A User's Guide to
the STRAINS program
(Version 1.0 for IBM PC & Compatibles)

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Disclaimer: Anyone using the computer programs described in this guide may do so entirely at his/her own risk. Whilst every effort has been made to ensure their correctness and this disclaimer is not intended to discourage their use, the user is strongly recommended to critically examine the results and consider whether the use of the program is appropriate. The author of the program and the Cambridge University Engineering Department are not responsible for any loss or damage whatsoever arising from errors, if any, in the programs or erroneous interpretation of the results produced by the program.

Contents

1. Introduction

1.1 History

The method of determining strains in soils by radiography was first developed at Cambridge in 1960. A detailed account of this method is given by Roscoe et al. (1963). The method consisted of recording the images of a plane regular grid of lead shot markers embedded in the soil on a radiographic film (figure 1.1). A semi-automatic film measurement machine (FMM) was used for establishing the co-ordinates of lead shot markers on these radiographs. The operations of this machine are described by James (1973). From successive radiographs, it is then possible to establish the displacement of the markers and hence the strains within the soil. Since the 1980s, soil strains are calculated based on the measurement of displacement of images approximately 0.25 mm in diameter, recorded on 50 mm by 50 mm photographic film negatives. These films are mainly of soil models in flight on the Cambridge University 10 m Beam Centrifuge and are taken using a Hasselblad camera synchronised with a short duration, high intensity flash unit (Schofield, 1980).
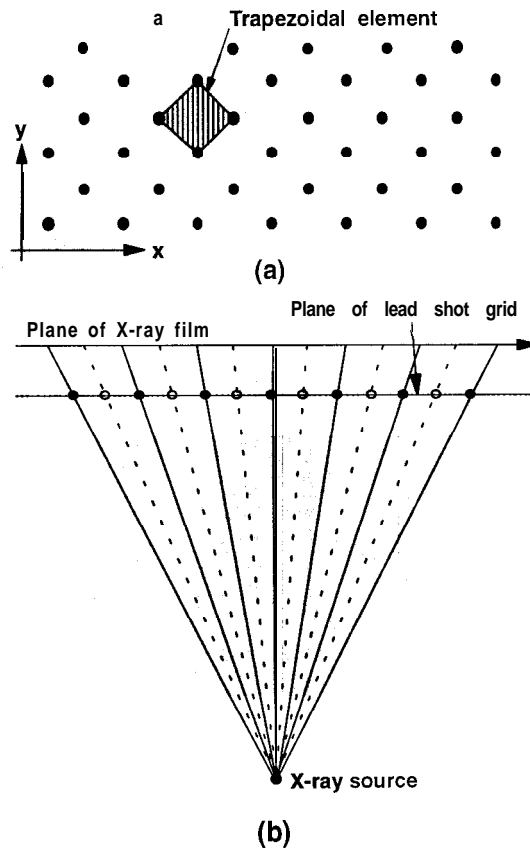
Figure 1.1 (a) The lead shot network in the plane of strain; (b) The projection of the lead shots on to the X-ray film

The computer code for calculating soil strains called "STRAINS", based on the displacement of markers, was first written by Orr in 1974 and was mounted on an IBM 370 mainframe computer. It was later modified by Britto in 1980 and was mounted on an IBM 3081 mainframe computer. The last modification to the STRAINS program was carried out by Britto in 1984. The program still exists on the IBM 3081 and is specified in its user's guide (Britto, 1984).

1.2 STRAINS for IBM PC & Compatibles

Although the STRAINS program can be run on the IBM 3081 computer, it has four major drawbacks:

(1)   The user has to get familiar with the Job Command Language (JCL) of the IBM 3081 computer because the only way the program can be run is in the background mode using submission of a job.

(2)   **The plot** files are generated using the **CAMPLOT** graphics library which was written and developed at the Computer Laboratories of Cambridge University and is unique to the IBM 3081 computer. Therefore, they can not easily be imported into any other computer (for editing using any standard graphics software, for example). Also, with the advent of sophisticated word processing softwares, the present day user demands direct incorporation of graphs, diagrams, etc. into his document. This is almost impossible to achieve using the plot files written in **CAMPLOT** format.

(3)   Hardcopies of the plots can only be obtained using the flatbed plotters located in the Computing Laboratories. These plotters use a 300 nun wide roll of paper. A job should be submitted to the operators requesting for hardcopies of the plots. The user has no control over the quality of these plots. Also, the plots can not be print-previewed before sending the request for hardcopies. There is an alternative way of obtaining hardcopies of the plots. It involves creating postscript files of the plots using the program **PLTOPS** (resident only on IBM **3081),** downloading these postscript files onto a floppy disk using any file transfer program (usually **FTP)** and printing them on a postscript laser printer. Both these ways are obviously cumbersome.

(4)   The mainframe version of STRAINS program does not generate any contour **plots (for example, shear** strain contours).

With the objective of obviating the above-mentioned drawbacks, it was decided to develop a new version of the STRAINS program. The fact that the IBM 3081 computer will be decommissioned by September 1995 contributed towards the urgency to develop the new version. It was decided to develop the new version on an IBM PC platform because now-a-days it is the most-used type of personal computer.

1.3 Capabilities of the IBM PC Version of the STRAINS Program

Version 1.0 of the STRAINS program is capable of producing basic strains data from raw unedited FMM data and displaying and plotting them suitably. **At present, it is** suitable only for regularly spaced rectangular grid of markers. No exact information is required about the number of rows (should be less than 36) of markers on a film, or the number of markers in a row (should be between 5 and 49). Should up to 10 consecutive markers be missing when measuring a film, the program will automatically insert markers as required. The data for duplicated markers are averaged. No data are plotted or printed for the inserted shots. The markers are automatically aligned using a least square method on each film and between films, to give a characteristic row and column number to each shot. All the strains are calculated based on the method described in Appendix A. The program generates plot files of the following parameters:

1. Zero extension line direction
2. Direction of largest compressive strain
3. Magnitude and direction of principal strains
4. Displacement of markers
5. Centre of gravity of each triangle formed by three markers

In addition, the program can produce contour plots of the following parameters:

1. Horizontal displacement
2. Vertical displacement
3. Shear strain
4. Volumetric strain
5. Angle of dilation

These plots can be viewed and print-previewed on either a standard VGA monitor or a high resolution SVGA monitor. Hardcopies of these plots are in the HP-GL (Hewlett-Packard Graphics Language) format. The HP-GL format allows the import of these plots into any graphics editor such as Lotus Freelance for Windows (see Appendix B) or into any word processor such as Microsoft Word for Windows. Since the program is compiled using the Salford University FTN77 compiler, it requires a run-time system (called DBOS) to be present on the computer for its execution.

2. Film Measurement

2.1 The Film Measurement Machine (FMM)

The design and operations of the FMM have been described in detail by Phillips (1991) and hence, only a brief description is provided here. The FMM comprises of a film carriage, a moire fringe co-ordinate measuring system and a 286 PC computer (figure 2.1). All controls are performed via the computer using a computer program written in Microsoft Quickbasic version 4.0. The accuracy of the FMM is about ±5 μm which is limited only by the CCTV system. At the end of the measurement of a film, an output file is created which contains the co-ordinates of the markers. This output file is then processed using the STRAINS program.

LEGEND :
A - Projector Illumination Source
B - Cooling Fan
C - Film Carriage
D - Film
E - Linear Encoder
F - Zoom Lens
G - Half-silvered Mirror
H - TV Camera
I - Video Overlay
J - TV Monitor
K - PC 266 Computer
L - Observation Screen
M - X-Drive Stepper Motor
N - Y-Drive Stepper Motor
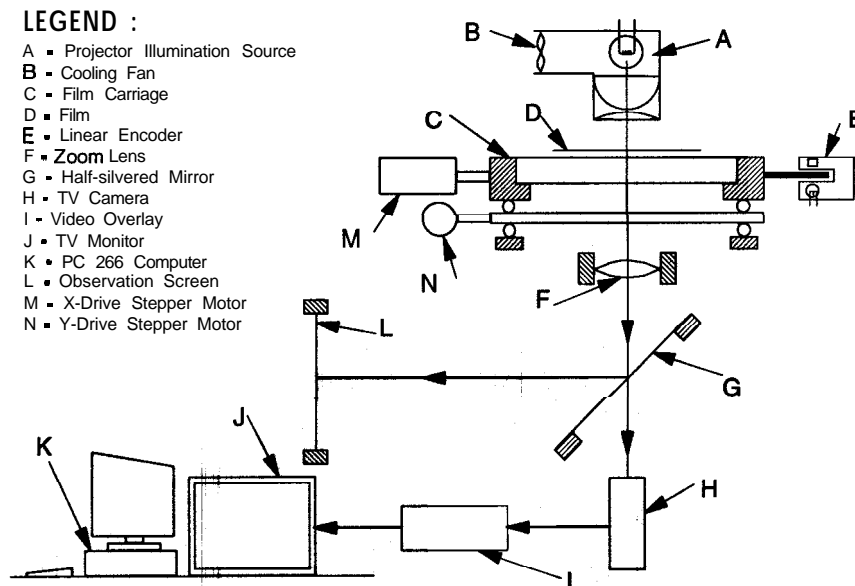
Figure 2.1 Schematic diagram of the Film Measurement Machine (FMM)

2.2 Film Measurement

Each film should have at least two reference markers on it. Two fixed markers, attached to the outside of the apparatus but inside the field view of the film, are suggested. The co-ordinates of these reference markers, (x_1, y_1) and (x_2, y_2), must be known with respect to a real space axis which must be chosen so that all of the markers in the grid lie in the first quadrant. Also, in the case of axisymmetric strain field, the user is advised to have two more reference markers defining the axis of symmetry. It is necessary to use a right-handed co-ordinate system with the x-axis horizontal and the y-axis vertical. Each row should have a nominally constant y value. The film should be placed on the FMM in such a way that the view as seen on the screen is the same as the view of the apparatus from the camera side and is the correct way up. It is not necessary to place all films on the carriage in exactly the

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same position. However, it is recommended that the films are placed at approximately the same position in order to avoid the errors in measurement due to optical non-linearity of the FMM.

Before starting the measurement, the cursor of the FMM should be moved to the extreme bottom left corner of the image and the origin of the FMM co-ordinate system should be established (called "zeroing" of counters). The positions, (u_1, v_1) and (u_2, v_2), of the two reference markers on the film should be measured a number of times before and after the main film measurements. During the course of a measuring a film, it is possible that the FMM might "lose" its zero (by accidental resetting of the origin, for example). In such a situation, the reference markers must be remeasured before any more soil markers. The soil marker grid should be measured in a zig-zag pattern starting at the marker which has maximum x co-ordinate and minimum y co-ordinate (in most cases, this is the bottom right hand marker as seen on the FMM screen) and then travelling left, i.e. x decreasing (figure 2.2). This means that the odd-numbered rows are measured starting from the extreme right hand marker on the screen and the even-numbered rows are measured starting from the extreme left hand marker. If a marker has been measured more than once, the co-ordinates for that marker are averaged by the STRAINS program.
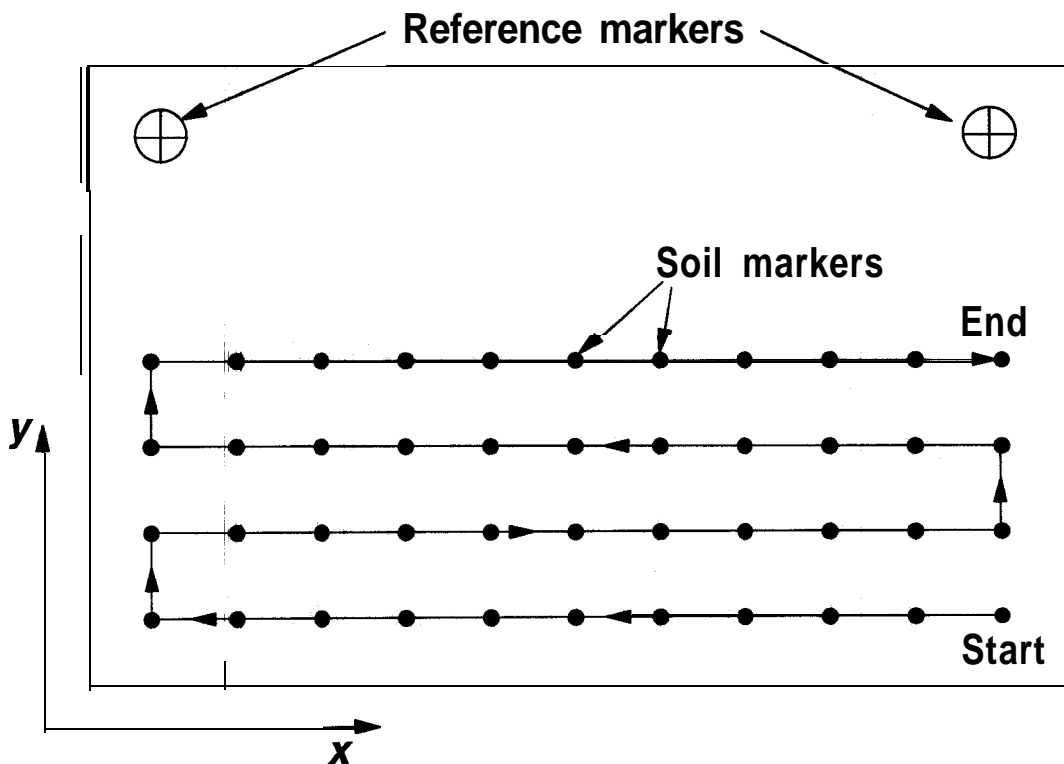

Figure 2.2 Zig-zag measurement of co-ordinates of soil markers

3. The STRAINS Program

3.1 An Overview

The STRAINS program is written to run on IBM PC and compatibles based on the INTEL 486 or higher processor. It supersedes the mainframe version of the STRAINS program. It is written in FORTRAN-77 and has been compiled and linked using the Salford University FTN77 compiler. It uses the INTERACTER graphics library for generating the plots. Since all the executable files created using the Salford University FTN77 compiler require a run-time system called DBOS for their execution, it must be present on the PC for running the STRAINS program.

3.2 Hardware and Software Requirements

STRAINS can be run on IBM PC and compatibles based on the INTEL 486 or higher processor. In addition, the computer should also satisfy the following requirements:

1. At least 4 Mb of RAM. 8 Mb preferred.
2. At least 20 Mb of hard disk space.
3. Maths co-processor
4. At least a VGA colour monitor (640 x 480 pixels). SVGA preferred.
5. MS-DOS 6.2 or higher.
6. DBOS run-time system (Version 2.73 or higher).

3.3 Installation of STRAINS

STRAINS is supplied on a 3.5" double-sided high-density (1.44 Mb) floppy disk. It needs to be installed on to the hard disk of the computer. It can not be run from the floppy disk. The following procedure should be followed for its correct installation on the hard disk:

1. Switch on the computer and wait for the DOS prompt

   ```
   C:\>
   ```

2. Insert the floppy disk containing the STRAINS program into the floppy drive (assumed to be drive A).

3. Switch to the floppy drive (assumed to be drive A) as follows:

   ```
   C:\>A: ↵
   ```

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4. At the prompt, type INSTALL and press RETURN (↵) as follows:

       A:\>INSTALL ↵

5. The installation program should now begin to copy the files from the floppy on to the hard disk in a directory called STRAINS. Wait for the installation to be complete. After the completion of the installation, the following message should be displayed on your computer:

       STRAINS program successfully installed !!

and the computer should return the following prompt:

       C:\STRAINS>

The STRAINS program is now ready for execution.

3.4 Running the STRAINS program

3.4.1 File Handling Strategy

The STRAINS program needs an analysis identifier before any of its modules can be executed. The analysis identifier should be less than or equal to 8 characters in length. It should be a valid DOS file name. For instance, the user may find it convenient give the centrifuge test code as the analysis identifier. All the files that are either used or created by the STRAINS program have the analysis identifier as their **name.** These files are distinguished from one another by different extensions. For example, the parametric file for an analysis called BOND007 is named as **BOND007.PAR** whereas the results file for the same analysis is named as **BOND007.RES.** The analysis identifier can be set using the DOS parameter STRFLN (acronym for **STRains** File Name). The user should type the following after the prompt to set the analysis identifier:

       SET STRFLN = <analysis identifier> ↵

For example, in order to set BOND007 as the analysis identifier, one should type:

       SET STRFLN = BOND007 ↵

The STRAINS program can now be started by typing STRAINS after the prompt and pressing RETURN. If STRFLN is not set, the execution of STRAINS will terminate after displaying the following message:

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```
The DOS Parameter STRFLN is not set.  In order to
use the STRAINS program, STRFLN must be set to the
test identifier. Quit the STRAINS main menu, return
to the DOS prompt and set STRFLN.
```

Table 3.1 below gives the description of all the files used or created by the STRAINS program.

Table 3.1 Description of files used or created by STRAINS

File description	Created by	Extension
Data file containing the co-ordinates of markers for the first film	FMM/User	.FL1
Data file containing the co-ordinates of markers for the second film	FMM/User	.FL2
Parametric file containing plotting instructions for STRAINS	User	.PAR
ASCII output file containing results produced by STRAINS	STRAINS	.RES
Binary file containing the basic strains data from previous run of STRAINS	STRAINS	.CUR
Binary file containing the basic strains data from current run of STRAINS	STRAINS	.CUW
Binary file containing data for contour plots	STRAINS	.CDF
Plot file for zero extension lines	STRAINS	.P01
Plot file for max. compressive strain direction	STRAINS	.P02
Plot file for displacement vectors	STRAINS	.P03
Plot file for magnitude and direction of principal strains	STRAINS	.P04
Plot file for centroids of triangles formed by STRAINS	STRAINS	.P05
Plot file for contours of horizontal displacement	STRAINS	.P06
Plot file for contours of vertical displacement	STRAINS	.P07
Plot file for contours of shear strain	STRAINS	.P08
Plot file for contours of volumetric strain	STRAINS	.P09
Plot file for contours of angle of dilation	STRAINS	.P10

3.4.2 *Various Menus in STRAINS*

After checking the DOS parameter STRFLN, STRAINS attempts to load DBOS, the FTN77 run-time system. If the DBOS is successfully loaded, the following menu appears on the screen:

```
************************************************
*            S  T  R  A  I  N  S  Suite of Progams      *
*            --------------------------------          *
*                       (Version 1.0)                  *
*                            by                        *
*                   Jitendra   Sharma                  *
*      Cambridge   University   Engineering   Deptt.   *
*                                                      *
*                    M  A  I  N    M  E  N  U          *
************************************************


              1.  Select the VGA chipset
              2.  Edit  raw  data  for  first  film
              3.  Edit  raw  data  for  second  film
              4.  Edit  the  parametric  file
              5.  Run  STRAINS  program  (Menu-1)
              6.  View  plots  generated  by  STRAINS
              7.  Exit  to  DOS
              ------------------------

              YOUR  CHOICE  (1-7)?
```

Option 1 lets STRAINS identify the VGA card present in your computer. Option nos. 2 & 3 allow the user to edit the raw data files for the two films using the MS-DOS editor. Option 4 allows the user to create or edit a parametric file that contains instructions about plots to be generated by STRAINS. Option 5 executes the main program, thus generating the plot files listed in table 3.1. Option 6 load the REPLAY program which facilitates viewing of all the plot files on screen. Option 7 terminates STRAINS, removes DBOS from memory and returns the DOS prompt. Each of these seven options are described below.

(1) <u>Selection of VGA chipset</u>

If STRAINS is being run for the very first time after its installation, the user must choose option 1 (selection of VGA chipset) of the main menu first.   Correct identification of VGA card is essential for viewing the plots generated by STRAINS. Once the VGA chipset has been correctly identified, the user need not run this program again. The information about the VGA chipset (type, resolutions and number of colours it can support) is contained in an initialisation file called

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STRAINS.INI. STRAINS reads this information prior to displaying its banners and plot files. At present, STRAINS can identify the following VGA chipsets:

Tseng Labs ET3000, Tseng Labs ET4000, Paradise, Video 7, **Everex, ATI,**
Trident, Chips & Technologies **82c452/82c453,** Ahead B, Oak Technology,
Genoa GVGA, NCR **77C20/21/22E,** S3 **86C911/924,** Cirrus 5442,
Primus 2000, Olivetti, Toshiba, Realtek, Vesa.

When the user runs the VGA chipset selection program, a menu is `displayed` on the screen which lists the above-mentioned chipsets. First seven chipsets are listed in the first menu (Menu-l), the next six chipsets are listed in the second menu (Menu-2) and the last six chipsets are listed in the third menu (Menu-3). If the user knows which chipset is present in his/her computer, he/she should choose the relevant option from one of these three menus. Once a chipset is selected, a menu-driven review program is loaded which lets the user check the resolution and the number of colours supported by that chipset. The user should check whether the selected chipset supports a resolution of 1024 x 768 pixels and 256 colours. This can be done by selecting the relevant option from the review program. Upon selection of the option, a picture similar to the one shown in figure 3.1 is displayed in full-colour on the screen, if the chipset has been correctly identified. If this picture is not displayed, the program has not been able to identify the chipset. The user should try selecting another chipset and repeat the above procedure till the picture shown in figure 3.1 is displayed properly. If, after trying all the chipsets supported by STRAINS, it is not possible to display the picture, STRAINS can only be run on a lower resolution (640 x 480 pixels) and less number of colours (16). It should be noted that lower screen resolution does not affect the quality of hardcopies of the plots produced by STRAINS. The quality of these plots is limited only by the resolution of the printer.
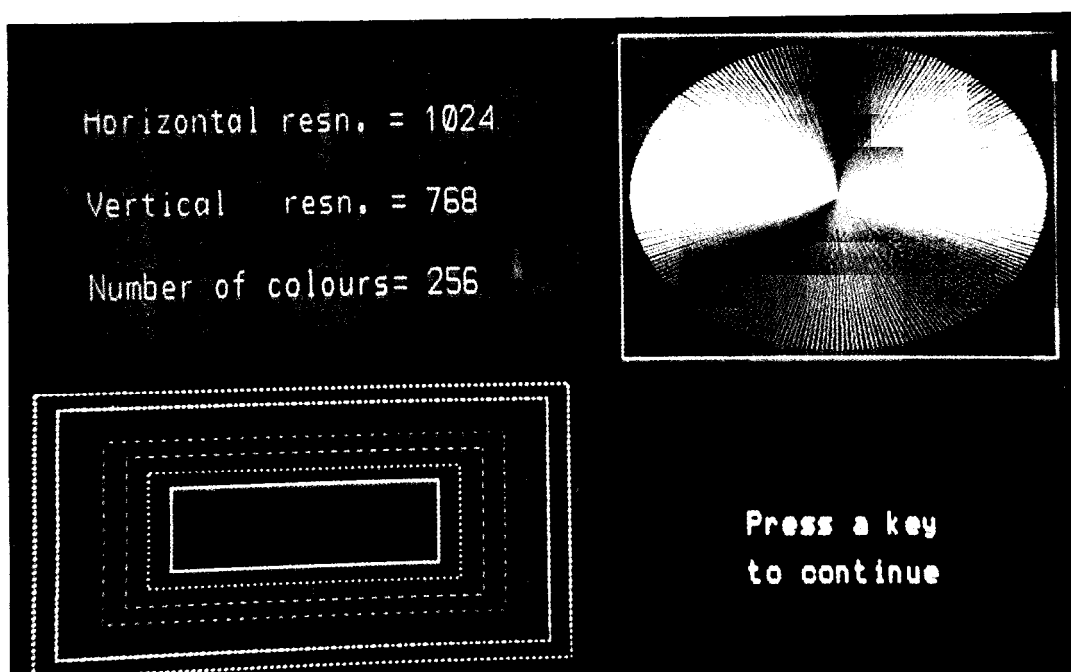

Figure 3.1 Graphics output produced by the VGA chipset identification program

(2) & (3) Editing raw data for the two films

As mentioned above, choosing option 2 (or option 3) loads the raw data file for first film (or second film) into the MS-DOS editor. All the steps required when editing the raw data file are given below:

(a) Place at the beginning of the data a film identification number. This number must be composed of exactly eight characters (or spaces). These eight characters (or spaces) should be typed in first eight columns of the first row. For example,

```
JFK1 F-1
SOS4F001
```

The first four characters can be test identifier and next four characters can be film identifier.

(b) In the next row, insert the true space co-ordinates of the reference markers (in millimetre). These values must be real numbers in free format and must be separated by at least two spaces. For example,

```
0.0   100.0   450.0   100.0
```

(c) Calculate the average values of the FMM co-ordinates for the reference markers and replace the repeated co-ordinates with these average values according to the form illustrated below. These values must be integers and must be separated by at least two spaces. For example,

```
+00647   +00321
+00653   +00325
   :        :
   :        :      become      +00650   +00323
   :        :                  +01839   +00295
   :        :
+01842   +00296
+01836   +00294
```

(d) Next follows the data for the soil markers, one marker per line. For example,

```
+010276   +00194
+010289   +00185
    :         :
    :         :
```

(e) If there has been a change of zero, a large number must be inserted as a warning. This number must exceed 8000000 and should be followed by two spaces and any other number. For example,

```
9000325   7
```

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(f)   Following this warning, a new set of real space reference marker co-ordinates and average FMM reference marker co-ordinates must be inserted as shown in steps (b) and (c).

(g)   The new FMM reference marker co-ordinates are followed by the soil marker co-ordinates as in step (d).

(h)   The FMM data are terminated by a negative number. For example,

```
-1   0
```

This should be the last line in the input data.

(4) Editing the parametric file

As mentioned above, choosing option 4 loads the parametric file into the MS-DOS editor. The parameters in this file control both the operation of the program and also the printed and plotted displays of the calculated strain information. The necessary parameters include such items as the minimum number of soil markers in a row, the nominal grid spacing, scales for the printer and plotter outputs and parameters to indicate which printer or plotter outputs are required. The general form of the parametric file is shown below:

```
ISTR   ICUM   INFO   ISTO
IPRINT(5)
IPLOT(5)
ICONT(5)
NCONT(5)
SCALPR   IROTPR
SCALPL
IROW   GRID   DISP   RNOIP
YTOP   YBTM   DISPT   DISPB
ITRY   IMISS
```

The explanation of each parameter is given in Table 3.1. It should be noted that the format for the parametric file is slightly different from that of the parametric file for previous version of STRAINS. There are two main differences between the present and the previous version:

1.   Parameters IROTPL (specifying 90" anti-clockwise rotation of the plots) and SPLEN (specifying page length for the plots) have been removed. The present version of STRAINS uses A4 paper in either the landscape or the portrait mode. It automatically decides which mode to use for plotting depending on the aspect ratio of the grid of soil markers.

2.   Parameters ICONT and NCONT, controlling the contour plots have been introduced.

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Therefore, the users of previous version of STRAINS upgrading to the present version, need to modify the existing parametric files to take into account the above changes.

Table 3.1 Description of various parameters specified in the parametric file

Parameter	Description	Possible values
ISTR	Test type	1 if plane strain 0 if axisymmetric
ICUM	Cumulative/incremental run	0 if incremental 1 if cumulative
INFO	printout of all shot/strain data	1 if yes, 0 if no
ISTO	Basic strain data from present run to be stored for future cumulative run	1 if yes 0 if no
IPRINT(1)	Printed display of x-disnlacements.	1 if yes, 0 if no
IPRINT(2)	Printed display of y-displacements	1 if yes, 0 if no
IPRINT(3)	Printed display of volumetric strain	1 if yes, 0 if no
IPRINT(4)	Printed display of shear strain	1 if yes, 0 if no
IPRINT(5)	Printed display angle of dilatancy	1 if yes, 0 if no
IPLOTS(1)	Plot of zero extension line directions	1 if yes, 0 if no
IPLOTS(2)	Plot of max. compressive strain direction	1 if yes, 0 if no
IPLOTS(3)	Plot of displacement vectors	1 if yes, 0 if no
IPLOTS(4)	Plot of principal strain magnitude and direction	1 if yes, 0 if no
IPLOTS(5)	Plot of centroids of triangles formed by STRAINS	1 if yes, 0 if no
ICONT(1)	Contour plot of horizontal displacement	1 if yes, 0 if no
ICONT(2)	Contour plot of vertical displacement	1 if yes, 0 if no
ICONT(3)	Contour plot of shear strain	1 if yes, 0 if no
ICONT(4)	Contour plot of volumetric strain	1 if yes, 0 if no
ICONT(5)	Contour plot of angle of dilation	1 if yes, 0 if no
NCONT(1)	No. of contours for horizontal displacement	between 1 & 12
NCONT(2)	No. of contours of vertical displacement	between 1 & 12
NCONT(3)	No. of contours of shear strain	between 1 & 12
NCONT(4)	No. of contours of volumetric strain	between 1 & 12
NCONT(5)	No. of contours of angle of dilation	between 1 & 12
SCALPR	Printer scale	e.g. 0.60
IROTPR	Rotate plotter output through 90°	1 if yes, 0 if no
SCALPL	Plotter scale	e.g. 0.50
IROW	Minimum no. of markers in a row	e.g. 23
GRID	Nominal grid spacing	e.g. 10.0
DISP	Magnification factor for displacements	e.g. 4.0
RNOIP	No. of mms. to 1% strain	e.g. 4.0
YTOP	Y-co-ordinate of top row of marker	e.g. 240.0
YBTM	Y-co-ordinate of bottom row of marker	e.g. 10.0
DISPT	Y-displacement due to consolidation (top row)	e.g. 0.86
DISPB	Y-displacement due to consolidation (bottom row)	0.15
ITRY	"Search distance" for aligning rows	e.g. 3
IMISS	No. of shots missed at beginning of row while performing alignment	e.g. 2

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Some notes on the parameters:

(1) **ISTR**   In the case of an axisymmetric problem, the parameter ISTR must be set equal to 0. Additionally, the position of the axis of symmetry for each film in terms of FMM x and y co-ordinates must be specified in the data files (**.FL1** & **.FL2**) immediately after the FMM co-ordinates for the reference markers. The position of the axis of symmetry is determined by measuring the co-ordinates of second set of reference markers defining the axis of symmetry.

(2) **SCALPR** The value given for this may be either positive or negative. A positive value indicates that the display outputs are to be printed to this given scale. However, should this scale be too large so that the display of the output will not fit the space available, the program will calculate the maximum possible scale for the output. A negative value indicates that the user wishes the program to calculate the scale for the output.

(3) IROTPR When **IROTPR = 0,** the maximum space available is 327 mm x 237 mm (one page of computer output, 132 columns) and when IRORPR = 1, the print is rotated and the maximum space available is 327 mm x 754 mm (three pages of computer output, 132 columns). The sizes quoted are for printed output produced in the CUED. Computer outputs printed on the Computing Service Reception printers has lines that are more closely spaced and hence the displays are correspondingly "shrunk" in the vertical direction.

(4) SCALPL This parameter is similar to **SCALPR,** i.e. it can have positive or negative values. A positive value indicates that the plots are to be plotted to this given scale. STRAINS first decides about the orientation of the plot (landscape or portrait) on an A4 paper based on the aspect ratio of the grid and then calculates the maximum scale for the plot based on this orientation. If SCALPL is greater than the maximum scale calculated by STRAINS, the plots are drawn to the maximum scale. A negative value indicates that the user wishes the program to calculate the scale of the output.

(5) **IROW**   This parameter specifies the minimum no. of soil markers in a row. It is used by STRAINS while aligning two rows of markers on each film. The row aligning algorithm is based on the horizontal distance between adjacent markers in a row.   If there has been large horizontal movements of markers, the aligning algorithm may not function properly.   In such a situation, it is advisable to skip the aligning process.   This can be done by giving a negative value for **IROW.** For example, if the minimum no. of markers in a row are 23, **IROW = -23.** However, it should be noted that in such a situation, it is better to edit the data file for each film so that each row contains the same number of markers. In other words, the grid should be rectangular and should not have uneven edges.   This will prevent STRAINS from getting

confused when it forms triangles with soil markers from two adjacent rows on a film.

(6) **YTOP, YBTM, DISPT, DISPB**

These values are used to provide a linear compensation to the y-co-ordinates of the second of a pair of films so as to compensate for the process of l-dimensional consolidation in the y-direction. The compensation is provided using the following equation:

$$y = y + \text{DISPB} + (y - \text{YBTM})\frac{(\text{DISPT} - \text{DISPB})}{(\text{YTOP} - \text{YBTM})} \quad (1)$$

(5) **Running** the **main program**

Once the data files and the parametric file have been edited according to the procedure described above, the user is all set to run the main program (Option 5) which would generate the plots. Upon selection of option 5, the user is presented with another menu as shown below:

```
************************************************
*           S  T  R  A  I  N  S  Main  Program        *
*           --------------------------------         *
*                   (Version 1.0)                    *
*                        by                          *
*               Jitendra   Sharma                    *
*     Cambridge  University  Engineering  Deptt.     *
*                                                    *
*                  M E N U - 1                       *
************************************************

1.  Incremental  run  only
2.  Incremental  run  followed  by  cumulative  run
3.  Cumulative  run
4.  Return  to  main  menu
5.  Exit  to  DOS


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

YOUR  CHOICE  (1-5)?
```

As seen from the menu, the main program can be run in three different ways which can be selected by one of the first three options. Option 1 assumes that the user wishes to do just one incremental run, i.e. comparing only a pair of films. In other words, the user does not want the main program to store the basic strains data (otherwise stored in a file with extension .CUW) from this incremental run. The flowchart for a purely incremental run is shown in figure 3.2.
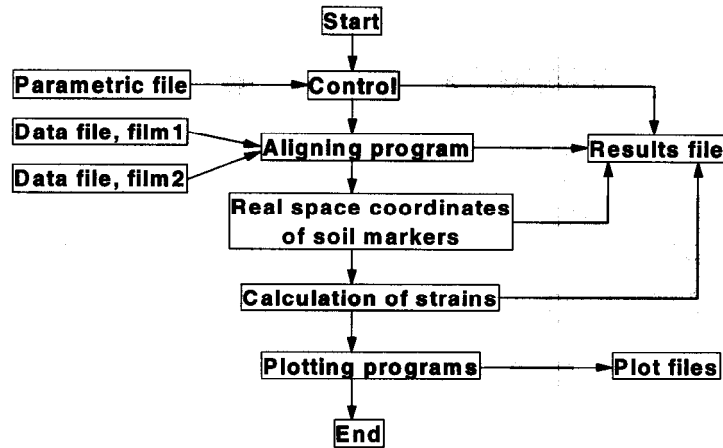
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```
                          ┌──────┐
                          │Start │
                          └──────┘
                             │
                             ▼
┌────────────────┐       ┌─────────┐
│ Parametric file│──────▶│ Control │──────────────────┐
└────────────────┘       └─────────┘                  │
┌────────────────┐          │                         │
│Data file, film1│          ▼                          ▼
└────────────────┐     ┌──────────────────┐       ┌─────────────┐
┌────────────────┐────▶│ Aligning program │──────▶│ Results file│
│Data file, film2│     └──────────────────┘       └─────────────┘
└────────────────┘          │                         ▲
                            ▼                          │
                  ┌──────────────────────┐             │
                  │ Real space coordinates│───────────┘
                  │    of soil markers    │
                  └──────────────────────┘
                            │
                            ▼
                  ┌────────────────────────┐
                  │ Calculation of strains │────────────┐
                  └────────────────────────┘            ▲
                            │
                            ▼
                  ┌────────────────────┐       ┌───────────┐
                  │ Plotting programs  │──────▶│ Plot files│
                  └────────────────────┘       └───────────┘
                            │
                            ▼
                          ┌──────┐
                          │ End  │
                          └──────┘
```

Figure 3.2 Flow diagram showing control of data and output files for an incremental run

However, if the user wants to carry out a cumulative measurement, i.e. measuring a series of films with accumulation of strains from one film to other, he/she should choose either option 2 or option 3. Option 2 is chosen only for the very first pair of films, e.g. film1 & film2. This option carries out an incremental run for the pair of films selected and stores the basic strains data from this incremental run in to a binary file (extension .CUW). For the measurement of next pair of films, e.g. film2 & film3, the user should choose option 3. This option first renames the file containing basic strains data (extension .CUW) as a file with extension .CUR. The main program then reads the basic strains data from this file, carries out incremental computation between film2 & film3, adds the basic strains data to the one it has read from the .CUR file and stores the new cumulative basic strains data in the .CUW file. This cumulative basic strains data is then used for the next pair of films, e.g. film3 & film4. The flowchart for a cumulative run is shown in figure 3.3.

```
                          ┌──────┐
                          │Start │
                          └──────┘
                             │
                             ▼
┌────────────────┐       ┌─────────┐
│ Parametric file│──────▶│ Control │──────────────────┐
└────────────────┘       └─────────┘                  │
┌────────────────┐          │                         │
│Data file, film1│          ▼                          ▼
└────────────────┐     ┌──────────────────┐       ┌─────────────┐
┌────────────────┐────▶│ Aligning program │──────▶│ Results file│
│Data file, film2│     └──────────────────┘       └─────────────┘
└────────────────┘          │                         ▲
                            ▼                          │
                  ┌──────────────────────┐             │
                  │ Real space coordinates│───────────┘
                  │    of soil markers    │
                  └──────────────────────┘
┌──────────────────┐        │
│ Incremental B.S.D.│◀──────┤
└──────────────────┘        ▼
┌──────────────────┐  ┌────────────────────────┐  ┌──────────────────┐
│ Previous B.S.D.  │─▶│ Calculation of strains │─▶│ Updated B.S.D.   │
│  (file *.CUR)    │  └────────────────────────┘  │  (file *.CUW)    │
└──────────────────┘        │                     └──────────────────┘
                            ▼
                  ┌────────────────────┐
                  │ Plotting programs  │──────────┐
                  └────────────────────┘          ▼
                            │              ┌───────────┐
                            ▼              │ Plot files│
                          ┌──────┐         └───────────┘
                          │ End  │
                          └──────┘
```
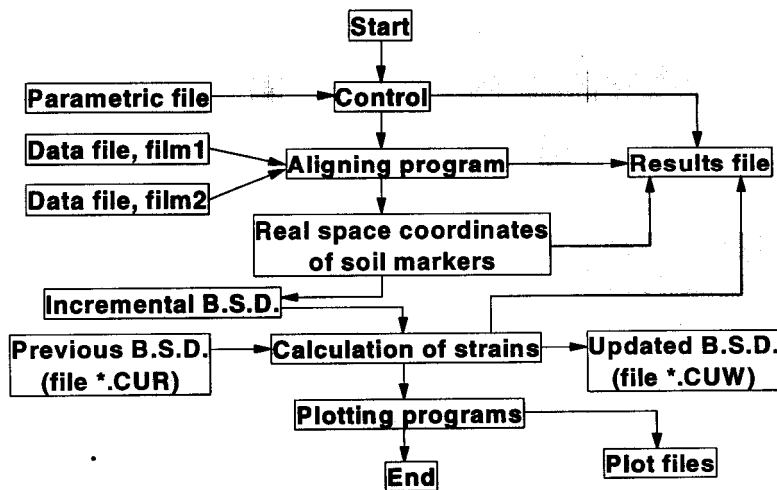
Figure 3.3 Flow diagram showing the control of data and output files for an incremental run followed by a cumulative run (B.S.D. → Basic Strains Data)

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After the relevant option has been selected, the main program displays its banner. The execution commences as soon as the user presses the RETURN key (+I). The main program then displays a banner asking user to wait while it generates the output (results and plots). The following message is displayed at the end of execution:

```
****** STRAINS RUN FINISHED.

The following file(s) have been created:

Printed Output (Results) :---- <analysis id.>.RES

Press any key to continue......
```

Pressing any key displays the main menu. The user can now view the plots generated by STRAINS on the VDU screen.

(6) **Viewing plots on the VDU screen**

If the user wishes to look at the plots generated by STRAINS, he/she can do it by choosing option 6. Selecting option 6 loads the REPLAY program. The REPLAY program lets the user view the plots on VDU screen. This program is also menu-driven. REPLAY recognises the plots using their extensions (*.P01 to *.P10). Since REPLAY can also display the plots generated from another analysis, the user is asked to enter the analysis identifier. By default, REPLAY will display plots generated by the analysis specified by the DOS parameter STRFLN. REPLAY can be terminated by typing S. After terminating REPLAY, the main menu is displayed once again.

(7) **Exit to DOS**

The STRAINS program can be terminated by choosing option 7 from the main menu. Upon selection of this option, the DBOS run-time system is removed from the memory. A message to this effect is displayed before the DOS prompt is returned. The user is advised to make sure this message is displayed before running any other program such as MS-Windows because if the DBOS is not removed from the memory, other programs won't work. Forced removal of DBOS can be done by typing the following after the DOS prompt:

```
KILL-DBOS  J
```

Appendix A: The Calculation of Strains

A.1 Introduction

The first attempt of computing strains in soil using displacement information obtained from successive radiograph was by Roscoe et al. (1963). They computed strains in soil by considering the displacements at the four corners of a diamond shaped element (figure A.l). This method was simple and direct but relied on the initial array of lead shots being quite regular and on geometry changes during distortion of an element remaining small. In order to overcome these restrictions, an improvement was suggested by James (1973). He suggested the use of triangular elements (figure A.2), thus obviating the need for a regular grid of lead shot markers and also reducing errors due to significant geometry changes. The STRAINS program is based on this method.

● **Marker before displacement**

0 **Marker after displacement**
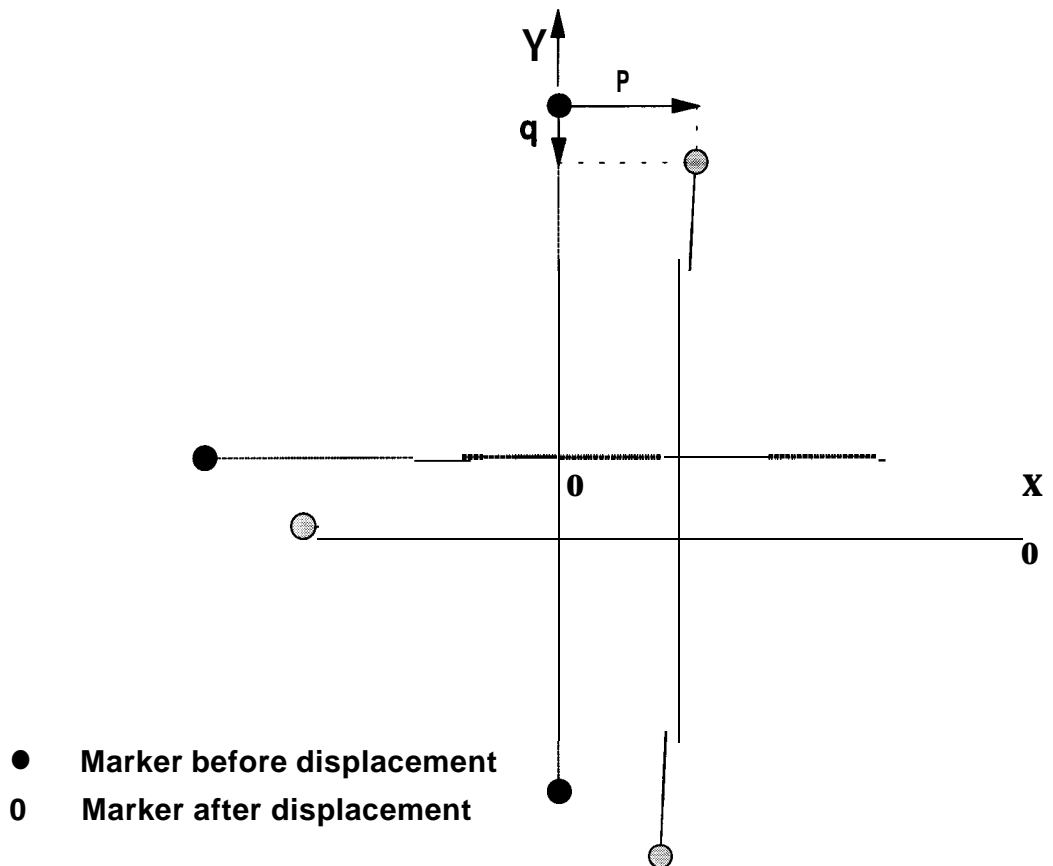
Figure A.1 Deformation of a trapezoidal soil element defined by four markers
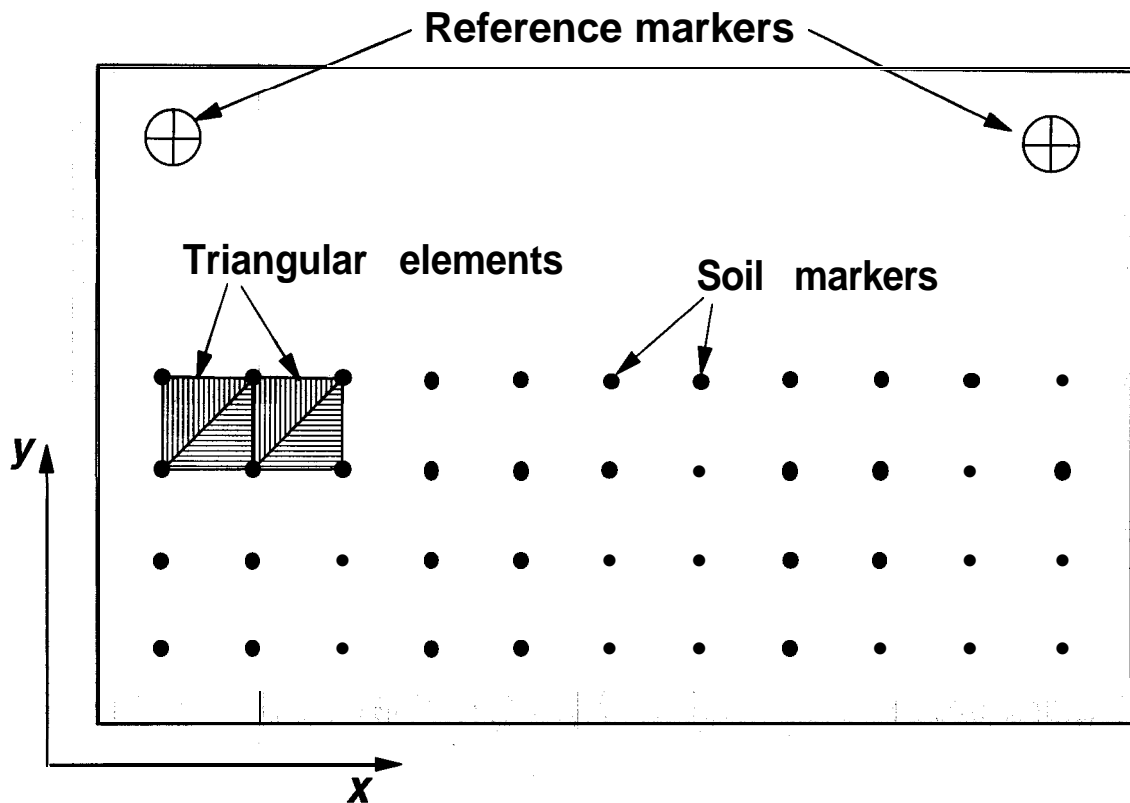
Figure A.2 Triangular elements formed from two adjacent row of soil markers

A.2 Assumptions

The following assumptions must be made (James, 1965) before strains in the soil mass may be calculated:

(1) Displacements of the soil marker represent displacements of the corners of the soil element defined by them.

(2) The element of soil defined by a single mesh of the soil marker network strains uniformly.

(3) The soil markers do not interfere with the behaviour of the soil element they define.

(4) The soil markers lie in and remain in a single vertical plane to which the calculated strains apply.

(5) Geometry changes of the system during the test have negligible effect **on the** calculated results.

A.3 The Transformation of Co-ordinates

The built-in co-ordinate system of the FMM is a normal right-handed Cartesian system with all distances measured in microns. However, since no two films can be placed in exactly the same position on the FMM, it is necessary to relate the FMM co-ordinate for each marker to the same co-ordinate system. The new co-ordinate system is related to the geometry of the apparatus (e.g. strongbox). Let us call this new co-ordinate system the <u>real space svstem</u>. The co-ordinates in the real space systems are expressed in millimetre. Since the co-ordinates of the reference markers are known both in the FMM space and in the real space system, it is possible to compute the transformation matrix between the two systems.

If $(x,$ y) are the co-ordinates in real space system and (u, $v)$ are the co-ordinates in FMM space system and assuming that both systems are right-handed, then in general:

$$x = a \cdot u + b \cdot v + c$$
$$y = -b \cdot u + a \cdot v + d$$

(1)

where a, b, c and d are all constants for a film.

For the reference markers in particular:

$$x_1 = a \cdot u_1 + b \cdot v_1 + c + 0$$
$$x_2 = a \cdot u_2 + b \cdot v_2 + c + 0$$
$$Y1 = -b \cdot u_1 + a \cdot v_1 + O + d$$
$$y_2 = -b \cdot u_2 + a \cdot v_2 + 0 + d$$

(2)

or

$$\begin{bmatrix} x_1 \\ x_2 \\ y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} u_1 & v_1 & 1 & 0 \\ u_2 & v_2 & 1 & 0 \\ -u_1 & v_1 & 0 & 1 \\ -u_2 & v_2 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}$$

(3)

where subscripts 1 and 2 refer to the first and the second reference markers respectively.

Using standard matrix notations,

$$[R] = [J] \cdot [S]$$

(4)

Therefore,

$$[S] = [J]^{-1} \cdot [R]$$

(5)

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Hence, the constants a, b, c and d can be found from the co-ordinates of the reference markers. It is now possible to use equation (1) to transform the co-ordinates of all the markers in the grid into the real space system. Consequently, the displacements of the markers between successive films can be calculated and strain information can be derived from these displacements.

A.4 Calculation of displacements and strains

The grid of soil markers is divided into a series of triangular elements (figure A.2). These triangular elements are used as a basis for strain computations. A typical triangular element is shown in figure A.3 where, for convenience, the origin of co-ordinates is taken at the corner i.
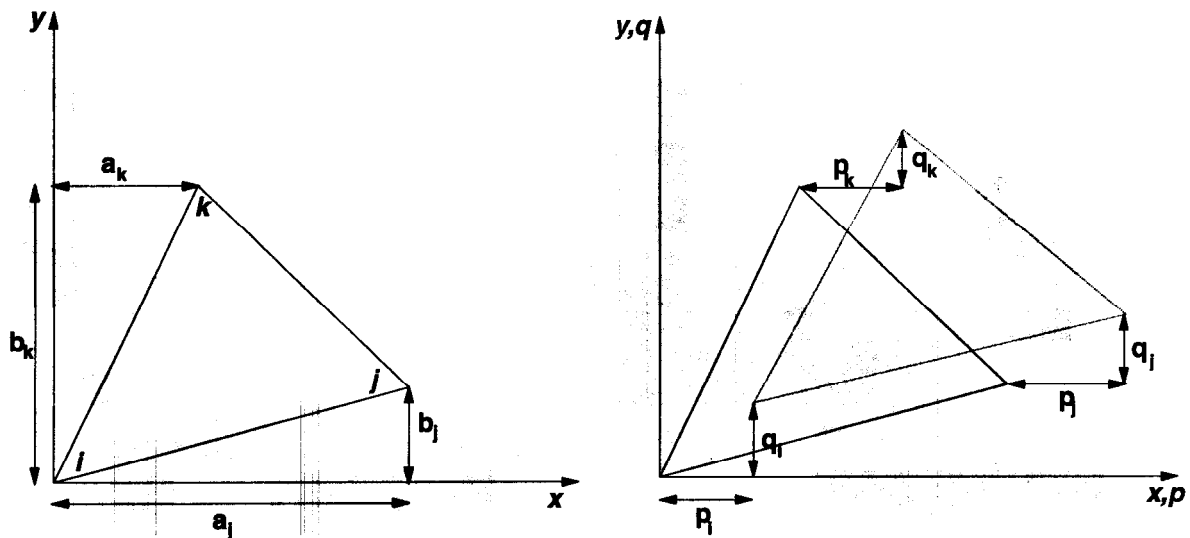

Figure A.3 Initial and displaced positions of a triangular element

The assumed uniform strain is taken to be caused by a linear displacement field. Thus, the displacements p and q are given by

$$p = p_i + A \cdot x + B \cdot y$$
$$q = q_i + C \cdot x + D \cdot y$$

(6)

where A, B, C and D are all constants and can be determined from the measured displacements of the corners.

Thus,

$$A = \frac{(p_j - p_i) \cdot y_k - (p_k - p_i) \cdot y_j}{z}$$

$$B = \frac{(p_j - p_i) \cdot x_k - (p_k - p_i) \cdot x_j}{z}$$

$$C = \frac{(q_j - q_i) \cdot y_k - (q_k - q_i) \cdot y_j}{z} \qquad (7)$$

$$D = \frac{(q_j - q_i) \cdot x_k - (q_k - q_i) \cdot x_j}{z}$$

where

$$z = y_j \cdot x_k - x_j \cdot y_k \qquad (8)$$

A.4.1 Plane strain

The strain increments associated with the displacement field of equation (6) are

$$\delta\varepsilon_x = \frac{\partial p}{\partial x} = -A$$

$$\delta\varepsilon_y = \frac{\partial q}{\partial y} = -D \qquad (9)$$

$$\delta\varepsilon_{xy} = -\frac{1}{2}\left(\frac{\partial q}{\partial x} + \frac{\partial p}{\partial y}\right) = -\frac{(B+C)}{2}$$

Thus, the strain increments can be obtained by substituting equation (7) into equation (9). Strictly, these equations apply only to small increments because the strains are calculated using the initial and final configurations of the triangle. Cole (1967) showed that the error in strains calculated using this method are very small.

The cumulative strains are calculated by summing the incremental strains. Therefore,

$$\varepsilon_x = \sum \delta\varepsilon_x$$

$$\varepsilon_y = \sum \delta\varepsilon_y \qquad (10)$$

$$\varepsilon_{xy} = \sum \delta\varepsilon_{xy}$$

The Mohr's circle of strain increment for a triangle is shown in figure A.4. Compressive strains are taken as positive.
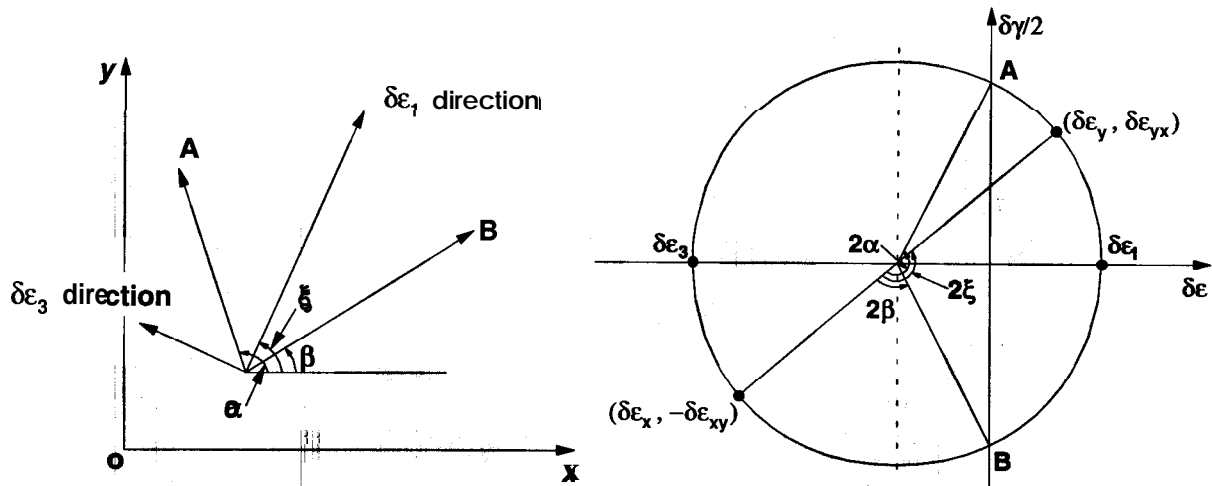
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Figure A.4 Zero extension lines, principal strain directions and associated Mohr's circle of strain increment

The following five parameters can be derived from the observed values of $\delta\varepsilon_x$, $\delta\varepsilon_y$ and $\delta\varepsilon_{xy}$:

1. Maximum shear strain increment

$$\delta\gamma = \delta\varepsilon_1 - \delta\varepsilon_3 = \sqrt{\left(\delta\varepsilon_x - \delta\varepsilon_y\right)^2 + 4 \cdot \delta\varepsilon_{xy}^{\;2}}$$ (11)

2. Volumetric strain increment

$$\delta V = \delta\varepsilon_1 + \delta\varepsilon_3 = \delta\varepsilon_x + \delta\varepsilon_y$$ (12)

3. The inclination of the principal compressive strain direction to the x-axis

$$\xi = \tfrac{1}{2}\tan^{-1}\left(\frac{2 \cdot \delta\varepsilon_{xy}}{\delta\varepsilon_x - \delta\varepsilon_y}\right)$$ (13)

4. The angle of dilation

$$\nu = \sin^{-1}\left(-\frac{\delta V}{\delta\gamma}\right)$$ (14)

(Note that the angle of dilation is positive for expansion of material.)

5. The inclinations of the zero extension line direction to the x-axis

$$\alpha = \xi + \frac{\pi}{4} - \frac{\nu}{2}$$
$$\beta = \xi - \frac{\pi}{4} + \frac{\nu}{2}$$

(15)

(If $|\delta V| > \delta \gamma$, zero extension lines do not exist.)

A.4.2 Axisymmetric strain

Under axisymmetric strain condition, the shear strain at any point is exactly the same as that in the case of plane strain condition. However, the volumetric strain is different in axisymmetric strain condition because it is a function of the radial distance r from the axis of symmetry as well as $\delta \varepsilon_x$ and $\delta \varepsilon_y$. It is given by

$$\delta V = \delta \varepsilon_x + \delta \varepsilon_y + \frac{\delta r}{r}$$

(16)

Derivation of other parameters is same as that for plane strain condition.

Appendix B: Editing the plot files using Lotus Freelance

B.l   Introduction

Although every effort has been made to generate plots which are self-explanatory, the user may wish to modify them to achieve better presentation of results. For example, the user may find it useful to draw the outline of the package around the grid of soil markers or to add few more captions. This can be achieved by importing the plot files into any graphics editor which has a filter for HP-GL files. One such graphics editor is the Lotus Freelance for Windows (ver. 2.01). This section of the manual briefly describes the procedure for editing the plot files using the Lotus Freelance for Windows.

B.2 Importing the plot file into Lotus Freelance

Before importing the plot files into Lotus Freelance, the user is strongly advised to critically examine the validity of results produced by STRAINS by previewing them on screen using the REPLAY program. Once the user is satisfied about the correctness of the results, he/she is ready to edit the plot files.

The graphics filter for importing HP-GL plot files is usually supplied with Lotus Freelance for Windows. However, it is a good idea to check whether the version being used has this filter. Start MS-Windows as usual and start the Lotus Freelance by double-clicking on its icon. Choose "blank" smartmaster background and choose "none" as the basic layout. This should display a white blank page. From the FILE menu, choose IMPORT. Another window should appear on top of the main window. Inside this window, there is a sub-window titled "File Type". Scroll inside this sub-window and look for "Hewlett-Packard Graphics Language (HGL)". If the user finds this inside the sub-window, the version of Lotus Freelance being used has a graphics filter for HP-GL plot files.

A peculiar thing about the HP-GL graphics filter available in Lotus Freelance is that it can recognise the HP-GL plot file solely on the basis of its extension. It expects the extension for such a file to be .HGL. However, the plot files generated by STRAINS have extensions .P01 to .P10. This means that the user has to either copy the plot file which he/she wants to edit to a new file having an extension .HGL or he/she may prefer to rename that plot file and specify a .HGL extension for it. Once this is done, the plot file can be imported by choosing IMPORT from the FILE menu as described above. The user may have to tell the location of the plot file (directory) to Lotus Freelance. After the completion of IMPORT, the plot file should appear in the main window.

B.3 Editing the imported plot file

The imported plot file is stored in vector format by Lotus Freelance, i.e. it contains nothing else but lines either joined or free. Even the alphabetical characters and numerals are stored as joined lines. By default, all the lines present in the imported plot files are grouped together by Lotus Freelance. In order to edit this file, it should be ungrouped. This can be done by choosing UNGROUP from the ARRANGE menu. Once the plot file is ungrouped, each line becomes an object and its properties can be manipulated using the tools available in Lotus Freelance. The user can now do whatever he/she wishes (within the capabilities of Lotus Freelance, of course !) to this file. For example, the outer frame of the plot can be deleted and replaced by a line diagram representing **boundary** of the package. New captions can be added. Colour, thickness or style of some of the lines may be changed.

Once the editing is complete, the user may save this file as Lotus Freelance presentation file (extension .PRE). Alternatively, he/she can store the plot as either a metafile or an encapsulated postscript file. This can be done by choosing EXPORT from the FILE menu and clicking on the relevant format. Once the edited file has been exported in any one of the many formats available in Lotus Freelance, it can easily be incorporated in any document using a sophisticated word processing software such as MS-Word for Windows or WordPerfect for Windows.

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