts. Then taking the moment of n partial strips ML/n as x is incremented by 1 from 1/2 to (n-1/2). The algebraic sum of these moments gives an approximate value of Ax.

i.e. $Ax \approx \sum_{x=1/2}^{x=(n-1/2)} xML/n.$

therefore,

$6Ax/L \approx 6/n \sum_{x=1/2}^{x=(n-1/2)} xM.$

If a multiple variation of all 3 are being applied on a span, the individual values of each 6Ax/L of each load is determined. The resultant values of 6Ax/L is the algebraic sum of each individual.

In order to determine if the approximate technique is required, production rules (see chapter 6) are used.

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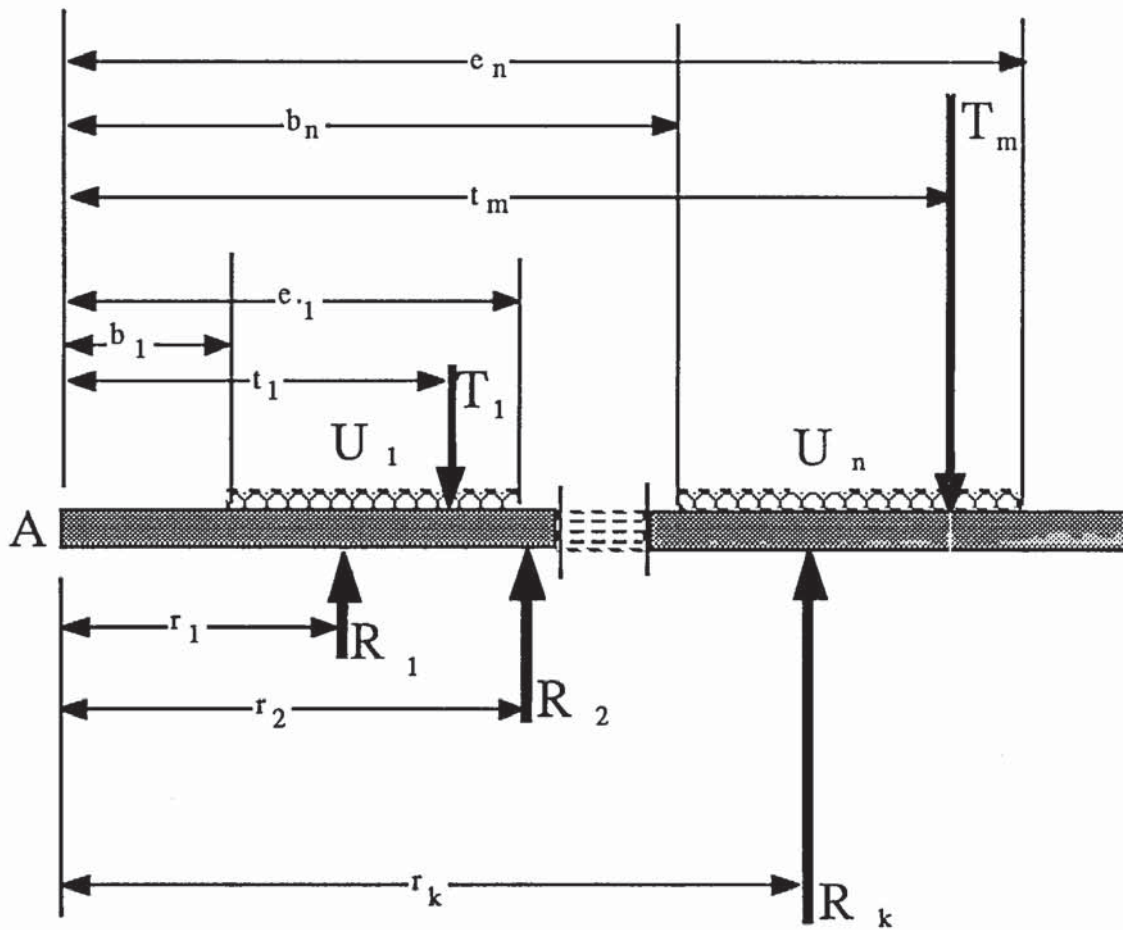
Diagram 5.9: Illustrating A continuous Beam Of Length L, With k Supports Subjected To m Point Loads, And n Uniform Distributive Loads.

Consider diagram 5.9, and consider the span between supports i, and i+1, which are at distances r_i, and r_{i+1}, from end A of the beam respectively. Then iterating from j=1 to n, the number of uniform distributive loads. The following rules are applied telling the computer which technique, or equation to use.

IF $(b_j > r_i$ and $b_j < r_{i+1})$ OR $(e_j > r_i$ and $e_j < r_{i+1})$

        THEN use the approximate method.

   ELSE IF $(b_j <= r_i$ and $e_j >= r_{i+1})$

        THEN use equation

   ELSE   goto next uniform distributive load.

5.3.3. Determination of Moments

Consider diagram 5.9, with k supports, then k-2 Clapeyron's equations can be obtained with k unknown moments. The first and last moments M_1 and M_k can be obtained by taking moments about the first and last support respectively. (i.e, M_1 can be obtained by taking moments from end A to the position of the first support, about the first support.)

Representing Clapeyron's equation as follows :-

$$a_{1,1}M_1 + a_{1,2}M_2 + a_{1,3}M_3 = a_{1,n+1}$$

where $a_{1,1}$, $a_{1,2}$, $a_{1,3}$, $a_{1,n+1}$, are constants.

The whole set can be written as :-

$$a_{1,1}M_1 + a_{1,2}M_2 + a_{1,3}M_3 \qquad\qquad = a_{1,n+1}$$

$$a_{2,2}M_2 + a_{2,3}M_3 + a_{2,4}M_4 \qquad\qquad = a_{2,n+1}$$

$$a_{3,3}M_3 + a_{3,4}M_4 + a_{3,5}M_5 \qquad\qquad = a_{3,n+1}$$

$$\cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots \qquad \cdots$$

$$a_{n-2,n-2}M_{n-2} + a_{n-2,n-1}M_{n-1} + a_{n-2,n}M_n \qquad = a_{n-2,n+1}$$

As M_1 and M_n are known the equations can be regarded as:-

$$
\begin{bmatrix}
a_{1,2} & a_{1,3} & \cdot & \cdot & \cdot & \cdot \\
a_{2,2} & a_{2,3} & a_{2,4} & \cdot & \cdot & \cdot \\
\cdot & a_{3,3} & a_{3,4} & a_{3,5} & \cdot & \cdot \\
\cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\
\cdot & \cdot & a_{n-2,n-2} & a_{n-2,n-1}
\end{bmatrix}
\begin{bmatrix}
M_2 \\
M_3 \\
M_4 \\
\cdots \\
M_{n-1}
\end{bmatrix}
=
\begin{bmatrix}
a_{1,n+1} \\
a_{2,n+1} \\
a_{3,n+1} \\
\cdots \\
a_{n-2,n+1}
\end{bmatrix}
$$

. Where $a_{1,n+1}$ and $a_{n-2,n+1}$ are new constants. Using the Gauss elimination technique[17] adopted for these equations and repeating the process below on each row consecutively.

where the new $\quad a_{i,i+1} = a_{i,i+1} - a_{i,i}\cdot a_{i-1,i+1}/ a_{i-1,i}$

and the new $\quad a_{i,n+1} = a_{i,n+1} - a_{i,i}\cdot a_{i-1,n+1}/ a_{i-1,i}$

and the new $\quad a_{i,i} = 0$

We obtain the following

$$
\begin{bmatrix}
a_{1,2} & a_{1,3} & . & . & . & . \\
. & a_{2,3} & a_{2,4} & . & . & . \\
. & . & a_{3,4} & a_{3,5} & . & . \\
... & ... & ... & ... & ... & ... \\
. & . & . & . & . & a_{n-2,n-1}
\end{bmatrix}
\begin{bmatrix}
M_2 \\
M_3 \\
M_4 \\
... \\
M_{n-1}
\end{bmatrix}
=
\begin{bmatrix}
a_{1,n+1} \\
a_{2,n+1} \\
a_{3,n+1} \\
... \\
a_{n-2,n+1}
\end{bmatrix}
$$

From which $\quad M_{n-1} = a_{n-2,n+1}/ a_{n-2,n-1}$

and by back tracking from i=n-3 to 1, using

$$M_{i+1} = (a_{i,n+1} - M_i\cdot a_{i,i-2}) / a_{i,i+1}$$

the other moments can be obtained.

5.3.4. Determination of Reactions

The Reactions can be obtained by taking moments about supports 2 to k respectively. Consider the diagram 5.9, taking moments about the second support :

$$M_2 \;=\; R_1(r_2 - r_1) \;-\; {}_{i=1}\Sigma^m \, T_i \cdot [r_2 - f_i]$$

$$-\; {}_{i=1}\Sigma^n \, U_i \cdot [r_2 - b_i]^2/2 \quad+\quad {}_{i=1}\Sigma^n \, U_i \cdot [r_2 - e_i]^2/2$$

Provided the term in the square brackets are only applied if they are positive when evaluated.

Therefore,

$$R_1 \;=\; \{ M_2 \;+\; {}_{i=1}\Sigma^m \, T_i \cdot [\, r_2 - f_i\,] \;+\; {}_{i=1}\Sigma^n \, U_i \cdot [r_2 - b_i]^2/2$$

$$-\; {}_{i=1}\Sigma^n \, U_i \cdot [r_2 - e_i]^2/2 \;\}/(\, r_2 - r_1)$$

and subsequently,

$$R_2 \;=\; \{ M_3 \;+\; {}_{i=1}\Sigma^m \, T_i \cdot [\, r_3 - f_i\,] \;+\; {}_{i=1}\Sigma^n \, U_i \cdot [r_3 - b_i]^2/2$$

$$-\; {}_{i=1}\Sigma^n \, U_i \cdot [r_3 - e_i]^2/2 \;-\; R_1(r_3 - r_1) \;\}/(\, r_3 - r_2)$$

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i.e,

$$R_j = \{ M_j + {}_{i=1}\Sigma^m T_i.[\ r_j - f_i\ ]$$

$$+ \ \ {}_{i=1}\Sigma^n U_i.[r_j - b_i]^2/2$$

$$- \ \ {}_{i=1}\Sigma^n U_i.[r_j - e_i]^2/2$$

$$- \ \ {}_{i=1}\Sigma^{j-2}R_i(r_j - r_i) \ \ \ \} \ /(r_j - r_{j-1})$$

where j changes from j=2 to j=k-1.

The reaction at k is determined by taking moments about support k-1, from the end away from A.

5.4 SHEAR STRESS, BENDING MOMENT, AND DEFLECTION.

In order to check the profile being designed, the shear stress, bending moment, and deflection have to be determined. The loading of the beam is variable, consequently the maximum values cannot be resolved easily.

Using Macaulay's method, it is possible to obtain the shear stress, S; bending moment, BM; and deflection, d; at a distance, x from end A.

i.e,

$$S = (1/A_s). \{ \sum_{i=1}^{m} T_i.[x - f_i] /(x - f_i) + \sum_{i=1}^{n} U_i.[x - b_i]$$

$$- \sum_{i=1}^{m} R_i.[x - r_i] /(x - r_i) - \sum_{i=1}^{n} U_i.[x - c_i] \}$$

$$BM = \sum_{i=1}^{m} T_i.[x - f_i] + \sum_{i=1}^{n} U_i.[x - b_i]^2/2$$

$$- \sum_{i=1}^{m} R_i.[x - r_i] - \sum_{i=1}^{n} U_i.[x - c_i]^2/2$$

$$d = (1/IE). \{ \sum_{i=1}^{m} T_i.[x - f_i]^3/6 + \sum_{i=1}^{n} U_i.[x - b_i]^4/24$$

$$- \sum_{i=1}^{m} R_i.[x - r_i]^3/6 - \sum_{i=1}^{n} U_i.[x - c_i]^4/24$$

$$+ C_1x + C_2\}$$

Where:-

the terms in the square brackets are only applied if they are positive when evaluated.

A_s is the cross-sectional area of the profile being considered.

C_1 and C_2 constants evaluated for different spans.

I is the area moment of inertia of the profile about the bending axis.

E is Youngs' modulas.

By varying the value of x across the beam the maximum values can be obtained for each.

The constants C_1 and C_2 are determined by considering two consecutive supports. The deflection at the supports is zero. By taking x to be at the same distance as each support, two simultaneous equation are obtained. The solution of the simultaneous equation resolves the values for the constants.

$$C_1 r_a + C_2 = - \sum_{i=1}^{m} T_i \cdot [\, r_a - f_i \,]^3/6 - \sum_{i=1}^{n} U_i \cdot [r_a - b_i]^4/24$$

$$+ \sum_{i=1}^{m} R_i \cdot [\, r_a - r_i \,]^3/6 + \sum_{i=1}^{n} U_i \cdot [r_a - c_i]^4/24 \quad ....(\text{eqn. 5.3})$$

$$C_1 r_b + C_2 = - \sum_{i=1}^{m} T_i \cdot [\, r_b - f_i \,]^3/6 - \sum_{i=1}^{n} U_i \cdot [r_b - b_i]^4/24$$

$$+ \sum_{i=1}^{m} R_i \cdot [\, r_b - r_i \,]^3/6 + \sum_{i=1}^{n} U_i \cdot [r_b - c_i]^4/24 \quad ....(\text{eqn. 5.3})$$

Where $\quad r_b = r_{(a + 1)}$

Then subtracting equation (5.4) from (5.3) and dividing by $(r_b - r_a)$ will give the value of C_1. Then by substituting C_1, into equation 5.3, C_2 can be obtained. The constants are evaluated for each span, where r_a and r_b are the supports for that span.

That is when evaluating the deflection at x then :-

If $\quad$ x $\quad < \quad r_1$ $\qquad\qquad$ then $\quad r_a \quad = \quad r_1$

If $\quad r_i < \quad$ x $\quad < \quad r_{i+1}$ $\qquad$ then $\quad r_a \quad = \quad r_i$

If $\quad$ x $\quad > \quad r_k$ $\qquad\qquad$ then $\quad r_a \quad = \quad r_{k-1}$

CHAPTER 6

DECISION

SUPPORT

DECISION SUPPORT

6.1 INTRODUCTION

The general idea of using computers is to help man perform tasks that are manually inefficient, undesirable or even impossible. Certain qualities of computers are difficult to match with human effort. Therefore in general, computers can play a very useful role, especially in areas where human handling has failed to work satisfactorily.

One such area where human handling has failed to work satisfactorily is the designing of cold formed sections. When investigating the existing method of designing cold formed section it was found that large safety factors were being employed, which is counteractive to the objective of optimum design. This was a consequence of using quick inaccurate methods of checking a designed profile with the loading.

Although the precise methods could be employed with the use of British Standards[18], these methods are lengthy, involving a lot of calculations, and still require expertise in their use, particularly for optimum design. Even when an expert is employed, the time from concept to actual design may take up to two years, making such methods impractical.

As a result an investigation was carried out on the use of these standards in combination with the Computer Aided Design system presently being employed. This resulted in the introduction of Artificial Intelligence concepts within a Computer Aided Design system to provide advice, inference and direction to the designer to try and achieve optimum design.

Artificial Intelligence is concerned with the designing of intelligent computer systems, that is,. systems that exhibit the characteristics associated with human behaviour. The objective of this research is to design an intelligent computer aided design system which caters for the freedom of design as well as leading to possible optimum solutions[19]. As a consequence only certain characteristics of Artificial Intelligence were employed, leaving some decision making to the designer.

6. 2. STANDARDS AND FREEDOM OF DESIGN.

One of the main human characteristics is making decisions based on the result of certain comparisons. This concept has been captured within this Decision Support System for the design of cold formed sections by the use of production rules. The British and European Standards for the design of cold formed section, after careful study, can

be used for this type of decision making. The advice in terms of recommendations, restrictions and optimal considerations have been determined by using the British and European Standards as a Knowledge Base to the system. This has the added benefits of making sure the designer is designing to the code of practice.

A new heuristic technique has been adopted based on information derived from the standards which directs the designer in the correct sequence of steps to try and achieve optimal designs. This direction is determined by a comparison of data and the result of specifics calculations carried out using equations specified by the standards.

Certain algorithms were developed to get the correct analysis on the design, as well as interpreting the information it is given correctly. The designer is given advice which directs the designer towards the full utilization of the profile strength, and consequently an optimal design. The freedom of design is not sacrificed as the designer is given options at various stages of the design and not take the path which leads to full utilization. Even in such cases the code of practice is still followed.

6.3. PRODUCTION RULES

A production rule is a situation action couple[20], meaning that when a certain situation is encountered, given as the left side of the rule, the action on the right is performed; very often the action is the taking of some decision, but this need not always be the case. There is no prior constraint on the form of the situation or of the action.

Most decisions in engineering are based on a comparison of data and results from calculation of equations. As a consequence production rules are found to be best suited for this type of system, where the data is compared with information from the standards. This information may be the result obtained from an equation given by the standards. The resultant action is performed either as directed by the standards or the heuristic method developed, based on their use.

To show how these rules are used to make decisions or actions, consider the method used to determine the design stress for cold formed sections. The British Standards give the following information in determining the design stress :-

The design stress P_y , should be taken as $0.95*Y_s$, but should not be greater than $0.78*U_s$

where, Y_s is the maximum yield strength, and U_s is the ultimate tensile strength.

This is determined by the system using production rules that is,. IF..THEN.. or IF..THEN..ELSE type rules. Y_s and U_s are entered into the system. The system allocates two variables to the possible design stress, d_1 and d_2 , that is,

$$d_1 = 0.78* U_s \ , \ \ d_2 = 0.95*Y_s$$

The design stress is then determined as follows :-

IF $d_1 <= d_2$ THEN $P_y := d_1$ ELSE $P_y := d_2$

-------   --------   --------

rule   Decision performed   Decision performed
                      if rule true.   if rule false.

Using these production rules the different concepts of Artificial Intelligence are introduced into the system.

6.4. ADVICE

The given is based around the method of design using the computer aided design system which performs repetitive and technical calculations. There are three distinctive ways in which the advice is

given to the designer:-

1) The advice is given directly from the British Standards.

2) · The advice is given as a result of information provided.

3) The advice is given when certain features of the design are inconsistent.

6.4.1. Direct Advice

This type of advice is straight forward to implement and does not require the use of production rules.

eg.,

Before the design stress is determined for the profile the designer is asked to give the yield stress and the Ultimate tensile stress. The code of practice gives the following information concerning the yield stress :-

If the yield stress is unclassified the value of yield stress should be given as ;

1) 210 N/mm^2 for hot rolled structural quality
2) 185 N/mm^2 for others.

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This information is provided to the designer when requested to enter the yield stress.

6.4.2. Conditional Advice

To show how the second type of advice is implemented, consider the restrictions on the flat widths on compressive and tensile elements, given by the British Standards.

Given the following information :-

1. Thickness of profile, t

2. The design stress, P_y

3. The depth of web, W

4. The percentage of curling, C

When considering the limitations due to curling, the maximum flat-widths for flanges disregarding intermediate stiffeners in tension and compression are :-

1. For element/flange connected to webs along both edges, the maximum length of element is given by $2*W_f$.

2. For element/flange connected to a web along one edge, the maximum length of element is given by W_f.

Where

$$W_f = (14800*t*W/P_y)^{1/2}*(C)^{1/4}$$

6.4.3. Optional Advice

This type of advice is based on variable factors, which may change due to other factors which are given at a later stage. Information and recommendations are based on how these changes will effect the optimal capacity of the profile under consideration. Production rules are important in determining if new factors will effect the changes.

The design stress is initially determined using the method already illustrated. When the profile is subjected to beam loading then the design stress may be affected by the size of the web.

The British Standards state that the compressive stress on the profile should not exceed the value P_c given by the following expression ie, :-

$$P_c = \{ 1.13 - (0.0019*D*(Y_s/280)^{1/2} / t) \} * P_y <= P_y \quad .....(eqn. \ 6.1)$$

Where,

D is the web depth

t is the section thickness

Y_s is the material yield stress

P_y is the design stress

The advice given is based on the value of the depth of the web. In order to determine when equation 6.1 is valid, the limiting value of the depth of web, D_1 is required. D_1 is determined by equation 6.2, which is given by assuming that $P_c = P_y$.

$$D_1 = 13*t*(280/ \ Y_s)^{1/2} / \ 0.19 \quad ....(eqn. \ 6.2)$$

After the designer has given the hight of the web which he wishes to use. This value is compared to D_1 with the use of production rules. If the height of the web is larger than D_1, the designer is

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informed that the height of the web which he wishes to use is too large to be fully effective. He is recommended that if he still wishes to use the same height, a web stiffener would give a more effective web, otherwise the design stress will be reduced in accordance to equation 6.1.

The recommendation for using a stiffener is derived from the British Standards which provide a second equation, when an web stiffener is used. Provided the stiffener satisfies the requirements of minimum moment of inertia, the new equation is given as :-

$$P_c = \{1.13 - 0.0019 * D_e * (Y_s/280)^{1/2} / t)\} * P_y <= P_y \quad .....(eqn. \ 6.3)$$

Where D_e is the larger of the values given by

$$D_e = D_z \qquad\qquad ....(eqn. \ 6.4)$$

$$D_e = D - D_z/4 \qquad\qquad ....(eqn. \ 6.5)$$

and D_z is the distance from the center line of the stiffener to the tensile edge.

Should the designer use a web stiffener as recommended then the designer is given advice on the optimal position of the stiffener on the web. This is derived from minimising the value D_e. This minimum value, D_{min} is obtained by equating equations 6.4 and 6.5. (i.e, $D_{min} = 4D/5$)

The designer is then requested to provide the distance from the center line of the stiffener to the tensile edge, so that the design stress can be determined.

Alternatively if the designer chooses not to use a stiffener, he is requested to re-enter the web height. This gives the option to the designer to either restrict the web height to the maximum effective height. Equation 6.1 is used to determine the new design stress if the height entered is still greater than the maximum effective height.

6.5 DETERMINATION OF EFFECTIVE WIDTHS

Artificial Intelligence concepts are also used in determining the section properties of a profile in accordance with the standards. In this case production rules used to determine if editing facilities are required, that is, if effective widths have to be taken.

The method of determining section properties requires the use of effective widths particularly when local buckling is likely to take place. Local buckling occurs on the compressive elements and effective widths are a method by which the area of the compressive element can be reduced for the purpose of calculating the moment of inertia. This is to give an accurate picture of the carrying capacity of the profile under loading. For the purpose of determining the effectiveness of

compressive elements they are classified into two types:-

1. Intermediate compressive elements, where the element is attached at both end either by web elements at each end, or by a web element at one end and a stiffener element at the other.

2. Edge compressive element, which is attached to a web element or stiffener element at one end, and no element at the other.

The kind of local buckling depends on the type of compressive element used. The edge compressive elements are not very resistant to local buckling, and in all cases effective widths have to be taken. Whereas the type and extent of local buckling on intermediate compressive elements depends on the thickness and width of each compressive element, and the actual stress acting on each one.

Production rules are used to determine if an intermediate compressive element is fully effective or if effective widths have to be taken. Initially the limiting case is established using the design stress, in the equations provided by the British Standards. This is also given as information to the designer as the maximum fully effective compressive width at the design stress, prior to entering the data of the profile.

After the profile data has been entered, all the compressive
elements are checked for effectiveness at the design stress. If an edge
compressive element is found, by being either the first entry or the last
entry in the data, effective widths for that element will have to be taken
on that element. The effective width, b_e for that element is determined
and substituted in with a dummy element, reconstructing the whole
length of the edge element (as shown in diagram 6.1a).
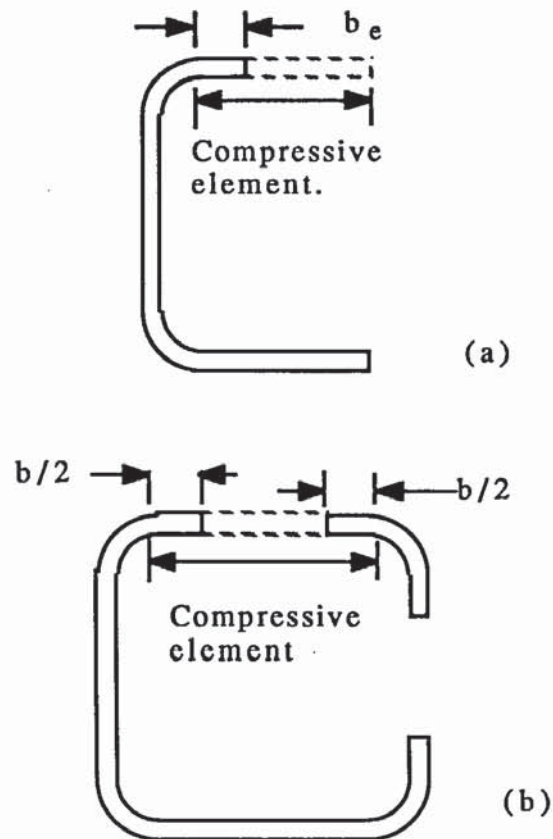
Diagram 6.1: Showing the profile data as seen by the computer for the
calculation of the section properties.

Where,

b_e - effective length of edge compressive element

b - effective length of intermediate compressive element

When intermediate compressive elements, are found ineffective by the production rules, their effective length, b is determined. Substitution is carried out by splitting b into two halves with a dummy element in the middle, reconstructing the whole length of the intermediate compressive element (as shown in diagram 6.1b).

The effectiveness of elements have to be determined at the actual stress on compressive elements at failure, rather than at the design stress. A method was developed to determine the actual stress on the compressive elements at failure, and hence obtain the true effectiveness of the compressive elements. From recognising the profile and determining the neutral axis, it can be decided whether the failure is at the tensile part of the profile or at the compressive part. If the failure is at the compressive end, the data does not need to be changed again.

But if the failure is at the tensile end, the actual stress at the compressive end has to be determined. This stress is obviously lower and the effective widths for the profile have to be determined again. Once the re-edited profile has been re-analysed, the actual stress at the compressive end will be at lower value. This change is due to the

increase in area on the compressive side due to more of the compressive elements being effective. The process is then repeated again until the change in the value of the effective widths when calculated is negligible.

When having to use effective widths, the whole profile is not being utilized to its maximum capacity. This cannot therefore be an optimum design. If large compressive elements are required then the use of stiffeners would be more appropriate then taking effective widths.

6.6 DESIGN OF STIFFENERS

The objective of the system is to try and maximise the use of the material for its structural requirements. As such, when effective widths are required, the objective is not achieved. So as a simple alternative, which makes a slight to the design, the use of stiffeners makes for a more effective profile. Stiffeners break up the formation of local buckling and as a consequence enable the profile to carry a greater load. So in keeping with the objective, whenever the system encounters in effective elements it advises on the use of stiffeners.

The advice on stiffeners is given by the system as if the designer is consulting an expert. The advice given by the system is related to the

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type of stiffener being required.

There are two types of stiffeners :-

1. Edge stiffeners - these are stiffeners such as simple lips, which are attached to edge compressive elements making them intermediate compressive elements.

2. intermediate stiffeners - these are bends or troughs designed in an intermediate compression element. Any number can be used provided they satisfy the condition required for their effectiveness.

Consider the advice on an edge stiffener. One of the most common stiffeners for edge compression elements is a simple bent lip. The system depending on the size of the edge compression element, that is its length and thickness, gives the length of the lip required.

Alternatively, should the designer require a different stiffener, the system will carry out a sequence of steps in conjunction with the designer. This sequence is as follows :-

1. The system will inform the designer the requirements of the stiffener designer, that is, the minimum moment of

inertia.

2. The designer is then requested to enter the design of the stiffener he requires, in a similar method to the profile data.

3. Determination of the moment of inertia for the designed stiffener.

4. Display of the designed stiffener.

5. The stiffener is then determined by the system to be either suitable or not. This is done by comparing the moment of inertia of the stiffener to the requirements.

6. If the stiffener is not suitable, the designer is requested to redesign.

This shows the combination of production rules with mathematical analysis of the stiffener data, combine to make decisions in a similar manner to an expert in this field.

The designing of inter-stiffeners is done in a similar way, but the requirements are more complex. There is no simple lip which can be used here, and therefore the stiffeners will always have to be designed.

The method used is as follows :-

1. The system identifies the ineffective intermediate compression elements.

2. The system estimates the number of stiffeners that will be required. This is done by dividing the length of the intermediate compression element by twice the maximum length of a fully effective compression element and approximating to the nearest high integer. This is the number of stiffeners that the designer is advice to use. Although the designer is given the option to enter the number being designed.

3. The required moment of inertia is determined by the system, depending on the length of the stiffener, the thickness of the profile and the number of stiffeners being designed.

4. The designer is requested if the stiffeners are identical or different, so that the system does not repeat the same process, making it laborious.

5. The designer is requested to enter the stiffener design.

6.   The system determines the moment of inertia for the designed stiffener and displays the designed stiffener giving information on its length and depth.

8.   The moment of inertia of the stiffener is then compared to the requirements by the system and determined to be suitable or not.

9.   If the stiffener is not suitable, the designer is requested to redesign.

10. If several stiffener are being designed and they are not identical, then steps 5-9 are repeated for each stiffener.

12. Once all stiffeners for the intermediate compression element are found to be suitable. The whole stiffened replacement for the compression element needs to be checked for effectiveness. The designer is requested to enter the whole stiffened replacement.

13. The moment of inertia is determine for the designed replacement, as well as being displayed with information of its total length and depth.

14. The effectiveness of the stiffened compression elements is established by calculating an equivalent thickness for the compression element between two webs or web and stiffener.

6.7 PROFILE RECOGNITION

For the system to recognise if elements are effective or not, it must understand the profile data presented to it. One of the features of a human is the ability to understand what is presented, and make decisions accordingly. When the human is given a profile to look at, the human can visualize the profile, determine where the loading is applied and what part of the profile is in compression.

Similarly, the systems needs to regard the data presented to it, so that it can be "visualized", determining the compression elements from the tensile elements and web elements. The method used to assist the system in this recognition is by symbolic representation or more accurately in this case, numerical representation. In the declaration of the data types, the elements are split to five different types, namely as shown below.

TYPE	MEANING
1.	Web element
2.	Compressive element
3.	Tensile element
4.	Circular element
5.	Dummy element

Types 1, 2, and 3 are flat elements. This reclassification makes the identification and determination of effective widths much easier. Each time the system encounters a compressive element it can then determine its effectiveness, and carry out the operations as directed by the designer.

The identification of an edge compressive element is more difficult. It is achieved by flagging the computer when it encounters either the first or the last compressive element as the first or last element in the profile data.

One of the principal problems in profile recognition is determining what part of an ineffective profile (that is,. tensile or compressive) is controlling the failure when used as a beam. This is required to determine the actual stress at failure on the compressive elements so that their effective widths can be calculated properly.

The system can decide if profile is effective or not by having a symbolic representation (that is, a profile type), telling it what type of profile data it is analysing. (This is so it can differentiate between ineffective profiles where the dummy elements are introduced for calculations, as compared to profiles where dummy elements represent slits, or holes.) Once the centroid of the ineffective profile is resolved, the maximum and minimum distances from the centroid are determined in vertical, y direction. The information about the type of elements at the extreme limits is recorded to enable the computer to determine which type of element is causing the failure.

To show how this is accomplished, consider an ineffective profile with n elements. Let type[i], ylen[i] be the variables containing the type information and the end y co-ordinates the ith element relative to the centroid. Using production rule on each element by iteration the task is carried out. Then production rules which are used on the ith element are as follows :-

IF   ylen[i] < = minyelem

THEN minyelem : = ylen[i]   and minytype : = type[i]

Where minyelem contains the minimum y distance from the centroid and minytype contain the type of element at that extreme.

IF   ylen[i] > = maxyelem

THEN maxyelem : = xlen[i]   and maxytype : = type[i]

Where maxyelem contains the maximum y distance from the centroid and maxytype contain the type of element at that extreme.

The rules would be applied on all the elements of the profile, from i=1 to i=n. This establishes the extreme distances from the centroid and what type of element is there. The actual kind of failure is determined by establishing the smaller of the extremes from the centroid. This extreme element is checked to see if it is either a compression element or a dummy element. Which if so would mean the failure is by the tensile side. The dummy element is looked for, by the system as it already knows the profile is ineffective, and the dummy element represent the ineffective part.

IF   {(absolute value of maxyelem < absolute value of minyelem)

      and   (maxytype : = 2 or maxytype : = 5)   or

      (absolute value of maxyelem > absolute value of minyelem)

      and   (minytype : = 2 or minytype : = 5)}

THEN the profile is failing due to the tensile side.

Once it has established the failure either way it can resolve the solution as described earlier.

6.8 LATERAL BUCKLING

One of the main considerations in the designing process is will the profile fail by lateral/lateral-torsional buckling. The British standards provide a set of equations and rules to determine the bending moment which may cause this kind of failure.

Using these rules and equations a consultancy type procedure was designed. This enables the system to determine the criteria for failure after a question and answer session with the designer. The initial consultation determines the effective length of the beam under consideration. This effective length is used in the equations which work out the bending moment to cause lateral failure. Then depending on the type of beam being designed the appropriate equation is applied to determine the bending moment to cause lateral failure. Comparing this value with the value of bending moment to cause normal failure gives information on the type of bending.

This consultation is only entered into if lateral/lateral-torsional buckling is likely. This is because lateral buckling will not occur if a beam is loaded in such a way that bending takes place about the minor

axis (x-axis), or if the beam is adequately restrained against lateral movement and twisting.

i.e,

IF $I_x > I_y$ THEN enter consultation.

Where I_x is the moment of inertia about the x-axis and I_y is the moment of inertia about the y-axis.

6.9 WEB CRUSHING

The British standards provide a complex set of rules to determine if web crushing is likely to occur. The loading is examined to determine which equation gives the limiting equation to use for each point load or reaction. Initially the systems determines if the equations are valid by consulting the designer on certain features of the profile and loading.

Using the production rules in a particular sequence the system can compare each load or reaction with the limiting condition given by the equations. The limiting conditions are different depending on where the load or reaction is acting from the edge of beam and if there is any interference from other loads. These rules are applied sequentially by analysing the loads first and then the reactions. There are four different

conditions which apply and these are split into two types :-

1. Where there is no interference from other loads or reactions. That is, the distance between opposite loads or reactions is greater than one and a half times greater the height of web (a and b in diagram 6.2).

2. Where there is interference from other loads or reactions. That is, the distance between opposite loads or reactions is less than one and a half times greater the height of web (c and d in diagram 6.2).

Each of these two types are split into the two following :-

1. The load or reaction is near the edge. That is the distance between the load and the edge is less than one and a half times greater the height of web (a and c in diagram 6.2).

2. The load or reaction is not near the edge. That is the distance between the load and the edge is greater than one and a half times greater the height of web (b and d in diagram 6.2).
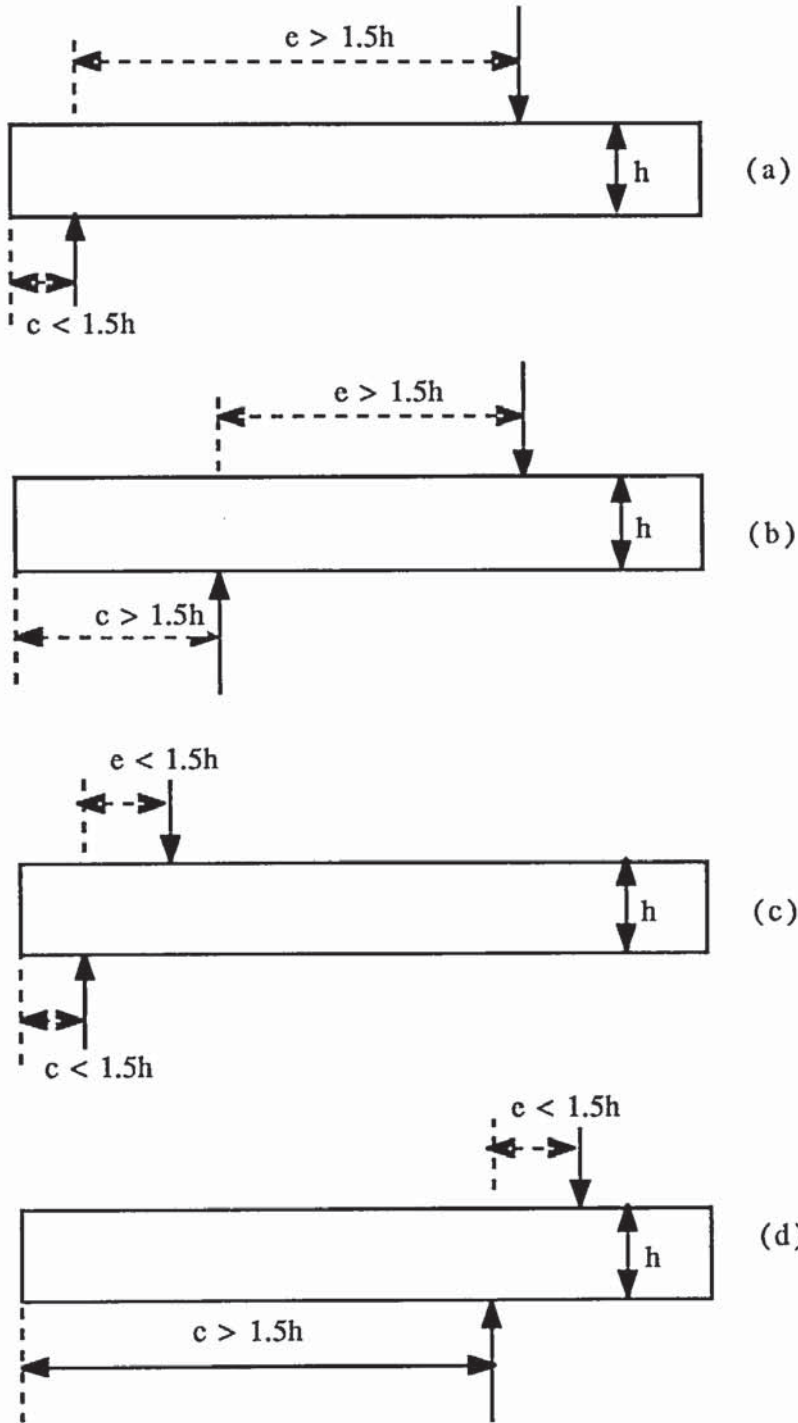
Diagram 6.2   Showing The Differing Conditions To Determine
The Limiting Equation For Web Crushing

Where, h is the height; c, the distance from the edge of the profile; and e, the distance between interfering loads or reactions

Consider the rules applied on the ith load, at a distance P from one end (end A), on a beam length L, with n supports.

IF   (P <= 1.5h)   or   ({L - P} <= 1.5h)   ... rule 6.1

THEN   Condition limit = (a)

      Unless IF   (absolute value of (P - M[j]) < 1.5n)   ... rule 6.2

           THEN   Condition limit = (c)

IF   (P > 1.5h)   or   ({L - P} > 1.5h)   ... rule 6.3

THEN   Condition limit = (b)

      Unless IF   (absolute value of (P - M[j]) < 1.5n)   ... rule 6.4

           THEN   Condition limit = (d)

where M[j] is the distance of the jth reaction from end A, and each reaction from j=1 to j=n is considered to determine if the second rule is true. If rule 6.1 is true then either condition a or condition c is true. Rule 6.2 resolves this because if during the iteration it is true then condition c applies otherwise condition a applies. Similarly rule 6.3 and 6.4 determine if conditions b and d apply. Rule 6.1 is complementary to rule 6.3 because if rule 6.1 applies then rule 6.3 does not and vice versa. This ensures that one condition always applies.
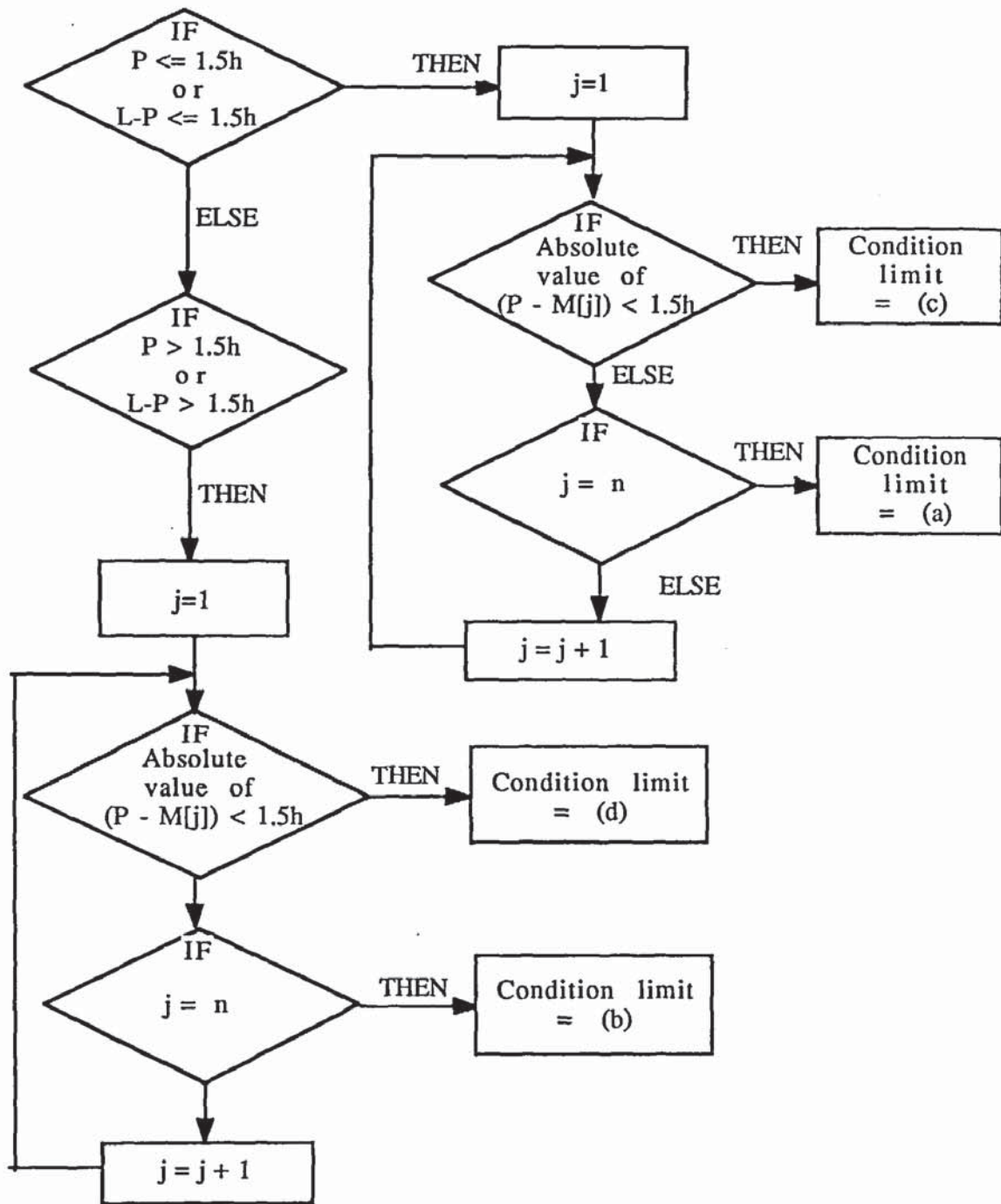
Diagram 6.3: Flow Chart Of How System Determines Which
Condition Applies To Check The Load Or Reaction

The Diagram 6.3 shows the flow of determining the actual condition limit. These conditions are applied repeatedly for each load and reaction.

6.10 CHECKING THE PROFILE TO THE LOADING

The following conditions are determined across the beam :-

(1)   The Bending Moment
(2)   The Shear Stress
(3)   The Deflection

The bending moment is then compared with the moment capacity of the profile across the beam. A graph is drawn showing the bending moment in relation to the moment capacity. If the moment capacity is exceeded the system reports failure of the profile to carry the designated load. Similarly, the shear stress across the beam is compared with the permissible shear given according to the standards.

The standards give the equations to be satisfied for the combination of bending moment and shear stress, and the combination of bending moment and web crushing. The former is determined across the beam and the later at the action of loads and reactions.

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The standards give some advice on the type of deflection ratio that should used for each type of beam. But the designer is required to supply the ratio to be used. The deflection ratio is determined across the beam by dividing the deflection by the particular span where the deflection is taking place. This then is compared with the deflection ratio given and failure is reported if this is the case.

The designer is given the type of failure occurring if this is the case, or graphs of the shear stress, bending moment, and deflection ratio as compared with their limit. Thus the designer can determine if the design is good or that changes are required.

CHAPTER 7

DESIGN

METHODOLOGY

DESIGN METHODOLOGY

7.1 INTRODUCTION

In the previous chapters, specific parts of the designing process have been detailed. From all these different aspects, it may be difficult to visualise how they help in the designing of cold formed sections. This chapter shows how all these different aspects have been combined in a design methodology, helping to obtain optimum designs.

The method used is carried out in three distinct stages. Although the method has incorporated some Artificial Intelligence concepts, the designer remains in complete control of the design. When all three stages have been followed, the designer makes the final decision on whether the design is satisfactory or a new one has to be designed.

The three stages in the design methodology are :-

1. The optimum analysis of the profile.
2. The beam loading design.
3. The testing of the profile with the loading.

7.2 OPTIMUM ANALYSIS

In the optimum analysis of the profile the designer is encouraged by the system to design a section which is fully effective. The system is designed to handle cases where the profile designed may not be fully effective. This gives maximum freedom of design to the designer and still perform the design in accordance with the British standards.

Diagram 7.1 illustrates the whole process of optimum analysis of the profile. This analysis consists of six main parts which are shown and numbered in the diagram.

1. The designer enters the information about the profile, while being given advice and restrictions.

2. The system validates the data and determines the effectiveness of the profile.

3. The method of editing the profile the profile data for reduction in area for the purpose of calculating the section properties. It also establishes if work hardening will be required.

4. The method by which assistance is given to the designer to determine effective stiffeners for the profile.

1 — Profile data entered into the system with decision support from the system.

4 — Stiffners designed in accordance with specifications given by British standards

2 — System checks to see if the design is fully effective.

No → Designer determines if stiffners are required.

Yes (up to box 4)

No → **3** — Calculates effective widths for the profile and changes the profile data.

Yes (from box 2, downward) → **6** — System calculates the section properties of the designed profile

Determines if the limiting stress is less than used for design.

Yes → box 3

No → System calculates the section properties of the designed profile

5 — Calculates the limiting stess upon the effective elements at full stength.

Diagram 7.1: Showing the Method of Optimization of the Profile.

5.   The optimum analysis of ineffective profiles.

6.   The determination of section properties and the display of
the section profile.

The method for points 5 and 6 have been explained previously in
chapters six and four respectively.

7.2.1 Initial Profile Decision Support

The flow diagram 7.2 illustrates the method of giving the
designer, decision support, informing him of restrictions and possible
improvements. The flow diagram is explained by the following
referenced points.

1.   The values of Section number, Ultimate Tensile stress, and the
Yield stress are requested, the later having some guidance to its value.
The section number is used for identification, when the data about the
profile is transferred from program to program. This can also be used to
build an archive of designed profiles.

2.   The Ultimate Tensile stress and the Yield stress are requested to
determine the design stress. This is evaluated as the lesser value of either
seventy eight percent of the Ultimate Tensile stress or ninety five
percent of the Yield stress.

```
┌─────────────────────────────────┐
│ System requests information     │
│ from designer as well as giving │
│ some informative advice.        │
└─────────────────────────────────┘
   (1)
          │
          ▼
┌─────────────────────┐
│ Determines   the    │
│ Design  Stress      │
└─────────────────────┘
   (2)
          │
          ▼
         Is                    No
      Thickness  ──────────────────►  End.
       < 8mm
   (3)
          │ Yes
          ▼
                                                    ┌──────────────────┐
         Is            Yes    ┌──────────────┐      │ Information       │
     Web height ──────────────►│ Web          │      │ on effective Web  │
       >H                     │ Information  │      └──────────────────┘
   (4)                        └──────────────┘         (6)
          │ No                   (5)         Does
          ▼                                the Web
┌─────────────────────┐                    have a
│ Restrictions due to │◄─────────────────  stiffener
│ Curling             │                        │ Yes
└─────────────────────┘         ┌──────────────┐
   (8)              ◄────────────│ Advice on     │
          │                  (7) │ Web stiffener │
          ▼                      └──────────────┘
┌─────────────────────┐
│ Restrictions on     │
│ Compressive elements│
└─────────────────────┘
   (9)
          │
          ▼
    ╭─────────────────╮
    │ Profile Validation │
    ╰─────────────────╯
```

Diagram 7.2 : Showing the Outline Method of Initial Decision Support.

3.   The British Standards for cold rolled sections do not apply for profiles whose thickness is greater than eight millimetres. Consequently as the advice of this method is based on these Standards, the designer cannot use this system.

4.   The section will fail at stresses lower than the yield if the web height is too large. The Standards provide equations for the reduction of design stress if the web height is too great. By determining the limiting condition of the height to produce this necessary reduction of stress, the designer can be informed of this requirement. This limiting height, H is obtained by the following equation:-

$$H = (1300/19)_*T_*(280/Y_s)^{1/2}$$

Where T is the thickness and Y_s is the yield stress.

5.   Should the web height be greater than the limiting value, further information about the web is given. Principally the system will advice the designer on the requirement of reducing the design stress, as well as informing him that the use of a web stiffener would enable the use of a larger web.

6.   If the designer decides to use a web stiffener, the designer is given the minimum moment of inertia requirement for that stiffener and its optimal placement. The maximum increase given from a stiffener

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in its web height without the reduction of the design stress is by twenty percent. If this height is still greater than this, the design stress is reduced accordingly.

7.   Alternatively, the designer is advised on the maximum height of web that does not require the reduction in the designing stress. The designer is asked to then enter the web height. This gives the option to the designer to change the web height should he wish to.

8.   The Standards give an equation by which the percentage of curling caused can be calculated. The Standards state that curling greater than five percent is excessive. As the curling depends on the size of the flanges, the limiting lengths can be estimated from this equation. The system determines the allowable flange lengths in compression and tension given the percentage of curling acceptable by the designer. The designer is informed that up to five percentage is not considered excessive. The amount of curling u, can be determined from the following equation :-

$$u = \frac{2 \cdot dy^2 \cdot b^2}{E^2 \cdot t^2 \cdot z}$$

Where

    dy   is the average stress on the flange being considered.

    b   is the width of the flange.

E   is Youngs Modulus.

z   is the distance from the neutral axis to the flange.

By approximating an estimation of the maximum flange width allowed can be made. This approximation is made by taking the worst possible case. That is using the design stress as the average stress on the flange and making the distance from the neutral axis to the flange equal to the height of the web.

Then diving each side of the equation by web height and multiplying by one hundred we obtain the curling as a percentage of the height of the web. Therefore the flange width b, can be given by the following expression :-

$$(E . t . h / (200 . dy))^{1/2} . (c)^{1/4}$$

Where

c   is the percentage of curling.

dy   is the design stress.

9.   The British Standards give the following information about compressive elements :-

The maximum width to thickness ratio for :-

(a) Stiffened elements having one longitudinal edge stiffener

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connected to a flange or web element, the other stiffened by:

Simple lip	60
Any other type of stiffener satisfying the minimum moment of inertia requirements	90

(b) Stiffened elements with both longitudinal edges connected to other stiffened elements   500

(c) Un-stiffened compression elements   60

Note: Un-stiffened compression elements that exceed ratios approximately thirty and stiffened compression elements that have ratios exceeding approximately two hundred and fifty are likely to develop noticeable deformation at the full working load, without affecting the ability of the member to carry this load.

This information is translated for the designer into actual widths, hence the designer can immediately see what his constraints are.

7. 2. 2 Profile Data Entry and Recognition

Given the decision support the designer is then required to enter the data of the profile he is designing. This initially requires the

starting angle. This is so that the system determine the section properties of the profile according to which way it is up. Then the actual profile data in terms of line and circular elements. The line and circular elements are defined in 5 types and displayed to the designer as shown in diagram 7.3 .

ADVICE

The maximum length of a full effective compressive element is xxx.xx mm. This is at the design stress .

Enter in the section profile into the text screen

Type

| Element No. | Type | length/radius | angle |

1. Web,lip or edge - flat
2. Compressive - flat
3. Tensile - flat
4. Angular
5. Dummy - flat
0. end of entry

Diagram 7.3 : Screen Layout Display during profile data entry

During the entry the system interactively validates the data and determines the status of the profile (i.e. if it is effective or not ? etc.). The method used is displayed in diagram 7.4 . Prior to the entry of data certain boolean variables are set to specific values which are changed when they encounter specific conditions. These variables enable the computer to recognised the profile and determine its status.

1.   Each element of the profile is entered into the system and

processed.

2. This element is checked with the web height as stated with by the designer. If the elemental height is greater than this value, the whole designing process has to be restarted.

3. If this element is the first element entered, then this is an un-stiffened compression flange and the system notes it as such. Otherwise it could be either the last element entered, in which case it would also be an un-stiffened compression flange; or an inter-compressive element. The system treats the element as an inter-compressive element at first, and determines if the element is effective or not. If the element is not effective, the system notes this and notes that work hardening cannot be taken into consideration in the design. Secondly it notes that it is the last element entered, until otherwise, and consequently an un-stiffened flange.

4. If the previous element was a compressive element, it would now not be considered an un-stiffened flange, unless it was the first element entered.
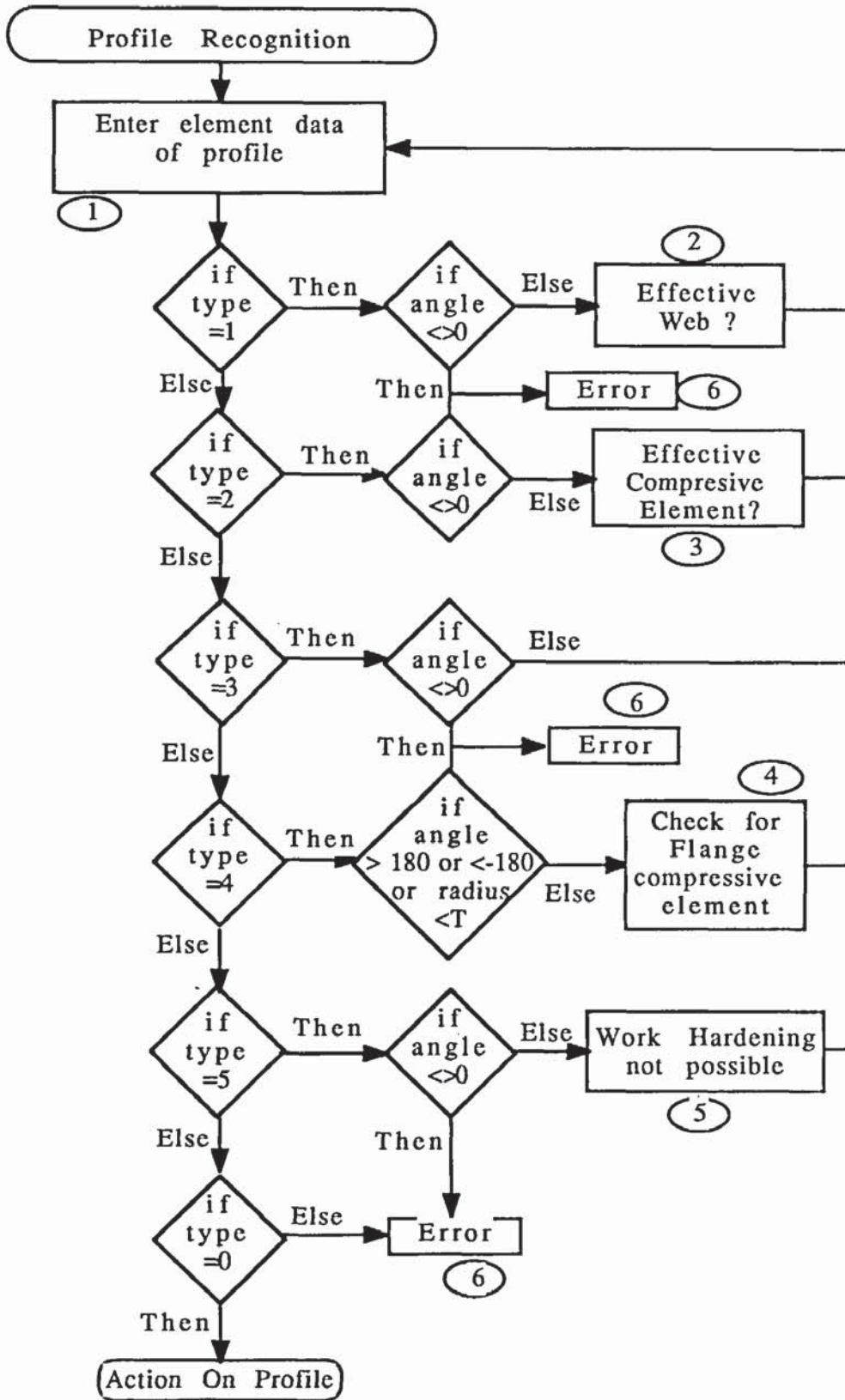
Diagram 7.4 : Showing the Method of Profile Recognition and Validation

5. When the system encounters this element type, it considers the profile to be not fully effective and consequently notes that work hardening cannot be taken into account.

6. The validation of the data is done by checking all flat elements for an angle, which should not exist. Angular elements are checked for limitations within their constraints and the internal radius which from practical methods of fabrication cannot be less than the thickness. When such an error is encountered the designer is required to re-enter the information of that element. This also enables the designer when making an erroneous entry in terms of type or length to re-enter that particular elemental data again.

7.2.3 Action on Profile

Once the process of validation an identification has taken place, the action for improvement or correct analysis is established as shown in diagram 7.5. The action is controlled by the system as shown in the diagram unless stated by an option, which give freedom to the designer.
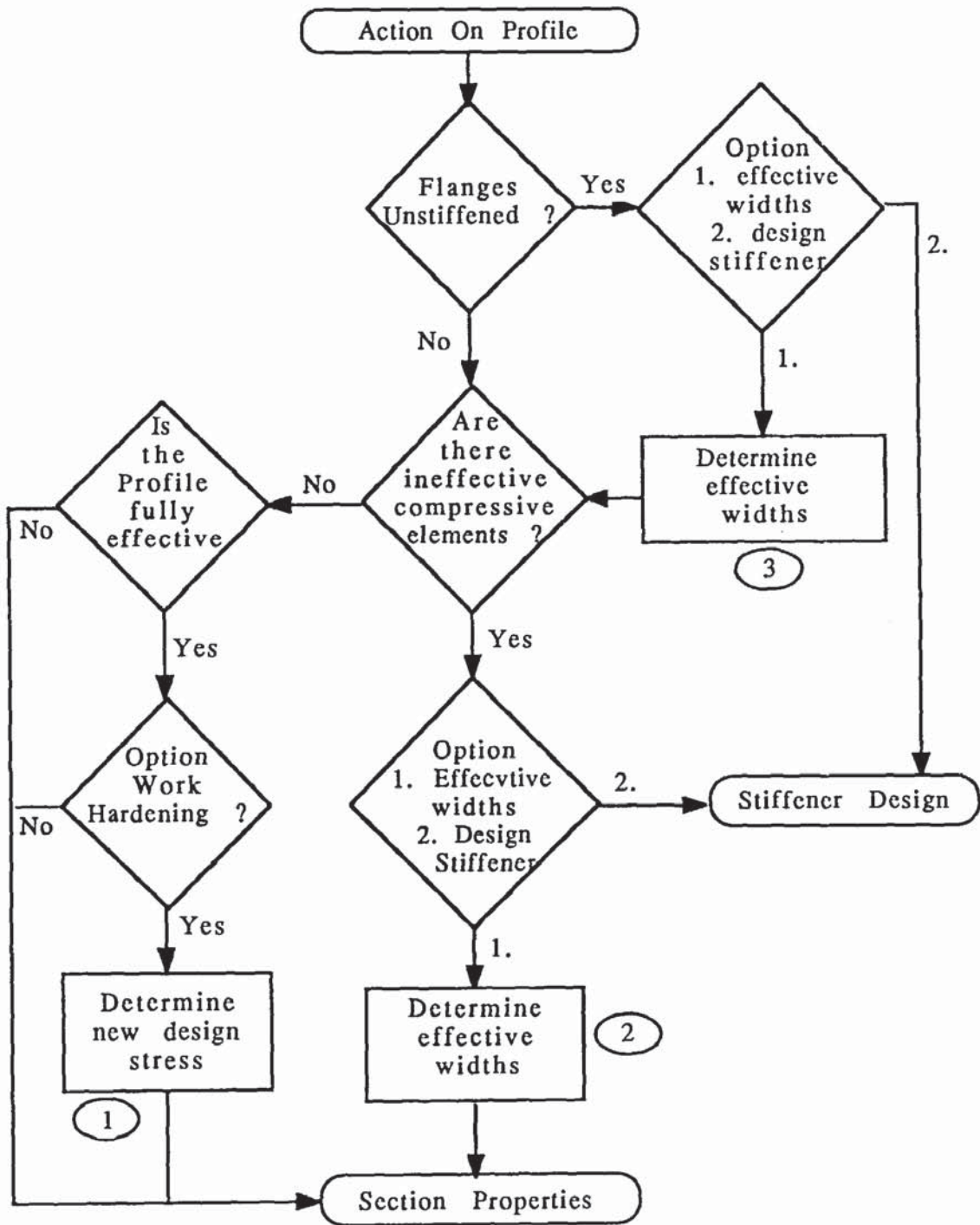
Diagram 7.5 : Showing How Action is taken for Analysis of Profile

1.   Work hardening is taken into consideration by determining a new design stress based on the equation provided by the British Standards.

$$Y_{sa} = Y_s + \{ 5*T^2*N*(U_s - Y_s) / A \}$$

Where

Y_{sa} is the new yield stress.

Y_s is the old yield stress.

T is the thickness.

U_s is the Ultimate Tensile stress.

A is the gross area of the cross-section.

N is total number of full 90° bends in the section. Fractions of 90° bends are counted as fraction of N

The design is re-determined in accordance to the method previously described.

2.   The editing of profile data for inter-effective elements is illustrated in diagram 7.6 . The method of replacing individual compressive elements was described in the previous chapter.

```
                    ┌────────────────────────────┐
                    │  Inter-elements   editing  │
                    └────────────────────────────┘
                                  │
                                  ▼
          ┌──────────────────────────────────────┐
          │         Read  Profile  data          │◄──┐
          └──────────────────────────────────────┘   │
                                  │                   │
                                  ▼                   │
                             ╱         ╲              │
              No            ╱    Is     ╲             │
      ┌──────────────────◄ ╱  element    ╲           │
      │                    ╲    type      ╱           │
      │                     ╲    4 ?     ╱            │
      │                      ╲         ╱              │
      │                           │                   │
      │                          Yes                  │
      │                           ▼                   │
      │                     ╱         ╲               │
      │        Yes         ╱    Is     ╲              │
      │  ┌──────────────◄ ╱  element    ╲             │
      │  │                ╲  effective ? ╱            │
      │  │                 ╲           ╱              │
      │  │                  ╲         ╱               │
      │  │                       │                    │
      │  │                       No                   │
      │  │                       ▼                    │
      │  │          ┌─────────────────────────┐       │
      │  │          │ Determine    effective  │       │
      │  │          │ widths                  │       │
      │  │          └─────────────────────────┘       │
      │  │                       │                    │
      │  │                       ▼                    │
      │  │          ┌─────────────────────────┐       │
      │  │          │   Replace   element     │       │
      │  │          │ with  effective widths  │       │
      │  │          │ and  dummy  elements    │       │
      │  │          └─────────────────────────┘       │
      │  │                       │                    │
      │  └───────────────────────┴────────────────────┘
      └──────────────────────────────────────────────┘
```
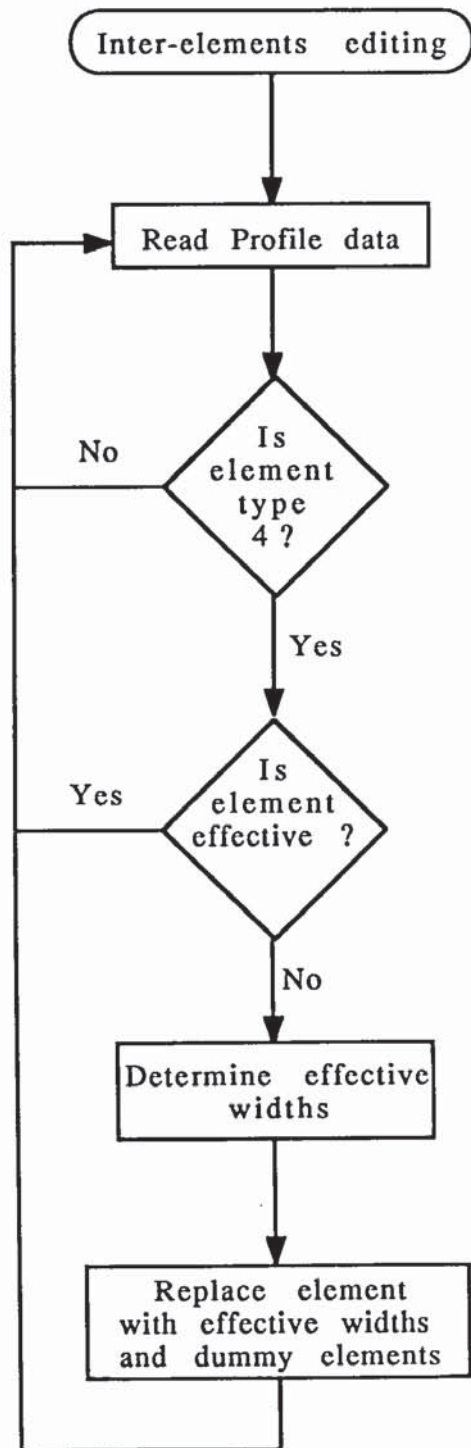
Diagram 7.6 : Showing the method of determining the profile
data of an ineffective profile requiring effective
widths

3.   Diagram 7.7 illustrates the method of editing the profile for un-stiffened flanges. Again the method of replacement was described in the previous chapter.
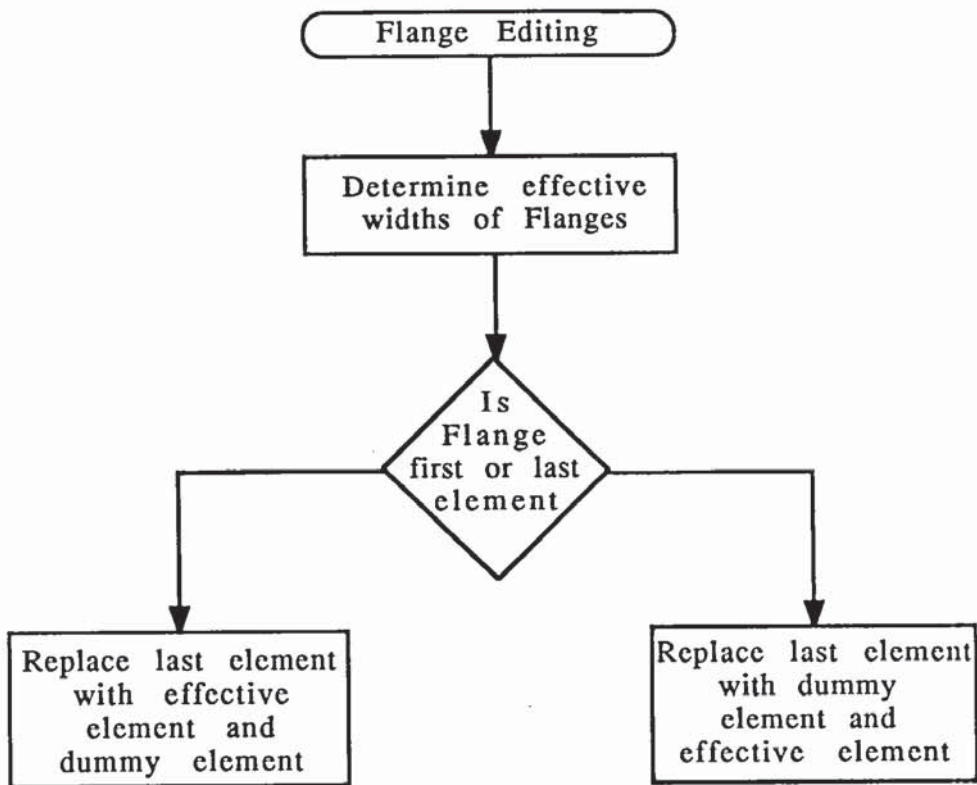
Diagram 7.7 : Showing method of editing data for un-stiffened flanges.

7.2.4 Stiffener Design

The design of stiffeners is carried out in two methods depending on the type of stiffener. That is either edge stiffeners or inter-stiffeners.

When designing an edge stiffener there are two routes which can be taken to assist the designer (see diagram 7.8). Namely the design of a simple lip, or a more complex stiffener. For the simple lip design, the size is given based on the standards. The size given is a fifth of the size of the flange from web to edge or inter-stiffener to edge.

Alternatively, the designer may require a more complex stiffener. The standards give the minimum moment of inertia, to be satisfied for an edge stiffener, as :-

$$I_{min} = T*(b/5 + r)^3/3$$

Where

I_{min} is the moment of inertia taken about the centre line of the flange.

T   is the thickness.

b   is the width of flange.

r   the centre line radius of the corner.

```
                    ┌─────────────────────────┐
                    │   Edge  stiffener  design │
                    └─────────────────────────┘
                                 │
                                 ▼
                            ╱        ╲
                          ╱  Option    ╲
                        ╱  1. simple lip  ╲ ──1.──►  ┌─────────────────┐
                        ╲  2.  another   ╱           │  Give   length  │
                          ╲            ╱             │  of simple lip  │
                            ╲   ▼    ╱               └─────────────────┘
                                │2.
                                ▼
                    ┌─────────────────────────┐
                    │   Give   information     │
                    │  on the  moment  of      │
                    │  inertia   requirements  │
                    └─────────────────────────┘
                                 │
        ┌────────────────────────┤
        │                        ▼
        │           ┌─────────────────────────┐
        │           │   Enter  stiffener  data,│
        │           │ determine  section properties,│
        │           │  and  display  stiffener.│
        │           └─────────────────────────┘
        │                        │
        │                        ▼
        │                   ╱        ╲
        │                 ╱    Is      ╲
        │   No          ╱  Stiffener    ╲
        └──────────────╲   O. K. ?     ╱
                         ╲            ╱
                           ╲   ▼    ╱
                               │ Yes
                               ▼
                    ┌─────────────────────────┐
                    │  Include  stiffener  in  │
                    │        design            │
                    └─────────────────────────┘
```
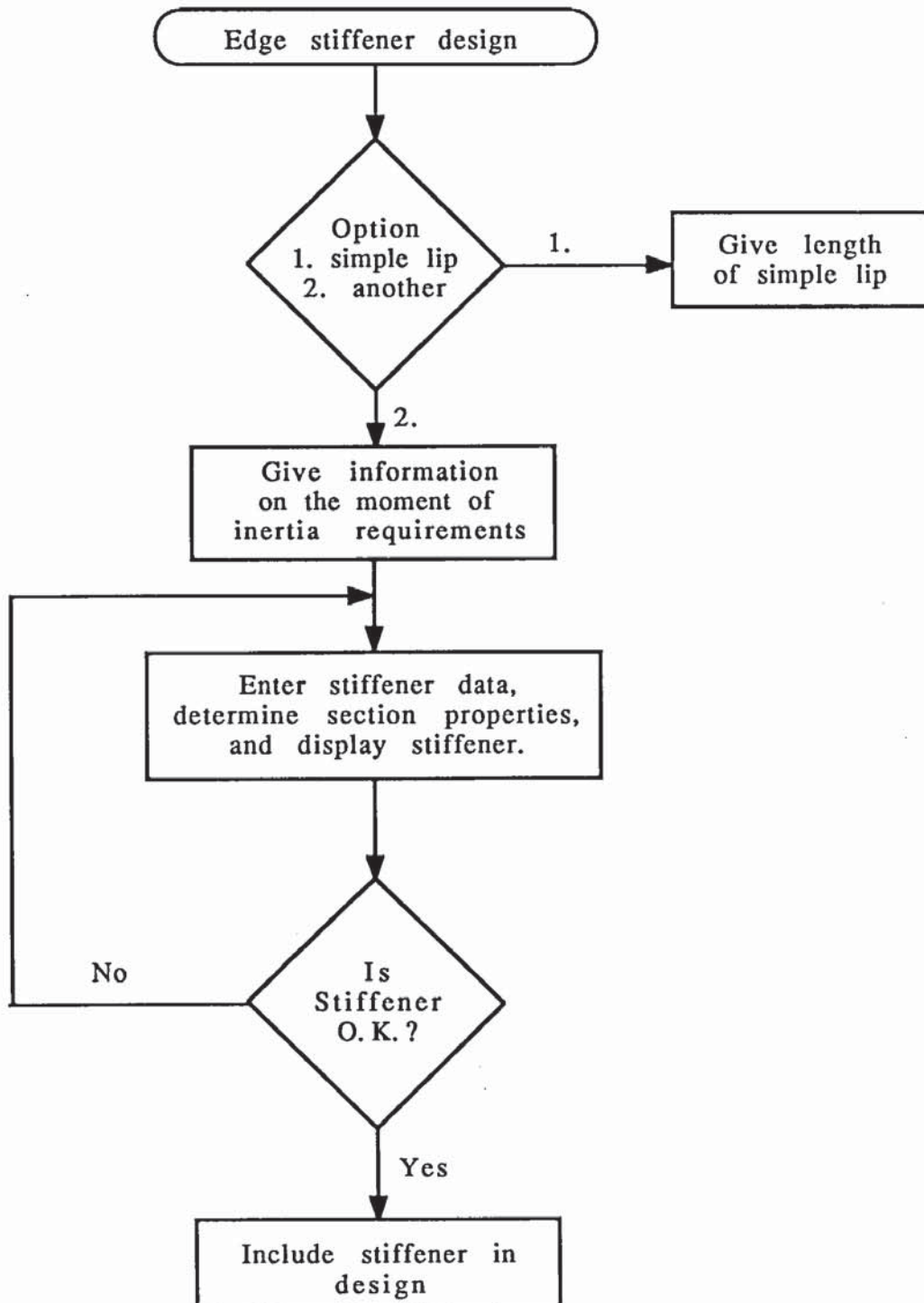
Diagram 7.8 : Showing the method of assistance given to designer in designing stiffeners

This can be modified to the following equation where the minimum moment of inertia is taken about the centroid of the stiffener:-

$$I_{min} = T*(b/5 + r + T/2)^3/12$$

Where

I_{min} is the moment of inertia taken about the centroid of the stiffener

T   is the thickness.

b   is the width of flange.

r   the internal radius of the corner.

The requirements are determined by assuming that r the internal radius is the same as the radius of the corner of the flange to the web.

The designer is then asked to enter the data of the stiffener in terms of line and circular elements. The moment of inertia of the stiffener are determined and the stiffener displayed (as described in chapter four). By comparing the moment of inertia of the stiffener to the requirements the designer is advised on the suitability of the stiffener.

The method for inter-stiffener is more complex. The outline method has been described in chapter six, and is illustrated in diagram 7.9.
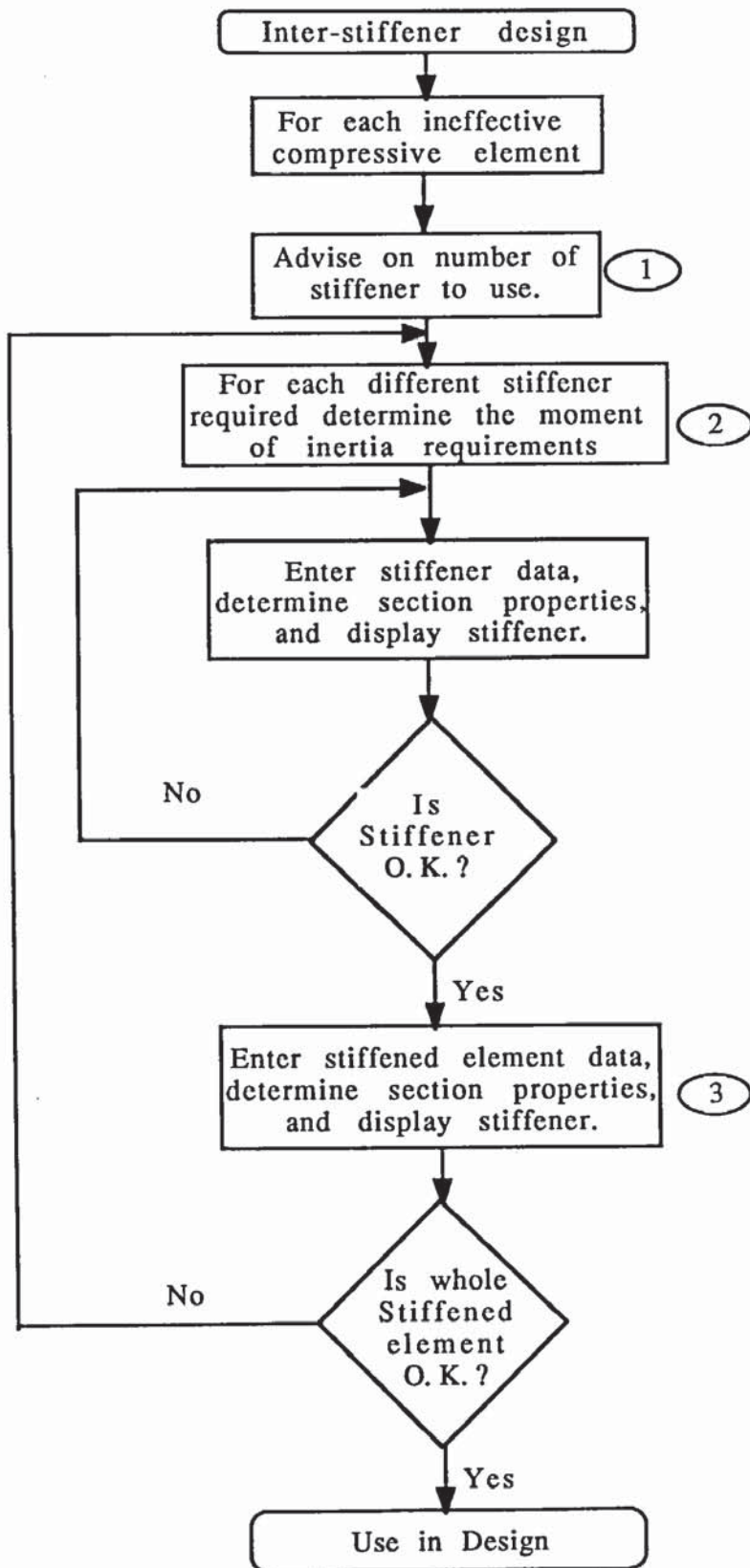
Diagram 7.9 : Showing the method of inter stiffener design

1.	The advice given on the number of stiffeners is based on the highest integer given by the following relationship :-

$$\frac{W_c}{2*W_e}$$

Where

W$_c$	is the width of the compression element.

W$_e$	is the maximum width of a fully effective compression element.

This relationship is used because the distance between stiffeners should be less than the width of a fully effective compressive element to be effective. Also this is to minimise the size of the stiffener to keep it a close to the original design. The designer is given the option to select the number he wishes to use.

2.	The minimum moment of inertia requirements are based on the equation given by the standards which is :-

$$I_{min} \quad = \quad 0.2 * T^4 * (w/T)^2 * Y_s / 280$$

Where

I$_{min}$	is the minimum allowable moment of inertia about an axis through the middle surface of the stiffened element.

w   is the flat width of the sub-element between stiffeners

Y_s is the yield stress of the section.

The value of the sub-element is determined by the number of stiffeners (n) being used. That is, w is given by W_c/n, where W_c is the width of the compressive element.

3.   The effectiveness of the whole stiffened element has to be checked. This is done by :-

$$W_s / T_s$$

Where

W_s is the whole width between two webs.

T_s is given by :

$$T_s = (12 * I_s / W_s)^{1/3}$$

Where

I_s is the moment of inertia of the full area of the multiple stiffened element, including the intermediate stiffeners, about its own neutral axis.

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7.3 BEAM LOADING DESIGN

The method of beam loading has been described in chapter five. The designer describes the beam loading condition to the system, which then computes the reaction on the supports. The designed beam is then displayed to the designer for conformation that the design is correct. A typical display is illustrated in diagram 7.10

1000N/m

1000N

239.6N   1604.2N   656.2N
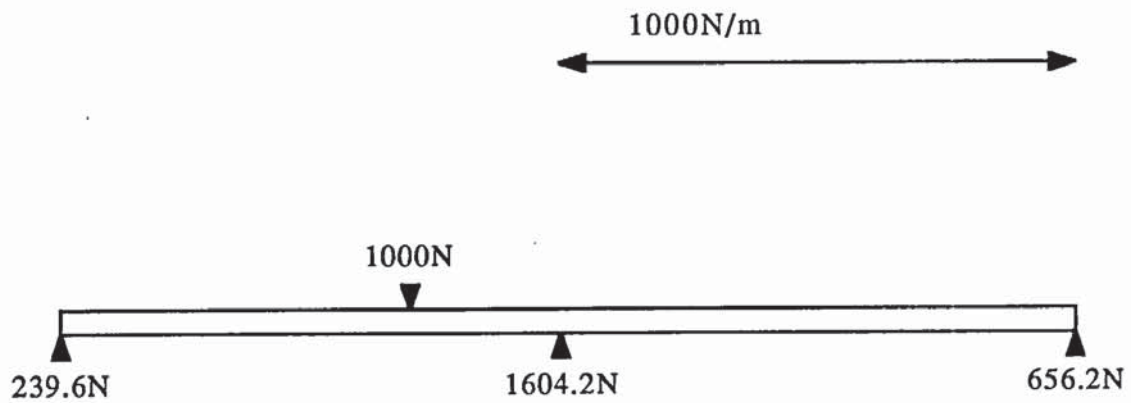
Diagram 7.10 : Showing the screen display of Beam Loading Analysis.

7.4 PROFILE TESTING

This is the stage where the profile is checked for failure. The types of failure criteria are determined and the suitability of the profile for the loading established (diagram 7.11).
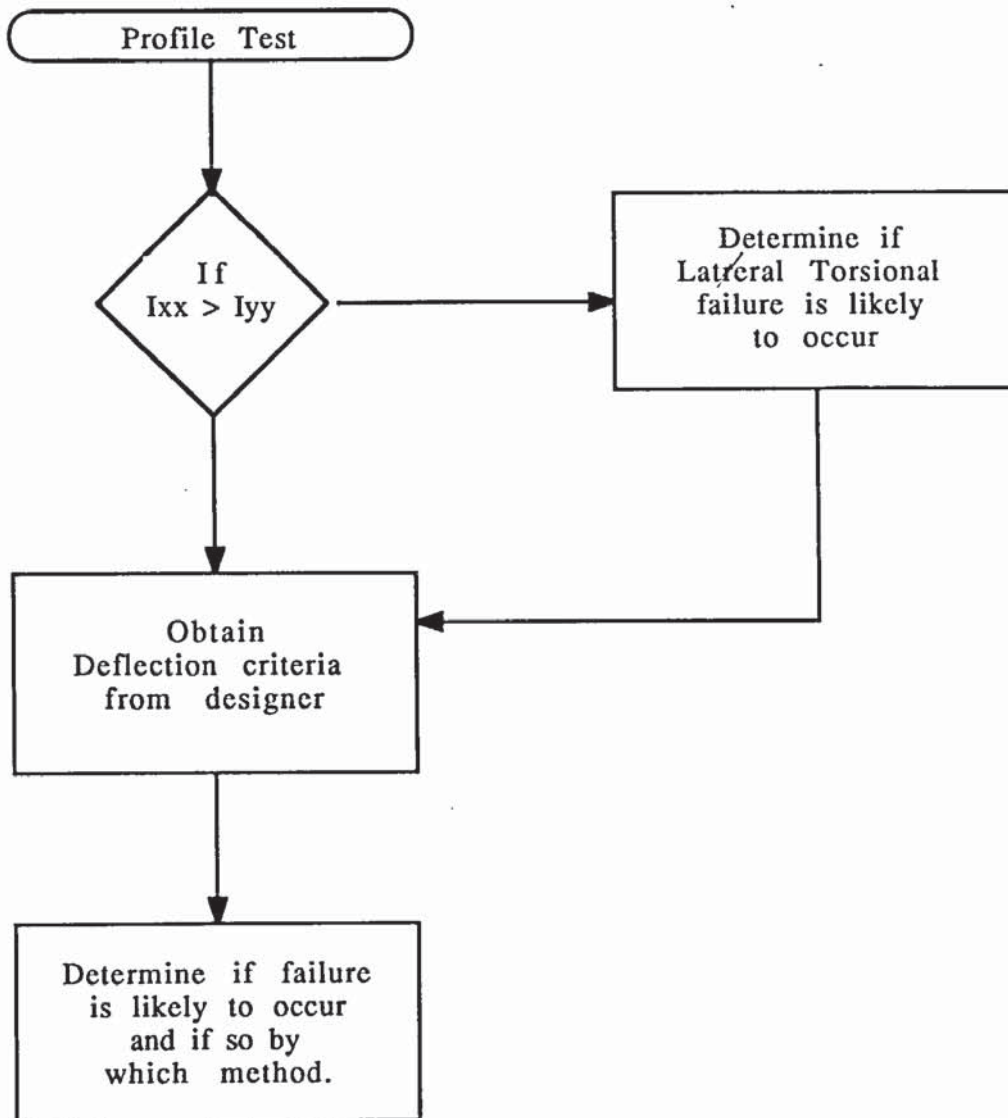
Diagram 7.10 : Showing the process of checking the profile.

7.4.1 Lateral Torsional Buckling

This is to establish if Lateral-Torsional Buckling will occur. This will only occur if the moment of inertia about the axis of bending (Ixx) is not the minor axis. The British Standards give the following equation to calculate the bending moment, M_b to cause lateral buckling :-

$$M_b = \frac{\{[\ M_p + (1+n)* M_e\ ] - (\ [M_p + (1+n)* M_e\ ]^2 - 4* M_p * M_e\ )^{1/2}\ \}}{2}$$

Where

M_p is the plastic moment capacity of the section.

M_e is the elastic lateral buckling capacity as determined from equations 7.1 to 7.4.

n is a constant, such that

when $L_e/r_y < 20$ $n = 0$

when $L_e/r_y > 20$ $n = 0.0035*(\ L_e/r_y - 20)$

and L_e is the effective length as given from the type of restraint applied to the section.

r_y is the radius of gyration of the section about its minor axis.

The elastic buckling capacity M_e is determined depending on the type of section being considered for lateral buckling.

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For I section and systematical channel beams bent in the plane of the web.

$$M_e = \frac{A*E*D*\pi^2}{2*(L_e/r_y)^2} * \left\{ 1+ \frac{1}{20} \left(\frac{L_e}{r_y} * \frac{t}{D} \right)^2 \right\}^{1/2} \quad \ldots\ldots\ldots(eqn7.1)$$

For Z section beams bent in the plane of the web.

$$M_e = \frac{A*E*D*\pi^2}{4*(L_e/r_y)^2} * \left\{ 1+ \frac{1}{20} \left(\frac{L_e}{r_y} * \frac{t}{D} \right)^2 \right\}^{1/2} \quad \ldots\ldots\ldots(eqn7.2)$$

For T section beams bent in the plane of symmetry such that the flanges are in compression.

$$M_e = \frac{A*E*D*\pi^2}{2*(L_e/r_y)^2} * c_t * \left[\left\{ 1 + \frac{1}{20} \left(\frac{L_e}{r_y} * \frac{t}{D} \right)^2 \right\}^{1/2} + 1 \right]^{1/2} \quad \ldots\ldots\ldots(eqn7.3)$$

For T section beams bent in the plane of symmetry such that the flanges are in tension.

$$M_e = \frac{A*E*D*\pi^2}{2*(L_e/r_y)^2} * c_t * \left[\left\{ 1 + \frac{1}{20} \left(\frac{L_e}{r_y} * \frac{t}{D} \right)^2 \right\}^{1/2} - 1 \right]^{1/2} \quad \ldots\ldots\ldots(eqn7.4)$$

Where

A is the cross-sectional area of the beam.

D is the section depth.

E is Youngs Modulus

c_t is a constant given by :

$$c_t = \frac{1 + 1.5*(B/D) - 0.25*(B/D)^3}{1 + 2*(B/D)}$$

The effective length L_e, is determine according to the type of restraint being applied.
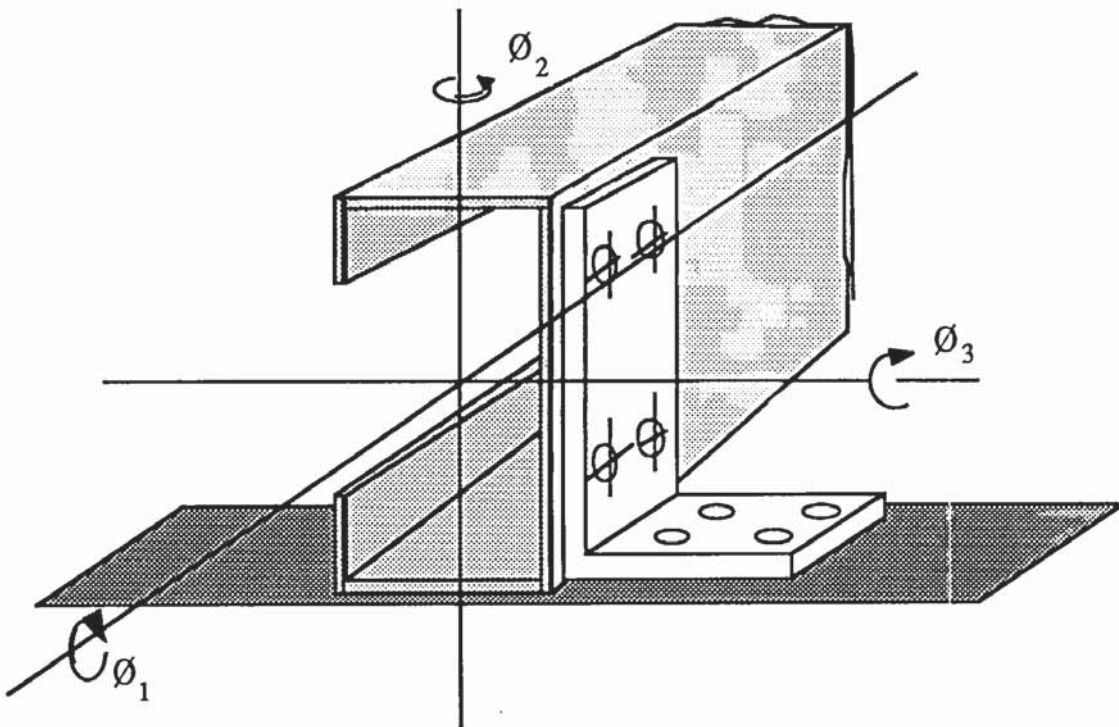
Diagram 7.12 : Restraint Conditions For Lateral Buckling

(a)   Where a beam is restrained at ends only the effective lengths should be, with reference to diagram 7.12 .

(i)   For beams not restrained from rotation in the $\emptyset_1$, $\emptyset_2$, or $\emptyset_3$ directions: $L_e = 1.1 * L$

(ii)   For beams restrained against torsional rotation, $\emptyset_1$, only :

$L_e = 0.9 * L$

(iii)   For beams restrained against torsional rotation, $\emptyset_1$, and rotation about the minor axis, $\emptyset_2$: $L_e = 0.81 * L$

(iv)   For beams completely restraint against rotation in any direction : $L_e = 0.7 * L$

Where L is the span between supports.

(b)   Where the beam is restrained at intervals by substantial connections to other steel members and is part of a fully framed structure, L_e should be taken as 81% of the distance between restraints. Where the beam is restrained at intervals by less substantial connections

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to other steel members and is part of a fully framed structure, L_e should be taken as 90% of the distance between restraints.

Where the length considered is the length between a support and a restraint L_e should be taken as the greater of the values obtained from (a) and (b).

The method adopted initially requires the effective length to be determined. This is done by asking questions about the restraints on the beam and calculating the effective length as given by the equations above. Then the information about the type of profile is asked so that the relevant equation for the moment capacity can be established. Consequently the moment to cause lateral buckling is determined. If this is less than for normal bending, then this is used in the checking for the failure due to bending.

7.4.2. Deflection Criteria

The deflection ratio for the beam is supplied by the designer. The value of deflection ratio as specified by the standards is given as advice. This is :

For cantilevers	Length/180
For all Beams	Length/200

7.4.3 Failure Analysis

There are 6 failure conditions which are checked.

1. Web crushing
2. Bending
3. Shear
4. Deflection
5. Combination of Bending and Shear
6. Combination of Bending and Web crushing

7.4.3.1 Web crushing

The method of determining the allowable load was described in chapter 6. There is an initial question and answer procedure to determine if these equation apply. The actual equation used and their limiting conditions are given in appendix 1.

7.4.3.2 Bending Moment, Shear, Deflection

The method used is described in chapter 5. A diagram of the analysis is shown to the designer, interactively as the Bending Moment, Shear, and Deflection are determined (diagram 7.13).

SHEAR
STRESS
ACCROSS
BEAM

BENDING
MOMENT
ACCROSS
BEAM

DEFLECTION
ACCROSS
BEAM
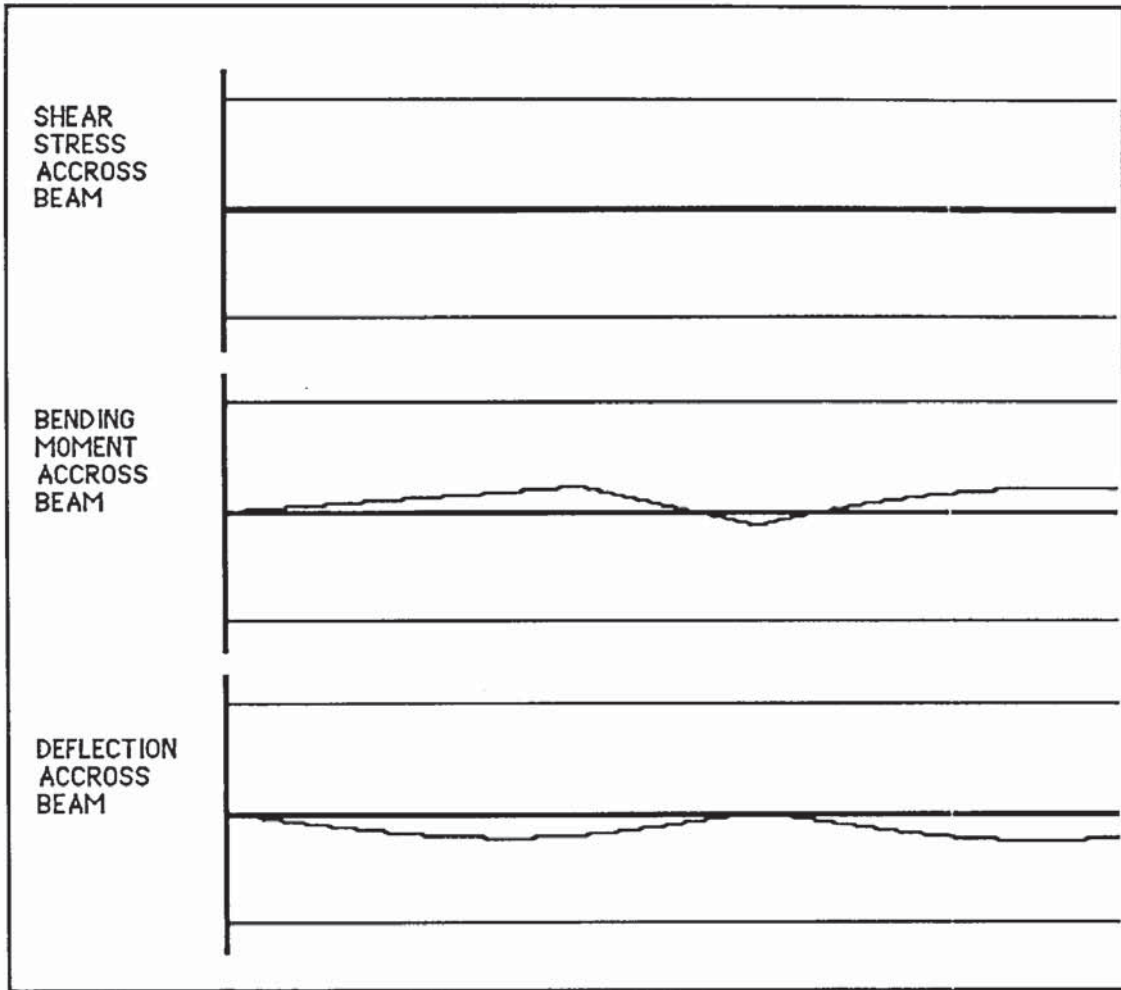
Diagram 7.13 : Showing part of the beam analysis display of a profile subjected to the loading as shown in diagram 7.10.

7.4.3.3 Combined Effects

The effect of the combined bending and shear is determined by the relationship given by the Standards :

$$(P/P_v) + (M/M_c) <= 1$$

Where

P is the shear load.

M is the value of the bending moment at the position at which P is calculated.

M_c is the moment capacity of the member.

P_v is the shear load at the limit state given by the smaller of the two equation below:

$$P_v = 0.6\ Y_s$$

$$P_v = 700000 * t^2/D^2\ N/mm^2$$

and Y_s is the yield stress,

t is the web thickness,

D is the total web depth between flanges.

The method used is similar to the determination of the individual effects (see chapter 5), and is checked at the same instant.

The effect of the combined bending and web crushing is similar to the method used above. But the iteration is done to the specific positions of both the point loads and the supports. The relationships which is applied here areas follows.

For sections having single-thickness webs:

$$1.2*(P/P_w) + (M/M_c) <= 1.5 \quad \text{and} \quad P/P_w<=1, \ M/M_c<=1$$

For I-beams made from two channels connected back to back, or similar sections which provide a high degree of restraint against rotation of the web :

$$1.1*(P/P_w) + (M/M_c) <= 1.5 \quad \text{and} \quad P/P_w<=1, \ M/M_c<=1$$

Where

P is the value of the concentrated load or reaction

P_w is the value of limit web crushing load in the absence of moment.

M is the value of the bending moment at the position at which P is calculated.

M_c is the moment capacity of the member.

CHAPTER 8

RESULTS

RESULTS.

This " Expert Design System " has been implemented on the Apple Macintosh microcomputer using the Pascal programming language. It is a very versatile system, and can be used for designing simple to very complex shapes. To show this flexibility, and the control of the designer has over the design, consider the design of two similar shapes. The one a simple Purlin with edge stiffeners only, the other with inter-stiffeners and web stiffeners., both are designed using the same general dimensions.

8.1 SIMPLE Z PURLIN DESIGN

Consider diagram 8.1 which show the designed Purlin. The Purlin is used as standardised profile and is also used for connecting Purlins together. This connection is shown in diagram 8.2, where the top profile is the connecting profile to two bottom Purlins. The size of the edge stiffeners are determined by the designer by entering the relevant data into the system as shown in the following example. The bold type is the communication from the system to the designer and the italic is the designers response.

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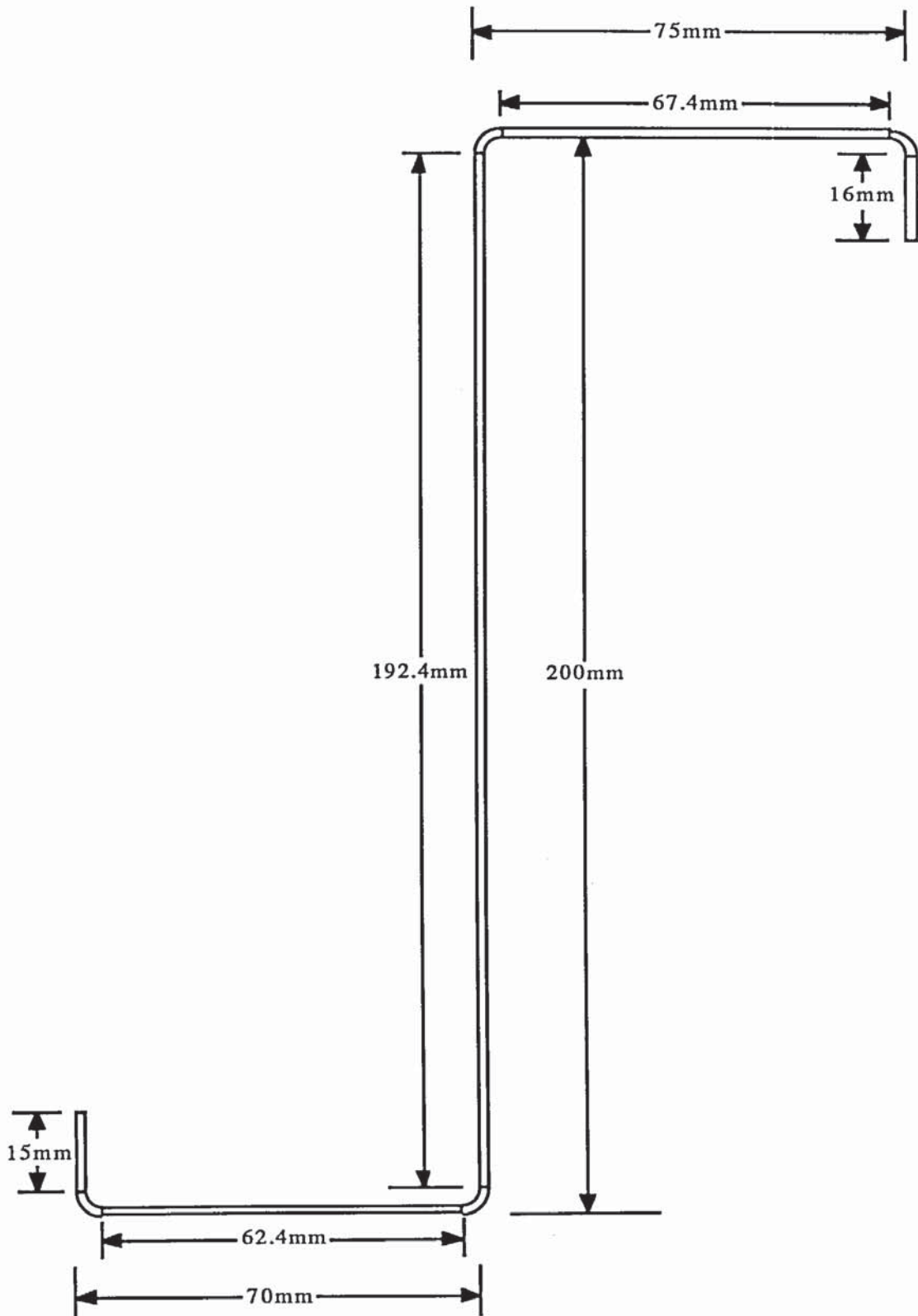
Diagram 8.1 : Showing the designed Purlin in the example given.
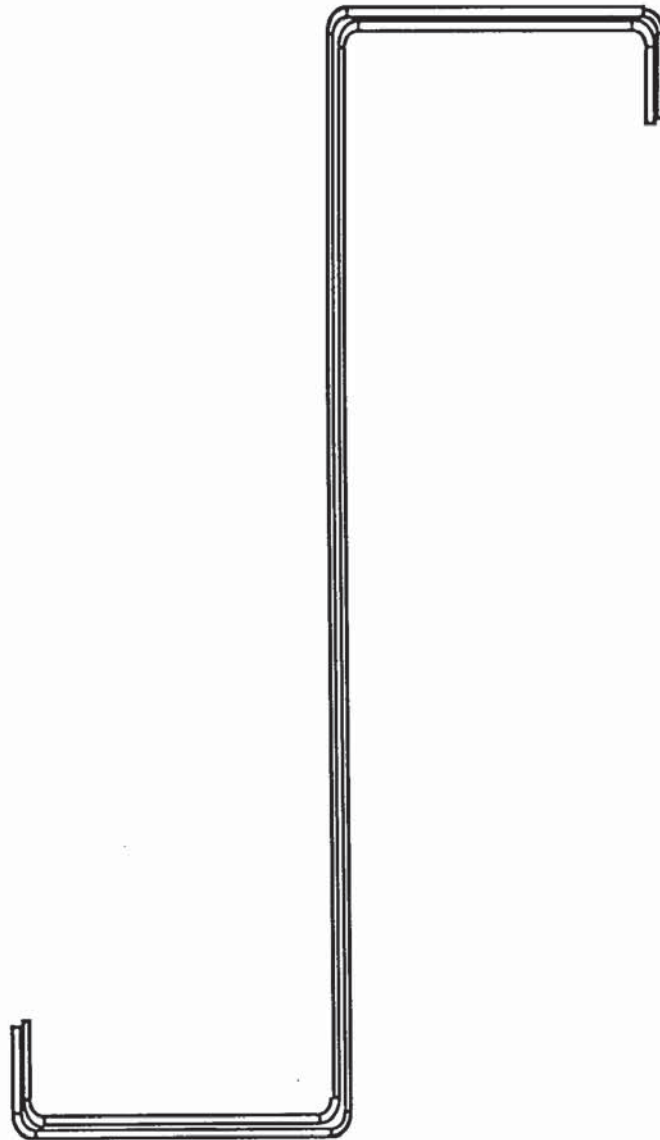
Diagram 8.2 : Showing how two Purlins are connected, consequently the reason for unequal flange lengths.

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<u>Stage 1</u>   (Preliminary   information)

   Please   give   a   section   number   for   the   design

100

   Give   the   following   information   :-

What   is   the   Ultimate   tensile   stress   in   N/mm^2.   of   the   steel
being   used   ?

390

What   is   the   Yield   stress   in   N/mm^2.   ?-   If   this   is   unclassified
then   this   value   can   be   given   as   210   N/mm^2.   for   hot   rolled
structural   quality   steel,   or   185   N/mm^2.   for   other   steels

280

What   is   the   thickness   of   material   in   mm.   ?

1.6

<u>Stage 2</u>   (Check Web effectiveness)

What is the maximum depth of Web in mm ?

200

The web height is too large to be fully effective, a web stiffener would give a more effective profile. Otherwise the design stress will be reduced.

(The system has recognised the web height is too large)

Are you including a stiffener for the web(s) in this profile ?

n

The maximum height of web to be fully effective is   109.5mm. Please re-enter the web height or if changed the new web height in mm.

200

<u>Stage 3</u>   (Advice on limitation on sizes of elements in tension and compression)

What is the maximum curling as a percentage of web depth that is permitted ? - 5% is thought not excessive for ordinary steel

5

Due to the limitations of curling the maximum flat widths disregarding intermediate stiffeners in tension and compression are :-

For element/flange connected to webs along both edges, the maximum length is 422.41mm.

For element/flange connected to web along one edge, the maximum length is 211.20mm.

The maximum allowable flat-widths disregarding intermediate stiffeners are as follows :-

For a stiffened compression element having one longitudinal edge connected to a web or flange element, the other stiffened by:

1. Simple lip is 96.00mm.

2. Any other kind of edge stiffener satisfying the requirements of minimum moment of inertia for edge stiffener is 144.00mm.

For unstiffened compression element is 80.00mm. @

@-NOTE:- Unstiffened compression elements that have flat-widths exceeding approximately 48.00mm. and stiffened compression elements exceeding approximately 400.00mm. are likely to develop noticeable deformation at the full allowable working stresses, without affecting the ability of the member to carry design loads.

Although these recommendations are for compressive elements they should be taken as a guide for tensile elements as well.

Stage 4   (Profile data entry)

Give the start angle

0

Element No.	Type	Length/Radius	Angle
1	2	67.4	0
2	4	3	90
3	0	0	0

(The data given by the designer to the system is only part of the profile to get advice on the size of the edge stiffener required. Because of the method the system recognises the compression element and aids the designer in the designing, not all the data of the profile is required at this stage. In this case it is the larger of the two flanges less the width of the two corners.)

Stage 5   (Profile Analysis)

There is an unstiffened edge element/flange in this section design which is subject to compression . The element should not be greater then 96.0mm. in length. The length of a fully effective unstiffened flange element is 5.8mm. For a flange of length greater than 5.8mm. effective lengths have to be taken

(The system has recognised the presence of an unstiffened flange)

Do you wish to:-

A._ take effective length of the unstiffened compression
    flange

o r

B._ design an edge stiffener for the compression element
of length 67.4mm.

Enter a or b

b

For the design of an edge stiffener the required minimum
moment of inertia about its centroid is 986.03mm^4. - about
the N.A. of the stiffener.

  Do you wish to use:-

      1. a bent lip
o r
      2. design an edge stiffener (enter 1 or 2)

1

Where the stiffener consists of a simple lip bent right angles to the stiffened element the minimum depth of the stiffener is:- 19.5mm. Please restart using this element in the design or design an edge stiffener.

The length of 19.5mm is the total length of the stiffener from the centreline of the flange, that is it includes the length of the corner and half the thickness of the profile. As the corner radius used is 3mm, the size of the lip can be worked out to be :-

$$19.5 - 3 - 0.8 = 15.7 \text{ mm}$$

So an approximate length of 16mm is the actual size required. By repeating this procedure the lip size for the other end of the profile is determined (i.e.,. 15mm). By repeating stages 1-3 again but this time entering the whole profile, the effectiveness of the profile is determined.

Stage 4

Give the start angle

-90

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Element No.	Type	Length/Radius	Angle
1	1	16	0
2	4	3	90
3	2	67.4	0
4	4	3	90
5	1	192.4	0
6	4	3	-90
7	3	62.4	0
8	4	3	-90
9	1	15	0
10	0	0	0

Stage 5

Effective widths are necessary for this profile on the compression elements between stiffeners/webs
This system assumes edge stiffeners are designed correctly

Do you wish to:-

A._ design stiffeners for them
or
B._take effective widths

b
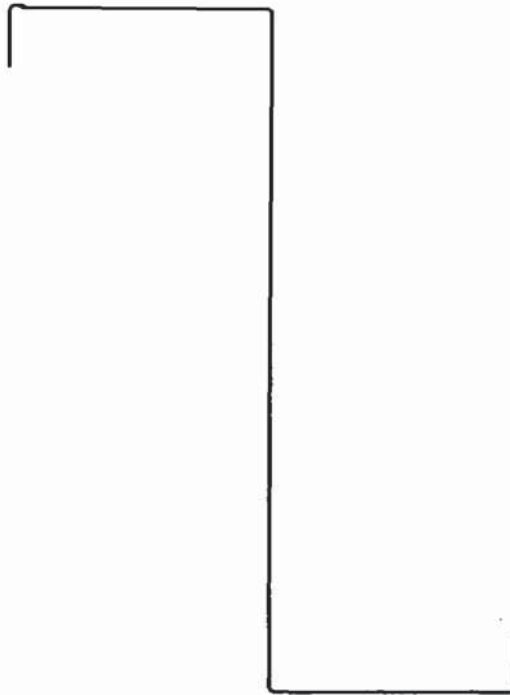
Diagram 8.3 : Showing the profile as shown on the screen to the designer

The designer can check to see if the data presented to the system is correct by obtaining a sketch of the profile of the section. This is shown in diagram 8.3.

The system then works out the new data of the effective profile for the determination of section properties. Once the effectiveness of the profile has been determined the section properties of the profile are determined. When the system is given the identification number the effective profile data is used to determine the section properties. That data is also printed for the designer on the screen as shown below.

Determination of section properties

Please enter the profile section number

1000

1	1.6	-90.0
(section type)	(thickness)	(starting angle)

Element No.	Type	Length/Radius	Angle
1	1	16.0	0.0
2	4	3.0	90.0
3	2	19.3	0.0
4	5	28.9	0.0
5	2	19.3	0.0
6	4	3.0	90.0
7	1	192.4	0.0
8	4	3.0	-90.0
9	3	62.4	0.0
10	4	3.0	-90.0
11	1	15.0	0.0
12	0	0.0	0.0

There are two extra element in the profile data, this is the replacement of the ineffective compression element by two halves of an effective element and a dummy element. That is compressive element number 4 has been replaced by element numbers 4, 5, and 6 as shown above.
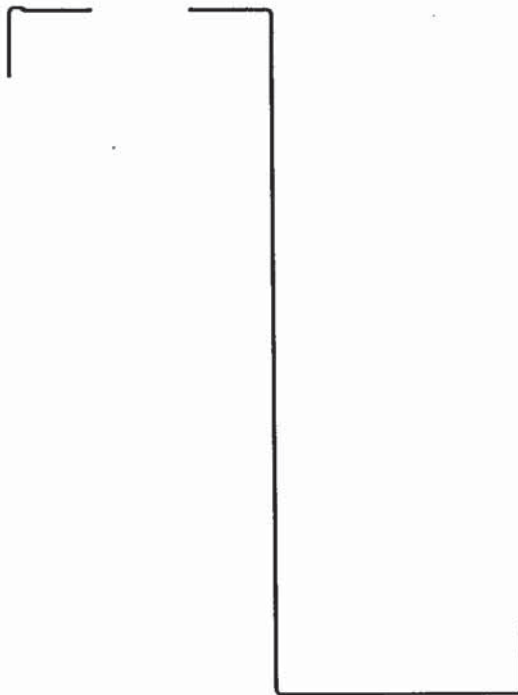
Diagram 8.4: Shows the effective profile as used in the determination of sectional properties

The designer can also obtain a sketch of the effective profile as shown in diagram 8.4. The missing part represents the dummy element 5 to get the effective sectional properties of the profile.

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8.2 COMPLEX Z PURLIN DESIGN

Consider the designed Purlin shown in diagram 8.5, it has the same overall dimensions as the simple profile but with inter-stiffeners and web stiffeners (diagrams 8.6, and 8.7). The example that follows shows the method by which the system can be used to design the inter-stiffeners. Stage 1 is the same as before, and therefore repeated.

Stage 2

What is the maximum depth of Web in mm ?

200

The web height is too large to be fully effective, a web stiffener would give a more effective profile. Otherwise the design stress will be reduced.   Are you including a stiffener for the web(s) in this profile ?

y

The stiffener should have the minimum moment of inertia of:- 20480.00mm^4.   The optimum place for it is about 4/5ths distance from the tensile edge.
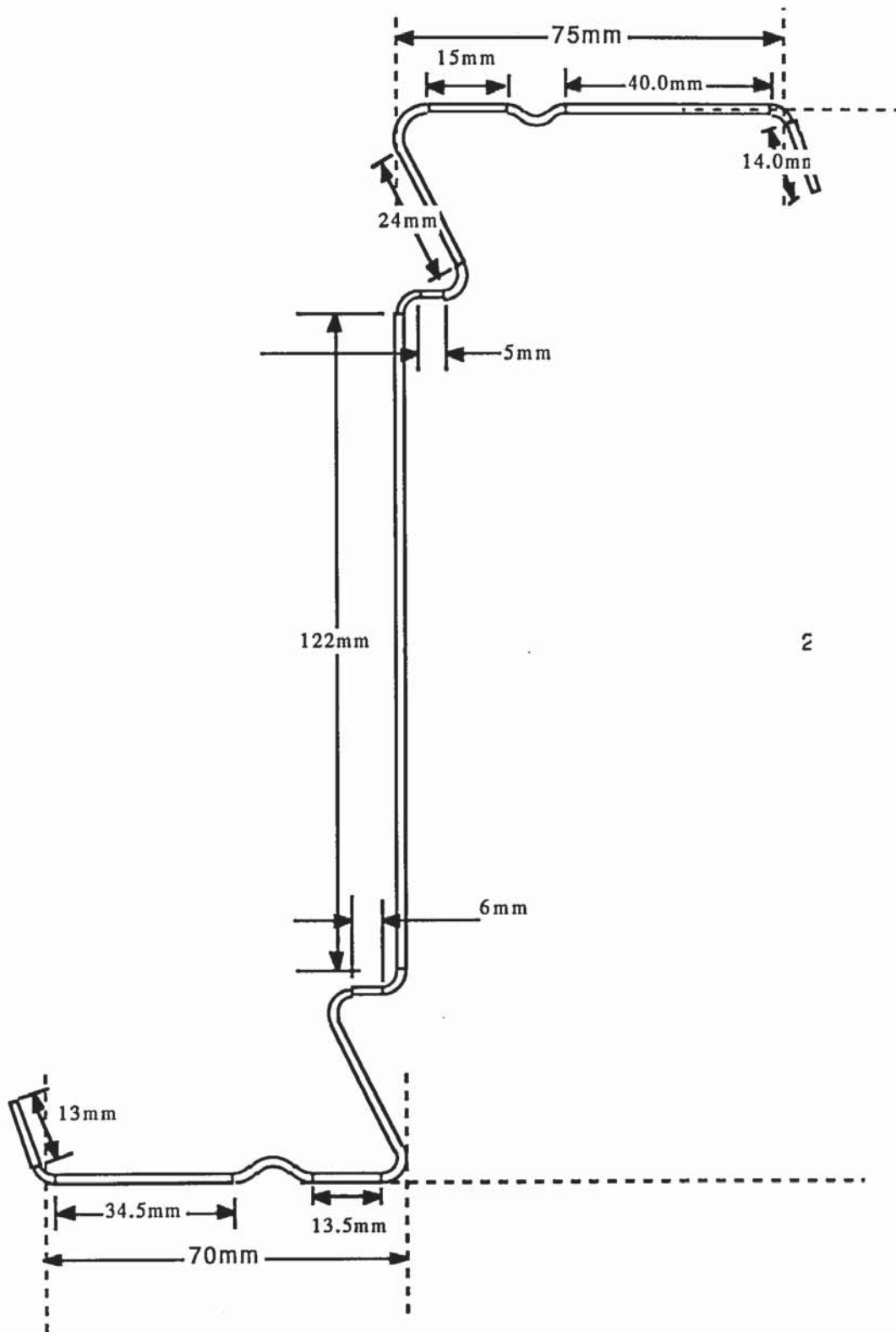
Diagram 8.5: Showing a complex stiffened Purlin.
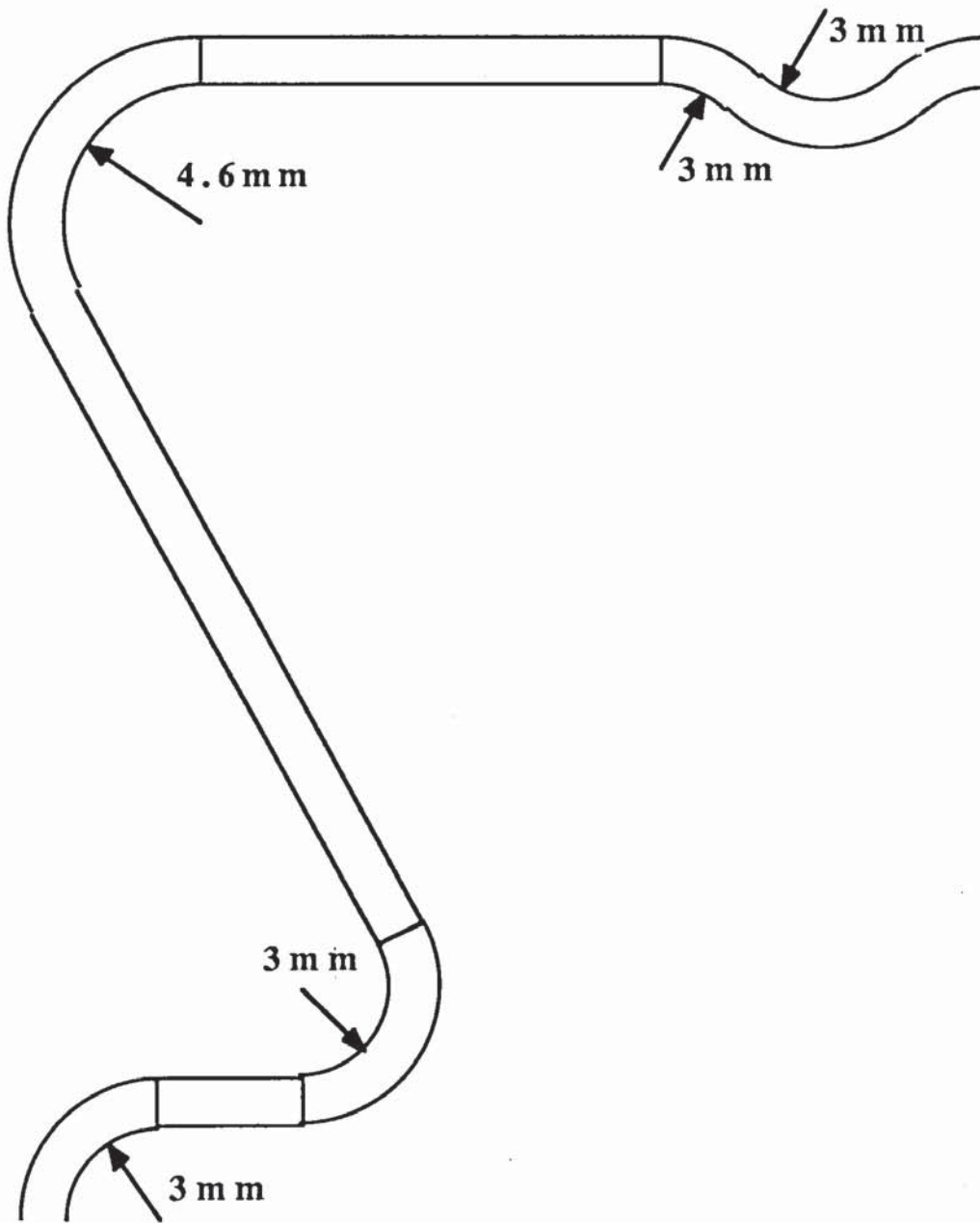
Diagram 8.6 : Showing details of stiffeners on larger flange.

3 mm

4.6mm

4.6mm

3 mm
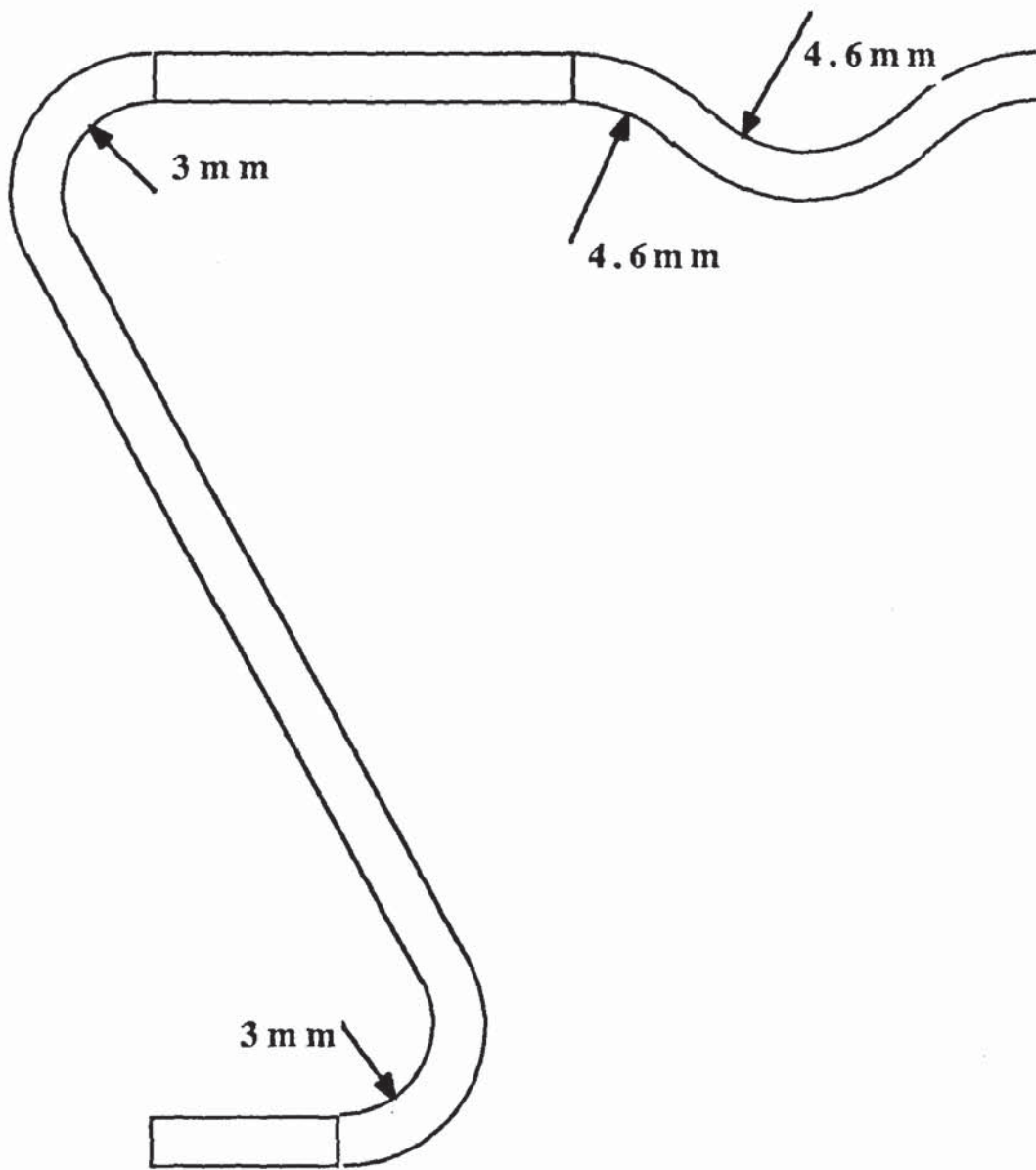
Diagram 8.7 :   Showing details of stiffeners on the smaller flange
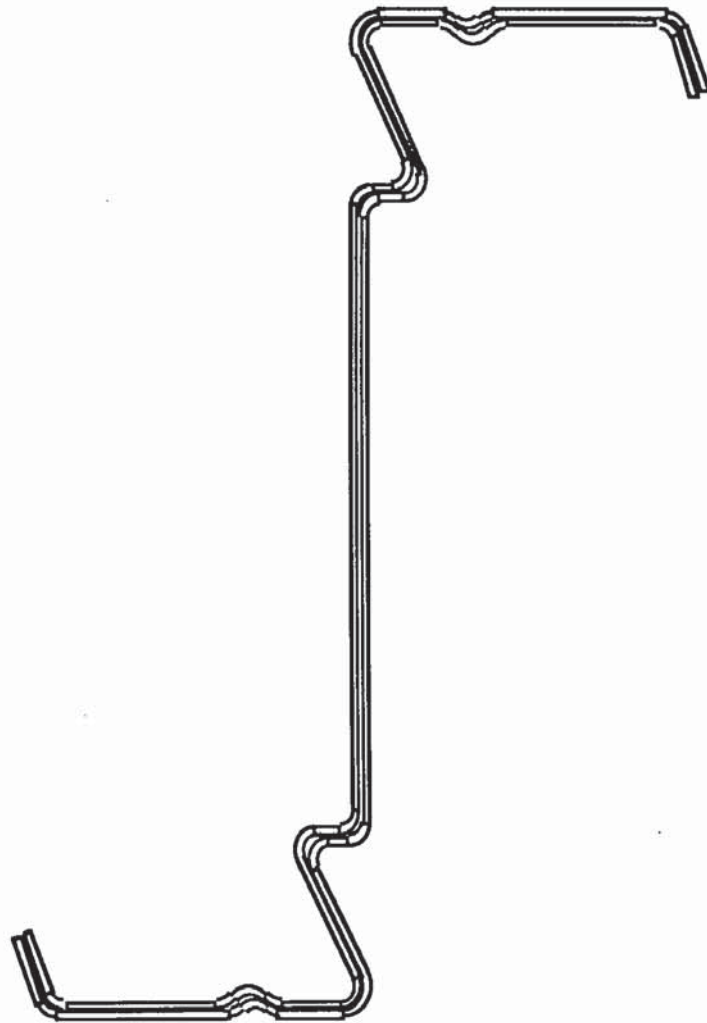
Diagram 8.8 : <u>Showing two complex sections, one used for connecting the sections.</u>

What is the distance from the centreline of stiffener(s) to the tensile edge ?

162

(This value is given to the system so as the designing stress can be computed correctly)

Stage 3

What is the maximum curling as a percentage of web depth that is permitted ? - 5% is thought not excessive for ordinary steel

5

Due to the limitations of curling the maximum flat widths disregarding intermediate stiffeners in tension and compression are :-

For element/flange connected to webs along both edges, the maximum length is 412.12mm.

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For element/flange connected to web along one edge, the maximum length is 206.06mm.

The maximum allowable flat-widths disregarding intermediate stiffeners are as follows :-

For a stiffened compression element having one longitudinal edge connected to a web or flange element, the other stiffened by:

1. Simple lip is 96.00mm.

2. Any other kind of edge stiffener satisfying the requirements of minimum moment of inertia for edge stiffener is 144.00mm.

For unstiffened compression element is 80.00mm. @

@-NOTE:- Unstiffened compression elements that have flat-widths exceeding approximately 48.00mm. and stiffened compression elements exceeding approximately 400.00mm. are likely to develop noticeable deformation at the full allowable working stresses, without affecting the ability of the member to carry design loads.

Although these recommendations are for compressive elements they should be taken as a guide for tensile elements

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as well.

Stage 4

Give the start angle

-90

Element No.	Type	Length/Radius	Angle
1	*1*	*16*	*0*
2	*4*	*3*	*90*
3	*2*	*67.4*	*0*
4	*4*	*3*	*90*
5	*0*	*0*	*0*

(Again a similar method to the previous example, is employed, a lip element is used so the system can be directed to analyse the data for consideration of an inter-stiffener)

Stage 5

Effective widths are necessary for this profile on the compression elements between stiffeners/webs   This system assumes edge stiffeners are designed correctly

Do you wish to:-

      A._ design stiffeners for them

o r

      B._take effective widths

a

Element number 3, of length 67.40, requires stiffeners. The effective length of an element of this design is 56.42mm. in width.

Please enter the stiffener design program.

The stiffener design program

What is the section number of the profile to be stiffened ?

100

Are you designing

      1. an edge stiffener

o r

      2. intermediate stiffeners (1 or 2)

2

Element number 3, of length 67.40, requires stiffeners. The effective length of an element of this design is 56.70mm. in width. The recommended number of stiffeners for this element is 1. If the design of the replacement element contains ineffective widths then only two of the stiffeners may be considered to be fully effective

What are the number of stiffeners you wish to use for this elemental length?

1

The required minimum moment of Inertia for each stiffener is , 2071.71mm^4.

Enter the stiffener profile

Element No.	Type	Length/Radius	Angle
1	4	3	45
2	4	3	-90
3	4	3	45
4	0	0	0

The width of the stiffener is, 10.75mm.

The height of the stiffener is, 2.22mm.

(This information enables the designer to determine the size of flat elements on either side of the stiffener to meet the original size of the element being stiffened)

The moment of inertia about the x-axis (horizontal) is, 7995.76mm^4.

The moment of inertia about the y-axis (vertical) is, 7962.97mm^4.

This stiffener is suitable as an intermediate stiffener for the section.

In order to check if the whole element replacement profile is not subject to local buckling, please enter the whole replacement profile

Element No.	Type	Length/Radius	Angle
1	1	40	0
2	4	3	45
3	4	3	-90
4	4	3	45
5	1	15	0
6	0	0	0

The width of the stiffener is,   65.75mm.

The height of the stiffener is,   2.22mm.

The moment of inertia about the x-axis (horizontal) is, 8015.20mm^4.

The moment of inertia about the y-axis (vertical) is, 45985.06mm^4.

This replacement stiffened element is suitable and fully

effective

By entering this stiffened profile into the system from start the designer can obtain advice on the edge stiffener for this profile. Repeating Stages 1 -3, as in the determination of inter-stiffener for the profile, the advice on edge stiffener is given as follows.

Stage 4

Give the start angle

0

Element No.	Type	Length/Radius	Angle
1	2	40	0
2	4	3	45
3	4	3	-90
4	4	3	45
5	2	15	0
6	0	0	0

Stage 5

There is an unstiffened edge element/flange in this section

design which is subject to compression . The element should not be greater then 96.0mm. in length.

The length of a fully effective unstiffened flange element is 5.6mm.

For a flange of length greater than 5.6mm. effective lengths have to be taken

Do you wish to:-

    A._ take effective length of the unstiffened compression flange
or
    B._ design an edge stiffener for the compression element of length 40.0mm.

Enter a or b

b

For the design of an edge stiffener the required minimum moment of inertia about its centroid is:- 364.85mm^4. - about the N.A. of the stiffener.

Do you wish to use:-

1. a bent lip

o r

2. design an edge stiffener (enter 1 or 2)

2

Please enter the stiffener design program

Stiffener Design Program

What is the section number of the profile to be stiffened ?

100   .

Are you designing

1. an edge stiffener

o r

2.   intermediate stiffeners (1 or 2)

1

what is the start angle in degrees ?

-70

Enter the stiffener profile

Element No.	Type	Length/Radius	Angle
1	1	14	0
2	4	3	70
3	0	0	0

The width of the stiffener is,   8.36mm.

The height of the stiffener is,   15.66mm.

The moment of inertia about the x-axis (horizontal) is, 3784.07mm^4.

The moment of inertia about the y-axis (vertical) is, 3186.63mm^4.

This stiffener is suitable as an edge stiffener for the section.

The smaller flange is designed in a similar manner. The design of web stiffeners is carried out in the same way, but the decision is left to the designer for its suitability in use. Then repeating stages 1-3 the final profile data can be entered into the system to obtain the analysis.

Stage 4

Give the start angle

-70

Element No.	Type	Length/Radius	Angle
1	1	14	0
2	4	3	70
3	2	40	0
4	4	3	45
5	4	3	-90
6	4	3	45
7	2	15	0
8	4	4.6	118
9	1	24	0
10	4	3	-118
11	1	5	0
12	4	3	90
13	1	122	0
14	4	3	-90
15	1	6	0
16	4	3	118
17	1	27	0
18	4	3	-118
19	3	13.5	0
20	4	4.6	-45
21	4	4.6	90
22	4	4.6	-45
23	3	34.5	0
24	4	3	-70
25	1	13	0
26	0	0	0

<u>Stage 5</u>

Do you wish to take work hardening into account ? (y / n)

y

(This shows that the profile is fully effective)
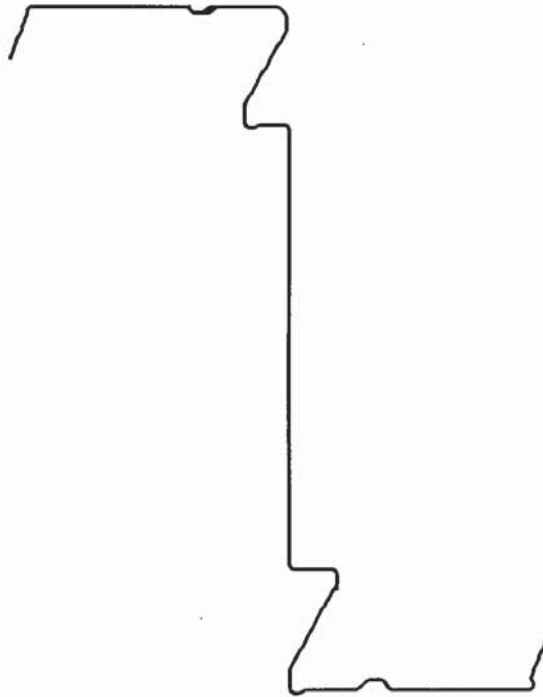
<u>Diagram 8.9:</u> <u>Showing the designed profile with stiffeners to the</u>

<u>designer.</u>

8.3 BEAM LOADING ANALYSIS ON THE TWO PROFILES

The two profiles can be compared by determining the load carrying capacity of the profile to simple loading. This loading was designed to be the same as when these profiles were tested experimentally. This is where a simply supported beam of span 3.58 metres is centrally loaded by a varying point load.

The point loads are considered ranging from a load of 0.8 Tonne-Force to 1.8 Tonne-Force in increments of 0.1 Tonne-Force (i.e., from 7848 N to 17658 N in increments of 981N). The following example shows how this loading is considered by the system.

Beam Loading Design

GIVE the loading condition number

0.8t

(The loading design once established can be stored according to file numbering system)

What is the length of the beam in metres ?

3.58

Enter the number of supports on the beam (min. of 2)

2

What is the distance of support no. 1 from A in metres ?

0

What is the distance of support no. 2 from A in metres ?

3.58

Enter the number of point loads on the beam

1

What is the distance of load no. 1 from A in metres ?

1.79

And its force in newtons ?

7848

Enter the number of U.D.L.s on the beam

0


```
 And its force in newtons ?
7848
 Enter the number of U.D.L.s on the beam
0
|
```

7848.0N

A   3.580m.

3924.0N

3924.0N
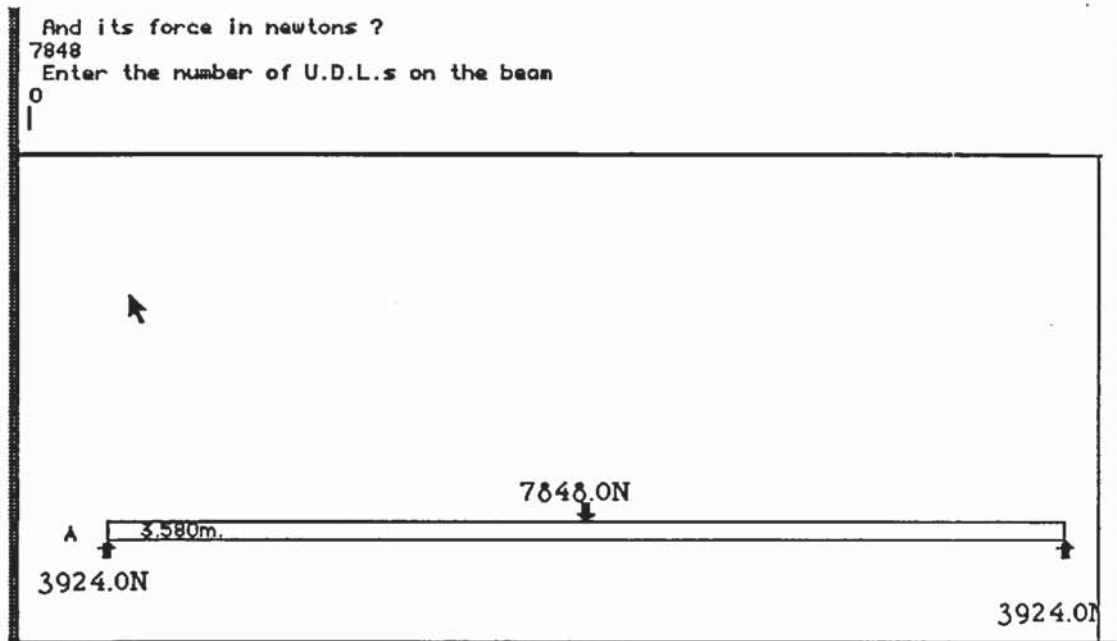
<u>Diagram 8.10 :</u>   <u>Showing display of the beam loading design to the</u>

<u>designer</u>

Once the beam loading has been designed, the profiles can be checked for the loading. The example which follows shows the simple section being checked for loading on the loading condition given in the previous example.

Beam Analysis

Enter the section number of the profile to be checked for loading

1000

Enter the loading condition number of the loading for this profile

0.8t

What is the deflection ratio allowed for this structure ?
It is recommended that :-

    1. for cantilevers this should be length/180

    2. beams carrying plaster or other brittle finish should be span/200

    3. all other beams span/200

0.005

Is this profile adequately restraint against lateral movement and twisting. (y/n)

If unsure answer "n".

y

What is the bearing length, in mm ?

120

What is the inside bend radius, in mm. ?

3

Give the inclination angle of web and plane of bearing surface. This should be greater than 50 degrees but not greater than 90 degrees

90

Is this a deck profile ? (y/n)

n

Are the flanges of the beam stiffened ? y/n

y

Give the type of profile shape being designed :-

1. shape with single thickness web

2. shape with restraint against rotation

1

Analysing the loads on beam

Analysing the reactions on beam

As no failures are reported the beam is secure for this particular loading. The analysis of the loading is given in diagram 8.8. Thus the designer can see where improvements could be made and where there is extra capacity.

SHEAR
STRESS
ACCROSS
BEAM

BENDING
MOMENT
ACCROSS
BEAM

DEFLECTION
ACCROSS
BEAM
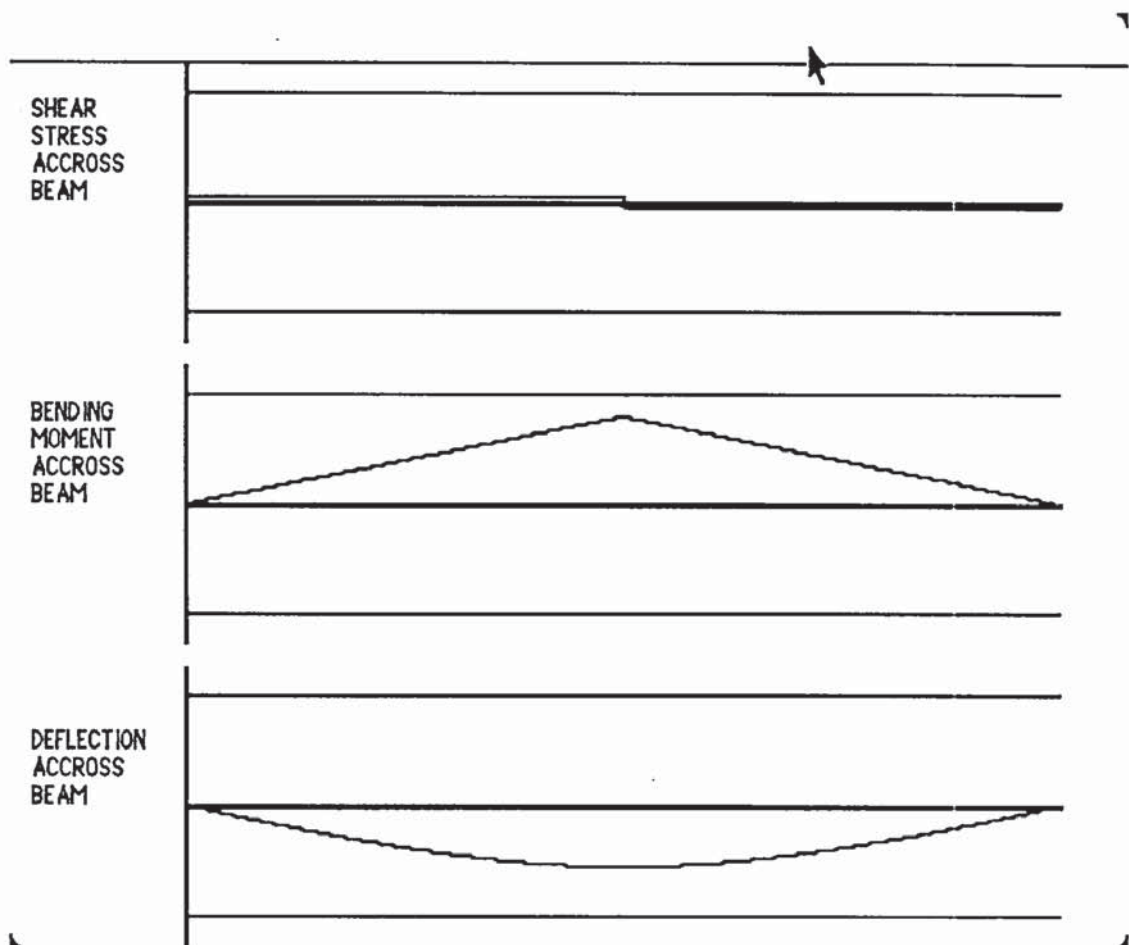
Diagram 8.11 :   Showing the analysis of the section to the loading condition.

The results for each of the profiles are given in Table 8.1.

Profile Type	Area mm^2	Moment of Inertia cm^4	Maximum Load Carried Tonne-Force	Deflection At Failure mm
Simple	603.5	375.0	0.9	12
Complex	634.9	396.2	1.3	15.5

Table 8.1 :   Showing the results of the two profile from the system

From Table 8.1 it can be seen the from a small increase in area the complex profile gives a large increase in the load carried (the increase in area is about 5% and the increase in load is about 44%.) It can be seen that using this system the profiles can be made more efficient in their carrying capacity.

8.4 EXPERIMENTAL RESULTS ON THE TWO PROFILES[21]

The experimental results on these two profile were carried out by Hadley Industries plc. The structures were loaded as given in the above example of beam loading design (i.e.,. a simply supported beam of span 3.58 metres carrying a centrally placed point load).   Table 8.2 shows the

result obtained experimentally.

Profile Type	Area mm^2	Moment of Inertia cm^4	Maximum Load Carried Tonne-Force	Deflection At Failure mm
Simple	603.5	375.0	1.2	15
Complex	634.9	396.2	1.8	28

Table 8.2 :   Showing the results of the two profile from
experiments

The structures were load till they failed to carry the given load.
This means that the structures were loaded beyond the elastic limit of the
material (i.e.,. plastic deformation has taken place, and the structures
will still function to carry the load although the would cease to be fit for
their intended use). This is beyond the limit state condition, that is a
condition beyond which the structure would cease to be fit for its
intended use. Therefore these results are expected to be greater than that
given by the system.

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In the results of both profiles the increase in the load carried experimentally is about the same in terms of percentage. This can be taken as the post buckling strength of the sections. The results show that the stiffened profile can carry far greater load than the unstiffened profile. This bears out the results obtained from the " Expert Design System ".

8.5 ANALYSIS OF ROOFING PROFILE

The system can also be used to improve profile sheeting. Consider the general profile illustrated in diagram 8.9. The loading is applied at the top of the profile downwards. Using the same procedure as before and entering the profile data, the system detected the compressive element of 80mm was too large to be effective. Given the options of either designing stiffeners or determining effective lengths, both options were taken into account.

On of the features of the "Expert Design System" is to optimise the profile data when determining effective lengths. When the option of determining effective length is taken the system initially edits the data of the profile. Then it determines the stress on the compressive elements which if shown not to be the design stress, the profile is re-edited. The example given (diagram 8.12 and 8.13) shows how this procedure is achieved on the ineffective roofing profile. After entering the profile data into the system the system begins to determine the section
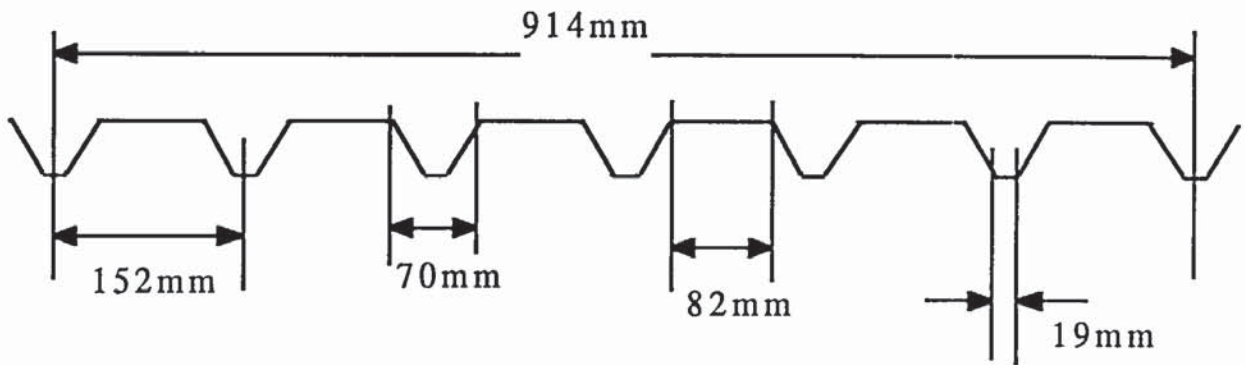
properties.

Diagram 8.12: Roofing profile to be tested for loading.
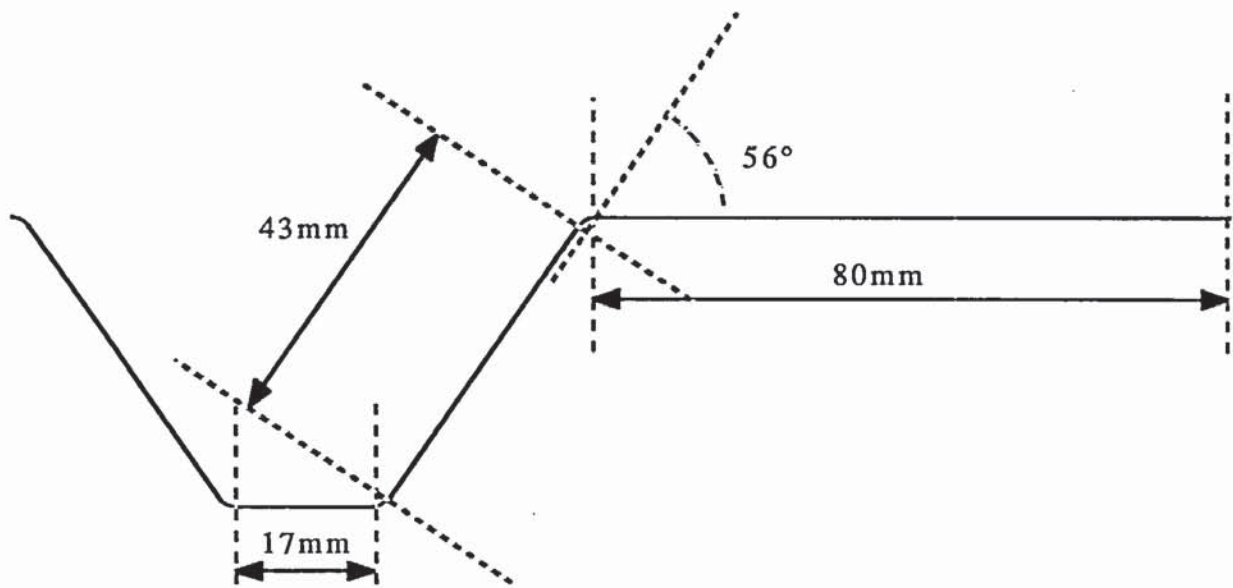
Diagram 8.13: Detailed roofing profile showing actual elemental lengths.

Determination of section properties

Please enter the profile section number

3800

	1	0.55	56.0
	(section type)	(thickness)	(starting angle)

Element No.	Type	Length/Radius	Angle
1	1	43.0	0.0
2	4	2.0	-56.0
3	3	17.0	0.0
4	4	2.0	-56.0
5	1	43.0	0.0
6	4	2.0	56.0
7	2	25.3	0.0
8	5	29.4	0.0
9	2	25.3	0.0
10	4	2.0	56.0
-	-	-	-

(Elements 1-10 are repeated until element 60)

-	-	-	-
60	4	2.0	56.0
61	1	43.0	0.0
62	4	2.0	-56.0
63	3	17.0	0.0
64	4	2.0	-56.0
65	1	43.0	0.0
66	0	0.0	0.0

The compression elements are not subjected to a stress of 199.50N/mm^2.

Please re-analyse the section

Re-Analysis Of Effective Widths

Please give a section number for the design

3800

Is this a re-analysis of effective_widths ?   (y/n)

y

The re-analysis is carried out using the same program as the initial profile data   entry, except the data is read from file and write to file after the re-analysis has taken place.

Effective widths are necessary for this profile on the compression elements between stiffeners/webs

This system assumes edge stiffeners are designed correctly

Do you wish to:-

A._ design stiffeners for them

or

B._take effective widths

b

Once the re-analysis has taken place the same editing procedure is repeated until the correct stress on the compressive element at failure has been established. The first re-analysis produces the following profile data:

Element No.	Type	Length/Radius	Angle
1	1	43.0	0.0
2	4	2.0	-56.0
3	3	17.0	0.0
4	4	2.0	-56.0
5	1	43.0	0.0
6	4	2.0	56.0
7	2	29.7	0.0
8	5	20.7	0.0
9	2	29.7	0.0
10	4	2.0	56.0
-	-	-	-

(Elements 1-10 are repeated until element 60)

Element No.	Type	Length/Radius	Angle
60	4	2.0	56.0
61	1	43.0	0.0
62	4	2.0	-56.0
63	3	17.0	0.0
64	4	2.0	-56.0
65	1	43.0	0.0
66	0	0.0	0.0

The first iteration has produced a more effective data profile, but again the compressive elements at failure are not subject to the new compressive stress. The value quoted is the design stress and not the stress at which the effective widths were determined. The second and final re-editing of data gives the following profile data:

Element No.	Type	Length/Radius	Angle
1	1	43.0	0.0
2	4	2.0	-56.0
3	3	17.0	0.0
4	4	2.0	-56.0
5	1	43.0	0.0
6	4	2.0	56.0
7	2	30.8	0.0
8	5	18.3	0.0
9	2	30.8	0.0
10	4	2.0	56.0
-	-	-	-

(Elements 1-10 are repeated until element 60)

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Element No.	Type	Length/Radius	Angle
60	4	2.0	56.0
61	1	43.0	0.0
62	4	2.0	-56.0
63	3	17.0	0.0
64	4	2.0	-56.0
65	1	43.0	0.0
66	0	0.0	0.0

The moment of inertia about the x-axis (horizontal) is 123307.1 mm^4

The moment of inertia about the y-axis (Vertical) is 54313840.0 mm^4

The area of the total profile is   692.0 mm^2

When this information is given it shows that the profile data has now been edited correctly and its basic properties are given. Using the advice given by the " Expert Design System ", the designer could have designed some stiffeners and obtained a more effective profile.

8.6 ROOFING PROFILE WITH STIFFENERS

The stiffener were designed using the assistance given to the designer by the " Expert Design System ". This stiffener is shown in diagram 8.14. Two of these stiffeners are used in the 80mm replacement

of the ineffective compressive element as shown in diagram 8.15.
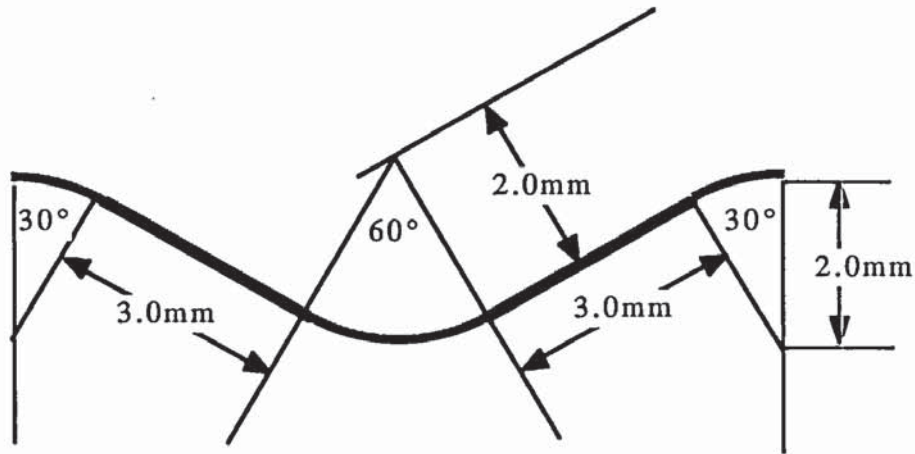
Diagram 8.14: The stiffener designed for the compression element
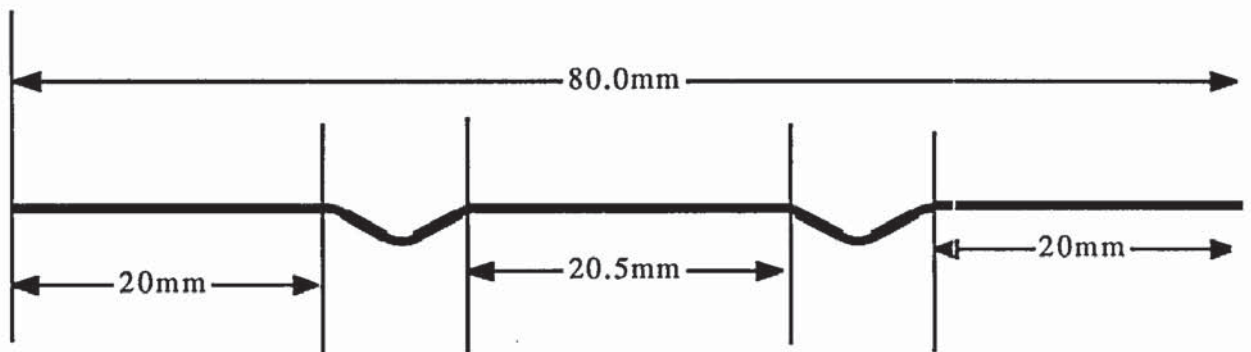
Diagram 8.15: The 80mm Stiffened Compression Element Replacement

The properties of the new profile were evaluated and its load carrying capacity determined. This capacity can be compared with the original profile. The type of loading used is a uniform distributive load across the whole beam. Both profiles were subjected to three types of

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beam loading: single span , double span and triple span. The results were determined for failure of the profile with a deflection limit of 0.01 and with a deflection ratio of 0.005. The span length considered for all 3 types of loading was 2 metres. The loading was designed as before but in increments of 50 N/m, ranging from 1000 N/m to 3000 N/m.

The results of the loading for both profiles are given in tables 8.3 and 8.4. The tables also show the type of failure which occurred. To obtain a better picture of the comparison of the two profile, table 8.5 shows the relative increases in the profile areas compared with the increases in the load carrying capacity.

ROOF SECTION TYPE	AREA OF PROFILE mm^2	ULTIMATE LIMIT UNIFORM DISTRIBUTIVE LOAD N/m		
		SINGLE SPAN	DOUBLE SPAN	TRIPLE SPAN
Effective 3800	692	2150	2100	2550
ANALYSIS OF FAILURE	/////	Failure At 2200 By Bending Stress	Failure At 2150 By Bending And Shear Stress	Failure At 2600 By Bending And Web Crushing
Stiffened 3900	699	2600	2400	3000
ANALYSIS OF FAILURE	/////	Failure At 2650 By Bending Stress	Failure At 2450 By Bending And Shear Stress	Failure At 3050 By Bending And Web Crushing

Table 8.3: Showing the results of the limit load capacity of the profiles at the deflection ratio of 0.01

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ROOF SECTION TYPE	AREA OF PROFILE mm^2	ULTIMATE LIMIT UNIFORM DISTRIBUTIVE LOAD N/m		
		SINGLE SPAN	DOUBLE SPAN	TRIPLE SPAN
Effective 3800	692	1200	2100	2250
ANALYSIS OF FAILURE	/////	Failure By Deflection	Failure At 2150 By Bending And Shear Stress	Failure By Deflection
Stiffened 3900	699	1450	2400	2800
ANALYSIS OF FAILURE	/////	Failure By Deflection	Failure At 2450 By Bending And Shear Stress	Failure By Deflection

Table 8.4:   Showing the results of the limit load capacity of the profiles at the deflection ratio of 0.005

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		LOAD CARRYING CAPACITY					
		DEFLECTION RATIO OF 0.01			DEFLECTION RATIO OF 0.005		
	AREA	Single Span	Double Span	Triple Span	Single Span	Double Span	Triple Span
% Increase In New Profile	1	21	14	17	29	14	24

Table 8.5: Showing the relative increases in Area to Load Carrying Capacity of the Stiffened Profile

The results show that by using the 'Expert Design System', the profile can be improved. By only a 1% increase in the cross-sectional area of the profile, the load carrying capacity can be increased in a range of 14% to 30%.

The results also show that the improvements in the profile vary according to the type of loading the profile is being designed for. The analysis can also give information to the designer on possible use of specific external stiffeners during the loading of the profile to counteract possible failures. An example of this can be the use of stiffeners attached to the web of the profile at the two inner supports on the triple span beams.

CHAPTER 9

CONCLUSIONS

AND

FUTURE WORK

CONCLUSIONS & FUTURE WORK

Computer Aided Design is an essential element in the designing process in today's industry. Therefore any major contribution at any level to the general body of expertise in the improvement and expansion of computer assistance to the designer is essential to achieving or maintaining competitiveness.

This research has been concerned with, not only the enhancement of Computer Aided Design facilities, but also with the provision of advice to the designer in the design of cold rolled sections. This sort of computer system can be accurately called an "Expert Design System". It has the general facilities to perform the tasks of mathematical analysis and graphics associated with Computer Aided Design systems and the additional provision of decision support, without restricting the creative talents of the designer. This work has been to expand the present barriers of the computer assistance given to the designer and can be considered as taking a large step towards a new generation of Computer Aided Design systems.

This "Expert Design System" contains a number of different and specific aspects which have been developed during the course of this research.

9.1 SECTION PROPERTIES AND DATA CHECKING

The method used for the determination of section properties on an earlier Computer Aided Design system was complex. By using the properties of line and circular elements it was possible to determine the section properties in a simple manner. This different method has also allowed for graphical display of the outline of the profile to be shown on screen. The start and finish position of each of the profile elements can be mapped on an imaginary set of axis. This mapping is then translated to the local mapping system of the screen as determined by the computer architecture. The outline of the profile is obtained by joining these positions according to the element type using the graphical routines available in the software used.

The data of the profile is described in terms of different line and circular elements. These line and circular elements have certain restrictions on their data. If these restrictions are exceeded the system would require the re-entering of the data for that element. For example, if the designer was entering a circular element and its internal bend radius was smaller than the thickness, an error would be reported as from manufacturing experience this is an impossibility. Secondly if more serious errors are not detected by the system, these would be seen by the designer from the drawing of the profile outline.

9.2 BEAM LOADING DESIGN AND ANALYSIS

One of the main features of this designing system is the variety of beam loading conditions which can be considered for the designed profile. Not only can the loading be on a single span simply supported beam but on any number of spans, with any number of point and uniform distributive loads. This is particularly important if the designer is designing a profile for a particular type of loading. The profile can then be checked for suitability for this loading. Unlike specific loading analysis such as central point load a single span beam the profile can now be custom built.

This is also essential to the optimisation of the profile to a specified loading, as a profile may be optimal for one type and not another. This can be illustrated by the variations in the amount of improvement on the new roofing profile given in the analysis of the results for loading in single, double and triple span.

The profile is not just checked for failure in bending stress and deflection; but also for failure in shear, web crushing, combined effects of shear and bending stress, or combined effects of web crushing and bending stress. This gives the designer a better understanding of the failure likely to occur for the given loading and consequently can take the appropriate steps.

9.3 DECISION SUPPORT

Unlike normal Computer Aided Design systems, this system has the facilities to give advice to the designer. When using the "Expert Design System" the designer is given advice on many features of design. All the advice is based on the British Standards. This makes the advice sound and acceptable.

There are a variety of methods used to give advice to the designer. Some of the advice is taken directly from the standards, such as the recommendation for the deflection ratio, and is presented to the designer before entry of the relevant information. Some of this guidance has been translated to a more relevant form, such as changing the allowable length to thickness ratios into actual allowable lengths for compression elements.

The more complex advice has been adopted through the use and construction of production rules. These have been used extensively in the design methodology for giving advice based on experience in the use of the standards and in the analysis of beam for loading. By the combination of symbolic representation and production rules, it is possible to optimise the editing of an in-effective profile, as shown.

9.4 STIFFENER DESIGN

The method of optimal design is based on the maximum use of the material, therefore, when a profile has need of effective widths it is not efficient. Consequently the designer is advised to use and design stiffeners, if effective widths are required.

The system is designed to help the designer by giving the facilities for the suitable design of stiffeners. There are two types where assistance is given, that is design of edge stiffeners or intermediate stiffeners.

In the design of an edge stiffener the system can either give the size of the lip required, or allow the designer to design a more complex stiffener through line and circular elements. The system then determines if the stiffener satisfies the minimum moment of inertia requirement and informing the designer on the width and height of the stiffener.

The assistance for the design of inter-stiffeners is given in a similar manner, although the requirements are more involved. The width and height of the stiffener is more important here as it assists the designer in determining the widths of the smaller compression elements between stiffeners, or the stiffener and the web.

9.5 DESIGN METHODOLOGY

The designing method is based on how best to assist the designer without making too many constraints on the design. As a consequence the designer is advised on possible methods of improving the design, such as the use of stiffeners, but allowed to reject that option. Thus, if the profile was not fully effective and the designer did not wish to use stiffeners, the system would evaluate the effective widths for the profile and edit the profile data accordingly.

The method is designed such that the profile is first, analysed with advise on possible improvements. The beam loading for which the profile is to be used is designed. Then the profile is analysed for suitability for that loading. This informs the designer whether or not the designed profile is useful for that loading.

Thus, the designer can carry out a variety of designs for a particular loading and see which is best suited or which gives the best results. Basically the system caters for the creative talents of the designer, instead of the designer being involved in repeated analysis and calculations.

9.6 RESULTS

The results on the "z" purlin show the system indicating the improvement in loading capabilities due to the suitable use and design of stiffeners. This improvement is also shown by the experimental results. The analysis given by the system shows the limit loading capacity of the profile. This is at the elastic limit and therefore the experimental results which were tested to failure (i.e., beyond the elastic and plastic limit of the structure) are much higher.

9.7 SUGGESTIONS FOR FUTURE WORK

There are many areas where research work in the design of cold formed section can continue.

In the improvement of the present system, work can be continued by extending the loading analysis to struts and beam-columns. This is because cold formed section are being used in the design of complex structural frames, and possibly the shapes being used are not the most economical.

The work done by this research can bring to light areas where experimental work may progress to achieve even better profiles. One such case is with the detail design of stiffeners. The standards do not give

the ideal placement of the stiffener on a flange or the shapes which give the optimum improvement. By working in this specific area, the standardization of stiffener shapes could be achieved, consequently a new "Expert Design System" for cold rolled sections will be able to give better advice on precisely which type of shape and its ideal placement should be to give a better profile.

The system may be integrated into the work on the computer aided manufacture of rolls for the rolling of these profiles, leading to a more comprehensive system of design to manufacture.

A lot of designing in other areas is done mainly by the use of standards. By adopting the methods shown in this research it may be possible to develop more "Expert Design Systems" , consequently making designs more efficient and low in cost.

APPENDIX

APPENDIX

Equations for the determination of web crushing

Consider the diagram 10.1, the values c and e are lengths, and h is the depth of the web.

For shapes having single thickness webs the following table gives the total allowable web load for conditions (a) to (d).

CONDITION   ALLOWABLE LOAD IN NEWTONS GIVEN BY

(a)

Stiffened Flanges

$$t^2*k*C_3*C_4*C_\emptyset * [2060 - 3.8*(h/t)] * [1 + 0.01*(N/t)]$$

Unstiffened Flanges

$$t^2*k*C_3*C_4*C_\emptyset * [1350 - 1.73*(h/t)] * [1 + 0.01*(N/t)]$$

Unstiffened Flanges and If N/t > 60 then

$$t^2*k*C_3*C_4*C_\emptyset * [1350 - 1.73*(h/t)] * [0.71 + 0.015*(N/t)]$$

(b)

$$t^2*k*C_1*C_2*C_\emptyset * [3350 - 4.6*(h/t)] * [1 + 0.007*(N/t)]$$

If N/t > 60 then

$$t^2*k*C_1*C_2*C_\emptyset * [3350 - 4.6*(h/t)] * [0.75 + 0.011*(N/t)]$$

(c)

$$t^2*k*C_3*C_4*C_\emptyset * [1520 - 3.57*(h/t)] * [1 + 0.01*(N/t)]$$

(d)

$$t^2*k*C_1*C_2*C_\emptyset * [4800 - 14*(h/t)] * [1 + 0.0013*(N/t)]$$

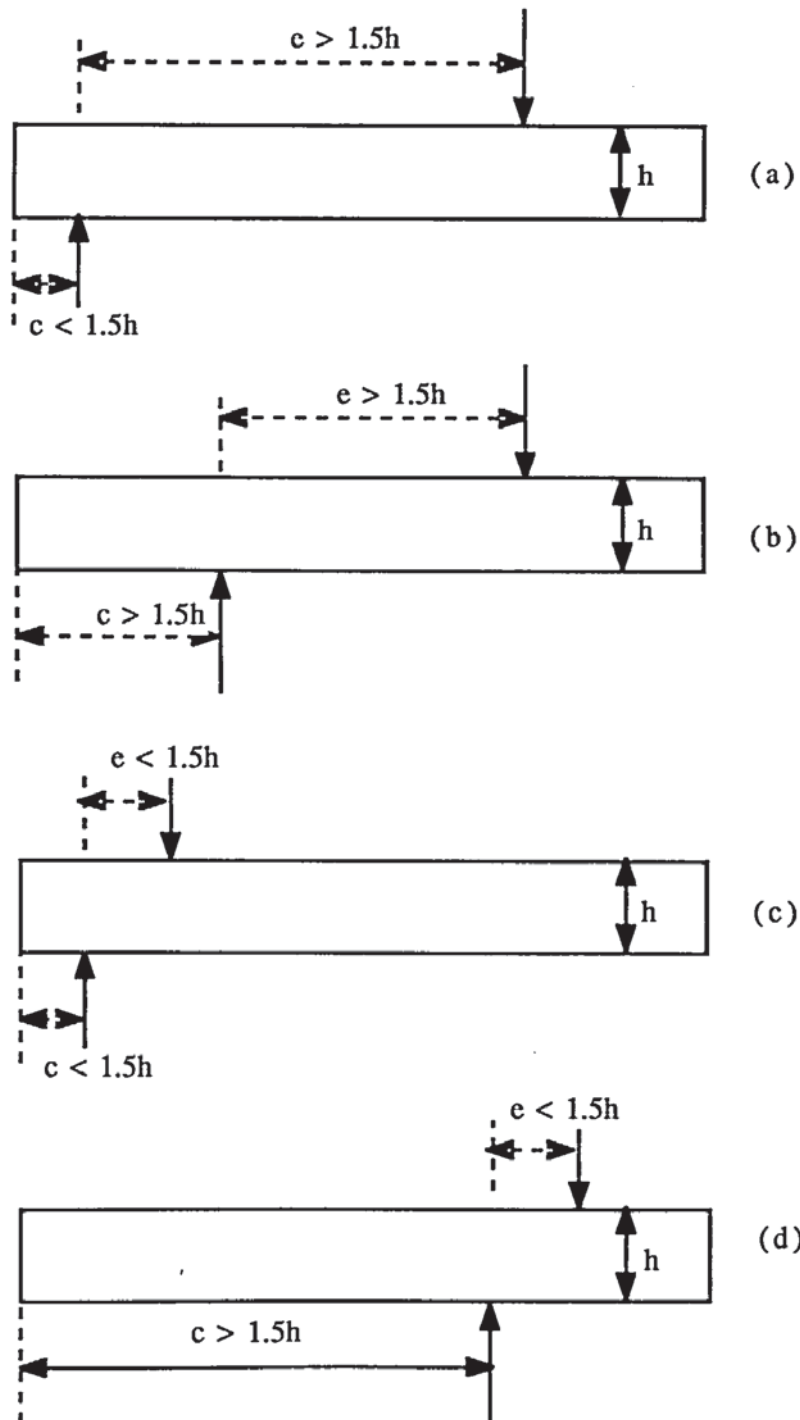
Diagram 10.1: Showing the different conditions for allowable load

For shapes restraint against web rotation the following table gives the total allowable web load for conditions (a) to (d).

CONDITION	ALLOWABLE LOAD IN NEWTONS GIVEN BY
(a)	$t^2 * C_7 * P_y * [8.8 + 1.11_*(N/t)^{1/2}]$
(b)	$t^2 * C_5 * C_6 * P_y * [13.2 + 1.63_*(N/t)^{1/2}]$
(c)	$t^2 * C_{10} * C_{11} * P_y * [8.8 + 1.11_*(N/t)^{1/2}]$
(d)	$t^2 * C_8 * C_9 * P_y * [13.2 + 1.63_*(N/t)^{1/2}]$

In both tables the symbols used are represented by the following.

P_y	-	Design stress of profile.	
C_1	=	$[1.22 - 0.22 * k]$	
C_2	=	$[1.06 - 0.06 * (R/t)]$	
C_3	=	$[1.33 - 0.33 * k]$	
C_4	=	$[1.15 - 0.15 * (R/t)]$	$0.05 < C_4 <= 1.0$
C_5	=	$[1.49 - 0.53 * k] >= 0.6$	
C_6	=	$[0.88 + 0.12 * m]$	
C_7	=	$1 + (h/t)/750$	when $h/t < 150$
C_7	=	1.2	when $h/t > 150$
C_8	=	$1/k$	when $h/t < 66.5$
C_8	=	$[1.1 - (h/t)/665]/k$	when $h/t > 66.5$

C_9 = $[0.82 + 0.15 * m]$

C_{10} = $[0.98 - (h/t)/865]/k$

C_{11} = $[0.64 + 0.31 * m]$

$C_\emptyset$ = $0.7 + 0.3 * (\emptyset/90)^2$

h = clear distance between flanges measured along plane of web, in mm.

k = $P_y/217$

m = t/1.9

t = web thickness in mm.

N = Actual length of bearing, in mm.

R = Inside bend radius in mm.

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