

THE DETERMINATION OF ROAD SECTIONS BY COMPUTER

FOR USE IN ROAD DESIGN

by

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I hereby certify that the entire thesis, as submitted, is my own work, other than references that have been used in the text as indicated.

The program coding in Appendix C, although devised and written under my direction, is not my work and is submitted in support of the thesis but not as forming part of my work.

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ACKNOWLEDGMENTS

The writer wishes to acknowledge the kind permission granted for the presentation of the SHARM User's Manual in Appendix A, and for the release of the portion of the program coding for reproduction in Appendix C, in support of this thesis, by Ninham Shand and Partners, for whom the program was written, and, accordingly, with whom the copyright for the remainder of the program rests.

He also acknowledges the contribution by Roger Pilot in writing the program and his fine spirit of co-operation during this period. Thanks are due to Dennis Bagnall for final drafting of the diagrams, to Melissa Blewett and Pam Daniel for their typing, and to colleagues and close relatives for their encouragement and support in the preparation of this thesis.

THE DETERMINATION OF ROAD SECTIONS BY COMPUTER  
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SYNOPSIS

A brief resumé of recent developments in the design of roads is given with special reference to the increasing part played by automated methods by means of which higher degrees of optimization may be achieved. Flow charts illustrating road design demonstrate the relative importance of the determination of the transverse road section by computer.

The finished transverse road section, called a template, consists of a central portion and the outer sloped cut and fill banks. The central portion covers the carriageway(s) and shoulders, the shape of which is predetermined by the geometric design of the road surface and is independent of ground shape. The outer sloped banks, called the side-drain template, are dependent upon the position of the ground surface in relation to the predetermined central portion. When a road is to be built, the road authority usually prescribes the final transverse shape of the road by specifying a standard road template. At every point along the road a specific template can then be determined in accordance with the standard template. However, problems are experienced because certain available computer programs are unable to execute the side-drain portion of the standard road template correctly while earthwork quantities are being calculated. Several available programs are investigated with regard to the procedures adopted by them for the selection of appropriate road side-drain templates. Deficiencies in these programs are noted.

A general solution to the problem of the logical determination of road sections by computer, namely, the method of the locus of the slope stake point, is introduced and elucidated. The success of the method is confirmed by the presentation of the completely operative computer program SHARM for the calculation of road earthworks quantities. The use of the program is demonstrated by a short sample run. Limitations of the method

of the locus of the slope stake point and of the SHARM program are noted, and finally some future developments are discussed.

In view of the ambiguity of words relating to the road cross-section, such as "section", "template", "cut or fill slope", "embankment", "drain", it has been necessary to standardize the usage of such terms for this project. The reader is urged to peruse the glossary on page xi before proceeding to the body of the document.

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GLOSSARY

N.B.: Familiarization with the definitions set out in this glossary is advised, before proceeding to the body of the document.

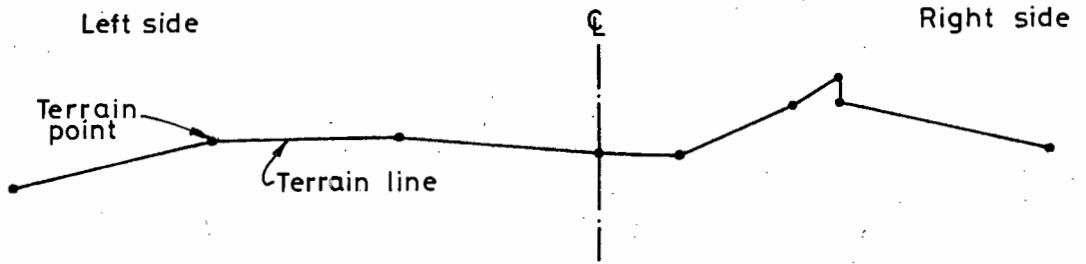
The subject of road design and the specification of road sections in particular requires the use of words and phrases having specific meanings. Unfortunately a considerable diversity of ambiguous terms such as "section", "template", "fill", "embankment", "cut slope" or "drain", is encountered in various texts. It is desirable that a word or phrase should be used in only one context; also that only one word or phrase should be used for a particular description, item or meaning.

The following usages have therefore been standardized for this project. The basic terminology is illustrated in Fig. G1.

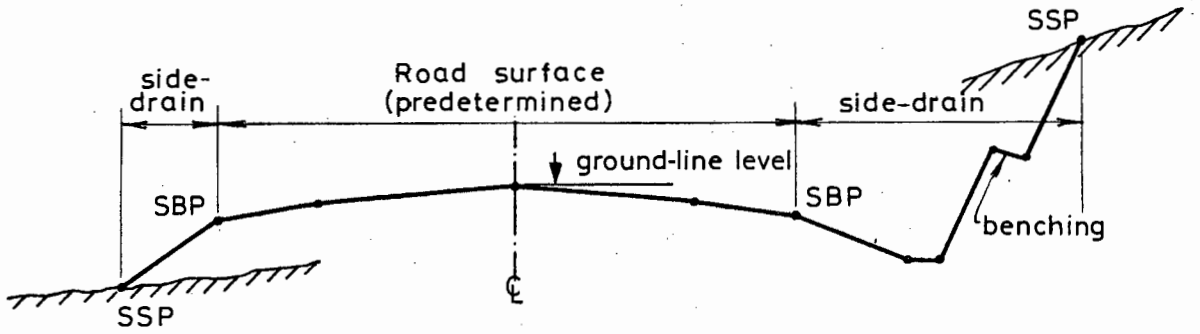
Many definitions use terms which are themselves defined in the glossary. Cross-referencing of these terms is indicated by (q.v.). At the end of some definitions, related expressions are listed.

With the exception of "Engineer" (see "Engineer" and "User" below), expressions standardized in this list, which is applicable to the project, have the same meaning as in the appended SHARM user's manual, which has its own list of definitions (see Appendix A, Section 3). In the user's manual, however, the usage of some terms is yet further restricted to conform with the requirements of the SHARM program.

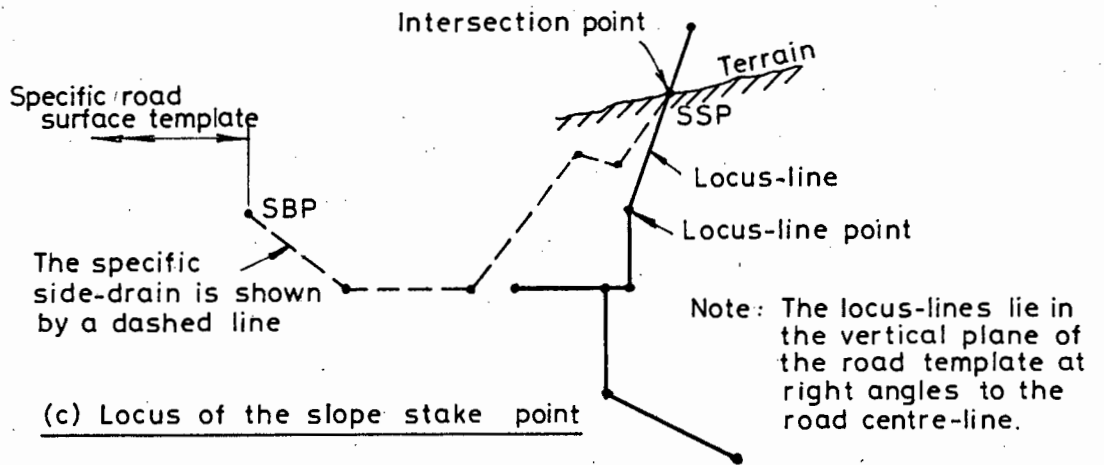
Where references by other authors are cited and words or phrases at variance with the writer's usage are quoted, the equivalent terms in this glossary are given in parenthesis.



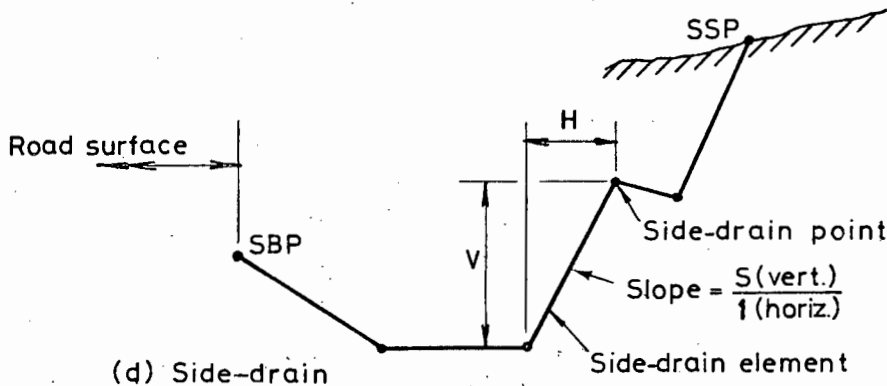
(a) Terrain cross-section prior to road construction



(b) Road template (i) Standard template as prescribed by Road Authority.  
(ii) Specific template as built.



(c) Locus of the slope stake point



(d) Side-drain

Basic terminology of Cross-sections and Templates,  
seen in transverse elevation

Blank A column space or a complete field (q.v.) on the input data that does not contain any information. Its presence is indicated by the use of the lower case "b". (See "Zero").

Chainage\* This defines the position of a point or station (q.v.) along the length of the road. Referred to by some engineers, particularly with regard to the DTM (q.v.), but not in this project, as the X co-ordinate.

Cross-section The use of this term is restricted to sections of the terrain (q.v.) at right-angles to the centre-line. A cross-section of the terrain (see Fig. G1(a)), prior to road construction, is defined by a series of horizontal and vertical offsets (q.v.). (See "Template").

Ditch A physical channel for collecting water and conveying it in a direction almost parallel to the road centre-line. (See Fig. G1(b)). (See "Side-drain").

DTM Abbreviation for Digital Terrain Model, which describes the ground surface by a set of X (longitudinal), Y (transverse) and Z (vertical) co-ordinates.

Elevation The reduced level of a point. All elevations in a job (q.v.) are based on one datum. Although referred to by some engineers as the Z co-ordinates, in this project elevations are called Y co-ordinates. (See "Offset").

Engineer The engineer concerned with drawing up the specification for writing or amending the computer program, and whose responsibility it is to ensure compliance with road engineering requirements. (See "Programmer" and "User").

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\* Note: As a result of metrication, many engineers have replaced the word "chainage" by terms such as "distance" or "kilometrage". The writer considers that the etymology of the word "chainage" need not bar its use in the abstract context of "definition of position along a road". As "distance" is not sufficiently distinctive for this purpose, "chainage" is retained in this project for this specific function.

Field A field consists of one or more columns of data on a computer card. Each individual but complete parameter, value, number or code is entered into its own field. Certain fields may remain blank (q.v.) as instructed.

Grade-line The grade-line is a profile (q.v.), consisting of straight-line grades and vertical curves, which defines the vertical alignment of the road. The elevations of the road template are determined from the grade-line.

Job A job consists of one or more runs (q.v.). The whole job is based on one line of continually increasing chainages (q.v.) (allowance being made for broken chainages) and it is based on one datum for all its elevations.

Length This is measured horizontally, along the terrain centre-line (q.v.).

Locus (= Locus of SSP) This is a pattern of lines in the vertical plane of a template, at right angles to the road centre-line. It is the pattern of a path traced out by all possible positions of the SSP as they are determined relatively to the SBP, by the complete range of varying terrain configurations, in accordance with a particular standard template. (See "SBP", "SSP", "standard template" and "template". See also par. 3.2).

(In the context of side-drain templates, locus of the SSP is not used for longitudinal line formed by joining actual SSP's at successive stations, i.e. it is not the toe-of-fill line or the top-of-cut line, which are roughly parallel to the road centre-line. A projection of the toe-of-fill or top-of-cut line into the plane of a template is, in fact, portion of the locus as defined above).

Locus method A method for determining specific side-drain templates (q.v.) in accordance with prescribed standard templates (q.v.), making use of the locus of the SSP (q.v.).

Offset The horizontal or vertical distance between two points lying in a template (q.v.) or cross-section (q.v.), measured at right-angles to the longitudinal centre-line. In the case of DTM's (q.v.) the horizontal offset is sometimes referred to as the Y co-ordinate. For this project, in the

analysis of the side-drain template and its locus in relation to the terrain cross-section, the horizontal offsets (H) are the differences in X co-ordinates, and vertical offsets (V) are differences in the Y co-ordinates. (See Fig. G1(d)).

Predetermined Refers to the shape of a template (q.v.) that is independent of terrain conditions. It is specified by the user (q.v.) to such an extent that the computer can fix the shape using the input data, but without referring to terrain data.

Profile A longitudinal section of the terrain (q.v.), grade-line, etc., in the vertical plane along the direction of the road.

Programmer The person responsible for writing or amending the computer program, according to directions given by the engineer (q.v.).

Road surface The uppermost surface of the finished road between the SBP's (q.v.). (See Fig. G1(b)).

Road surface template The predetermined (q.v.) geometric specification of the road surface (q.v.). The two sides of the road are sometimes treated separately. It is modified by the user (q.v.) as required to accommodate superelevation, widening, etc. A parking strip, side walk or ditch of a shape not affected by terrain conditions could also be included in the road surface template.

Run A run by the computer may cover the whole or any section of a job (q.v.) and may overlap with earlier runs. It is dealt with in its entirety "at one go" by the computer. All data applicable to the run must be available before the start of the run. Input data may be modified as necessary between runs.

SBP Abbreviation for Shoulder Break Point (q.v.). (See Fig. G1(b)).

Section This word is not used in a restricted sense, and refers to any line, curve, shape or form in a vertical plane. (See "Cross-section", "Profile" and "Template").

SHARE SHand Road Earthworks program. The original program produced for Ninham Shand and Partners.

SHARM SHand Road earthworks (Metric) program. The revised and updated version of SHARE (q.v.). (See chapter 4).

Shoulder break point The outermost point of the road surface (q.v.) which is predetermined (q.v.) by the grade-line (q.v.), horizontal offset adjustments and the road surface template (q.v.). Beyond the shoulder break point the determination of the template (q.v.) is also controlled by terrain conditions.

Side-drain That part of the template (q.v.) that lies beyond the SBP (q.v.) and up to the SSP (q.v.). It includes the side slopes in cut or fill, and any ditch (q.v.) or benching which may be required to collect water between the SBP and the SSP. Its shape at a particular station (q.v.) is not predetermined (q.v.) (see Fig. 1.9). It consists of one or more successive side-drain elements (q.v.) joining a series of side-drain points between, and including, the SBP and the SSP. (See Figs. G1(b) and (d), and 3.4).

Side-drain components Each side-drain element (q.v.) has three components, i.e. the slope (q.v.) of the element, and the horizontal and vertical offsets (q.v.) of the point further in series from the SBP (q.v.), relative to the point closer to the SBP. (See Figs. G1(d) and 3.4).

Side-drain configuration This refers to a side-drain template (q.v.) in which the geometrical shape, or layout, has been defined, but which contains certain undefined dimensions. It is, in effect, a type of side-drain shape which is to be applied when the depth of cut or fill lies within a particular range. Commonly, different side-drain configurations are specified for cases of shallow cut, shallow fill, deep cut

and deep fill\* . A complete standard road template (q.v.) contains a separate side-drain configuration for each such case that is applicable. A particular configuration consists of a fixed number of template points, some (but not all) of which may have fixed offsets (q.v.) interrelating them. The undefined offsets will be fixed when the side-drain configuration is applied at a particular station (q.v.). Figs. 1.11, 1.12, and 1.13 illustrate side-drain configurations.

Side-drain element A portion of the side-drain template (q.v.) consisting of a single straight line terminated by two side-drain points. (See Figs. G1(d) and 3.4).

Slope Only applicable within cross-sections (q.v.) and templates (q.v.) (i.e. at right-angles to the centre-line). It is expressed as a natural ratio of

$$\frac{\text{vertical difference}}{\text{corresponding horizontal transverse difference}}$$

Positive is up, away from the road or terrain centre-line. (See Fig. G1(d)).

Slope stake point The outermost point of the complete template (q.v.). It always lies on the terrain cross-section (q.v.). If the side-drain template is determined by the locus method (q.v.), the accepted point of intersection between the locus (q.v.) and the terrain cross-section is the slope stake point. (See Fig. G1(c)).

Specific template This consists entirely of fixed geometric dimensions which have been determined by the combination of the standard template (q.v.) with the grade-line (q.v.), the locus (q.v.) and the terrain cross-section (q.v.) at a particular station (q.v.).

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\* The terms shallow cut, shallow fill, deep cut and deep fill are used only in a general sense in this project and are not rigidly defined.

SSP Abbreviation for Slope Stake Point (q.v.). (See Fig. G1(b)).

Standard template This is commonly called the "typical road cross-section" and is specified by the road authority to be applicable to a particular length of road being designed. It is a set of geometrical data, which consists of fixed and variable dimensions, some of which are restricted to apply within given limits. (See par. 1.3).

The standard template in combination with the grade-line (q.v.) and the terrain cross-section (q.v.) at a station (q.v.) determines the specific template (q.v.) for that station.

Station A point, defined by its chainage (q.v.), at which a cross-section (q.v.) of the terrain is available.

Template A section in the vertical plane lying at right-angles to the centre-line of the road, defining the road surface (q.v.), materials design layers, median and/or side-drain (q.v.). It refers to all or part of the geometrical layout of the road section between the SSP's on either side of the road, but not to the terrain cross-section. (See Figs. G1(b) and 1.9).

Template centre-line The horizontal origin on which the road template (q.v.) is based. If the template centre-line does not coincide with the terrain centre-line (q.v.), they must be related by a defined centre-line offset.

Terrain Original ground surface, prior to road construction. As the terrain cross-section (q.v.) is often, by its nature, an irregular line, it is in general represented by a free-hand line in the diagrams in this project, although computer programs deal with it as a series of straight lines joining discrete points.

Terrain centre-line A longitudinal line on which the horizontal offsets (q.v.) of terrain cross-sections (q.v.) are based.

User The client who makes use of the computer program in the course of his work designing roads. He is responsible for the preparation and accuracy of input data. In the SHARM user's manual he is referred to as "Engineer".

Zero (Comment on the use of zeros in computer input data:  
An input parameter that has a fixed value of zero, must have at least one zero entered in its field (q.v.). A parameter that is not being defined in the input data may not have any zero, or other number, in its field, but it must remain blank (q.v.)).

THE OBJECTIVE OF THE THESIS

(Some terms used below are defined in the Glossary)

The purpose of this thesis is:

1. To show the need for the determination of transverse road sections by computer in order to achieve optimized road designs.
2. To establish the need for a new general method for the accurate determination of the side-drain template, i.e. the portion of the transverse road section that lies beyond the shoulder break point, by reviewing deficiencies in existing computer programs.
3. To introduce the method of the locus of the slope stake point for determining road sections.
4. To demonstrate the success of the method by presenting the SHARM program.

Note: This thesis is concerned with the practical specification of the road design engineer's requirements that are to be met by a program, rather than the discussion of programming techniques.

CHAPTER 1ROAD DESIGN1.1 MODERN AIDS TO OPTIMIZE ROAD DESIGN1.1.1 Rationale

Design is the detailed evaluation of relevant factors and the specification of the manner in which the work is to be executed.

In the planning and design processes all information whose acquisition is economically justifiable should be considered. The cost of planning and design should not exceed the benefits derived from it. For this reason rule-of-thumb selection, short-cut methods and approximations based on convenient assumptions have been used in the past, as more precise evaluation tended to cost more than the saving derived from the refinement in design. (Approximations used in most earthwork quantities programs are discussed in par. 1.2.2, and in chapter 2 the restricted ability of some programs to deal with certain aspects essential for the proper calculation of earthworks quantities is investigated.)

With the upward trend in the cost of projects, it is becoming increasingly important that approximations be eliminated from the design processes, and that the empirical formula be replaced by precise calculation in order to approach the true optimal solution. An advantage of computer work is that it often suggests precise solutions based on fundamental principles in place of empirical methods which give approximate answers. Many of our empirical design processes should be reappraised. It becomes essential to define the fundamental problem, correctly and precisely.

Civil engineering planning particularly is a field with great scope for computer usage, because much of the planning and control of the design require consideration of so many details, that it is very difficult for the human mind to take adequate cognizance of them all.

Computers are today solving problems and answering questions, which until a few years ago were completely beyond the time capacity of human beings to solve or answer. If a complex functional relationship exists among the parameters defining the problem, it is not always possible to determine the effect of all the factors on the required function, except by trial. The computer is eminently suited for this.

Computer usage is already widespread in civil engineering, but it would seem that it is such a powerful medium that the most significant developments in highway location and design are yet to come.

At all stages, engineering judgment will still be necessary to determine whether the results produced by the computer are consistent with good practice. The use of the computer, if properly applied, can greatly aid the engineer in his judgment.

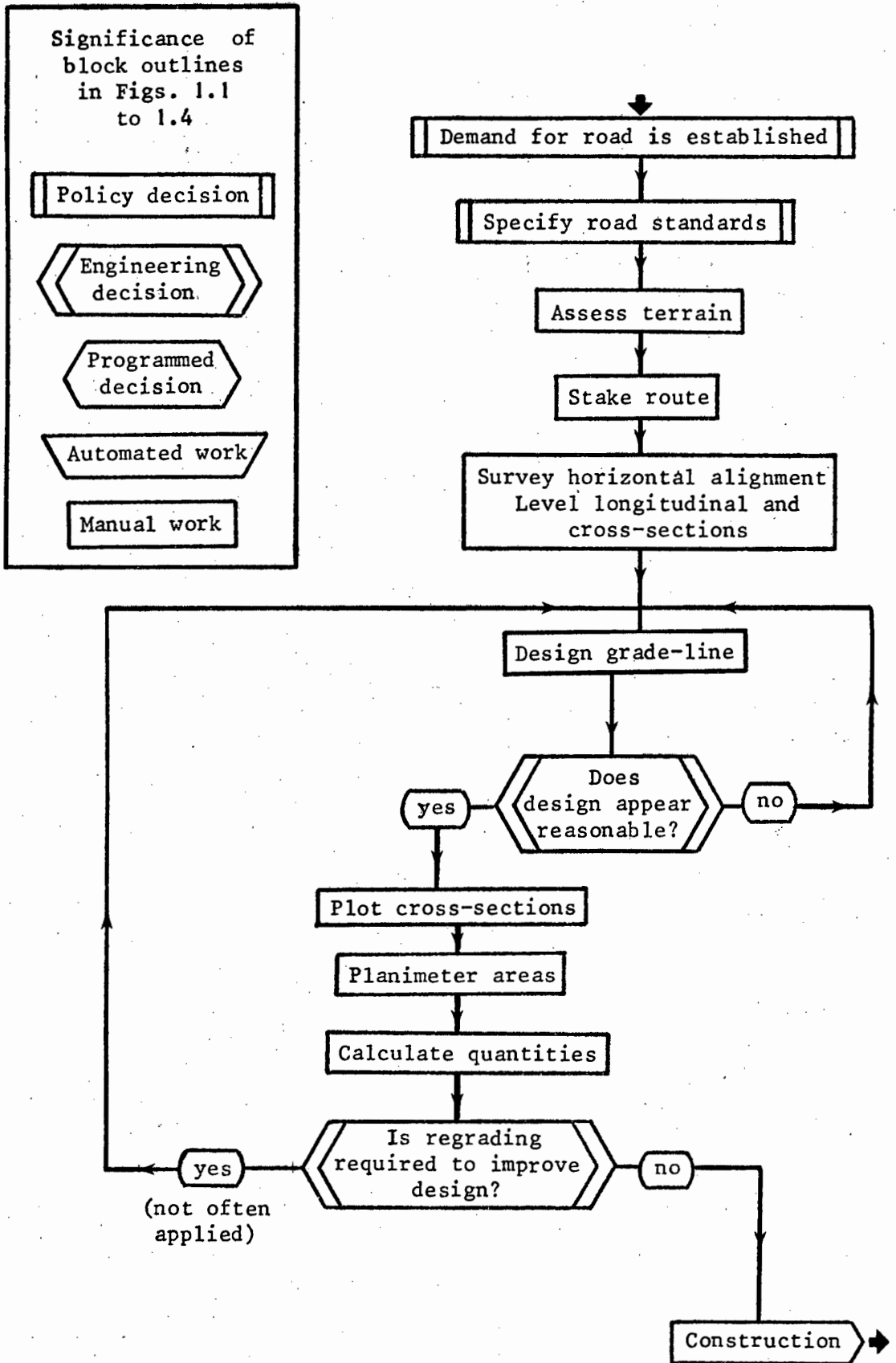
#### 1.1.2 Increasing Sophistication in Design Methods

The methods used in the design of roads have been changed remarkably as a result of new tools that have been developed during the past one and a half decades, particularly in respect of the gathering and processing of information, and optimizing the final design.

Before the start of this era (see Fig. 1.1), road design consisted\* of:

---

\* Aspects of road design concerned with materials investigation, hydraulic structures and cadastral work are not considered here.



Significance of  
block outlines  
in Figs. 1.1  
to 1.4

Policy decision

Engineering  
decision

Programmed  
decision

Automated work

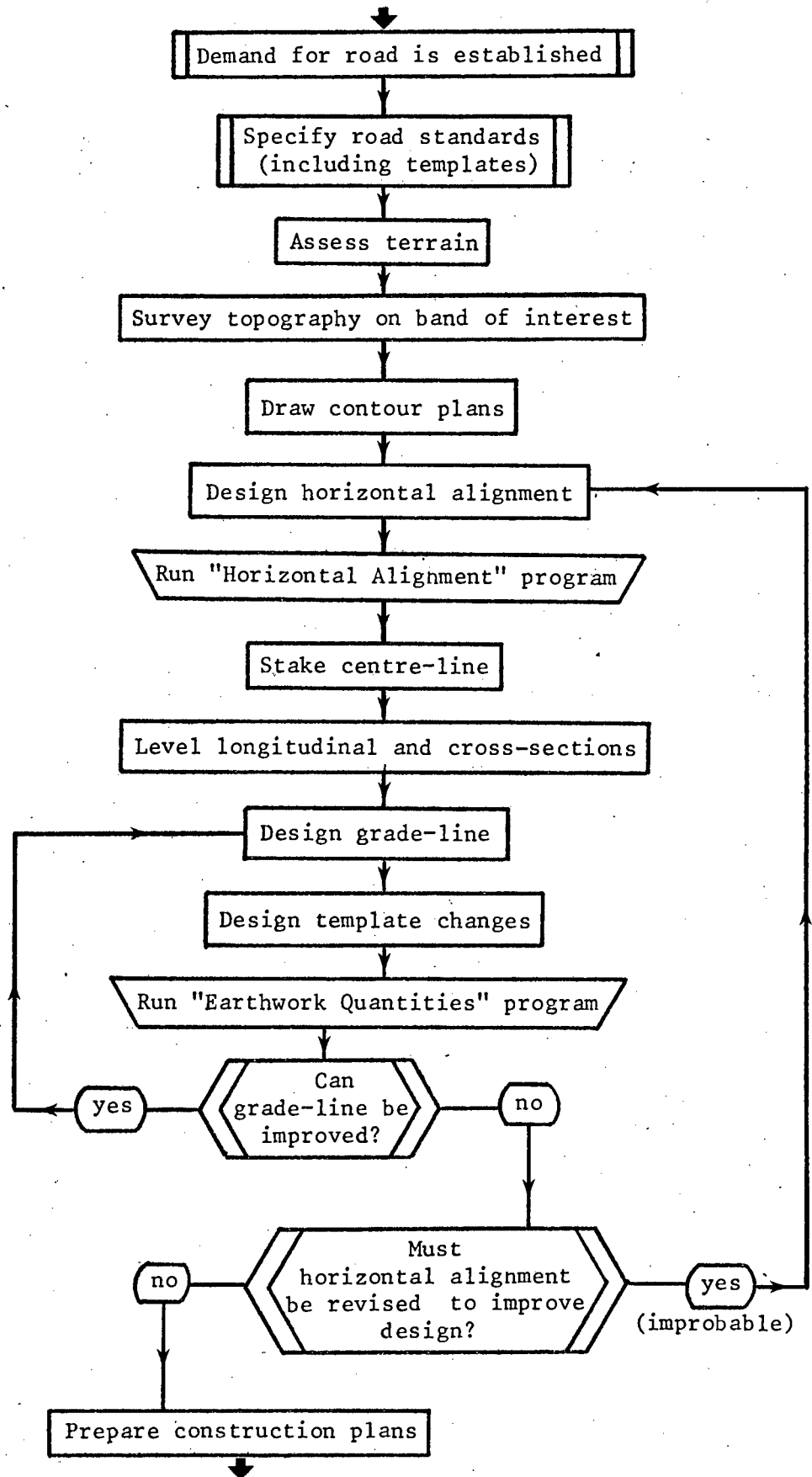
Manual work

MANUAL ROAD DESIGN (before the introduction of computers).

FIG. 1.1

1. Specification of geometric standards by road authorities
2. Field work, entailing
  - on-site inspection to determine feasibility of routes,
  - tachymetric survey,
  - centre-line staking,
  - longitudinal levelling,
  - cross-section levelling.
3. Office work, involving
  - plotting and drawing topographical plans,
  - drawing longitudinal sections,
  - fixing horizontal alignments,
  - designing the vertical alignment (i.e. "grading" which required considerable skill to balance cut and fill, particularly as the first time was often the only attempt),
  - the tedious exercise of drawing out ground sections and regular road templates,
  - planimetering and
  - calculating quantities.

The first breakthrough came with the development of relatively simple cut and fill computer programs. In 1955 the Arizona Highway Department and the California Division of Highways pioneered the way in adapting electronic data processing devices to calculate transverse and earthwork quantities. The benefits of the computer, such as extremely rapid calculation processes, elimination of errors which had occurred during manual operation, rapid and easy revision and appraisal of alternatives (see Fig. 1.2), and more accurate and comprehensive results, were quickly accepted as routine.



ROAD DESIGN, using manual Site Survey and a computer program to calculate earthwork quantities

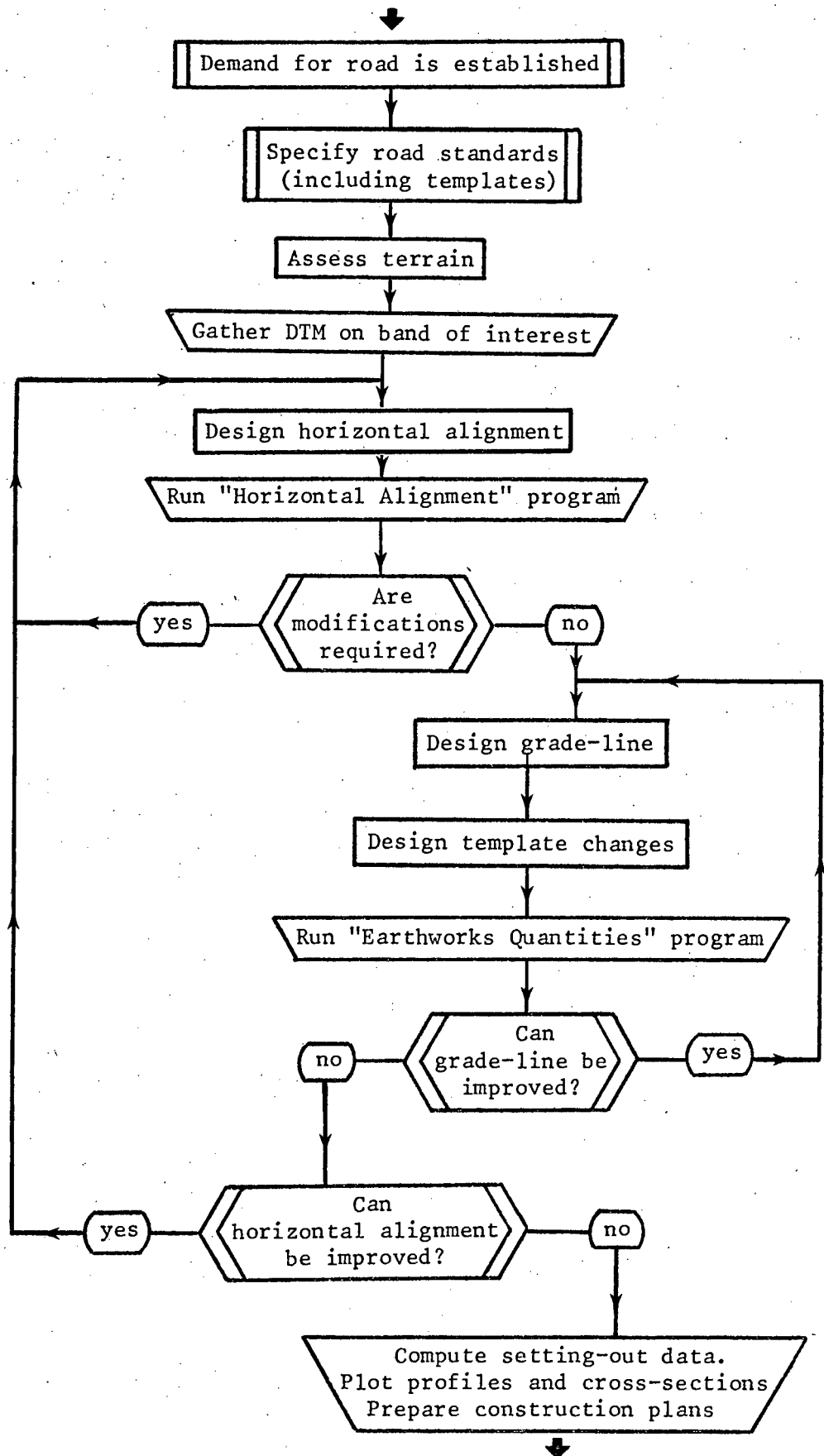
FIG. 1.2

More recent advances in the photogrammetric field have extended these benefits to certain aspects of the field work, particularly where access to the terrain is difficult. Flying at a height of 600 m enables spot heights to be fixed to an accuracy of  $\pm 100$  mm, which is quite acceptable for most purposes provided that all systematic error patterns are avoided. A further development from aerial photography is the use of the digital terrain model (D.T.M.), consisting of a regular grid of spot heights over a band of interest. This provides the benefit of allowing all possible routes to be tested and quantities to be calculated and optimized before staking the centre-line (see Fig. 1.3). Manual work is eliminated by inputting the horizontal alignment to the stereoplotter which automatically interpolates longitudinal and cross-sections from the digital terrain model and digitises the photogrammetric measurements of X, Y and Z co-ordinates<sup>(15)</sup>, outputting directly on to punched cards or tape, for use by the earthworks program.

Ultimately optimization of road grade-line and location within a selected band can be carried out entirely by computer using design factors specified by the engineer (see Fig. 1.4).

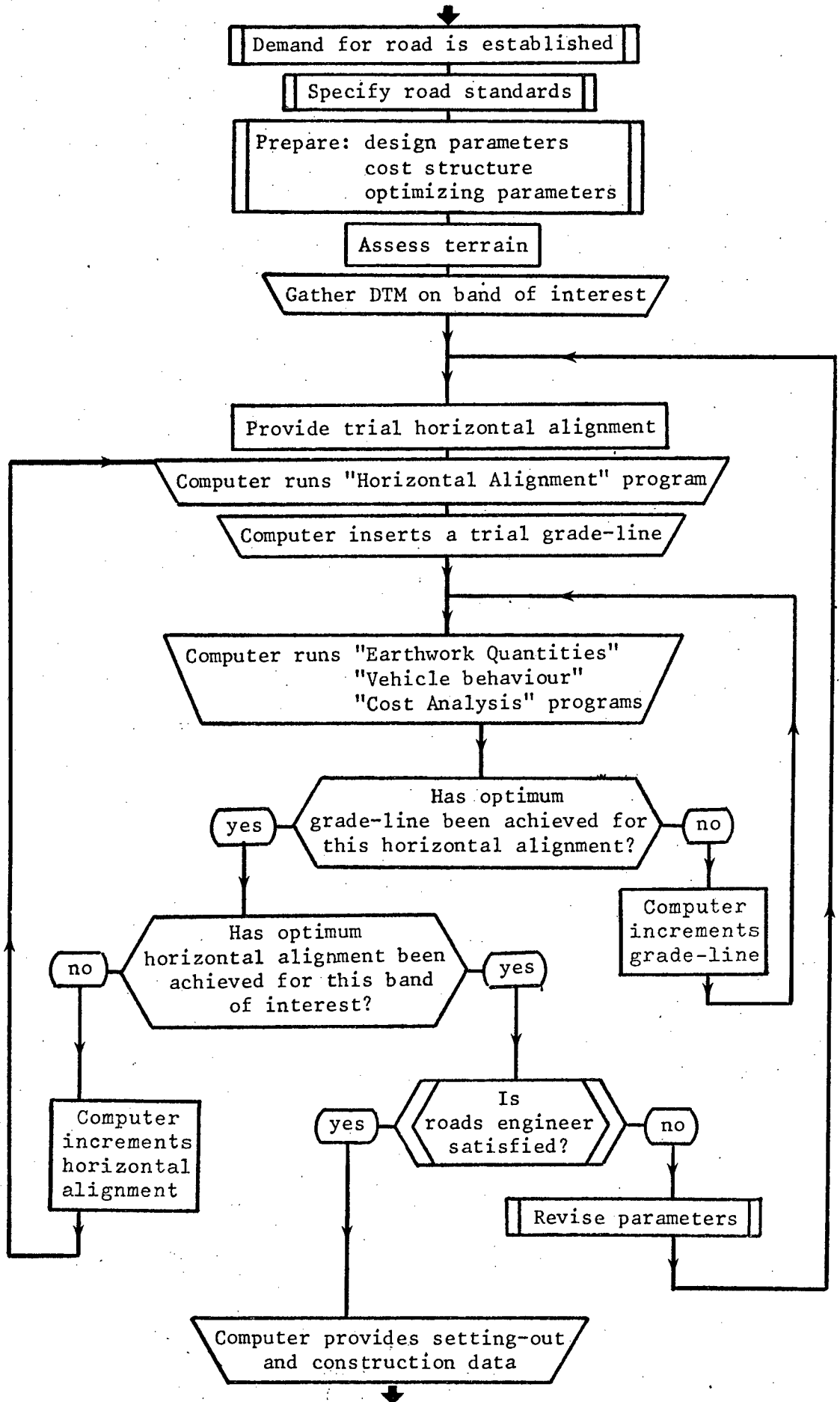
Visual screen displays of profiles, templates and the "driver's eyeview" of the road assist in achieving good design.

The overall benefit derived from the use of these aids can be a significant saving of public funds as a result of being able to optimize the design of the route and grading. The engineer using the aids retains total design responsibility and selects those parameters he wishes to be the basis of his design. The final results given by the computer will be nothing more nor less than a reflection of his ability. The use of these sophisticated tools has advanced the application



ROAD DESIGN, using aerial survey and Digital Terrain Model.

FIG 1.3



ROAD DESIGN, optimised by computer

FIG. 1. 4

of his design skills, and will further enhance them as the versatility and precision of the systems are improved.

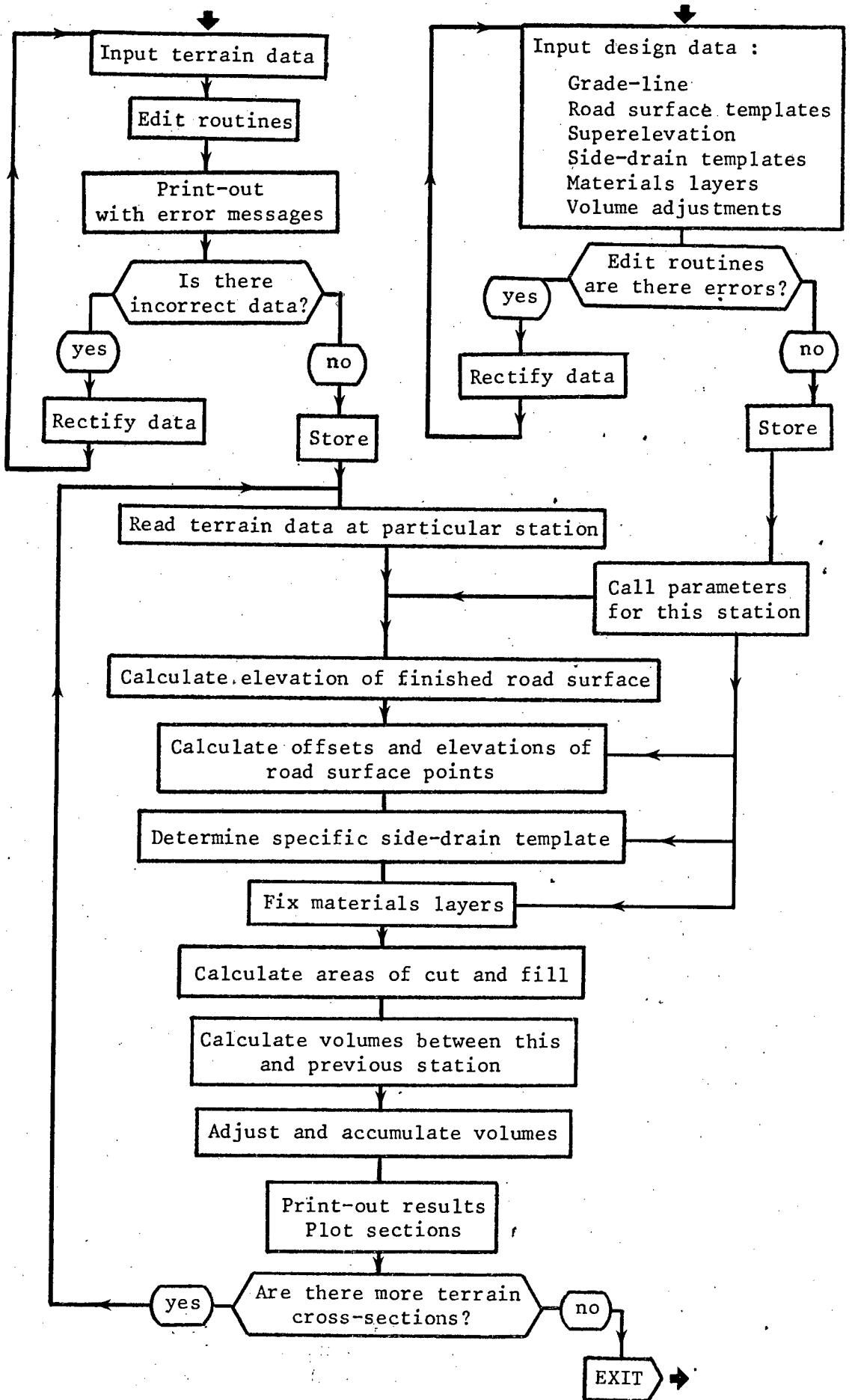
### 1.1.3 Use of Accurate Calculations during Construction

Thus far, consideration has been given to the design of the road. Further major uses for earthworks programs occur during the course of construction. The accurate listings of slope stake point offsets are of considerable use to the surveyors in setting profiles in preparation for the earthworks. The availability of cut and fill volumes for payment purposes is of obvious benefit, particularly where it is possible at little cost and effort to obtain accurate recalculation of modified data, if the design should require amendment during construction. Arrangement is usually made for the reasonable estimation of provisional quantities of partially completed earthworks for interim payment certificates<sup>(24)</sup>. But in view of the large portion of road-building money spent on earthworks, it is essential that the calculation of the final quantities should be precise.

### 1.1.4 Necessity for the Determination of Side-drain Templates by Computer

In Figs. 1.2 to 1.4 the position of the calculation of quantities is shown within the overall design process. Steps in the routine for the calculation of quantities are shown in Fig. 1.5 and are enumerated in par. 1.2.1 .

The calculation of quantities must include a process for determining the specific side-drain template at each station according to the specification for the standard road template laid down by the road authority. It is apparent that, if the design of the road is to be assisted by automated means, it is essential that the computer be given the necessary information and capability to generate the required templates precisely, expeditiously and automatically.



Calculation of earthwork Quantities by Computer

FIG. 1.5

## 1.2 THE CALCULATION OF EARTHWORK QUANTITIES

### 1.2.1 Calculation Procedure

In order to calculate quantities of cut and fill, terrain cross-sections and road templates must be defined so that the areas enclosed by them may be determined. Terrain varies disorderly and irregularly, but is represented by a set of discrete offset values given at each station. The road templates, however, are derived from regular geometric parameters selected by the user, before computation commences, in compliance with the specification of the road authority, as described in par. 1.3 .

The calculation of earthworks quantities during the design of a portion of road, irrespective of whether it is done manually or by computer, requires the following basic steps:

- (i) A longitudinal "base" or centre-line is established along the route of the road, fixing the horizontal alignment. This could be a physically staked line in the field, or, as in the case of the digital terrain model, a set of geometrical data.
- (ii) Along this line "stations" are marked off.
- (iii) At each station a transverse cross-section of the original ground (terrain) surface normal to the centre-line is picked up, either by field survey or by photogrammetry.
- (iv) The terrain cross-section consists of the elevation and horizontal offset distance from the centre-line for each of a series of points on the original ground surface.

- (v) A grade-line is established along the horizontal centre-line to describe the proposed vertical alignment of the road. It defines the elevation of the finished road surface at each station.
- (vi) Parameters are fixed to describe the standard road template relative to the grade-line. These include information on the roadway shape and width, construction material layer thickness, and the shape of the side-drain covering various cases of cut and fill. (Items that influence the choice of parameters fixing the shape of the side-drain are described in par. 1.3).
- (vii) At each station, the specific road surface template is determined by the standard template and the grade-line. The terrain cross-section, specific road surface template and standard side-drain template are superimposed, fixing the position of the slope stake point. Thereby the specific side-drain template is determined and the areas of cut and fill are defined. (The requirements for a computer program to do this are set out in par. 2.1).
- (viii) Corresponding areas of cut and fill at adjacent stations are averaged and multiplied by the intervening longitudinal distance to give volumes. (Inaccuracies in these calculations are dealt with in par. 1.2.2).
- (ix) Volumes are accumulated to give totals for various portions of the job.

- (x) Adjustments may be made to the volumes by  
leaving gaps at bridge sites, and  
applying a swell or shrinkage factor  
to either cut or fill.
- (xi) The adjusted cut and fill volumes are combined  
to give ordinates for a mass diagram which is  
used for planning the overhaul of material  
during construction.

As seen in Fig. 1.5, the generation of specific road templates is a critical aspect of the earthwork quantities program.

#### 1.2.2 Inaccuracies in the Calculation of Earthwork Quantities

Inaccuracies present in the calculation of earthworks fall into two categories:

- (i) Inability of the program to determine the specific side-drain template accurately.
- and (ii) Short-cut methods used in the calculation of volumes, as set out below.
- (i) The calculation of earthworks by computer is impaired by some programs because of their inability to deal precisely with the variety of side-drain specifications as required in step 1.2.1(vi). The methods used by various programs to determine side-drain templates are reviewed in chapter 2. It is primarily with the object to provide a procedure for the accurate determination of side-drain templates by computer program that the method of the locus of the slope stake point, as described in chapter 3, has been devised.

- (ii) Before proceeding with the treatment of side-drains, attention is drawn to three types of minor inaccuracy commonly accepted in the calculation of volumes from areas (step 1.2.1(viii)), which have been inherited from the manual method of calculation. As computers are to be employed to optimize the design, it is now opportune to diminish or eliminate such imprecision.

The three types of inaccuracy are due to:

- (a) using the method of "average end areas"
- (b) ignoring stations at which earthwork solids run down to zero
- (c) ignoring the eccentricity of the centroid of areas on horizontal curves.

More precise results can be achieved as follows:

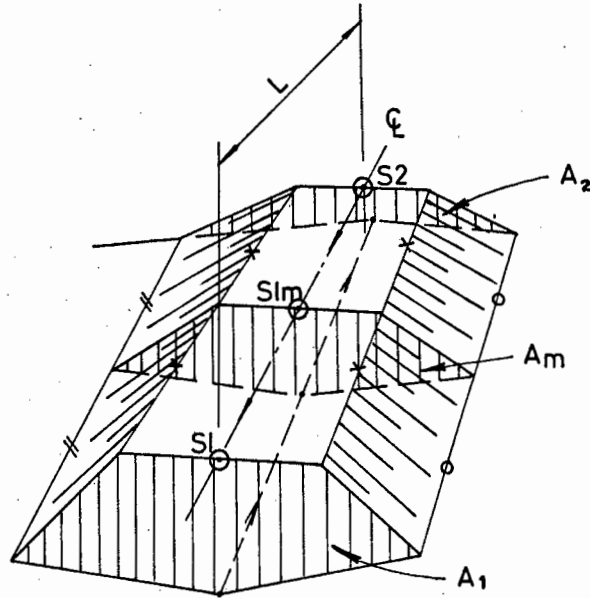
- (a) Use of the prismatic instead of "average end areas" formula

Many contracts for roadworks stipulate: "Volumes shall be measured by the method of average end areas", since precise determination is more complicated, and in the case of manual calculation, is generally not warranted. Most computer programs have followed suit and are based on this formula. In the method of "average end areas", the solid between the stations is considered a prism, whose right cross-sectional area is the average of the end areas.

The "average end areas" (or trapezoidal) formula for volume between stations S1 and S2, having end areas of  $A_1$  and  $A_2$  and which are  $L$  apart, (see Fig. 1.6), is

$$V = L \left( \frac{A_1 + A_2}{2} \right)$$

— 1.1



### Use of the Prismoidal Formula

FIG.1.6

This formula, however, is only exact when the end areas are equal. For other cases it gives volumes larger than their true values. If it were applied to a pyramid having its apex at one end of the sections, the error would be 50% of the correct volume. In practice, however, the total error in a long road is rarely more than a few percent.

Accuracy can be considerably improved by using the prismoidal formula in place of the "average end areas" formula. (A prismoid is a solid whose ends are un-

equal, parallel, rectilinear plane surfaces and whose sides are plane or warped surfaces). For the above case (see Fig. 1.6), the prismoidal formula for volume is

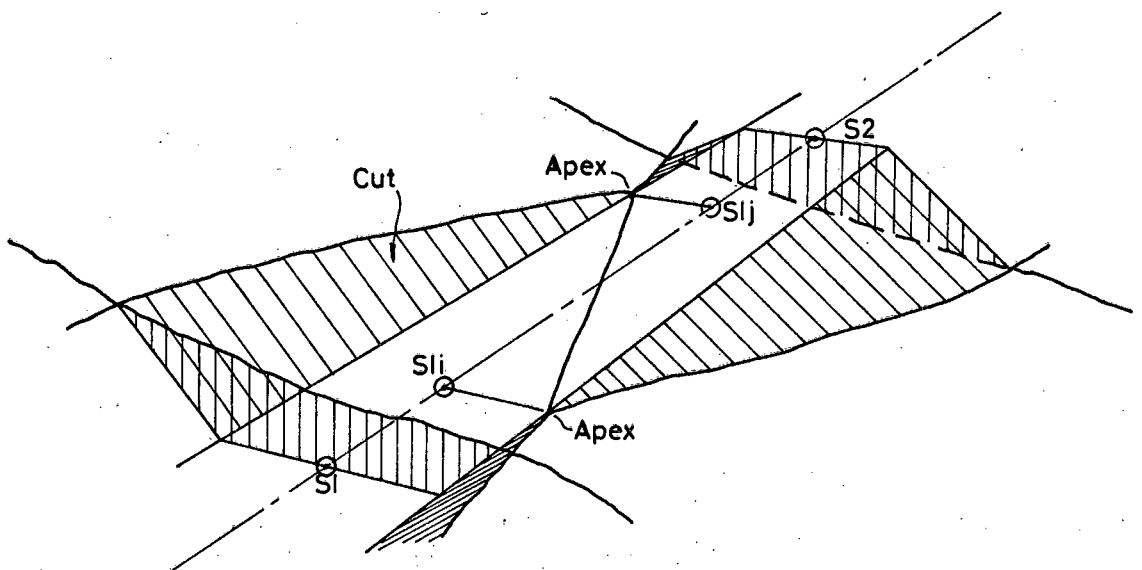
$$V = L \left( \frac{A_1 + 4A_m + A_2}{6} \right)$$

— 1.2

where  $A_m$  is the area of the section at a point midway between stations  $S_1$  and  $S_2$ . The relevant section is the plane rectilinear surface having linear dimensions each of which is an average of the corresponding dimensions of  $A_1$  and  $A_2$ .

(b) Insertion of intermediate stations at which solids run down to zero

A further error (which is always + ve) occurs when the station is ignored at which the apex of a pyramid is situated, as at the transition from cut to fill (see Fig. 1.7). Barrett<sup>(1)</sup> has reported an average error of 0,5% of total volumes in the 12 jobs investigated by him.



Apexes of Pyramids at Intermediate Stations

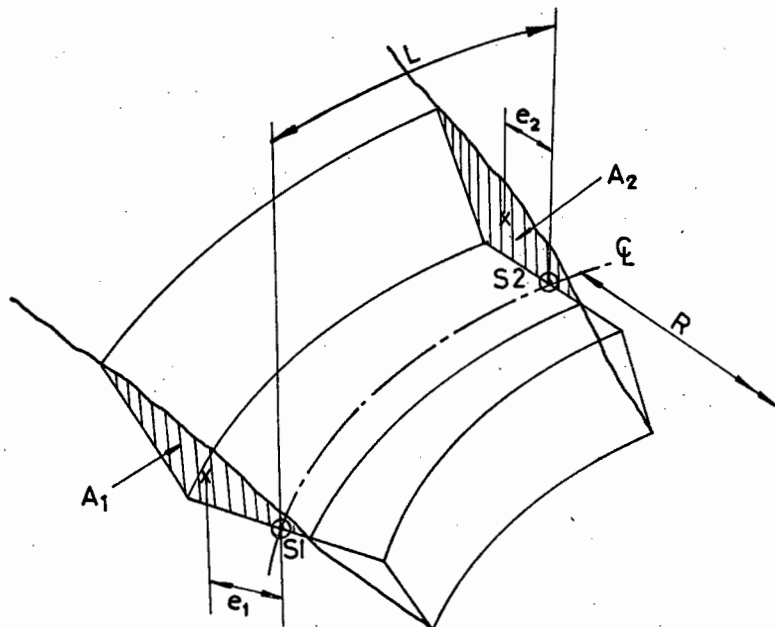
FIG. 1.7

The error is reduced by taking stations at closer intervals. The computer could therefore be programmed to interpolate hypothetical intermediate stations using proportional linear dimensions, whenever a section of material occurs at one station but not at the adjacent one. (Note that the use of the prismoidal formula instead of the "average end areas" method, will in itself reduce errors from this source, on the average, by one half).

(c) Allowing for eccentricity on horizontal curves

If the centroids of the end areas do not lie on the centre-line along which the longitudinal distance between the stations is measured, an error (which may be + ve or - ve) is introduced at horizontal curves).

If the centroid of area  $A_1$  (see Fig. 1.8) lies at an eccentricity (offset) of  $e_1$ , from



Eccentricity on Horizontal Curves.

FIG. 1.8

the centre-line, and similarly the area  $A_2$  has an eccentricity of  $e_2$ , the volume between stations S1 and S2 is given approximately (by Pappus's second theorem (21)), for the method of "average end areas", by:

$$V = \frac{L}{2} (A_1 + A_2) \left[ 1 + \frac{1}{2R} (e_1 + e_2) \right] \quad \text{--- 1.3}$$

where  $R$  is the horizontal radius of curvature of the centre-line.

If the prismoidal formula is used, and the eccentricity of the mid-section area,  $A_m$ , is  $e_m$ , the volume is:

$$V = \frac{L}{6} \left[ A_1 + 4A_m + A_2 + A_1 \left( \frac{e_1 + 2e_m}{3R} \right) + 2A_m \left( \frac{e_1 + 4e_m + e_2}{3R} \right) + A_2 \left( \frac{2e_m + e_2}{3R} \right) \right] \quad \text{--- 1.4}$$

If the centroid of an area lies on the inside of the curve, its eccentricity,  $e$ , is negative.

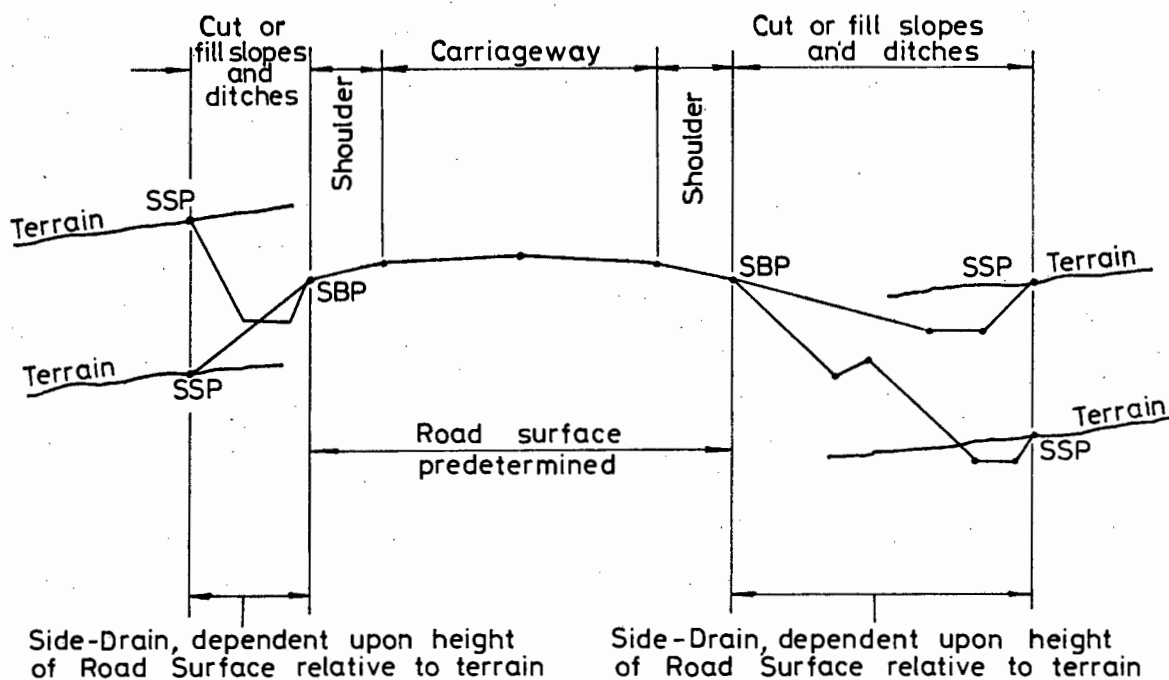
The adjustments set out in (a), (b) and (c) above are all suitable for incorporation into computer programs. The computer is able to calculate the additional hypothetical stations and the eccentricities of the areas, using data already needed to run the program. The inputting of additional data is therefore not required. Admittedly, the source programs and storage requirements would be extended.

SPECIFICATION OF ROAD SECTIONS  
BY ROAD AUTHORITIES

Note: The following paragraphs are not restricted to road design using computers, but provide for the general specification of standard road sections on a consistent and sound engineering basis.

1.3.1 Portions of the Road Template

When a road is being designed, an important aspect to be considered is the standard template of the road, often referred to as the typical cross-section. The complete road template consists of two portions (see Fig. 1.9):



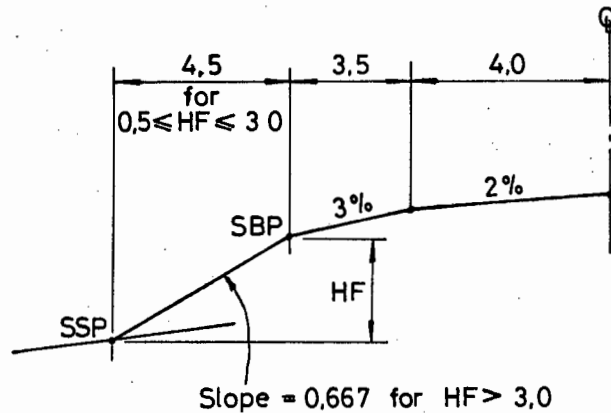
Portions of Road Template

FIG. 1.9

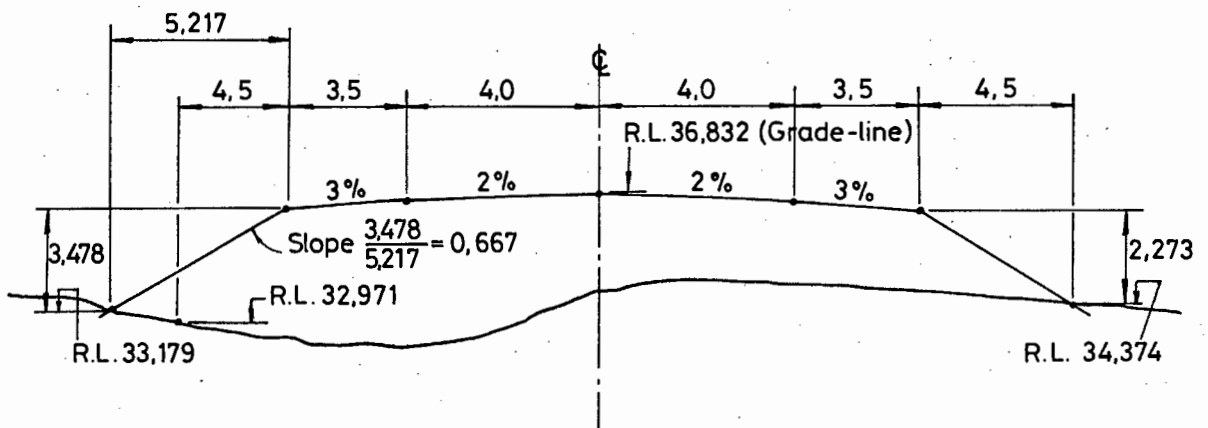
- (i) a predetermined central portion, called the road surface, comprising carriageway and shoulders and any other part of the template that is not affected by the terrain,
- (ii) the portion of the template, called the side-drain, the shape of which is dependent upon the heights

of the terrain and the predetermined road surface relative to one another, and which lies between the shoulder break point (SBP) and the slope stake point (SSP).

The standard template is applicable over a particular length of road being designed, and in the side-drain portion it contains some dimensions that are variable (not predetermined). These dimensions become fixed when the standard template is applied, using the appropriate grade-line level at any station, thereby producing the specific template at that station. Fig. 1.10 illustrates the application of a standard template to produce a specific template.



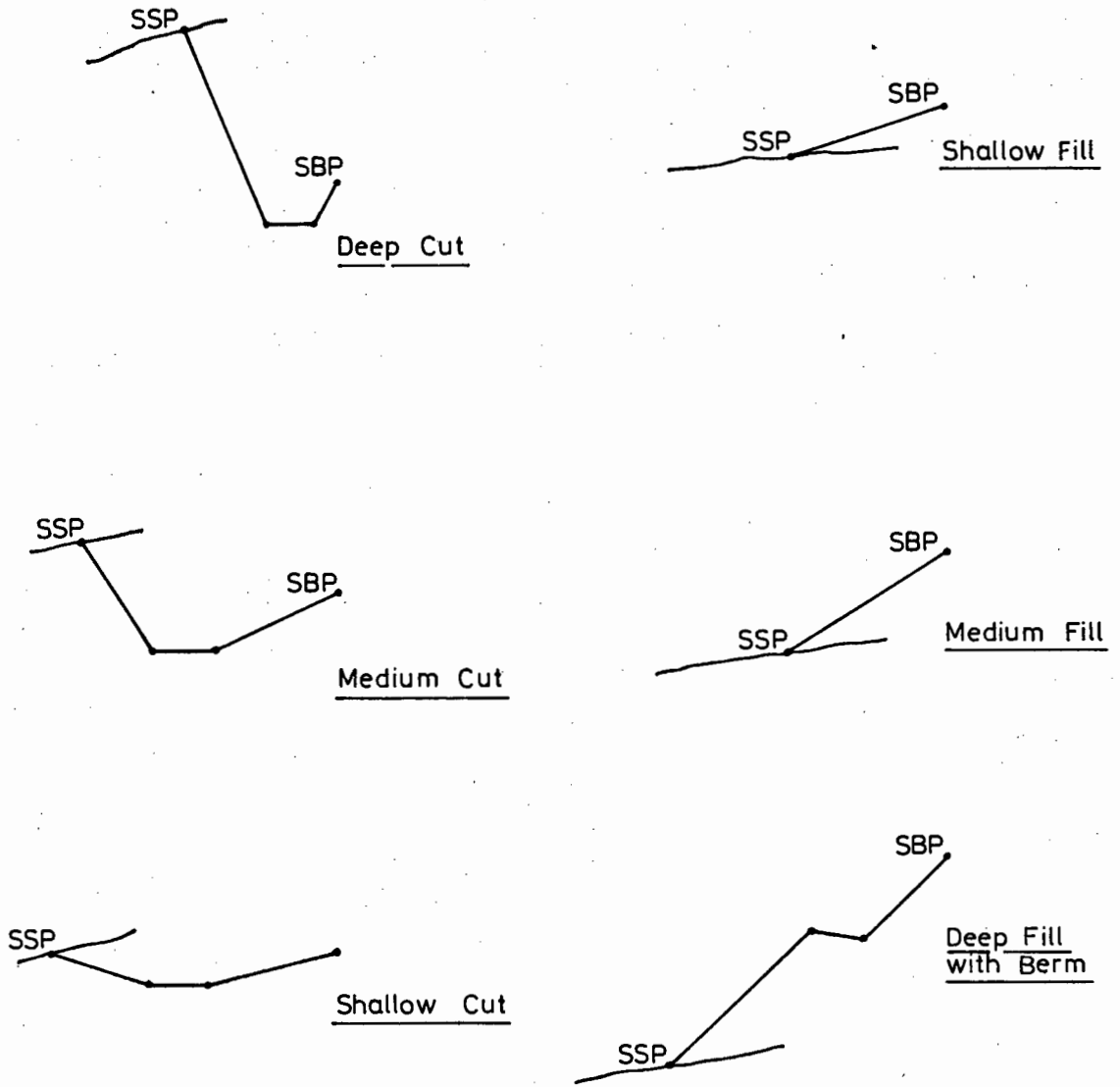
Extract of Standard Road Template, applicable to whole length of road



Specific Road Template at a Particular Station

Standard and Specific Road Templates

FIG. 1.10



A Selection of Side-Drain Configurations

FIG. 1.11

A particular standard template usually includes several different configurations of side-drains to cover various conditions of deep cut, shallow cut, shallow fill or deep fill. A selection of configurations is shown in Fig. 1.11. Every configuration in the standard template will have some variable dimension(s) in order to accommodate the changes in depth of cut or fill from station to station.

Although there are two side-drain portions per complete template, each side-drain is usually treated independently of the other (see Fig. 1.10). For convenience, therefore, further discussion of the side-drains is in the singular.

The application of the illustrations to rural roads is obvious. The discussion is, however, valid even in the case of urban roads where the predetermined road surface includes sidewalks, and continues up to the road reserve boundary, to be terminated in a vertical retaining wall. The side-drain, in this case, consists of a vertical line through the shoulder break point, and its vertical length is determined at each station by the difference in level between the SBP and terrain.

IMPORTANT. The remainder of this chapter, and chapters 2 and 3, are concerned only with the side-drain portion of the road template, (ii) above.

### 1.3.2 Specifications for Standard Side-drain Templates

Road-building authorities usually specify their requirements by standard templates that have been developed, with due regard to conditions encountered within their territory. The type of side-drain is dependent on the general standard, or class, of the road. That there is some difference of opinion as to the optimum arrangement, even for similar classes of road, is reflected by the disparities in the types of standard side-drain template that can be accepted by computer programs developed by, or for, various road agencies. These disparities are discussed under the headings of the available programs in chapter 2.

When drawing up a new standard template for a particular class of road, the following items concerning the side-drain require attention by the road authority:

- (i) flattened side slopes promote safety for road users in the event of a vehicle going out of control
- (ii) steepened side slopes reduce the cost of earthworks
- (iii) stable fill slopes depend on the safe angle of repose of the embankment materials
- (iv) safe cut slopes depend on the type of material being cut
- (v) satisfactory drainage of stormwater requires the provision of ditches
- (vi) erosion of deep cut or fill slopes is controlled by suitable berms
- (vii) the geometry of the side-drain influences the ease of maintenance of the side slopes.

Even for a particular class of road the standard template may be modified according to the general nature of the terrain, e.g. the template for flat and gently sloping country may be more generous with flatter slopes than for a mountainous region, even when other factors, such as type of material and depth of cut or fill, are the same.

Drawing up the specification for the standard template will therefore require taking cognizance of the above items, while providing the various con-



horizontal positions, relative to the shoulder break point, suddenly as the depth of cut, HC, increases from slightly less to slightly more than 1,0 m.

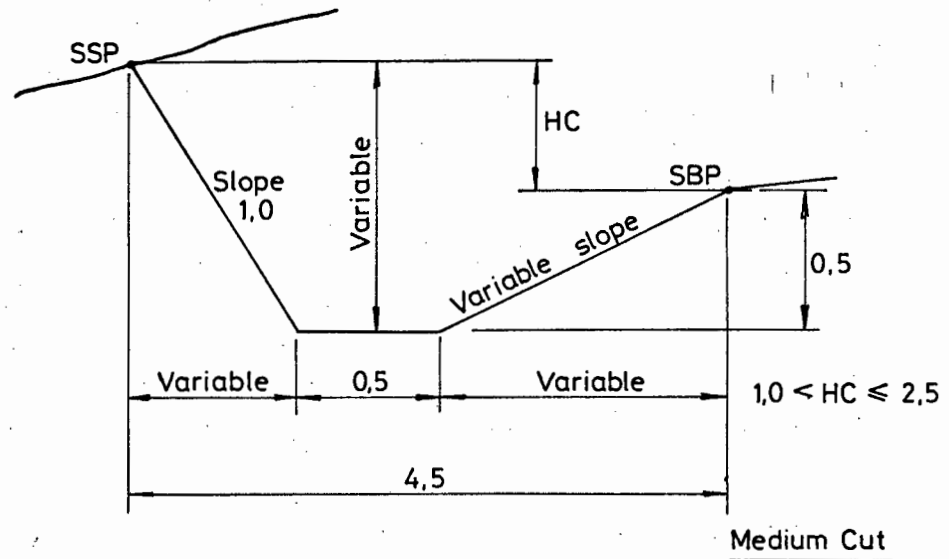
Further inspection of Fig. 1.12 reveals that:

- (c) if the terrain has a slope down away from the centre-line, both configurations could be applied since HC could be more than 1,0 m at a distance of 3,0 m from the SBP (i.e. deep cut applies) and also less than 1,0 m at a distance of 4,5 m from the SBP (i.e. shallow cut applies). The standard template would have to provide for the appropriate exclusion.
- (d) Conversely, if the terrain slopes up away from the centre-line, a gap may be left where neither configuration applies (HC could be less than 1,0 m at 3,0 m from SBP, and also greater than 1,0 m at 4,5 m from SBP).

The smooth transition needed (a & b above) could be obtained, and the ambiguity (c) and the gap (d) removed, by inserting an additional side-drain configuration (medium cut, Fig. 1.13) and modifying the deep cut configuration to apply only when HC is greater than 2,5 m.

(Note that in spite of the several dimensions shown as variable in Fig. 1.13, a specific side-drain is completely fixed when the SSP has been established relative to the SBP at a station).

A standard template must provide within itself sufficient configurations of side-drain so that one, and only one, satisfactory specific template can be established at every station along the length of the road to which this standard template applies.

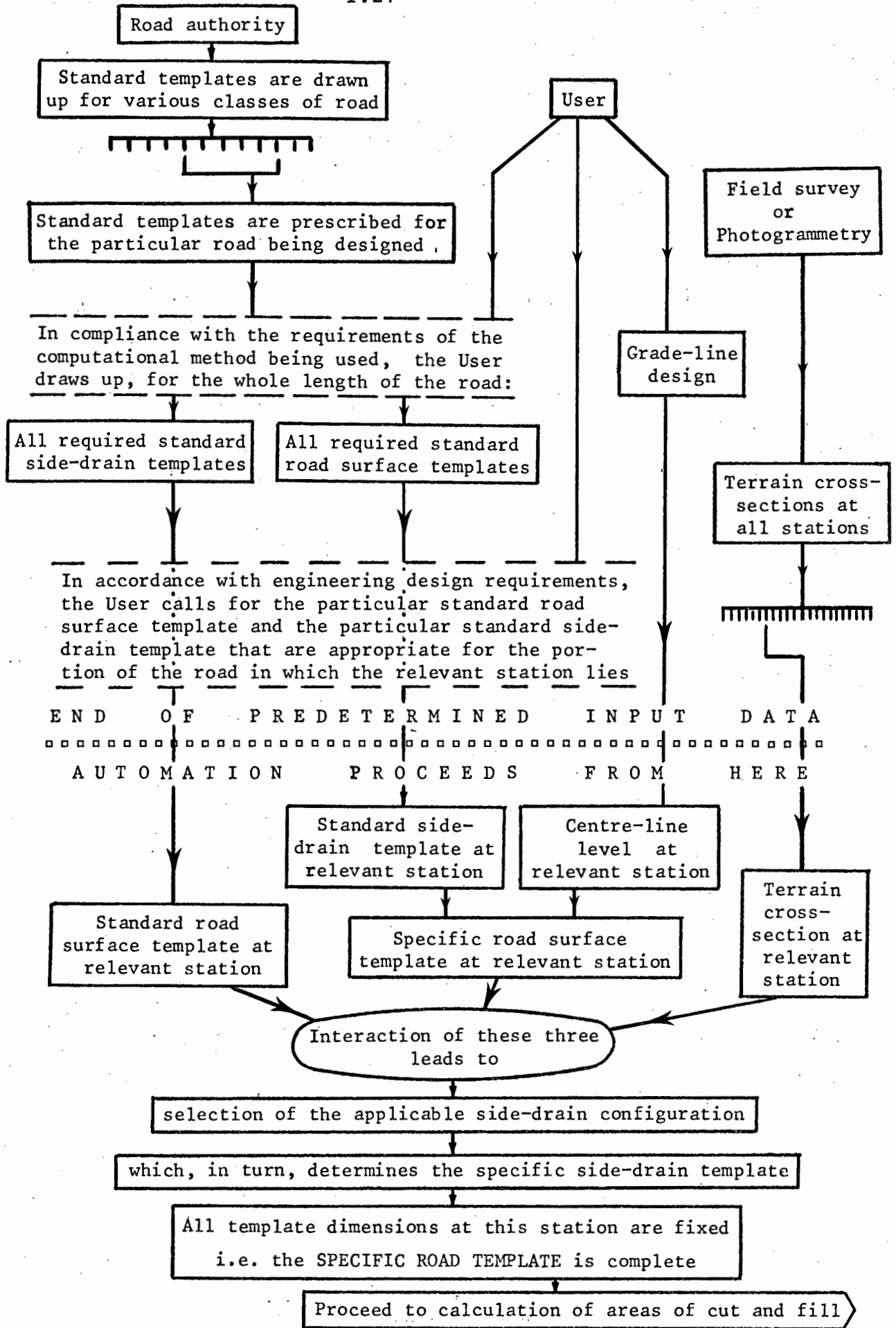


Side - Drain Configuration  
to provide smooth transition

FIG. 1. 13

Furthermore, it is desirable that within a standard template, adjacent configurations should provide a smooth transition along the length of the road when depths of cut and fill vary gradually.

Finally, it is to be noted that the user may require a change in the standard template along the length of the road in order to accommodate a change in design parameters, such as a different road width or other side slopes in a different cut material. This calls for one or more additional standard templates. Each standard template must be complete within itself and be able to allow the determination of side-drain templates to proceed on that portion of the job to which it applies. The point at which one standard template is exchanged for another is always predetermined by the user (see Fig. 1.14). The particular side-drain configuration used to make up the specific template at a station is selected mechanically, during the computation of earthworks quantities.



Determination of appropriate Road Section as specified by Road Authority

FIG. 1.14

List of Symbols used in Chapter 1

$A_1$	area of a particular material in the plane of the template at station $S_1$
$A_2$	area of the same type of material at $S_2$
$A_m$	area at a point midway between stations $S_1$ and $S_2$
$e_1$	eccentricity of centroid of area, $A_1$
$e_2$	eccentricity of $A_2$
$e_m$	eccentricity of $A_m$
$L$	length measured along the centre-line of the road from $S_1$ to $S_2$
$R$	radius of horizontal curvature, to the road centre-line
$S_1$	initial station
$S_2$	end station
$V$	volume of the particular type of material between stations $S_1$ and $S_2$

CHAPTER 2REVIEW OF METHODS USED IN  
AVAILABLE COMPUTER PROGRAMS  
TO DETERMINE SIDE-DRAIN TEMPLATES2.1 REQUIREMENTS FOR A PROGRAM TO  
DETERMINE ROAD TEMPLATES

One of the points given by Hobbs<sup>(8)</sup> under his problem definition in preparation for writing an earthworks program was:

"The system should cope with all geometric standards in current use in South Africa".

This underlines the principle that the program should be written to cope with the engineering requirements, without imposing undesirable restrictions on the design procedure.

The specification of standard road sections, as dealt with in par. 1.3, should rightly ignore the possibility that processing may be assisted by computer. It is the duty of the engineer concerned with writing a road design program for a computer, to ensure that his program will handle the standard road section as specified.

With regard to the requirements in par. 1.2.1(vii), that a specific template be determined to define areas of cut and fill at each station, and in par. 1.1.4 that the complete process be automated, THE PRIMARY OBLIGATION manifests itself thus:

THE PROGRAM MUST BE ABLE TO DETERMINE

- (i) ONE, AND ONLY ONE, SPECIFIC ROAD TEMPLATE
- (ii) COMPLETELY,
- (iii) WITH FIDELITY, in accordance with the standard template appropriate to the portion of road being designed

- (iv) AT EVERY STATION REQUIRED BY THE USER,  
if necessary at irregular chainages  
and (v) BY THE USE OF A BASIC SET OF STANDARD  
TEMPLATE PARAMETERS, obviating the need  
for the user to input template data at  
each station.

In addition, with respect to the determination of side-drain templates, desirable attributes of earthworks programs are as follows:

Concerning Terrain Data:

- (a) Cross-section data should be accepted by the computer in forms familiar to field surveyors to ease inputting data.
- (b) The computer should accept cross-sections at irregular chainages, so that accurate volumes can be calculated at sudden changes in terrain.
- (c) The computer should be able to accept as many terrain points at a cross-section as reasonably provided by the field surveyor.
- (d) A minimum of two terrain points should be sufficient to define a terrain cross-section in flat country.
- (e) Provision should be made to deal in a rational manner with a cross-section, when its terrain data does not extend far enough to reach the slope stake point. The treatment adopted should be set out clearly, so that a manual adjustment may subsequently be made, if considered necessary.

Concerning the Program in General:

- (f) When dealing with simple roads the inputting of data should be straightforward and easy.
- (g) It should not demand the insertion of data that is of no consequence in a particular job.

- (h) It should be adequate to deal with all standard road templates in use. If it forms part of a sophisticated design system, it should accommodate dual-carriageways and other complex road and side-drain templates.
- (j) Changes in design parameters (such as the standard template) called for by the user along the length of the road should require a minimum of supplementary input data.
- (k) The program should include editing routines to check thoroughly the validity\* and, if possible, the reasonableness\* of all input data. This is necessary to eliminate as many errors in the data as possible and to avoid mid-run stoppages.
- (l) Restrictions and limitations in the program should be annotated in the user's manual.
- (m) If intended for wider use, a user's manual with explicit instructions should be provided to enable users, with little knowledge of the program, to prepare input data correctly.

---

\* Input data, in general, is valid if it is in the required format and if it lies within any range of values that may be applicable. Data that, although being valid, is unreasonable, may cause problems or a stoppage during a run. Test values for unreasonableness could well be under the control of the user.

(e.g. Two terrain points 20 m apart, have a difference in level of 10 m. The level difference is valid; in rough country it is probably acceptable as reasonable, but in flat country it would be unreasonable).

## 2.2 REVIEW OF AVAILABLE PROGRAMS

In this review of programs, the methods used in them to determine side-drain templates are inspected to assess their abilities to comply with the requirements set out in par. 2.1. Other aspects of the programs are not considered.

In most programs the full range of standard side-drain configurations used may be illustrated in a limited number of diagrams, in contrast to the unlimited range of configurations in a program, using the locus of the slope stake point method (introduced in Chapter 3), from which specific templates would have to be selected for illustration. In the following paragraphs, the standard side-drain configurations for each program have been illustrated, showing the parameters which the particular program can accommodate.

### (i) Glossaries

The names of variables used in the original programs have been retained and are summarized in brief glossaries under their respective headings. Such glossaries are only applicable to the relevant program.

### (ii) Suffixes signifying degrees of freedom

When a computer program is written, the programmer accords the parameters used therein various degrees of freedom of choice. These are indicated by the appended suffixes as follows:

R = Fixed in program, cannot be changed other than by source deck modification.

F = Fixed by user, must remain constant for a complete run.

V = Fixed by user, variable within a run at chainages fixed by user before run commences.

D = Determined by computer during run,  
dependent on combination of terrain,  
grade-line and template.

+ = A dimension marked thus may not be  
negative.

(Note: R, F, and V denote predetermined values)

(iii) Inexact programs

For the purposes of rough estimation of costs or preliminary design, a number of programs\* are available for the calculation of earthworks quantities rapidly on an approximate basis. Terrain data and template specification are of necessity brief and devoid of refinement, in order to achieve rapid processing at minimum cost. Such programs fulfill a useful purpose. Unfortunately, precise determination of road sections and low cost calculation of earthworks are, as yet, incompatible. Since the capabilities of programs for the approximate calculation of quantities cannot be compared fairly with those of comprehensive programs intended for precise calculation, such inexact programs are not considered further in this review.

- 
- \* (1) C.P.A. Earthwork Quantities (Preliminary Design Stage) : Cape Provincial Roads Department.
- (2) PERTH (Preliminary road earthwork quantities) : Van Niekerk, Kleyn and Edwards.
- (3) RCFX Cut and fill by table look-up : Bureau of Engineering Computer Services.

2.2.1 C.S.I.R. - I.B.M. Highway Cut  
and Fill Quantities Program

(ref.: Council of Scientific and Industrial Research.  
I.B.M. program 80/80, Highway cut and fill  
quantity calculations. 1962)

This program was prepared by the National Institute for  
Road Research of the C.S.I.R. and I.B.M. during 1962.

The portion of the program dealing with the selection  
of the side-drain template operates as follows:

The program accommodates up to four different typical  
sections (standard templates) for a single lane highway,  
e.g.

type 1 : straight road;

type 2 : left curve, 2% straight-line  
superelevation;

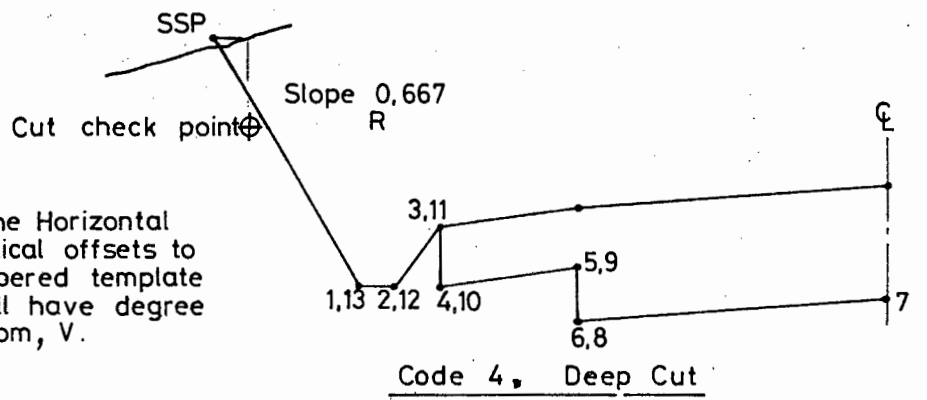
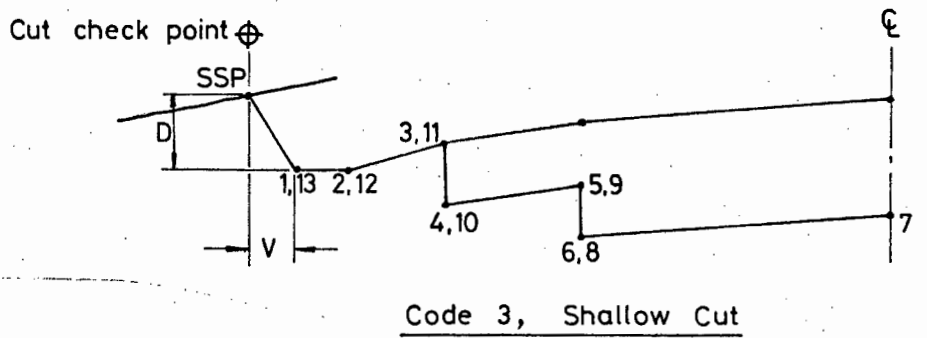
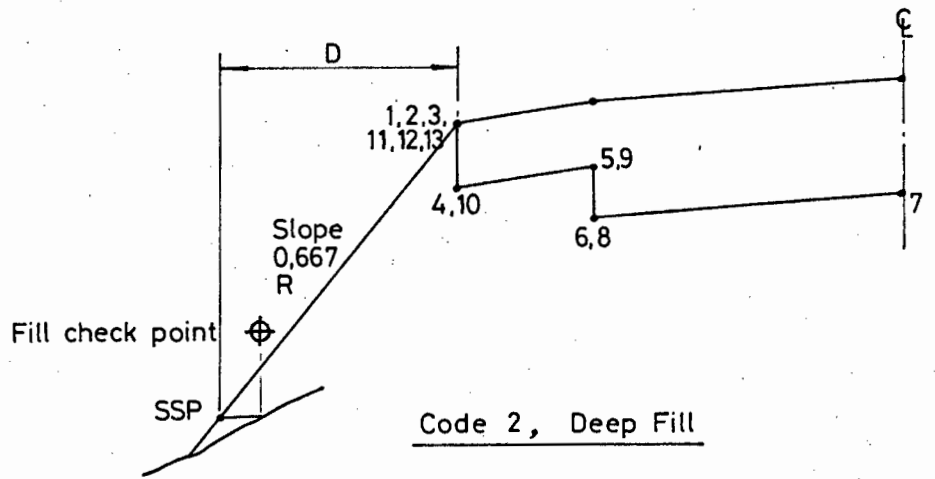
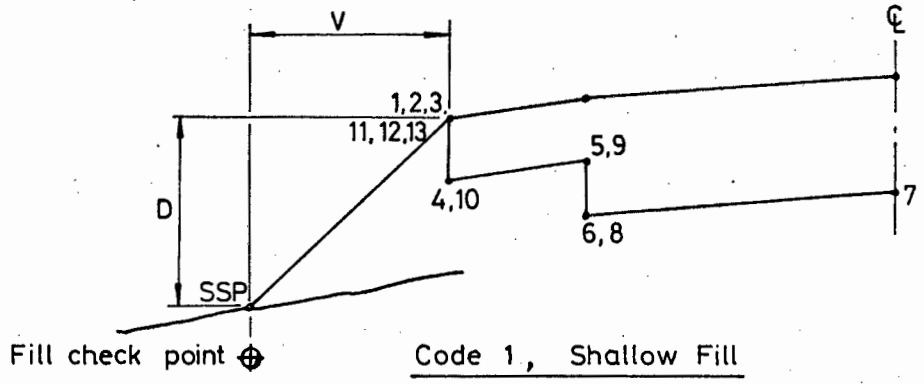
type 3 : right curve, 2% straight-line  
superelevation;

type 4 : right curve, 3,5% straight-line  
superelevation.

Each typical section (standard template) has four  
possible variations of cut/bank conditions (side-drain  
configurations) for each side of the road, referred to  
as codes. The four codes (side-drain configurations)  
are illustrated in Fig. 2.1.1 .

Glossary

Check distance: The distance, from the centre-line,  
on both left and right sides at which the program  
interpolates terrain levels, and then compares  
these terrain levels with the finished centre-line  
level.



Note: The Horizontal and Vertical offsets to the numbered template points all have degree of freedom, V.

4 Side-Drain Configurations used by the "CSIR-IBM" Program

FIG. 2.11

**Fill check height:** If the difference between the finished centre-line and the terrain level at the check distance is less than the fill check height, code 1, shallow fill applies; if it exceeds the fill check height, code 2, deep fill, applies.

**Cut check height:** If the difference between the terrain level and finished centre-line level at the check distance is less than the cut height, code 3, shallow cut, applies; if it exceeds the cut check height, code 4, deep cut, applies.

**Profile (template) co-ordinates:** Horizontal and vertical offsets to a set of 13 points defining a standard template relative to the centre-line and the grade-line.

#### Input data

The input data, all of which has the degree of freedom, V, for each of the four typical sections (standard templates), consists of:

A check distance	)	
A cut check height	)	All three are applicable to both sides of the road
A fill check height	)	

A set of 25 pairs of profile co-ordinates, which define 13 template points;

the 2 outermost points on either side are each given 4 alternative pairs of offsets corresponding with codes 1, 2, 3 and 4, while the 9 inner pairs of offsets remain constant.

(The undefined slope stake points bring the total number of template points to 15).

The typical sections (standard templates) are called in as required, by the user simply listing chainages from which a new typical section is applicable and its type number.

Method.

As the computer deals with each station in turn, it applies the typical section (standard template) last called in by the user, to fix the 9 inner template points. By the use of the check heights it selects one of the four codes (side-drain configurations) on each side according to the terrain level at the check distance. To complete the specific template, the "point where the cut or fill at the edge of the earthworks cuts the ground profile" (the slope stake point) is fixed on either side as follows:

Codes 1 and 3, shallow fill and cut: The slope stake point is the point on the terrain cross-section lying at the check distance (offset) from the centre-line.

Codes 2 and 4, deep fill and cut: The level of the slope stake point is assumed to be the same as the terrain level at the check distance (offset). The horizontal offset of the slope stake point is calculated by adopting an outer slope of 0,667 (degree of freedom, R) from the outermost defined template point.

Comments.

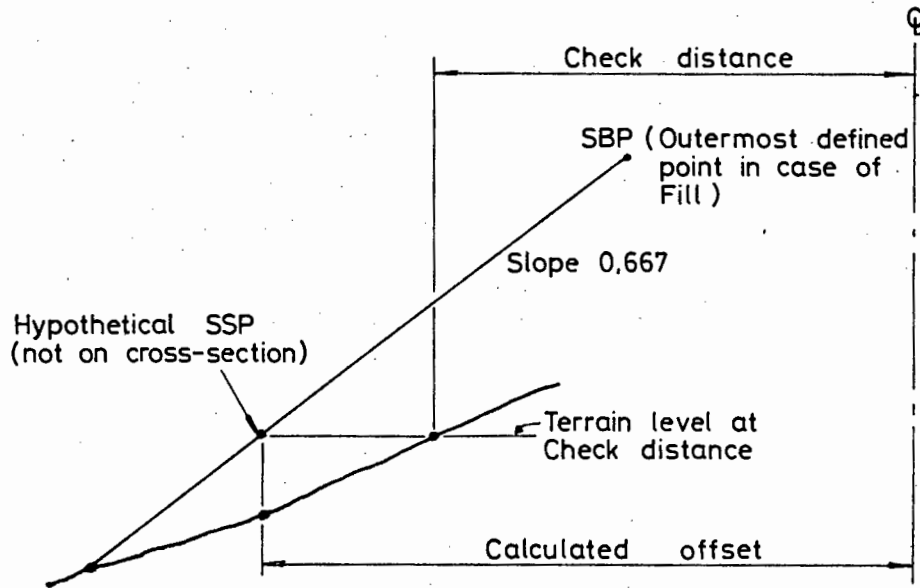
- (1) The design of the side-drain template is restricted, since:
  - (a) the outermost slope is fixed at 0,667 in deep cuts and fills.
  - (b) only two template points can be used between the shoulder break point and the slope stake point.

Standard templates having a different specification cannot be accommodated.

(refer : 2.1(iii) and (h))

- (2) If the terrain has a cross slope, the fixing of the slope stake point is imprecise, see Fig. 2.1.2 .

(refer : 2.1(iii))



Imprecise fixing of Slope Stake Point

FIG. 2.1.2

- (3) One horizontal check distance is applicable to both sides at a station. An eccentric road having shoulder break points at different horizontal offsets, cannot therefore have identical side-drain widths on both sides in the case of shallow cuts and fills.

(refer : 2.1(iii))

- (4) Similarly the cut and fill check heights, applied to both sides at a station, are given relative to the centre-line level. Therefore, when the road is superelevated, the use of "shallow" or "deep" codes will be determined by height controls that are different on the two sides, relative to the shoulder break point.

(refer : 2.1(iii))

2.11

- (5) If the lateral position of the ditch is to be different in codes 3 and 4, no smooth transition is possible.

(refer : 1.3.2(a))

- (6) In codes 1 and 2, shallow and deep fill, the two outermost points on either side are redundant, since they are the same as the third outermost point, i.e. the shoulder break point.

(refer : 2.1(g))

### 2.2.2 C.P.A. Final Quantities (N.O. Marriott)

(ref.: Marriott, N.O. Final Quantities, Cape  
Provincial Administration. 1965)

Marriott pioneered the writing of earthwork programs for successive computers, installed primarily for commercial purposes by the Provincial Administration in Cape Town in the early 1960's. His program, in the form developed during 1963 to 1965, has enjoyed considerable use during the execution of many road-construction projects undertaken in those and subsequent years.

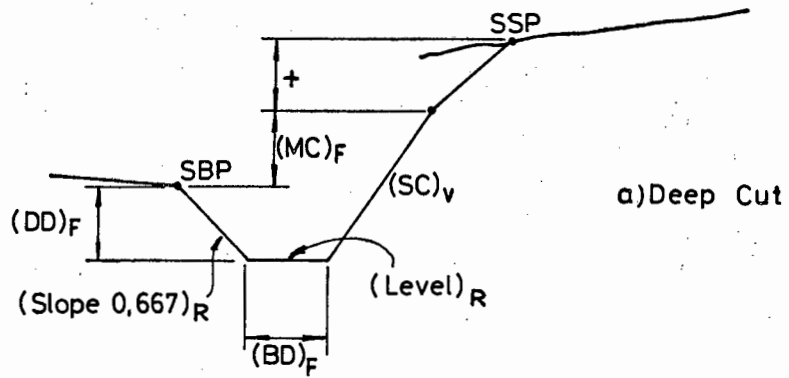
The program allows the selection of one of four standard side-drain configurations representing shallow fill, deep fill, shallow cut, and deep cut, as shown in Fig. 2.2.1 . It provides for varying cut and fill side slopes along the road by calling new values at appropriate chainages, before the start of the run. The computer will flatten slopes at those stations where the depth of cut or fill is less than the critical height of cut or fill specified for the run. The width and depth of the ditch invert may be varied for each run. Input data is commendably concise as will be seen from the data sheet, Fig. 2.2.2 .

The input of terrain data presents one of the main limitations of the program. The cross-section at a station has to consist of three terrain levels, one on centre-line and one on each side, at a distance which is fixed for a particular run. In effect the terrain cross-section consists of a terrain point on centre-line and constant terrain cross-slopes outwards. This has a considerable effect on simplifying the determination of the specific side-drain template.

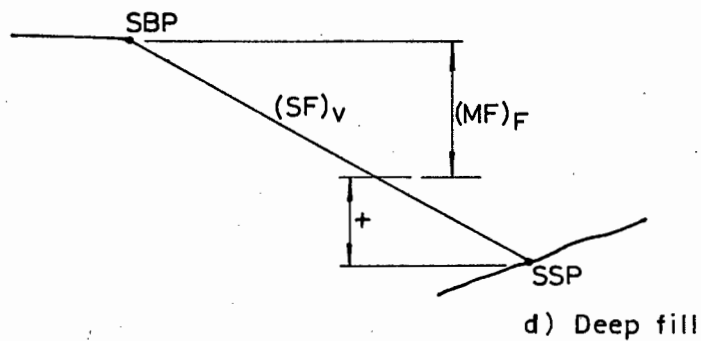
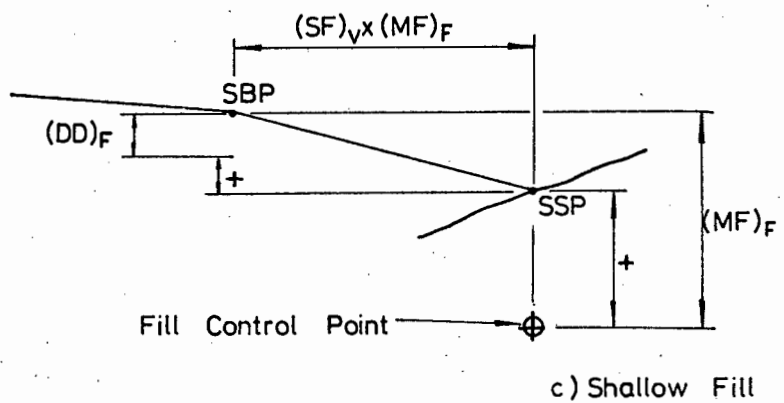
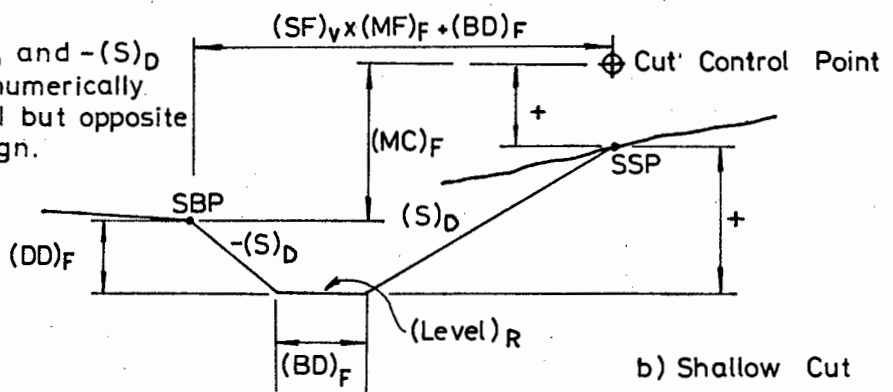
#### Glossary.

$BD_F$  Ditch width

$DD_F$  Depth of ditch invert below SBP



Note:  $(S)_D$  and  $-(S)_D$  are numerically equal but opposite in sign.



C.P.A. Final Quantities: Side-Drain Configurations

FIG. 2.2.1

CORRECTIONS	LABEL												Job No.			
Repunch →	E/B	—	F	Q	C	O	N	S	T	—				—	—	—
	FIXED CONSTANTS															
	Road Width R	Shoulder Drop Q	Dist. to Side Levels D	Camber % C				Min. Ht. for Flattening Fill Cut MH MC		Drain Width BD		Depth DD	No. of Copies			
Repunch →																
	VARIABLE CONSTANTS															
	Chainage Chains Ft				Side Cut SC	Slopes Fill SF		Thick Base & Subbase T		Swell Factor SW						
Repunch →	I	N	I	T	—	—										
CORRECTIONS	Chainage, at which Change to															

C. P. A. FINAL QUANTITIES: DATA SHEET  
FIG.2.2.2

- MC<sub>F</sub> Critical height above SBP, below which cut slope is flattened
- MH<sub>F</sub> Critical height below SBP, above which fill slope is flattened
- SC<sub>v</sub> Outside slope, in deep cut
- SF<sub>v</sub> Slope, in deep fill

Method.

The computer will select one of the 4 side-drain configurations shown in Fig. 2.2.1 according to whether the terrain cross-section lies above or below control points defined by the parameters. Provision is also made for a vertical cut-off wall through the shoulder

break point in certain cases of deep fill, when the extended terrain cross-section lies below a defined "wall" control point.

As the terrain cross-section consists simply of three points at regular transverse spacing, the number of alternatives that have to be considered in the selection of a side-drain configuration, is reduced, compared to when dealing with a multi-point terrain cross-section.

Comments.

- (1) The program is able to deal satisfactorily with the type of standard side-drain template for which it was written, as is evident from its extensive use. Other types of side-drain standard can at best, however, only be accommodated approximately.

(refer : 2.1(iii) and (h))

- (2) Discontinuity in the side-drain configuration, along the length of road, occurs at transfer from "deep cut" to "shallow cut" and from "shallow cut" to "shallow fill".

(refer : 1.3.2(a) and (b))

- (3) Modifying actual terrain cross-sections into a 3-point cross-section acceptable to the program, requires effort if the terrain is irregular, and can result in hypothetical templates and earthwork volumes at variance with the road as built.

(refer : 2.1(iii) and (c))

2.2.3 Road Earthworks Application for  
NCR "315" Computer (Rhodesia Government)

(ref.: Ministry of roads and road traffic, Rhodesia Government. Road earthworks application for N.C.R. "315" Computer. Engineer's reference manual. 1965)

The document to which reference is made, is a comprehensive user's manual which states:

"The program caters for a completely variable road cross-section (standard road template). The design engineer (user) is given complete freedom in his choice of variables so that the definition of the transverse profile (specific template) will, as far as possible, be identical to the shape of the road as constructed".

In essence the side-drain template selected is one of four side-drain configurations (see Figs. 2.3.1 and 2.3.2).

Glossary.

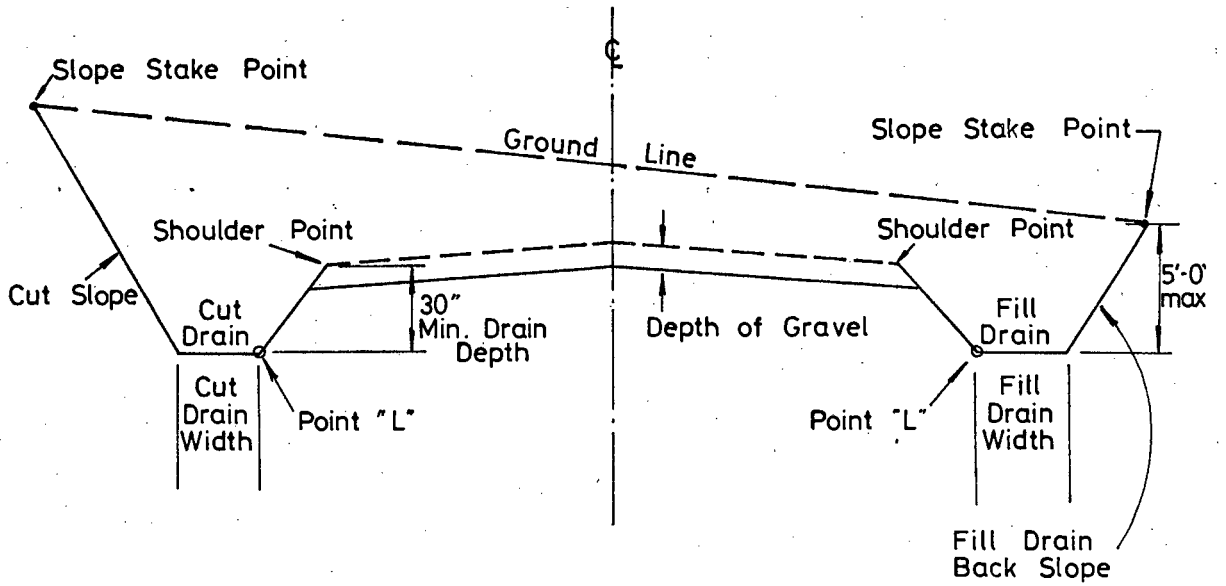
Back slope : the outermost slope intersecting the terrain cross-section at the stake point

Drain : generally implies "ditch" as defined in the project glossary on page xi

Ground : "terrain" as defined

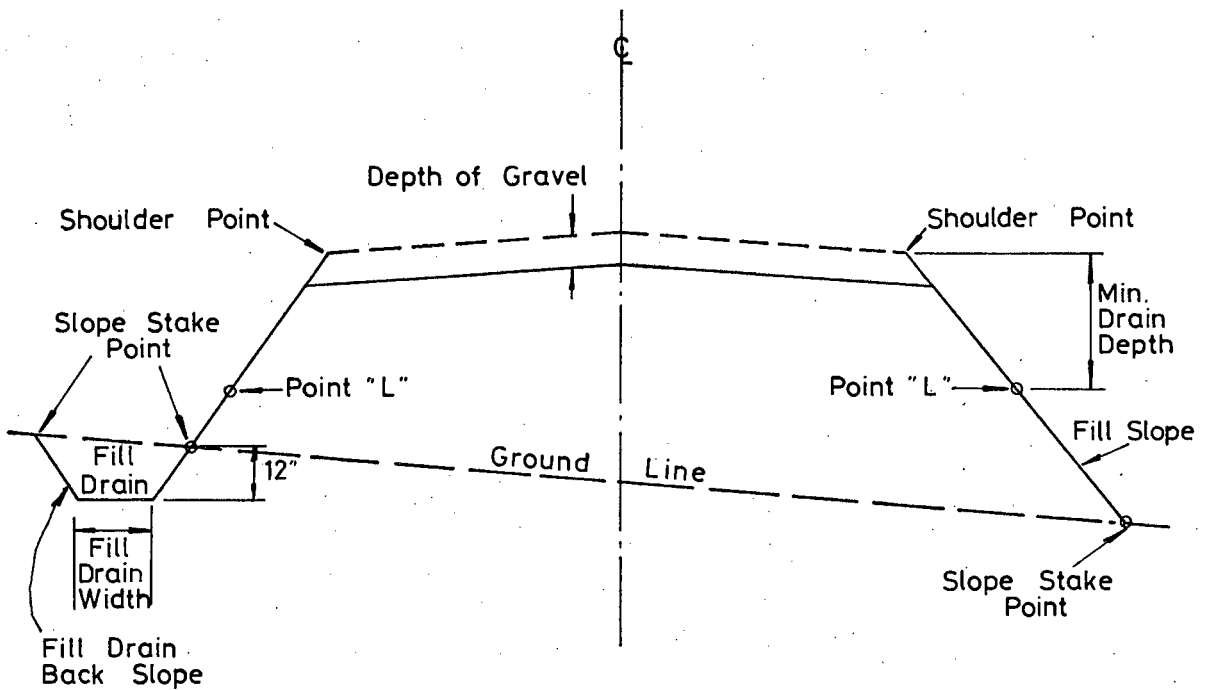
Point "L" : or Limiter point : that point on the fill which lies at a vertical distance below the shoulder break point equal to the minimum drain depth

Shoulder point : "Shoulder break point" as defined.



Rhodesia : NCR 315 program : Typical Cut Section

FIG. 2.3.1



Rhodesia : NCR 315 program : Typical Fill Section

FIG. 2.3.2

Input data.

Compulsory design variables which have to be submitted include:

Fill slope  
 Cut slope  
 Fill drain width  
 Cut drain width  
 Fill drain back slope

In addition, optional design variables allow the pre-selection of certain alternatives.

These parameters may all be changed along the length of the road as required by the user (degree of freedom, V).

Input data concerning the side-drain templates is commendably brief.

Method.

The manual sets out a detailed, if diffuse, explanation of the complex logic routine followed in the determination of a specific template. In essence, one side-drain configuration is selected from the four available.

Comments.

- (1) Although the program can deal accurately with the type of standard template for which it was written, it is, in spite of the above-mentioned quotation from the manual, considered to be particularly restrictive with regard to other specifications of standard templates.

(refer : 2.1(iii) and (h))

- (2) The user's manual was drawn up as a guide to engineers of the Rhodesian Ministry; and, as such, was probably not intended for wider use. Even so, it is considered that the full implication of the values, assigned to some of the variables, may be lost to an inexperienced user, as a result of the obtruse explanation of the method used to determine the side-drain template.

(refer : 2.1(m))

2.2.4 BECS RCFB: Cut and Fill Quantities

(ref.: Bureau of Engineering Computer Services (Pty.)  
Ltd. Road cut and fill programs. 1968)

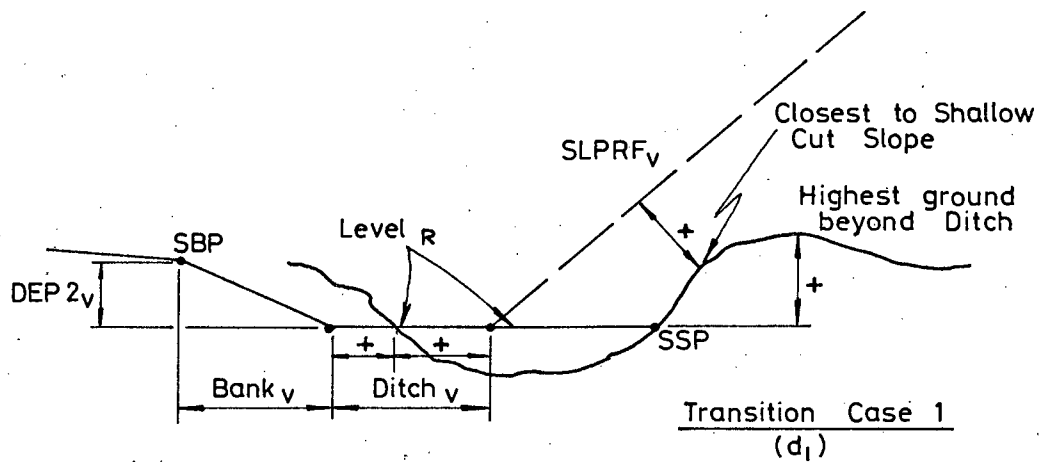
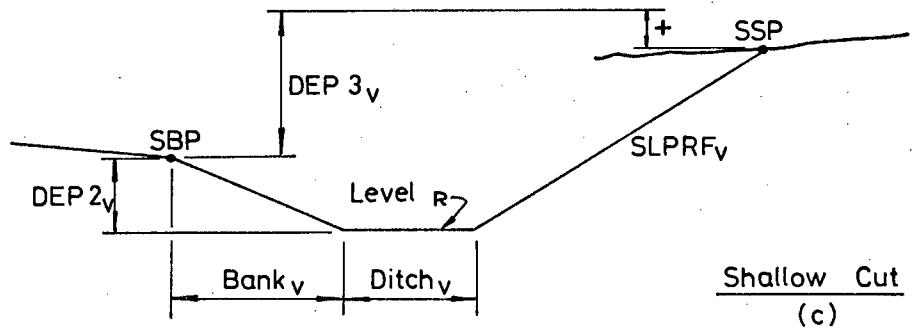
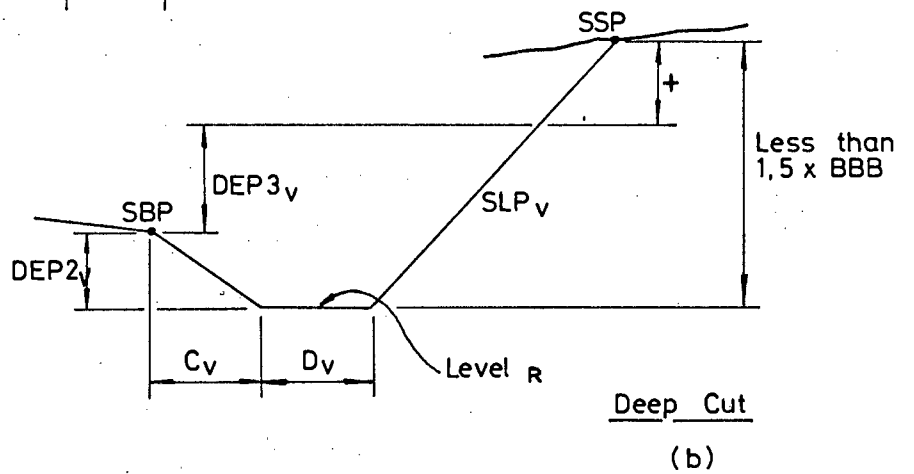
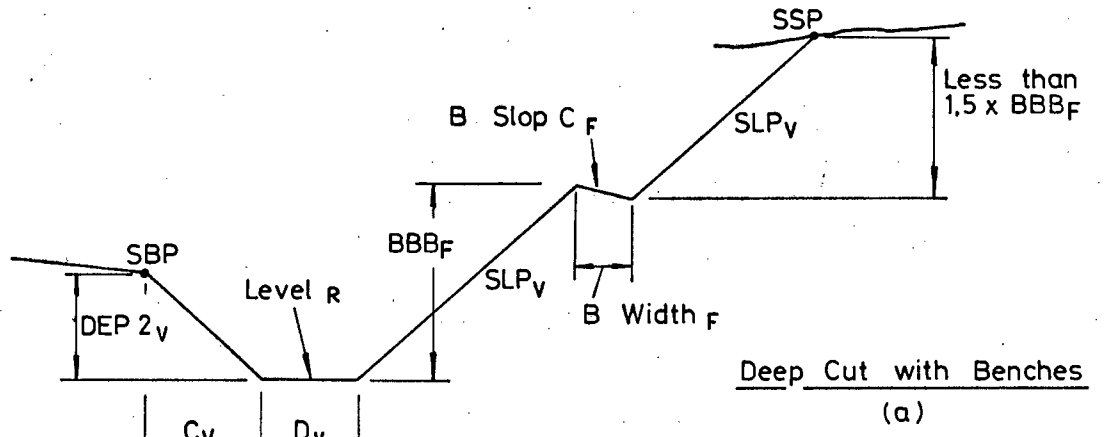
The programming of the RCF suite was originally started by the C.S.I.R. at the request of a firm of consulting engineers. After the work had been abandoned at an intermediate stage, the consulting engineers took over the programming and completed the work with the assistance of V.E. Marting and Associates. The use of the program was subsequently placed under the control of B.E.C.S.

The engineer is given great freedom in selecting and changing the dimensions of the various elements comprising this standard template design.

Considerable effort has been made to deal with special cases and this appears to be one of the most successful routines for selecting side-drain templates.

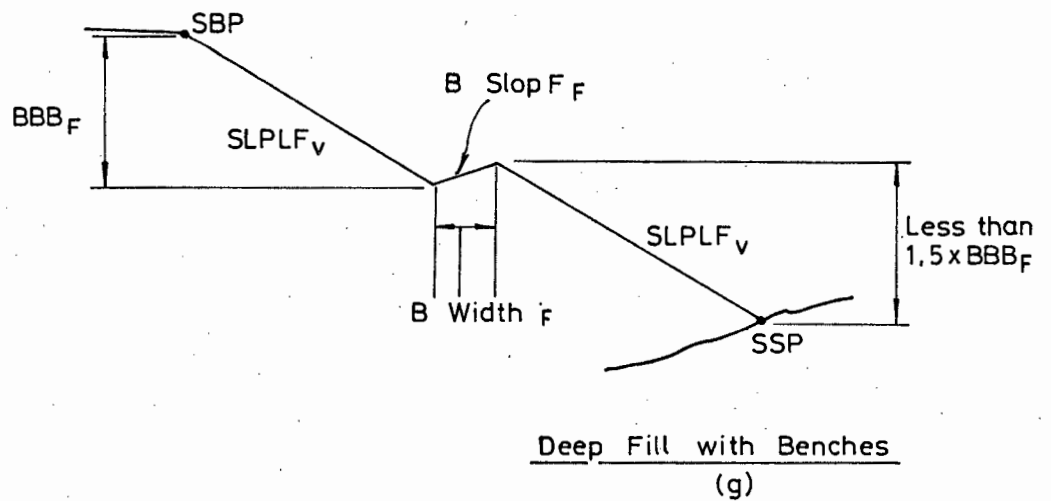
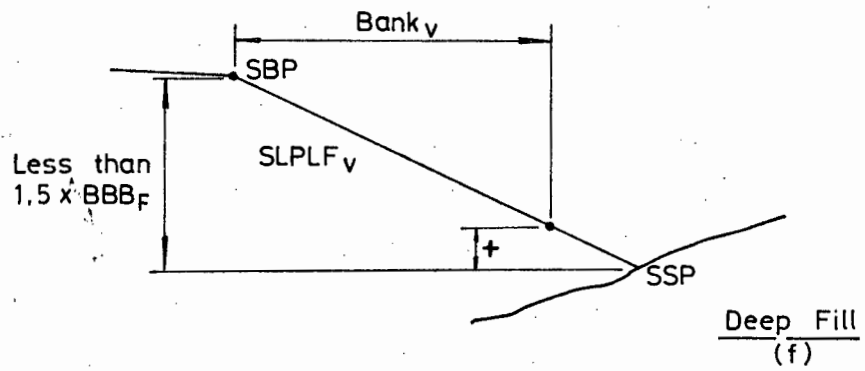
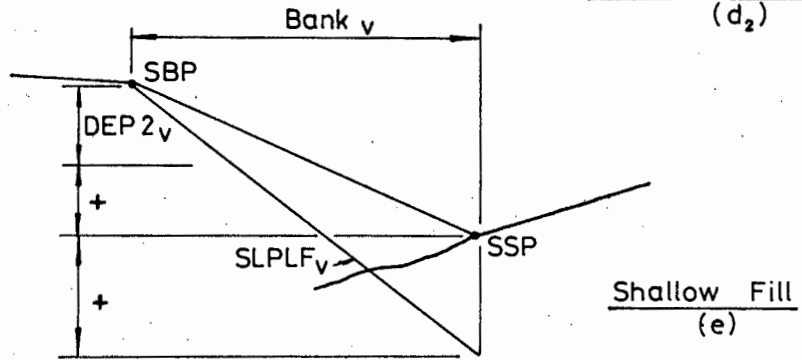
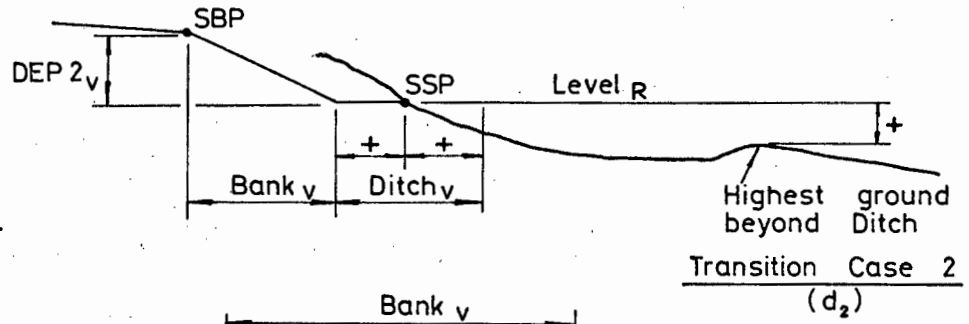
Glossary.

BANK <sub>V</sub>	Width of inside slope, from SBP, for shallow cuts
C <sub>V</sub>	Width of inside slope, from SBP, for deep cuts
D <sub>V</sub>	Ditch width for deep cut
DEP2 <sub>V</sub>	Depth of ditch invert below SBP
DEP3 <sub>V</sub>	Critical height above SBP for change from shallow to deep cut
DITCH <sub>V</sub>	Ditch width for shallow cut
SLP <sub>V</sub>	Outside slope, deep cut (different values may be selected for left and right side of road; all other parameters must be the same on both sides)
SLPLF <sub>V</sub>	Slope, deep fill
SLPRF <sub>V</sub>	Outside slope, shallow cut
BBB <sub>F</sub>	Bench height interval, cut and fill



**BECS RCFB: Side-Drain Configurations**

**FIG. 2.4.1 (a) to (d<sub>1</sub>)**



BECS RCFB : Side - Drain Configurations

FIG. 2.4.1 ( $d_2$ ) to (g)

BWIDTH<sub>F</sub> Bench width, cut and fill  
 BSLOPC<sub>F</sub> Slope of cut bench  
 BSLOPF<sub>F</sub> Slope of fill bench

Method.

By following through a logical routine of check point controls the program selects one of the 7 possible basic side-drain configurations, according to the combination of template and terrain, see Figs. 2.4.1(a) to (g).

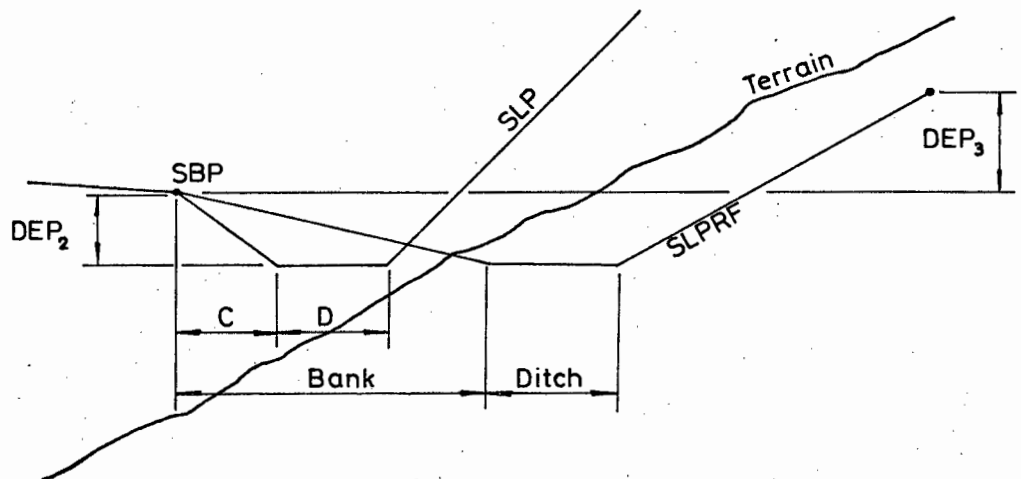
Comments.

- (1) A discontinuity in the position of the ditch and the SSP occurs between the "deep cut" and "shallow cut" conditions, Figs. 2.4.1(b) and (c).

(refer : 1.3.2(a) and (b))

- (2) In spite of the ability to handle many special combinations of terrain levels and slopes, the situation depicted in Fig. 2.4.2 is not dealt with. In this case the terrain line does not intersect the shallow slope line, SLPRF, below a height of DEP<sub>3</sub> above SBP, nor the deep cut slope line, SLP, but lies between them.

(refer : 2.1(ii))



Case not dealt with in BECS RCFB Program

FIG. 2.4.2

- (3) When the terrain data does not extend far enough to meet the specified slopes, the cut-off treatment applied by the program is somewhat strange. The SSP is placed at the outermost given terrain point and the slope of the outermost template line is steepened, which produce an odd-shaped triangle of inaccuracy. Manual adjustments are more complicated than when a vertical cut-off has been made at a specific offset.

(refer : 2.1(e))

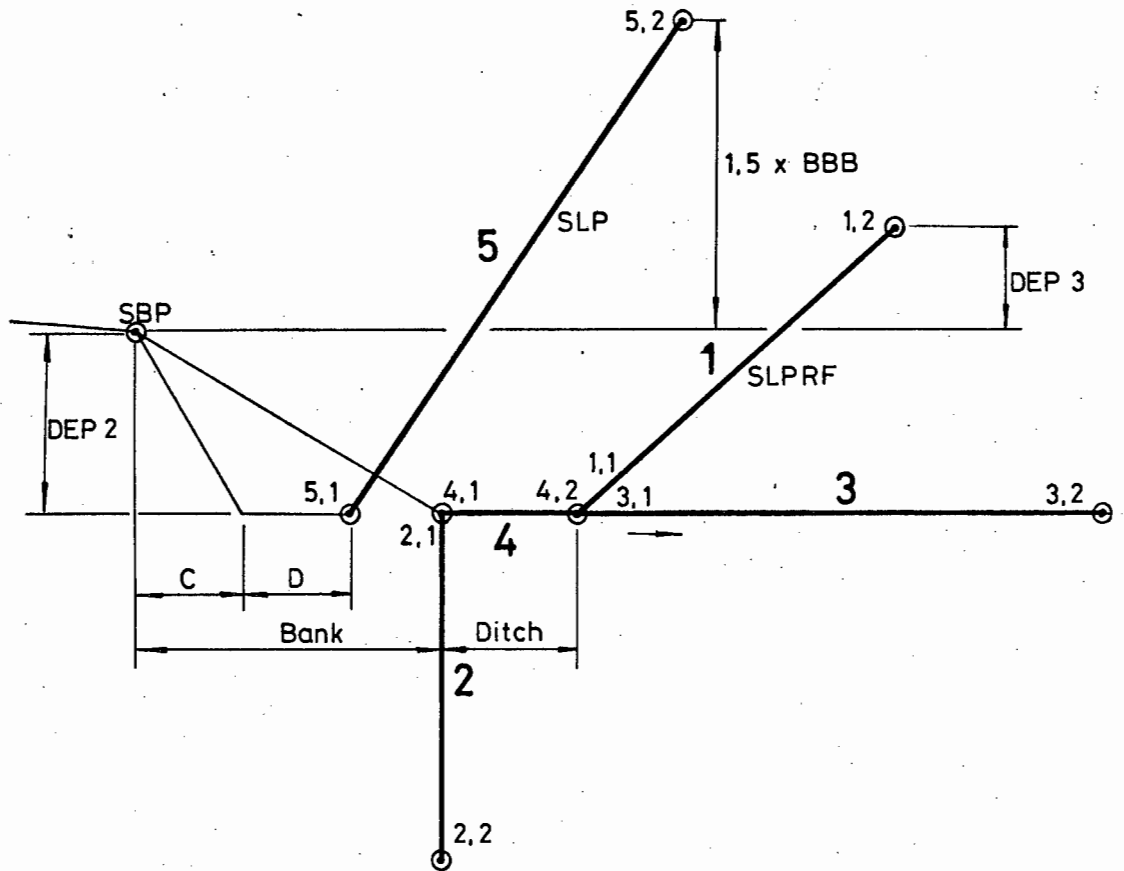
- (4) Although the parameters of the standard side-drain may be varied along the length of the road, the same parameter is always applied on both sides of the road (with the exception of SLP). The program, therefore, cannot meet a user's requirement for different templates on either side of the road.

(refer : 2.1(iii) and (h))

#### SPECIAL CONFIGURATION.

In this program a rather special condition has been imposed for dealing with the transition between "shallow cut" and "shallow fill" in two alternative ways, as depicted in Figs. 2.4.1(d1) and 2.4.1(d2). Irrespective of whether this was pre-specified by the engineer or whether it was introduced by the programmer, it binds all users of this program (refer 2.1(iii)).

It is noteworthy that if this condition were, in fact, required in a job to be run by a program incorporating the method of the locus of the slope stake point (see chapter 3), it could be executed explicitly by assigning locus-line weights as shown in Fig. 2.4.3 .



Locus-Lines for BECS RCFB cases (d<sub>1</sub>) and (d<sub>2</sub>)

FIG. 2.4.3

(Note: Fig. 2.4.3 illustrates the weights of locus-lines that would be used in the method of the locus of the SSP to accommodate the two special side-drain configurations provided between "shallow cut" and "shallow fill" in the RCFB program. This is not a satisfactory locus as a "gap" exists between the left hand extremities of locus-lines 4 and 5; this agrees with Comment 2 (Fig. 2.4.2) above. The locus as shown does, however, execute the RCFB logic precisely).

2.2.5 ICES ROADS I : Roadway Analysis  
and Design System

(ref.: Suhrbier, J.H. ICES ROADS I : A general description. M.I.T. research report R68-1. 1968  
Suhrbier, J.H., Prokopy, J.C. and Sullivan, E.C. ICES ROADS I : Roadway analysis and design system. Engineer's reference manual. M.I.T. research report R68-9. 1968)

The Roadway Analysis and Design System forms part of the comprehensive Integrated Civil Engineering System developed by the Civil Engineering Systems Laboratory at Massachusetts Institute of Technology. ROADS is a comprehensive and integrated engineering computer system for use in the solution of problems associated with the location and design of transportation roadways. It is written in a problem oriented language\* which provides a command-structured input, an example of which is given in Fig. 2.5.1 .

The program, which uses considerable storage capacity, is a powerful system giving the user much freedom in his design. All parameters given by the user have the

---

\* Problem oriented language (POL) : A code designed for convenience of problem specification, rather than for easy conversion to machine-instruction code or for easy execution (by the computer) of programs written in the code (ex: British Standard Glossary of terms used in automatic data processing, B.S. 3527 : 1962).

This mode of communication of the user with the computer is similar to that of one engineer with another, and enables an engineer (user) to describe his problem in familiar terms, and to make standard engineering requests for specific information to be computed and stored or to be presented in either a tabular or graphical format.

## TYPICAL 'DES-T1'

FINISH GRADE DYTIE 0. DZTIE 0. SUBGRADE THICKNESS 1.42

ROADWAY RIGHT DY 12.0 S -.25 10. SLOPE -.375

ROADWAY LEFT DY 12.0 SLP -.25 IN/FT

SHOULDER RIGHT 3.0 SLP -.375

SHOULDER LEFT 4.0 SLP -.375

DITCH BOTH DY 14.0 S -4. DP 4.0 0.0 .

CUT SLOPES 'ROCK'

TRANSITION SLOPE 10. RISE/RUN CRITERIA 15.0

BENCH DY 3. DZ -.5 SLP 10. RISE/RUN

FINAL BENCH DY 3. DZ -.5

\*

CUT SLOPES 'EARTH'

SLOPE 3. CRIT. 10.

TRANS SLP 2.

\*

FILL SLOPES

5.0 0.0 SLP 2.0

\*

SUBGRADE BOTH SLP -0.25

END OF TYPICAL, PRINT

highest degree of freedom allowed for predetermined dimensions, i.e. "V". In the event that an "on-line" or "time-shared" system is used an even greater degree of freedom is allowed, as the user is able to modify parameters during a run, but for the purpose of the determination of the specific side-drain template, these parameters still remain predetermined.

Allowing easy "discussion" between the user and the computer, the system is pre-eminently suited to non-automated optimization of the design.

### Glossary.

Final transition slope : The defined slope of the outermost closing link of the side-drain template

Cut slope : The portion of the side-drain that lies between the ditch and the SSP

Fill slope : The full side-drain between SBP and SSP

Link : A straight-line element of the side-drain

DY : Horizontal offset

DZ : Vertical offset

CRIT : Height criterion used to determine which slope is applicable.

### Input.

The use of a problem orientated language for a program such as a road earthworks system, that requires a large volume of data, makes the preparation and checking of input through command statements laborious. ICES ROADS I does, however, allow the user to design his own forms for inputting data in tabular form.

Three types of design input are required for road template definition.

- (i) Definition of a "typical" roadway cross-section (template).

- (ii) Statement of all changes to be applied to the typical section during a design run.
- (iii) Definition of certain basic roadway design data.

A "typical" roadway template is separated for definition into the following segments:

roadway, subgrade, shoulders, ditches, cut slopes, and fill slopes.

A slope consists of a number of links and a slope height criterion, specifying the allowable difference in elevation between the slope intercept and the initial link. A final transition slope must be given for all cut and fill slopes.

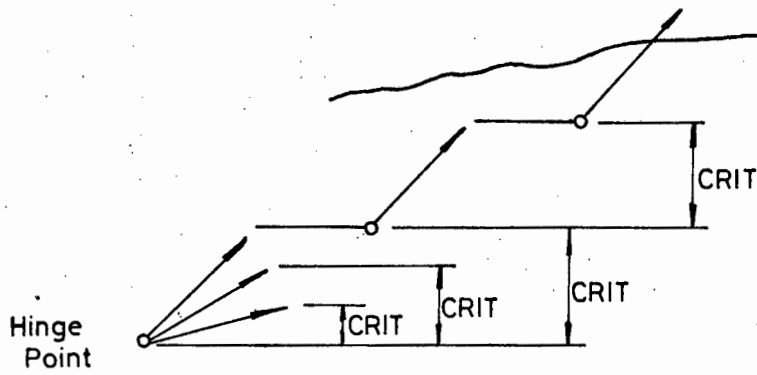
An individual template link can be defined by specifying either DY and DZ, DY and slope, or DZ and slope. (This fundamental concept is also applied in the method of the locus of the SSP, see par. 3.2).

#### Method.

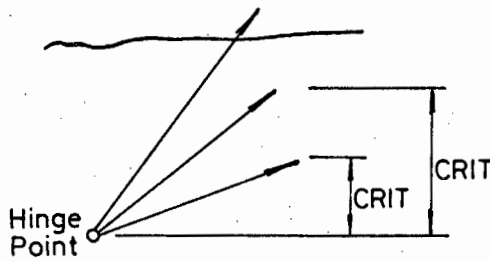
Height criteria are used to select the appropriate side-drain, from several optional configurations at a station. If the criterion is exceeded for a particular slope, subsequent slopes can either replace the current slope, or be added to the outside edge of the current slope to achieve benching on cut or fill slopes. A selection of configurations is shown in Fig. 2.5.2 .

#### Comments.

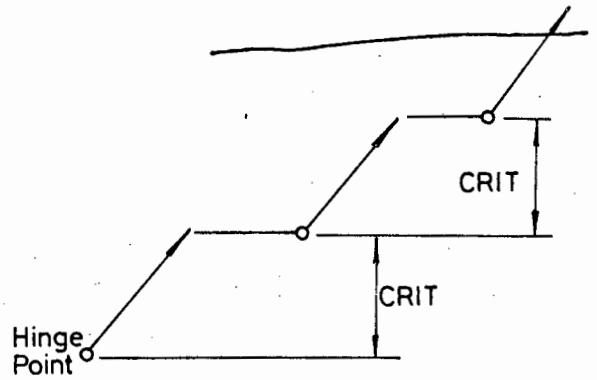
- (1) This program allows a greater degree of freedom in defining the side-drain outside the "hinge-point", i.e. beyond the ditch, than has been found in any of the earlier programs investigated. The definition of the ditch is, however, particularly inflexible as its dimensions, although variable within the run, are all predetermined.



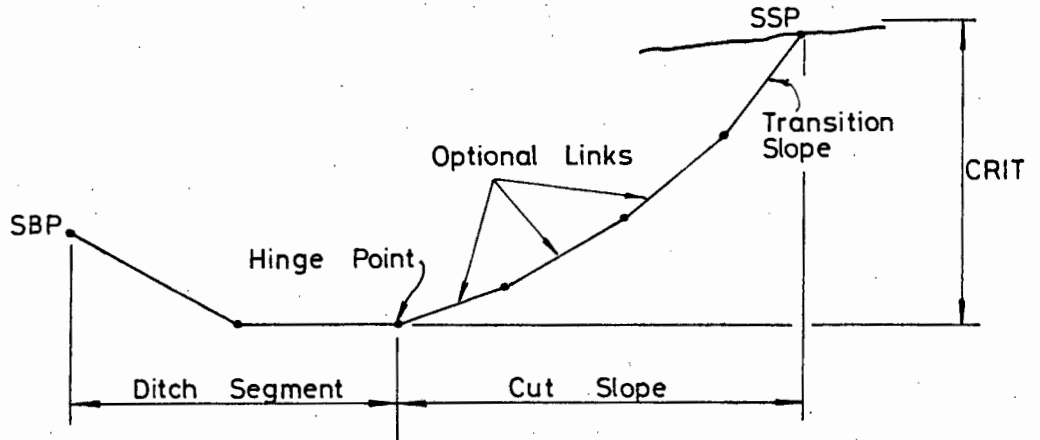
(e) Combination of Replacement and Benching Slopes



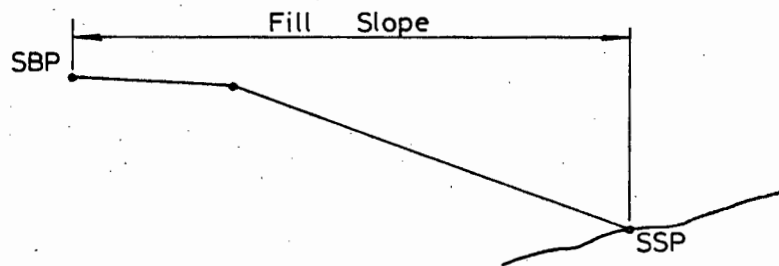
(c) Replacement Slopes



(d) Benching Slopes



(b) Cut Slope



(a) Fill Slope

ICES ROADS I: Typical Side-Drain Configurations

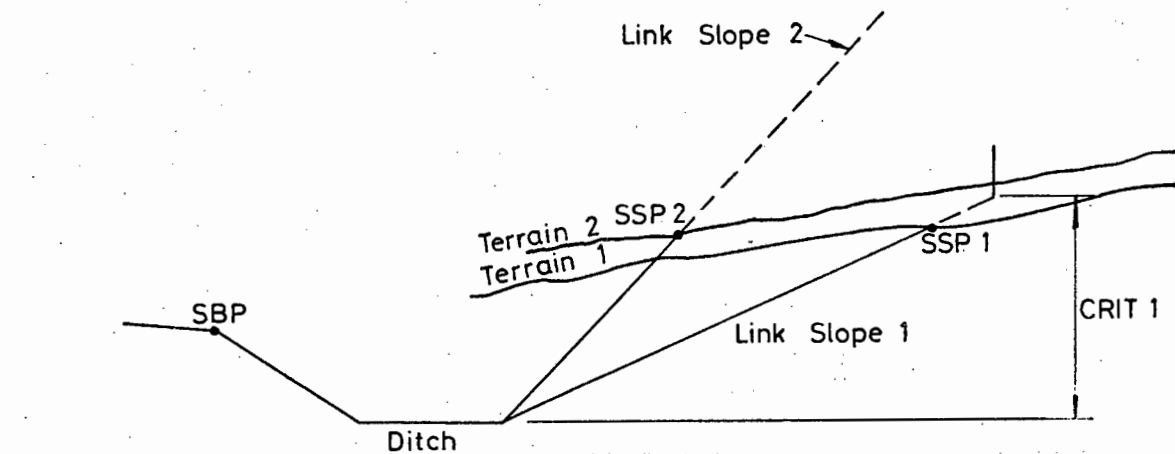
FIG. 2.5.2

There is no provision for making the innermost slope next to the SBP or the ditch dimensions directly dependent on the depth of the cut. It cannot reproduce the essential side-drain configuration for "shallow cut" in the C.P.A. Final Quantities program, as shown in Fig. 2.2.2(b). It therefore suffers from the same type of inability to deal with other forms of standard template as found in many other programs investigated.

(refer : 2.1(iii) and (h))

- (2) As the link slopes are all predetermined there is a discontinuity in the position of the SSP, as the slope height criterion is gradually passed, as shown in Fig. 2.5.3 .

(refer : 1.3.2(b))



Discontinuity of position of SSP

FIG. 2.5.3

- (3) Discontinuities also occur at the transition from shallow cut to shallow fill.

(refer : 1.3.2(b))

2.2.6 CEP - HIDES : Highway Design System

(ref.: International Business Machines. CEP-HIDES Highway design system. IBM Program Order No. 1130 - 16.2.760. 1970)

The system consists of an integrated set of 12 programs for the solution of numerical problems encountered in Highway Design. Although the system is most comprehensive, dealing with, inter alia, photogrammetric terrain input, two centre-lines, complex road surface templates, subgrade layers, topsoil stripping and cover, it can be operated on the IBM 1130 (8K storage). Each of the 12 programs applies to a particular phase of the design work. Program 11D "determines the shape of the earth body for all cross-sections of a fully specified highway."

The system is intended as a general roads design system, but, as it was developed in Germany, it makes specific provision for treatment of the side-drain in conformity with the German RAL-Q Specifications for Highway Construction\*.

This program is unique amongst those investigated as it contains curvilinear elements; the invert of the ditch may be a segment of a circle, and an option for rounding at the SSP is given.

Input.

The data for the standard side-drain templates consists of:

- (i) a number of execution codes

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\* Richtlinien für die Anlage von Landstrassen —  
Querschnitt-gestaltung (Kirschbaum Verlag, Bielefeld).

- (ii) a complex set of geometric instructions which are specified in one or more sets of "control profile" cards. Some of the parameters are fixed in accordance with the RAL-Q specification and therefore have degree of freedom, R.

"Cut" configurations provide for a ditch having predetermined dimensions.

Method.

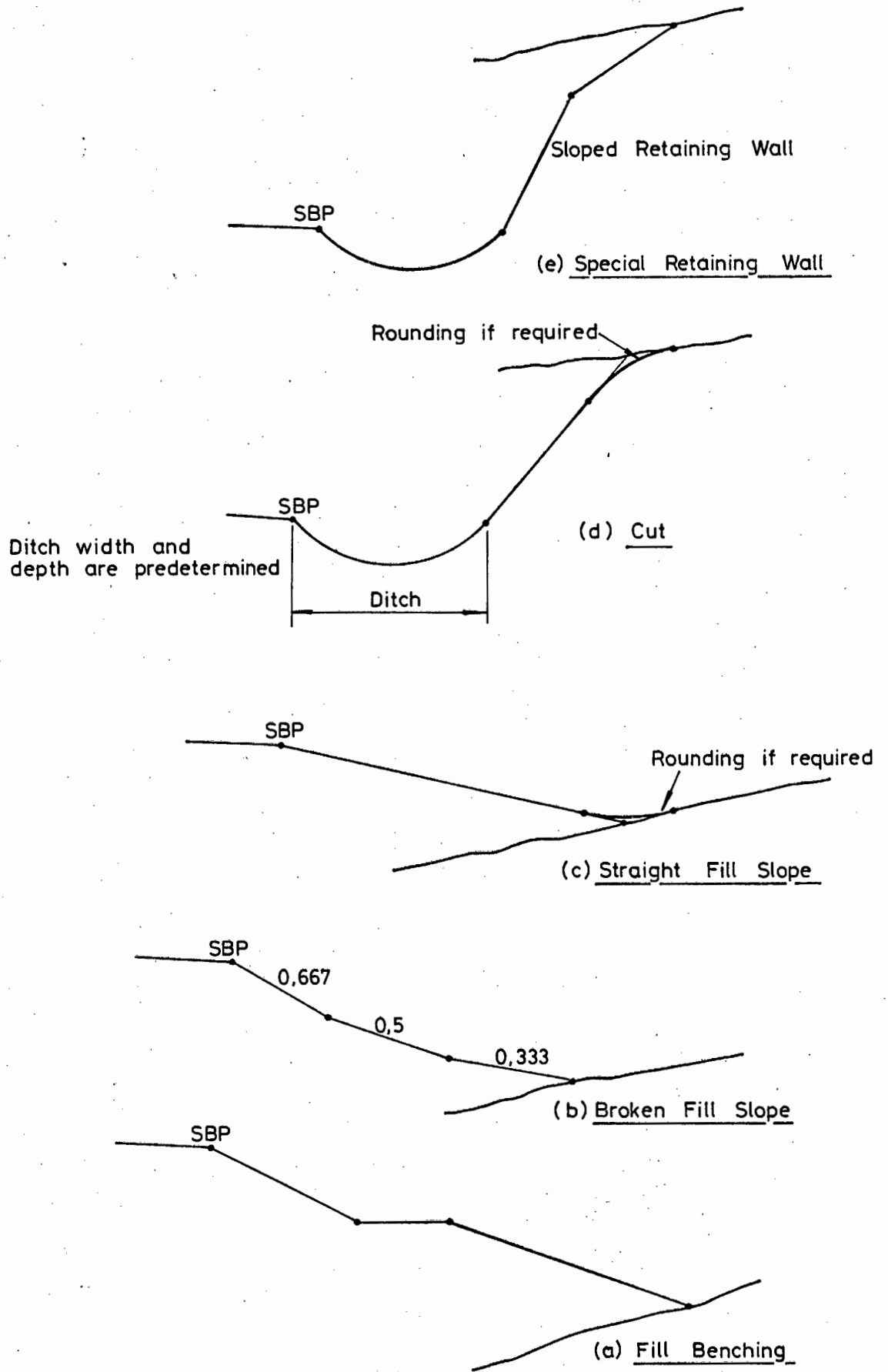
By prescribing the various side-slope codes (degree of freedom, V) the user can implement a considerable variety of side-drain configurations, a selection of which is shown in Fig. 2.6.1 .

The routine followed in selecting the appropriate configuration is clearly set out in the manual, and the transition from "shallow cut" to "shallow fill" is treated in detail.

Comment.

- (1) With regard to the design of the side-drain template, this system has much in common with ICES ROADS I. The comment upon that program in par. 2.2.5(1) is also fully applicable to CEP-HIDES.

(refer : 2.1(ii) and (h))



CEP - HIDES : Typical Side-Drain Configurations  
FIG. 2.6.1

2.2.7 INGRESS (Integrand)

(ref.: McIntosh, W.B., Cassarkis, A.G., and Moultrie, I.A. INGRESS. Integrand Scientific Computing (Pty.) Ltd. 1967)

INGRESS (Integrand's Generalized Road Earthworks System Solver) is based on the method of the locus of the slope stake point. It is the first successful application of the concept.

It was specified originally in its entirety by the writer and programmed by the authors of the above-mentioned reference manual, for execution on the IBM 1130 computer operated by Integrand Scientific Computing. It was operative in the latter half of 1966.

The section of the INGRESS program dealing with the selection of the side-drain template, is virtually identical in its specification to the SHARE-SHARM program, except for variations in the dimension statements affecting the capacities of the programs, i.e. the numbers of loci per run, lines per locus and side-drain points per template. Since comments made on the limitations of the locus method, in par. 3.5, are also applicable to INGRESS, as far as the treatment of the side-drain is concerned, no further comment is made here.

### 2.3 APPRAISAL OF AVAILABLE PROGRAMS

It is clear that all programs investigated, with the exception of INGRESS, have been written originally with a limited number of specific types of standard template in mind. Even systems that are claimed to have "wide and general application", allowing the user "complete freedom" in his choice of parameters, are found, on investigation, to be restrictive to a greater or lesser degree.

The incompatibility can be easily realized when one program is required to accept the standard template on which another program is based. Even comprehensive systems such as ICES ROADS I and CEP-HIDES, which are conceptually similar, are unable to deal with similar ditches; the former allows only a trapezoidal ditch, the latter provides a ditch of either triangular or circular section.

The user, having a commission to design a road according to a standard road template prescribed by the road authority, finds himself confronted with a number of programs, most, if not all, of which will not give him the facility or accuracy that he needs. If he does have a program that meets his needs, he might find, upon being directed by his client or chief engineer to use a new standard template, or upon receiving a commission from another client, that the program, in which he has experience, is no longer suitable. As a solution to his dilemma he could improvise as best possible those facilities not available in the program which he has at his disposal, but this is seldom satisfactory when the high cost of running a program, the inaccurate results and their influence on the final cost of the road are considered.

Some of the programs investigated are found to have inherent weaknesses, such as:

- (i) being unable to determine a prescribed template in certain cases (Fig. 2.4.2). (Provision may be made in a program to circumvent mid-run stoppages due to such causes, but the specific template adopted could be abnormal).
- (ii) being unable to provide a transitioned change in position of prominently visible features of the side-drain, such as the ditch, or SSP (Fig. 2.4.1(b) and (c)).
- (iii) the use of 3-point terrain cross-sections being imposed in order to avoid complications during the selection of the side-drain configuration (par. 2.2.2(3)).

However, it is essentially in the search for a general earthworks program, which can deal effectively and accurately with virtually any type of side-drain configuration which may be prescribed, that the method of the locus of the slope stake point has been devised.

CHAPTER 3THE METHOD OF THE LOCUS OF THE SLOPE STAKE POINT3.1 ORIGINAL IDEA (1965)

During the years 1962 to 1964 the writer had, in the course of the design of rural trunk roads in the Cape Province, encountered the problem, as set out in par. 2.3, that available computer programs for the calculation of earthwork quantities were unable to reproduce, with fidelity, all types of side-drain template required for a satisfactory engineering design.

The adaptation of available programs was tried by using the parameters and data to give the closest approximation to the required standard template. In the C.S.I.R. - I.B.M. highway cut and fill quantities program (par. 2.2.1), single fill and cut check heights at superelevated curves were chosen so as to give the best approximation to both of the side-drains, which were intended to be at different levels. In the C.P.A. final quantities program (par. 2.2.2) many terrain cross-sections had to be adjusted to provide hypothetical cross-sections, acceptable by the program, which would give nearly the same areas of cut and fill as were derived from the cross-section as actually surveyed.

This adaptation and trying to make parameters fit led the writer to the following concept:

If the locus\* of the slope stake point could be drawn out in the plane of the template for all possible

---

\* A locus (pl. loci) is defined as the curve or line traced out by all possible positions, and by only those positions, of a point moving to satisfy a definite set of geometric conditions.

cases of cut and fill, as prescribed by the standard side-drain template, i.e. for all combinations of terrain shapes and levels relative to the shoulder break point, it would be possible to decide on values to be inserted for the parameters of the available program, so that the corresponding locus produced by the program would match the prescribed locus as closely as possible.

It appeared that the locus of the slope stake point derived from any standard template practically always consisted of a series of straight lines with fixed end points, and that each individual straight line of the locus had one and only one side-drain configuration associated with it.

The writer's original notes setting out this proposition are reproduced in Appendix E.

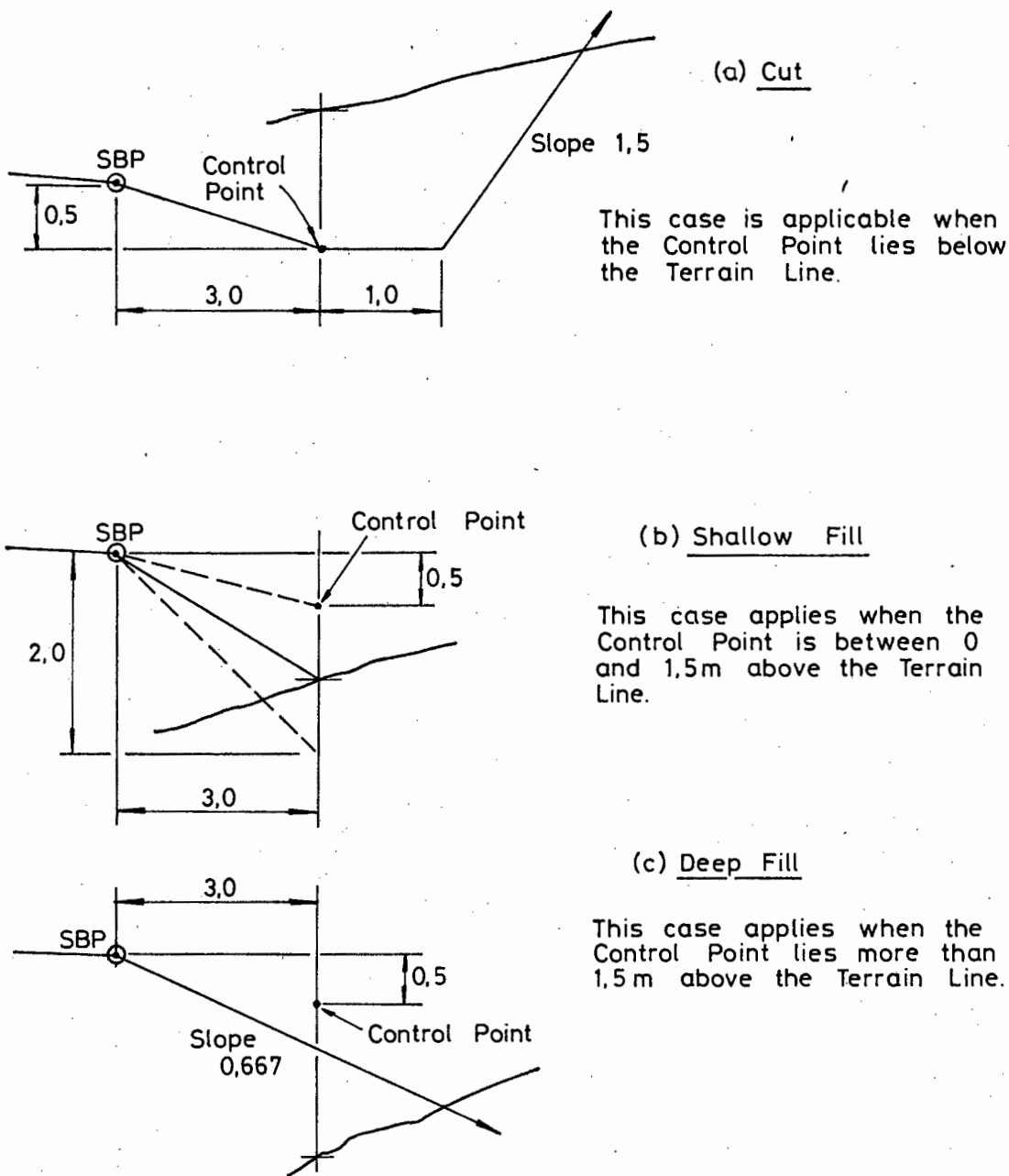
It was soon realized that a computer program written specifically around the concept of the locus of the slope stake point would offer a much wider capability in dealing with side-drain templates and would in effect provide a significant advance in the search for a general earthworks program. A detailed description of the treatment of side-drains by the locus method in a manner suitable for use by computer, is given in par. 3.2.

The first such program, INGRESS (par. 2.2.7), was completed by Integrand under the direction of the writer towards the end of 1966. Upon the acquisition of a computer by Ninham Shand and Partners, a new program was written, incorporating several improvements that had become evident during the intervening period. By March 1969 SHARE (SHAND ROAD EARTHWORKS) was in operation. This has been constantly updated and improved, and in 1972 the revised metricated version, SHARM (SHAND ROAD earthworks - Metric) was available. The program SHARM is presented in Chapter 4.

3.2 DESCRIPTION OF THE METHOD

3.2.1 Introduction

The concept of the locus of the slope stake point is introduced by illustrating, as an example, the preparation of the simple standard side-drain template shown in Fig. 3.1, for use in the design of a road.



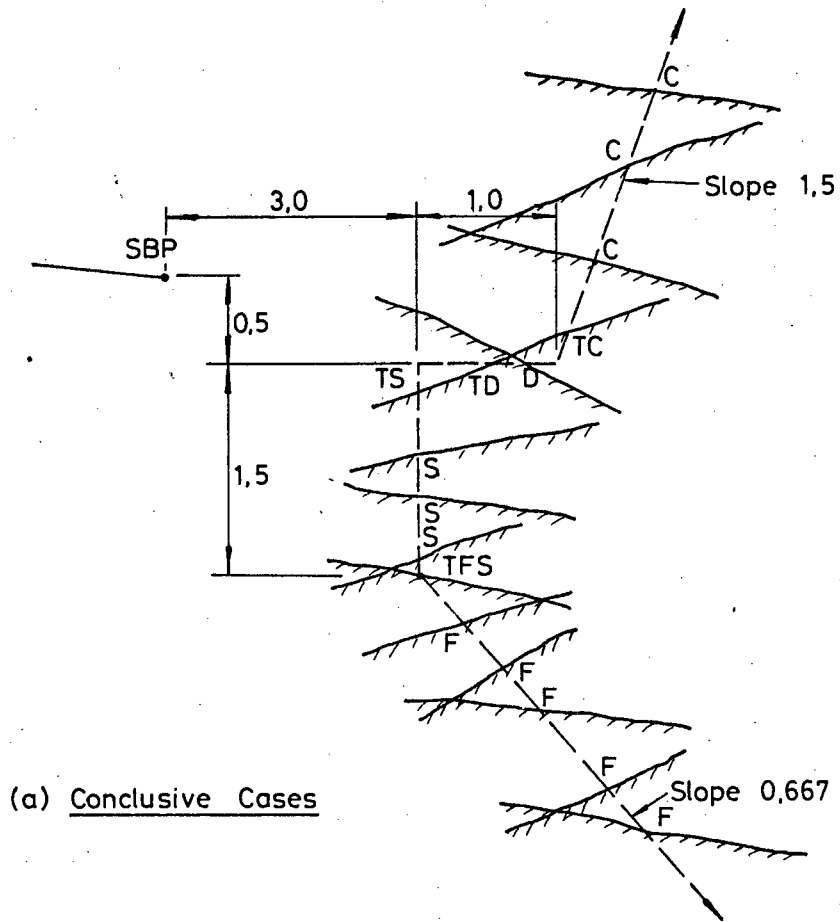
Simple Standard Side-drain Template

FIG. 3.1

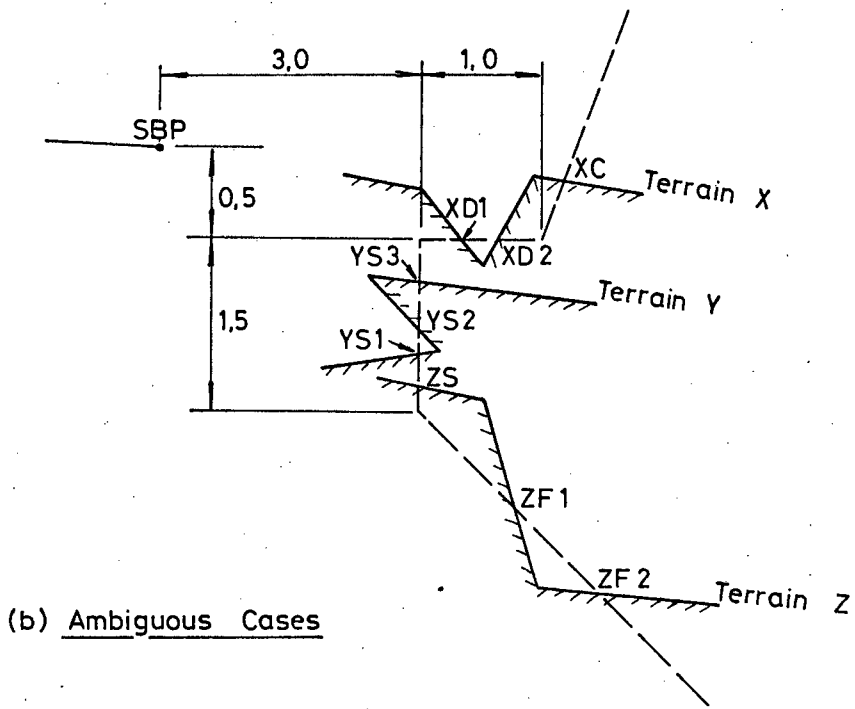
The first step to be taken by the user in applying this template to the road being designed, is to draw out in one diagram a number of hypothetical but possible terrain cross-sections of various shapes and at various levels relative to one fixed SBP. This diagram is a view in elevation of the plane of the template. On each sample terrain cross-section the SSP is fixed in accordance with the given standard template, as shown in Fig. 3.2. For clarity the "ambiguous" cases referred to in par. (iv) below have been shown separately.

The following observations are now made:

- (i) All the SSP's lie on a limited number of straight lines. All the lines together are, in fact, the locus of the SSP for this particular standard template. (For ease of reference the codes C (cut), D (ditch), S (shallow fill) and F (deep fill) are used for the respective locus-lines).
- (ii) Each of the locus-lines bears a fixed and definite relationship to the SBP. Each locus-line can be rigidly specified by quoting the horizontal and vertical offsets (relative to the SBP) for both of its ends. (Note that although lines C and F theoretically go off to infinity, they may be terminated at the far side for practical purposes by a point whose offsets are very large).
- (iii) Each locus-line has associated with it one side-drain configuration as shown in Fig. 3.3. Each configuration:
  - (a) is terminated by the SBP and the SSP.
  - (b) has a fixed number,  $n$ , of straight-line side-drain elements.

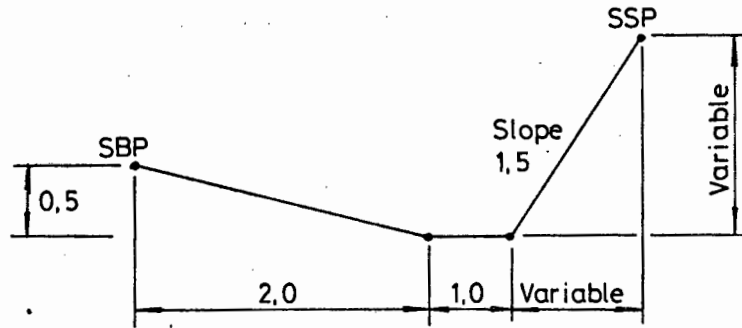


(a) Conclusive Cases

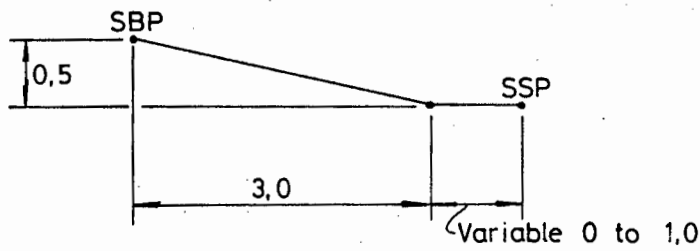


(b) Ambiguous Cases

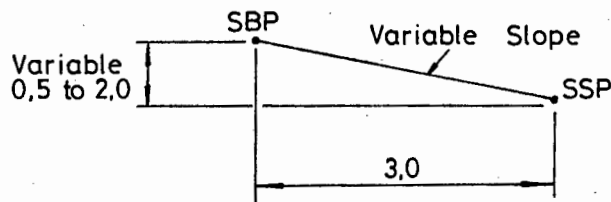
Positions for SSP's  
FIG. 3.2



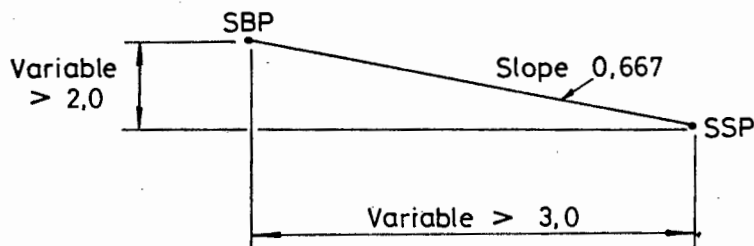
Configuration "C"



Configuration "D"



Configuration "S"



Configuration "F"

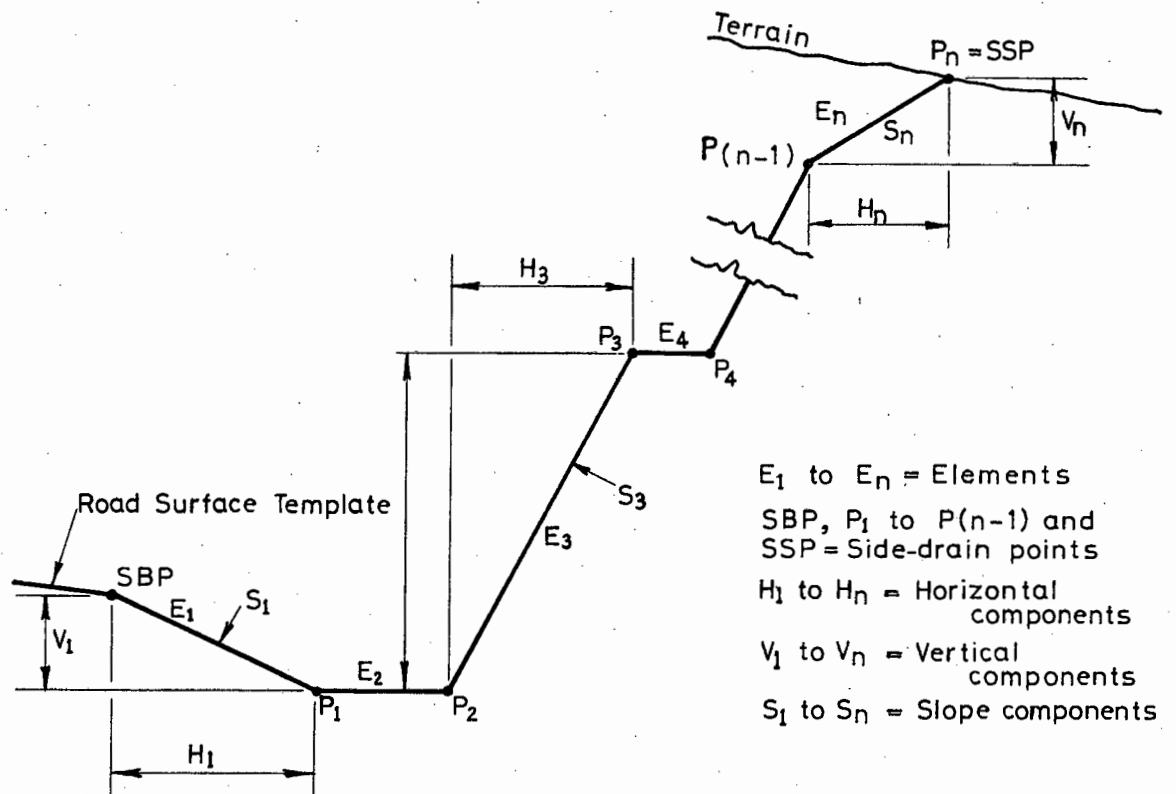
The four Side-drain Configurations

FIG. 3.3

(Each element has a horizontal component, a vertical component and a slope component).

- (c) has  $(2n-2)$  fixed side-drain components,  
 $n$  redundant side-drain components  
 and  $2$  unfixed side-drain components  
 where  $n$  is the number of side-drain elements.

For clarification of these terms the reader is referred to the Glossary and Fig. 3.4.



Side - Drain : Elements, Points and Components

FIG. 3.4

The above observations (i), (ii) and (iii) comprise the basic conception of the method of the locus of the slope stake point. The use of this method for the determination of side-drain templates is clarified in par. 3.2.2.

But before proceeding, it is necessary to comment on the ambiguous cases observed in Fig. 3.2(b).

- (iv) Certain terrain cross-sections produce more than one SSP.

(It should be noted that terrain line TS - TD - TC in Fig. 3.2(a) does not give an ambiguous result since the control point is above the terrain and TS is therefore the only SSP. On the other hand, TFS which falls on the extremity of both locus-lines S and F, could be ambiguous since the "S" and "F" configurations might be different for an SSP at TFS. For the given standard template, however, there is no difference and thus no ambiguity).

Referring to Fig. 3.2(b), it is seen that each terrain line X, Y and Z, produces three SSP's complying with the standard template. It becomes obvious that certain further constraints must be made applicable to the standard template shown in Fig. 3.1.

These constraints require careful engineering judgment in order to comply with practical execution of the work. It is easily seen that YS1 or YS2 are unacceptable as an SSP since an overhang would be left encroaching over the toe of the fill; YS3 would probably be the best solution for terrain cross-section Y. The choice of XD1, XD2 or XC as the SSP

for terrain line X and of ZS, ZF1 or ZF2 for terrain line Z should be considered carefully from the engineering point of view. Here the merits of the practical execution of the work are not under discussion; a method is being sought whereby the choice of the user as agent of the road authority, shall be faithfully executed by the program.

Such constraints may be of the following types:

- (a) the locus-lines are each assigned an order of merit, giving a graded preference for the selection of the SSP
  - locus-line priority
- (b) one end of each locus-line is given preference, so that the SSP closest to this point is selected
  - locus-line direction
- (c) the slope of the terrain cross-section at any selected point is tested and used to accept or reject the relevant SSP, provided that further alternative SSP's exist
  - terrain slope preference

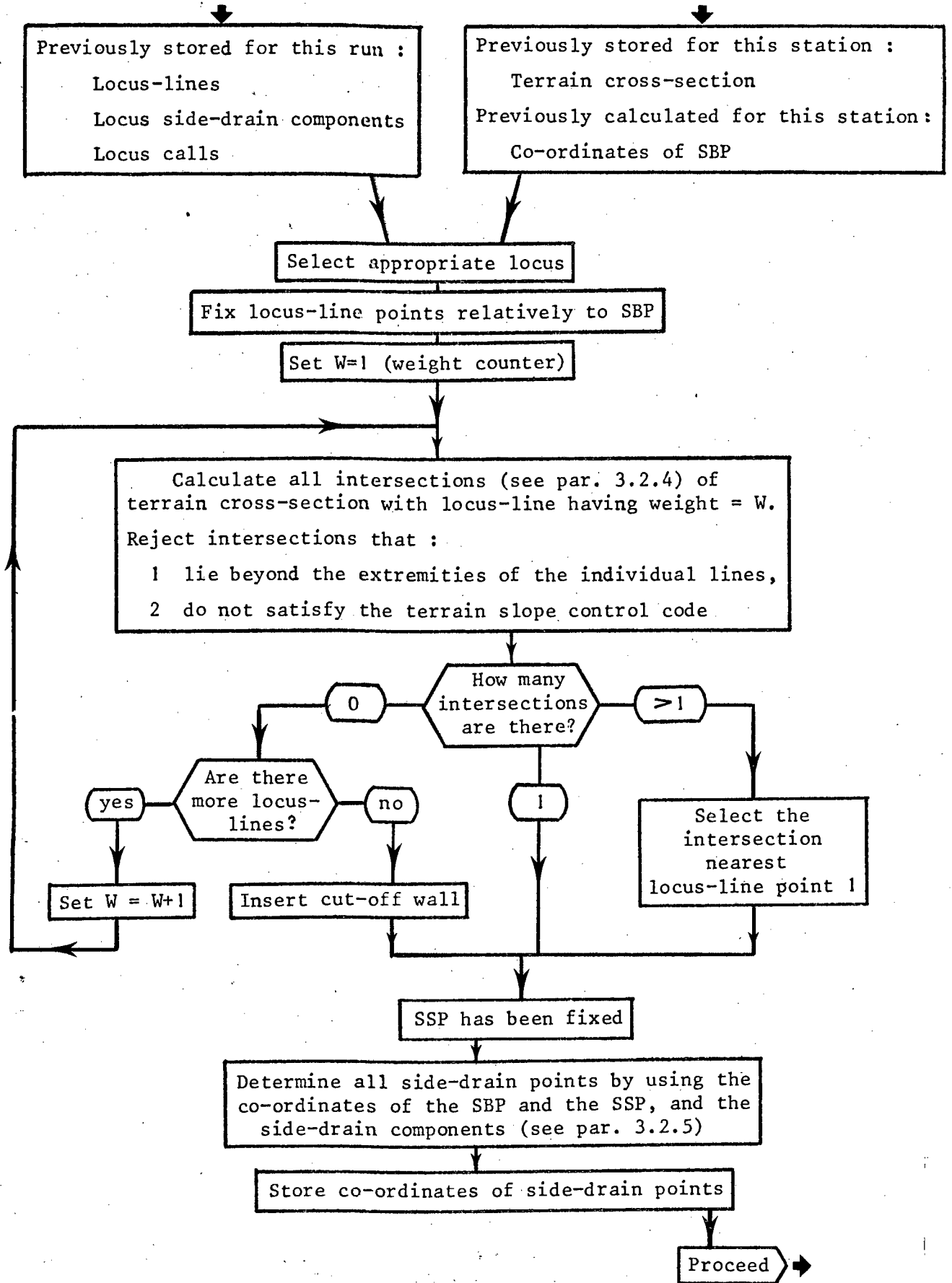
The coding of these constraints is set out in par. 3.2.3(ii)(c).

These constraints rightly form part of the standard road template specified by the road-building authority, but it is often left to the discretion of the design and construction engineers to deal with such moot cases on merit. The user of the program must in all cases be able to dictate the logic routine to be followed by the computer in selecting the appropriate SSP, in accordance with engineering practice.

### 3.2.2 The Locus Method to Determine Side-drain Templates

The application of the concept as described in par. 3.2.1(i), (ii) and (iii) to determine the specific side-drain template on either side of the road at a particular station, is presented as a flow diagram in Fig. 3.5. The basic steps proceed as follows:

- (i) the user :
  - (a) defines a locus with all its associated parameters for each standard side-drain template required for the whole road
  - (b) signifies the chainages at which a new locus is to be called in, treating each side of the road separately
  - (c) presents terrain cross-section data
- (ii) a program is available that can :
  - (a) fix the SBP to the same horizontal and vertical datum origins as the terrain cross-section at the station being considered
  - (b) select the appropriate locus with all its parameters at the particular station, in accordance with (i)(b) above
  - (c) calculate the position of the potential SSP's by geometrically intersecting the terrain cross-section with the locus-lines
  - (d) reject undesired intersections in compliance with the constraints and preferences, thereby fixing the successful SSP



Determination of the Specific Side-drain Template  
by the Locus Method

FIG. 3.5

- (e) select the side-drain configuration associated with the locus-line on which the successful SSP has been found
- (f) calculate all side-drain points between the SBP and SSP, according to the selected configuration, thereby establishing the full specific side-drain template.

Comparison with Fig. 1.14 will prove that the above steps conform to the accepted design procedure.

The above items (i)(a), (ii)(c), and (ii)(f) will be treated in detail in pars. 3.2.4 and 3.2.5 respectively. The intervening items represent routine procedures and do not warrant further comment.

### 3.2.3 Definition of the Locus by the User

It has been seen that the design of a road requires one or more standard templates specified by the road authority. A locus must be defined by the user for each standard side-drain template.

The definition of a locus covers the following items:

- (i) Its name (a code, or locus type number) by which it will be called in for a particular portion of the road.
- (ii) A set of straight locus-lines, each of which comprises
  - (a) a locus-line number, for identification
  - (b) horizontal and vertical offsets of the two end points of the locus-line, relative to the SBP
  - (c) a set of control codes, used to select the preferred intersection as the successful SSP
  - (d) a set of defined side-drain components (offsets and slopes of side-drain configuration elements) which will be used to calculate the side-drain points.

The following comments should be noted with regard to the above items:

- (i) Locus type. Any one or more of the defined parameters of a side-drain configuration in a locus may require modification during a run from a particular chainage onwards to accommodate a predetermined change in template, due to different road construction standard, cut material slope, ditch waterway capacity, or other requirement. In such

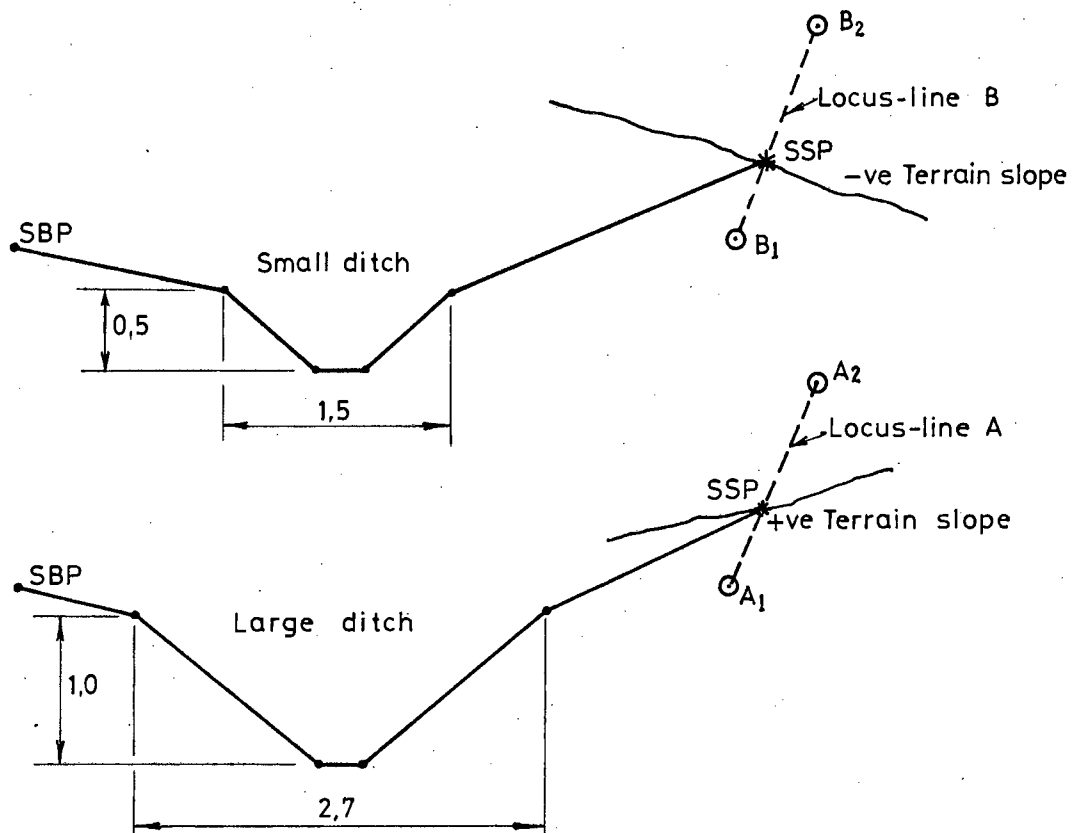
case, a completely separate locus must be defined and called in at that chainage. Unaltered parameters remain applicable or are repeated in the definition of the new locus. As an example, soft cut material requires an outside cut slope of 0,667 whereas in rock cut an outside cut slope of 4,0 is allowed. Separate loci, each with its own complete set of parameters, must be defined for soft material and for rock, and must be called in, predeterminedly, as changes in material occur along the increasing road chainage. Each side of the road may be treated independently.

- (ii) (a) Locus-line number. A sufficient number of individual straight locus-lines are required to cover the full locus of the slope stake point.

The user is assisted in defining the locus-lines by drawing a diagram as suggested in par. 3.2.1 and illustrated in Fig. 3.2. It is important that no gap be left between locus-lines where a terrain cross-section would be unable to find an intersection. This will avoid the type of defect found in the BECS RCFB program illustrated in par. 2.2.4.2 and Fig. 2.4.2. In the BECS RCFB program it is an omission made during the original program coding; in the locus method it would be an omission by the user in the preparation of the parameters.

An important feature is that two or more locus-lines within one locus may overlap partially or entirely, or may cross one another. The use of this lies in the possible rejection of an intersection found

on a locus-line of higher priority upon consideration of the terrain slope, and subsequently finding another intersection at the identical location, but on a locus-line of lower priority. This second intersection could then be the successful SSP. The configuration applicable would be the one associated with the locus-line of lower priority. This feature is illustrated in Fig. 3.6.



Selecting different Side-Drain Configurations  
according to slope of terrain

FIG. 3.6

In this example, locus-lines A and B lie in the same position and have the same offset values for the end points. A programmed test of the terrain slope at the position of the SSP allows the user to choose a smaller ditch if the terrain slopes down away from the road, or a larger ditch if surface stormwater runs down towards the road.

- (ii) (b) Locus-line points. The end points of the locus-line are significant. The locus-lines are not extended and no intersection is found beyond these points.

A locus-line that theoretically extends to infinity is terminated by an end point having very large offset values, which will cover all practical cases. Normally a vertical offset of 99 m, or in severe cases of cut or fill, 999 m, would be adequate to cover the greatest vertical distance between SBP and SSP.

- (ii) (c) Preference Codes. Three types of control codes, mentioned in par. 3.2.1(iv), are listed here, but others could be devised.

Locus-line priority (i.e. locus-line weight): The locus-line identification numbers could be applied to determine the order in which locus-lines will be used to try to find an intersection with the terrain cross-section. If no intersection is accepted on the locus-line of highest priority, the program will proceed to try to find an intersection on the next locus-line.

Locus-line direction: A simple code rates one end of the locus-line at higher priority and gives preference to the intersection which is closest to it.

Terrain slope preference: A simple code allows acceptance or rejection of an intersection according to the slope of the terrain cross-section at a specified point.

It is important for the user to ensure that, if an intersection is rejected by a control code, a further intersection that can be accepted will be found either on the same locus-line or on a locus-line of lower priority.

- (ii) (d) Components. The applicable side-drain configuration consisting of a set of side-drain components defined by the user, is used by the computer to calculate the positions of the side-drain points.

The computer will apply the set of components to the SBP and SSP that it has fixed i.e. the SSP will be rigidly fixed relative to the SBP. The user, however, must give certain unfixed components, representing the variable dimensions in the configuration, when he defines the set of components, to allow the SSP to range over the full length of the locus-line.

Considerable versatility is achieved by the locus method, because the user may choose fixed and unfixed components as necessary to create the required configuration, in accordance with the prescribed standard template. A few special cases are illustrated in par. 3.3.

The configuration consists of a fixed number,  $n$ , of straight-line side-drain elements, which join the SBP,  $(n-1)$  intermediate side-drain points, and the SSP, in series, (see Fig. 3.4).

Each element<sub>i</sub> has a

horizontal offset,  $H_i$

vertical offset,  $V_i$

and a slope component,  $S_i$  ( $i \leq n$ )

The  $H_i$  and  $V_i$  are respectively the horizontal and vertical distances between the initial side-drain point ( $i-1$ ) and the concluding side-drain point<sub>i</sub> of element<sub>i</sub>.

Element<sub>1</sub> has the SBP as the initial point, and element<sub>n</sub> has the SSP as the concluding point.

The three components of an element<sub>i</sub> are interrelated, since

$$S_i = \frac{V_i}{H_i}$$

— 3.1

If any two components of an element are known, the third component is redundant; the two side-drain points are fixed predeterminedly relative to one another.

If one component of an element is given, a restriction is imposed on the relationship between the two points, but they are not fixed relatively.

If no component is given for an element, its two points are independent of one another. In this case, the initial point of the element would be fixed relative to the SBP, and the concluding point would be fixed to the SSP.

In order to exclude redundant data, the set of components must be defined subject to the following rules:

- R1 (2n-2) components must be given fixed values, some or all of which may have a value of zero. A clear distinction must be made between a component which is given a value of zero, and which is therefore defined, and an undefined component which must remain blank.
- R2 (n+2) components must remain blank as unfixed values; n of these are redundant through the n equations \_\_\_ 3.1 above, and two of them, representing the variable parameters in the configuration, become redundant when the SSP is fixed relative to the SBP.
- R3 All three components to a point may not be given, as one is redundant.
- R4 Not more than (n-1) horizontal offsets may be given in the set.

(Note: If both vertical and slope components to an element are given, the horizontal component is thereby also fixed, and must be counted as "given" under rule R4).

- R5 Not more than (n-1) vertical offsets may be given in the set.

(Note: Similarly, under rule R5 a vertical component must be counted as "given" when the horizontal and slope components to an element have both been given).

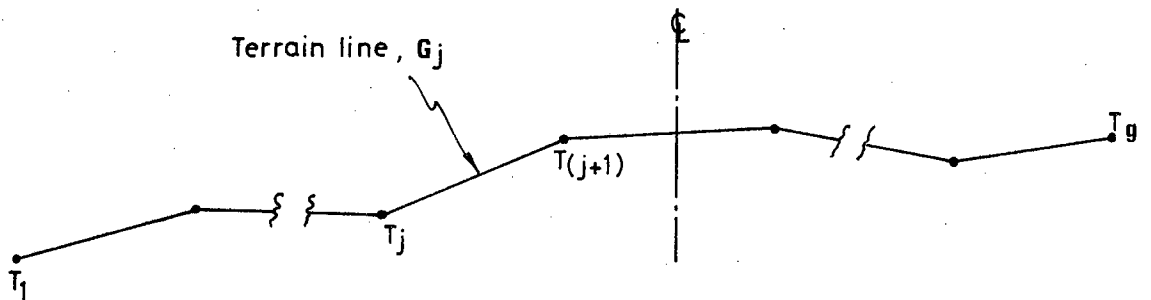
- R6 Not more than two slope components that are not accompanied by a horizontal or vertical component for the element may be given.
- R7 An unaccompanied slope component may not be 0 (i.e. level) if an unaccompanied vertical component is given for any other element in this configuration. (A component is "unaccompanied" when it is the sole component to an element that is given, the other two components being undefined).
- R8 An unaccompanied slope component may not be  $+\infty$  or  $-\infty$  (i.e. vertical) if an unaccompanied horizontal component is given for any other element in this configuration.
- R9 If 2 unaccompanied slopes are given they may not have the same algebraic value.
- R10 One set of side-drain components applies for an SSP found anywhere within the length of the relevant locus-line, and therefore the components must be validly applicable as a set over the full length of the locus-line.

Inspection of these 10 rules will reveal that sufficient parameters will be available to the computer to fix a series of  $n$  straight-line elements between two known end-points (the SBP and the SSP), without introducing any redundancy.

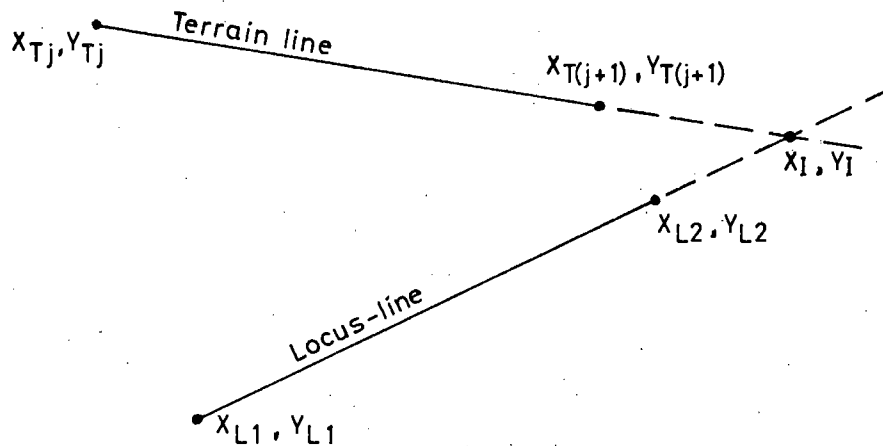
### 3.2.4 Calculation of the Position of the Slope Stake Point by Intersection

When the computer has calculated the position of the SBP, and has called up the terrain cross-section and the locus-type applicable at the station being dealt with, the following step is fixing the position of the slope stake point.

It is assumed that the terrain cross-section consists of a series of  $g$  consecutive terrain points defined by  $X$  (horizontal) and  $Y$  (vertical) co-ordinates (offsets), based on the same datum origins as used for the offsets defining the specific road surface template and SBP. Successive terrain points  $T_j$  and  $T_{(j+1)}$  are joined by a straight terrain line,  $G_j$ , where  $j \leq g - 1$  (see Fig. 3.7(a)).



(a) TERRAIN CROSS-SECTION



(b) INTERSECTION OF LOCUS-LINE AND TERRAIN LINE

The routine to find the intersection includes the following steps:

- S1        The locus-line having the highest priority is selected. The X and Y co-ordinates of its end points, L1 and L2, are obtained by adding the offsets of the locus-line points, as given by the user, to the co-ordinates of the SBP.
- S2        Each terrain line j is dealt with in turn, incrementing j from 1 to (g-1).
- S3        The slopes of the terrain line and the locus-line are compared :
- (a)      If the produced lines are parallel but not coincident, no intersection exists and the following terrain line is dealt with (return to step S2).
  - (b)      If the produced lines are parallel and coincident, tests (similar to step S5 below) are carried out to determine whether the unproduced lines overlap. If they do not overlap, nor touch at end-points, no intersection exists and the following terrain line is dealt with (return to step S2). If they do overlap, the X and Y co-ordinates of the two end-points of the coincident section of the unproduced lines are both determined and stored as potential SSP's. Treatment continues in step S6.
  - (c)      If the lines are not parallel treatment continues in step S4.

S4 The intersection of the locus-line and the terrain line, both extended if necessary, is determined by calculating the X and Y co-ordinates of the intersection point I by the following formulae, see Fig. 3.7(b):

$$\text{Let } H_G = X_{T(j+1)} - X_{Tj} \quad \text{--- 3.2}$$

$$V_G = Y_{T(j+1)} - Y_{Tj} \quad \text{--- 3.3}$$

$$H_L = X_{L2} - X_{L1} \quad \text{--- 3.4}$$

$$V_L = Y_{L2} - Y_{L1} \quad \text{--- 3.5}$$

Then

$$X_I = \frac{\left( Y_{L1} \cdot X_{L2} - X_{L1} \cdot Y_{L2} \right) H_G - \left( Y_{Tj} \cdot X_{T(j+1)} - X_{Tj} \cdot Y_{T(j+1)} \right) H_L}{V_G \cdot H_L - H_G \cdot V_L} \quad \text{--- 3.6}$$

$$Y_I = \frac{\left( Y_{L1} \cdot X_{L2} - X_{L1} \cdot Y_{L2} \right) V_G - \left( Y_{Tj} \cdot X_{T(j+1)} - X_{Tj} \cdot Y_{T(j+1)} \right) V_L}{V_G \cdot H_L - H_G \cdot V_L} \quad \text{--- 3.7}$$

S5 The intersection calculated in step S4 can only be considered valid if it does not lie beyond the end-points of the terrain line and locus-line. A series of tests must be carried out to exclude an intersection lying beyond an end-point. Such tests include:

$$\text{If } X_{L1} \geq X_{L2},$$

$$\text{then } X_{L2} \leq X_I \leq X_{L1} \quad \text{--- 3.8}$$

or if  $X_{L1} < X_{L2}$ ,

then  $X_{L1} \leq X_I \leq X_{L2}$ . — 3.9

If  $X_{Tj} \geq X_{T(j+1)}$ ,

$X_{T(j+1)} \geq X_I \geq X_{Tj}$  — 3.10

or if  $X_{Tj} < X_{T(j+1)}$

$X_{Tj} \leq X_I \leq X_{T(j+1)}$ , — 3.11

and similarly for the Y co-ordinates.

If the full series of tests confirms that the intersection is obtained by the unproduced lines, the co-ordinates  $X_I$  and  $Y_I$  are stored as a potential SSP.

- S6 A terrain line may intersect once or not at all with the locus-line, (two "intersections" are stored if the lines overlap, see step S3(b) above). As subsequent terrain lines may intersect this locus-line, the next terrain line (j+1) is similarly treated (return to step S2) until all (g-1) terrain lines have been dealt with.
- S7 If no potential SSP has been found, the routine is repeated with the locus-line next in priority, (return to step S1).
- S8 Depending on the number of terrain lines that intersect the particular locus-line, one or more potential SSP's may have been stored. The constraints in par. 3.2.3(ii)(c) are applied to each potential SSP in turn to accept or reject it.

If it is accepted, the specific SSP at this station and on this side of the road has been located, and all further searching for an SSP ceases (go to step S8).

If an SSP is rejected, the following potential SSP is tested against the constraints, or if there is no other potential SSP for the particular locus-line, the next locus-line in priority is called in (return to step S1).

Note: An acceptable SSP must be found by an intersection of the terrain cross-section with one or other of the locus-lines of the locus applicable at the particular station. A cut-off routine which can fix an SSP in extreme cases, would also be acceptable. Failure to find an acceptable SSP indicates faulty parameters or data input by the user, or a defective program.

S8 When the first acceptable SSP has been found, no further attempt is made to locate any other SSP as it could only have a lower priority. The coordinates  $X_I$  and  $Y_I$  of the first acceptable SSP are thus  $X_{SSP}$  and  $Y_{SSP}$ .

The locus-line on which the successful SSP has been found, determines, through its set of side-drain components, the side-drain configuration to be applied. The application of the components to fix the specific side-drain template is set out in par.

3.2.5.

#### Possible rejection through rounding-off inaccuracy

All tests carried out in steps S3 and S5 must include a tolerance factor to overcome the possibility that an acceptable intersection that lies very close to an end-point is rejected as a result of rounding-off inaccuracies<sup>(14)</sup>. Such

unwarranted rejection would be serious, as the correct solution could be foiled through a missing SSP.

As an example of inclusion of the tolerance factor, the first test listed under step S5 above (equation 3.8) would read :

$$X_{L2} - \text{tolerance factor} \leq X_I \leq X_{L1} + \text{tolerance factor} \quad \text{— 3.12}$$

### 3.2.5 Calculation of the Intermediate Side-drain Points

When the co-ordinates of the SSP ( $X_{SSP}$  and  $Y_{SSP}$ ) have been fixed on a common grid origin, as described in par. 3.2.4, the side-drain template is fully defined by the set of side-drain components associated with the intersected locus-line and the co-ordinates of the intermediate side-drain points can now be calculated.

As shown in Fig. 3.4, the side-drain template consists of:

n straight-line elements

which join in sequence

the SBP (= point<sub>0</sub>),

(n-1) intermediate side-drain points,

and the SSP (= point<sub>n</sub>).

Any two adjacent side-drain points, (i-1) and i, being the end points of the element i, are related by the horizontal ( $H_i$ ), vertical ( $V_i$ ) and slope ( $S_i$ ) components thus:

$$S_i = \frac{V_i}{H_i} \quad (\text{for } i \leq n) \quad \text{--- 3.1}$$

The X and Y co-ordinates of these two end points, (i-1) and i, are related by the two equations

$$X_i - X_{(i-1)} = H_i \quad \text{--- 3.13}$$

$$Y_i - Y_{(i-1)} = V_i \quad \text{--- 3.14}$$

The co-ordinates of the SBP ( $X_0$  and  $Y_0$ ) and of the SSP ( $X_n$  and  $Y_n$ ) are known.

It is required to calculate  $X_i$  and  $Y_i$  for  $i$  from 1 to  $(n-1)$ , given a selected set of  $(2n-2)$  components.

Two methods are presented for the calculation of the co-ordinates of the side-drain points:

(i) a geometric (or "brute-force") method

and (ii) the solution of a set of simultaneous linear equations by inverting a matrix formed by the given side-drain components.

Although the geometric method could be programmed for computer solution, it is presented here essentially for the purpose of amplifying insight into the potential use of the locus of the slope stake point. The matrix solution is eminently suited for computer application, and has accordingly been used in the SHARM program, as set out in par. 4.2.2.

(i) The Geometric Method

The geometric method may be described briefly as consisting of one or more of the following steps.

- (a) As many co-ordinates of side-drain points as possible are fixed directly to the SBP, treating X and Y co-ordinates separately.
- (b) As many co-ordinates as possible are fixed directly to the SSP.
- (c) All elements for which two components have been given, but which have not yet been tied to the SBP or SSP, are formed into a continuous linked series. This is slid into the gap between the fixed points on either side, in accordance with slope components that may be applicable.

The geometric method is described in detail in the following steps:

(Note:  $1 \leq i \leq n$ )

G1 Wherever  $S_i$  is accompanied by  $V_i$ , calculate

$$H_i = \frac{V_i}{S_i} \quad \text{--- 3.15}$$

G2 Wherever  $S_i$  is accompanied by  $H_i$ , calculate

$$V_i = S_i \cdot H_i \quad \text{--- 3.16}$$

G3 Calculate as many  $X_i$  as possible, using given and calculated H's, from

$$\begin{array}{rcll}
 X_1 & = & X_0 & + H_1 & ) \\
 X_2 & = & X_1 & + H_2 & ) \\
 X_3 & = & X_2 & + H_3 & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 X_i & = & X_{(i-1)} & + H_i & )
 \end{array}
 \quad \begin{array}{l}
 \\
 \\
 \downarrow \text{from} \\
 \text{SBP} \\
 \text{outwards} \\
 \\
 \\
 \\
 \\
 \end{array}
 \quad \text{--- 3.17}$$

This process will be interrupted, possibly before the first point, as a result of an  $H_i$  being blank.

Similarly calculate as many  $X_i$  from

$$\begin{array}{rcll}
 X_{(n-1)} & = & X_n & - H_n & ) \\
 X_{(n-2)} & = & X_{(n-1)} & - H_{(n-1)} & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 X_i & = & X_{(i+1)} & - H_{(i+1)} & )
 \end{array}
 \quad \begin{array}{l}
 \\
 \\
 \\
 \downarrow \text{from} \\
 \text{SSP} \\
 \text{inwards} \\
 \\
 \\
 \\
 \end{array}
 \quad \text{--- 3.18}$$

Again the process will be interrupted by a blank  $H_{(i+1)}$ .

G4 Similarly calculate as many  $Y_i$  as possible

$$\begin{array}{rcll}
 Y_1 & = & Y_0 & + V_1 & ) \\
 Y_2 & = & Y_1 & + V_2 & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 \cdot & & & & ) \\
 Y_i & = & Y_{(i-1)} & + V_i & )
 \end{array}
 \quad \begin{array}{l}
 \\
 \\
 \\
 \downarrow \\
 \\
 \\
 \\
 \end{array}
 \quad \text{--- 3.19}$$

and from

$$\begin{array}{rcl}
 Y_{(n-1)} & = & Y_n & ) \\
 & & & ) \\
 Y_{(n-2)} & = & Y_{(n-1)} - V_{(n-1)} & ) \\
 & & & ) \\
 \cdot & & & ) \\
 & & & ) \\
 \cdot & & & ) \\
 & & & ) \\
 & & & ) \\
 & & & ) \\
 Y_i & = & Y_{(i+1)} - V_{(i+1)} & ) \\
 & & & )
 \end{array} \quad \begin{array}{l} \\ \\ \\ \\ \downarrow \\ \\ \\ \\ \\ \end{array} \quad \begin{array}{l} \\ \\ \\ \\ \\ \text{--- } 3.20 \\ \\ \\ \\ \\ \end{array}$$

If there is no  $S_i$  that is not accompanied by either  $H_i$  or  $V_i$ , all required co-ordinates are now known.

EXIT →

If there are one or two unaccompanied slopes, go to step G5. ↷

G5 For every given  $S_i$  that is unaccompanied, one of the two ends of the element  $i$  will be fixed, i.e.

either co-ordinates  $X_{(i-1)}$  and  $Y_{(i-1)}$   
or  $X_i$  and  $Y_i$

will, by now, be known.

In order to determine the equation of the line, find the constant,  $c_i$ , for each unaccompanied  $S_i$ ,

either from  $c_i = Y_{(i-1)} - S_i \cdot X_{(i-1)}$  — 3.21

or from  $c_i = Y_i - S_i \cdot X_i$  — 3.22

If there are two such unaccompanied slopes, go to step G7. ↷

If there is only one unaccompanied slope, go to step G6. ↷

G6 In addition to both co-ordinates of the fixed end, one co-ordinate of the unfixed end of element  $i$  is known,

i.e. if equation 3.21 was used to find  $c_i$ ,  $X_i$  or  $Y_i$  will also be known,

alternatively, if equation 3.22 was used to find  $c_i$ ,  $X_{(i-1)}$  or  $Y_{(i-1)}$  will be known.


The one remaining unknown co-ordinate of the two points on this line is found from

$$X_{(i-1)} = \frac{Y_{(i-1)} - c_i}{S_i} \quad \text{--- 3.23}$$

$$\text{or } Y_{(i-1)} = S_i \cdot X_{(i-1)} + c_i \quad \text{--- 3.24}$$

$$\text{or } X_i = \frac{Y_i - c_i}{S_i} \quad \text{--- 3.25}$$

$$\text{or } Y_i = S_i \cdot X_i + c_i \quad \text{--- 3.26}$$


Return to steps G3 and G4 to calculate all outstanding co-ordinates by means of equations 3.17, 3.18, 3.19 and 3.20. 


G7 As there are two unaccompanied slope components, call them  $S_k$  and  $S_t$ , with constants  $c_k$  and  $c_t$  respectively, as determined in step G5,

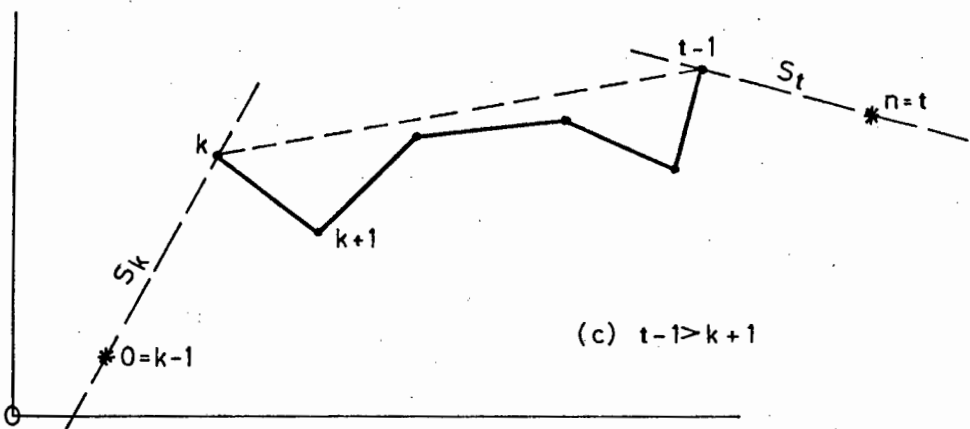
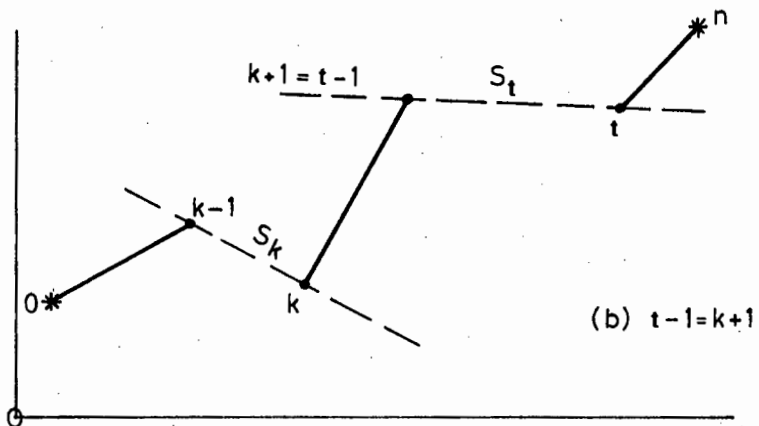
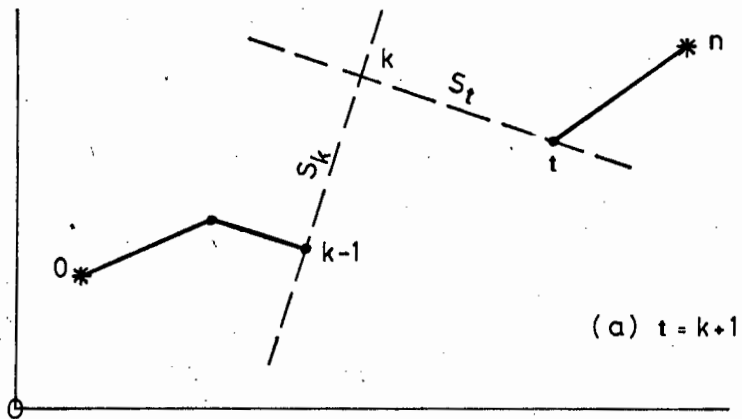
where  $k < t$

and  $t \leq k \leq n-1$

$2 \leq t \leq n$

If  $t = k + 1$  (see Fig. 3.8(a)), go to step G8. 

If  $t > k + 1$  (see Fig. 3.8(b) and (c)), go to step G9. 



Specimen Side-drain Configurations having two unaccompanied slope components

FIG. 3.8

- G8 Calculate the intersection  $(X_k, Y_k)$  of the two straight lines

$$Y = S_k \cdot X + c_k \quad \text{--- 3.27}$$

$$Y = S_t \cdot X + c_t \quad \text{--- 3.28}$$

$$\text{whence } X_k = \frac{c_k - c_t}{S_t - S_k} \quad \text{--- 3.29}$$

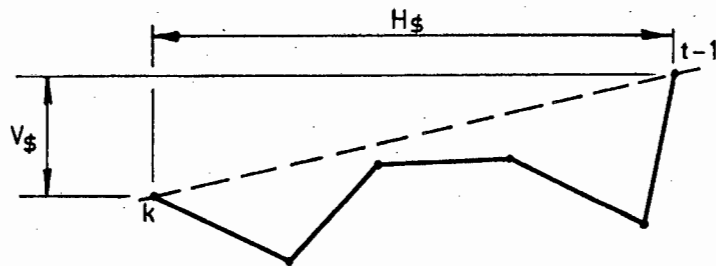
$$Y_k = \frac{S_t \cdot c_k - S_k \cdot c_t}{S_t - S_k} \quad \text{--- 3.30}$$

All co-ordinates are now known. EXIT →

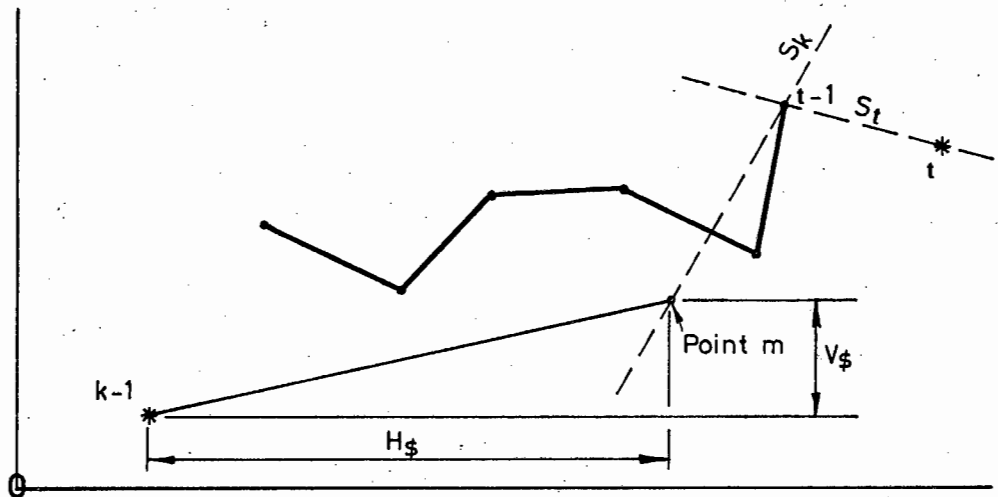
- G9 All  $H_i$  and  $V_i$  will be known for  $k + 1 \leq i \leq t - 1$  (see Fig. 3.9(a))

$$\text{Find } H_{\$} = \sum_{i=k+1}^{t-1} H_i \quad \text{--- 3.31}$$

$$\text{and } V_{\$} = \sum_{i=k+1}^{t-1} V_i \quad \text{--- 3.32}$$



(a)



(b)

Geometric solution of Type (C) in Fig. 3.8

FIG. 3.9

Find the co-ordinates of point m  
 $(X_m, Y_m)$  (which does not lie on the  
 side-drain, see Fig. 3.9(b))

where

$$X_m = X_{(k-1)} + H_{\$} \quad \text{--- 3.33}$$

$$Y_m = Y_{(k-1)} + V_{\$} \quad \text{--- 3.34}$$

Put a line with slope  $S_k$  through point  
 m. The equation of the line is

$$Y = S_k \cdot X + c_m \quad \text{--- 3.35}$$

where

$$c_m = Y_m - S_k \cdot X_m$$


Equation 3.28 is the equation of the  
 line with slope  $S_t$  through point t

$$\text{i.e. } Y = S_t \cdot X + c_t \quad \text{--- 3.28}$$

Find the co-ordinates of the inter-  
 section of the two lines having  
 equations 3.35 and 3.28. These are  
 the co-ordinates of side-drain point  
 (t-1).

$$X_{(t-1)} = \frac{c_m - c_t}{S_t - S_k} \quad \text{--- 3.36}$$

$$\text{and } Y_{(t-1)} = \frac{S_t \cdot c_m - S_k \cdot c_t}{S_t - S_k} \quad \text{--- 3.37}$$

Return to steps G3 and G4 to calculate  
 all outstanding co-ordinates by means  
 of equations 3.17, 3.18, 3.19 and 3.20. 

(ii) The general Matrix Solution

The calculation of the co-ordinates of the (n-1) intermediate side-drain points between the SBP and the SSP can be executed conveniently by computer, by using Gauss's systematic method to solve a set of simultaneous linear equations numerically, by inverting the matrix formed by the coefficients.

From equations 3.1, 3.13 and 3.14

$$S_i(X_i - X_{(i-1)}) = V_i \quad \text{--- 3.38}$$

$$\text{and } Y_i - Y_{(i-1)} = S_i(X_i - X_{(i-1)}) \quad \text{--- 3.39}$$

Re-arranging equations 3.13, 3.39, and 3.14 gives, respectively,

$$- X_{(i-1)} + X_i = H_i \quad \text{--- 3.40}$$

$$+ S_i \cdot X_{(i-1)} - Y_{(i-1)} - S_i \cdot X_i + Y_i = 0 \quad \text{--- 3.41}$$

$$- Y_{(i-1)} + Y_i = V_i \quad \text{--- 3.42}$$

A form containing these three equations, 3.40, 3.41 and 3.42, for each of the n elements, i.e. a total of 3 n equations, 3.43, can be drawn up as shown on page 3.37.

$X_0$	$Y_0$	$X_1$	$Y_1$	$X_2$	$Y_2$	$X_3$	$Y_3$	— —	$X_{(n-2)}$	$Y_{(n-2)}$	$X_{(n-1)}$	$Y_{(n-1)}$	$X_n$	$Y_n$
-1		+1												
$+S_1$	-1	$-S_1$	+1											
	-1		+1											
		-1		+1										
		$+S_2$	-1	$-S_2$	+1									
			-1		+1									
				-1		+1								
				$+S_3$	-1	$-S_3$	+1							
					-1		+1							
									-1		+1			
									$+S_{(n-1)}$	-1	$-S_{(n-1)}$	+1		
										-1		+1		
											-1		+1	
											$+S_n$	-1	+1	
												-1		
													+1	+1
													$-S_n$	
														+1

$$\begin{aligned}
&= H_1 \\
&= 0 \\
&= V_1 \\
&= H_2 \\
&= 0 \\
&= V_2 \\
&= H_3 \\
&= 0 \\
&= V_3 \\
&| \\
&| \\
&= H_{(n-1)} \\
&= 0 \\
&= V_{(n-1)} \\
&= H_n \\
&= 0 \\
&= V_n
\end{aligned}$$

3.37

However, since some components have not been given values in the definition of the locus-line, not all of these equations are available, nor are they needed, for the solution. The definition of the locus-line includes a set of  $(2n-2)$  given component values. For each component given, one equation in the set 3.43 is completed. Out of the  $3n$  equations in the set,  $(2n-2)$  equations will thus be available.

In addition, the X and Y co-ordinates of the SBP (point<sub>0</sub>) and SSP (point<sub>n</sub>), which are known, are necessary to set up the matrix equation

$$A \cdot B = C$$

— 3.44

where

A is a square matrix of  $(2n+2)$  rows and columns consisting of coefficients,

B is a column matrix of  $(2n+2)$  elements of X and Y co-ordinates of all side-drain points, representing the vector to be solved,

and C is a column matrix also of  $(2n+2)$  elements of known X and Y co-ordinates and known horizontal and vertical components.

The matrix equation, 3.45, is shown on page 3.39 .



The matrices A and C are set up for the computer by inserting in the respective rows the defined values of the S, H and V components, where these have been given, even if they are zero, and by ignoring entirely those rows for which the relevant component has been left blank when inputting the locus-line parameters. Thus, if the slope  $i$  is the only component given for element  $i$ , the rows corresponding to equations 3.40 and 3.42 would be omitted, and subsequent rows in the matrices would shift up, so that no blank rows are left.  $(n+2)$  rows are left out and thus  $(2n-2)$  rows based on components and 4 rows based on known co-ordinates make up the matrix equation.

The inversion of the matrix A leads to the solution of the X and Y co-ordinates of the intermediate side-drain points contained in matrix B, through the equation

$$B = A^{-1}.C$$

— 3.46

Let  $A^{-1}$  = square matrix D of  $(2n+2)$  rows and columns.

The equations, which use elements of the matrix D, give the required X and Y co-ordinates as set out on page 3.41.

$$X_1 = D_{3,1} \cdot X_0 + D_{3,2} \cdot Y_0 + \sum_{d=3}^{2n} (D_{3,d} \cdot C_d) + D_{3,(2n+1)} \cdot X_n + D_{3,(2n+2)} \cdot Y_n \quad \text{--- 3.47}$$

$$Y_1 = D_{4,1} \cdot X_0 + D_{4,2} \cdot Y_0 + \sum_{d=3}^{2n} (D_{4,d} \cdot C_d) + D_{4,(2n+1)} \cdot X_n + D_{4,(2n+2)} \cdot Y_n \quad \text{--- 3.48}$$

and letting  $p = 2i+1$   
and  $r = 2i+2$

$$X_i = D_{p,1} \cdot X_0 + D_{p,2} \cdot Y_0 + \sum_{d=3}^{2n} (D_{p,d} \cdot C_d) + D_{p,(2n+1)} \cdot X_n + D_{p,(2n+2)} \cdot Y_n \quad \text{--- 3.49}$$

$$Y_i = D_{r,1} \cdot X_0 + D_{r,2} \cdot Y_0 + \sum_{d=3}^{2n} (D_{r,d} \cdot C_d) + D_{r,(2n+1)} \cdot X_n + D_{r,(2n+2)} \cdot Y_n \quad \text{--- 3.50}$$

$X_i$  and  $Y_i$ , for all values of  $i$  from 1 to  $(n-1)$ , are the required horizontal and vertical co-ordinates, or offsets, relative to the same datum origin as for the SBP and the SSP, for all the intermediate side-drain points.

The specific template has now been completed and the computer can proceed to calculate areas of cut and fill.

### 3.3 APPLICATION OF THE LOCUS METHOD

The method of the locus of the slope stake point has been presented as a general procedure by which a computer can be programmed to determine side-drain templates (see Fig. 3.5).

The concept can be incorporated in an existing road earthworks program by rewriting the relevant routines dealing with the side-drain template; alternatively, an entirely new road design system can include the locus method as a basic feature.

The engineer in charge of specifying the requirements to be met by the program being written and the programmer have to decide on the following matters:

- (a) The number of loci per run, locus-lines per locus and side-drain elements per configuration, that the program will handle, must be fixed in consideration of the storage capacity of the computer. The matrix method set out in par. 3.2.5 allows for easy extension of the number of loci, locus-lines and elements if the program is later transferred to a computer with larger storage capacity.
- (b) The engineer, when directing the writing of the program, has some option in the manner whereby the acceptable SSP is chosen in accordance with the constraints referred to in par. 3.2.3(ii)(c). The procedure adopted in SHARE - SHARM in applying the terrain slope preference has worked well, but it does introduce a constraint which may be not entirely suited to a particular standard template.
- (c) In order to ease the tracing of errors in input data, the programmer should incorporate as many logic tests with appropriate

error messages in his program as possible. Such tests must in particular cover the rules R1 to R10 set out in par. 3.2.3(ii)(d), and must exclude bands of values that would lead to an ill-conditioned set under rules R7, R8 and R9.

- (d) By efficient coding practice the programmer is able to shorten processing time. Considerable attention was paid to this aspect, as well as to making the best use of the storage available on the IBM 1130 8 K computer, during the coding of the SHARE - SHARM programs.

### 3.3.1 Comment on writing road design programs

Road design systems consist of numerous sub-programs and sub-routines and are complicated, not mathematically, but because of the interaction of the various routines and parameters, and the large bulk of data to be stored and dealt with. Because computer capacities are not limitless, programs are subjected to restrictions on the size of a job that can be handled, even when the facilities are used to best advantage. In view of this complexity, it is essential that programming be carried out efficiently.

Severe demands are placed on an engineer's skills if, in addition to being a capable roads engineer, he is required to be adept in, and to keep abreast of, developing computer techniques. The ideal team could well consist of a proficient roads engineer and a specialist programmer who are conversant with each other's problems.

A clear distinction should be drawn between the fields of the computer programmer and the roads engineer. The programmer should be well-versed in the skillful use of the type of computer for which the program is

being written. He would also have to be able to accept and understand instructions and directions from the engineer. The engineer, on the other hand, concerned with writing a road design program should have a clear grasp of the engineering requirements that must be met. He must ensure that these are met explicitly by the program that is produced, and he is responsible for producing the user's manual in a form that is intelligible to road engineers not versed in computer programming. The writer has not involved himself directly with the coding of the INGRESS or SHARE - SHARM programs, but has restricted himself to the full specification and verification of the engineering requirements to be met by these programs.

This thesis is not concerned with coding techniques. The SHARM user's manual (Appendix A), the flow-charts for the determination of the side-drain templates (Appendix B), and the coding of the relevant SHARM programs (Appendix C) corroborate the successful application of the locus method.

### 3.4 CAPABILITIES OF THE LOCUS METHOD

The technique described in par. 3.2, whereby a computer is enabled to determine specific side-drain templates in accordance with the user's wishes, is basically elementary in concept. However, subject to the limitations set out in par. 3.5, an extensive range of side-drain configurations can be specified and executed with absolute accuracy.

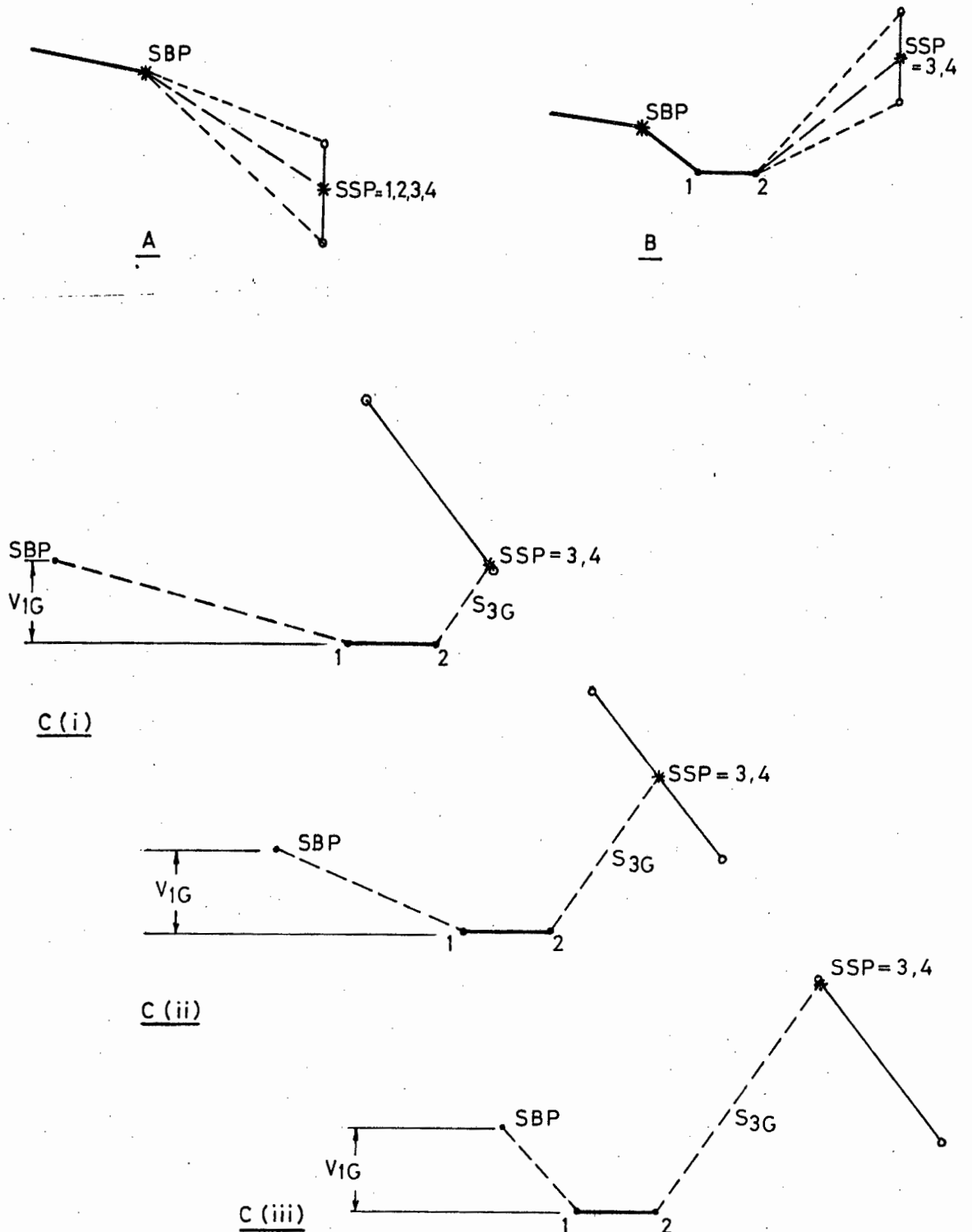
It is noteworthy that all but three of the configurations, which can be produced by the six programs investigated in pars. 2.2.1 to 2.2.6, can be represented accurately by the locus method. The problems encountered are explained in par. 3.5(i)(b), 3.5(i)(c) and 3.5(ii).



As the user has freedom (subject to the rules listed in par. 3.2.3(ii)(d), in selecting the  $(2n-2)$  components which he has to define, a considerable variety of side-drain configurations can be specified.

A side-drain template having less than the maximum number of side-drain points provided in the program, is accommodated by making two or more points coincident (point  $i$  is made coincident with point  $(i-1)$  by giving  $H_i = 0$  and  $V_i = 0$ ). A selection of types using 5 side-drain elements is given in Fig. 3.10.

A and B show simple fill and cut side-drain types having the SSP at fixed horizontal distances.

C(i), (ii) and (iii) show how the position of the ditch may be moved inwards, as the depth of the cut increases, while the outer cut slope is kept constant.



- Notes:
1. The relevant locus-line is shown thus 
  2. Both H and V components are given for elements shown as a solid line 
  3. Unaccompanied components are subscripted G

A selection of Specimen Side-drain Configurations  
 FIG. 3.10

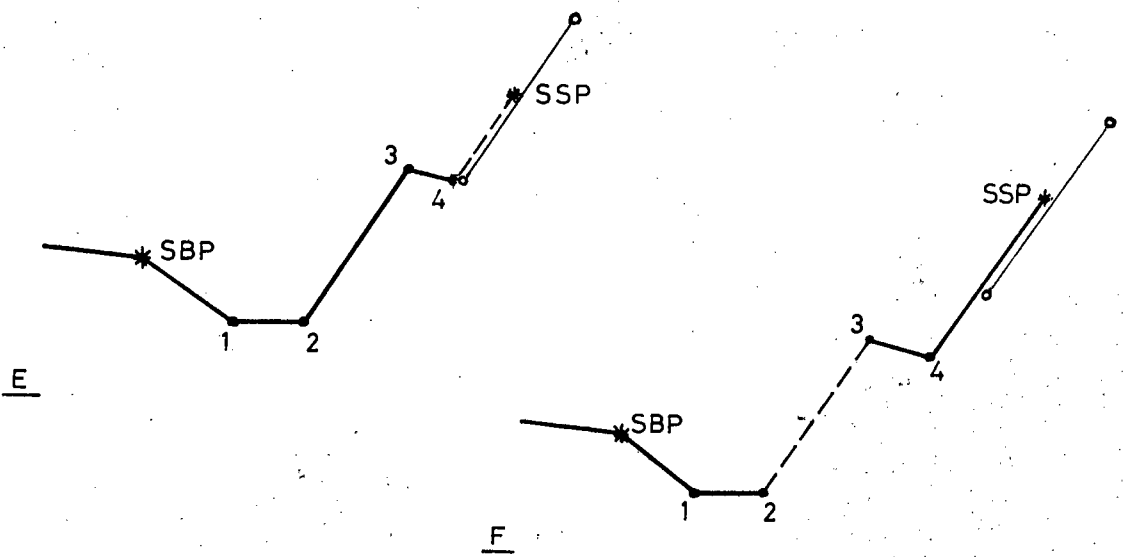
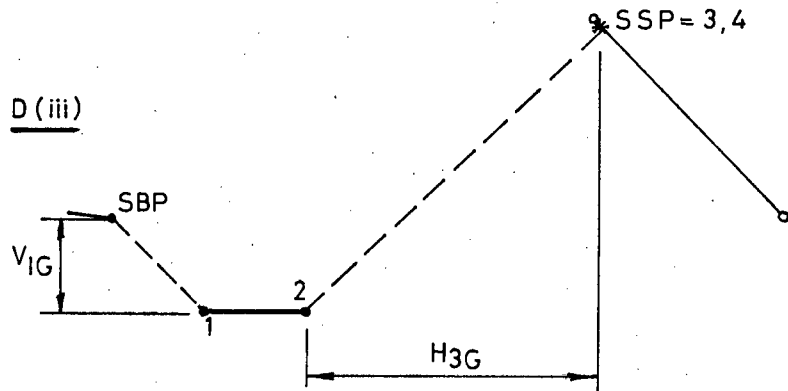
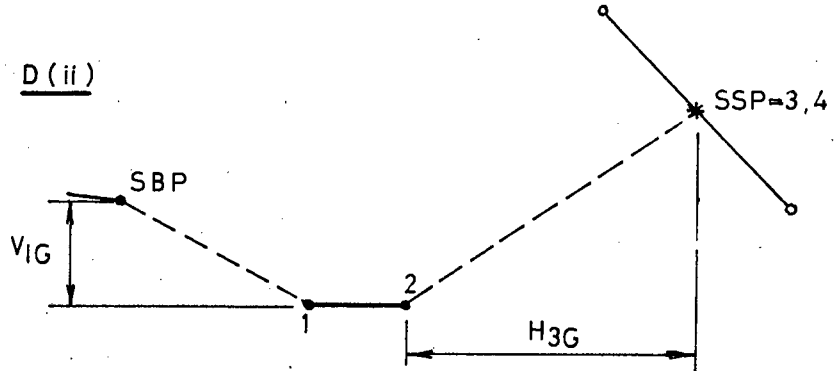
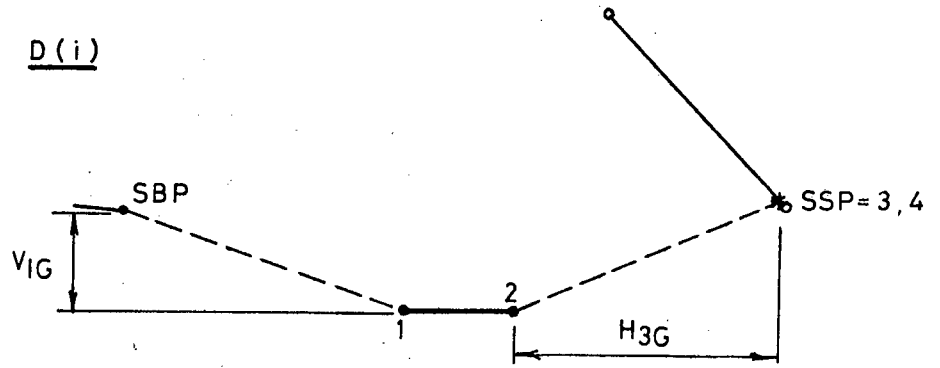


FIG. 3.10 (continued)

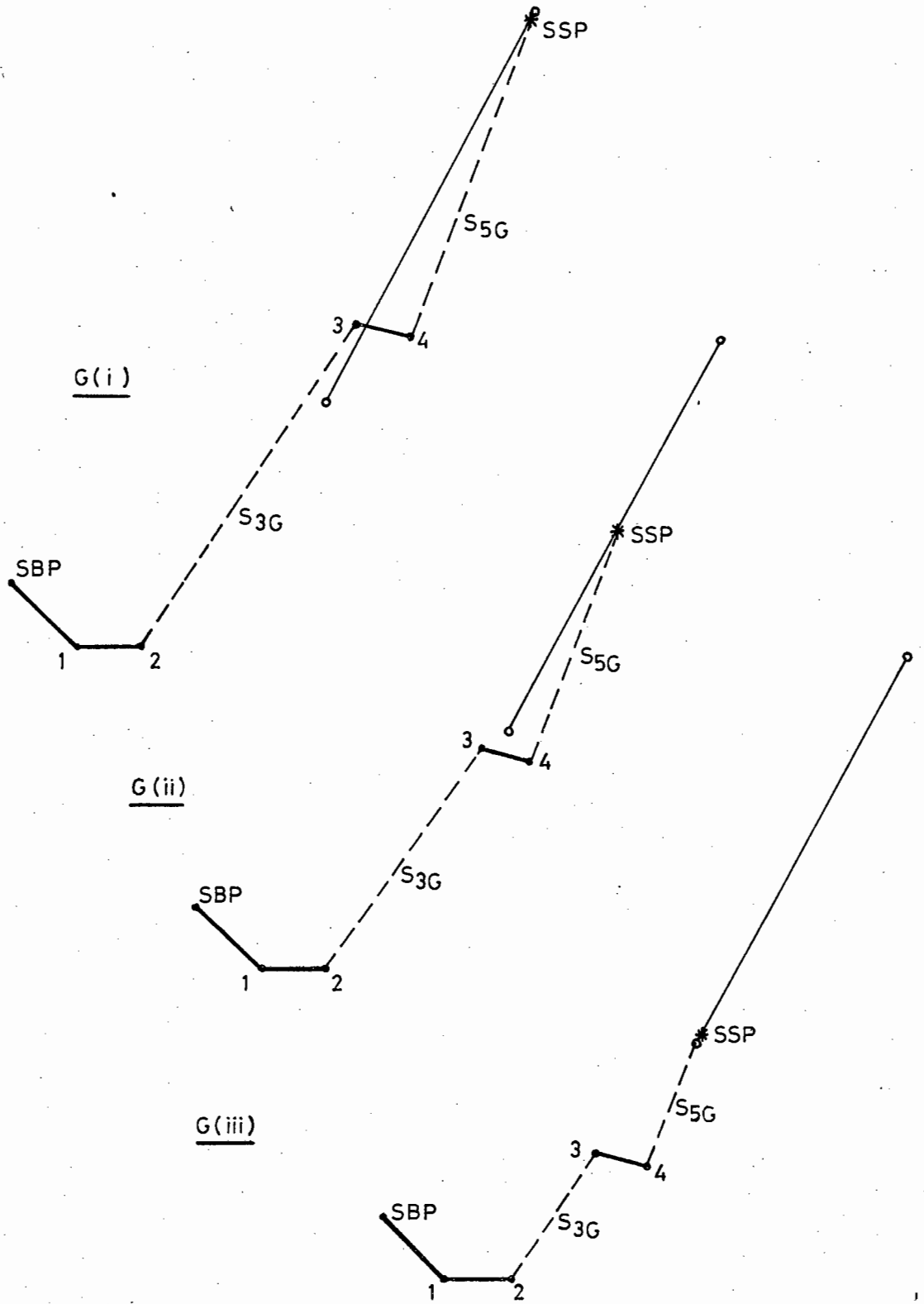


FIG. 3.10 (continued)

D(i), (ii) and (iii) show a similar effect, whereby the inner and outer slopes may be steepened simultaneously to keep them approximately equal but opposite in sign, as the depth of cut increases.

E shows a deep cut with a bench positioned at a constant height above the ditch invert, whereas in F the bench is a constant distance from the top of the cut slope.

G(i), (ii) and (iii) show how a bench may be positioned half-way up a cut slope, provided that the slopes above and below the bench have slightly different values.

The configuration needed to implement a particular standard template may not always be immediately obvious, but the user will usually be rewarded by a careful appraisal of the variable parameters that he has to accommodate.

The locus, when once defined, is independent of the job. It may therefore be used by a particular program in the solution of many jobs using the same standard side-drain template. It is considered a benefit that, in drawing up the locus to conform with the prescribed standard template, the user will become aware of any deficient configurations in the standard. In fact, drawing up the locus for a standard template enables its engineering soundness to be easily appraised.

### 3.5 LIMITATIONS OF THE LOCUS METHOD

#### (i) Inability to deal with curved lines

The method as described in par. 3.2 is restricted to dealing with straight lines.

Three aspects are considered:

##### (a) Curvilinear Locus-Lines

The possibility exists that a portion of the SSP as demanded by the prescribed template, consists of a curve. This could, however, be approximated fairly closely by replacing each curved locus-line by a series of straight locus-lines, provided that the capacity of the program for accepting locus-lines is large enough.

(b) A portion of the side-drain configuration may consist of a predetermined curve e.g. the circular ditch in CEP-HIDES, par. 2.2.6. In such case the curved element could be approximated by a series of straight-line elements, provided that the program has the capacity for dealing with sufficient elements (i.e. that  $n$  is large enough).

(c) A curved element of the side-drain may be not predetermined, e.g. rounding at the SSP may depend on a parameter, such as width or radius, which is affected by the difference in slope between the terrain and the outermost slope. This case cannot be dealt with directly by the locus method. A separate routine could be included in the program to amend the template by introducing rounding, after the specific side-drain template, consisting of straight lines, has been established by the locus method.

- (ii) Inability to relate two or more components of one type within a set

No provision is made for specifying

$S_i$  in terms of  $S_q$

$H_i$  in terms of  $H_q$

or  $V_i$  in terms of  $V_q$

e.g. the program cannot deal with conditions such as

$$S_i = -S_q$$

$$H_i = 2.(H_q)$$

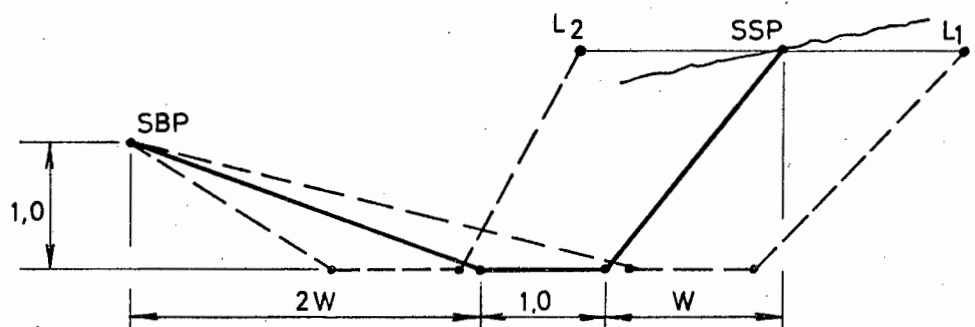
or  $H_i = H_q + W$

where  $i$  and  $q$  are elements of a configuration,

$W$  is a constant given by the user and

$S_i$ ,  $S_q$ ,  $H_i$  and  $H_q$  are otherwise undefined.

For example, a side-drain configuration as shown in Fig. 3.11 which requires the inside slope twice as wide as the outermost slope,



Inner Slope Width = 2 x (Outer Slope Width)

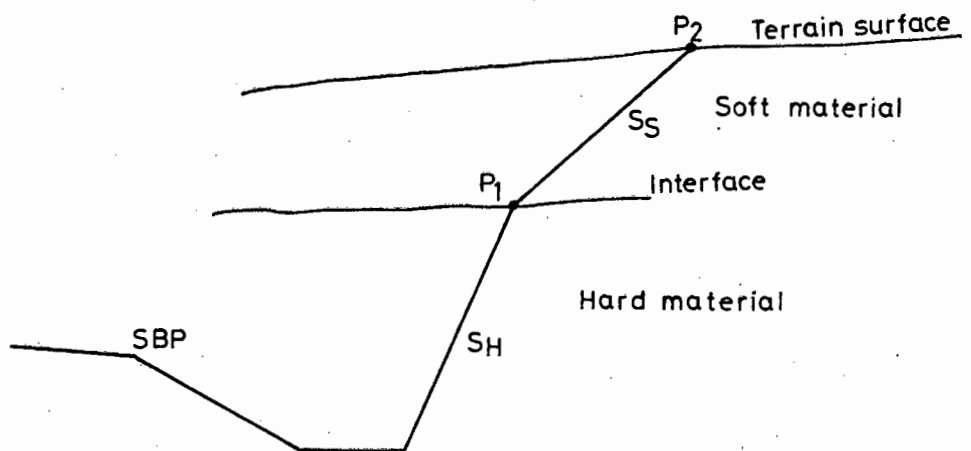
FIG. 3.11

cannot be dealt with by the locus method as described. The inclusion of the ability to deal precisely with this type of requirement in a general system would complicate the program considerably.

It must be stressed that many such cases can be approximated with sufficient accuracy by the existing locus method by using configurations as shown in Fig. 3.10(D) and (G).

(iii) Inability to adapt configuration to subsoil conditions

No provision is made for changing the value of a cut slope at the interface of different soils, if they vary in depth, as shown in Fig. 3.12. An approximation that can be achieved easily with the existent locus method



Change in Cut Slope at Material Interface

FIG. 3.12

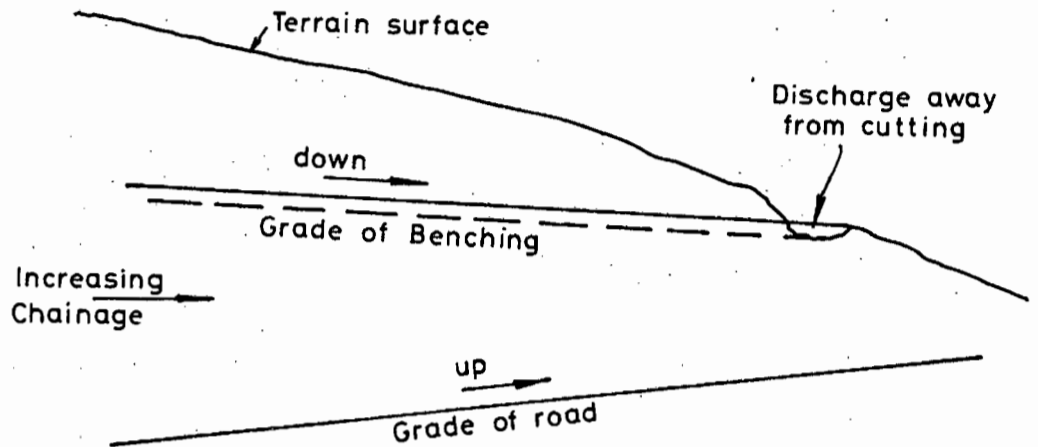
is to provide a configuration that has a change in cut slope at a fixed depth below the SSP; i.e.  $P_1$  is fixed relative to  $P_2$  (the SSP) and is unable to follow a variation in the depth of the interface. Different loci can be used for various ranges of depth of overlying material.

Precise solution requires:

- (a) A separate terrain cross-section for each interface to be dealt with.
  - (b) Fixing the intersection point  $P_1$ , as if it were the SSP, on the interfacial cross-section, by the locus method. Special constraints are needed to give the user control in selecting side-drain configurations depending on the depth of the overlying material.
  - (c) Extension of the side-drain template above  $P_1$  at the slope appropriate to the overlying material to intersect the upper surface at  $P_2$ , which is the true SSP.
- (iv) Inability to grade drainage structures independently

An aspect of side-drain design that is not directly dealt with by the locus method, is the control of the invert grades of drainage structures (ditches, benching) embodied in the side-drain, independently of the road grades or the terrain levels. For instance, passing out of a deep cut, the road may be on an up-grade while the terrain falls rapidly with

increasing chainage. Optimum drainage might require the benching to fall gently in the direction of increasing chainage, as shown in Fig. 3.13.



Benching graded independently of Road:  
Longitudinal Section

FIG. 3.13

If the levels of the drainage invert can be predetermined relative to the SBP, a new locus can be specified and called in at each station within the length of road requiring differently graded drainage. This, however, is most cumbersome and the user will run out of loci if the affected length contains more than a few loci.

---

q	side-drain element number
r	column number in matrix D
S	slope component, i.e. slope of element
\$	sum of all elements between points between k and (t-1)

## List symbols in chapter 3 (continued)

T	terrain point
t	side-drain point number
V	vertical component, i.e. vertical distance between the initial and concluding points of an element
W	constant
X	horizontal (transverse) co-ordinate
Y	vertical co-ordinate (elevation)

CHAPTER 4THE S H A R M PROGRAM4.1 DEVELOPMENT

During 1968, shortly after Ninham Shand and Partners had acquired a computer, a decision was taken to develop a new program for the computation of road earthwork quantities. The writer was entrusted with specifying the requirements to be met by the program, while the task of committing these demands into FORTRAN, and of fitting the bulky source program and large quantities of data into the available storage, was assigned to Roger Pilot. By March 1969 SHARM was in operation.

In subsequent years while debugging continued, various modifications and improvements of a minor nature were carried out by various members of the computer staff. In 1971, following the country-wide introduction of metrication, the conversion into the metric format, accompanied by a partial revision of some routines, was commenced. Desmond Walton was responsible for most of the recoding that had to be done. During 1972 SHARM was put into general use.

The SHARM system consists of 18 main programs, supported by 63 subroutine and function subprograms. It is written for the IBM 1130 Model 2B (8 K 16 bit words) computer operating under the Disk Monitor System, version 2, and is coded for the FORTRAN IV compiler using the IDEAL 1130 FORTRAN subroutine system and the IBM 1130 scientific subroutine package.

The reason for using IDEAL subroutines is explained in par. 4.2.

This chapter serves as an introduction to Appendices A, B and C, which present, in support of the thesis:

- A The SHARM user's manual
- B The flow diagram of the portion of the system dealing with the determination of the side-drain template
- C The coding of the portion of the SHARM programs dealing with the determination of the side-drain template.

#### 4.2 IDEAL subroutines : ref. (11)

Basic FORTRAN IV has some shortcomings that inconvenience the inputting of extensive data of the type required for a road earthworks program. Such difficulties are:

- (a) The format of input data must be programmed into the computer before the data is read.
- (b) Alphameric data cannot be used as a variable.
- (c) A blank field of input data cannot be "read".

An essential part of the locus method is the differentiation between a blank (i.e. undefined value) and a defined value that may be zero. (Note : CEP-HIDES, par. 2.2.6, requires the entry of "a rather small value, very close to zero, e.g. 0,0001 when the input value is to be zero.")

The use of IDEAL subroutines overcomes the above problems since:

- (a) The format can be determined, after the data has been read, in accordance with a variable contained within that line of data.

- (b) Alphamerical codes can be used in control statements.
- (c) Blank fields and zeros can be correctly interpreted.

In addition the IDEAL subroutines allow the "packing in" of data, thereby conserving valuable storage.

On the other hand, the use of IDEAL subroutines complicates the coding and lengthens the source program. In spite of this, and although the points (a), (b) and (c) could be overcome, albeit less elegantly, by straight FORTRAN, it was decided to give the greatest possible benefit directly to the user. The engineer, freed of normal FORTRAN requirements, is able to dictate concise input and explicatory output formats and codes as he wishes, without using special control cards.

## 4.3

THE CAPACITY OF THE S H A R M SIDE-DRAIN ROUTINES

Provision is made for storing a maximum of 12 locus types for a run. These are called in as required, left and right sides of the road being treated separately or together.

Each locus provides a maximum of 12 locus-lines. Locus-lines are used in the sequence and direction specified to find an acceptable SSP. The rejection of a potential SSP if the terrain slope at that SSP is not as required, allows an alternative SSP or side-drain configuration to be selected.

Each side-drain configuration consists of 5 elements, but since the H and V components for any element may both be zero, one or more side-drain points can be coincident, and any number of effective elements up to 5 may therefore be used.

The available capacity as described above has in general been found adequate, but requests for enlarging the number of locus-lines per locus and the number of elements per configuration have been received. The former can be achieved easily, in effect by doubling up the number of locus-lines and halving the number of loci per run. Increasing the number of elements, on the other hand, involves revision of a number of DIMENSION and Control statements, and the provision of additional storage capacity.

#### 4.4 FURTHER DEVELOPMENT OF S H A R M PROGRAM

As stated in par. 4.1 above, improvements are continually being incorporated, often upon the suggestions of various users.

For instance, an option is being introduced whereby 6 locus types each having 24 locus-lines may be used in a run, instead of 12 locus types having 12 locus-lines each.

Much work is at present being done on the preparation of graphical plotting routines for presenting longitudinal profiles of terrain centre-line and proposed grade-line, mass-haul diagrams, terrain cross-sections and road templates.

Other general features that may be considered for inclusion in the program in future are:

- (a) Independent grade-lines for left and right carriageways for dual carriageway roads. At present separate grade-lines can be handled to a limited extent but the method is cumbersome.
- (b) Flexibility in accommodating a multitude of median designs for dual carriageway roads, with the provision for independent grading of the median ditch.

- (c) Calculation of areas and volumes of top soil stripped from construction areas.
- (d) Calculation of slope areas of cut and fill banks, for seeding purposes.
- (e) Calculation of volumes of top soil spread on side-drain slopes for grassing (or frost-protection in cold climates).
- (f) Calculation of road reserve boundary coordinates on the national survey grid, based on the slope stake points and allowing for an undeveloped verge.

Three aspects concerning the design of the side-drain that warrant further development are:

- (g) The provision of a greater maximum number of side-drain elements per configuration, i.e. say 9 instead of 5.
- (h) The incorporation of a routine for changing the cut slope at the interface of different subsoils (see par. 3.5(iii)).
- (i) The ability to cut off a long shallow fill by a retaining wall of economical height, when the terrain slope is nearly equal to the steepest fill slope allowed.

CHAPTER 5A SAMPLE RUN ON THE S H A R M PROGRAM

The facilities of the SHARM program are demonstrated by a hypothetical set of input data which has been compiled and processed through the computer.

The input data sheets and the print-outs of the Terrain Edit, Grade-line, Locus Edit and Quantities runs are reproduced in Appendix D.

5.1 SELECTION OF DATA

A hypothetical set of data has been used because no normal job is likely, within a reasonable length of road, to call on the full range of facilities available. Furthermore, the checking and comparison of results are simplified by selecting particular values for stations, terrain levels, road templates, and other selected data. Changes in parameters have been separated from one another by spreading along the length of the job, so that individual effects can be studied by the reader.

Even by using hypothetical data, this run is yet only a sample, as it is impossible to demonstrate exhaustively the full range of possibilities. The unusual cases shown in par. 3.4 indicate the facility of the method of the locus of the slope stake point. Many other arrangements are feasible. The sample selected here for numerical demonstration suffices, as the solution of other types of template is executed in a similar way.

## 5.2 FACILITIES USED

The following facilities have been applied:

### General

Title

Broken Chainage (overlapping type)

### Terrain

Cross-sections by staff readings and by reduced levels

All programmed error messages are tested in the Terrain Edit print-out (Cross-sections having invalid data are excluded from the remainder of the sample run).

### Grade-line

Vertical curves, with and without intervening straight grades

Kinks in grade-line

Grade-line adjustment

Levels at regular intervals and at selected chainages

### Template

Single carriageway template

Transitioned widening and superelevation

Side-drain template

Locus type 1 is the example used in the SHARM user's manual (see Fig. 11.1 in Appendix A). (The detection of an error in the input data for the set of components for locus-line no. 5 is shown).

Locus type 2 represents the National Roads  
Batter Policy of the Division of National  
Roads (see Fig. 2-105.3(1) in ref. (6)).

Materials Design Layers

Centre-line shift

Quantities

Bulking factor

Gap

Borrow-to-fill

Continuation volumes

CHAPTER 6CONCLUSION

The SHARE program was used regularly during the years 1969 to 1972. Since the inception of the metric version in 1972, use of the original program has fallen off, but the SHARM program is now used frequently in several consulting engineers' design offices. It is estimated that about 1 400 km of rural roads and 150 km of urban streets have been processed during 5 years by these programs. Rural roads have involved runs of up to 120 km. Urban jobs usually consist of a batch of short streets, requiring frequent parameter changes.

These figures show that substantial use is made of programs employing the locus method. The locus method is being applied effectively. Various suggestions for improving the SHARE - SHARM program have been made by experienced users. However, no suggestion reflecting a basic incapability in dealing with side-drains by the locus method has been received.

It is suggested that the concept of the locus of the slope stake point (i.e. what happens to the slope stake point under various cut and fill conditions) be borne in mind, during the drawing up of new specifications. Standard templates, thus drawn up, are likely to be sound, and present a rational engineering design. It has been used in this way by engineers in the Division of National Roads of the Department of Transport in drawing up the National Roads Batter Policy (1971), where the term "slope stake locus" has found official recognition (see Fig. 2-105.3(1) in ref. (6)).

In chapter 1 the determination of side-drain templates is shown to be an essential part of any road earthworks program. Several computer routines, investigated in chapter 2, are unable to select diverse side-drain templates satisfactorily. On the other hand, computer programs based on the locus method are able to calculate a wide range of template types accurately and in accordance with most of the user's various demands.

As indicated in par. 3.3, the method of the locus of the slope stake point, as it stands, can be incorporated in a new or re-worked road earthworks program. Meanwhile, the development of efficient routines to overcome the limitations listed in par. 3.5, is warranted.

In order to build better roads, highway engineers will continue to strive after the optimum compromise between the conflicting interests in construction. In a comprehensive optimization process, they will consider

the effect of the characteristics of the soils,  
encountered on the routes, on the construction  
of the road,

the effect of alternative routes on environmental  
conditions,

the effect of various horizontal and vertical align-  
ments on driver and vehicle behaviour,

and the effect of the cost structure (e.g. land acquisition  
vs. earthworks) on route location.

Computers are well suited to assist in this process. It is probable that larger programs will be written to enable computers to carry out this procedure of selection, as envisaged in Fig. 1.4.

The use of the method of the locus of the slope stake point in road design systems, yet to be developed or adapted to provide automatic optimization, is clearly indicated.

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# SHARM

## SHAND ROAD EARTHWORKS PROGRAM

### METRIC VERSION



### USER'S MANUAL

S H A R M

Shand Road Earthworks Program  
(Metric Version)

Developed by  
G. Keuck and R. Pilot

NINHAM SHAND AND PARTNERS  
Consulting Engineers  
Cape Town

Program Managed by  
Engineering Computing Company  
Cape Town

U S E R ' S M A N U A L

Updating: A distribution list is maintained by Engineering Computing Co. (ECC) and as revisions are made to the program, updated pages or sections will be distributed to all recipients of this write-up. Kindly keep ECC informed of any change of address. If you have no further use for this write-up, kindly return it to ECC.

Suggestions: The authors welcome suggestions to improve the write-up or any other aspect of the program.

Disclaimer: Although the program has been tested, no warranty, expressed or implied, is made by the program owners as to the accuracy and functioning of the program and related material, nor shall the fact of distribution constitute any such warranty, and no responsibility is assumed by the owners for any damages whatsoever, including consequential damages, arising from the use of the program.

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SECTION 1SHARM: Shand Road Earthworks  
(Metric Version)GENERAL INTRODUCTION

1.1 PURPOSE: To check ground data, and produce grade-line and accurate earthwork quantities, for single and dual carriageway roads or similar earthwork jobs.

1.2 CAPABILITIES:

Input:

Ground surface cross-sections (given by reduced levels or unreduced staff readings), easily modified grade-line, broken chainages, various types of road surface and side-drain templates, logic-test limits, centre-line shift, gaps, bulking, borrow and spoil, materials design layers.

Output:

- (1) Edited list of ground data.
- (2) Grade-line print-out (independent and optional).
- (3) Earthwork Quantities, listing chainage, grade-line level, slope stake point distances, areas of cut and fill, and 11 columns of volumes (cut, fill, cross-haul, materials design layers, mass diagram, etc.), at each cross-section.

(Print-out of geometric details of road templates and plotting routines for longitudinal and cross-sections and templates, grade-line, and mass diagram are being developed at present).

1.3 RESTRICTIONS: No allowance is made for the cosine of angle between centre-lines of ground data and finished road if not parallel, nor for change in length of lines that are offset from centre-line on horizontal curves.

1.4 THEORETICAL BASIS OF CALCULATION:

Parabolic vertical curves.  
Volumes by average end areas.  
Metric units.

1.5 REMARKS: The automatic and accurate design of the side-drain template is controlled by the locus of the slope stake point.

All parameters can be changed ad lib. and independently of any other factor along the length of the job.

It is a clear and versatile system, not restricted to any specific type of design, and does not contain unnecessary internal restrictions. On first perusal of this write-up it might appear that this system is rather complicated, or too tedious for easy use, particularly if the potential user has a relatively plain road in mind. It must therefore be made clear that certain sections might not apply to a particular job at all, and are left out entirely. Other bits of information that are required by the program but, being irrelevant to the job on hand, are disposed of quickly by being given the value zero. Elaborate provision has been made for changing parameters and factors etc., along the length of the job during a run, but this obviously falls away if not applicable. The program has been drawn up to provide as many facilities as possible for use when required without encumbering data preparation for a simple job.

SECTION 2PRESENTATION OF INPUT DATA

- 2.1 Before starting on the preparation of data, it is suggested that the Engineer reads through this Section, Presentation of Input Data and Section 3: Definitions and General Data, and glances through the initial paragraphs of all other sections. Each section can then be studied in detail when its use becomes necessary. If any part of the write-up or the program is not understood by the Engineer, he is advised to get clarification from ECC before proceeding with the preparation of input data.
- 2.2 Care is required while reading to differentiate between options and obligations. The instructions embodying "may", "should", "can" etc. indicate optional treatments, neither of which would disrupt the running of the program, although it may be preferable to use a particular form of treatment. Explicit instructions using "must", "shall", "is required", "is necessary" etc. have to be carried out exactly as required.
- 2.3 The data describing the road and its design is prepared by the Engineer and his staff by entering each type of data as a set, on its own input data sheets. From the input sheets, one card per line of data is punched and verified by ECC. Standard Input data sheets showing the fields for all types of data are available upon request from ECC. Samples are included with each section in this write-up.
- 2.4 To avoid errors, most of which are costly, it is necessary that writing-up of data be done clearly and legibly, and checked by the client before sending in for punching. A soft pencil (HB) should be used and any erasures should be done clearly and completely and carefully re-written.

- 2.5 When a fixed value in a particular field is repeated on subsequent lines, it must be written out in full every time. Ditto signs and squiggly arrows may be misunderstood.
- 2.6 Except for the letter code, which is preprinted in column 1 of each line, the title card and the broken chainage capital "B" where required in the chainages, all data will consist only of "1 2 3 4 5 6 7 8 9 0 -" and blanks. Where letters are used, these must be in capitals. Some handwritten digits and letters can be confused; therefore they must be written as follows:

Digit	Letter
-------	--------

0	ø
---	---

1	I
---	---

2	Z
---	---

5	S
---	---

- 2.7 Care must be taken in leaving a field blank or inserting zeros depending on which is required. The computer places different interpretations upon these.
- 2.8 An important rule is that for each set of data the chainages must be arranged in increasing order.
- 2.9 In reading-in data the computer carries out a number of tests so that errors may be eliminated before the run. In the event that an error message is given, reference will be made to the Engineer, and the edit print-out and/or the input data sheets will be returned to him for correction of all unacceptable data, and of individual figures that, although acceptable to the computer, are found to be in error. The Engineer, i.e. Client, is held responsible for all costs incurred as a result of incorrect data, other than is allowed for in the edit runs as detailed in the price-list. He is therefore advised that in the event of any uncertainty with regard to filling in of input data, he should get clarification from ECC.

- 2.10 At any stage while work is proceeding on one job, input data might have to be modified between runs as a result of re-design or an alternative design required by the Engineer. This is done by manual replacement of the punched input data cards. When instructions are given by the Engineer, modified lines must be clearly marked by a red pencil in the left margin with a "D", "A" or "I" to indicate respectively a deletion, alteration or insertion. Corrections to data which has already been punched, must similarly be marked by a red "C".
- 2.11 The end of each set of data must be indicated on the input data sheets by ruling through the line immediately following the last line which has to be punched.
- 2.12 As the preparation of input data for the terrain cross-sections is usually a lengthy item, and as this data is often available before the rest of the road design has been finalized, it is suggested that the terrain cross-section be sent through for punching and editing, possibly in batches if the job is long, before the rest of the data is available. This gives time for proof-reading and correcting errors.
- 2.13 Upon the completion of a run the input data sheets are returned to the client, and input data cards may be stored by ECC at client's risk or returned to the client at his request. The client is advised to keep a copy of the input data sheets when sending these in for punching, as all handling and storage of input data sheets and data cards by ECC is at client's risk.

2.14 Three types of run may be executed, i.e.

Terrain Edit

Grade-line

Quantities

The outputs are described in Sections 7, 9 and 16 respectively. Table 2.1 summarizes the input data.

Des- cribed in Section	Type of Data	Card Code in Col.1	Maximum Number of Cards per Run	Input Data Required for		
				Terrain Edit Run	Grade Line print- out	Quan- tities print- out
				C = Compulsory O = Optional		
5	Title	A	1	C	C	C
6	Broken Chainages	B	9	O	O	O
8	Grade-line VPI's	C	398		C	C
8	Grade-line Adjust- ment	D	*		O	O
10	Road Surface Template Types	E	108			C
11	Side-Drain Locus Types	F	*			C
11	Side-Drain Components	G	*			C
10	Road Surface Template Calls	H	230			C
11	Locus Calls	I	108			C
12	Materials Design Layers	J	60			C
13	Bulking Factors	K	109			C
14	Centre-line Shifts	L	62			O
15	Gaps	M	20			O
15	Cut-to-spoil and Borrow-to-fill	N	25			O
15	Continuation Volumes	P	1			O
9	Grade-line Intervals	V	79		O	
9	Grade-line Start-stop	W	1		C	
9	Chainages at which levels are required	X	*		O	
7	Terrain Edit Para- meters	Y	1	C		
7	Terrain	Z	*	C		C

D \* Unlimited, except by the number of VPI's.

F \* Maximum 12 loci per run and maximum 12 lines per locus.

G \* Number of G data lines = number of F data lines.

X \* Unlimited.

Z \* Unlimited.

Table 2.1

SECTION 3DEFINITIONS AND GENERAL DETAILAlphabetical Index

Blank	7	Modification of Input Data	42
Broken Chainages	18	Negative Chainage	21
Card	4	Offsets	23
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Engineer	2	Set	13
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Instantaneous and Transi- tional changes of Para- meters	40	SSP	38
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		VPI	27
		Zeros	10

- 3.1 NOTE: It is desirable that a word or phrase should be used in only one context; also, that only one word or phrase should be used for a particular description, item or meaning. The following usages have been standardized for this write-up. The fundamental ideas are stressed by being underlined.
- 3.2 ENGINEER: The client who makes use of the program to assist him in his design and measurement calculations. He is responsible for the preparation and accuracy of the input data.
- 3.3 LINE OF INPUT DATA: Consists of 80 columns. It contains one or more fields, possibly interspersed with blank columns. As many lines as convenient are entered on one sheet of the input data.
- 3.4 CARD: One line of input data is punched onto one card. "Card" and "Line of Input Data" are synonymous as far as the Engineer is concerned.
- 3.5 COLUMN: (Abbreviated: Col.) A single space containing a single character, or being blank, on an input data line or card. There are 80 columns to an input line or card.

- 3.6 FIELD: A field consists of one or more columns. Each individual but complete parameter, value, number or code is entered into its own field. Certain fields may remain blank as instructed.
- 3.7 BLANK: A column space or a complete field on the input data that does not contain any information. Its presence is indicated in this write-up by the use of the lower case "b", which must not be inserted on the input data sheets.
- 3.8 DECIMAL POSITION: The position of the decimal point is shown between two columns on the input data sheets, i.e. the decimal point is not given a column.

Significant digits must appear in their correct columns in relation to the decimal position. The Computer inserts leading or following zeros where necessary, when one or more digits have been given in the field.

- 3.9 SIGNS: When a negative value is given in the input data, a - sign must be placed immediately to the left (in front) of that value; no blank spaces may intervene. Leading zeros may be inserted between the - sign and the significant figures. When a positive value is given, no sign is used. The + sign may not be used at all in the input data.
- 3.10 ZEROS: Leading zeros to the left and following zeros to the right of the significant digits may be omitted (left blank) in the input data. Significant zeros contained within the value must always be given. A parameter that has a fixed value of zero, must have at least one zero entered in its field. A parameter that is not being defined in the input data may not have any zero in its field, but it must remain blank.
- 3.11 JOB: A job consists of one or more runs. The whole job is based on one line of continually increasing chainages (allowance for broken chainages) and it is based on one datum for all its elevations.
- 3.12 RUN: A run may cover the whole or any section of a job and may overlap with earlier runs. It is dealt with in its entirety "at one go" by the computer. All data applicable to the section being run must be available. Input data may be modified as necessary between runs. The terrain data edit and earthwork quantities programs run from the first station to the last station on the section of road selected for that run. If a job is broken down into successive runs, each starting at the end of the previous run, the last station of the previous run should be duplicated as the first station of the following run, to ensure continuity of terrain editing and quantities. If a later run goes continuously through from before this station to beyond it, one copy of the duplicated station must be removed from the terrain data. The grade-line print-out runs from the start chainage to the stop chainage specially given. For each run, all grade-line and parameter data must be available at or before the start chainage

and up to, or beyond the stop chainage; data lying outside the section and which is superfluous to these runs need not be removed from the data files, as it is ignored.

- 3.13 SET OF DATA: Consists of only one type of data, i.e. the letter code in column 1 is the same for the complete set. For each run all data of one type must be presented as one continuous set.
- 3.14 LIMITS TO QUANTITY OF DATA: The minimum and maximum number of entries of each type of data that may be used for one run are indicated. The types of data that are shown as having a minimum quantity of zero, are optional and may be left out entirely.
- 3.15 STATION: A point defined by its chainage at which a cross-section of the terrain is available.

The computer derives the road template from the grade-line level at the chainage of the station, calculates areas, prints out quantities and template co-ordinates and plots the terrain cross-section at the station, having calculated the earthwork volumes between adjacent stations. A station may be at an intermediate chainage.

- 3.16 TERRAIN: The original ground surface. As the terrain cross-section is often by nature an irregular line, it is generally represented in the sketches in this write-up by a free-hand line, although it is dealt with by the program as a series of straight lines joining discreet points.
- 3.17 CHAINAGE: This defines the position of a point or station along the length of the road. The computer calculates the distance between two points by finding the true difference in the chainages, allowing for amendments due to broken chainages. Where required at overlapping Broken Chainages, the capital letter "B" is an essential and integral part of the chainage.
- 3.18 BROKEN CHAINAGES: A discontinuity in the regular progression of chainages. See Section 6: Broken Chainages.
- 3.19 ROUND CHAINAGE: A chainage consisting only of an integral (whole) number of regular staking intervals. The right-hand following zeros may be omitted in the input.

- 3.20 INTERMEDIATE CHAINAGE: A chainage lying between two adjacent round chainages.
- 3.21 NEGATIVE CHAINAGE: This is acceptable. A negative sign must be placed immediately to the left of the kilometres, (not in the B-column) thereby limiting the value to -99.99999 km. The negative sign applies to the full value including the decimal portion.
- 3.22 LENGTHS: (i.e. vertical curve lengths, transition lengths, etc.) are measured horizontally, along the terrain centre-line. The true distance must be given, including the increase or decrease in length through a broken chainage.
- 3.23 OFFSETS: are measured at right-angles to the centre-line, horizontally or vertically.
- 3.24 ELEVATION: The reduced level of a point. All elevations are referred to one fixed datum which must remain constant for all data for the whole job. The datum may be chosen to ease preparation of data and need not be sea-level. Negative elevations (limited to -999.999 m) referring to the same datum may be used. The -ve sign applies to the full value including the decimal portion.
- 3.25 PROFILE: A longitudinal section of the terrain, grade-line etc., along the direction of the road.
- 3.26 GRADE-LINE: A profile consisting of straight-line grades, connected by vertical curves or by kinks. It is designed by the Engineer defining the VPI's. The elevations of the road template are determined from the grade-line, which need not lie on the finished road surface, i.e. the grade-line is the vertical origin of the road template.
- 3.27 VPI: Vertical Point of Intersection. The intersection of two adjacent straight grades (produced, if these grades are connected by a vertical curve).
- 3.28 VERTICAL CURVE: A parabolic vertical curve connecting two adjacent straight grades. The beginning and end of the vertical curve are respectively positioned horizontally one half of the vertical curve length before and after the VPI.
- 3.29 GRADE: Only applicable to the grade-line. It is given as 
$$\frac{\text{vertical difference} \times 100}{\text{horizontal longitudinal difference}}$$
. +ve is up, with increasing chainage.
- 3.30 SLOPE: Only applicable to cross-sections and templates (i.e. at right-angles to the centre-line). It is given as the natural ratio of 
$$\frac{\text{vertical difference}}{\text{horizontal transverse difference}}$$
. +ve is up, away from the centre-line.

- 3.31 TEMPLATE: A section lying at right-angles to the centre-line of the road, defining the finished road surface, materials design layers, median and/or side-drain. It refers to all or part of the geometrical layout of the road cross-section between the SSP's, but not to the terrain cross-section.
- 3.32 SUPERELEVATION: For the treatment of superelevation see Section 10: Road Surface Templates.
- 3.33 ROAD SURFACE TEMPLATES: That part of the finished road surface that lies between the template centre-line and the SBP, including a section of the median in a dual carriageway road. A parking strip, side-walk or channel of a shape which is not affected by terrain conditions could also be included in the road surface template. Road surface data for the left and right sides are treated independently.
- 3.34 SIDE-DRAIN: That part of the template that lies beyond the SBP up to the SSP. It includes the side slopes in cut or fill and any ditch that may be required. When a locus of the SSP has been specified, the shape of the side-drain is determined by the position of the SBP relative to the terrain cross-section. Left and right side-drains are treated independently.
- 3.35 TEMPLATE CENTRE-LINE: The horizontal origin on which the road template is based. If a horizontal centre-line shift (see Section 13) be made, the template centre-line is shifted relative to the terrain centre-line, after which, template offsets are referred to the terrain centre-line.
- 3.36 TERRAIN CENTRE-LINE: A longitudinal line on which the terrain cross-sections are based, and along which differences in chainages give true distances.
- 3.37 SBP: Shoulder Break Point. The outermost point of the finished road surface which is independent of terrain conditions and is determined by the grade-line, horizontal offset shift and the road surface template. Beyond the SBP the template is also determined by terrain conditions.
- 3.38 SSP: Slope Stake Point. The outermost point of the road template. It always lies on the terrain cross-section, produced where necessary.
- 3.39 LOCUS OF THE SSP: The path traced out by the SSP as it is determined by the complete range of varying terrain configurations in accordance with the Engineer's design. (See Section 11: Side Drain Templates).
- 3.40 INSTANTANEOUS AND TRANSITIONED CHANGES OF PARAMETERS: The horizontal centre-line shift and the horizontal and vertical offsets of the road surface template can be changed transitionally. All other parameters in the program must be changed instantaneously. When a transition length is

given, the parameter is varied linearly over this distance, to give the value of the parameter at any station(s) that may fall within the transition length. A station at the chainage at which a transitioned change is called, is calculated on the previously existing parameter. A station at, or more than, the transition length beyond the calling chainage, is calculated on the parameter which has just been called. When a transition length is given, it is not necessary that any stations actually lie on it.

These parameters may also be changed instantaneously by giving the transition length as zero or leaving it blank.

When a parameter is changed instantaneously, a station lying before the chainage at which the parameter is changed, is calculated on the previously existing parameter. A station at or after the chainage is calculated on the newly given parameter.

Note: The word "instantaneous" is not quite accurate, because there is a "smoothing-off" effect in calculating the volumes. The templates and areas are calculated strictly according to the above rules but, by using the method of average end-areas to calculate volumes, the effects of the previous and the new parameters are combined. For instance, a new bulking factor is actually applied over the full distance between two stations irrespective of whether it is introduced instantaneously just after the first station, anywhere between the stations, or exactly at the second station. However, this "smoothing-off" effect can be eliminated, and a true sudden change achieved, by providing two stations which are positioned at two chainages, 0,01 m apart, and bringing in the instantaneous change in parameter on the chainage of the second station. These two stations (repeating a terrain cross-section that has been derived, if necessary, by interpolation by the Engineer) must be given when the terrain data is prepared.

Cut-to-spoil and Borrow-to-fill, when applied over a given length, are not "smoothed-off" at the ends, but the true volumes are added to the mass diagram ordinates at the appropriate stations.

- 3.41 CORRECTION OF INPUT DATA: Elimination of unacceptable data and individual figures that are found to be in error in the input data.
- 3.42 MODIFICATION OF INPUT DATA: This is necessary when the Engineer requires a revised design or an alternative design.

SECTION 4UNITS, CAPACITY AND PRECISION

- 4.1 Units, capacity of input and output fields and precision are set out in Table 4.1.

Item	Unit	Input(I) and/or Output(O)	Capacity	Pre- cision
Chainages	kilo- metres	I,O	-99,99999 (+)999,99999	0,00001
Lengths, horizontal offset and widths	metres	I,O	as necessary	0,01
Vertical offsets, staff readings, elevations, heights, depths, etc.	metres	I,O	as necessary	0,001
Grades	%	O	(±) 99,9999	0,0001
Slopes	natural	I	-99,99 (+) 999,99	0,01
Bulking Factor	%	I,O	999	1
Areas	square metres	O	9999,9	0,1
Volumes	cubic metres	I,O	as necessary	1

Table 4.1

- 4.2 Precision: Calculations carried out by the program are usually precise to 7 or 8 digits and this precision is maintained through subsequent calculations. Immediately before print-out the figure is rounded up (if the rejected figure is 5 or more), or truncated, to give the print-out precision.
- 4.3 Road Surface Template: The difference in elevation of the highest and lowest points of a finished road surface template, both sides taken together and including the grade-line and both SBP's but excluding the side-drains, may not exceed 32,767 metres.

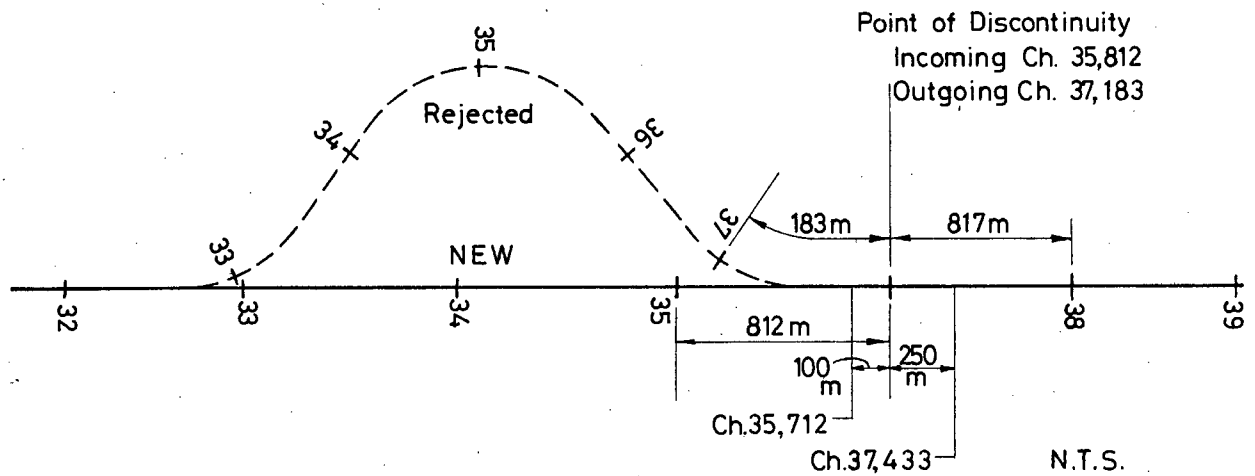


SECTION 6BROKEN CHAINAGES

(Refer to Card B : Broken Chainages)

- 6.1 The term "broken chainage" refers to a discontinuity in the chainages along the length of the road. This occurs usually when a section of the road has been realigned. The program can deal with up to 9 separate broken chainages per run. If there are no broken chainages for the job to be run, no data is required.
- 6.2 The broken chainage data must be stored in the computer before the terrain data edit, grade-line and quantities runs. It is essential to establish all broken chainages before proceeding onto terrain data, vertical profile and design parameters.
- 6.3 Wherever a broken chainage occurs, one point of discontinuity must be selected, at any convenient position in the vicinity. The data is recorded by equating the incoming and the outgoing chainages at this point of discontinuity. The incoming chainage at a point is the chainage of that point according to the preceding system of chainage; similarly the outgoing chainage refers to the chainage system following the point of discontinuity.
- 6.4 If the outgoing chainage is more than the incoming chainage at the point of discontinuity, it is the "short-fall" type of broken chainage.
- 6.5 If the outgoing is less than the incoming chainage, it is the "overlapping" type of broken chainage, and a block of chainages lying between these two values will be repeated. Wherever reference is made within this job to the 2nd section (i.e. from the point of discontinuity onwards) a capital "B" must be inserted in the B column of the chainage. This applies to all data, i.e. terrain, grade-line, parameters, etc.
- 6.6 The computer will make allowance for the loss or gain in length when calculating grades or quantities, etc. across the broken chainage.

- 6.7 Important Rule: The outgoing chainage (ignoring a prefixed "B", if such be present) at a broken chainage must always be greater than the incoming chainage at any previous broken chainage.
- 6.8 Fig. 6.1 shows an example of a short-fall type of broken chainage.

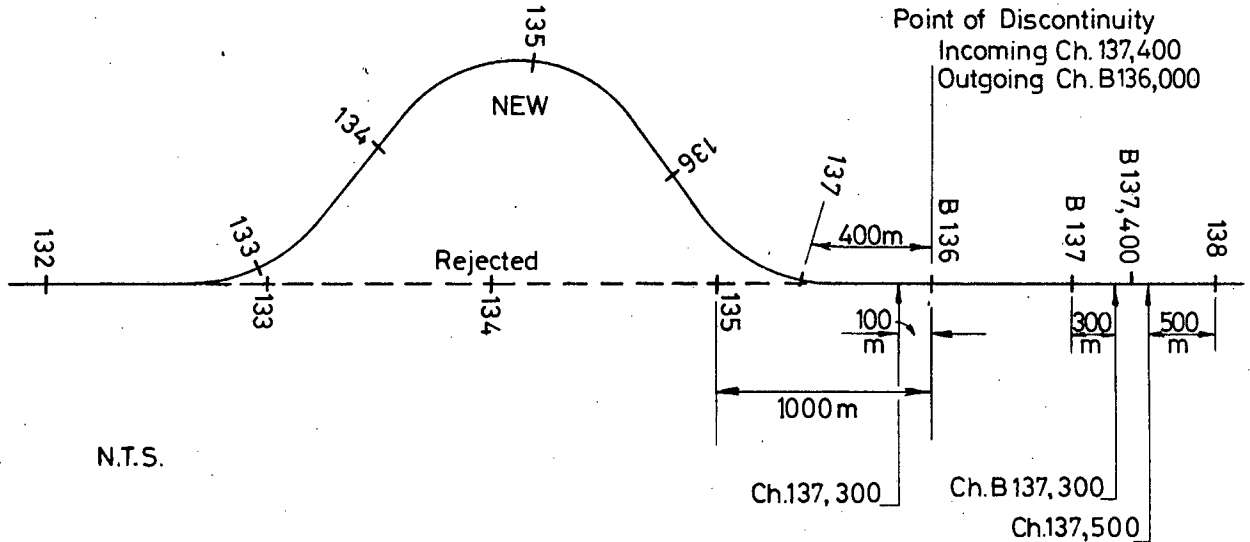


### BROKEN CHAINAGE (Shortfall type)

FIG. 6.1

Note: No chainages between incoming chainage 35,812 and outgoing chainage 37,183 may be used on this job (Fig. 6.1), unless prefixed with a "B" when used with another broken chainage. (See Fig. 6.3 below).

6.9 Fig. 6.2 shows an example of an overlapping type of broken chainage.



BROKEN CHAINAGE (Overlapping type)

FIG. 6.2

Notes: The following are valid chainages in this example, Fig. 6.2, given in sequence increasing along the road:

- 135,000
  - 136
  - 136,100
  - 137,300
  - 137,399
  - 137,400
  - B 136
  - B 136,100
  - B 137,400
  - 137,40001
  - 137,500
- These two figures are the same point. There is no distance between them. Either may be used for this point, at any time in this job.
- The distance between these two points is 0,01 m

The distance between ch. 137,400 and ch. 137,40001 is 1400,01 m. Chainages of less than 136,000 and more than 137,400 may not be prefixed with a "B" in the B column, except when used with another broken chainage.



SECTION 7TERRAIN CROSS-SECTIONS

(Refer to Cards Y : Terrain Edit Parameters  
Z : Terrain).

- 7.1 The terrain cross-section at a station is defined by a series of points along a line lying at right-angles to the previously fixed terrain centre-line. These points are fixed by giving their horizontal offsets measured from the terrain centre-line and their elevations. Cross-sections may be taken with sufficient width so that minor relocations of the horizontal alignment of the proposed road may be made (see Section 14: Centre-line Shift).
- 7.2 The points at a station must be listed in sequence from left to right. Horizontal offsets to the left of the terrain centre-line are negative. At least one point to the left and one point to the right of the centre-line are required at a station. A terrain point on the centre-line is optional; if not given, the computer will linearly interpolate the elevation on the centre-line when this is required later. If the given cross-section does not extend outwards far enough to meet the road template, the computer will extrapolate the slope between the last two points on that side as far as necessary. Horizontal offsets for adjacent points must increase from left to right i.e. vertical walls and overhangs are not allowed. Adjacent points may be at the same level.
- 7.3 The number of terrain cross-sections that may be submitted for one run is unlimited. Any number of points to a maximum number of 20 may be given at a station. Up to 9 lines may be used per station and any number of points up to 5 may be given per line even when there are subsequent lines to complete this station.

7.4 The elevations may be given in 2 types:-

- (a) Reduced levels above datum (Code 2 in Col. 2).
- (b) Unreduced staff readings with a height of collimation above datum (Code 1 in Col. 2).

7.4.1 At any station either or both of these types may be used. Only one type is applicable to each line. It is permissible at any station, to give some points as reduced levels and some as staff readings. If this is done a new line is required as the data changes from one type to the other. Three types of data sheets are available: one for reduced levels only (the 2 in column 2 is preprinted), one for staff readings only (the 3 or 1 in column 2 is preprinted), and one if both forms are to be used (in this case, the code in column 2 must be inserted by the user, and care is required in filling in the data in the correct columns according to the fields as shown in the applicable heading).

7.4.2 Every line giving staff readings must have a height of collimation inserted and this height of collimation must apply for all staff readings on that line. Consecutive lines may use the same or different heights of collimation.

7.5 When more than one line is used per station, column 80 of each line is numbered in descending order starting with the total number of lines for that section (e.g. if three lines are used, the first, second and third lines will be numbered 3, 2, 1 respectively). If only one line is used, a "1", is filled in in column 3.

7.5.1 If more than one line is used per cross-section, the station chainage must be repeated on each line.

7.6 Each line must be completed from the left, without leaving blank offsets before the last point for that line has been given. The computer reads the cards from left to right and as soon as a blank offset is encountered, the next card is read. Therefore any point on the right of a blank field will be ignored. IMPORTANT: For this reason, the horizontal offset of a point on the centre-line must be filled as 0,0 and not left blank.

- 7.7 A thorough editing routine is carried out on the terrain cross-sections to spot errors that would disrupt the computer run and to highlight possible errors by logical testing.
- 7.8 In the terrain edit print-out, each line containing an error, or possible error, is terminated by the error message code, as follows:

(An asterisk denotes unacceptable terrain data which must be corrected; the other codes indicate either errors in terrain data or valid data that exceeds the test-limit).

A*	Denotes	Chainages not increasing.
B*	"	Horizontal offsets not increasing from left to right.
E	"	Distance between two stations exceeds E metres.
F	"	Difference in elevations of adjacent points at a station exceeds F metres.
G	"	The average of the maximum elevation and the minimum elevation calculated at a station differs from the similarly averaged elevation at the previous station by more than G metres.
H	"	Outermost point less than H metres from centre-line.
J	"	Slope between two outermost points on the one side exceeds J vertical in 1 horizontal.

- 7.8.1 E, F, G, H and J are test parameters that are selected by the engineer for each edit run. The type of terrain should be borne in mind when selecting these parameters so that by keeping them as small as possible, the testing is as thorough as possible. On the other hand, the parameters should be large enough so that only very occasionally is valid data highlighted by the error message. If there are no error messages of a particular code, that parameter should have been smaller. If there are more than about 1 or 2% of all stations which have been highlighted but that are, in fact, correct, the parameter could be increased somewhat to reduce





SECTION 8GRADE-LINE

(Refer to Cards C : Grade-line VPI's  
D : Grade-line Adjustment).

- 8.1 The grade-line of the road is determined by the chainage and elevation of the vertical points of intersection (VPI's) and the length of vertical curve at each of these points. The grade-line determines, at any required chainage, the elevation of the origin of the road template.
- 8.2 All VPI's that are required for the grade-line print-out or quantities run, including those before the start chainage or beyond the stop chainage, are stored in the computer before the run and are called upon when the grade-line level at any point is required. The maximum number of VPI's for one run is 398.
- 8.3 The length of a vertical curve may be 0, i.e. a kink or instantaneous change in the grade-line.
- 8.4 The computer carries out checks to ensure that the chainages of successive points increase and that vertical curves do not overlap one another. If these rules are violated, an error message is printed out, and the input must be corrected and fed in again.
- 8.5 Adjacent vertical curves may touch one another, i.e. the beginning of a vertical curve may be coincident with the end of the previous curve. The length of a vertical curve may be zero, resulting in a kink in the grade-line or an instantaneous change in the grade. A kink may be situated at the beginning or end of a vertical curve by providing a coincident VPI with curve length = 0.
- 8.6 The grade-line may be modified between runs by deleting, altering or inserting VPI's as required.



SECTION 9GRADE-LINE PRINT-OUT

(Refer to Card V : Grade-line intervals  
 Card W : Grade-line print-out, Start and Stop  
 Card X : Chainages at which levels are required).

- 9.1 When the grade-line data has been stored, a print-out of the grade-line can be obtained with an optional program. This enables the grade-line levels to be obtained at regular intervals along the road and at individual intermediate chainages wherever they are needed. The length of the intervals can be varied at any point if required.
- 9.2 If points at which the level is printed out, fall within a vertical curve, the grade of the road will also be printed out.
- 9.3 The chainage, grade-line level and grade at the beginning and end of all vertical curves are given.
- 9.4 The print-out also contains the chainages and elevations of the VPI's as well as the length and K value of each vertical curve.

$$(K = \frac{L}{G_2 - G_1})$$

where L = length of vertical curve  
 $G_1$  = grade at beginning of vertical curve  
 $G_2$  = grade at end of vertical curve.

A crest curve has a +ve K and a sag curve a -ve K).

- 9.5 If this grade-line print-out program is required, a start chainage and a stop chainage must be given on the title sheet. A VPI at or before the start chainage and another VPI at or beyond the stop chainage must be given,

otherwise the program will not run. In addition, if the start lies within a vertical curve, the VPI before the beginning of the vertical curve containing the start must be given; similarly, at the stop, one VPI further on must be given. If the additional VPI's have not been given, the computer will disregard the vertical curve and calculate the levels on a straight grade through from the first or on to the last VPI.

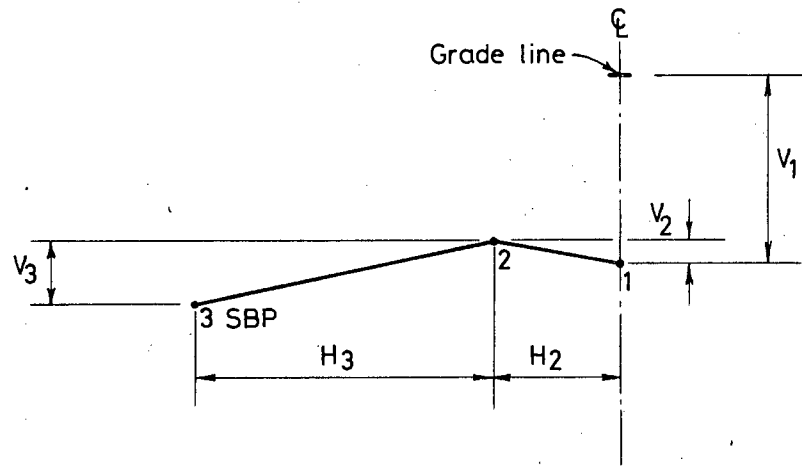
- 9.6 The points at which regular grade-line levels are required are specified by giving the interval in feet and the chainage to which the intervals are to be repeatedly added. The chainage may be intermediate and the interval may be given to an accuracy of 0,01 m.
- 9.7 The first chainage specifying intervals should preferably be not more than a few intervals before the start chainage for that run, to avoid adding intervals unnecessarily. The interval length may be changed up to 78 times within a run. Levels at regular intervals over a particular section of the grade-line can be skipped by inserting an interval length equal to the length of the section to be skipped. All data at the beginning and end of vertical curves and VPI's and individual points are however still printed out.
- 9.8 Grade-line levels at individual points are obtained by listing the chainages of all these points. This is useful in checking level control points at intermediate chainages. There is no limit to the number of points at which levels may be required.
- 9.9 All VPI's that are required to determine the grade-line at the start and at the stop, including those that lie before the start and beyond the stop, and all VPI's between the start and stop will be printed out with all



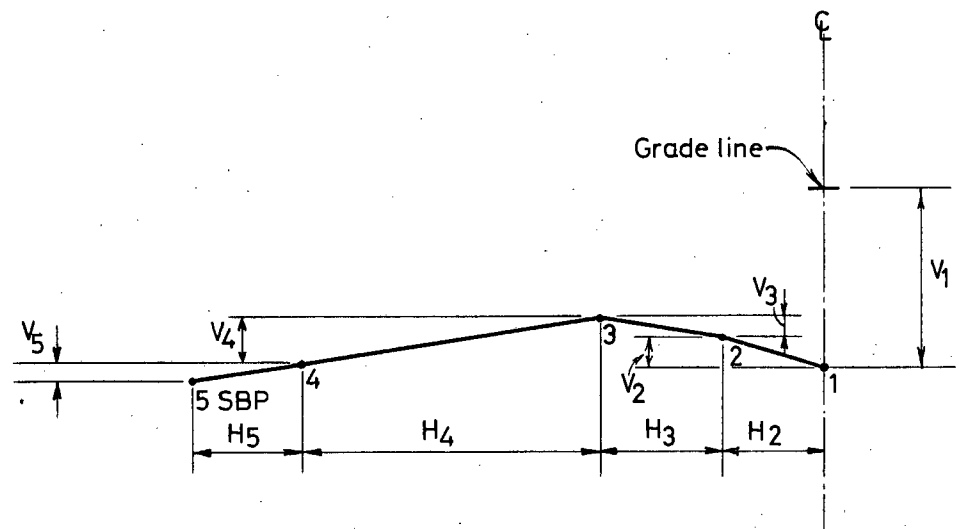
SECTION 10ROAD SURFACE TEMPLATES

(Refer to Card E: Road Surface Template Types  
Card H: Road Surface Template Calls).

- 10.1 The road surface template data defines the transverse template of the top of the finished road surface between the shoulder break points. A list of "Template-types" is prepared in advance, each having a "type number", and these are called in as required along the length of the job.
- 10.2 To ensure that the system can accommodate any type of design of superelevation for horizontal curves, superelevations are not calculated by the computer. The template has to be changed from one 'type' to another along the line of the road to accommodate changes in crossfall, superelevation and widths of lane or shoulder. Up to 108 different types of road surface template may be used on a job, and each may be called as often as required at the chainages specified by the engineer, provided that the total number of calls does not exceed 230 per run. Changes from one type to another may be 'instantaneous' or, provided the two template-types have the same number of points, 'transitioned'.
- 10.3 A 'template-type' defines one half of the road surface, from the template centre-line up to the SBP, by giving horizontal and vertical offsets for each successive point outwards. (See Fig. 10.1). Any number of points up to eight may be used for a 'template-type', i.e. up to 15 points for the full road width.



TYPE No. m



TYPE No. n

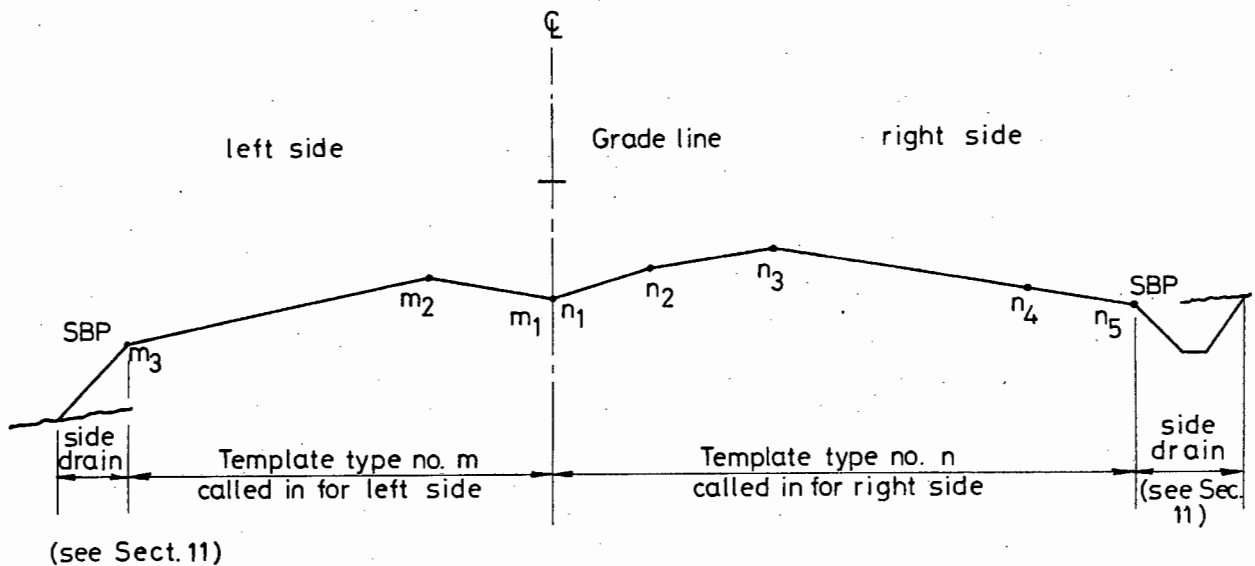
TEMPLATE TYPES

FIG. 10.1

The points defining the template are numbered from the origin outwards, the last point given being SBP. The horizontal offset of the first point must be zero, but

it may have a vertical value, i.e. the first point must lie on the template centre-line but need not be at the level of the grade-line. All horizontal offsets must be positive, (i.e. Outwards) or zero (with the exception mentioned in 10.7 below), but vertical offsets may be positive (upwards), zero or negative. Both offsets for each point are measured relative to the previous template point. Side walks and raised or sunken medians can be incorporated in the road surface.

- 10.4 When the template is symmetrical about the centre-line the same type number will be called in on both sides. When the template is not symmetrical about the centre-line (e.g. with superelevation), different template-type numbers must be given for the left and right-hand sides, see Fig. 10.2.



### ASSYMETRICAL ROAD SURFACE

FIG. 10.2

NOTE 1: Point 1 on the right side must always be the same as Point 1 on the left hand side at any station; i.e. the vertical offsets to the points 1 for both templates applicable must be the same.

NOTE 2: The difference in elevation of the highest and lowest points of a finished road surface template, both sides taken together and including the grade-line and both SBP's, may not exceed 32,767 metres.

10.5 Changes on the left and right sides of the centre-line are dealt with independently of one another and may, chainage-wise be staggered, or overlap partially or entirely, provided that chainages increase continually with each call. On one side, however, a new change may not be called within the transition distance of the previous change.

10.6 IMPORTANT: When two 'template-types' which have a different number of points are to be called in succession on one side of the road, the change must be instantaneous. A true transitioned change, however, can be brought in by calling an additional template-type containing dummy points with zero offsets.

It must be remembered that the Materials Design Layers Data probably requires a change when a template-type is called having a different number of points to the previous template-type.

10.7 To enable the slope control of the Material Design Layers to be executed. (see 12.6.1.S), it is necessary that the horizontal offsets of the elements of the template used for the slope control, are not zero, but are at least 0,01 m.



SECTION 11SIDE-DRAIN TEMPLATES

(Refer to Card F: Side-Drain Locus Types  
Card G: Side-Drain Components  
Card I: Locus Calls)

11.1 The program is versatile in that it is not restricted to any specific standard pattern for the side-drain, but allows the engineer a particularly wide scope in his design. It makes use of a locus of the slope stake points to ensure that the side-drain shape and dimensions adopted at every station conform as closely as possible to the particular requirements of the engineer.

The locus of the slope stake point is the path that is traced out, in the vertical plane of the template, by the slope stake point, in accordance with the engineer's requirements, as the terrain varies through all possible shapes and levels, relatively to the SBP.

A number of different loci, each with its own set of parameters, is prepared in advance, and these are called in during the run as required at chainages preselected by the engineer.

11.2 The procedure is as follows (refer to Fig. 11.1, at end of this section):

11.2.1 The engineer decides upon the design of the side-drain as required by the Road Authority.

11.2.2 The locus data is prepared by the engineer. This may be eased by drawing dimensioned sketches of typical side-drain templates corresponding to different terrain configurations, and showing the range through which the SSP can move in straight lines. The locus will consist of a series of

straight lines, (limited to 12 in number), called locus-lines, chosen to pass through these slope stake points.

Each locus-line will have one type of side-drain configuration consisting of five straight-line elements, some of which may be of zero length, others of which may have variable slopes and/or lengths, and all of which can be described by a selected set of fixed offsets and fixed slopes.

- 11.2.3 To accommodate changes in side-drain design (e.g. a change in the type of material which requires a different cut-slope at the same depth of cut) along a job, provision has been made for a maximum of 12 different locus types to be stored before the run. The loci, referenced by means of locus numbers, are called in by the program at appropriate chainages, and remain in use until a different locus number is called. Only one locus, selected before the computer run by the engineer, is available on each side at a particular station and this one locus must cater for all possible conditions of cut and fill that could occur at this station.
- 11.2.4 Before the run the engineer specifies the chainages at which the various locus types will be called in. A locus type can be used on the right or left side of the road. At any station the same or different loci may be used on the right and left sides, and the loci on the two sides may be changed independently of one another.
- 11.2.5 Immediately in advance of the earthwork quantities run, the computer will check and store all locus types, each with its set of locus-lines, each of which in turn has its own set of side-drain components.

- 11.2.6 As the run proceeds the program calls in the appropriate locus types for left and right sides.
- 11.2.7 A valid intersection of one of the locus-lines with the terrain line will be determined by the computer, the intersection being fixed as the slope stake point. Validity is explained in 11.3.2.4.
- 11.2.8 The intermediate side-drain points will then be determined, using the given set of side-drain components of the locus-line used for the valid intersection.
- 11.2.9 The road template will now be fully fixed.
- 11.3 The various items of the locus will now be described in detail.
- 11.3.1 The locus consists of:-
- 11.3.1.1 Its locus number (from 1 to 12 but not more than the total number of loci), used during the run for calling in the relevant locus.
- 11.3.1.2 Any number of locus-lines, but not more than 12, each having a line number, a line weight, a slope preference, and defined by two points. In addition, each locus-line has a set of 8 defined and 7 blank offset components determining one type of side-drain configuration.
- 11.3.2 The locus-lines: The locus-line is defined by giving the horizontal and vertical offsets of the two end points of the line. The line is not extended beyond these points.
- Care must be taken to ensure that no possible terrain line, no matter how theoretical, can 'get through' between locus-lines, without finding a valid intersection on a locus-line. For example, referring to the sample given in Fig. 11.1, if locus-line No. 4 were left out, a gap would exist for negative slopes

to get through. The terrain of course, may not contain any vertical line, or an overhang.

The whole or any portion of two or more locus-lines may be coincident, but each locus-line will be treated individually. With each locus-line are associated:-

- 11.3.2.1 A locus-line number: from 1 to 12, but not more than the total number of lines for this locus. Refer to 11.4 below for the sequence of numbering.
- 11.3.2.2 Two points defining the locus-line: The horizontal and vertical offsets of points 1 and 2, which fix the limits of each straight line portion of the locus, are each measured from the SBP.
- Horizontal offsets may not be negative; no sign is used. One or both horizontal offsets may be zero, but if any horizontal offset is zero, the slope control point for the materials layers may not lie beyond the SBP (see paragraph 12.6.3 ). Vertical offsets are positive when the point lies higher than the SBP, negative when lower and may be 0. Horizontal or vertical offsets to points 1 and 2 for one locus-line may be identical.
- Several locus-lines may use the same point, which must then be repeated for each line.
- Point 1 of locus-line No. 1 and point 2 of the last locus-line have a special significance (see 11.4 below).
- 11.3.2.3 The weight of the line: This is a number from 1 to 12 but may not be more than the total number of locus-lines for this locus. It may be preceded by a negative sign which does not alter the weight-value order, but is used if more than one intersection occurs on this line. The computer will try to find an intersection on the locus-line having the lowest numerical weight-value first. If an intersection, even at the extremity of the locus-line, i.e. on one

of its points, is found, and is accepted as valid, this intersection is fixed as the slope stake point and the computer proceeds to determine the profile of the side-drain. If no valid intersection is found on this locus-line, the computer proceeds to the locus-line having the next higher weight-value. If the terrain line intersects a locus-line more than once, the intersection nearest to point 1 is considered first for validity, unless the 'line weight' is preceded by a negative sign, in which case the intersection nearest to point 2 has priority. It is an advantage to the computer (time-wise) to give priority (lowest weight-value) to locus-lines which will have most valid intersections, (i.e. generally low fills and shallow cuts) provided that the intended design of the engineer is not violated.

11.3.2.4 A slope preference: This can be -1, 0 or 1. If the number is 0, no test on the terrain slope is done, and the first intersection found is valid.

If the slope preference associated with a certain line is 1, an intersection of the terrain with this line will only be accepted as valid if the slope of the terrain at this point is zero or positive, (i.e. up away from the centre-line).

If the slope preference is -1, only negative or zero slopes are accepted.

If the terrain slope is wrong (i.e. down away from the centre-line with slope preference = 1 or up with -1), the intersection is invalid, is rejected and the computer will proceed to find the next intersection, on the same line if possible.

Care must be taken to ensure that, if an intersection is rejected, on account of slope preference, another intersection that will be valid can be found, further along that line or on another locus-line of lesser priority.

11.3.2.5 Side-drain components: Once a valid intersection between locus and terrain lines has been found, the complete side-drain template is determined by the set of components, associated with the locus-line containing the SSP.

The drain points are numbered consecutively from 1 to 5 from the SBP towards the SSP.

If curved lines are used by the engineer in his design of the side-drain, these curves will have to be approximated by breaking the side-drain template down into a series of not more than 5 straight lines.

A side-drain point is related to the previous side-drain point by specifying one or two out of three possible 'offset components': horizontal offset, vertical offset or slope. These components are abbreviated to H, V and S respectively, and are given with the relevant drain point number.

The first side-drain point is defined relative to the SBP. Point 1 is the first point beyond the SBP but, as its horizontal and vertical offsets may be 0, it can thus be made coincident with the SBP. Point 5 is always the SSP (except in the case of a vertical cut-off, see paragraph 11.4 below).

When the drain template has less than 5 points, five points must be numbered but two or more of them are made coincident; e.g. point 3 is made coincident with point 2 by putting  $H_3 = 0$ ,  $V_3 = 0$ ;  $S_3$  must remain blank.

Eight of the available fifteen offset components to the 5 side-drain points must be selected by the engineer in order to define the side-drain configuration that he requires.

Some or all of the eight given components may be 0; the remaining 7 must be left entirely blank.

If 2 components to a side-drain point are given, the point is fixed relative to the previous one.

If 1 component to a side-drain point is given, a restriction is imposed but the point is not fixed.

If no component to a side-drain point is given, (all 3 fields H, V, and S are left blank), the point is independent of the previous one. In this case the relevant point is fixed relative to the SSP, while the previous point is fixed relative to the SBP.

The rules for giving the 8 side-drain components in a set are as follows:

All three components to a point may not be given, as one is redundant.

Horizontal offsets may not be negative, but may be 0. Vertical elements of the side-drain are thus allowed but overhangs are not.

The sum of all given horizontal offsets may not be more than the smaller horizontal offset of the two points defining the locus-line.

Vertical offsets and slopes may be +ve (no sign is used), 0 or -ve.

Zero values are not to be left blank, but must have at least one 0 inserted in the field.

Not more than 4 horizontal offsets, or more than 4 vertical offsets may be given.

Not more than two slope components that are not accompanied by horizontal or vertical components may be given.

If one unaccompanied slope is given, its absolute value may be:

not less than 0,02, if an unaccompanied vertical component is given, and  
 not more than 50, if an unaccompanied horizontal component is given.

(This is to avoid problems resulting from poor intersections of nearly parallel lines).

Similarly, if 2 unaccompanied slopes are given they may not be close together in algebraic value.

One set of side-drain components applies for an SSP found anywhere within the length of a locus-line and therefore the components must be validly applicable over the full length of the locus line.

### 11.3.3

While preparing the locus data the engineer will often realize that several alternative sets of data, none of which violates any rules, would give the same result. In the example given in Fig. 11.1, the slope preference for locus-line No. 5 may be -1 or 0, various alternatives for numbering side-drain points are shown in Step 6, and the side-drain components in Step 7 may often be presented in a variety of sets. In all these and other such cases where identical results would be achieved, any alternative may be used.

### 11.4

Vertical cut-offs: If the intersection has not been achieved below the uppermost point and above the lowest point defining the locus, a vertical cut-off is applied. The first point defining the first locus-line (which must be locus-line number 1) and the second point defining the last locus-line (having the highest locus-line number) are the points from which the vertical cut-offs are applied below and above respectively. (For example, in Fig. 11.1 the vertical cut-off would be applied below point 1 of locus-line 1 or above point 2 of locus-line 7).

This must be kept in mind when numbering the locus-lines. The intermediate locus-lines need not be numbered in sequence.

Where there is a vertical cut-off, the side-drain template consists of 6 points, point 6 being the SSP. Point 5 is then the locus-line point at which the cut-off is applied. The drain type is the one associated with the first or last locus-line according to whether the ground lies below or above the locus.

If no vertical cut-offs are desired, the locus must be extended far enough so that an intersection will be found with the ground in all cases.

11.5 Insufficient terrain data: If the terrain data does not extend far enough to meet the locus-lines, the terrain is extended by extrapolation of the slope between the two outermost terrain points on that side. It is to avoid unintentional shortfalls of the terrain that tests with error messages H and J are applied during the editing of the terrain data.

11.6 Calling loci: The locus will be changed along the road at the chainages as called. Up to 108 locus call cards may be used, per run.

The first line (card) must contain a locus number for both the left side and the right side of the road, and must have a chainage smaller than or equal to the starting chainage of the quantities run.

A section at the chainage at which a new locus is called, will be computed using the new locus.

If at a certain chainage the locus changes only on one side, the other one may be left blank.

See also Sections 6: Broken Chainages.

7: Terrain Cross-sections.

10: Road Surface Templates.

16: Quantities Print-out.



SECTION 12MATERIALS DESIGN LAYERS

(Refer to Card J: Materials Design Layers).

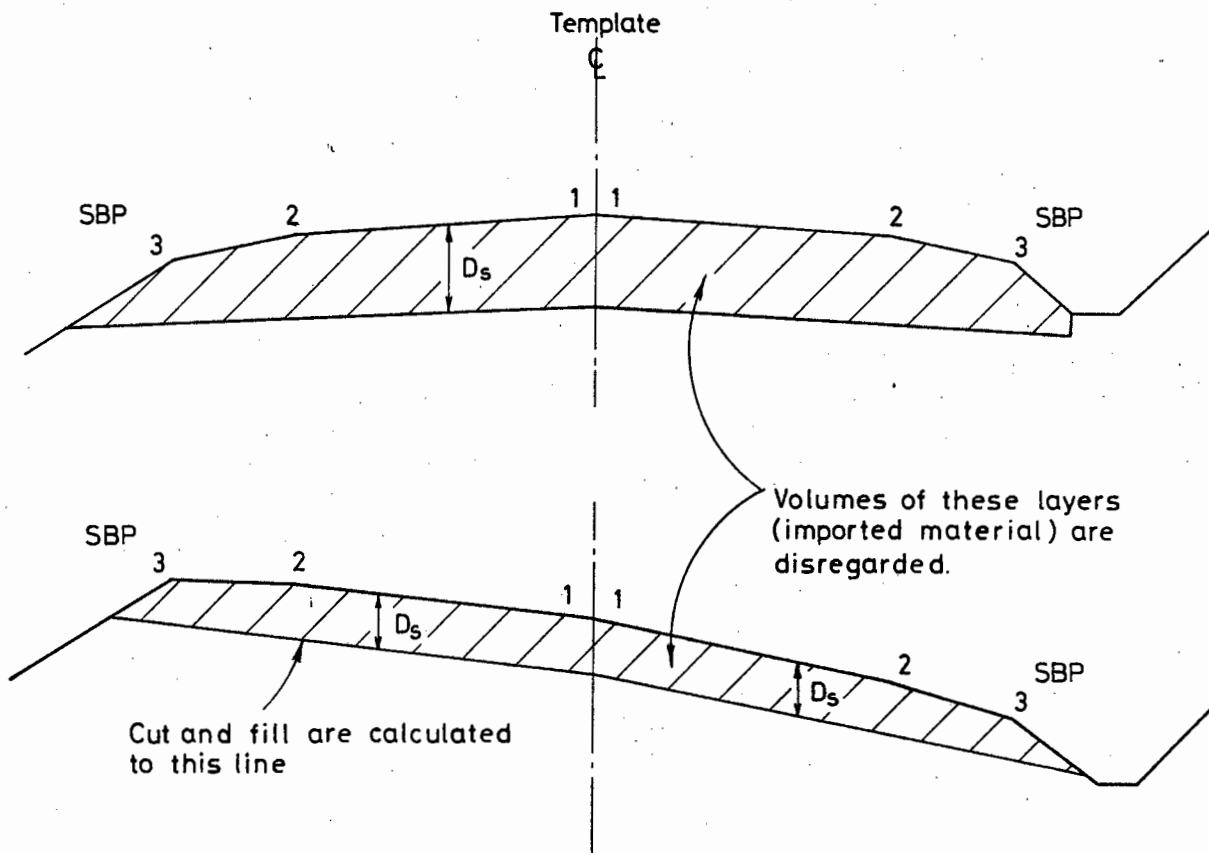
- 12.1 Minimum requirements: If no materials design layers are to be considered, the user is required to fill in one line of "J" data exactly as given in Fig. 12.1 below, giving the appropriate chainage at the start of his job.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44					
	CHAINAGE									S	S	S	S	C	C	C	C	M	M	M	M																											
										L	L	R	R	L	L	R	R	L	L	R	R	D1																										
	B km									O	I	I	O	O	I	I	O	O	I	I	O																											
J									2		22		22		22		2		0'0																													

No Materials Layers required

FIG.12.1

If the user has a simple rural road with a cross-section as shown in Fig. 12.2, (i.e. a road surface template having 3 points, with or without superelevation, sub-grade crossfall to be the same as carriageway surface, independent of shoulder crossfalls), a line of "J" data as given in Fig. 12.3 can be used to obtain quantities of cut and fill correct to the bottom of the layer of imported material. Insert the actual thickness of this layer,  $D_s$  (in metres) in fields D1, D2 and D3.



SIMPLE RURAL ROAD

FIG. 12.2

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44			
	CHAINAGE									S	S	S	S	C	C	C	C	M	M	M																										
										L	L	R	R	L	L	R	R	L	L	R	R			D1				D2				D3														PARAMETER
B km										O	I	I	O	O	I	I	O	O	I	I	O																									
J										2		24			44		4						$D_s$				$D_s$					$D_s$													-32767	

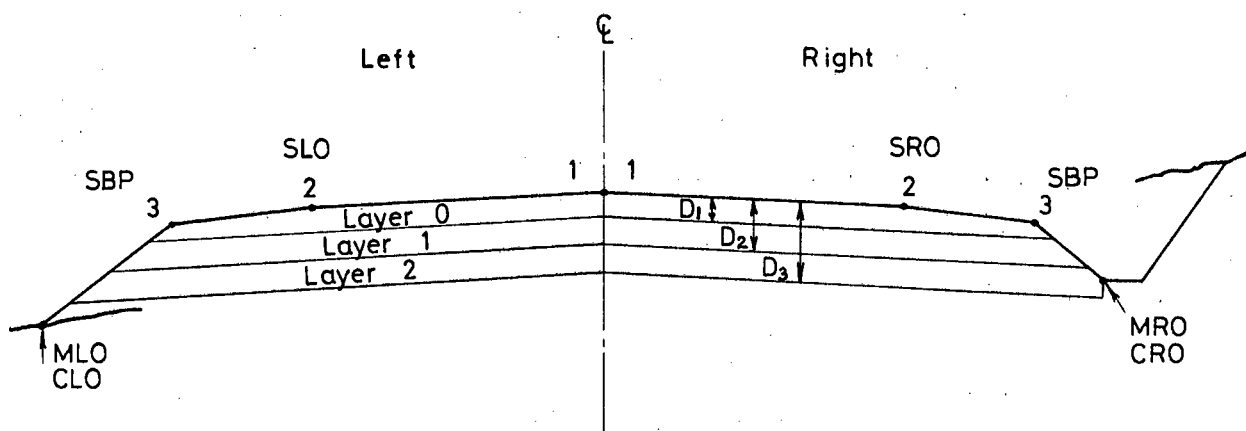
Top Layer (Imported Material) to be disregarded in Volume Calculations

FIG. 12.3

If the road surface template consists of more than 3 points per side, or if more complex treatment of the materials layers is required, the remainder of this section must be studied.

12.2 To assist the engineer in his materials design, the computer calculates the volumes in cut and fill of material lying in parallel layers beneath the road surface. These volumes are accumulated independently, enabling the engineer to study the effect over a specified length of the road, of, for instance, an extra layer of cut or imported material, or to cut a rejected layer away to spoil while filling in the same position from approved cut. Any parameter in the materials design may be changed as required at the chainages specified by the engineer. Up to 60 material design cards may be submitted.

12.3 Provision is made for 3 layers, numbered 0, 1 and 2 from the top downwards, as shown in Fig. 12.4.



MATERIALS DESIGN LAYERS

FIG. 12.4

The top layer 0, normally representing imported materials (Base and Subbase), is not calculated. However, if the volume of these materials is required, the upper layer is given zero thickness and layer 1 gives the required volumes.

- 12.4 The areas which are used in calculating the volumes are detailed in Section 16: Quantities Print-out.
- 12.5 The layers are specified by giving the depth of each layer below the road surface; D1 for the top of layer 1, D2 for the top of layer 2 and D3 for the underside of layer 2. D2 may not be less than D1, and D3 may not be less than D2. Any or all layers may however be deleted from the calculations by making  $D1 = 0$ ,  $D2 = D1$ , and/or  $D3 = D2$  as is required. Provided that these rules are maintained, D1, D2 and D3 may be changed independently of one another at any point along the run. A layer-depth is applicable to both sides of the road.
- 12.6 Layer edge control points: A single carriageway has a left (outer) edge and a right (outer) edge; a dual carriageway has a left outer edge, left inner edge, right inner edge and right outer edge. To control the edge conditions of the materials layers, use is made of three types of control points, viz. layer slope, total material cut-off and cut-off of layers 1 and 2, one of each type per edge of carriageway. The engineer must select these control points from the template point numbers of the template-type(s) that is (are) applicable at this portion of the road. Care must be taken that, when a new template-type is called, the control points are also amended at that chainage if this is necessary.
- 12.6.1 The codes of the three types of control points are:-
- S : Slope control. Underneath the carriageway and up to these points the materials layers follow the road surface template in parallel layers at

depths D1, D2 and D3. Where the layers extend beyond this point, the bottom surfaces of the layers are extended at the same slope (which may not be infinity) that they had just before the S point, i.e. they no longer lie parallel to the surface.

At the inner edges (in the case of a dual carriageway road) the slope of the layers just beyond the S point is extended inwards towards the template centre-line.

C : Total materials cut-off: Each materials layer, (0,1 or 2) that has not been terminated by the road template, is cut off vertically below this point.

M : Materials layers 1 and 2 cut-off: Layers 1 and 2, if not terminated by the road template are cut-off vertically below this point. (Layers 1 and 2 cannot be treated differently).

12.6.2 To identify the edge of the road being considered the following codes are used:

L : Left side of template centre-line.  
 R : Right side of template centre-line.  
 I : Inner point (i.e. median edge of carriageway).  
 O : Outer point.

12.6.3 For a dual carriageway road the following twelve points must be given in sequence:

SLO, SLI, SRI, SRO, CLO, CLI, CRI, CRO, MLO, MLI, MRI and MRO.

For a single carriageway, the six I points are left blank.

The L points are selected from the template-type which is applicable to the left side of the road at this portion of the road, similarly, the R points from the template-type applicable to the right side.

Any 0 point could have a value of 1 higher than the number of the SBP. In such a case the control point would be the first point on the side-drain template which lies beyond the SBP and which is not coincident with the SBP.

12.6.4 Rules: Always referring to one side of the road only.

- (1) SO must be at least 1 greater than SI.
- (2) SI must be  $\geq$  CI.
- (3) CO must be  $\geq$  SO.
- (4) MI must be  $\geq$  CI.
- (5) CO must be  $\geq$  MO.

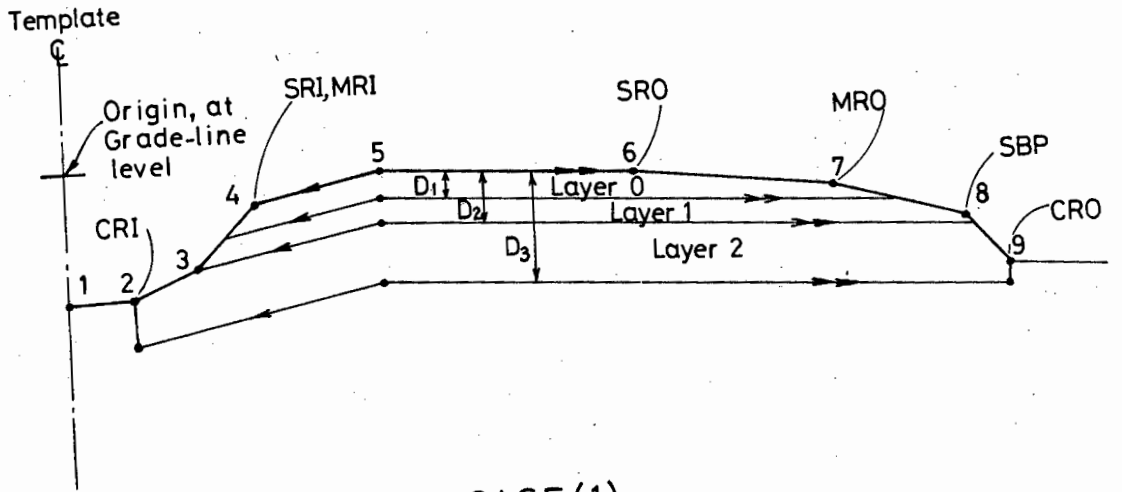
12.7 Layer edge determination: The materials layers follow the road surface from the inner to the outer control points.

The line forming the top of layer 1 is extended outwards, and, for a dual carriageway road, inwards, beyond the "S" point, at the same slope that it has just before that "S" point, until it first cuts the road template or until it is vertically below the "C" point. The area lying above this line (layer 0) is not calculated.

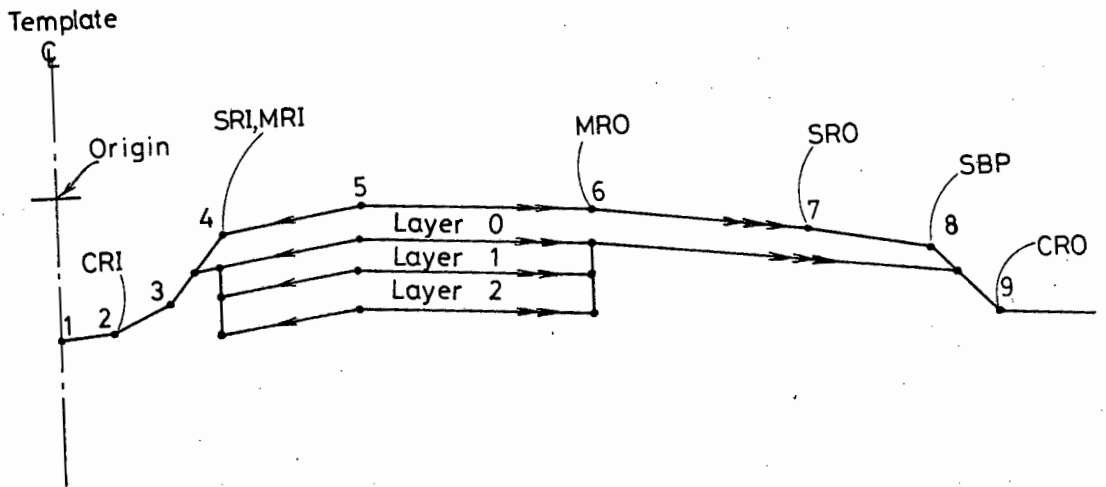
The engineer may select the termination of layers 1 and 2 by using a parameter "P" as follows:

Layers 1 and 2 may be either:

- (i) extended beyond the "M" point to meet the road template as in Fig. 12.5, Case (1), or
- (ii) stopped vertically at the "M" point as in Fig. 12.6, Case (2).



CASE (1)  
FIG. 12.5



CASE (2)  
FIG. 12.6







SECTION 15QUANTITIES ADJUSTMENTS

(Refer to Card M: Gaps  
Card N: Cut-to-Spoil and Borrow-to-Fill  
Card P: Continuation Volumes)

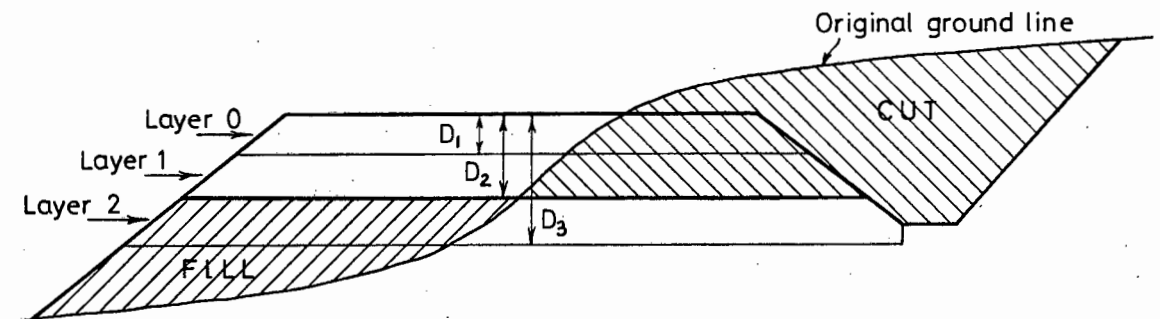
- 15.1 The following adjustments may be made to the earthworks volumes:
- (a) Gaps
  - (b) Cut-to-spoil and Borrow-to-fill
  - (c) Continuation volumes.
- 15.2 Gaps: Provision is made that, when required, no earthwork volumes are computed along a section of road. This would occur for instance when a bridge is crossed. The accumulated figures are kept constant through this section. Up to 20 gaps can be dealt with.
- The gap is given by its beginning and end chainages, which should lie on stations.
- If the "gap begin" chainage does not coincide with a station, the volumes will only be calculated up to the station immediately preceding this "gap begin" chainage. If the "gap end" chainage does not fall on a station, volumes will be calculated from the station immediately preceding this "gap end" chainage. In effect the gap is moved backwards until the beginning and end do lie on stations.
- 15.3 Cut-to-spoil and Borrow-to-fill: Provision is made to spoil material from the road works or to import material from outside the road works, applied either as a lump quantity or as a continuous uniform rate over a length of road. It could be used as follows: A ramp to a bridge falling outside the road works is required to be built up of cut material from the road works, i.e. a fixed quantity of material must be set aside for this purpose at a particular chainage. Up to 25 cards may be submitted.





SECTION 16QUANTITIES PRINT-OUT

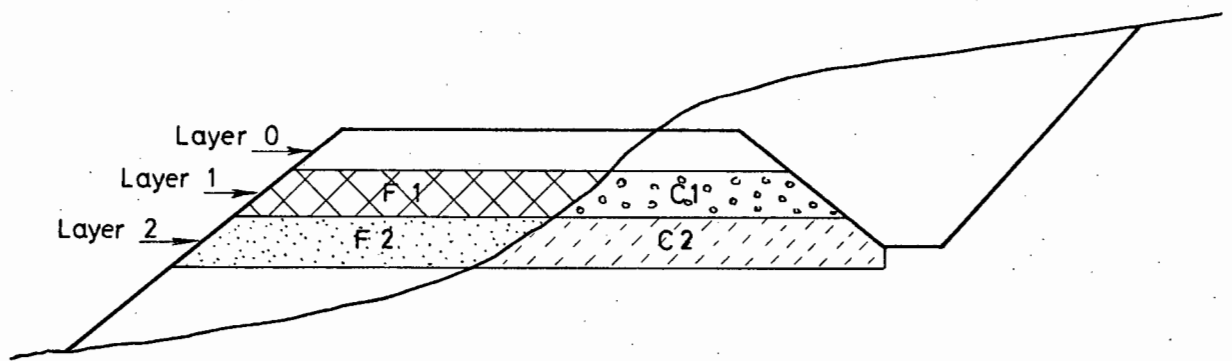
- 16.1 When all data (excluding the terrain cross-sections) has been stored in the computer, immediately before an earthwork quantities run is made, a print-out of all this data is given, so that the quantities print-out that follows, may be checked against the input parameters.
- 16.2 The earthwork quantities print-out consists of, for each station, a line of data giving:
- 16.2.1 The chainage at that station.
- 16.2.2 Areas of cut and fill at that station. The balance line passes between layers 1 and 2. These areas are shown hatched in Fig. 16.1.



Areas of cut and fill, as used for calculating cut and fill Volumes, Crosshaul, Mass Diagram 1

FIG. 16.1

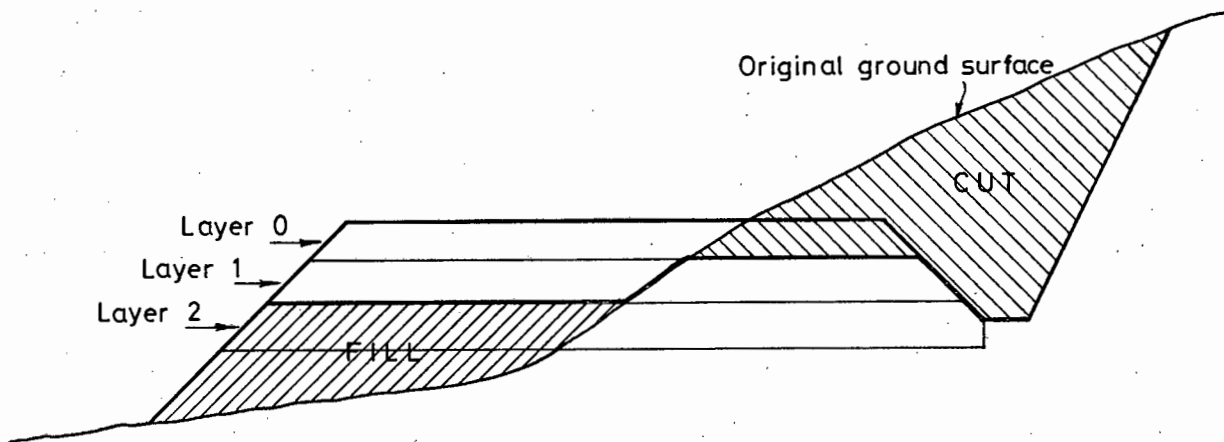
- 16.2.3 Volumes of cut and fill between that station and the previous one. The quantity of cut is obtained by adding the area of cut at that station as found in 16.2.2 above to the corresponding area at the previous station, and multiplying this sum by half the distance between the stations. The quantity of fill is found similarly from the fill areas.
- 16.2.4 The accumulated volumes of cut and fill up to that station. These are obtained by adding the volumes found in 16.2.3 above to the respective accumulated volumes at the previous station.
- 16.2.5 Accumulated volumes for Layer 1 Cut, Layer 1 Fill, Layer 2 Cut and Layer 2 Fill, as calculated in similar fashion from the respective areas C1, F1, C2 and F2 shown in Fig. 16.2.



Areas used in calculating cut and fill volumes of Layers 1 and 2

FIG. 16.2

- 16.2.6 The bulking factor (see Section 14: Bulking Factor).
- 16.2.7 Accumulated cross-haul. The volume of cut as found in 16.2.3 is multiplied by the bulking factor. The resulting bulked cut is compared to the volume of fill, the lesser of the two is the cross-haul and this is added to the accumulated cross-haul volume at the previous station.
- 16.2.8 Mass diagram 1. The volumes of cut and fill found in 16.2.3 are used. The volume of cut is multiplied by the bulking factor and subtracted from the fill. The difference is added to the accumulated volume at the previous station (see Fig. 16.1).
- A minus sign preceding a quantity in the mass diagram shows an excess of cut.
- 16.2.9 Mass diagram 2. This is similar to Mass diagram 1, the only difference being that the volume of cut excludes Layer 1 Cut (C1), i.e. the balance line has been raised above layer 1 in cut. (See Fig. 16.3).



Areas used for calculating Mass Diagram 2

FIG. 16.3

- 16.2.10 The horizontal offset distances of the slope stake points, left and right, measured from the terrain centre-line.
- 16.2.11 The grade-line level at that station.
- 16.3 The accumulated figures that are printed out enable the engineer to determine by subtraction the volume of any layer for any particular portion of the road.

See also Sections 4: Units Capacity and Precision.

5: Title Sheet.

6: Broken Chainages.

7: Terrain Cross-sections.

8: Grade-line.

12: Materials Design Layers.

13: Bulking Factors.

15: Quantities Adjustments.

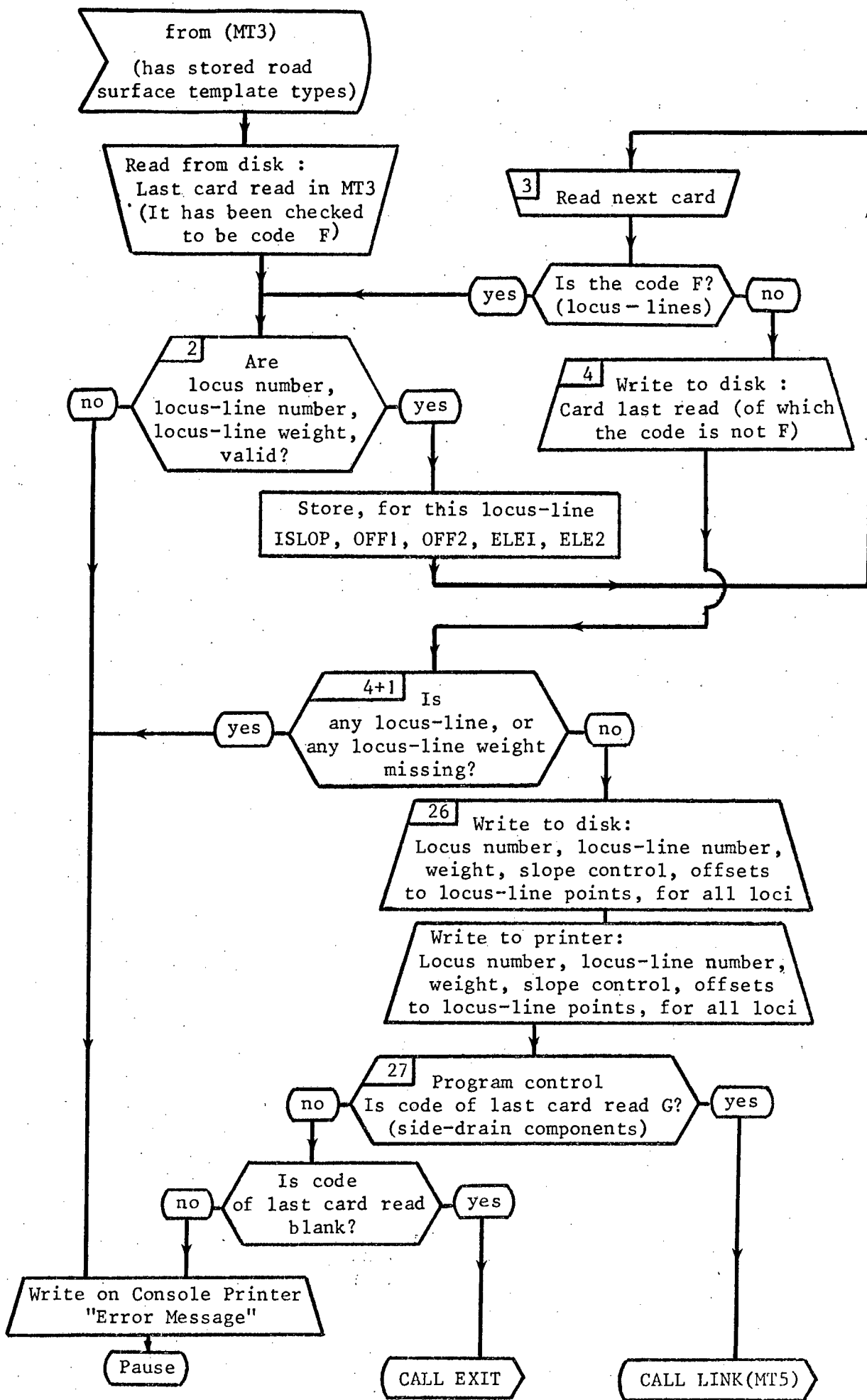
F L O W - C H A R T SFOR THE S H A R M PROGRAMS  
USED IN THE DETERMINATION OF  
SIDE-DRAIN TEMPLATES

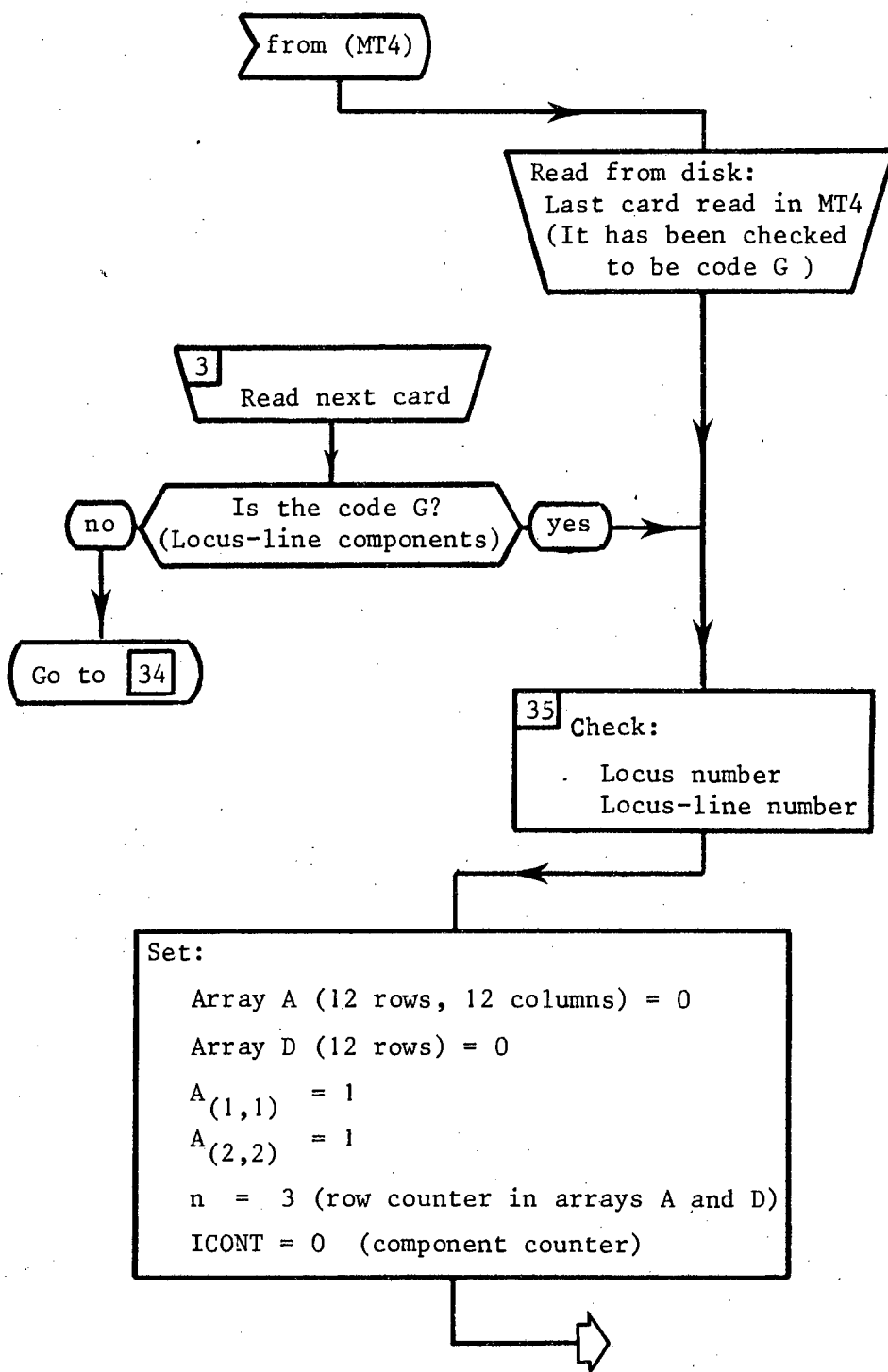
	<u>PROGRAM</u>	<u>Page</u>
MT4	Checks and stores loci	B2
MT5	Stores side-drain components	B3
MT10	Finds slope stake points	B7
MT11	Calculates side-drain points	B11

Variable names appearing in these flow-charts are the same as the FORTRAN variables used in the source programs. The variables are described in the lists which precede the listings of the source programs in Appendix C. Note that a separate list of variables is given for each program.

FORTRAN statement numbers, used in the source programs, are shown boxed in the flow-charts.

MT4 CHECKS AND STORES LOCI



MT5 STORES SIDE-DRAIN COMPONENTS

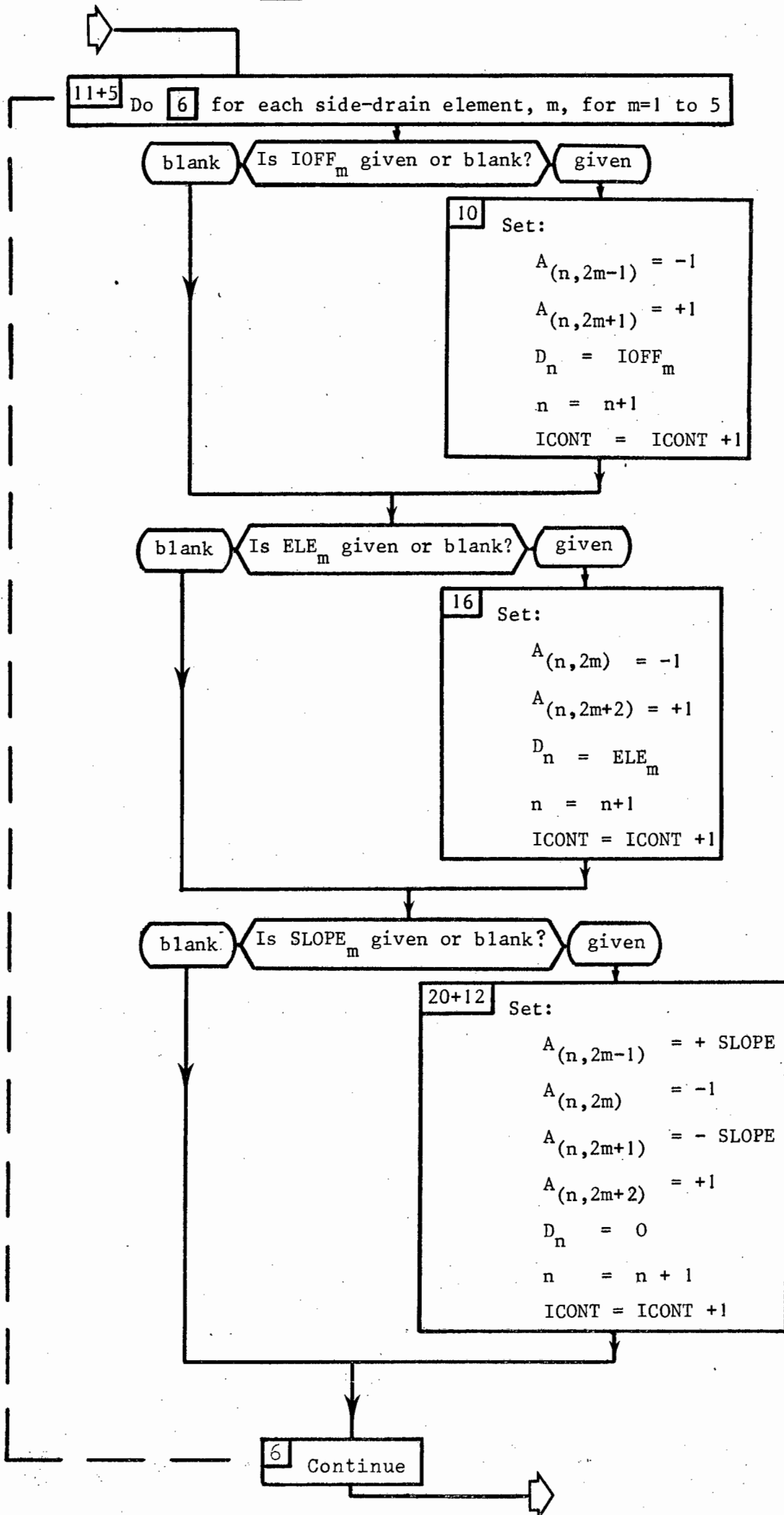
Comment 1 : Load arrays A and D, for  $n = 3$  to 10, as follows:

For every component, in the sequence IOFF<sub>1</sub> ELE<sub>1</sub> SLOPE<sub>1</sub> IOFF<sub>2</sub> ELE<sub>2</sub> SLOPE<sub>2</sub> IOFF<sub>3</sub>, and so forth, up to SLOPE<sub>5</sub>, that has a given input value (not blank), complete the next row,  $n$ ;  $n$  increases by 1.

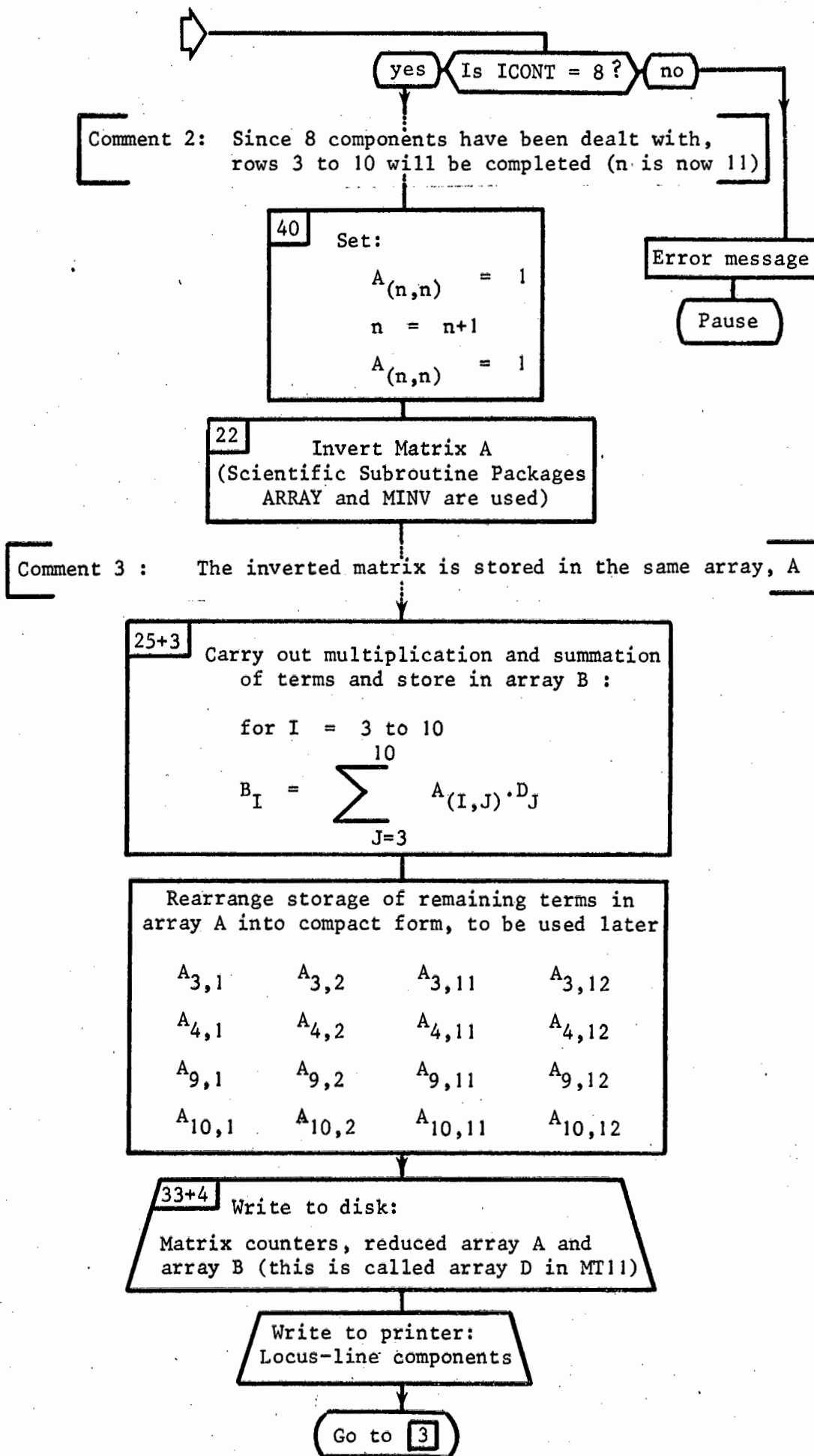
If a component's field is blank, proceed with the next component, without increasing  $n$ , i.e. do not skip any row.

(Note: IOFF, ELE and SLOPE are respectively the horizontal, vertical and slope components)

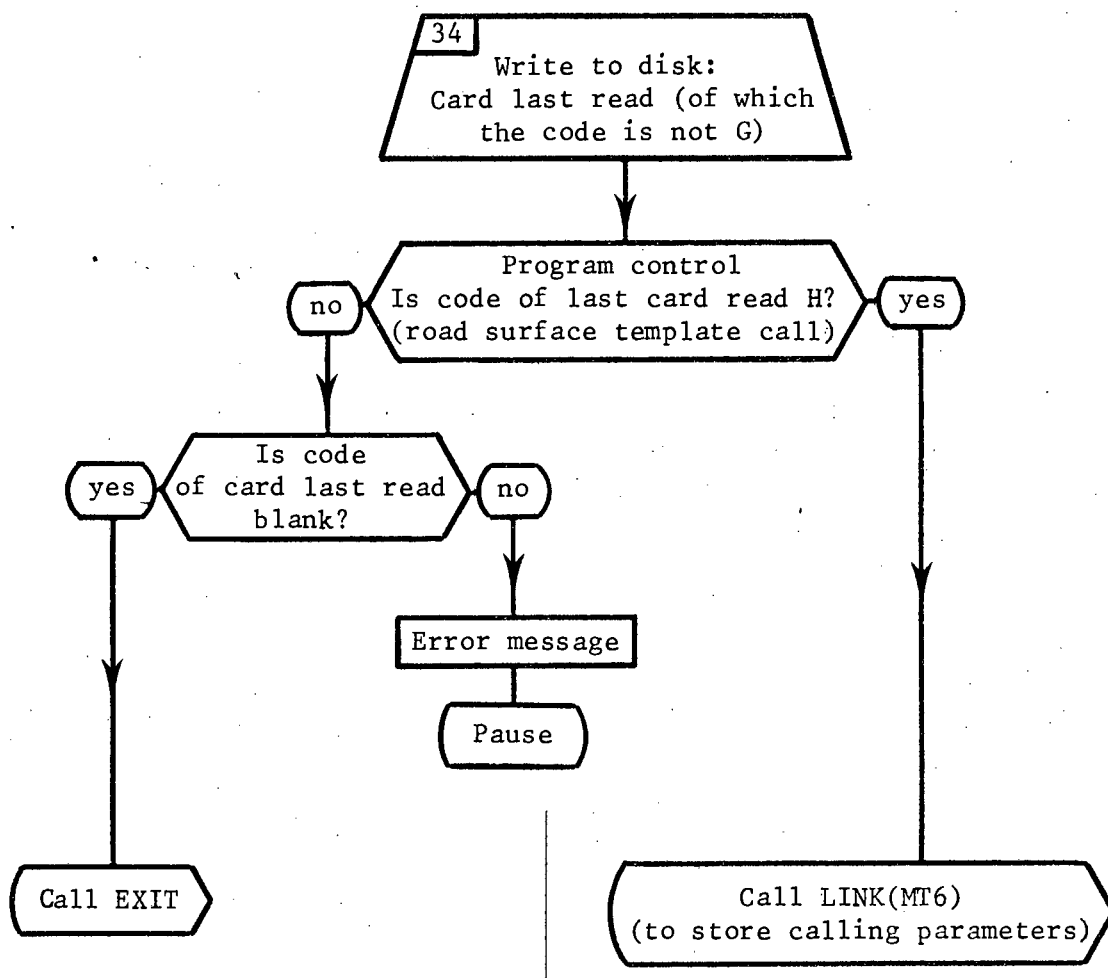
MT5 (continued)



## MT5 (continued)



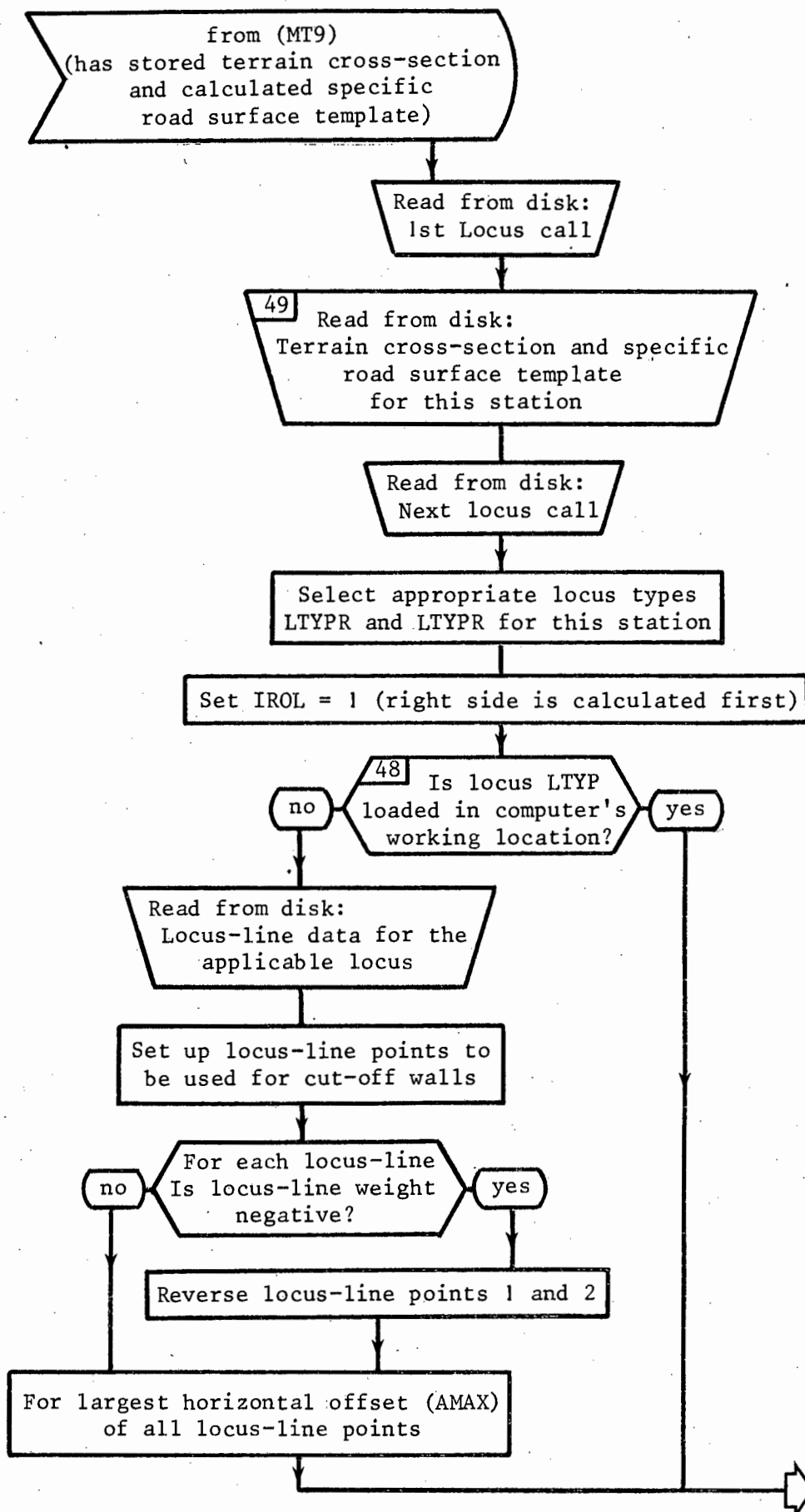
## MT5 (continued)



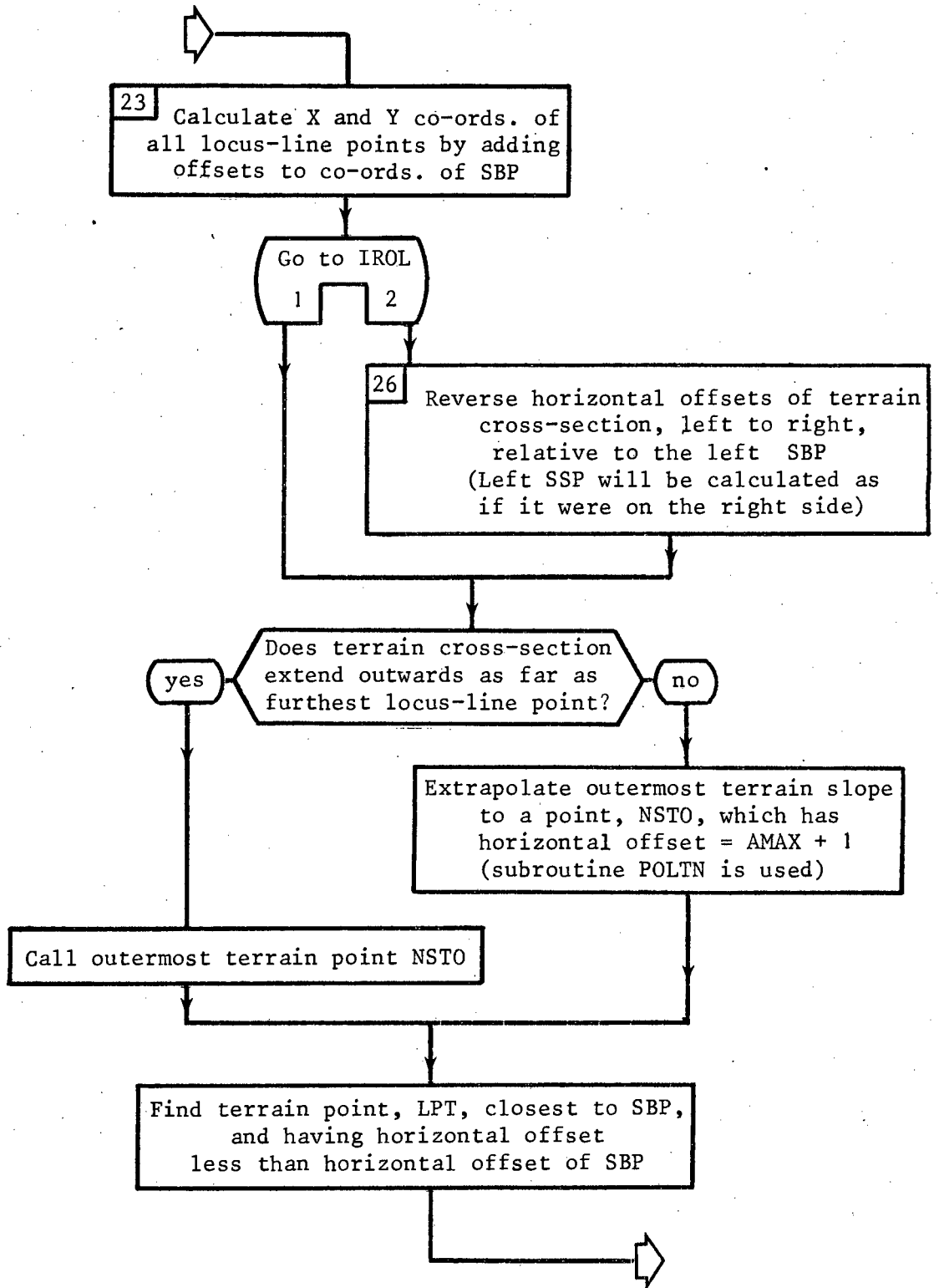
Comment 4 : The flow diagram for loading arrays A and D, as set out above between [11+5] and [6], is the basic process as formulated in par. 3.2.5(ii) of the thesis.

In the program as coded (see Appendix C, MT5), execution time has been shortened in the following way. Whenever  $IOFF_i$  and  $ELE_i$  are both given as zero, (i.e. side-drain point,  $i$ , is identical with the previous point,  $(i-1)$ ), the number of elements in the side-drain is reduced by 1. This is implemented by [19]  $K=K+1$ . Thus,  $m$  is 1 less, and the dimensions of matrices A and D are reduced by 2. Counters, used to index the revised size of the matrices, must be carried through the program.

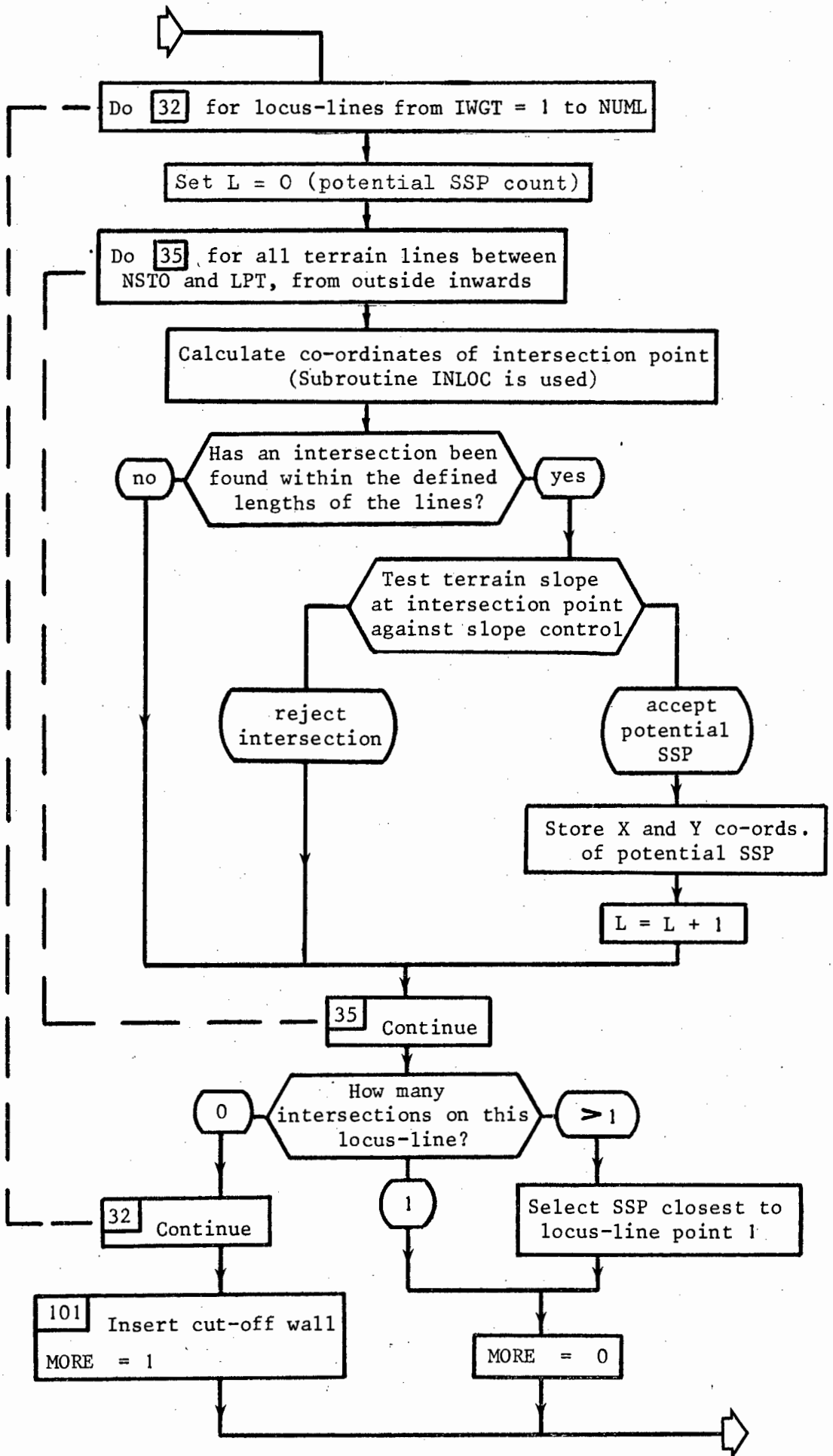
Although this refinement complicates the source program, much time is saved, since the number of elements is often less than the maximum of 5. When 4 horizontal components and 4 vertical components are given as zero (i.e. the side-drain consists of one straight line between SBP and SSP, the typical "shallow fill" case), no intermediate points need be calculated, and the setting up of the matrix and its inversion are dispensed with entirely (see [21]).

MT10 FINDS SLOPE STAKE POINTS

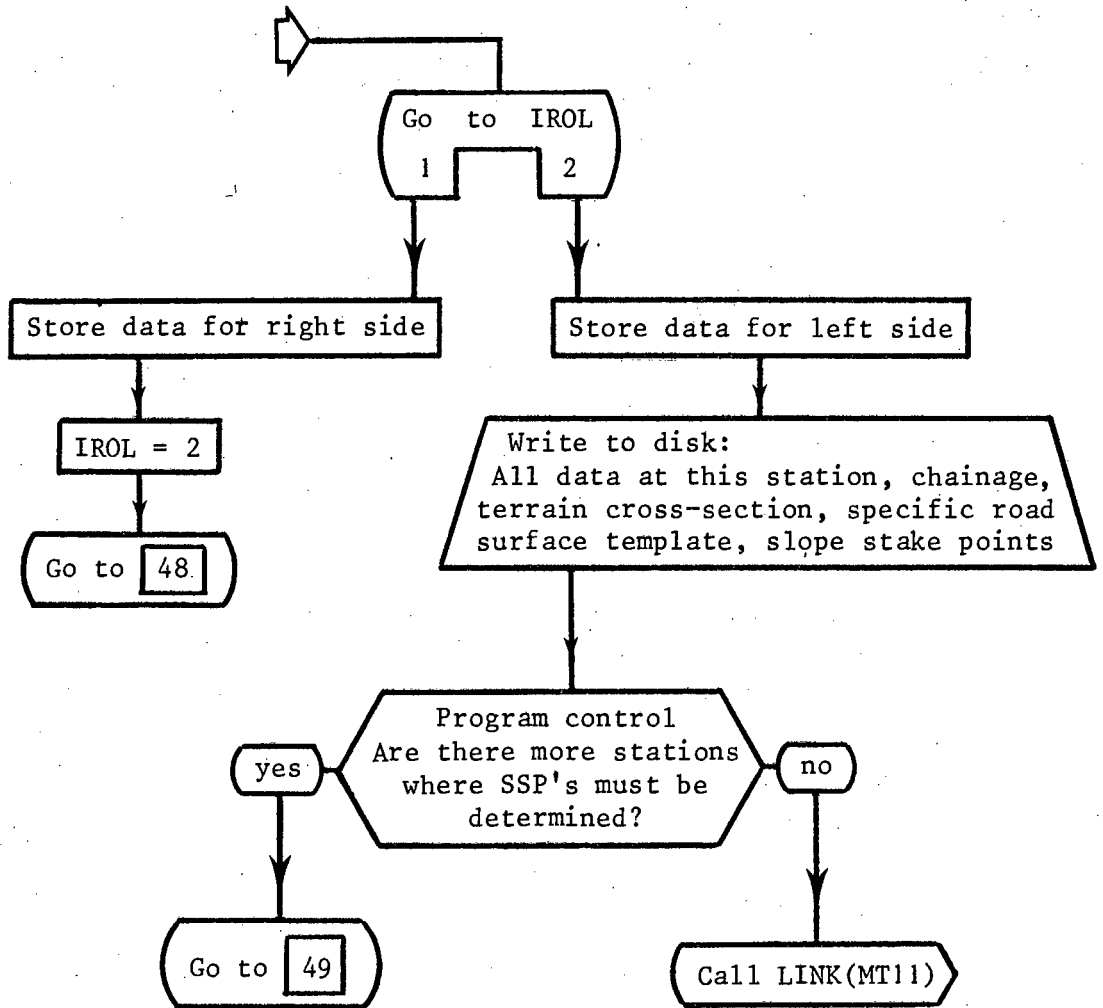
## MT10 (continued)

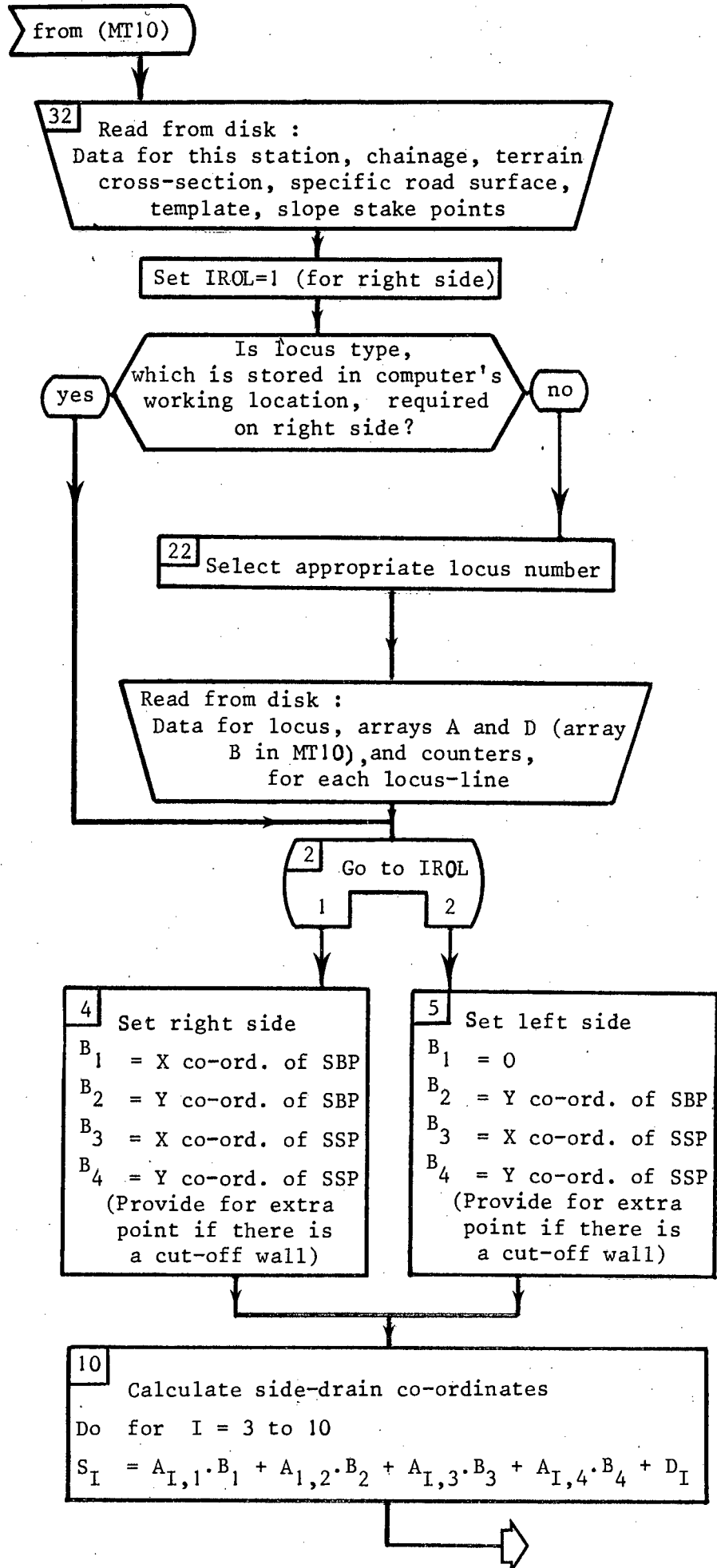


MT10 (continued)

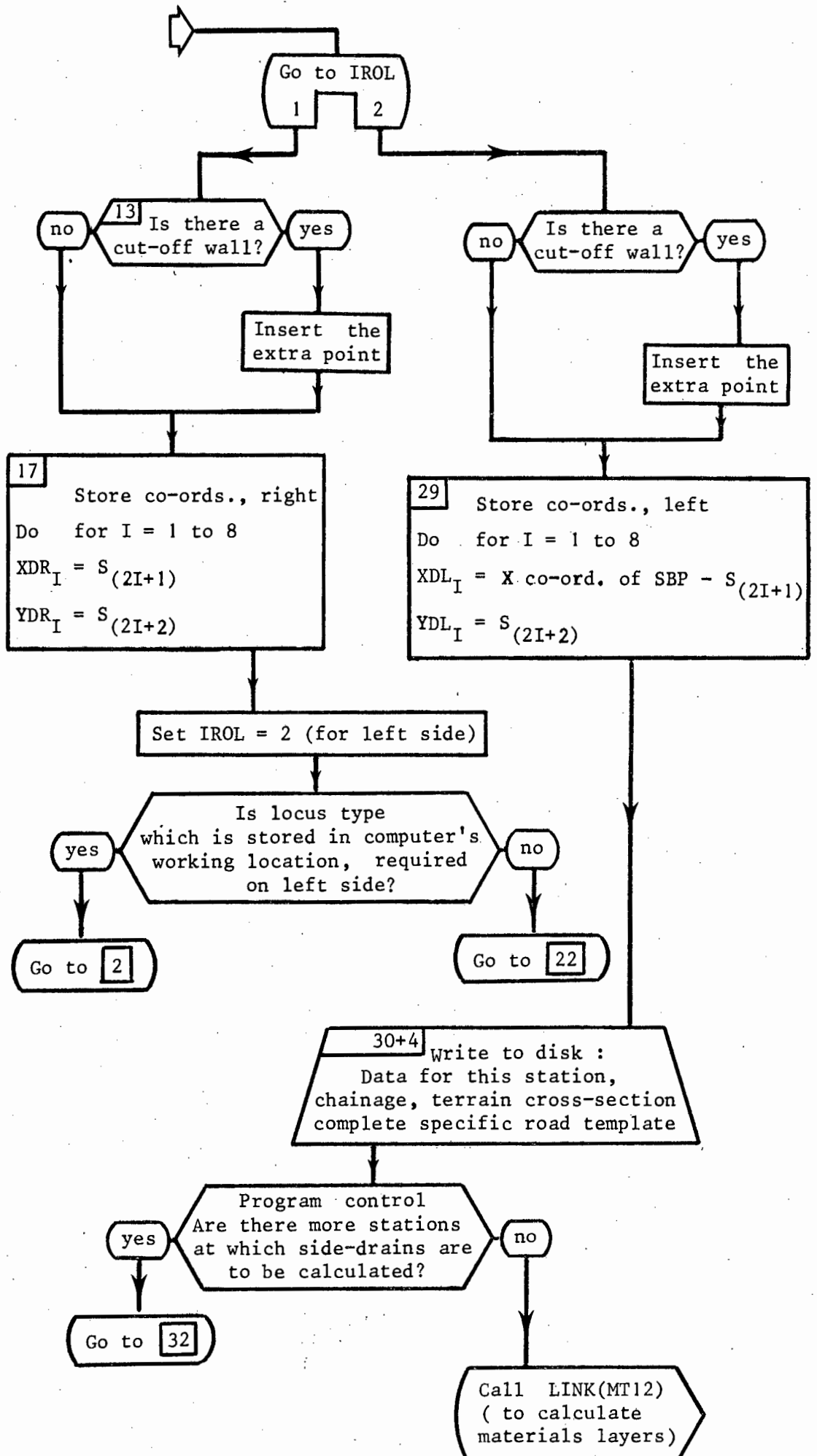


## MT10 (continued)



MT11 CALCULATES SIDE-DRAIN POINTS

## MT11 (continued)



CODING  
OF S H A R M PROGRAMS  
USED IN THE DETERMINATION  
OF SIDE-DRAIN TEMPLATES

Written for: IBM 1130 Computer Model 2B, 8 K,  
Disk Monitor System, version 2.

Compiler: FORTRAN IV

Using: (i) IDEAL 1130 FORTRAN Subroutine  
System  
(ii) IBM 1130 Scientific Subroutine  
Package

	<u>Page</u>
<u>FORTRAN Variable Names</u>	
MT4	C2
MT5	C3
MT10	C5
MT11	C9

<u>Listing of Source Programs</u>		
MT4	Checks and stores loci	C11
MT5	Stores side-drain components	C14
MT10	Finds slope stake points	C18
MT11	Calculates side-drain points	C22

MT4 Variables

ELE1	vertical offset of locus-line point 1
ELE2	vertical offset of locus-line point 2
I	counter
IND	counter
ISLOP	slope preference
IWGT	weight
J	counter
K	counter
K1	locus type count
K2	locus-line count
L	counter
LOC	locus number
OFF1	horizontal offset of locus-line point 1
OFF2	horizontal offset of locus-line point 2

MT5 Variables

A double subscripted array. (This storage location is used for both matrix A before its inversion and matrix  $A^{-1}$  after the inversion).

B vector of summations to be used by program MT11 in calculating co-ordinates of side-drain points.

D single vector array in matrix equations

$$\begin{aligned} & A \cdot B = D \\ \text{and } B & = A^{-1} \cdot D \end{aligned}$$

(comprises all given horizontal and vertical components, and zeros when slope components are given).

DET determinant

ELE vertical component, V

I counter

IBL switch indicator for "blank" field  
(If field has a value, IBL = 1  
If field is blank, IBL = 2)

ICONT component count

IOFF horizontal component, H

J counter

JS sign indicator for ELE

K counter

L counter

LOC1 locus-line count for the full job

LWV1 working vector 1

LWV2 working vector 2

M counter

N counter

NB counter

NC counter

NCHEC indicator to test presence of a locus-line

ND counter

MT5 Variables (contd.)

ND2	counter
NE	counter
NLINE	locus-line number
NLOC	locus type number
S	single vector array (for matrix inversion)
SLOPE	slope component, S

MT10 Variables

AMAX largest of all horizontal offsets to locus-line points  
 BOTX X co-ordinate of locus-line point used for bottom cut-off wall (i.e. fill)  
 BOTY Y co-ordinate of locus-line point used for bottom cut-off wall  
 BTX horizontal offset of point 1 of locus-line 1  
 BTY vertical offset of point 1 of locus-line 1  
 CH nominal chainage  
 CH2 corrected chainage at which subsequent locus is called in  
 CHV corrected chainage at this station  
 DIST distance of potential SSP from locus-line point  
 FRL finished road level  
 GX X co-ordinate of terrain point  
 GY Y co-ordinate of terrain point  
 I counter  
 ICTR template point number on centre-line  
 IND indicator for an intersection within defined lengths of lines  
 (If there is an intersection, IND = 1  
 If there is no intersection, IND = 2)  
 IROL indicator for right or left side  
 (right, IROL = 1  
 left, IROL = 2)  
 ISLP terrain slope control code  
 ITX horizontal offset of terrain point  
 ITY vertical offset of terrain point  
 IWGT locus-line weight code  
 J counter  
 K counter  
 L counter  
 LINL locus-line number on which SSP lies, left

MT10 Variables (contd.)

LINR locus-line number on which SSP lies, right  
 LOC locus type number last called  
 LONUM locus type number applicable at this station  
 LPT terrain point number  
 LSWTH indicator to test chainage for next locus call  
 LTPL2 subsequent locus type, left  
 LTPR2 subsequent locus type, right  
 LTYP locus type applicable at this station  
 LTYPL LTYP, left  
 LTYPR LTYP, right  
 LWICH potential SSP number  
 MORE indicator for cut-off wall  
 (If no cut-off wall, MORE = 0  
 If cut-off wall is applied, MORE = 1)  
 MOREL MORE, left  
 MORER MORE, right  
 NSTA terrain point count  
 NSTO outermost terrain point number (i.e. the extrapolated  
 point, if the terrain cross-section is extended)  
 NUMBT number of given points in this road surface template  
 NUMG number of terrain points in this cross-section  
 NUML number of locus-lines in this locus  
 NUMLL NUML, left  
 NUMLR NUML, right  
 SBP a term used in transposing the X co-ordinates of the  
 terrain cross-section left to right  
 SBPX X co-ordinate of shoulder break point  
 SBPY Y co-ordinate of shoulder break point  
 SMALL smallest DIST

MT10 Variables (contd.)

TEMP temporary storage while switching offsets of locus-line points around, when IWGT is -ve  
 TOPX X co-ordinate of locus-line point used for top cut-off wall (i.e. cut)  
 TOPY Y co-ordinate of locus-line point used for top cut-off wall  
 TPX horizontal offset of point 2 of the locus-line having the highest number  
 TPY vertical offset of point 2 of the locus-line having the highest number  
 X X co-ordinate of intersection point  
 X1 horizontal offset to locus-line point 1  
 X1MAX largest X1  
 X2 horizontal offset to locus-line point 2  
 X2MAX largest X2  
 XG horizontal offset of terrain point  
 XL1 X co-ordinate of locus-line point 1  
 XL2 X co-ordinate of locus-line point 2  
 XMAX (the largest of all X co-ordinates of locus-line points) + 1  
 XST X co-ordinate of accepted SSP  
 XSTP X co-ordinate of potential SSP  
 XSTPL XSTP, left  
 XSTPR XSTP, right  
 Y Y co-ordinate of intersection point  
 Y1 vertical offset to locus-line point 1  
 Y2 vertical offset to locus-line point 2  
 YEF Y co-ordinate of terrain at cut-off wall (i.e. at actual SSP. In this case the computer considers the SSP to be the relevant locus-line point).  
 YEFL YEF, left  
 YEFR YEF, right

MT11 Variables

A triple subscripted array, containing a double vector matrix of elements (after the inversion), for each locus-line in the locus

B(1) X co-ordinate of SBP

B(2) Y co-ordinate of SBP

B(3) X co-ordinate of SSP

B(4) Y co-ordinate of SSP

D double vector array containing a single vector matrix of summations obtained in MT5, for each locus-line in the locus

IND2 counter

IR counter

IROL indicator for left or right side  
(left, IROL = 1  
right, IROL = 2)

ITX horizontal offset of road surface template point

ITY vertical offset of road surface template point

KN counter

KNDL number of intermediate side-drain points, left

KNDR number of intermediate side-drain points, right

L1NL locus-line number on which SSP lies, left

L1NR locus-line number on which SSP lies, right

LOFIL locus-line count for the full job

LTYP locus type number

LTYPPL LTYP, left

LTYPRL LTYP, right

MOREL cut-off wall indicator, left

MORER cut-off wall indicator, right

N counter

NB counter

ND counter

MT11 Variables (contd.)

ND2 counter

NDK counter

NDRL number of side-drain points, left

NDRR number of side-drain points, right

NUMBT number of road surface template points

NUML number of locus-lines in the locus

NUMLL NUML, left

NUMLR NUML, right

S co-ordinate of side-drain point  
(odd subscripts indicate X co-ordinates  
even subscripts indicate Y co-ordinates)

XDL X co-ordinate of side-drain point, left

XDR X co-ordinate of side-drain point, right

XSTPL X co-ordinate of SSP, left

XSTPR X co-ordinate of SSP, right

YDL Y co-ordinate of side-drain point, left

YDR Y co-ordinate of side-drain point, right

YEFL Y co-ordinate of terrain at cut-off wall, left

YEFR Y co-ordinate of terrain at cut-off wall, right

YSTPL Y co-ordinate of SSP, left

YSTPR Y co-ordinate of SSP, right

MT4 Checks and Stores Loci

```

// JOB
// FOR
*ONE WORD INTEGERS
*IOCS(TYPEWRITER)
*IOCS(CARD,1132PRINTER,DISK)
*NAME MT4
**  MT4    STORES AND CHECKS LOCI
    DIMENSION IWGT(12,12),ICARD(80),ISLOP(12,12),OFF1(12,12),OFF2(12,1
12),ELE1(12,12),ELE2(12,12),LOC(12)
    COMMON JJJJJ
    COMMON NUM,ND,ND2,NUMLA,NUMLB,NUMRA,NUMRB,NUMBT,NUMG,NUML,NDK
    COMMON NDRL,NDRR
    DEFINE FILE 7(12,160,U,LONUM)
    DEFINE FILE 15(1,80,U,LKARD)
    DEFINE FILE 11(320,1,U,IPAR)
    IPAR=100
    DO 1 I=1,12
    LOC(I)=0
    DO 1 J=1,12
1  IWGT(I,J)=0
    READ(15'1)ICARD
    GO TO 2
3  READ(2,200)ICARD
200 FORMAT(80A1)
    IF(ICARD(1)+14784)4,2,4
2  CALL MASI(ICARD,2,3,K1)
    IF(K1)5,5,6
5  WRITE(1,201)ICARD
201 FORMAT(80A1)
    WRITE(1,202)K1
202 FORMAT(I3,' INVALID LOCUS NO')
300 PAUSE 1111
    GO TO 300
6  IF(12-K1)5,7,7
7  CALL MASI(ICARD,4,5,K2)
    IF(K2)8,8,9
8  WRITE(1,201)ICARD
    WRITE(1,203)K2
203 FORMAT(I3,' INVALID LINE NO')
    GO TO 300
9  IF(12-K2)8,10,10
10 IF(IWGT(K1,K2))11,12,11
11 WRITE(1,201)ICARD
    WRITE(1,204)K1,K2
204 FORMAT('LOCUS ',I3,' LINE ',I3,' ALREADY READ')
    GO TO 300
12 CALL MASI(ICARD,7,8,IWGT(K1,K2))
    CALL TSGNI(ICARD,6,8,IWGT(K1,K2))
    IF(IWGT(K1,K2))13,14,13
14 WRITE(1,201)ICARD
    WRITE(1,205)IWGT(K1,K2)
205 FORMAT(I4,' INVALID WEIGHT')
    GO TO 300
13 IF(12-IWGT(K1,K2))14,15,15
15 CALL MASI(ICARD,9,10,ISLOP(K1,K2))
    CALL TSGNI(ICARD,9,10,ISLOP(K1,K2))
    CALL MADI(ICARD,11,15,OFF1(K1,K2))
    CALL DFLT(OFF1(K1,K2))
    OFF1(K1,K2)=OFF1(K1,K2)/100.
    CALL MADI(ICARD,23,27,OFF2(K1,K2))

```

page 2 MT4 (continued)

```

CALLDFLT(OFF2(K1,K2))
OFF2(K1,K2)=OFF2(K1,K2)/100.
CALL MADI(ICARD,17,22,ELE1(K1,K2))
CALL TSGND(ICARD,16,22,ELE1(K1,K2))
CALL DFLT(ELE1(K1,K2))
ELE1(K1,K2)=ELE1(K1,K2)/1000.
CALL MADI(ICARD,29,34,ELE2(K1,K2))
CALL TSGND(ICARD,28,34,ELE2(K1,K2))
CALL DFLT(ELE2(K1,K2))
ELE2(K1,K2)=ELE2(K1,K2)/1000.
GO TO 3
4 WRITE(15'1')ICARD
DO 18 I=1,12
  IND=1
  DO 18 J=1,12
    IF(IWGT(I,J))20,19,20
20 GO TO(21,22),IND
22 K=J-1
  WRITE(1,207)I,K
207 FORMAT('LOCUS ',I3,' LINE ',I3,' MISSING')
  GO TO 300
21 LOC(I)=J
  GO TO 18
19 IND=2
18 CONTINUE
  DO 23 I=1,12
    IND=LOC(I)
    IF(IND)23,23,24
24 DO 50 J=1,IND
  DO 25 K=1,IND
    IF(J-IABS(IWGT(I,K)))25,50,25
25 CONTINUE
  WRITE(1,208)I,J
208 FORMAT('LOCUS ',I3,' WEIGHT ',I3,' MISSING')
  GO TO 300
50 CONTINUE
23 CONTINUE
  DO 26 I=1,12
26 WRITE(7'I)LOC(I),(IWGT(I,J),ISLOP(I,J),OFF1(I,J),ELE1(I,J),OFF2(I,
1J),ELE2(I,J),J=1,12)
  WRITE(11'IPAR)LOC
  WRITE(3,400)
400 FORMAT('1',27X,'SIDE DRAIN LOCUS LINES'//)
  WRITE(3,401)
401 FORMAT(' ', ' LOCUS NO ', 'LINE NO',3X,'WEIGHT',4X,'SLOPE',8X,
12('HOR',8X,'VERT',17X)/)
  L=0
  DO 27 I=1,12
    K=LOC(I)
    IF(K)27,27,28
28 L=L+1
  IF(L-5)29,30,30
30 WRITE(3,402)
402 FORMAT(1H1)
  WRITE(3,401)
  L=0
29 WRITE(3,403)
403 FORMAT(1H0)
  DO 31 J=1,K
31 WRITE(3,404)I,J,IWGT(I,J),ISLOP(I,J),OFF1(I,J),ELE1(I,J),OFF2(I,J)
1 ,ELE2(I,J)

```

page 3 MT4 (continued)

```
404 FORMAT(' ',5X,4(I3,7X),2(F6.2,4X,F8.3,14X))
27 CONTINUE
   CALL DATSW(14,J)
   GO TO(581,582),J
581 PAUSE 4
582 IF(ICARD(1)+14528)583,584,583
584 CALL LINK(MT5)
583 IF(ICARD(1)-16448)585,586,585
585 WRITE(1,200)ICARD
   WRITE(1,500)
500 FORMAT('INCORRECT CODE')
   GO TO 300
586 CALL EXIT
   END.
```

// DUP

```
*STORECI    WS  UA  MT4    1
*FILES(7,LOCUS)
```

MT5 Stores Side-drain Components

```

// JOB
// FOR
*ONE WORD INTEGERS
*NAME MT5
** MT5 STORES SIDE DRAIN COMPONENTS
*IOCS(DISK)
  DIMENSION A(12,12),S(144),D(12),LWV1(12),LWV2(12),ICARD(80),LINE(1
120),IDATA(13),LIN(120),LTITL(60),B(12),NCHEC(12,12)
  COMMON JJJJJ
  COMMON NUM,ND,ND2,NUMLA,NUMLB,NUMRA,NUMRB,NUMBT,NUMG,NUML,NDK
  COMMON NDRL,NDRR
  DEFINE FILE 4(144,106,U,LOC1)
  DEFINE FILE 15(1,80,U,KCARD)
  DEFINE FILE 11(320,1,U,IPAR)
  DEFINE FILE 55(4,120,U,JTITL)
  DATA LTITL/' ','H1',3*' ','V1',3*' ','S',1',2*' ','H2',3*'
1 ','V2',3*' ','S',2',2*' ','H3',3*' ','V3',3*' ','S',3',
22*' ','H4',3*' ','V4',3*' ','S',4',2*' ','H5',3*' ','V5',3
3*' ','S',5',1' /
  DATA IDATA/'LO','CU','S ','LI','NE','ST','GR','ED','CO','DE','E',
1'RR','OR' /
  IPAR=112
  DO 70 I=1,12
  DO 70 J=1,12
70 NCHEC(I,J)=0
  DO 4 I=1,120
  LINE(I)=16448
  4 LIN(I)=16448
  IOFLO=2
  CALL SKSP(1)
  LCCOD=2
  IEROR=1
  READ(15'1)ICARD
  GO TO 35
  3 CALL READ(ICARD,80,LCCOD)
  IF(ICARD(1)+14528)34,35,34
35 CALL MASI(ICARD,2,3,NLOC)
  CALL MASI(ICARD,4,5,NLINE)
  IF(NLOC)24,24,54
54 IF(12-NLOC)24,55,55
55 IF(NLINE)24,24,56
56 IF(12-NLINE)24,57,57
57 ICONT=0
  1 DO 11 I=1,12
  DO 12 J=1,12
12 A(I,J)=0.
11 D(I)=0.
  A(1,1)=1.
  A(2,2)=1.
  N=3
  K=0
  DO 6 L=1,5
  M=L-K
  ISTA=L*15-9
  ISTO=ISTA+3
  CALL BLANK(ICARD,ISTA,ISTO,IBL)
  GO TO (7,8),IBL
  7 CALL MASI(ICARD,ISTA,ISTO,IOFF)
  ICONT=ICONT+1

```

page 2 MT5 (continued)

```

    LINST=24*L-23
    LAST=ISTA+1
    CALL MOVE(ICARD,ISTA,LAST,LIN,LINST)
    LIN(LINST+2)=19264
    LIN(LINST+3)=ICARD(ISTA+2)
    LIN(LINST+4)=ICARD(ISTO)
    IF(IOFF)9,9,10
10  ICHEC=2
    A(N,2*M-1)=-1.
    A(N,2*M+1)=1.
    D(N)=(FLOAT(IOFF))/100.
    N=N+1
    GO TO 13
    9  ICHEC=1
    GO TO 13
    8  ICHEC=3
13  ISTA=L*15-5
    ISTO=ISTA+5
    CALL BLANK(ICARD,ISTA,ISTO,IBL)
    GO TO (14,41),IBL
41  GO TO (10,15,15),ICHEC
14  CALL MADI(ICARD,ISTA,ISTO,ELE)
    CALL TSGND(ICARD,ISTA,ISTO,ELE)
    CALL DISGN(ELE,JS)
    ICONT=ICONT+1
    LINST=24*L-16
    LAST=ISTA+2
    CALL MOVE(ICARD,ISTA,LAST,LIN,LINST)
    LIN(LINST+3)=19264
    LIN(LINST+4)=ICARD(ISTA+3)
    LIN(LINST+5)=ICARD(ISTA+4)
    LIN(LINST+6)=ICARD(ISTO)
    GO TO (17,16,16),ICHEC
16  A(N,2*M)=-1.
    A(N,2*M+2)=1.
    CALL DFLT(ELE)
    D(N)=ELE/1000.
    N=N+1
    GO TO (6,6,15),ICHEC
17  IF(JS)18,19,18
18  A(N,2*M-1)=-1.
    A(N,2*M+1)=+1.
    N=N+1
    GO TO 16
19  K=K+1
    GO TO 6
15  ISTA=15*L+1
    ISTO=ISTA+4
    CALL BLANK(ICARD,ISTA,ISTO,IBL)
    GO TO (20,6),IBL
20  CALL MADI(ICARD,ISTA,ISTO,SLOPE)
    CALL TSGND(ICARD,ISTA,ISTO,SLOPE)
    CALL DFLT(SLOPE)
    LINST=24*L-7
    ICONT=ICONT+1
    LAST=ISTA+2
    CALL MOVE(ICARD,ISTA,LAST,LIN,LINST)
    LIN(LINST+3)=19264
    LFST=ISTA+3
    LINST=LINST+4
    CALL MOVE(ICARD,LFST,ISTO,LIN,LINST)

```

page 3 MT5 (continued)

```

SLOPE=SLOPE/100.
A(N,2*M-1)=SLOPE
A(N,2*M)=-1.
A(N,2*M+1)=-SLOPE
A(N,2*M+2)=1.
N=N+1
6 CONTINUE
IF(ICONT-8)24,40,24
40 A(N,N)=1.
N=N+1
A(N,N)=1.
IF(N-4)21,21,22
21 ND=0
NB=1
ND2=3
X=0.
Y=0.
NCHEC(NLOC,NLINE)=1
LOC1=(NLOC-1)*12+NLINE
WRITE(4'LOC1)N,ND,NB,ND2,X,Y
GO TO 26
22 CALL ARRAY(2,N,N,12,12,S,A)
CALL MINV(S,N,DET,LWV1,LWV2)
IF(DET)25,24,25
25 CALL ARRAY(1,N,N,12,12,S,A)
ND=N-4
ND2=ND+2
DO 31 I=3,ND2
B(I)=0.
DO 31 J=3,ND2
31 B(I)=B(I)+A(I,J)*D(J)
DO 32 J=1,2
DO 32 I=1,ND
32 A(I,J)=A(I+2,J)
NC=N-1
DO 33 J=NC,N
NE=J-N+4
DO 33 I=1,ND
33 A(I,NE)=A(I+2,J)
NB=J*ND
NCHEC(NLOC,NLINE)=1
LOC1=(NLOC-1)*12+NLINE
WRITE(4'LOC1)N,ND,NB,ND2,((A(I,J),I=1,ND),J=1,4),(B(I),I=3,ND2)
26 CALL UNPK(LINE,40,45,IDATA,6)
GO TO 27
24 CALL UNPK(LINE,50,55,IDATA,11)
IEROR=2
27 CALL UNPK(LINE,3,8,IDATA,1)
CALL UNPK(LINE,15,18,IDATA,4)
CALL MSIA(LINE,9,10,NLOC,-1)
CALL MSIA(LINE,20,21,NLINE,-1)
CALL WRTS(LINE,120,IOFLO)
CALL UNPK(LINE,1,120,LTITL,1)
CALL SKSP(-1)
CALL WRTS(LINE,120,IOFLO)
CALL WRTS(LIN,120,IOFLO)
CALL SKSP(-3)
GO TO(3,58),IEROR
58 PAUSE 1111
GO TO 58
34 WRITE(15'1)ICARD

```

page 4 MT5 (continued)

```
WRITE(11,'IPAR)NCHEC
CALL DATSW(14,J)
GO TO(63,64),J
63 PAUSE 5
64 IF(ICARD(1)+14272)71,65,71
71 IF(ICARD(1)-16448)72,73,72
73 CALL EXIT
72 CALL UNPK(LINE,5,14,IData,9)
CALL WRTS(LINE,120,IOFLO)
GO TO 58
65 CALL LINK(MT6)
END
```

// DUP

\*DELETE

MT5

\*STORE

WS UA MT5

MT10 Finds Slope Stake Points

```

// JOB
// FOR
*ONE WORD INTEGERS
*NAME MT10
** MT10 FINDS SLOPE STAKE POINTS
*IOCS(DISK)
  DIMENSION XG(20),YG(20),GX(21),GY(21),ITX(15),ITY(15),XSTP(5),YSTP
  1(5),X1(12),X2(12),Y1(12),Y2(12),XL1(12),XL2(12),YL1(12),YL2(12),IS
  2LP(12),IWGT(12)
  COMMON JJJJJ
  COMMON NUM,ND,ND2,NUMLA,NUMLB,NUMRA,NUMRB,NUMBT,NUMG,NUML,NDK
  COMMON NDRL,NDRR
  DEFINE FILE 20(500,320,U,IFIL)
  DEFINE FILE 2(424,6,U,IVPI)
  DEFINE FILE 7(12,160,U,LONUM)
  DEFINE FILE 8(240,4,U,ICAL2)
  DEFINE FILE 55(4,120,U,JTITL)
  LOC=0
  IFIL=1
  READ(8'1)LAST
  READ(2'410)NU
  LSWTH=1
  ISTAR=1
  READ(8'2)CH2,LTYPL,LTYPR
  ISTAR=1
  LREC=3
49 READ(20'IFIL)CH,CHV,FRL,NUMG,(XG(I),YG(I),I=1,NUMG),NUMBT,ICTR,(IT
  1X(I),ITY(I),I=1,NUMBT)
  GO TO (2,3),ISTAR
  2 ISTAR=2
  GO TO 8
  3 IF(LSWTH)1,1,4
  4 CALL SD(TEST,CH2,CHV)
  CALL DISGN(TEST,J)
  IF(J)5,5,1
  5 IF(LTPL2)6,6,7
  7 LTYPL=LTPL2
  6 IF(LTPR2)8,8,9
  9 LTYPR=LTPR2
  8 IF(LAST-LREC)10,52,52
52 READ(8'LREC)CH2,LTPL2,LTPR2
  LREC=LREC+1
  GO TO 4
  10 LSWTH=0
  1 LTYP=LTYPR
  IROL=1
48 IF(LTYP-LOC)11,12,11
  11 LONUM=LTYP
  LOC=LTYP
100 READ(7'LONUM)NUML,(IWGT(L),ISLP(L),X1(L),Y1(L),X2(L),Y2(L),L=1,NUM
  1L)
  BTX=X1(1)
  BTY=Y1(1)
  TPX=X2(NUML)
  TPY=Y2(NUML)
  DO 13 I=1,NUML
  IF(IWGT(I))14,14,13
  14 TEMP=X1(I)
  X1(I)=X2(I)
  X2(I)=TEMP
  TEMP=Y1(I)

```

page 2 MT10 (continued)

```

Y1(I)=Y2(I)
Y2(I)= TEMP
13 CONTINUE
X1MAX=X1(1)
X2MAX=X2(1)
DO 15 I=2,NUML
  IF(X1(I)-X1MAX)16,16,17
17 X1MAX=X1(I)
16 IF(X2(I)-X2MAX)15,15,18
18 X2MAX=X2(I)
15 CONTINUE
  IF(X1MAX-X2MAX)19,20,20
19 AMAX=X2MAX
  GO TO 12
20 AMAX=X1MAX
12 GO TO (21,22),IROL
21 SBPX=FLOAT(ITX(NUMBT))/100.
  SBPY=FLOAT(ITY(NUMBT))/1000.
  GO TO 23
22 SBPX=FLOAT(ITX(1))/100.
  SBPY=FLOAT(ITY(1))/1000.
23 DO 24 I=1,NUML
  XL1(I)=SBPX+X1(I)
  XL2(I)=SBPX+X2(I)
  YL1(I)=SBPY+Y1(I)
24 YL2(I)=SBPY+Y2(I)
  BOTX=SBPX+BTX
  TOPX=SBPX+TPX
  BOTY=SBPY+BTY
  TOPY=SBPY+TPY
  XMAX=SBPX+AMAX+1.
  GO TO (25,26),IROL
25 DO 27 I=1,NUMG
  GX(I)=XG(I)
27 GY(I)=YG(I)
  GO TO 28
26 SRP=2*SBPX
  DO 29 I=1,NUMG
  J=NUMG-I+1
  GX(J)=SRP-XG(I)
29 GY(J)=YG(I)
28 IF(XMAX-GX(NUMG))51,51,30
30 NSTO=NUMG+1
  GX(NSTO)=XMAX
  GY(NSTO)=POLTN(GX(NUMG-1),GY(NUMG-1),GX(NUMG),GY(NUMG),XMAX)
  GO TO 31
51 NSTO=NUMG
31 DO 61 I=1,NSTO
  LPT=NSTO-I+1
  IF(GX(LPT)-SBPX)62,61,61
61 CONTINUE
62 NSTA=LPT+1
  DO 32 J=1,NUML
  DO 33 I=1,NUML
  K=I
  IF(IARS(IWGT(I))-J)33,34,33
33 CONTINUE
34 L=0
  DO 35 I=NSTA,NSTO
  EPSIL=10.**(-20)
  CALL INLOC(XL1(K),YL1(K),XL2(K),YL2(K),GX(I-1),GY(I-1),GX(I),GY(I))

```

page 3 MT10 (continued)

```

1, EPSIL, X, Y, IND)
  GO TO (36,35), IND
36 IF (ISLP(K)) 37,38,39
37 IF (GY(I)-GY(I-1)) 38,38,35
39 IF (GY(I)-GY(I-1)) 35,38,38
38 L=L+1
  XSTP(L)=X
  YSTP(L)=Y
35 CONTINUE
  IF (L-1) 32,40,43
32 CONTINUE
101 XST=TOPX
  CALL CTVRT(GX,GY,XST,YST,1,NSTO,I,ISTO)
  K=NUML
  MORE=1
  YEF=TOPY
  IF (TOPY-YST) 41,41,42
42 XST=BOTX
  CALL CTVRT(GX,GY,XST,YST,1,NSTO,I,ISTO)
  YEF=BOTY
  K=1
  GO TO 41
43 SMALL=DISQD(XL1(K),YL1(K),XSTP(1),YSTP(1))
  LWICH=1
  DO 44 I=2,L
    DIST=DISQD(XL1(K),YL1(K),XSTP(I),YSTP(I))
    IF (SMALL-DIST) 44,44,45
45 SMALL=DIST
  LWICH=I
44 CONTINUE
  XST=XSTP(LWICH)
  YST=YSTP(LWICH)
  MORE=0
  GO TO 41
40 MORE=0
  XST=XSTP(1)
  YST=YSTP(1)
41 GO TO (46,47), IROL
46 XSTPR=XST
  YEFR=YEF
  NUMLR=NUML
  YSTPR=YST
  LINR=K
  MORER=MORE
  LTYPL=LTYPL
  IROL=2
  GO TO 48
47 XSTPL=SBP-XST
  YFFL=YEF
  NUMLL=NUML
  YSTPL=YST
  LINL=K
  MOREL=MORE
  IFIL=IFIL-1
  WRITE (20, IFIL) CH, CHV, FRL, NUMG, (XG(I), YG(I), I=1, NUMG), NUMBT, ICTR, (I
  1TX(I), ITY(I), I=1, NUMBT), LTYPL, LINL, MOREL, XSTPL, YSTPL, LTYPR, LINR, MO
  2RER, XSTPR, YSTPR, YEFR, YEFL, NUMLL, NUMLR
  IF (IFIL=NU) 49,49,50
50 CALL DATSW(14,J)
  GO TO (53,54), J
53 PAUSE 10

```

page 4 MT10 (continued)

54 CALL LINK(MT11)

END

// DUP

\*DELETE

MT10

\*STORE

WS UA

MT10

MT11 Calculates Drain Points

```

// JOB
// FOR
*NAME MT11
**   MT11   CALCULATES DRAIN POINTS
*IOCS(DISK)
*ONE WORD INTEGERS
  DIMENSION GX(20),GY(20),ITX(15),ITY(15),N(12),ND(12),NB(12),ND2(12
1),A(8,4,12),D(8,12),B(4),S(12),XDR(6),YDR(6),XDL(6),YDL(6)
  COMMON JJJJJ
  COMMON NUM,ND,ND2,NUMLA,NUMLB,NUMRA,NUMRB,NUMBT,NUMG,NUML,NDK
  COMMON NDRL,NDRR
  DEFINE FILE 20(500,320,U,IFIL)
  DEFINE FILE 2(424,6,U,IVPI)
  DEFINE FILE 4(144,106,U,LOCI)
  DEFINE FILE 55(4,120,U,JTITL)
  LTYP=0
  IFIL=1
  READ(2,410)NU
32 READ(20,IFIL)CH,CHV,FRL,NUMG,(GX(I),GY(I),I=1,NUMG),NUMBT,iOCR,(IT
1X(I),ITY(I),I=1,NUMBT),LTYPL,LINL,MOREL,XSTPL,YSTPL,LTYPR,LINR,MOR
2ER,XSTPR,YSTPR,YEFR,YEFL,NUMLL,NUMLR
  IROL=1
  YEFL=YEFL
  IF(LTYPR-LTYP)1,2,1
1. NUML=NUMLR
  LTYP=LTYPR
22 DO 3 K=1,NUML
  LOFIL=(LTYP-1)*12+K
  READ(4,LOFIL)N(K),NDK,NB(K),ND2(K),((A(I,J,K),I=1,NDK),J=1,4),(D(I
1,K),I=1,NDK)
  3 ND(K)=NDK
  2 GO TO(4,5),IROL
  4 B(1)=FLOAT(ITX(NUMBT))/100.
  B(2)=FLOAT(ITY(NUMBT))/1000.
  B(3)=XSTPR
  IF(MORER)6,6,7
  6 B(4)=YSTPR
  GO TO 8
  7 B(4)=YEFR
  8 K=LINR
26 IF(ND(K))9,9,10
10 IND2=ND2(K)
  DO 11 I=3,IND2
  S(I)=0
  IR=I-2
  DO 12 J=1,4
12 S(I)=S(I)+A(IR,J,K)*B(J)
11 S(I)=S(I)+D(IR,K)
  9 S(1)=B(1)
  S(2)=B(2)
  KN=N(K)
  S(KN-1)=B(3)
  S(KN)=B(4)
  GO TO(13,14),IROL
13 IF(MORER)16,16,15
15 NDRR=N(K)/2
  XDR(NDRR)=XSTPR
  YDR(NDRR)=YSTPR
  KNDR=NDRR-1
  GO TO 17

```

page 2 MT11 (continued)

```

16 NDRR=N(K)/2-1
   KNDR=NDRR
17 DO 18 I=1,KNDR
   XDR(I)=S(2*I+1)
18 YDR(I)=S(2*I+2)
   IROL=2
   IF(LTYPL-LTYP)21,2,21
21 NUML=NUMLL
   LTYP=LTYPL
   GO TO 22
   5 B(1)=0.
   B(2)=FLOAT(ITY(1))/1000.
   B(3)=FLOAT(ITX(1))/100.-XSTPL
   IF(MOREL)23,23,24
23 B(4)=YSTPL
   GO TO 25
24 B(4)=YEFL
25 K=LINL
   GO TO 26
14 IF(MOREL)28,28,27
27 NDRL=N(K)/2
   XDL(NDRL)=XSTPL
   YDL(NDRL)=YSTPL
   KNDL=NDRL-1
   GO TO 29
28 NDRL=N(K)/2-1
   KNDL=NDRL
29 DO 30 I=1,KNDL
   XDL(I)=FLOAT(ITX(1))/100.-S(2*I+1)
30 YDL(I)=S(2*I+2)
   ICODL=100*LTYPL+LINL
   ICODR=100*LTYPR+LINR
   IFIL=IFIL-1
   WRITE(20,IFIL)CH,CHV,FRL,NUMG,(GX(I),GY(I),I=1,NUMG),NUMBT,IOCR,(I
1TX(I),ITY(I),I=1,NUMBT),NDRL,(XDL(I),YDL(I),I=1,NDRL),NDRR,(XDR(I)
2,YDR(I),I=1,NDRR),ICODL,ICODR
   IF(IFIL-NU)32,32,31
31 CALL DATSW(14,J)
   GO TO(33,34),J
33 PAUSE 11
34 CALL LINK(MT12)
END

```

// DUP

\*DELETE

MT11

\*STORE

WS UA

MT11

SAMPLE PROBLEM

	<u>Page</u>
Input data sheets	D2
Terrain Edit print-out	D13
Grade-line print-out	D17
Locus Edit print-out	D19
Quantities print-out	D23

# E.C.G. SHARM

## TITLE SHEET

17/9/73 Date	GK1 Job	J.K. Eng.	Sheet 1 of 19 Sheets
-----------------	------------	--------------	-------------------------

A  
Y  
V

Client: <b>G. KEUCK,</b> Address: <b>P.O. Box 1347,</b> <b>Cape Town.</b>	Client's Ref No <b>U.C.T.</b>	Remarks:
	E.C.C. Ref No <b>24</b> (Leave blank)	
Refer to Engineer: <b>G. KEUCK</b>	Upon completion of this run cards must be Stored by E.C.C. <input type="checkbox"/> Sent to Client <input checked="" type="checkbox"/>	

Are any sets of cards required for this run(s) already with E.C.C.  Yes <input type="checkbox"/>  No <input checked="" type="checkbox"/>	Which Sets?	Do they require?		Is a quantities print-out required?  Yes <input checked="" type="checkbox"/> No <input type="checkbox"/>  Insert chainages from <b>B. 2.0</b> to <b>3.95</b>
		Attached Modifications and/or Corrections	No Amendments	

Please tick (✓) blocks that apply.

Enter descriptive title of present run(s).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
* A	TEST RUN --- M. SC. ENG. THESIS --- G. KEUCK. SEPTEMBER 1973																																																																															

Do new, modified or corrected Terrain Cross Sections accompany this sheet?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	E	F	G	H	J																																																																											
* Y	1.20	1.60	1.00	2.0	0.5																																																																											

Yes 

Insert Terrain data edit parameters

from chainage **B. 1.95**  
to chainage **3.95**No 

Delete "Y" line

Is a grade-line print-out required?

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	S	T	A	R	T	S	T	O	P																																																																							
	@ km					@ km																																																																										
* W	-1.1					B	2.95																																																																									

Yes 

Insert start and stop chainages

No 

Delete "W" line

\* These lines to be punched if not deleted.

**E.C.C. SHARM**

**BROKEN CHAINAGES**

17/9/73 Date	GKI Job	J.K. Eng.	Sheet 2 of 19 Sheets
-----------------	------------	--------------	-------------------------

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
	INCOMING										OUT GOING								
B											B								
B					3.000						B			2.800					
B																			

**E.C.C. SHARM**

**GRADE-LINE V.P.I.'S**

17/9/73 Date	GKI Job	J.K. Eng.	Sheet 3 of 19 Sheets
-----------------	------------	--------------	-------------------------

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	CHAINAGE											ELEVATION					LENGTH OF							
												P.I.					VERT. CURVE							
B	km											METRES					METRES							
C																								
C																								
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	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	CHAINAGE											ELEVATION					LENGTH OF							
												P.I.					VERT. CURVE							
B	km											METRES					METRES							
C																								
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# E.G.G. SHARM SIDE DRAIN LOCUS TYPES

17/2/73 Date	G121 Job	<i>R.K.</i> Eng.	Sheet 6 of 19 Sheets
-----------------	-------------	---------------------	-------------------------

Locus Line No.	Weight	Slope		P		I		N		T		V		T		I		2		
		Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal	Vertical	
F 1	1	-7	0	156	0	-110	40					6								-4
F 1	2	5	0	6		-4						6								-1
F 1	3	-4	-1	6		-1						7								-1
F 1	4	-3	1	6		-1						7								-1
F 1	5	1	0	7		-1						7								1
F 1	6	2	0	7		1						7								3
F 1	7	6	0	7		3						107								103
F 2	1	3	0	156		-104						6								-4
F 2	2	2	0	6		-4						6								-2
F 2	3	1	0	6		-2						6								2
F 2	4	4	0	6		2						106								102

**E.C.C. SHARM**

**SIDE DRAIN COMPONENTS**

17/9/73 Date  
 GK1 Job  
 P.K. Eng.  
 Sheet 7 of 19 Sheets

**G**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80
	Locus No	Line No	H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5																																																															
G	1	1	0	0		0	0		0	0		0	0																																																																			
G	1	2				0	0		0	0		0	0		0	0																																																																
G	1	3	6	-1		0	0		0	0		0	0																																																																			
G	1	4		-1		1			0	0		0	0		0	0																																																																
G	1	5		-1		1	0			0.5		0	0		0	0																																																																
G	1	6	0	0			-1	-0.5	1		0	0	0																																																																			
G	1	7	0	0		0	0		2	-1		1	0																																																																			
G	2	1				0	0		0	0		0	0		0	0																																																																
G	2	2				0	0		0	0		0	0		0	0																																																																
G	2	3	3	-1					0	0		0	0		0	0																																																																
G	2	4	3	-1					0	0		0	0		0	0																																																																
G	1	5		-1		1	0				0.5	0	0		0	0																																																																

5 V's x

Corrected after error was shown up by Edit routine

D6

**E.C.C. SHARM**

**ROAD SURFACE TEMPLATE CALLS**

17/9/73 Date      GKI Job      P.K. Eng.      Sheet 8 of 19 Sheets **H**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	CHAINAGE										TYPE		TRANSITION		TYPE		TRANSITION											
	B										LEFT		LENGTH		RT.		LENGTH											
H	20										1		0		1		0											
H	35										1				2		20000											
H																												

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	CHAINAGE										TYPE		TRANSITION		TYPE		TRANSITION											
	B										LEFT		LENGTH		RT.		LENGTH											
H																												
H																												
H																												

**E.C.C. SHARM**

**LOCUS CALLS**

17/9/73 Date      GKI Job      P.K. Eng.      Sheet 9 of 19 Sheets

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	CHAINAGE										Locus Lt		Locus Rt	
	B km													
I	2										1		1	
I	375										1		2	
I														

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	CHAINAGE										Locus Lt		Locus Rt	
	B km													
I														
I														
I														

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	CHAINAGE										Locus Lt		Locus Rt	
	B km													
I														
I														
I														

**E.C.C. SHARM**

**MATERIALS DESIGN LAYERS**

17/9/73 Date      GKI Job      P.K. Eng.      Sheet 10 of 19 Sheets **J**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
	CHAINAGE										SSSS		CCCC		MMMM																													
	B km										LLRR		LLRR		LLRR		D1		D2		D3		PARAMETER																					
J	2										2		24		43		3		2		2		2		-1																			
I																																												

**E.C.C. SHARM**

**BULKING FACTORS**

17/9/73 Date      GKI Job      *P.K.* Eng.      Sheet 11 of 19 Sheets

	2	3	4	5	6	7	8	9	10	11	12	13
	CHAINAGE											Bulking Factor
	B km											
K		2										150
K		2.2										50
K												

	2	3	4	5	6	7	8	9	10	11	12	13
	CHAINAGE											Bulking Factor
	B km											
K												
K												
K												

	2	3	4	5	6	7	8	9	10	11	12	13
	CHAINAGE											Bulking Factor
	B km											
K												
K												
K												

**E.C.C. SHARM**

**CENTRE-LINE SHIFTS**

17/9/73 Date      GKI Job      *P.K.* Eng.      Sheet 12 of 19 Sheets

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
	CHAINAGE											SHIFT	TRANSITION										
	B km												LENGTH										
L		3	7	5																			
L		3	7	5	0	0	1																99.99
L																							

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
	CHAINAGE											SHIFT	TRANSITION										
	B km												LENGTH										
L																							
L																							
L																							

K

L



**E.C.C. SHARM**

**GRADE-LINE INTERVALS**

17/9/73 Date      GKI Job      R.K. Eng.      Sheet 16 of 19 Sheets

V

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	CHAINAGE																		
	B km																		
V																			50'
V																			800'
V																			20'
V																			100'
V																			40'
V																			2100'
V																			25'
V																			

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	CHAINAGE																		
	B km																		
V																			
V																			
V																			
V																			
V																			
V																			
V																			
V																			
V																			

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
	CHAINAGE																		
	B km																		
V																			
V																			
V																			
V																			
V																			
V																			
V																			
V																			
V																			

**E.C.C. SHARM**

**CHAINAGES AT WHICH LEVELS ARE REQUIRED**

17/9/73 Date      GKI Job      R.K. Eng.      Sheet 17 of 19 Sheets

X

	1	2	3	4	5	6	7	8	9	10	
	CHAINAGE										
	B km										
X											
X											
X											
X											
X											
X											

	1	2	3	4	5	6	7	8	9	10
	CHAINAGE									
	B km									
X										
X										
X										
X										
X										
X										

	1	2	3	4	5	6	7	8	9	10
	CHAINAGE									
	B km									
X										
X										
X										
X										
X										
X										

# E.C.C. SHARM

## TERRAIN (by Staff Readings)

17/9/73 Date	R.K.I. Job	R.K. Eng.	Sheet 18 of 19 Sheets
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ZI

	CHAINAGE									HEIGHT OF OFFSETS		STAFF		OFFSETS		STAFF		OFFSETS		STAFF		OFFSETS		STAFF		OFFSETS		STAFF		OFFSETS		STAFF		
	B	km	COLLIMATION																															
ZI		195							90			-40	32			40			0.8															
ZI		197							95			-40	15			-40			0.5			40			0.5									
ZI		196							105			-32	20			0			3.0			32			4.0									
ZI		2							110			-32	0			32			2.0			33			2.0									
ZI		21							110			-32	1			32			1.9			33			1.9									
ZI		22							110			-32	2			32			1.8			33			1.8									
ZI		23							90			-10	1			0			2			10			1									
ZI		235							90			-20	0			0			2			20			0									
ZI		245							90			-20	0			0			2			20			0									
ZI		255							90			-20	0			0			2			20			0									
ZI		270							101			-16	2			-15.50			1.4			15.50			1.4			1.6			1.55		2.0	1.55
ZI		285							999			-20	0			20			0															
ZI		2999							110			-20	0			20			0															
ZI	B	2899							90			-20	0			20			0															
ZI		32							994			-25	0			25			0															
ZI		321							996			-25	0			25			0															
ZI		322							998			-25	0			25			0															
ZI		323							100			-25	0			25			0															
ZI		350							104			-25	10			-0.01			1.0			0.01			0			25					0	
ZI		360							105			-25	12			-0.01			1.2			0.01			0			25					0	
ZI		370							106			-25	13			-0.01			1.3			0.01			0			25					0	
ZI																																		



ROAD EARTHWORKS

TERRAIN DATA EDIT

JOB IDENTIFICATION TEST RUN --- M.SC.ENG. THESIS --- G. KEUCK. SEPTEMBER 1973

ERROR LISTING

=====

ASTERISK DENOTES UNACCEPTABLE TERRAIN DATA

A\* = CHAINAGES NOT INCREASING

B\* = OFFSETS NOT INCREASING FROM LEFT TO RIGHT

E = DIST BETWEEN STATIONS EXCEEDS 120. METRES

F = DIFF IN LEVEL BETWEEN ADJACENT PTS EXCEEDS 16.0 METRES

G = DIFF IN MEANS OF MAX AND MIN LEVELS AT SUCCESSIVE STATIONS EXCEEDS 10.0 METRES

H = OUTERMOST PT ON ONE OR BOTH SIDES LESS THAN 20. METRES FROM CENTRE LINE

J = SLOPE BETWEEN 2 OUTERMOST PTS ON ONE OR BOTH SIDES EXCEEDS 0.50 VERT IN 1 HORIZ.

01-533

CHAINAGE	HEIGHT OF COLL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	ERRORS
1.95	90.000	- 40.00 3.200 86.800	40.00 .800 89.200				
1.97	95.000	- 40.00 1.500 93.500	- 40.00 .500 94.500	40.00 .500 94.500			B* J
1.96	105.000	- 32.00 2.000 103.000	.00 3.000 102.000	32.00 4.000 101.000			A*
2.00	110.000	- 32.00 .000 110.000	32.00 20.000 90.000	33.00 20.000 90.000			F
2.10	110.000	- 32.00 1.000 109.000	32.00 19.000 91.000	33.00 19.000 91.000			F
2.20	110.000	- 32.00 2.000 108.000	32.00 18.000 92.000	33.00 18.000 92.000			
2.30	90.000	- 10.00 1.000 89.000	.00 2.000 88.000	10.00 1.000 89.000			GH
2.35	90.000	- 20.00 .000 90.000	.00 2.000 88.000	20.00 .000 90.000			
2.45	90.000	- 20.00 .000 90.000	.00 2.000 88.000	20.00 .000 90.000			
2.55	90.000	- 20.00 .000 90.000	.00 2.000 88.000	20.00 .000 90.000			

CHAINAGE	HEIGHT OF COLL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	ERRORS
2.70	101.000	- 16.00 2.000 99.000	- 15.50 1.400 99.600	15.50 1.400 99.600	16.00 1.550 99.450	20.00 1.550 99.450	E GHJ
2.85	99.900	- 20.00 .000 99.900	20.00 .000 99.900				E
2.99900	110.000	- 20.00 .000 110.000	20.00 .000 110.000				E G
P 2.89900	90.000	- 20.00 .000 90.000	20.00 .000 90.000				G
3.20	99.400	- 25.00 .000 99.400	25.00 .000 99.400				E
3.21	99.600	- 25.00 .000 99.600	25.00 .000 99.600				
3.22	99.800	- 25.00 .000 99.800	25.00 .000 99.800				
3.23	100.000	- 25.00 .000 100.000	25.00 .000 100.000				
3.50	104.000	- 25.00 10.000 94.000	- .01 10.000 94.000	.01 .000 104.000	25.00 .000 104.000		E

CHAINAGE	HEIGHT OF COLL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	OFFSET STAFF LEVEL	ERRORS
3.60	105.000	- 25.00 12.000 93.000	- .01 12.000 93.000	.01 .000 105.000	25.00 .000 105.000		
3.70	106.000	- 25.00 13.000 93.000	- .01 13.000 93.000	.01 .000 106.000	25.00 .000 106.000		
3.75		- 25.00 93.000	- .01 93.000	.01 103.000	25.00 103.000		
3.80		- 25.00 93.000	- .01 93.000	.01 103.000	25.00 103.000		
3.85		- 25.00 93.000	- .01 93.000	.01 103.000	25.00 103.000		
3.95		- 25.00 93.000	- .01 93.000	.01 103.000	25.00 103.000		

ROAD EARTHWORKS

VERTICAL PROFILE

JOB IDENTIFICATION TEST RUN --- M.SC.ENG. THESIS --- G. KEUCK. SEPTEMBER 1973

CHAINAGE	GRADE LINE	GRADIENT	ELEV.PI	VERT CURVE .L	K
- 1.20	VPI				
- 1.20	EVC		148.000	.00	.00
- 1.10		- 8.0000			
- 1.05					
- 1.00					
- .95					
- .90					
- .85					
- .80					
- .75	BVC				
- .72		- 8.0000			
- .71		- 7.9479			
- .70		- 7.8954			
- .69		- 7.8433			
- .68	VPI				
- .67			60.000	300.00	25.53-
- .66		1.7917			
- .65		2.5750			
- .64		3.3583			
- .63	EVC	3.7500			
- .62	BVC	3.7500			
- .61		3.7244			
- .60		3.6731			
- .59		3.6218			
- .58		3.3654			
- .57		3.1090			
- .56		2.8526			
- .55		2.5962			
- .54		2.5449			
- .53		2.4423			
- .52		2.3397			
- .51		2.2372			
- .50		2.1346			
- .49	VPI				
- .48			90.000	1300.00	390.00
- .47		2.0321			
- .46		1.9295			
- .45		1.8269			
- .44		0.4167			
- .43	EVC	0.4167			
- .42	BVC				
- .41	VPI				
- .40			95.000	3.30	.72-
- .39	EVC	5.0000			
- .38	BVC	5.0000			
- .37	VPI				
- .36			100.000	.00	.00
- .35	EVC	0.0000			
- .34					
- .33					
- .32					
- .31					
- .30					
- .29					
- .28					
- .27					
- .26					
- .25					
- .24					
- .23					
- .22					
- .21					
- .20					
- .19					
- .18					
- .17					
- .16					
- .15					
- .14					
- .13					
- .12					
- .11					
- .10					
- .09					
- .08					
- .07					
- .06					
- .05					
- .04					
- .03					
- .02					
- .01					
- 0.00					
- 0.01					
- 0.02					
- 0.03					
- 0.04					
- 0.05					
- 0.06					
- 0.07					
- 0.08					
- 0.09					
- 0.10					
- 0.11					
- 0.12					
- 0.13					
- 0.14					
- 0.15					
- 0.16					
- 0.17					
- 0.18					
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- 0.25					
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- 0.29					
- 0.30					
- 0.31					
- 0.32					
- 0.33					
- 0.34					
- 0.35					
- 0.36					
- 0.37					
- 0.38					
- 0.39					
- 0.40					
- 0.41					
- 0.42					
- 0.43					
- 0.44					
- 0.45					
- 0.46					
- 0.47					
- 0.48					
- 0.49					
- 0.50					
- 0.51					
- 0.52					
- 0.53					
- 0.54					
- 0.55					
- 0.56					
- 0.57					
- 0.58					
- 0.59					
- 0.60					
- 0.61					
- 0.62					
- 0.63					
- 0.64					
- 0.65					
- 0.66					
- 0.67					
- 0.68					
- 0.69					
- 0.70					
- 0.71					
- 0.72					
- 0.73					
- 0.74					
- 0.75					
- 0.76					
- 0.77					
- 0.78					
- 0.79					
- 0.80					
- 0.81					
- 0.82					
- 0.83					
- 0.84					
- 0.85					
- 0.86					
- 0.87					
- 0.88					
- 0.89					
- 0.90					
- 0.91					
- 0.92					
- 0.93					
- 0.94					
- 0.95					
- 0.96					
- 0.97					
- 0.98					
- 0.99					
- 1.00					

## ROAD EARTHWORKS

## VERTICAL PROFILE

JOB IDENTIFICATION TEST RUN --- M.SC.ENG. THESIS --- G. KEUCK. SEPTEMBER 1973

CHAINAGE	GRADE LINE	GRADIENT	ELEV.PI	VERT. CURVE L	K
2.90	100.000				
2.95	100.000				
2.97500	100.000				
2.99900BVC	100.000	0.0000			
2.99900VPI			100.000	.00	.00
2.99900EVC	100.000	18.1818			
2.99910BVC	100.018	18.1818			
B 2.80	100.105	1.0000			
B 2.80010VPI			100.200	2.00	.05
B 2.80110EVC	100.000	-20.0000			
B 2.80110BVC	100.000	-20.0000			
B 2.80110VPI			100.000	.00	.00
B 2.80110EVC	100.000	0.0000			
B 2.82500	100.000				
B 2.85	100.000				
B 2.87500	100.000				
B 2.90	100.000				
B 2.92500	100.000				
B 2.95	100.000				

PAGE 1

// JOB 0002

LOG DRIVE CART SPEC CART AVAIL PHY DRIVE  
0000 0002 0002 0000

V2 M10 ACTUAL 16K CONFIG 16K

// XEQ METRE

JOB IDENTIFICATION TEST RUN --- M.SC.ENG. THESIS --- G. KEUCK. SEPTEMBER 1973

BROKEN CHAINAGES

INCOMING	OUTGOING
3.00	2.80

STORED

V.P.1. INPUT

DATA SUPPORTED

TEMPLATE TYPES

TYPE NUM	HOR	VERT	HOR	VERT	HOR	VERT	HOR	VERT	HOR	VERT	HOR	VERT	HOR	VERT	HOR	VERT
1	3	0.00	0.600	8.00	-0.100	2.00	-0.500									
2	3	0.00	0.600	16.00	1.120	4.00	0.280									

SIDE DRAIN LOCUS LINES

LOCUS NO	LINE NO	WEIGHT	SLOPE	HOR	VERT	HOR	VERT
1	1	-7	0	156.00	-104.000	6.00	-4.000
1	2	5	0	6.00	-4.000	6.00	-1.000
1	3	-4	-1	6.00	-1.000	7.00	-1.000
1	4	-3	1	6.00	-1.000	7.00	-1.000
1	5	1	0	7.00	-1.000	7.00	1.000
1	6	2	0	7.00	1.000	7.00	3.000
1	7	6	0	7.00	3.000	107.00	103.000
2	1	3	0	156.00	-104.000	6.00	-4.000
2	2	2	0	6.00	-4.000	6.00	-2.000
2	3	1	0	6.00	-2.000	6.00	2.000
2	4	4	0	6.00	2.000	106.00	102.000

LOCUS 1		LINE 1			STORED									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
0.	0.		0.	0.		0.	0.		0.	0.				

LOCUS 1		LINE 2			STORED									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
			0.	0.		0.	0.		0.	0.		0.	0.	

LOCUS 1		LINE 3			STORED									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
6.	-1.		0.	0.		0.	0.		0.	0.				

LOCUS 1		LINE 4			STORED									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
	-1.		1.			0.	0.		0.	0.		0.	0.	

LOCUS 1		LINE 5			ERROR									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
	-1.		1.	0.			0.5		0.	0.		0.	0.	

After re-loading —

LOCUS 1		LINE 5			STORED									
H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
	-1.		1.	0.			0.5		0.	0.		0.	0.	

LOCUS 1 LINE 6 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
0.	0.			-1.	-0.5	1.		0.	0.	0.				

LOCUS 1 LINE 7 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
0.	0.		0.	0.		2.	-1.		1.	0.				

LOCUS 2 LINE 1 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
			0.	0.		0.	0.		0.	0.		0.	0.	

LOCUS 2 LINE 2 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
			0.	0.		0.	0.		0.	0.		0.	0.	

LOCUS 2 LINE 3 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
3.	-1.					0.	0.		0.	0.		0.	0.	

LOCUS 2 LINE 4 STORED

H1	V1	S1	H2	V2	S2	H3	V3	S3	H4	V4	S4	H5	V5	S5
3.	-1.					0.	0.		0.	0.		0.	0.	

JOB IDENTIFICATION TEST RUN --- M.SC.ENG. THESIS --- G. KEUCK. SEPTEMBER 1973

ROAD EARTHWORKS

CONSTRUCTION QUANTITIES

CHAINAGE	AREAS		CUT	ACC CUT	FILL	ACC FILL	LYR1 CUT	LYR1 FILL	LYR2 CUT	LYR2 FILL	BLK FAC	ACC X-HAUL	MASS DIAGRAM		SSP L	DIST R	FIN.LEV
	CUT	FILL											1	2			
2.00	47.2	32.9	0	100000	0	200000	30000	40000	50000	60000	150700000	800000	900000	20.36	18.82	100.000	
2.10	40.7	27.8	4391	104391	3034	203034	30292	40000	50000	60000	150703034	796448	896886	19.48	17.30	100.000	
2.20	34.7	23.5	3766	108157	2567	205601	30549	40000	50000	60000	50704917	797132	897699	18.67	16.00	100.000	
2.30	.0	394.3	1733	109890	20889	226490	30669	40000	50000	60000	50705784	817154	917781	24.35	24.35	100.000	
2.35	.0	394.3	0	109890	19713	246203	30669	40000	50000	60000	50705784	836867	937494	24.35	24.35	100.000	
2.45	.0	394.3	0	109890	0	246203	30669	40000	50000	60000	50705784	836867	937494	24.35	24.35	100.000	
2.55	.0	394.3	0	109890	0	246203	30669	40000	50000	60000	50705784	836867	937494	24.35	24.35	100.000	
2.70	2.6	15.3	195	110085	30718	276921	30669	40000	50000	60000	100705979	867390	968017	16.00	17.00	100.000	
2.85	6.8	8.5	706	110791	1784	278705	30669	40000	50000	60000	100706685	868468	969095	17.00	17.00	100.000	
2.99900	401.1	.0	30391	141182	631	279336	32349	40000	50000	60000	100707316	838708	941014	24.00	24.00	100.000	
B 2.89900	.0	356.4	20056	161238	17821	297157	33476	40000	50000	60000	100725137	836474	939907	25.00	25.00	100.000	
3.20	2.0	20.3	294	161532	56698	353855	33476	40000	50000	60000	100725431	892878	996311	17.00	17.00	100.000	
3.21	3.6	15.2	28	161560	5177	359032	33476	40000	50000	60000	100725459	898027	996460	17.00	17.00	100.000	
3.22	5.7	10.6	47	161607	5129	364161	33476	40000	50000	60000	100725506	903109	996542	17.00	17.00	100.000	
3.23	8.0	6.4	68	161675	85	364246	33476	40000	50000	60000	100725574	903126	996559	17.00	17.00	100.000	
3.50	67.6	90.2	10203	171878	13044	377290	34058	40000	50000	60000	100735777	905967	999983	19.00	18.00	100.000	
3.60	92.6	109.9	8007	179885	10006	387296	34367	40000	50000	60000	100743784	907966	1002291	20.50	23.00	100.000	
3.70	124.5	109.9	10852	190737	10993	398289	34459	40000	50000	60000	100754636	908108	1002524	20.50	28.00	100.000	
3.75	23.0	187.4	3688	194425	7435	405724	34458	40000	50000	60000	100758324	911855	1006270	30.50	16.00	100.000	
3.80	33.4	147.7	1411	195836	8380	414104	34458	40000	50000	60000	100759735	918823	1013238	25.49	21.01	100.000	
3.85	45.5	109.9	1974	197810	6442	420546	34458	40000	50000	60000	100761709	923291	1017706	20.50	26.00	100.000	
3.95	45.5	109.9	4553	202363	10995	431541	34458	40000	50000	60000	100766262	929733	1024148	20.50	26.00	100.000	

ORIGINAL NOTES  
FORMULATING THE CONCEPT OF  
THE LOCUS OF THE SLOPE STAKE POINT  
(1965)

E.34/GK/MB

11th May, 1965.

SIDE SLOPE TREATMENT.

Adaption of a computer programme to a design which does not conform to the programme, by using the locus of the slope stake point.

1. Different methods of treatment of side slope and side drain may be accommodated by a programme not specifically written for this treatment by using the available parameters of the road template in the programme to conform as closely as possible to the particular method required. This is made easier by determining the locus of the slope stake points and adapting the available parameters to give a locus as similar as possible.

2. For any particular design, the position of the slope stake point (S.S.P.) is determined by the terrain cross-section, the position of the shoulder break point (S.B.P.) and the parameters of the road template between the S.B.P. and the S.S.P. The locus of the S.S.P. is found if a series of terrain cross-sections is used to determine the S.S.P. relative to the S.B.P. by the treatment according to the particular design.

The parameters of the template may vary over various portions of the locus.

3. The Locus of the S.S.P.'s is defined by a series of points (A,B,C,etc.) in sequence from top to bottom, joined by a series of straight lines AB, BC, CD, etc. One or more of these straights may have a direction from bottom to top but the predominant flow from top to bottom determines the positive sense of each straight. (See page 4.)

4. Each point (A, B, C, etc.) in sequence is referred to the S.B.P. by vertical and horizontal offsets ( $A_v, A_h, B_v, B_h, C_v, C_h, \dots$  etc.)

5. Each straight line (AB, BC, CD; etc.) is assigned an order of merit importance with a sign which is -ve if the "bottom" end of that straight is of higher importance. (AB = -9; CD = +3; DE = -5; EF = -2; FG = -1; GH = 6; HI = 7; IH = 8). BC = +4;

6. The profile of the side slopes from the S.B.P. to the S.S.P. is fixed by the template points : 17 (=S.B.P.), 18, 19 and 20 (or more if necessary.) Each of these template points is determined by vertical and horizontal offsets and slopes from the previous template point (ie.  $V_{18}, H_{18}, S_{18}$ , - fix 18 with regard to 17)

7. For each of the straight lines (AB, BC, CD, etc.) four values out of the following 9 possible values must be given (assuming 3 template points to beyond the S.B.P. to be sufficient)

$V_{18}$	$H_{18}$	$S_{18}$
$V_{19}$	$H_{19}$	$S_{19}$
$V_{20}$	$H_{20}$	$S_{20}$

A maximum of two values may be given for one template point as the third one is redundant.

2.

8. The four values given will enable the remaining values to be determined when the S.S.P. has been found.

9. A check would be necessary to see that the four values are valid over the whole length of the straight line.

10. If, as in the case of fill, the S.B.P. is connected by a straight line to the S.S.P.,  $V_{18}$ ,  $H_{18}$ ,  $V_{19}$ ,  $H_{19}$ , are all equal to 0. These are the four values required.

11. The actual position of the S.S.P. is taken as the intersection of the terrain cross-section with the locus. When more than one intersection is found, that one occurring in the section of the locus of highest importance is applicable. (i.e. in the above-given order of merit, the computer would try to find an intersection in the following sequence: first on straight FG, starting at the G end; next on the straight EF starting at the F end; next on CD starting at C; next on BC starting at B, etc.)

12. If the intersection (S.S.P.) has not been achieved below the uppermost point (A) and above the lowest point defining the locus, a vertical cut-off (V.C.O.) may be applied at the template point 19 (equivalent to 17 in the case of fill). Therefore the offsets of A and of the lowest point of the locus must be sufficiently large to cover all normal valid cases.

13. When the intersection (i.e. S.S.P.) has been found, the missing values of V, H, and S for 18, 19 and 20 are determined. This determines the complete road template. Areas of cut are calculated for all portions between the two S.S.P.'s where the road template lies below the terrain cross-section; areas of fill where the road template lies above the terrain cross-section.

14. Different types of locus may be used over succeeding sections of the job. Each type of locus with its set of defining points, order of merit and template point values is named and specified at the beginning of the job and is called in as required during the job by its name. It then applies to all cross-sections until another type is called in by name.

Signed by candidate

SAMPLE DEFINITION OF A LOCUS

<u>Locus Points</u>	<u>V</u>	<u>Offsets</u>	<u>H</u>
A	+99.50		-29.50
B	+17.50		- 9.00
C	+ 3.25		- 9.00
D	+ 5.50		-14.75
E	+ 1.00		-14.75
F	- 0.87		-14.75
G	- 1.50		-11.00
H	- 1.50		- 9.00
I	- 6.00		- 9.00
J	-100.00		-150.00

ORDER OF MERIT

AB	-9	
BC	+4	
CD	+3	(note sign)
DE	-5	
EF	-2	
FG	-1	
GH	+6	
HI	+7	
IJ	+8	

TEMPLATE POINTS.

	<u>V<sub>18</sub></u>	<u>H<sub>18</sub></u>	<u>S<sub>18</sub></u>	<u>V<sub>19</sub></u>	<u>H<sub>19</sub></u>	<u>S<sub>19</sub></u>	<u>V<sub>20</sub></u>	<u>H<sub>20</sub></u>	<u>S<sub>20</sub></u>
AB	-1.50		+1.50	0.00	-2.00				
BC	-1.50		+1.50	0.00	-2.00				
CD	-1.50		+1.50	0.00	-2.00				
DE	-1.50			0.00	-2.00				-1.50
EF	-1.50	-9.00		0.00	-2.00				
FG	-1.50	-9.00		0.00	-2.00				
GH	-1.50	-9.00					0.00	0.00	
HI	0.00	0.00		0.00	0.00				
IJ	0.00	0.00		0.00	0.00				

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