THE APPLICATION OF COMPUTER-AIDED DESIGN TECHNIQUES TO SITE LAYOUT AND PLANNING

by

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ABSTRACT

A general purpose computer aided design system, based on a mini-computer, has been extended to allow its use in developing a site layout. Emphasis has been placed on an integrated system which will become readily familiar to a designer.

Two methods of utilising the mini-computer are presented. The first involves the off-line preparation of data to a stress analysis program. The stress analysis being carried out on a large mainframe computer.

The second method of utilising the mini-computer is as a self-contained computing unit for the development of a site layout. The development of a site layout is carried out from the initial site survey up to the detailed analysis of the finished site layout.

Various methods are presented, e.g., contouring, construction of sections, perspective views, etc., whereby the site may be appreciated and understood. All existing features of the site, such as trees and site boundaries, may be entered into the computer model of the site.

Design features of a three dimensional nature may also be entered on the site layout. The most important features of this class being roads and buildings. Consideration is given to the method by which interaction with a three dimensional model is achieved, using a two dimensional graphics system and its associated devices.

Finally several analyses, e.g., sunlight received, earth movement, visual effect, etc., may be carried out on the computer model in order that the viability of the finished layout may be judged by the designer.

ACKNOWLEDGEMENT

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CHAPTER ONE

INTRODUCTION

The last decade has seen the rapid development of computer aided design systems, indeed the only surprising fact is the length of time it has taken. At first the introduction of computers brought great relief to hard-pressed designers striving to keep pace with an ever-increasing volume of work. However all was still less than perfect, the designer had to fill out complicated and numerous input forms and was presented in return with a mass of figures, which could not easily be assimilated and understood. Furthermore the designers never really worked with or understood the computer, instead all they saw was a mass of paperwork. The obvious answer was to work in terms which the designers are familiar with, and understand, namely to represent the information pictorially. This has lead to the introduction of computer graphics and computer aided design systems, where information can be presented as a picture on a flat screen. In addition the designers may interact with this picture to indicate their wishes to the computer. Instead, for example, of presenting a large table of figures, a graph may be drawn on the screen, allowing a designer to pick out erroneous values far more quickly than by scanning a typed list.

There has also been a rapid development of mini-computers, small computers (no larger than a couple of filing cabinets) capable of being situated where they are needed and low in cost. So fast has been the development of mini-computers, that the name no longer implies small in capabilities, and probably the best definition of a mini-computer is a computer which may be operated from a standard 13 amp electrical socket. Thus a mini-computer may be placed at the side of the designer and be dedicated to the designer's work. In such a situation a designer can work directly with the computer, without any intervening paper work. By giving the designer direct access to the computer it should be possible to obtain quicker and more accurate solutions to the problems he faces.

One area where designers have faced considerable difficulties in the past, is that of site layout and planning. Many aspects of the work have not been considered for solution by computer, and those aspects which have, present many diverse input conventions to the designer. The bulk of the present work concerns a unified approach to site layout work, and a system has been developed which the designer can readily understand and which provides a solution to the design problem at a reasonable cost. The following chapters present a detailed look at each application of the computer aided design system, and they are described briefly in the remainder of this section.

Chapters Two and Three introduce the basic computer system and explain improvements that have been made to it, to further simplify its use.

Chapter Four deals with the first major application of the computer aided design system, as a means of preparing data for a beam analysis program, and shows how using a large computer can be simplified for the designer.

Chapters Five-Eleven describe the second major application of the computer aided design system, for site layout and planning. The mini-computer is used as a self-contained computing unit, and designers are presented with a standard interface for solving all their problems. All parts of the site layout work may be used by the designer as needed, and the designer can easily swap between one part of the system and another part.

Chapter Five concerns a contouring package and explains how a regular model of the existing ground is built up from a set of random survey points. It then shows how the existing ground model may be presented to the designer, by a variety of methods, such as contouring, construction of sections, semi-oblique projection and perspective projection, in order for the designer to'understand' the site he is working with.

Chapter Six expands the consideration of the existing site to allow the incorporation of existing site features, e.g., trees, site boundaries, ditches, telegraph lines, etc., into the computer model. These features may be entered from either a survey plan or directly from the surveyor's notebook. The inclusion of these features allows a complete description of the existing site to be held by the computer, and this description may be analysed by the procedures of Chapter Seven.

Chapter Seven allows the quick and accurate measurement of areas or distances from graphic information held within the computer aided design system. For example, the total site area, the length of site boundaries, and other similar information, can easily be found and output in any units of measurement.

Chapter Eight explains how the design features (roads and buildings) may be entered on the site layout. In dealing with the design features it is necessary to handle three dimensional information, and a description is given of how the designer may interact with a three dimensional model of the features, using only the two dimensional graphic devices. This is the central problem in all site layout work, the actual site is three dimensional, but the tools of the designer are only two dimensional. Once a model of the design features has been entered by the designer the feasability of the layout may be determined using the analyses of Chapters Nine-Eleven.

Chapter Nine enables the designer to determine the visual effect of his site. The land, the roads, and the buildings may be displayed in a perspective projection. The projection being from any viewpoint (inside or outside the site) and in any direction. The speed with which a perspective can be generated by the computer, allows unsightly features to be quickly determined. So fast is the computer generation of perspectives compared with traditional methods that one can say the computer generation of perspectives provides designers with a new tool in their site layout work.

Chapter Ten explores an often forgotten aspect of site layout work, the amount of sunlight received by buildings within the layout. The traditional techniques of analysing received sunlight are slow and inflexible, and the computer solution shows how a quick and much more precise answer may be provided. Sunlight analysis is becoming an increasingly important factor in site layout work, and designers are just beginning to ask for better techniques to help them undertake a sunlight analysis.

Chapter Eleven presents the final analysis of the current work, the evaluation of earth volumes. Once a site layout has been specified and the finished ground level ascertained, the designer needs to know by how much the finished ground level differs from the original ground level. Ideally the amount of earh removed (cut) and the amount of earth inserted (fill) should be approximately the same over the total area of the site, otherwise a large amount of earth movement might have to be undertaken, and this could be a costly business.

Once an analysis has been carried out by the user, he is free, should it prove unsatisfactory, to return to earlier sections and change his site layout until the optimum solution is found.

The final chapter summarises the main benefits and conclusions of the present work.

CHAPTER TWO

THE COMPUTER AIDED DESIGN SYSTEM

HARDWARE

At the start of the present work there existed within the department a CADMAC 1) computer aided design system (Figure 1). The system forms a general purpose draughting facility and details of the system and the method of adding application programs to it are given in an earlier thesis by Hamlyn 2). A brief description of the system is given here for convenience and to aid understanding of the later chapters.

Figure 2 represents a block diagram of the system configuration, which comprises : -

a) PDP11/45 mini-computer supplied by Digital Equipment Corporation with 16K words of memory.

b) RK05 Disk Cartridge System employing a cartridge similar to the IBM 2315 but with twelve sectors, 2.4 million bytes may be stored on the cartridge, which has an average access time of 90 milliseconds.

c) LA30 DECwriter capable of printing from a set of sixty-four characters at a speed of 15 characters/second. Characters are generated as a 5 x 7 dot matrix, by seven solenoid driven spring-loaded pins arranged vertically in the printing head.

d) PR11 High Speed Paper Tape Reader, capable of reading eight hole perforated paper at 300 characters/second.

e) PC11 High Speed Paper Tape Punch, capable of producing eight hole perforated tape at 50 characters/second.

FIG 1 THE COMPUTER AIDED DESIGN SYSTEM

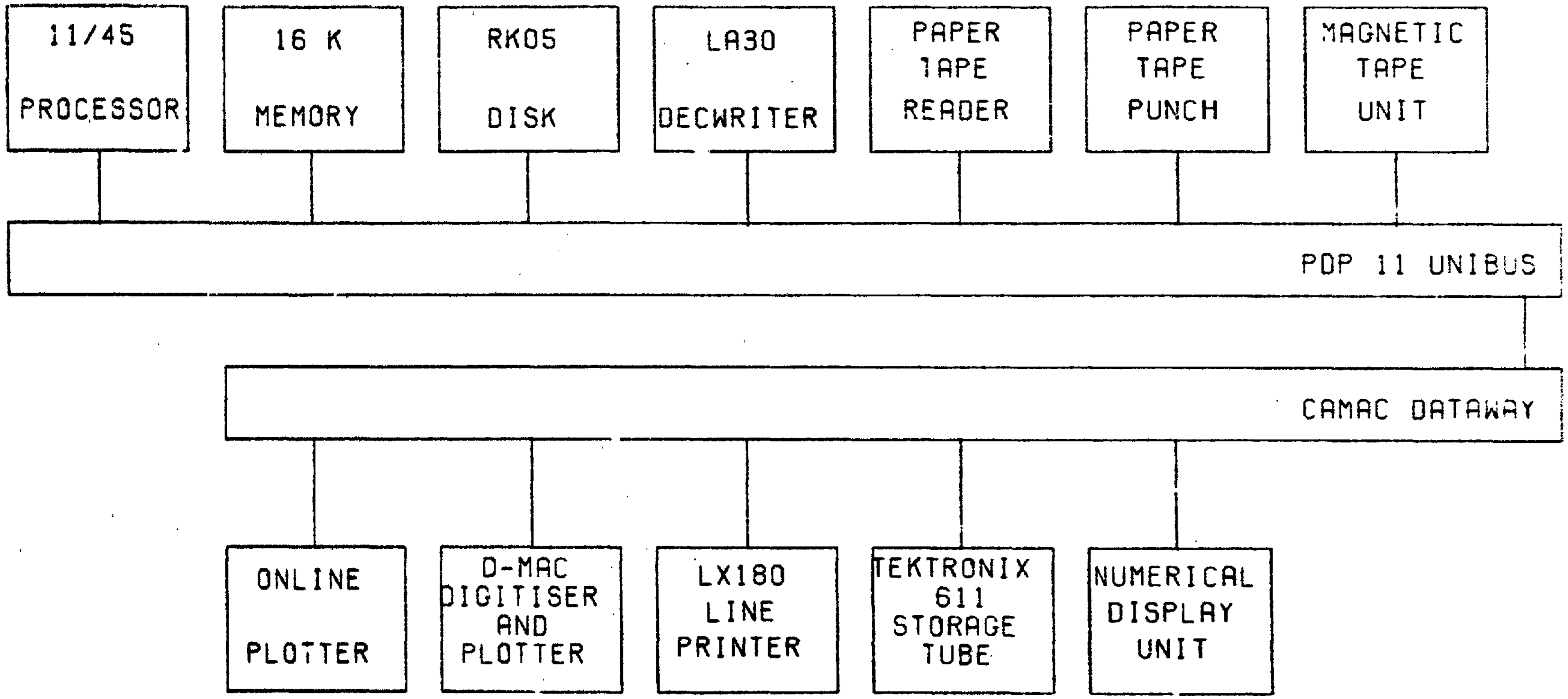


FIG 2 BLOCK DIAGRAM OF THE BASIC SYSTEM

f) M9000 Digital Magnetic Tape Recorder, supplied by Kennedy Corporation capable of reading and writing IBM compatible tapes at tape speeds of 10-45 inches/second. The rewind speed is 150 inches/second.

g) CAMAC Data Interface, a general purpose interface providing access to a variety of peripheral devices, a complete description of all aspects of the interface is given elsewhere 3).

h) LX180 Logabax Line Printer, printing from a sixty-four character set on a 5 x 7 dot matrix, at up to 180 characters/second.

i) TEKTRONIX 611 Storage Tube, with vector and character generators. The screen has a resolution of 1023 x 760 visible points, four intensity levels, may be operated in store mode or non store mode, and full screen erasure takes half a second.

j) D-MAC Digitiser/Plotter Table, a flat surface (1m x 1.2m) which can be set to a convenient height and angle by the user. A 'pen' creates an inductive field which is detected and followed by a servo-driven carriageway running on bearings on the reverse side of the table. The carriageway is moved in each axis by a stepped belt; separate drives rotate Moire fringe encoders which transmit distance pulses to the CAMAC interface. The carriageway can be driven independently of the pen, under program control, to allow plotting of a drawing. The pen provides eight function buttons which send interrupts to the CAMAC interface when pressed.

k) Numerical Display Unit, consisting of two sets of six Nixie tubes which may be used to display any numerical information to the user.

l) Online DC Plotter, this was constructed within the department to provide a low cost flat bed plotter; it is capable of plotting speeds of 10-20 inches/second, with an overall accuracy of 0. 002 inches.

SOFTWARE

As the amount of core space is limited, a fast overlay system is used. A program using overlays can be much larger than the core size, since portions of the program, called overlays, are kept on backup storage (i. e. disk or magtape) and are brought into core as required. The system splits the computer core into two sections, a resident section containing the main control programs and a data storage area,and an overlay section into which overlays are called as required. As a new overlay is called into core the old one is overwritten by it, the resident section however is not overwritten.

Each of the overlays is designed to perform a specific task, hence to add a new task to the system it only requires a further overlay or module. The modular nature of the system springs directly from its physical structure.

Within the general computer aided design system there exists modules to perform the following tasks : -

a) initialisation of the system.

b) production of messages informing the user of the operational mode.

c) monitoring of the users actions and commands.

d) error reporting.

e) display or on-line plotting of a drawing.

f) window handler, allows a portion of a drawing to be enlarged to fill the screen.

g) file handler, takes care of all filing operations.

h) editing of points, lines, picture components and symbols.

i) output or input of files to or from a peripheral device for archival purposes.

j) creation and manipulation of picture components. Any group of lines may be considered as a single entity or picture component and a single editing command then applies to all lines within the group.

k) creation of symbols, e.g. arcs, circles, fillets, text, etc.

l) free hand digitising, or cubic spline fitting, to produce curves.

m) garbage collection to remove deleted objects from the data structure.

In addition to the program modules of the computer aided design system, the user has access to a library of standard subroutines. These subroutines allow the user direct communication with all the graphical devices, provide a number of commonly used functions which are not supplied in the Fortran library and allow the user communication with sixteen direct access files, for the fast transference of data from the computer core to disk, or vice versa.

SYSTEM OPERATION

The system is designed to be simple in use, to give the maximum assistance to a user without being tiresome, and to provide a rapid response to all commands. While awaiting a command from the user, the computer is constantly providing two sets of information, which indicate the operational state of the system.

The first set of information describes the position of the pen, this is given in two ways, by a cross wire cursor on the display screen, and by the cartesian and polar coordinates relative to the last point entered. The coordinates are displayed both on the screen and by the numerical display unit.

The second set of information is a series of messages, displayed on the screen. These messages inform the user of the current operational mode, and in certain modes, they indicate what action the user should follow next, or provide a list of options from which the user can select the next command. For example, when the user elects to enter a circle, messages will display the fact that circle mode has been entered, and inform the user whether the centre point, or a point on the circumference of the circle, is expected by the computer.

Priority commands are available on eight push buttons, situated on the pen. These allow actions such as, input of coordinates, placing of picture components, windowing of the picture, redisplay of the picture, and other frequently used commands, to be initiated immediately.

Other functions may be specified by positioning the pen over a 'menu' situated at the left hand side of the digitising table. The menu consists of an array of 20mm squares, each marked with a function. The menu is divided into five sections, system commands (Figure 3), user commands (Figure 4), symbols and construction techniques (Figure 5), file designation area, and level designation

SYSTEM COMMANDS	WORKING PARAMETERS	SET INPUT LEVEL	SET SKEW	SET INPUT ORIGIN	SET GRID FACTOR	SET INPUT SCALE	SET OUTPUT SCALE	90° LOCK	15° LOCK	RESET WINDOW	SET ALPHAN SIZE
		PEN 1	PEN 2	PEN 3	PEN 4	LINE TYPE 1	LINE TYPE 2	LINE TYPE 3	LINE TYPE 4	TRAILING ORIGIN	ABSOLUTE ORIGIN
	FILING AND DISPLAY	FILING					DISPLAY				
		WORKSPACE TO FILE ↑	FILE TO WORKSPACE ↓	I/O TO ASSIGNED DEVICE	ZERO FILE	CLEAR WORKSPACE	ERASE SCREEN	DISPLAY WORKSPACE	DISPLAY FILE	DISPLAY NO LEVELS	DISPLAY ALL LEVELS
	PICTURE COMPONENTS (P.C.)	USE FILE AS P.C.	DISPLAY ACTIVE P.C. PROCESSES	SELECT P.C. START	SELECT P.C. END	SELECT P.C. SCALE	ROTATION				TYPE ROTATION
							0	90	180	270	
	EDITORS	LINE EDITOR	POINT EDITOR	MACRO EDITOR	WINDOW EDITOR						MIRROR
	MISCELLANEOUS	PLOT WORKSPACE	-	CONTINUOUS MODE	DEBUG	FIT TO PAPER	CURVE FIT WORKSPACE				

FIG 3 THE MENU OF SYSTEM COMMANDS

<table>
<tr><td rowspan="8">USER COMMANDS</td><td rowspan="2"></td><td colspan="5">BASIC LAND MODEL</td><td rowspan="2"></td><td colspan="4">EXISTING SITE FEATURES</td></tr>
<tr><td>DIGITISE SPOT HEIGHTS</td><td>INPUT SURVEY DATA</td><td>CONTOUR MAP</td><td>CROSS-SECTION LAND</td><td>SET VERTICAL SCALE</td><td>INPUT</td><td>SPECIFY</td><td>DELETE</td><td>INTEROGATE</td></tr>
<tr><td rowspan="2"></td><td colspan="4">ROADS</td><td rowspan="2"></td><td colspan="2">BUILDING</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>HORIZONTAL ALIGNMENT</td><td>VERTICAL ALIGNMENT</td><td>EDITOR</td><td>ARCHIVE</td><td>CREATE LIBRARY</td><td>INPUT AND EDITOR</td></tr>
<tr><td rowspan="3"></td><td colspan="5">PERSPECTIVE DISPLAY</td><td rowspan="3">SEMI OBLIQUE VIEWING</td><td rowspan="3"></td><td colspan="3">DATA.PREPARATION SUITE</td></tr>
<tr><td rowspan="2">GENERATE VIEW</td><td rowspan="2">DISPLAY VIEW</td><td colspan="2">VIEW POINTS</td><td rowspan="2">SET APERTURE</td><td rowspan="2">INITIALISE SYSTEM</td><td rowspan="2">INPUT BEAM DATA</td><td rowspan="2">INPUT COLUMN DATA</td></tr>
<tr><td>FROM</td><td>TO</td></tr>
<tr><td></td><td>EARTH VOLUME ANALYSIS</td><td>SUNLIGHT ANALYSIS</td><td>PLAN MEASUREMENT</td><td></td><td>RESTORE WORKSPACE</td><td>DELETE A LEVEL</td><td>PLOT ON CADMAC</td><td>PLOT ON MICROFILM</td><td></td><td></td></tr>
</table>

FIG 4 THE MENU OF USER COMMANDS

CONSTRUCTION TECHNIQUES	LINE INTERSECTION	PERPENDICULAR LINE	LINE STRETCH OR SHRINK	FILLET OF KNOWN RADIUS	FILLET OF UNKNOWN RADIUS					
SYMBOLS	LINE	ARC WITH KNOWN CENTRE	ARC DEFINED BY 3 PNTS	CIRCLE	-	DIAG-DIAG RECTGLE	CENTRE-DIAG RECTGLE	DIMENSN	-	TEXT

FIG 5 THE MENU OF SYMBOLS AND CONSTRUCTION AIDS

area. The menu is expandable and allocation of the squares is completely at the user's discretion.

Whenever the pen is placed in the menu area, the resulting coordinates are recognised by the system, which flags the identity of the square in which they fall and then initiates the appropriate command. Typically the command might be to file a picture, to display a picture, to alter the scale of a picture, etc. Programs written by the user may also be initiated from the menu. A complete list of commands which may be currently initiated from the menu is given by Figures 3,4 and 5.

At certain points within the system use is also made of a screen menu. In this case a description of each command and an associated number are displayed on the screen. By means of the eight function buttons on the pen, the user can then enter the number next to the command he desires. There are three major advantages in using screen menus, firstly the size of the table menu is kept reasonably small, secondly the user experiences a variety of input methods and is thus less likely to become bored, and finally screen means are easily alterable to display new options.

Finally, complex alphanumeric data can be entered into the system by means of the DECwriter, as can certain numerical parameters.

ADVANTAGES

The most important advantage of the computer aided design system is the ability to present information in the form of a picture, which the eye can quickly and easily scan for relevant information.

Each user action usually leads to a reply from the computer on the display screen. The user looking at the display screen for confirmation of his action, notices immediately if some information is incorrect, hence the interactive system provides a very rapid method of detecting errors, and allows their speedy correction.

By implementing the computer aided design system on a mini-computer we also incur further benefits. We can place the equipment in the design office, where its potential users can access it as and when they want. In such a situation the designers readily become accustomed to working with the computer. And as more application software is written the designer obtains a standard interface, applicable to a large number of different jobs. There is no need for the designer to consult a large number of users manuals in order to discover the quirks of each input system. As a result the designers work more efficiently and are able to apply their effort solely to the design problem.

In order that the full advantage is obtained from using a computer aided design system, the method of interaction with the user must be well thought out 4). It is vital that all parts of the system are within easy reach of a designer, from the position at which he sits, and that he should be able to input data in the order that he thinks of it and not be forced to follow a standard pattern. A good system will allow flexibility in use, giving more than one method to achieve a specific result, thus allowing the designer to pick the one he finds simplest and allowing variety in operation.

CHAPTER THREE

ENHANCEMENT OF THE COMPUTER AIDED DESIGN SYSTEM

THE NEED FOR IMPROVEMENT

The advantages mentioned in the previous chapter can only be fully achieved by careful programming of the computer. And while these advantages had generally been attained by the computer aided design system, there were felt to be several areas causing difficulty, which should be removed, before the application programs were written.

A major problem was the input of numerical data such as a new input scale, while the user indicated that he wished to do this by means of the menu (Figure 3), he had then to turn to the DECwriter to type in the required figure. As the DECwriter was at a lower level than the digitising table and placed at the side, this meant that the user had to perform a rather awkward movement. To overcome this problem a method of entering numerical data from the digitising table was evolved (the keyboard area).

Other changes were made to speed up the operation of the system, to give a quicker response to the user. The robustness of the system was also improved and all procedures requiring several sequential operations were given an escape road by means of which the procedure could be terminated at any time. Obviously a designer using the system might decide on a certain feature, but realise soon afterwards that it is not the best solution. Certain of the system facilities were expanded to give them more scope and to allow easier specification of complex commands. All of these changes sprang from the difficulties encountered when using the original system.

Further changes were made to the system which are not apparent to the user, but which allow the application programmer more flexibility. The aim being to allow the production of new programs with the minimum of time and effort being spent on programming, other than that directly relevant to the application. The major changes are presented in the following sections together with the resulting improvements.

THE KEYBOARD AREA

Just below the menu area of the digitising table a small patch was added (Figure 6), this patch is set out in the manner of a desk calculator. When a program requires numerical data a message is displayed on the screen informing the user what data is required and the keyboard area becomes active. When the keyboard area is active, if the user digitises a point over one of the 'keys' then that number is entered into the computer. The number is displayed on the screen and the computer waits for further input. The numbers entered may be positive or negative and can be of an integer, real or exponential form. If the user makes a mistake the number being entered can be cancelled and the user can try again. When the enter key is digitised, the keyboard area is deactivated and the numerical data passed to the program for processing.

The scheme is easy to us (most designers being already familiar with a desk calculator) and permits numerical data to be entered without changing the users focus of attention. In short an annoying operational defect has been removed and the better ergonomic design should lead to greater user acceptance.

CONSTRUCTION TECHNIQUES

As more complex drawings are built up, it becomes necessary to provide the designer with more aids in the construction of them. The computer aided design system allows these construction aids to be added to the system as required, their introduction does not involve any major programming effort and further aids, other than

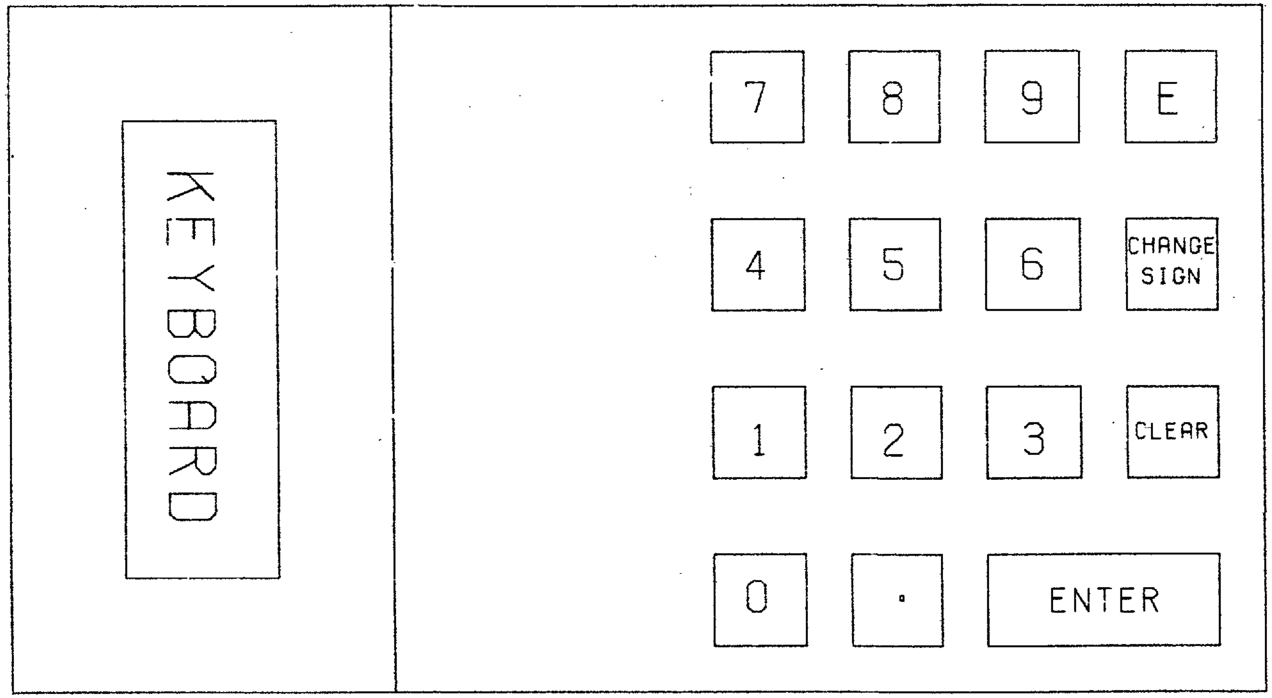


FIG 6 THE KEYBOARD AREA

those described here, could be employed as needed. For the present work three basic aids were introduced into the computer aided design system.

The first aid concerns the finding of line intersections. If we have a picture containing two lines which intersect, the computer only holds the end points of the lines, it does not hold the intersection point. But the user will often consider the intersection as a viable point and wish to draw a line to the intersection. To accomplish this a procedure has been written whereby, given a point near to the intersection, the computer will search through the data structure examining each line to find the two lines nearest to the given point. The computer then calculates the exact intersection point of the two lines and enters it into the data structure.

The second aid concerns the drawing of fillets. These are a common feature in many drawings and a procedure was written to place a fillet in a drawing, given two straight lines. The fillet can be of an unspecified radius (in which case it is constructed tangentially from the end point of the first line) or the radius may be specified by the user. When the fillet is entered the end points of the straight lines are adjusted to produce a perfect fit.

The third aid allows the construction of lines perpendicular to a line already existing in a drawing, or existing lines may be stretched or shrunk as desired. Hence once a line's direction is determined this may be left unaltered while the user concentrates on its other attributes.

These three construction aids allow the user greater flexibility in the input of a drawing and speed up the input of complex shapes. Unfortunately if used incorrectly they tend to make the designer ignore the necessity of planning his work beforehand, on the assumption that the computer will sort everything out for him. However, there is no real substitute for careful planning.

DISPLAY HANDLER

The display handler was written to supplement the basic computer operating system DOS [5)] as supplied by Digital Equipment Corporation. The program allows the standard computer files to be displayed on the Tektronix 611 display screen. It also allows information to be sent to the display screen by means of a WRITE statement in the FORTRAN [6)] operating system. The program was written due to a shortage of paper for the line printer and besides saving paper it has saved a great deal of time and furthermore it allows data to be viewed on the screen without the user having to change his position.

PLOTTING FACILITIES

When a user is satisfied with a drawing on the display screen he may require a hard copy plot. To meet this need the department built a low cost flat bed plotter; however this plotter received very heavy usage and so it was decided to extend the plotting facilities. A program was written to drive the CADMAC digitiser/plotter in its plot mode and this allowed a plot to be produced on the lower surface of the digitiser.

Both the department's plotter and the CADMAC plotter are driven on-line by the computer and take up valuable machine time when other work cannot be undertaken. This lead to a further program being written to allow the off-line plotting of drawings. Each drawing to be plotted is processed by the computer and written onto magnetic tape. The magnetic tape can be transferred to the college's main computer facility and there further processed for off-line plotting on either of three plotters, a Kingmatic flat bed plotter, a Calcomp drum plotter or a Calcomp microfilm plotter.

The use of off-line plotting has allowed a greater proportion of computer time to be spent on production and development work and has removed the need for heavy usage of the on-line plotters. The user also has the ability to plot information overnight and can return to his job with all the relevant drawings in the morning.

All the drawings in this thesis were prepared on the computer aided design system and plotted off-line by the Calcomp microfilm plotter.

WINDOW EDITOR

If a large number of lines are to be removed from a drawing then deleting them one at a time may become rather tedious. To avoid this tedium a procedure was written whereby a perimeter could be digitised by the user. On completion of the perimeter all lines lying inside the perimeter are automatically deleted by the computer. This allows a large part of a drawing to be erased very quickly. Once again the aim in improving the system is to carry out a fairly complex task with the minimum of effort from the user.

IMPROVED FILE HANDLING

All project data is held in a number of contiguous direct access files, which reside on the disk. The application programmer is provided with a set of routines which enables him to access the data. In the present work the scope of these routines has been extended. The number of files has been increased up to a maximum of sixteen, they may reside on any disk unit (for computer systems with several disks) and they may be given any name the user requires. This flexibility is derived by allowing the user to create a small information file, giving a list of the file numbers, names and the units on which they reside. When the computer aided design system is first entered the program reads this information file to determine where the files to be used are stored. Thus in order to change the file configuration all the user has to do is to alter the list in the information file, this can be done using the standard editing facility 7).

The ease with which a different configuration may be used allows the computer aided design system to be easily transported between different computer systems and the increased number of files gives the application programmer greater scope and storage space. The basic idea could be also extended to other default values required by the system, such as the standard input scale. Each user would then have his own information file describing the system configuration he wished to use.

RESTART FACILITY

A procedure was written to allow a restart if the system should fail unexpectedly. If the user is in the middle of a drawing when a failure should occur, he may restart the system and restore the drawing he was working on. Obviously the system should not fail very often (preferably never), but on the rare occasions that it does it is reassuring to the user to know that he will not lose a large amount of work.

LEVELS

When a user is digitising a drawing he may split it up into several sections, called levels. Each level can be operated on separately from the others, and the user has the option of displaying only particular levels from a drawing. To further aid the user these facilities have been extended to allow the user to change a level designation once it has been input and to delete an entire level from the drawing. This again provides the user with a simple means of carrying out a complex task and gives the user considerable variety in the method by which he enters a drawing.

CHAPTER FOUR

A METHOD OF PREPARING DATA FOR A BEAM ANALYSIS PROGRAM

THE BEAM ANALYSIS PROGRAM

John Laing Design Associates were operating a suite of programs to perform the analysis, design and detailing of reinforced concrete structures. In addition the programs produce reinforcement bending schedules and summaries of quantities for concrete formwork and reinforcement. The elements covered by the programs include slabs, beams, columns and foundations.

Originally written in France for an IBM 1130 computer by Brun and Jallut the system was brought to England and modified to comply with British Codes of Practice by Building Computer Services Ltd. It is now implemented on an IBM 360 by John Laing Computer Services.

The program must be run in a fixed time slot and all input is via punched cards. A typical data form is shown for a beam analysis (Figure 7). As can be seen from Figure 7 a large quantity of information must be supplied by the engineer and this must be correctly interpreted and punched onto cards for the program to run successfully. It had been found that this large amount of data preparation severely restricted the number of cases in which the analysis program was useful.

THE DATA PREPARATION SYSTEM

The aim of the data preparation system was to reduce the amount of work required from the engineer to fill out the input forms and also to lessen the chances of error in the input data; thus ensuring a greater number of successful runs of the analysis program and cutting the cost of using the program.

By using a computer aided design system the engineer's work can be shifted from the job of filling in input forms to that of building up a description of the structure on the mini-computer, much of the description of the building structure being graphical in nature and

ELEMENT TYPE	SPAN/SUPPORT IDENTITY	FIXITY OF SUPPORT	WIDTH MM	LD TYPE	DEAD LOAD KN	LIVE LOAD KN	A1 MM	A2 MM	B MM	DEPTH OF BEAM	BREADTH OF BEAM	DEPTH OF SLAB	BREADTH OF SLAB	DEPTH TO STEEL	CONCRETE COVER				SPEC FEAT	FLGT END	JOB END
															TOP	BTM	LFT	RGH			

FIG 7 INPUT FORM FOR BEAM ANALYSIS PROGRAM

usually derived from general arrangement drawings. The computer can then derive the input forms from the building model which the engineer has produced. The advantage of having an independent model in the mini-computer is that only the output section of the program need be changed to allow input to a different analysis program (GENESYS, for example).

The data preparation system saves the engineer work by : -

a) giving an immediate visual check of data, allowing errors to be found as quickly as possible.

b) making duplication of standard elements possible.

c) removing the burden of many trivial load calculations, for example, the computer automatically distributes loads from slabs onto beams.

d) producing punched cards for input to the analysis program.

THE BUILDING MODEL

The user can enter three basic element types, beams, columns, and slabs, each of these is described in the building model by an element record. The element records are stored in an element file which is indexed for quick access to any particular element. Beams are classified as being either main beams, supported by columns, or as secondary beams, supported by other beams. Each element record contains thirty slots (each slot is equivalent to one real variable) and the content of these slots is given in Figures 8, 9, 10 and 11 for each of the element types.

Referring to Figure 8 the element record contains the basic dimensions of the beam (slots 1, 2 and 11) pointers to a load file indicating which loads have been placed on the beam (slots 4-7), the connection of the beam to other elements in the structure

SLOT NO	DATA DESCRIPTION
1	DEPTH
2	BREADTH
3	1ST POINTER TO LOAD FILE
4	2ND POINTER TO LOAD FILE
5	3RD POINTER TO LOAD FILE
6	4TH POINTER TO LOAD FILE
7	5TH POINTER TO LOAD FILE
8	NOT USED
9	SECONDARY BEAM CONNECTED TO THE BEAM
10	NOT USED
11	LENGTH
12	NOT USED
13	NOT USED
14	NOT USED
15	CONCRETE COVER INDEX
16	SPECIAL FEATURE DIMENSIONS
17	DEAD LOAD AT START OF BEAM
18	SLAB CONNECTED TO THE BEAM
19	SECONDARY BEAM CONNECTED TO THE BEAM
20	NOT USED
21	NOT USED
22	NOT USED
23	NOT USED
24	NOT USED
25	SPECIAL FEATURE CODE
26	SPECIAL FEATURE DIMENSIONS
27	DEAD LOAD AT END OF BEAM
28	SLAB CONNECTED TO THE BEAM
29	LIVE LOAD AT START OF BEAM
30	LIVE LOAD AT END OF BEAM

FIG 8 A MAIN BEAM ELEMENT RECORD

SLOT NO	DATA DESCRIPTION
1	DEPTH
2	BREADTH
3	1ST POINTER TO LOAD FILE
4	2ND POINTER TO LOAD FILE
5	3RD POINTER TO LOAD FILE
6	4TH POINTER TO LOAD FILE
7	5TH POINTER TO LOAD FILE
8	NOT USED
9	MAIN BEAM CONNECTED TO THE BEAM
10	MAIN BEAM CONNECTED TO THE BEAM
11	LENGTH
12	NOT USED
13	NOT USED
14	NOT USED
15	CONCRETE COVER INDEX
16	SPECIAL FEATURE DIMENSIONS
17	DEAD LOAD AT START OF BEAM
18	SLAB CONNECTED TO THE BEAM
19	DISTANCE FROM START OF BEAM TO A COLUMN
20	DISTANCE FROM END OF BEAM TO A COLUMN
21	NOT USED
22	NOT USED
23	NOT USED
24	NOT USED
25	SPECIAL FEATURE CODE
26	SPECIAL FEATURE DIMENSIONS
27	DEAD LOAD AT END OF BEAM
28	SLAB CONNECTED TO THE BEAM
29	LIVE LOAD AT START OF BEAM
30	LIVE LOAD AT END OF BEAM

FIG 9 A SECONDARY BEAM ELEMENT RECORD

SLOT NO.	DATA DESCRIPTION
1	HORIZONTAL GRID IDENTIFIER
2	VERTICAL GRID IDENTIFIER
3	HEIGHT
4	1ST BEAM SUPPORTED BY COLUMN
5	2ND BEAM SUPPORTED BY COLUMN
6	3RD BEAM SUPPORTED BY COLUMN
7	4TH BEAM SUPPORTED BY COLUMN
8	NOT USED
9	NOT USED
10	NOT USED
11	NOT USED
12	NOT USED
13	SELF WEIGHT
14	END SUPPORT (PENULTIMATE SUPPORT ONLY)
15	PERCENTAGE FIXITY
16	COLUMN ABOVE
17	TOTAL LOAD AT BASE OF COLUMN
18	NOT USED
19	NOT USED
20	NOT USED
21	BREADTH
22	WIDTH
23	LOAD FROM SUPPORTED BEAMS
24	NOT USED
25	COLUMN TRUNCATION
26	COLUMN BELOW
27	NOT USED
28	NOT USED
29	NOT USED
30	NOT USED

FIG 10 A COLUMN ELEMENT RECORD

SLOT NO	DATA DESCRIPTION
1	BREADTH .
2	1ST BEAM CONNECTED TO SLAB
3	2ND BEAM CONNECTED TO SLAB
4	3RD BEAM CONNECTED TO SLAB
5	4TH BEAM CONNECTED TO SLAB
6	1ST POINTER TO LOAD FILE
7	2ND POINTER TO LOAD FILE
8	NOT USED
9	NOT USED
10	NOT USED
11	DEPTH
12	DIST FROM SLAB CORNER TO SUPPORTING BEAM START
13	DIST FROM SLAB CORNER TO SUPPORTING BEAM START
14	DIST FROM SLAB CORNER TO SUPPORTING BEAM START
15	DIST FROM SLAB CORNER TO SUPPORTING BEAM START
16	NOT USED
17	NOT USED
18	NOT USED
19	NOT USED
20	NOT USED
21	SPANNING CODE
22	DIST FROM SLAB CORNER TO SUPPORTING BEAM END
23	DIST FROM SLAB CORNER TO SUPPORTING BEAM END
24	DIST FROM SLAB CORNER TO SUPPORTING BEAM END
25	DIST FROM SLAB CORNER TO SUPPORTING BEAM END
26	NOT USED
27	NOT USED
28	NOT USED
29	NOT USED
30	NOT USED

FIG 11 A SLAB ELEMENT RECORD

(slots 9, 18, 19 and 28), the total loads at the beam ends (slots 17, 27, 29 and 30) and various properties of the beam. The element records form the basic model of the structure.

Beside the element file, information is stored in two further files, the load file and the flight file (Figure 12). The load file contains all loads that the structure is subjected to and a pointer to each load is placed in an element record. The flight file contains a list of the elements which are to be considered for analysis as the engineer may only require to analyse part of a structure.

A graphical description of the structure is generated from information in the element records and a schematic diagram (Figure 13) of each floor of the structure may be seen by the user. By interaction with the graphic display file the user is able to alter the contents of the element records and to indicate the placing of loads, fixities of support, etc. When output is required the flight file is scanned to determine the relevant elements and information is taken from the element records and the load file,placed in the correct format and then inserted in the output file. The output file may be transferred via magnetic tape to the IBM 360 where it becomes the input to the stress analysis program, the information in the output file being in exactly the same format as the information usually produced from the input forms.

OPERATION OF THE SYSTEM

The purpose of this section is to give a brief introduction of how the system works from the users' point of view, a fuller description is given elsewhere 8). Figure 14 shows a flowchart of the system operation. The user can enter the system from one of three entry points each connected with a square on the user command section of the menu (Figure 4). The first entry point allows the system to be initialised and all previous data is cleared from the files. The second entry point allows the user to modify the geometry of his structure and previous information is retained.

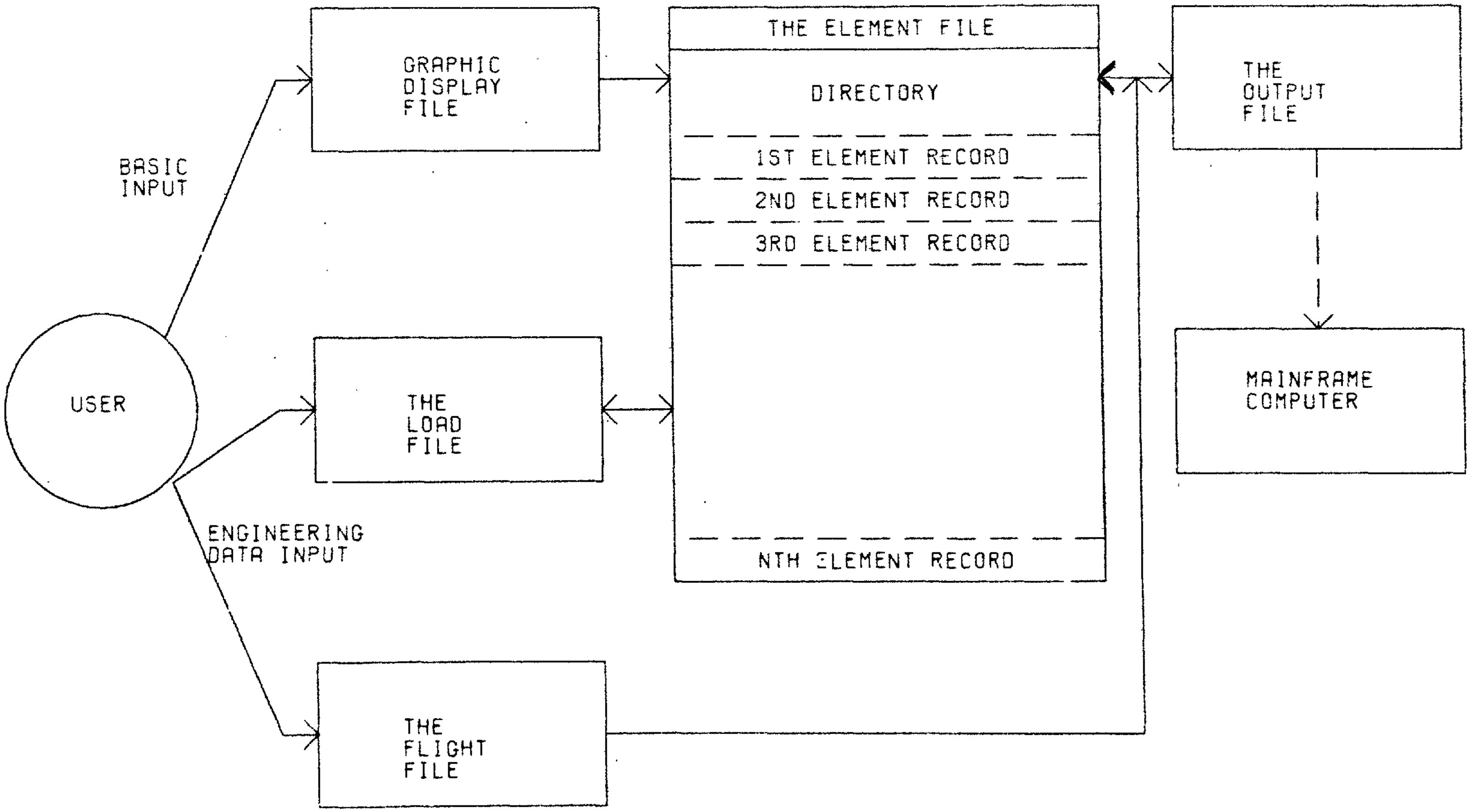


FIG 12 BLOCK DIAGRAM OF THE DATA PREPARATION SYSTEM

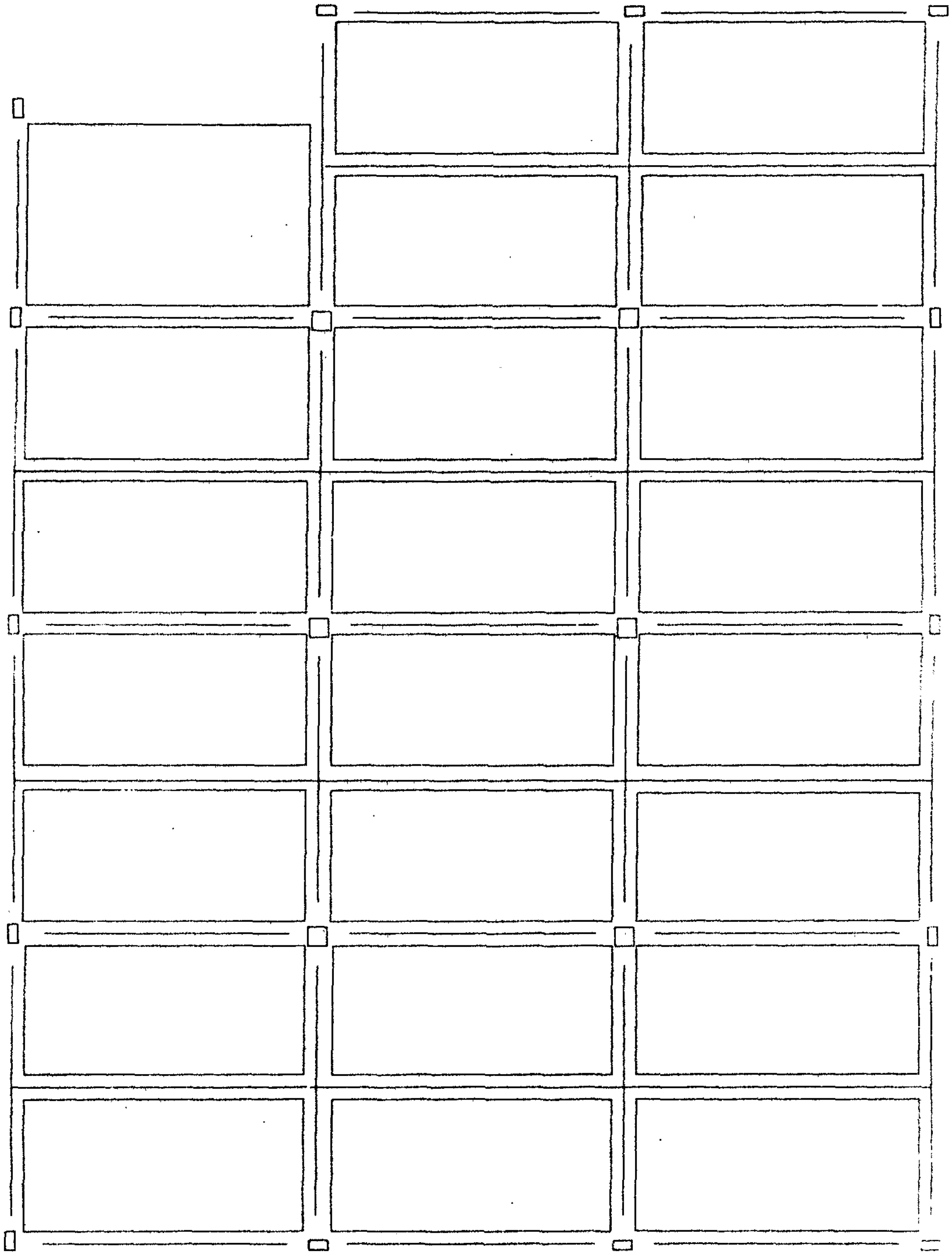


FIG 13 SCHEMATIC DIAGRAM OF A STRUCTURE, SHOWING ALL FOUR ELEMENT TYPES.

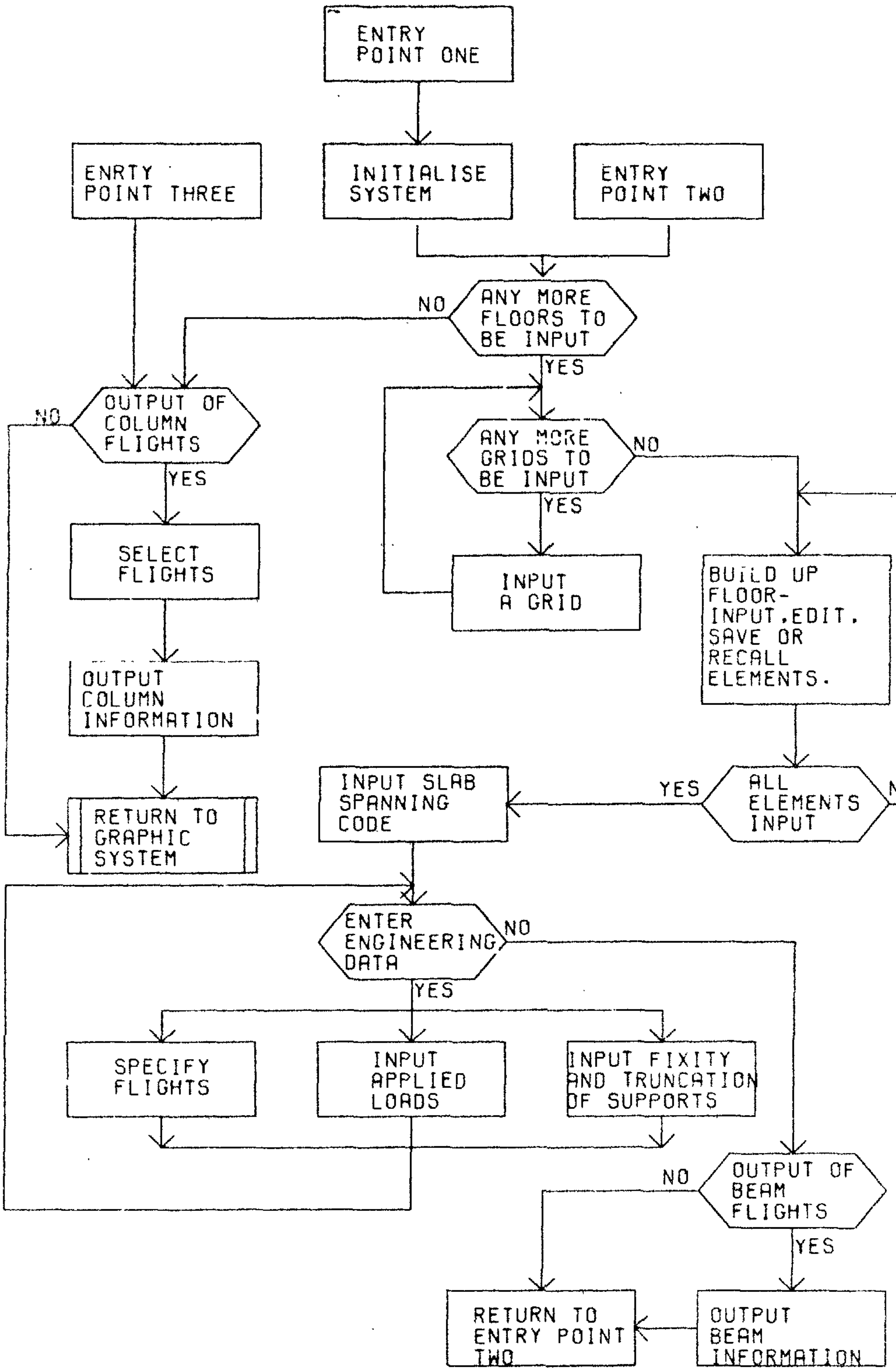


FIG 14 FLOWCHART OF SYSTEM OPERATION

The user creates the building structure one floor at a time, firstly he can specify several grids which may be labelled and later used as a guide in the positioning of elements. The user supplies the grid interval, the extent of the grid and the grid orientation and from this information the computer generates the full grid. Once a grid has been entered it may be used on any level of the building. Having defined his grid the user may enter the basic building elements.

To bring down an element, such as a main beam, the user will select, by means of the function buttons, a size from the beam list and then indicate the columns between which the beam will span. Standard elements can be entered once and then repeated anywhere else in the building structure. As the user creates the building structure a schematic diagram (Figure 13) of the floor on which he is working is displayed to show which elements have been entered and to allow positioning of new elements. When the user has completed one floor of the structure he indicates the method of spanning for each slab in the floor.

Once the geometry of the structure is completed the user can, if he wishes, enter the engineering data for the elements. This includes such information as the user applied loads (the self weight of the elements is calculated and distributed throughout the building by the computer), the fixity and truncation of supports and a specification of which beam flights are to be analysed. Having given all the engineering data required, the user can output the information for the analysis program, or defer output to a later time.

The third entry point allows the preparation of column flights for the analysis program. It is assumed that the user will have entered all the relevant information for the building structure, hence at this stage he only enters the flights which are to be considered by the analysis program. When all flights have been specified, the computer outputs the information required by the analysis program.

The output file, which may contain both beam and column flights, is transferred onto a magnetic tape and the tape then carried to the large computer to be read by the analysis program. After studying the results of the analysis the user is free to re-etner the data preparation system and alter his building structure if it is unsatisfactory.

EXTENSION OF THE WORK

The present work has been extremely useful and it would be desirable to extend the system to provide input for the slab and foundation sections of the analysis program. In spite of the system's limitations, it has clearly demonstrated the advantages of using a mini-computer for data preparation purposes. Unfortunately it was not possible to link the IBM 360 computer and the mini-computer as closely as would have been liked. Either a direct link between the computers or the ability to transfer tapes from either machine to the other is required. With such a link not only could the mini-computer be used to provide input for the analysis program but it could also provide a means of evaluating the results from the analysis program. The computer aided design system could easily be used to construct any graphs, tables or figures that the engineer required for a better appreciation of the structure.

This would result in the mini-computer completely masking the nature of the other machine and indeed defects in the other machine would be unnoticed by the user, he would only see the interface to the building model. In fact, the engineer might use the same interface to provide input to several analysis programs.

Having once established the use of a mini-computer for data preparation purposes, it was natural to think about the analyses which could be carried out by the mini-computer without the need to employ a larger computer. The following chapters detail the work carried out to develop a system for site layout and planning using a mini-computer in the 'stand alone' mode. The independent computing unit so provided would require less capital outlay, would utilise the mini-computer more efficiently and would provide a quicker response to the user.

CHAPTER FIVE

A CONTOURING PACKAGE

PURPOSE

The purpose of the contouring package is twofold. The first purpose is the obvious one, of drawing contours of a given function (in this case height of land). The second purpose is to build up a regular model of the land which can be conveniently held by the computer and from which new values at any point may be quickly and accurately estimated. This is necessary because the original data describing the land (random spot heights) cannot be easily used to estimate a new height value at an unsurveyed point.

SYSTEM PHILOSOPHY

The aim of the work in the following chapters was to produce a system to aid a designer in site layout and planning. The scope of the system was to extend from input of the raw data (site survey) to the design and analysis of the proposed construction. Throughout the work the system was to be used by a designer (not a computer operator) and had to be simple and straightforward to use.

These requirements could be met by the use of a mini-computer based graphics system. But the question remained of whether the analyses should be carried out on a large computer (e.g. IBM 360) or should the mini-computer perform the analyses. In Chapter Four this problem was pre-empted by the fact that the analysis program was extremely complex and transferring it to the mini-computer would have been a long and laborious task. Besides such large analyses are more efficiently carried out on a large mainframe computer. However, in the site layout work the analyses are of a less complicated nature and may be easily implemented on the mini-computer. Several advantages result from using a mini-computer, namely : -

a) no need for a direct link to a further computer.

b) by performing more work on the mini-computer it becomes a more economic unit and when fully utilised provides a cheaper solution to a problem than using a larger computer.

c) the user can be presented with a coherent and unified approach to his work and may use the same communication techniques to handle all problems.

d) the user does not have to wait to get access to a larger computer, he can initiate an analysis immediately.

e) results from one analysis may be saved on the mini-computer and used for input to other analyses. Results may also be used by other sections of the design team, the mini-computer improving inter-section communication.

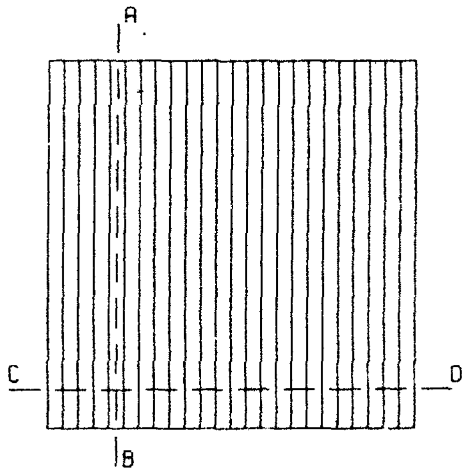
DATA STRUCTURE

The basic land model consists of a large array, the X and Y coordinates of a point can be found from the column and row number of a position in the array and the value stored at that position gives the associated Z (height) coordinate. To represent the land accurately the interval between grid points should not be too large and it is desirable to use a grid size of at least 90 x 90 to represent a medium sized site. However, it is impossible to hold a 90 x 90 array in the small amount of core available in the mini-computer. It thus becomes necessary to partition the array and hold only one partition in core at any time, the rest of the array being held on the disk where an access to it will take about ninety milliseconds. Once partitioned the maximum size of the array is determined by the amount of disk space available for its storage at present arrays of up to 128 x 128 can be handled, although given sufficient disk space this could be increased to a 512 x 512 array.

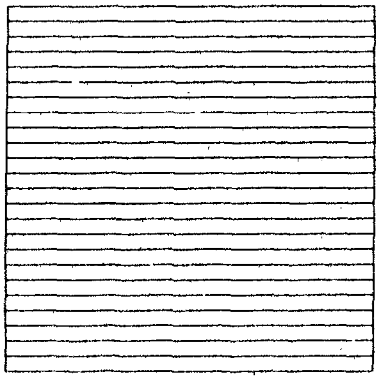
There are three basic methods of partitioning the array, in rows, in columns, or in blocks, these are shown diagrammatically in Figure 15. Before considering how the array will be partitioned, it is necessary to examine how the land model will be used. A typical operation is the construction of a section through the land along a given line. In order to generate this points at a fixed interval along the line must be calculated and the height at these points found. Considering Figure 15a to be a 100 x 100 array partitioned in columns it is seen that to draw a section AB would require access to one partition, but to draw a section CD would require access to all hundred partitions. Furthermore a general section would require access to a large number of partitions. However, considering Figure 15c it is seen that to draw a section, AB would require access to six partitions and to draw a section CD would require access to three partitions, a general section would only require access to, at most, eight partitions.

Hence, by choosing a block partitioning, the number of accesses is roughly the same no matter where the section is drawn and the average number of accesses is lower than if partitioning is by row or column. Although each of the block partitions is larger than the column partitions, this does not greatly increase the time to swap a partition from disk to core. This is due to the characteristics of the disk, the time taken to find the required information being much longer than the time to actually transfer the information. A further advantage of block partitioning is that any localised analysis will probably require only one partition to be accessed.

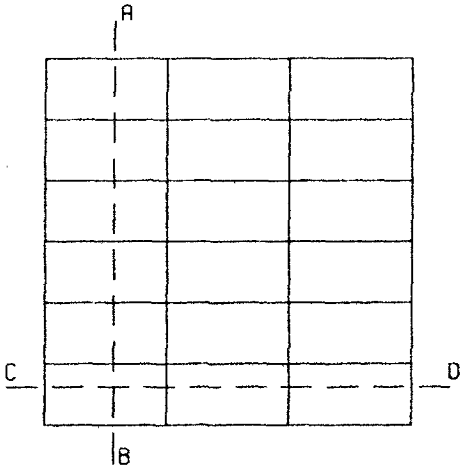
Due to the advantage of block partitioning this was the method used to store the land model, each block consisting of a 32 x 16 segment of the array. A set of subroutines was written to allow access to the data in terms of the row and column number, all swapping to and from the disk being looked after by these subroutines.



A) COLUMN PARTITION



B) ROW PARTITION



C) BLOCK OR AREA PARTITION

FIG 15 METHODS OF PARTITIONING A LARGE ARRAY.

An application programmer can then write his program in almost the same manner as if the whole array was stored in core.

METHOD OF CONTOURING

The initial input to the contouring program is a series of irregularly placed spot heights. Before contouring of the data takes place a regular grid of data values is built up by the program from the spot heights. This grid is kept in a large array as mentioned in the last section and the height of land is found for all grid positions. To build this regular grid of height values the program generates a triangular grid over the random spot heights, such that each spot height is at the vertex of a triangle. The program attempts to form triangles that are of an equilateral nature and long thin triangles are discriminated against by using the sum of the squares of the sides as a measure of a triangle's suitability. Each triangle is checked to see that it does not intersect any of the grid already formed and if no intersection occurs, the triangle is added to the grid.

When the complete grid has been formed the program continues with the next stage, to determine the rate of change of height in the X and Y directions at each survey point. If this information is known it may be supplied by the user and the program proceeds to the next stage, if the information is not known (the usual case in a site survey), then the program will estimate the rate of change of height. The program does this by finding the five nearest points to a survey point and then examining the five triangles, formed by these five points around the survey point. For each triangle the rate of change of height in the X and Y directions is calculated, assuming the triangle to be a flat plane and a weighted average of the five results is formed, points nearest the survey point having the largest weight. The weighted average is used as an estimate of the rate of change of height at the survey point. When an estimate of the rate of change of height has been calculated for all the survey points the program proceeds to the next stage.

In the third stage each triangle formed between the survey points is considered in turn and a bi-cubic patch fitted through its three vertices. A bi-cubic approximation ensures that there is continuity of height and slope at all points along the sides of the triangle. Each position in the regular grid is then examined to determine if it lies within the triangle, if so the height value at that position is calculated and placed in the grid. In this manner a regular grid of height values is built up for the entire site area.

Finally, the actual contouring of the regular grid takes place, this is done by a standard method which is described elsewhere 9).

The contouring package was originally written to operate on a large computer (CDC6400) and has been in use for some years. In transferring the program to the mini-computer it had to be split up into six overlays and whilst transferring the program the opportunity was taken to add further features to the program. Three major improvements were made to the program, firstly the estimation of the rate of change of height was speeded up, secondly the ability to produce stereoscopic pairs of contours was introduced and thirdly the ability to save the regular grid from one program run, for use at a later date (or as the basic land model) was introduced.

FACILITIES OF THE PACKAGE

The package is designed to give the user a large number of options while, at the same time, requiring only a minimum of information from the user. This is achieved by a series of default values, whereby if the user does not enter a variable then the program will use the preset value (or default) of that variable.

Facilities exist to define the type of input data, to define the disk files to be used for the temporary storage of data, to define the format of the input data, to define the scale of the contour plot, to define the rotation of the contour plot, to define the size of the contour plot, to draw lines, boxes or text on the contour plot, to suppress contouring of certain areas of the contour plot, to sort irregular data into regular data, to define the contour levels to be drawn, to define how the contour levels will be drawn, to define which pen type will be used, and finally to define if stereoscopic pairs of contours are to be drawn. All the commands and usage of the package are described in detail elsewhere 10).

In operation the package expects input in the form of punch cards or as a card image file. When using the package on the mini-computer there exists a program to aid the user in production of the card image file. Although this file may be prepared at the DECwriter, this is a difficult task as the user has no indication of which column the next character will be placed in. A program to align data automatically and allow input from the screen was thus devised. When using this program the user is presented with the view shown in Figure 16. The two columns of boxes on the left each represent a command to the contouring package. The two columns of boxes on the right each represent a data value which may be required with one of the commands 10). At the bottom of the screen the line currently being created is shown.

To input a new command the digitiser pen is moved until the cursor lies inside the box labelled with the appropriate command and one of the pen buttons is then pressed. To input a data value the appropriate box is again picked with the cursor and push buttons and the data value is then entered using the keyboard area (Chapter Three). The data values and commands can be overwritten should a mistake be made and the program ensures that the data values are aligned into the correct columns of the card. In addition a partially completed file may be saved and work resumed on it at a later time. In summary the program provides a screen editing facility by means of which a card image file for input to the contouring package can be produced.

VISUALISATION OF THE LAND MODEL

When the regular grid of height values has been generated, this model of the land may be presented to the user in any of four ways,

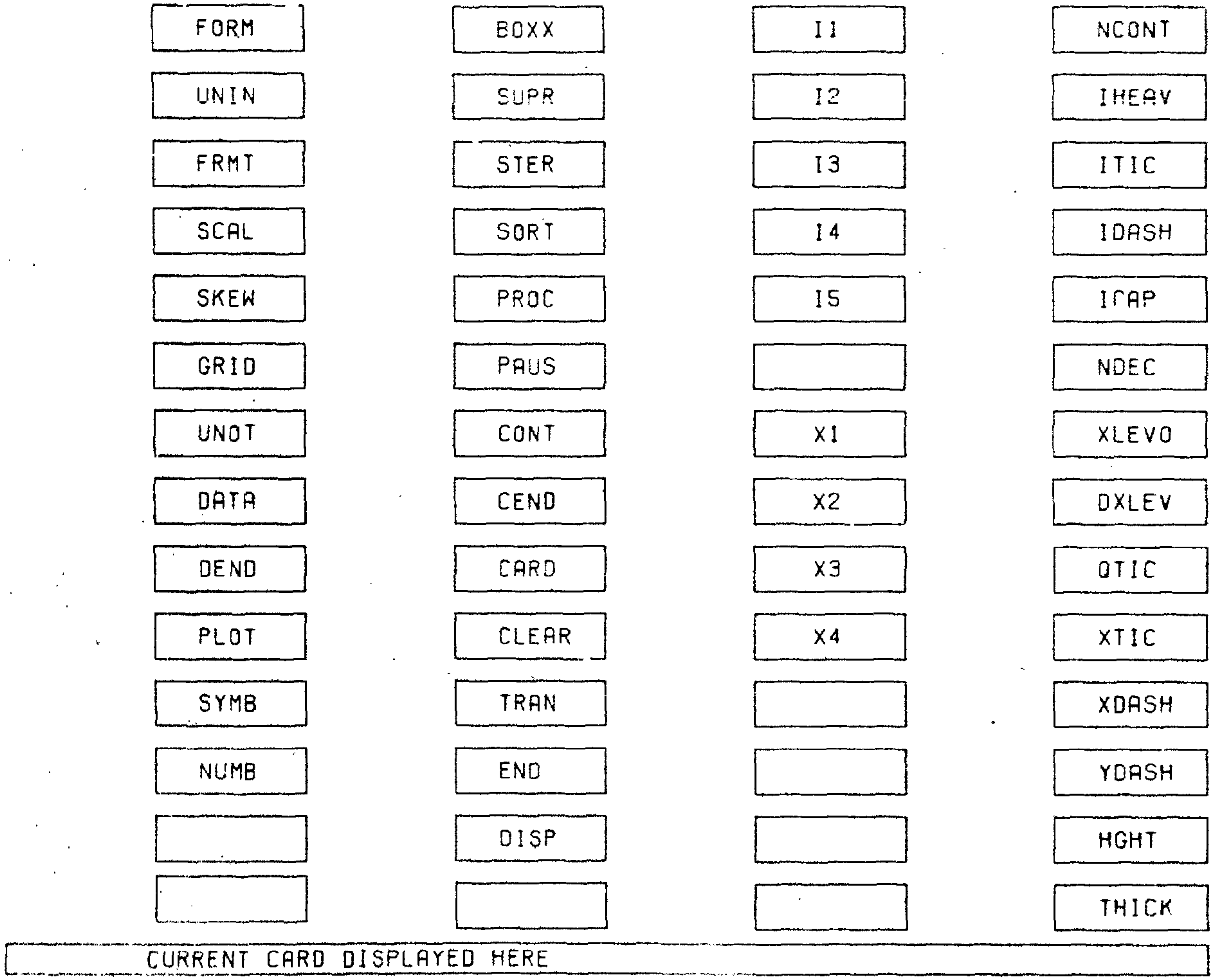


FIG 16 A USERS VIEW OF THE SCREEN WHEN CREATING A FILE OF INSTRUCTIONS FOR THE CONTOURING PACKAGE

as a contour map, as a section, as a semi-oblique projection, or as a perspective projection.

To produce a contour map the user defines the type of plot required and the data to be operated on by means of the contouring commands, forming a card image file of these commands as mentioned in the last two sections. This card image file forms the input to the contouring package, the program produces an output listing of the cards it has processed together with error messages indicating any incorrect data. The program also constructs the contour plot, placing this in the general computer aided design system where it may be viewed and edited in the same manner as any other drawing in the system. An example of a contour plot is shown in Figure 17.

Many people find contour plots difficult to interpret and fail to grasp the true nature of a site from them. It was found when transferring the contour-package to the mini-computer that once the regular grid of land heights was retained (and not discarded as was the case on the mainframe computer), further analyses could easily be applied to the data, certain of these analyses being methods of showing the user the nature of the basic site.

The first of the new analyses is a program to generate a section through the land, between any two points on the site. The user indicates the two points on a plan of the site and the computer then draws the section at the top of the display screen. The datum point and vertical scale of the section can be altered whenever the user requires, an example is given (Figure 17) showing sections along three different lines AB,CD and EF. The section is not drawn across the full width of the section line in every case,as if the section crosses an area which has not been surveyed then no line is drawn to mark the land.

The computer generates the section by splitting the line joining the two given points into an equal number of short links, the height at each of the points forming these links is found from the

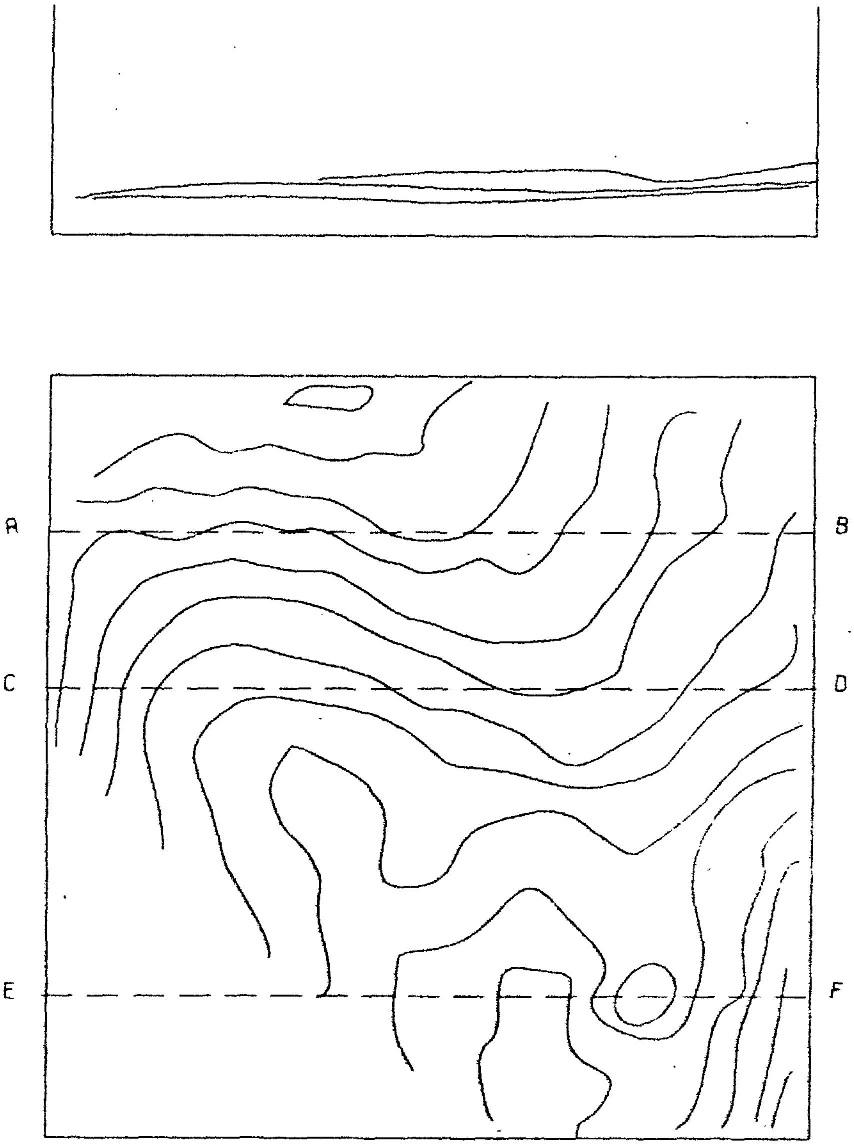


FIG 17 A CONTOUR MAP AND SECTIONS OF A SITE

land model. The nearest grid point to a point is determined and the height value at the grid point used as the height of the point. Although straight line interpolation between grid points could be used, it was found that the grid was fine enough to make interpolation unnecessary without lowering the accuracy of the section generated.

Buildings are also displayed on sections and the program checks any building entered on the site to determine if it intersects the line of the section. If an intersection occurs the building is shown by a horizontal line at its ground floor level and the ground floor level is displayed in numerals just above this line.

The ability to produce a section along any given line almost instantaneously is obviously a great advantage to a designer, not only does it allow a better appreciation of the site to be developed but the sections can also be used for simple cut and fill calculations and other design calculations.

The second of the new analyses is a program to display a semi-oblique projection of the land. Unlike the two previous methods of displaying the land, this method involves an attempt to show the three dimensional nature of the land. The ease with which the computer can draw a three dimensional projection is one of the major advantages of using the computer. Without the computer drawing such a view is tedious and the correct viewpoint must be chosen, with the computer a large number of viewpoints can be quickly investigated.

A semi-oblique projection is drawn as a facet point, e.g. a set of traverses parallel to the X axis and another set of traverses parallel to the Y axis. As the computer draws each traverse it checks that the line is not obscured by a previous traverse, if the line is below a previous traverse it is not drawn and this produces a display with the elimination of hidden lines (Figures 18 and 19).

During operation of the program the user firstly specifies four variables defining the view required, the variables being : -

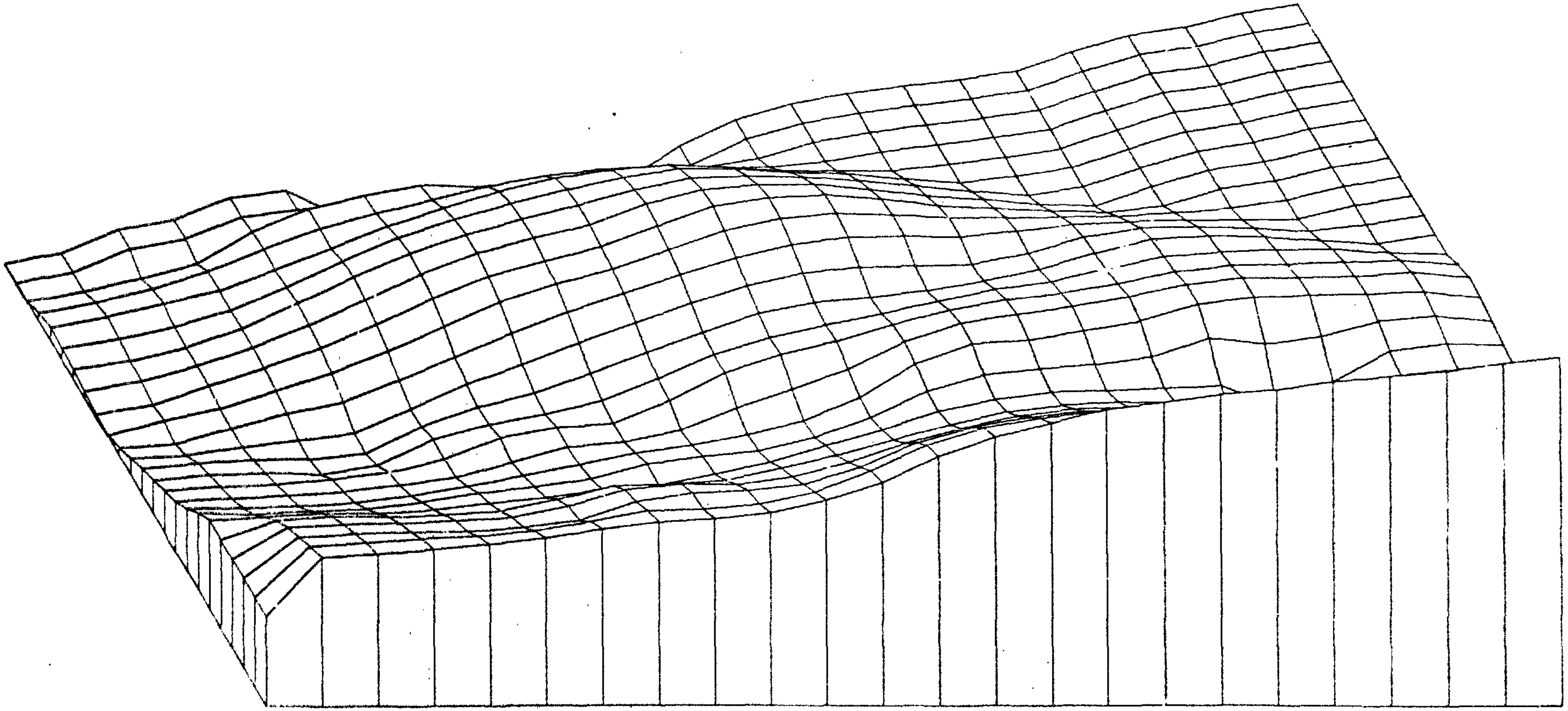


FIG 18 A SEMI OBLIQUE PROJECTION OF THE LAND MODEL, WITH VISIBLE SIDES ADDED

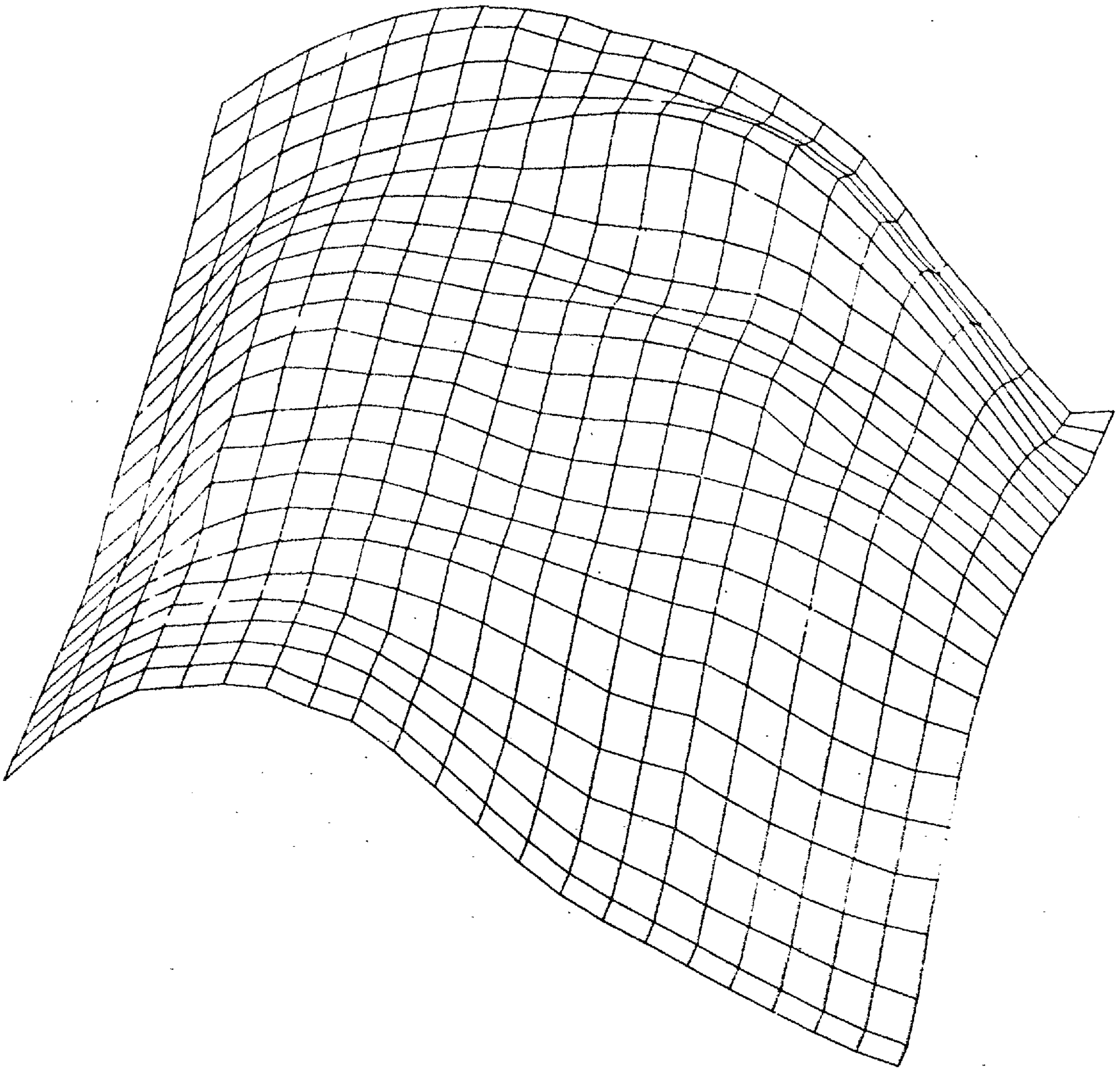


FIG 19 A SEMI OBLIQUE PROJECTION ,WITH THE SIDES REMOVED

a) the size of the picture.

b) the percentage deformation of the block to either the right or left.

c) the viewing angle, relative to the horizon.

d) the depth of sides, if the sides are to be displayed.

When all variables have been specified the program constructs the view and places it in the computer aided design system.

The third and final of the new analyses is a program to display a perspective projection of the land. Once again this is quickly constructed by the computer and the user can choose any viewpoints, details of this program and examples of the output are given in Chapter Nine.

SUMMARY

Having transferred an existing contouring package from a large computer to a mini-computer we find that the user can more easily understand the site he is dealing with, new features could easily be added to the system and by retaining the land model for later use, sections, semi-oblique projections and perspective projections could be quickly generated.

Although the mini-computer might take ten minutes processing a typical contour plot whereas on a CDC6400 it only took eighty seconds, from the user's point of view the mini-computer was still the quickest way to arrive at the final solution, because obtaining access to and waiting for output from the CDC6400 took several hours or more. Overall the mini-computer provided the designer with a better understanding of a site and could also provide a cheaper solution than the mainframe computer.

CHAPTER SIX

SITE LAYOUT: THE EXISTING FEATURES

INTRODUCTION

The existing features are those features which occur on the site before its development. The position and size of such features is recorded when a site survey is undertaken, the surveyor usually drawing a rough sketch of the site from which he later constructs an accurate site survey plan.

The existing features may or may not be incorporated in the final site layout, old buildings may be demolished, hedges and bushes cleared, etc., before building is undertaken. Some features, protected trees, site boundaries, etc., will however be included in the final layout and the architect is interested in their position throughout the design of the site layout. The information describing the existing features is of two forms, the graphic information showing where they are, and written information indicating their type and size. The written information usually being placed alongside the graphic information on the site plan.

The designer wishes to input both a graphic and a written description of each feature, and it is desirable that information of both types should be input as easily as possible. It is necessary for the designer to have one focus of attention while using the system, and the designer should not be asked to supply part of the information on a graphical device (digitiser), and then have to supply the rest of the information on an alpha-numeric device (DECwriter) immediately afterwards. This will only lead to uncomfortable working conditions for the designer and his dissatisfaction with the computer system.

Any proposed system must be capable of entering information either directly from a sketch in the surveyor's notebook or from an accurate site plan. This means the computer system can not only process the company's own surveys, but sub-contracted survey work, previous surveys and ordnance survey maps can also be used to derive input to the system.

USING THE SYSTEM

The purpose of this section is to outline the system from the designers' point of view, the internal details of the system are developed in the next section. This section is not meant to be a complete guide to using the system, a users' manual is available for the purpose and this is presented in Appendix One.

The user indicates the type of feature he wishes to enter from a list of standard types which is displayed on the storage tube. The types of feature included in the present system are given in Figure 20, and a full list of all the sub-categories is given in Appendix Two. Having selected a feature type, the user can then digitise the graphic information relevant to that feature. The user may input as many features as he wants before entering the written description of a feature.

When entering the graphic information for a feature the user is not required to draw the full outline of the feature. If for example he wishes to indicate a telegraph line, all that needs to be given are the points at which the line changes direction. The computer automatically draws the correct symbol for a telegraph line, consisting of a dashed line with T's placed in the spaces. An example of part of a site plan, developed using the system, is shown in Figure 21.

To input the written description of a feature the user enters the specification procedure. Here he indicates, by moving the cursor to a feature, which feature he is considering, he is then presented with a list of the possible sub-categories for that feature. The user may then enter the exact type and dimensions of the feature. This specification varies from feature type to feature type and comprises the additional information shown in Figure 20. The written information is not drawn on the site plan but the user may at any time inspect the specification of a feature, and add to it or edit it as required.

FEATURE	ADDITIONAL INFORMATION
BUILDING	TYPE
WALL	TYPE AND HEIGHT
FENCE OR HEDGE	TYPE, HEIGHT AND WIDTH
TREE OR BUSH	TYPE, HEIGHT, SPREAD AND GIRTH
ROAD, FOOTPATH OR RAILWAY	TYPE
CANAL, RIVER OR STREAM	TYPE
POND OR LAKE	TYPE
ELECTRICITY OR TELEGRAPH	-
MANHOLE	PIPE DIAMETER
GENERAL	TYPE

FIG 20 TYPES OF SITE FEATURES

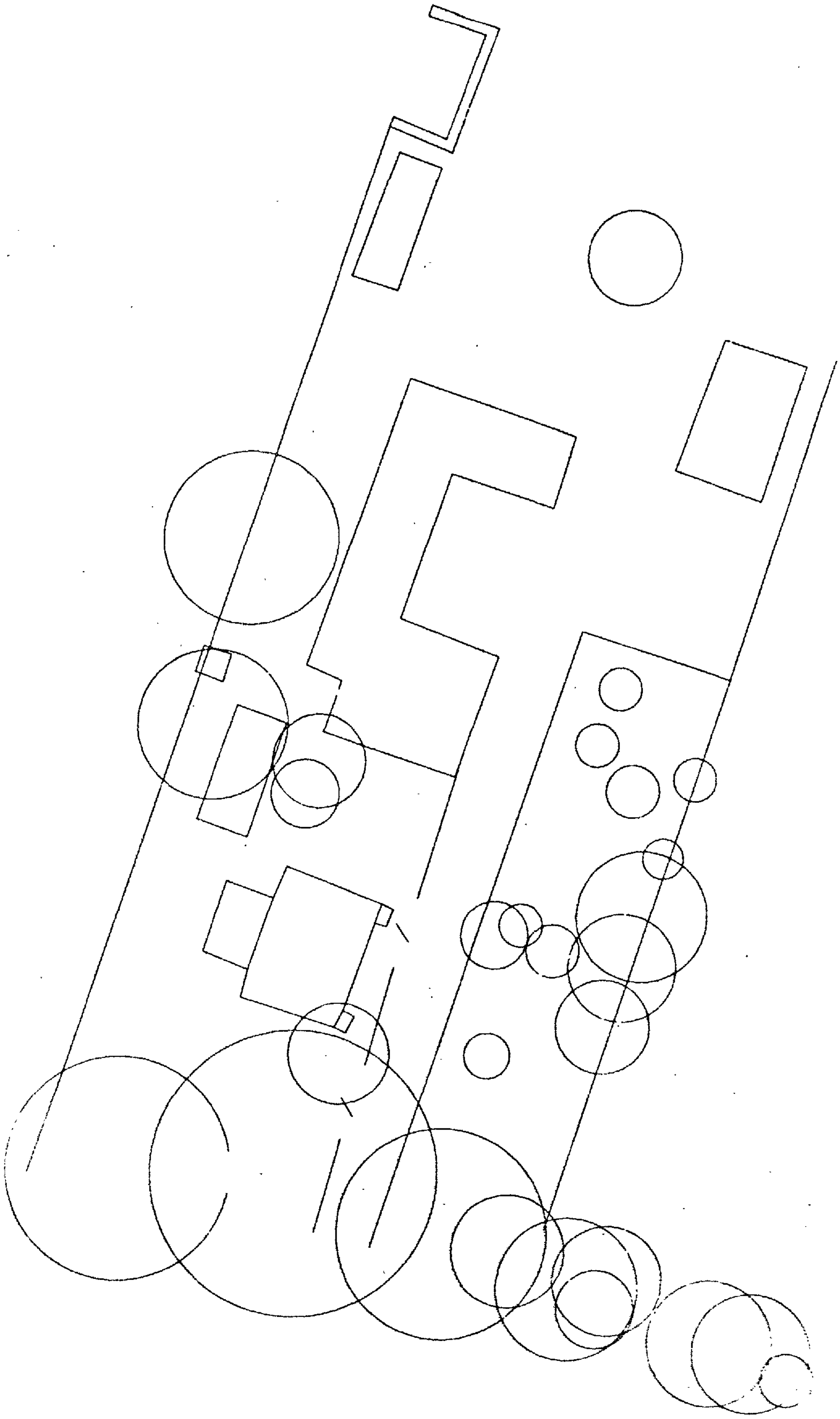


FIG 21 EXAMPLE OF THE EXISTING FEATURES

IMPLEMENTATION OF THE SYSTEM

By using lists containing all feature types likely to be needed on a site plan, the user can concentrate solely on the display screen and establish a comfortable mode of operation. Furthermore no tedious typing of written descriptions is required from the user. However this creates a problem in that we must use the storage screen for the display of the site plan, and for display of the lists, when the user requires them. Once the user has selected an option from a list, the screen has to be erased and the site plan redisplayed quickly, so that the user does not have to wait before entering the features position.

In order to lessen the display time it is necessary to reduce the complexity of the drawing shown, without reducing the useful information it contains. This is done in two ways. Firstly the written description of each feature is not displayed. The display of alpha-numerics is undertaken by computer software and not by display hardware, and this is a relatively slow process. It was felt that the written descriptions of other features only cluttered up the drawing when positioning a new feature, and providing the user could, if desired, see a feature's written description at a later time, this would be sufficient.

Secondly, when the user is entering new information only the basic outlines of the features are displayed. For example, a telegraph line is shown only by a solid line and not by the standard symbol. However on exit from the system the basic outlines are replaced by the full symbolic form, traditionally used. It is found in practice that these two reductions in displayed information are perfectly acceptable and reduce the re-display time sufficiently for the user to be unaware of it.

The basic outline of a feature and its full symbolic form are both stored in the graphic display file, though separate levels (see Chapter Three) are used to hold them. This means that a certain amount of the data held is redundant, however since the basic outline of most features is extremely simple (for example, a tree only requires two points) the amount of redundant data is small, and thus acceptable, since it leads to a reduction in the complexity of the program. The program automatically decides whether the basic outline or full symbolic form will be displayed, and using standard procedures in the computer aided design system, controls the display of information in the graphic display file.

Obviously if either two storage screens were available, or a refreshed screen was available, or the picture display time was substantially quicker, this problem would not have arisen. But it does lead one to question just how frequently certain information is actually used. Further the simplified display reduces the amount of computer processing required, and this could be an advantage in a time sharing environment.

When compiling the lists of feature sub-categories (Appendix Two) no attempt was made to exhaustively list all possibilities. Instead the system is designed to be as flexible as possible and to allow the addition of new feature types without any re-programming. New features may be introduced merely by adding to the display lists, each display list is held as a file in the computer system, where it may be edited by the standard editing facility 7). When the display lists are generated the text to be displayed is entered on sequential lines. Besides the text two numbers are also entered to indicate the nature of the line of text, these numbers are not displayed on the screen but are used in the program to determine the action to be followed. The first number indicates what type of action the user wishes to undertake and can have four values, namely : -

0 redisplay list.

1 end of specification.

2 specification of a feature type.

3 specification of a feature dimension.

The second of the two numbers only applies if a dimension is being specified, and it is used to indicate the position of the dimension being entered. For example, if the number is a two, then the second dimension associated with the feature is to be entered.

As the written description of a feature is entered the specification code, stored with the graphic information, is updated to reflect the exact type of feature input. When the user requests to view the written description of a feature the specification code is used to access the relevant display list, to find the description. No feature descriptions are held in the program, or in the graphic display file, giving the user the ability to describe a feature type in his own words, simply by editing the display list.

A final point concerning positioning of features is that the computer makes no attempt to determine clashes between different features, nor at a later time is a check made to ensure that the design features are not placed on top of existing features. It is felt, at the present time, that decisions of this nature are more efficiently taken by the designer, and if he wishes to design unfeasible layouts the computer will merely help him do it more rapidly.

FUTURE WORK

The use of display lists has made it easy for a user to input both graphical and written descriptions of features,in addition a flexible and wide ranging system is possible, without any extensive re-programming. Future extension of the work might be undertaken along three lines.

Firstly, if new display hardware is developed and the cost is low enough the system might be altered to always work with the full symbolic descriptions of the features.

Secondly, the system could be extended to consider the features as three dimensional objects. At present the computer aided design system is two dimensional in nature, but should a three dimensional system be introduced, the features could have a three dimensional symbolic form programmed, to replace the present two dimensional form.

Thirdly, the problem of feature clashes could, if required, be undertaken. In such a case it would probably be best if the user was free to input his design unrestrained until a certain point, at which he would wish to check for clashes. The computer might also undertake further checks on the site layout, checking fire resistance, spacing, and other matters determined by a standard and often obligatory building code. The computer could list features infringing the code and also list questionable features, the architect could then improve his layout to meet the code.

CHAPTER SEVEN

AREA AND DISTANCE MEASUREMENT

SYSTEM DESCRIPTION AND OPERATION

The aim of the system is to allow the measurement of either distances or areas from a drawing existing in the computer aided design system, or from a map or drawing from other sources. Measurement is possible in any units whatsoever. A designer frequently requires to know the distance between objects and the area enclosed by objects, this program provides such information.

Any two dimensional information can be used as input and the program enables immediate and accurate measurement to be made of areas or distances simply by indicating points around the perimeter or along the distance to be measured.

Operation of the system is simple (a users' manual is given in Appendix Three), a sample user-machine dialogue is given in Figure 22. Following this example we see that on entry to the program it prints a title and asks what units we are measuring in. The user then supplies the units of measurement for distance and area, and the correspondence between them. This is accomplished by three user responses. The user then attempts to measure an area but is told that this can not be done until a chart scale is established. To establish a chart scale the user types the command SC, then using the digitiser enters the start and end point of a known distance (the scale) and types the distance at the DECwriter. The user then types the HELP command (only the first two letters of a command are processed by the computer) to obtain a list of all possible commands.

The user then begins a measurement of area, after typing the command, he inputs the points around the perimeter of the area, using button one of the eight push buttons on the pen. When all points have been input the user presses button two and the program prints out the

```
                    PLAN EVALUATION SYSTEM

           DISTANCES WILL BE GIVEN IN : -

YARDS

           AREAS WILL BE GIVEN IN :  -

ACRES

           HOW MANY DISTANCE UNIT, SQUARED, IN ONE AREA UNIT ?

4840

MA

           SCALE HAS NOT BEEN GIVEN

SC

           HOW MANY SCALE UNITS WAS THAT ?

90. 025

HELP

           THE BASIC COMMANDS ARE : -

           SC     ESTABLISH CHART SCALE

           NP     CHANGE MEASURING UNITS

           HE     TYPE THIS DOCUMENT

           TE     TERMINATE THE CURRENT SESSION

           CO     PRINT OUT SOME USEFUL CONVERSION FACTORS

           MD     TO MEASURE DISTANCE

           CD     TO MEASURE DISTANCE CUMULATIVELY

           MA     TO MEASURE AREA

           CA     TO MEASURE AREA CUMULATIVELY

MA

           AREA          0. 873 ACRES

CA
```

FIGURE 22 SAMPLE DIALOGUE WITH PLAN EVALUATION SYSTEM

```
        AREA        1.218 ACRES          TOTAL     1.218 ACRES
        AREA        0.589 ACRES          TOTAL     1.807 ACRES
        AREA        0.873 ACRES          TOTAL     2.680 ACRES
NP
        DISTANCES WILL BE GIVEN IN : -
METRES
        AREAS WILL BE GIVEN IN : -
SQU.KMS
        HOW MANY DISTANCE UNITS, SQUARED, IN ONE AREA UNIT ?
1000000
SC
        HOW MANY SCALE UNITS WAS THAT ?
60
CD
        DISTANCE    54.405 METRES     TOTAL     66.405 METRES
        DISTANCE    56.766 METRES     TOTAL    123.702 METRES
        DISTANCE    39.666 METRES     TOTAL    162.838 METRES
        DISTANCE    49.337 METRES     TOTAL    212.175 METRES
        DISTANCE    54.470 METRES     TOTAL    266.645 METRES
TE
```

N. B. THE USERS RESPONSES ARE UNDERLINED

FIG 22 SAMPLE DIALOGUE WITH PLAN EVALUATION SYSTEM (CONT).

area in the given units. When measuring area or distance cumulatively the user presses button five to indicate the input of all areas or distances in the sequence. In the example the user goes on to change the measuring units and measures a series of five distances before terminating the program.

ADVANTAGES

Briefly the main advantages of the system are simple and quick operation, the ability to produce accurate results in any units required, and the ability to analyse either previously stored drawings or drawings of a standard nature on paper. The system is also tolerant of receiving wrong information. Obviously if the chart scale is inaccurately given then the program's results will be rubbish, but if the user attempts to type an incorrect command the program will inform him of the error and wait for a correct reply. Similarly, when entering numerical data if the user should type it incorrectly the program will repeat the question and wait for the correct number. The user thus develops confidence in the system and is not continually straining to type the correct input. Finally once the user has learnt how to operate the digitiser, using the system presents no difficulties at all.

CHAPTER EIGHT

SITE LAYOUT : THE DESIGN FEATURES

SYSTEM APPROACH

Architectural design can be thought to consist of three phases or layers, each one more detailed than the last. In the first stage of the design process the architect is involved in checking his client's brief and building up a feel for the site, considering such factors as orientation, prevailing wind, vistas, existing features, noise nuisance, etc. With this understanding of the site the architect is able to layout the main structure and to determine the basic type of access to and within the site. This layer of the design process may be termed the sketch level, the architect literally sketching his solution on paper.

Having established the basic concept of the design, the sketch solution is enlarged and a more detailed work up produced. The architect expands general features of the site layout into their component parts and begins to determine the feasability of the site layout (is the housing density satisfactory, is the access adequate, etc). This layer may be termed the basic level of design.

Once the architect is satisfied that the basic design will meet his client's brief he begins to analyse the site in detail, to ensure that the site is a workable proposal and meets any building code and regulations which are applicable. Other members of the design team such as road engineers, drainage engineers, service engineers, etc., will also be involved with this layer. This final layer of the design process may be termed the detail level.

Although the design process can be considered in such layers, each layer is developed from the previous one and the divisions between layers may not, in practice, be noticed. The present work retains this structure of the design process, the three design layers remaining within the computer programs. However the use of computer aided design techniques eases the work load of the architect and allows him to concentrate on producing a good design. Finally as the structure of the design process is unaltered by the use of a computer, the architect can work in a manner to which he is accustomed, and with the use of a computer at all levels of the design process, the overall efficiency in designing may be improved.

METHOD OF INTERACTION

A major problem occurring in all attempts at site layout is that while any site is of a three dimensional nature most of the present means of describing it are of a two dimensional nature (this includes present graphics systems, where we have a flat digitising table or tablet and a display screen). Any attempt at appraising the three dimensional nature of the site (e. g. model making) tending to be rather costly and inflexible. The computer model of the site must reflect the three dimensional nature of the real site and an efficient means of altering this three dimensional information, by a user having only a two dimensional means of interaction, must be provided.

To solve this problem the computer program has been arranged to split the specification of design features into two parts. The architect firstly specifying a design feature in plan and later using a section through the feature to determine heights. Such a solution follows the established method familiar to an architect, and the process differs slightly according to the design feature being considered. The solution is described further in the section on system operation.

Because the computer is holding a full three dimensional model of the site the architect may easily appreciate the site's true nature by means of perspective displays of the land and the design features. Perspectives can be generated from any viewpoint and the architect may even place himself within the site to check particular vistas to and from the site. Details of the perspective generation are given in chapter nine.

THE COMPUTER MODEL

The design features are split into two classes, roads and buildings, and before discussing the computer model we should state the requirements of the model. For the road model the basic requirements are : -

a) to allow a horizontal road alignment to be constructed and modified by a series of simple user procedures.

b) to allow a vertical alignment of a road.

c) to allow an earth volume analysis to be undertaken on the road data.

d) to allow a perspective display of the road data.

For the building model the requirements are : -

a) to allow buildings to be freely positioned anywhere on the site by a series of simple user procedures.

b) to allow automatic specification of a building's ground floor level, with provision for over-riding this choice if necessary.

c) to allow an earth volume analysis to be undertaken on the building data.

d) to allow a perspective display of the building data.

e) to allow a sunlight analysis to be undertaken on the building data.

f) to allow buildings to be shown on sections through the site.

In summary, the computer model of the design features should allow easy input and modification of three dimensional data by the user, and easy access to the data for analysis by further programs (Chapters 9, 10 and 11).

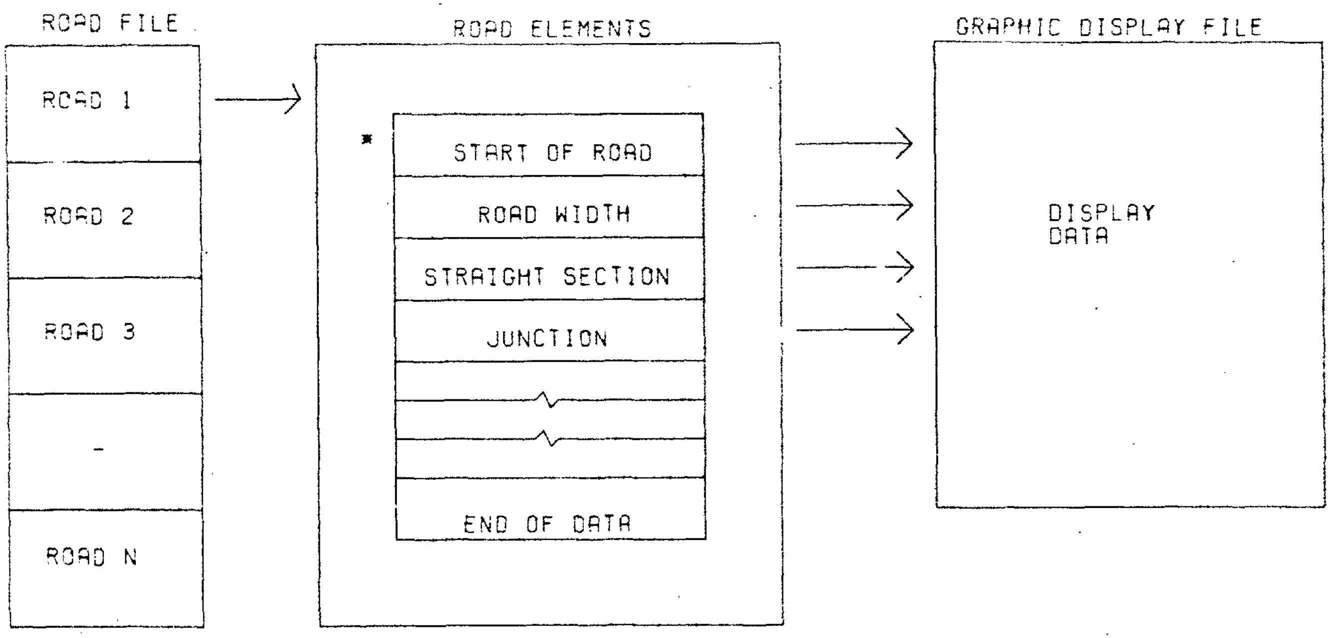
Figure 23 shows a diagrammatic view of the computer model of the roads. The data describing each road is held, on disk, in the road file. The size of the road file determines the maximum number of roads the system can handle. The data for one road is called into core as required, each road occupies up to 512 computer variables. A road is built up from a number of standard elements, each element is designated by a code word, followed by a list of variables specifying the element, full details of all elements and variables are given in Appendix Four.

From the road elements a picture of the road plan, or a section through the road, is generated and placed in the graphic display file. The user may interact with the data in the graphic display file and through it indicate changes and additions to the road elements. When the road data is accessed by a further analysis program, the road elements in the road file are processed as required. The road elements provide a compact and versatile method of storing the road data, allowing easy access for analysis programs and simple interaction procedures with the user.

The road data is not held directly in the graphic display file for the following reasons : -

a) the road data is three dimensional, whereas the graphic display file is two dimensional.

b) the picture data would be cumbersome to analyse.



* DETAILS GIVEN IN APPENDIX FOUR

FIG 23 COMPUTER MODEL OF THE ROADS

c) a separate road file represents the same information as a picture much more concisely.

d) one set of road data represents several pictures (plan, section and perspective).

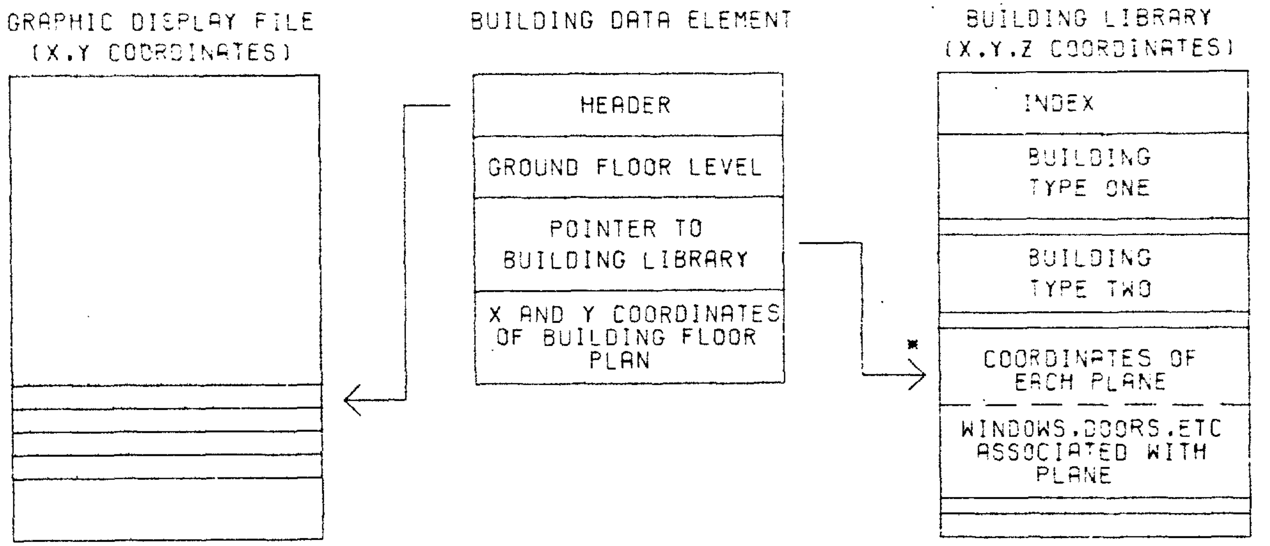
Figure 24 shows a diagrammatic view of the computer model of the buildings. Before using a building type the user must first write a specification of that type and place this in the building library, to specify a type each plane of the building is described by a series of X, Y and Z coordinates. Details of the specification are given in Appendix Five.

When a building is placed on the site a building data element is entered in the graphic display file. This element contains a header indicating it is associated with a building, the X and Y coordinates of the building floor plan, the ground floor level of the building, and a pointer to the building library. The first and second coordinate pair of the building floor plan give the origin and rotation at which the building is placed and this transformation can be applied to the building library contents to give the buildings true three dimensional coordinates.

The advantage of having a building library is that each building type need only be held in its full three dimensional form once. If each building were held as a separate three dimensional entity it would take about 500 variables to describe each building, using a library it takes 20-30 variables to describe each building.

SYSTEM OPERATION

Once the architect has viewed the existing site with the procedures available (Chapters 5, 6 and 7) he can begin to consider the design features. Naturally the architect is continually thinking of both the roads and the buildings when deciding on the site layout. However for the purpose of description they are kept separate in the



* DETAILS GIVEN IN APPENDIX FIVE

FIG 24 COMPUTER MODEL OF THE BUILDINGS

following discussion.

Layout of roads

The architect is allowed to build up a road plan from a selection of basic road sections (Figure 25). A list of options being displayed on the screen, any one of which may be chosen as desired. If, for example, the architect selects the option of entering a straight section of road, he is asked to digitise the start and end points of the section's centre line. The right hand and left hand sides are automatically added by the computer and the full road section displayed. The input procedure for each of the basic road sections is similar to that just described and in all cases prompting messages are displayed, and the option of terminating the input before completion is allowed. Additionally various error messages will be displayed if the user's actions cannot be applied to the data base.

A list of parameters describing the basic road sections is kept and the user may display its contents and change any of the parameters he requires. Once changed a parameter remains in force until the next alteration. There are eight parameters in the list namely : -

1) left hand side road width.

2) right hand side road width.

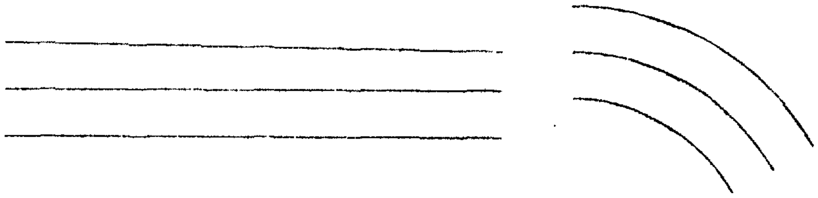
3) radius of a curved section.

4) radius of fillets at a junction.

5) width of a L-shaped road end.

6) length of a L-shaped road end.

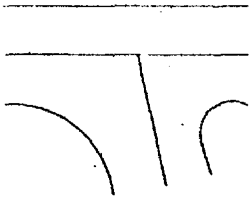
7) width of a T-shaped road end.



A STRAIGHT B CURVED

C T-SHAPED ROAD END D STRAIGHT ROAD END

E1 L-SHAPED ROAD END E2 L-SHAPED ROAD END



F JUNCTION

FIG 25 THE BASIC ROAD SECTIONS

8) length of a T-shaped road end.

Initially only the straight sections are positioned and a sketch level design created (Figure 26). Once the sketch level is complete the architect can begin to produce a basic design of the road plan by means of the other road sections (Figure 25b - 25f). As these sections are entered the straight sections are shortened or lengthened to accommodate the new sections (Figure 27). Any road section that has been incorrectly specified may be deleted and the correct section then entered.

Having completed the road plan the vertical alignment of each road may be entered. Firstly the computer calculates the order of each road and determines the chainage of each road element (the road does not have to be entered in the correct order). Inconsistencies within the road data are displayed on the screen for the user to examine. If the road data is correct the user is allowed to proceed. It is at this point that the user begins to interact with the third dimension of the road model.

The user selects the road he wishes to align and a section along it is displayed, showing the position of each basic road section and the original ground level along the road (Figure 28). The finished road level is entered as a series of straight gradients which are specified by their start and end point, or by their start point and slope. The height, chainage and slope of each road gradient are displayed to help the user. Existing points of the finished road may be freely moved and road gradients can also be deleted.

When all roads have had their vertical alignment entered the basic level of the road design is completed. The user is then free to enter the detail level and begin analysis of the road data. Two principle analyses are available, the ability to generate a three dimensional perspective display (Chapter Nine) and the ability to undertake an earth volume analysis (Chapter Eleven) to find the amount

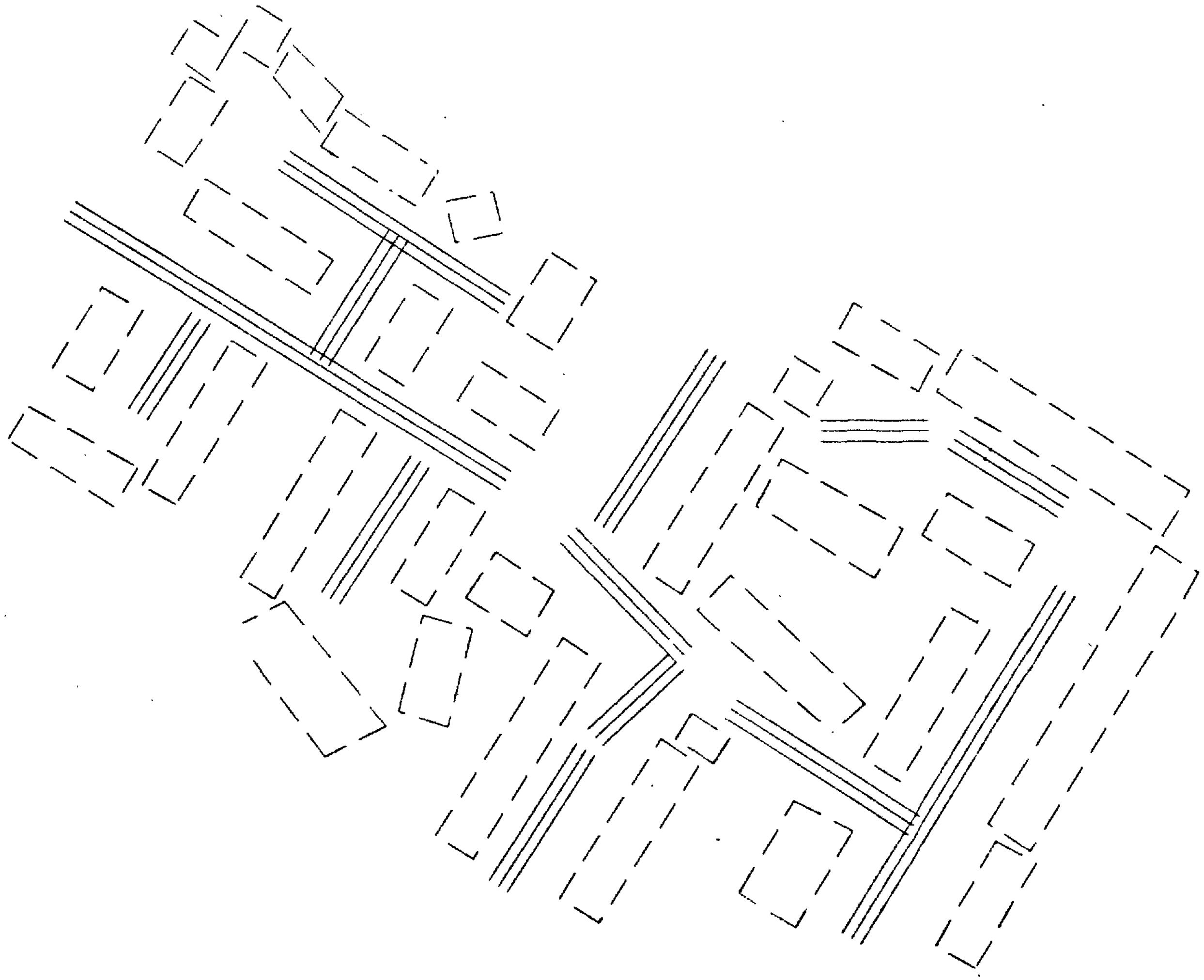


FIG 26 A ROAD AND BUILDING LAYOUT AT THE SKETCH LEVEL OF DESIGN

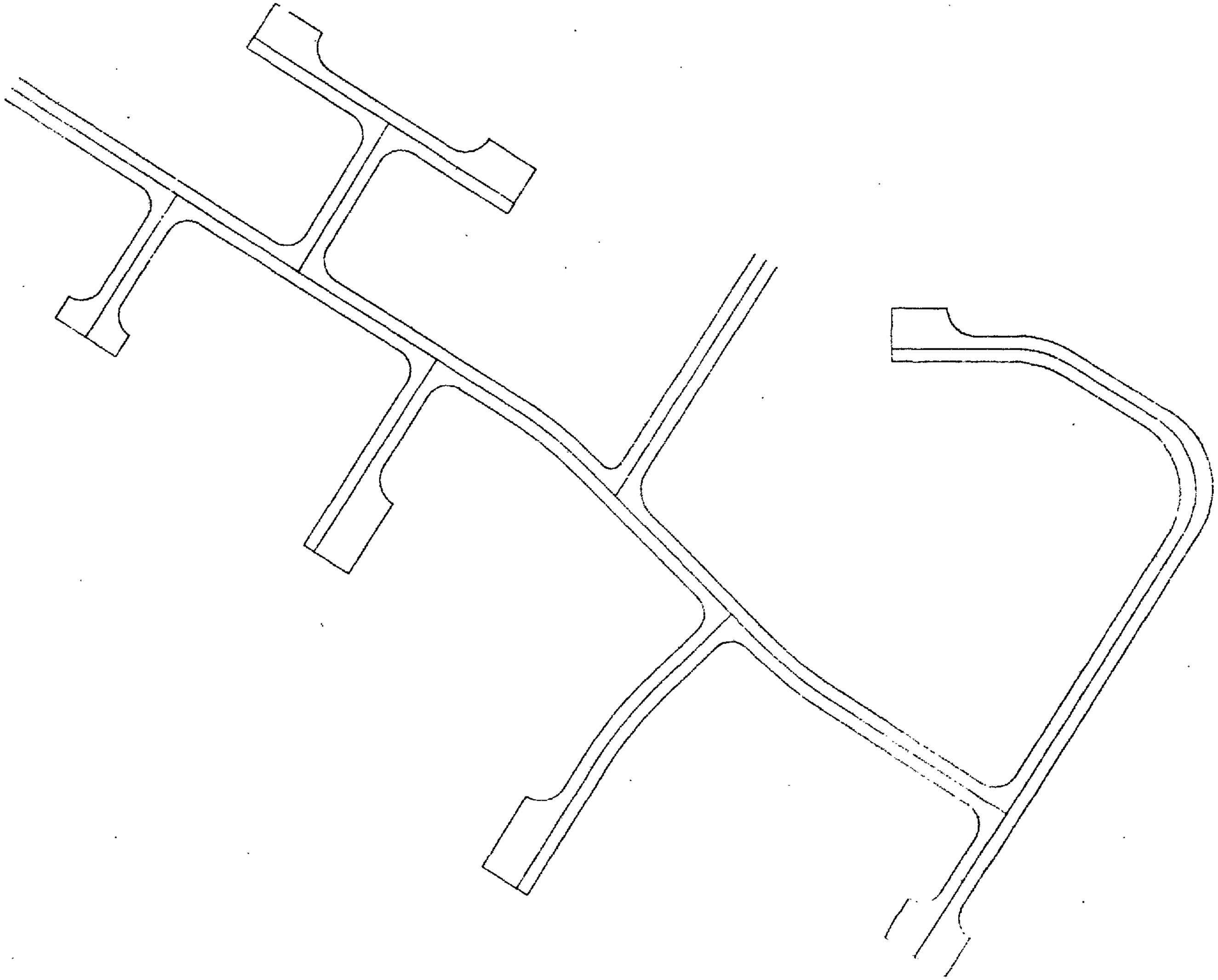


FIG 27 A ROAD LAYOUT AT THE BASIC DESIGN LEVEL

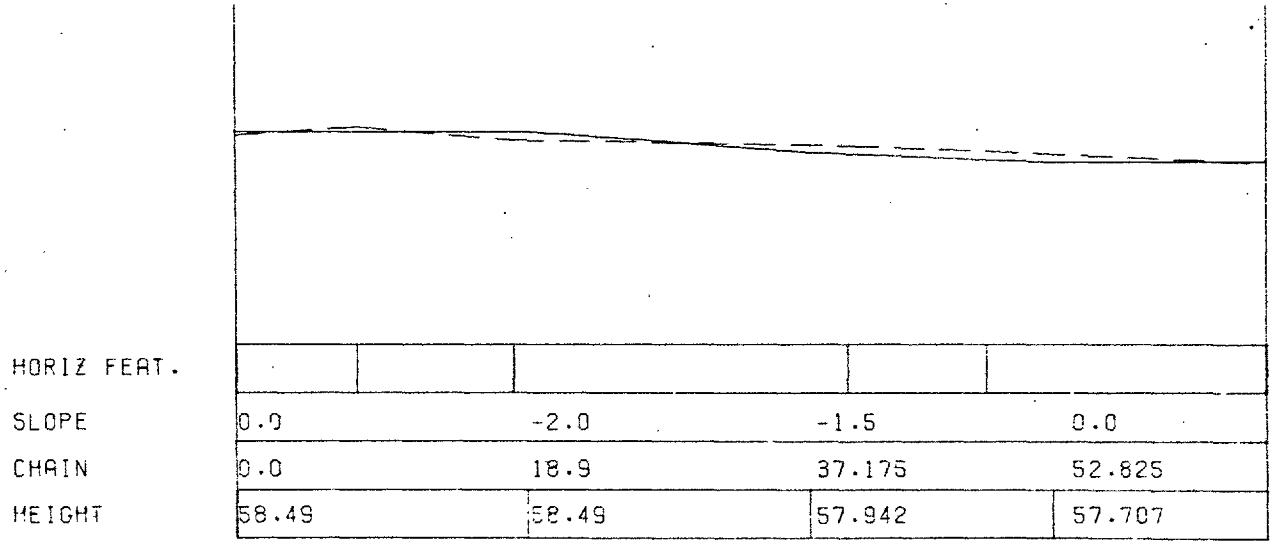


FIG 28 A VERTICAL SECTION THROUGH A ROAD, SHOWING THE ORIGINAL GROUND LEVEL (DOTTED LINE) AND THE FINISHED ROAD LEVEL (SOLID LINE).

of cut and fill necessary for laying out the road. If the analysis should reveal that the road layout is unsatisfactory the user is free to go back to any stage of his design and make alterations to it.

Layout of buildings

All buildings added to the site layout are considered to be of a standard form, and relative to an origin on the building the three coordinate dimensions remain constant, wherever the building is placed on the site. This allows a complete three dimensional specification of the building to be made, prior to its positioning on the site layout. The specification when complete is added to a building library, this library may be built up to contain all the standard forms that will be used on a particular site layout.

Currently the specification is typed in at the DECwriter from a series of coded input forms, though it is hoped, in the future to employ graphical aids to speed up the specification of new building forms. The computer does, however, automatically generate the mirror image of a building type, so the user need only prepare one building specification before entering both a right handed and left handed version of a building to the site layout.

The sketch level design of buildings is undertaken within the computer aided design system and a series of simple boxes may be drawn for each building or row of buildings (Figure 26).

At the sketch level only two dimensional (plan) information is held. The basic design level concerns the full three dimensional specification of the buildings. In order to specify the building the architect selects the type required from a list of the building library contents (a description of the building type being first placed in the library) and then gives the point and rotation at which the building is to be positioned. Once he has selected a building type he may continue entering buildings of that type or select a different type. Existing buildings may be rotated, moved or deleted to produce the finished layout (Figure 29). As each building is placed within the site, the existing ground level at its location is determined and using this, a ground floor level is automatically set by the program. The level may be inspected by the user and changed if necessary.

At the detail design level there are four principle analyses which may be undertaken on the building data. Firstly buildings may be shown on sections through the land, to aid determination of their floor level. Secondly a perspective display of the buildings either with or without features such as windows and doors is possible (Chapter Nine). Thirdly an earth volume analysis can be undertaken to determine cut and fill values (Chapter Eleven). Fourthly an analysis of the sunlight received by any building on the site, at any time of year may undertaken (Chapter Ten).

LIMITATIONS

The main limitation of the present work is the inability to handle vertical curves in the vertical road alignment. Although for most purposes they may be approximated to by a straight gradient, this does not give a true representation of the desired road. In an expanded system the first task would be to allow vertical curves in a road alignment thus giving an accurate representation of a road.

A second limitation of the present system is the small set of design features it handles. This set could be expanded to include new forms, for example, footpaths, and additional road elements could be introduced into the system. This would increase the number of sites to which the computer system was applicable.

A third limitation of the system is the analyses carried out on the data are not as extensive as they could be, for example, it would be simple to accept further information regarding the position of drains and to then go on and perform the drainage calculations. The positioning of other services such as gas and electricity could also be considered.

However none of the limitations is serious, in as much as, given

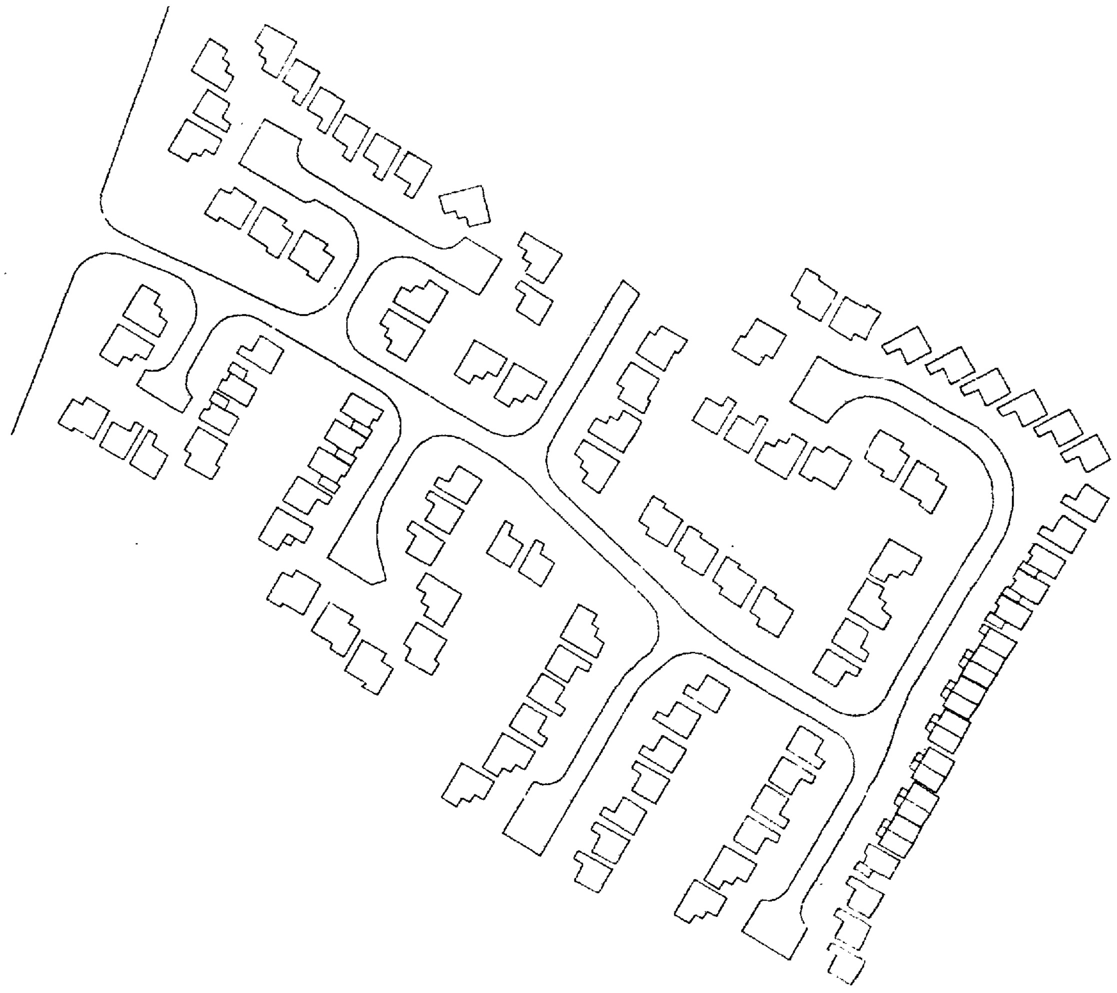


FIG 29 A BUILDING LAYOUT AT THE BASIC DESIGN LEVEL

more programming effort the system could easily be extended to cover all the areas mentioned.

CHAPTER NINE

THE GENERATION OF PERSPECTIVE DISPLAYS

INTRODUCTION

Once a three dimensional model of a site layout is entered into the computer, by the procedures of the last chapter, perspective displays of this model may be used to provide the user with a means to the better understanding of the site layout. Perspective displays can be prepared by hand, but this is an extremely tedious process and requires that the correct viewpoint be chosen. By using a computer graphics facility perspectives can be readily generated and as many viewpoints as required may be inspected, giving the user a fuller appreciation of the site layout.

If the model data is used in its full state, the display generated is known as a wire frame model. This suffers from the disadvantage that all lines are shown whether or not they are really visible from the chosen viewpoint, but it can be produced quickly. However when a complex picture is displayed a wire frame picture becomes difficult to interpret and the viewer must be given some clues as to the real nature of the picture.

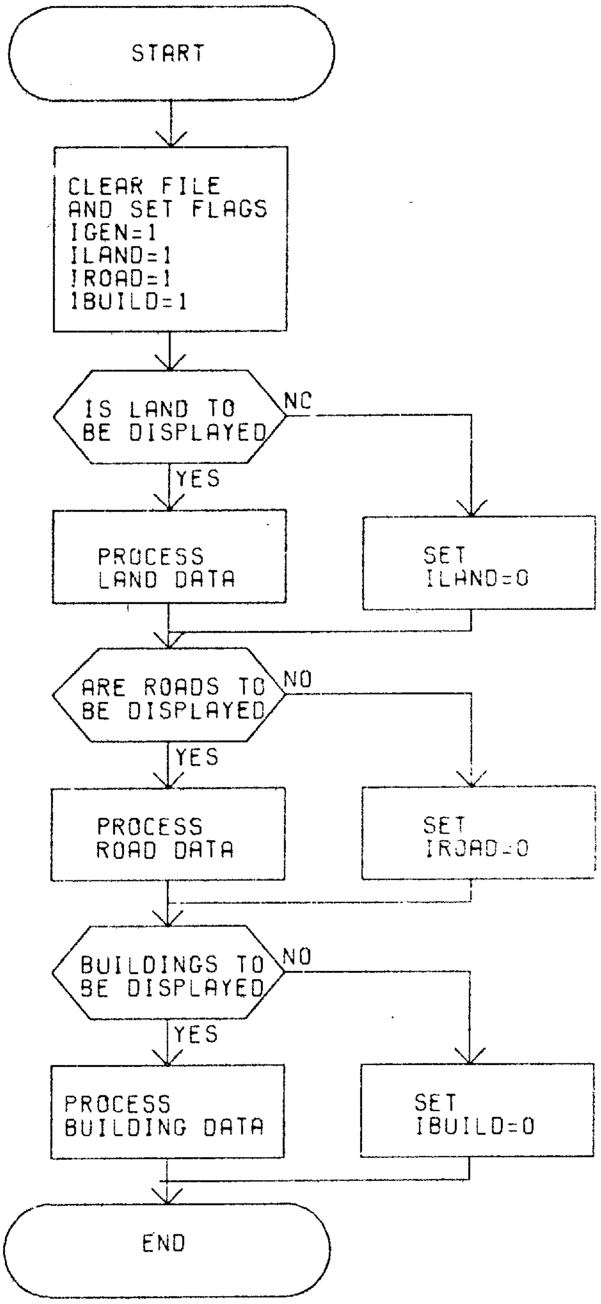
One method of providing a clue to the interpretation of a picture, known as depth modulation, requires that lines farthest away from the viewpoint are drawn with less intensity (fainter) than lines near to the viewpoint. Although useful this could not be used on the present display screen, as this had an insufficient range of intensities. The Tektronix 611 has only four intensity levels and for the method to be successful at least eight distinct levels of intensity are needed. A further method is to rotate the picture or wobble it about a fixed point, but again the display hardware prevented this, a refreshed screen being required to effect this. For pictures of any complexity the Tektronix 611 cannot display information at a fast enough rate for the real time rotation of objects.

The best way to remove ambiguities from the perspective display is to remove the lines which cannot be seen from the chosen viewpoint (hidden lines). This procedure however requires complex programming and a relatively large amount of computer time. Much work has been carried out elsewhere on this problem.11),12) A reasonable picture can be produced by employing local hidden line removal, in this case each plan of an object is examined to determine its visibility, but the plane is not compared with the other planes in the picture, to determine if it is obstructed by these planes. Local hidden line removal is readily programmed and provides an adequate display and does not require complex display hardware, for these reasons it was employed in the present work.

SYSTEM OPERATION

The user can select to view any of the three major site features, namely, the land, the roads, and the buildings. In order to do this he enters a generation procedure, a flowchart of which is given in Figure 30. The user is asked which of the features he wishes to view, and as the user enters his choice the program sets decision flags to indicate the user's choice and builds up the required picture in a three dimensional display file, accessing each of the three computer models for the relevant data.

The data of the computer models is not simply transferred to the three dimensional display file but may be modified under user control. For the land the user can specify the spacing of traverses across the site, this is done in terms of the number of grid squares between traverses. A large spacing leading to fewer lines in the picture, the picture is then less detailed but can be displayed more rapidly. The road data is modified by the computer program, the curved sections of the road being approximated to by straight lines in the three dimensional display file. This reduces the complexity of the display program (only straight lines need be processed) and enables a faster display time. Finally the user can specify whether the buildings are to be displayed



PROGRAM FLAGS -
IGEN =1.DATA GENERATED.BUT NOT DISPLAYED
=0.DATA GENERATED AND DISPLAYED
IROAD =1.ROADS TO BE DISPLAYED
=0.ROADS NOT DISPLAYED
ILAND =1.LAND TO BE DISPLAYED
=0.LAND NOT DISPLAYED
IBUILD =1.BUILDINGS TO BE DISPLAYED
=0.BUILDINGS NOT DISPLAYED

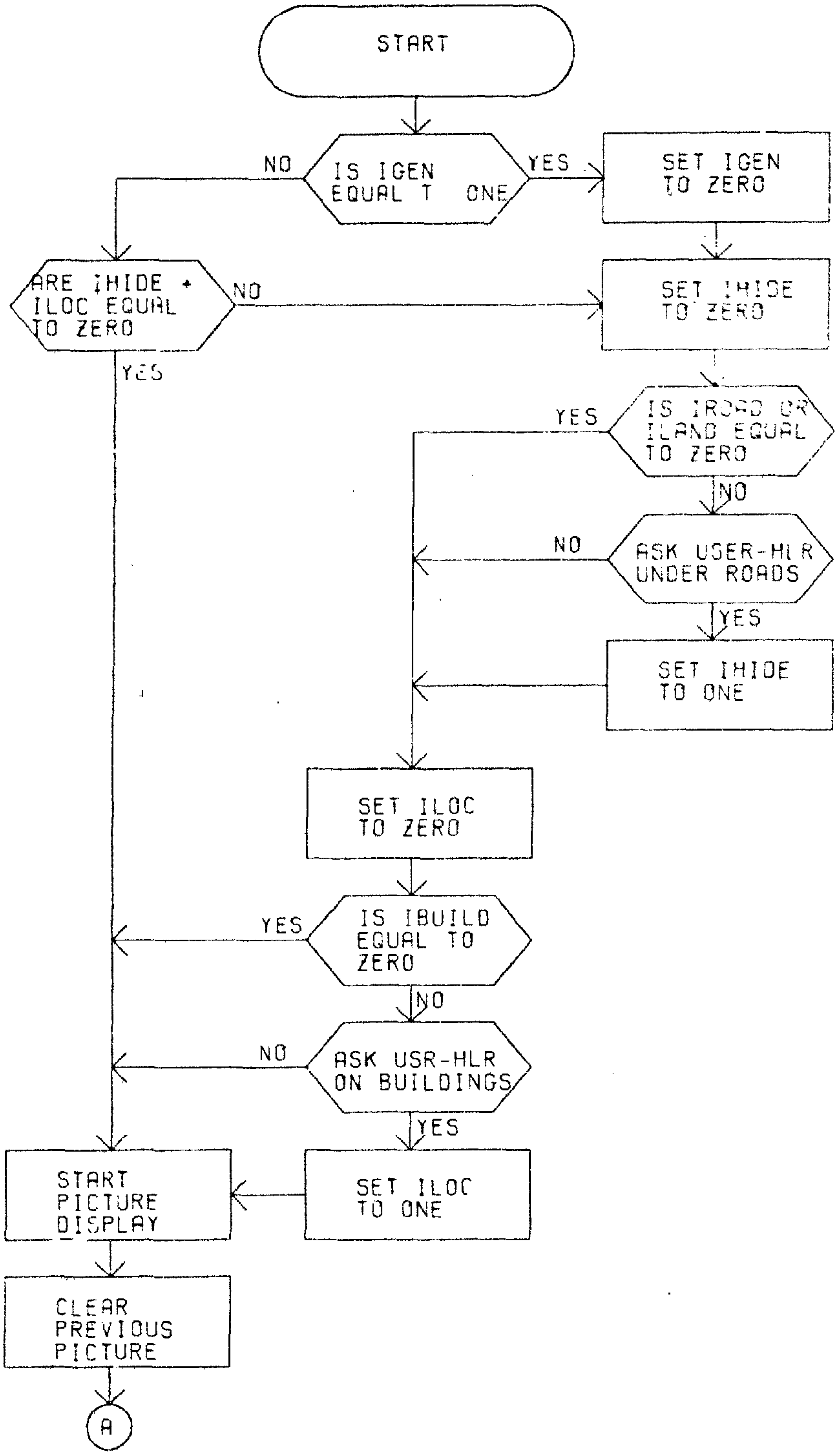
FIG 30 GENERATION OF THE THREE-DIMENSIONAL DISPLAY FILE with or without features such as windows and doors on the faces of the building.

The user is free at any time, whilst operating the computer aided design system, to define the point the perspective view is to be from, the point the perspective view is to be towards, and the aperture of the perspective view. The aperture of the view is the ratio of the screen height over the viewer's distance from the screen. A small aperture produces a wide angle lens effect and a large aperture produces a telephoto lens effect. The viewpoints are specified by their X, Y and Z coordinates and the three coordinate values are entered via the keyboard area of the digitiser.

When the user initiates the display of a perspective view the program either uses the viewpoints last set by the user, or else the user has the option of specifying the viewpoints with the digitiser. If the viewpoints are specified with the digitiser the user may view a plan of the site to aid input of the viewpoints. The program then interrogates the land model to determine the height value at the point the view is to be from, and adds 1.75 m to this, to form the height of the viewpoints. When the user has specified the viewpoints the program begins the procedure shown diagrammatically in Figure 31.

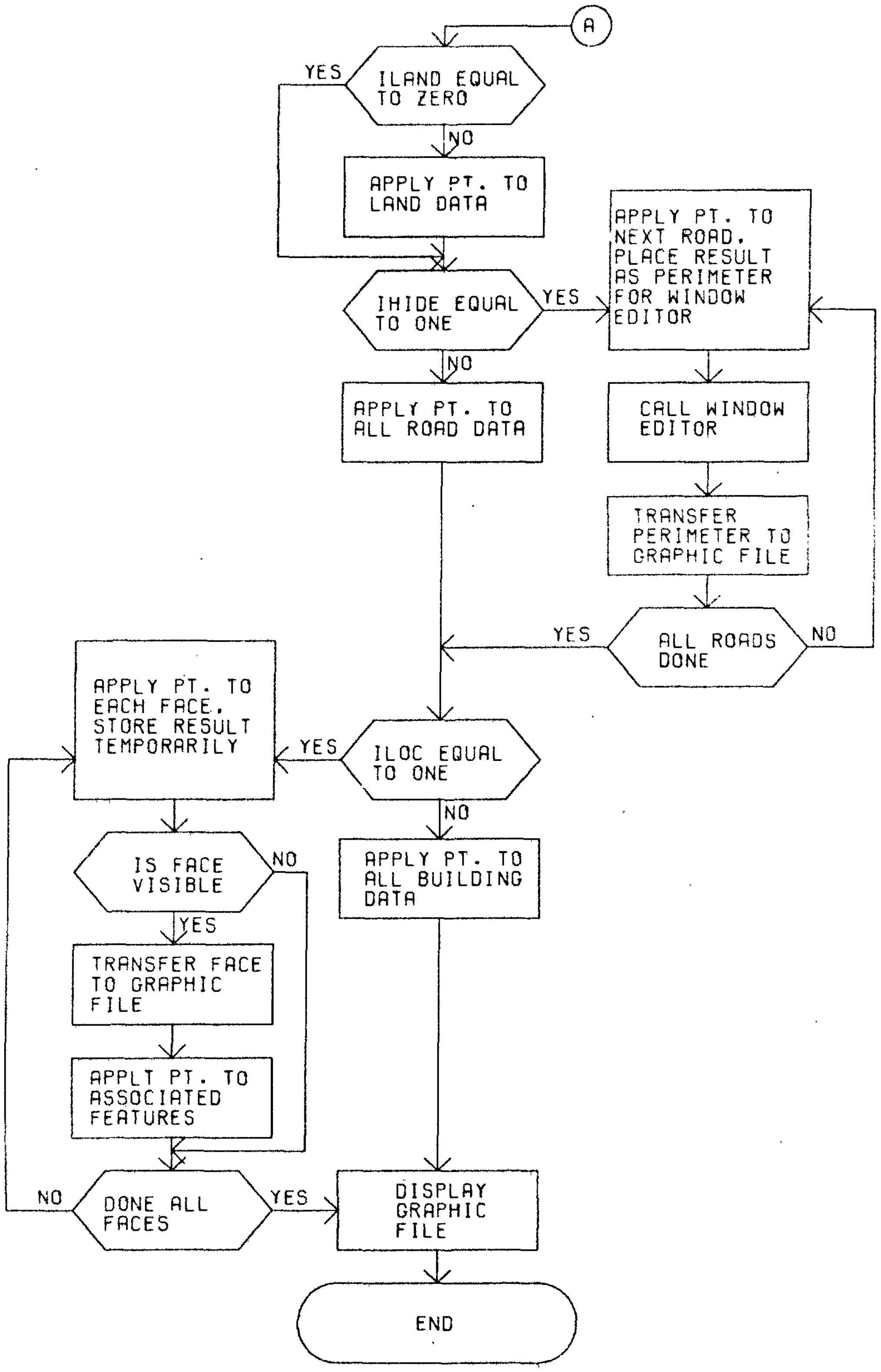
The program examines the decision flags set by the generation procedure to see if hidden line removal can be carried out. If, for example, no buildings occur in the three dimensional display file, the program does not ask the user if he wants local hidden line removal applied to the buildings. The purpose of this section of the procedure is to reduce the amount of user intervention, without reducing the options available to the user.

When a picture is displayed without hidden line removal the view points may be changed and the picture redisplayed without further user intervention, otherwise the program asks if hidden line removal is required each time the viewpoints are altered. It should be noted that the program does not automatically undertake hidden line removal,



PROGRAM FLAGS -
IHIDE =1.PERFORM HIDDEN LINE REMOVAL UNDER ROADS
=0.DISPLAY ALL LAND GRID
ILOC =1.PERFORM LOCAL HIDDEN LINE REMOVAL ON BUILDINGS
=0.DISPLAY ALL BUILDING LINES

FIG 31 DISPLAY PROCEDURE FOR THE THREE-DIMENSIONAL DISPLAY FILE



N.B. PT. = PERSPECTIVE TRANSFORM

FIG 31 DISPLAY PROCEDURE FOR THE THREE-DIMENSIONAL DISPLAY FILE (CONT).

but also provides the user with a means of displaying wire frame pictures. This means if the user is investigating a large number of views he may dispense with hidden line removal, and thus speed up operation of the display program.

Having determined the wishes of the user the program begins the display proper. Firstly the perspective transformation is applied to the land data (if displayed) and the result placed in the two dimensional graphic file. The program then processes the road data.

Either the perspective transformation is applied to all roads, the result being placed in the two dimensional graphic file. or if hidden line removal of the land under the roads is required, each road is processed in turn. The perspective transformation is applied to the road data, which is then communicated to the window editor program (Chapter Three). This program removes all lines of the land data occurring within the perimeter of the road, and is exactly the same program as may be directly called by the user, to deleter an area of the drawing. When the window editor has completed its task control is returned to the perspective display program which then transfers the road data (still held in the perimeter file of the window editor program) to the two dimensional graphic file. Having processed all roads the program considers the building data.

Either the perspective transformation is applied to all the building data, the result being placed in the two dimensional graphic file, or if local hidden line removal is required on the buildings, each face of a building is processed in turn. The perspective transformation is applied to each face, and the face then checked to determine its visibility. Each face is entered into the building library in clockwise order, when looking from outside the building towards the inside, therefore if the area of the face when transformed is positive, the face is visible and if the area is negative, the face is not visible and is discarded. When a plane is not visible all features (windows, doors, etc) associated with that plane are also considered as not visible. By associating all features with a plane one simple test can determine whether a large group of lines should or should not be displayed, this leads to a fast hidden line removal program. All visible planes are transferred into the two dimensional graphic file, and when all buildings have been considered the two dimensional graphic file is displayed on the screen, examples of perspective displays are shown in Figures 32-34.

DATA STORAGE

The three dimensional display file consists of a series of integer quadruples : -

I IX IY IZ

The I value signifies the meaning of the data stored. The I values and their meanings are : -

0	End of file
1	Scale factors, true value = given value x scale factor.
2	Move to point with pen down.
3	Move to point with pen up.
4	New level.
5	Redundant data.
6	Line type.
10	Start of a building face.
11	End of a building face.
12	End of all features on a building face.

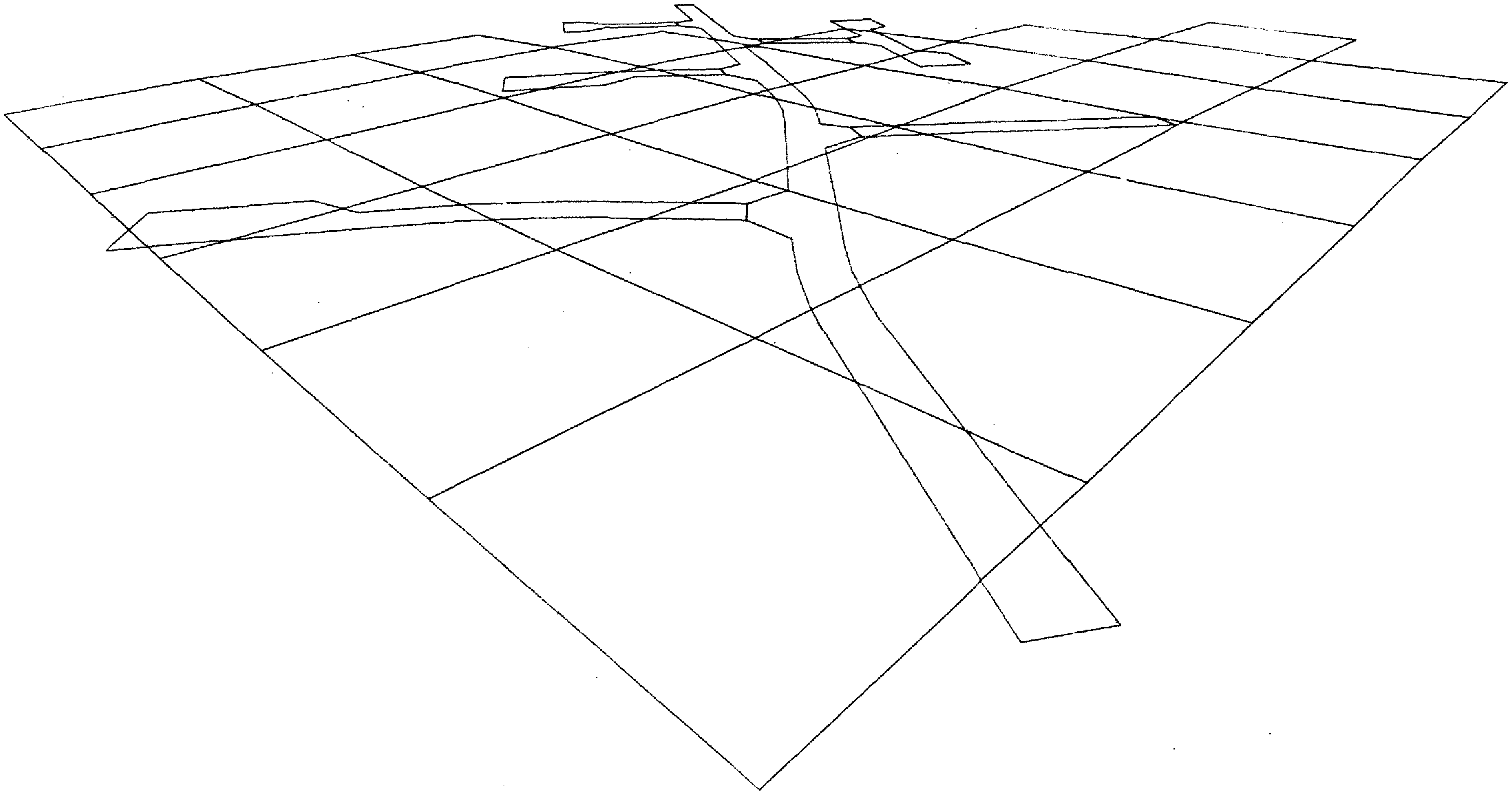


FIG 32 A PERSPECTIVE DISPLAY OF A ROAD LAYOUT SUPERIMPOSED UPON THE LAND GRID (NO HIDDEN REMOVAL)

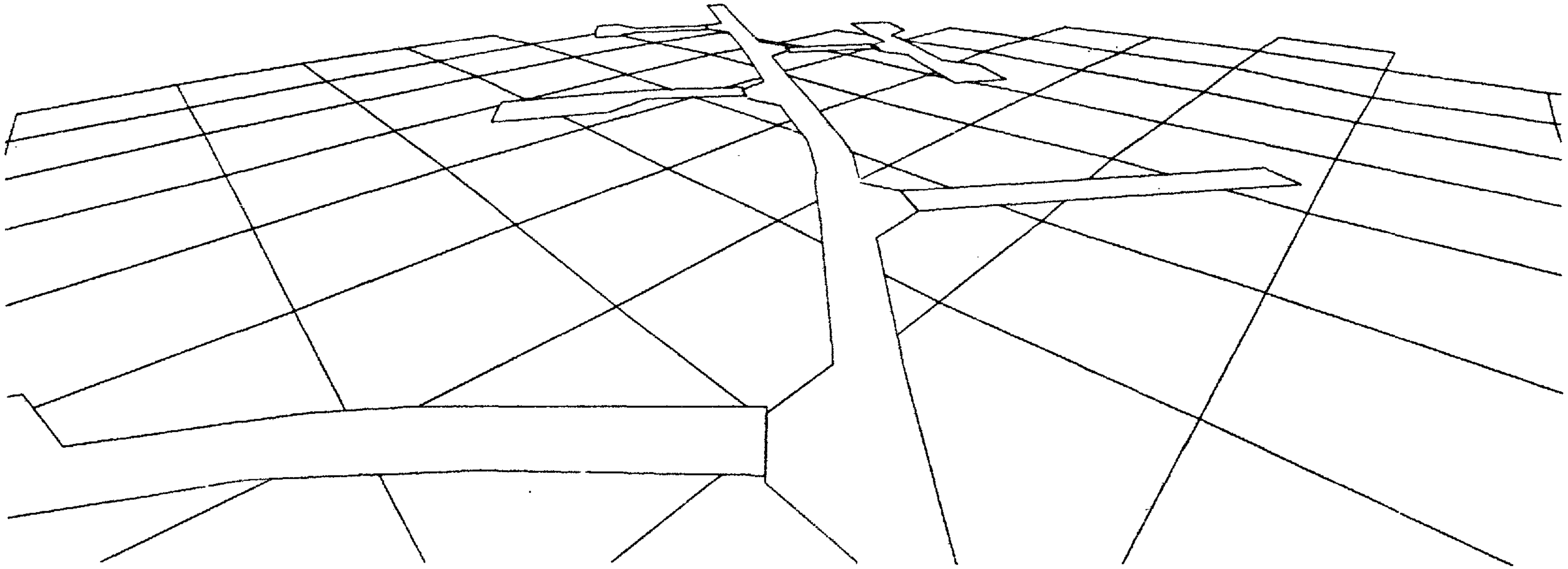


FIG 33 A PERSPECTIVE DISPLAY OF A ROAD LAYOUT SUPERIMPOSED UPON THE LAND GRID (WITH HIDDEN LINE REMOVAL)

FIG 34 A PERSPECTIVE DISPLAY OF
A GROUP OF BUILDINGS

The coordinates IX, IY, IZ are given in terms of the digitiser position, the units being tenths of a millimetre. Hence the true coordinates of a point are obtained by multiplying the data by the input scale.

The data held in the three dimensional display file is described in a right handed cartesian coordinate system (Figure 35) and before a perspective transformation is applied to the data it must be transformed to a left handed viewing coordinate system (Figure 36). The viewing coordinate system has the X and Y axes along the sides of the display screen and the Z axis goes into the screen, passing through its centre. The origin of the viewing coordinate system is at the observer's eye.

Generating a true perspective image requires dividing by the depth of each point, there are however several ways in which this can be done. The method chosen is the simplest case, where a straight line is drawn from a point on the object to the origin, the point at which it cuts the viewing plane (display screen) giving its transformed coordinates. Looking at Figure 37 we see that by similar triangles : -

$$XS = A.XE/ZE$$

$$YS = A.YE/ZE$$

Where XE, YE, ZE are the coordinates of the point in the viewing coordinate system and XS, YS are the display coordinates of the transformed point.

Once we have found the transformed coordinates of a point we must discover if it is within the observer's range of view. Any part of a line lying outside the pyramid formed by the origin and the four corners of the screen is not visible and must be scissored, that is removed from the display. This is performed using an algorithm devised by Evans and Sutherland which is described in Newman and Sproull.[13)] The algorithm is given in ALGOL and this was translated into FORTRAN for use in the present work.

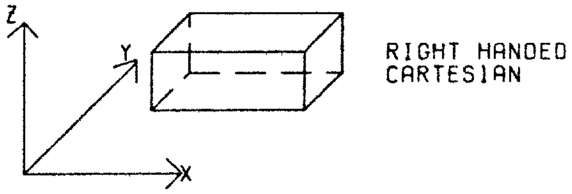


FIG 35 OBJECT COORDINATE SYSTEM

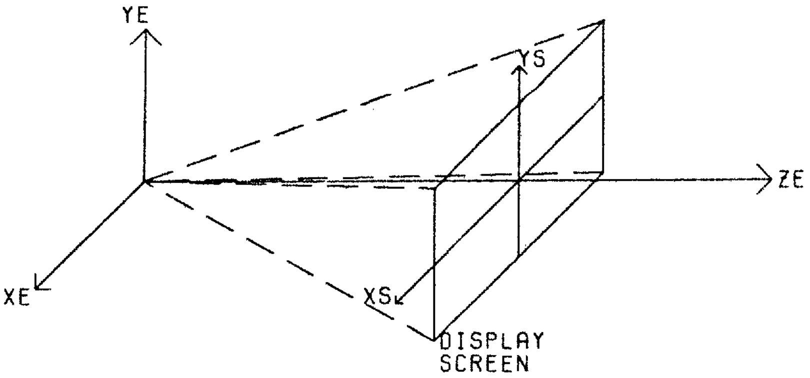


FIG 36 EYE COORDINATE SYSTEM

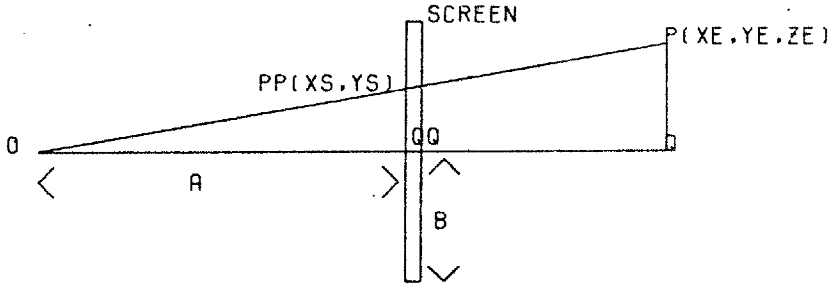


FIG 37 PROJECTION ONTO DISPLAY SCREEN

SUMMARY

The perspective display system provides the architect with a means of viewing the true three dimensional nature of a site. Although the display generated is relatively simple and no details of the individual features are given, it nevertheless allows the architect to develop a much better understanding of the site. The display of perspective views is one feature of the computer system for which a counterpart is not found in the traditional methods used. The architect is thus provided with a new tool in his site layout work, and furthermore the perspectives may be shown to a client at the early stages of the design work, to help him clarify his requirements.

Intelligent programming has reduced the amount of user intervention needed, without lowering the number of options available, and the system is flexible and easy to use.

One possible extension of the system would be the production of drawings with full hidden line removal. This might be achieved by using one of the general purpose hidden line removal algoriths already developed and adapting it for use on the mini-computer.

CHAPTER TEN

SUNLIGHT IN BUILDING DESIGN

THE IMPORTANCE OF SUNLIGHT

The analysis of the sunlight received at different parts of a site layout, is a subject which has been neglected in the past. This may be due to the fact that the present procedures are somewhat cumbersome and inflexible, and the attitude that sunlight is the last thing you have to worry about in the English climate. Nevertheless a building layout should make the best use of what little sunlight we get, and in Scotland (where daylight hours are shorter) building regulations do specify a minimum requirement for the living room of a house.

Recent developments such as the interest shown in the possible uses of solar energy and increased building programs in the Middle East, are leading to an increased awareness of the role of sunlight and the need to predict its impact on a site layout.

It has been shown 14),15) that people expect to have a reasonable amount of sunlight in their homes and at their place of work. Many housewives like to have sunlight in the room they are working in, implying sunlight entering the kitchen during the morning and moving round to the living room in the afternoon. And many factory layouts provide an area of grass to sit out on, and sunlight must be received by this area during the lunch break, even if during the morning or afternoon the area is in shadow.

There are five basic reasons why people like to see sunlight in their homes and those stem from the visual properties of the sunlight they are : -

1) It creates the type of environment which we associate with pleasantness, warmth, sparkle and variety.

2) It enhances colours and contrasts, reveals texture and form.

3) It adds to the amount of working light available in remoter parts of a room.

4) It provides a strong source of directional light.

5) It provides a visual link with the outdoors in a way diffused daylight does not.

The only visual disadvantage of sunlight is glare, which must be eliminated, particularly from special buildings such as school classrooms and hospital wards.

The thermal properties of sunlight must also be considered and evaluated. In this country people often derive a pleasing warmth from sunlight entering their rooms. But in countries nearer the equator both the glare and heat from the sun can be excessive and measures have to be taken to shade the sun.

Apart from unwanted glare, the visual effects of sunlight are wholly beneficial, and people may be prepared to put up with some glare at times if they can have the advantages of sunlight at other times. Further surveys need to be carried out to determine the exact requirements for sunlight, though the present surveys have clearly shown that sunlight is an important part of the working environment.

THE COMPUTER MODEL AND OPERATION OF THE SYSTEM

Having determined a building layout by the procedures of Chapter Eight, the architect can investigate the amount of sunlight received by any building. This information can be generated for sites at all latitudes, and all times of year. The computer program is simple to use and has far greater flexibility than the traditional methods (shadow graph protractors, etc).

In order to use the program the architect must supply four items of information, namely : -

a) the latitude of the site.

b) the date for which the analysis will be carried out.

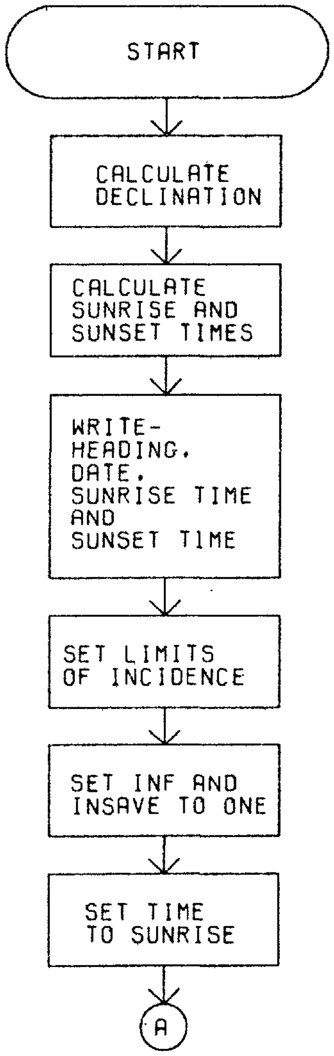
c) the site orientation (specified by a North-South line).

d) the window position.

The program maintains a list of the four variables, and displays their current values for user inspection. The user may alter any one of the variables, and once entered a variable is saved by the program for use with more than one analysis. Thus if the architect requires to run a second analysis with a different date, then only a new date need be entered, the other three variables remain set from the first analysis. As the user only specifies a variable when it is changed, and not every time an analysis is run, the workload of the user is reduced and the program is easy to run.

The latitude and date are entered by means of the keyboard area, latitudes in the northern hemisphere being entered as positive numbers, and latitudes in the southern hemisphere being entered as negative numbers. The date is entered in two parts, firstly the day, and secondly the month in the form of a number between one and twelve. To enter the site orientation two points are digitised, the second point being placed to the north of the first point. Finally, the window position is entered by digitising a point near to a building. the program searches for the nearest building and enters the window position as the point on the building nearest to the given point. The user then enters the window height by means of the keyboard area. The window position is marked by a small cross. When all four variables are specified to the user's satisfaction the analysis procedure may be initiated and the program carries out the procedure shown in Figure 38.

The program only considers sunlight as received if there is no building obstructing the sun and if the conditions of the British Standard 16) are met. The British Standard recommends that one of the main windows in living rooms and, if practicable, in kitchens



```
PROGRAM FLAGS -
     INF     =0.SUNLIGHT RECEIVED BY POINT
             =1.SUNLIGHT NOT RECEIVED
     INSAVE = LAST VALUE OF INF
```

FIG 38 THE PROCEDURE FOR A SUNLIGHT ANALYSIS

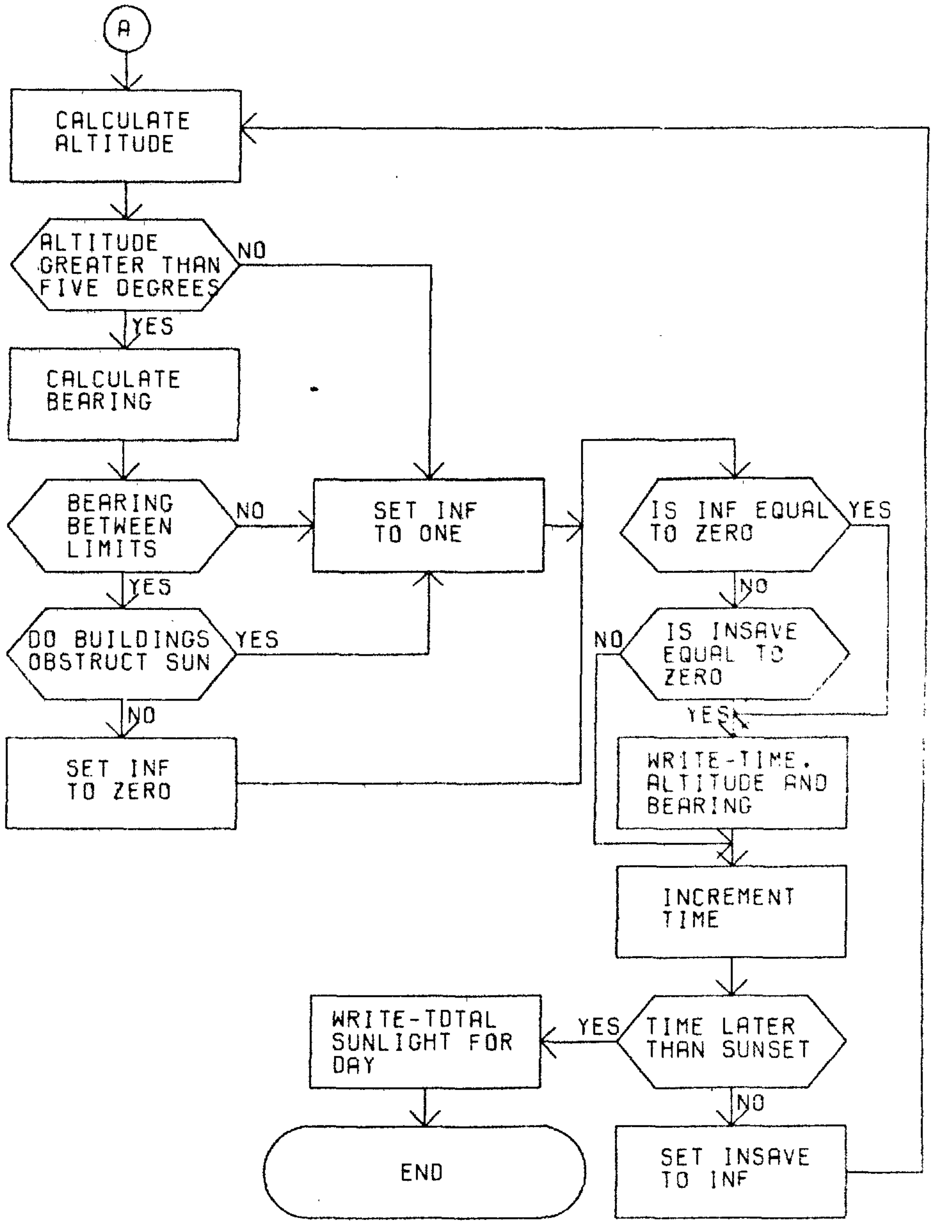


FIG 38 THE PROCEDURE FOR A SUNLIGHT ANALYSIS (CONT)

and bedrooms also, should be so placed that sunlight can enter for at least an hour at some time of day during not less than ten months of the year from February to November. In arriving at this standard,

a) sunlight is not considered as entering a room if the horizontal angle between the sun's rays and the plane of the window is less than $22\frac{1}{2}$ degrees.

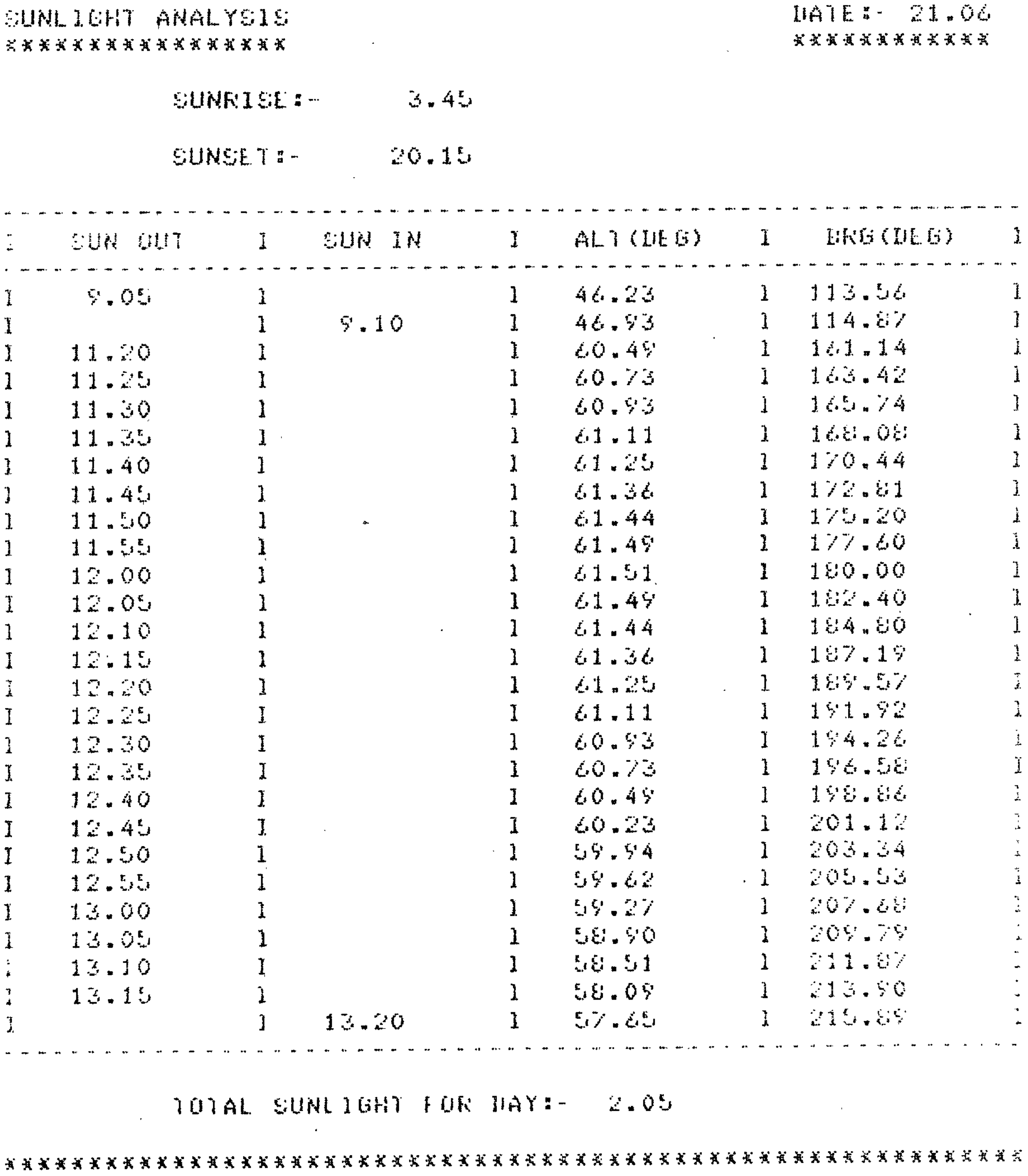
b) sunlight is not considered to be useful unless the sun has an altitude above the horizon of more than 5 degrees.

The program checks that all the necessary conditions are met and prints a list of the times at which the sun is visible, the results being at five minute intervals. An example of the program output is shown in Figure 39.

The program uses a simple model of the sun and earth in order to determine the altitude and bearing of the sun at any time and latitude, details of this model are given in Appendix Six.

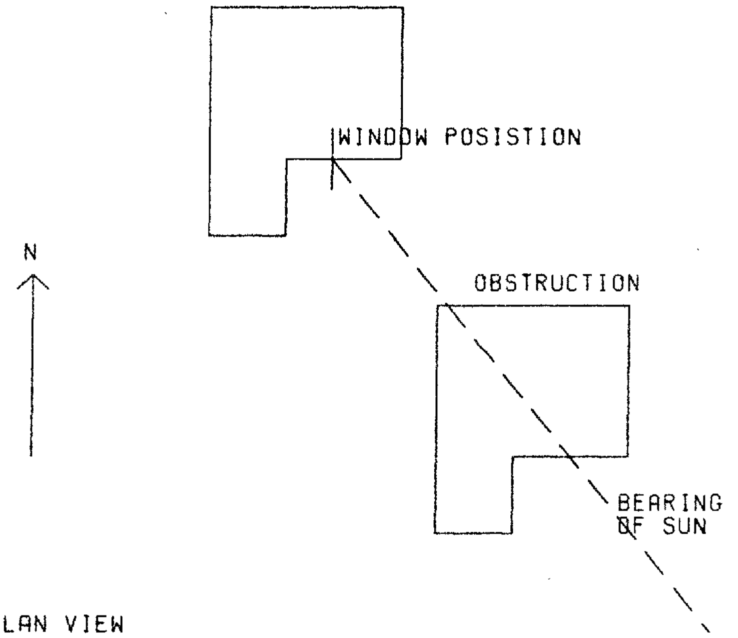
In order to decide if any building obstructs the sun, the program firstly considers if a line at the bearing of the sun intersects the plan view of any building (Figure 40). The plan view of a building is held in the graphic display file and each point is specified by a X and Y coordinate. If the line to the sun does not intersect a building in a plan view, the sun is not obstructed. This test may be carried out on two dimensional data, and performed without accessing the building library, it thus provides a quick method of eliminating many cases where the sun is unobstructed.

If, however, an intersection occurs the three dimensional building information must be considered. Each plane of a building is considered in turn to determine if a line at the bearing of the sun intersects it. If an intersection occurs the height of the plane at the intersection point is found and the angle subtended between that point,

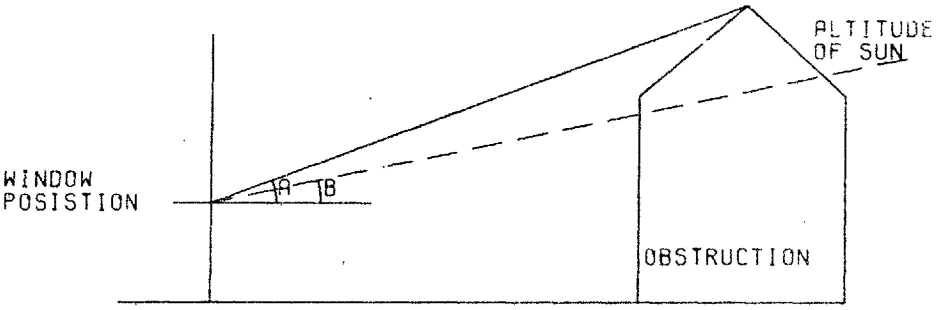


```
SUNLIGHT ANALYSIS                                   DATE:- 21.06
*****************                                   ************

           SUNRISE:-        3.45

           SUNSET:-        20.15

------------------------------------------------------------------------
I   SUN OUT     I    SUN IN      I    ALT(DEG)    I    BRG(DEG)     I
------------------------------------------------------------------------
I     9.05      I                I    46.23       I   113.56        I
I               I     9.10       I    46.93       I   114.87        I
I    11.20      I                I    60.49       I   161.14        I
I    11.25      I                I    60.73       I   163.42        I
I    11.30      I                I    60.93       I   165.74        I
I    11.35      I                I    61.11       I   168.08        I
I    11.40      I                I    61.25       I   170.44        I
I    11.45      I                I    61.36       I   172.81        I
I    11.50      I                I    61.44       I   175.20        I
I    11.55      I                I    61.49       I   177.60        I
I    12.00      I                I    61.51       I   180.00        I
I    12.05      I                I    61.49       I   182.40        I
I    12.10      I                I    61.44       I   184.80        I
I    12.15      I                I    61.36       I   187.19        I
I    12.20      I                I    61.25       I   189.57        I
I    12.25      I                I    61.11       I   191.92        I
I    12.30      I                I    60.93       I   194.26        I
I    12.35      I                I    60.73       I   196.58        I
I    12.40      I                I    60.49       I   198.86        I
I    12.45      I                I    60.23       I   201.12        I
I    12.50      I                I    59.94       I   203.34        I
I    12.55      I                I    59.62       I   205.53        I
I    13.00      I                I    59.27       I   207.68        I
I    13.05      I                I    58.90       I   209.79        I
I    13.10      I                I    58.51       I   211.87        I
I    13.15      I                I    58.09       I   213.90        I
I               I    13.20       I    57.65       I   215.89        I
------------------------------------------------------------------------

           TOTAL SUNLIGHT FOR DAY:-    2.05

************************************************************************
```

FIG 39 A SAMPLE OUTPUT FROM A SUNLIGHT ANALYSIS



PLAN VIEW



SIDE VIEW

FIG 40 METHOD OF DETERMINING WHETHER
THE SUN IS OBSTRUCTED
BY A BUILDING

the window position, and the horizon calculated. The largest angle subtended by any intersection point is saved as 'A' (Figure 40). This angle is then compared with the altitude of the sun. If the altitude of the sun is greater than 'A' the sun is unobstructed, otherwise the sun is obstructed.

When checking for intersections the program considers all buildings, including the one containing the window. This allows buildings containing recessed features to be correctly analysed, where part of a building might shade a further part of the same building. The program also caters for buildings with pitched roofs.

Received sunlight is checked for at intervals of five minutes between the sunrise time and sunset time, after considering all times the total sunlight for the day is printed and the program returns to the state where the user may change the input variable.

FUTURE WORK

It is worth noting that the work in this chapter and the last chapter could be combined to give the architect an even better appreciation of the sunlight received. If the perspective display system were extended to perform full hidden line removal (this would require a general purpose algorithm being produced for use on a mini-computer) then the site might be viewed from the direction of the sun. The visible areas would then be those areas receiving sunlight. By choosing several times during the day the architect could find areas receiving insufficient sunlight and areas receiving too much sunlight. It would also be possible to adapt the hidden line removal algorithm, to draw the shadows created by the buildings and show the effect of these on the site layout.

CHAPTER ELEVEN

THE CALCULATION OF EARTH VOLUMES

INTRODUCTION

The evaluation of earth volumes forms the most important analysis carried out in the present work. It enables the difference between the original ground level and the finished ground level to be found, and decisions on the site viability can be made from this information. The system is of an extremely general nature and analysis can be carried out on five basic types of element. The five basic elements are : -

a) any or all roads.

b) any or all buildings.

c) a finished level described by a flat plane.

d) a landscape element, this might be a pond which might require filling, a bank which is to be built as a screen, or any other general earth movement.

e) a series of points with an original and finished ground level. This element is similar to the data input for a program operating in batch mode and is included for compatibility with previous work.

The system allows up to thirty data elements to be considered at any one time, this allows up to thirty aspects of a site to be investigated independently and provides considerable flexibility for the user. Each element is described by a type code and title. The title is entered by the user and the type codes are as follows : -

0 Empty element.

1 Road element.

2 Building element.

3 Landscape element.

4 Flat plane element.

5 Typed input element.

Finally besides providing a general earth volume evaluation facility the program is designed to provide accurate results and a quick response time.

DATA STORAGE AND PROGRAMMING TECHNIQUES

When a large area is to be considered, this necessarily gives rise to a large amount of data, and in order that the mini-computer can handle the analysis it is important that thought is given to how and where data is to be stored to allow quick and easy access. However long a user may be prepared to wait for a batch service, it seems that once placed in an interactive environment he requires results instantly and becomes worried if the computer cannot be seen to be doing anything, for a period of greater than several seconds.

Each element type is described by a series of triangles built up to form a grid over the area of consideration. In the case of road and building elements this grid is generated automatically by the program, otherwise the grid is specified by the user. Examples of typical grids are shown in Figures 41 and 42. The information describing these grids is held in the graphic display file, for ease of access: this is feasible since the picture form of the data can easily be analysed. The layout of the data is shown in Figure 43. Data held in the graphic display

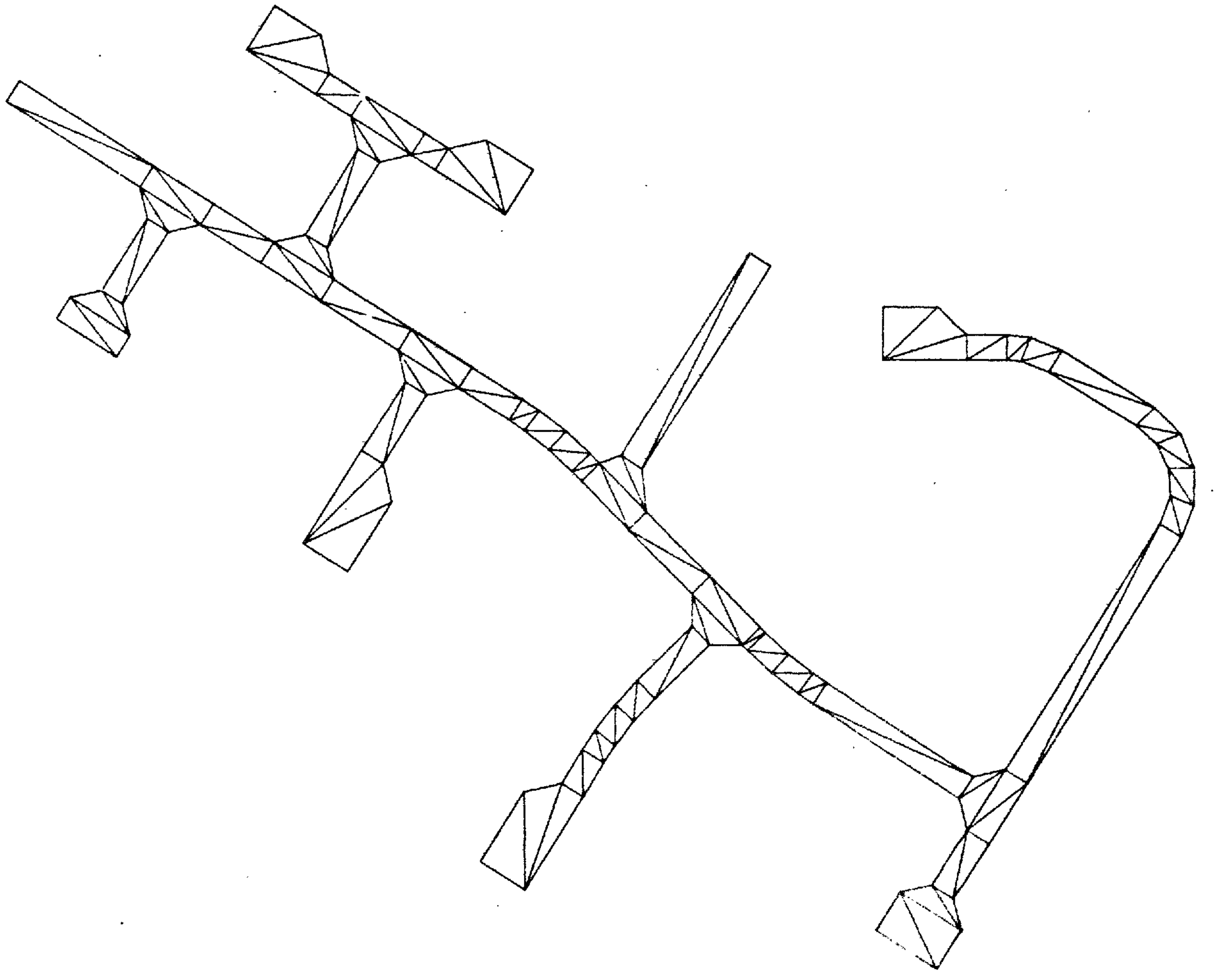


FIG 41 AN EXAMPLE OF A TRIANGULAR GRID.
AS GENERATED OVER A ROAD NETWORK

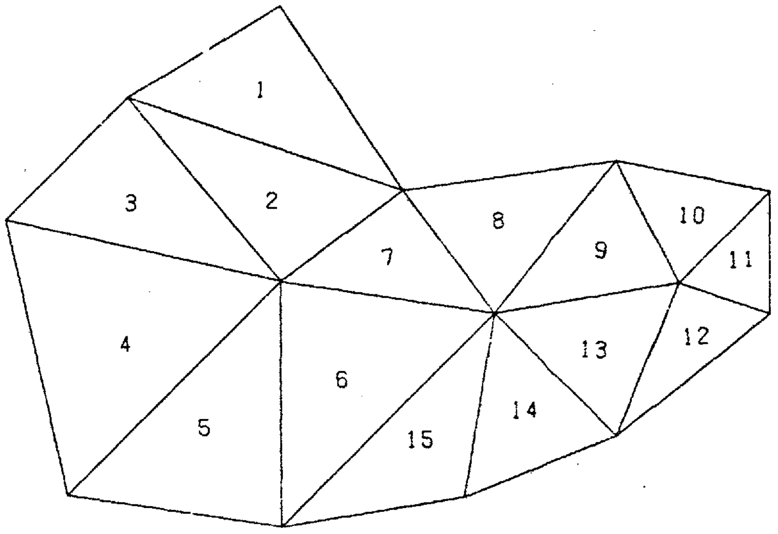
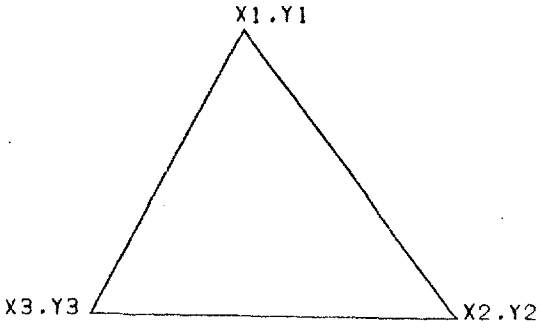


FIG 42 A TRIANGULAR GRID AS INPUT BY A USER



DISPLAY CODE	FIRST VARIABLE	SECOND VARIABLE	DESCRIPTION
1	X1	Y1	COORDINATES OF THREE POINTS FORMING TRIANGLE
2	X2	Y2	
2	X3	Y3	
2	X1	Y1	
3	Z01	ZN1	ZO.ZN ARE THE OLD AND NEW GROUND LEVELS RESPECTIVLY
3	Z02	ZN2	
3	Z03	ZN3	

FIG 43 DATA STORAGE OF ONE TRIANGULAR ELEMENT OF THE EARTH VOLUME EVALUATION SYSTEM

file may be accessed quickly and the mini-computer never takes more than a few seconds to generate or analyse any element of data.

The original ground levels are found from the land model generated by the contouring package (Chapter Five) except in the case of a typed input element, when the original ground level is supplied by the user. The finished ground level of road and building elements is derived from the respective models of the design features. The finished ground level of flat plane elements and typed input elements is supplied by the user, and finally the finished ground level of landscape elements is derived from a land model of the finished site, this model is generated from a series of notional contours input by the user.

When the cut and fill analysis is undertaken, each part of the grid is considered as a triangular prism, the volume being calculated as the area of a face, times the difference between the mean heights of the faces. The volumes of all parts of the grid are summed to find the total difference in volume between the original ground level and the finished ground level.

OPERATION OF THE EARTH VOLUME EVALUATION SYSTEM

Figure 44 is a brief flow diagram of the system operation, it presents the main facilities available to the user. On entry to the system the user can choose from nine major facilities of the system, besides the options of redisplaying the graphic file, or returning to the computer aided design system. The nine options of the earth volume evaluation system are described below.

Entering a road element

Any group of roads may be considered as an entity for analysis. The user simply inputs the road numbers he is interested in. The computer checks the legality of the input and then generates the triangular elements for each of the roads. The roads are split into triangular elements on a predetermined pattern. Each of the sections

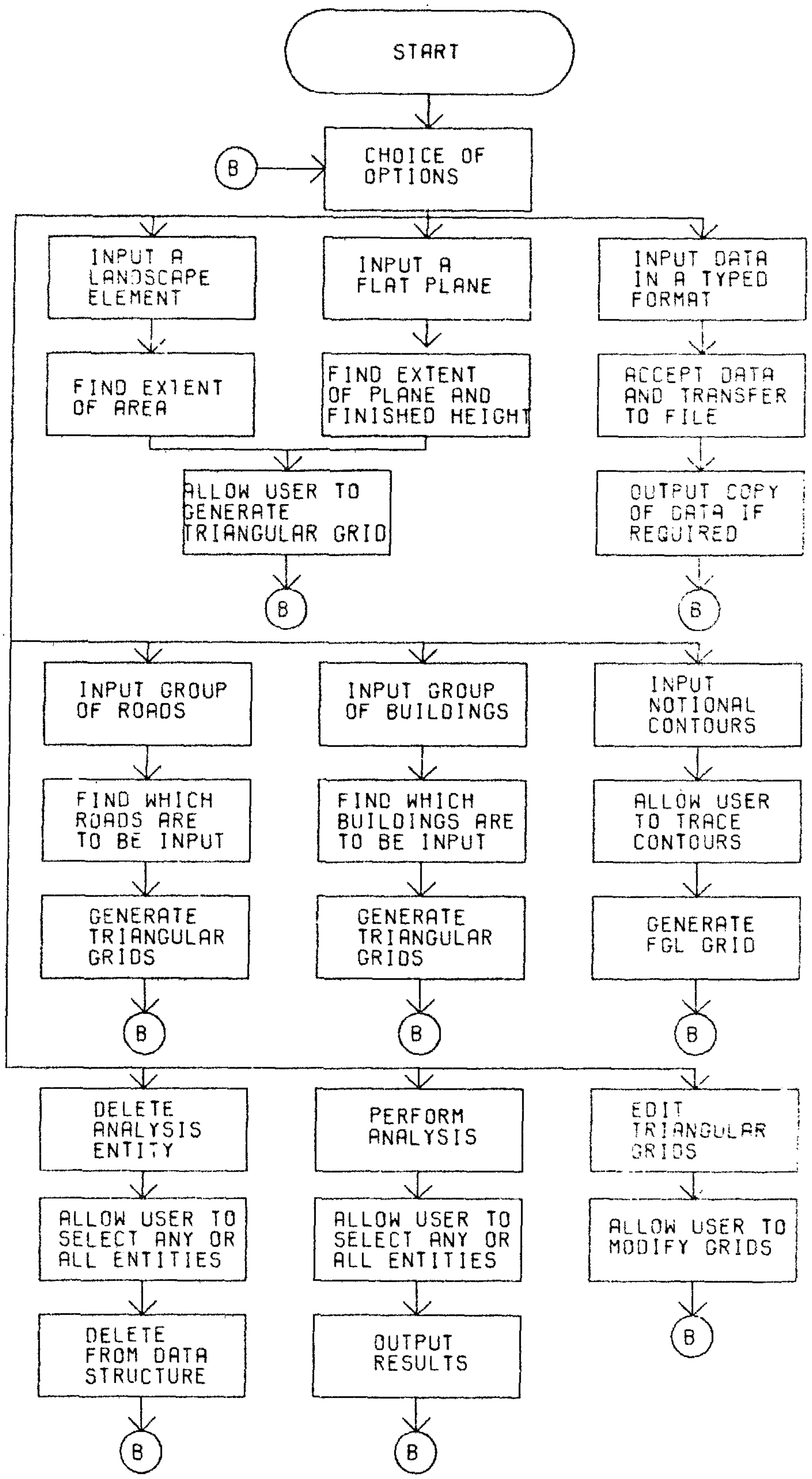


FIG 44 OUTLINE PROCEDURE OF THE EARTH VOLUME EVALUATION SYSTEM

from which a road can be built is split into triangles by a standard programmed method, thus allowing even complex road networks to be easily split into a series of triangles. The user has the ability to alter the triangular grid, if he so desires.

Entering a building element

Any group of buildings may be considered as an entity for analysis. The user digitises the perimeter of the area in which the buildings are to be analysed, this provides a quick, easy and natural manner of selecting the relevant buildings. Each building is split into a series of triangular elements, the pattern for triangulation is supplied by the user when the building type is first entered into the building library (Chapter Eight). In both the case of the roads, and the buildings the program also generates a series of spot heights giving the finished ground level at certain points on the roads and buildings. These spot heights may be later used as an aid when drawing notional contours of the finished ground level.

Entering a flat plane element

A flat plane element may be defined by digitising its perimeter and then entering the finished ground level by means of the keyboard area. Flat plane elements are a quick method of specifying such features as playing fields, car parks, or other level areas, which occur in many site layouts. Having defined the extent of the flat plane, the user defines the triangular grid by simply drawing each of the triangular elements.

While drawing the triangular grid the user may use all the standard facilities of the computer aided design system, and in addition, if a point is entered near to the perimeter of the area, the point will be automatically adjusted by the program to lie exactly on the line of the perimeter. This allows the complete area of the plane to be speedily split into triangular elements.

Entering a landscape element

A landscape element is entered in a similar manner to a flat plane element. The user firstly defines the area of consideration by its perimeter and then splits it up into triangular elements. In this case however the program determines the finished ground level from a model of the finished site. This model is generated by the contouring package, from the notional contours drawn by the user. If the notional contours have not been given the program does not allow landscape elements to be entered.

Entering a typed input element

A typed input element may be entered either directly from the DECwriter or from a file that has been previously saved on disk. The information entered consists of a list of points, followed by a list of triangles. Each point is described by a X coordinate, a Y coordinate, an original ground level, and a finished ground level, and each triangle is described by the numbers of the points which form its vertices. This information is read in by the program, checked for validity, reformated, and output as a series of standard triangular elements. Although this part of the system is only included for compatibility with a previous batch program, the fact that data may quickly be verified by means of the graphic display is an advantage over the batch program.

Entering notional contours

The user defines the finished ground level by tracing a series of notional contours. A contour height is specified, by means of the keyboard area, and then the proposed line of that contour drawn. To aid the user in drawing the notional contours, the original ground level contours may be viewed, and spot heights describing the finished ground level at the perimeter of the design features may also be viewed. These spot heights are generated when the design features are considered as entities for analysis by the earth volume evaluation system. When all the notional contour levels have been input the program calls the contouring package, to produce a regular grid of the finished land data. This grid is saved for later use.

It is only necessary to input the notional contours if it is desired to consider landscape elements, analysis of all other elements does not require the generation of a regular finished ground model.

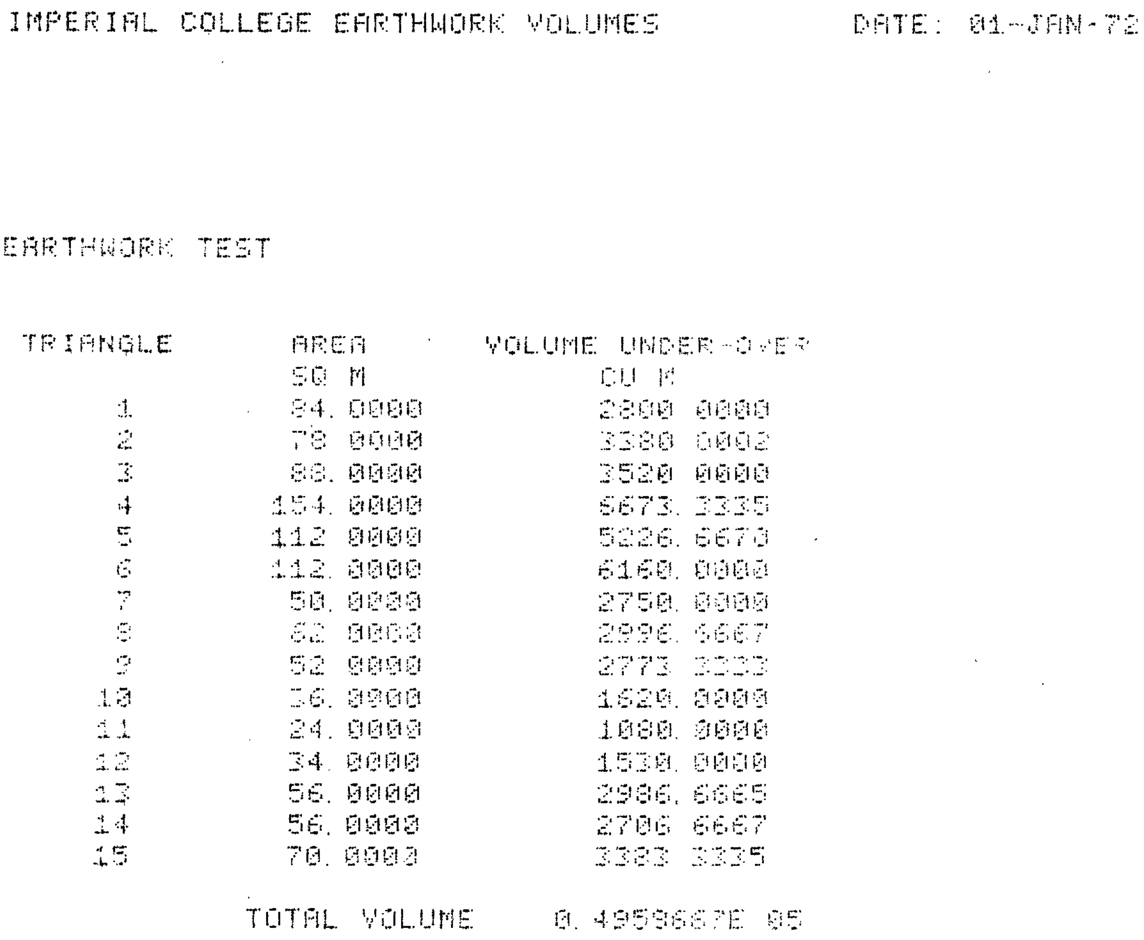
Analysis of an element

When the user enters an element, the program merely generates the triangular grid and collects together all the necessary information, placing this information in the graphic display file, in the format shown in Figure 43. The analysis of an element is carried out at a later time, this allows the user to select all aspects of the site, in which he is interested, and then perform a single analysis on all of them, taking the results away for consideration. Also any analysis can easily be repeated on the same or slightly modified data.

At the beginning of an analysis the user is presented with a list of the element titles, and any element can be selected from this list. The user continues selecting elements, until he has chosen all the elements he is interested in. The analysis is then performed and the program prints a list of the triangles, giving their number, area, and volume of cut or fill. Each list is preceeded by the element title, and the total volume of cut or fill is given at the end of the list. The program defines a quantity of earth to be excavated as positive and a quantity of fill as negative, a sample output is shown in Figure 45.

Deletion of an element

Once the user has finished consideration of an element he may delete all references to it from the system. A list of the element titles is presented to the user, and the user may select the elements he wishes to delete from this list. Several elements may be chosen for deletion at one time, and the option also exists to delete all the current elements.



```
IMPERIAL COLLEGE EARTHWORK VOLUMES            DATE: 01-JAN-72



EARTHWORK TEST

 TRIANGLE        AREA       VOLUME UNDER-OVER
                 SQ  M           CU  M
       1        84.0000         2800.0000
       2        78.0000         3380.0002
       3        88.0000         3520.0000
       4       154.0000         5673.3335
       5       112.0000         5226.6670
       6       112.0000         6160.0000
       7        50.0000         2750.0000
       8        62.0000         2996.6667
       9        52.0000         2773.3333
      10        36.0000         1620.0000
      11        24.0000         1080.0000
      12        34.0000         1530.0000
      13        56.0000         2986.6665
      14        56.0000         2706.6667
      15        70.0000         3383.3335

             TOTAL VOLUME     0.4959667E 05
```

FIG 45 A SAMPLE OUTPUT FROM THE EARTH VOLUME EVALUATION SYSTEM

Editing of an element

If an error occurs when defining a triangular element the user can correct this. The modification procedure does not allow the creation of further triangular elements, but does allow existing triangles in the grid to be either altered or deleted. Both the plan coordinates and the levels of any point in the grid may be altered. A display of the triangle numbers can also be generated, an example being shown in Figure 42.

When the user is employing the modification procedure, the program is continually monitoring the position of the digitising pen and finding which triangle the pen coordinates lie inside. When a triangle is found it is continually displayed by the program, so that it appears brightened up on the screen. The user moves the cursor inside the triangle he wishes to modify and may then apply any of the modification commands to that triangle.

As the computer is continually searching through the data structure, steps must be taken to reduce the search time. This is achieved by the program 'remembering' which parts of the data structure hold relevant information. On the first pass through the data structure, each section is examined to determine if any triangular grids are stored within it, if no grids occur in the section then it it marked as empty and is not processed on further passes through the data structure. This greatly reduces the search time and it appears to the user as if the computer finds each triangle instantaneously.

A search loop is employed because once again this reduces the workload of the user. No direct commands have to be entered, either via the function buttons or via the DECwriter, in order to select a triangle for modification, the user need only move the pen to the relevant triangle and can change his choice by simply changing the pen position.

FURTHER WORK

It would be possible to extend the automatic generation of the triangular grids to the flat plane elements and landscape elements, however for the program to cope with the general case this requires complex progamming, so at present,it is felt more worthwhile to allow the user to define his own triangular grid. Such an automatic generation procedure could, however, be easily added to the system at a later date.

The most useful extension to the system would be easier methods of determining the finished ground levels. The visualisation of contours is not easy, and does not necessarily give the best blending between the design features and the land. It might be possible to define the finished ground levels from a series of sections taken through the site. The section would show the original ground level and the design features, to which could be added the finished ground level. Also some automatic specification of the finished ground level would be desirable. Where, for example, a building is deliberately dug into the existing ground it is usual to move some earth back from the walls of the building and leave a certain area around the building level. If the program could carry out this smoothing process the desinger's task would be much simpler, and more accurate results would be obtained.

Finally as building land becomes scarcer and more and more sites have considerable gradients in them, the need for easy to use and accurate earth volume evaluation programs will be increased.

CHAPTER TWELVE

CONCLUSION

REVIEW

The present work covers all levels of the design process and provides a standard interface for all aspects of the design procedure. Once all project information is held by the computer considerable savings in time can be effected and communications between the various design teams improved. The amount of time spent in data preparation can be reduced by holding one design model, from which the data input for several analyses can be derived. It is realised that not all aspects of the design process have been covered, but a standard framework exists into which they can be fitted. An example of further work would be the production of site drawings and schedules from the design model held by the computer.

The work carried out so far shows how a general purpose computer aided design system can be extended (Chapter Three) and then used for a variety of applications. Two successful applications of the computer aided design system have been demonstrated. Firstly as a means of preparing data to a large mainframe computer (Chapter Four), allowing the characteristics of the larger computer to be hidden from the user. And secondly as a means of developing a site layout (Chapters Five-Eleven), the mini-computer being capable of undertaking all the tasks required of it, without recourse to further computing power.

The site layout work has shown how two dimensional features (Chapter Six) and three dimensional features (Chapter Eight) may be entered into a computer model of a site layout, by means of a two dimensional input device. It has also been shown how the user may interact with and modify three dimensional features held in the computer model.

The ability of the mini-computer to analyse the three dimensional site model has been established (Chapters Nine-Eleven), stress being placed on how the designer communicates with the computer system. Many of the analysis techniques developed provide the designer with new tools in his site layout work and the mini-computer has proved capable of undertaking all but the most complicated analyses.

APPRAISAL OF THE HUMAN ASPECT

It is important to realise that in computer aided design systems the human user is still providing the function of taking decisions, based on the facts presented to him by the computer, and on his previous experience and judgement. In order that he may fulfil this function efficiently it is necessary that the computer is not tiresome to use. It is vital that the ergonomics of the system are well thought out and that in use the system is flexible, durable and quick to respond. These aims are only achieved by careful programming.

APPRAISAL OF THE MINI-COMPUTER

Although posing problems for the programmer, the use of a mini-computer has proved the ideal computer tool for the designer. By taking greater care at the programming stage the resulting program can save much frustration when in use. The programmer must, however, consider carefully how large amounts of data are to be stored. While the idea of a virtual storage scheme may seem attractive, if implemented without thought, 'thrasing' will occur and the program will run inefficiently. The programmer must strive for a storage scheme which will minimise the number of times the disk is accessed, and thus allow efficient program operation. Providing that the data storage scheme is well thought out the size limitations of the mini-computer are not serious and are more than compensated for by the ease of use of the final system.

A mini-computer provides the designer with the computing power he requires at far less cost than a large mainframe computer (accessed through a terminal). In addition by dividing the computer power up into a series of small units, the total system reliability is greatly increased. Mini-computers provide systems for a large range of needs, a small firm can have the ability to buy a single mini-computer, while in a large firm a number of mini-computers can be connected together to form a network. In each of these systems expansion would be simple, and compatible software could be written for the two systems.

FINAL NOTE

The experience gained with the present suite of programs has been extremely useful, and the programs have been used to educate practising architects and engineers in the use and advantages of graphical techniques. It is hoped that the work may be developed for full production use, and this aspect of the work will be carried out by John Laing Design Associates.

APPENDIX ONE

A USERS MANUAL FOR FEATURE

INTRODUCTION

The FEATURE system enables a graphic description and a written description of existing site features, e.g. trees, fences, footpaths, etc., which may be encountered in surveying work, to be held in the computer aided design system (CADS).

The system allows such features to be input, either directly from a surveyor's notebook or from a survey plan as obtained from a previous survey.

The written description or specification of the features may be chosen from a standard list, no laborious typing is required. The standard specifications are easily alterable to suit a particular set of conditions and no new programming is required to extend or change these lists.

All specifications can be over-ridden if desired and incorrect features may be deleted, before their correct form is input.

To provide a quick and easily readable display, the specifications are only shown on request from the operator and while the data is being manipulated a 'shorthand' display of the symbols is used.

INPUT OF FEATURES

To input a feature the operator first enters the CADS system and sets the input scale for the plan in use. Any other graphical information may be held with the existing features generated by this system. And on exit from this system the operator may display, file and retrieve the existing features in the same manner as any other graphical file.

When the CADS initialisation is complete the user may enter the FEATURE system by digitising the menu square 'INPUT FEATURES'. The procedure to input a feature is then as follows : -

a) The computer will display a list of the feature types that may be input. Alongside each feature is an identifying number, to select a feature the operator inputs this number, using one of the eight pen buttons. If the first option is chosen, control will be returned to the CADS system.

b) The operator may digitise around the complete outline of the feature to be input. An exception to this is the case of trees and bushes, where only the centre and a point on the outer edge need be digitised. The feature is terminated by pressing pen button five. The actions of the pen buttons at this point are almost identical to their actions in the CADS system and briefly they are : -

B1	Input a point.
B2	Break line.
B3	Not used.
B4	Window facility.
B5	End of feature.
B6	Control mode.
B7	Find point.
B8	Drive mode.

c) After a complete feature has been input the operator is returned to the list of standard features and proceeds as in a) above.

On termination of the system the simple outlines of the features will be replaced by their symbolic forms, e.g. in the case of a brick wall the single centre line will be replaced by the usual double line form.

SPECIFICATION OF FEATURES

To add a written description or specification to any existing feature, the operator firstly enters the CADS system and brings the file in which he is interested to the workspace. The operator then digitises the menu square 'SPECIFY FEATURES '. The procedure to specify a feature is then as follows : -

a) The computer displays the basic outline of each feature and the operator has two options : -

  1) Press button five, control will return to the CADS system.
  2) Press button one to select the feature to be specified.

b) If button one is pressed the computer will search for a feature near to the point indicated by the operator. If it fails to find one it will display the message 'NO FEATURE FOUND' and return to a). When a feature is found, the relevant specification list is displayed by the computer. The operator may then use one of the pen buttons to select the required specification, this may include both a written description and information such as the height of a feature. This phase may be terminated by selecting the first option in each list, i. e. 'SPECIFICATION FINISHED'. The computer will then return to part a) above.

On termination of the system the simple outlines of the features will be replaced by their symbolic forms, updated if necessary, to reflect the given specification.

EDITING OR INTEROGATION OF FEATURES

Deletion

In order to delete a feature the operator enters the CADS system and digitises the menu square 'EDIT FEATURES'. The procedure for editing is then as follows : -

a) The operator moves the pen towards the feature he wishes to delete, as the pen moves near to a feature the computer finds the feature and draws a box around it. This box is drawn automatically by the computer and appears on the screen 'brighted up'. When the operator has the box around the desired feature he has two options : -

  1) Press button five, control will return to the CADS system.

2) Press button one, causes the feature to be deleted and the computer continues searching for further features, as in a) above.

Button five causes a return to the CADS system at any time whether or not a feature has currently been found by the computer.

Interrogation

In order to display the written description of a feature when in the CADS system the operator digitises the menu square 'INTERROGATE FEATURES'

The procedure is exactly the same as in the case of deletion, except that if button one is pressed the specification of the feature will be displayed on the screen.

The procedures of deletion and interrogation may be repeated for as many features as required before a return to the CADS system is made.

APPENDIX TWO

EXISTING FEATURES : SPECIFICATION CODES

CODE	FEATURE
1.0	WALL
1.01	Brick wall
1.02	Retaining wall
1.03	Ornamental wall
2.00	FENCE OR HEDGE
2.01	Barbed wire fence
2.02	Rough post and barbed wire fence
2.03	Wooden stake and barbed wire fence
2.04	Wooden stake and iron railing fence
2.05	Iron railing fence
2.06	Wooden rail fence
2.07	Close boarded fence
2.08	Chain link fence
2.09	Post and chain link fence
2.10	Post and wire fence
2.11	Mesh fence
2.12	Corrugated iron fence
2.13	Bramble and willow hedge
2.14	Hazel hedge
2.15	Hawthorn hedge
2.16	Holly hedge
2.17	Privet hedge
2.18	Privet and holly hedge
3.00	TREE OR BUSH
3.01	Ash
3.02	Elm
3.03	Holly
3.04	Horse chestnut
3.05	Oak
3.06	Sycamore

CODE	FEATURE
4.00	BUILDING
4.01	House
4.02	Cottage
4.03	Brick building
4.04	Brick and wood building
4.05	Concrete
4.06	Barn
4.07	Shed
4.08	Brick shed
4.09	Garage
4.10	Sub station
4.11	Factory
4.12	Shop
4.13	Canopy
4.14	Corrugated covering
5.00	ELECTRICITY OR TELEGRAPH
5.01	Overhead line
5.02	Underground cable
5.03	Telegraph line
5.04	Telegraph cable
6.00	CANAL RIVER OR STREAM
6.01	Canal
6.02	River
6.03	Stream
7.00	MANHOLE
8.00	GENERAL
8.01	GPO
8.02	Gully

CODE	FEATURE
8.03	Stop cock
8.04	Telegraph pole
8.05	Water valve
8.06	Fire hydrant
8.07	Lamp post
9.00	POND OR LAKE
9.01	Pond
9.02	Lake
9.03	Well
9.04	Open pit
10.00	ROAD FOOTPATH OR RAILWAY
10.01	Tarmac road
10.02	Concrete road
10.03	Track
10.04	Footpath
10.05	Railway

APPENDIX THREE

A USERS MANUAL FOR PLANE

INTRODUCTION

The PLAN Evaluation system enables immediate and accurate measurement to be made of areas or distances simply by indicating points around the perimeter or along the distance to be measured.

The program will operate on any information within the computer aided design system (CADS) or on any standard drawing.

SYSTEM OPERATION

The drawing to be measured is either placed on the digitising table or if it is already in the CADS system retrieved from file. The operator then enters the CADS system and digitises the menu square 'PLANE'.

For any given measurement of distance or area the system is first fed with data that establishes the chart scale and units of measurement. When this preliminary data has been given, measurement can proceed.

TO ESTABLISH DISTANCE AND AREA UNITS

At the DECwriter the following sequence is followed : -

a) The computer types a heading, followed by the line 'SCALE UNITS WILL BE GIVEN IN : -'

b) The name of the distance units, e.g., inches, millimetres, etc., is typed by the operator. Up to a maximum of twenty characters may be used.

c) The computer types the line 'AREA UNITS WILL BE GIVEN IN : - '

d) The name of the area units is typed by the operator.

e) The computer types the lines 'HOW MANY SCALE UNITS, SQUARED, IN ONE AREA UNIT ? '

f) The operator types the appropriate quantity, e.g., if the distance is in millimetres and the area in square centimetres, the operator types '100'.

g) The computer is now ready to accept a command.

All numbers must contain a decimal point, any incorrect input will cause the computer to repeat the question.

TO ESTABLISH CHART SCALE

The chart scale is fed in as follows : -

a) With the computer waiting the operator types a SC command at the DECwriter.

b) The operator then positions the pen at one end of the chart scale and inputs the coordinates with either button one or seven.

c) The pen is then positioned at the other end of the scale and the coordinates again input. The computer then types 'HOW MANY SCALE UNITS WAS THAT?'

d) The operator replies by typing the appropriate number.

TO MEASURE DISTANCE

Distances are measured as follows : -

a) With the computer waiting the operator types a MD command.

b) The operator then inputs points along the distance to be measured with either button one or button seven. At the end of the distance to be measured the operator presses button two.

c) The computer then prints the calculated result and returns to its waiting state.

If at any time the operator wishes to return to the waiting state without printing out a result, then button five may be pressed.

At the end of a trace if the pen is within a given distance from its start point, then the loop will be automatically closed by the computer.

TO MEASURE DISTANCE CUMULATIVELY

In this mode two sets of data are produced. Between each successive line measurement a print out of both, the last line measured and a running total of successive measurements is given. The procedure is as follows : -

a) With the computer waiting the operator types a CD command.

b) Each line is input as before with buttons one and seven. Button two terminating each of the traces.

c) To terminate the cumulative line measurement mode the operator presses button five and the computer will return to the waiting state.

TO MEASURE AREA

The method used for area measurement is very similar to that for measuring distances and is as follows : -

a) With the computer waiting the operator types a MA command.

b) The points on the area perimeter are then input, using button one or button seven.

c) The area is terminated by pressing button two. The computer then prints out the calculated result and returns to the waiting state.

At the end of a perimeter if the pen is within a given distance from its start point, then the loop will be automatically closed by the computer.

TO MEASURE AREA CUMULATIVELY

In this mode two sets of data are produced. Between each successive area measurement a print out of both, the area last measured and a running total of successive area measurements is given. The procedure is as follows : -

a) With the computer waiting the operator types a CA command.

b) Each area is traced in turn, using button one or button seven, each trace being terminated by a button two. The computer then types out of the two calculated results.

c) To terminate the cumulative area measurement mode the operator presses button five and the computer will return to the waiting state.

TO CHANGE A PARAMETER

When measuring distances or areas on drawings of varying scale and only the chart needs to be changed, i.e. the distance and area units are to remain the same, then the operator types a SC command when the computer is waiting. The operator then proceeds as in the section to establish chart scale.

When the measuring units are also to be changed the operator types a NP command and then proceeds as in the section to establish distance and area units.

CONVERSION FACTORS

If the operator types a CO command when the computer is waiting, the computer will print a list of conversion factors from British to metric units, and then return to the waiting state.

TO OBTAIN HELP

When the computer is waiting if the ~~computer~~ operator types a HE command, the computer will list the nine basic commands and a brief summary of what each of them means. The computer will then return to the waiting state.

TO END A SESSION

When the operator has obtained all the results he requires, by typing a TE command, when the computer is in the waiting state, control will be transferred back to the CADS system.

APPENDIX FOUR

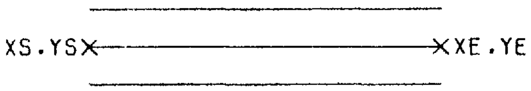
DATA STORAGE OF THE ROAD SECTIONS

IDENTITY CODE ONE	X COORD. OF START	Y COORD. OF START	ORIGINAL GROUND LEVEL AT START

FIG 46 STORAGE OF A ROAD START

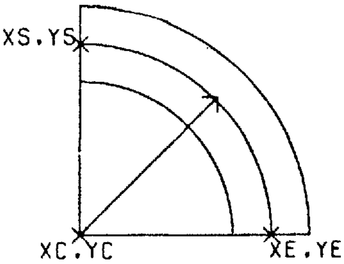
IDENTITY CODE SIX	LEFT HAND SIDE ROAD WIDTH	RIGHT HAND SIDE ROAD WIDTH	—

FIG 47 STORAGE OF THE ROAD WIDTH



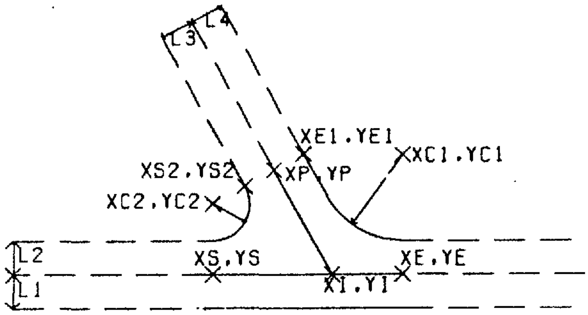
XS	YS	ORIGINAL GROUND LEVEL AT START	CHAINAGE AT START
XE	YE	ORIGINAL GROUND LEVEL AT END	CHAINAGE AT END

FIG 48 STORAGE OF A STRAIGHT ROAD SECTION



IDENTITY CODE 3 - CW. 4 - CCW.	XC	YC	—
XS	YS	ORIGINAL GROUND LEVEL AT START	CHAINAGE AT START
XE	YE	ORIGINAL GROUND LEVEL AT END	CHAINAGE AT END

FIG 49 STORAGE OF A CURVED ROAD SECTION



IDENTITY CODE FIFTY	XI	YI	ORIGINAL GROUND LEVEL AT INTERSECT.
XS	YS	XE	YE
XC1	YC1	XC2	YC2
XE1	YE1	XS2	YS2
XP	YP	POINTER TO SPUR ROAD	START/END FLAG
L1	L2	L3	L4

FIG 50 STORAGE OF A ROAD JUNCTION

IDENTITY CODE 61	MAIN ROAD NUMBER	POINTER TO MAIN ROAD	—

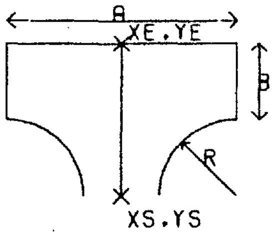
FIG 51 STORAGE OF A START JUNCTION

IDENTITY CODE 62	MAIN ROAD NUMBER	POINTER TO MAIN ROAD	—

FIG 52 STORAGE OF AN END JUNCTION

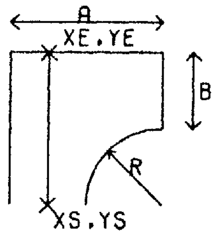
IDENTITY CODE TWENTY	X COORD. OF ROAD END	Y COORD. OF ROAD END	ORIGINAL GROUND LEVEL AT ROAD END

FIG 53 STORAGE OF A SIMPLE ROAD END



IDENTITY CODE 21	A	B	R
XS	YS	ORIGINAL GROUND LEVEL AT START	CHAINAGE AT START
XE	YE	ORIGINAL GROUND LEVEL AT END	CHAINAGE AT END

FIG 54 STORAGE OF A T-SHAPED ROAD END



IDENTITY CODE 22 - RHS 23 - LHS	A	B	R
XS	YS	ORIGINAL GROUND LEVEL AT START	CHAINAGE AT START
XE	YE	ORIGINAL GROUND LEVEL AT END	CHAINAGE AT END

FIG 55 STORAGE OF A L-SHAPED ROAD END

IDENTITY CODE 71	ORIGINAL GROUND LEVEL	—	CHAINAGE

FIG 56 STORAGE OF A GROUND LEVEL MARKER

IDENTITY CODE 7 AND * GRADIENT	LENGHT OF SECTION	ROAD LEVEL AT START	CHAINAGE AT START

*NB. GRADIENT IS STORED AS A PERCENTAGE IN THE FIRST THREE PLACES AFTER THE DECIMAL POINT

FIG 57 STORAGE OF A VERTICAL GRADIENT

APPENDIX FIVE

CONTENTS OF THE BUILDING LIBRARY : EXAMPLE OF A BUILDING TYPE

N.B. FOR NOTES SEE NEXT PAGE

-1.			(1)
0.0	0.0	0.0	(2)
2.5	0.0	0.0	
2.5	3.25	0.0	
8.0	3.25	0.0	
8.0	11.25	0.0	
0.0	11.25	0.0	
0.0	0.0	0.0	
-2.	0.0		(3)
-1.			(4)
0.0	0.0	0.0	
0.0	0.0	2.5	
2.5	0.0	2.5	
2.5	0.0	0.0	
0.0	0.0	0.0	
-2.	2.0	0.0	(5)
1.0	0.2	0.0	(6)
2.0	0.2	2.3	
2.0	2.3	2.3	
2.0	2.3	0.0	
-1.			
4.0	3.25	7.0	
4.0	11.25	7.0	
8.0	11.25	5.0	
8.0	3.25	5.0	
4.0	3.25	7.0	
-2.	0.		
-3.			(7)

FIG 58 DIAGRAMMATIC REPRESENTATION OF BUILDING LIBRARY CONTENTS

(1) Minus one code indicates the start of a new plane.

(2) The x, y and z coordinate of each point on the perimeter of the plane, given in clockwise order, looking from outside the building towards the inside.

(3) Minus two code indicates the start of features on the plane. A zero in the second column implies no features on the plane.

(4) Start of a further plane.

(5) The two in the second column indicates the features occur solely in one y plane. The third column specifies the y plane. If a one or three appears in the second column, this indicates the features lie in a x or y plane respectively.

(6) The first column indicates whether the pen is up or down when drawing the feature. A one means pen up, a two means pen down. The second and third columns. give the x and z coordinates of a feature point.

(7) End of information.

FIG 58 DIAGRAMMATIC REPRESENTATION OF BUILDING LIBRARY CONTENTS (CONT).

APPENDIX SIX

THE GEOMETRY OF THE SUN

DEFINITIONS OF THE TERMS USED

Altitude	Vertical angle of the sun above the horizon.
Azimuth	Horizontal angle between direction of sun's rays and another fixed point. Usually north is chosen as the fixed point and the term bearing used.
Declination	The seasonal variation in the apparent position of the sun relative to the equator. Due to the rotation of the earth, with its tilted axis, around the sun.

MODEL OF THE EARTH-SUN SYSTEM

In order that we may calculate the position of the sun at all latitudes and all dates, we must first derive formulae representing the altitude and bearing of the sun in terms of the given values of latitude, date and time.

The earth revolves about the sun once a year and about its own axis once a day. The earth's axis is not normal to the plane of rotation, but is inclined at an angle of $23\frac{1}{2}$ degrees. The nature of the earth's movement is shown in Figure 59. For calculation purposes it is more convenient to consider the movements of the sun relative to a stationary earth. Figures 60-62 show the apparent movement of the sun in such a system.

CALCULATION OF DECLINATION

From Figure 63 it can be seen that : -

(1) $\tan(D) = \dfrac{X}{Y}$

(2) $X = A\cos(WT)$

(3) $Y = \dfrac{A}{\tan(23\frac{1}{2})} = \dfrac{A}{0.435}$

Therefore : - $\tan(D) = 0.435\cos(WT)$

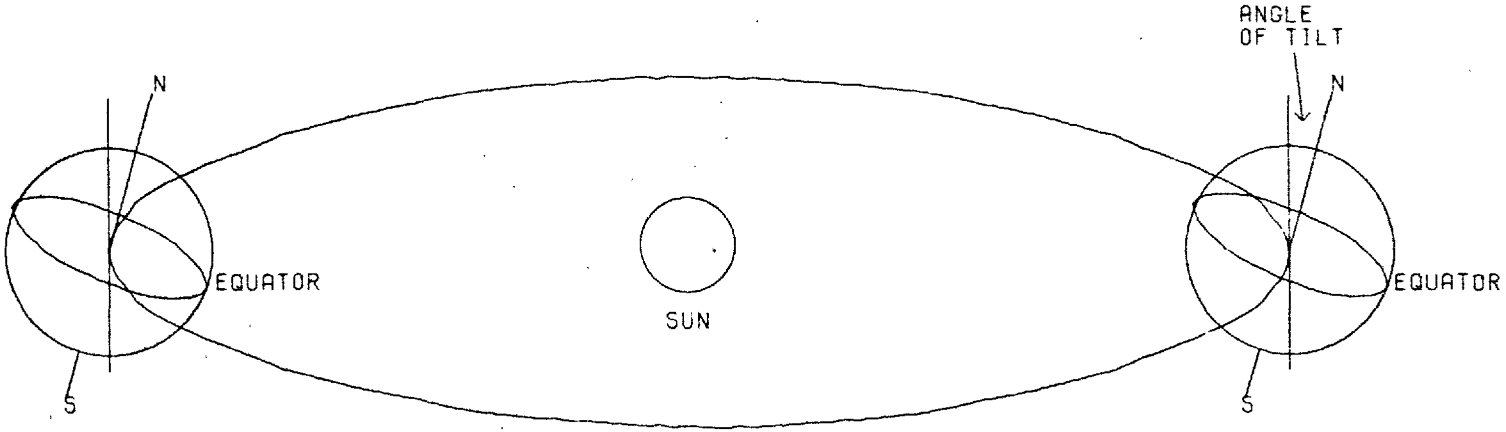


FIG 59 ANNUAL MOTION OF THE EARTH ABOUT THE SUN

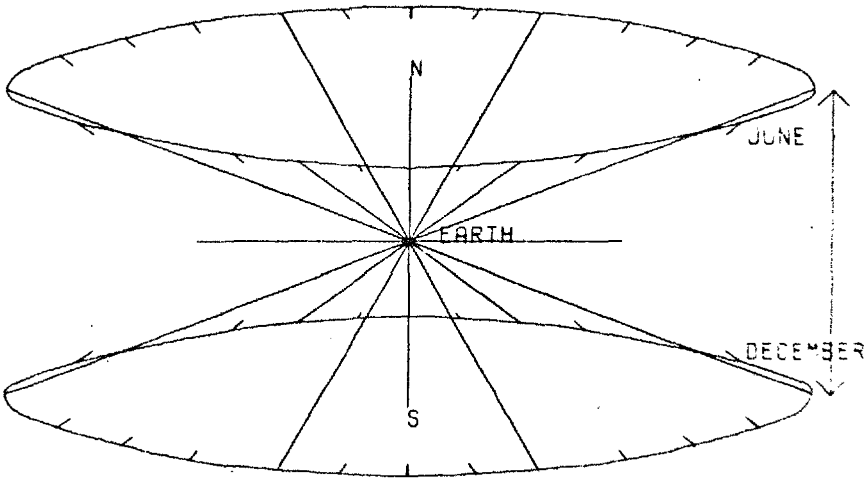


FIG 60 APPARENT SEASONAL MOVEMENT OF THE SUN

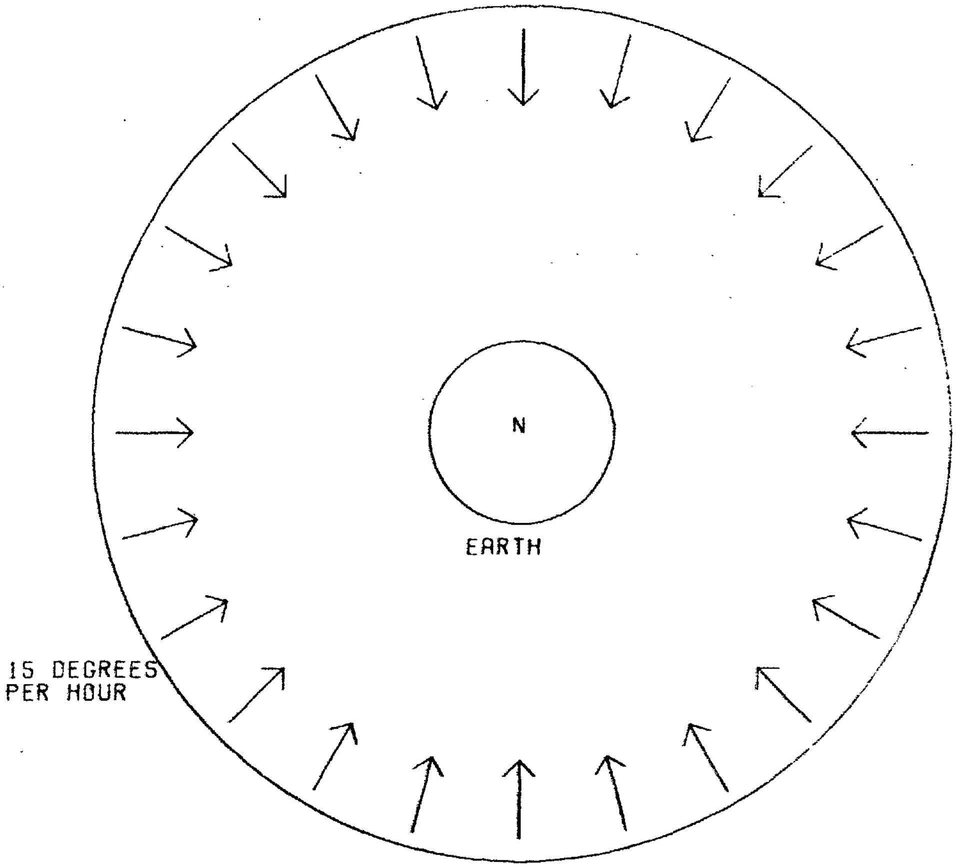


FIG 61 APPARENT DAILY ROTATION OF THE SUN

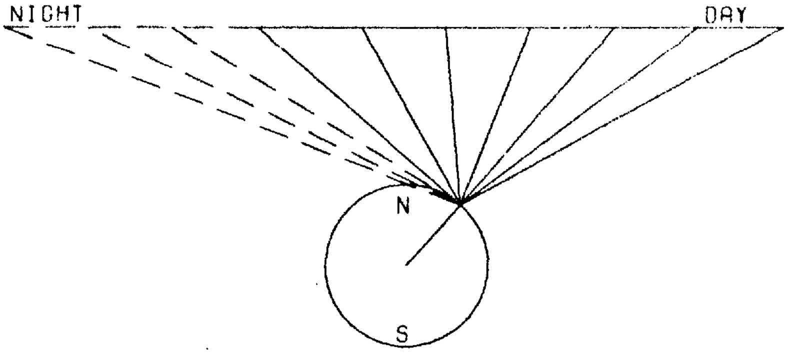


FIG 62 APPARENT MOVEMENT OF THE SUN FROM A POINT IN THE NORTHERN HEMISPHERE

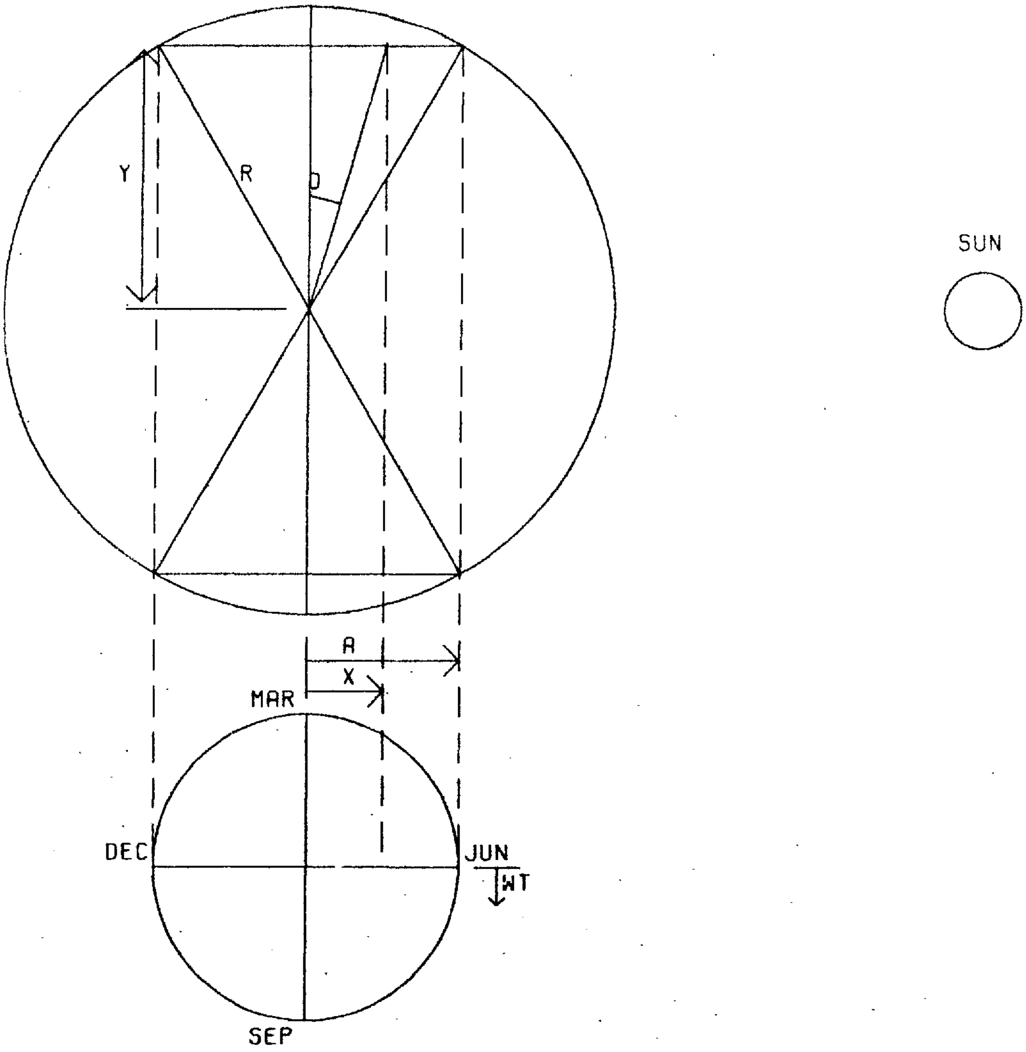


FIG 63 CALCULATION OF THE ANGLE OF DECLINATION

Hence : - Angle of Declination = $\tan^{-1}(0.435 \cos(6.28t))$

Where t = time as a fraction of year from 21st June.

CALCULATION OF ALTITUDE

From Figure 64 it can be seen that : -

(1) $P = R(1-\cos(WT))\cos(A) = C\cos(D)\cos(A)(1-\cos(WT))$

(2) $H = C\sin(M) = C\sin(90-A+D) = C\cos(A-D)$

(3) $\sin(N) = \frac{L}{C} \quad \frac{H-P}{C}$

Therefore : -
$$\begin{aligned}\sin(N) &= \cos(A-D) - \cos(D)\cos(A)(1-\cos(WT)) \\ &= \sin(A)\sin(D) + \cos(A)\cos(D) \\ &\qquad - \cos(A)\cos(D)(1-\cos(WT)) \\ &= \sin(A)\sin(D) + \cos(A)\cos(D)\cos(WT)\end{aligned}$$

Hence : - $\sin(ALT) = \sin(LAT)\sin(DEC) + \cos(LAT)\cos(DEC)\cos(6.28t)$

Where ALT = Altitude

LAT = Latitude

DEC = Declination

t = time as fraction of day from noon.

CALCULATION OF BEARING

From Figure 64 it can be seen that : -

(1) $\sin(BRG) = \frac{X}{Y}$

(2) $X = R\sin(WT) = C\cos(D)\sin(WT)$

(3) $Y = C\cos(N)$

Therefore : - $\sin(BRG) = \frac{\cos(D)\sin(WT)}{\cos(N)}$

Hence : - $\sin(BRG) = \frac{\cos(DEC)\sin(6.28t)}{\cos(ALT)}$

Where BRG = Bearing

ALT = Altitude

DEC = Declination

t = time as fraction of a day from noon.

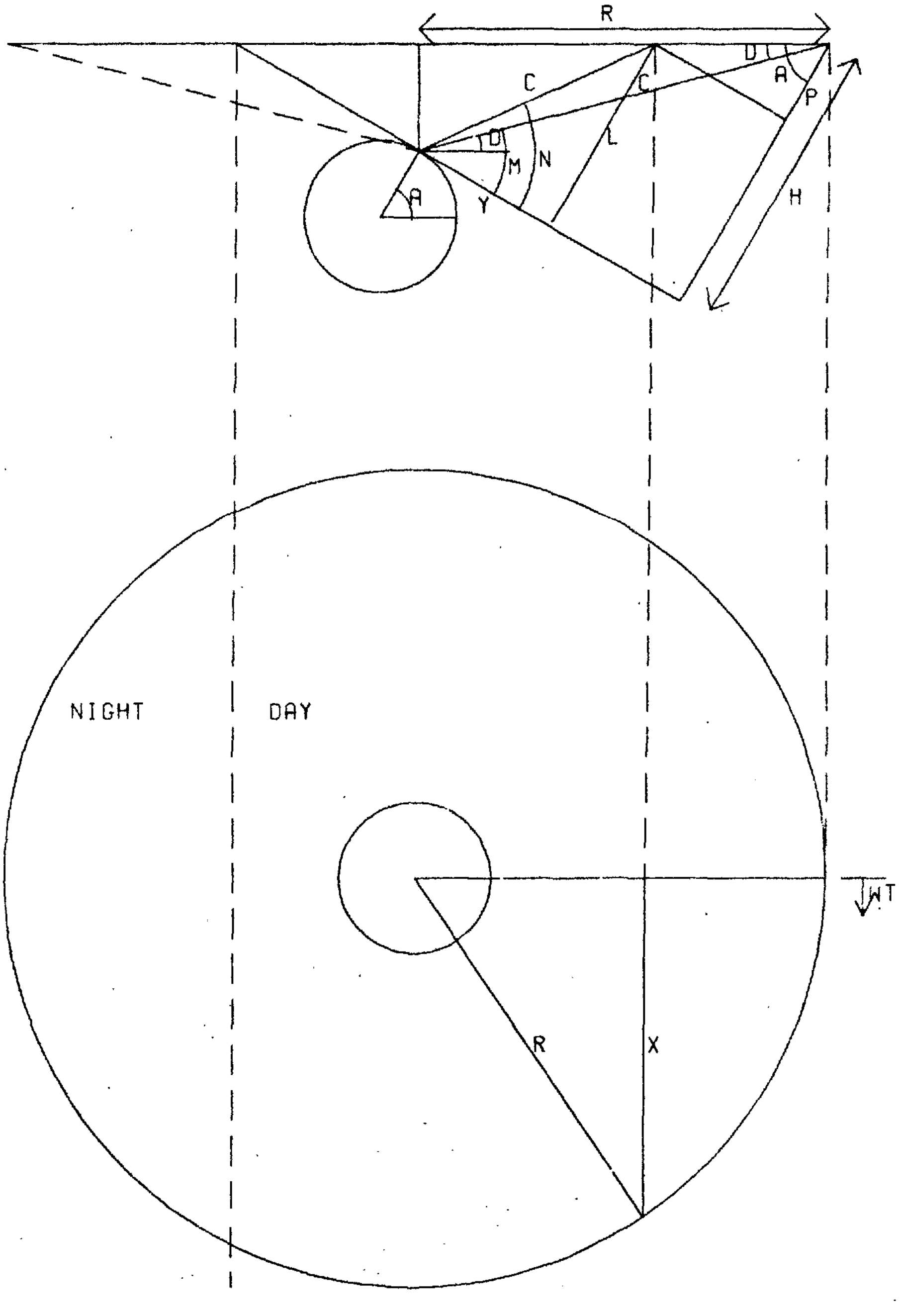


FIG 64 CALCULATION OF ALTITUDE AND BEARING

APPENDIX SEVEN

OVERLAY MODULES FOR THE DATA PREPARATION SYSTEM

OVERLAY	NAME	DESCRIPTION
41	INGRID	Handles the input,labelling and display of primary grids. Handles the input options.
42	INELEM	Handles input of beams, columns and slabs.
43	ELEGEN	Forms the basic element file from the graphic file. Generates the self weight of elements.
44	LNKGEN	Forms links from slabs to beams. Inputs a load onto a beam.
45	FLIGHT	Forms links between beams and columns. Inputs flights to be considered in analysis.
46	SLABLD	Initialises the system. Inputs loads on slabs.
47	LOADER	Handles the load options. Evaluates uniform load due to a slab.
48	PENSUP	Determines the penultimate support in each total flight.
49	DISTLD	Distributes loads from secondary beams to main beams.
50	OUTBM	Extracts data from the model for the beam analysis.
51	MACROS	Handles the input of repeated features.

OVERLAY	NAME	DESCRIPTION
52	LEVCON	Forms the vertical links in the building. Evaluates load at the base of each column.
53	OUTCL	Extracts data from the model for the column analysis.

APPENDIX EIGHT

OVERLAY MODULES FOR THE SITE LAYOUT AND PLANNING SYSTEM

OVERLAY	NAME	DESCRIPTION
14	DLEVEL	Deletes a level from the workspace or changes the level number.
27	WEDIT	Window editor, deletes all data in a given area.
46	RECKOV	Restores data after a system failure.
81	STRUCT	Allows location of line intersections, input of perpendicular lines and lengthening/ shortening of lines.
82	ARCOV	Allows input of fillets.
56	CECPLT	Drives the CADMAC on-line plotter.
69	OFPLOT	Prepares data for off-line plotting.
70	CONPCK	Main entry to contouring package, handles the basic commands.
71	PHASE2	Processes input data for the contouring package.
72	PHASE3	Estimates derivatires of a survey plot and generates a triangular grid over the survey points.
73	PHASE4	Handles commands annotating or specifying the contour plot area.

OVERLAY	NAME	DESCRIPTION
74	PHASE5	Draws contours from a regular grid of heights.
75	PHAS3B	Fits bi-cubic patches to each triangle formed within the contour package.
49	SECTOV	Draws sections through the land.
67	HIDER1	Allows input of the viewing position for a semi-oblique projection.
68	HIDER	Draws a semi-oblique projection showing the land mass.
43	PICTOV	Generates a three dimensional display file.
50	DISS3D	Draws a perspective projection of data in the three dimensional display file.
41	MAPOV	Inputs survey spot heights from a site plan.
42	GINCON	Allows the display screen to be used to form a file of commands for the contouring package.
45	IANFOV	Inputs existing site features.
47	ANSPOV	Specifies existing site features.
44	EDANOV	Deletes or interogates existing site features.

OVERLAY	NAME	DESCRIPTION
59	PLANE	Calculates areas and distances for any chart or drawing.
80	LIBRY	Creates a library of building types.
58	INPT3	Inputs, modifies or deletes buildings.
76	HORIZA	Performs a horizontal road alignment.
77	VERTA	Performs a vertical road alignment.
85	JUNCTS	Inputs road junctions.
83	RDFIND	Finds the road section nearest to a given point.
78	ROADWK	Deletes road sections.
79	ROADSV	Archives road information for later use.
84	DISRD	Generates the plan view of a road layout.
86	VRTDIS	Generates a section along the centre line of a road.
66	SUNNY	Performs a sunlight analysis on a given building.
63	EXVOL	Main entry tothe Earth Volume analysis.

OVERLAY	NAME	DESCRIPTION
88	BLDGN	Inputs a group of buildings as an analysis feature in the Earth Volume Evaluation system.
89	ROADGN	Inputs a group of roads as an analysis feature in the Earth Volume Evaluation system.
61	TYPEIN	Inputs typed data as an analysis feature in the Earth Volume Evaluation system.
62	TRIG	Inputs a flat plane or landscape area as an analysis feature in the Earth Volume Evaluation system.
91	CUTED	Edits the triangular grid of an analysis feature in the Earth Volume Evaluation system.
90	EARTH	Calculates earth volumes for selected features.

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