EXPERT SYSTEM DESIGN FOR COLD FORM SECTIONS

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February 1991

Declaration

The work described in this thesis has been carried out independently and submitted for no other degree

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Summary

The concept of an Expert System has been acknowledged as a very useful tool, but few studies have been carried out in its application to the design of cold rolled sections. This study involves primarily the use of an Expert System as a tool to improve the design process and to capture the designer's knowledge. Its main purpose is to reduce substantially the time taken to produce a section drawing, thereby facilitating a speedy feedback to the customer.

In order to communicate with a designer, it is necessary to use sketches, symbolic representations and numerical data. This increases the complexity of programming an Expert System, as it is necessary to use a combination of languages so that decisions, calculations, graphical drawings and control of the system can be effected.

A production system approach is used and a further step has been taken by introducing an Activator which is an autoexecute operation set up by the Expert System to operate an external program automatically. To speed up the absorption of new knowledge into the knowledge base, a new Learning System has been constructed.

In addition to developing the Expert System, other software has been written to assist the design process. The section properties software has been introduced to improve the speed and consistency of calculating the section properties. A method of selecting or comparing the most appropriate section for a given specification is also implemented. Simple loading facilities have been introduced to guide the designer as to the loading capacity of the section.

This research has concluded that the application of an Expert System is beneficial and, with the activator approach, automated designing can be achieved. On average, a complex drawing can be displayed on the screen in about 100 seconds, where over 95% of the initial section design time for a repetitive or similar profile can be saved.

KEYWORDS

Expert System,
Cold Form Sections,
Learning System.
Activator,
Computer Aided Design,

To my family

ACKNOWLEDGEMENT

It is my pleasure to thank everyone who has assisted me throughout this research. The author is particularly indebted to the following for their assistance and enthusiasm :

Dr. J E T Penny (Supervisor) for his advice and the opportunity to carry out this project in the Department of Mechanical and Production Engineering.

Dr. D A Milner (Associate Supervisor) for his supervision, encouragement and valuable advice throughout the research period.

Mr. G Deeley (Technical Director of Hadley Industries Plc) for contributing his own personal knowledge and experience during the course of research. Also, many thanks to the designers of Hadley Sections Ltd. for their time and advice.

Mr. M J Scattergood (Departmental Technical Superintendent) for allowing me to use the computer during the writing up of this thesis. My thanks to all members of staff of the Department and also others who have contributed and helped in one way or another.

Dr. Raj Shah for his comments about the thesis.

Last, but not least, thanks to Melissa for being understanding and supportive throughout the course of my research.

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CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

The increased use of cold rolled products during the last decade has led to pricing competition between manufacturers. There are many areas where the production cost of a rolled product can be reduced, for example, by decreasing the set-up time, strip-down time, coil change time and most of all the time spent on producing the drawing. The ability of some manufacturers to produce a product at a lower price always makes their competitors question themselves as to where their weaknesses lie.

Although research work (Yoder,1937 and Warwick,1949) has been carried out just before the second world war, the knowledge of designing cold rolled products and the techniques for designing form rolls (Halmos,1985; Secco,1985 and Faulkner,1984) are just beginning to turn from art to science.

There are many aspects of the designing and manufacturing of cold rolled products which can be further improved. More new techniques to improve efficiency are continuously being investigated with the hope that they can be introduced throughout the whole manufacturing process.

The Department of Mechanical and Production Engineering at Aston University is involved in one of the most active research areas since the late seventies (Ng, 1981), namely in the application of computers to the Cold Roll

Forming (CRF) industries. There are no standard rules as to how tooling for the CRF process should be designed, and the knowledge is highly dependent on the experience of the designer (Secco,1985 and Rhodes, 1981). This work is aimed to investigate an alternative technique to improve the efficiency and productivity of the designer during the initial stage of the product design for cold rolled sections.

One of the main research areas in computing technology is Artificial Intelligence (AI), which is an important technology for software development in the future. AI research covers the area of Expert System (ES), learning system, speech generation, natural language translation, image processing and others.

The philosophy of Expert System (Barr & Feigenbaum, 1981) which consists of the inference engine, knowledge base and the data base has existed since the late 1970's. There is still a great deal of research work taking place at the moment concerning Expert System technique, such as knowledge engineering, improving the type of computer languages used, the type of inference engine, and the application of these ES's in different environments or expert domains.

In a lecture given by Professor Edward Feigenbaum (1989) at Aston University, the type of savings made by the world leading companies who had used Expert System techniques were discussed. With such enormous savings, it is undoubted that manufacturing companies in the United Kingdom should consider investing in such systems.

In the fast growing market of cold rolled products, there is a greater need for engineers and designers. This creates a shortage of skilled personnel. It is in the company's interest to look for an alternative method for preserving the skill that these trained personnel have accumulated. A large part of the designed profiles are repetitious in one form or another and it is hoped that such skill can be captured in the computer, and retrieved when necessary.

The design and manufacture of cold rolled products is still at its infant stage and expertise in this field is scarce. Although Expert System is quite a well known technique for capturing the expertise of an expert, there is still a lack of knowledge as to how and where such a technique can be applied to the manufacture of cold rolled products.

This research is the study of where and how an Expert System technique can be applied to capture the knowledge of the designer in designing cold rolled sections.

The research centres on the initial stage of designing the section profile and the ability to produce a drawing as quickly as possible (for repetitive or similar shapes where knowledge exists). It covers the process from the time when the customer enquires about a product to when a proper drawing is presented. It is aimed to improve the productivity of the designer, the efficiency of designing and the consistency of the decision-making process.

The work investigated includes the efficient use of material, routine engineering calculations, data communications, and presentation.

The work carried out includes the following:-

a, Design of conventional computer programs for routine engineering calculations.

b, Construction of an Expert System working with the conventional computer programs.

c, Introduction of an Activator.

d, Building of a Learning system for designing cold rolled sections.

1.2 STRUCTURE OF THE THESIS

The whole concept of a design of toolings for cold rolled forming process is detailed in Chapter 2. The main work that is identified is described under two main groups:-

Firstly, it is essential to clarify all the problems that are routine and can be overcome by using conventional programming techniques. The set of conventional programs is then constructed to handle these routine problems. This is mainly described in Chapter 3 and 4.

Secondly, after the routine problems have been overcome by the conventional programs, only then identifying areas where an Expert System can best be applied. The Expert System can then be constructed as an independent advisory system, or it can also be organized as a system that has the knowledge and can operate the conventional programs automatically. Chapter 5, 6 and 7 describe the concept and its applications.

Results obtained from testing can be seen in Chapter 8, and the conclusions have been written in chapter 9.

CHAPTER 2

COLD ROLL FORMING

2.1 COLD FORMING PROCESS

Products made from sheet metal are normally manufactured by a process called cold forming. It is a process of forming a strip or sheet of material with uniform thickness in the cold state. Cold form products can be manufactured mainly by folding, press-braking and rolling.

Folding is a very simple process whereby the sheet metal is formed. It involves folding a series of bends using a simple folding machine. The geometries of the products produced from folding are very simple, and it is mainly a one off production.

Press Braking is a process whereby short lengths of sheet metal are pressed around shaped dies to form the required shape. In this process the complexity of the shape is limited as well as the length of the product, which is usually less than 5 metres.

Cold rolling (as shown in fig.2.1) is a process of forming material in the cold state from a coil of sheet metal of uniform thickness which is fed continuously through successive pairs of form rolls acting as a male and female die. Each pair of form rolls progressively forms the strip of sheet metal until the desired cross-sectional shape is produced.

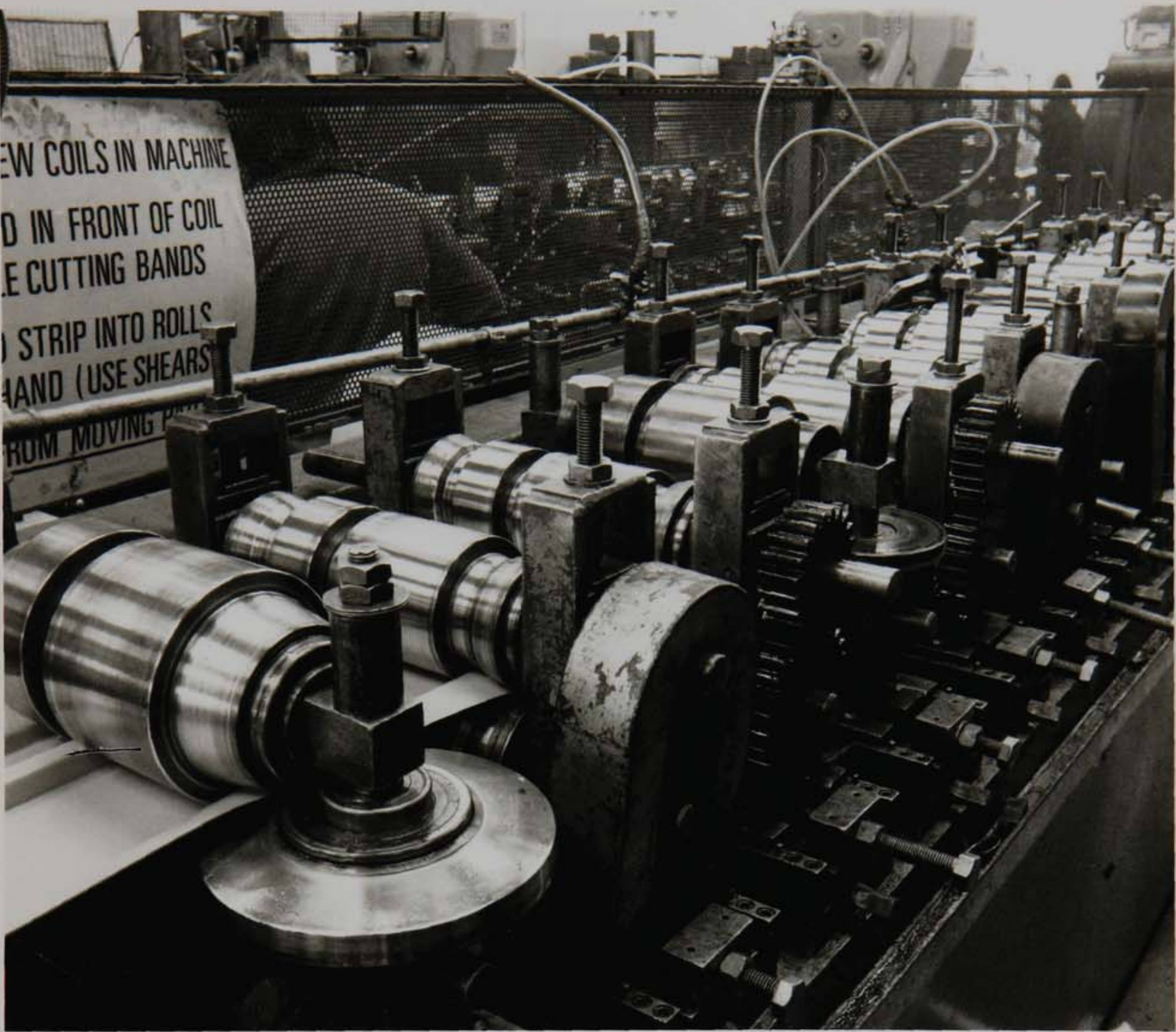

Fig. 2.1 Cold rolling process

The formed shape is then passed through a guillotine and cut to the required length. This product is called the cold rolled section or sometimes the cold rolled member. Details of how the cold roll tooling design process is carried out will be discussed later in this chapter.

2.2 TYPES OF PRODUCTS

The range of products that the cold roll forming process can produce is extensive and some of the shapes can be seen in Fig. 2.2. In recent years, there has been an increase in the production of coated steel strips, in spite of the decrease of steel production in the United Kingdom. The coated sheet metals have a better corrosion resistance and there is also a wide range of attractive coatings to choose from. This is one of the main factors that contributes to the increase in the usage of cold rolled products.

Furthermore, the advancement of CAD facilities has enabled the manufacturers to produce the appropriate tooling for manufacturing. This capability for producing different profiles is another factor which brings about an increase in the production of cold rolled sections. The product groupings are split into two major groups, namely structural product and non-structural product.

Structural products are normally used in construction, warehouse rack, car frame and others where the ability of the product to withstand a certain loading condition is an important requirement. Therefore, their section properties and loading capacity are required to be calculated. Most of these products will have to be tested before they are recommended to the customer. Loading capacity and the shape are the most important requirements for a structural product.

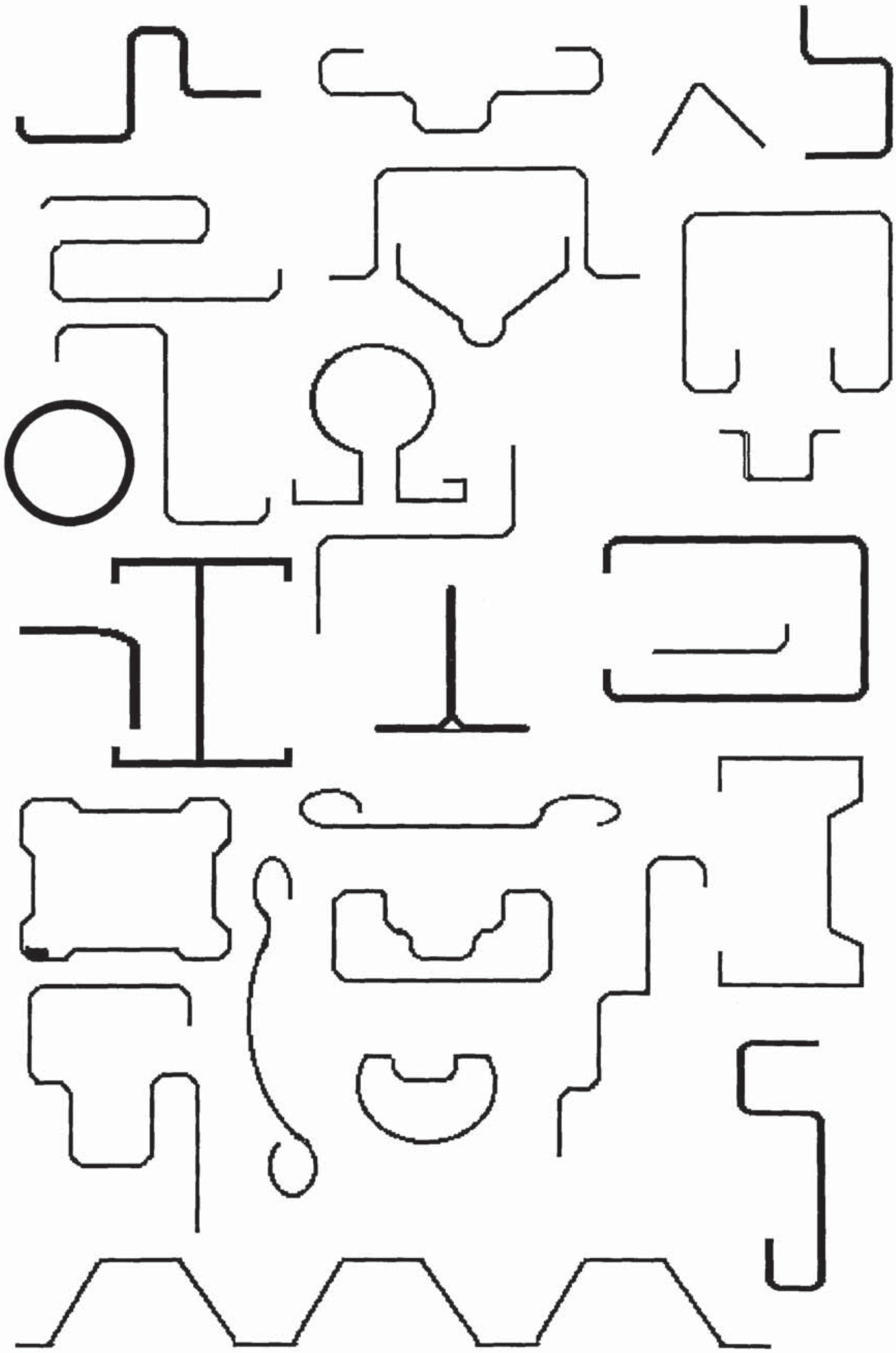

Fig. 2.2 Some of the cold rolled products

Non-structural products are normally used for decorative purposes. Even if load is applied onto these sections, it will be so minute that it can be ignored. The important requirement for a non-structural product is the appearance which covers the appropriate material, types of coating and colouring of the surface.

2.3 USES OF THIN WALL SECTIONS

Cold roll forming process can produce a wide range of sheet metal products. Everywhere we see cold rolled products in one form or the other. Although the construction industries consumed a large part of the cold rolled sections, these sections are also used in the manufacture of automobiles frame, agricultural tools, domestic appliances, office equipment, domestic fencing (fig.2.3), storage equipment, electrical cabling frame (fig.2.4) and buildings.

Due to the high strength to weight ratio, a large part of the old hot rolled sections are replaced by these cold rolled products. In the last decade, the facilities available for designing distinctive profile coupled with the ability to coat attractive materials onto these sheet metals have given the consumers a more acceptable approach towards the use of these sections. These cheap, reliable and pleasing appearances have made cold rolled products more popular than ever before.

Industrial buildings, modern warehouses and indoor sports arena are now constructed using mainly cold rolled sections rather than bricks or hot rolled sections. The most popular sections used are zed purlins, columns, cable channels, window frames, partition sections, door frames, weather surroundings, insulation support sections, corrugated sheet metals etc.

Fig. 2.3 Domestic fencing

Fig. 2.4 Electrical cabling frame

2.4 TOOLING DESIGN FOR COLD ROLL FORMING PROCESS

Cold roll forming is the most widely used of the cold forming process. The design of tooling as shown in Fig. 2.5 for a cold rolling process (Ng,1981) requires the following stages :-

1 Design of finished section
2 Design of flower pattern
3 Wire template design
4 Roll design
5 Die design
6 Roll machining
7 Die machining

Roll gauge can also be designed (Shae,1987) and manufactured by Computer Numerical Control (CNC) wire Electrode Discharge Machining (EDM) process where worn out rolls can be checked or recovered.

2.4.1 FINISHED SECTION DESIGN

The initial step of a cold rolling process is to design a finished section (ie. the shape required by the customer as shown in fig.2.6). The design produced by this finished section program only acts as a goal for which the rest of the tooling design process focuses on. There is no guarantee that the final outcome of the shape from the manufacturing process is completely accurate compared with the finished section design.

There will always be a compromise between the manufacturer and the customer towards the level of precision required. It is the same as any other precision engineering work, where it will cost more when a high level of precision is required.

Although the section design process consists only of a two-dimensional approach with two types of elements which are linear and circular, it can handle complex shapes too. It is at this initial step that the design of the profile must be right before it can proceed to the next step. The designer has to consider carefully and predict the possibility of this shape being produced successfully as required by the customer. Careful considerations must be given when high precision, or piercing is required. At this stage the designer also needs to foresee the type of cutting off technique to be used, which can produce the type of edge which is acceptable to the customer.

Normally only certain dimensions have to be precise while for others, it is less important. Sometimes the required holes are in such an awkward position that it is difficult for the punch to get in, or even if the punch is able to get in, it may destroy other parts of the section. The designer will have to make sure that the sections can be cut off without damaging the edges. This type of problem is common and usually an alternative shape is suggested by the designer to the customer to reconsider the required profile.

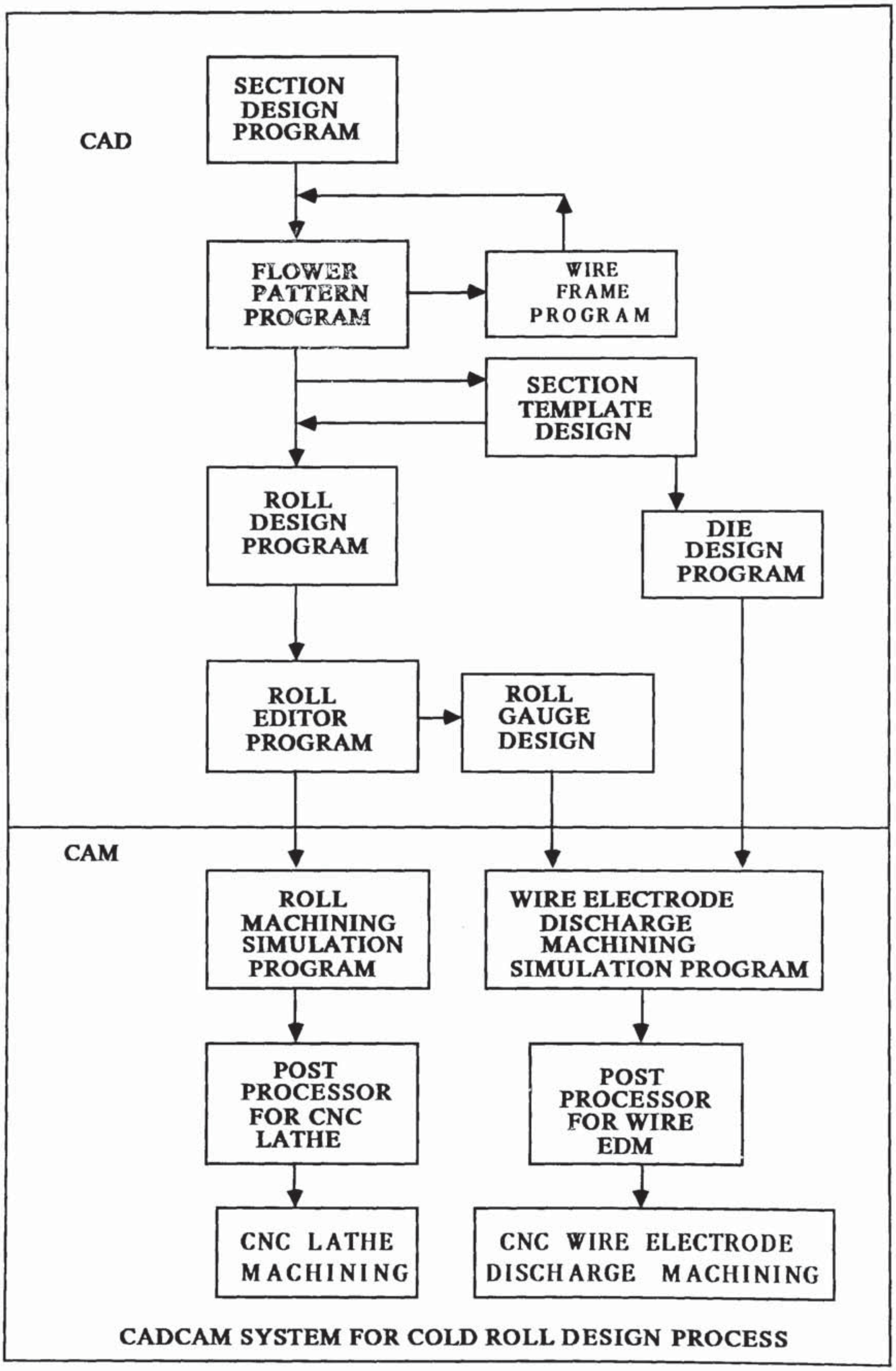

Fig. 2.5 CADCAM system for cold roll design process

Making decisions without the necessary knowledge can be very risky. Where a computer program is used for designing, knowledge is still required to operate the computer program and the design process. Therefore, the designer has to be adequately trained for the job.

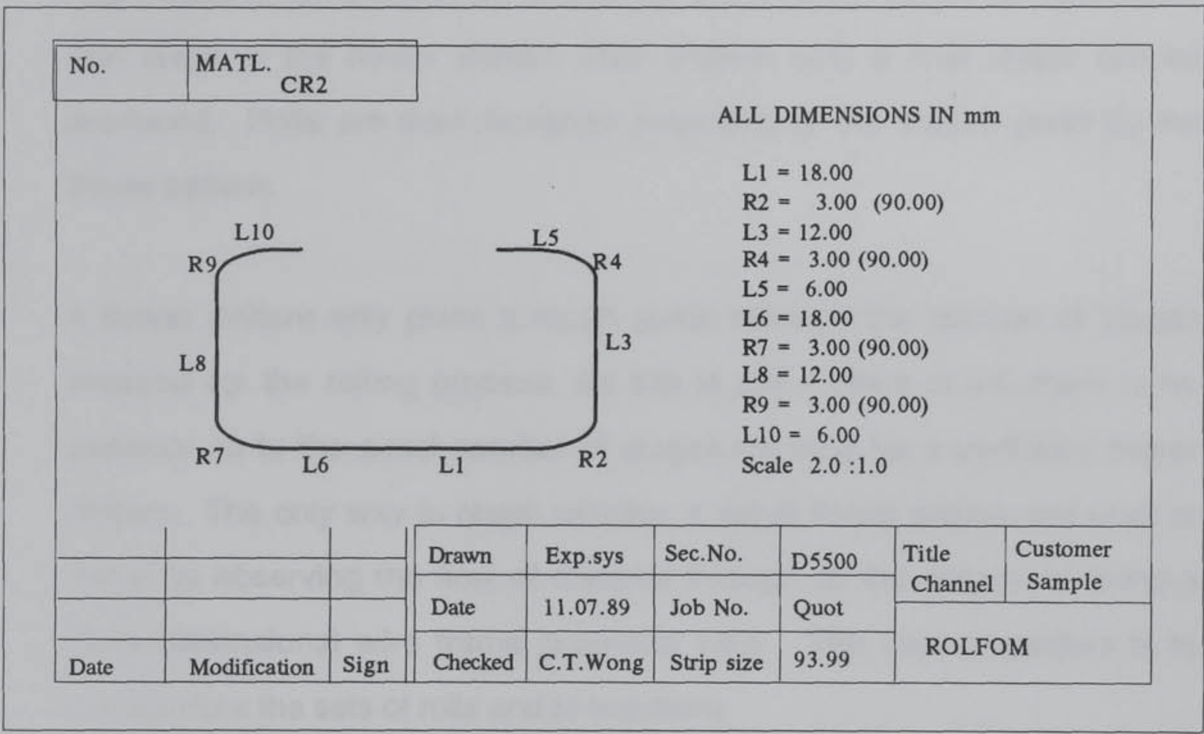

Fig. 2.6 Finished section design

2.4.2 DESIGN OF FLOWER PATTERN

The design of a flower pattern as shown in fig.2.7 and fig.2.8 shows how a flat sheet of metal goes through each stage of the rolling operation to form the required profile. The designer has to identify the bending sequence and, at each stage, what angle the bend should be. Wherever possible, fresh air bending should be avoided, but there are occasions where it is inevitable, then the designer has to design with extra caution. Fresh air bending is bending an angle with no support to it.

Designing a flower pattern is itself a skillful job. Theories available in this area are very limited (this has also been verified by Panton,1987) and a large part of the design process is dependent on the experience of the designer. With a given material, the designer has to ascertain the maximum angle that can be used at the bends and possibly the type of springback that might occur when the product comes out of the pass. This in turn generates one stage of the flower pattern after another until a final shape can be produced. Rolls are then designed according to the stages given by the flower pattern.

A flower pattern only gives a rough guide towards the number of stages required for the rolling process. As this is still a piece of art, there is no certainty as to the exact number of stages required for a particular flower pattern. The only way to check whether a set of flower pattern will work or not is by observing the flow of material through all the stages by using a three-dimensional wire frame graphical view. The next procedure is to manufacture the sets of rolls and to test them.

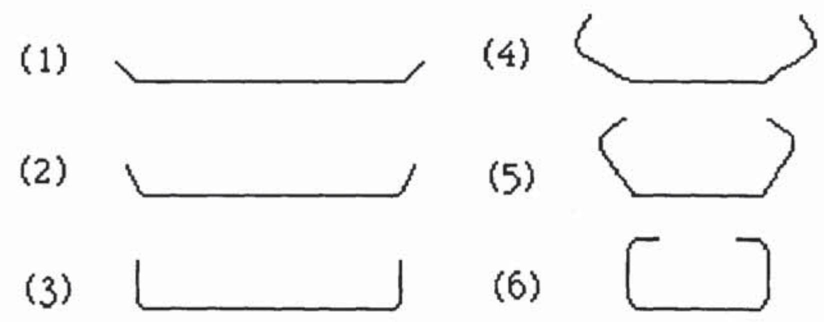

Fig. 2.7 Single stage of flower pattern

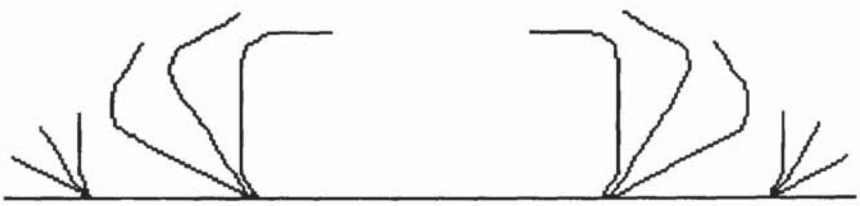

Fig. 2.8 Overall view of flower pattern

2.4.3 DESIGN OF WIRE TEMPLATE

When the section to be produced is very small, it is difficult to check or measure the dimensions of each individual element in both the flower pattern and the roll design. Thus, in order to check the profile, a wire template is used where the shape of the particular design stage has been enlarged to ten times its original dimension. Such enlargement can be done using a wire template program instead of using a shadowgraph. The template drawing produced by the software is sometimes called the 10 to 1 template which is then compared with the actual cross-section of the product.

This wire template drawing is also used for checking the geometric accuracy of the product. It is called wire template because in former times, when computer facilities were not widely used, the designer had to make the shape of the flower pattern out of wire and this wire was then used for measuring the rolls produced by the conventional lathe. The accuracy of the roll was far from precise, but now, with the aid of computer and the availability of CNC machining facilities, the rolls can be manufactured to a very high precision.

2.4.4 DESIGN OF ROLLS

The design of form rolls (as shown in fig. 2.9) is based on the sequence of bending angles produced by the flower pattern and the template. A large part of the roll profile coordinates are obtained from the template geometry. A roll design program normally generates the roll profile coordinates to a file where they are used for CNC lathe machining simulation, and later for producing the NC data listing.

A set of roll design programs available at Aston University offers the facilities to design up to four rolls (i.e. top, bottom, left and right). There are other features such as choosing the pass height, strip tolerance, pinch difference and extension contour. During the roll design process, the designer has to specify the part of the profile that does the gripping and pulling the material towards the next pass.

After the design of the required rolls, the data are checked by a program called the editor. This editor provides the facilities to eliminate unnecessary sharp corners and it can even modify the shape of the rolls so that the section profile can be produced without much problems. Roll profile modifications are highly dependent on the skill of the roll designer and such skill normally varies between companies.

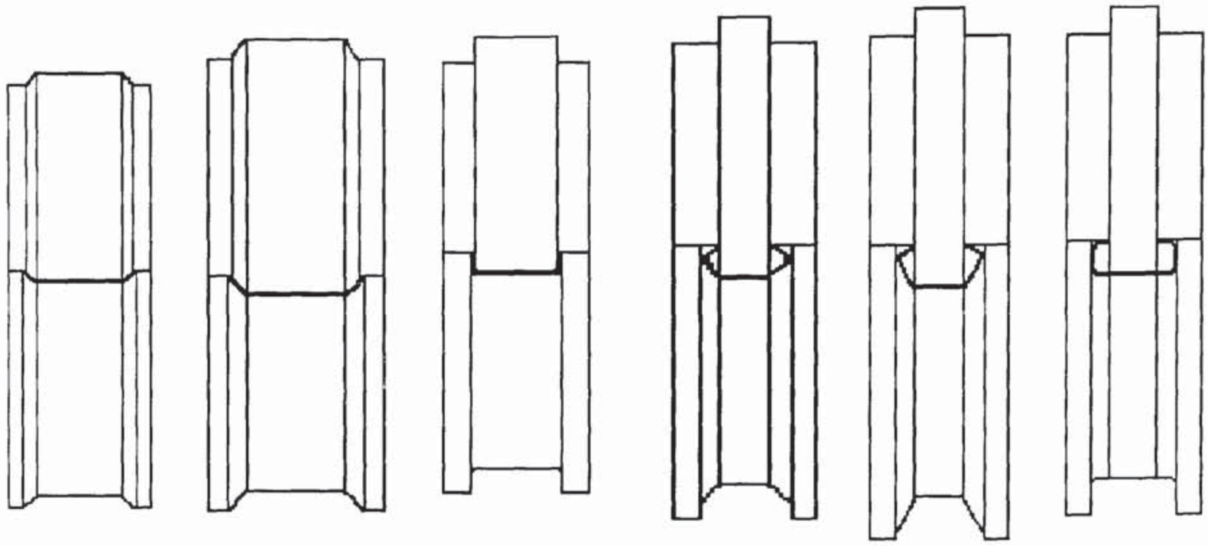

Fig. 2.9 Form rolls

2.4.5 ROLL MACHINING SIMULATION

When the rolls are ready for machining, the data are read in by the CNC lathe machining simulation program. The machining simulation program provides a set of tool libraries with information of the types and sizes of cutting tools.

The main types of tools are as follows :-

1	Right hand roughing tool	5	Right hand finishing tool
2	Left hand roughing tool	6	Left hand finishing tool
3	Right hand pocketing tool	7	Grooving tool
4	Left hand pocketing tool	8	Parting off tool

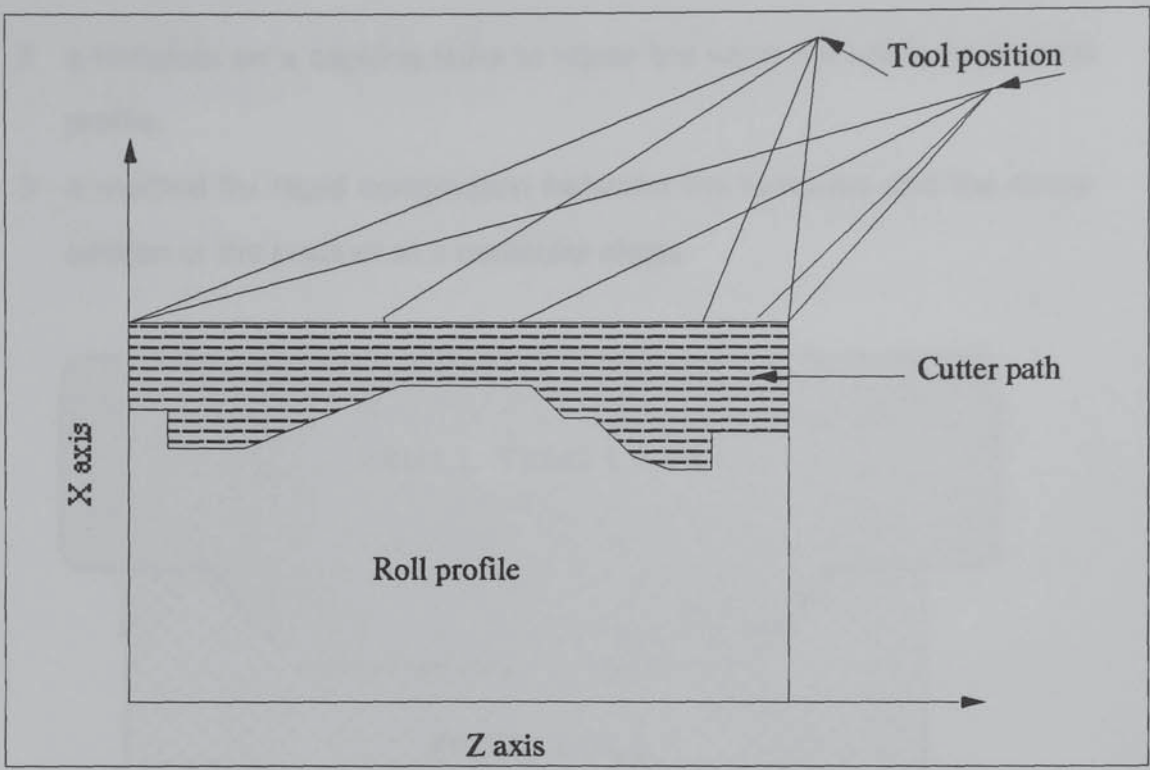

Fig. 2.10 Cutter path movement

The designer will select the appropriate tools for the necessary operations. These tool data, combined with the roll profile data, produce a simulated machining process (as shown in fig.2.10) which is then displayed on the screen to show that the operations are right. These data are later passed through a post-processor and generate the NC data. After generating the data in NC data format, these data are double checked by the post-processor before sending to the CNC lathe.

2.4.6 ROLL GAUGE DESIGN

Roll gauge is also known as the roll template (as shown in fig.2.11) which is made from sheet metal. This roll gauge is used as

1 a visual inspection gauge for the roll

2 a template on a copying lathe to repair the worn out roll to its original profile.

3 a method for rapid comparison between the template and the cross-section of the product at a particular stage.

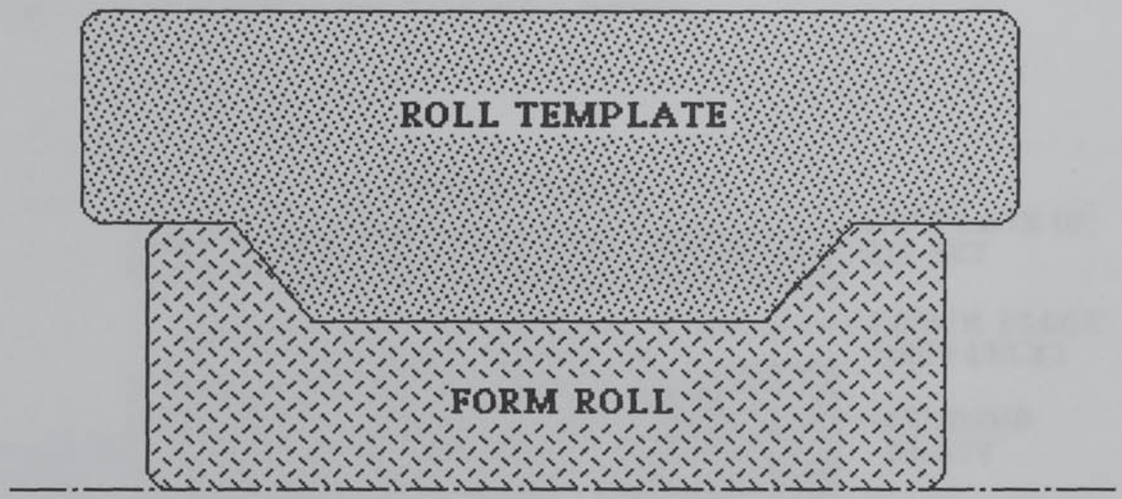

Fig. 2.11 Roll template

2.4.7 DIE DESIGN

The design of die is carried out after the set of rolls has been designed. There are normally two types of die used for cutting off the section to the required length. Firstly, a die which uses a double shearing technique is most commonly used. This technique can be applied to both complex and simple shapes and it is also cheap to produce. Secondly, a die which uses single shear cutting technique is becoming increasingly popular. When a section is cut off using the single shear technique, scrap is eliminated and hence material savings are provided. Futhermore, the cost of removal of scrap is also saved. A die using the single shear technique (as shown in fig.2.12) is more expensive and difficult to produce. With the availability of the wire electrode discharge machining technique, the production of a single shear cutting die has been made much simpler.

The single shear cutting off die involves using two tool steel blocks with a hole in the middle, which is shaped like the profile of the section. One piece of the tool steel is fixed and the other is movable.

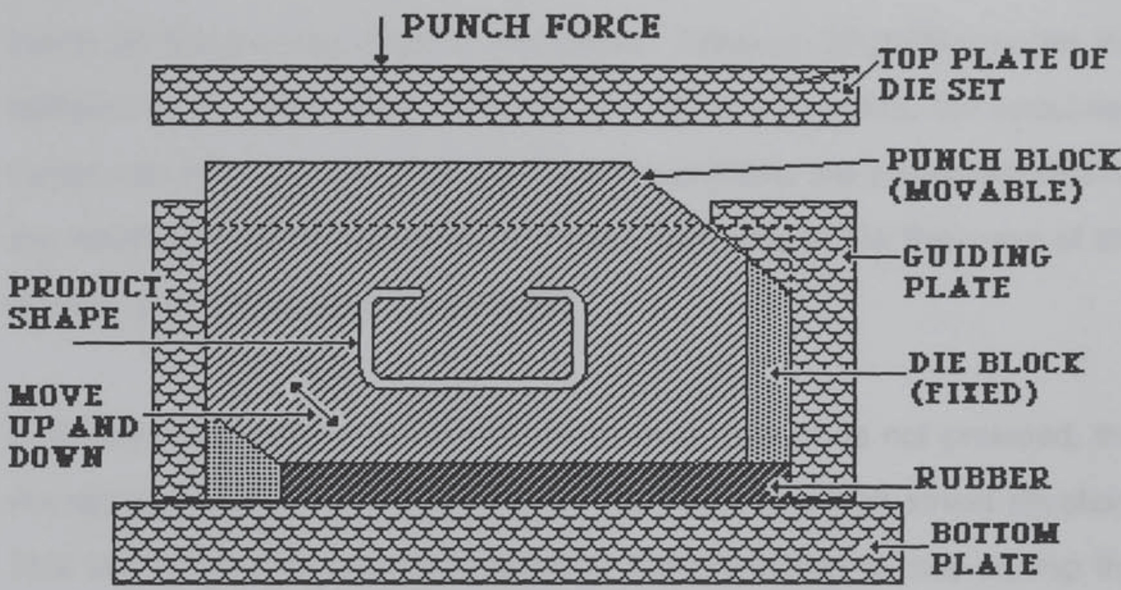

Fig. 2.12 Cutting off tool

When a force is exerted onto the movable piece of the die, it acts like a pair of scissors and cuts off the section to the required length. The hole in the die is slightly bigger than the size of the product. The geometrical data required for designing a die can be obtained from the final stage of the ten-to-one template drawing which should also be the same as the finished section dimension.

While generating the data from the template file towards the new set of data for the die, there are conditions which the designer has to consider, namely:

1 elimination of sharp corners which can easily cause the die to crack.

2 increase in the dimension of the end elements due to reduction in cross-sectional area at the bends which increases the overall width of the material.

It is always better to design the hole of the die to be larger than with a tight tolerance. The extra material produced at the end elements is caused mainly by the thinning effect of the bends. Although BS2994 provides the facilities for calculating the reduction of thickness at bends, the calculated values can only be taken as a guideline. In practice, the actual reduction in the material thickness at bends can vary according to the thickness of the material and the type of material used.

If sufficient gap for the extra material to pass through is not provided, the corners of the end elements of the die can result in a high stress situation. This can cause the corners to crack or the production to stop during the middle of the operation. In order to overcome this, facilities for extending the length of end elements and also rounding off corners are available in this design stage.

2.4.8 WIRE ELECTRODE DISCHARGE MACHINING SIMULATION

When the shape of the roll template (for measuring the roll profile) or the die (for the cutting off process) has been finalized, a cutting simulation is carried out. This cutting process is based on the wire Electrode Discharge Machining (EDM) simulation technique as shown in fig.2.13 and fig.2.14. The simulation process will then be carried out dependent upon the design geometry of the die or the roll template.

A small hole is always drilled as a start hole on the unwanted part of the steel block for the copper wire to pass through. The position of the hole has to be carefully determined by the designer so that the hole is not drilled at the weak point of the die or punch block. The diameter of the wire used varies from 0.152 mm to 0.3 mm, while the hole is normally drilled with a diameter of 2.0 mm to 3.0 mm.

After the simulation has been carried out, a set of NC data can be produced via a post-processor and later fed into the CNC wire EDM machine.

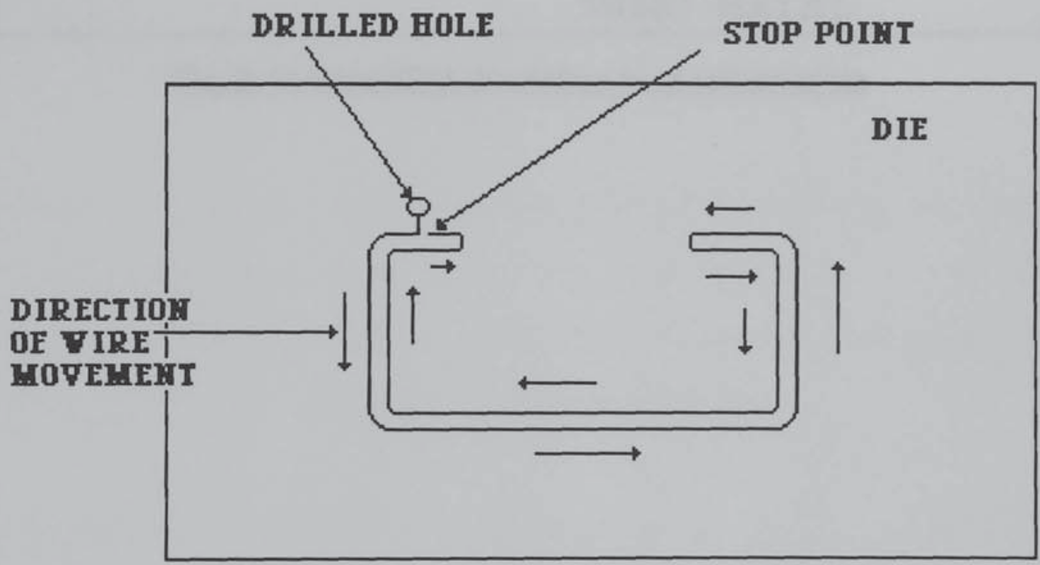

Fig. 2.13 Wire EDM simulation on a die

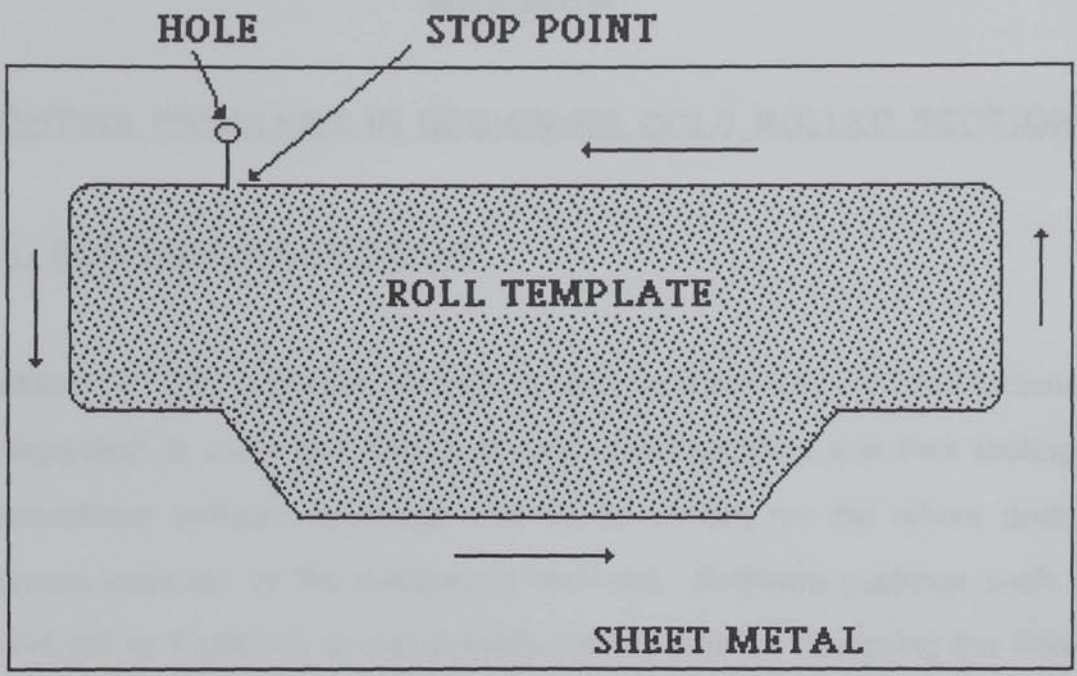

Fig. 2.14 Wire EDM simulation for a roll template

CHAPTER 3

ROUTINE PROBLEMS IN DESIGNING COLD ROLLED SECTIONS

3.1 DESIGNING A SECTION

Customized CAD software package is used (in most cold roll manufacturing companies) to assist the design of cold rolled sections and their toolings. Specialized software package has to be written for the whole design process because of the complexity involved. Software package such as AutoCAD or FastCAD do not provide the facilities for designing the flower pattern or the rolls as a whole package.

The data files generated by any specialized software package are normally only compatible with software within that specific package. It is therefore wrong to assume that the data output from this specialized software package can be read directly by any other commercial packages.

If a section has been drawn by the specialized package and the data are later required for calculation or presentation using a commercial software package, the designer has to type the whole set of the design data in an format acceptable to the commercial package. Alternatively, intermediate software programs can be written to interpret the data from one format to another. Both can be very time consuming when dealing with complex shapes. The manufacturer also finds it difficult to see how the calculations are carried out by this commercial software package. They can only use it as an executable image file, as there is no room for any modification to suit their needs.

3.2 CALCULATION OF THE SECTION PROPERTIES

Calculating the section properties of a finished section manually can be a tedious task for a designer. It is time-consuming and prone to error, especially for complicated shapes. At the moment, the section properties are either calculated manually with the aid of an electronic calculator or using a very simple computer program. These methods only produce a set of numbers and it is difficult for the the user to know where the point of origin of the section is without any graphical representation.

Alternatively, the set of design data can be passed to a specialist so that the section properties can be calculated elsewhere and later fed back to the company. Such an operation is too time consuming and sometimes can be costly.

Since section properties of a profile are needed before load testing calculation can be carried out, it is essential to provide them to the designer as quickly as possible. If the result of the load test is unsatisfactory, the section has to be modified and, consequently, the section properties re-calculated. This is an ongoing process until the result of the load test is satisfactory.

If calculations of these section properties take a long time on every occasion, it then becomes impracticable for the designer to carry out more load test calculations on the section in order to satisfy the specification. Instead, he will choose a product from BS2994 where all the section properties are readily available and recommend it to the customer.

To eliminate the burden involved in calculating section properties from the designer, a software package is required which can read the design data directly from the section design program and produce a set of section properties without having to type the whole set of design data twice. The software package should have the facilities to produce the section properties data in a file, which can be easily acceptable by other software program within the specialized package. A computer program which satisfies the above requirements has been written and will be described in Chapter 4.

3.3 CHECK ON THE LOADING CAPACITY OF A GIVEN SECTION

A load test on the computer for some of the sections used for loading purposes is essential, as this will give the designer a guideline as to the load the section can carry. In this initial stage of the design process, it is difficult to judge the exact load that the designed section can carry without carrying out the load test physically.

To carry out a physical test for a section is a very expensive process. If a section has to be load tested physically, the section will have to be manufactured, including all the required rolls. The manufacturer is very unlikely to recover the costs of such physical test, especially when the order of the section has not been confirmed. If the customer refuses to accept the order because the section cannot meet its specifications, the company will have to write off the costs already incurred.

It is useful to be able to calculate the load carrying capacity by using computer simulation as this gives a guideline to the designer as to the range of loading capacity of the section.

Calculating the load capacity of a section differs according to the shape of the section. Research study in the type of structural calculation used for rolled sections has been an ongoing project for many years throughout the United Kingdom especially at Strathclyde University and Salford University.

It is impractical to write a program with a new formula for each new shape. Thus, in order to carry out load test based on computer simulation, a general formula must be used.

If such a software program is used in this area, this will enable the designer to advise the customer of an estimate of the loading capacity of the section and the calculations that have been carried out. With this information the customer can then decide whether to confirm the order or not.

3.4 TYPES OF MATERIAL USED

Throughout the years, manufacturers have used a large number of different materials for their products. The main materials used are aluminum, steel, copper and brass, but the majority of the products are made from different grades of steel.

Whenever section loading calculation is carried out, the material properties of that particular section must be known. Most of the time the designer can only give a good guess as to the values of the material properties. Many companies have few or no records of the type and grade of material used. As a result, the advice on the loading capacity of a section given to customers may not be accurate.

This shows that it is important and necessary to collect all the material properties such as the grade, yield strength, ultimate strength, density and modulus of elasticity. These are the pieces of information which are most frequently used in the calculation. If a file is created with all this information, the designer can extract the relevant details from the file. In this way, unnecessary human error can be overcome.

3.5 SELECTING AN APPROPRIATE SECTION

It is common for a customer to approach a company with some load specification and to ask the designer whether there is any section available which matches the given specification. If the company has manufactured a similar section previously, the tooling will be available within the company. Otherwise, the tools have to be manufactured. Undoubtedly a large part of the product cost comes from the design and manufacture of the tools required for that specific shape.

If the customer can avoid the tooling cost by being flexible and using an existing shape for which the tools are available, the cost of designing and manufacture of the tools will be saved. This will provide a better utilization of the tools as well as lowering the cost of the products. Such a pricing approach will be more attractive to the customer.

At the moment there are no facilities available for selecting an appropriate section from the types of product that the company have manufactured before. The usual way of doing this is by going through the product file page by page, until the designer has found a shape which he thinks will meet the load specification.

The designer then searches manually through the design data files of that given shape. After the designer has found the data, he calculates the section properties and the load to check whether this section meets the specification. This is a very lengthy process.

Once a shape which meets the specification has been found, the designer will usually stop at this point and not proceed to look for other possible profiles. There may well be other profiles available, which require less material to produce than the one that has been chosen by the designer. These possibilities have not been explored at all.

In order to provide a fast feedback to the customer, it is necessary to use the computer to select the products instead of doing it manually. A product data base can be created to store all the products available in the company. Whenever there is a need to search for an appropriate product, the designer can retrieve the data easily from the file.

3.6 COMPARISONS BETWEEN DIFFERENT SECTIONS

Whenever the manufacturer proposes to produce an In-house product, he normally has to assess whether a potential market exists before proceeding any further. Very often, it is necessary to design a series of different profiles, compare them and find the best profile before carrying out the manufacturing process.

The manual way of comparing the sections is by drawing a few sketches with different shapes, choosing the shape which is thought best and finally proceeding to the manufacturing process. After the product has been manufactured, physical testing is carried out to examine the load capacity of the section.

The above approach only selects one profile to be considered for manufacture. It is highly possible that those drawings that have not been considered can provide a better performance than the one that has been produced.

There are no facilities available for calculating the load carrying capacity before considering the most economical shape to produce. If comparison has to be carried out between all the different shapes it will be very time consuming to check and calculate every profile.

3.7 PROFILE EFFECTIVENESS

In order to achieve an economical design of a cold rolled section, the thickness of the profile or the amount of material used must be minimised. In doing so, certain modes of failure will be encountered, as follows:

1) Local buckling
2) Web crushing
3) Lateral buckling
4) Shear buckling
5) Torsional flexural buckling

While designing a section, the designer must be aware of or foresee the types of problems that are likely to arise in the manufacturing process. Therefore it is important for the designer to receive relevant training so that the types of failure modes that are encountered in by cold rolled sections can be understood, i.e., problems such as slipping, changes of material grain structural, stress at coners, thinning of material thickness and others.

3.7.1 LOCAL BUCKLING

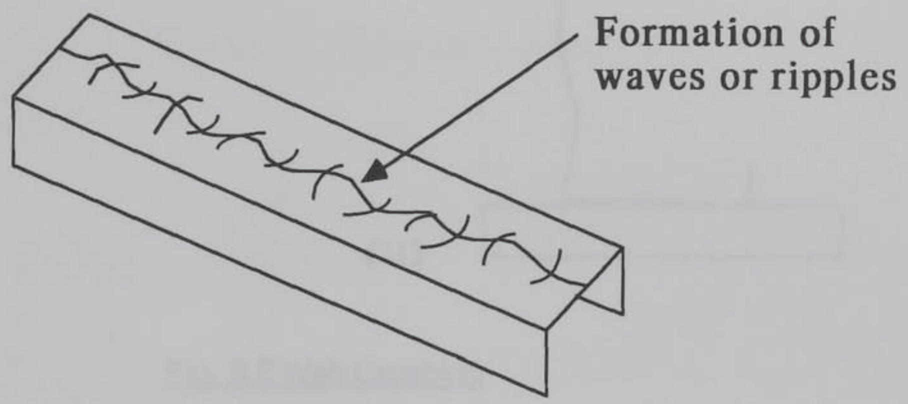

Fig. 3.1 Local Buckling

Buckling of the elements, shown in Fig. 3.1, of a section is characterized by the formation of waves or ripples along the members. These elements buckle at stress levels less than the yield point if they are subjected to compression, direct loading or shear loading.

This does not necessarily cause a sudden collapse of the section but, if the stiffness of the section is reduced, then collapse can occur at a lower load than in the absence of local buckling. When the section continues to carry greater load in excess of the first local buckling, this is known as the "post-buckling strength", which is normally taken into account in the design calculation.

3.7.2 WEB CRUSHING

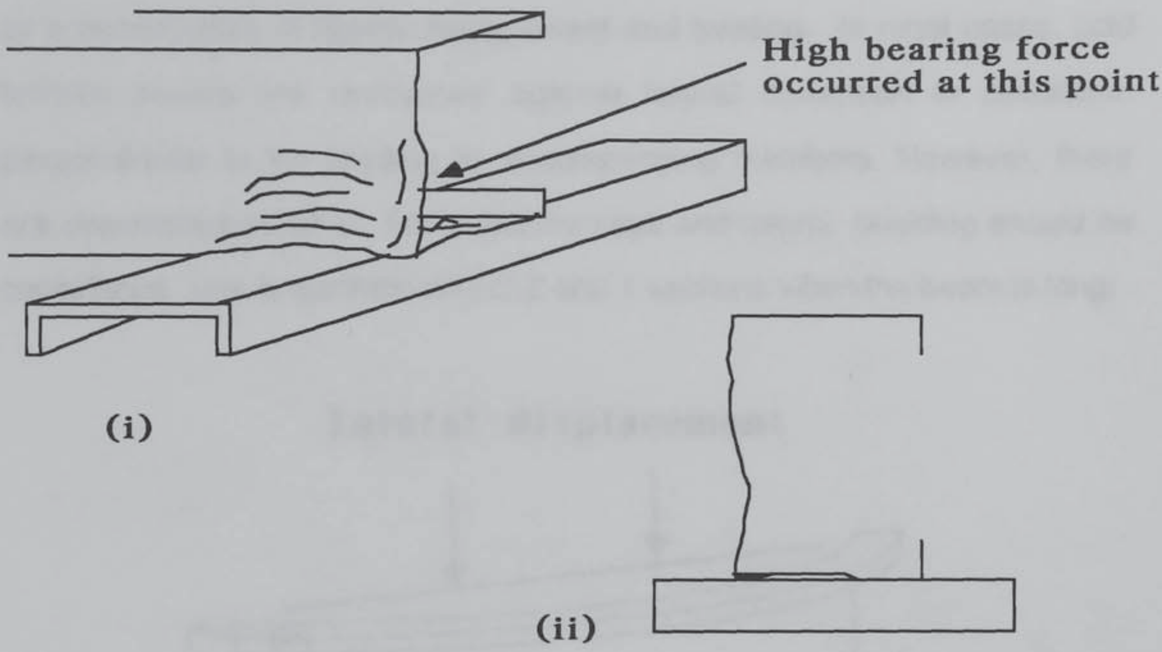

Fig. 3.2 Web Crushing

Local failure of the web, shown in Fig. 3.2, at the support point normally occurs on beams with deep slender webs. This is caused by the reactions of the support when concentrated loads are imposed on the section.

3.7.3 LATERAL BUCKLING

Lateral buckling is the buckling of a beam, shown in Fig. 3.3, accompanied by a combination of lateral displacement and twisting. In most cases, cold formed beams are restrained against lateral deflection or deflection perpendicular to the loading by accompanying members. However, there are circumstances when this is not the case and lateral buckling should be considered. This is common on I,C,Z and T sections when the beam is long.

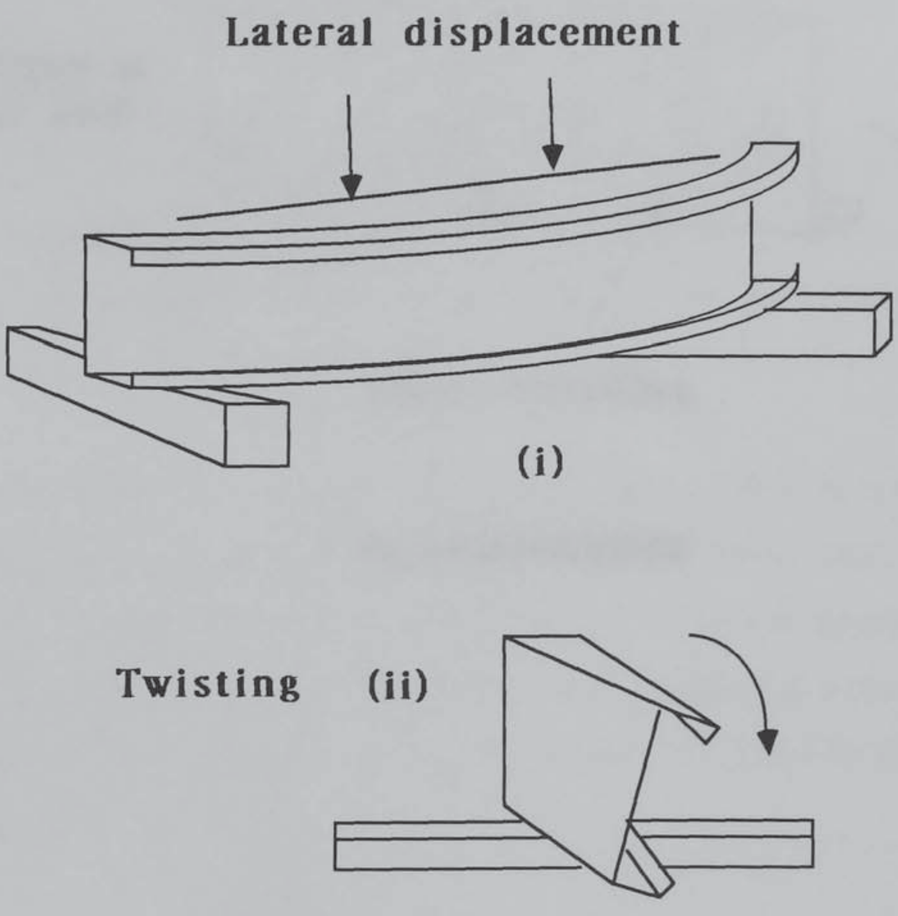

Fig. 3.3 Lateral buckling

3.7.4 SHEAR BUCKLING

Shear buckling, as shown in Fig. 3.4, can be caused by shear stresses in beam web as a result of the lightness and thinness of the section. This must be taken into account in the designing stage of the section.

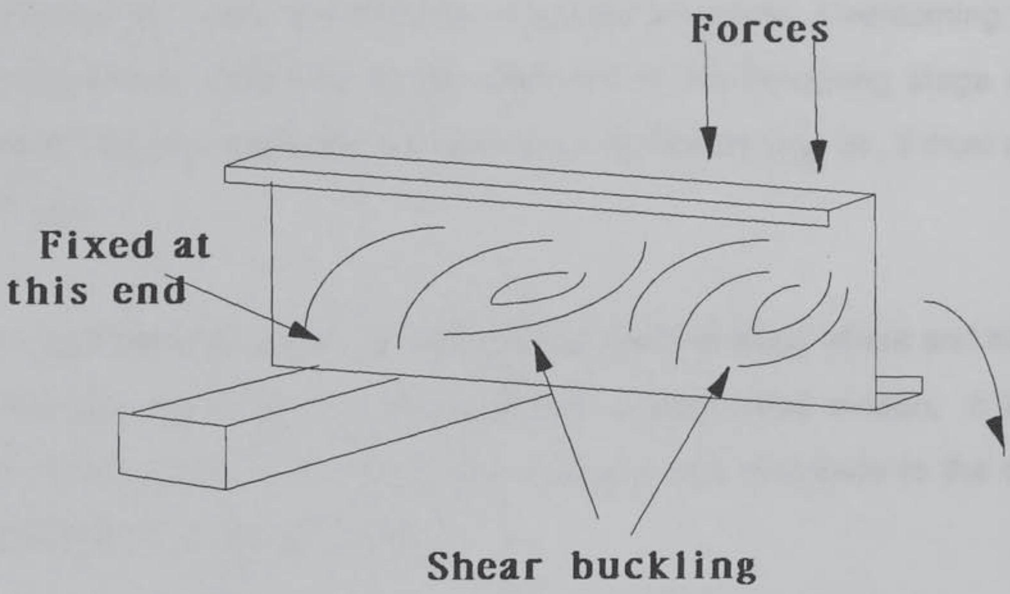

Fig. 3.4 Shear Buckling

CHAPTER 4

OVERCOMING ROUTINE DESIGN PROBLEMS

4.1 ROUTINE WORK IN DESIGNING SECTION PROFILE

Routine engineering design problems mentioned in Chapter 3 can be overcome by using conventional computer programs. Overcoming these problems will contribute to the efficiency of the designing stage of the finished section, therefore, whatever the contribution may be, it must not be ignored.

Although the core of this research programme is to study where and how ES technique can be applied in the design of cold rolled section, it is also necessary to look at the supporting domains that contribute to the overall efficiency of the design process.

Supporting domains such as the routine calculations within the initial stage of the design process must be studied and developed into computer programs, if overall efficiency is to be achieved. ES is best applied to non-routine decision making processes. Therefore, constructing a conventional computer program to handle most of the routine work helps to simplify the construction of an ES.

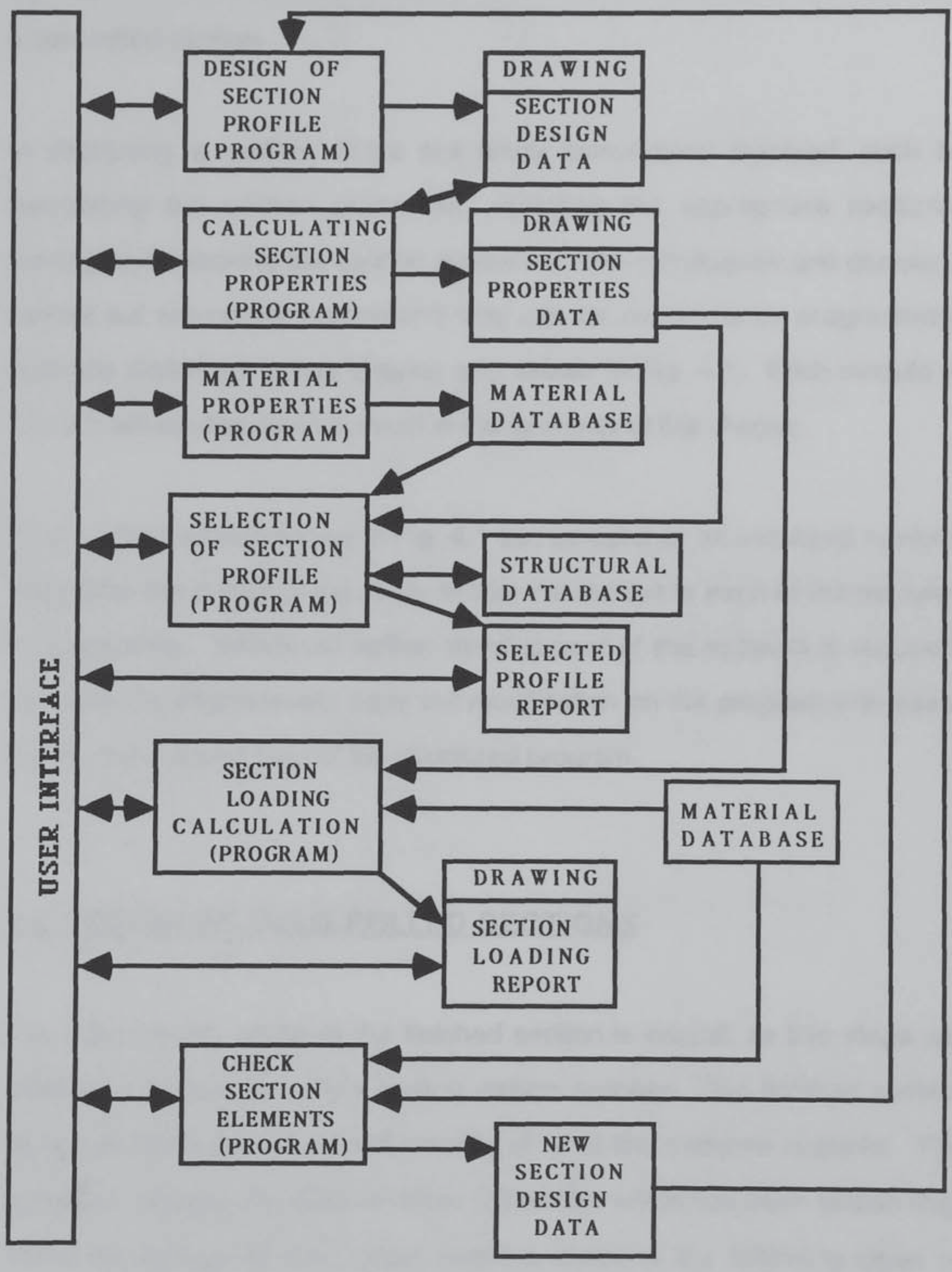

Fig. 4.1 Layout of routine work in designing section profiles

The use of an ES technique will be described in the following chapters showing where and how ES can best be applied. The methods to be discussed in this chapter involve the use of conventional programming techniques to overcome routine problems in the process of the designing of a cold rolled section.

In designing a section, there are many calculations involved, such as calculating the section properties, selecting the appropriate sections, loading and checking the section elements. The calculations and decisions carried out are mostly routine and they can be overcome by programming methods discussed in this chapter and shown in Fig. 4.1. Each module in Fig. 4.1 will be discussed in detail in the later part of this chapter.

Each of the methods shown in Fig. 4.1 can be used as an individual module. This gives the designer the ability to test the section in each of the modules independently. Whenever further development of the software is required, the software engineer can carry out modification on the program with ease, due to the modular form of the structured program.

4.2 DESIGN OF COLD ROLLED SECTIONS

The initial design stage of the finished section is crucial, as this stage will ultimately govern the whole tooling design process. This finished section design program provides a full drawing of what the customer requires. The computer program available in Aston University which has been written (Ng, 1981) for designing cold rolled sections contains the following types of elements:

1. Linear elements
2. Circular elements
3. Dummy elements (for holes pierced in the section)

INPUT UNIT	OUTPUT UNIT	THICKNESS mm	ORIGIN
2	2	2.0	5
ELEMENT NO	ELEMENT TYPE	LENGTH/ RADIUS	ANGLE
1	1	15.0	0.0
2	2	3.0	90.0
3	1	10.0	0.0
4	2	3.0	90.0
5	1	5.0	0.0

Table 4.1 Section data

Data from Table 4.1 can be used to produce the information on fig.4.3 and a a full drawing can be obtained from Fig. 4.2. The types of data to be typed into the computer are

type of UNIT used and the option where ORIGIN start

the THICKNESS of the material

LINEAR element and its LENGTH

CIRCULAR element, its INNER RADIUS and BENDING ANGLE

DUMMY element and its LENGTH

All calculations concerning the linear, circular and dummy elements which join each other are carried out by the computer. The only calculation to be carried out by the designer involves translating the basic dimensions of the profile given by the customer to specific values for each element. With this CAD program, the designer can redraw the drawing in a much shorter time, whereas the conventional method will take at least 3 to 4 hours. Therefore, it becomes relatively quicker to get the drawing right by using the CAD program.

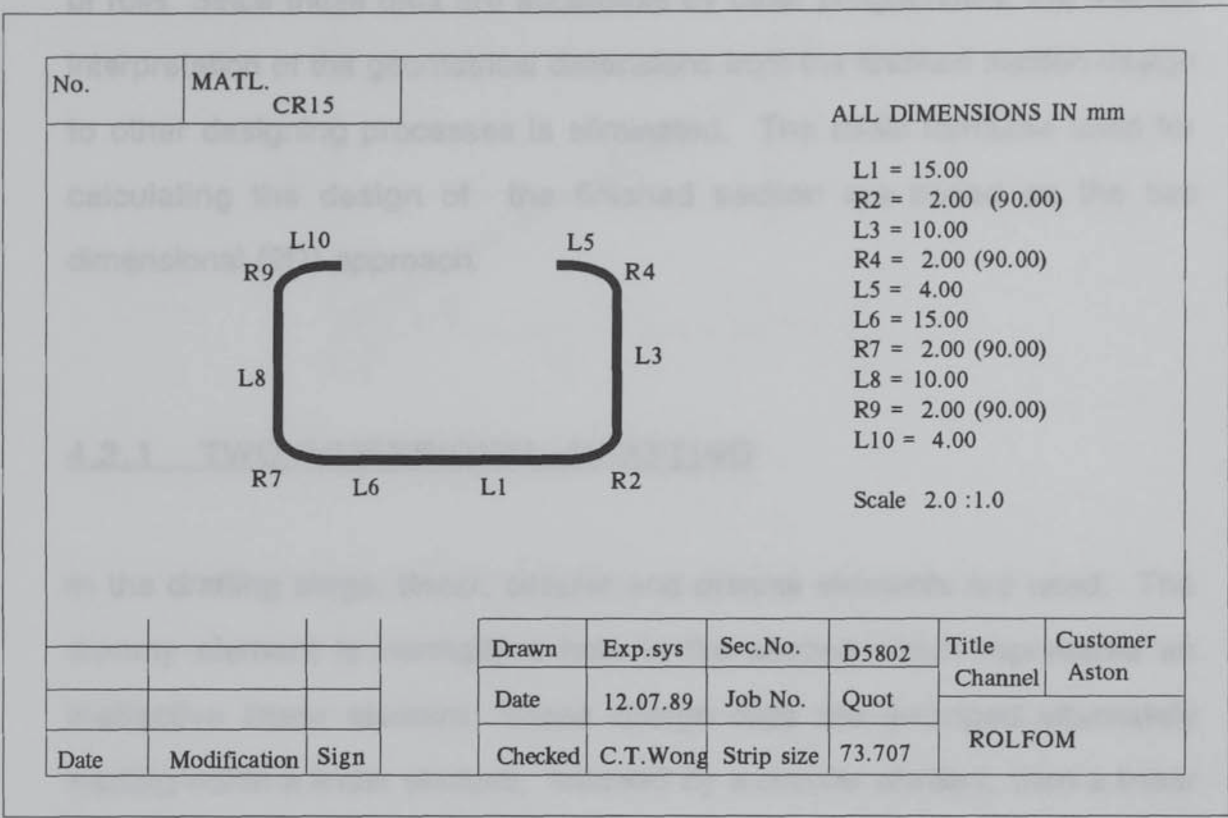

Fig. 4.2 Section design drawing

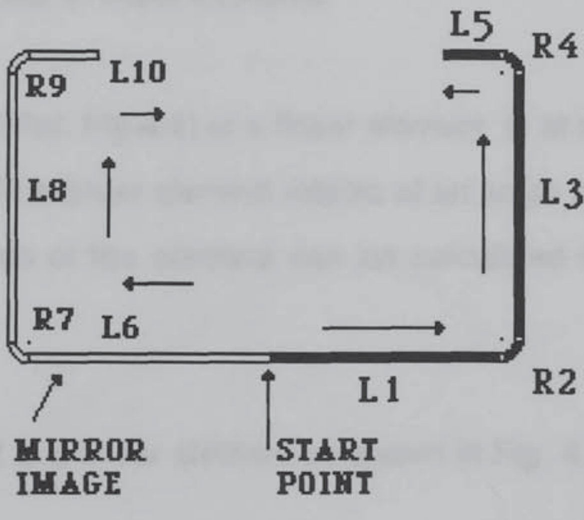

Fig. 4.3 Section design

The design data as shown in Table 4.1 are stored in the computer memory and are accessible by other programs such as the programs for calculating section properties, design of flower patterns, design of templates and design of rolls. Since these data are accessible by other programmes, the manual interpretation of the geometrical dimensions from the finished section design to other designing processes is eliminated. The basic formulae used for calculating the design of the finished section are based on the two dimensional (2D) approach.

4.2.1 TWO DIMENSIONAL DRAFTING

In the drafting stage, linear, circular and dummy elements are used. The dummy element is normally a hole in the section which represents an ineffective linear element. These design data are arranged alternately starting within a linear element, followed by a circular element, then a linear element again and so on. The set of design data always starts with a linear element and ends with a linear element. Dummy elements are all in linear form which are similar to linear elements.

The start position (Ref. Fig.4.4) of a linear element is at (0,0) while the end position at (a,b). The linear element rotates at an angle of ø with the length L_1, the end position of the element can be calculated from the following equations :-

When the element is a linear element as shown in Fig. 4.4 the end position will be

$$a = L_1 \cos ø \qquad (4.1)$$

$$b = L_1 \sin ø \qquad (4.2)$$

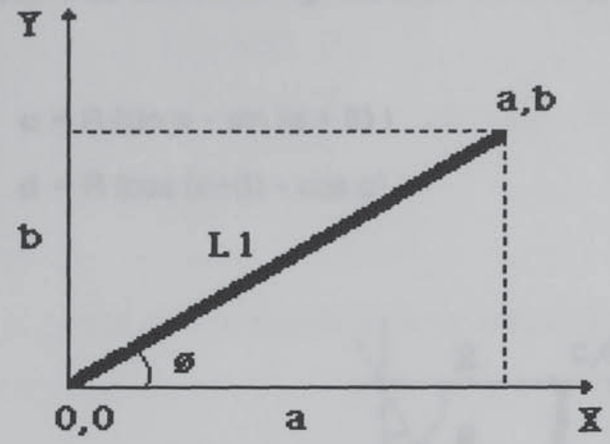

Fig. 4.4 Linear element

A circular element starts from position (a,b) and ends at position (c,d) with the radius R and the arc angle of ß radian. This circular element can be positive or negative, in either case, the end position (c,d) can be obtained from the following equations :-

when ß is positive (as shown in Fig. 4.5) then

$$c = R(\sin(ø + ß) - \sin ø) \quad (4.3)$$

$$d = R(\cos ø - \cos(ø + ß)) \quad (4.4)$$

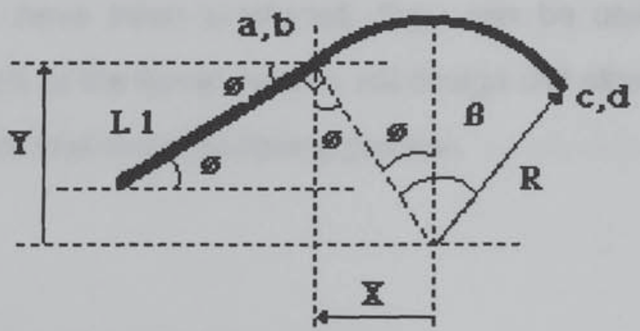

Fig. 4.5 Positive circular element

when ß is negative as shown in Fig. 4.6 then the end position will be

$$c = R(\sin \phi - \sin(\phi + \beta)) \quad (4.5)$$

$$d = R(\cos(\phi+\beta) - \cos \phi) \quad (4.6)$$

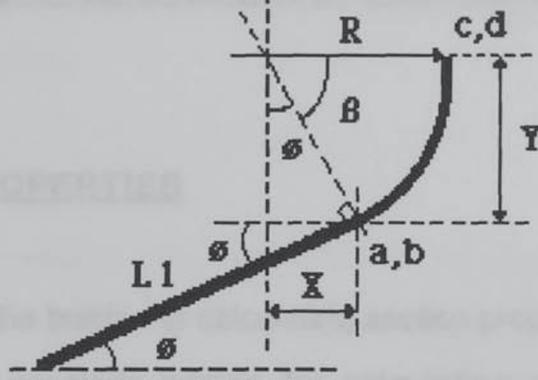

Fig. 4.6 Negative circular element

4.2.2 METHOD USED FOR DESIGNING SECTION

When the section design program is executed, it will produce a drawing and a section design data file as shown in Fig. 4.7. This section design data file contains each individual element of a given section. When the section design data have been produced, they can be used by other design programs such as the flower pattern, roll design and others. It is also the key data file for the rest of the designing process.

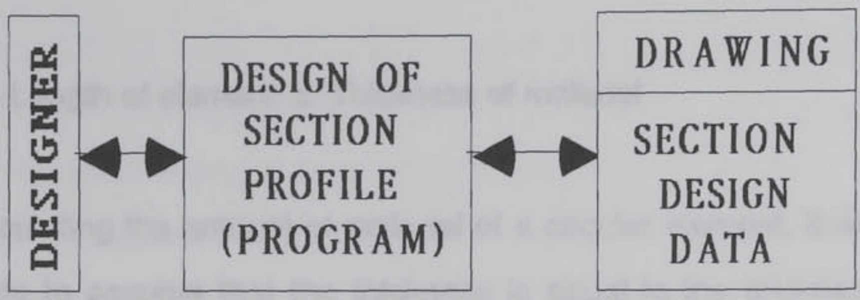

Fig. 4.7 Layout for Section design program

4.3 SECTION PROPERTIES

In order to eliminate the burden of calculating section properties, a computer program has been specially written for calculating section properties automatically. These calculations can be readily found in most Applied Mechanics text books.

The calculations of section properties in the program are based on the equations from 4.7 to 4.26. Since this program is adaptable to any shapes and is specially designed for general purposes, it does not take into account the effective width of an element.

In the section properties program, the properties of the section profile are calculated based on the "Linear" method (also known as the "Centre-line" method). The types of calculations used are described below.

4.3.1 CROSS-SECTIONAL AREA

The cross-sectional area (CSA) of a linear element is the multiplication of the thickness of the material and the length of that element.

CSA = Length of element x Thickness of material (4.7)

When calculating the amount of material of a circular element, it will not be appropriate to assume that the thickness is equal to the thickness of the sheet metal. For any circular element, there will be a reduction in area due to thinning effect on bends.

REDUCTION IN AREA AT BENDS

Whenever a sheet metal is rolled and bent at an angle, there will be a decrease in thickness at the bend as shown in fig.4.8. The decrease in thickness can be estimated by the following equations based on BS2994.

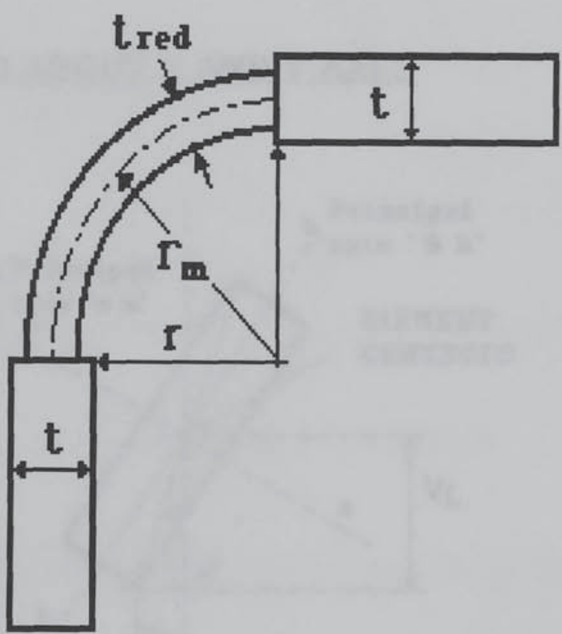

Fig. 4.8 Reduction in cross section area

$$t_{red} = ((r + Xt) / (r + 0.5t))\,t \qquad (4.8)$$

$r_m = r + 0.5t$

for $t <= 6.0$ mm

$X = 0.3$ for $r/t <= 1.0$

$X = 0.35$ for $r/t > 1.0$ and $r/t <= 1.5$

Where

t = thickness of the material (mm)

t_{red} = reduced thickness due to bending (mm)

X is the thickness reduction factor

r = internal radius (mm)

r_m = mean radius (mm)

From the above equation, the cross-sectional area of a circular element is calculated as follows:

$$CSA = ø\ (\pi / 180)\ r_m\ t_{red}\ \ mm^2 \qquad (4.9)$$

ø = Bending angle in degree

4.3.2 CENTROID ABOUT X AND Y AXES

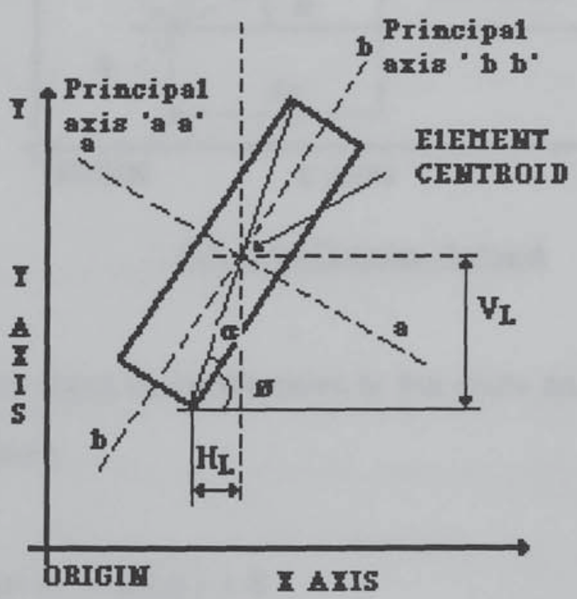

Fig. 4.9 Linear element

The centroid of a line element as shown in Fig. 4.9 is calculated as follows:

$$H_L = [\,0.5\ \ (t^2 + L^2)^{0.5}\ ]\ \cos\,(a+ø) \qquad (4.10)$$

$$V_L = [\,0.5\ \ (t^2 + L^2)^{0.5}\ ]\ \sin\ (a+ø) \qquad (4.11)$$

or this flat element can also be taken as follows:

$$H_L = \text{Length of element} \ / \ 2 \qquad (4.12)$$

$$V_L = \text{Thickness of material} \ / \ 2 \qquad (4.13)$$

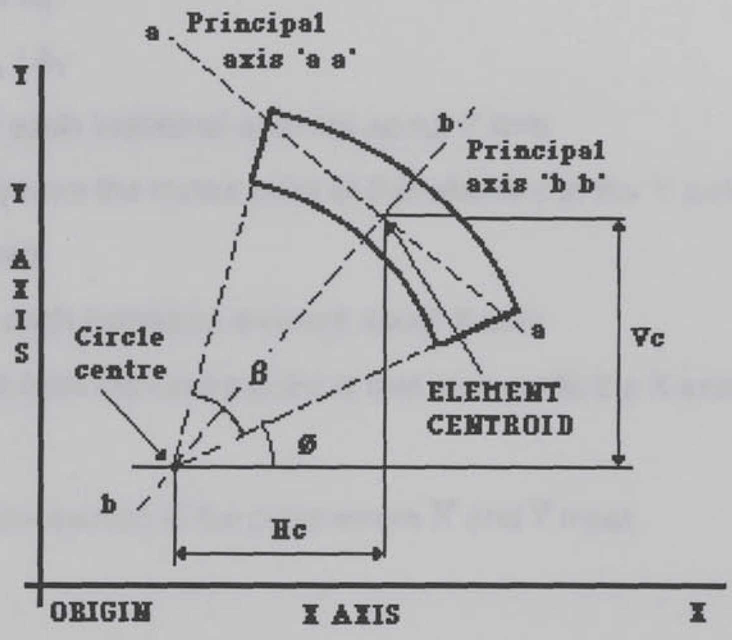

Fig. 4.10 Circular element

Centroid of an arc about its centre point of the circle as shown in Fig. 4.9 is calculated as follows:

$$H_c = r_m\ \ (\sin\,(ø+ß)\ -\ \sin ø\ )\ /\ ß \qquad (4.14)$$

$$V_c = r_m\ \ (\cos ø\ -\ \cos\,(ø+ß)\,)\ /\ ß \qquad (4.15)$$

ß = bending angle in radian

The dimensions of H and V are the distances from the centroid of a particular element to the starting point of the element. These dimensions are converted to the corresponding values about the horizontal and vertical axes which are then transferred to the point of origin for summation. The thickness of the material is introduced after the computation of each linear or circular element. This technique is only justified for thin sections and the values obtained are slightly conservative.

$\overline{X} = \sum A_y D_y / A_T$

$\overline{Y} = \sum A_x D_x / A_T$

A_y = CSA of each individual element about Y axis

D_y = Distance from the centre point of that element to the Y axis

A_T = Total Area

A_x = CSA of each individual element about X axis

D_x = Distance from the centre point of that element to the X axis

The Centroid of the section is the point where $\overline{X}$ and $\overline{Y}$ meet.

4.3.3 SECOND MOMENT OF AREA

The data calculated from the cross-sectional area and the centroid of each individual element corresponding to the point of origin enable the second moment of area about a section to be calculated.

Values calculated for second moments of area of a linear or a circular element about `a-a' and `b-b' axis (as shown in Fig. 4.9 and 4.10) are converted to the horizontal and vertical axes, which are then transferred to the origin for summation by using the parallel axes theorem.

Second moment of area of a section about X and Y axis are given by:-

$$I_{xx} = \int y^2 \, \partial A \qquad (4.16)$$

$$I_{yy} = \int x^2 \, \partial A \qquad (4.17)$$

The product second moment of area of a section about X and Y axes is defined as

$$I_{xy} = \int xy \, \partial A \qquad (4.18)$$

Polar second moment of area in mm^4 is given by

$$J = I_{xx} + I_{yy} \qquad (4.19)$$

Where ø is the angle between the u and x axes

$$ø / 2 = \arctan((2I_{xy}) / (I_{yy} - I_{xx}))$$

$$\tan 2ø = 2I_{xy} / (I_{yy} - I_{xx}) \qquad (4.20)$$

The second moment about different axes such as uu, and vv are given as

$$I_{uu} = 0.5 (I_{xx} + I_{yy}) + 0.5 (I_{xx} - I_{yy}) \sec 2ø \qquad (4.21)$$

$$I_{vv} = 0.5 (I_{xx} + I_{yy}) - 0.5 (I_{xx} - I_{yy}) \sec 2ø \qquad (4.22)$$

$$I_{uv} = I_{xy} \cos 2ø + 0.5 (I_{xx} - I_{yy}) \sin 2ø$$

Sum of the second moment of area about uu and vv is equal to the sum of the second moment of area about xx and yy which is given by

$$I_{uu} + I_{vv} = I_{xx} + I_{yy}$$

where I is the second moment of area about a given axis.

4.3.4 RADIUS OF GYRATION

The radius of gyration R about a given axis is as follows:

$$R_{xx} = (I_{xx} \;/\; CSA)^{0.5} \qquad (4.23)$$

$$R_{yy} = (I_{yy} \;/\; CSA)^{0.5} \qquad (4.24)$$

$$R_{zz} = (J \;/\; CSA)^{0.5}$$

4.3.5 SECTION MODULUS

$$S_x = I_{xx} \;/ Y_{max} \qquad (4.25)$$

$$S_y = I_{yy} \;/ X_{max} \qquad (4.26)$$

where

S = section modulus about a given axis.

Y_{max} = distance of extreme fibres from neutral axis about X axis.

X_{max} = distance of extreme fibres (mm) from neutral axis about Y axis.

4.3.6 LAYOUT OF SECTION PROPERTIES PROGRAM

A new section properties program as shown in fig.4.11 has been produced for calculating section properties for thin wall sections. The calculations are based on the types of formula used in part 4.3 of this Chapter. This program is specially designed so that it is compatible with the section design program. It can accept data produced by the section design program and it can also run independently on its own as a design program.

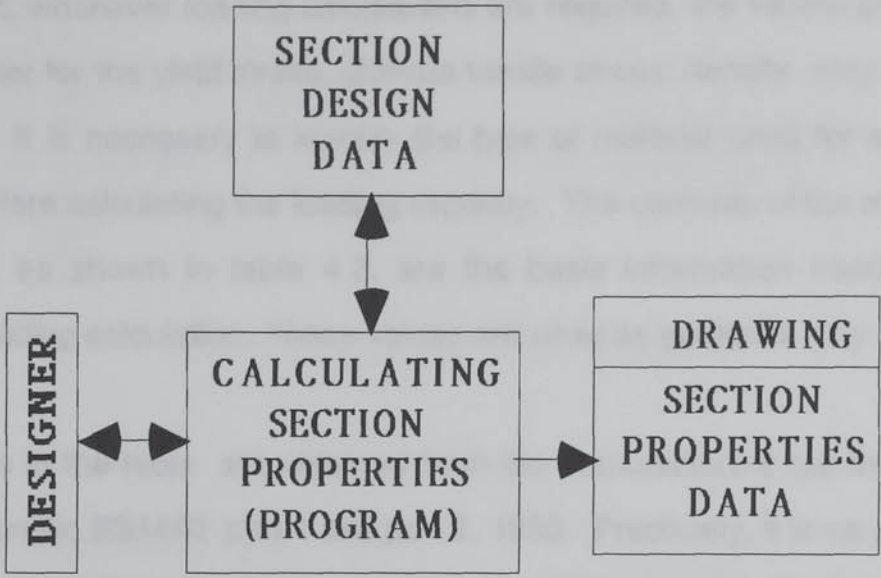

Fig. 4.11 Layout of the section properties program

The output of this section properties program is a section drawing (which is shown in Chapter 8) with all the section properties printed on it, a section properties data file and also the section design data file.

Before any loading calculation can be carried out, the section properties of the given section must be available, otherwise loading calculations cannot be computed. Thus the availability of the given section properties and material properties are essential information for a loading calculation.

4.4 LAYOUT OF MATERIAL DATABASE

A new material properties program as shown in fig.4.12 has been developed so that the material used by the company can be properly recorded in the material database. It is extremely difficult for the designers to remember all the material properties that they have used.

As a result, whenever loading calculations are required, the values given by the designer for the yield stress, ultimate tensile stress, density may not be accurate. It is necessary to identify the type of material used for a given section before calculating the loading capacity. The contents of the material database, as shown in table 4.2, are the basic information needed for general loading calculation. These values are used as guidance only.

The values in the table are obtained from the manufacturers but they can also be found in BS1449 part 1 and part 2, 1983. Practically, it is very costly to check the detailed chemical compositions of the material, therefore they are not normally looked into, and are not included in the database. If detailed information is needed, such as whether the material is annealed, skin passed, tempered etc., it is best to check against BS1449.

Item No. (Int)	Material name (max16)	Grade (max8)	Yield stress (MN/m^2)	Ultimate stress (MN/m^2)	Modulus of Elasticity (GN/m^2)	Density (Mg/m^3)
1	Galv. steel	Z1	210	270	205	7.85
2	Galv. steel	Z2	210	270	205	7.85
3	Galv. steel	Z22	220	290	205	7.85
4	Galv. steel	Z25	250	350	205	7.85
5	Galv. steel	Z28	280	390	205	7.85
6	Galv. steel	Z35	350	450	205	7.85
7	Cold-reduced	CR1	140	280	205	7.85
8	Cold-reduced	CR2	140	280	205	7.85
9	Cold-reduced	CR3	140	280	205	7.85
10	Cold-reduced	CR4	140	280	205	7.85

Table 4.2 Material listing

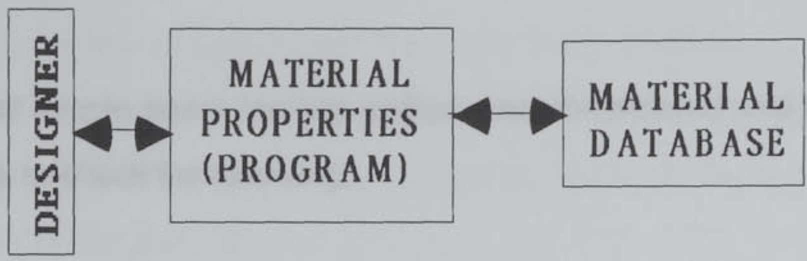

Fig. 4.12 Layout of material database

4.5 LOADING ANALYSIS

The loading analysis program covers some of the simple beam and column theorems. These calculations of beam and column can be found in most Applied Mechanics textbooks, and the calculations used for the loading purposes are listed in Appendix A. These loading analyses are simplified by the computer program so that the user can obtain the solutions to the problems in a report form. The report will state the type of formula used in that particular calculation. This analysis only acts as a quick check of the section and gives the users an idea of the range of load which the product can withstand.

The design rules set by British Standard 5950 part 5, merely acts as a guideline for certain shapes or some general shapes. This has been discussed by Rhodes (1989) in a private communication. The values obtained by these calculations are estimates. To obtain the actual values, it is necessary to test the section physically. All load carrying sections that are new must be tested before recommending their loading capacity to the customers.

4.5.1 BEAMS

Five types of simple beam loading analysis are considered and their main functions are to check the following:

i) the maximum load allowed for the beam with a given deflection ratio.
ii) the maximum deflection produced by the beam for a given load, so that the user can check if the deflection ratio is acceptable.

From the results produced by the computer program, the designer can advise the user on the range of load that the section can carry or the type of deflection which the section will produce if the given load is imposed. The calculations used are derived from Macaulay's method (Hearn,1977) and the differences are listed in Appendix A. The five types of beam loading are:-

a) A simply supported beam with a concentrated load at mid span.
b) A simply supported beam with uniformly distributed load (UDL).
c) A built in beam with a concentrated load at mid span.
d) A built in beam with uniformly distributed load over the whole span.
e) A continuous, three equally-spaced simply supported beam with uniformly distributed load over the whole span.

4.5.2 COLUMNS

This part of the loading analysis computes the crippling load of a column for a given cross section profile. The formula used in the calculation for these columns is based on the Perry-Robertson formula and these formulae can be seen in Appendix A.

After computing the crippling load from the Perry-Robertson formula, a theoretical analysis can be made to check whether the given eccentric loads, together with any other direct concentric loads, can be safely applied using the interaction formula.

A computer program has been written to carry out the five types of column loading calculations and they can be used :-

a) When a column is pinned at both ends.
b) When a column is fixed at both ends.
c) When a column is fixed at the bottom and pinned at the top.
d) When a column is fixed at the bottom and fixed in rotation at the top.
e) When a column is fixed at the bottom and free at the top.

4.5.3 LAYOUT OF THE LOAD TESTING PROGRAM

When the material properties and the section properties are available, the designer can use the loading program (as shown in fig.4.13) for calculating the loading capacity of the section. The loading program provides a report, and a hard copy can also be obtained if needed.

This report also provides all information as to how the calculations are carried out. Those data produced by the section properties program and the material properties can be read in directly by this loading program. Such a layout will prevent the user from typing the information twice and also avoid human error in data transfer. Without the availability of the section properties and the material properties data, this loading program cannot operate.

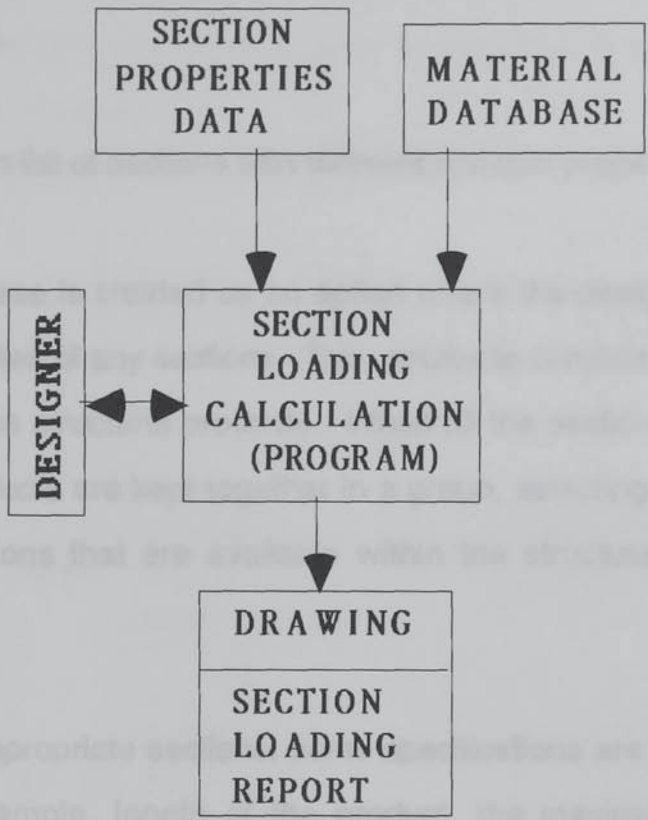

Fig. 4.13 Layout of the load testing program

4.6 METHOD USED FOR SELECTING OR COMPARING THE APPROPRIATE SECTIONS

The designer can select the appropriate section or compare different sections from this new section selection program as shown in fig.4.14. There are three options available to the designer thus:

1) update the structural database by reading in the section properties produced by the section properties program and transfer them to the structural database.

2) select a product from the structural database based on the given length and load imposed.

3) compare a given list of sections with different material properties.

A structural database is created as an option where the designer can keep the section properties of any sections. This database consists of the section properties of all the structural products. When all the section properties of the structural products are kept together in a group, selecting or comparing the different sections that are available within the structural database is simple.

In selecting the appropriate sections, some specifications are required from the user: for example, length of the product, the maximum deflection allowed or the load that the user requires the section to withstand.

Calculations are carried out on each section available in the structural database, and when the section which satisfies the specification is found, the program will alert the designer. Sections can also be compared with each other using different materials. This helps the designer to decide whether the chosen material satisfies the specification.

This selection program requires information from the material database and the structural database. The calculations produced are based on a simply supported beam with a concentrated load at mid-span. An option is also available to the designer to add the effect of work hardening into the calculation.

In both the selection and comparison options, the output is a full report showing how these sections are compared or selected. The designer can obtain a hard copy, if needed.

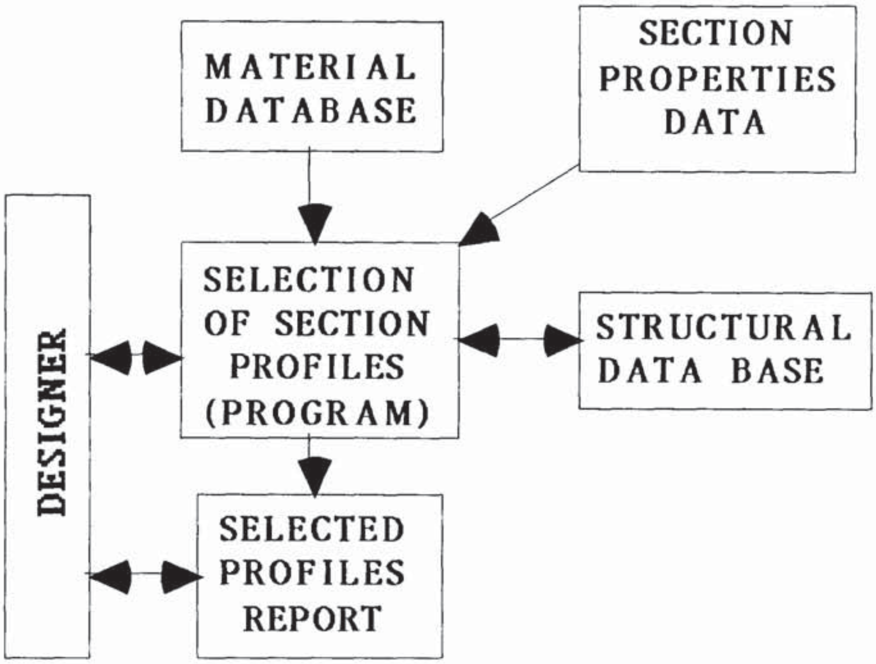

Fig. 4.14 Method used for selecting required profile

4.7 PRACTICAL APPROACH TO PREVENT SECTION FAILURE

Some of the modes of failure to which cold rolled sections are subject, can be overcome using physical holding techniques and fasteners. The following are examples of some of the techniques used.

4.7.1 CLEATING

Cleats are used at the support point to prevent web crushing. The bottom flange of the section is raised to avoid high bearing forces which cause web

In both the selection and comparison options, the output is a full report showing how these sections are compared or selected. The designer can obtain a hard copy, if needed.

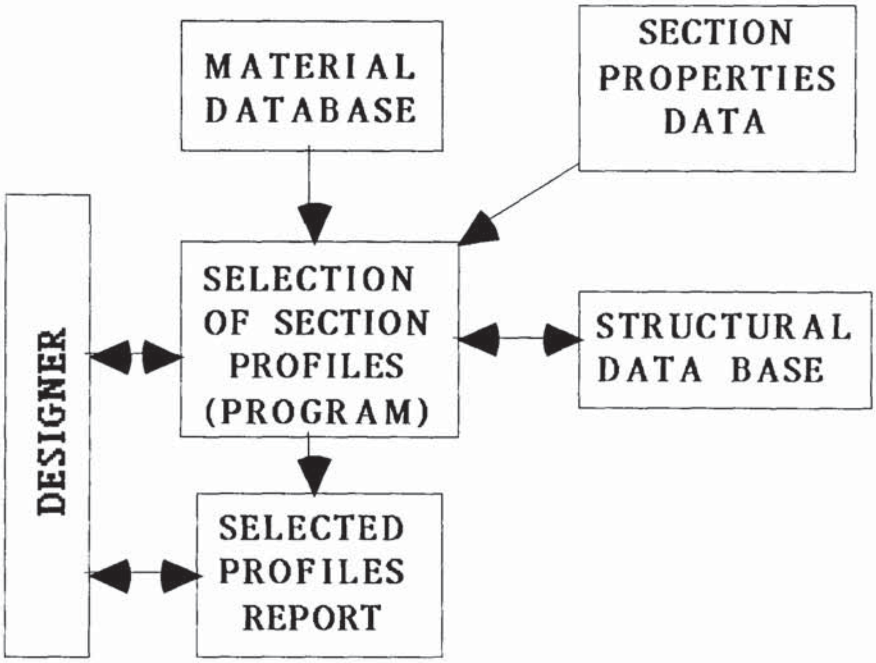

Fig. 4.14 Method used for selecting required profile

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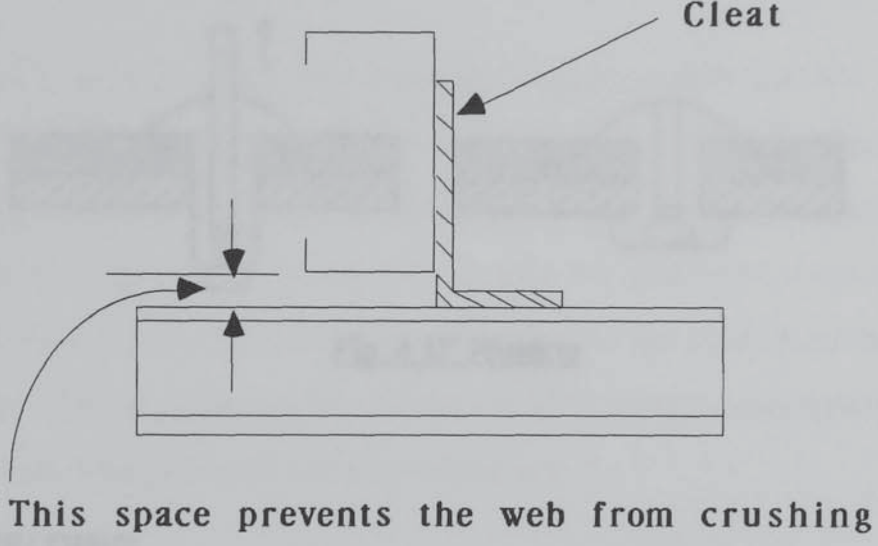


Fig. 4.15 Cleating

4.7.2 FASTENING

When a section is fastened onto a much stronger piece of metal and restrained from rotation, it helps to prevent the section from twisting. Some of the fastening techniques are shown in Fig. 4.16 and Fig.4.17. Techniques involving the use of nuts and bolts, riveting, self-tapping screws, fire-pins, spot welding and arc welding are quite common.

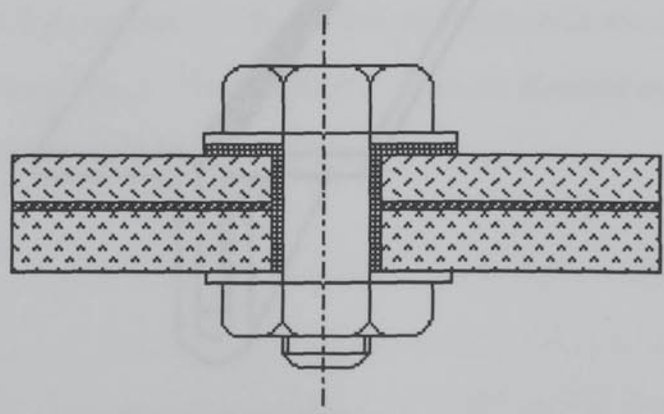


Fig. 4.16 Using nut and bolt

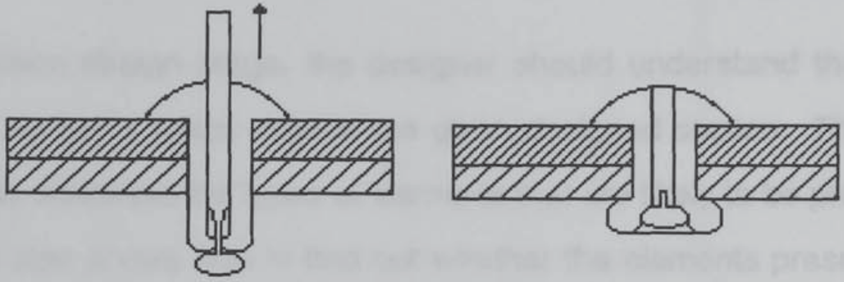


Fig. 4.17 Riveting

4.7.3 WELDING

Welding two or more sections together also helps to increase the strength of the section. It is very common to weld the ends of a section together to make a closed section, as they are normally stronger than those with their ends joined by folding together. It will be more costly to produce a section, if welding is to be carried out because extra tooling will be implemented and the whole process has to slow down in order to produce a proper joint as shown in fig.4.18.

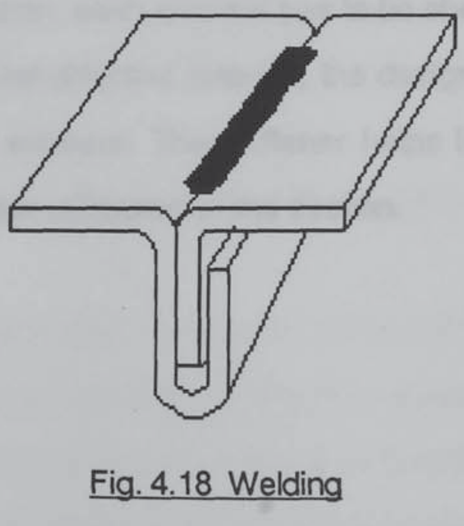


Fig. 4.18 Welding

4.8 CHECK FOR EFFECTIVE WIDTH OF AN ELEMENT

In the section design stage, the designer should understand the type of structural elements which exist in the given designed section. This part of the chapter discusses the types of elements that are likely to be present in a profile. It also shows how to find out whether the elements present in the profile are effective or not. If the element is not effective, then it can be made effective by using a stiffener. The questions as to when to use stiffener and which type of stiffener to use are also discussed.

4.8.1 TYPES OF ELEMENTS

There are two main types of structural elements in a section namely:-

1 Stiffened elements

2 Unstiffened elements

An unstiffened element is one which is supported along one edge only, while a stiffened element is one which is supported by webs along both its longitudinal edges. (The illustration can best be represented by fig.4.19). For a structural section, each element has to be checked for its effectiveness. When the width is not effective enough, the designer has an option to apply stiffeners onto the element. This stiffener helps to strengthen the element which results in better utilization of the section.

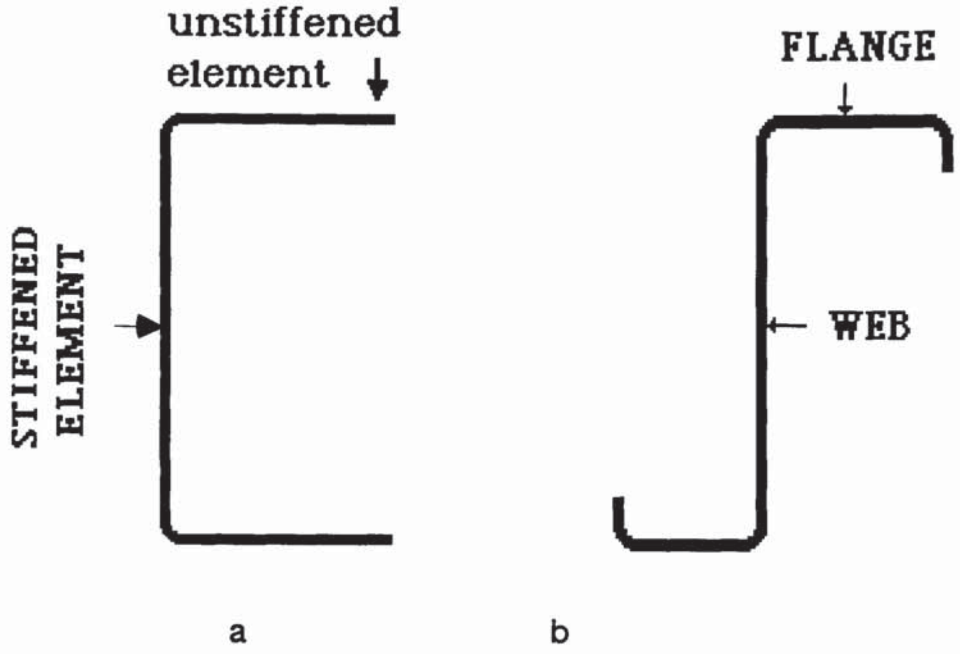


Fig. 4.19 Types of elements

UNSTIFFENED ELEMENT

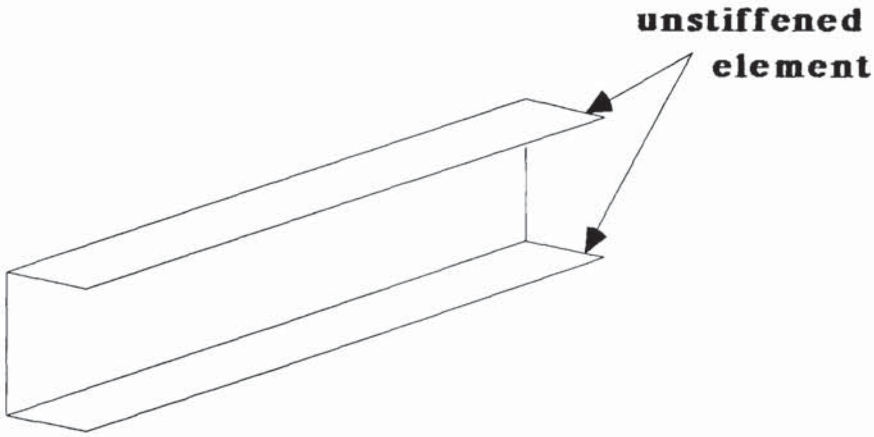


Fig. 4.20 Unstiffened element

Most unstiffened elements (as shown in fig.4.20) have less resistance to buckling than stiffened elements. The conservative buckling coefficient K factor of an unstiffened element used is 0.425 and it has a maximum possible value of 1.4. This values can be obtained from BS5950 part 5.

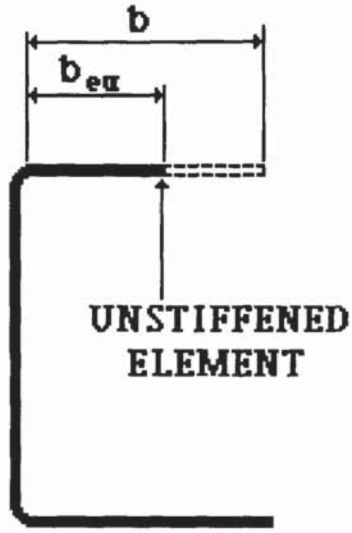


Fig. 4.21 Effective width of an unstiffened element

$b_{eu}= 0.89\ b_{eff} + 0.11\ b$ (4.27)

b_{eu}= increased in effective width of an unstiffened element

b_{eff} can be obtained from equation 4.31

An unstiffened element can be strengthened by adding a simple lip edge stiffener or a compound edge stiffener with a minimum second moment of area I_{min}. The design for an unstiffened element is limited to a b/t ratio of 60. For b / t ratio greater than 30, local deformations may be considerable. If b / t ratio is less than 30 the element is stable. The maximum b/t ratio of 90 is the design limit allowed for load bearing edge stiffened element.

$I_{min}= t B^3 / 375$ (4.28)

I_{min} is the minimum allowable second moment of area about an axis through the surface of the element to be stiffened.

B = overall width of the element to be stiffened

t = material thickness

When applying a simple lip, the lip should not be splayed by more than 20 degrees from the perpendicular. The applied stiffener must have a rigidity equal to or greater than that required by equation 4.28. Stiffeners with less rigidity than I_{min} but with ability to carry a higher load are not recommended.

STIFFENED ELEMENT

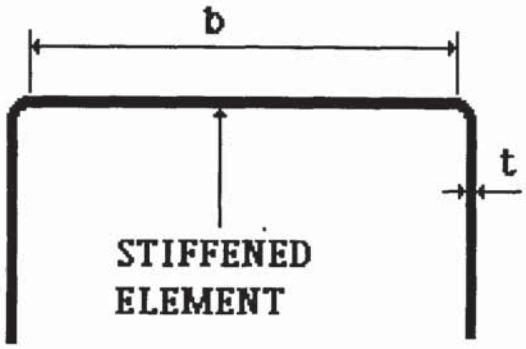


Fig. 4.22 Stiffened element

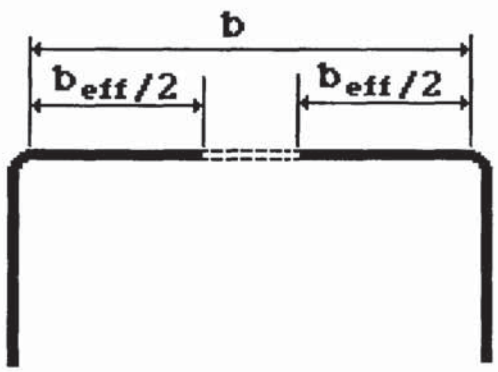


Fig. 4.23 Effective width of a stiffened element

As the width b (shown in fig.4.23) of a stiffened element increases, local buckling will start to occur at the middle region where formation of ripples appears. A stiffened element becomes weaker as the width increases. Visually, it can be seen that a stiffened element with a large width tends to be weaker on the centre area while both sides that are near the bends are stronger and are known as the "effective width". The effective width b_{eff} can be calculated from the equations given below. (based on BS5950 part 5 pp.15)

$$P_{cr} = 185000\, k\, (t / b)^2 \qquad (4.29)$$

Basic effective width expression

if $f_c / p_{cr} < 0.123$

then $b_{eff} / b = 1$ (4.30)

if $f_c / P_{cr} >= 0.123$

then $b_{eff} / b = [\, 1 + 14 \{ (f_c / p_{cr})^{0.5} - 0.35 \}^4 \,]^{-0.2}$ (4.31)

Where :

f_c = compressive stress on the effective element

P_{cr} = Critical stress to cause local buckling on the element

b_{eff} = effective width

b = full width

k = buckling coefficient

A conservative estimate of the buckling coefficient k for a stiffened element can be taken as 4 and the highest value taken as 7. When the width of the stiffened element is large, one or more stiffeners have to be added to the element for strengthening and to overcome local buckling.

The stiffener which is designed within a stiffened element is called the intermediate stiffener. Although the strength of the element can be improved by adding a series of intermediate stiffeners, there is a limit to the overall width of the stiffened element. The maximum permissible value of the width to thickness ratio of a stiffened element is 500 (b / t <= 500), and when the ratio is greater than 250, local out-of-plane deflections may be considerable.

4.8.2 TYPES OF STIFFENERS

There are three main groups of stiffeners that are normally used to strengthen the weak elements of a given profile. The three main groups are:-

1) Simple lip edge stiffener
2) Compound edge stiffener
3) Intermediate stiffener

SIMPLE LIP EDGE STIFFENER

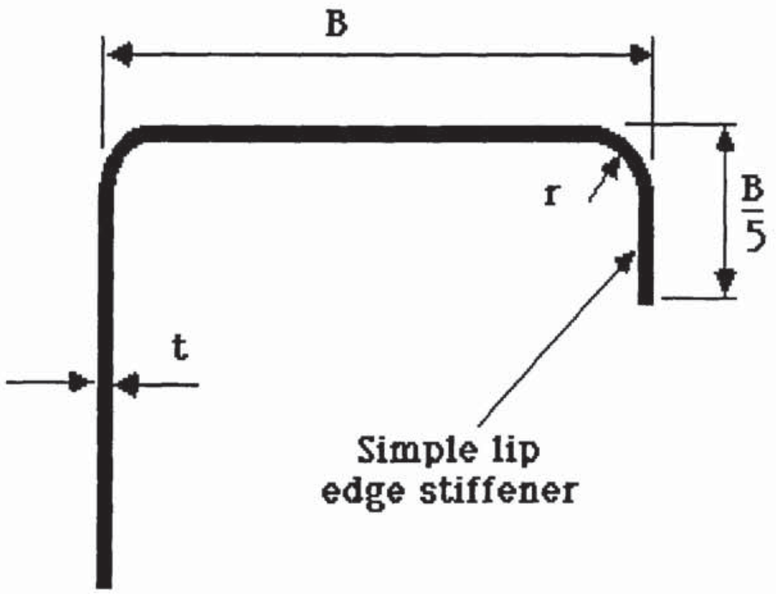


Fig. 4.24 Simple lip edge stiffener

The length of a simple edge stiffener can be estimated as B/5 and this is sufficient to represent the minimum second moment of area as illustrated in equation 4.28. A simple lip edge stiffener is required when b/t is greater than 30 and less than or equal to 60.

Apply simple lip edge stiffener when $30 < b/t <= 60$

COMPOUND EDGE STIFFENER

When b / t is greater than 60 and less than 90, a compound lip is required with the second moment of area greater than or equal to I_{min} as described in equation 4.28. Some of the compound edge stiffeners can be seen in fig.4.25.

Apply compound lip when $60 < b/t <= 90$

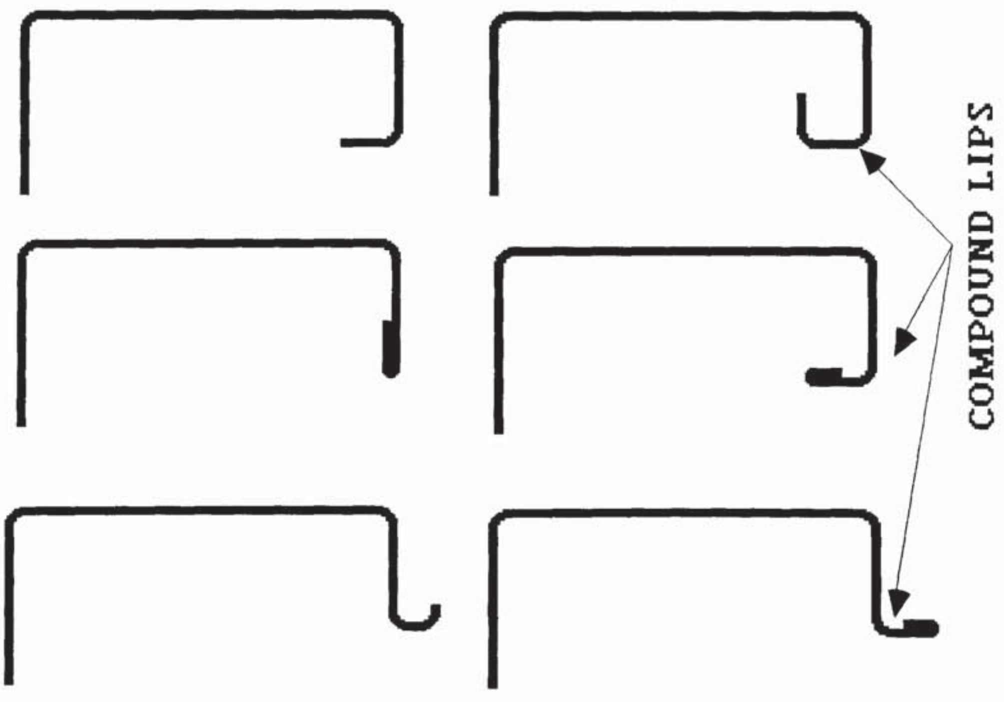


Fig. 4.25 Compound edge stiffeners

INTERMEDIATE STIFFENER

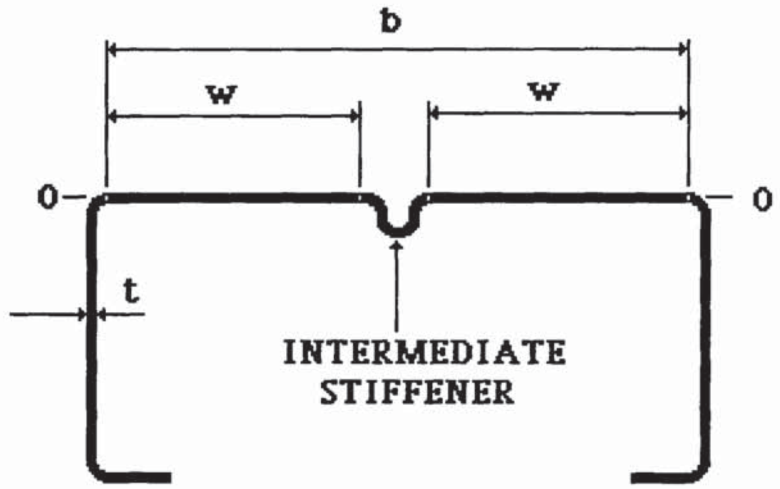


Fig. 4.26 Intermediate stiffener

The width b of a stiffened element (shown in fig. 4.26) can be made effective by introducing a series of narrow intermediate stiffeners consisting of small highly effective elements with width w. The second moment of area of the stiffener is calculated about the axis through the element middle surface of 0-0 and the value can only be considered if it is >= I_{min}. (based on BS5950 part 5 p.18)

$$I_{min} = 0.2\, t^4 \; (w/t)^2 \; (Y_s/280) \tag{4.32}$$

w = the flat width of the sub-element between stiffener

I_{min} = the minimum allowable second moment of area about an axis through the middle surface of the stiffened element.

Y_s = yield strength

By adding more materials acting as stiffeners, the width of the element can be strengthened easily. These stiffeners help to strenghthen the width and result in a fully effective element.

When the overall width consists of stiffeners packed closely together and w is less than 30t, all the elements are considered effective. This whole element can be represented by a new fictitious thickness t_s.

$$t_s = (12\, I_s / b)^{0.33} \qquad (4.33)$$

I_s = Second moment of area of complete element about 00

4.8.3 LIMIT STRESS IN WEB OF A BEAM

When a beam with a large web (that is depth to thickness ratio greater than 70) is subjected to bending moment, there will be a tendency to cause web buckling. In a limit state design approach, the design stress P_d can be taken as equal to the yield strength of the material Y_s. The maximum stress that can be applied onto the web is obtained from the expression based on BS5950 part 5 p.20.

$$P_{web} = [1.13 - 0.0019\ (D / t)\ (Y_s / 280)^{0.5}\ ]\ P_d \qquad (4.34)$$

where

P_{web} = limiting web stress

D = overall depth of the web

The limiting stress P_{web} cannot be greater than the yield stress of the material.

4.8.4 SHEAR BUCKLING

Shear buckling is more severe for a thin web manufactured from cold rolling than one from hot rolling. The maximum shear stress in a beam web is limited to 0.7 multiplied by the yield strength. To avoid shear stress on the web, the average stress on the web must be less than P_v (taken from BS5950 part 5 p.22)

$$P_v = (1000t / D)^2 \quad N / mm^2 \qquad (4.35)$$

Where

D = depth of web

P_v = Average shear stress

t = Web thickness

Average shear stress < P_v

4.8.5 PROGRAM LAYOUT FOR CHECKING SECTION ELEMENTS

A program has been developed for checking each linear element of the section based on the equations given in section 4.8. The overall flange or the web can also be checked and general advice can be obtained from this program. There are options available in the program to the user to choose what to analyse. The options are of modular form, whereby checking of the element is only carried out according to the requested option.

Stiffeners can be added to the linear element when requested. Whenever the design data require modification, a new set of section data will be generated (as shown in fig.4.27) and stored in a new data file. This new data file can be operated by the section properties program and the design program.

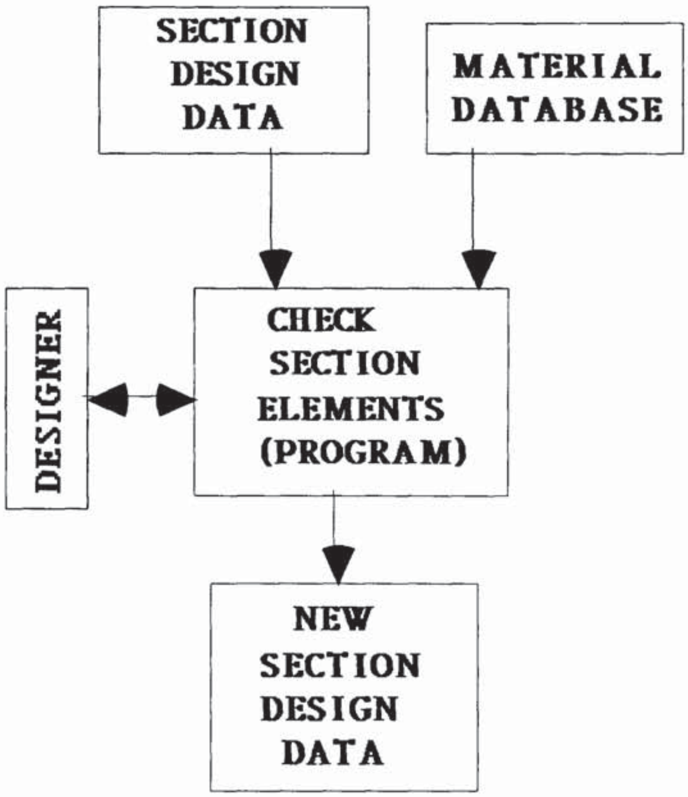


Fig. 4.27 Program layout for checking section elements

CHAPTER 5

PRACTICAL KNOWLEDGE AND EXPERIENCE

5.1 EXPERT SYSTEM IN COLD ROLLING PROCESS

The application of Expert System is new to the design of cold rolled sections. Research work carried out by Vasiliou (1986) and Shah (1987) had attempted to use an ES approach in their decision making process which was incorporated into their conventional programs. Both the researchers had developed a constructive approach in the way decisions were made and the way advice were given.

However, the drawbacks in their programming techniques are that their decision making processes are embedded in their functional routines, and their production rules are not separated out as a different component in the system.

It is difficult to alter the production rules when they are not kept in a seperate knowledge base. If alterations are required to be carried out, it may be necessary to change the whole program before any constructive results can be obtained. Such an operation is very lengthy.

A study related to the application of ES in the field of engineering design has been carried out by Pychener (1985). Although his study is restricted to problems in Chemical Engineering and Civil Engineering, he has highlighted that it is necessary to look firstly at the specialized areas within the design disciplines in order to apply the current ES technique. He stated that "When a number of areas within the discipline have been explored in this way, we will be in a better position to integrate the results into a more comprehensive, automated design system". However, he did not mention how the automated system can be constructed.

The work carried out will show how the ES is constructed, the way new knowledge are learned by the system and how external CAD program can be operated by the ES to provide an automated design process.

5.2 PRACTICAL APPROACH IN DESIGNING ROLLED SECTION

The work in Chapter 5, 6 and 7 will concentrate on discussing the practical approach to designing a section using the present system and how a new system can be introduced to capture the knowledge of the designer. Fig. 5.1 shows the current way in which decisions and information flow in the initial design process of cold rolled sections.

It is usual for a customer to present a sketch to the technical salesman and request the company to manufacture the given shape. The salesman consults an experienced technical man as to the possibility of the product being manufactured as required by the customer. After this, the salesman will feed back the comments of the technical man to the customer.

The drawing is then produced by a designer. The time taken to produce the drawing depends on the complexity of the drawing. When the drawing is completed, it is sent to the customer. If the customer is satisfied with the drawing, the designer will carry on with the rest of the design process.

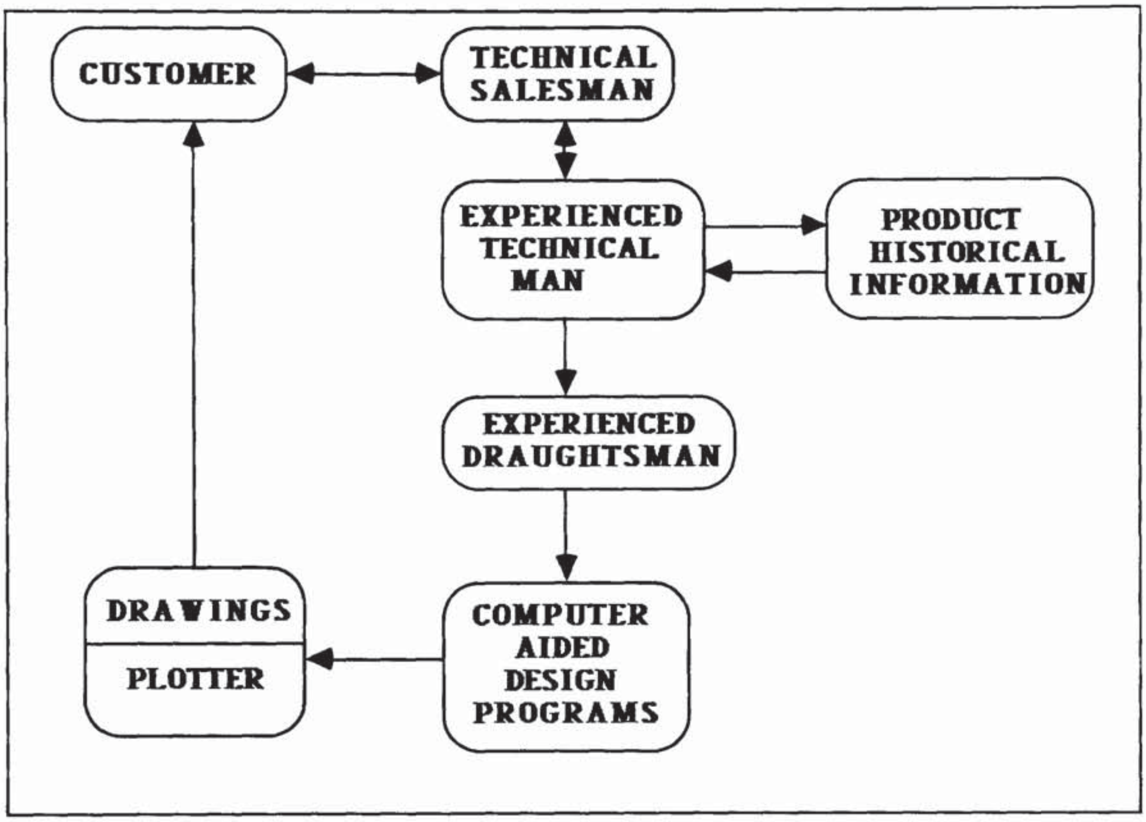


Fig. 5.1 Design sections without an Expert System

If the customer is not fully satisfied with the finished section drawing, the whole drawing has to be redrawn. This happens in most of the cases as the customer usually requires some changes to the initial design, or the design may need a slight modification for ease of manufacturing.

It is cumbersome for the designer to redraw the drawing, especially for a complex shape where the whole range of the geometrical positions of each element have to be recalculated. This creates unnecessary work for the designer and can make the job very monotonous.

The whole tooling design for the rolling process is based on the finished section design. However, once the tooling design process is completed, even a slight alteration in the finished section design requires, a complete redesign of the whole set of tooling for the rolling process. Such inefficiency can be very costly and therefore it is vital to get the design right at the initial stage of the design process.

5.3 PRACTICAL EXPERIENCE IN DESIGNING A SECTION

A number of operations are carried out by the designer, from the time the customer presents a sketch to the salesman until the section drawing is produced. These operations require adequate experience and knowledge of the design of the section and the roll forming process.

Without the knowledge of how the roll forming process works, it is very likely that the designer will get the design wrong. This is mainly due to a lack of knowledge as to how a profile should be positioned or the areas required to be gripped by rolls during manufacturing. Basically the main type of operations usually carried out by the designer are :-

1) Translation of the basic dimensions of a sketch.
2) Trigonometric calculation for each element of the profile.
3) Positioning of the profile.
4) Other considerations.
5) Typing design data onto the CAD program.

The major operations required in designing a section are involved with decisions based on the experience of the designer. A hypothetical case of a common slant Zed which is used for supporting the crash barrier all along the motorway will now be studied.

5.3.1 TRANSLATION OF THE BASIC DIMENSIONS OF A SKETCH.

In the initial stage of communication with the customer, it is very important to have a product sketch in one form or another. The customer provides a sketch of the required product and few main dimensions. In Chapter 4, it was stated that a section consists of linear and circular elements; therefore, it is vital to note that the CAD program can only accept dimensions for a linear or a circular element.

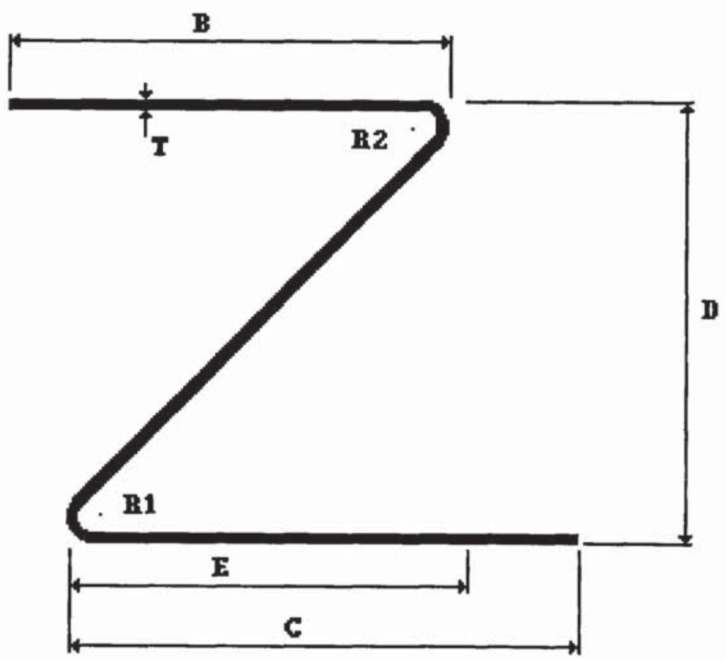


Fig. 5.2 Sketch for a slant Zed

It will be very unlikely for a customer to present the complete detailed dimensions of a section with all the linear and circular elements specified. More likely, a normal sketch will consist of a few dimensions as shown in Fig. 5.2. Instead of the variable symbols shown as B, C, D, T, R_1 and R_2, they will be numerical values given by the customer.

The designer cannot input this set of main dimensions into the CAD program. As a result, in order for the CAD program to draw this section, the designer needs to obtain all the dimensions of the circular and linear elements. There are two ways in which these dimension can be obtained, they are:

1) by drawing the sketch to a much larger scale, measure the dimensions from the drawing and then entering the measured dimensions into the CAD program.

This technique is very often used when the designer finds it difficult to calculate the dimensions of the elements or when the designer finds it much quicker to use this method compared to calculation. This method can be applied when the design is a one off type where the dimensions are fixed.

In cases where a small alteration is required in the main dimensions, (for example an alteration is needed in one of the variable in the drawing shown in Fig. 5.2) the designer has to redraw the whole drawing and measure the dimensions again. This approach is not practical for sections that need many modifications.

2) by using trigonometric functions to calculate the dimension for each of the elements. This is a more accurate way of obtaining the dimensions. The dimension of each linear and circular elements are derived from the trigonometric functions based on the key values given by the customer.

5.3.2 TRIGONOMETRY CALCULATION FOR EACH ELEMENT OF THE PROFILE

Since the calculated values based on trigonometric functions are more accurate than values measured from the drawing, the calculation method is recommended for identifying the dimensions on the section's elements. The first thing the designer must do is to obtain all the correct dimensions of all elements within a section. In this case the designer has to calculate each individual element length based on the main dimensions given by the customer.

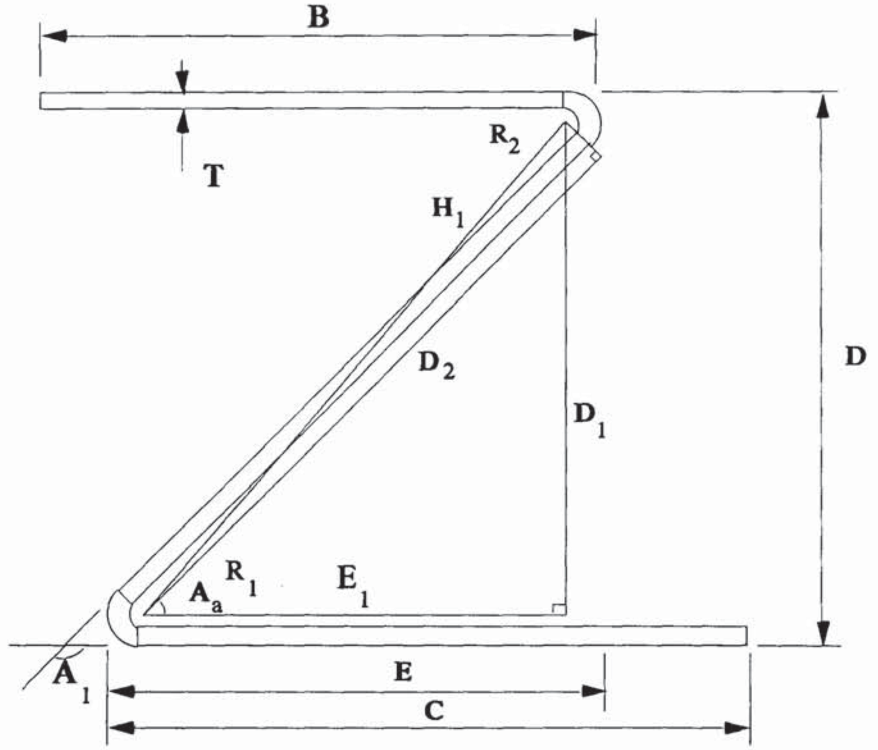


Fig. 5.3 Elements calculation of a slant Zed

Each element of the profile shown in Fig. 5.3 can be calculated by:-

$D_1 = D - R_1 - R_2 - (2T)$

$E_1 = E - R_1 - R_2 - (2T)$

$H_1 = (E_1^2 + D_1^2)^{0.5}$

$A_a = \arcsin(D_1 / H_1)$

$A_1 = 180 - A_a$

$D_2 = (H_1^2 - (R_1 + R_2 + T)^2)^{0.5}$

Taking the bottom element of the section as element 1

Element 1 , Length = $C - R_1 - T$

Element 2 , Radius = R_1 , Angle = A_1

Element 3 , Length = D_2

Element 4 , Radius = R_2 , Angle = $-A_1$

Element 5 , Length = $B - R_2 - T$

In order to carry out the calculations as previously shown, the designer needs to have a good understanding of trigonometry. Without carrying out this set of calculation, the designer will not be able to get the dimensions of each element unless he chooses to measure them from the drawing. The example shown is of moderate complexity, and there are sections that are far more complex than this example. This indicates the importance of calculating the elements of the section (which can be simple or complex) before starting to use the CAD program.

The process of translating the basic dimensions into specific values for each element can vary from one designer to another. The complexity of the calculations will also vary according to the profile of the sections. Understanding trigonometry is itself a piece of knowledge which forms part of the expertise of the designer, as recognised by Halmos (1985). It may be easy for a human being to understand trigonometry, but to construct an ES so that it can use trigonometric functions requires demanding thought processes.

5.3.3 POSITIONING OF THE PROFILE

When the dimensions of each element are known, the designer needs to position the product so that there are areas in the section where the form rolls can grip during the manufacturing stage. During the rolling process of a section, the material flowing from one pass to the next is normally gripped by the top and bottom rolls.

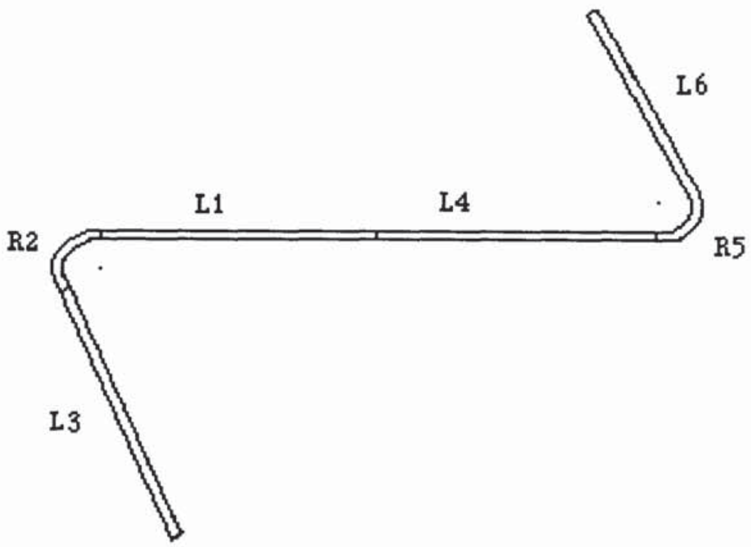


Fig. 5.4 Product positioning

If the top and bottom rolls cannot grip the section, the material will slip which, in turn, damages the material. If this is so, production has to stop. Since the the bottom rolls are usually driven by the gears (and the top rolls are not always driven), it is advisable to position the product in such a way so that the top and bottom rolls can provide a good grip on the material.

In Fig. 5.4, the area where the rolls can grip will be on element L_1 and element L_4. It is essential to consider the way the product is going to flow through the rolls at this stage, because the design of the flower pattern, template, rolls and cut-off tool will all depend on the way this section is positioned. Such positioning is based on the experience of the designer. Good positioning may help to decrease the number of rolls used, and in some cases two rolls can be used instead of four.

5.3.4 OTHER CONSIDERATIONS

There are other considerations which the designer has to take into account at this stage before accepting the order, such as :-

It may sometimes be difficult to pierce the holes on the product as required by the customer. If the holes cannot be pierced, the designer will have to think of an alternative solution, and possibly modify the design until it is acceptable by the customer.

The designer always has to compromise with the customer as to the availability of other simplier shapes in the company which may be cheaper to produce and at the same time fulfil the requirements of the customer.

5.3.5 ENTERING DESIGN DATA INTO THE CAD PROGRAM

When all the dimensions of the elements are available, the designer will use the CAD software to design the section. After the change in position from Fig. 5.3 to Fig. 5.4, a slight alteration in the calculation may be required. This example has been shown with the variable symbols as B, C, D, R_1, R_2 and T, rather than the actual numerical values given by the customer, because it is easier to generalize a piece of knowledge by representing it with variable symbols rather than the actual values.

When the CAD program for designing rolled section is executed by the designer, with origin chosen at option 4, the drawing will start from the origin and plot towards the left and then from origin and plot towards the right.

If the main dimensions given by the customer for the above shape are:-

T = 2.5 mm B = 40.0 mm C = 38.0 mm D = 60.0 mm E = 35.0 mm

R_1 = 20.0 mm R_2 = 2.5 mm

(Values input into the CAD program will be embolded below.)

Mentally the designer will allocate each element length as :-

Elements start from origin towards left.

Element 1, Length = $\mathbf{D_2 / 2.0}$

Element 2, Radius = $\mathbf{R_1}$, Angle = $\mathbf{A_1}$

Element 3, Length = **C - R_1 - T**

Elements start from origin towards right.

Element 4, Length = $\mathbf{D_2 /2}$

Element 5, Radius = $\mathbf{R_2}$, Angle = $\mathbf{-A_1}$

Element 6, Length = **B - R_2 - T**

When executing the design program, the following conversational mode can be seen:

CHOICE : **SECTION**

Please input the Section Number.

ZS101

Input Unit (1=imperial) (2=metric)	Output Unit (1=imperial) (2=metric)	Thickness (mm)	Origin (Int.)
2	2	2.5000	4

Element Number	Element Type	Length or Radius	Bending Angle
1	1	28.0691	0.0000
2	2	2.0000	116.7915
3	1	33.5000	0.0000
0	0	0.0000	0.0000
1	1	28.0691	0.0000
2	2	2.0000	116.7915
3	1	35.0000	0.0000
0	0	0.0000	0.0000

Paper Size	Scale
4	1.3333

Is dimensioning needed ? (1=yes 0=no)

1

Is title block needed ? (1=yes 0= no)

0

Table 5.1 Dimensions entered for Slant Zed section

When the data are entered into the executing CAD program, it will take about a minute to obtain the drawing. This hypothetical case has shown that from the main dimensions given by the customer, it has been necessary for the designer to carry out a series of calculations, make decisions according to the way the product is going to be positioned, based on his experience, and type all the calculated values into the CAD program before a drawing can be produced. If a more complicated shape is to be produced, it will take the designer much longer to do this.

Such operation require both knowledge and experience which can be captured by using an ES technique. Whenever this piece of knowledge is required, it can be retrieved from the knowledge base. With different profiles, the knowledge will be different and this makes it ideal for an ES to be built. This is because the need to write a computer program for each individual shape is eliminated by using ES. If the knowledge in the knowledge base can be retrieved and the whole operation can be operated by the knowledge, then an automated design can be achieved.

5.4 APPROPRIATE DOMAIN FOR BUILDING AN ES

Not all domains studied within the initial design stage are suitable for applying an ES approach. Domains that are more appropriate for conventional program are mentioned in Chapter 3 and 4. This chapter will discuss domains that are more appropriate for ES application. The ES applied to this design work is not a consultation system. It performs a learning process on how and what information is input into the CAD system to generate a drawing, it then absorbes the knowledge and performs an automated design process.

The application of an ES technique to the design of finished section is more suited to:

1) repetitive or similar shapes
2) section where large number of calculations are needed
3) section with large amount of input data

5.4.1 REPETITIVE OR SIMILAR SHAPES

It is very common to manufacture products with the same basic shape but with slight variations in their general dimensions. The most common variation is the change in thickness of the material, where a range of products varying from 0.8 mm to 2.5 mm can be manufactured with the same set of rolls. The repetition in similar shapes is common and can be seen in BS2994 where there are 583 products with only 11 basic shapes. Tests carried out by Griffin (1982) and Halmos (1982) are of similar shape with only slight differences in their overall dimensions.

When products have to be redesigned in order to optimise dimensions or performance, it will be of benefit if the knowledge and the experience of designing the product for the first time is captured. This will allow the designer to use the captured knowledge when a redesign is to be carried out. This will help in the consistency in the decisions making process and also in speeding up the whole design process.

Studies carried out by Ji et al (1988), have acknowledged that redesign is a key to scheme optimization design. Optimum design of designing cold rolled sections does not mainly apply numerical optimization but depends on the designer's knowledge and experience.

5.4.2 LARGE NUMBER OF CALCULATIONS WITHIN A SHAPE

When a shape is complex, there are normally many calculations which are required to be carried out by the designer. Translating the basic dimensions of a complex shape to the dimensions of each individual element for the

CAD program demand an experienced designer with a good knowledge of trigonometry. This type of calculation is normally lengthy. The calculations required to translate the main dimensions shown in Fig. 5.5 to the detailed element lengths shown in Fig. 5.6 can take hours.

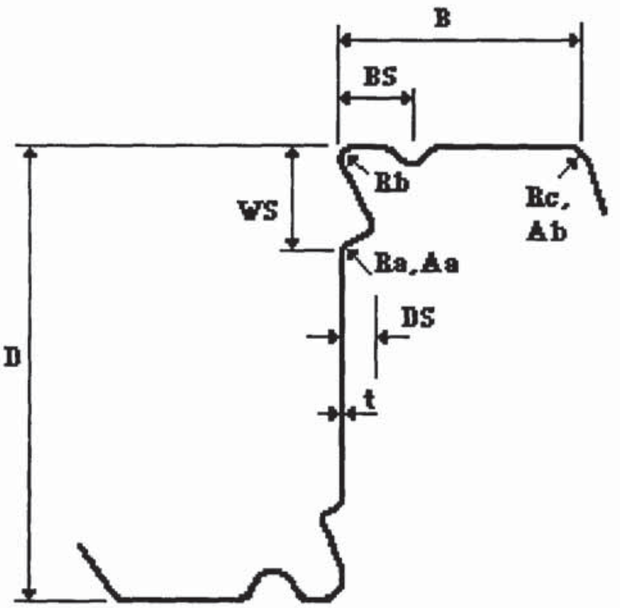


Fig. 5.5 Main dimensions of a sketch

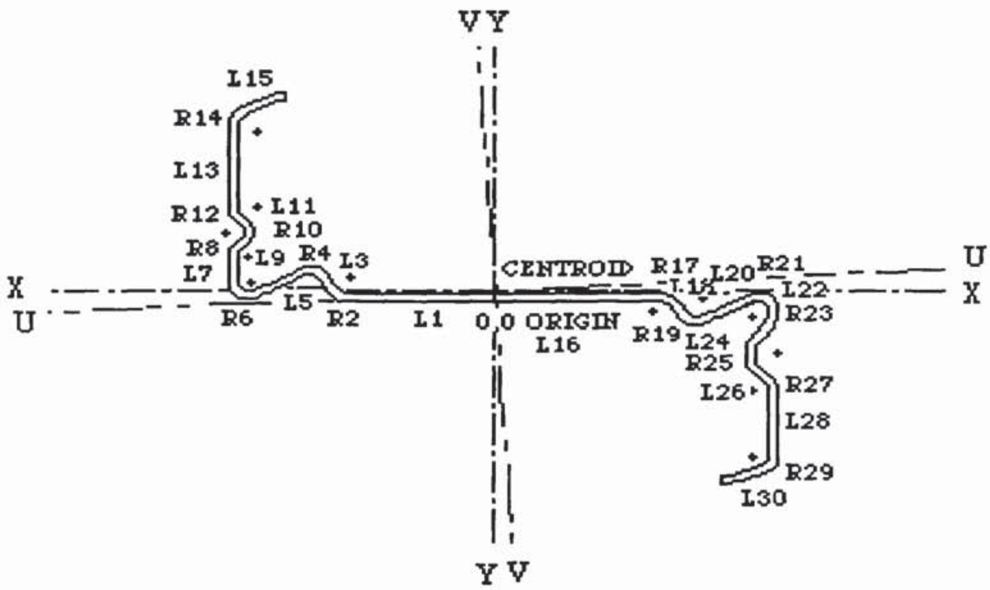


Fig. 5.6 Detailed amount of elements in a section

After the calculations have been carried out, it is useful to record them, so that whenever modification is needed, they can be reused. If the calculations are recorded in the knowledge base, the designer will only have to type in the main dimensions and he will be able to obtain all the calculated values. Under such a circumstance, the designer can keep modifying the shape until an optimum is reached.

5.4.3 SHAPES WITH A LARGE NUMBER OF ELEMENTS

Shape such as corrugated sheet (as shown in Fig. 5.7) contains a large amount of input data, since the dimensions are repeating themselves all along the profile. Whenever a slight modification is needed, the whole range of data has to be altered. This can be time consuming and monotonous. It will be more productive if only a few main dimensions are altered and the ES can generate the rest of the dimension automatically.

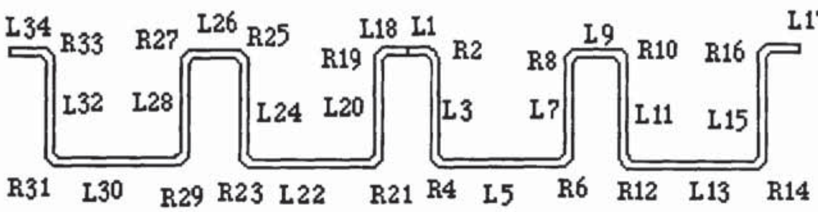


Fig. 5.7 Section with repetition in its dimension

CHAPTER 6

PRODUCTION SYSTEM FOR DESIGNING ROLLED SECTION

6.1 INCORPORATING AN EXPERT SYSTEM TO SECTION DESIGN

In order to incorporate an Expert System to the design of a cold rolled section, it is essential to have an adequate in-depth knowledge of ES's, their capabilities and limitations. The general concept of an ES will not be discussed in this thesis but can be found in most ES textbooks such as those written by Barr & Feigenbaum (1981), Hu (1987), Hunt (1986), Waterman (1987) and others. Feigenbaum gives a general introduction to AI in the 3 volume of the handbook of AI. Waterman provides good advice on constructing an ES. Hu provides a more detailed structure in building an ES. Hunt gives a very good collection of AI terminology definitions. Townsend & Feucht have also written a good book for introducing Expert System to novices.

A formal definition of Expert System approved by the British Computer Society Committee (Naylor, 1986) of the specialist group is :-

"An Expert System is regarded as the embodiment within a computer of a knowledge-based component from an expert skill in such a form that the system can offer intelligent advice or take an intelligent decision about a processing function. A desirable additional characteristic, which many would consider fundamental, is the capability of the system, on demand, to justify its own line of reasoning in a manner directly intelligible to the enquirer. The style adopted to attain these characteristics is rule-based programming".

Expert System is also defined by Harget (1987) as, "a computing system which embodies organized knowledge concerning some specific area of human expertise, sufficient to perform as a skilful and cost effective consultant".

Feigenbaum (1986) defined the term as, "an intelligent computer that uses knowledge and inference procedures to solve problems that are difficult enough to require significant human expertise for their solution."

This research has produced an alternative solution (as shown in Fig. 6.1 and comparing it with Fig. 5.1) towards how the expertise of a designer can be captured in this specialized field, and also offers the ability to automate the design process for similar or repetitive profiles.

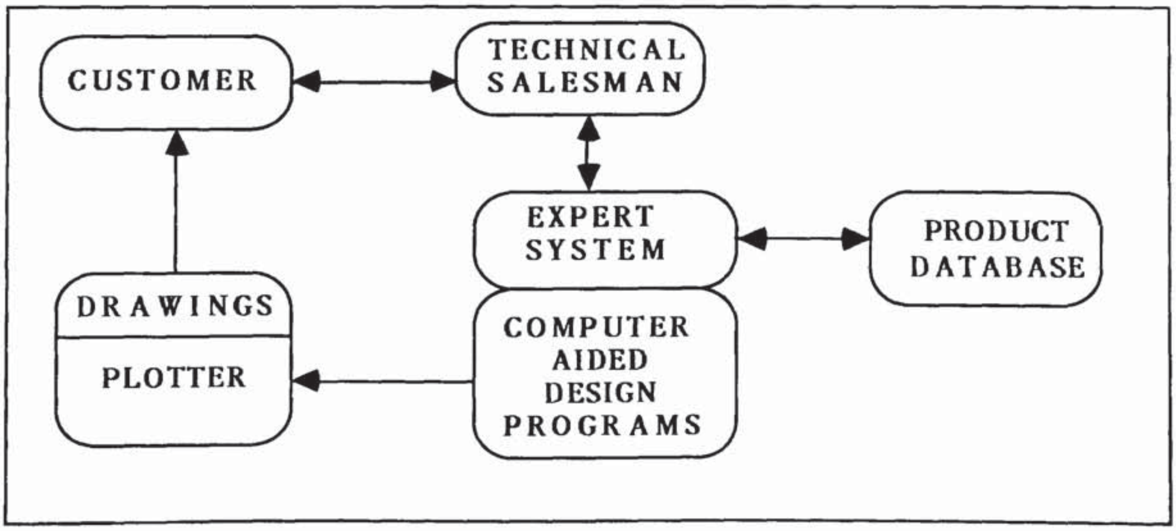


Fig. 6.1 Design sections with the aid of an Expert System

The new system consists mainly of the ES, a product data base, external CAD programs and the plotter. This ES provides the facilities to link external routines and execute external executable design programs. The information that is needed to operate the CAD programs is decided by this ES and a further step is taken by carrying out the actions rather than simply advising the user what to do. The construction of this ES and the language used will be discussed in details.

6.2 DIFFERENCES BETWEEN EXPERT SYSTEMS AND CONVENTIONAL PROGRAMS

The words "Expert" and "Intelligent" are common jargon often used by salesmen to impress their potential customers. However, the use of such jargon always confuses the customers, who may wonder what exactly are "Intelligent system", "Intelligent shop floor terminals", "Expert design System", "Expert program" and many other such terms. These systems are considered as conventional programs which are good for calculations and manipulation of data, whereas an ES articulates Knowledge.

A conventional program may consist of many "If... Then .... " rules and it can also give advice based on these rules. The conventional program consists of calculations, data manipulation and advice all packed into a single program with no specific components within its own system. If an alteration is required on the "If....Then..." statement or even on the advice, the programmer has to understand the whole program before any modification of this program can be carried out.

If the program is complex and long, it can take months before a simple modification can be completed. In most cases, the rules presented in a conventional program are not meant to be altered. Therefore, the knowledge of a domain is also limited to that of the programmer.

An ES has three main components namely, the inference engine, knowledge base and working memory. Each of these three components has its own separate identity. The inference engine is used to articulate knowledge and it is a fixed component which does not require alteration after the initial stage of the design.

It is at the knowledge base where changes of knowledge often take place. A simple piece of knowledge can be represented by one rule and for a complex piece of knowledge, it can be represented by a module of rules. Knowledge can be built interactively (which is through the executable image file), or through the text editor, depending on the type of AI languages used. Alternatively a separate Learning System can be used to extract new knowledge from the expert and place the knowledge onto the knowledge base. The knowledge from the knowledge base can be built, modified or deleted when necessary.

6.3 PLANNING FOR CONSTRUCTION OF AN EXPERT SYSTEM

To construct an ES, it is essential to prepare a plan detailing how the success of that ES can be achieved. This will involve studying the practical decisions and types of actions taken, which are then formed into rules that are acceptable by the ES using an appropriate ES tool.

A Knowledge Engineer (KE) is a person who implements an ES. In choosing an appropriate software for building an ES, the KE has to investigate if that language is appropriate for developing the ES. The KE must see that the chosen software is compatible with the hardware that the ES is going to be built on.

There are limitation to what an ES can do, and the KE must not be over ambitious and make a plan that is beyond what his resources can satisfy. During the planning stage, the KE should analyse the pitfalls that are likely to occur before going ahead with the development process.

6.3.1 PROTOTYPING DEVELOPMENT PROCESS

In building an ES, the first step that the KE is required to do is to design a prototype of that ES (as shown in Fig. 6.2) before the full development plan is carried out.

Initially, the KE has to carry out the first phase of the knowledge acquisition in order to see whether the domain is appropriate for an ES. When the KE questions the expert during the initial phase, the KE will find out the scope of the problems to be solved. The KE is also required to find a suitable AI language and computer hardware for developing the ES.

If the KE knows that this problem can be solved by using a traditional software technique, then it will not be necessary for a company to invest in such a system, nor to go through the difficult process of introducing a new piece of technology into the company.

When the problem domain and the size of the task is known, the KE will proceed to develop the architecture for ES. This is where the KE constructs the pseudorules to represent the way decisions and actions are made. Pseudorules are rules of a production written in English form.

The basic structure of an ES can be built from the pseudorules that have been constructed previously, by rewriting them into the appropriate code acceptable to the ES. After the basic structure of the ES has been developed, the KE can proceed to test the system together with the expert. At this stage, the KE may find that certain features are missing or some part of the knowledge has been misunderstood. If the system is not acceptable, it can be revised and the test procedure is repeated until a satisfactory result is obtained.

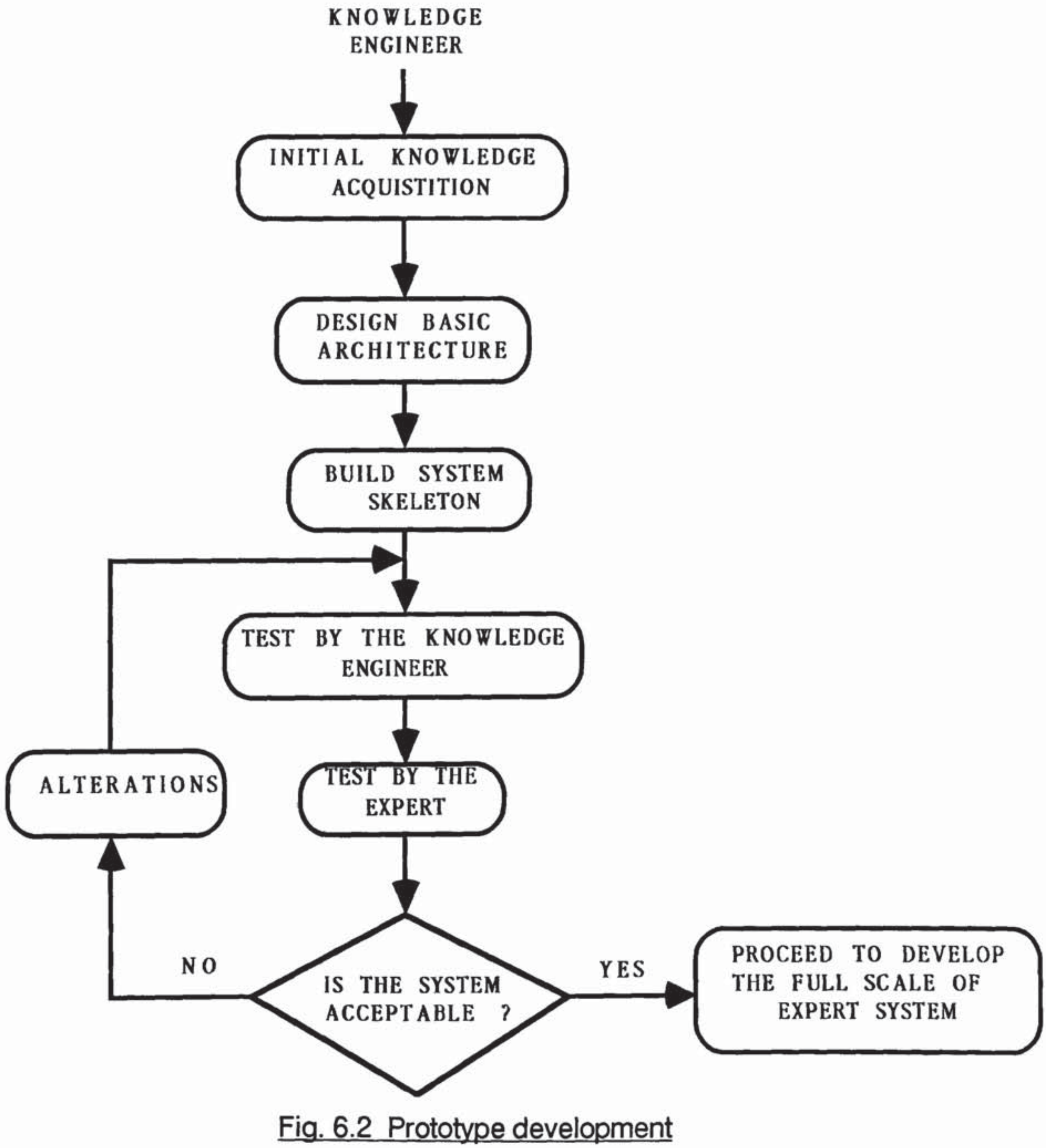


Fig. 6.2 Prototype development

Once the prototype is in the final stage, the full range of the knowledge of a domain can be added on over a period of time. If the system is large, the KE has to be prepared to treat it as a long term planning process with capital investment to support the development program. A simple ES will take at least 3 to 5 years to develop while a moderately complex system will take a minimum of 8 to 10 man years before reaching a reasonable mature stage.

Waterman (1987) has commented that increasing the number of personnel in the development process does not necessarily mean that the amount of time required to build the system will be decreased proportionately. In designing the prototype, the knowledge of a domain must be specific and if the KE tries to cover an area that is too large the chance of failing is high.

6.3.2 INITIAL KNOWLEDGE ACQUISITION

Knowledge acquisition is a process of extracting rules, facts, and data useful for the knowledge base from a domain expert. This knowledge is encoded into a form which is understood by the programs by using the knowledge representation techniques.

The main function of an KE (as shown in Fig. 6.3) is to interview experts and/or extract raw knowledge from published papers. The knowledge is then formulated into a rule form where it is structured and kept in the knowledge base.

There are basically four steps in a knowledge acquisition process (as shown in Fig.6.4) as follows:

1 Interviewing the expert

2 Content analysis

3 Knowledge organization

4 Knowledge validation

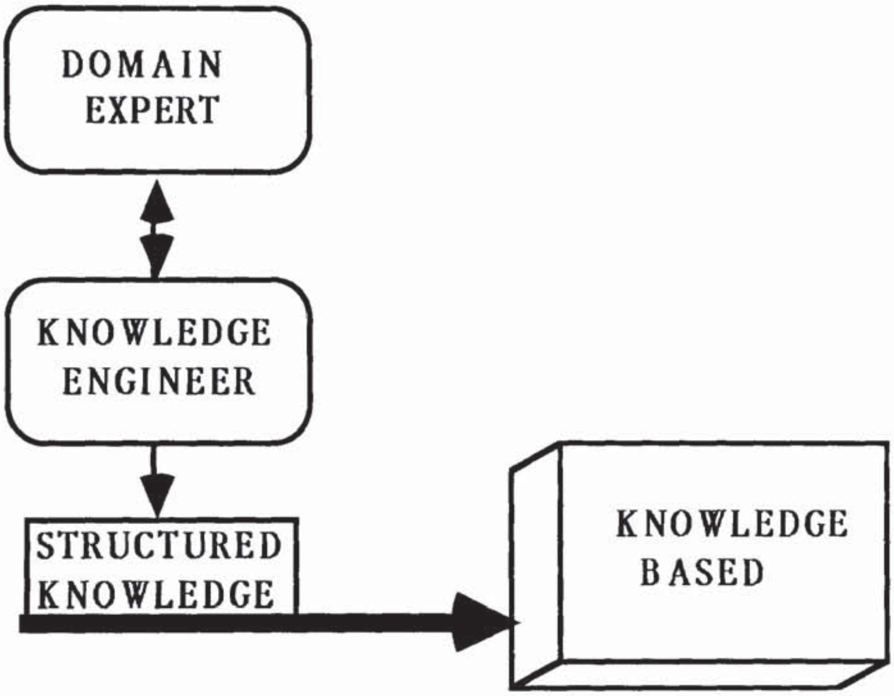


Fig. 6.3 Knowledge acquisition process

Interviewing is an important step to extract knowledge from the expert. The KE must carry out an initial study of the background materials and obtain an understanding of the domain or related domains before approaching the experts.

However, in the practical world, it is impossible for a single expert to master all aspects of detailed knowledge of a given domain. Trying to extract an in depth knowledge for a complex problem can be tedious, but more valid knowledge can be extracted by breaking down the complex problem into smaller manageable sub-problems.

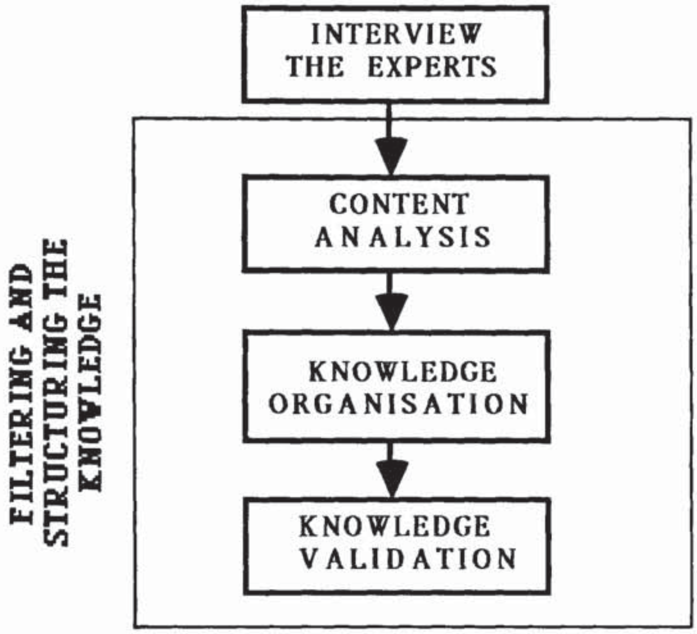


Fig. 6.4 Extracting useful knowledge

The facts, rules, and data collected from the interview carried out by Hu (1987) can be classified into three main groups (as shown in Fig.6.5) namely:

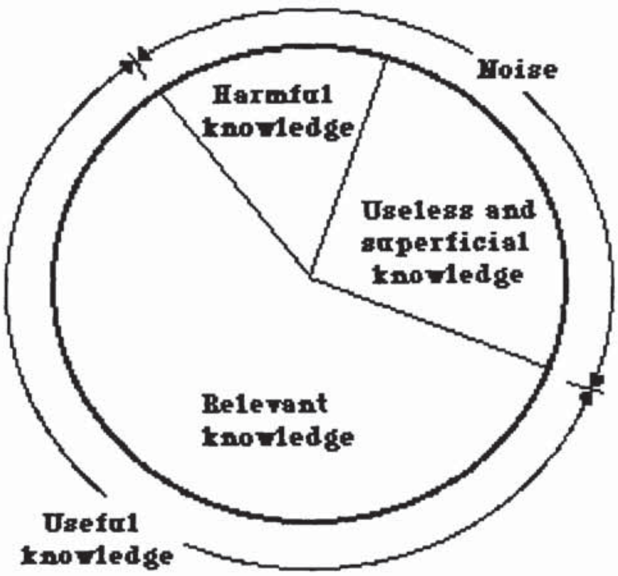


Fig. 6.5 Knowledge extracted from the experts

1 Relevant knowledge
2 Superficial and useless knowledge
3 Harmful knowledge

Not all knowledge extracted from the expert are useful. Those that are useless or harmful are sometimes known as the noise. Noise must be filtered out in order to obtain a knowledge base consisting only of relevant knowledge. The relevant knowledge must be tested for its validity before the rules are accepted by the experts.

6.3.3 SELECTING AN APPROPRIATE LANGUAGE

Waterman (1987) has given a very good introduction to the types of ES tools available for designing an ES. At the moment, there is no single ES language that can handle all types of engineering problems, but a better result can be produced with a combination of possibly two or more languages. This does not mean that the ES language cannot be used on its own.

Although all AI languages have their own limitations depending on their applications, they are definitely suitable for symbolic manipulation. The fifth generation languages are much easier to use than other lower level languages and they are specially designed for decision making processes. To write an ES based on a third generation language or lower, the KE needs to derive all the supportive functions from the beginning.

Apart from the languages available for developing ES, there are ES shells that can be used. ES shells are ES's with an empty knowledge base. ES shells are normally designed for general purpose use. These are also ES's designed for specific applications and later sold as ES shells for other purposes (i.e., without the knowledge in the knowledge base).

ES's that are designed for general purpose can be too general and it is highly possible that they may not be suitable for the specific domain that a potential customer has in mind. In contrast, those shells that have been developed for a specific application can be too biased towards the original intended application, and hence may not be suitable for the potential customer's new application.

It will cost a few hundreds pounds to purchase an ES shell for use as a learning tool or to become familiar with its functions. An ES shell is normally used on the personal computer and the size and the number of rules that can be added to the shell is very limited. If the knowledge is complex and the size of the rules is large, the small ES shell will definitely not be ideal for the application in such cases. To purchase a large ES shell can easily cost in a region of £15,000 to £60,000. This large system is expensive, and there is no guarantee that the system is appropriate for handling the intended domain problems. A list of prices can be seen in a survey done by Stock (1988).

If the ES that is intended to be built is large, then it is advisable to select an appropriate AI language and start from the beginning rather than to purchase a shell package, unless it is clear that the ES shell suits the requirements.

When solving normal engineering problems, there are two main areas which the Knowledge Engineer must consider:-

Firstly there are problems that can be solved by direct analytical means, this is where heavy calculations are involved. For instance, solving an Applied Mechanics problem is best handled by writing a computer program in a high level language such as Fortran, Pascal or Basic and the computed values can be more error free. In such cases, AI language will not be suitable as numerical calculations are involved. However, this does not mean that problems that are analytical have no expertise in them.

Secondly, there are problems that cannot be well defined analytically. These problems can be formulated and the number of alternative solutions varies. Thus to finalize the solution, relevant knowledge will need to be used selectively. In this domain AI languages are more relevant than the traditional high level languages.

In this project, a third type of problem arises where decisions have to be carried out and where calculations are also involved. Since it is a combination of two types of problems, it is necessary to merge the AI and the conventional languages. Although most ES's are written in AI languages, some are also written in Fortran or Pascal. These are slow for symbolic representation but fast in numerical calculation.

To develop an ES where operations such as calculations, graphics presentations or port communications are all required, normally a mixture of both AI language and other low level languages are used. Some programmers might prefer to build an ES using a low level language (Bamforth,1989) which gives them some specific features that they want.

Whereas others might prefer to use the AI language where most of the facilities already exist in the language itself, for example, interactive debugging facilities, input-output routines, editing and others.

The success of building an Expert System will depend on both the hardware and software used. Since the CAD software for designing cold rolled sections were written in Fortran and used on the VAX VMS operating system, it is advisable to construct the ES in the same environment.

OPS5 language has been chosen because:-

a, This language is developed at Carnegie Mellon University in Pittsburgh, United States, a reputable University in the research of AI. OPS5 has produced the first successful commercial ES called XCON.

b, This software is available at Aston University and software technical support is available.

c, This language uses production rules which are very similar to our natural way of making decisions and it is quite easy to learn.

d, It has the ability to call up routines written in other languages and also has built-in conflict resolution strategies.

There are facilities within OPS5 language which handle compiled routines written in a foreign language and presented in the form of an object file. Since most of the applications software in the cold rolled design process are written in Fortran 77, some Fortran routines are used in the actions taken by the ES. The graphic and calculations needed in this process are written in Fortran 77 and GINO-F library is used for the graphic routines. These externally compiled object routines can be linked with the object files compiled by the OPS5 compiler to form an executable image file and run as an OPS5 program.

In using OPS5 language, it is difficult to execute a foreign program which is in the form of an executable image file that has been compiled by a foreign language. Since external routines can be linked to an OPS5 program, those executable image files produced by a foreign compiler (not OPS5) can be executed indirectly via rules written in OPS5 language as a background job.

OPS5 can set up the required data in a format which can be understood by the foreign programs. Within the VMS environment, this information can be set by using the DEC Command Language (DCL). The foreign program can then be executed exactly in the same way as a designer will operate the program which provides the automated actions for the design process.

6.3.4 PITFALLS AND LIMITATIONS

While developing an Expert System, the Knowledge Engineer must be aware of some of the common pitfalls and limitations of an ES. Some of these are given by Waterman (1987) and Townsend & Feucht, (1986) .

In the initial stage of planning to build an Expert System, the Knowledge Engineer must not address a problem that is so difficult or so large that it is restricted by its own resources. The problem should not be too general where no benefits can be accomplished, or too complex where the Knowledge Engineer finds it difficult to get a solution out of it.

Management should not assume that an Expert System can be built by any programmers as long as the problem specifications and the right programming environment are given, nor should the ES be built within a restricted time limit.

It can be a trap to pick the most familiar tool for designing an ES. Using a conventional language to build an ES is normally much slower than using an ES language. Choosing an appropriate tool is difficult, but the KE must see that the tool is not too new or too old that it is not supported by the distribution company. It will be safer to check who has developed the tool, the success of the tool and its reliability.

The Expert and the Knowledge Engineer should have enough time for each other when formulating the knowledge into rules. KE must keep the Expert interested in the development process, it will be a drawback if the Expert finds the work uninteresting.

The KE or the user of an ES cannot expect the system to be able to handle all problems, as there are limitations to what an ES can do.

ES is not good at representing temporal or spatial knowledge. To handle such a problem, the KE will require a very large memory space and also a clever way of representing the search techniques in the inference engine. The Knowledge engineering approach is likely to fail if the KE expects the system to use common sense or general knowledge about the world.

An ES can only handle problems of a specific domain and it is wrong to expect the system to handle problems that it is not designed to solve. ES will have difficulties in dealing with erroneous or inconsistent knowledge. The capacity of an ES is limited by the tools from which it is built.

Expert System is not good at performing knowledge acquisition during the development process and this always results in the bottle neck effect. It is not appropriate to expect the ES to refine its own knowledge base.

6.4 DECISION CONCEPT OF AN EXPERT SYSTEM

Whenever a drawing is needed by the salesman, the practical procedure carried out by the manager (or an experienced technical man) can be described as discussion, decision and action as shown in Fig. 6.6. The manager will initially discuss what to do, followed by a decision as to what action to take, and finally he will allow the designer to carry out the action decided upon. Alternatively the manager can decide what to do and carry out the action directly.

Fig. 6.6 Practical operation approach

Most consultation ES's provide a different approach when compared with the practical approach as shown in Fig.6.6. It normally considers the information provided before making a decision. An expert can make a decision and/or even give advice to the third party based on the decision made. In such a case, only verbal advice is given with no physical action taken as shown in Fig. 6.7.

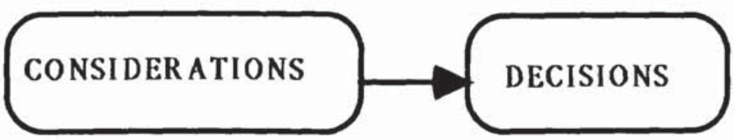


Fig. 6.7 General Expert system approach

If the ES approach shown by Fig. 6.7 is modified and combined with Fig. 6.6 to carry out the actions as shown in Fig. 6.8, then a single practical operation can be carried out. An ES does not discuss a piece of information but it considers it internally within the computer. From the considerations, it can make its own decisions. The decisions can be an advice to the third party, or it can be a set of orders to the third party. This set of orders can be arranged in a form according to the designer's actions. The ES then executes this set of orders to the CAD software, thus providing a direct execution of the CAD program.

Fig. 6.8 Automation with the aid of an Expert System

This ES provides the facilities to run the section design program or the section properties program automatically (as shown in Fig. 6.9). The ES activates an external software by first down loading the information to the activator and later executing it by an external routine which is placed at the RHS of the production where actions are taken.

The designer can operate the ES directly as an individual piece of software. Although the section design program and the section properties program can be operated by the ES directly, it can also be used independently on its own. Section properties program produces a data file which can be used by the loading or selection programs.

The loading or selection programs can be operated independently without the assistance of any other software but it requires the section properties and the material properties data. Since the section properties data can be obtained from the section properties program and the material properties come from a standard file, by producing a set of section properties data into a file, it provides the facilities for other software to excess this file independently.

This ES is specially built to automate the designing process of rolled sections and, for any shapes that have been standardized, it can easily produce a drawing automatically.

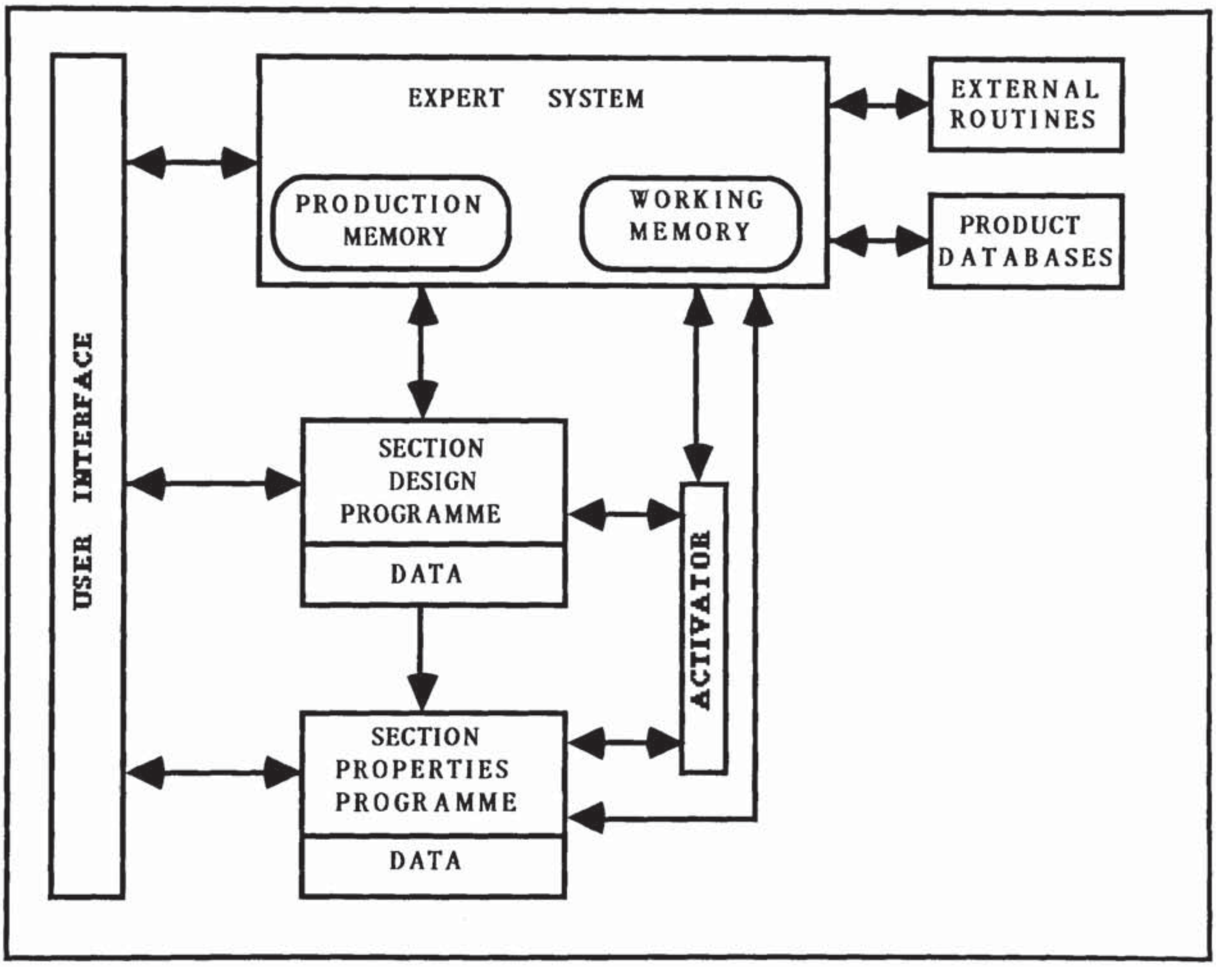


Fig. 6.9 Expert system for designing cold rolled sections

6.5 A PRODUCTION SYSTEM

An ES which is designed by using OPS5 language is known as a Production System (PS) (Brownston et al,1985 and McDermott,1982). It is called a PS because the knowledge base composes primarily of production rules which are conditions-actions statements.

There are three main parts in a PS (as shown in Fig. 6.10) namely :-

1 Inference engine
2 Production memory
3 Working memory

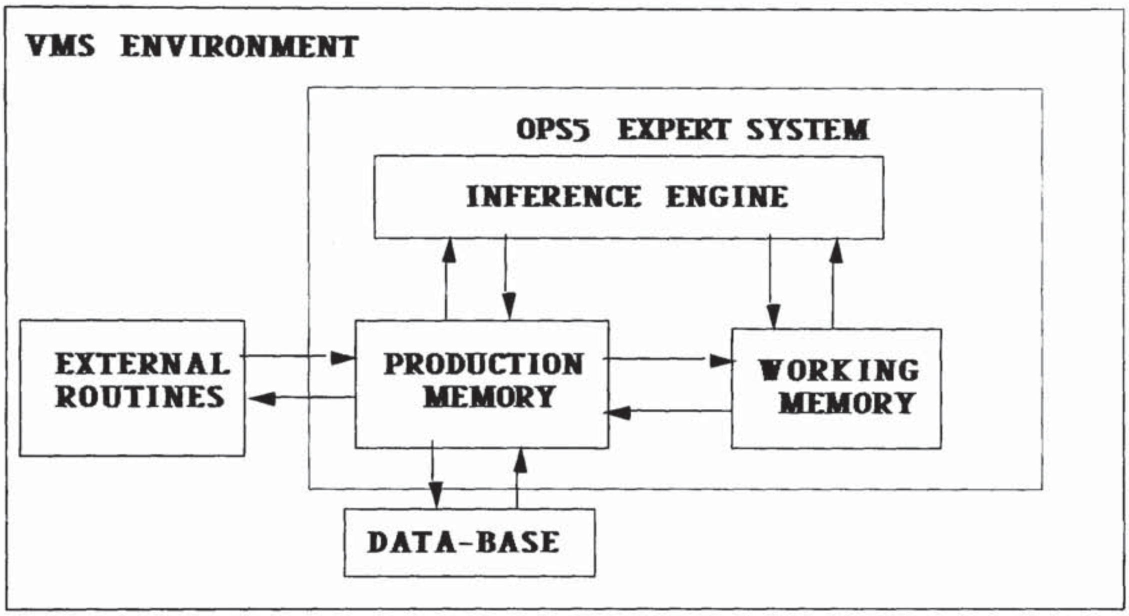


Fig. 6.10 OPS5 production system

When the program is executed, the active data operated by the program are kept in the working memory in the form of working memory element (WME).

Production rules in an OPS5 program are called **productions**. These productions operate on expressions stored in a global database called production memory.

The inference engine controls the flow of information within the system. This inference engine will ensure that the elements in the working memory and the external routines used by the action part of the productions are declared.

6.5.1 WORKING MEMORY

Working memory is a dynamic database which contains the data representations on which the productions operate. These representations consist of an element class name and a collection of associated attributes and its values, all of which are enclosed in parentheses. The value of these element attributes are either scalar or sequence of scalars.

For example, the OPS5 program requires the following information in the working memory to check for an existence of a product :

Product

Group	Family	Sub-family	Section No.	Dim-B	Dim-C	Dim-t
Inhouse	Hat	Equal-sides	1000	30.0	10.0	1.5
Inhouse	Hat	Equal-sides	1011	40.0	15.0	1.4
Inhouse	Hat	Equal-sides	1032	35.0	10.0	1.2
Inhouse	Hat	Equal-sides	1015	28.0	5.0	1.0
Inhouse	Hat	Equal-sides	1023	20.0	8.0	1.2

The typical form of a working memory element (WME) is :

(Class-name ^attribute value)

The information can be represented by the five working memory elements. "**Product**" can be classified as the **Class-name**. "**Group, Family, Sub-family, Section-No, Dim-B, Dim-C, Dim-t**" can be classified as the

attributes and the **data** are classified as the **values** of the given attributes.

Examples of two working memory elements are:

(Product ^Group Inhouse ^Family Hat ^Sub-family Equal-sides ^Section-No 1015 ^Dim-B 28.0 ^Dim-C 5.0 ^Dim-t 1.0)
(Product ^Group Inhouse ^Family Hat ^Sub-family Equal-sides ^Section-No 1023 ^Dim-B 20.0 ^Dim-C 8.0 ^Dim-t 1.2)

The prefix operator, ^ , is used to distinguish attributes from values. Before any working memory elements are discovered, the attributes must first be declared at the beginning of the program. The usual way in which working memory elements are declared is by using the LITERALIZE, a class name and a list of all the attributes of that class, all enclosed in parentheses. For example, a declaration for the above elements would be:

```
(LITERALIZE   Product
              Group
              Family
              Sub-family
              Section-No
              Dim-A
              Dim-B
              Dim-C
              Dim-D
              Dim-t
              Dim-r )
```

Every working memory element must be declared in this manner and each literalized element must have a unique name. The attribute values are stored in the working memory initially and later these elements can be shrunk for grown dynamically when acted upon by production memory at system run time. In the working memory, the number of WME's is to be kept as small as possible by splitting the problems into sub-tasks.

6.5.2 PRODUCTION MEMORY

The production memory is also known as the knowledge base by other ES's. The Productions consist of condition-action statements which operate on working memory elements. Each production has a unique name and consists of left-hand side (LHS) and right-hand side (RHS) of the production. The LHS consists of one or more conditions and the RHS carries out the necessary actions as required by that production. Every rule in the PS must be entered into the production memory explicitly.

```
( PRODUCTION  NAME
    IF              given Conditions  are true
                    Condition 1 is true
                    Condition 2 is true
                    .......
                    Condition i  is true
    THEN            carry out the following Actions
                    Action 1
                    Action 2
                    ......
                    Action j    )
```

Productions in this program can be expanded quite easily in the production memory. An example of a production can be represented by Fig. 6.11 .

```
IF              (P Inhouse-stage-two::Equal-angles
   LHS          {<task> (task ^name Inhouse-stage-two) }
Conditions      {<local> (stage ^Stage2-shape Equal-angles) }
 THEN           -->
                (remove <local> )
                (openfile plot plot.dat out )
                (write plot | LEVEL3 | )
   RHS          (write plot (crlf) | ANGLES | )
  Actions       (write plot (crlf) | EQUAL-ANGLES | )
                (closefile plot)
                (call plotshapes)
                (write (crlf) executed successfully )
                (halt) )
```

Fig. 6.11 A Production rule

LEFT HAND SIDE OF A PRODUCTION

The LHS of the production is made up of one or more expressions that describe the WME. During system execution, the interpreter compares each condition element on the LHS with the current elements located in working memory, in order to determine if the pattern is matched by any WME. If each condition element is matched by some WME, then the conditions on the LHS are considered satisfied. The LHS of the production is the equivalent of the IF part of an IF -- THEN statement. When the LHS of the production is satisfied, the RHS of that production is executed.

RIGHT HAND SIDE OF A PRODUCTION

RHS of the production contains a list of actions which are executed if and when the LHS of the production becomes satisfied. An action consists of an action name and its arguments, and this is usually used for manipulating or modifying the contents of working memory. In OPS5 there are predefined actions types available within the system.

The types of actions that will directly affect the WME's are **make**, **modify** and **remove**. Action such as **openfile** and **closefile** are used for opening and closing a file of a given name. Action **call** is used for calling external routines and any external routines used must be declared at the declaration section before that particular routine can be accessed. In general, most of the RHS of a production is used for giving advice or making a decision. The RHS of this system does not only make decisions but also carries out the necessary actions such as operating an external program automatically.

6.5.3 RECOGNIZE-ACT CYCLE (Inference engine)

The recognize-act cycle is also known as the inference engine of an ES. When a PS is executed, it performs a sequence of operations called the recongnize-act cycle as shown in Fig. 6.12.

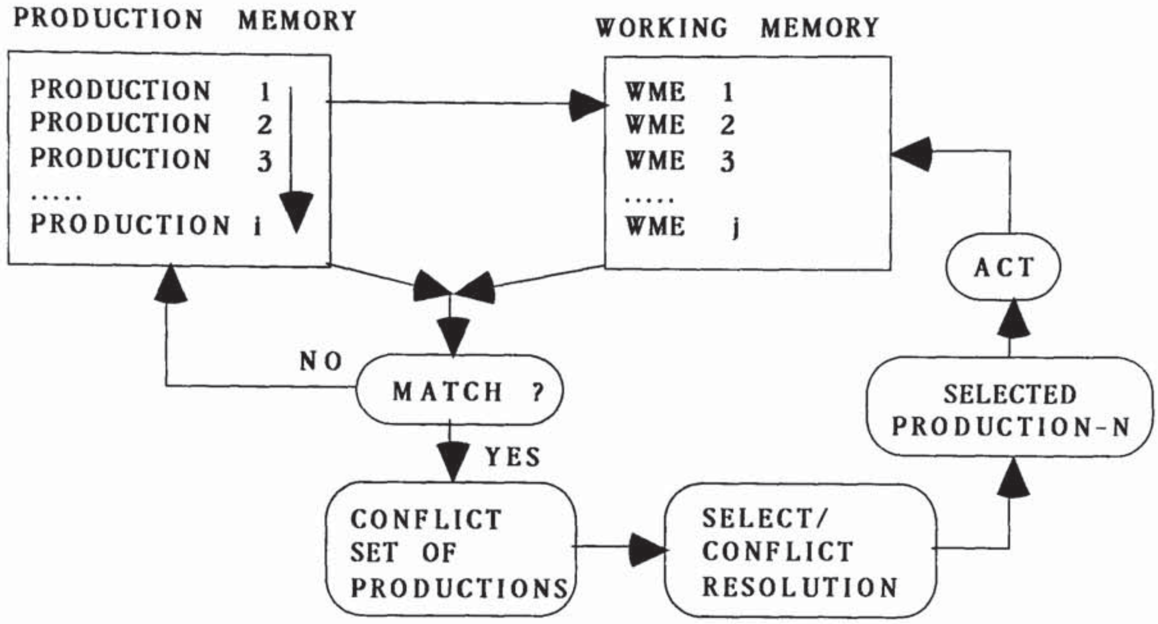


Fig. 6.12 Inference engine

This cycle consists of the following three steps:

1 Matching the WME
2 Conflict resolution
3 Actions

This PS provides a forward chaining search technique, where the depth first search method is used for searching the productions in the production memory as shown in Fig. 6.13.

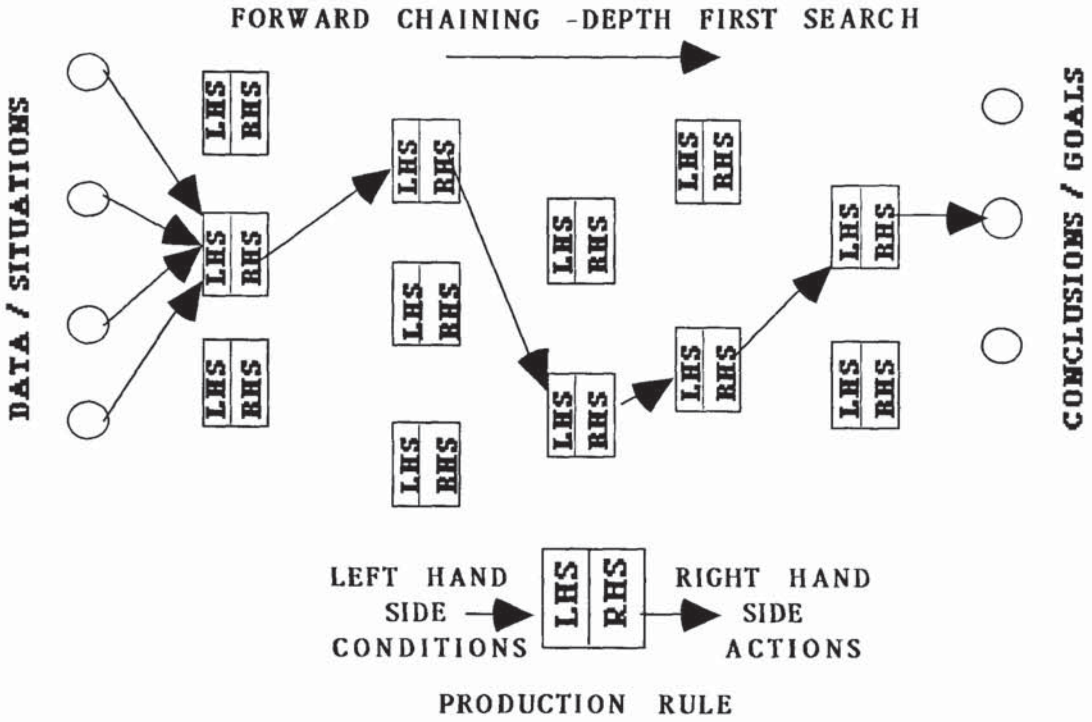


Fig. 6.13 OPS5 forward Chaining system

MATCHING THE WME

In a match phase of the recognize-act cycle, the LHS of the production's conditions are compared with the elements present in the working memory. A production is pronounced to be satisfied when all the LHS conditions of the production are matched against the WME's. If none of the LHS of the productions satisfies the WME, the program execution stops.

When more than one of the LHS of the productions are satisfied, the run-time system creates a conflict set containing records of the WME's that match the conditions elements of the productions. These records, consisting of production name and a list of time tags of WMEs that match the LHS of the productions are called instantiations. In a conflict stage, they usually contain more than one instantiation.

CONFLICT RESOLUTION

The output of this match process, which is the input to the conflict resolution, is called the conflict set of productions. There are currently two different conflict strategies built into OPS5 language (Brownston et al, 1985) that determine which production from the conflict set should be executed first. The two types of conflicts strategies are called the Lexicographic-sort (LEX) strategy and the Mean-End-Analysis (MEA) strategy. These strategies can best be described in the VAX OPS5 Reference manual and Brownston et al, (1985). A brief summary can be seen in Appendix B.

During a conflict resolution, either LEX strategy or MEA strategy can be used. In this application, the default LEX strategy is used because it does not depend on the order in which the productions are executed.

ACTIONS

In the act phase of the cycle, the actions in a chosen production are executed one at a time, in the order they have been written. Actions take effect immediately. Hence if a RHS contains `Make' or `modify' actions, the element added by the last action in the RHS is more recent than the elements added by previous production executions.

6.6 USING EXTERNAL ROUTINES

Within OPS5 program, all user routines must be declared to the interpreter (as shown in fig.6.14) before they are used in a RHS of the production. The way to declare an external routine in the OPS5 program is to type in "EXTERNAL" then the subroutine name "PLOTSHAPES" and enclose them in parentheses thus:

(EXTERNAL PLOTSHAPES)

The action "CALL" calls up the subroutine written in a foreign language and makes it active. The following action calls the subroutine "PLOTSHAPES" with the variable <NAME> as an argument:

(CALL PLOTSHAPES <NAME>)

The syntax to call any user-written subroutines is identical to the syntax of a call on a standard subroutine. The call consists of an open parenthesis, the name of the subroutine, the arguments to the subroutine (if any), and a close parenthesis.

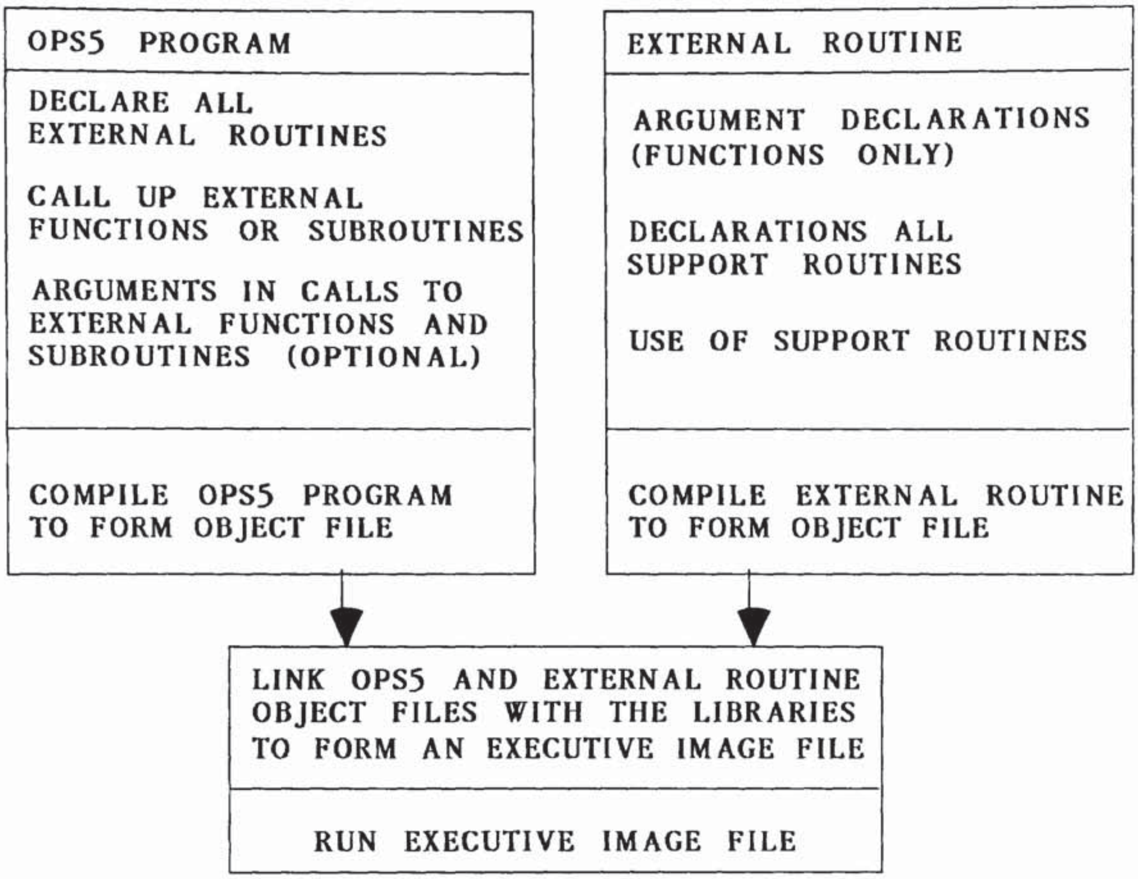


Fig. 6.14 Linking to external routines

When writing a routine in a foreign language such as BASIC, FORTRAN and PASCAL, the programmer must declare the OPS5 support routines so that the arguments can be passed onto the external routine and vice-versa. There is a listing of support routines available for different compiler, and it is advisable to put these support routines in a separate file and give it a name (e.g., OPSDEF.FOR), then use the INCLUDE statement at the beginning of the external routine to include the list of support routines in the program.

```
INCLUDE 'OPSDEF.FOR'
```

For a subroutine which has been written in Fortran 77 in VMS environment, the PLOTSHAPES.FOR subroutine can be compiled using the Fortran compiler

```
$ FORTRAN PLOTSHAPES
```

after the Fortran compilation, an object file "PLOTSHAPES.OBJ;1" is formed. Then compile the OPS5 program ESDESIGN.OPS by using the OPS compiler.

```
$ OPS ESDESIGN
```

After the compilation, an OPS5 object file "ESDESIGN.OBJ;1" will be formed. The next step is to link the object files together with the OPS library routines and OPS interpreter library.

```
$ LINK ESDESIGN,PLOTSHAPES,OPS$LIBRARY:OPSINTERP/LIBRARY
```

this forms an executable image file "ESDESIGN.EXE;1" , which can be executed by the RUN command.

```
$ RUN ESDESIGN
```

This will run the ESDESIGN program, where the call up routine will be within the program.

6.7 ACTIVATOR

An activator is an auto execute operation set up by the ES in an environmental language for operating an external program without having to type in the necessary information, while the external program is in its executing state. In this research, the ES is derived from OPS5 language and it is running in the VMS environment.

Taking a case of a Slant_Zed shown in Fig. 5.2, a simple production rule can be written as :-

```
;
; RULE DEALING WITH SLANT_ZED
;
 ( P SLANT_ZED::operating_propert
 {<task> (task ^name SLANT_ZED ) }
 (subfamily  ^subfamilyname SLANT_ZED )
 -->
 ( call SLANT_ZED)
 ( call activate )
 ( modify <task> name start))
```

Within the VMS environment, an activator is set up by the ES in DEC Command Language (DCL) and this can activate those executable design programs written in Fortran 77 (shown in Fig. 6.15). An example of an activator which has been set up by the ES through calling the slant_zed routine (based on the seven input of Fig. 5.2), can be seen as:-

```
$ ty live.com
$ RUN  [WONGCT.ok]opsPROPERT
1
zs102
  2   2     3.0000   4
    1  1  28.6923   0.0000
    2  2   3.0000 -101.8886
```

```
    3  1  24.0000   0.0000
    0  0   0.0000   0.0000
    1  1  28.6923   0.0000
    2  2   4.0000 101.8886
    3  1  33.0000   0.0000
    0  0   0.0000   0.0000
   4   1.1429
  1
  0
$ RUN  [WONGCT.ok]opsSELECT
2
Y
zs102
N
$
```

This activator runs the section properties design program (opsPROPERT), and sets up all the necessary information exactly like a designer would operate the program. It then runs the selection program (opsSELECT), and updates the section properties onto the structural database. The whole operation can be automated (or made active) by one of the external routines. The external routine can be written as :-

```
Subroutine activate
Integer*4 Lib$spawn
call lib$spawn('@live')
end
```

The knowledge of operating an executable design program is captured in the ES. Knowing how to operate a program and operating a program are two different things, i.e., one is the "ability" which is the knowledge and the experience of operating that particular program, and the other is the "action" which is the operation of the program.

Automation can be achieved by combining the ability to do a piece of work and doing it physically without any human resources. With the availability of such an automation facility, the system can run the external CAD program without the aid of a designer.

Most commercial application programs can only be bought in as an executable image form, on which the programmers or the KE cannot carry out any modification. With the increased use of ES's, many companies will consider implementing such systems. By implementing ES technique, manufacturers will wonder what to do with their existing application programs and their personnel that have been trained to operate these programs.

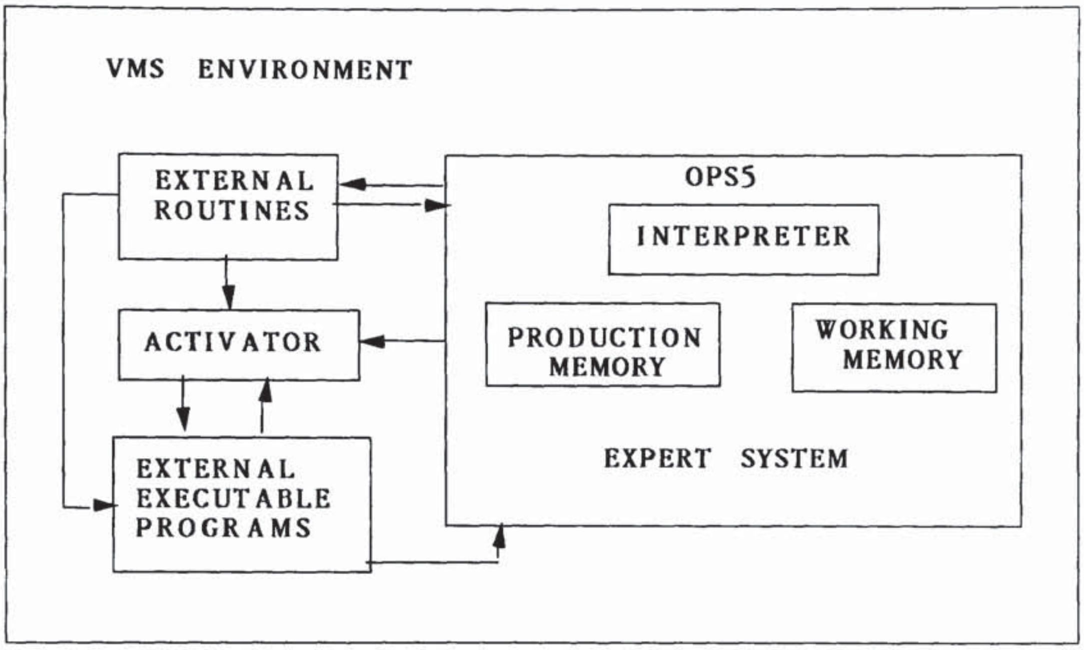


Fig. 6.15 Interacting with VMS environment

By using an ES and incorporate it with an activator, the knowledge of operating external program can be set up to carry out the operation automatically. In such a case, the external program can be operated without the expert.

If an ES only offers advice to a designer, the designer still has to operate the design programs manually with the aid of the given advice. When designing a complex shape, it can be quite time consuming for the designer to type in all the information as required by the CAD package in order to produce a drawing. If the ES takes a step further by not only making the appropriate decisions but also setting up the information that are required when operating the CAD package, then executing these setup operations directly to the CAD program will eliminate the manual input of data (by the designer) to the CAD package.

It is obvious that there are times when the ES runs an external executable program at the expense of the ES. The time required by the ES to operate the CAD program directly is only a few seconds. Whereas if the designer has to type in the information onto the CAD program manually, it can take anything from 5 minutes for a simple shape to 45 minutes (excluding any calculations) for a complex shape. The time saved by the automated approach is significant and the cost of that few seconds is negligible when compared to the 3/4 of an hour cost of a designer.

CHAPTER 7

KNOWLEDGE ORGANIZATION

7.1 PRODUCT HIERARCHY

The products which exist within the company can be classified under two main groups, namely:

1 In-house products and

2 products from BS2994

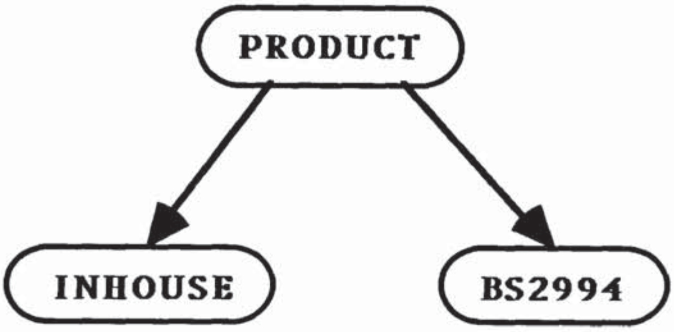


Fig. 7.1 Main grouping of the products

In the first level of the product selection process, the designer identifies whether the product is obtained from BS2994 or from the In-house group (where the sections are designed and produced within the company). This is the first level of the decision making process.

7.1.1 IN-HOUSE SECTIONS

Products classified as In-house sections are mainly designed within the company. They are products that have been requested by the customers with given profile specifications for manufacturing. Very often, modifications of the given profile is necessary so that the manufacturer can cut down the cost of tooling and also the complexity of the profile.

Shapes that are similar within the In-house products are grouped into main families and subfamilies. As from level 1 (which is the In-house products), the products are then split into main families such as Tee, Channel, Zed, I, Angles, Hat and so on. By making a decision in selecting one of the main families, decision in level 2 is accomplished. Thus decision in level 2 represents the main family of the In-house products.

From the main family in level 2 of the decision making process, the products are then split into sub-families. A decision taken as to which sub-family is appropriate for the required section, satisfies the decision taken at level 3.

Once a sub-family has been identified, a sketch of that particular sub-family (at decision level 4) will be displayed on the screen. The sketched subfamily is followed by some questions requesting for the unknown dimensions. When the dimensions are given, the ES will decide which rule or rules to use and arrange the data in an appropriate form which can be understood by the CAD program. The ES then commands the execution of the CAD program and produces the necessary drawing.

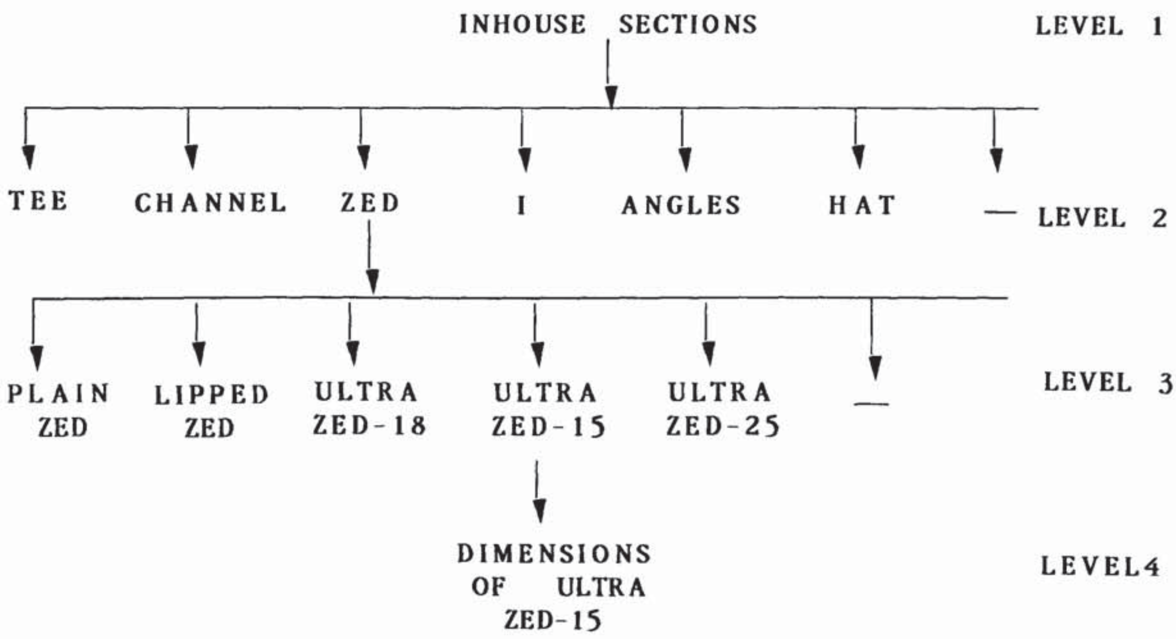


Fig. 7.2 In-house sections

7.1.2 BS2994 SECTIONS

The BS2994 contains sections profile together with the given section properties data which can be readily used by the designer. There is an option available to the designer, he can either search the product through BS2994 manual or select directly from this system. There are only three levels in which decisions have to be made.

Level 1 is the decision of using a BS2994 section, or check if the appropriate shape exists within BS2994. When level 1 of the decision making process is reached, the computer displays on the screen the range of profiles which exist in BS2994. From the displayed profiles, the designer will select one of them which is similar to the required shape and this represents decision level 2.

Once level 2 of the decision is made, the chosen profile will be displayed on the screen. The displayed profile is followed by questions which request for dimensional information. By answering those questions, level three of the decision making process is satisfied. With the allocated dimensions, the ES will search through the data base for the available products. It then decides and arranges the given information in a form that can be accepted by the CAD program. The ES will later execute the arranged information via the activator and plot the section drawing on the screen or the plotter.

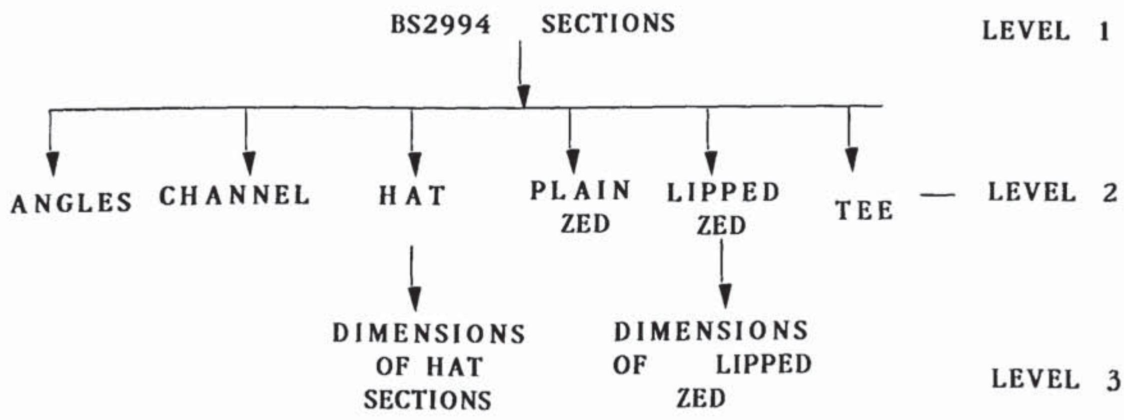


Fig. 7.3 BS2994 Sections

The way decisions are made in selecting a section profile as mentioned in paragraphs 7.1.1 and 7.1.2 is very consistent. In this new approach, decisions are taken one individual step at a time and it is better than having to look through the product files by the technical man. It means that designer has to search through all the products manually from the first to the last section available in the files.

In the last level of the decision making process, dimensions for a chosen profile are fed into the system in order for the system to decide what data to use and to set them in a form that can be understood by the CAD program. The way in which information is set can be best described in the acquiring new knowledge paragraph. This is the action part of the production and the amount of actions taken by each individual production can be large according to the complexity of the profile.

7.2 PRODUCT CLASSIFICATION

Sections that have similar shapes but different in the number of elements are classified under a main family. Those sections that have the same profile but only with different dimensions are classified under a sub-family in the product hierarchy.

Under the main family name "ZED" at level 2 of the In-house product, there is a range of sections having shapes that are similar to zed. Thus, they are classified under the sub-families of zed. Amongst the sub-families of zed at level 3, the number of element contents are different from each other. Within a sub-family of zed at level 3, such as 'Lipped Zed' the shape of that particular sub-family will be similar, so is the number of elements contained in it.

It should be noted that sections under this sub-family (such as the lipped-zed section) should have the "same designing approach" if they are to be designed using the same CAD software. The design approach is the decisions and actions that the designer have taken to operate step by step on the CAD program in order to obtain the drawing. Productions are drawn based on the conditions required by the designer and a series of decisions and actions that have been taken by the designer.

When the designing approach of a section is the same as one of the sub-family products, this section falls into that particular class of sub-family. Thus sections are classified under a sub-family when the number of elements used, the calculations applied and their designing and decision making approach are the same.

The classification of sections under the main family such as zed does not depend on the number of elements in the sections. It only takes into account the overall appearance of the shape.

7.3 ACQUIRING NEW KNOWLEDGE

The aim of this ES is to automate the design process by capturing the knowledge of the designer and the actions that he will carry out in order to produce a drawing to the customer.

The whole operation is complex and every single step that has been carried out by the designer is carefully studied.

This covers :-

1) Initial observations of the sketch given by the customer
2) Consideration made by the designer
3) Requesting for the dimensions of the sketch

4) Decide what program to use.

5) From the main dimensions, the designer will have to breakdown the sketch into every single element (either linear, circular or blank) and carry out all the calculations for every single element.

6) Positioning of the section.

7) The dimensions that are needed for typing onto the CAD executing design program.

The above operations carried out by the designer for designing a section are repeated whenever a product is required. These operations can be captured by writing them into a form of production rules.

Men have to be trained to carry out the above operations. The designer has to calculate each element before entering them onto the CAD program. The way calculations are carried out can be studied and formulated as part of a production rule for a specific shape. Once the whole operation is transformed into production rules, it can then be used over and over again, provided that the shape is similar, regardless of the variation in dimensions. Thus, once the production rule or rules of a particular sub-family is formed, a less experienced person can operate the ES and produce the required drawing without having to master the techniques involved in operating the CAD program or the methods for calculating the elements.

A designer is not always aware of how he has made his decisions, calculated the elements and operated the CAD program. To him, these procedures are almost his second nature. Different calculations are carried out by the designer depending on the shape of the profile. These geometrical calculations might seem very simple for the well-qualified, but for others it might take a long time before they can reach such a level of understanding. When ES can be trained to such a high level of understanding, and the knowledge can be applied in the later stage, then the applied knowledge is known as artificial intelligence.

There are three ways in which knowledge can be captured into the ES, namely :-

1) Creating new rules by using the BUILD command available in the OPS5 language.
2) Using the EDITOR for creating the new rules.
3) Constructing an external learning system.

7.3.1 CREATING NEW RULES BY USING THE BUILD COMMAND

A "BUILD" action command can be used in the RHS of the production where new rules can be added to an executing program. Using the BUILD statement to build a production with varying number of conditions and varying number of actions is complex. This BUILD command is more applicable to productions that are more consistent and the number of conditions and actions in each production does not vary much. There is also another disadvantage by using the BUILD command, namely, once the command is written within the production memory, it will be very easy to use and thus can produce many unwanted productions which have to be discarded later on.

When new production can be produced too easily, it tends to have bad documentation. Thus the BUILD command is not used for this ES. The KE has to be careful that not everyone is allowed to alter the production in the production memory, or else the knowledge contents in the production memory will be useless.

7.3.2 USING THE EDITOR

In a design case, the designer is free to express the way he intends to carry out the operations of the CAD package. To provide such a flexible facility, the derived productions will be different from shape to shape. The contents of both the LHS and RHS of a production can vary and sometimes external routines or external programs are used according to the actions taken by the designer.

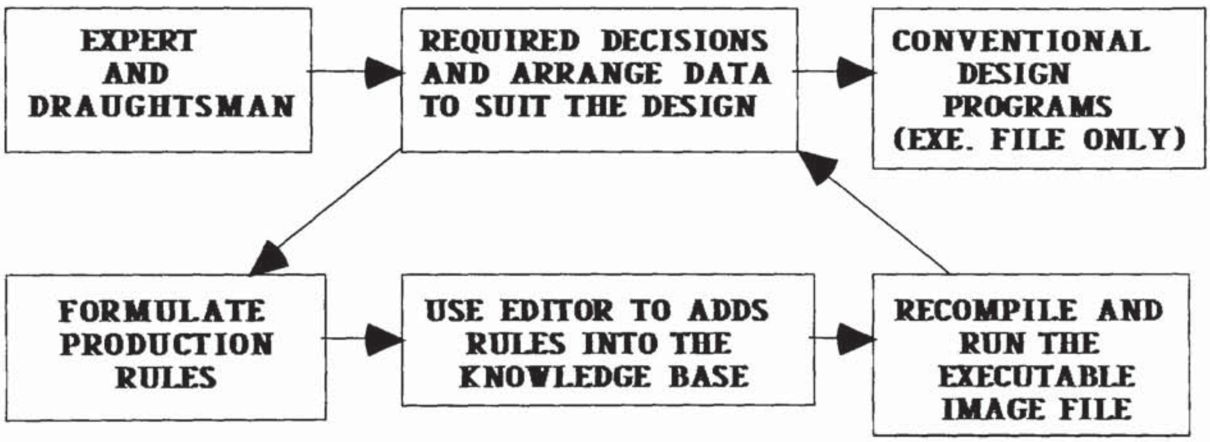


Fig. 7.4 Adding new rules to the production memory

When external routines are used, they must first be declared before they can be executed. Thus, in such a complex situation, it is best to use the editor to add the new piece of production onto the knowledge base. It is not difficult to write a production using OPS5 language. In fact, individuals can be trained to write productions in a very short time.

In the VMS environment, editor can be used for adding new rules to the production memory which can then be compiled and executed by the ES, as shown in fig. 7.4 and fig.7.5. There are many compilers that offer the same approach but there are also some compilers which provide an integrated editor which comes together with the AI language compiler.

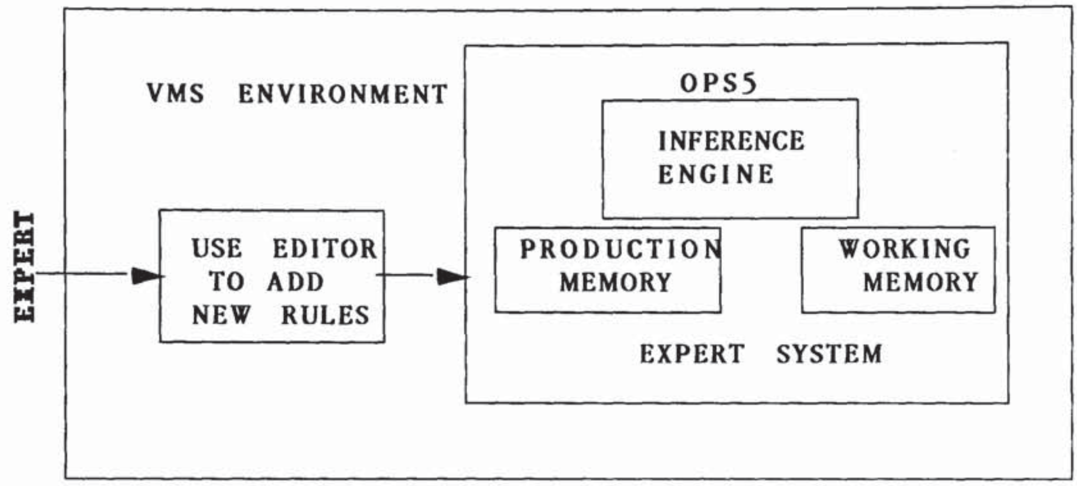


Fig. 7.5 Adding new rules by using editor

7.3.3 SEPARATE LEARNING SYSTEM

The third method of learning new knowledge from the expert is by designing a separate learning system which is completely separated from the ES but has the facilities to incorporate new knowledge onto the knowledge base. There will be extra work involved in constructing this learning system, but it will help to cut down the time in generating new productions or routines.

In practice, it takes longer to produce new rules and routines manually than generating them from a learning system. A detail of how a learning system will operate will be discussed later in this chapter.

7.4 EXPLANATIONS

The main aim of this ES is to enable decisions to be made and the series of appropriate actions to be carried out, similar to what an experienced designer would do when asked to design a section with the given CAD software. This ES offers the ability to produce an automated drawing, instead of only providing the explanations and information to the designer, which he still has to enter onto an executing CAD program manually. The actions taken by the productions in this ES are interacting directly with the CAD software.

Although a general-purpose explanation system can be built from OPS5, it is questionable whether it is justified to implement such a facility. The cost of storage and the time involved in writing a production rule which consists of good explanation facility coupled with the series of actions that have to be taken by the production can make the production very large and awkward to manage. Since OPS5 is a language which can be easily understood, the KE can easily identify what the production is representing.

In this case, it is not necessary to advise the designer what to do or how to operate the CAD software. A study has also been carried out by Pollitt (1986) in reducing the complexity of the ES by rejecting the consultation model. It will be a waste of resources if the system gives advice to the designer of what actions to take who then proceeds to operate the CAD program manually. Undoubtedly, it is more productive to operate the CAD software automatically rather than having it operated manually by the designer.

Where sections are required to be tested for their loading capacity, a full report is available which sets out how the calculations have been carried out, the type of information used and the results produced. This report is readily obtainable after the execution of the structural programs.

7.5 CERTAINTY FACTOR

Many ES's apply a Certainty Factor (CF), which is a numerical value given to a fact or relationship to indicate the level of confidence in the fact or relationship. The CF's are set between -1.0 (for definitely not) to 1.0 (definite). There are ES's that do not use CF, these mainly apply to those that require precise answers.

When dealing with engineering problems, the CF is not normally used because the answers or actions required in a decision process are usually definite rather than variable. Since a definite or precise fact or relationship of a production is necessary, and with the CF as one, the system can be designed by an AI language with no CF facility.

7.6 METHOD USED FOR LEARNING SYSTEM

A learning system is a system which is able to analyse a group of knowledge or absorb a piece of knowledge from the expert and form a new set of knowledge in the knowledge base of an ES. There are many ways in which a human learns new events and stores them in the brain. One very common way of learning is by attending a lecture in a classroom where the students learn by being told what to do by the lecturer.

A normal way in which a lecturer teaches the students is by showing them an example of an event. The students absorb whatever the lecturer has said and remember it as a piece of knowledge. Whenever a same or similar type of event arises, the students will recall that piece of knowledge which has been taught by the lecturer and apply it to that particular event.

If that particular event has been altered but nevertheless, still requires the same piece of knowledge, the students will need to apply their common sense before the required knowledge can be chosen for use. The drawback about a computer is that they do not have common sense, but they can definitely learn by being told (Michalski & Chilauski, 1980) of what to do for a given event.

A new learning system for designing cold rolled section based on learning by being told has been specially constructed to improve the efficiency of knowledge acquisition. The method used in the learning system can be seen in Fig. 7.6.

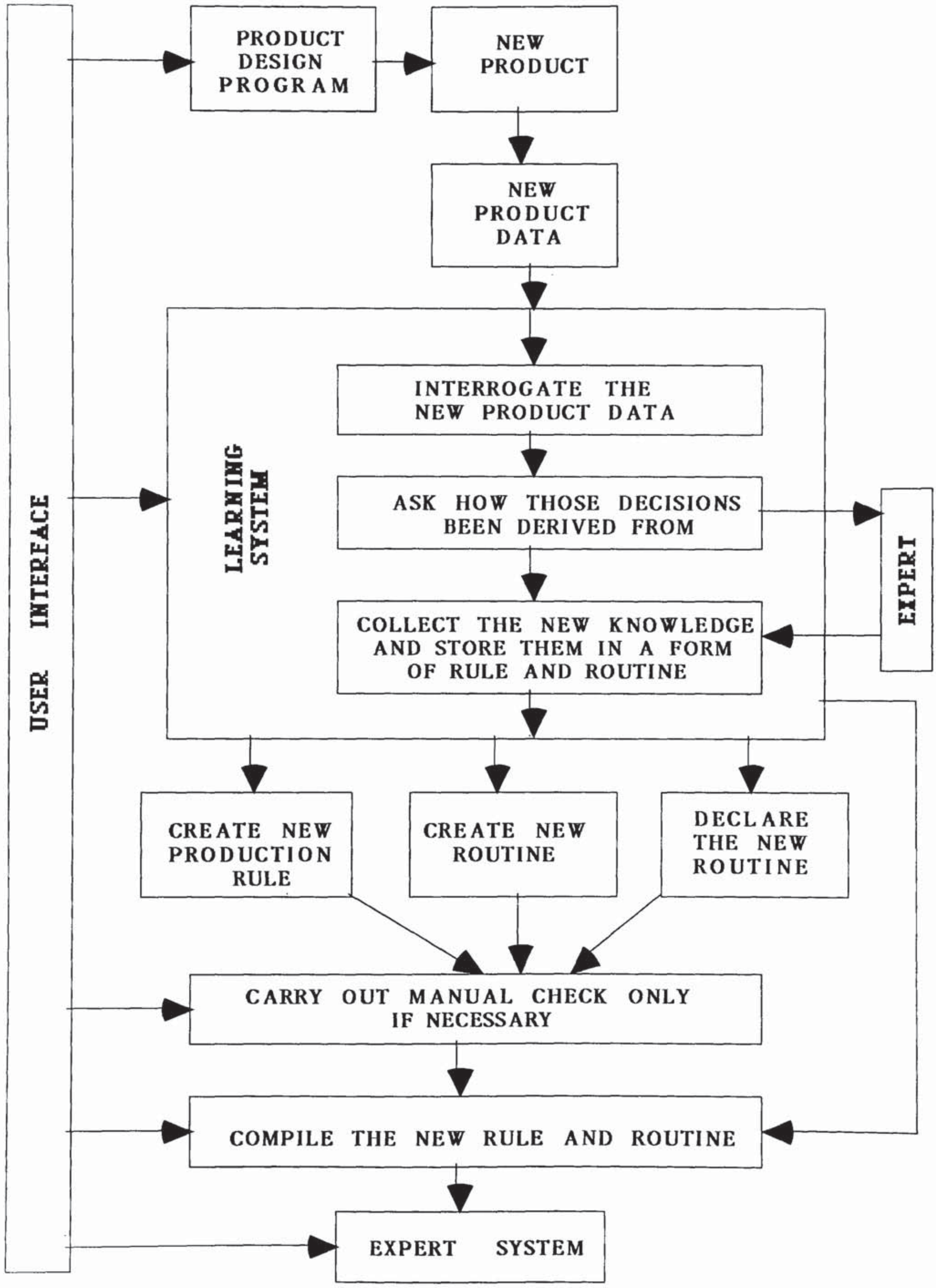


Fig. 7.6 The method used for learning system

This learning system acts like a novice designer where it reads data of the section profile and interrogates them by asking the designer (Expert) as to how these data are obtained and the basis for the decision. The learning system then collects the new piece of knowledge, writes them in the form of production rules and external routines, and declare them in the ES. There is an option where the KE can check or alter the new piece of knowledge manually by using the editor if necessary. These new rules can then be recompiled and used as a piece of new existing knowledge in the knowledge base.

7.6.1 SETTING THE SKETCH

Before the learning process can be carried out, it is necessary to set up a sketch of the section. The sketch can be set up using the FULLSEC program. Since a sketch is drawn specially to make it simpler for the customer to understand, therefore the way it is set up can be different from the actual drawing. The FULLSEC program is very user friendly and the general operation of the program can be described as :-
(note:- the highlighted typing are information input by the user)

$ Fullsec

Please input section number ?

1001

Please input the sub_family name ?

Plain_Zed

1 for dimensioning

2 no dimension require

3 Exit

1

Please choose the required option

1 Dimension length

2 Dimension radius

3 Dimension thickness

4 Dimension angles

5 Exit

These options are used and the sketch can be set up as shown in Fig. 7.7, and to check this sketch, another program can be used by typing DIMSEC.

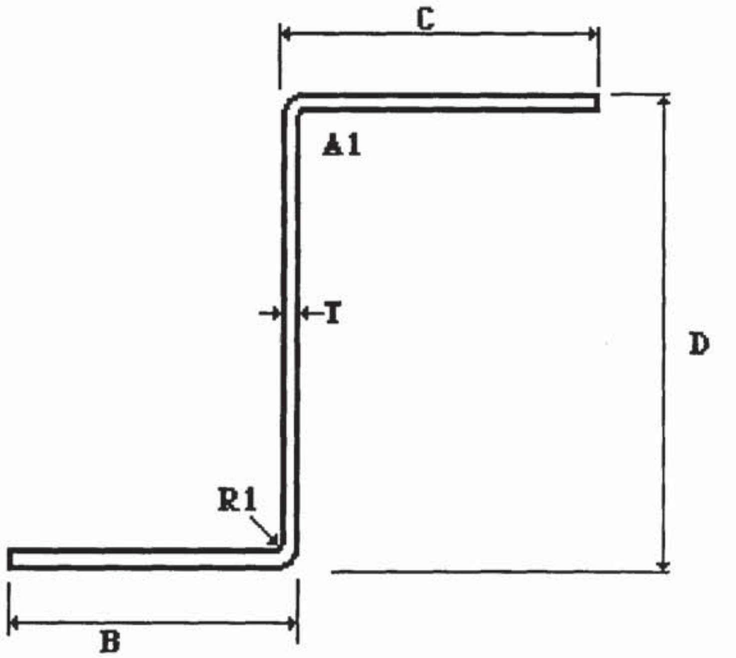


Fig. 7.7 A dimension sketch for Plain-Zed

7.6.2 INTERROGATING THE SECTION PROFILE

The design data produced by the design program are interrogated by the learning system. Every single information shown in the design data file is input by the designer. The designer has to make decisions on all the design data typed onto the CAD program. This learning system will interrogate each information available in the design data file. By doing so, such interrogation is similar to the series of questions asked by the novices during their learning stage. Learning system program can be operated as follow :-

CHOICE: **Learning**

Main menu for control of new rules.

Type

1. Add dimension symbols to a given shape
2. Creating new rules for a given shape
3. Updating the recently created rules.
4. Exit

2

Sub-menu for forming new rules

1 Declare the new routine used

2 Learn from a given shape (drawn by the Expert)

3 Build new production rule

4 Exit

2

Please input section number

1002

```
 2  2   1.5000   4
   1  1  30.0000   0.0000
   2  2   1.5000 -90.0000
   3  1  30.0000   0.0000
   0  0   0.0000   0.0000
   1  1  30.0000   0.0000
   2  2   1.5000  90.0000
   3  1  30.0000   0.0000
   0  0   0.0000   0.0000
  4   1.5000
```

1

0

Please give the new rule name

Plain-Zed

In order to maintain consistency, do use the given variables.

T for thickness (automatically asked)

B, C, D, E, F, G and H are used for main dimensioning

R_1, R_2, R_3, R_4 and R_5 are used for main radius

A_1, A_2, A_3, A_4 and A_5 are used for main Angles

How many dimension symbols are used (from B, C, D, E, F, G,and H) ?

3

How many radius symbols are used (from R_1, R_2, R_3, R_4 and R_5) ?

1

How many Angles symbols are used (from A_1, A_2, A_3, A_4, and A_5) ?

1

Is additional information required before going into each

element ?(Y/N)

N

What is the equation for linear element 1 ?

Length = ?

$(D/2.0)-R_1-T$

What is the equations for circular element 2?

Radius=?

R_1

Angle=?

$-A_1$

What is the equation for linear element 3 ?

Length = ?

B-R_1-T

What is the equation for linear element 5 ?

Length = ?

B-R_1-T

What is the equations for circular element 6?

Radius=?

R_1

Angle=?

A_1

What is the equation for linear element 7 ?

Length = ?

C-R_1-T

What is the largest dimension ?

D

Do you want to update the structural data ? (Y/N)

Y

Sub-menu for forming new rules

1 Declare the new routine used
2 Learn from a given shape (drawn by the Expert)
3 Build new production rule
4 Exit

(option 1 to 4 will be used for creating the new rules)

Sub_menu for updating new rules

1 Update External declaration
2 update routines
3 Update Production rules
4 Update the Expert system
5 Exit to the main menu

(option 1 to 5 will be used for updating the new rules)

7.6.3 PRODUCTION RULE PRODUCED BY THE LEARNING SYSTEM

When the learning system has been used for interrogating a design, a production rule based on OPS5 will be created automatically. A simple production rule of the plain-zed can be described as :-

```
;; ======================================
;; DEALING WITH PLAIN_ZED
;;
 ( P PLAIN_ZED::operating_propert
 {<task> (task ^name PLAIN_ZED ) }
 (subfamily  ^subfamilyname PLAIN_ZED )
 -->
 ( call PLAIN_ZED )
 ( call activate )
 ( modify <task> name start) )
```

7.6.4 ROUTINE PRODUCED BY THE LEARNING SYSTEM

When the learning system is run, a routine based on Fortran is also created automatically by the system. This routine is used for calculating each element and setting up the data in the environmental language. A set of tool library has been designed to assist the routine in setting up the operations that are needed to execute the CAD program. An example of the routine can be described as :-

```
C  ==============================================
C     THIS ROUTINE IS DEALING WITH PLAIN_ZED
      SUBROUTINE PLAIN_ZED
```

```
CHARACTER SECNO*8

CALL GET_SECNO(SECNO)
CALL GET_THICKNESS(T)
CALL GET_DIM_B(B)
CALL GET_DIM_C(C)
CALL GET_DIM_D(D)
CALL GET_RADIUS_R1(R1)
A1=90.0
CALL OPENLIVE

CALL RUNPROPERT(SECNO)

CALL SET_ORIGIN(2,2,T,4)
E1 = (D/2.0)-R1-T

CALL SET_ELEMENT(1,1,abs(E1),0.0)
RADIUS2 = R1
ANGLE2 = -A1
CALL SET_ELEMENT(2,2,RADIUS2,ANGLE2)
E3 = B-R1-T

CALL SET_ELEMENT(3,1,abs(E3),0.0)

CALL SET_ELEMENT(0,0,0.0,0.0)
E5 = (D/2.0)-R1-T

CALL SET_ELEMENT(1,1,abs(E5),0.0)
RADIUS6 = R1
ANGLE6 = A1
CALL SET_ELEMENT(2,2,RADIUS6,ANGLE6)
```

```
E7 = C-R1-T
CALL SET_ELEMENT(3,1,ABS(E7),0.0)
CALL SET_ELEMENT(0,0,0.0,0.0)
CAll SET_SCALE(4,80.0/D)
CALL UPDATE(SECNO)
CALL CLOSELIVE
RETURN
END
```

7.6.5 TESTING THE NEW RULE

Whenever new rules have been created, they must be tested before they can be used. After the creation of the new rules and routines, they are updated onto the ES. When the designer is in doubt about the rules, editor can be used for checking or altering them, before the updating take place. Once the knowledge has been updated, the user can design the section by just operating the ES.

The operation of the ES can be described as :-
(note:- only the highlighted information are input by the user)

$ CRDEX
Which level of hierarchy you would like to look into ?
1 = Main group (level1)
2 = Main family (level2)
3 = Sub-family (level3)
4 = Exit
3
Please identify which sub-family that is most appropriate to the required profile ?
Plain_Zed

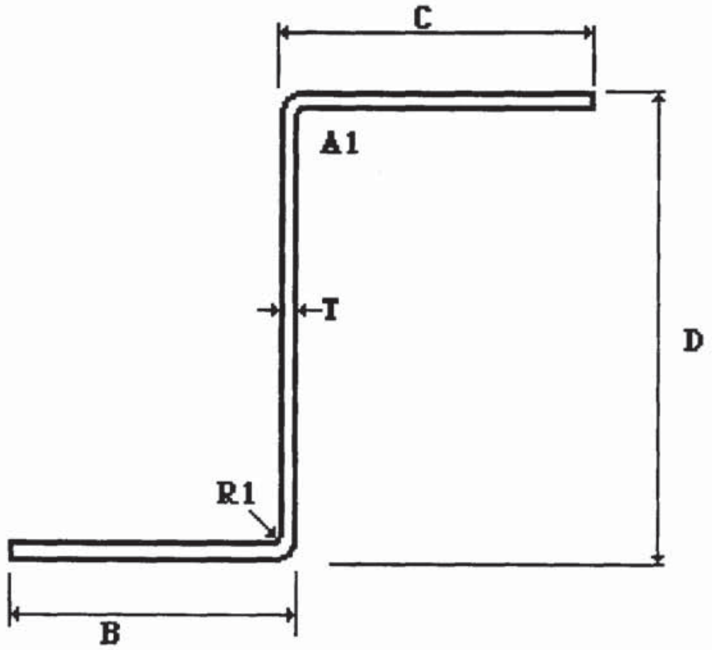


Fig. 7.8 Sketch of a Plain_Zed profile

Section number

1004

Input Thickness of material T ?

2.0

Input dimension B ?

20.0

Input dimension C ?

30.0

Input dimension D ?

25.0

Input Radius R_1 ?

2.0

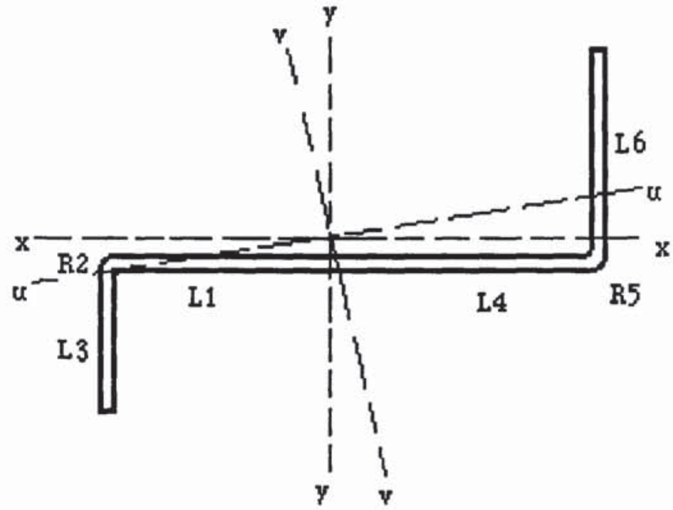


Fig. 7.9 Actual section of the required Plain_Zed

CHAPTER 8

RESULTS

8.1 SECTION DESIGN USING THE EXPERT SYSTEM

Graphical drawing is an excellent universal language for describing an object. It is easier and quicker for a person to understand a drawing than to read a paragraph of words. When writing a computer program, it will be more difficult to represent an object in a graphical term than in text form. Nevertheless, to assist the decision making process in this ES, graphical presentations are used.

The practicality of this ES lies in its ability to use the available knowledge in the knowledge base and to draw a profile at the shortest time possible with minimum amount of input information. In practice, it is difficult to describe a problem to a designer without representing the problem in a rough sketch form. Since the ultimate solution of a problem is represented by a drawing, it is inevitable that rough sketches are used to help in the decision making process (as shown in Fig. 8.1, 8.2, and 8.3).

The whole operation of the design process, starting from the salesman to the completion of the product drawing are carefully studied. The designer's knowledge is entered into the knowledge base of the ES. This enables the ES to perform the operation automatically in the same manner as if carried out manually by the designer.

8.1.1 DESIGNING AN IN-HOUSE SECTION

Consider a case where the salesman is required to design a section within the range of the In-house products. The ES has to be executed first and the salesman will be asked whether the required section is selected from the In-house products or the BS2994 range. When the answer to the question is In-house products, the graphical drawing (as shown in Fig. 8.1) will be displayed on the computer screen.

$ PROFILE

Which type of products you would like to look into ?.

[either IHSECTIONS = Design products from In-house sections

or BS2994 = Design products amongst the BS2994]

IHSECTIONS

Fig. 8.1 shows an approximate profile of the main families which exist within the company's product range. From the screen, the user will be asked to enter the type of family name that has been chosen which roughly resembles the required product shape.

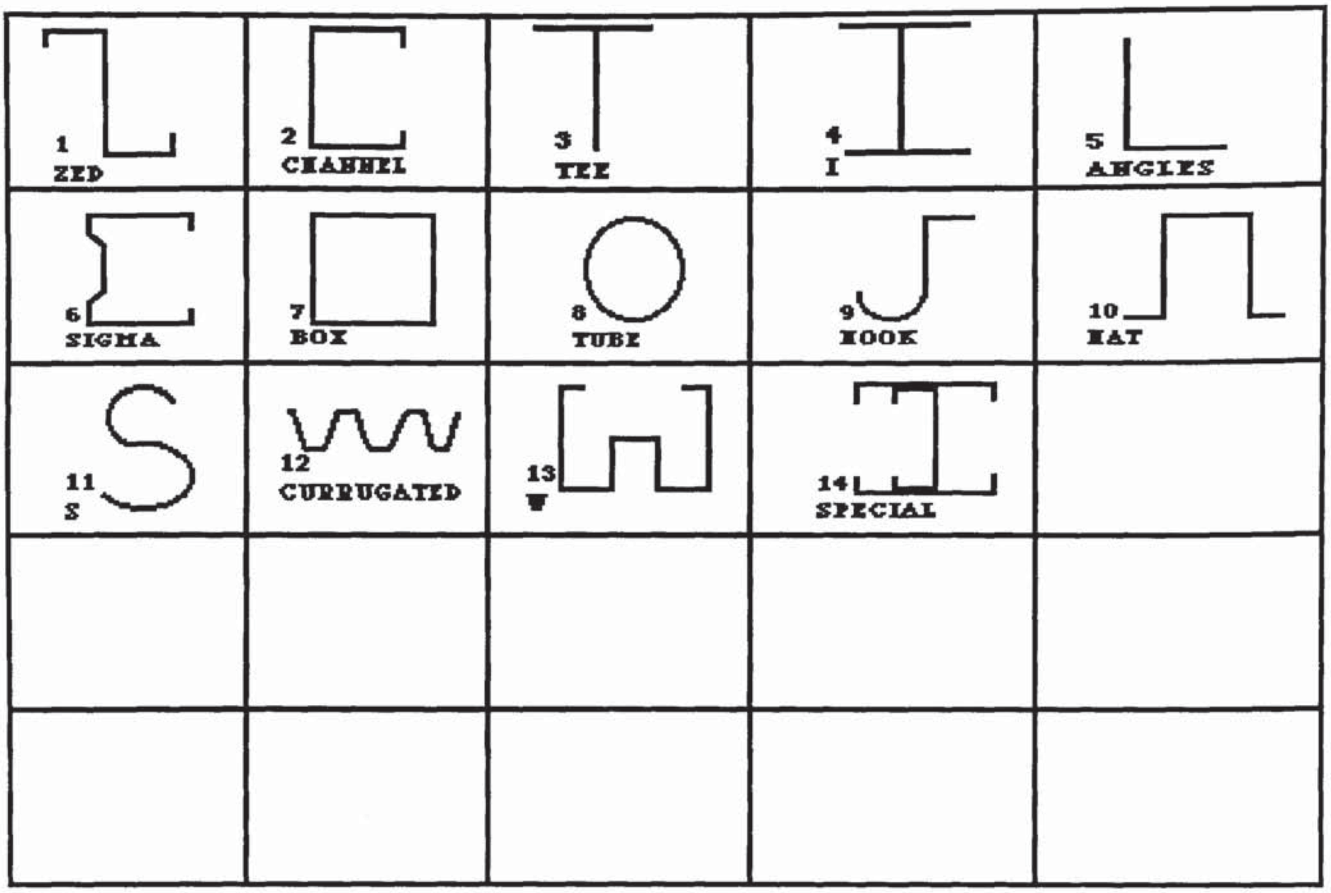


Fig. 8.1 Main families of In-house products

What sort of main family do you think your product is likely to be under ?

ZED

When the main family name is given, the system will search through the profiles that belong to this main family and display them on screen for the user to select the most appropriate profile. Fig. 8.2 shows the sub-families of the Zed sections from which the user chooses the most appropriate shape as originally required. This sub-families drawing gives a more precise guide towards the requested shape.

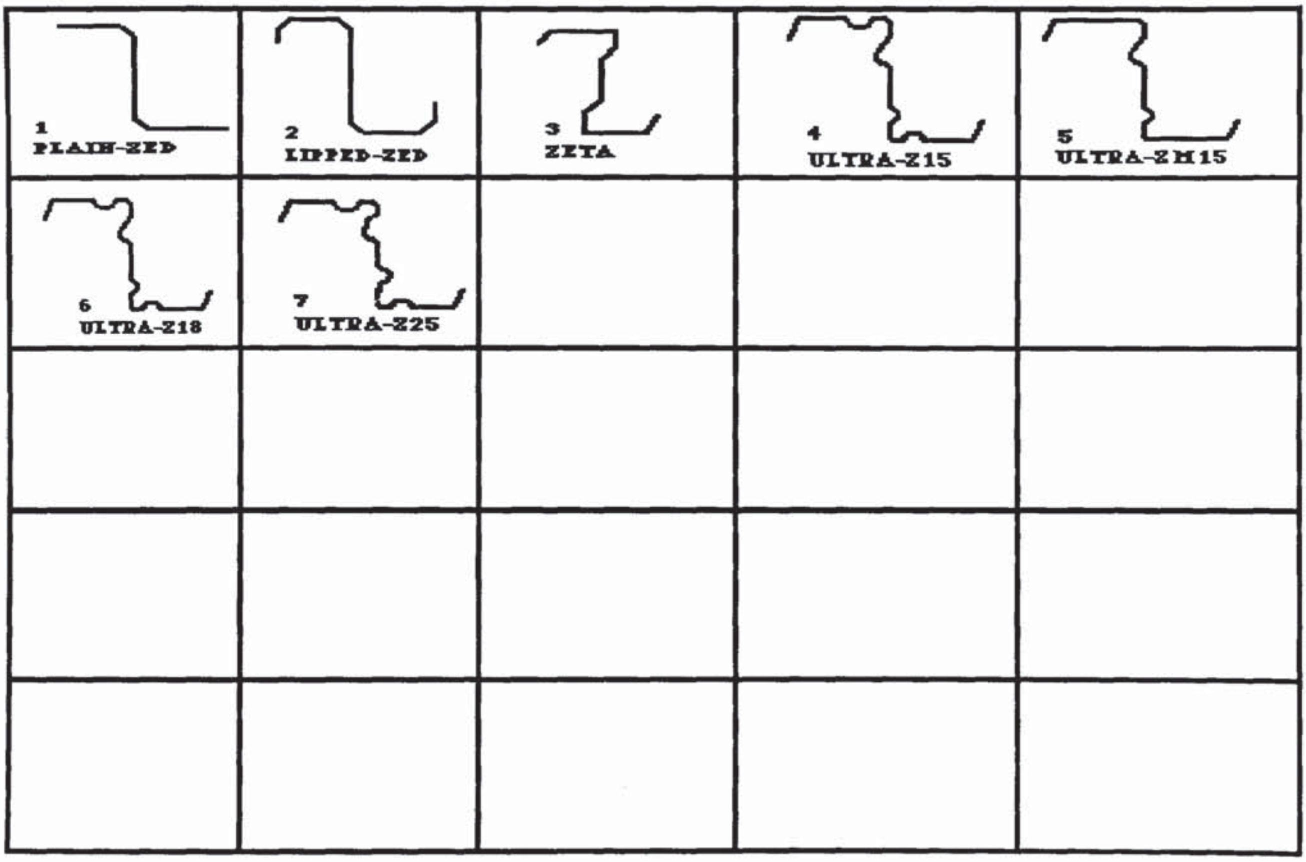


Fig. 8.2 Sub-families group under zed profile

Please identify which sub-family that is most appropriate to the required profile ?

ULTRA-ZM15

When identifying the required sub-family, the displayed sketch will give a guideline towards the overall shape of the section. However, the dimensions of the actual profile may be different. An example can be seen on Fig. 8.3 where a rough sketch of a modified Zed is displayed. Following the sketch, a series of short questions will be asked where the user inputs the appropriate information as requested.

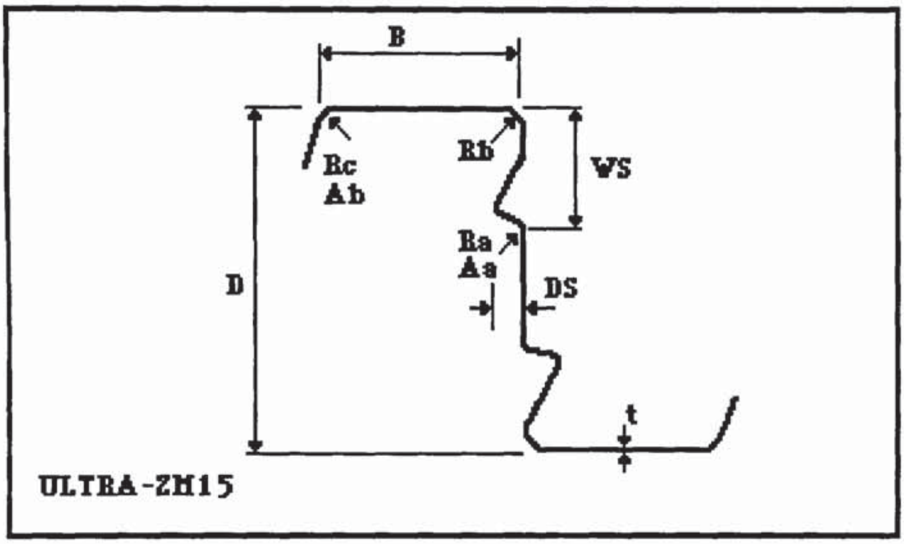


Fig. 8.3 Sketch of the required profile

Please enter the following information.

Section Number ?

ZM6032H

(Maximum thickness allowable is 1.5 mm)

Thickness of material t mm ?

1.2

Overall Depth D mm ?

60.0

Largest width of the flange B mm ?

36.5

Radius R_a, R_b and R_c mm ?

(minimum radius is taken as t+0.5 mm)

2.0,3.0,2.0

Angle A_a, A_b in degree ?

(Angle for lips must not be less than 70 degree)

70.0,70.0

The depth of stiffener DS mm ?

(DS must be greater than 4.277 mm)

4.3

The height of the web stiffener WS mm ?

(WS must be greater than 17.677 mm)

17.7

(The smaller side of the flange is 32.00 mm)

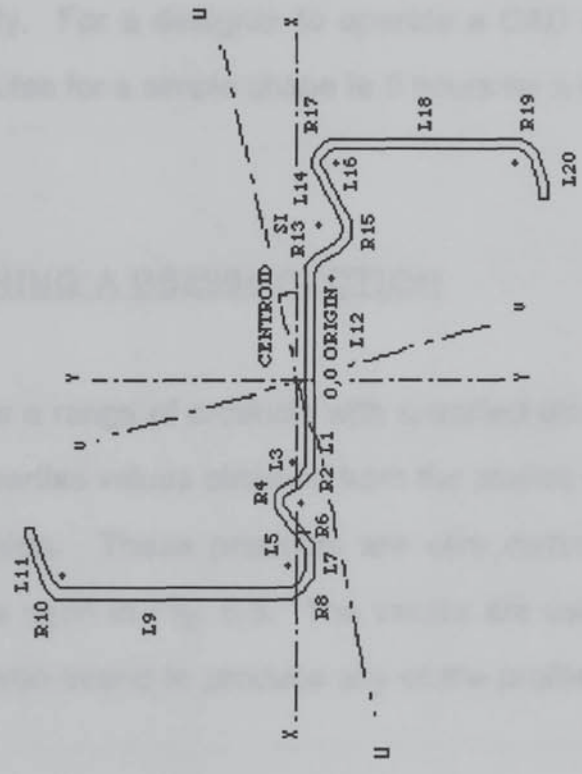
Based on the above given information, the system will analyse them and decide what to do in the same manner as a designer. The system will then automatically operate the CAD software step by step as set up by the ES. The result produced is shown in Fig. 8.4 and this is the actual drawing of the requested profile. Those information that has been input by the user when operating the ES is only a small fraction of the actual information needed for the CAD program.

This comparison can be observed by comparing the highlighted information input by the user who operate the ES, to the list of information shown in Table 8.1 which have to be input by the person who operates the CAD program.

ALL DIMENSIONS IN MM

L 1= 12.300
R 2= 2.000 (70.00 DEG.)
L 3= 0.999
R 4= 2.000 (-120.09 DEG.)
L 5= 2.209
R 6= 3.000 (50.09 DEG.)
L 7= 1.500
R 8= 3.000 (90.00 DEG.)
L 9= 32.459
R10= 2.000 (70.00 DEG.)
L11= 6.909
L12=12.300
R13= 2.000 (-70.00 DEG.)
L14= 1.649
R15= 2.500 (-101.70 DEG.)
L16= 6.564
R17= 2.000 (-121.70 DEG.)
L18=26.559
R19= 2.000 (-70.00 DEG.)
L20= 5.653

SCALE 1.3 : 1.0



IXXmm^4	IYYmm^4	IXYmm^4	IUUmm^4	IVVmm^4	Jmm^4	RXmm	RYmm	SXmm^3	SYmm^3
59342.33	101981.88	11868.18	56261.26	105062.66	161324.22	18.309	24.002	1544.17	3257.20
CSAmm^2	T mm	XBARmm	YBARmm	SI Deg.	No.90Deg				SECTION
177.023	1.200	-1.310	2.472	14.2505	8.48				DZM6032H

Fig. 8.4 Drawing of the requested profile

This automated design process with the aid of the ES is very much simplified in the way that rough sketches are used to help in each stage of the decision making process. The final drawing can normally be displayed on the screen in less than a minute and a complex shape will take approximately 100 seconds depending on the number of users of the computer system.

The time taken to obtain a hard copy of the drawing will depend highly on the speed of the plotter which varies from 30 seconds to 2 minutes.

Such a speed of producing a drawing can never be achieved if the drawing is done manually. For a designer to operate a CAD software, it will vary between 10 minutes for a simple shape to 5 hours for a complex shape.

8.1.2 DESIGNING A BS2994 SECTION

The BS2994 lists a range of products with specified dimensional information and section properties values obtained from the studies carried out by British Standard Instititíon. These products are very common and their rough sketches can be seen in Fig. 8.5. The values are used as guidelines by manufacturers who intend to produce any of the profiles within the BS2994 range.

A data base is produced where the tabulated values given by BS2994 are kept. The ES will perform exactly what the technical man will do when given a shape similar to the BS2994. First, the system will check against the table provided by BS2994. If the required profile exists, the values from the

BS2994 are used for further analysis. If the profile does not exist within the BS2994, the system will proceed automatically to operate the CAD software by generating all the necessary information. Whether the product exists or not, the system provides the option to the user to plot the drawing.

$ PROFILE

Which type of products you would like to look into ?.

[either IHSECTIONS = Design products from In-house sections

or BS2994 = Design products amongst the BS 2994]

BS2994

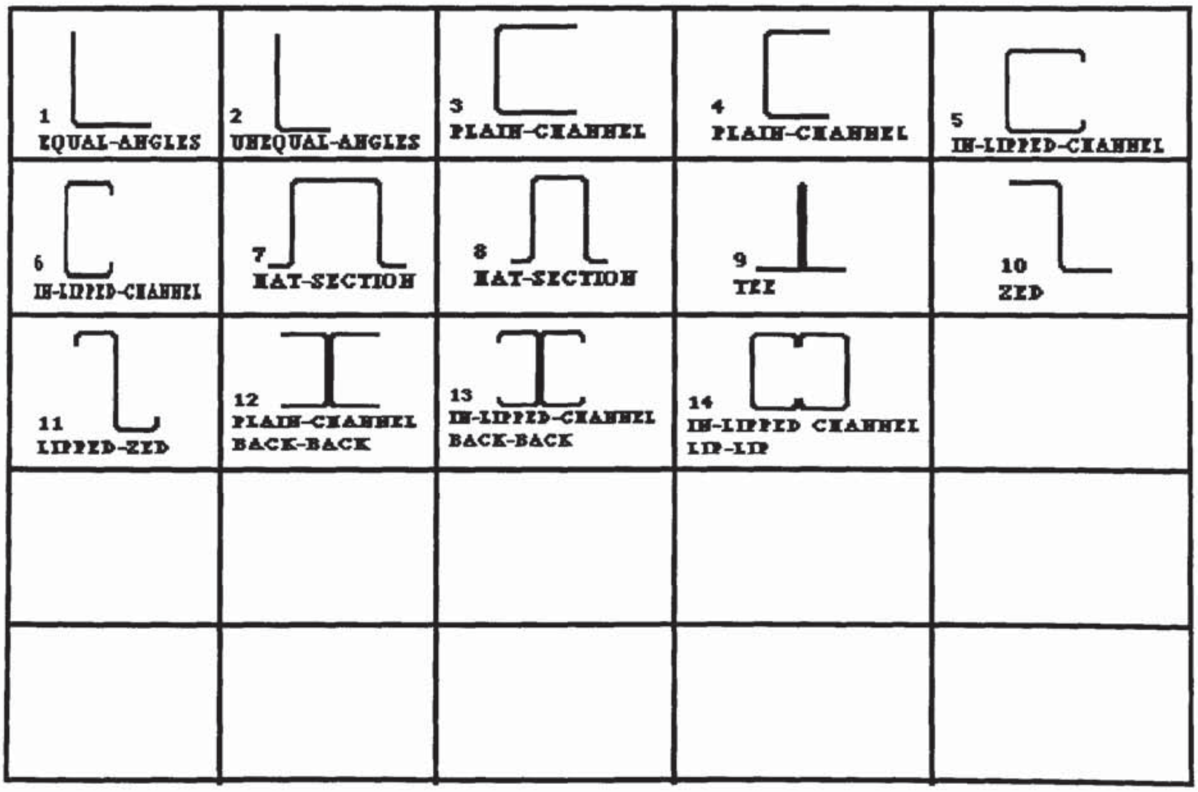


Fig. 8.5 Families of the BS2994

What sort of family do you think your product is likely to be under ?

TEE

Unlike the stages provided by the In-house products group where it is required to search through two generation before reaching its immediate family, this BS2994 provides only one generation to the immediate families. Within each immediate family, there is a range of 30 to over 100 similar profiles with only slight differences in its dimensions.

If the tooling design for the product is required to be produced from the cold roll design package, the required profile must be designed using the CAD software within the package. This gives the consistency of data transfer from one software to the other, otherwise the user will have to type in the data many times.

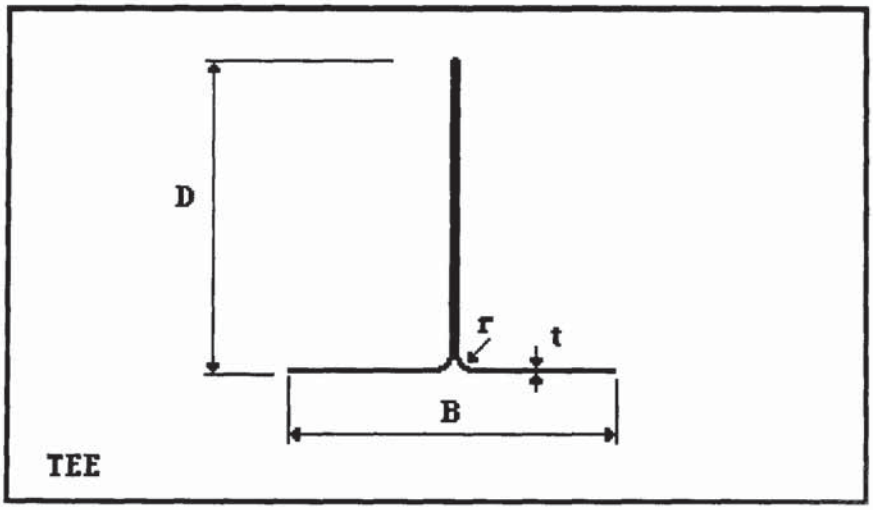


Fig. 8.6 Sketch of a Tee profile

Please enter the following information.

Height (of WEB) D mm = **80.0**

Width (of flange) B mm = **60.0**

Thickness of material t mm = **2.0**

Radius r mm = **2.5**

This product does not exist !!

Do you want to draw the drawing from the information

that you have given me ?

Y

Section number ?

T80602

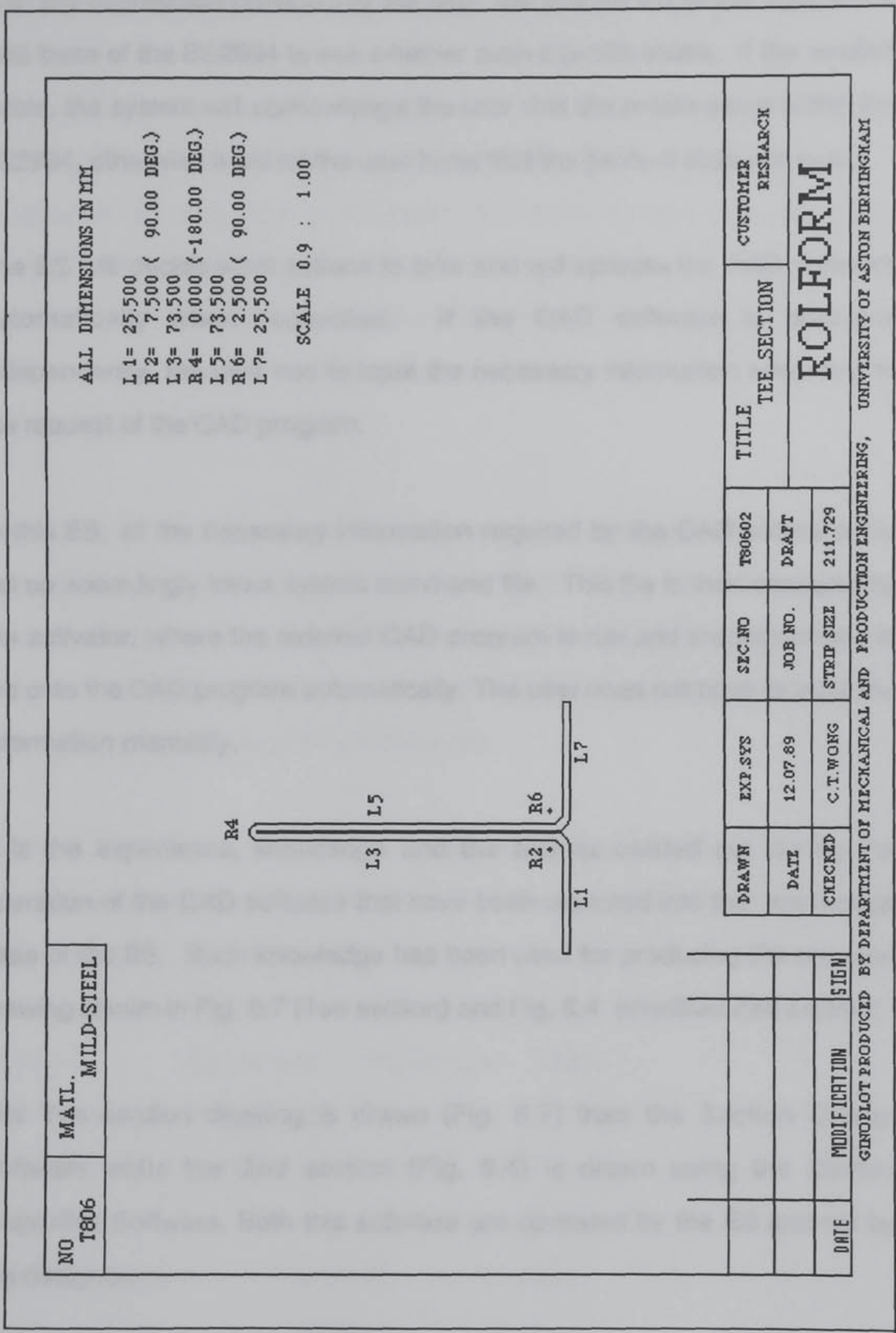


Fig. 8.7 Drawing of the required Tee section

With the information provided by the user, the system will check against the data base of the BS2994 to see whether such a profile exists. If the product exists, the system will acknowledge the user that the profile exists within the BS2994, otherwise it will let the user know that the product does not exist.

The ES will decide what actions to take and will operate the CAD software automatically when requested. If the CAD software is operated independently, the user has to input the necessary information according to the request of the CAD program.

In this ES, all the necessary information required by the CAD software are set up accordingly into a system command file. This file is then executed by the activator, where the external CAD program is run and the information is fed onto the CAD program automatically. The user does not have to input the information manually.

It is the experience, knowledge and the actions carried out during the operation of the CAD software that have been captured into the knowledge base of the ES. Such knowledge has been used for producing the required drawing shown in Fig. 8.7 (Tee section) and Fig. 8.4 (modified Zed section).

The Tee section drawing is drawn (Fig. 8.7) from the Section Design Software while the Zed section (Fig. 8.4) is drawn using the Section Properties Software. Both this software are operated by the ES and not by the designer.

8.2 THE USE OF SECTION PROPERTIES PROGRAM

A program has been written to calculate the section properties automatically with the ability to read in the design data produced from the Section Design program or the data input by the designer. It is an independent program on its own, and it can be operated by the user directly or by the ES automatically. This software has the ability to accept data generated by the CAD software, therefore, the previous section data files produced by the CAD program can still be used.

Fig. 8.8 is an example of how section dimensions and section properties of a profile are presented in the graphical form. Such a drawing can be produced in a few seconds. This program does not only provide a speedy result but it also provides a full drawing with the section properties values for the customer to take away for consideration.

Table 8.1 shows a listing of the profile dimensions in details. This information is stored in a file where it can be extracted by other programs when needed.

Input unit (1=imperial) (2=metric)	Output unit (1=imperial) (2=metric)	Thickness mm	Origin
2	2	1.3000	4

Element number	Element type	Length or radius	Bending angle
1	1	43.2500	0.0000
2	2	2.5000	80.0000
3	1	3.2000	0.0000

4	2	2.5000	-108.0000
5	1	17.0000	0.0000
6	2	3.0000	118.0000
7	1	9.4000	0.0000
8	2	4.0000	66.0000
9	1	0.0000	0.0000
10	2	3.0000	-132.0000
11	1	0.0000	0.0000
12	2	4.0000	66.0000
13	1	29.5000	0.0000
14	2	2.5000	70.0000
15	1	12.5000	0.0000
0	0	0.0000	0.0000
1	1	43.2500	0.0000
2	2	2.5000	-80.0000
3	1	4.0000	0.0000
4	2	2.5000	108.0000
5	1	18.3500	0.0000
6	2	2.0000	-118.0000
7	1	6.9500	0.0000
8	2	4.0000	-52.0000
9	1	2.9000	0.0000
10	2	4.0000	105.0000
11	1	2.9000	0.0000
12	2	4.0000	-52.0000
13	1	24.2500	0.0000
14	2	2.5000	-70.0000
15	1	11.2500	0.0000

0 0 0.0000 0.0000

4 (A4) 0.500 (scale of 0.5 :1.0)

1

1

1 (Below are the drawing information)

25 145/130 ULTRA-ZED SECTION

2

19 STRUCTURAL SECTIONS

3

7 D145130

4

6 145130

6

8 C.T.WONG

7

9 27.09.89

10

15 GALV. STEEL Z35

0

Table 8.1 Listing of the dimensions of section 145130

With the information provided in Table 8.1, the section properties can be calculated by the section properties software. The short report shown in table 8.2 is the section properties values of section 145130.

This report is very useful for further calculations especially when the profile is required to be checked for loading capacities. To carry out any loading check, it is necessary to have the values of section properties and the material properties available before any formula can be applied to loading calculation.

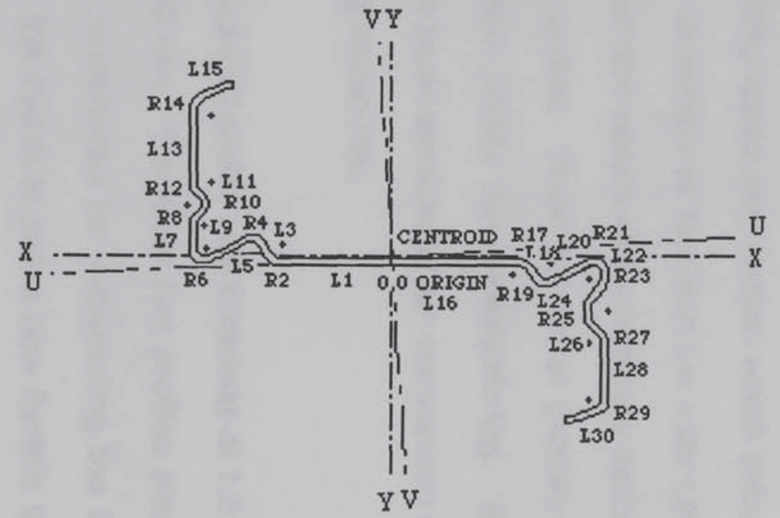
SECTION PROPERTIES FOR SECTION NUMBER 145130

SECOND MOMENT OF AREA mm^4

I_{xx}	mm^4	=	290604.969
I_{yy}	mm^4	=	1306189.500
I_{xy}	mm^4	=	52760.637
I_{uu}	mm^4	=	287871.406
I_{vv}	mm^4	=	1308923.125
J	mm^4	=	1596794.500

RADIUS OF GYRATION	R_x mm	=	27.021
	R_y mm	=	57.286
SECTION MODULUS	S_x mm^3	=	4646.794
	S_y mm^3	=	17647.031
POSITION OF CENTRIOD	$\overline{X}$ mm	=	-1.272
	$\overline{Y}$ mm	=	2.032
CROSS SECTION AREA	mm^2	=	398.018
THICKNESS	mm	=	1.300
SI ANGLE (degree)		=	2.9633
No.OF 90.0 degree (where r <= 5t)		=	13.620

Table 8.2 Section properties report for section 145130



IXXmm^4	IYYmm^4	IXYmm^4	IUUmm^4	IVVmm^4	Jmm^4	RXmm	RYmm	SXmm^3	SYmm^3
290604.97	1306189.50	52760.64	287871.41	1308923.12	1596794.50	27.021	57.286	4646.79	17647.03
CSAmm^2	T mm	XBARmm	YBARmm	SI Deg.	No.90Deg				SECTION
398.018	1.300	-1.272	2.032	2.9633	13.62				D145130

Fig. 8.8 Section properties produced for a given profile

The example shown in Fig. 8.8 is a drawing of an Ultra-Zed section number 145130 with full section properties information and profile dimensions detailed. This information, which is available in the drawing and report form, provides the key data for loading calculations.

8.3 PRODUCT COMPARISONS

A series of design trials have been carried out to find a profile that best replaces an existing lipped zed section which belongs to a competitor. This ES can produce drawings so fast that the user can easily produce a list of profiles for comparison before even making a decision to go ahead with the production of a section. From the list of profiles produced, the user can select the optimum profile for manufacturing. Below are three types of profiles that have been considered for comparison of the amount of material used and loading capacities.

Fig. 8.9 is a Lipped-Zed profile with thickness of 1.5 mm, flange of 32.00 mm and web of 60.00 mm. The other two profiles shown in Fig. 8.10 and Fig. 8.11 have been considered for substituting the Lipped-Zed section. The main purpose of the trial is to prove how flexible the programs can be and also to show its ability to obtain the optimum profile out of the listing produced by the ES.

It is very costly to produce a profile and test them physically. The company has to produce the sets of rolls before the product can be manufacured. The design of a complicated shape can take days. In order to save the company from incurring such costs, the trials of sections that are carried out by this system are very much based on computer simulation on the designed section. The time taken to produce a new product can take in a region of 3 weeks for a simple urgent job to 18 months for a complicated In-house non-urgent product.

Although a list of Ultra-Zeds and Modified Ultra-Zeds profiles have been looked into in this selection process, Table 8.3 represents a summary of the selected profiles which are worth considering for comparison.

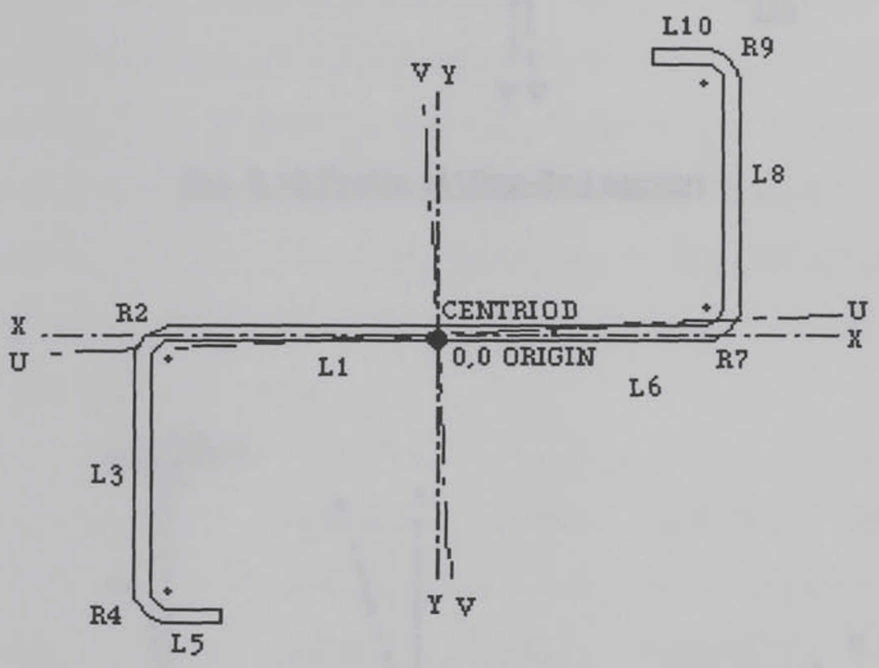


Fig. 8.9 Profile of a Lipped-Zed section Z6032B

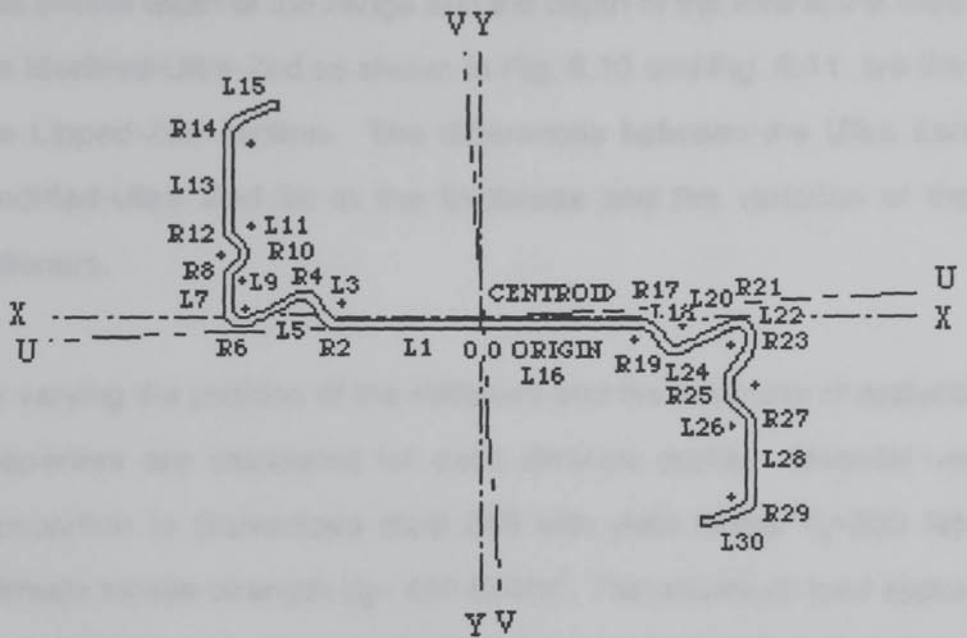


Fig. 8.10 Profile of Ultra-Zed section

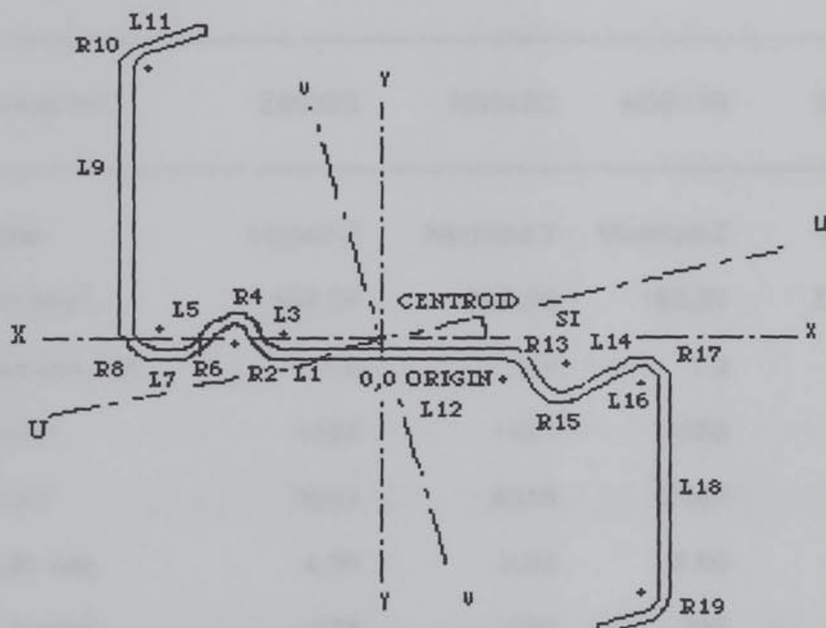


Fig. 8.11 Profile of Modified Ultra-Zed section

The overall width of the flange and the depth of the web of the Ultra-Zed and the Modified-Ultra-Zed as shown in Fig. 8.10 and Fig. 8.11 are the same as the Lipped-Zed section. The differences between the Ultra Zed and the Modified-Ultra Zed lie in the thickness and the variation of the applied stiffeners.

By varying the position of the stiffeners and the thickness of material, section properties are calculated for each different profile. Material used in the calculation is Galvanized steel Z35 with yield stress Y_s=350 MN/m^2 and Ultimate tensile strength U_s= 450 MN/m^2. The maximum load applied to both X and Y, is based on equation of the simply supported beam with a concentrated load at mid-span. The value of improved yield strength Y_{im}, which has been used in the calculation, is obtained by using the equation shown in Appendix A. The length of the section is taken as 3.0 metre for calculation purposes.

Section No.	Z6032B	M6012C	M6313B	6012C	6012F
Profile	Lipped-Z	Modified-Z	Modified-Z	Ultra-Z	Ultra-Z
CSA mm^2	193.29	192.18	192.31	185.56	184.72
Thickness mm	1.5	1.2	1.3	1.2	1.2
S_x mm^3	1462	1441	1683	1407	1491
S_y mm^3	3682	4015	3565	3538	3510
No.90 deg.	4.00	9.89	8.60	10.29	14.16
Y_{im} MN/m^2	373	387	387	389	405
When work hardening is not considered in the calculation					
B.M on X axis	512	505	589	493	522
B.M on Y axis	1289	1406	1248	1238	1228

Max. load on X	683	673	786	657	696
Max. load on Y	1718	1874	1664	1651	1638

When work hardening is considered in the calculation

B.M on X axis	546	558	653	549	605
B.M on Y axis	1375	1554	1383	1380	1423
Max. load on X	728	744	871	732	806
Max. load on Y	1833	2073	1843	1839	1897

(Note B.M =NM and Max load = N)

Table 8.3 Replacing a lipped-zed section

Section No.	Z6032B	M6012C	M6313B	6012C	6012F
C.S. Area	0.00%	-0.58%	-0.511%	-4.00%	-4.43%
B.M on X axis	0.00%	2.23%	19.61%	0.51%	10.73%
B.M on Y axis	0.00%	13.08%	0.58%	0.36%	3.50%
Load on X axis	0.00%	2.23%	19.61%	0.51%	10.73%
Load on Y axis	0.00%	13.08%	0.58%	0.36%	3.50%

The comparison are based on the work hardening values

Table 8.4 Comparison of values against section Z6032B

Values obtained from other sections are compared to those that are obtained form section Z6032B in Table 8.4 . From the table, section M6013C requires 0.58% less material than Z6032B but can carry 13.08% more in the maximum load on Y axis. It is important to note that when loads are applied on these three profiles, they normally act upon the Y axis of the section.

Section 6012F also gives promising result with the material decreased by 4.43% and the maximum load on the Y axis increased by 3.50%.

Now that the best of two profiles are known, it is then up to the manufacturer to select the section to produce. To produce section 6012F will require more passes due to additional stiffeners and this means more work and resources are required. Since this is a one off fixed cost for the tooling and the variable cost of the material will be reduced with increase in production, the manufacturer is more likely to produce the Ultra-Zed profiles.

The M6013C is a much simpler shape to produce and the material saving is not as good as the Ultra-Zed but it is still better than the lipped zed section.

8.4 TEST FOR BEAM SECTION

When the section design has been completed for the load carrying sections, simulation test can be carried out individually to predict the loading capacity of the section. This program can be operated without the needs of an ES, as long as the section properties and the material properties are available. Programs have been written to predict the loading capacity based on the classical applied mechanic in Appendix A. Below is a test that has been carried out for an Ultra-Zed section number 145130.

$ graph

Choose terminal Type

1. Input data only
2. Draw on screen (T4107)
3. T4105

4. T4014

5. End

2

Please input section number

145130

Please indicate the type of problem to be solved.

Enter 1. When a simply supported beam with a concentrated load on mid-span.

2. When a simply supported beam with a uniformly distributed load over the whole span.

3. When a built in beam with a concentrated load at mid span.

4. When a built in beam with a uniformly distributed load over the whole span.

5. When a continuous, three equally spaced simply supported beam with an uniformly distributed load over both span.

1

Item No. (Int)	Material name (max16)	Grade (max8)	Yield stress (MN/m^2)	Ultimate stress (MN/m^2)	Modulus of Elasticity (GN/m^2)	Density (Mg/m^3)
1	Galv. steel	Z1	210	270	205	7.85
2	Galv. steel	Z2	210	270	205	7.85
3	Galv. steel	Z22	220	290	205	7.85
4	Galv. steel	Z25	250	350	205	7.85
5	Galv. steel	Z28	280	390	205	7.85
6	Galv. steel	Z35	350	450	205	7.85

7	Cold-reduced	CR1	140	280	205	7.85
8	Cold-reduced	CR2	140	280	205	7.85
9	Cold-reduced	CR3	140	280	205	7.85
10	Cold-reduced	CR4	140	280	205	7.85

Please input the item number to be used

6

Item No. (Int)	Material name (max16)	Grade (max8)	Yield stress (MN/m^2)	Ultimate stress (MN/m^2)	Modulus of Elasticity (GN/m^2)	Density (Mg/m^3)
6	Galv. steel	Z35	350	450	205	7.85

Is this the correct material ? (Y/N)

Y

Please indicate which direction has the load been applied

(Refer to the section properties drawing)

By typing :-

1 = Load applied onto the X-axis

2 = Load applied onto the Y-axis

2

Span length (lower limit), span length (upper limit) m

span length limits = Range of values of span length to be included on graph.

(N.B must be whole numbers)

2.0,3.0

Xload, Deflection ratio

Xload = Either point load at mid span (N) or U.D.L load over whole
span (N/m)
Deflection ratio = Value of deflection/length of span (No units)

To produce a graph of load/length of span put loads=0.0
To produce a graph of Deflection/length of span put Deflection Ratio=0.0

0.0, 0.002

A report can be obtained from IG145130.dat file

While running the program, it produces a graph and a report where the user can check both the data and the calculations used in the process.

The following is a report which is available after the execution of the graph program. This is a list of data which represents the span that has been calculated and the given span is split into 500 segments for calculations. Only some of the data are represented in the following listing.

$ type IG145130.dat;

SECTION NUMBER = 145130

1

When a simply supported beam with a concentrated load at mid-span
deflection ratio = length of product / deflection

CALCULATION FOR GRAPH OF LOAD AGAINST SPAN LENGTH

Allowable Load (W) (limited by a fixed deflection ratio)

$W = (48EId)/(L^2)$

Maximum load (limited by yield stress)

$W_{max} = (4Y_sS_x)/L$

CALCULATION FOR GRAPH OF DEFLECTION AGAINST LENGTH

Deflection d (mm) obtained from a given load)

$d = (WL^3)/(48EI)$

YIELD STRESS Y_s = 350 MN/m^2

YOUNGS MODULUS E = 205 GN/m^2

SECOND MOMENT OF AREA I_{xx} (or I_{yy}) = 1306189.5 mm^4

SECTION MODULUS S_x (or S_y) = 17647.0 mm^3

WEIGHT PER METRE LENGTH OF RAW MATERIAL = 30.651 N/m

SPAN LENGTH L

LOWER LIMIT = 2 m

UPPER LIMIT = 3 m

XLOAD W = 0.000 N

DEFLECTION RATIO = 0.002

LENGTH OF SPAN (M)	LOAD FOR DEFLECTION (N or N/m)	LOAD FOR FAILURE (N or N/m)	LENGTH OF SPAN (m)	LOAD FOR DEFLECTION (N or N/m)	LOAD FOR FAILURE (N or N/m)
2.000	6426.453	12352.922	2.002	6413.619	12340.581
2.004	6400.822	12328.265	2.006	6388.064	12315.973
2.008	6375.346	12303.705	2.010	6362.664	12291.462
2.012	6350.020	12279.243	2.014	6337.414	12267.049
2.016	6324.846	12254.878	2.018	6312.314	12242.732

....

....

2.492	4139.303	9913.971	2.494	4132.667	9906.021
2.496	4126.046	9898.083	2.498	4119.441	9890.157
2.500	4112.853	9882.245	2.502	4106.280	9874.346
2.504	4099.723	9866.458	2.506	4093.181	9858.584
2.508	4086.655	9850.722	2.510	4080.145	9842.872
....					
....					
2.984	2886.824	8279.311	2.986	2882.958	8273.765
2.988	2879.100	8268.227	2.990	2875.249	8262.696
2.992	2871.406	8257.173	2.994	2867.571	8251.657
2.996	2863.744	8246.148	2.998	2859.924	8240.646
3.000	2856.112	8235.153	0.000	0.000	0.000

The above trial was carried out and the calculation was based on the classical mechanics theory. From the report, the designer can advise the customer the load which can be accepted by the product.

There are many thin wall profiles which are difficult to prove by calculations and in such cases, test are carried out to confirm the loading capacity and then a safety margin is used.

Since the calculated values are only predictions of the section loading capacity, a normal practice is to give an allowance towards the predicted values.

8.5 CREATING NEW RULES

In order to create a new rule or rules for a particular profile, the KE will be required to study each of the considerations, decisions and actions carried out by the designer. Here are two sets of results showing how decisions are analysed, and the way rules can be formulated.

There are calculations involved when transferring the rough sketch dimensions to the dimensions required by the CAD program. These are mainly represented by trigonometric equations in relationship to the few dimensions given by the customer. The designer will have to position the design so that the product can be produced by the form rolls and also can be cut off without much difficulty.

8.5.1 A CHANNEL SECTION

A customer will provide a rough sketch consisting of a few overall dimensions. For example, the drawing shown in Fig. 8.12 of a channel shape.

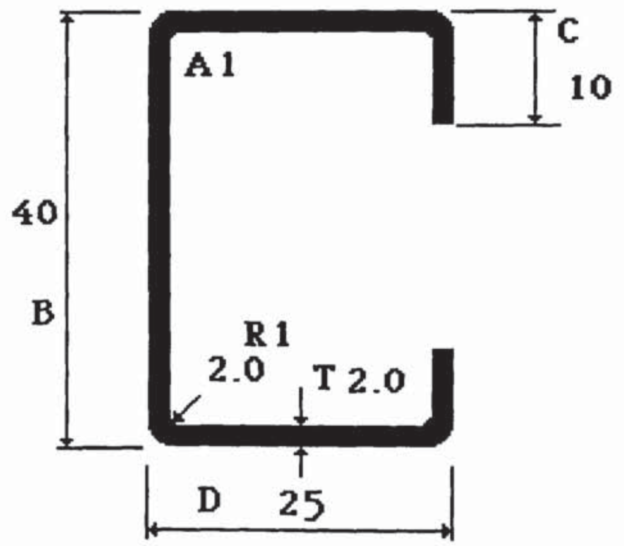


Fig. 8.12 Channel section

The overall dimensions given by the customer can be represented by B, C, D, radius (R_1) and angle (A_1). In order to design the section using either the section design program or the section properties program, the designer needs to rearrange the shape so that it can be rolled and cut off into the required length without much difficulty. Since the output data of the initial design program is related to the design of flower pattern and the design of rolls, therefore, the designer must consider the element(s) that is needed for the form-rolls to grip. Thus, the design is rearranged as shown in Fig. 8.13 .

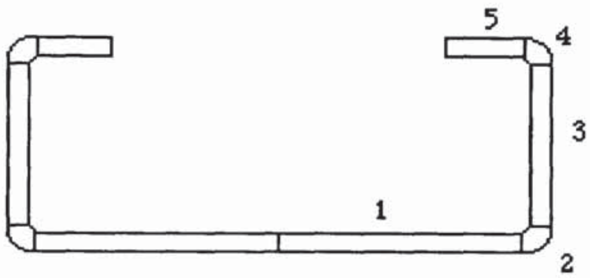


Fig. 8.13 Re-arranged section

This arrangement has allowed the form rolls to grip the bottom flat element of the section. It also permits the cutting off tool to punch down from the vertical direction. Now that the arrangement of the section is fixed, the next thing the designer has to do is to calculate each individual element and type them onto the CAD program manually. If the shape is symmetrical, the designer only has to consider half the information.

Some calculations are easy and others can be slightly more difficult. Whenever the designer finds it too difficult to calculate the dimensions, he will draw the section ten times its original size, measure the dimension, and later feed the values onto the executing program. From the observation of the drawing (shown in Fig. 8.13) the designer will input each element value as :

Element 1 = **(40.0/2) -2.0 - 2.0 = 16.0**

Element 2 = Radius =**2.0**, Angle = **90.0**

Element 3 = **25.0- (2.0x2.0) - (2.0x2.0) = 17.0**

Element 4 = Radius = **2.0**, Angle =**90.0**

Element 5 = **10.0 - 2.0 - 2.0 = 6.0**

Although the designer does not formulate the way the calculation has been carried out, but whenever a similar section is given to the him to produce a drawing, the same calculation approach is performed. Thus, the KE summarizes the pattern of which decisions are made for each element (such as Fig. 8.12), which can be represented as :

Element 1 = $(B/2.0) - T - R_1$

Element 2 = Radius = R_1, Angle = A_1

Element 3 = $D - (T \times 2.0) - (R_1 \times 2.0)$

Element 4 = Radius = R_1, Angle = A_1

Element 5 = $C - T - R_1$

Whenever a channel section is required, the same pattern of decision making process is carried out, and the only differences between them are the dimensions. This shows that such a design follows a routine decision pattern. The given set of rule for the channel can also produce a box shape as shown in Fig. 8.14, which consists of the same amount of elements and using the same calculation. The box shape is rolled from sheet metal and the best way to handle the production is to apply the same method used by the channel section.

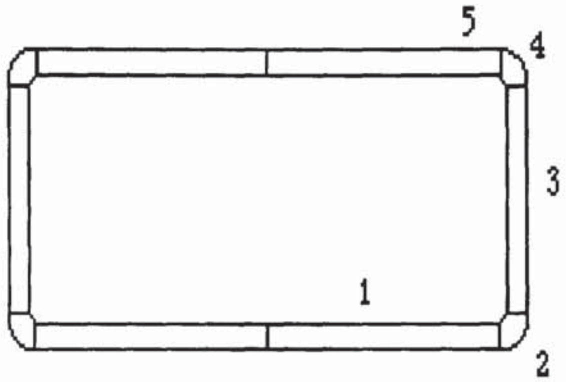


Fig. 8.14 Box shape

The production rule written using an OPS5 is as follow :

```
; Rule1
;  Dealing with lipped channel profile
;
(p Lipped_Channel::Obtain_information    ; rule name
( maingroup ^manigroupname IHsection )
(mainfamily ^mainfamilyname Channel )
(subfamily ^subfamilyname Lipped_channel)
-->
(write (crlf)  | Please provide the following information |)
(write (crlf)  | Dimension B mm ? |)
 (bind <B> (accept))
(write (crlf)  | Dimension C mm ? |)
 (bind <C> (accept))
(write (crlf)  | Dimension D mm ? |)
 (bind <C> (accept))
(write (crlf)  | Thickness T mm ? |)
 (bind <T> (accept))
(write (crlf)  | Angle A1 Degree ? |)
 (bind <A1> (accept))
```

```
(write (crlf)  | Radius R1 mm ? |)
 (bind <R1> (accept))
(make dimension ^B <B> ^C <C> ^D <D> ^R1 <R1> ^T <T> ^A1 <A1> ))
; Rule2
;  Dealing with lipped channel profile
;
(p Lipped_Channel::Perform_actions    ; rule name
( maingroup ^manigroupname IHsection )
(mainfamily ^mainfamilyname Channel )
(subfamily ^subfamilyname Lipped_channel)
(make dimension ^B <B> ^C <C> ^D <D> ^R1 <R1> ^T <T> ^A1 <A1> )
-->
(write (crlf) | Please give the section number |)
(bind <section_number> (accept) )
(openfile live live.com out)
(default live write)
(write (crlf)|$ opspropert |)
(write (crlf)|1|)
(write (crlf) <section_number> )
(write (crlf) |1,1,| (compute (<B> // 2.0) - <T> - <R1> ) |,0.0| )
(write (crlf) |2,2,| <R1> , <A1> )
(write (crlf) |3,1,| (compute <D> -(2.0*<T>) -(2.0*<R1>)) |,0.0|)
(write (crlf) |4,2,| <R1> , <A1> )
(write (crlf) |5,1,| (compute <C> - <T> - <R1> ) |,0.0| )
(write (crlf) |0,0,0.0,0.0|)
(write (crlf) |4,| (compute 80.0 // <B>) )
(write (crlf) |1|)
(write (crlf) |0|)
( Call Activate )
```

(halt))

These rules do not provide advices as it is difficult to advise the designer on how to operate the design program and at the same time run the ES on the same computer. Thus the advice is given in a file which has been set up based on the information that is required to be entered onto the CAD program. The output information is written onto a system command file which is in a form of :-

```
$ type Live.com;1
$ Run OPSpropert
1
TEST100
1,1,16.0,0.0
2,2,2.0,90.0
3,1,17.0,0.0
4,2,2.0,90.0
5,1,6.0,0.0
0,0,0.0,0.0
4,2.0
1
0
```

The above list of information is set up exactly the same as what the designer will use for input onto the design program if operated manually. If the list is getting longer and the calculation is getting more difficult, it will take a much longer time to perform the whole operation. The list of information is written onto a command file, which when activated, will perform automated operation of the design program.

8.5.2 A WBOX SECTION

Another test is represented by Fig. 8.15 where the amount of basic dimensions are different from the channel section. The amount of elements for a given profile can vary enormously. Thus, it is difficult to construct new rules internally because the number of decisions and actions carried out by the designer are not fixed. An alternative way is to use standard routines to carry out the calculations which can be executed by the ES later .

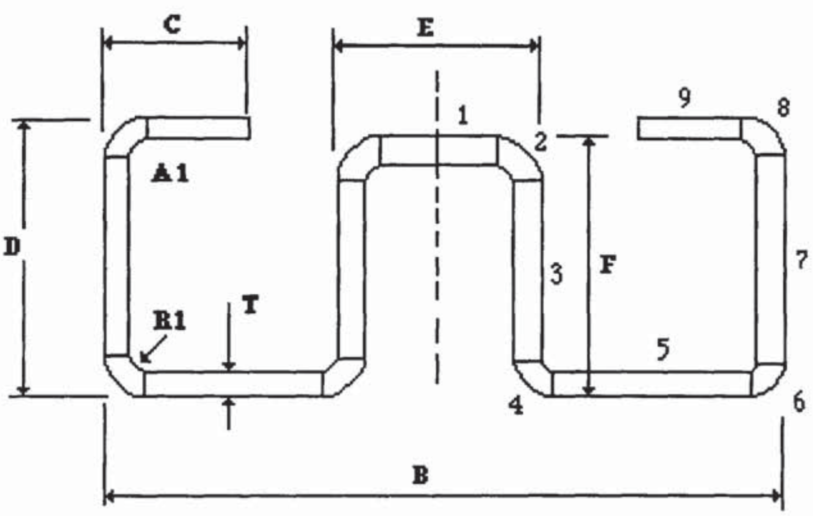


Fig. 8.15 Wbox family

Fig. 8.15 represents a symmetrical shape. This implies that only half the amount of elements are required for considerations. The dimensions for the elements for Fig. 8.15 are formulated as :-

Element 1 = $(E/2.0) - T - R_1$

Element 2 = Radius 2 = R_1, Angle 2 = $-A_1$

Element 3 = $F - (R_1 x2.0) - (Tx2.0)$

Element 4 = Radius 4 = R_1, Angle 4 = A_1

Element 5 = $(B/2.0) - (E/2.0) - (R_1x2.0) - T$

Element 6 = Radius 6 = R_1, Angle 6 = A_1

Element 7 = $D - (R_1x2.0) - (Tx2.0)$

Element 8 = Radius 8 = R_1, Angle 8 = A_1

Element 9 = $C - R_1 - T$

When the knowledge has been defined the designer will used the learning system to interrogate each element of the section and input the method of calculation into the system. Initially a production rule based on OPS5 will be created and a sample can be shown as :-

```
(P WBOX::Carry_out _WBOX_Design
{<task> (task ^name Wbox)}
(Subfamily ^Subfamilyname Wbox)
(operate ^programname Propert)
-->
(call opswbox)
(call activate)
(Modify <task> name start))
```

Once the method used for calculation can be captured using the learning system and a routine is constructed which can be represented as :-

```
c
c    Routine dealing  with Wbox shape
c
     subroutine WBOX
     Character secno*8
     call GET_SECNO(SECNO)
```

```
call Display(Secno)
call openlive
call Get_Thickness(T)
call Get_Dim_B(B)
call Get_Dim_C(C)
call Get_Dim_D(D)
call Get_Dim_E(E)
call Get_Dim_F(F)
call Get_Radius_R1(R1)
A1=90.0
call runpropert(secno)
call set_origin(2,2,T,5)
E1 = (E/2.0) - R1 - T
call set_element(1,1,E1,0.0)
Radius2= R1
Angle2 = -A1
call set_element(2,2,Radius2,Angle2)
E3 = F- (R1*2.0) - (T*2.0)
call set_element(3,1,E3,0.0)
Radius4=R1
Angle4=A1
call set_element(4,2,Radius4,Angle4)
E5 = (B/2.0) - (E/2.0) - (R1*2.0) - T
call set_element(5,1,E5,0.0)
Radius6=R1
Angle6=A1
call set_element(6,2,Radius6,Angle6)
E7 = D- (R1*2.0)- (T*2.0)
call set_element(7,1,E7,0.0)
```

```
Radius8=R1
Angle8=A1
call set_element(8,2,Radius8,Angle8)
E9 = C - R1 - T
call set_element(9,1,E9,0.0)
call set_element(0,0,0.0,0.0)
call set_scale(4,(80.0/B))
call update(secno)
call closelive
return
end
```

After the production rule and the routine has been constructed, it can executed the routine (provided it has been declared) to perform an automated design process.

The basic decision approach in designing a section is :-

IF

the required shape is similar to WBOX

and the program to operate is PROPERT

THEN

display the sketch

get the information

interprete those given information into linear and circular elements

write to the system command file according to the way the designer would operate the CAD program

activate the system command file

This production rule that has been constructed can be called up again when needed. Thus, the decision approach used by Fig. 8.15 can also be applied to Fig. 8.16 and 8.17 as their decisions and actions are the same. The manufacturer will see that the decisions carried out for the whole manufacturing process is very similar too. The only differences is in the variation of the input value. More of these type of rules and routines can be seen in Appendix C.

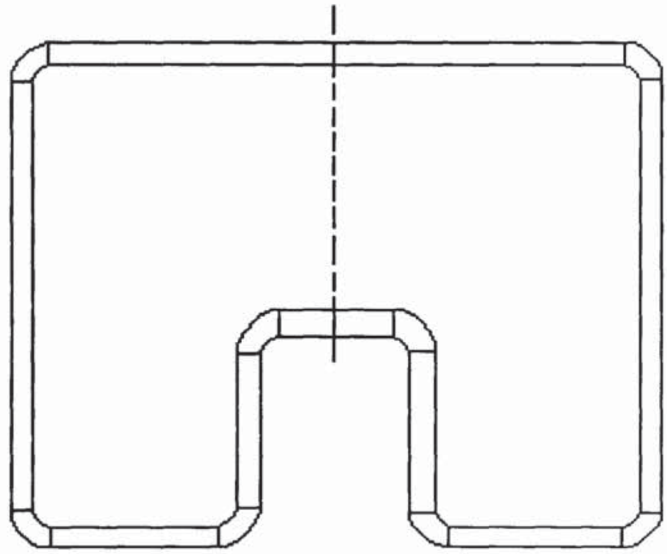


Fig. 8.16 Section number WB6060

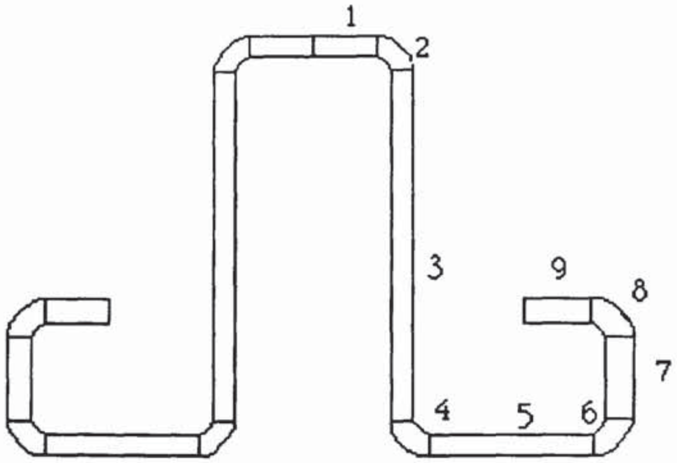


Fig. 8.17 Section number WB6020

CHAPTER 9

CONCLUSION AND FUTURE WORK

9.1 CONCLUSIONS

This research work has shown how Expert System can best be applied in the design of cold rolled sections. A contribution to knowledge has been made in the form of new methodology for automated design process and method of learning new knowledge from the expert. The main conclusions of the research are :-

1) An Expert System can be constructed as an independent advisory system to the design program, or as a system that (has the knowledge and,) can operate the conventional programs automatically.

2) A method was established by which the Expert System can set up an "Activator" that performs the design process automatically. The "Activator" initiates and runs an external program without having to enter the necessary information.

3) A Learning System has been constructed, which interrogate the experts by asking how each individual decision is made. The system then encodes this information into rules for the Expert System.

4) Computer software has also been developed for calculating `Sectional Properties', `Load carrying capacity of the section', `Profile Comparison' and `Material Data Base' to assist the general engineering problems faced by

the designer.

This concept of using an Activator and a Learning System in conjunction with the Expert System has led to successful results in reducing the design time by 95% compared to the current design times. If this concept is to be applied to a different design package, the setting up of the Expert System will have to be tailored to suit.

When trying to apply an Expert System technique to an engineering environment, it is essential to solve all the routine problems by using conventional programming techniques before even considering the use of an Expert System.

The software is constructed in the form of production rules and procedures which uses OPS5, Fortran77, Gino-F graphic tool library and DCL command language. This Expert System has been built on the VAX Cluster, which comprised of two 8650 systems, each consists of 24 Megabyte RAM, 6.5 Mips (Million Information per Second) and running at a baud rate of 9600. Graphics are displayed by using the Textronic 4107 terminal.

It takes 35 to 100 seconds to display a drawing on the screen which is dependent upon the number of users on the system and also the complexity of the profile. This approach can best be applied to designing repetitive or similar profiles, where optimum design can be achieved by modifying the profiles several times in a short time interval.

The limitation of the Expert System is restricted by the knowledge captured. It will be difficult to construct an Expert System that can gererate its own intelligence for designing new products.

9.2 FUTURE WORK

Further research work concerning the application of Expert System technique (in the cold roll manufacturing environment) can be carried out in the three main areas, namely :-

1) The application of Expert System to handle new and unknown profiles instead of similar or the same profiles where the rules exist.

2) The application of Expert System technique to other individual parts of the cold roll tooling design process, like the design of flower patterns, design of rolls and the machining process.

3) Introducing a Supervisory Expert System to those Expert Systems that are to be constructed for other individual parts of the cold roll tooling design process.

Findings from this research have shown how knowledge within the initial design stage can be captured. Design of the finished section is always the key reference to the rest of the tooling design functions. Thus, the potential research area for the future is to apply the Expert System approach with the activator to automate the cold roll tooling design process.

The technique developed from the research work can also be applied independently to the design of flower patterns. In the design of flower patterns, the number of stages required are very much dependent on the number of elements and their angles. Thus, if the product is under a certain family, the design of flower patterns will be similar within that given family. As a result, the same flower patterns approach can be used, since their bending sequences are the same. It is an area that can be looked into.

In the design of form rolls, the expertise involved can be difficult to capture, since it is the largest part of the tooling design process. This research has made the first move by capturing the knowledge of designing a section, and if the same approach is applied step by step, the expertise in the design of form rolls can also be captured.

The types and numbers of cutting tools used in the machining process are very consistent. Therefore, the application of an Expert System is highly probable. This is another area where further research can be carried out.

This research has given a background as to how an Expert System and the activator approach can be used. By applying the same technique to the design of the flower patterns, the design of form rolls and the machining process, the full knowledge of the tooling design can be captured. When these individual expert systems are built for different stages of the tooling design process, another supervisory Expert System can be constructed to supervise the existing Expert Systems. The supervisory Expert System can then carry out the automation for the whole tooling design process .

To capture the knowledge of the tooling design process requires careful studies on one specific domain at a time. The work may take at least 4 to 6 man years and it requires the full cooperation of the expert before the first stage of the automated tooling design can be achieved. This is also highly dependent on the support given to the Knowledge Engineer.

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APPENDIX A

CALCULATION FOR LOADING ANALYSIS

A computer program has been written for analysing the loading capacity of simple beams and columns. The formulae used in the calculation within the computer program are described below. Since the detailed explainations of each of the formula can be obtained from general applied mechanic textbook, therefore it has not been described here.

BEAMS

The calculations used for the beams are derived from Macaulay's method and the formulae are shown below. Calculation for simple beams can be obtained from Hearn (1977) Volume 1, Chapter 5, page 95. The five types of simple beam loading analysis are:-

A tabulated formula can be written as:

	Max. pt. or udl load	Deflection ∂
Simply supported beam with mid. span load W	$4\, Y_s S_x / L$	$W L^2 / 48\, E\, I$
Simply supported beam with udl load w	$8\, Y_s S_x \;/\; L^2$	$5WL^3 / 384E\, I$
Fixed beam with midspan load W	$8\, Y_s S_x \;/\; L$	$WL^2 / 192\, E\, I$
Fixed beam with udl w	$12\, Y_s S_x \;/\; L^2$	$WL^3 / 384\, E\, I$
3 equal span simply supported beam with udl w	$8\, Y_s S_x \;/\; L^2$	$4WL^2 / 751\, E\, I$

COLUMNS

This part of the loading analysis computes the crippling load of a column for a given cross section profile. The formula used in the calculation for these columns is based on Perry-Robertson formula. The summarized calculations for Columns can be obtained from Hearn (1977) Volume 2, Chapter 17, page 465.

$$X = 0.3 [L/(100k)]^2$$

$$Y_a=[Y_s+(X+1)Y_e]/2 - \{ [Y_a+(X+1)Y_e]/2 - Y_sY_e \}^{0.5}$$

Y_e = Euler stress

Y_S = Yield stress

E = Young modulus of elasticity

I = Moment of inertia

k =radius of gyration = $(I/A)^{0.5}$

A =Minimum cross section area

L_e=Effective length of the column

X =allowance factor for the imperfections in the column

After computing the crippling load from the Perry-Robertson formula, a theoretical analysis can be made to check whether the given eccentric loads together with any other direct concentric loads can be safely applied using the interaction formula :-

$$F_a/P_a + F_{bx}/P_b + F_{by}/P_b <= 1.0$$

F_a =Actual direct stress

F_{bx} =Actual bending stress on X axis

F_{by} =Actual bending stress on Y axis

P_a =Maximum allowable direct stress in the column when acting alone

P_b =Maximum allowable bending stress in the column when acting alone.

A tabulated formula for column can be describe as:

	Euler load P_e	Euler stress Y_e	Effective length Le
Column with both end pinned	$\pi^2 E A/ (L/k)^2$	$\pi^2 E / (L/k)^2$	Actual length
Column with both end fixed	$4\pi^2 E A/ (L/k)^2$	$4\pi^2 E / (L/k)^2$	0.5 x ActualLength
Column with one end fixed and pinned on the other	$2\pi^2 E A/ (L/k)^2$	$2\pi^2 E / (L/k)^2$	0.7 x Actual Length
Column with one end fixed and other fixed in rotation	$\pi^2 E A/ (L/k)^2$	$\pi^2 E / (L/k)^2$	1.5 x Actual Length
Column with one end fixed and the other free	$\pi^2 E A/ 4(L/k)^2$	$\pi^2 E / 4(L/k)^2$	2.0 x Actual Length

WORK HARDENING

Cold rolling process causes work hardening effect on a form section. In bending and compressing the corners of a form section, the yield strength can be increased by up to 25%. The increased yield strength can be estimated by using the formula (based on BS5950 part 5 pp.13)

$$Y_{im} = \{ (5Nt^2/Area) \ (U_s - Y_s) \} + Y_s$$

where

Y_{im} = improved Yield strength

(Y_{im} should be <=1.25 Y_s or <= U_s)

U_s = minimum ultimate tensile strength

Y_s = Yield strength

t = thickness of the material

N = number of 90 degree bends with internal radius of <= 5t

(fractions of 90 degree are also taken into account)

This improved yield strength calculation cannot be applied to a section that needs heat treatment after the rolling process.

APPENDIX B

CONFLICT RESOLUTION STRATEGIES

The details of Lexicographic-sort (LEX) strategy and the Mean-ends-analysis (MEA) strategy can be obtained from VAXOPS5 Reference Manual, page 4-6 to 4-7.

Meaning of some of the key words used :

Refraction prevents a program from looping infinitely on the same data by removing instantiations from the conflict set after they have been selected.

Recency determines the instantiation that refers to the most recent data in the working memory or the WME that has the highest time tag.

Specificity selects an instantiation of a production whose LHS is the most specific.

Instatiations are records which consists of production name and a list of time tags of WMEs that match the LHS of the productions.

1) LEXICOGRAPHIC-SORT STRATEGY

The LEX strategy (as shown in Fig. B.1) fires according to the following four rules:-

1 Apply refraction so that all rules that have already been fired from the set are discarded.

2 The most recently changed elements in working memory are fired first.

3 If more than one element has been changed recently, rank for firing according to a specificity rule and then fire the most specific first.

4 Otherwise, fire arbitrarily

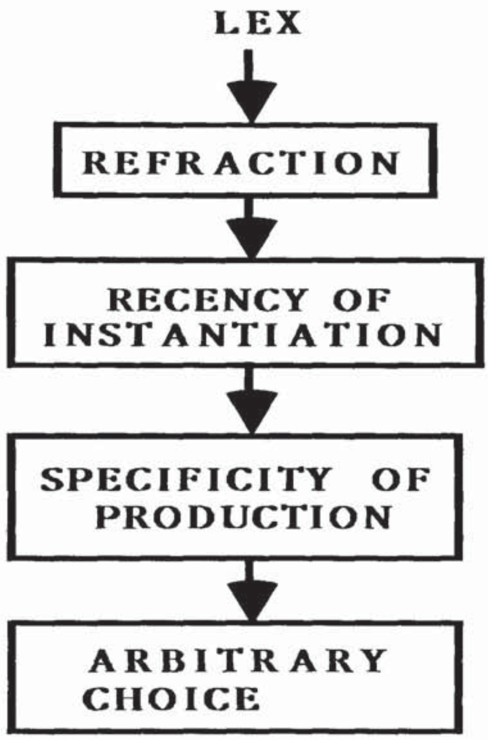

Fig. B.1 Lexicographic-Sort strategy

2) MEANS-ENDS-ANALYSIS STRATEGY

The rules for means-ends-analysis (as shown in Fig. B.2) firing are as follows :-

1 Discard all rules that have already been fired.
2 Compare the first time tag of each rule still remaining in the conflict set and select the rule with the highest level of recency.
3 If more than one rule has the same highest level of recency for the first time tag, then rank according to their recency and fire the most recent.
4 If more than one rule has the same level (highest) of recency, then rank according to their specificity and fire the most specific.
5 Otherwise, fire arbitrarily.

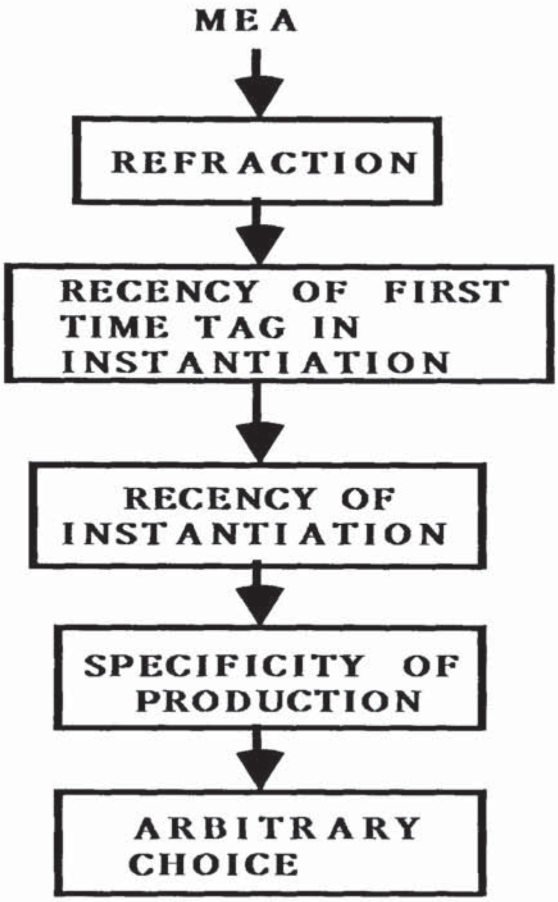

Fig. B.2 Means-Ends-Analysis

APPENDIX C

MORE CASES FOR CREATING NEW RULES

Here are two more examples to show how production rules and the routines are constructed. The user can either uses the learning system or the editor to construct these rules.

CORRUGATE_B SUBFAMILY

$ CRDEX

Which level of hierarchy you would like to look into ?
1 = Main group (level1)
2 = Main family (level2)
3 = Sub-family (level3)
4 = Exit
3

Please identify which sub-family that is most appropriate to the required profile ?
Corrugate_B

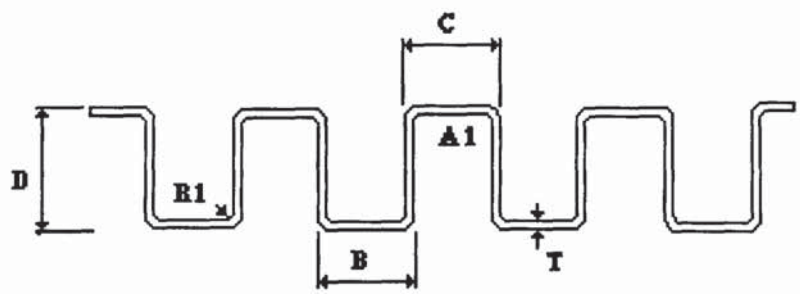

Fig. C1 Sketch of a Corrugate_B profile

Section number
C2001
Input Thickness of material T ?
0.5

Input dimension B ?

30.0

Input dimension C ?

15.0

Input dimension D ?

20.0

Input Radius R1 ?

0.5

Input Angle A1 ?

90.0

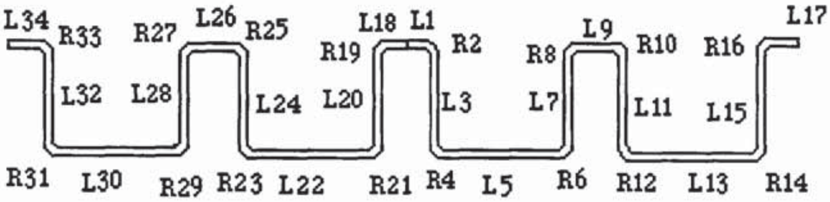

Fig. C2 Actual shape of the required Corrugate_B

```
;; Production rule for  CORRUGATE_B   sub-family
;;
 ( P CORRUGATE_B::operating_propert
 {<task> (task ^name CORRUGATE_B    ) }
 (subfamily  ^subfamilyname CORRUGATE_B     )
 -->
 ( call CORRUGATE_B    )
 ( call activate )
 ( modify <task> name start) )

 C  Routine dealing with  CORRUGATE_B sub-family

      SUBROUTINE CORRUGATE_B

     CHARACTER SECNO*8
     CALL GET_SECNO(SECNO)
```

```
CALL GET_THICKNESS(T)
CALL GET_DIM_B(B)
CALL GET_DIM_C(C)
CALL GET_DIM_D(D)
CALL GET_RADIUS_R1(R1)
CALL GET_ANGLE_A1(A1)

CALL OPENLIVE

CALL RUNPROPERT(SECNO)

CALL SET_ORIGIN(2,2,T,5)
E1 = (C/2.0)-R1-T

CALL SET_ELEMENT(1,1,abs(E1),0.0)
RADIUS2 = R1
ANGLE2 = -A1
CALL SET_ELEMENT(2,2,RADIUS2,ANGLE2)
E3 = D-(2.0*R1)-(2.0*T)

CALL SET_ELEMENT(3,1,abs(E3),0.0)
RADIUS4 = R1
ANGLE4 = A1
CALL SET_ELEMENT(4,2,RADIUS4,ANGLE4)
E5 = B-(2.0*R1)-(2.0*T)

CALL SET_ELEMENT(5,1,abs(E5),0.0)
RADIUS6 = R1
ANGLE6 = A1
CALL SET_ELEMENT(6,2,RADIUS6,ANGLE6)
E7 = E3

CALL SET_ELEMENT(7,1,abs(E7),0.0)
RADIUS8 = R1
ANGLE8 = -A1
```

```
CALL SET_ELEMENT(8,2,RADIUS8,ANGLE8)
E9 = C-(2.0*R1)-(2.0*T)

CALL SET_ELEMENT(9,1,abs(E9),0.0)
RADIUS10 = R1
ANGLE10 = -A1
CALL SET_ELEMENT(10,2,RADIUS10,ANGLE10)
E11 = E3

CALL SET_ELEMENT(11,1,abs(E11),0.0)
RADIUS12 = R1
ANGLE12 = A1
CALL SET_ELEMENT(12,2,RADIUS12,ANGLE12)
E13 = E5

CALL SET_ELEMENT(13,1,abs(E13),0.0)
RADIUS14 = R1
ANGLE14 = A1
CALL SET_ELEMENT(14,2,RADIUS14,ANGLE14)
E15 = E3
CALL SET_ELEMENT(15,1,abs(E15),0.0)
RADIUS16 = R1
ANGLE16 = -A1
CALL SET_ELEMENT(16,2,RADIUS16,ANGLE16)
E17 = E1
CALL SET_ELEMENT(17,1,abs(E17),0.0)
CALL SET_ELEMENT(0,0,0.0,0.0)
call set_scale(4,80.0/(4.0*(B+C)))

CALL UPDATE(SECNO)
CALL CLOSELIVE
RETURN
END
```

==

TUBEA SUB-FAMILY

$ CRDEX

Which level of hierarchy you would like to look into ?

1 = Main group (level1)

2 = Main family (level2)

3 = Sub-family (level3)

4 = Exit

3

Please identify which sub-family that is most appropriate to the required profile ?

TubeA

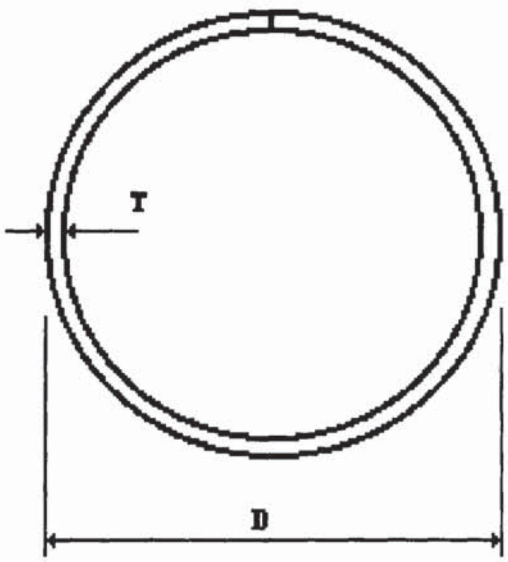

Fig. C3 sketch of a TubeA profile

Section number

T3001

Input Thickness of material T ?

1.5

Input dimension D ?

25.0

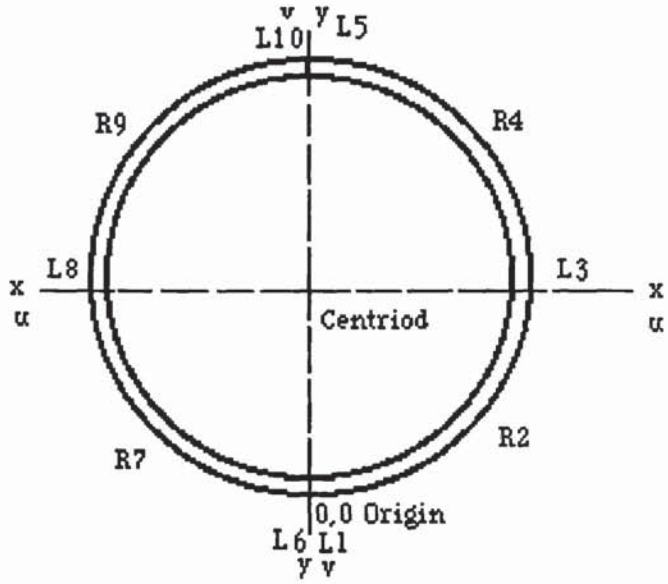

Fig.C4 Actual section of the required TubeA

```
;;    Production rule dealing with  TUBEA subfamily
;;
 ( P tubea::operating_propert
 {<task> (task ^name tubea          ) }
 (subfamily  ^subfamilyname tubea           )
 -->
 ( call tubea          )
 ( call activate )
 ( modify <task> name start) )
;;

C   Routine dealing with TUBEA   subfamily

     SUBROUTINE TUBEA

     CHARACTER SECNO*8
     CALL GET_SECNO(SECNO)
     CALL DISPLAY(SECNO)

     CALL OPENLIVE
```

```
CALL GET_THICKNESS(T)
CALL GET_DIM_D(D)
R1=(D/2.0)-T
A1=90.0
 CALL GET_RADIUS_R1(R1)
 CALL GET_ANGLE_A1(A1)

CALL RUNPROPERT(SECNO)
CALL SET_ORIGIN(2,2,T,5)
E1 = 0.0
CALL SET_ELEMENT(1,1,E1,0.0)
RADIUS2 = (D/2.0)-T
ANGLE2 = A1
CALL SET_ELEMENT(2,2,RADIUS2,ANGLE2)
E3 = 0.0
CALL SET_ELEMENT(3,1,E3,0.0)
RADIUS4 = (D/2.0)-T
ANGLE4 = A1
CALL SET_ELEMENT(4,2,RADIUS4,ANGLE4)
E5 = 0.0
CALL SET_ELEMENT(5,1,E5,0.0)
CALL SET_ELEMENT(0,0,0.0,0.0)
call set_scale(4,80.0/D)
CALL UPDATE(SECNO)
CALL CLOSELIVE
RETURN
END
```

COMPUTER AIDED DESIGN FOR OPTIMIZATION OF STRUCTURAL DESIGN OF COLD ROLLED SECTION

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Introduction

The increased use of cold rolled products during the last decade has led to pricing competitions between manufacturers. Although research work has been carried out since the second world war to minimize the amount of material used for a given product, the technology and the knowledge behind these thin wall cold rolled sections are still very young. Manufacturers have always wanted to be able to produce their sections

-: as cheaply as possible
-: within the given tolerance
-: which can withstand the given loading conditions
-: as fast as possible
-: to earn enough to keep the company going

These expectations have been on for many years but in reality they have not been very successful. It is difficult to produce a high quality product at a very cheap price. This research work is aimed to improve productivity of the draughtsman, the efficiency of designing and decision making process. There are two types of optimizations, namely to minimize the cost of production and to maximize the loading capacity with the minimum cross sectional area of the section.

Constraints affecting the optimization of cold rolled sections

The costs of production and the amount of material used for a particular product are still the main constraints affecting the final price of the product. Amongst the main pricing constraints the outstanding ones are the varying cost for

-: design and manufacture of rolls
-: time spend on calculations
-: the amount of materials needed

Designing and manufacturing of rolls for a particular section is an expensive process. This involves designing the final product, the flower pattern, the templates, the rolls and manufacture of the rolls. The time required for calculations in each particular stage of the designing process is enormous. Minimizing the material used is an important factor that must be remembered while making the initial decision in accepting a particular product shape. To minimize the material used means having to reduce the cross sectional area of a section, and this creates problems in loading capacity. Calculating the section properties of a section is very time consuming and can be error prone especially for a complex shape. Since this is a thin wall cold rolled section, the effective length of each cross section element must be taken into consideration when calculating the loading capacity.

Methods for overcoming these constraints

The decision making process can be handled in four ways whereby the salesman can persuade the customer to...

-: accept an existing product where the rolls are ready made.

-: accept a product where it can be produced by existing rolls whereby slight modification of these rolls might be needed.

-: accept one of the products shown in the British Standard.

-: design a new product.

The best way to minimize the production cost is to accept one of the first two options. Since the total costs for designing and manufacture of the rolls have been apportioned to other orders, then even if costs are to be allocated to this particular order they will be kept to the minimum. If a set of rolls are in stock, no time is required for the designing process and there will be no material required for manufacturing the rolls.

There are two solutions to the four available options which are :-

Firstly, by writing computer programs using Fortran 77 to overcome a large part of the design process which is mainly involved with pure calculations. A new set of computer programs has been produced for designing the finished section, with the ability to check the effective length of the elements and to calculate the section properties. Other features include calculating the bending moments, deflection, stress and loading capacity. Results produced from these programs can be obtained in a matter of seconds which can never be achieved if done manually. Most of the structural calculations required for producing the minimum cross sectional area of the section are based on British Standard BS5950 part 5.

Secondly, by building an Expert system to handle the problems arising from the decision making process and the manipulation of product data. This area does not require many calculations, but is mainly to do with manipulation of symbolic representation and it can be achieved by using an Artificial Intelligent (AI) language. In this case Official Production System (OPS5) language is us d. An Expert system has been produced with a data base that consists of the available products data and a knowledge base with the production rules derived from encountered experience.

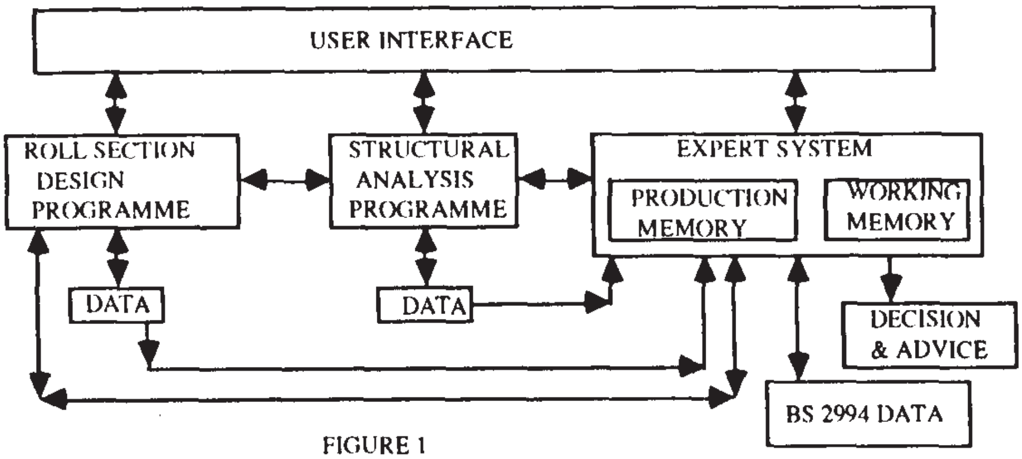

FIGURE 1

EXPERT SYSTEM FOR DESIGN OF COLD ROLL SECTION

CAD and Structural Analysis

A draughting package has been produced for designing cold rolled sections. The types of elements contained in the designing of cold rolled sections are linear and circular elements. With this CAD package, the draughtsman can redraw the drawing in a few seconds and if slight alterations are required by the custome, they can easily be done.

Data typed in by the draughtsman are stored in the computer disc and these data can also be used by other programs to calculate the section properties, the loading capacity, the design of flower patterns and the design of rolls. Since these data are accessible by other programs, the manual transfer of the geometrical dimensions from the finished section design to other designing process is virtually eliminated.

2D draughting

The 2D draughting consists of only linear and circular elements. The start position of a linear element is at [0,0], while the end position at [a,b] which rotates at an angle of ø with the length L_1.

$a = L_1 * \cos \phi$ $\qquad$ $b = L_1 * \sin \phi$

Circular element starts from position [a,b] and ends at position[c,d] with the radius R and the arc angle of ß radian.

when ß is positive $\qquad c = R*(\sin(\phi+\beta) - \sin \phi)$

(clockwise movement) $\qquad d = R*(\cos \phi - \cos(\phi+\beta))$

when ß is negative $\qquad c = R*(\sin \phi - \sin(\phi+\beta))$

(anti-clockwise movement) $d = R*(\cos(\phi+\beta) - \cos \phi)$

Section properties

The properties for each thin wall sections are calculated by the "Linear" method, also known as the "Centre-line" method. Values for moments of inertia of a Linear or circular elements are calculated about the principle axes of the element through its centroid, which are then converted to the corresponding values about the horizontal and vertical axes through its centroid. These values are transferred to the origin for summation by using the parallel theorem.

The thickness of the material is introduced after the computation of each linear or circular element is completed. This technique is only justified for thin sections and the values obtained are slightly conservative.

Effective width of each elements are checked and these calculations are based on British Standard BS5950:part 5. Stiffeners are introduced to the weak elements whenever necessary.

Structure of the Expert System

Expert System is a new field to the cold roll manufacturers and very few will be interested to invest in this type of project unless it has been justified.

Two main steps are required to build an expert system. Firstly, a prototype is built to acquire a reasonable amount of knowledge and to understand the decision making pattern. Secondly, the proper Expert system will have to be constructed based on the knowledge obtained from first step, and then the decision pattern will have to be tested before it is used. As a result, knowledge acquisition of the type of problems arising and the type of decisions taken during the process must be noted. With these acquired knowledge a prototype has been built to show the expert the appropriate decision making and data retrieval approaches. This prototype also acts as a learning tool which enables more knowledge acquisition to be carried out.

Information acquired by the prototype should be able to finalize the element class names needed, the attributes of the specific class name and the general production rules for building the full system.

The final Expert system, as shown in figure 1, consists of 1) production rules 2) working memory elements (WME) 3) data . This system has a built-in recognized- act- cycle in the run-time system, which is the basic mechanism of controlling the production system. Its function is to match, select and execute. During a conflict resolution either Lexicographic-Sort (LEX) strategy or Means-Ends-Analysis (MEA) strategy is used. Both strategies first apply refraction, followed by recency and then specificity to the instantiations in the conflict set. Production rules in this program can be expanded quite easily in the production memory. In the working memory, the numbers of WME are kept as small as possible by splitting the problems into a sub-task in which only the required WME's exist. Data from the section design program, the structural program and BS2994 can be read into this system for analysis when necessary.

Conclusion

There are two objectives in the optimization of a cold rolled section. These are :-

a, optimizing the cross sectional area of the product and

b, optimizing the overall production cost for the whole process.

These two objectives must be looked at in parallel rather than just concentrating on optimizing the cross sectional area alone. The actual objective behind the whole thing is to minimize the product cost.

Three main programs have been produced from the research work. The first two main programs are for drafting the 2D drawings and optimizing the cross sectional area of the product. They also have the facilities to check the effective length of the elements, the deflection, bending moments, stress and the loading capacity of that particular section. These two programs are written in Fortran 77 on the VAX computer.

The third program is the Expert System which handles the non-analytical problems. This Expert System mainly deals with the decision making process and selecting a product from the existing listing with the rollers in stock or from the listing available from the British Standard BS2994 where the sectional properties are available for further uses. OPS5 is used for the design of this Expert System and DCL command language is used for managing these software.

The authors would like to acknowledge the very helpful contributions of Mr G.T. Deeley, Technical Director of Hadley Industries P.L.C, Smethwick, West Midland.

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An Expert System for the design of cold rolled sections.

Introduction

The principle of this work is to build an Expert system for the design of cold rolled sections which acts as a consultant to an ordinary draughtsman. The knowledge engineer would look into the finished section design and improve the productivity of the draughtsman and the whole efficiency of this process. It is important that one must not only come with a perspective view of the 2D drawings, but careful considerations of the fast, reliable and retrievable storage of all the geometrical data and the information concerning these products are essential.

This paper will discuss the conventional and modern methods of designing cold rolled sections, the basic theories used in the process and how this knowledge is absorbed and stored for further use with the help of an Expert system. In the investigation the type of analytical problems which have arisen are solved by using high level language and those belonging to the non-analytical type are solved by using Artificial Intelligence language.

Conventional method of designing cold-rolled section

The design of the finished section is critical since this will ultimately govern the design of the whole rolling process. The finished section drawing not only acts as an ultimate goal for the design of the whole rolling process, but it also has to meet the customer's requirement. The conventional way of designing this section is by using traditional manual draughting techniques and any calculations will be done manually.

When the customer is not fully satisfied with the finished drawing, the whole drawing has to be redrawn and this is not uncommon. This can be very annoying for the draughtsman, especially if one has to do the whole range of calculations again. This is not only time consuming, it also creates unnecessary stress for the draughtsman and can make the job very expensive.

The finished section design is the main goal upon which the whole design of the rolling process is based. It is important to note that should even a slight alteration of the finished section design be needed, this would require a complete redesign of the whole rolling process. This could be a very lengthy and costly process.

It is difficult to translate the geometrical data obtained from a 2D drawing of a finished section for further use, such as machining the roll profile on a conventional lathe machine. It is equally time consuming to translate the data for CNC machining. Unfortunately, apart from the dimensions and the information that has been written onto the 2D drawing, there is no other information recorded for further use. Even to design the flower patterns one has to start from fresh.

The structural engineer has to calculate the section properties of the finished section manually. This is a painstaking task, and not only time consuming but also prone to errors especially for complicated shapes. This conventional method of design is very unproductive and a large part of an unnecessary waste of time and the frustration imposed on the draughtsman or the structural engineer can be eliminated.

Computer aided design (CAD) of cold rolled section

A computer program has been designed especially to cater for the design of cold rolled sections. The types of elements contained in the cold rolled sections are 1, Linear elements and 2, Circular elements. The type of data to be input into the computer are shown in Table 1 and this set of data is enough to produce the full drawing of figure 1.

All calculations concerning the linear and circular elements are carried out by the computer, and no calculation is required by the draughtsman. With this CAD program, the draughtsman can redraw the drawing in a few seconds. For the conventional method it would take at least 3 to 4 hours to redraw. With the CAD system the slight alterations required by the customer can be easily achieved.

The data in Table 1. are stored on the computer disc and are accessible by other programs such as programs for calculating the section properties, the design of flower patterns, the design of templates and the design of rolls. Since these data are accessible for further analysis, the manual transfer of the geometrical dimensions from the finished section design to other designing process are virtually eliminated.

Data from Table 1 can be extracted automatically by the structure program and the required section properties, and even the loading capacity of any particular section can be calculated. As a result, the structural engineer will no longer be required to do the calculations and the computer results can be obtained in a matter of seconds rather than days.

Cold rolled sections are classified under the two main categories a) non-structural products b) structural products. Those products belonging to the non structural products category are mainly for decorative purposes and normally no load is imposed onto these section while they are being used. Even if a load is imposed onto the section, it will be so small that it can be ignored. The structural products, which are normally for loading purposes, will have to pass through the structural program for calculating their section properties and their loading capacity.

The basic formulae used in designing the finished section

2D design

At the draughting stage only linear and circular elements are used.

The start position of a linear element is at [0,0], while the end position is at [a,b] which rotated at an angle of ø with the length L_1. As shown in figure 2a.

$$a = L_1 * \cos ø$$
$$b = L_1 * \sin ø$$

Circular element start from position [a,b] and ends at position[c,d] with the radius R and the arc angle of ß radian.

if ß is positive

(as shown in figure 2b)

$$c = R*(\sin(ø+ß) - \sin ø)$$
$$d = R*(\cos ø - \cos(ø+ß))$$

if ß is negative

(as shown in figure 2c)

$$c = R*(\sin ø - \sin(ø+ß))$$
$$d = R*(\cos(ø+ß) - \cos ø)$$

Calculation for section properties

The properties of this thin wall section are calculated by the "Linear" method, also known as the "Centre-line" method.

Linear elements are calculated about the principle axes (figure 3a) of the element through its centroid, which are then converted to the corresponding values about the horizontal and vertical axes through its centroid. These values are transfered to the origin for summation by using the parallel theorem.

Values calculated for moments of inertia of a circular element about the 'a-a' and 'b-b' axes (figure 3b) are converted to the horizontal and vertical axes, which are then transfered to the origin for summation.

The thickness of the material is introduced after the computation of each linear or circular element is completed. This technique is only justified for thin sections and the values obtained are slightly conservative.

Feasibility study in building the expert system

Careful studies have been carried out not only on the conventional and modern methods of design but also the problems of the design process. From these finding,s there are two main areas where problems are involved.

Firstly, the problems directly involved in the draughting of the 2D drawing of any specific shapes or in calculating the section properties. This area mainly deal with large number of complex calculations. Formulae for the required calculations can be obtained from BS5950, BS2994, BS449, text books and other well recognized theories. Precise numerical results can be obtained directly from these computer programs with the built in formulae, only on the assumption that the input numerical data is correct. Information pertaining to 2D drawing can be obtained from these programs based on the formula applied and their appropriate numerical comparison. It is clear that problems in this area are purely of an analytical nature, such problems can be overcome by the use of an "Expert design system". An Expert design system is a large programme that can handle analytical design problems of a specific domain and give precise advice based on the numerical calculated values. This advice is fixed and is compiled into the program. If alterations or more advice are required, it is necessary to rewrite and recompile the whole program.

Another type of problem may be encountered either before or after the draughting process. Before any draughting is carried out, either the customer or the draughtsman may query the application of the section, the shape, the size of the loading capacity, etc. Sometimes the required shape is not available, however if a similar type of shape could be used as a substitute, the design of the whole rolling process will not be necessary. This can mean a great saving to the company if the available sets of rollers can be used.

When the required drawings have been completed, advice and decisions of the post-draughting will have to be looked into before further actions are taken for designing the whole rolling process. Advice and decisions concerning the past history of the similar shape will be given, so that the designer is able to avoid or reduce unnecessary errors that have been previously encountered. In this second problem the type of decisions are non-analytical and therefore an Expert system is suitable to be used.

The types of computer languages used

All computer languages have their limitations. Most high level language is reasonably acceptable for complex calculation and manipulation of numerical data, especially for engineering and scientific purposes. Fortran 77 has proven to be an excellent language, thus is used in the 2D drafting and for the calculation of section properties. Based on the input and calculated data a large amount of fixed advice such as

```
        IF  (width_Lip.LT.(B/5))  then
            write(*,10)width_lip
          endif
10          format(' width lip =',F5.2,' which is less than the recommended
        &  value. which should be greater or equal than b/5')
```

can also be generated just with the Fortran programs alone.

When it comes to symbolic representation, most high level language are not as effective as most of the Artificial Intelligence(AI) languages. Official Production System (OPS5) language is currently available and as a result is used for the design of this Expert system which acts as a consultant to the designer. OPS5 is a very good and effective language for symbolic manipulation, but when it comes to numerical arrangement or calculation it is not suitable.

Although OPS5 can link directly to Fortran object files, it is not used in this system. The reason being that the finished section design program, the structural program, the flower pattern program, the roll design program, etc. are a complete individual module on their own. The good point about these programs is that data can be easily accessed by any of the available programs with no repetition over their data. In the same way this Expert system written in OPS5 can retrieve the same required data for their own use and not involved with any complex calculations which can best be done by the Fortran language.

The same approach is applied to the Fortran programs where the complex symbolic manipulation is left for the OPS5 to handle. By this, the best of both languages are extracted and fully made use of in this process. Since the system is designed on the VAX computer, the third language DCL command language, is used to manage the available programs.

Building an Expert system for the design of cold rolled section

It is apparent that Expert system is an alien field to many manufacturing companies and few will invest money or time into this type of project unless they have been shown that this type of system is really worth the investment. Experts are usually valuable members of the company, and the knowledge engineer must make full use of the time when carrying out knowledge acquisition with the expert.

There are two main steps required to build an expert system. First to build a prototype to acquire a reasonable amount of knowledge and understand the decision making pattern. Secondly, the proper Expert system will have to be constructed based on the recent knowledge obtained from first step, and then the decision pattern will have to be tested before it is used. As a result, careful knowledge acquisition of the type of problems arising and the type of decisions taken during both the pre-draughting and post-draughting process must be made and properly recorded. With this information a prototype has been built to show the expert that the type of decision making and data retrieval approach is applicable, while at the same time this prototype acts as a learning tool which enables more knowledge acquisition to be carried out.

Skeleton of the Expert system

The prototype should have acquired enough information to conclude the element class names to be used, the attributes of the specific class name and the general production rules required for building the full system. These are quite different when compared to the type of rules written in Fortran. An example of the production is shown here

```
(p availability::existed-product
{<task> (subtask ^stepto availability)}
{<pre-draft> (pre-drafting ^shape z ^application roof ^es-width
        <es-width> ^es-web <es-web>)}
{<secnum> (section-number ^shape z ^width <es-width> ^web <es-web>
        ^A-secno <secno>) }
-->
(write (crlf) | This section exist and the section number is |<secno>)
(write (crlf) | Do check this section to see if it is appropriate|)
(modify <task> subtask ^stepto recheck-secno))
```

The final expert system, as shown in figure 4, consists of 1) production rules 2) working memory elements (WME) 3) data . This system has a built-in recognized- act- cycle in the run-time system, which is the basic mechanism of controlling the production system. Its function is to match, select and execute. During a conflict resolution either Lexicographic-Sort (LEX) strategy or Means-Ends-Analysis (MEA) strategy is used. Both strategies first applied refraction, followed by recency and then specificity to the instantiations in the conflict set. Production rules in this program can be expended quite easily in the production memory. In the working memory, the number of WME are kept as small as possible by splitting the problems into a sub-task in which only required WME's exist. Data from the section design program and the structural program can be read into this system for analysis when necessary.

Conclusion

Three main programs are required to handle the two main types of problems which have arisen from the findings.

The analytical problems can be solved by the first two main programs written in Fortran 77 which are

1) for drafting the 2D drawings

2) for structural analysis of the given section only when required.

Non-analytical problems can be solved by a third program, the Expert system written in OPS5 language. These programs are then managed by DCL command language on the VAX computer.

The Expert system is not required for the draughting and the structural analysis problems. Advice or decisions can be built into the program, as these are based on numerical data. To make decisions or give advice based on precise calculated numerical values, this can be best achieved by using any high level language.

Decisions or advice made can be complex and these decisions are normally made based on symbolic representation, which are better solved by using AI languages.

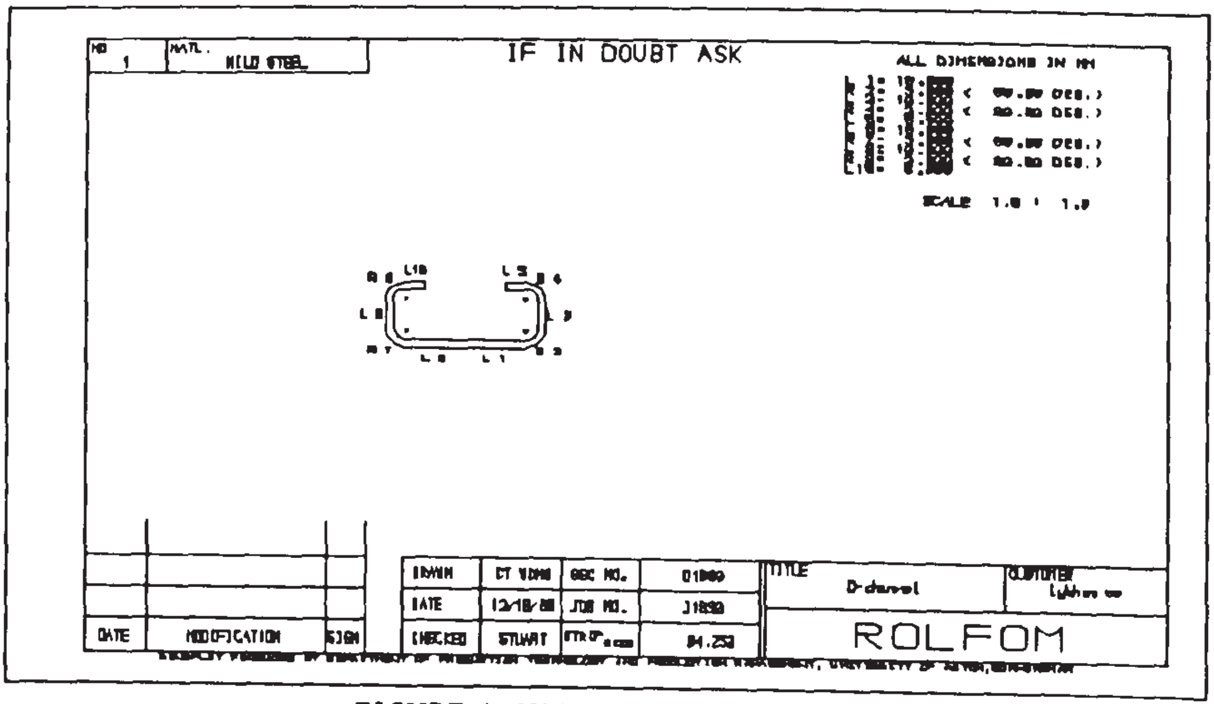

FIGURE 1. CHANNEL SECTION

INPUT UNIT	OUTPUT UNIT	THICKNESS	ORIGIN
2	2	2.0	5
ELEMENT NO	ELEMENT TYPE	LENGTH/ RADIUS	ANGLE
1	1	15.0	0.0
2	2	3.0	90.0
3	1	10.0	0.0
4	2	3.0	90.0
5	1	5.0	0.0

TABLE 1 SECTION DESIGN DATA

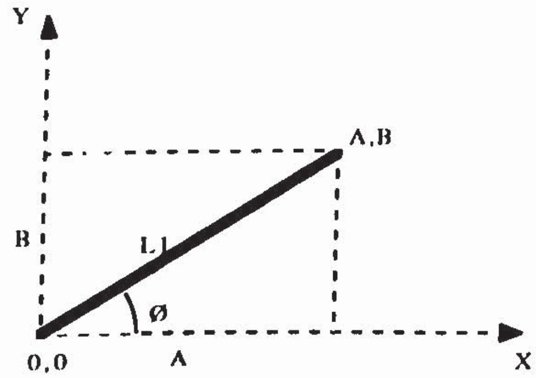

FIGURE 2A LINEAR ELEMENT

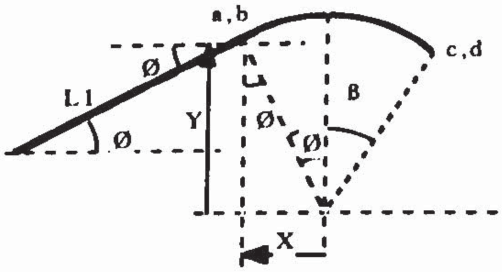

FIGURE 2B POSITIVE CIRCULAR ELEMENT

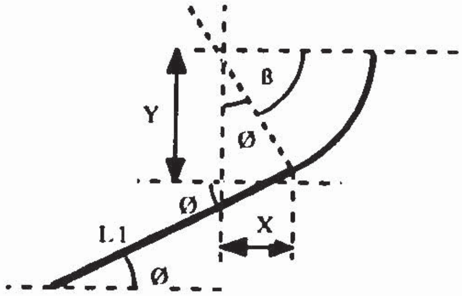

FIGURE 2C NEGATIVE CIRCULAR ELEMENT