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SPASID: A COMPUTER PROGRAM FOR PREDICTING GROUND MOVEMENT DUE TO UNDERGROUND MINING; USER MANUAL

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16. Abstract (Limit: 200 words)

This report is a self-contained User Manual for a computer program called SPASID -- Subsidence Prediction and System Identification. The program has two primary functions: (i) Precalculation of ground movements due to underground mining operations using the influence function method; (ii) Computation of influence function and site parameters from measured displacements. SPASID is written in FORTRAN and consists of four modules: (i) Preprocessor Module that prepares and maintains surface and mine data bases; (ii) Subsidence Computation Module that predicts movements of the surface; (iii) System Identification Module which is used to calculate the optimal influence function parameters, and (iv) Postprocessor Module for generating graphic displays of subsidence data. The last module is somewhat machine dependent but has internal documentation to indicate potential changes. All of the modules may be run in either batch or interactive mode. The manual does not assume previous knowledge of the influence function method or programming competence.

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FOREWORD

This report was prepared by The Pennsylvania State University, College of Earth and Mineral Sciences, Department of Mineral Engineering, University Park, Pennsylvania, under United States Bureau of Mines Contract No. J0295031. The contract was initiated under the Conservation and Development Program. It was administered under the technical direction of the USBM Twin Cities Research Center with Dr. Sathit Tandanand acting as Technical Project Officer. Mr. Howard Cole was the contract adminstrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period October 1, 1979 to March 31, 1983. This report was submitted by the authors on August 1, 1983.

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1. GENERAL INFORMATION

1.1 Introduction

SPASID (Subsidence Prediction and System Identification) is a computer program that serves two primary functions, as suggested by its title:

(i) Prediction of ground subsidence caused by underground mining operations, using the influence function method.

(ii) Identification of the system parameters from surface displacements measured on the site.

The influence method was chosen over other possible models because it does not require a detailed knowledge of the geological structure of the site, and the in-situ mechanical properties of the overburden. It appears to be the only practical method presently available for predicting subsidence over a reasonably wide variety of site conditions.

The basic premise of the influence function method is that the relationship between the extraction of material and the resulting ground movement is linear. This in turn implies that superposition is applicable; that is, the subsidence at any point on the surface can be obtained by summing the contributions of all the extraction volumes within the mine panels.

Before the influence function method can be implemented for a given site, the parameters associated with the method must be determined from experimental data. These parameters, described in detail in the next chapter, can be divided into two categories:

(i) Influence Function Parameters. These are adjustable constants appearing in the influence functions themselves.

(ii) Site Parameters. These parameters describe the radius influence, edge effect and the time lag between extraction and subsidence.

SPASID supports two influence functions: the well-known function proposed by Knothe [1], and an influence function derived from transversely isotropic elasticity theory [2]. A brief discussion of these influence functions, the site parameters and the method in general appears in Chapter 2. For a general presentation of the influence function method the reader is referred to a treatise by Brauner [3].

The parameter or system identification can be accomplished by SPASID provided that the appropriate data, consisting of the mining and subsidence history of a similar site, is available. It follows that a system of measuring and recording surface displacements is a prerequisite for successful application of SPASID.

The report is divided into two parts: a theoretical and user manual part of the program, and the Appendices. The manual provides the user with the information necessary to run the program. It assumes neither previous knowledge of the influence function method nor programming experience. In an attempt to make the presentation as simple as possible, only the knowledge essential for the operation of the program is included.

Information that would contribute to a more in-depth comprehension of the program has been placed in the Appendices. This includes detailed analysis of the influence function used in SPASID, methods used for parameter identification and a sample computer run.

1.2 Program Structure

SPASID consists of four autonomous modules that share a common data base. The modules are:

(i) Preprocessor is responsible for the creation and modification of the data base that contains information about the mine and the topology of the surface.

(ii) Subsidence computes the predicted subsidence of the surface using the data base prepared by the Preprocessor, and the influence function and site parameters prescribed by the user.

(iii) System Identification calculates the influence function parameters of the site from measured surface displacements, utilizing the data base set up by the Preprocessor.

(iv) Postprocessor uses the data base and the results obtained from the Subsidence module to display surface movements on a graphics device.

Detailed descriptions of each of the modules are presented in Chapters 3 to 6. The source code is written entirely in FORTRAN IV and is, for the most part, machine-independent. The Postprocessor supports Tektronix 4000 series graphics devices, as well as CALCOMP style equipment. Routines are included to produce X-Y plots, contour maps (on a line printer), and a surface perspective plot. Because of the high degree of modularity of the Postprocessor, installations with locally supported graph producing software may be easily interfaced.

The use of the Postprocessor is not essential to utilization of the program. Its absence would only deprive the user of graphical representation of the subsidence; the numerical data would still be available.

Each module of SPASID can be run in either batch or interactive mode. The latter would, of course, require the insertion of appropriate control cards into the source deck, depending on the system being used. At the present time, interactive versions of the program are available for the IBM/CMS system, CDC 6400, and HP1000. Relatively simple changes would be needed for other systems. The programs are converted to batch mode with one parameter change in the main body of each module.

All the program modules consist of separate tasks which must be called by the user in logical sequence. In other words, the user custom designs each run deck by specifying the tasks to be executed. This scheme is particularly useful in an interactive mode, since it allows the results of each task to be inspected before the next task is decided upon. Each task is described with the help of simple examples in Chapters 3 to 6; a summary of the tasks and the commands is given in Chapter 7.

1.3 Storage Arrangement

The organization of data storage plays an important part in the operation of SPASID, and the user should have some knowledge of its arrangement.

The program uses five external, sequentially-accessible data files, as indicated in Figure 1.1. The two permanent storage files, called Backup Storage, are the only means of communication between the individual program modules. The first of these contains the data base of the site (surface topology and mine data). As mentioned previously, the function of the Preprocessor is to prepare and maintain this data for other program modules. The second Backup Storage file is used for saving the results of subsidence computation for subsequent retrieval by the Postprocessor.

The temporary files, referred to as Disk Storage, form the working storage of the program. The Disk Storage is the only form of external storage that is directly accessible to the various tasks of the program. Consequently, before any task can be executed, the appropriate data must first be loaded from Backup into Disk Storage. Each program module contains a special task for accomplishing this. Similarly, any changes or additions to the data base must be saved in Backup Storage before logging off.

Dynamic allocation of core storage is utilized in each program module; that is, all the arrays used by the program are stored in a single working array, S, of dimension MTOT. The size of the array may be changed by altering the following two statements in the source program:

```
DIMENSION S(16000)

MTOT = 16000
```

The core requirements of the program can thus be tailored for the machine being used.

Once the value of MTOT has been set, any attempt to use more array storage will terminate the run with an error message. It is important to point out that the demands placed on the array S are

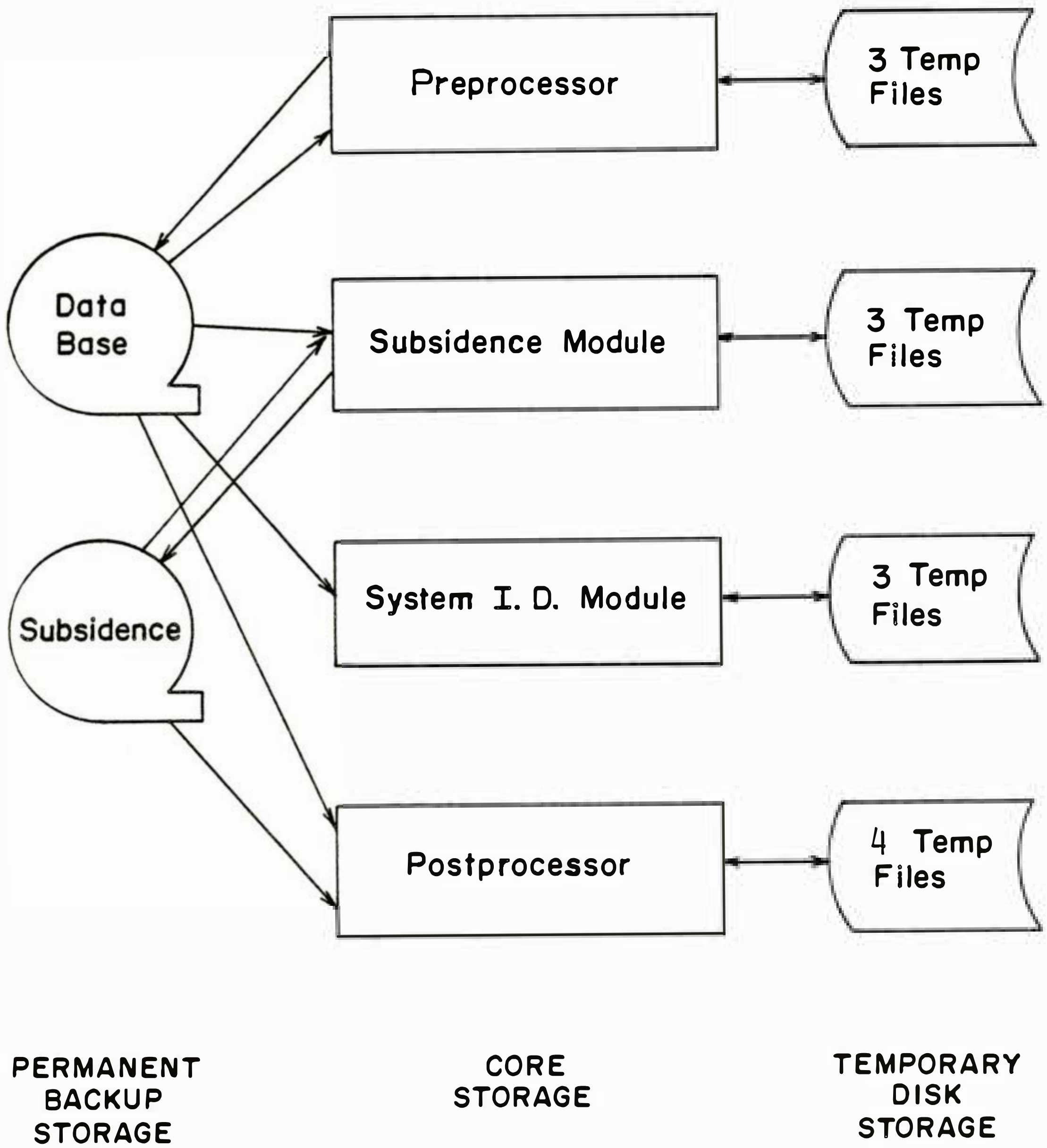


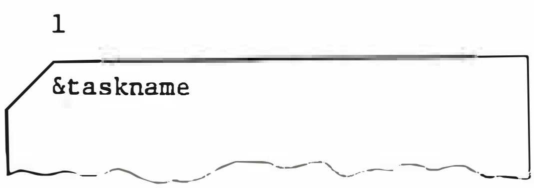
FIGURE 1.1 Storage Organization

largely determined by input data. In other words, the user is in control of the storage requirements of each run. A small value of MTOT does not necessarily imply that a small data base must be used, or that the subsidence computations must be confined to a few points. It does, however, mean that more care must be exercised in the planning and preparation of input data; for example, subdividing the data base into smaller units, using more than one run to calculate the subsidence, etc. Hints on saving core storage are explained under the descriptions of individual program modules.

1.4 Arrangement of Input Deck

It was previously stated that each program module consists of individual tasks. The execution of a task requires an input deck as shown in Figure 1.2. Any number of such decks, placed end-to-end, constitutes an input deck for a program module. An echo of each card in the deck, except for the data cards, is displayed by the output unit (e.g., line printer) as the program is run.

Task Card



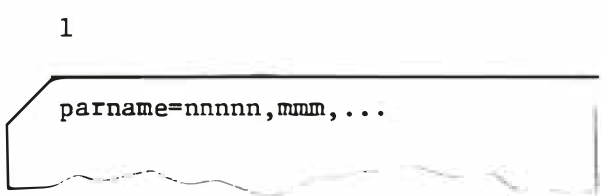
The Task Card is identified by an ampersand in column 1, followed by the name of the task (taskname). It specifies the task to be executed. Only the ampersand and the first four characters of taskname are scanned; the other characters may be added for the sake of clarity.

Parameter Cards

The Parameter Cards specify the values of the parameters that are to be used in the execution of the task. Most parameters have default values which are used if the corresponding parameter card is omitted. The parameter cards may be placed in the Task Deck in any order, unless specified otherwise.

a) Numerical Parameter Cards

Numerical Parameter Cards are used to specify numerical values (integer of floating-point numbers) of parameters. The card layout is shown below.



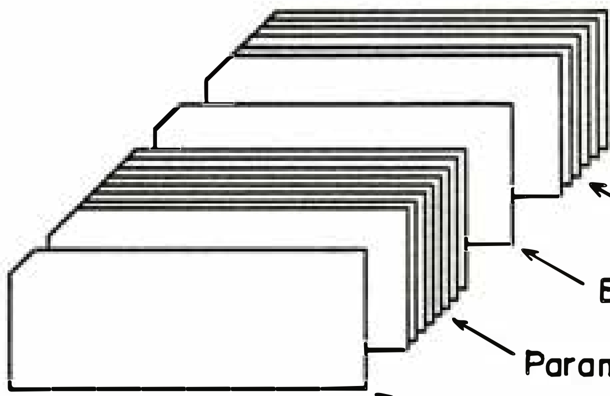


FIGURE 1.2 Input Deck for a Task

The equal sign separates the parameter name (parname) and the numerical values of the parameter (nnnnn,mmm,...). Only the first four characters of "parname" are significant.

The numerical values of the parameters must be separated by a blank, comma, or @ but otherwise they can be placed anywhere to the right of the equal sign. The use of the decimal point for a floating point number is not mandatory.

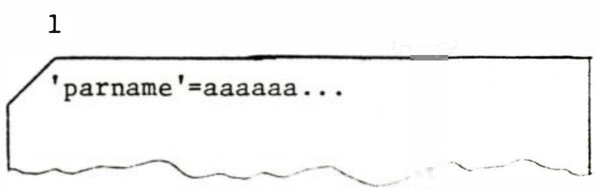
Non-numerical characters found to the right of the equal sign will be ignored, but a warning message will be issued. Exceptions are a leading plus or minus sign, and the most right-hand decimal point of each numerical value.

A semicolon may be used after the last parameter value, in which case all characters to the right of the semicolon will be interpreted as comments, and ignored by the program.

Continuation cards are allowed; the last character of the card to be continued must be a comma.

b) Alphabetic Parameter Cards

Alphabetic Parameter Cards are used to transmit character strings to the program. These cards are identified by single quotation marks that enclose the parameter name (parname).

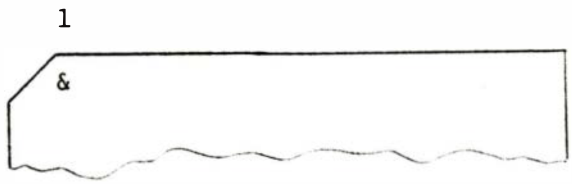


The entire card to the right of the equal sign (aaaaaa...) is treated as the character field associated with the parameter name.

Only the first quotation mark and the first four characters of parname are scanned; the second quotation mark and additional characters of "parname" may be added for clarity.

The Alphabetic Parameter Cards are used mainly for reading execution-time formats and titles that are to appear with the output. Continuation cards are not permitted.

c) End-of-Task Card



The End-of-Task Card contains an ampersand in column 1. It indicates the end of Parameter Cards and initiates execution of the task. If the task requires input data other than Parameter cards, these must immediately follow the End-of-Task card, as shown in Figure 1.2.

1.5 Error Messages

As the Task and Parameter cards are read in, but before the task is executed, the input deck is examined by the program. If it contains obvious mistakes, an appropriate error message is issued and the run is terminated (batch mode) or the control is returned to the user (interactive mode). The most commonly encountered error messages are:

a) "PARAMETER CARD FOR *parname* DOES NOT CONTAIN THE REQUIRED *n* PARAMETER VALUES," where *parname* refers to the parameter name.
b) "PARAMETER *parname* DOES NOT HAVE DEFAULT VALUES. THE PARAMETER CARD MUST BE READ IN."
c) "PARAMETER NAME *parname* IS ILLEGAL."
d) "THIS TASK REQUIRES AT LEAST *n* PARAMETERS, BUT ONLY *m* PARAMETERS WERE READ IN."
e) "VALUE NUMBER *n* OF PARAMETER *parname* IS OUT OF ALLOWABLE RANGE OR CONTRADICTS OTHER DATA."
f) "TASK CARD PRECEDING PARAMETER CARDS IS MISSING."
g) "END-OF-TASK CARD WAS NOT READ IN; LAST TASK WAS NOT EXECUTED."

In addition to the above, other error checks are contained in the various parts of the program. The most important of these deals with inadequacy of allocated Core Storage:

"INSUFFICIENT SPACE IN ARRAYS: ALLOCATED SPACE = *n* WORDS, REQUIRED SPACE = *m* WORDS"

where *n* is equal to MTOT, the specified dimension of the working array (see Section 1.3 for explanation).

2. INFLUENCE FUNCTION METHOD

2.1 Discussion of Existing Methods.

Existing methods of predicting surface subsidence due to underground mining operations fall, essentially, into two categories: continuum mechanical and semi-empirical models.

The former is virtually synonymous with the finite element method which has become the main tool of analysis is most branches of continuum mechanics. Although mining engineers were among the early proponents of the method and have developed some sophisticated computer programs, the initial promise of the method for problems of subsidence is yet to be fulfilled. In the finite element method the difficulty lies in the requirement for a detailed model of the entire geological structure between the mine floor and the surface. Consequently, the subsidence analysis of a typical mine site requires the determination of dozens of parameters that characterize the in-situ bulk material behaviour--a problem that still defies solution. The lack of a priori knowledge of material properties means that finite element programs must be used in a semi-empirical mode, i.e., the material constants have to be found by a trial-and-error procedure, where the program is run repeatedly until satisfactory agreement between prediction and observation is obtained. Most advantages of the finite element method are lost in this process, and other, explicitly semi-empirical methods become more attractive.

The semi-empirical techniques consist of the influence function method, favoured in Europe, and the profile method, adopted in Great Britain. The profile method is designed for two-dimensional subsidence problems; it is thus suited only for determining the trough profile along the centerline of a near-rectangular extraction area. It may be used for three-dimensional problems to a limited extent, but at the expense of additional, rather tenuous mathematical assumptions. On the credit side, the method can be quite accurate, since the profile functions may be derived directly from measurement of actual subsidence.

The influence function method is based on the postulate that the effects of extraction on the subsidence of a point on the surface can be superimposed. The mathematical relationship that establishes the displacement of a surface point due to an infinitesimal extraction volume is known as the influence function; it is essentially a Green's function of the subsidence problem. The method is very versatile, suffering none of the geometrical restriction of the profile functions.

2.2 Fundamental Assumptions

The influence function model is based on two fundamental assumptions. The first of these presumes that the subsidence of the surface is proportional to the volume of material extracted from the seam. Figure 2.1 shows the incremental displacements dw and du_r of a surface point P caused by an infinitesimal extraction volume dV at Q. Due to the assumed proportionality between subsidence and the extraction volume, we can write

$$dw = F_v dV, \qquad du_r = F_H dV. \tag{2.1}$$

We follow the common practice and take the horizontal displacement to be directed from P towards Q', the point directly above Q. The constants of proportionality F_v and F_H must clearly depend on the depth of seam h and the horizontal distance r between P and Q. In particular, if P is sufficiently far from Q, say $r \geq b$, the displacements will become imperceptibly small. The distance b is called the radius of influence, and the region $r < b$ the zone of influence.

In order to determine how F_v and F_H depend on the depth of the seam, a second postulate is necessary. This postulate can be stated in various different ways, as has been the case in existing literature. Perhaps the most concise and intuitively acceptable form is the principle of scaling. Consider two hypothetical sites that are identical except for the scale, i.e., all the dimensions of the second site are proportional to the corresponding dimensions of the first site. Let the proportionality constant or the scale factor be k. The principle of scaling assumes that the surface displacements and the radius of influence of the two sites differ by the same scale factor.

According to the scaling principle, $dw \propto k$ and $dV \propto k^3$, which leads us to conclude by inspection of (2.1) that

$$F_v \propto 1/k^2. \tag{a}$$

In other words F_v must be inversely proportional to h^2 or b^2, since both of these dimensions are representative of the scale of the site. Condition (a) can thus be satisfied once and for all by expressing F_v in the form

$$F_v = \frac{1}{b^2} f_v (r/b), \tag{b}$$

where f_v is a function of the dimensionless quantity r/b only, i.e., it is independent of the site dimensions. In a similar fashion, we would obtain

$$F_H = \frac{1}{b^2} f_H (r/b), \tag{c}$$

so that (2.1) become

$$dw = tf_v (r/b)dA/b^2, \qquad du_r = tf_H (r/b)dA/b^2, \tag{2.2}$$

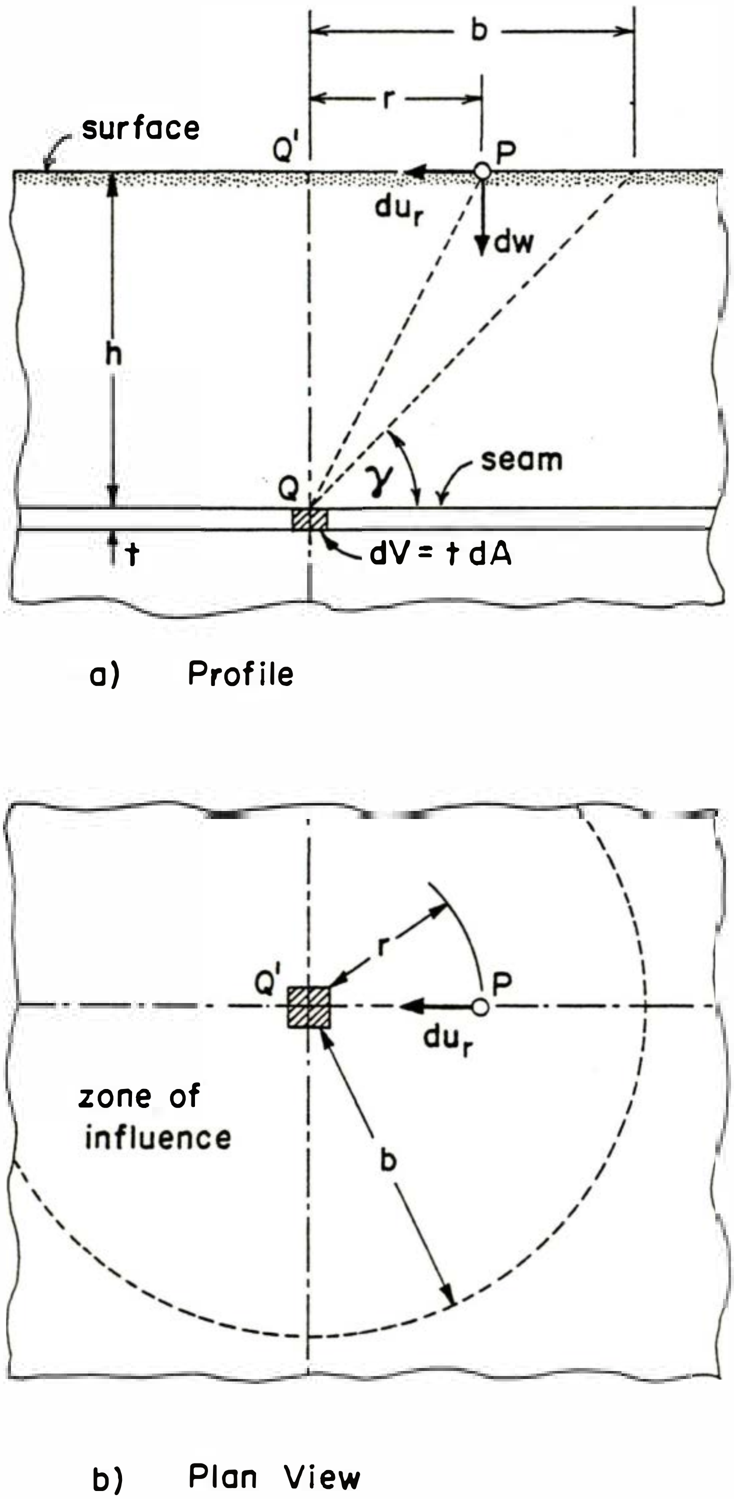


FIGURE 2.1 Subsidence Caused by an Infinitesimal Extraction Volume

where we replaced dV by tdA, t being the extraction height and dA the horizontal area of the extracted element. The dimensionless functions f_V and f_H are the influence functions of the site.

An important parameter of the site is the angle of influence γ, defined by

$$\cot \gamma = b/h$$

(see Figure 2.1a). Since the scaling principle implies that $b \propto h$, we conclude that the influence angle is independent of the dimensions of the site.

The assumed proportionality between subsidence and extraction means that the surface displacements may be computed by superposition of the contributions of the extraction elements. Once the influence functions and the influence angle of a site are known, the vertical displacement of any surface point is thus given by

$$w = \iint_A dw$$

and the cartesian components of the horizontal displacements are obtainable from

$$u = - \iint_A du_r \cos\theta, \qquad v = - \iint_A du_r \sin\theta,$$

where θ is the polar angle defined in Figure 2.2, and the integration is carried out over the extraction area A. The expressions for dw and du_r are given by (2.2).

The topology of most mines, however, is too complex for closed-form integration. In that case the mine panel may be divided into a grid, and each integral approximated by a sum over the grid elements:

$$w = \sum_i \Delta w_i ,$$

$$u = - \sum_i (\Delta u_r)_i \cos\theta_i , \qquad (2.3)$$

$$v = - \sum_i (\Delta u_r)_i \sin\theta_i ,$$

where

$$\Delta w_i = t_i f_V (r_i/b) \Delta A_i/b^2,$$

$$(\Delta u_r)_i = t_i f_H (r_i/b) \Delta A_i/b^2 \qquad (2.4)$$

and the subscript refers to the ith grid element.

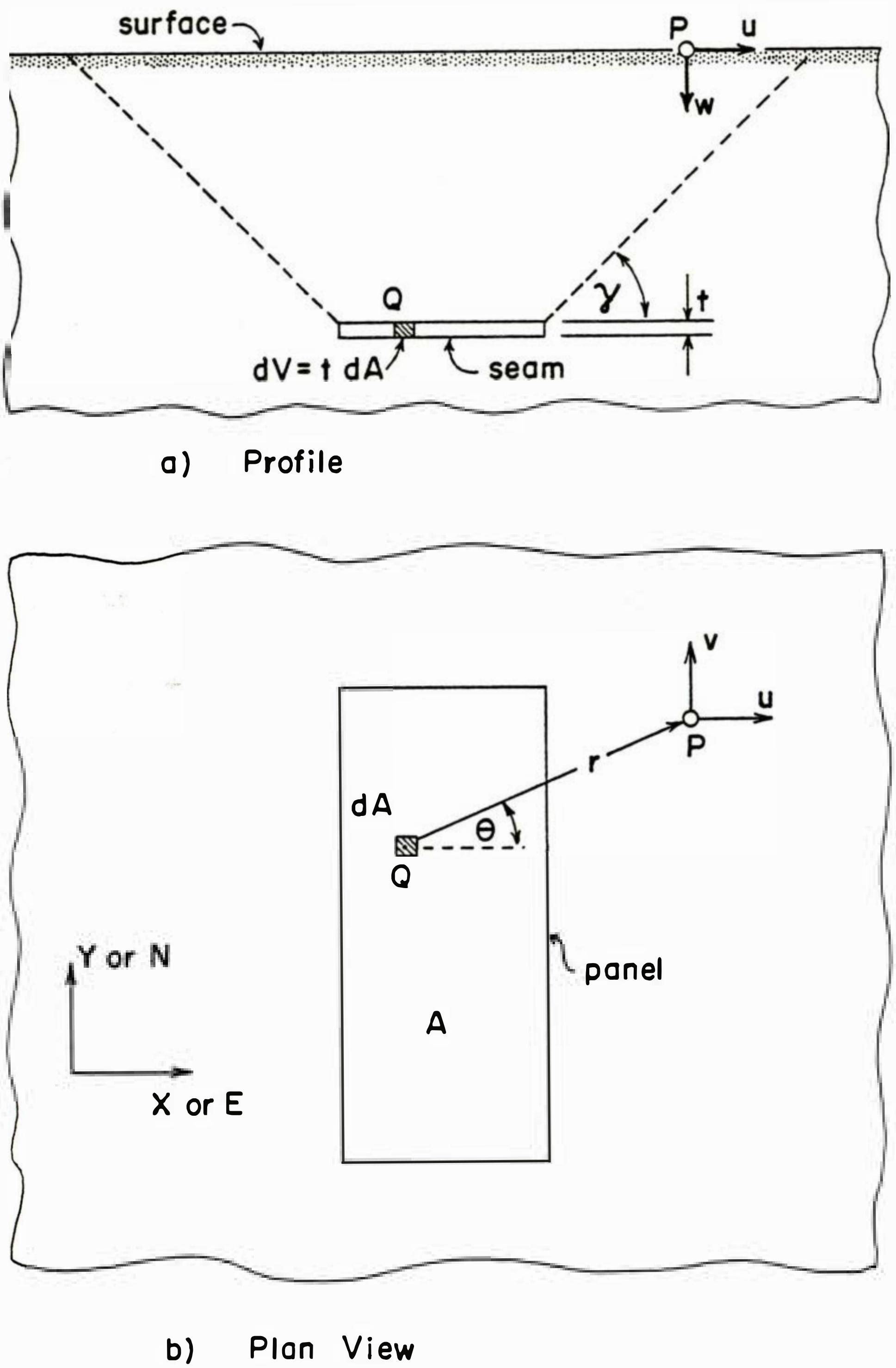


FIGURE 2.2 Surface Displacements Caused by Extraction of a Panel

The grid method is used throughout SPASID for computation of subsidence. There exist more accurate techniques of integration, for example Gauss quadrature, but due to complications described in the next few sections, the use of these methods would be impractical.

2.3 Influence Functions Used In SPASID

The choice of influence functions is not an entirely rational process. Mathematically, the number of potential candidates is infinite. In practice, about half-a-dozen influence functions have been used with various degrees of success. The right choice is, of course, the function that best fits the experimental data for the site for which it is to be used. Therefore, it seems that considerable experimentation may be required before a suitable influence function is found. Fortunately, the situation is not as difficult as it appears at first. After extensive testing of several functions, it was concluded that the choice of the function is far less important than implied in existing literature. In fact, it was hard to differentiate between results obtained from different influence functions, provided that the parameters appearing in these functions were optimized.

Two influence functions were incorporated into SPASID. The function proposed by Knothe [1] was chosen because of its simplicity and wide popularity, particularly in the Eastern European coalfields. The other function is obtained from the solution of the subsidence problem within the framework of linear elasticity. Although its use has been advocated [2], the suggestion does not appear to have been implemented until now, except for profile functions.

2.3.1. Knothe's Influence Function

The influence function suggested by Knothe for the vertical displacement is

$$f_v = C_v \exp[-\pi N (r/b)^2] \,, \qquad (2.5a)$$

where the parameters C_v and N are to be determined experimentally for the site in question. The horizontal scale or shape of the function is determined by N, whereas C_v controls the amplitude.

Knothe assumed that the horizontal displacement du_r is proportional to the slope of the vertical subsidence dw. Hence $f_H \propto df_v/d(r/b)$, from which we get

$$f_H = C_H \, (r/b) \exp\,[-\pi N \, (r/b)^2] \,, \qquad (2.5b)$$

where C_H is another parameter. Equations (2.5) are essentially ad hoc assumptions, i.e., they are not derivable.

2.3.2. Elastic Influence Function

The computation of surface displacements shown in Figure 2.1 can be cast as a boundary value problem in elasticity theory. The ground is considered to be an elastic semi-infinite medium with transversely isotropic properties (the vertical direction being the axis of rotational symmetry). The deformation is caused by removing the infinitesimal volume element dV, and then closing the resulting gap. The resulting surface displacements can be shown to be (see Appendix A)

$$dw = t \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)} (R_1^{-3} - R_2^{-3}) \frac{dA}{b^2},$$

$$du_r = t \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)} \frac{r}{b} (R_1^{-3} - R_2^{-3}) \frac{dA}{b^2},$$

where

$$R_i^2 = (r/b)^2 + \left(\frac{\tan\gamma}{\alpha_i}\right)^2 \qquad (i = 1,2),$$

α_1 and α_2 are functions of the elastic constants, and γ is the limit angle. The α's must satisfy the inequality $\alpha_1 < \alpha_2$. Letting

$$C_V = \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)}, \qquad C_H = \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)}, \qquad k_i = \frac{\tan\gamma}{\alpha_i}$$

and comparing the solution with (2.2), we conclude that

$$f_V = C_V(R_1^{-3} - R_2^{-3}), \qquad f_H = C_H\,(r/b)(R_1^{-3} - R_2^{-3}), \qquad (2.6)$$

with

$$R_i^2 = (r/b)^2 + k_i^2 \qquad (i = 1,2), \qquad (2.7)$$

where C_V, C_H, k_1 and k_2 are the parameters to be determined, subject to the constraint $k_1 < k_2$.

The functions in (2.6) contain two shape parameters, k_1 and k_2, as opposed to the single parameter N found in Knothe's influence function. Hence they have a better potential for fitting given experimental data. An in-depth discussion of both influence functions can be found in Appendix B, where in particular, the relationships between the influence parameters, the limit angle and subsidence factors are derived.

2.4 Pitching Seams

The method of subsidence computation described in the previous sections is applicable to horizontal seams only. In order to obtain reasonable agreement with pitching seams, the technique must be modified.

2.4.1 Vertical Subsidence

Figure 2.3a shows the subsidence profile obtained over a horizontal rectangular panel. As expected, the displacements are symmetric about the centerline of the panel, the maximum subsidence occurring at the center. If the panel slopes, as in Figure 2.3b, the subsidence profile more-or-less retains its shape, but is shifted "downslope". The maximum displacement now occurs near the point where the normal from the center of the panel intersects the surface. This effect could not be reproduced with a straight application of the influence function method.

The method employed in SPASID is quite simple: the surface point Q' in Figure 2.1 is redefined as the intersection of the normal to the seam with the surface. The result is illustrated in Figure 2.4. This enables computation of the incremental vertical displacement from the first equation (2.4) without further modifications. This technique is similar to the method suggested in the Subsidence Engineers' Handbook [4] for British mines.

2.4.2 Horizontal Subsidence

The behavior of horizontal displacements is in a sense opposite to that of vertical subsidence (see Figure 2.5). The location of zero displacement remains directly over the center of the panel, but the shape of the displacement profile changes considerably: the "downslope" displacements are magnified and the "upslope" displacements reduced.

Existing literature is singularly lacking in suggestions on how this effect might be reproduced by the influence function methods. After experimentation, using U.K. Coal Board data from the Subsidence Engineers' Handbook [4], the only extensive data available on horizontal movement, it was concluded that horizontal displacements are influenced by the vertical subsidence. Satisfactory agreement with British data was obtained if the following scheme of slope correction was applied to equations (2.3):

$$u = \sum_i [-(\Delta u_r)_i \cos\theta_i + \eta_p \Delta w_i (\tan\alpha_x)_i], \qquad (2.8)$$

$$v = \sum_i [-(\Delta u_r)_i \sin\theta_i + \eta_p \Delta w_i (\tan\alpha_x)_i],$$

where $(\Delta u_r)_i$ and (Δw_i) are given by (2.4)as before, $(\tan\alpha_x)_i$, $(\tan\alpha_y)_i$ are the cartesian components of seam slope and η_p is called <u>the pitch factor.</u> In computing $(\Delta u_r)_i$ and Δw_i, the definitions of r and b shown in Figure 2.4 are employed. The pitch factor is a site parameter that ranges from 0 to 1. The best fit with coal board data is obtained with $\eta_p = 0.65$.

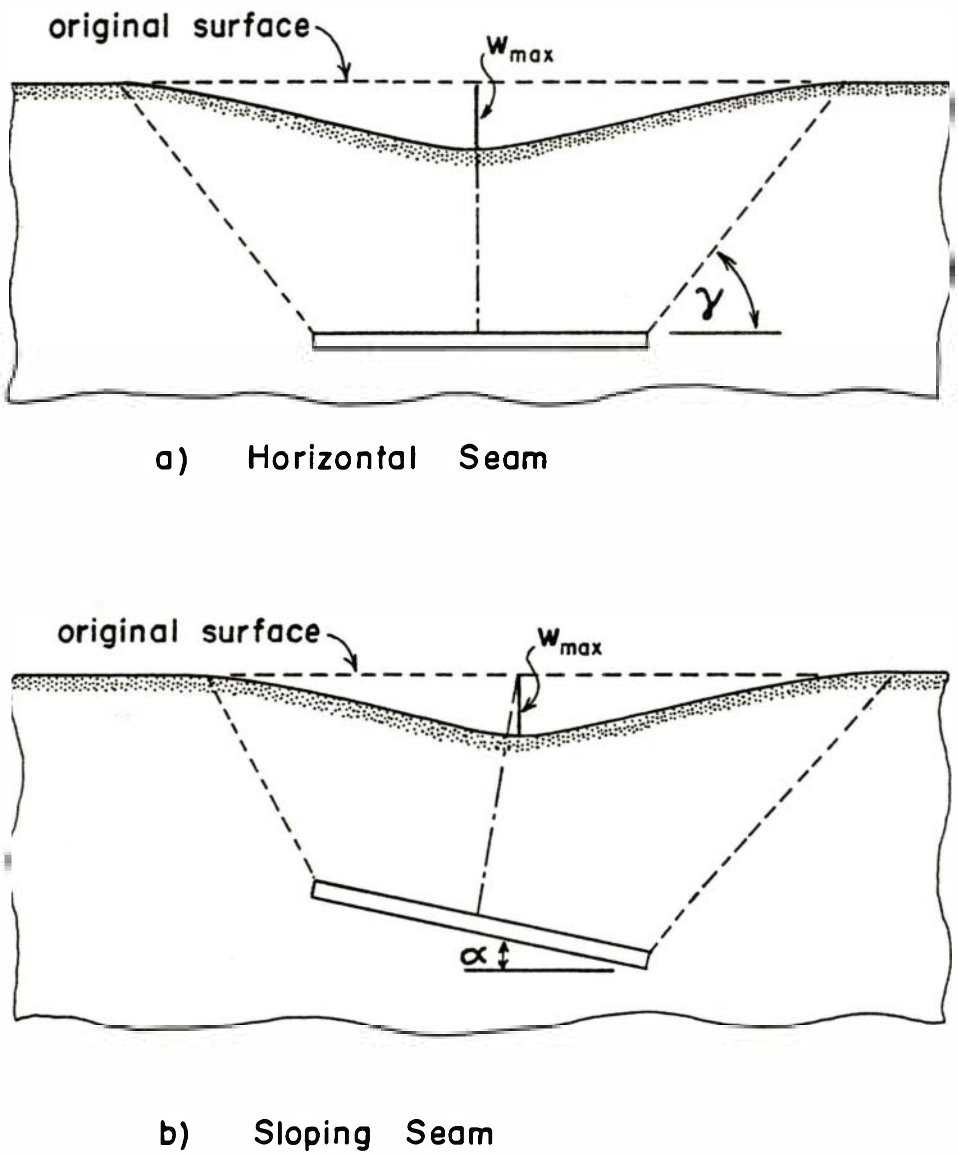


FIGURE 2.3 Vertical Subsidence Profiles for Rectangular Panels

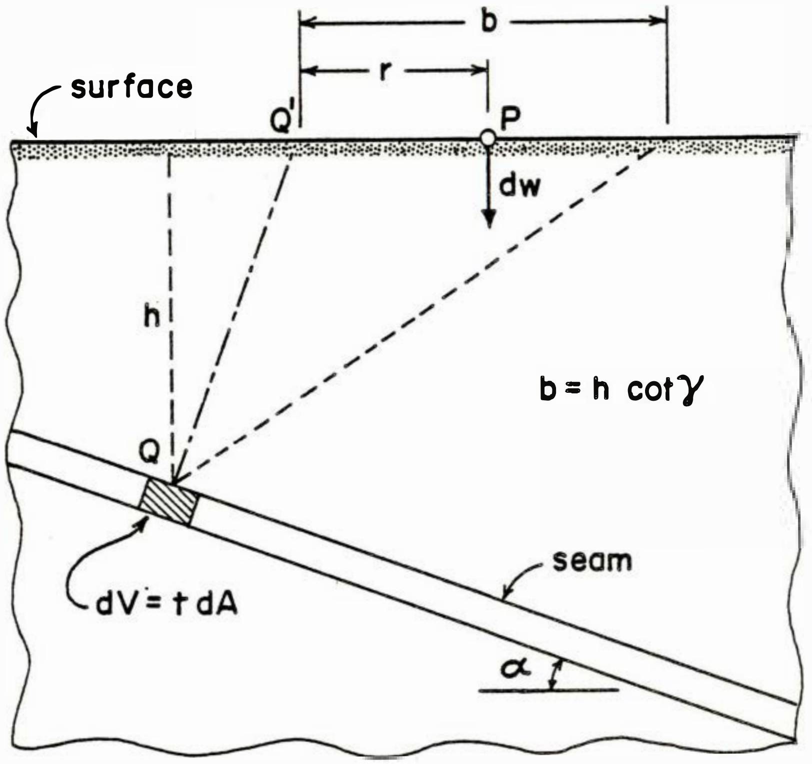


FIGURE 2.4 Vertical Incremental Subsidence for Pitching Seam

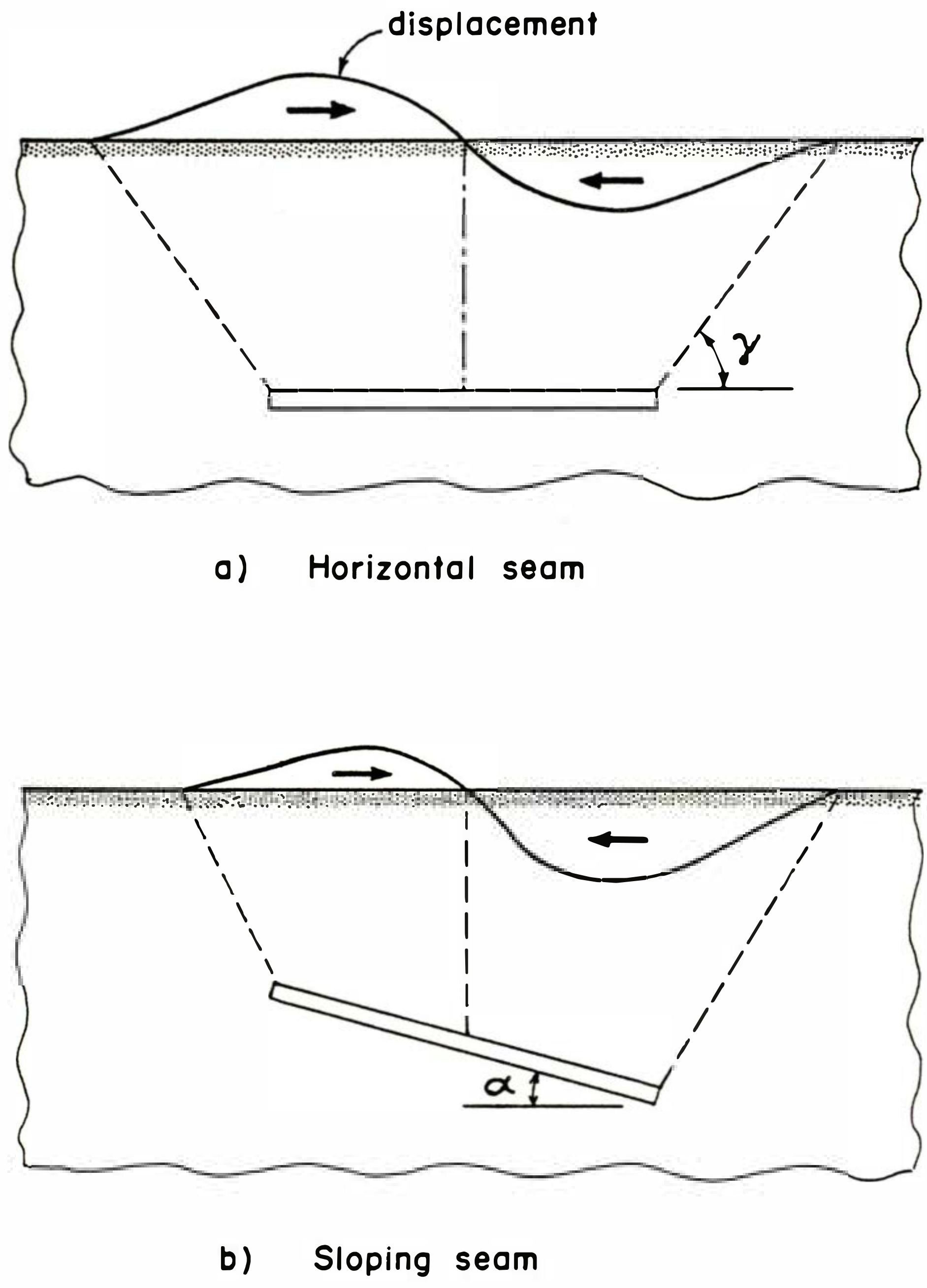


FIGURE 2.5 Horizontal Displacement Profiles for Rectangular Panels

2.5 The Edge Effect

An extremely important feature of SPASID is the inclusion of the effect that the edges of the mine workings have on subsidence. Although this effect has been known for about 30 years and has been the topic of several papers, particularly by Fläschenträger [5], it is still sometimes ignored in the computation of subsidence.

It has been observed that the subsidence above edges of a mine panel is considerably smaller than predicted by calculations. The reason for this appears to be incomplete closure of the mine seam after extraction, as illustrated in Figure 2.6. The edge effect can be duplicated in computations by replacing the seam thickness t in (2.4) by the effective thickness t_e shown in Figure 2.6. Assuming a linear relationship between t_e and distance d from the edge of the workings, we have

$$t_e = t_o + (t - t_o)\, d/\ell \,, \qquad (2.9)$$

where t_o is the subsidence of the mine roof at the edge, and ℓ represents the width of the edge effect zone.

From observation of published data it appears that the edge zone width is proportional to the depth of cover; that is

$$\ell = \eta_\ell \, h \,, \qquad (2.10)$$

where η_ℓ is a site parameter, which we will call the width factor of the edge effect. The other parameter of the site is taken to be η_t, the subsidence factor of the mine roof edge, defined by

$$t_o = \eta_t \, t. \qquad (2.11)$$

For example, British data [4] can be fitted best with $\eta_t = 0$ and $\eta_\ell = 0.28$. Experience has shown that the value of η_t is not very important, but η_ℓ is the most important parameter of the site. Good correlation between predicted and observed displacements cannot be obtained unless η_ℓ is accurately determined.

2.6 Time Lag Effect

For many sites subsidence is a time-dependent phenomenon. It may take considerable time (usually months) before the final subsidence is reached. Currently existing data is not adequate for accurate determination of the subsidence versus time relationship. In SPASID we have followed the lead of several prior publications by assuming the time lag between extraction and subsidence to be an exponentially decaying function. If time-dependency exists, the first equation of (2.3) and (2.8) are replaced by

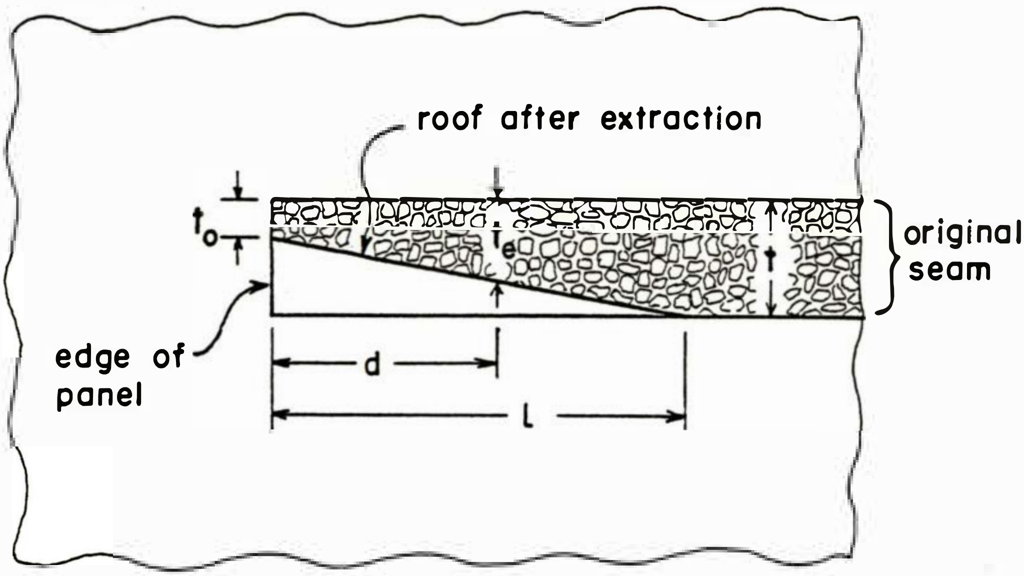


FIGURE 2.6 Edge Effect

$$w = \sum_i \Delta w_i [1 - \exp(-T_i/\tau)] ,$$

$$u = \sum_i [-(\Delta u_r)_i \cos\theta_i + \Delta w_i (\tan\alpha_x)_i][1 - \exp(-T_i/\tau)], \quad (2.12)$$

$$v = \sum_i [-(\Delta u_r)_i \sin\theta_i + \Delta w_i (\tan\alpha_y)_i][1 - \exp(-T_i/\tau)].$$

In (2.12) T_i represents the time difference between the extraction of the ith volume element and the resulting subsidence. The parameter τ is called the characteristic time of subsidence for the site; it has to be obtained from experimental data.

3. PREPROCESSOR MODULE

3.1 General Information

The function of the Preprocessor is to prepare the data base used by other program modules. The data base consists of two units: surface data and mine data. These units contain all the information about the topology of the site and the operation of the mine that is necessary for computation of subsidence. The Preprocessor is also the only means of adding, deleting, altering or printing the data.

The data base is essentially a collection of regular rectangular grids that represent the surface overlying the mine and the underground panels to be extracted (an arbitrary collection of points is also permitted for the surface). The data consists of values, such as surface elevation, depth of seam, scheduled date of extraction etc. at each grid point or for each grid element.

Apart from the grid data, the data base also contains Surface and Mine Directories, which are simply tables that contain all the information necessary to reproduce each grid. The Directories are always stored in core memory during execution of the program. The grid data, on the other hand, reside in disk storage. Grid data is brought into core memory only as needed, but only one surface and one mine grid can be stored in core memory at any one time. A similar storage arrangement is used in all the other program modules. More information about the organization of storage is found in Section 1.3.

A concise summary of the Preprocessor is given in Section 7.2. It includes a listing of all the tasks and the input instructions for each task (arranged in alphabetical order by task name). The remainder of this chapter is intended to give the user an overview of the Preprocessor and sufficient working knowledge to use the program efficiently with the help of the input instructions in Section 7.2.

3.2 Reading and Saving a Data Base

A data base previously saved in Backup Storage can be brought into Disk Storage by executing the task &LOAD. An example of the input deck to accomplish this is:

```
&LOAD
TAPE=1Ø
&
```

The parameter TAPE is the data set reference number of the external storage unit on which the data base is stored (1Ø in this example). After the transfer of data has been accomplished, the program prints the Directories of all the Surface and Mine Grids contained in the data base. Note that the data base must reside in Disk Storage before any operations can be performed on it.

The session is terminated by the task &TERMINATE, which may also be used to save the data base in Backup Storage. The following deck would save the data on the same external unit that was used in &LOAD:

```
&TERMINATE
TAPE=1Ø
&
```

The parameter TAPE is in this case optional. If it is omitted, the data base will not be saved.

3.3 Reading and Interpolating Field Data

3.3.1. Reading Data

In order to create a Mine or Surface Grid for the data base, the topology of the site must be described in the form of field data. The latter consists of surface elevations for a Surface Grid, or borehole data for a Mine Grid. The task &INPUT is capable of reading both kinds of data from card images.

Suppose that 43 borehole readings are available in the following form:

COORDINATES		DEPTH OF COVER	SEAM THICK-NESS	SURFACE ELEVATION
Y(North)	X(South)			
3329.4	283.6	365.8	4.65	1248.3
-2170.8	488.0	412.8	5.18	1330.1
		etc.		

If batch processing is used, each line of the table must be placed on a separate card image, but the order of the data on each card and its format are arbitrary, as long as they are consistent. Let us assume that the data is entered in the order shown using the format 3F1Ø.1,F5.2,F1Ø.1. The input deck would then be:

```
&INPUT
NUMPOINTS=43
DATAID=2,1,6,4,3
'FORMAT'=(3F1Ø.1,F5.2,F1Ø.1)
UNIT=5
&
Borehole data cards
```

The parameter DATAID identifies the data and its order on each card according to the DATAID code shown in Section 7.2. The five digits imply that five data items exist on each card, the first being the Y-coordinate of the point (DATAID=2), the second the X-coordinate (DATAID=1) etc. The parameter UNIT shows that the input unit is 5, a card reader in most installations. In interactive mode the usual free-format input of data from the keyboard must be employed, in which case the FORMAT parameter is not needed.

In addition to the data shown in the table, a Mine Grid also requires the seam bottom elevation of each point. But seam elevation can be computed from the given data, and this is automatically done by the program. In fact if any one of the following four items:

i) surface elevation
ii) seam thickness
iii) seam bottom elevation
iv) depth of cover

is omitted, it is computed and stored by the program. The two coordinates of each point, however, must always be specified.

The data entered in the above example can be used to generate either a Mine or Surface Grid. Actually a Surface Grid requires only two coordinates and the surface elevation. Hence for the purposes of generating a Surface Grid only, the input deck could be changed to:

```
&INPUT
NUMPOINTS=43
DATAID=2,1,3
'FORMAT'=(2F1Ø.1,15X,F1Ø.1)
UNIT=5
&
Borehole data cards
```

3.3.2. Interpolation

All the data at grid points is obtained by interpolation or extrapolation of Field Data. Since this operation is present in several tasks that are covered in the remainder of this chapter, it seems appropriate to discuss it here.

Interpolation addresses the following problem: given a discrete set of surface elevation measurements or other data $Z_i=Z(X_i,Y_i)$; $i=1,2,...N$; estimate $Z_o=Z(X_o,Y_o)$; for example the surface elevation at (X_o,Y_o).

The method used in the Preprocessor fits a quadratic surface $Z=a_1+a_2X + a_3Y + a_4X^2 + a_5XY + a_6Y^2$ to M data points that lie closest to (X_o,Y_o). The desired surface elevation is then obtained as $Z_o = a_1 + a_2X_o + a_3Y_o + a_4X_o^2 + a_5X_oY_o + a_6Y_o^2$.

Since it takes six data points to define a quadratic surface, that is to compute the six coefficients $a_1, a_2,...a_6$, we must take $M \geq 6$. With M=6, we have the case of pure interpolation, where the quadratic surface passes through all six data points. When $M > 6$, the exact fit is no longer possible, and a criterion of "best possible fit" must be used. We have now the case of interpolation with averaging, where the degree of averaging depends on the value of M.

Best mean square fit is used in the Preprocessor, where the weighted square error between the M data points and the interpolating surface

$$\varepsilon = \sum_{i=1}^{M} W_i(Z_o - Z_i)^2$$

is minimized. The weights W_i depend on the distance

$$r_i = \sqrt{(X_o - X_i)^2 + (Y_o - Y_i)^2}$$

such that the data points closest to (X_o,Y_o) are given the most weight. We use

$$W_i = \left(1 - \frac{r_i}{\sigma r_{max}}\right)^2, \qquad (3.1)$$

where r_{max} is the distance between (X_o,Y_o) and the furthest of the M data points, and σ is a numerical parameter. If $\sigma=1$, we have the extreme case where the furthest of the M data points is given a zero weight. The other extreme is obtained as $\sigma \to \infty$, when all data points have the same weight.

As a result of experimentation with published test problems [6], M=9 and σ=1.1 were chosen as the default values for the Preprocessor but it may be advisable to use other values, depending on the location of field data points. It is important to choose M large enough so that all the M nearest data points do not lie near one or two straight lines. If this precaution is not heeded, an ill-conditioned set of equations for the coefficients will be produced, resulting in almost random values for the interpolated data.

3.4 Generation of Mine Grids

The model of a mine panel used in SPASID is a rectangular grid that covers the area of the panel as shown in Figure 3.1. The following data is calculated for each grid point by interpolation of borehole data:

i) global E coordinate
ii) global N coordinate
iii) surface elevation
iv) seam thickness
v) seam bottom elevation
vi) depth of cover.

This data forms part of the data base for the site. A data base for a site may contain up to 12 Mine Grids.

3.4.1. Choice of Grid Size

The number of grid lines chosen by the user is very important, because it determines the core storage requirements during subsidence computation. A careless choice can easily overload the memory, forcing upon the user the annoying and time consuming task of altering the mine grids.

Subsidence is calculated by adding the contributions of all the mine grid elements to the surface displacements, using equations (2.12). The contribution of a grid element is in turn obtained by subdividing the element into a subgrid and summing the contributions of the subgrid elements. The desired size of the element subgrid is specified by the user in the Subsidence Module, and the corresponding subdivision is performed automatically by the program. Since the accuracy of the computed subsidence depends on the size of the subgrid, it should be apparent that the original Mine Grid has no bearing on the results.

As subsidence is computed, one Mine Grid and one Subgrid must be in Core Storage at the same time. This enables us to evaluate and minimize the storage requirements by adjustments to the Mine Grid.

Suppose that the desired size of a subgrid element for the example in Figure 3.1 is 10' x 10'. The subgrid would thus contain 11 x 11 = 121 grid points, and the Mine Grid 23 x 5 = 115 points, resulting in a total of 236 grid points that must be in Core Storage during subsidence computation. This is an example of efficient storage utilization.

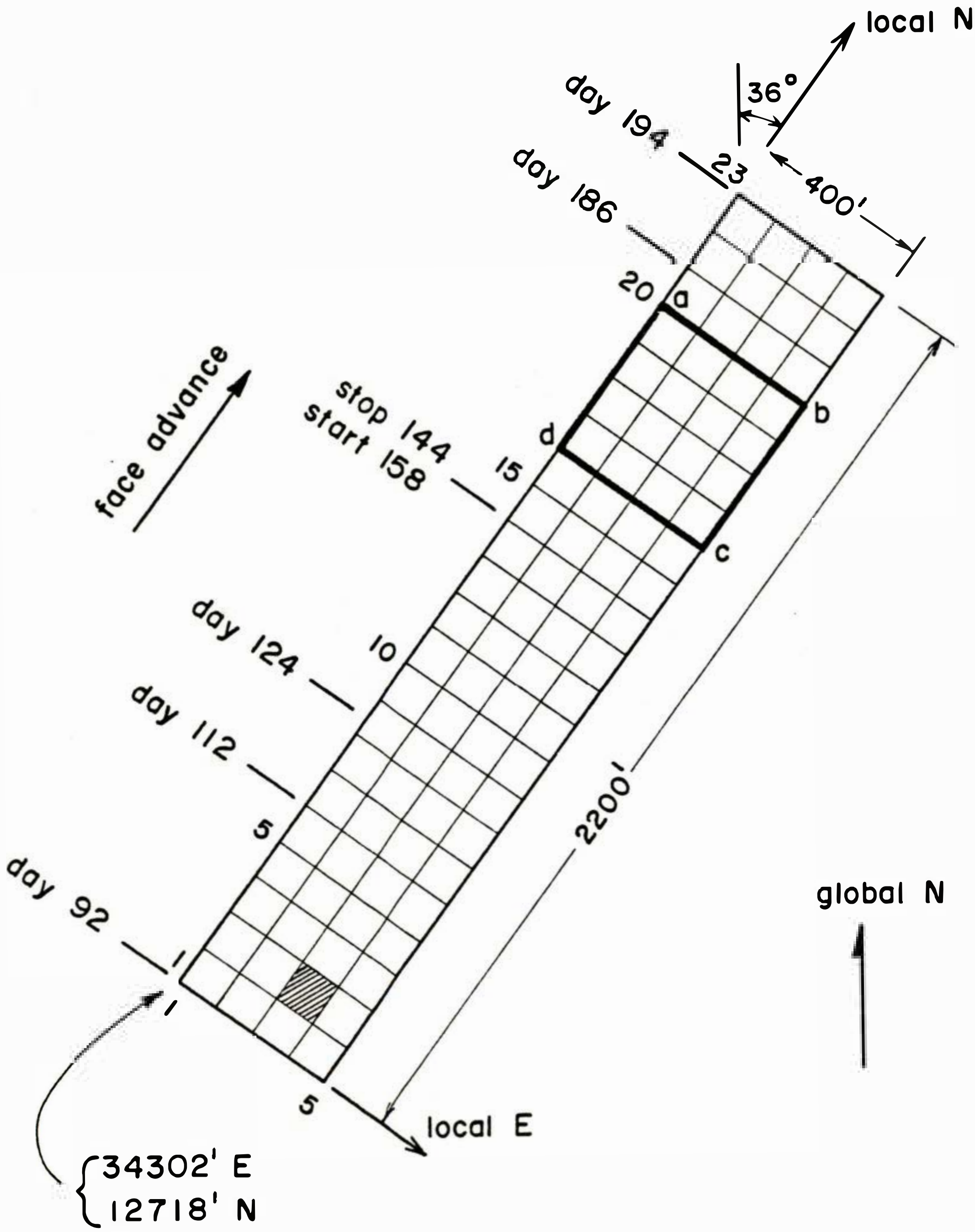


FIGURE 3.1 Longwall Panel

Let us now double the element size of the Mine Grid, resulting in 12 x 3 = 36 grid points and an element size of 200' x 200'. The subgrid would then contain 21 x 21 = 441 grid points, assuming that the 10' x 10' subelement size is to be maintained. Core Storage must now accomodate 477 grid points, which is about double the number required before.

The data at the grid points of a subgrid are obtained by bilinear interpolation of Mine Grid data. This will have some bearing on the choice of Mine Grid: the grid elements should be small enough for the interpolation to be sufficiently accurate.

When dealing with a room-and-pillar operation, the choice of the Mine Grid is more restrictive, since the grid lines must follow the outlines of pillars. As a rule, each pillar must form a grid element, or it may be divided into several elements. It should be noted that the use of SPASID is applicable only if the pillars are removed. If this is not the case, subsidence will not occur until the pillars deteriorate and collapse, which could take many years.

Mine Grids are generated by the task &GENMINE. Needless to say, the appropriate borehole data must reside in Core Storage before &GENMINE can be executed. When the generation is completed, the grid data automatically becomes part of the data base; that is, it is entered into Disk Storage, and the Mine Directory is updated.

The following input deck will generate the Mine Grid for the longwall panel in Figure 3.1.

```
&GENMINE
ORIGIN=343Ø2,12718
AZIMUTH=36
EGRID=5@1ØØ
NGRID=23@1ØØ
TYPE=1
PARMS=12,1.1
&
```

The parameters EGRID and NGRID specify the number of grid lines and their spacing in the directions of the local or grid coordinates. For a longwall panel, the direction of local North must coincide with the direction of face advance. TYPE=1 means a longwall panel; TYPE=2 would be used for a room-and-pillar operation. The first value of PARMS specifies the number of nearest points to be used in the interpolation of field data, namely the value of M in Section 3.3. The second value represents the weighting factor σ in equation (3.1).

The grids will be automatically numbered by the program in the order in which they were generated. All subsequent references to any one grid must use the appropriate Mine Grid number.

3.5 Specifying the Height of Cut

After a Mine Grid is generated, but before subsidence can be calculated, the height of cut must be specified and incorporated into the data base. This can be accomplished with the task &CHGCUT. A card deck that will call for a constant cut height of 5.5 feet for Mine Grid number 3, and a variable cut height for Grid number 5 would be:

```
&CHGCUT
CUTHEIGHT=3@5.5
CUTHEIGHT=5@4.Ø,6.Ø
&
```

The first value of CUTHEIGHT is the grid number, the other values specifying the height of cut. If only one height is given, it is interpreted as a constant value. Two heights imply a cut equal to the seam thickness, but never less than the first value nor greater than the second. In this example, grid number 5 will have a maximum allowable cut height of 6 feet, and a minimum height of 4 feet.

Execution of &CHGCUT will not involve Disk Storage because the heights of cut are stored in the Mine Grid Directory.

3.6 Specifying Extraction Schedule

A schedule of extraction must be prescribed for each Mine Grid before subsidence can be computed. This can be done with the task &CHGDATES after the Mine Grid has been generated. Different methods for describing the scheduled timetable must be used for longwall and room-and-pillar workings.

For a longwall, the face advance method is used. Figure 3.1 shows the location of the mine face, measured from the Southern end at various times. Days were chosen as the units of time in this example, starting from an arbitrary date. The input deck that would transmit this information to the program is:

```
&CHGDATES
MNGR=3
ADVANCE=Ø@92,51Ø@112,75Ø@124,13ØØ@144,
13Ø1@158,21ØØ@186,22ØØ@194
&
```

MNGR refers to the Mine Grid number, and ADVANCE specifies the locations of the face at different dates. Note that there is a two week work stoppage when the face advance is at 1300 feet. Since the distances appearing in ADVANCE must be in ascending order, a face advance of 1300 feet was specified where the work stopped, and 1301 was used when the work resumed.

The extraction schedule is stored in the data base in the form of an extraction date for each grid line parallel to the face advance. Each date represents the day (or other unit of time) when the face reaches that grid line, and is obtained by linear interpolation of input data.

An alternative method of describing the extraction schedule of a longwall panel is to date the grid lines directly:

```
&CHGDATES
MNGR=3
DATE=1@92,6@5ØØ,9@129, etc.
&
```

The numbers entered with DATE are the grid line numbers and the dates when the face reaches these lines. Omitted grid lines are again dated by linear interpolation.

In the case of a room and pillar operation, each grid element must be dated separately. The extraction date should specify the time when the removal of the grid element (i.e. pillar) is completed, and the roof supports removed. A typical input deck would be:

```
&CHGDATES
MNGR=5
EXTRACT=1 1 92, 1 2 94, 2 2 98,   etc.
&
```

The first two numbers in each triplet of EXTRACT specify the location of the grid element, the third number being the extraction date. The element location is determined by the two grid line numbers that intersect at the Southeastern corner of the element. For example, the location of the shaded element in Figure 3.1 would be 3,2 (the East Coordinate followed by the North coordinate).

The portions of the grid that are not dated with &CHGDATES are assigned very high extraction dates by the program. This applies to both longwall and room-and-pillar operations.

3.7 Generating Surface Grids

Surface Grids form the network of points (grid points) where subsidence can be computed. As will be explained in Chapter 4, it is not necessary to compute the subsidence at all the points of a grid. Therefore, Surface Grids should cover all the regions where it might be desirable to compute surface displacements, but they do not commit the user to carrying out the computations.

The data that is calculated and stored at each grid point consists of

- i) global E coordinate
- ii) global N coordinate
- iii) surface elevation.

The three additional items described in Section 3.4:

- iv) seam thickness
- v) seam bottom elevation
- vi) depth of cover

may also be interpolated and printed, but these will not be stored in the data base, since they are not required for subsidence calculations. Up to six Surface Grids are accomodated in the data base of a site.

Two types of Surface Grids may be generated by SPASID:

i) Rectangular grids of uniform mesh size (Grid Type 1)
ii) Irregular collections of surface points, or points evenly spaced on a straight line (Grid Type 2).

Both types of grids are illustrated in Figure 3.2.

3.7.1. Rectangular Grids

Rectangular grids are generated by the task &GENSURFACE. The input deck is almost identical to that used for a Mine Grid. For the rectangular grid in Figure 3.2 it would be:

```
&GENSURFACE
ORIGIN=8400,2700
AZIMUTH=-40
EGRID=10@50
NGRID=9@40
PARMS=9,1.1
NUMDATA=3
&
```

Comparing this input with the deck shown in Section 3.4 for a Mine Grid, we note only two differences. First, the TYPE parameter is missing. It will be automatically supplied by the program because &GENSURFACE can only be used to generate Type 1 grids. Secondly, the parameter NUMDATA has been added. This specifies the number of data items that are to be interpolated for each grid point. In the example, we request the first three items from the list given above; that is the two coordinates and the surface elevation.

3.7.2. Collections of Points

Collections of points are generated by &GENPOINTS. It must be pointed out that this is the only type of Surface Grid that may be used in the System Identification Module; that is, the stations (monuments) where surface displacements are measured must be collected into a Type 2 grid, even when the monuments form a rectangular gridwork. The azimuth angle for a Type 2 grid is automatically set to zero.

The "grid" of 12 points shown in Figure 3.2 is generated by the input deck:

```
&GENPOINTS
NUMDATA=3
PARMS=9,1.1
LOCATION=8450,2850,0,5,50; GENERATES PTS 1-5
LOCATION=8475,3050,180,5,50; GENERATES PTS 6-10
LOCATION=8425,2975; GENERATES PT 11
LOCATION=8500,2975; GENERATES PT 12
&
```

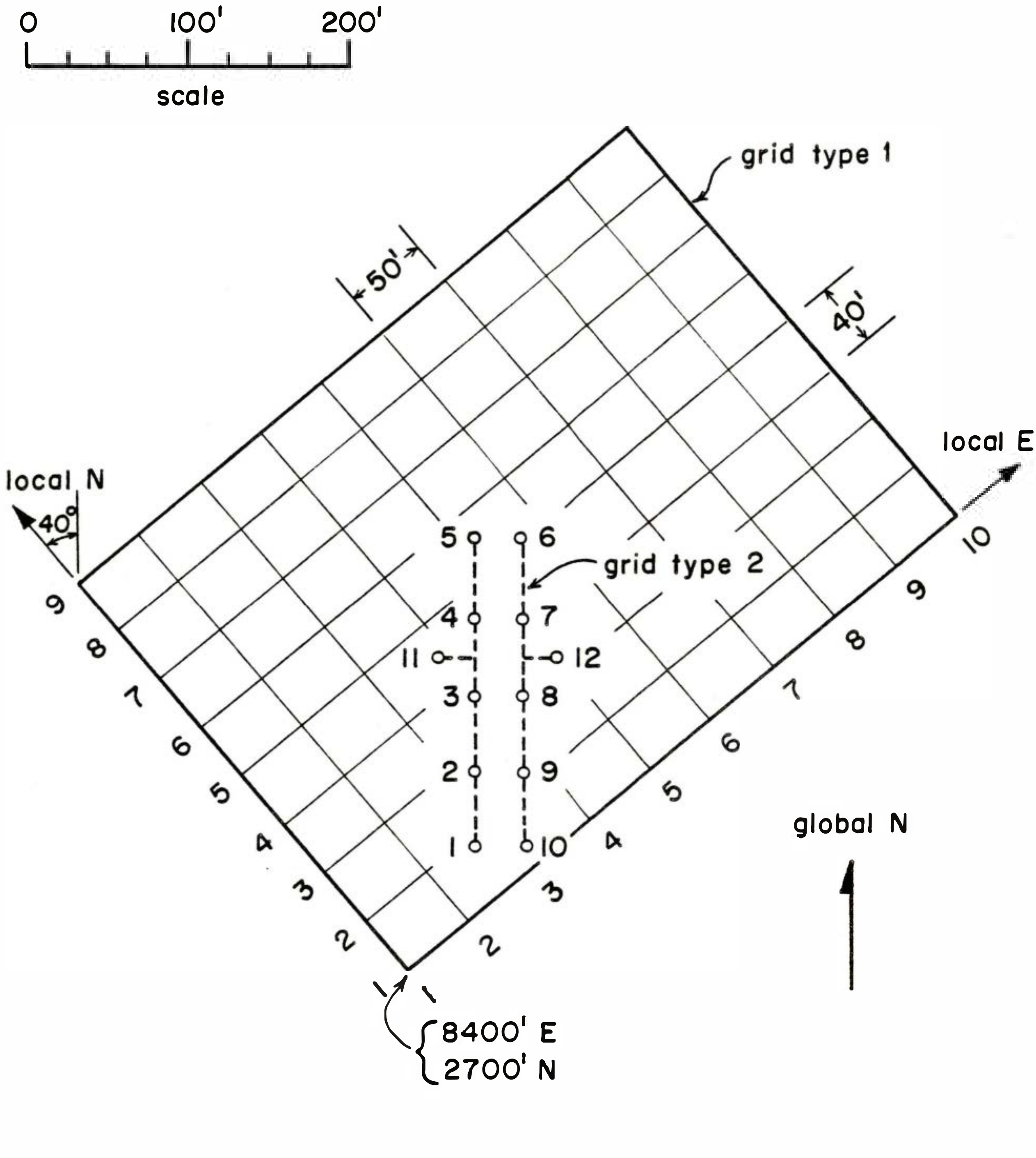


FIGURE 3.2 Surface Grids

Note that the provisions for comments has been utilized in the input deck (comments must be preceded by a semicolon). Each LOCATION parameter card starts with the global coordinates of the point to be generated. This is sufficient to generate a single point. A series of equally spaced points on a straight line are generated if the coordinates, now interpreted as the coordinates of the first point of the line, are followed by the azimuth of the line, number of points, and the distance between them.

Some of the comments that were made in Section 3.4 about Mine Grids are also applicable to Surface Grids: the appropriate field data must first be read into Core Storage, and the grids are automatically numbered as they are generated and placed into the data base.

3.8 Modifying and Printing of Data

3.8.1. Making Changes

Once a Surface or Mine Grid has been entered into the data base, it cannot be altered. The exceptions are cut height and extraction schedule associated with a Mine Grid -- see &CHGUT and &CHGDATES in Chapter 7. New grids may be added at any time using &GENMINE, &GENSURFACE or &GENPOINTS in the manner described previously. To delete an existing grid, the task &DELETE must be used. The following example will purge a Surface Grid from the data base, including the Surface Grid Directory.

```
&DELETE
SFGR=3; DELETE SURFACE GRID 3
&
```

A Mine Grid is deleted with the same task, replacing the parameter SFGR with MNGR:

```
&DELETE
MNGR=2; DELETE MINE GRID 2
&
```

Once a grid has been deleted, the numbers of the remaining grids are compressed. In the last example, the previous Mine Grid number 3 will become number 2 etc.

3.8.2. Printing Data

It is possible to print any portion of the data base with special printing tasks. These are

&PRTMINE -- prints Mine Grid Data
&PRTSURFACE -- prints Surface Grid Data
&PRTDATES -- prints extraction schedule of a Mine Grid
&PRTINPUT -- prints Field Data.

Only the data that reside in Core Storage can be printed. Since there is no provision for saving Field Data in SPASID, &PRTINPUT should be used immediately after the data has been read in. Mine and Surface Grids may be brought into Core Storage with the tasks &GETMINE and &GETSURFACE before printing.

Assume, for example, that we wish to print out the data for portion abcd of the Mine Grid in Figure 3.1. The corresponding input deck would be:

```
&GETMINE
MNGR=2
&
&PRTMINE
UNIT=6
NRANGE=16,2Ø
'TITLE'=MINE GRID 2--N GRID LINES 16-20 INCL.
&
```

The parameter UNIT refers to the DSR (Data Set Reference) number of the printer. The portion of the grid for which data is to be printed is specified by NRANGE and ERANGE. In this example, grid lines 16 to 20, counting North, are printed. The parameter card for ERANGE has been omitted, in which case all the grid lines across the panel (Easterly direction) will be included. The optional parameter 'TITLE' contains the heading that is to appear with the printed data. The task &GETMINE may be omitted if the Mine Grid is already in Core Storage prior to printing, for example immediately after its generation with &GENMINE.

Suppose that we now wish to print the data for the centerline of the panel, without using a title. This can be done by

```
&PRTMINE
ERANGE=3
&
```

There is no need to use &GETMINE, since the data is already in Core Storage. Parameter UNIT was omitted, which means that the default value UNIT=6 is used by the program. ERANGE=3 refers to the grid line that coincides with the centerline of the panel.

As the Mine Grid is still in Core Storage, we can conveniently print its extraction schedule next:

```
&PRTDATES
UNIT=6
NRANGE=1,14
'TITLE' = EXTRACTION SCHEDULE--DAY 92 to 144
&
```

Again, UNIT could be omitted since its default value is 6. Parameter NRANGE limits the printing to grid lines 1 to 14 (counting North). If this card were omitted, the schedule for the entire panel would be printed.

Surface Grids are printed in the same manner as Mine Grids. For example, data for the Eastern half of the rectangular grid in Figure 3.2 can be printed with

```
&GETSURFACE
SFGR=3
&
&PRTSURFACE
ERANGE=6,1Ø
&
```

Parameters UNIT, NRANGE and TITLE also exist for Surface Grids, but were not needed in this example. Parameter ERANGE is not applicable to Surface Grids of Type 2 because the grid data is stored in one-dimensional "Northerly" arrays. To print data for points 1 to 5 of the irregular "grid" shown in Figure 3.2, for example, the following input deck must be used:

```
&GETSURFACE
SFGR=4
&
&PRTSURFACE
NRANGE=1,5
&
```

A typical input deck for printing Field Data would not differ significantly from Mine or Surface data:

```
&PRTPRINT
UNIT=6
RANGE=1,21
'TITLE'=BOREHOLE DATA FOR HOLES 1-21
&
```

The parameter RANGE specifies the range of data points to be printed; all the points will be included in the printout if the card is omitted.

4. SUBSIDENCE MODULE

4.1 General Information

The function of the subsidence module is computation of surface displacements. All the necessary Surface and Mine Grid data must be generated beforehand by the Preprocessor, including the heights of cut to be used and the extraction schedules. Needless to say, this data base must be retrieved from Backup Storage before subsidence computation can proceed. In addition to the data base, the Subsidence Module also needs influence functions and site parameters which must be passed to the program by appropriate tasks.

The results of subsidence computation are placed in Disk Storage and can be saved in Backup Storage before terminating the session. This data can then be retrieved and plotted in various ways by the Postprocessor. The computed displacements can also be printed by the Subsidence Module.

Storage of surface displacements is organized in the same manner as mine and surface data; that is, it is grid-oriented. Each call of the subsidence computation task results in the creation of a Subsidence Grid, which is identical to the Surface Grid for which subsidence was computed. In addition to the grid point coordinates and surface elevations, the grid data will also contain the three displacement components of each grid point. However, a Subsidence Grid does not have to incorporate the entire Surface Grid; the user may designate any portion of a Surface Grid to be a Subsidence Grid.

Subsidence Grids have their own Directory, which is automatically maintained by the program. The maximum number of Subsidence Grids that may be generated in any session is six.

For detailed description of input for the Subsidence Module, the user is referred to Section 7.3.

4.2 Reading and Saving of Data

The first task in any run should be &LOAD, which transfers the appropriate data base (Mine and Surface Grids) from Backup into Core Storage. A sample input deck is

```
&LOAD
TAPE=1Ø
&
```

where TAPE specifies the DSR number of the Backup Storage device. Execution of &LOAD will also result in printing of Mine and Surface Directories.

A session is terminated with the task &TERMINATE, which also prints the Subsidence Grid Directory. If the Subsidence Grid Data is to be saved for the Postprocessor, it must be placed in Backup Storage. An input deck that would save the data on DSR number 11 is

```
&TERMINATE
TAPE=11
&
```

If the TAPE parameter is omitted, the data will not be saved.

4.3 Specifying Site Parameters and Influence Functions

The site parameters were introduced in Chapter 2. They were

i) Limit Angle γ
ii) Characteristic time τ
iii) Width factor of the edge effect η_ℓ
iv) Subsidence factor of the edge effect η_t
v) Pitch factor η_p

Most important of these are τ and η_ℓ. The exact value of the limit angle does not affect the subsidence significantly, as long as it is not too far off the mark; 50-60 degrees should work well in most cases. Similarly, the subsidence factor η_t is not very influential; $\eta_t = 0$ seems to be a reasonable value. The pitch factor η_p is involved only in the horizontal displacement of pitching seams.

The site parameters must be passed to the program by executing &RDPARAMS. An example input deck is

```
&RDPARAMS
LANGLE=55
CTIME=Ø
WFACTOR=Ø.28
SFACTOR=Ø
PFACTOR=0.65
&
```

By setting characteristic time (CTIME) to be zero, subsidence was specified to be instantaneous. &RDPARAMS will also print a table of input values.

SPASID does not use influence functions explicitly, but employs a table containing the numerical values of the functions at equally spaced intervals of r/b between $0 \leq r/b \leq 1$. In between the tabulated values, the program uses linear interpolation. Up to 26 function values can be accommodated for the horizontal as well as for the vertical influence function.

The influence function tables may be entered by two different methods. The task &RDFUNCT can be used to read the function values directly. The data cards must be in ascending order of r/b and each card must contain the value of the vertical and horizontal influence function (in that order). The card format is arbitrary. An example input deck for batch processing is

```
&RDFUNCT
NUMF=21
'FORMAT'=(5X,2F8.5)
UNIT=5
&
Data cards
```

NUMF prescribes the number of r/b values at which the influence functions were evaluated. Note that r/b must cover the entire range between zero and one at equally spaced intervals. The parameter 'FORMAT' specifies the format of each data card, and UNIT is the DSR number of the input unit. If interactive mode is used, the FORMAT parameter is not necessary, since the data is entered from the keyboard in free format.

Another approach is to let the program calculate the tables from given influence function parameters. For example, a table of Knothe's vertical and horizontal influence functions would be created by the following input:

```
&KNOTHE
NUMF=21
N=3.895
CVERT=3.169
CHORIZ=4.995
&
```

where N, CVERT and CHORIZ are the parameters N, C_V and C_H, respectively, defined in (2.5) of Section 2.2.

For the elastic influence functions, the corresponding input deck would be:

```
&ELASTICITY
NUMF=21
K1=Ø.2868
K2=Ø.2958
CVERT=1.2958
CHORIZ=2.ØØ2
&
```

The parameters K1, K2, CVERT and CHORIZ represent k_1, k_2, C_V and C_H in equations (2.6) and (2.7).

4.4 Computing Subsidence

Once the data base has been placed in Disk Storage, and the influence function and site parameters have been entered, subsidence can be computed with &CMPSUBS. Because subsidence is time-dependent due to ongoing mining and the time lag effect, each call of &CMPSUBS must not only specify the surface points, but also the time period over which the displacements are to be computed.

As an example, let us compute the displacements of the rectangular Surface Grid in Figure 3.2 that occur between the dates 78 and 212. The corresponding input deck would be

```
&CMPSUBS
SFGR=3
DATES=78,212
NUMINT=25
&
```

Execution of this deck would create a Subsidence Grid that contains the entire Surface Grid, and compute the displacements of each grid point that became part of the Subsidence Grid data. Parameter NUMINT refers to the number of integration points, or Mine Subgrid elements that are to be employed in computation of subsidence, as explained in Section 3.4. If, for example, the radius of influence at the site is 800 feet, then the side length of each subgrid element would be no greater than 800/25 = 32 feet. It should be recalled that larger values of NUMINT increase the accuracy of computation but place greater demands on Core Storage.

In order to include only a portion of a Surface Grid into a Subsidence Grid, the now familiar parameters ERANGE and NRANGE must be used. This is illustrated by the input deck:

```
&CMPSUBS
SFGR=3
DATES=78,328,5
ERANGE=6,1Ø
NUMINT=25
&
```

The Subsidence Grid would now consist of the Eastern half of the Surface Grid shown in Figure 3.2. It should also be noted that the values of the DATES parameter have been changed from the previous example. The new values request subsidence at five different, equally spaced dates, the datum date being 78 and the last date 328. Hence subsidence would be computed for dates 128,178,228,278, and 328. Since all these displacements become part of the same Subsidence Grid Data, it is possible that Core Storage will become overloaded. In that case it becomes necessary to break the subsidence computation into several tasks, each covering a different period of subsidence or a smaller portion of the Surface Grid.

4.5 Printing Subsidence

There is a good deal of similarity between printing Subsidence Grid data and Mine or Surface Grid data. Therefore, some of the details covered in Section 3.7 will not be elaborated here.

The task &PRTDISPLTS is dedicated to printout of Subsidence Grid Data. The output contains the grid line numbers plus the vertical and horizontal displacements of each grid point. Printout of the horizontal displacements includes the cartesian components in the local East and North directions, as well as the magnitude and direction (measured clockwise from local North). It should be noted that for Type 2 grids the azimuth angle is always zero so that local and global directions coincide.

The grid line numbering system of the original Surface Grid is used throughout; that is, generation of a Subsidence Grid does not change the line numbers.

If the subsidence was computed for several dates, as in the last example of Section 4.4, then the displacements at all these dates will be printed, unless the user requests otherwise. The input deck

```
&PRTDISPLTS
UNIT=6
'TITLE'=SUBSIDENCE OVER EASTERN HALF OF SURFACE GRID 2
&
```

would print all the displacements computed in that example, UNIT being the DSR number of the printer. However, if the Subsidence Grid is not in Core Storage, the above input deck must be preceded by

```
&GETSUBS
GRID=2
&
```

where GRID defines the Subsidence Grid number to be transfered to Core Storage.

The user can employ parameters ERANGE and NRANGE to limit the output to a portion of the Subsidence Grid. A similar parameter TRANGE controls the range of dates of subsidence. In order to print the subsidence profiles along grid line 8 East of Figure 3.2, for example, the following parameter card must be added

ERANGE=8.

If, in addition, we wish to suppress the printout of displacements on dates 128 and 178, we must include the card

TRANGE=3,5

which requests output for third to fifth dates only.

5. SYSTEM IDENTIFICATION MODULE

5.1 General Information

The System Identification Module is used to compute the site parameters and the parameters of the influence functions from measured surface displacements. More specifically, it finds the influence function parameters that minimize the RMS (root-mean-square) error between measured and computed displacements. In other words, it optimizes the influence functions for a given set of site parameters.

In order to find the site parameters τ and η_ℓ -- the characteristic time and the width factor of the edge effect defined in Sections 2.5 and 2.6 -- the influence function optimization must be performed for several values of τ and η_ℓ. The optimal values of these site parameters can then be determined by observing the trend of the RMS error as τ and η_ℓ are varied. No specific provision has been made for finding the less important site parameters γ, η_t and η_p (limit angle, subsidence factor of the edge effect, and pitch factor).

The optimization of influence function parameters involves setting up and solving a set of rather complex nonlinear equations. The solution of these equations is accomplished by iterative methods, the details of which are given in Appendix C. All iterative techniques have a common feature: they require a set of starting values (initial guess of the solution) on which the convergence to a solution depends. Therefore, it may be necessary to run the program with more than one set of starting values before satisfactory results are obtained. In order to aid the user in the choice of starting values, the history of each iterative solution procedure is printed out. An inspection of this printout should be more than sufficient in determining the required changes to the input.

All system parameters (parameters of the site and the influence functions) are determined from measured vertical displacements, with the exception of C_H and η_p of the horizontal influence function--see equations (2.5b) and (2.6). The reason for this is that the vertical displacements are easier to measure and are thus more reliable. Horizontal displacements are need only for C_H, and η_p, but here only a few readings will be sufficient.

The System Identification Module requires a data base for the site, which must include the Surface Grid on which the displacements were measured. Only Type 2 grids (where grid point data is stored in one-dimensional arrays) are allowed for that purpose. Of course, it is also necessary to read in the measured displacements before the parameters can be computed.

Detailed input instructions for the System Identification Module are given in Section 7.4.

5.2 Reading Data

The first task in any run of the System Identification Module must be the transfer of the appropriate data base from Backup to Core Storage. The task &LOAD which accomplishes the transfer is identical to its namesake in the Subsidence Module (Section 4.2):

```
&LOAD
TAPE=1Ø
&
```

The second task must be &DISPL, which reads the measured surface displacements into Core Storage. Once the system parameters have been determined using these displacements, it is possible to read in another set without reloading the data base. Only the vertical or the horizontal subsidence may be in Core Storage at any one time, never both. It is not necessary to have a displacement reading for each point of a Surface Grid; the measurements may be restricted to any selection of grid points.

Each displacement reading must be on a separate card image and the card must identify the grid point number. Recalling that subsidence measurements must be restricted to Type 2 grids which use one-dimensional data storage, only one number is required to identify the grid point.

For vertical displacements, each card must contain the grid point number and the displacement, in that order. A horizontal displacement card will have the grid point number followed by the global East and North components of the displacement. An alternative format is to specify the magnitude and the direction of the displacement (measured clockwise from global North). The three different forms of input are identified by a code (1, 2 or 3), which must be passed to the program. For further details see "Description of Data Cards" in Section 7.4.

Consider as an example the Type 2 grid shown in Figure 3.2. Let us assume that vertical displacements were measured at all points except 3, 4, 7 and 8. An appropriate input deck would be:

```
&DISPL
SFGRID=4
NUMPTS=8
CODE=1
TIME=78,212
UNIT=5
'FORMAT'=(I2,F5.2)
'TITLE'= EXPERIMENTAL DATA
&
```

```
 1 Ø.84
 2 1.28
 5 Ø.7Ø
10 Ø.89
 9 1.36
 6 Ø.47
11 1.51
12 1.7Ø
```

SFGRID is the Surface Grid number, NUMPTS represents the number of data cards, CODE identifies the data as vertical displacements, and UNIT is the DSR number of the card reader. The parameter TIME identifies the time period over which the readings were taken; in this case the displacements occurred between dates 78 and 212. As always, 'FORMAT' describes the format of each data card (batch processing only), and 'TITLE' is the heading that would appear over the printout of the displacements (&DISPL automatically prints the input).

A similar deck would be used for horizontal displacements, for example:

```
&DISPL
SFGRID=4
NUMPTS=3
CODE=3
TIME=78,212
'FORMAT'=(I2,F5.2,F6.1)
&
11 Ø.36  88.3
12 Ø.32 -93.6
 4 Ø.11  76.Ø
```

where the magnitude and direction of each displacement (CODE=3) was used as input.

5.3 Knothe's Vertical Influence Function

The task &VKNOTHE computes the optimal values of the parameters C_v and N in Knothe's vertical influence function (2.5a)

$$f_v = C_v \exp\left[-\pi N(r/b)^2\right]$$

for a given set of site parameters. Before &VKNOTHE is executed, the vertical surface displacements must be in Core Storage. As mentioned before, several values of site parameters τ and η_ℓ (characteristic time and width factor of edge effect) may be specified, in which case C_v and N will be optimized for each combination of τ and η_ℓ.

It would help the user to know something about the method employed in the computation. It turns out that N can be optimized independently of C_v. Once N is available, C_v can be calculated without trouble. The first part of the solution procedure is to set up a nonlinear equation

H(N)=0 for N, and then sample the values of H(N) at equal intervals of N until H(N) changes sign, indicating the presence of a root. A sequence of linear interpolations, known as the Secant Method [7] is then used to find the root; that is, the value of N, to within a prescribed accuracy. More details of the procedure are found in Section C.3 of Appendix C.

All the steps of the solution are printed as shown in the following sample printout:

	N	CVERT	RMS ERROR	H(N)
	Searching for a Root			
1	0.0	0.12162	0.17788	-0.00835
2	0.63662	0.26930	0.14291	-0.01120
3	1.27324	0.44372	0.13081	-0.00352
4	1.90986	0.61556	0.13168	0.00723
	Solving for Root			
1	1.48164	0.61556	0.13168	0.00723
2	1.47975	0.50084	0.13031	0.00003
	Solution Converged			

Of particular significance is the RMS error between the computed and actual displacements, since it measures the accuracy of the subsidence model.

The input deck that produced the above output was

```
&VKNOTHE
CTIME=1ØØ
WFACT=Ø.28
&
```

The computed N and C_v are thus the optimal values for the site parameters τ=100 and η_ℓ=0.28. Default values were used for all other parameters.

An example of the complete input deck for &VKNOTHE would be

```
&VKNOTHE
CUTOFF=25,Ø.ØØ1
SEARCH=Ø,6@1Ø
NUMFV=16
NUMINT=2Ø
LANGLE=55
SFACT=Ø
WFACT=Ø.28
CTIME=1ØØ
&
```

The parameter CUTOFF contains the cutoff criteria for the Secant Method. The first number specifies the maximum allowable number of iterations, the second number being the convergence parameter ε. Convergence is achieved if $|H(N)| \le \varepsilon$. Parameter SEARCH describes how the function H(N) is to be sampled in the first phase of the solution process. In the example shown, the sampling is to be carried out from N=0 to N=6 at 10 equally spaced points.

NUMFV prescribes the number of equally spaced r/b values used in the influence function table. For details, Section 4.3 should be consulted. The number of subgrid elements (integration points) employed in the subsidence computation is determined by NUMINT. This concept was explained under "Choice of Grid Size" in Section 3.4. Parameters LANGLE, SFACT, WFACT and CTIME are the site parameters γ, η_t, η_ℓ and τ respectively, described in Chapter 2.

By replacing the last two parameter cards with

```
WFACT=Ø.2,Ø.3@6
CTIME=5Ø,2ØØ@4
```

would result in 24 separate computations of N and C_v. The first card specifies six equally spaced values of η_ℓ ranging from η_ℓ=0.2 to η_ℓ=0.3, whereas the second card defines four equidistant values of τ between 50 and 200, inclusive. This amounts to 24 combinations of η_ℓ and τ. The results may be used to estimate the optimal values of η_ℓ and τ by scanning the output for minimum RMS error. The program will actually do this work for the user -- it will identify the best combination of η_ℓ and τ and store these together with corresponding values of N and C_v as the default values for the task &HKNOTHE (see the next section).

Another option of the program is to include the parameter card

```
PARMS=1.48
```

or

```
PARMS=1.48,Ø.5Ø
```

The first value on the card represents the parameter N, the second value, if any, is C_v. These are interpreted by the program to be prescribed values and they will not be recomputed. Thus the first card would result in the calculation of C_v and RMS error only. The second card would limit the computation to the RMS error.

5.4 Knothe's Horizontal Influence Function

The parameter C_H in Knothe's horizontal influence function (2.5b)

$$f_H = C_H(r/b)\exp[-\pi N(r/b)^2]$$

may be calculated with &HKNOTHE. Parameter N is presumed to be known, and the measured horizontal surface displacements must be in Core Storage.

If &VKNOTHE has already been executed, and if the resulting optimal system parameters were satisfactory, only the following input deck is necessary:

```
&HKNOTHE
PFACT=0.6
&
```

Any of the parameter values previously used or calculated by &VKNOTHE may be overidden by including the appropriate parameter cards in the input deck. For a listing of the parameter cards see Section 7.4. Inclusion of the card

```
CHORIZ=Ø.487
```

prescribes the value of C_H, resulting in computation of the RMS error only.

If the seam pitches and the pitch factor PFACT is not known, it is advisable to run &HKNOTHE for several values of PFACT. The results can then be used to estimate the value of the pitch factor that yields the lowest RMS error. In doing this, it must be noted that the measured horizontal surface displacements that were read into the core with &DISPL are altered every time &HKNOTHE is executed. It is thus necessary to precede every call to &HKNOTHE with an execution of &DISPL.

5.5 Vertical Elastic Influence Function

The influence function is (2.6-2.7):

$$f_v = C_v(R_1^{-3} - R_2^{-3}), \qquad R_i^2 = (r/b)^2 + k_i^2,$$

where $k_1 < k_2$. The presence of three parameters: C_v, k_1, and k_2, makes the optimization procedure somewhat more complicated than the technique described for Knothe's influence function. Again k_1 and k_2 are found independently of C_v, so that the RMS error is now a function of two variables (k_1 and k_2). The problem of finding k_1 and k_2 thus involves minimization of a multivariate function, namely the RMS error. The method of Steepest Descent with Golden Section Search [7] is utilized in SPASID to obtain a solution.

The method is somewhat complicated -- see Section C.4 of Appendix C. Essentially the procedure consists of a series of "moves" in the k_1-k_2 plane, starting from the prescribed initial values of k_1 and k_2. Before each move, the slopes $\partial E/\partial k_1$ and $\partial E/\partial k_2$ are calculated, where E is the RMS error. The direction of the move, defined by $\Delta k_1/\Delta k_2$, Δk_i representing the change in k_i, is determined by the direction of the steepest slope. The move magnitude $k = (k_1^2 + k_2^2)^{\frac{1}{2}}$ is found by the Golden Section Search procedure.

The results of each move are printed out as shown in the following example:

COMPUTATION HISTORY

	K1	K2	CVERT	RMS ERROR
0	0.29283	0.29670	3.61408	0.02358
1	0.32055	0.32612	3.11039	0.01690
2	0.31997	0.32680	2.53451	0.01690
	SOLUTION CONVERGED			

The input deck used was:

```
&VELAST
CUTOFF=5Ø,Ø.ØØ1
MOVELENGTH=Ø.Ø1
KLIMIT=Ø.3
NUMFV=16
NUMINT=2Ø
LANGLE=55
SFACT=Ø
WFACT=Ø.28
CTIME=1ØØ
PARMS=Ø.29283,Ø.2967Ø
&
```

The parameter CUTOFF again describes the cutoff criteria. In this case up to 50 moves are permitted, and convergence is defined as $\Delta k \leq 0.001$. MOVELENGTH is the initial value of Δk used in the Golden Section Search; it will be automatically adjusted by the program during computation. KLIMIT specifies the maximum allowable move length Δk, and PARMS gives the starting values of k_1 and k_2. The remaining parameter cards are the same as described for &VKNOTHE in Section 5.3; this includes the option of prescribing multiple values for site parameters η_ℓ and τ.

The only significant difference between &VKNOTHE and &VELAST is the way in which the parameter card PARMS is interpreted by the program. In the last example we had:

```
PARMS=Ø.29283,Ø.2967Ø
```

which transmits the starting values of k_1 and k_2 to the program. If the CUTOFF card was now changed to CUTOFF=Ø (zero allowable moves), the values of PARMS would be viewed as the prescribed values of k_1 and k_2, and only C_v and the RMS error would be calculated. Adding the value of C_v to the PARMS card, for example

```
PARMS=Ø.29283,Ø.2967Ø,3.614Ø8
```

would result in the computation of the RMS error and nothing else.

Normal termination of the computation concludes with the printed line "solution converged" or "no further decrease in R.M.S. error was achieved." The first message indicates that the convergence criterion was reached; that is, Δk became sufficiently small. The second message shows that the minimum RMS error was reached, although the last value of Δk exceeded the convergence parameter.

5.6 Horizontal Elastic Influence Function

The horizontal elastic influence function is (2.6)

$$f_H = C_H(r/b)(R_1^{-3} - R_2^{-3}), \qquad R_i^2 = (r/b)^2 + k_i^2.$$

The optimal value of parameter C_H may be calculated by executing the task &HELAST. All the comments made in Section 5.4 about &HKNOTHE also apply here. In particular, if the system parameters computed by &VELAST are accepted, there is no need to read them into &HELAST. For further details of the input deck see &HELAST in Section 7.4.

6. POSTPROCESSOR MODULE

6.1 General Information

The function of the Postprocessor Module is the generation of displays of surface and subsidence grids generated by the previous modules. As such, it reads both data bases from Backup Storage created by the Subsidence and Preprocessor Modules, places them on on-line disk storage units, and creates directories of this information for aiding in the selection of the data to be displayed. Included are routines to produce X v.s. Y plots, contour maps, and spatial perspectives. In each case, minimum information is required from the user, as many automatic scaling and sizing operations are done by the program.

6.2 Module Organization

The following sections describe the overall organization of the Postprocessor Module.

6.2.1 Main Program

Level one consists of the main program and the support routines for reading the task and parameter cards from the user's input stream. The main program collects parameter cards and information for a task and then calls the selected task level routine for further action. After a task is completed, it returns to the main program level to process the next task. An error in interactive mode will also return to this level.

6.2.2 Task Level Routines

The second level of the Postprocessor Module consists of the task level routines which perform the work of choosing the data to be displayed, checking for inconsistencies in data selection, and insuring that the data to be displayed is in active storage. In any case, the first task to be executed in any Postprocessor run is the &LOAD task, which retrieves the Subsidence and Mine grids from Backup Storage. Section 7.5 lists the tasks and parameters for their use. Each task is serially reusable.

6.2.3 Plot Interface Routines

Once the data to be displayed has been chosen by the user, the next level of processing consists of three routines that take the specific data for display and derive appropriate scaling and plotting parameters. One routine was written for each of the three types of plots the Postprocessor can create. Basically, these routines act as a funnel to the actual picture generating software, since only the specifically selected data form the data bases as known at this level. A minimum amount of error checking is done to avoid 'null' plots when, for example, a user has selected only one point pair for an X v.s. Y plot, or only one slice of a grid for a perspective or contour plot. The data supplied to a Plot Interface Routine is reviewed to automatically calculate the necessary scaling and option parameters needed by each Plot Routine. The user may change these defaults through options in tasks &CONTOUR, &SURFACE, and &XYPLOT.

6.2.4 Plot Routines

Three modular Plot Routines are included in the Postprocessor, one for two dimensional (X v.s. Y) plots, one for contour maps (of grids) and one for spatial perspective plots (of grids). Each routine takes a set of data selected by the user, and creates 'moves' and 'draws' to produce a display. In order to translate these 'moves' and 'draws' so that they produce a picture on a display device, a Plotter Code Generation package is included. The complexity of each Plot Routine is such that a detailed description is outside of the scope of this report.

6.2.5 Plotter Code Generation

Perhaps the most involved level of coding relates to the generation of hardware dependent output to instruct the graphics device to create lines and symbols which are combined to create each specific display. The Plotter Code Generation routines are reasonably flexible, in that they support two major hardware protocols: Tektronix 4000 series devices, and Calcomp 500 series devices. Many installations have conversion software for taking Calcomp plotter instructions to produce another hardware protocol, thus the Postprocessor is reasonably capable of being used in a wide variety of installations if such translation software is available.

6.3 Reading the Data Base

The first step in running the Postprocessor is to load in the previously generated Preprocessor and Subsidence data bases from Backup Storage and write the on-line disk storage files. This action also creates the master directories of the information stored on these devices, which can be printed for user reference. This is done as follows:

```
&LOAD
TAPE=11,12
&
```

The TAPE parameter must be specified and two file unit numbers must be given; the first specifies where the Preprocessor Backup Storage information is to be found, and the second indicates the same for the Subsidence data base. These two data bases are a result of running the Preprocessor and Subsidence Modules and saving on backup storage the data bases created by the &TERMINATE task. If no data bases are stored by either Preprocessor or Subsidence, then this information is unavailable to the Postprocessor.

Once the Backup Storage device is opened by the program, three files of on-line disk storage are created to provide a master library of grids of which selected portions are brought into core storage to process for plotting. The directories are then printed in summary form. It is suggested that the output of the summary be compared with the list of data items saved during the execution of the &TERMINATE task of both the Preprocessor and Subsidence Modules.

6.4 System Parameter Selection

The selection of System Parameters is to provide a number of details necessary for each Plot Routine to produce a picture. For example, the perspective plot routine has options to change the viewing angle, the angle of observer's eye, and the ratio of height of displacement the the scale of the X and Y axes. These parameters are set up with reasonable defaults to provide 'nice' plots, but the user may change the options at will by executing the appropriate parameter setting task for the plot to be produced. These tasks, &XYPLOT, &CONTOUR, and &SURFACE are described in Section 7.5, and must be executed before the plot is created with one of the '&PLT' routines. The parameters changed stay so for the remainder of the Postprocessor run, unless changed again by a System Parameter Selection routine.

6.5 Selecting the Data for Display

This phase of the Postprocessor selects the data to be displayed, calls the selected plotting routine with the selected data, and returns to the user task level for the next command. In the same way as a user selects data to be printed from the Preprocessor and Subsidence grids, a 'slice' or a grid of one parameter is chosen and plotted.

The procedure is logically developed in this way. If the user desires an X v.s. Y plot, then this two dimensional plot requires two data items per point, where Y represents the value to be plotted and X represents the grid location in north or east coordinates. The slices and grids are a result of running the Preprocessor and Subsidence modules, so that if only slices were produced as values in the data bases, then only the X v.s. Y plot would be applied. If grids were generated, then either slices or entire grids could be plotted. The contour and spatial perspective plots require a grid to produce a plot.

The procedure is as follows for the case of a Mine Grid data base:

```
&GMINE
MNGRID = 1
&
&PLTMINE
ERANGE = 1
GSELECT = 1
&
```

The task &GMINE loads the number one Mine Grid data base into core storage, if not currently loaded. Task &PLTMINE selects the first slice along the East range, so that the points are limited to a set along one grid 'line'. Parameter GSELECT is set to one, which chooses the Mine Grid parameter 'seam thickness' to be plotted. Unless otherwise specified, the X v.s. Y plot will now be produced (parameter PTYPE defaults to 1). The Y axis will be the seam thickness, plotted against the X axis which gives the global coordinate locations of the slice.

If a contour or perspective plot were desired instead, then the following commands would be issued (in this case for a contour map).

```
&PLTMINE
PTYPE = 2
GSELECT = 1
&
```

Thus the entire seam thickness grid would be plotted as a contour map.

A similar procedure is followed for plotting any other grids or slices produced by the Preprocessor and Subsidence Modules, and can be restated simply as follows: choose the appropriate data base, then load the set of grids from that data base, select the subset of data for the intended plot both as to parameter and slice or grid, and finally, choose the plot type.

Because the Postprocessor has been designed to accomodate only one set of grids for each data base (Surface, Mine, and Subsidence), it is suggested that to save time in reading the on-line storage devices that all plots for a given set of grids be produced before the next set. No information in the storage locations for the data base are modified during the plotting process, so it is possible to rexecute the plot routine command with different parameter settings to select whatever data is to be plotted.

6.6 Terminating the Session

After all plotting is done, task &TERMINATE closes all data files and stops execution of the program. There are no parameters for this task as there is nothing to save for future use, the Backup Storage devices will still contain the data bases, and the on-line disk storage units will be released.

7. SUMMARY OF INPUT DATA

7.1 Conventions

Notation	Explanation
Upper case words	Parameter or task names.
Underlined upper case characters or special symbols	Keywords that must be typed exactly as shown.
Non-underlined upper case characters	Non-essential characters that may be typed for clarity.
Lower case words	Parameter values that are to be specified by the user.
[ ] (brackets)	Optional parameters. If omitted, default values will be used if appropriate.
{ } (braces)	Use one of the options enclosed within the braces.
← (arrow)	Indicates default parameter values.
, (comma) b̸ (blank) @ (at)	Separators between parameter values. If the last nonblank character on a parameter card is a comma, the next card is understood to be a continuation card.
; (semicolon)	Optional terminator of parameter field. Characters to the right are interpreted as comments.
⋮	Indicates that as many parameter cards as necessary may be used.
. . .	Indicates that as many parameter values as necessary may be used on the card.

7.2 Preprocessor Module

Summary of Tasks

Task Name	Description
&CHGCUT	Changes height of cut within a Mine Grid
&CHGDATES	Changes extraction schedule within a Mine Grid
&DELETE	Deletes a Surface or Mine Grid
&GENMINE	Generates a Mine Grid
&GENPOINTS	Generates an irregular Surface Grid
&GENSURFACE	Generates a regular, rectangular Surface Grid
&GETMINE	Loads a Mine Grid into Core Storage
&GETSURFACE	Loads a Surface Grid into Core Storage
&INPUT	Reads Field Data from card images
&LOAD	Loads data base from Backup into Disk Storage
&PRTDATES	Prints extraction schedule of a Mine Grid
&PRTINPUT	Prints Field Data
&PRTMINE	Prints a Mine Grid
&PRTSURFACE	Prints a Surface Grid
&TERMINATE	Saves data base in Backup Storage and terminates the session

&CHGCUT	Changes the height of cut for one or more mine grids

```
&CHGCUT
CUTHEIGHT = { gridNbr, constHt        }
            { gridNbr, minHt, maxHt   }
          :
&
```

gridNbr = number of the Mine Grid

$1 \leq \text{gridNbr} \leq \text{nbrGrids}$

nbrGrids = number of Mine Grids in Disk Storage

constHt = constant height of cut

constHt > 0

minHt, maxHt } minimum and maximum allowable heights of cut

$0 < \text{minHt} \leq \text{maxHt}$

Note

If minHt and maxHt are specified, the height of cut h will be determined by

h = t if	minHt < t ≤ maxHt
h = minHt if	t < minHt
h = maxHt if	t > maxHt

where t is the seam thickness.

&CHGDATES	Changes the extraction schedule of a Mine Grid. The changes may be made to the entire grid, or to any portion of the grid. The grid does not have to reside in core storage.

```
For longwall grid (Grid Type 1):
&CHGDATES
MNGRID = gridNbr      must be the first parameter card
{ ADVANCE = dist1, date1, dist2, date2, [, dist3, date3, ...] }
{ DATE = lineLocn1, date1 [, lineLocn2, date2, ...]           }
      .
      .
      .
&
```

```
For room-and-pillar grid (Grid Type 2):
&CHGDATES
MNGRID = gridNbr      must be the first parameter card
EXTRACT = locnE1, locnN1, date1, [, locnE2, locnN2, date2, ...]
      .
      .
      .
&
```

gridNbr = number of the Mine Grid

$$1 \le gridNbr \le nbrGrids$$

nbrGrids = number of Mine Grids in Disk Storage

Face advance method for longwall (ADVANCE)

$dist_i$ = distance of the mine face from the South end of the panel, i.e. face advance.

$$0 \le dist \le panLgth$$

$date_i$ = the date when the mine face reaches $dist_i$.

panLgth = length of panel

Direct dating of grid lines for longwall (DATE)

$lineLocn_i$ = North location number of a grid line

$$1 \le lineLocn_i \le nbrLines$$

$date_i$ = the date when the mine face reaches grid line ($lineLoc_i$)

nbrLines = number of grid lines in the direction of face advance (localNorth)

Direct dating of pillars for room & pillar operation (EXTRACT)

$locnE_i$, $locnN_i$ } East and North Location Numbers of a grid element (pillar)

$date_i$ = date when the extraction of the pillar ($locnE_i$, $locnN_i$) is to be completed.

$$1 \le locnE_i \le nbrLinesE - 1$$
$$1 \le locnN_i \le nbrLinesN - 1$$

nbrLinesE, nbrLinesN — number of grid lines in direction of East and North, respectively

Notes

A. Any Surface or Mine Grid in Core Storage prior to the execution of &CHGDATES will be destroyed and replaced by Mine Grid (gridNbr).

B. The face advance method for a longwall uses linear interpolation for assigning extraction dates to all grid lines located between $dist_i$ and $dist_{i+1}$.

&DELETE — Deletes a Surface Grid (SFGD) or a Mine Grid (MNGD) from Disk Storage and the Directory, and compresses the grid numbers of the remaining surface of Mine Grids.
&DELETE { SFGRID / MNGRID } = gridNbr &

gridNbr = number of the Surface or Mine Grid to be deleted

$$1 \leq gridNbr \leq nbrGrids$$

nbrGrids = number of Surface (SFGD) or Mine (MNGD) Grids in Disk Storage

Note

Any Surface or Mine Grid data in Core Storage prior to execution of &DELETE will be overwritten, but Field Data will not be affected.

&GENMINE	Generates a rectangular Mine Grid of equally spaced grid lines and computes the following data items for each grid point:
	1) Global East coordinate 2) Global North coordinate 3) Seam thickness 4) Seam bottom elevation 5) Depth of cover

```
&GENMINE
ORIGIN = coordE, coordN
AZIMUTH = azim
EGRID = nbrLines, dist
NGRID = nbrLines, dist
[PARMS = nearPts, weight] ← 9, 1.1
[TYPE = mineType] ← 1 (longwall)
[SAVE = dsrNbr] ← 0
&
```

coordE, coordN = global East and North coordinates of the grid origin; origin must be a corner of the grid.

azim = azimuth angle of the grid, measured clockwise in degrees. For a longwall panel, the local North must point in the direction of advance.

nbrLines = number of grid lines in direction of local East (EGRID) or local North (NGRID).

$nbrLines \geq 2$

dist = distance between grid lines in the direction of local East (EGRID) or local North (NGRID).

$dist > 0.0$

nearPts = number of nearest neighbor points used in interpolation of Field Data.

$nearPts \geq 6$

weight = weighting factor used in the interpolation of Field Data. Controls the degree of averaging (increasing "weight" causes a greater degree of smoothing).

$weight > 1.0$

mineType = type of mine operation.

mineType = 1 : longwall
mineType = 2 : room and pillar

dsrNbr = data set reference number under which the grid is to be saved in addition to the Disk Storage used by the program. If dsrNbr = 0, data is not saved.

Notes

A. Since the data at grid points is obtained by interpolation of Field Data, the latter must reside in Core Storage prior to the execution of &GENMINE (see &INPUT).

B. At the completion of &GENMINE, the generated data will reside in both Core and Disk Storage. It may be printed using &PRTMINE.

C. &GENMINE does create Core and Disk Storage for the Extraction Schedule, but enters 99 999 999. for each extraction date. These dates may be changed via &CHGDATES.

D. &GENMINE assigns 99 999 999. for minimum and maximum height of cuts. These values may be changed by &CHGCUT.

```
&GENPOINTS   Generates a Surface Grid consisting of individually
placed points and/or points equally spaced on straight lines (Grid
Type 2).  The data items computed for each grid point are:
    1) Global East Coordinate
    2) Global North Coordinate
    3) Surface elevation.
The user may request the following additional data:
    4) Seam thickness
    5) Seam bottom elevation
    6) Depth of cover
```

```
&GENPOINTS
[NUMDATA = nbrData] ← 3
[PARMS = nearPts, weight] ← 9, 1.1
LOCATION = { coordE, coordN                              }
           { coordE, coordN, azim, nbrPts, dist          }
         .
         .
         .
&
```

nbrData = number of data items to be generated at each grid point (see above for the list of data)

$3 \leq nbrData \leq 6$

nearPts, weight } interpolation parameters (see &GENMINE)

coordE, coordN } global East and North coordinates of the point (for individual points), or the origin of the line (for points lying on a line). The latter must be an end-point of the line.

azim = azimuth angle of the line, measured clockwise in degrees.

nbrPts = number of points on the line. The first generated point will be the origin of the line.

$nbrPts \geq 2$

dist = distance between points on the line

$dist > 0.0$

Notes

A. The corresponding Field Data must be in Core Storage prior to execution of &GENPOINTS.

B. At the completion of &GENPOINTS, all the generated data will reside in Core Storage, but only the coordinates and surface elevation (data items 1, 2 and 3) will be in Disk Storage, since these items only are needed for subsidence computation. There is no provision to save data items 4, 5 and 6, except in printed form using &PRTSURFACE

&GENSURFACE Generates a rectangular Surface Grid of equally spaced grid lines (Grid Type 1) and computes the following data at each grid point:

1) Global East coordinate
2) Global North coordinate
3) Surface elevation.

The following additional data may be calculated at the request of the user:

4) Seam thickness
5) Seam bottom elevation
6) Depth of cover

```
&GENSURFACE
[NUMDATA = nbrData] ← 3
[PARMS = nearPts, weight] ← 9, 1.1
ORIGIN = coordE, coordN
AZIMUTH = azim
EGRID = nbrLines, dist      dist ← 0 if nbrLines = 1
NGRID = nbrLines, dist
[SAVE = dsrNbr] ← 0
&
```

nbrData = number of data items to be generated (see &GENPOINTS)

$3 \le nbrData \le 6$

nearPts } weight } interpolation parameters (see &GENMINE)

$nearPts \ge 6$, $weight > 1.0$

coordE } coordN } coordinates of grid origin (see &GENMINE)

azim = azimuth angle of the grid (see &GENMINE)

nbrLines = number of grid lines (see &GENMINE)

$nbrLines \ge 1$

dist = distance between grid lines (see &GENMINE)

$dist \ge 0.0$

dsrNbr = data set reference number (see &GENMINE)

Notes

A. The corresponding Field Data must be in Core Storage prior to execution of &GENSURFACE

B. As in the case of &GENPOINTS, all the generated data will reside in Core Storage at the completion of &GENSURFACE, but only data items 1, 2 and 3 will be in Disk Storage. However, the entire Surface Grid, including data items 4, 5 and 6 may be printed using &PRTSURFACE.

C. All the generated data will be saved in the data set specified by "dsrNbr" on the SAVE Parameter Card.

D. It is permissible to generate a Surface Grid consisting of a single grid line by specifying nbrLines = 1 on the EGRID (or NGRID) Parameter Cord. In that case, it is not necessary to specify the value of "dist" on the same Parameter Card. (This option does not exist in &GENMINE.)

&GETMINE	Loads a Mine Grid from Disk Storage into Core Storage

```
&GETMINE
MNGRID = gridNbr
&
```

gridNbr = Mine Grid number

Note

Any Surface or Mine Grid in Core Storage prior to the execution of &GETMINE will be overwritten, but Field Data will remain intact.

&GETSURFACE	Loads a Surface Grid from Disk Storage into Core Storage

```
&GETSURFACE
SFGRID = gridNbr
&
```

gridNbr = Surface Grid number

Note

As in the case of &GETMINE, the execution of &GETSURFACE will destroy any grid data in Core Storage, but not Field Data.

&INPUT Reads Field Data from card images into Core Storage. The data for each Field Data point must be contained on a separate card. The Field Data may consist of some or all of the following:

Data ID	Description	
1	Global East coordinate	must be read in
2	Global North coordinate	
3	Surface elevation	at least item 3 must be read in
4	Seam thickness	
5	Seam bottom elevation	
6	Depth of cover	

The Data ID number is used to identify the data during input.

```
&INPUT
NUMPOINTS = nbrPts
DATAID = id1, id2, id3 [, id4, id5, id6]
[UNIT = dsrNbr] ← 5
['FORMAT' = fmt] ← (6F10.0)
&
Data cards
```

nbrPts = number of Field Data points (card images) to be read

$nbrPts \geq 1$

id1, id2, ... = Data ID numbers that identify the data on each card. Must be listed in the same sequence in which the corresponding data is written on each card.

$1 \leq id1, id2, \ldots \leq 6$

dsrNbr = data set reference number of the input device.

fmt = format in which the Field Data appears on each card image (execution-time format)

Notes

A. Execution of &INPUT destroys any Field, Mine Grid or Surface Grid Data residing in the core. Note that Mine and Surface Grids are automatically backed up in Disk storage and may be recalled by &GETMINE or &GETSURFACE. No such facility exists for Field Data.

B. Field Data items 3-6 are not independent; any one of the items may be computed from the remaining four. &INPUT will automatically perform this calculation.

C. Field Data, including the calculated data (see Note B), may be printed by &PRTINPUT.

&LOAD — Loads all Surface and Mine Grids from Backup Storage (e.g., magnetic tape) into Disk Storage, and prints the corresponding Directories. Must be the first task in the Run Deck.
&LOAD TAPE = dsrNbr &

dsrNbr = data set reference number for the Backup Storage device.

Note

The data may be placed into Backup Storage by &TERMINATE

&PRTDATES Prints the Extraction Schedule of the Mine Grid located in Core Storage. The dates may be printed for all grid locations, or for a portion of the grid.

```
For longwall grid (Grid Type 1):
&PRTDATES
[UNIT = dsrNbr] ← 6
[NRANGE = {lineLocn
          {firstLine, lastLine}]      ← 1, nbrLines
['TITLE' = title] ← blank
&
```

```
For room-and-pillar grid (Grid Type 2):
&PRTDATES
[UNIT = dsrNbr] ← 6
[ERANGE = {elemLocn
          {firstElem, lastElem}]      ← 1, nbrLines-1
[NRANGE = {elemLocn
          {firstElem, lastElem}]      ← 1, nbrLines-1
['TITLE' = title] ← blank
&
```

dsrNbr = data set reference number of the printer

lineLocn = North Location Number of the grid line for which the extraction date is to be printed. Prints a single date.

$1 \leq \text{lineLocn} \leq \text{nbrLines}$

firstLine, lastLine: North Location Numbers of the first and last grid lines for which the extraction dates are to be printed.

$1 \leq \text{firstLine} \leq \text{lastLine}$,
$\text{firstLine} \leq \text{lastLine} \leq \text{nbrLines}$

nbrLines = number of lines in the Mine Grid in the direction of East (ERANGE) or North (NRANGE).

title = alphameric title to appear with the printout.

elemLocn = East (ERANGE) or North (NRANGE) Location Number of the row of grid elements (pillars) for which the extraction dates are to be printed. Prints dates for a single row of grid elements.

$1 \leq \text{elemLocn} \leq \text{nbrLines} - 1$

firstElem, lastElem: East (ERANGE) or North (NRANGE) Location Numbers of first and last row of grid elements for which the extraction dates are to be printed.

$1 \leq \text{firstElem} \leq \text{lastElem} \leq \text{nbrLines} - 1$

Notes

A. The Mine Grid to be printed may be placed in Core Storage by &GETMINE.

B. For a longwall panel, the extraction dates are associated with grid lines that are perpendicular to the direction of mining (North). They represent the dates when the face of the mine reaches these grid lines.

C. In the case of a room and pillar operation, the extraction dates are associated with grid elements (pillars). They show the date when the removal of each pillar is to be completed.

&PRTINPUT	Prints the Field Data located in Core Storage. All or some of the data points may be printed.

```
&PRTINPUT
[UNIT = dsrNbr] ← 6
[RANGE = {ptNbr            }]
         {firstPt, lastPt  }]   ← 1, nbrPts
['TITLE' = title] ← blank
&
```

dsrNbr = data set reference number of the printer.

ptNbr = number of the point for which the Field Data is to be printed. Prints data for a single point only.

$$1 \leq ptNbr \leq nbrPts$$

firstPt, lastPt } numbers of the first and last point for which the Field Data is to be printed.

$$1 \leq firstPt \leq lastPt \leq nbrPts$$

nbrPts = number of data points in Field Data

title = alphameric title to appear with the printout

Note

Prints all the Field Data items in core storage, including the calculated data (see Note B of &INPUT)

```
&PRTMINE     Prints all five data items (see &GENMINE for the list)
of the Mine Grid located in Core Storage.  Data for any portion of the
grid may be chosen for the printout.
```

```
&PRTMINE
[UNIT = dsrNbr] ← 6
[ERANGE = {lineLocn
           {firstLine, lastLine}]   ← 1, nbrLines
[NRANGE = {lineLocn
           {firstLine, lastLine}]   ← 1, nbrLines
['TITLE' = title] ← blank
&
```

dsrNbr = data set reference number of the printer

lineLocn = East (ERANGE) or North (NRANGE) Location Number of the grid line. Prints data for one grid line only.

$$1 \leq lineLocn \leq nbrLines$$

firstLine, lastLine } East (ERANGE) or NORTH (NRANGE) Location Numbers of the first and last grid line for which the data is to be printed.

$$1 \leq firstLine \leq lastLine \leq nbrLines$$

nbrLines = number of lines in the Mine Grid in the direction of East (ERANGE) or North (NRANGE)

title = alphameric title to appear with printout

Note

The Mine Grid may be loaded into Core Storage by executing &GETMINE

&PRTSURFACE Prints user-selected data items of the Surface Grid located in Core Storage. Between three and six data items may be printed at each grid point. The chosen data must contain successive items from the following list, starting with item 1:

1) Global East coordinate
2) Global North coordinate
3) Surface elevation
4) Seam thickness
5) Seam bottom elevation
6) Depth of cover

For rectangular grid (Grid Type 1):

```
&PRTSURFACE
[NUMDATA = nbrData] ← 3
[UNIT = dsrNbr] ← 6
[ERANGE = {lineLocn               }]
[         {firstLine, lastLine    }]   ← 1, nbrLines
[NRANGE = {lineLocn               }]
[         {firstLine, lastLine    }]   ← 1, nbrLines
['TITLE' = title] ← blank
&
```

For nonrectangular grid (Grid Type 2):

```
&PRTSURFACE
[NUMDATA = nbrData] ← 3
[UNIT = dsrNbr] ← 6
[NRANGE = {ptNbr             }]
[         {firstPt, lastPt   }]   ← 1, nbrPts
['TITLE' = title] ← blank
&
```

nbrData = number of data items to be printed for each grid point (see data list above)

$$3 \le nbrData \le 6$$

dsrNbr = data set reference number of printer

lineLoc = East (ERANGE) or North (NRANGE) Location Number of the grid line for which data is to be printed. Prints data for points on this line only.

$$1 \le lineLoc \le nbrLines$$

firstLine, lastLine = East (ERANGE) or North (NRANGE) Location Numbers of the first and last line for which data is to be printed.

$$1 \le firstLine \le lastLine \le nbrLines$$

nbrLines = number of lines in the Surface Grid in the direction of East (ERANGE) or North (NRANGE)

title = alphameric title to appear with printout

ptNbr = surface point number for which data is to be printed. Prints data for this point only.

$1 \leq ptNbr \leq nbrPts$

firstPt, lastPt } numbers of the first and last points for which data is to be printed. Prints data for this point only.

$1 \leq firstPt \leq lastPt \leq nbrPts$

nbrPts = number of points in the surface grid.

Notes

A. The Surface Grid may be loaded into Core Storage by &GETSURFACE

B. Since the last three data items are not saved in Disk Storage, they cannot be recovered once the Surface Grid data is destroyed in Core Storage (see Note B in &GENPOINTS and &GENMINE). Therefore, this data should be printed immediately after it has been generated by &GENPOINTS or &GENMINE.

&TERMINATE Prints the current Surface and Mine Grid Directories, places the grids into Backup Storage (optional) and terminates the session.
&TERMINATE [TAPE = dsrNbr] ← 0 &

dsrNbr = data set reference number of the Backup Storage device. If dsrNbr = 0, the grids will not be saved in Backup-Storage.

7.3 Subsidence Module

Summary of Tasks

Task	Description
&CMPSUBS	Computes displacements at grid points of a Surface Grid
&ELASTICITY	Computes table of influence functions from transversely isotropic elasticity theory
&GETSUBS	Loads a Subsidence Grid into Core Storage
&KNOTHE	Computes table of Knothe's influence functions
&LOAD	Loads data base from Backup into Disk Storage
&PRTDISPLTS	Prints displacements of a Subsidence Grid
&RDFUNCT	Reads influence function from card images
&RDPARAMS	Reads subsidence parameters
&TERMINATE	Saves data base in Backup Storage and terminates the session.

&CMPSUBS Computes vertical and horizontal displacements of a Surface Grid. The displacements that occur between two dates, or between an initial date (datum date) and a series of equally spaced dates may be obtained. The computations may be confined to any rectangular portion of the Surface Grid.
&CMPSUBS SFGRID = gridNbr [ERANGE = {lineLoc | firstLine, lastLine}] ← 1, nbrLines [NRANGE = {lineLoc | firstLine, lastLine}] ← 1, nbrLines [DATES = {datum, date | datum, lastDate, nbrDates}] ← -9.0E8, 9.0E8, 1 [NUMINT = nbrIntPts] ← 20 [SAVE = dsrNbr] ← 0 &

gridNbr = number of the Surface Grid

$1 \leq gridNbr \leq nbrGrids$

nbrGrids = number of Surface Grids in Disk Storage

lineLoc = E or N Location Number of the Surface Grid line on which the displacements are calculated. Use to obtain displacements on this line only.

$1 \leq lineLoc \leq nbrLines$

firstLine, lastLine: E or N Location Numbers of the first and the last Surface Grid lines on which the displacements are calculates.

$1 \leq firstLine \leq lastLine \leq nbrLines$

nbrLines = number of E or N lines in the Surface Grid

datum = datum date. Displacements represent changes that occur from this date on.

date = date on which displacements are calculated. Use to obtain displacements on this date only.

date > datum

lastDate = last date on which displacements are calculated. Use to obtain displacements on a series of equally spaced dates.

lastDate > datum

nbrDates = number of equally spaced dates, including lastDate, on which the displacements are calculated.

nbrDates $\geq$ 1

nbrIntPts = number of integration points in the radius of influence that are used in displacement computation. Controls the accuracy of numerical integration.

nbrIntPts $\geq$ 1

dsrNbr = data set reference number under which the displacements are to be saved in addition to Disk Storage used by the program. If dsrNbr = 0, displacements will be saved in Disk Storage only. Format of saved data is I5, 4F10.5, F10.2 (See Note D).

Notes

A. At the completion of &CMPSUBS, the surface displacements will reside in both Core and Disk Storage. They may be printed using &PRTDISPLTS.

B. The calculated displacements will include the contribution of each Mine Grid in Disk Storage.

C. The portion of the Surface Grid where the displacements are calculated (as defined by ERANGE and NRANGE) is called the Subsidence Grid.

D. Surface displacements are saved in the following format:

1	6	16	26	36	46
n	w	u	v	magnitude	angle
		horizontal displacements			

n = sequence number
w = vertical displacement
u = horizontal displacement in local E-direction
v = horizontal displacement in local N-direction

magnitude = $\sqrt{u^2 + v^2}$

angle = $\tan^{-1}(u/v)$

&ELASTICITY Calculates and prints table of vertical and horizontal influence functions according to transversely isotropic elasticity theory: $$f_V = C_V\,(1/R_1^3 - 1/R_2^3),\quad f_H = C_H\,(r/b)(1/R_1^3 - 1/R_2^3)$$ where $R_i = [(r/b)^2 + k_i^2]^{\frac{1}{2}}$ and $k_1 < k_2$ at equally spaced intervals between r = 0 and r = b (b = radius of influence).
&ELASTICITY [NUMF = nbrFuncPts] ← 16 [K1 = k_1] ← 0.28324 [K2 = k_2] ← 0.30281 [CVERT = C_V] ← 0.6390 [CHORIZ = C_H] ← 1.3980 &

nbrFuncPts = number of equally spaced points in the interval $0 \le r/b \le 1$ at which the influence functions are calculated

$$2 \le \text{nbrFuncPts} \le 26$$

k_1, k_2 } the parameters k_1 and k_2

$$k_1 < k_2$$

C_V = amplitude parameter of the vertical influence function

C_H = amplitude parameter of the horizontal influence function

Note

The default values of k_1, k_2, C_V and C_H represent the best fit to British mine data, using a limit angle of 55 degrees. These values should be replaced by parameters for your own site.

&GETSUBS Loads a Subsidence Grid from Disk Storage into Core Storage.	
&GETSUBS GRID = gridNbr &	

gridNbr = number of the Subsidence Grid

$1 \leq gridNbr \leq nbrGrids$

nbrGrids = number of Surface Grids in Disk Storage

Note

&GETSUBS will destroy the Subsidence Grid data that resided in Core Storage prior to its execution.

&KNOTHE	Calculates and prints table of Knothe's vertical and horizontal influence functions:

$$f_V = C_V \exp[-N\pi(r/b)^2], \qquad f_H = C_H(r/b) \exp[-N\pi(r/b)^2]$$

at equally spaced intervals between r=0 and r=b (b = radius of influence).

```
&KNOTHE
[NUMF = nbrFuncPts] ← 16
[N = n] ← 3.6126
[CVERT = C_V] ← 3.2583
[CHORIZ = C_H] ← 6.7590
&
```

nbrFuncPts = number of equally spaced points in the interval $0 \leq r/b \leq 1$ of which the influence functions are calculated

$$2 \leq \text{nbrFuncPts} \leq 26$$

n = the parameter N

C_V = the amplitude of the vertical influence function.

C_H = the amplitude of the horizontal influence function.

Note

The default values of N, C_V, and C_H represent the best fit to British mine data when a limit angle of 55 degrees is used. They should be replaced by the values obtained for your own site.

&LOAD Loads all Surface and Mine Grids from Backup Storage (e.g., magnetic tape) into Disk Storage, and prints the corresponding Directories. Must be the first task in a Run Deck.
&LOAD TAPE = dsrNbr &

dsrNbr = data set refence number of the Backup Storage device

Note

The grids can be generated, deleted, altered and placed in Backup Storage by the Preprocessor Module only.

&PRTDISPLTS	Prints the surface displacements of the Subsidence Grid located in Core Storage. The printout may include all the displacements, or it may be confined to a portion of the Surface/Time Grid.

```
&PRTDISPLTS
[UNIT = dsrNbr] ← 6
[ERANGE = {spaceLoc                }]
[         {firstSpace, lastSpace   }]   ← firstLine, lastLine
[NRANGE = {spaceLoc                }]
[         {firstSpace, lastSpace   }]   ← firstLine, lastLine
[TRANGE = {timeLoc                 }]
[         {firstTime, lastTime     }]   ← firstDate, lastDate
['TITLE' = title] ← blank
&
```

dsrNbr = data set reference number of the printer

spaceLoc = E or N Location Number of the Surface Grid line for which the displacements are printed. Use to print displacements on this grid line only.

$$\text{firstLine} \leq \text{spaceLoc} \leq \text{lastLine}$$

firstSpace, lastSpace } E or N Location Numbers of the first and last Surface Grid lines for which the displacements are printed.

$$\text{firstLine} \leq \text{firstSpace} \leq \text{lastSpace} \leq \text{lastLine}$$

firstLine, lastLine } E or N Location Numbers of the first and last Surface Grid lines for which the displacements were calculated (see &CMPSUBS).

timeLoc = date Location Number at which the displacements are printed. Use for printout of displacements at this date only.

$$1 \leq \text{timeLoc} \leq \text{nbrDates}$$

firstTime, lastTime } date Location Numbers of the first and last dates at which the displacements are printed.

$$1 \leq \text{firstTime} \leq \text{lastTime} \leq \text{nbrDates}$$

nbrDates = number of equally spaced dates at which the displacements were calculated (see &CMPSUBS).

title = alphameric title to appear with the printout

Note

The Subsidence Grid to be printed may be placed into Core Storage by &GETSUBS.

&RDFUNCT Reads vertical and horizontal influence functions from card images. Each card must contain the value of f_V and f_H (in that order) at one data point (one value of r/b). The data points must be evenly spaced and cover the entire range of influence $0 \leq r/b < 1$. Prints the influence function table.
&RDFUNCT NUMF = nbrFuncPts [UNIT = dsrNrb] ← 5 ['FORMAT' = fmt] ← (2F10.0) & Data cards

nbrFuncPts = number of equally spaced data points, starting at r/b = 0 and ending at r/b = 1

$1 \leq$ nbrFuncPts ≤ 26

dsrNbr = data set reference number of the input device

fmt = format of each card image (execution-time format)

```
&RDPARAMS     Reads Subsidence Parameters and prints Parameter Table.

&RDPARAMS
[LANGLE = limAngle] ← 55.0°
[WFACT = widthFact] ← 0.28
[SFACT = subsFact] ← 0.0
[PFACT = pitchFact] ← 0.65
[CTIME = charTime] ← 0.0
&
```

limAngle = limit angle of the site, measured in degrees from the horizontal

widthFact = factor that determines the width of the edge effect (width) from the depth of cover (dpCover): width = widthFac*dpCover

widthFac $\geq$ 0

subsFact = subsidence factor of the mine roof at the edge of extracted area. The subsidence of the roof (roofSubs) is related to the height of cut (cutHt) by: roofSubs = subsFac*cutHt.

subsFac $\leq$ 1

pitchFact = pitch factor used for computing horizontal displacement over pitching seams -- see equation (2.8).

charTime = characteristic time of subsidence for the site. The subsidence S_t at time t is given in terms of the final subsidence S_∞ by $S_t = S_\infty$ [1-exp(-t/charTime)]. If CharTime $\leq$ 0.0, the subsidence is considered to be instantaneous.

Note

The default values represent data that fits the mines in Great Britain. Once the corresponding data has been determined for your region, the default values should be charged accordingly.

&TERMINATE Prints the current Subsidence Grid Directory, places the Subsidence Grids into Backup Storage (optional) and terminates the session.
&TERMINATE [TAPE = dsrNbr] ← 0 &

dsrNbr = data set reference number of the Backup Storage device. If dsrNbr = 0, Backup Storage will not be used.

7.4 System Identification Module

Summary of Tasks

Task	Description
&DISPL	Reads vertical or horizontal surface displacements
&HELAST	Computes optimal parameters of horizontal elastic influence function
&HKNOTHE	Computers optimal parameters of horizontal Knothe's influence function
&LOAD	Loads data base from Backup into Disk Storage
&TERMINATE	Terminates the session
&VELAST	Computes optimal parameters of vertical elastic influence function
&VKNOTHE	Computes optimal parameters of vertical Knothe's influence function

&DISPL Reads vertical & horizontal surface displacements from card images, and prints the input.
&DISPL SFGRID = gridNbr [NUMPTS = nbrPts] ← nbrTotal [CODE = dataCode] ← 1 ['FORMAT' = fmt] ← (I5, 2F10.0) TIME = datum, date [UNIT = dsrNbr] ← 5 ['TITLE' = title] ← blank & Data Cards

gridNbr = number of the Surface Grid on which the displacements were measured. Must be a Type 2 grid (stored as a one-dimensional array).

$1 \leq gridNbr \leq nbrGrids$

nbrGrids = number of Surface Grids in Disk Storage

nbrPts = number of Surface Grid points at which the displacements were measured, i.e., the number of card images to be read.

$nbrPts \leq nbrTotal$

nbrTotal = total number of points in the Surface Grid

dataCode = code that identifies the data on each card image (see Description of Data Cards)

fmt = format of each card image

datum = datum date for displacement measurements

date = date on which the displacements were measured. Note that the measured displacements represent changes that occurred between "datum" and "date."

$date > datum$

dsrNbr = data set reference number at the input device that reads the card images

title = title that is to appear with the printout

Description of Data Cards

The displacement of each Surface Grid point must be on a separate card image. The following forms of data are allowed:

Card Image			Code	Notes
Word 1	Word 2	Word 3		
ptNbr	displacement		1	Vert. displ. only
ptNbr	displacement	direction	2	} Horz. displ. only
ptNbr	E-component	N-component	3	} Horz. displ. only

ptNbr = number of the Surface Grid Point

displacement = measured displacement

direction = direction of the displacement, measured clockwise from the global N-direction (degrees). Used for horizontal displacements only.

E-component } N-component } components of the displacement in the global E and N directions. Used for horizontal displacements only.

&HELAST | Computes the optimal value of the parameter C_H in the horizontal influence function:

$$f_H = C_H\ (r/b)\ (1/R_1^3 - 1/R_2^3), \text{ where}$$

$$R_1^2 = (r/b)^2 + k_1^2, \quad R_2^2 = (r/b)^2 + k_2^2,$$

by minimizing the r.m.s. error between the measured and computed displacements. The parameters C_V (see &VELAST), k_1 and k_2 must be known, or computed beforehand by executing &VELAST.

```
&HELAST
[NUMFH = nbrFhPts]     ← 16   }
[NUMINT = nbrIntPts]   ← 20   }  See Note A
[LANGLE = limAngle]    ← 55.0 }
[SFACT = subsFact]     ← 0.0  }
[WFACT = widthFact]    ←      }
[CTIME = charTime]     ←      }  See Note B
[PARMS = k1, k2, CV]   ←      }
[CHORIZ = CH]
[PFACT = pitchFact]    ← 0.65
&
```

nbrFhPts = number of equally spaced data points used in describing f_H in the interval $0 \leq r/b \leq 1$

$2 \leq \text{nbrFhPts} \leq 26$

nbrIntPts = number integration points used in the interval $0 \leq r/b \leq 1$ during subsidence computation

limAngle = limit angle, measured in degrees from the horizontal

subsFact = subsidence factor of the mine roof edge (see &RDPARAMS in Subsidence Module)

widthFact = width factor of the edge effect (see &RDPARAMS)

charTime = characteristic time of subsidence for the site (see &RDPARAMS). If charTime = 0.0, then instantaneous subsidence is assumed.

k_1, k_2 = parameters k_1 and k_2

C_V = parameter C_V of the vertical influence function (see &VELAST)

C_H = parameter C_H. If C_H is read in, then only the r.m.s. error will be computed. Otherwise the optimal value of C_H will be computed.

pitchFact = pitch factor for horizontal displacement (see &RDPARAMS)

Notes

A. Input values of these parameters automatically become the new default values in all subsequent tasks of a computer run.

B. The default values will be the optimal values computed by &VELAST. If &VELAST was not the last System I.D. task executed, then defaults will not exist.

C. Before &HELAST can be executed, the measured horizontal displacements of the surface must be placed into Core Storage via &DISPL. This must be done every time that &HELAST is run.

&HKNOTHE Computes the optimal parameter C_H in Knothe's horizontal influence function:

$$f_H = C_H\ (r/b)\ \exp\ [-N\pi(r/b)^2]$$

by minimizing the r.m.s. error between the measured and computed surface displacements. The parameters C_V (see &VKNOTHE) and N must be known, or computed beforehand by executing &VKNOTHE.

```
&HKNOTHE
[NUMFH = nbrFhPts]    ← 16    }
[NUMINT = nbrIntPts]  ← 20    } See Note A
[LANGLE = limAngle]   ← 55.0  }
[SFACT = subsFact]    ← 0.0   }
[WFACT = widthFact]   ←       }
[CTIME = charTime]    ←       } See Note B
[PARMS = N, C_V]      ←       }
[CHORIZ = C_H]
[PFACT = pitchFact]   ← 0.65
&
```

nbrFhPts = number of equally spaced data points used in describing f_H in the interval $0 \leq r/b \leq 1$

$$2 \leq \text{nbrFhPts} \leq 26$$

nbrIntPts = number of integration points used in the interval $0 \leq r/b \leq 1$ during subsidence computation

limAngle = limit angle, measured in degrees from horizontal

subsFact = subsidence factor of mine roof edge (see &RDPARAMS in Subsidence Module)

widthFact = width factor of the edge effect (see &RDPARAMS)

charTime = characteristic time of subsidence for the site (see &RDPARAMS). If charTime = 0.0, then instantaneous subsidence is assumed.

N = parameter N

C_V = parameter C_V of vertical influence function (see &VKNOTHE)

C_H = parameter C_H. If C_H is read in, then only the r.m.s. error will be computed. Otherwise, the optimal value of C_H will be calculated.

pitchFact = pitch factor used for horizontal displacement at pitching seams (see &RDPARAMS)

Notes

A. Input values of these parameters automatically become the new default values for all subsequent tasks of a computer run.

B. The default values will be the optimal values computed by &VKNOTHE. If &VKNOTHE was not the last System I.D. task executed, then defaults will not exist.

C. Before &HKNOTHE can be executed, the measured horizontal displacements of the surface must be placed into Core Storage via &DISPL. This must be done every time that &HKNOTHE is run.

&LOAD Loads Surface and Mine Grids from Backup Storage into Disk Storage, and prints the Directories. Must be the first task in a Run Deck.
&LOAD TAPE = dsrNbr &

dsrNbr = data set reference number of the Backup Storage Device

Note

Surface and Mine Grids can be generated, deleted and altered by the Preprocessor Module only.

&TERMINATE	Terminates the session
&TERMINATE &	

&VELAST — Computes the optimal values of parameters C_V and/or k_1 and k_2 in the vertical influence function:

$$f_V = C_V \, (1/R_1^3 - 1/R_2^3), \text{ where}$$

$$R_1^2 = (r/b)^2 + k_1^2, \qquad R_2^2 = (r/b)^2 + k_2^2,$$

by minimizing the r.m.s. error between the measured and computed displacements. The computation may be carried out for several values of site parameters charTime and widthFac, provided that these values are equally spaced.

Parameters k_1 and k_2 are obtained by a series of iterations (moves) based on the method of steepest descent.

```
&VELAST
[CUTOFF = {Ø                  }]
          {nbrItern, epsilon  }]  ← 50, 0.001
[NUMFV = nbrFvPts]    ← 16    }
[NUMINT = nbrIntPts]  ← 20    }
[LANGLE = limAngle]   ← 55.0  }  See Note D
[SFACT = subsFact]    ← 0.0   }
[PARMS = {k1, k2    }]  ← 0.28, 0.30
         {k1, k2, CV}]
CTIME = {charTime               }
        {TStart, TStop [,nbrT]  }  ← 2
WFACT = {widthFac               }
        {WStart, WStop [,nbrW]  }  ← 2
[MOVELENGTH = moveLength]  ← 0.01
[KLIMIT = moveLim]  ← 0.3
&
```

nbrItern = max. allowable number of iterations in the computation of k_1 and k_2. If k_1 and k_2 are not to be computed, use nbrItern = Ø.

epsilon = convergence parameter used in the computation of k_1 and k_2. The convergence criterion is $(dk_1)^2 + (dk_2)^2 \leq (\text{epsilon})^2$, where dk_1 and dk_2 are the computed changes of k_1 and k_2. If nbrItern = Ø, then "epsilon" does not have to be specified.

epsilon ≥ 0

nbrFvPts = number of equally spaced data points used in describing f_V in the interval $0 \leq r/b \leq 1$

$2 \leq$ nbrFvPts ≤ 26

nbrIntPts = number of integration points used in the interval $0 \leq r/b \leq 1$ during subsidence computation

limAngle = limit angle, measured in degrees from the horizontal

subsFact = subsidence factor of the mine roof edge (see &RDPARAMS in Subsidence Module)

k_1, k_2 = parameters k_1 and k_2. If nbrItern = Ø, then k_1 and k_2 are interpreted as known values; consequently only C_V and/or r.m.s. error will be computed. If nbrItern ≠ Ø, then k_1 and k_2 are taken to be the starting values for the iterative computation; in this case k_1, k_2, C_V and r.m.s. error will be calculated.

$k_1 < k_2$

C_V = parameter C_V. If C_V is read in, then only r.m.s. error will be calculated. If C_V is omitted, then it will be computed by the program.

charTime = characteristic time of subsidence for the site (see &RDPARAMS). If charTime = 0.0, instantaneous subsidence will be assumed. Optimal parameters (C_V and/or k_1 and k_2) will be computed for this value of charTime only.

TStart, interval, nbrT } specify nbrT equally spaced values of charTime in the interval TStart ≤ charTime ≤ TStop for which the optimal parameters will be computed.

widthFact = width factor of the edge effect (see &RDPARAMS). Optimal parameters will be computed for this value of widthFact only.

WStart, WStop, nbrW } specify nbrW equally spaced values of widthFact in the interval WStart ≤ WidthFact ≤ WStop for which the optimal parameters will be computed.

moveLength = initial move length, i.e., the value of dk = $[(dk_1)^2 + (dk_2)^2]^{1/2}$ used in the method of steepest descent. This value will be adjusted by the program for moves other than the first.

moveLim = maximum tolerable value of dk (see moveLength). If dk exceeds this value during any one iteration, the run will be terminated.

Notes

A. The printout will display the computation history for each combination of charTime and widthFact used.

B. The combination of charTime and widthFact that resulted in the smallest r.m.s. error, together with the corresponding values of k_1, k_2 and C_V, become the default values in subsequent tasks.

C. Before &VELAST can be executed, the vertical displacements of the surface must be placed in Core Storage with &DISPL.

D. Input values of these parameters automatically become the new default values in all subsequent tasks in the Run Deck.

&VKNOTHE Computes the optimal values of parameters C_V and/or N in Knothe's influence function for vertical displacements:

$$f_V = C_V \exp[-N\pi(r/b)^2]$$

by minimizing the r.m.s. error between the measured and computed surface displacements. The computation may be performed for several values of site parameters charTime and widthFact, provided that these values are equally spaced.

The parameter N is obtained by solving a nonlinear equation H(N) = 0 by a series of linearized iterations (Secant method)

```
&VKNOTHE
[CUTOFF = nbrItern, epsilon] ← 25, 0.001
[SEARCH = NStart, NStop, nbrN] ← 0.0, 20.0/π, 10
[NUMFV = nbrFvPts] ← 16
[NUMINT = nbrIntPts] ← 20      }
[LANGLE = limAngle] ← 55.0     }  See Note D
[SFACT = SubsFact] ← 0.0       }
[PARMS = {N | N, Cv}]
CTIME = {charTime | TStart, TStop [,nbrT]} ← 2
WFACT = {widthFact | WStart, WStop [,nbrW]} ← 2
&
```

nbrItern = maximum allowable number of iterations in the solution of H(N) = 0

epsilon = convergence parameter used in the solution of H(N) = 0. The convergence criterion is $|H(N)| \leq$ (epsilon).

NStart, NStop, nbrN = search parameters used in locating the approximate root of H(N) = 0. The program searches for roots in the interval NStart $\leq$ N $\leq$ NStop by sampling H(N) at nbrN equally spaced points in this interval.

nbrFvPts = number of equally spaced data points used in describing f_V in the interval $0 \leq r/b \leq 1$.

$$2 \leq \text{nbrFvPts} \leq 26$$

nbrIntPts = number of integration points used in the interval $0 \leq r/b \leq 1$ during subsidence computation.

limAngle = limit angle measured in degrees from the horizontal.

subsFact = subsidence factor of the mine roof edge (see &RDPARAMS in Subsidence Module).

N = parameter N. If N is not read in, it will be computed. Otherwise the r.m.s. error and/or C_V only will be calculated.

C_V = parameter C_V. If C_V is not read in, it will be computed. Otherwise only the r.m.s. error will be calculated.

charTime = characteristic time of subsidence for the site (see &RDPARAMS). If charTime = 0.0, instantaneous subsidence will be assumed. Optimal parameters (C_V and/or N) will be computed for this value of charTime only.

TStart, TStop, nbrT: Specify nbrT equally spaced values of charTime in the interval TStart $\leq$ charTime $\leq$ TStop for which the optimal parameters will be computed.

widthFact = width factor of the edge effect (see &RDPARAMS). Optimal parameters will be computed for this value of widthFact only.

WStart, WStop, nbrW: Specify nbrW equally spaced values of widthFact in the interval WStart $\leq$ widthFact $\leq$ WStop for which the optimal parameters will be computed.

Notes

A. The printout will display the computation history for each combination of charTime and widthFact used.

B. The combination of charTime and widthFact that resulted in the smallest r.m.s. error, together with the corresponding values of N and C_V, become the default values in subsequent tasks.

C. Before &VKNOTHE can be executed, the vertical displacements of the surface must be placed in Core Storage with &DISPL.

D. Input values of these parameters automatically become the new default values in all subsequent tasks in the Run Deck.

7.5 Postprocessor Module

Summary of Tasks

Task	Description
&CONTOUR	Sets optional parameters for contour map
&DEVICE	Sets graphics device type
&GMINE	Reads into Core Storage the selected Mine Grids
&GSUBSIDENCE	Reads into Core Storage the selected Subsidence Grids
&GSURFACE	Reads into Core Storage the selected Surface Grids
&LOAD	Loads from Backup Storage the previously generated Preprocessor and Subsidence data bases and writes them to on-line disk storage units
&PLTDISPLTS	Choose a parameter and subset of the Subsidence grids for plotting, as well as the type of plot. Produces a plot as output.
&PLTMINE	Chooses a parameter and subset of the Mine Grids for plotting, as well as the type of plot. Produces a plot as output.
&PLTSURFACE	Chooses a subset of the Surface Grid for plotting, and the type of plot. Produces a plot as output.
&PRTDISPLTS	Prints selected information about Subsidence grids.
&PRTMINE	Prints selected information about Mine Grids.
&PRTSURFACE	Prints selected information about a Surface grid.
&SURFACE	Sets optional parameters for perspective plots.
&TERMINATE	Stops program execution and releases on-line storage units.
&XYPLOT	Sets optional parameters for X v.s. Y plots.

&CONTOUR	Sets optional parameters for contour map routine.

```
&CONTOUR
['TITLE' = title]
[NLEVELS = nbrLevels]  ← 6
[CELLSIZE = nbrXcells, nbrYcells]  ← 4 , 3
[SYMBOLS  = typeSymbol] ← 1
&
```

title = optional alphameric title to appear on map

nbrLevels = number of equally spaced contour intervals to represent the range of data in the grid.

nbrXcells, nbrYcells: the number of X and Y character postitions to represent the grid item. Since a printer has a typical aspect ratio of 4/3, this parameter defaults to a minimum character cell size for one grid element. Thus if a grid consisted of 25 x 25 elements the number of characters on one print line would be 100, while the number of lines for one row of grid elements would be 3 (typically 1/2 inch).

typeSymbol = mode to print symbols on contour map. The options are as follows:

typeSymbol	Contour Characters	Grid Marks
0	. and *	no
1	numbers	yes
2	. and *	yes
3	numbers	no
4	. and *	yes
5	numbers	yes
6	. and *	no
7	numbers	yes

&DEVICE	Sets the low-level hardware dependent graphics output to match the device code chosen.

```
&DEVICE
DEVICE = deviceType
&
```

deviceType = 563 (Calcomp style pen codes), 4662 (Tektronix flat-bed plotter), 4012, 4051, 4052 (Tektronix 8" CRT devices), 4054 (Tektronix 17" CRT device)

Note

This task is used to set the device type before producing a plot. Based on settings in the BLOCK DATA section of the Postprocessor Module, the device type defaults to 4662. The device type will be set to this default if an invalid choice is made.

The internal drivers for the 4054 mode expect that the full addressable display space is available through the Data Communications Interface. Early models of the 4054 may have an interface installed that emulates a 4052/4051 mode. If this is the case, simply select the 4052 device type to overcome this problem.

&GMINE	Loads a Mine Grid from Disk Storage into Core Storage

```
&GMINE
MNGRID = gridNbr
&
```

gridNbr = Mine Grid number

Note

Any surface, mine, or subsidence grid in core storage prior to the execution of &GMINE will be replaced with the newly requested Mine Grid. If the newly requested Mine Grid is the same as that already in core storage, than the task will not be executed.

&GSUBSIDENCE Loads a Subsidence Grid from Disk Storage into Core Storage.
&GSUBSIDENCE SGRID = gridNbr &

gridNbr = number of the Subsidence Grid

Note

&GSUBSIDENCE will replace any Mine, Surface or Subsidence Grid data that was already in core storage prior to its execution. If the newly requested Subsidence Grid is already in core storage, then this task is not executed.

&GSURFACE	Loads a Surface Grid from Disk Storage into Core Storage

```
&GSURFACE
SFGRID = gridNbr
&
```

gridNbr = Surface Grid Number

Note

As in the case of &GMINE and &GSUBSIDENCE, any other grids in core storage will be replaced with the newly requested Surface Grid. If the newly requested Surface Grid is already in core, the task is not executed.

&LOAD	Loads all Surface, Subsidence, and Mine Grids from Backup Storage (e.g., magnetic tape) into Disk Storage, and prints the corresponding Directories. Must be the first task in the Run Deck.

```
&LOAD
TAPE = dsrnNbr1 , dsrnNbr2
&
```

dsrnNbr1 = data set reference number for the Backup Storage device where the Surface and Mine Grids were stored at the end of the Preprocessor Run.

dsrnNbr2 = data set reference number for the Backup Storage Device where the Subsidence Grids were stored at the end of the Subsidence Module run.

Note

Both numbers are required, and if all of the data resides on the same unit, it is permissable to use the same reference number for both.

&PLTDISPLTS Chooses the subset of the Subsidence Grid information for plotting and produces a plot.

```
&PLTDISPLTS
[UNIT = dsrnNbr] ← 7
[ERANGE = {spaceLoc
           {firstSpace, lastSpace}]          ← firstLine, lastLine
[NRANGE = {spaceLoc
           {firstSpace, lastSpace}]          ← firstLine, lastLine
[TRANGE = {timeLoc
           {firstTime, lastTime}  ]          ← firstDate, lastDate
['TITLE' = title]
[PTYPE = graphType] ← 1
GSELECT = gridNbr
&
```

graphType = value to select type of display required - 1 = X-Y plot, 2 = contour map, 3 = perspective plot

gridNbr = value to select which of the three parameters to use for plotting - 1 = W, 2 = U, 3 = V, 4 = Magnitude, 5 = Direction

Note

The parameters UNIT, ERANGE, NRANGE, TRANGE and TITLE are identical to those described for the task &PRTDISPLTS, except that their function is to select an appropriate subset of data for plotting. See the descripion of how this subset is formed in the 'Note' task &PLTMINE.

```
&PLTMINE    Plot a Mine Grid

&PLTMINE
[UNIT = dsrnNbr] ← 7
[ERANGE =       ]
[NRANGE =       ]
['TITLE' =      ]
[PTYPE  = graphType] ← 1
GSELECT = gridNbr
&
```

graphType = value to select type of display required - 1 = X-Y plot, 2 = contour map, 3 = perspective plot

gridNbr = value to select which of the three parameters to use for plotting - 1 = seam thickness, 2 = seam bottom elevation, 3 = depth of cover

Note

The parameters UNIT, ERANGE, NRANGE and TITLE are identical to those described for the task &PRTMINE, except that their function is to select the appropriate subset of data for plotting. The X-Y plot expects a 'slice' or a set of x or y location points with a paired sample value to be plotted. Likewise, the perspective and contour plots expect a subset of data to be a matrix of values. If the data base contains only 'slices' (i.e., only sets of data where either the x or y locations remain constant) then no perspective or contour plots may be generated. Otherwise, slices may be taken from the grid matrix values by using the optional parameters so that the X-Y plotting routine receives a proper subset of values. Error messages will be issued if these rules are violated and the plot will be terminated.

If a contour map is selected, the UNIT parameter may be used to direct the output to other than the current printer device number (defaults to 6).

&PLTSURFACE	Selects a Surface Grid and subset and produces a plot.

```
&PLTSURFACE
[NUMDATA = nbrData] ← 3
[UNIT    = dsrnNbr] ← 7
[ERANGE  =        ]
[NRANGE  =        ]
['TITLE' =        ]
[PTYPE   = graphType] ← 1
&
```

nbrData = item number for plotting. Since only the surface grid was saved by the Preprocessor in this data base, the only valid choice for NUMDATA is the default, 3.

graphType = value to select which type of graph is to be produced - 1 = X-Y plot, 2 = contour map, 3 = perspective plot.

Note

The parameters NUMDATA, ERANGE, NRANGE and 'TITLE' have the same meaning as they do in task &PRTSURFACE, except that their action here is to form either a slice for an X-Y plot, or a matrix of values for a contour or perspective plot. A Type 2 grid (a collection of non-rectangular points) may not be used for plotting. See the description of the parameters in &PRTSURFACE .

```
&PRTDISPLTS  Prints the surface displacements of the Subsidence Grid
located in Core Storage.  The printout may include all the displace-
ments, or it may be confined to a portion of the Surface/Time Grid.
```

```
&PRTDISPLTS
[UNIT = dsrnNbr] ← 6
[ERANGE = {spaceLoc                 }]   ← firstLine, lastLine
          {firstSpace, lastSpace    }
[NRANGE = {spaceLoc                 }]   ← firstLine, lastLine
          {firstSpace, lastSpace    }
[TRANGE = {timeLoc                  }]   ← firstDate, lastDate
          {firstTime, lastTime      }
['TITLE' = title]
&
```

dsrnNbr = data set reference number of the printer

spaceLoc = E or N Location Number of the Surface Grid Line for which the displacements are printed. Use to print displacements on this grid line only.

firstLine $\leq$ spaceLoc $\leq$ lastLine

firstSpace, lastSpace } E or N Location Numbers of the first and last Surface Grid line for which the displacements are printed.

firstLine $\leq$ firstSpace $\leq$ lastSpace $\leq$ lastLine

firstLine, lastLine } E or N location Numbers of the first and last Surface Grid lines for which the displacements were calculated. (Refer to Directory printed when &LOAD is executed.)

timeLoc = date Location Number at which the displacements are printed. Use for printout of displacements at this date only.

1 $\leq$ timeLoc $\leq$ nbrDates

firstTime, lastTime } date Location Numbers of the first and last dates at which the displacements are printed.

1 $\leq$ firstTime $\leq$ lastTime $\leq$ nbrDates

nbrDates = number of equally spaced dates at which the displacements were calculated. (See Directory printed at execution of task &LOAD.)

title = alphameric title to appear with the printout.

Note

The Subsidence Grid to be printed must first be placed in Core Storage by &GSUBS.

```
&PRTSURFACE  Prints user-selected data items of the Surface Grid in
Core Storage.  Three items may be printed at each grid point as
follows:
                1) Global East Coordinate
                2) Global North Coordinate
                3) Surface Elevation
```

```
For a rectangular grid (Grid Type = 1)
&PRTSURFACE
[NUMDATA = nbrData] ← 3
[UNIT    = dsnrNbr] ← 6

[ERANGE  = {lineLocn              }]   ← 1, nbrLines
[          {firstLine, lastLine   }]
[NRANGE  = {lineLocn              }]   ← 1, nbrLines
[          {firstLine, lastLine   }]
['TITLE' = title]  ← blank
&
```

```
For non-rectangular grid (Grid Type = 2)
&PRTSURFACE
[NUMDATA = nbrData] ← 3
[UNIT    = dsrnNbr] ← 6

[NRANGE  = {ptNbr           }]         ← 1, nbrPts
[          {firstPt, lastPt }]

['TITLE' = title] ← blank
&
```

nbrData = number of data items to be printed for each grid point (3 is only choice because the Preprocessor does not save the other parameters in this data base).

dsrnNbr = data set reference number for the printer

lineLoc = East (ERANGE) or North (NRANGE) Location Number of the grid line for which this data is to be printed. Prints data for points on this line only.

$$1 \le \text{lineLoc} \le \text{nbrLines}$$

firstLine, lastLine — East (ERANGE) or North (NRANGE) Location Numbers of the first and last line for which data is to be printed.

$$1 \le \text{firstLine} \le \text{lastLine} \le \text{nbrLines}$$

nbrLines = number of lines in the Surface Grid in the direction of East (ERANGE) or North (NRANGE).

```
&XYPLOT   Sets optional parameters for X v.s. Y Plot

&XYPLOT
['XLABEL' = xlabel]
['YLABEL' = ylabel]
[PMODE = plotMode] ← -1
[SCALE = scalefactor] ← 1
&
```

xlabel = label to appear on the X axis

ylabel = label to appear on the Y axis

plotMode = choose plotting mode as follows: 1 = plot only the points with a symbol (*), 0 = solid line without symbols at points, -1 = plot a solid line with symbols at the points.

scaleFactor = a value multiplied by the internal scaling calculations for the finish size of the plot. The internal routines scale the size of the plot to fit 'nicely' for each possible display device. A value of 2 would double the size.

&PRTMINE Prints all five data items of the Mine Grid located in Core Storage. Data for any portion of the grid may be chosen for the printout.

```
&PRTMINE
[UNIT = dsrNbr] ← 6
[ERANGE = {lineLocn | firstLine, lastLine}] ← 1, nbrLines
[NRANGE = {lineLocn | firstLine, lastline}] ← 1, nbrLines
['TITLE'= title] ← blank
&
```

dsrNbr = data set reference number of the printer

lineLocn = East (ERANGE) or North (NRANGE) Location Number of the grid line. Prints data for on grid line only.

$1 \leq$ lineLocn $\leq$ nbrLines

firstLine, lastLine = East (ERANGE) or NORTH (NRANGE) Location Numbers of the first and last grid line for which the data is to be printed.

$1 \leq$ firstLine $\leq$ lastLine $\leq$ nbrLines

nbrLines = number of lines in the Mine Grid in the direction of East (ERANGE) or North (NRANGE)

title = alphameric title to appear with printout

Note

The Mine Grid may be loaded into Core Storage by executing &GMINE.

title = alphameric title to appear with printout

ptNbr = surface point number for which data is to be printed. Prints data for this point only.

$1 \leq ptNbr \leq nbrPts$

firstPt, lastPt — numbers of the first and last points for which data is to be printed. Prints data for this point only.

$1 \leq firstPt \leq lastPt \leq nbrPts$

nbrPts = number of points in the surface grid.

Notes

A. The Surface Grid may be loaded into Core Storage by &GSURFACE.

&SURFACE	Sets optional parameters for Perspective Plots

```
&SURFACE
[AZIMUTH = angle] ← 135
[ELEVATION = angle] ← 45
[PROJECTION = projectionType] ← 1
[SCALE = scaleFactor] ← 1
[BASE = baseSize] ← .25
[MAXHEIGHT = maxZht] ← 3.
&
```

angle = in degrees, for the azimuth of the observer. An azimuth of 90 degrees indicates a view from the north edge of the grid, while an angle of 270 indicates a view from the southern edge of the grid.

$$0 \leq angle \leq 360$$

angle = in degrees, for the elevation of the observer. The angle formed by the observer's line of sight with the plane of observation.

$$15 \leq angle \leq 75$$

projectionType = 1 denotes a perspective projection, 2 = isomeric projection

scaleFactor = value to multiply axes length for changing the scale size of the picture. The default is to produce a plot that is 5" by 5" (if the number of grid elements are equal in X and Y), values of this parameter are multiplied by the default size to scale the actual plot.

baseSize = size, in inches, of base below wurface plot. A value of 0 will remove the base from the picture.

maxZht = maximum Z value in grid will produce this amount of Z deflection in inches in the projection and plot.

&TERMINATE	Terminates the session
&TERMINATE &	

8. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

SPASID appears to be the first attempt at using the influence function method over an extensive range of topological conditions. By far the biggest difficulty encountered in the work was the lack of published experimental data. It is thus inevitable that some parts of the program are somewhat speculative in nature, and should be reviewed over the next few years as experience in the use of the program is accumulated.

We are rather confident about the ability of the program to predict subsidence for level or very slightly inclined seams (say, less than six degrees) under favorable geological conditions. If the slope angle of the mine floor is ten degrees or larger, the predicted vertical displacement should still be acceptable, but considerable uncertainty exists about the horizontal movements. The method of handling the latter in SPASID is based on very limited data, most of it qualitative rather than quantitative. It is imperative that the method of slope correction for horizontal displacements outlined in Section 2.4 be reevaluated and adjusted as soon as reliable experimental data becomes available. This suggestion is particularly important because horizontal strains are responsible for most damage to surface structures.

Another untested aspect of the program is the time lag between extraction and subsidence. Such questions as whether the exponential decay is really representative of reality, and if the time lag can be characterized by a single parameter, such as the characteristic time used in SPASID, can be answered only by experimentation.

There are other parts of the program that deserve close scrutiny. For example, the subsidence factor (maximum attainable vertical displacement divided by depth of cut) was assumed to be independent of seam depth and the presence of adjacent panels. This may not be true for some sites, as evidenced by data collected in the Appalachian coalfields [8]. But again, lack of data from other geographical areas prevented us from drawing general conclusions.

The authors recommend that two programs be implemented in the near future:

(1) A combined experimental-theoretical study of subsidence in order to resolve the questions raised above. The experimental part should be carefully coordinated, so that it would be aimed at specific problems and not result in a haphazard collection of subsidence data. The initial portion of the study should have a modest scope, perhaps covering only a single geological region. The overall objective should be the fine-tuning of the predictive methods, starting with the most questionable aspects of the "state of the art". SPASID should be ideally suited as the theoretical basis of the study.

(2) A center for collecting user input and maintaining the program should be created. Such an arrangement would have a twofold purpose: detection and correction of "bugs", and improvement of the program in general. Errors in the source deck are unavoidable in a program of the complexity of SPASID. It usually takes about a year of extensive usage before all bugs are found. Therefore, the users must not only have the opportunity to report program errors, but should be actively encouraged to do so.

Since the users are also the best critics of a program, their suggestions for improvements or modification are extremely valuable. These may range from addition of convenience features to major changes in computational procedures.

The suggested center would not only provide the vehicle for user input, but it would also lead to better user satisfaction, thus encouraging more widespread use of the program.

9. REFERENCES

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APPENDIX A: DERIVATION OF ELASTIC INFLUENCE FUNCTIONS

A.1 Solution of Berry and Sales

Subsidence of an elastic medium has been treated by Berry and Sales [2]. They considered the boundary value problem illustrated in Figure A.1. The medium is semi-infinite with transversely isotropic elastic properties, the x-axis being the axis of symmetry. The deformation is due to a self-stress caused by removal of the material from the region representing the seam and closing the resulting opening. This result is the displacement discontinuity at the seam

$$w(x,y,h^-) - w(x,y,h^+) = t(x,y), \tag{A.1}$$

where h^+ and h^- refer to the upper and lower surfaces of the seam.

The solution for the displacement field given in [2] is

$$u(x,y,z) = \frac{\partial}{\partial x}(\phi_1 + \phi_2), \qquad v(x,y,z,) = \frac{\partial}{\partial y}(\phi_1 + \phi_2), \tag{A.2}$$

$$w(x,y,z) = \frac{\partial}{\partial z}(q_1\,\phi_1 + q_2\,\phi_2).$$

The functions ϕ_1 and ϕ_2 are related to a "potential function" Φ by

$$\begin{aligned}
\phi_1 &= \frac{\alpha_1}{1+q_1}\Bigg\{\Phi(x,y,z_1+h_1) + \Phi(x,y,z_1-h_1) \\
&\quad - \frac{2}{\alpha_1-\alpha_2}\left[\alpha_1\,\Phi(x,y,z_1-h_1) - \alpha_2\,\Phi(x,y,z_1-h_2)\right]\Bigg\}, \\
\phi_2 &= -\frac{\alpha_2}{1+q_2}\Bigg\{\Phi(x,y,z_2+h_2) + \Phi(x,y,z_2-h_2) \\
&\quad - \frac{2}{\alpha_1-\alpha_2}\left[\alpha_1\,\Phi(x,y,z_2-h_1) - \alpha_2\,\Phi(x,y,z_2-h_2)\right]\Bigg\},
\end{aligned} \tag{A.3}$$

where

$$\Phi(x,y,z) = \frac{(1+q_1)(1+q_2)}{4\pi\,(q_1-q_2)} \iint_A \frac{t(\S,\eta)\,d\S\,d\eta}{\rho}, \tag{A.4a}$$

$$\rho = \sqrt{(x-\S)^2 + (y-\eta)^2 + z^2}, \tag{A.4b}$$

$$z_i = z/\alpha_i, \qquad h_i = h/\alpha_i, \qquad (i=1,2) \tag{A.4c}$$

and the integral is taken over the area A of the seam.

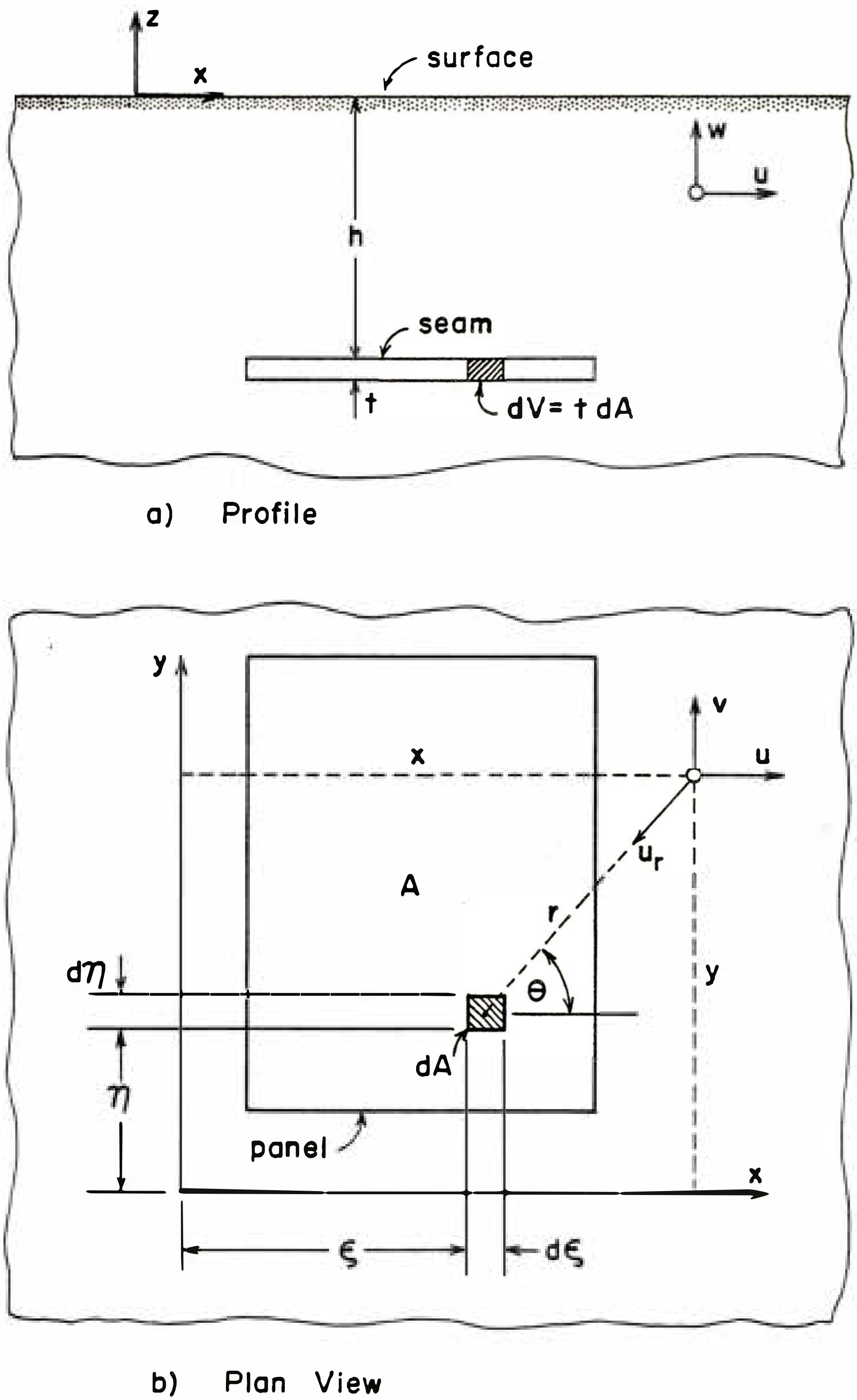


FIGURE A.1 Notation Used in Elastic Solution of Subsidence Problem

The constants α_i and q_i depend on the elastic constants of the medium. The latter are defined by stress-strain relations, which for transverse anisotropy take the form

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} \\ C_{12} & C_{11} & C_{13} \\ C_{13} & C_{13} & C_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \end{bmatrix} \quad \text{(A.5a)}$$

$$\tau_{xy} = (C_{11} - C_{12})\gamma_{xy}, \quad \tau_{yz} = 2C_{44}\,\gamma_{yz}, \quad \tau_{zx} = 2C_{44}\,\gamma_{zx}. \quad \text{(A.5b)}$$

The constants α_i are the two positive roots of the biquadratic equation

$$C_{11}C_{44}\alpha^4 + [C_{13}(2C_{44} + C_{13}) - C_{11}C_{33}]\,\alpha^2 + C_{33}C_{44} = 0, \quad \text{(A.6)}$$

with $\alpha_1 < \alpha_2$. In general the roots of (A.6) could be complex, but this possibility will not be considered here. The values of q_i are given by

$$q_i = (C_{11}\alpha_i^2 - C_{44}) \,/\, (C_{13} + C_{44}) \qquad (i=1,2). \quad \text{(A.7)}$$

A.2 Influence Functions

It is convenient to rewrite (A.4) in the form

$$\Phi(x,y,z) = \iint_A \Phi^o\, t\, dA,$$

where

$$\Phi^o = \frac{(1 + q_1)(1 + q_2)}{4\pi\,(q_1 - q_2)} \quad \frac{1}{\rho} \quad \text{(A.8)}$$

represents the contribution of a unit extraction volume to the function Φ. The corresponding contributions to ϕ_1 and ϕ_2 are obtained from (A.3) by simply replacing Φ by Φ^o:

$$\phi_1^{\,o} = \frac{\alpha_1}{1 + q_1} \left\{ \Phi^o(x,y,z_1+h_1) + \Phi^o(x,y,z_1-h_1) - \frac{2}{\alpha_1 - \alpha_2}\,[\alpha_1\,\Phi^o(x,y,z_1-h_1) - \alpha_2\,\Phi^o(x,y,z_1-h_2)] \right\}.$$

$$\phi_2^{\,o} = -\frac{\alpha_2}{1 + q_2} \left\{ \Phi^o(x,y,z_2+h_2) + \Phi^o(x,y,z_2-h_2) - \frac{2}{\alpha_1 - \alpha_2}\,[\alpha_1\,\Phi^o(x,y,z_2-h_1) - \alpha_2\,\Phi^o(x,y,z_2-h_2)] \right\}. \quad \text{(A.9)}$$

The displacements of the surface caused by a unit extraction volume are, from (A.2)

$$u^o(x,y,0) = \frac{\partial}{\partial x}(\phi_1{}^o + \phi_2{}^o)_{z=0}, \quad v^o(x,y,0) = \frac{\partial}{\partial y}(\phi_1{}^o + \phi_2{}^o)_{z=0},$$

$$w^o(x,y,0) = [\frac{\partial}{\partial z}(q_1\phi_1{}^o + q_2\phi_2{}^o)]_{z=0}. \qquad (A.10)$$

The horizontal displacement directed from the surface point towards the point over the extraction element, as shown in Figure A.1, is

$$\begin{aligned} u_r{}^o &= -u^o \cos\theta - v^o \sin\theta \\ &= -(\cos\theta \frac{\partial}{\partial x} + \sin\theta \frac{\partial}{\partial y})(\phi_1{}^o + \phi_2{}^o)_{z=0} \\ &= -\frac{\partial}{\partial r}(\phi_1{}^o + \phi_2{}^o)_{z=0} \end{aligned} \qquad (A.11)$$

where

$$r = \sqrt{(x - \xi)^2 + (y - \eta)^2} \qquad (A.12)$$

The incremental displacements due to extraction of the volume element t dA can be calculated from

$$dw = w^o t\, dA, \qquad du_r = u_r{}^o t\, dA. \qquad (A.13)$$

In order to evaluate w_o from (A.10), we must start by differentiating (A.8):

$$\left.\frac{\partial\Phi^o(x,y,z_i \pm h_i)}{\partial z}\right|_{z=0} = \mp \frac{(1 + q_1)(1 + q_2)h_j}{4\pi\ \alpha_i(q_1 - q_2)}\ \rho_j{}^{-3} \quad (i,j=1,2), \qquad (A.14)$$

where

$$\rho_j = \sqrt{(x - \xi)^2 + (y - \xi)^2 + h_j{}^2} = \sqrt{r^2 + (h/\alpha_j)^2}. \qquad (A.15)$$

Next, we differentiate (A.9) with respect to z and then substitute (A.14) in the right-hand-side. The results are

$$\left.\frac{\partial\phi_1{}^o}{\partial z}\right|_{z=0} = -\frac{(1 + q_2)h}{2\pi(\alpha_1 - \alpha_2)(q_1 - q_2)}(\rho_1{}^{-3} - \rho_2{}^{-3}),$$

$$\left.\frac{\partial\phi_2{}^o}{\partial z}\right|_{z=0} = \frac{(1 + q_1)h}{2\pi(\alpha_1 - \alpha_2)(q_1 - q_2)}(\rho_1{}^{-3} - \rho_2{}^{-3}),$$

which, upon substitution in (A.10) yield

$$w_o = - \frac{h}{2\pi(\alpha_1 - \alpha_2)} (\rho_1^{-3} - \rho_2^{-3})$$

Replacing h by b tan γ, where b is the radius of influence and γ the limit angle shown in Figure 2.1, we get

$$w_o = - \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)b^2} (R_1^{-3} - R_2^{-3}),$$

with

$$R_i = \sqrt{(r/b)^2 + (\tan\gamma/\alpha_i)^2} \qquad (i=1,2). \qquad (A.16)$$

The incremental surface displacement in (A.13), therefore, is

$$dw = -t \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)} (R_1^{-3} - R_2^{-3}) \frac{dA}{b^2}, \qquad (A.17)$$

which agrees with (b) in Sec. 2.2, except for the minus sign. The latter is due to the different sign convention used for w by Berry and Sales, and this report.

To evaluate u_r^o we need

$$\left.\frac{\partial\Phi^o(x,y,z_i \pm h_i)}{\partial r}\right|_{z=0} = - \frac{(1 + q_1)(1 + q_2)}{4\pi\ (q_1 - q_2)} r\rho_i^{-3}.$$

Hence (A.9) yield

$$\left.\frac{\partial\phi_1}{\partial r}\right|_{z=0} = \frac{\alpha_1\alpha_2(1 + q_2)}{2\pi(\alpha_1 - \alpha_2)(q_1 - q_2)} r(\rho_1^{-3} - \rho_2^{-3}),$$

$$\left.\frac{\partial\phi_2}{\partial r}\right|_{z=0} = - \frac{\alpha_1\alpha_2(1 + q_1)}{2\pi(\alpha_1 - \alpha_2)(q_1 - q_2)} r(\rho_1^{-3} - \rho_2^{-3})$$

and (A.11) becomes

$$u_r^o = \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)b^2} \frac{r}{b} (R_1^{-3} - R_2^{-3}).$$

Consequently, we obtain from (A.13)

$$du_r = t \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)} \frac{r}{b} (R_1^{-3} - R_2^{-3}) \frac{dA}{b^2} , \qquad (A.18)$$

which is identical to the result in Sec. 2.3.2.

The corresponding influence functions are -- see (2.2) --

$$f_v = \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)} (R_1^{-3} - R_2^{-3}), \qquad f_H = \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)} \frac{r}{b} (R_1^{-3} - R_2^{-3}) \qquad (A.19)$$

There is no practical advantage to leaving the influence functions in this form. Firstly, it is not possible to measure the in-situ elastic constants of the overburden in order to calculate α_1 and α_2. Secondly, subsidence is not an elastic process, so that such a computation, even if it were feasible, would not be very meaningful. Consequently, f_V and f_H should be considered as just another set of influence functions; where the parameters

$$C_v = \frac{\tan\gamma}{2\pi(\alpha_1 - \alpha_2)} , \qquad C_H = \frac{\alpha_1\alpha_2}{2\pi(\alpha_1 - \alpha_2)} ,$$

$$k_i = \tan\gamma/\alpha_i \qquad (i=1,2)$$

are to be determined from actual subsidence measurements, as was done in (2.6) and (2.7). In other words, elasticity theory gives some legitimacy to the form of the influence functions, but it contributes nothing to the computation of the parameters.

APPENDIX B: DISCUSSION OF INFLUENCE FUNCTIONS

B.1 Influence Functions for Vertical Displacements

The vertical Knothe's influence function (2.5a) was

$$f_v = C_v \exp\left[-\pi N (r/b)^2\right] \tag{B.1}$$

and its elastic counterpart (2.6)

$$f_v = C_v \left(R_1^{-3} - R_2^{-3}\right), \tag{B.2}$$

where

$$R_i = \sqrt{(r/b)^2 + k_i^2} \qquad (i=1,2). \tag{B.3}$$

In order to compare these functions, we must first establish a basis for the comparison, i.e. we must define an equivalence group for the influence functions, and restrict the comparison to members of this group. A convenient and practically significant definition of an equivalence group would be the collection of all influence functions that have the same limit angle and subsidence factor.

The subsidence factor a_v is defined as

$$a_v = w_{max}/t, \tag{B.4}$$

where w_{max} is the maximum attainable subsidence and t represents the extraction height. In practice, w_{max} is attained at a surface point if all the material within the radius of influence b has been extracted. However, in theory the extraction area must extend to infinity because the influence functions used in SPASID do not vanish completely at r=b, but go to zero asymptotically as $r \to \infty$. This means that the extraction between r=b and $r \to \infty$ will contribute a small amount to w_{max}. Hence, we define w_{max} as

$$w_{max} = \iint_A dw = \int_{\theta=0}^{2\pi} \int_{r=0}^{\infty} dw\,, \tag{B.5}$$

where r and θ are the polar coordinates shown in Figure 2.2. Substituting for dw from (2.2), we have

$$w_{max} = t \int_{\theta=0}^{2\pi} \int_{r=0}^{\infty} \frac{1}{b^2} f_v (r/b) r \, dr \, d\theta \tag{B.6}$$

$$= 2\pi t \int_0^{\infty} \frac{1}{b^2} f_v (r/b) r \, dr .$$

For Knothe's influence function (B.2) this becomes

$$w_{max} = t \, C_v/N,$$

so that the subsidence factor is

$$a_v = C_v/N. \tag{B.7}$$

Using the elastic influence function (B.3), we get

$$w_{max} = 2\pi t \, C_v (k_1^{-1} - k_2^{-1}),$$

and

$$a_v = 2\pi C_v (k_1^{-1} - k_2^{-1}). \tag{B.8}$$

We must next arrive at a definition of the limit angle γ, or equivalently, the radius of influence b. The qualitative definition used in Sec. 2.1 was that at r=b, the influence function becomes "imperceptibly small". A useful quantitative definition of b would be based on the requirement that the contribution of the extraction area between r=b and $r \to \infty$ to w_{max} be sufficiently small. In other words, if the upper limit of the integral in (B.6) were changed from ∞ to b, the corresponding change in w_{max} should be insignificant.

Using the notation

$$w'_{max} = 2\pi t \int_0^{b} \frac{1}{b^2} f_v(r/b) r \, dr , \tag{B.9}$$

the above requirement could be expressed as

$$(w_{max} - w'_{max})/w_{max} = \varepsilon, \tag{B.10}$$

where ε is a small prescribed number that represents the percentage discrepancy between the two computations of w_{max}.

Substituting Knothe's influence function in (B.9), we get

$$w'_{max} = \frac{tC_v}{N} [1 - \exp(-\pi N)].$$

Hence,

$$\varepsilon = \exp(-\pi N), \tag{B.11}$$

or if ε is prescribed,

$$N = -\log_e \varepsilon/\pi. \tag{B.12}$$

For the elastic influence function, (B.9) yields

$$w'_{max} = 2\pi C_v t\{(k_1^{-1} - k_2^{-1}) - [(1 + k_1^2)^{-\frac{1}{2}} - (1 + k_2^2)^{-\frac{1}{2}}]\},$$

from which we get

$$\varepsilon = [(1 + k_1^2)^{-\frac{1}{2}} - (1 + k_2^2)^{-\frac{1}{2}}] / (k_1^{-1} - k_2^{-1}). \tag{B.13}$$

By our previous definition, all the influence functions that have the same values of a_v and ε are equivalent. As can be seen from (B.7) and (B.12), Knothe's influence function is completely determined by prescribing a_v and ε. Hence an equivalence group contains only one Knothe's influence function. On the other hand, there are infinitely many combinations of C_v, k_1 and k_2 in the elastic influence function that result in a given set of a_v and ε. The combinations of k_1 and k_2 that result in ε=0.05, obtained by numerically solving (B.13), are shown in Figure B.1. It is interesting to note that the equation k_1k_2=0.155 represents a good approximation of (B.13) in this particular case. The figure also indicates that the constraint $k_1 < k_2$ requires $k_1 < 0.395$. Of course, other values of ε would produce different numerical results.

The influence function of Knothe and two of the elastic influence functions that belong to the equivalence group defined by a_v=1, ε=0.05 have been plotted in Figure B.2. It is seen that an elastic influence function reaches a considerably higher peak value at r/b=0 as compared to Knothe's function, but decreases more rapidly as $r/b \to 1$. As $r/b \to \infty$, however, Knothe's influence function decays much faster than its elastic counterpart.

B.2 Profile Influence Functions

Let us assume that the surface elevation, depth of cover, and the extraction height do not vary along the length of the panel. If in addition, the length of the extracted panel is much greater than the radius of influence, the subsidence profile across the middle portion of the panel will be independent of the panel length (see Figure B.3). The surface displacement in the y-direction will vanish, and the remaining displacements u and w will be functions of the x-coordinate only.

Using the coordinate system shown in Figure B.3, the vertical displacement for such a panel will be

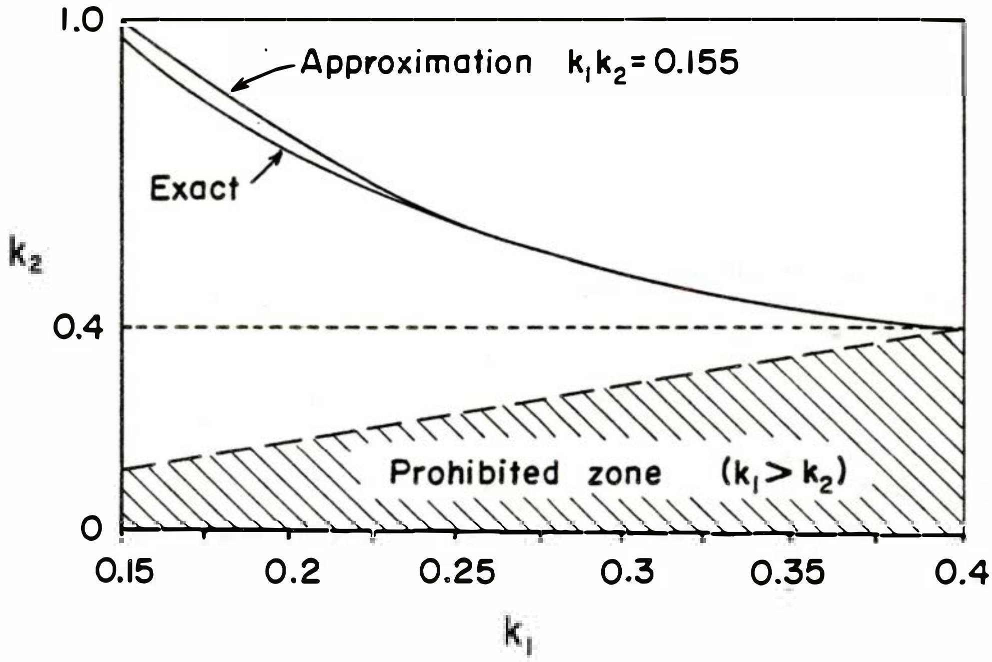


FIGURE B.1 Plot of Equation B.13 For $\varepsilon=0.05$

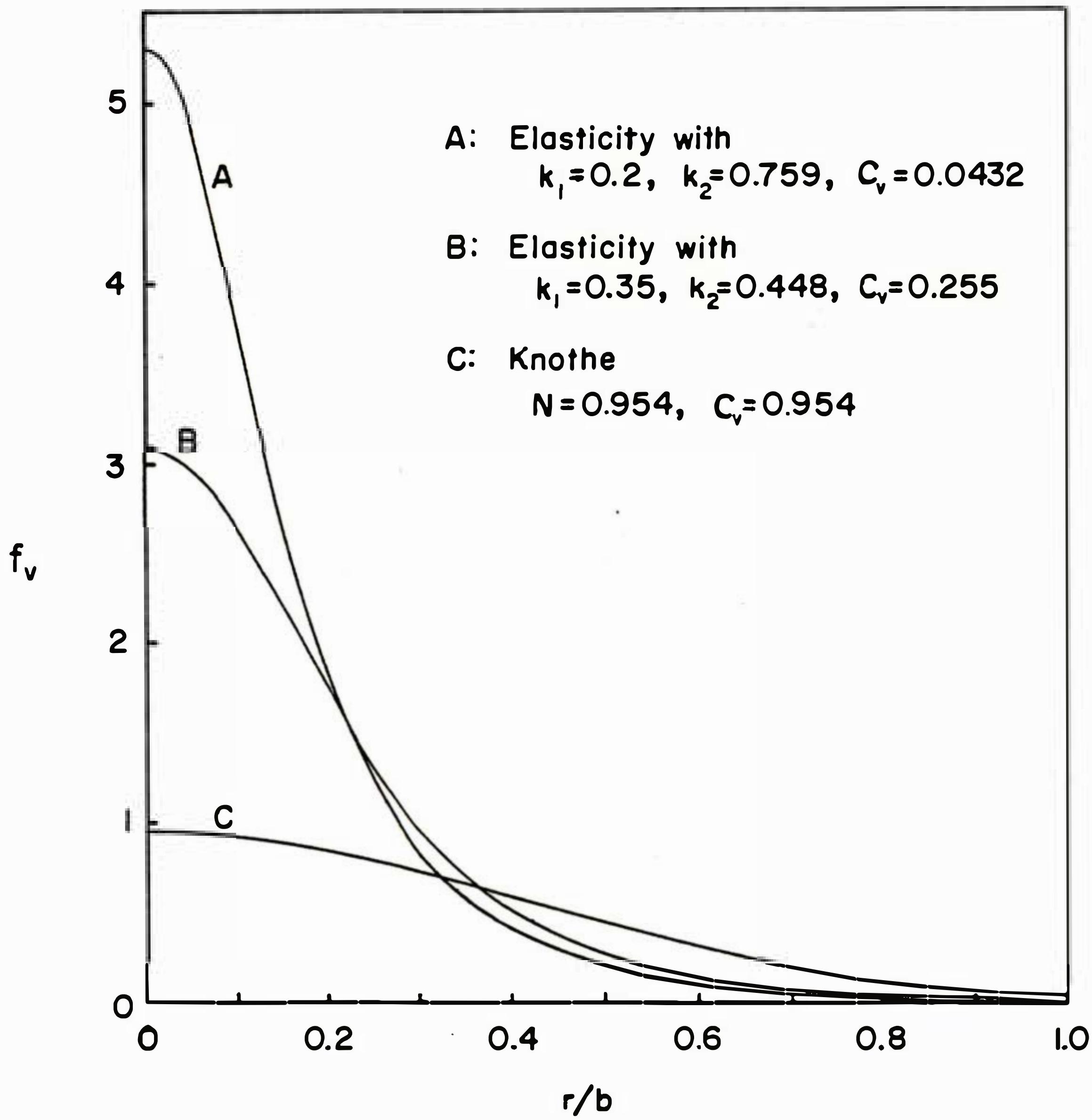
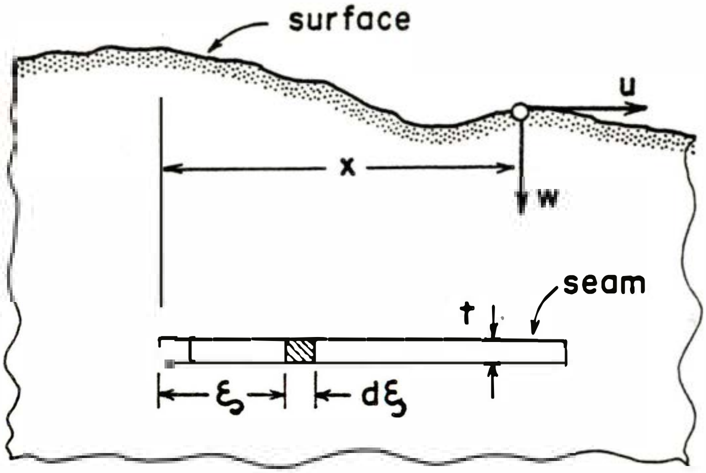
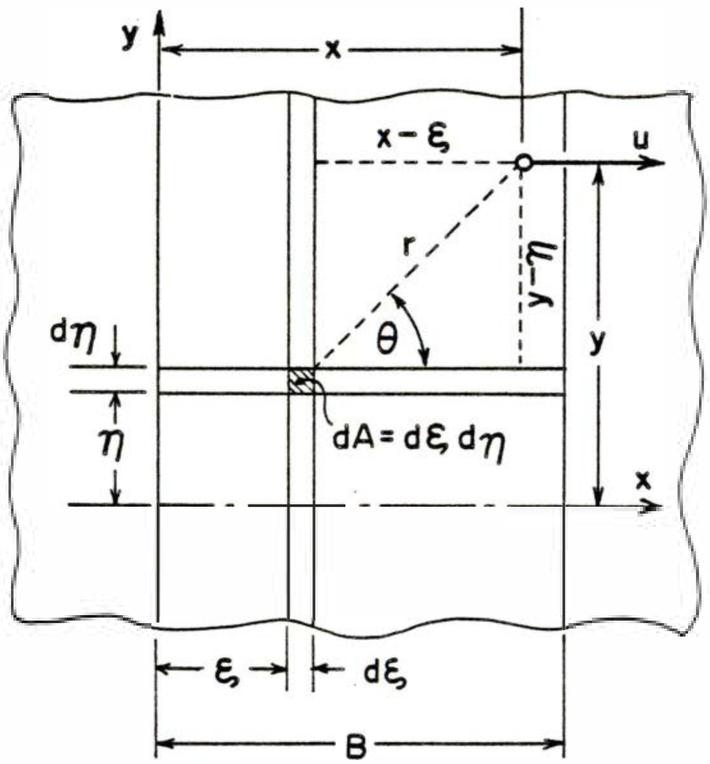


FIGURE B.2 Influence Functions for Vertical Displacements with a_v=1 and ε=0.05



a) Profile



b) Plan View

FIGURE B.3 Computation of Surface Displacements Over a Long Panel

$$w = \iint_A dw = \int_{\xi=0}^{B} \int_{\eta=-\infty}^{\infty} dw ,$$

where B is the width of the panel. Replacing dw by (2.2) and noting that $dA = d\xi\, d\eta$, we get

$$w = \int_{\xi=0}^{B} \int_{\eta=-\infty}^{\infty} \frac{t}{b^2} f_v(r/b)\, d\xi\, d\eta. \tag{B.14}$$

Upon substituting

$$r = \sqrt{(x - \xi)^2 + (y - \eta)^2} \tag{B.15}$$

and integrating with respect to η, (B.14) can be expressed in the form

$$w(x) = \int_0^B \frac{t}{b} g_v\left(\frac{x - \xi}{b}\right) d\xi, \tag{B.16}$$

where

$$g_v = \int_{-\infty}^{\infty} \frac{1}{b} f_v (r/b)\, d\eta \tag{B.17}$$

is the <u>profile influence function</u> of the vertical displacement. It is the one-dimensional counterpart of the two-dimensional influence function f_v.

With Knothe's influence function (2.5a) in (B.17) we get upon integration.

$$g_v = \frac{C_v}{\sqrt{N}} \exp[-\pi N (x - \xi)^2 / b^2]. \tag{B.18}$$

For the elastic influence function (2.6) the result is

$$g_v = 2C_v (\rho_1^{-2} - \rho_2^{-2}), \tag{B.19}$$

where

$$\rho_i = \sqrt{(x - \xi)^2 / b^2 + k_i^2} \qquad (i=1,2). \tag{B.20}$$

The horizontal displacement is given by (see Sec. 2.2):

$$u = -\iint_A du_r \cos\theta = - \int_{\xi=0}^{B} \int_{\eta=-\infty}^{\infty} (x - \xi) / r\, du_r$$

Substitution for du_r from (2.2) yields

$$u = - \int_{\S=0}^{B} \int_{\eta=-\infty}^{\infty} \frac{t}{b^2} \frac{x - \S}{r} f_H (r/b)\, d\S\, d\eta,$$

which can be written as

$$u(x) = \int_0^B \frac{t}{b} g_H \left(\frac{x - \S}{b}\right) d\S \qquad \text{(B.21)}$$

where

$$g_H = - \int_{-\infty}^{\infty} \frac{1}{b} \frac{x - \S}{r} f_H (r/b)\, d\eta \qquad \text{(B.22)}$$

is the profile influence function for the horizontal displacement.

Equation (B.22) becomes for Knothe's (2.5b) and elastic (2.6) influence functions, respectively

$$g_H = - \frac{C_H}{\sqrt{N}} [(x - \S)/b] \exp[-\pi N(x - \S)^2/b^2] \qquad \text{(B.23)}$$

and

$$g_H = -2C_H [(x - \S)/b] (\rho_1^{-2} - \rho_2^{-2}), \qquad \text{(B.24)}$$

where ρ_i are given by (B.20).

B.3 Profile Functions for Supercritical Panel Width

The displacement profiles w(x) and u(x) for a level seam, horizontal surface and constant extraction height are commonly known as the profile functions. A number of such functions have been described by Bräuner [3]. An important special case occurs where the width of the panel exceeds twice the radius of influence, i.e B > 2b, when the surface displacement near one edge of the panel is not influenced by the presence of the other edge.

For such a supercritical panel width, the vertical profile function for the left edge of the panel (B.16) can be rewritten as

$$w(x) = t \int_0^{\infty} \frac{1}{b} g_v \left(\frac{x - \S}{b}\right) d\S. \qquad \text{(B.25)}$$

For Knothe's profile influence function (B.18) this becomes

$$w(x) = \frac{C_v t}{2N} [1 + \Phi (\sqrt{\pi N}\, x /b)], \qquad \text{(B.26)}$$

where

$$\Phi(x) = \frac{2}{\pi} \int_0^x \exp(-\S^2)\, d\S \qquad \text{(B.27)}$$

is the error function [9], sometimes also denoted by erf(x). Using the elastic profile influence function (B.14) gives us

$$w(x) = 2C_v\, t\, [\frac{1}{k_1} (\frac{\pi}{2} + \tan^{-1} \frac{x}{bk_1}) - \frac{1}{k_2} (\frac{\pi}{2} + \tan^{-1} \frac{x}{bk_2})] \qquad (B.28)$$

These profile functions are shown in Figure B.4; the same parameters were used as employed for the influence functions of Figure B.2. Comparing the two figures, we see that despite the large differences in the influence functions, the profile functions do not differ radically from each other. In other words, the surface displacements are quite insensitive to variations in the influence functions.

The profile functions for horizontal displacements are -- see (B.21) --

$$u(x) = t \int_0^{\infty} \frac{1}{b}\, g_H\, (\frac{x - \xi}{b})\, d\xi .$$

Using (B.23) for g_H, we obtain Knothe's profile function

$$u(x) = \frac{t\, C_H}{2\pi\, N^{3/2}} \exp[-\pi\, N\, (x/b)^2]. \qquad (B.29)$$

Substitution of (B.24) for g_H yields the elastic profile function

$$u(x) = t\, C_H \log_e \frac{(x/b)^2 + k_2^{\,2}}{(x/b)^2 + k_1^{\,2}} . \qquad (B.30)$$

The maximum horizontal displacement occurs at x=0. This is also the largest displacement attainable with any extraction geometry. For Knothe's case we have

$$u_{max} = t\, C_H \,/\, (2\pi N^{3/2}). \qquad (B.31)$$

Therefore, the subsidence factor for the horizontal displacement is

$$a_H = u_{max}/t = C_H \,/\, (2\pi\, N^{3/2}). \qquad (B.32)$$

For the elastic profile function, the maximum horizontal displacement is

$$u_{max} = 2\, C_H\, t \log_e (k_2/k_1), \qquad (B.33)$$

so that

$$a_H = 2\, C_H \log_e (k_2/k_1). \qquad (B.34)$$

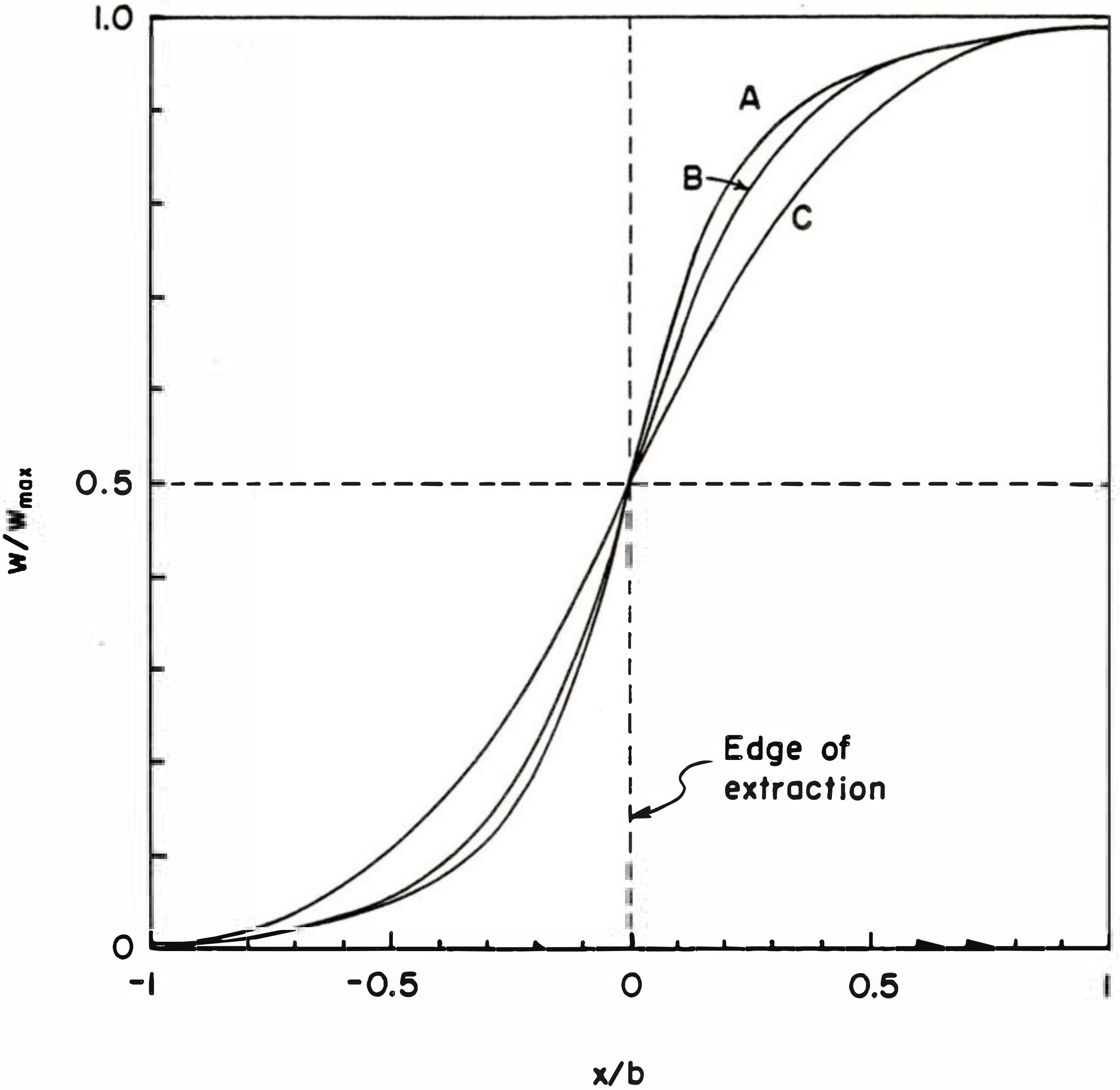


FIGURE B.4 Vertical Profile Functions for Supercritical Panel Width

Figure B.5 shows the profile functions for the horizontal displacement. The same values of N, k_1 and k_2 were used as for the vertical displacements in Figures B.2 and B.4. The corresponding influence functions (2.5b) and (2.6) are shown in Figure B.6. The amplitude of each function was normalized by computing the values of C_H from (B.31) or (B.34) using $a_H=1$, i.e. the functions are equivalent in the same sense as the vertical influence functions. The figures again illustrate the insensitivity of the displacements to variations in the influence function.

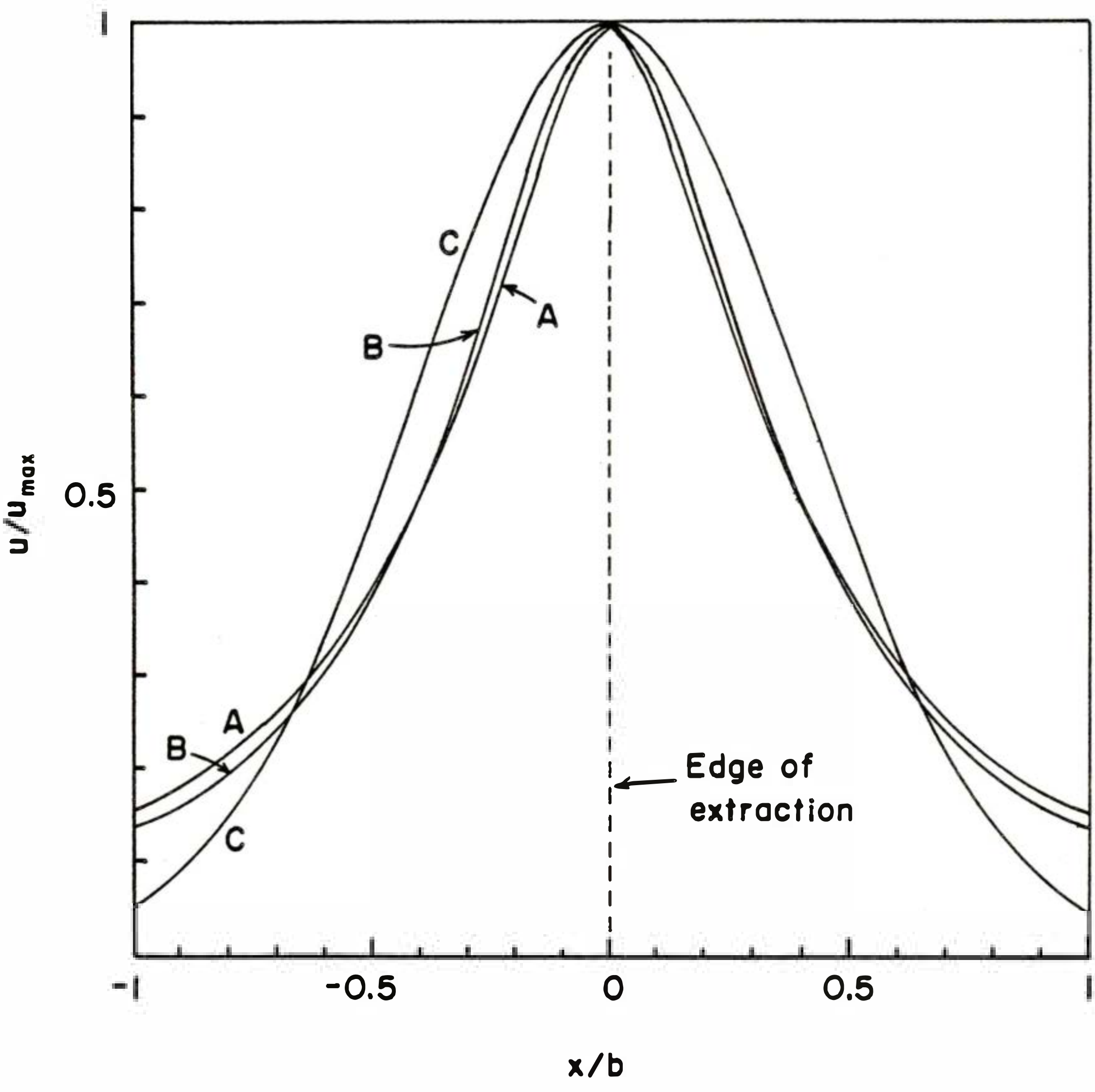


FIGURE B.5 Horizontal Profile Functions for Supercritical Panel Width

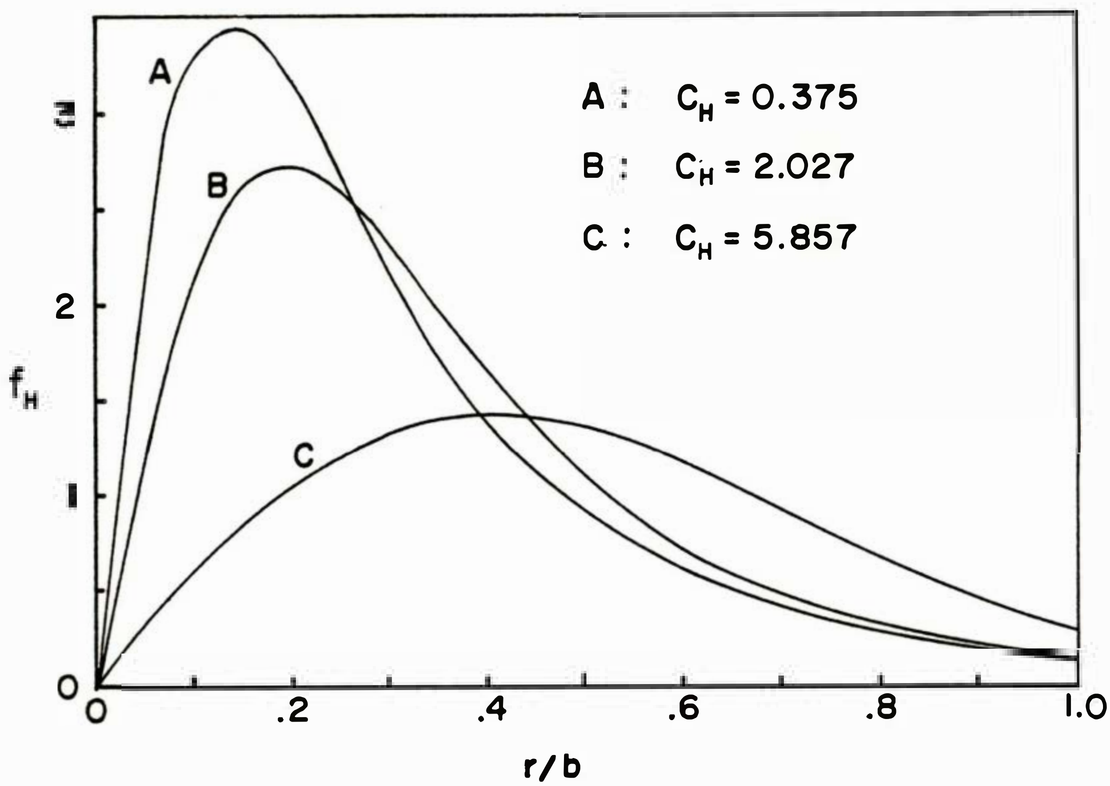


FIGURE B.6 Influence Functions for Horizontal Displacements with a_H=1 and ε=0.05

APPENDIX C: COMPUTATION OF INFLUENCE FUNCTION PARAMETERS FROM MEASURED DISPLACEMENTS

C.1 Influence Table

As pointed out in Sec. 2.2, the displacement at a surface point is obtained by summing the contribution of small extraction elements. Denoting the contribution of extraction element ΔA_k to the vertical displacement of surface point j by Δw_{jk} (see Figure C.1), we have from (2.4)

$$\Delta w_{jk} = f(r_{jk}/b)\ \Delta A_k\ t_k/b^2, \qquad (C.1)$$

where r_{jk} is the horizontal distance between points j and k, and the subscript "v" has been dropped from f. For a sloping seam a modified definition of r_{jk} is used, as explained in Figure 2.4.

It was mentioned in Sec. 4.3 that SPASID stores the influence function f(r/b) in the form of a table that contains the values of f at equally spaced intervals of r/b betweem r/b=0 and r/b=1. The influence function inbetween the tabulated values is evaluated by linear interpolation. The influence function is thus approximated by piecewise linear segments as shown in Figure C.2a. Linear interpolation within a segment (Figure C.2b) will yield

$$f(r_{jk}/b) = (m_k - 1)\ f_i + m_k\ f_{i+1}, \qquad (C.2)$$

where

$$m_k = (r_{jk}/b - r_i/b)\ /\ \Delta(r/b), \qquad (C.3)$$

f_i is the tabulated value of f at $r=r_i$ and $\Delta(r/b)$ is the interval of tabulation. The value of i, which specifies the interval of interpolation, is chosen such that $r_i < r_{jk} < r_{i+1}$. It can be shown this is equivalent to

$$i = \text{Int}\ [(r_{jk}/b)\ /\Delta(r/b)] + 1, \qquad (C.4)$$

where "Int" stands for "integral part of".

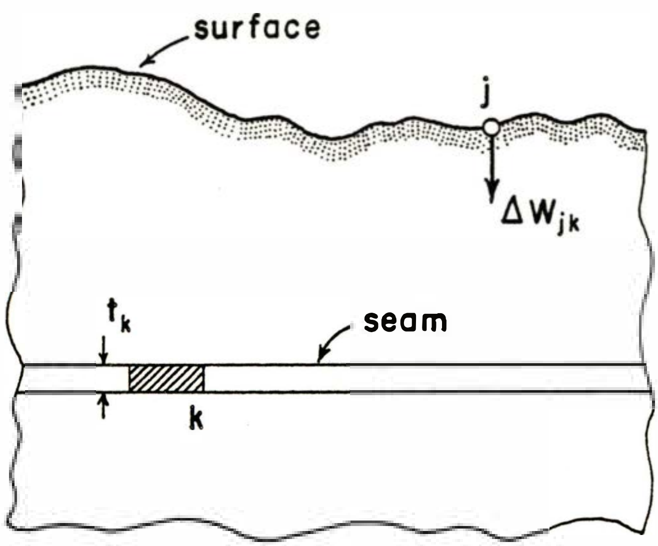
Summing the contributions of the extraction elements, we obtain for the displacement of point j

$$w_j = \sum_k \Delta w_{jk} = \sum_k\ [(1 - m_k)\ f_i + m_k\ f_{i+1}]\ \Delta A_k\ t_k/b^2. \qquad (C.5)$$

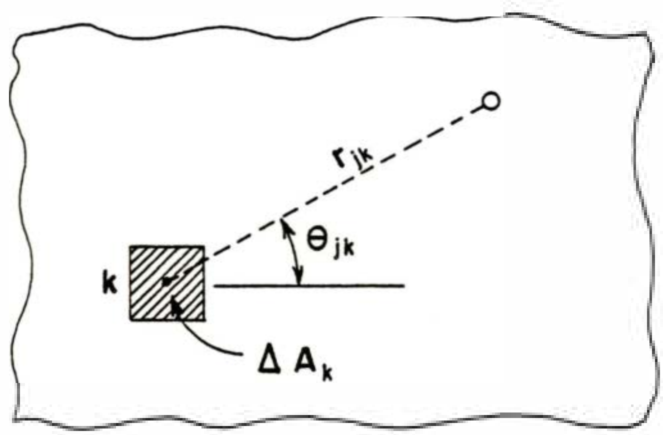
If a time lag between extraction and subsidence is of importance, (C.5) should be replaced by -- see (2.12) --

$$w_j = \sum_k \Delta w_{jk}\ [1 - \exp(-T_{jk}/\tau)]. \qquad (C.6)$$

where T_{jk} is the time difference between extraction of the element ΔA_k and the measurement of the displacement at j, and τ is the characteristic time of the site.

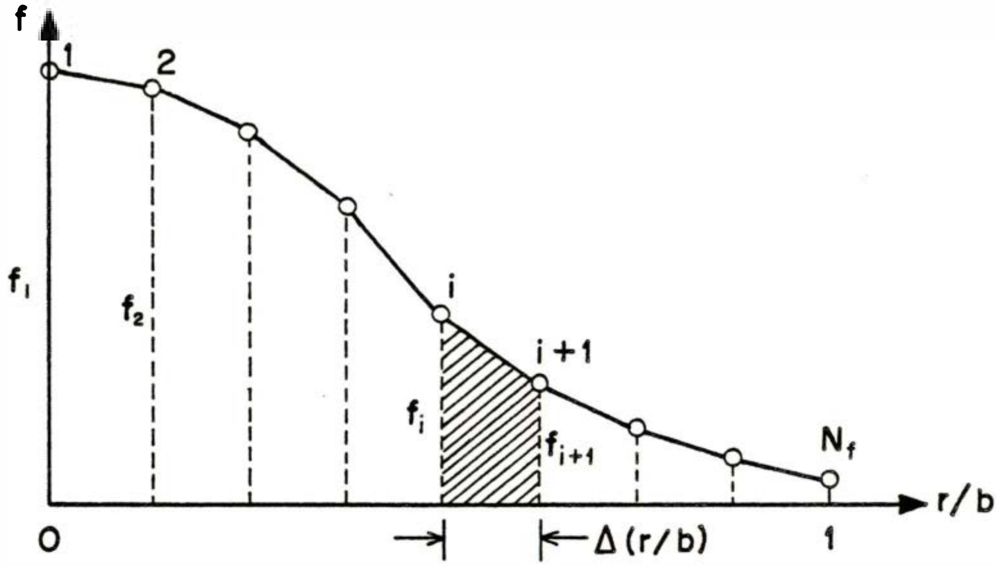


a) Profile

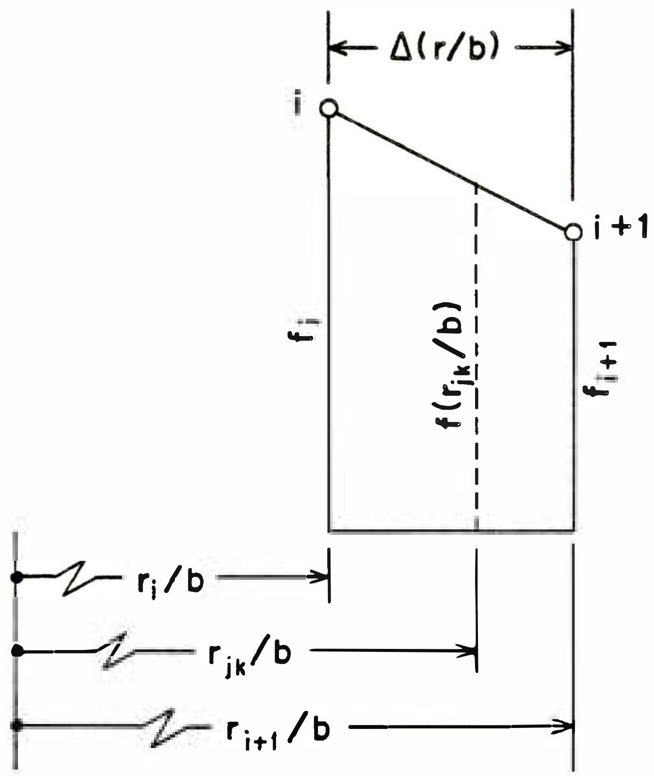


b) Plan View

FIGURE C.1 Displacement of a Surface Point Due to an Extraction Element



a) Tabulation of Influence Function



b) Interpolation Within the Shaded Panel

FIGURE C.2 Linear Interpolation of Influence Function Table

It should be recalled at this time that we are in the process of finding the influence function parameters, so that the values of f_i are still unknown. However, if the site parameters (limit angle γ, edge effect factors η_ℓ and η_t, and τ) are available, all the remaining terms in (C.5) or (C.6) can be evaluated. Therefore, w_j becomes a linear form in f_i with known coefficients:

$$w_j = \sum_i A_{ji} f_i, \tag{C.7a}$$

or, using matrix notation

$$\{w\} = [A]\{f\}. \tag{C.7b}$$

We call the coefficient matrix [A] the <u>influence table</u>. Physically, A_{ji} represents the contribution of a unit value of f_i to the displacement w_j. Thus dimensions of [A] are N_f times N_p, where N_f represents the number of entries in the influence function table, and N_p is the number of surface points where displacements are to be evaluated.

Computation of the influence table in the System Identification module of SPASID is almost identical to the calculation of surface displacements in the subsidence module. Only a few statements had to be changed in order to make the end product the influence table rather than the displacements.

C.2 Square Error and Its Gradients

The object of the System Identification module is to find the influence function parameters that minimize the root mean square (r.m.s.) error between the computed and measured displacements, w_i and w_i^*, respectively. The r.m.s. error is

$$\overline{E}(q_1,q_2,\ldots) = \sqrt{\sum_{j=1}^{N_p} (w_j - w_j^*)^2 / N_p}, \tag{C.8}$$

where q_n represent the influence function parameters. Minimizing $\overline{E}$ is equivalent to finding the values of q_n that minimize the total square error

$$E(q_1,q_2,\ldots) = \sum_{j=1}^{N_p} (w_j - w_j^*)^2. \tag{C.9}$$

Using matrix notation, (C.9) is

$$E = (\{w\} - \{w^*\})^T (\{w\} - \{w^*\}), \tag{C.9b}$$

the superscript T denoting the transpose of the matrix or vector. Thus $\{w\}$ is used to represent a column vector and $\{w\}^T$ a row vector. Substitution of (C.7b) in (C.9b) yields

$$E = ([A]\ \{f\} - \{w^*\})^T\ ([A]\ \{f\} - \{w^*\}). \tag{C.10}$$

In order to minimize (C.10), the gradients of E with respect to q_n must be calculated. Noting that only {f} in (C.10) depends on the influence function parameters, we have

$$\partial E/\partial q_n = 2([A]\ \partial\{f\}/\partial q_n)^T\ ([A]\ [f] - \{w^*\}). \tag{C.11}$$

It is convenient to introduce the notation

$$\{g_n\} = \partial\{f\}/\partial q_n, \tag{C.12}$$

$$\{b_n\} = [A]\ \ \{g_n\} \tag{C.13}$$

and

$$\{e\} = [A]\ \{f\} - \{w^*\}, \tag{C.14}$$

where {e} is the error vector containing the differences between the computed and measured displacements. Hence (C.11) can be written as

$$\partial E/\partial q_n = 2\{b_n\}^T\ \{e\} \tag{C.15}$$

The choice of the minimization algorithm is largely determined by the number of unknown variables. It turns out that the parameters C_v and N of Knothe's influence function can be found by the well-known secant method (regula falsi), whereas the elastic influence function requires a somewhat more elaborate technique known as the method of steepest descent.

C.3 Knothe's Influence Function

Knothe's influence function for vertical displacements (2.5a) yields

$$f_i = C_v\ \exp[-\pi N\ (r_i/b)^2]. \tag{C.16}$$

Letting q_1=N and q_2=C_v, we obtain

$$(g_1)_i = \partial f_i/\partial N = -\pi\ C_v(r_i/b)^2\ \exp[-\pi N\ (r_i/b)^2], \tag{C.17a}$$

$$(g_2)_i = \partial f_i/\partial C_v = \exp[-\pi N\ (r_i/b)^2]. \tag{C.17b}$$

Noting that $\{f\} = C_v\{g_2\}$, the error vector (C.14) becomes

$$\{e\} = C_v\ \{b_2\} - \{w^*\}, \tag{C.18}$$

so that (C.15) becomes

$$\partial E/\partial q_n = 2\ \{b_n\}^T\ (C_v\{b_2\} - \{w^*\}) \qquad (n=1,2). \tag{C.19}$$

When E is at its minimum value with respect to variations of C_V and N, then $\partial E/\partial q_n=0$, n=1,2. This results in two nonlinear equations

$$\{b_n\}^T (C_v \{b_2\} - \{w^*\}) = 0 \qquad (n=1,2). \qquad (C.20)$$

Solving both equations for C_v yields

$$C_v = (\{b_n\}^T \{w^*\}) / (\{b_n\}^T \{b_2\}) \qquad (n=1,2). \qquad (C.21)$$

Since both equations must result in the same value of C_V, (C.21) is equivalent to

$$H(N) = \frac{\{b_1\}^T \{w^*\}}{\{b_1\}^T \{b_2\}} - \frac{\{b_2\}^T \{w^*\}}{\{b_2\}^T \{b_2\}} = 0. \qquad (C.22)$$

It should be noted that $\{b_2\}$ is independent of C_v, whereas $\{b_1\}$ is proportional to C_V. Consequently, C_V cancels in the denominator and numerator of the first term in (C.22), so that the equation contains only one unknown, namely N. Once N has been obtained by solving (C.22), C_V may be computed from (C.21) using either n=1 or n=2.

The secant method [7] is ideally suited for solving a nonlinear equation of the type represented by (C.22). A simplified flow diagram of the algorithm used in SPASID is shown in Figure C.3. Before the algorithm can be implemented, the influence table [A] must be calculated and two starting values, N_I and N_{II}, must be determined. The latter is accomplished by computing H(N) at equal intervals of N until a change of sign is detected. The last two values of N are then chosen as N_I and N_{II}. The computation of H(N) is straightforward:

(i) Calculate $\{g_1\}$ and $\{g_2\}$ from (C.17). Since the value of C_V is irrelevant, $C_V=1$ may be used.
(ii) Compute $\{b_1\}$ and $\{b_2\}$ using (C.13)
(iii) Compute H(N) from (C.22).

The r.m.s. error between computed and predicted displacements may be obtained by first calculating the error vector (C.18) and then utilizing (C.8), which is

$$\bar{E} = \sqrt{\{e\}^T \{e\}/N_p} \qquad (C.23)$$

After C_V and N have been determined by the procedure described above, the parameter C_H in the horizontal influence function (2.5b) can be calculated from an equation analagous to (C.21), namely

$$C_H = (\{b_n\}^T \{u^*\}) / (\{b_n\}^T \{b_2\}) \qquad (n=1,2) \qquad (C.24)$$

where $\{u^*\}$ now contains the measured horizontal displacements, and $\{b_n\}$ are obtained from (C.11 - C.12) by using [A] and $\{g_n\}$ for the horizontal displacements. As in the case of vertical displacements, time lag, edge effects and modifications for sloping seams are taken care of in the computation of the influence function table [A].

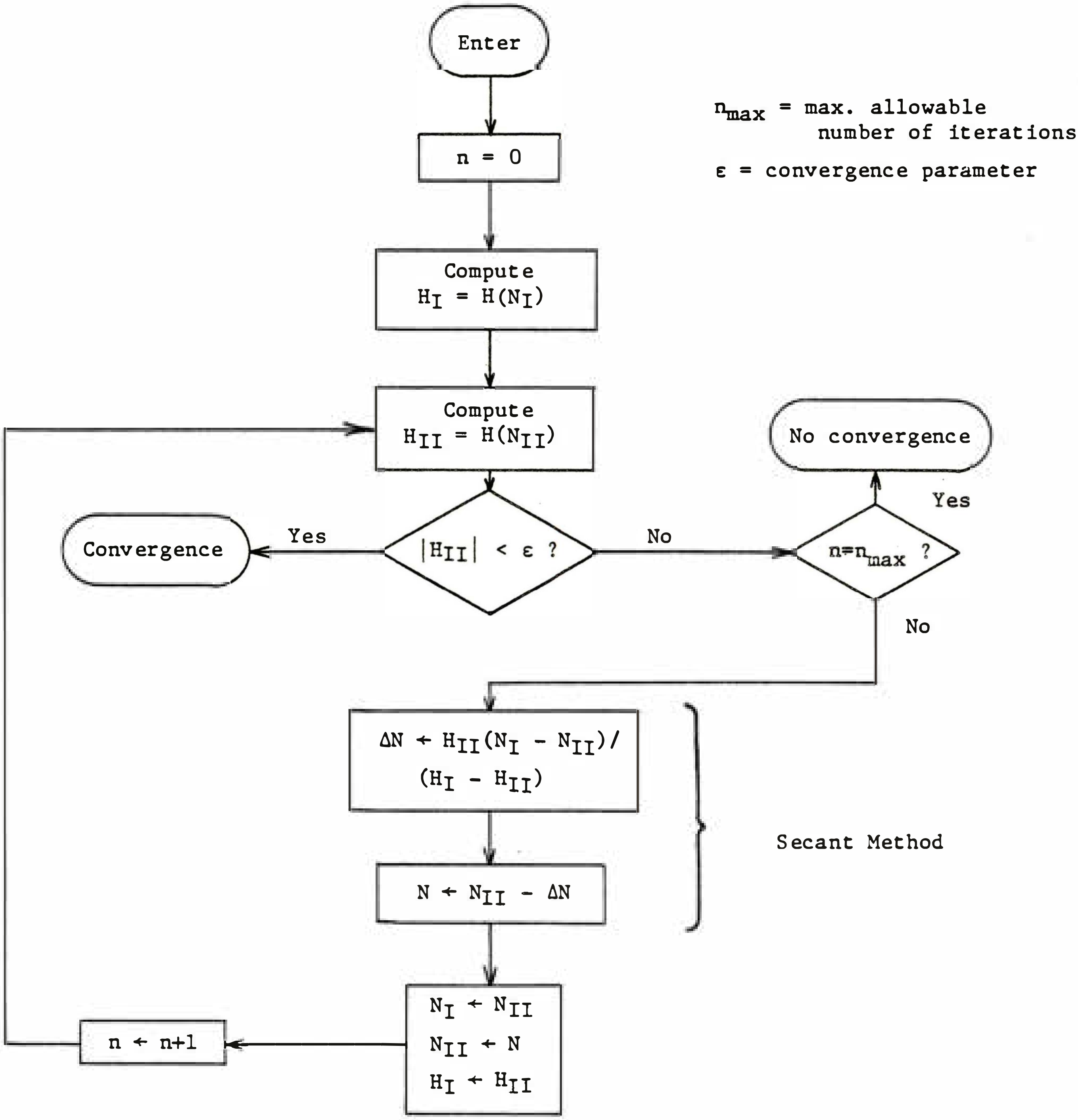


FIGURE C.3 Flow Diagram for Secant Method

C.4 Elastic Influence Function

From the influence function for the vertical displacements (2.6-2.7) we get

$$f_i = C_v \{[(r_i/b)^2 + k_1^2]^{-3/2} - [(r_i/b)^2 + k_2^2]^{-3/2}\}. \quad \text{(C.25)}$$

With $q_1=k_1$, $q_2=k_2$ and $q_3=C_v$, equations (C.12) become

$$(g_1)_i = \partial f_i/\partial k_1 = -3\ C_v k_1\ [(r_i/b)^2 + k_1^2]^{-5/2}, \quad \text{(C.26a)}$$

$$(g_2)_i = \partial f_i/\partial k_2 = 3\ C_v k_2\ [(r_i/b)^2 + k_2^2]^{-5/2}, \quad \text{(C.26b)}$$

$$(g_3)_i = \partial f_i/\partial C_v = f_i/C_v. \quad \text{(C.26c)}$$

The error vector (C.14) can now be written with the aid of (C.12-C.13) as

$$\{e\} = C_v\{b_3\} - \{w^*\}, \quad \text{(C.27)}$$

and the gradients (C.15) of the total square error take the same form as for Knothe's case:

$$\partial E/\partial q_n = 2\ \{b_n\}^T\ (C_v\ \{b_3\} - \{w^*\}) \quad (n=1,2,3). \quad \text{(C.28a)}$$

Solving (C.28) with n=3 for C_v yields

$$C_v = (\{b_3\}^T\ \{w^*\})\ /\ (\{b_3\}^T\ \{b_3\}). \quad \text{(C.28b)}$$

Since $\{b_3\}$ does not contain C_v, (C.28) can be used to compute the optimal value of C_v for any combination of k_1 and k_2. In other words, the total square error (C.10)

$$E(k_1,k_2) = \{e\}^T\ \{e\}, \quad \text{(C.29)}$$

where $\{e\}$ is given by (C.27), can now be considered to be a function of k_1 and k_2 only. The problem has thus been reduced to finding k_1 and k_2 that minimize E.

Because E is a function of more than one variable, the use of the secant method and similar techniques is no longer practical (we tried a few of these methods, but the convergence was extremely slow or absent altogether). The algorithm that worked best was a direct minimization procedure known as the method of steepest descent.

The method of steepest descent is outlined in Figure C.4. The drawing shows the contour map of the E-surface in the $k_1 - k_2$ plane. The search for the lowest point on the surface starts from some initial point, such as 0. The slopes of the surface at 0, obtainable from (C.28), are then used to find the direction of the steepest descent (downward slope). Next we "move" in the direction of steepest descent until we reach the lowest point on the path, represented by P. At this point the slopes of the surface are recomputed, and the whole process is repeated. This procedure is continued until no further descent is possible. The method thus consists of a series of moves in the $k_1 - k_2$ plane, each move involving two basic steps: establishing the direction of the move and computation of the move length, Δk.

The negative gradients of the E-surface are denoted by

$$G_n = - \partial E/\partial k_n \qquad (n=1,2). \tag{C.30}$$

where $\partial E/\partial k_n$ can be computed for any combination of k_1 and k_2 from (C.28). Using the notation

$$G = \sqrt{G_1^2 + G_2^2} \tag{C.31}$$

and referring to Figure C.5a, we see that the direction of the move is specified by $\Delta k_n/\Delta k = G_n/G$, or

$$\Delta k_n = \Delta k \, (G_n/G) \qquad (n=1,2), \tag{C.32}$$

where the move length Δk is presently unknown.

The computation of Δk consists of two distinct parts. The first part establishes an upper limit b on the move length:

$$0 \leq \Delta k < b,$$

whereas the second part finds the value of Δk in the interval (0,b) by a systematic search procedure.

Recalling that the end-point P of the move (see Figure C.5) is the lowest point on the path, we can detect its presence by sampling E at equal intervals along the path until an increase in E takes place. This procedure has been illustrated in Figure C.5b. The search interval δ is initially prescribed by the user (parameter "movelength" in Sec. 7.4 under &VELAST). In the example shown in Figure C.5b, the search is concluded at point B, when $E_B > E_C$. The search is also terminated with an error message when the value of b becomes too large: $b > \beta$, where β is the parameter "moveLim" described in Sec. 7.4.

A typical step in the second part of the procedure is illustrated in Figure C.6. The end-point P of the move is known to be in the interval $a < \Delta k < b$ (this interval was initially established by the upper limit search described above), and it is now necessary to reduce this interval

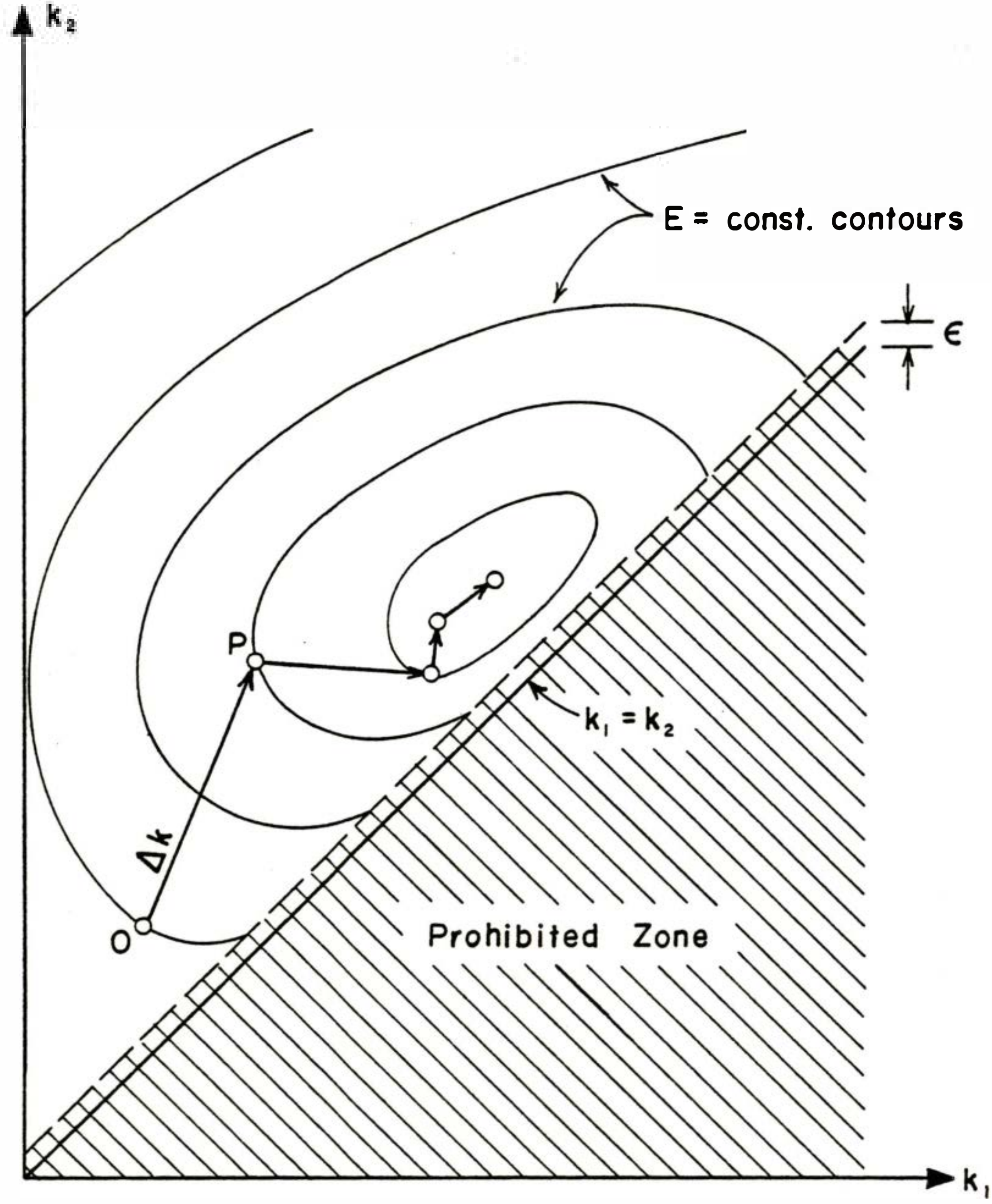
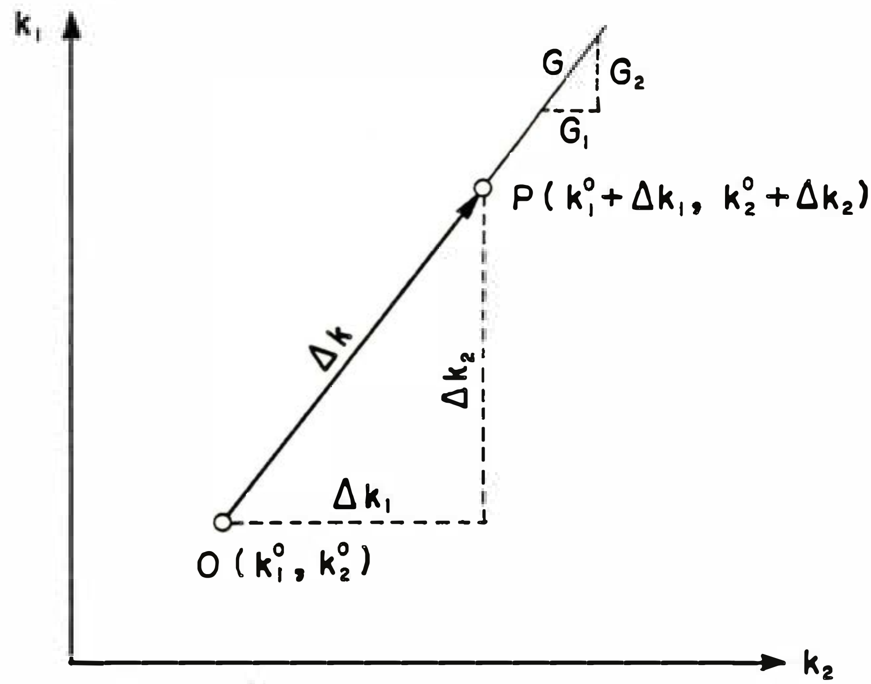
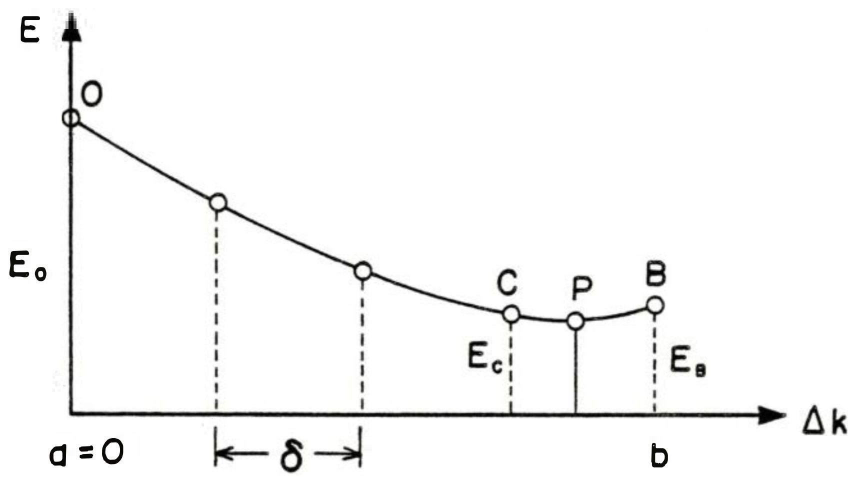


FIGURE C.4 Method of Steepest Descent



a) View of $k_1 - k_2$ Plane



b) Profile Along Path OP

FIGURE C.5 Search for Upper Limit

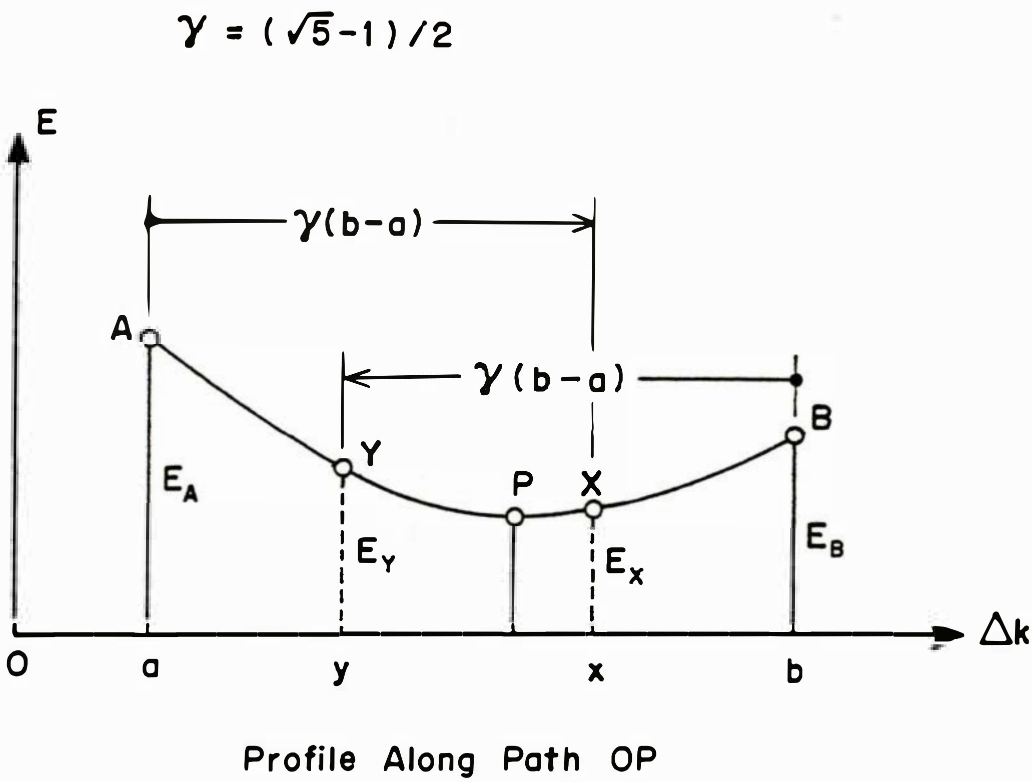


FIGURE C.6 Golden Section Search for P

further. This can be accomplished by computing E at two points X and Y, located at

$$x = a + \gamma(b - a), \qquad (C.33a)$$

$$y = b - \gamma(b - a), \qquad (C.33b)$$

where $\gamma = (\sqrt{5} - 1)/2$ is the Golden Section ratio of classical Greece. It is a solution of the equation

$$\gamma^2 = (1 - \gamma).$$

If $E_X > E_Y$, then P must lie inside AX, i.e. in the interval $a < \Delta k < x$. If on the other hand $E_X \leq E_Y$, the interval is reduced to $y < \Delta k < b$. This process is repeated until the interval has been diminished to

$$b - a < \varepsilon/2,$$

where ε is a user-prescribed parameter (parameter "epsilon" in Sec. 7.4). The move length is then obtained from

$$\Delta k = (a + b)/2,$$

and the changes in k_1 and k_2 are computed from (C.32). This completes one move in the $k_1 - k_2$ plane. Incidentally, the search interval δ used in the upper limit search is replaced by Δk during the next move.

Moves in the $k_1 - k_2$ plane are continued until the gradient of the E-surface or the move length becomes very small, i.e.

$$G < \varepsilon^2,$$

or

$$\Delta k < \varepsilon.$$

Termination with an error message is produced when the number of moves exceeds a user-prescribed limit, "nbrItern" of Sec. 7.4.

The algorithms described are illustrated by flow diagrams in Figures C.7 and C.8. The diagrams omit the procedure used in keeping the moves out of the prohibited zone $k_1 > k_2$: any move that had a tendency to enter this zone was simply terminated at the boundary of the shaded region $k_2 = k_1 + \varepsilon$ (see Figure C.4).

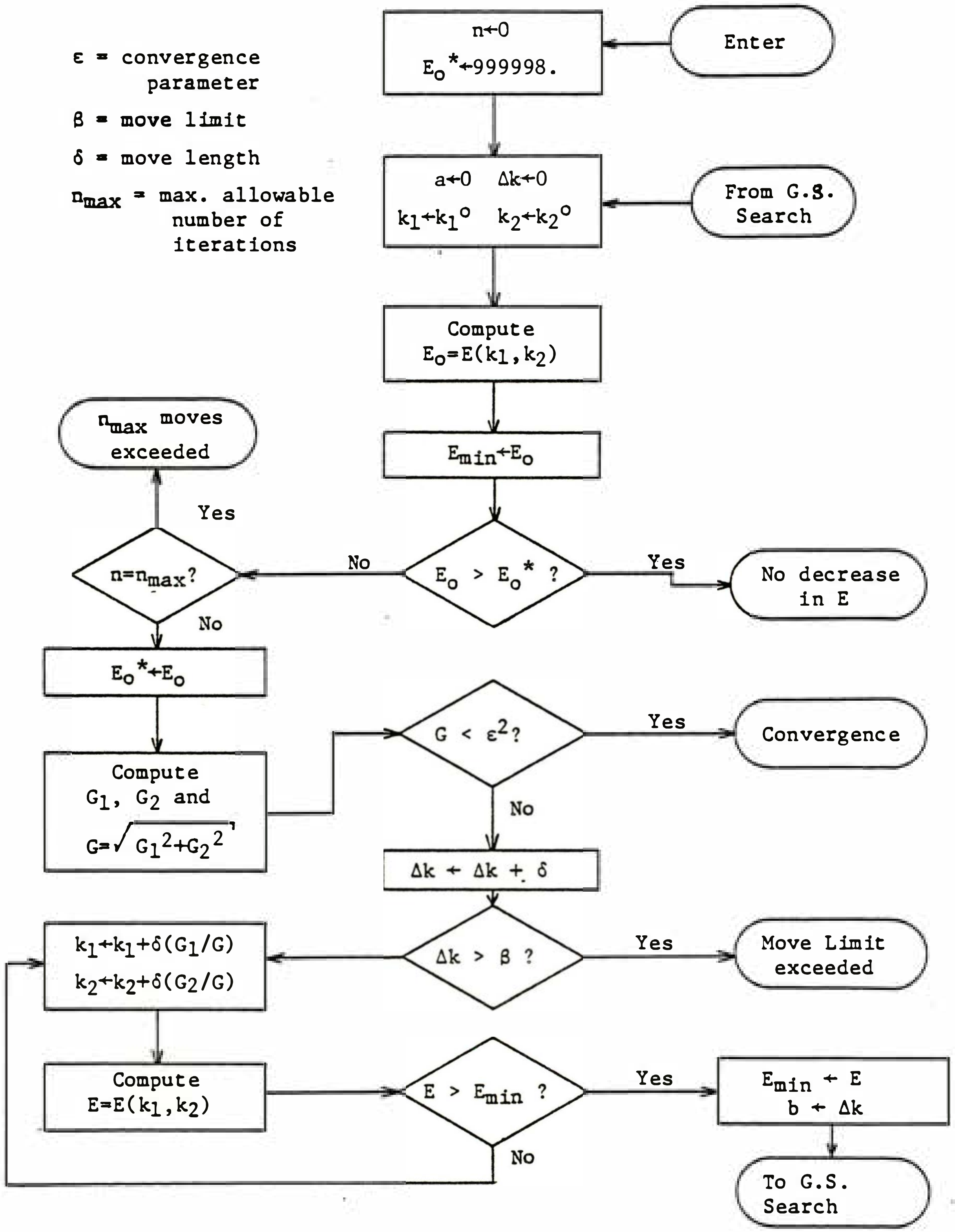


FIGURE C.7 Flow Diagram for Upper Limit Search

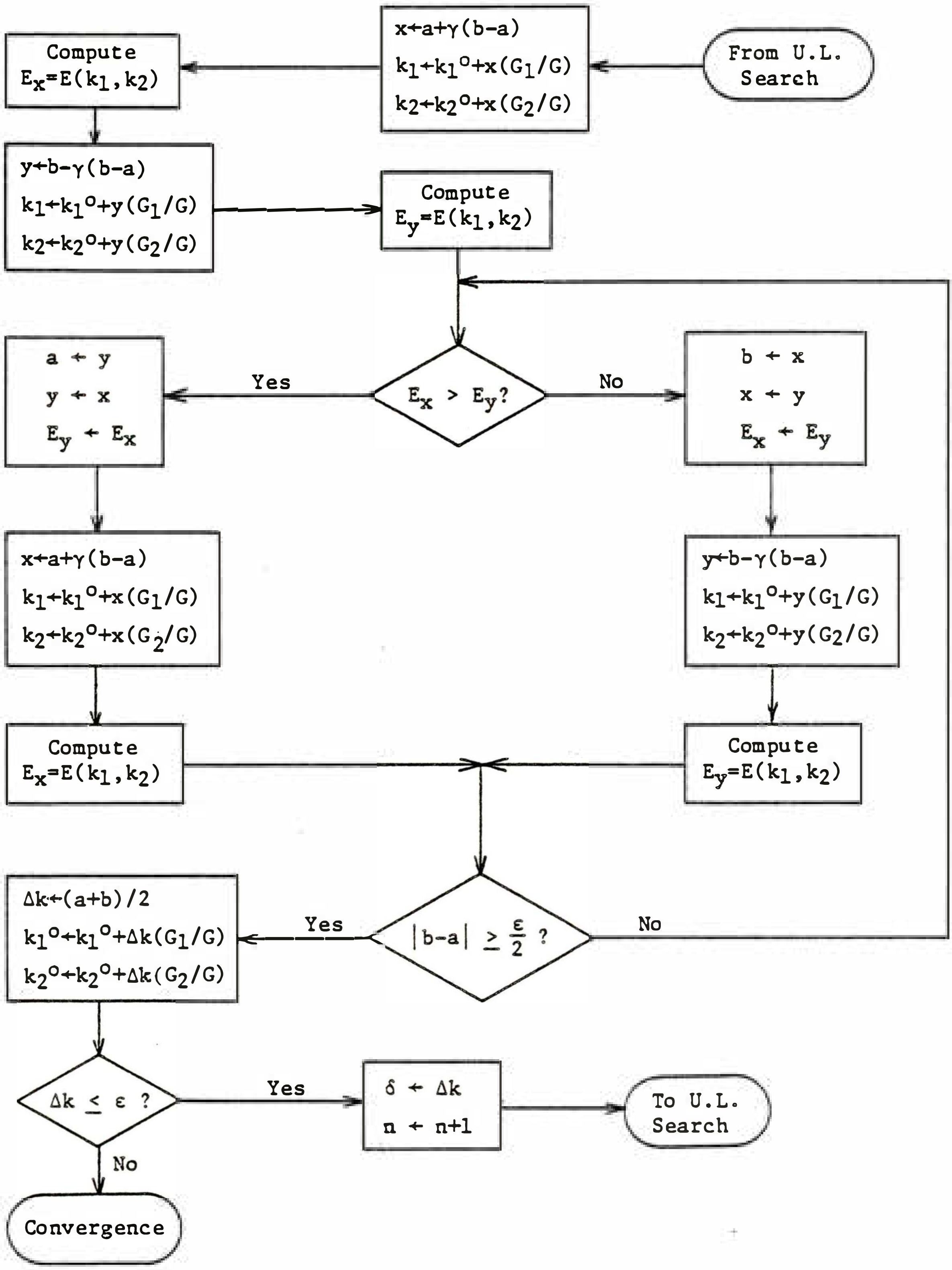


FIGURE C.8 Flow Diagram for Golden Section Search

C.5 Postscript

It might appear to the casual observer that the influence functions could be obtained from measured displacements without any prior assumptions regarding the form of these functions (e.g., exponential). In fact, we expended considerable effort during the initial stages of the project on such endeavor, encouraged by a previous publication on the subject [10]. It turned out that although the problem is easy to program, the results, i.e. the computed influence functions, are of no practical use. The cause of the trouble is the extreme sensitivity of the computed influence function to small changes in the displacements, as demonstrated in Appendix B.

Some results of the numerical experiments that we carried out are shown in Figure C.9. We started computing vertical displacements of the surface from Knothe's influence function (curve I). Then we reversed the procedure: the displacements became the input and the influence function was calculated. The result was a perfect fit of the original function (curveI), proving that our algorithm worked. The next step involved the addition of random numbers to the originally calculated displacements. The amplitude of these numbers was confined to within 5% of the maximum displacement. The resulting influence function, curve II of Figure C.9, was found to be in error by as much as 135%. In other words, the small perturbations on the displacements become magnified in the influence function by a factor of 27.

The results cannot be blamed on the algorithm used for computing the influence function. On the contrary, the algorithm worked too well: when the influence function (curve II) was used to compute the displacements, the latter were reproduced almost perfectly, random errors and all. The foregoing results clearly imply that some smoothing constraints must be imposed on the influence function prior to its computation. Expressing the influence function in the form of a prescribed function with unknown parameters, as was done in SPASID, is the easiest and perhaps the most effective way of accomplishing this. Regrettably, Ref. [10] does not explain how the smoothness of the influence functions displayed in that publication was achieved.

Since the 5% errors used in the example are well below the errors expected in field measurements, it is obvious that smoothing is an essential part of any algorithm used for computation of influence functions. The method employed in SPASID has the added advantage that the measured vertical subsidence not only completely determined the vertical influence function, but also the shape of the horizontal influence function. Therefore, only a few (minimum of one) horizontal displacements readings are required to compute the amplitude parameter C_H. This is a significant practical asset of the program, because horizontal displacements are apparently seldom measured in practice.

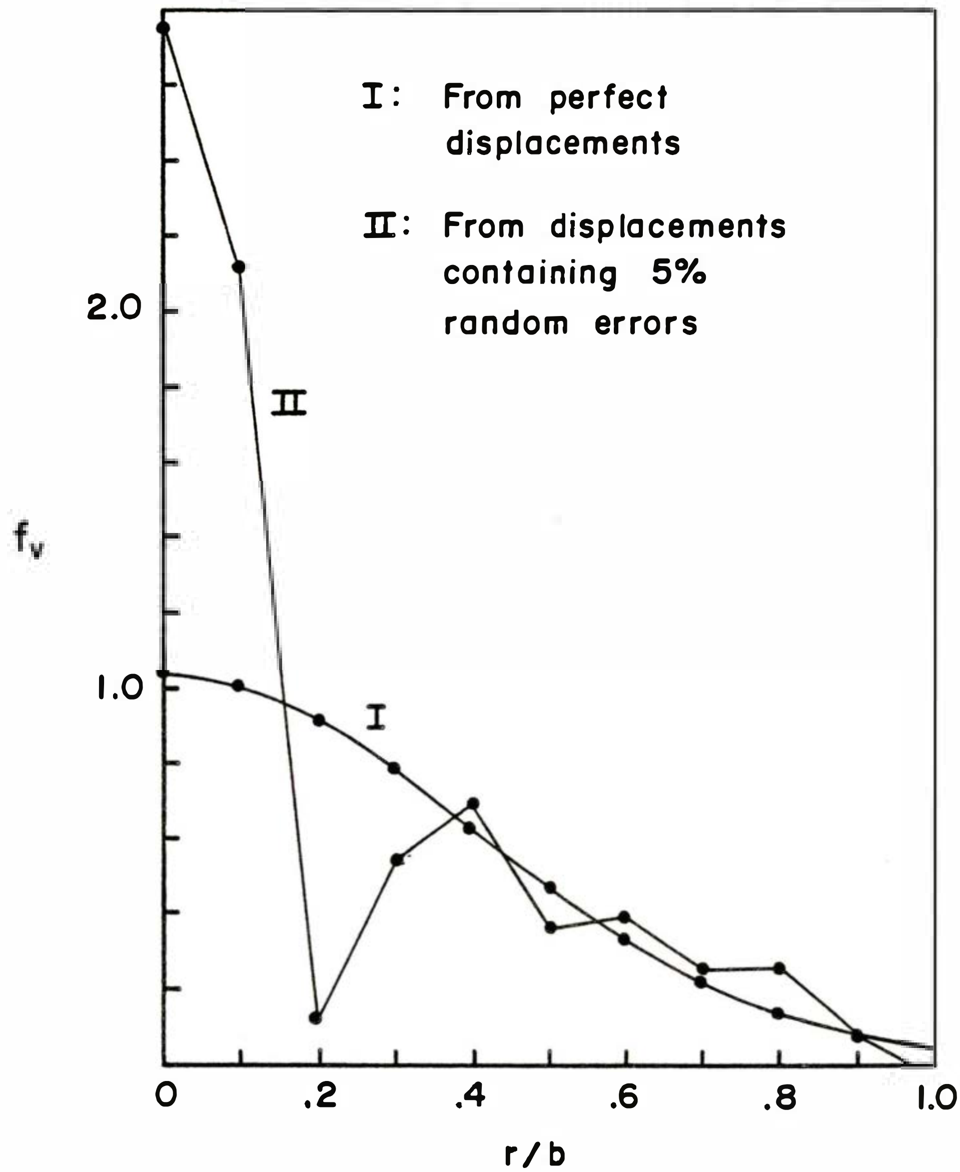


FIGURE C.9 Influence Functions Computed from Vertical Displacements Without Prior Restrictions on Shape

APPENDIX D: EXAMPLE PROBLEM

D.1 Description of the Problem

The example presented is meant to serve a twofold purpose: to familiarize the potential user with the input/output of the program and to instill confidence in its capabilities. Since we did not have reliable data from an actual site, the example deals with a single hypothetical longwall panel shown in Figure D.1. Profile functions used by the National Coal Board of U.K. [4] were substituted for measured surface displacements.

The complete example required three runs of SPASID using the batch mode. The printed output of each run has been reproduced in Section D.5. The Preprocessor was employed in the first run to establish the data base (Mine and Surface Grids). The second run, using the System Identification Module, calculated the influence function parameters and the width factor of the edge effect (the elastic influence function was chosen arbitrarily). The Subsidence Module was run last in order to compare the displacements computed from the influence functions with the "experimental" data, i.e. the National Coal Board profile functions.

D.2 Preprocessor Run

Since the surface of the site is flat and the seam is level, the Field Data -- see &INPUT in Section D.5 -- consisted of only nine points (six points would have been the minimum allowable number) located at points shown in Figure D.1.b.

The mine panel was modelled with a 9 x 15 grid, the grid lines being 40 m. apart. In order to check the generated mine data, a profile of the mine along the line AB was printed out with the task &PRTMINE. The height of cut and the extraction schedule were specified next, using &CHGCUT and &CHGDATES, respectively. It was assumed that the panel is fully extracted in 360 days at a constant rate of face advance. The task &PRTDATES displayed the generated extraction schedule.

Two Surface Grids were generated, both being located along AB. The first of these, generated by &GENPOINTS, is a Type 2 grid (collection of points) that will be used in the System Identification Module. The locations of the grid points are not evenly spaced along AB, but coincide with the tabulated data points in [4], i.e. the hypothetical monuments. The second grid, consisting of eleven equidistant points, was generated with &GENSURFACE. This grid will be used for the computation of displacements with the Subsidence Module.

Note that it is necessary to save the data base with &TERMINATE before logging off.

D.3 System Identification Run

The computation of the influence function parameters consisted of two parts. The first part determined the parameters k_1, k_2, C_v and η_ℓ (width factor of the edge effect) from the vertical displacements tabulated in [4]. The twelve points of surface grid #1, generated by the Preprocessor, were used for data input. The locations of the points and the corresponding displacements are automatically printed by the input routine &DISPL (see Sec. D.5). These points are also shown on the plot of the "experimental" subsidence profile in Figure D.2.

In order to obtain an estimate of the best value of η_ℓ, the parameter computation task &VELAST was run with three different values: η_ℓ=0.24, 0.28 and 0.32. Actually it was known beforehand from the data in [4] that the correct value is 0.28, but we wanted to demonstrate how the program can be used to determine η_ℓ. As in Reference [4], we assumed the time lag effect to be absent. The printout clearly demonstrates how strongly the results depend on the edge effect. With η_ℓ=0.28 the r.m.s. error between the "measured" displacements and those computed with the best values of k_1, k_2 and C_v is about, 2.5 times smaller than for the other two values of η_ℓ. Also note how SPASID automatically stores the best values of the parameters for use in the task &HELAST.

Default values of γ=55 degrees (limit angle) and η_t=0 (subsidence factor of the edge effect) were used for the remaining two site parameters. As pointed out in the main body of the report, the subsidence model is quite insensitive to the values of these parameters. If the limit angle of the site is entirely unknown, an estimate on the small side should be made. After the System Identification Module has determined k_1 and k_2, the initial estimate of γ can be checked using (B.13), or (B.11) if Knothe's influence function is used. Using the values of k_1 and k_2 obtained for our current problem, (B.13) yields ε=0.0294, which is on the conservative side if ε=0.05 is taken as the "normal" value. In other words, it seems that γ could have been taken as 60 or even 65 degrees without appreciable ill effects.

The subsidence factor of the site can be obtained (B.8). Substituting the influence function parameters obtained by SPASID we get a_v=0.920.

The second part of the System Identification run computed the value of C_H in the influence function for the horizontal displacements using &HELAST. Note that C_H specifies the amplitude of the function only; its shape was already determined when k_1 and k_2 were computed in the first part. The "measured" displacements at only three points of surface grid #1 were used -- see Figure D.3a and the printout obtained from &DISPL -- in an attempt to simulate the scarcity of horizontal displacement measurements at a typical site. Using the result C_H=0.2490 in (B.31) yields the horizontal subsidence factor of a_H=0.173.

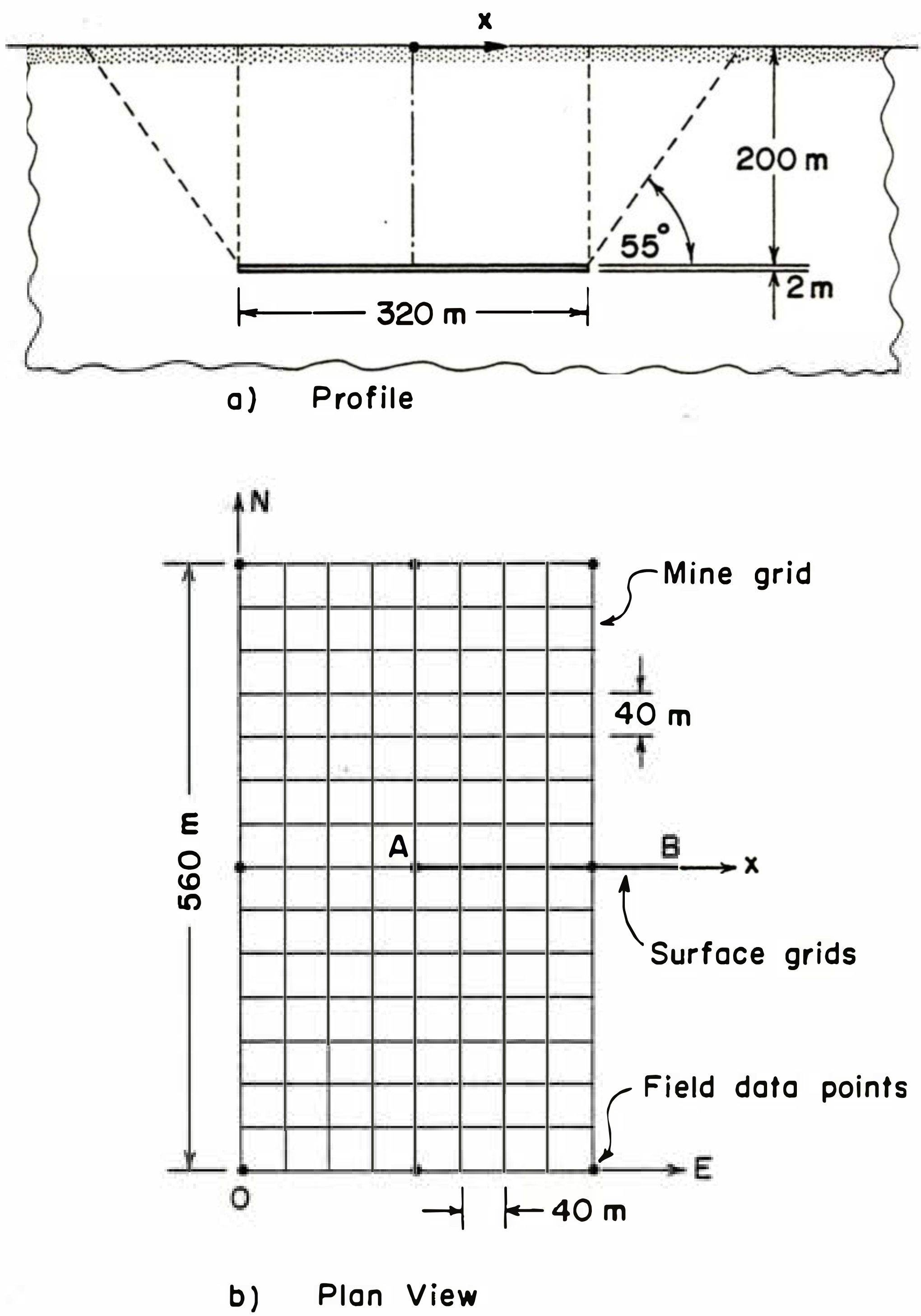


FIGURE D.1 Hypothetical Longwall Panel
Used With Coal Board Data

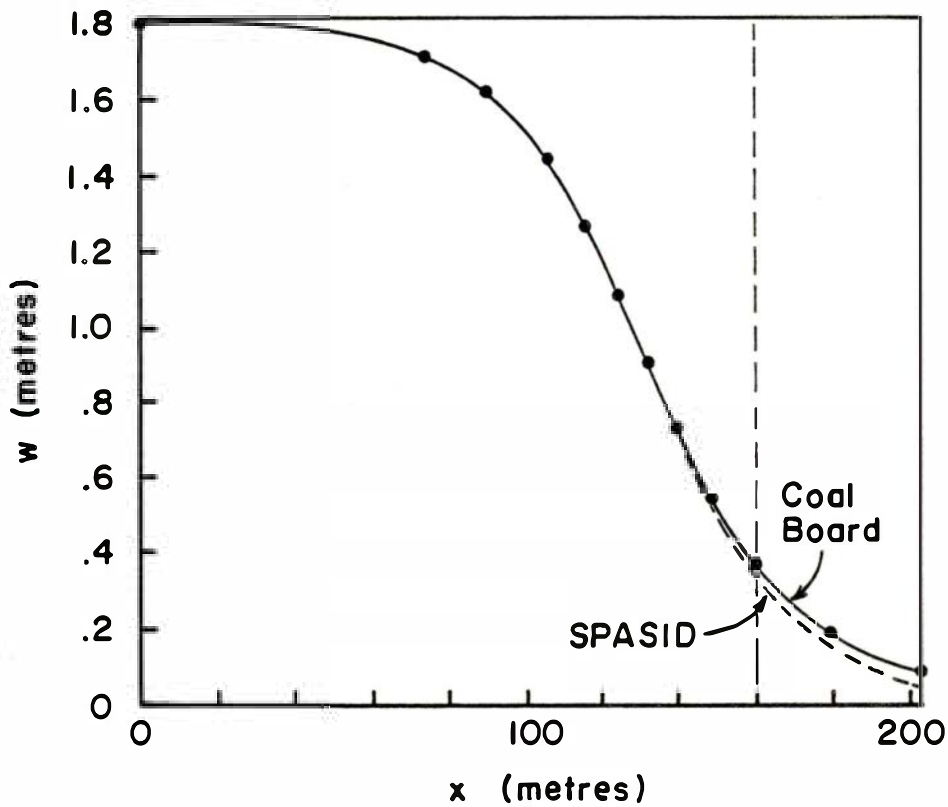


FIGURE D.2 Comparison of Vertical Displacement (Circles Denote Points Used In System Identification)

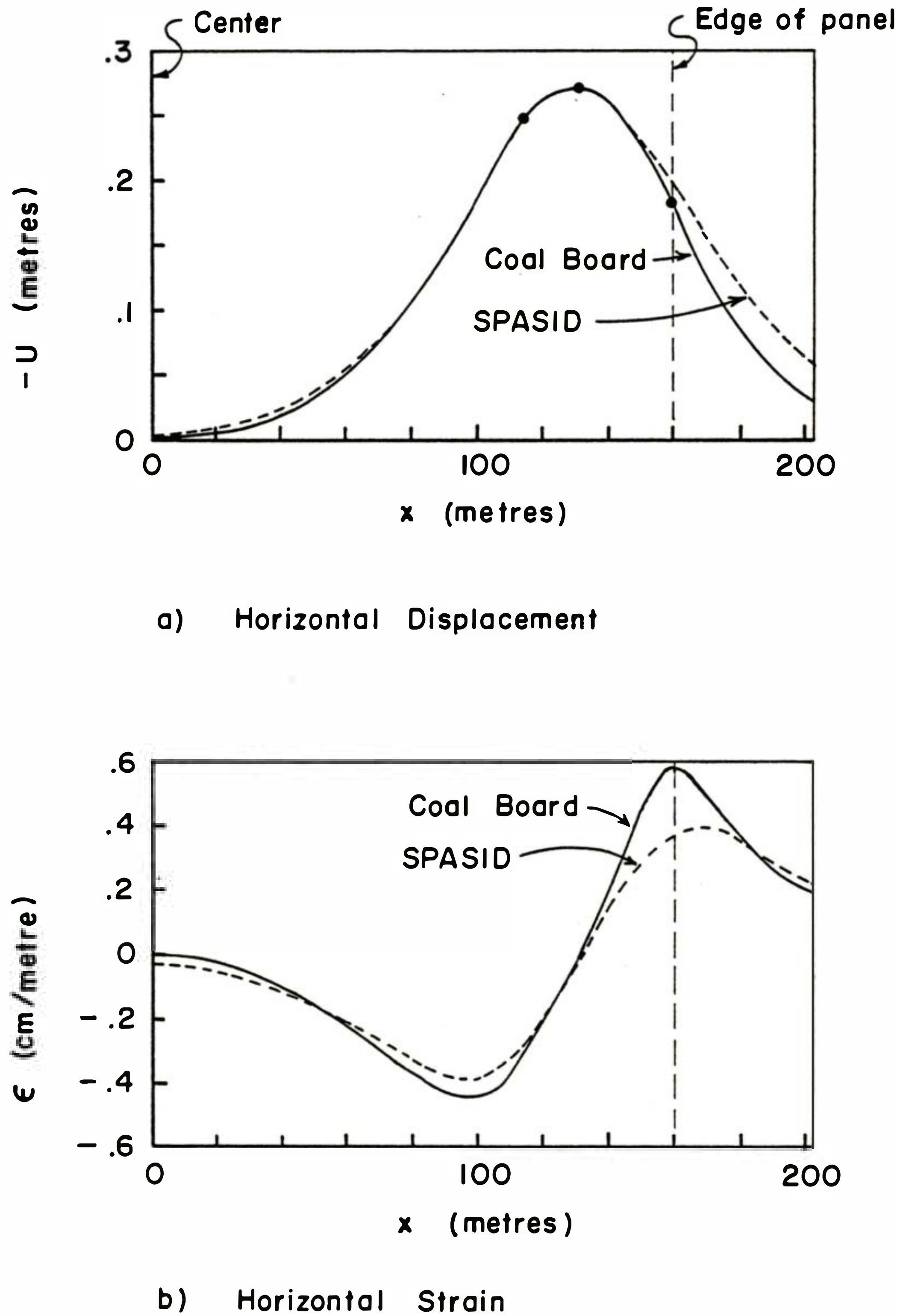


FIGURE D.3 Comparison of Horizontal Displacement and Strain. (Circles Denote Points Used in System Identification)

It should be mentioned that Reference [4] contains tables of horizontal strain, not horizontal displacement. The displacement profile in Figure D.3a was obtained by numerically integrating the strain profile.

D.4 Subsidence Module Run

The primary purpose of this run was to verify the results obtained by the System Identification Module by comparing the displacements computed from the influence functions against the "experimental" results of Reference [4]. After loading the data base &LOAD tables of the vertical and horizontal influence functions were generated with &ELASTICITY. Twenty-one table entries were requested, and the function parameters calculated by the System Indentification Module were used. The site parameters were read in next with &RDPARAMS.

This was followed by the computation of displacements (&CMPSUBS) and printout of the results (&PRTDISPL). The calculated displacements have also been plotted in Figures D.2 and D.3a. As can be seen, the results compare well with the data of Ref. [4]. Particularly remarkable is the agreement in the horizontal displacements considering that the shape of the calculated profile was determined by the vertical displacements, i.e. an autonomous influence function was not employed for the horizontal displacements.

The horizontal strain profiles are also shown in Figure D.3b. The SPASID results were obtained by numerical differentiation of the horizontal displacements. As expected, the agreement is not as good as for the displacements. The most noticeable discrepancy is confined to a region over the edge of the panel, where the data of Reference [4] displays a sharp peak. It is doubtful that any influence function is capable of reproducing such an anomaly.

We have repeated the computation using Knothe's influence function and found that the results are essentially the same. This seems to indicate that the choice of the influence function is not crucial, but we lack sufficient experience to make this into a general rule. At this time we recommend the elastic influence function because it contains an extra parameter, which endows the function with greater shape flexibility (see Section B.1 for a discussion of this point).

D.5 Listing of Output

The output listings for the Preprocessor, the System Identification Module, and the Subsidence Module follow.

PREPROCESSOR RUN

```
&INPUT
NUMP=9;
'FORM=(5F5.0);
DATAID=1,2,6,4,3;
&
```

--- TASK &INPUT HAS BEEN COMPLETED ---

```
&PRTINPUT
&
```

	COORDS OF DATA POINTS E	N	SURFACE ELEVATION	SEAM THICKNESS	SEAM BOTTOM ELEVATION	DEPTH OF COVER
1	0.0	0.0	0.0	2.00	-202.00	200.00
2	0.0	280.00	0.0	2.00	-202.00	200.00
3	0.0	560.00	0.0	2.00	-202.00	200.00
4	160.00	0.0	0.0	2.00	-202.00	200.00
5	160.00	280.00	0.0	2.00	-202.00	200.00
6	160.00	560.00	0.0	2.00	-202.00	200.00
7	320.00	0.0	0.0	2.00	-202.00	200.00
8	320.00	280.00	0.0	2.00	-202.00	200.00
9	320.00	560.00	0.0	2.00	-202.00	200.00

--- TASK &PRTINPUT HAS BEEN COMPLETED ---

```
&GENMINE
ORIG=0,0;
AZIM=0;
EGRID=9@40;
NGRID=15@40;
&
```

--- TASK &GENMINE HAS BEEN COMPLETED ---

```
&PRTMINE                                                                        00002450
NRANGE=8;                                                                       00002500
'TITLE=CROSS SECTION ALONG X-AXIS;                                              00002550
&                                                                               00002600
```

CROSS SECTION ALONG X-AXIS

GRID LOCN E	GRID LOCN N	COORDS OF GRID POINT E	COORDS OF GRID POINT N	SEAM THICKNESS	SEAM BOTT ELEVATION	DEPTH OF COVER
1	8	0.0	280.00	2.00	-202.00	200.00
2	8	40.00	280.00	2.00	-202.00	200.00
3	8	80.00	280.00	2.00	-202.00	200.00
4	8	120.00	280.00	2.00	-202.00	200.00
5	8	160.00	280.00	2.00	-202.00	200.00
6	8	200.00	280.00	2.00	-202.00	200.00
7	8	240.00	280.00	2.00	-202.00	200.00
8	8	280.00	280.00	2.00	-202.00	200.00
9	8	320.00	280.00	2.00	-202.00	200.00

--- MINE GRID NUMBER 1 ---

--- TASK &PRTMINE HAS BEEN COMPLETED ---

```
&CHGCUT                                                                         00002650
CUTHEIGHT=1,2;                                                                  00002700
&                                                                               00002750
```

--- TASK &CHGCUT HAS BEEN COMPLETED ---

```
&GENSURFACE                                                  00003700
ORIG=160,280;                                                00003750
AZIM=90;                                                     00003760
EGRID=1;                                                     00003770
NGRID=11820;                                                 00003780
&                                                            00003850
```

--- TASK &GENSURF HAS BEEN COMPLETED ---

```
&PRTSURF                                                     00003900
'TITLE=LOCATIONS OF POINTS FOR COMPUTED DISPLACEMENTS;       00003910
&                                                            00003950
```

LOCATIONS OF POINTS FOR COMPUTED DISPLACEMENTS

GRID LOCN E	GRID LOCN N	COORDS OF GRID POINT E	COORDS OF GRID POINT N	SURFACE ELEVATION	SEAM THICKNESS	SEAM BOTT ELEVATION	DEPTH OF COVER
1	1	160.00	280.00	0.0	**********	**********	**********
1	2	180.00	280.00	0.0	**********	**********	**********
1	3	200.00	280.00	0.0	**********	**********	**********
1	4	220.00	280.00	0.0	**********	**********	**********
1	5	240.00	280.00	0.0	**********	**********	**********
1	6	260.00	280.00	0.0	**********	**********	**********
1	7	280.00	280.00	0.0	**********	**********	**********
1	8	300.00	280.00	0.0	**********	**********	**********
1	9	320.00	280.00	0.0	**********	**********	**********
1	10	340.00	280.00	0.0	**********	**********	**********
1	11	360.00	280.00	0.0	**********	**********	**********

--- SURFACE GRID NUMBER 2 ---

--- TASK &PRTSURF HAS BEEN COMPLETED ---

```
&TERMINATE                                                    00004000
TAPE=10;                                                      00004050
&                                                             00004100
```

SURFACE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	2	1	12	**********	**********	0.0	0.0	**********
2	1	1	11	160.00	280.00	90.00	0.0	20.00

MINE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	1	9	15	0.0	0.0	0.0	40.00	40.00

GRID NUMB	DATES OF EXTRACT MIN	DATES OF EXTRACT MAX	HEIGHT OF CUT MIN	HEIGHT OF CUT MAX
1	0.0	300.00	2.00	2.00

--- TASK &TERMIN HAS BEEN COMPLETED ---

SURFACE & MINE GRIDS WERE SAVED ON DSRN= 10

```
&LOAD
TAPE=10;
&
```

SURFACE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	2	1	12	**********	**********	0.0	0.0	**********
2	1	1	11	160.00	280.00	90.00	0.0	20.00

MINE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	1	9	15	0.0	0.0	0.0	40.00	40.00

GRID NUMB	DATES OF EXTRACT MIN	DATES OF EXTRACT MAX	HEIGHT OF CUT MIN	HEIGHT OF CUT MAX
1	0.0	300.00	2.00	2.00

--- TASK &LOAD HAS BEEN COMPLETED ---

```
&DISPL
SFGRID=1;
NUMPTS=12;
'FORMAT=(I2,F5.0);
TIME=0,300;
'TITLE=U. K. NATIONAL COAL BOARD DATA;
&
```

U. K. NATIONAL COAL BOARD DATA

GRID LOCN	COORDS OF GRID POINTS E	COORDS OF GRID POINTS N	SURFACE DISPLACEMENTS VERTICAL	SURFACE DISPLACEMENTS HORIZONTAL	SURFACE DISPLACEMENTS ANGLE
1	160.00	280.00	1.8000	**********	*******
2	234.00	280.00	1.7100	**********	*******
3	250.00	280.00	1.6200	**********	*******
4	266.00	280.00	1.4400	**********	*******
5	276.00	280.00	1.2600	**********	*******
6	284.00	280.00	1.0800	**********	*******
7	292.00	280.00	0.9000	**********	*******
8	300.00	280.00	0.7200	**********	*******
9	308.00	280.00	0.5400	**********	*******
10	320.00	280.00	0.3600	**********	*******
11	340.00	280.00	0.1800	**********	*******
12	362.00	280.00	0.0900	**********	*******

CHANGES IN DISPLACEMENTS OF SURFACE GRID NUMBER 1
BETWEEN DATES 0.0 AND 300.00

--- TASK &RDDISPLTS HAS BEEN COMPLETED ---

```
------------------------------------------------------------------------------------------
&CHGDATES                                                                        00002800
MNGRID=1;                                                                        00002850
ADVANCE=0@0,560@300;                                                             00002900
&                                                                                00002950
```

-----> MINE GRID 1 HAS BEEN SUCCESSFULLY REDATED

--- TASK &REDATE HAS BEEN COMPLETED ---

```
------------------------------------------------------------------------------------------
&PRTDATES                                                                        00003000
&                                                                                00003050
```

ADVANCE OF FACE	GRID LOCN N COORD	DATE
0.0	1	0.0
40.00	2	21.43
80.00	3	42.86
120.00	4	64.29
160.00	5	85.71
200.00	6	107.14
240.00	7	128.57
280.00	8	150.00
320.00	9	171.43
360.00	10	192.86
400.00	11	214.29
440.00	12	235.71
480.00	13	257.14
520.00	14	278.57
560.00	15	300.00

--- MINE GRID NUMBER 1 ---

--- TASK &PRTDATE HAS BEEN COMPLETED ---

```
------------------------------------------------------------------------------------------
&GENPOINTS                                                                        00003100
LOCAT=160,280;                                                                    00003150
LOCAT=234,280,90,2@16;                                                            00003200
LOCAT=266,280;                                                                    00003250
LOCAT=276,280,90,5@8;                                                             00003300
LOCAT=320,280;                                                                    00003350
LOCAT=340,280;                                                                    00003400
LOCAT=362,280;                                                                    00003450
&                                                                                 00003550
```

--- TASK &GENPTS HAS BEEN COMPLETED

```
------------------------------------------------------------------------------------------
&PRTSURF                                                                          00003600
'TITLE=LOCATIONS OF HYPOTHETICAL MONUMENTS;                                       00003610
&                                                                                 00003650
```

LOCATIONS OF HYPOTHETICAL MONUMENTS

GRID E	LOCN N	COORDS OF GRID POINT E	N	SURFACE ELEVATION	SEAM THICKNESS	SEAM BOTT ELEVATION	DEPTH OF COVER
1	1	160.00	280.00	0.0	**********	**********	**********
1	2	234.00	280.00	0.0	**********	**********	**********
1	3	250.00	280.00	0.0	**********	**********	**********
1	4	266.00	280.00	0.0	**********	**********	**********
1	5	276.00	280.00	0.0	**********	**********	**********
1	6	284.00	280.00	0.0	**********	**********	**********
1	7	292.00	280.00	0.0	**********	**********	**********
1	8	300.00	280.00	0.0	**********	**********	**********
1	9	308.00	280.00	0.0	**********	**********	**********
1	10	320.00	280.00	0.0	**********	**********	**********
1	11	340.00	280.00	0.0	**********	**********	**********
1	12	362.00	280.00	0.0	**********	**********	**********

--- SURFACE GRID NUMBER 1 ---

--- TASK &PRTSURF HAS BEEN COMPLETED ---

&VELAST
CUTOFF=25,0.005; 00002120
NUMFV=21;
CTIME=0;
WFACT=0.24,0.32,3;
&

COMPUTATION HISTORY

WIDTH FACTOR OF EDGE EFFECT= 0.24000
CHARACTERISTIC TIME = 0.0

	K1	K2	CVERT	RMS ERROR
0	0.28000	0.30000	0.58839	0.04419
1	0.27429	0.29525	0.53998	0.04410
2	0.27350	0.29563	0.51054	0.04410
	SOLUTION CONVERGED			

WIDTH FACTOR OF EDGE EFFECT= 0.28000
CHARACTERISTIC TIME = 0.0

	K1	K2	CVERT	RMS ERROR
0	0.27350	0.29563	0.53231	0.01849
1	0.28190	0.30447	0.55617	0.01796
2	0.24471	0.34848	0.12008	0.01780
3	0.24795	0.35116	0.12344	0.01771
	SOLUTION CONVERGED			

WIDTH FACTOR OF EDGE EFFECT= 0.32000
CHARACTERISTIC TIME = 0.0

	K1	K2	CVERT	RMS ERROR
0	0.24795	0.35116	0.12875	0.04487
1	0.27806	0.36990	0.17306	0.04304
2	0.25592	0.39664	0.11130	0.04297
3	0.26058	0.40047	0.11536	0.04292
4	0.24034	0.42998	0.08414	0.04282
5	0.24545	0.43352	0.08757	0.04275
6	0.21291	0.51214	0.05638	0.04242
7	0.21981	0.51498	0.05953	0.04230
8	0.18526	0.68165	0.03965	0.04159
9	0.19210	0.68307	0.04181	0.04143
10	0.18418	0.71768	0.03874	0.04134
11	0.18826	0.71866	0.03998	0.04128
	SOLUTION CONVERGED			

BEST VALUES OF SYSTEM PARAMETERS WERE:
LIMIT ANGLE (LIMANGLE) = 55.0000
WIDTH FACTOR (WFACTOR) = 0.2800
EDGE SUBS FACT (SFACTOR) = 0.0
CHARACT TIME (CHTIME) = 0.0
PARAMETER K1 (K1) = 0.2479
PARAMETER K2 (K2) = 0.3512
PARAMETER CVERT (CVERT) = 0.1234
THESE ARE THE DEFAULT VALUES FOR SUBSEQUENT TASKS

--- TASK &VELAST HAS BEEN COMPLETED ---

```
--------------------------------------------------------------------------------
&DISPL
SFGPID=1;
NUMPTS=3;
CODE=3;
'FORMAT=(I2,2F6.0);
'TITLE=NATIONAL COAL BOARD DATA;
TIME=0,300;
&
```

NATIONAL COAL BOARD DATA

GRID LOCN	COORDS OF GRID POINTS E	N	SURFACE DISPLACEMENTS VERTICAL	HORIZONTAL	ANGLE
5	276.00	280.00	**********	0.2480	-90.00
7	292.00	280.00	**********	0.2710	-90.00
10	320.00	280.00	**********	0.1820	-90.00

CHANGES IN DISPLACEMENTS OF SURFACE GRID NUMBER 1
BETWEEN DATES 0.0 AND 300.00

--- TASK &RDDISPLTS HAS BEEN COMPLETED ---

```
--------------------------------------------------------------------------------
&HELAST
NUMFH=21;
&
```

```
SYSTEM PARAMETERS USED IN THIS TASK WERE:
    LIMIT ANGLE     (LIMANGLE)=  55.0000
    WIDTH FACTOR    (WFACTOR) =   0.2800
    EDGE SUBS FACT  (SFACTOR) =   0.0
    CHARACT TIME    (CHTIME)  =   0.0
    PARAMETER K1    (K1)      =   0.2479
    PARAMETER K2    (K2)      =   0.3512
    PARAMETER CVERT (CVERT)   =   0.1234
    PITCH FACTOR    (PFACT)   =   0.6500

THE FOLLOWING "BEST" VALUES WERE COMPUTED:
    PARAM CHORIZ (CHORIZ)     =   0.2490
    RMS ERROR                 =   0.0115
```

```
--------------------------------------------------------------------------------
&TERMINATE
&
```

--- TASK &TERMINATE HAS BEEN COMPLETED ---

SUBSIDENCE MODULE RUN

```
&LOAD                                                              00001550
TAPE=10;                                                           00001600
&                                                                  00001650
```

SURFACE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	2	1	12	**********	**********	0.0	0.0	**********
2	1	1	11	160.00	280.00	90.00	0.0	20.00

MINE GRID DIRECTORY

GRID NBR	GRID TYPE	GRID SIZE EAST	GRID SIZE NORTH	COORDS OF ORIGIN EAST	COORDS OF ORIGIN NORTH	AZIM (DEG)	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH
1	1	9	15	0.0	0.0	0.0	40.00	40.00

GRID NUMB	DATES OF EXTRACT MIN	DATES OF EXTRACT MAX	HEIGHT OF CUT MIN	HEIGHT OF CUT MAX
1	0.0	300.00	2.00	2.00

--- TASK &LOAD HAS BEEN COMPLETED ---

```
&ELASTICITY
NUMF=21;
K1=0.2479;
K2=0.3512;
CVERT=0.1234;
CHORIZ=0.249;
&
```

PARAMETERS USED IN ELASTIC INFLUENCE FUNCTIONS:
K(1) = 0.24790 K(2) = 0.35120
CVERT= 0.12340 CHORIZ= 0.24900

R/B	VERTICAL	HORIZONT
0.0	5.2513	0.0
0.0500	4.8655	0.4909
0.1000	3.9262	0.7922
0.1500	2.8572	0.8648
0.2000	1.9494	0.7867
0.2500	1.2873	0.6494
0.3000	0.8413	0.5093
0.3500	0.5517	0.3896
0.4000	0.3659	0.2953
0.4500	0.2465	0.2238
0.5000	0.1690	0.1705
0.5500	0.1179	0.1309
0.6000	0.0838	0.1014
0.6500	0.0605	0.0794
0.7000	0.0444	0.0628
0.7500	0.0331	0.0501
0.8000	0.0250	0.0404
0.8500	0.0191	0.0328
0.9000	0.0148	0.0269
0.9500	0.0116	0.0223
1.0000	0.0092	0.0186

--- INFLUENCE FUNCTIONS ---

--- TASK &ELAS HAS BEEN COMPLETED ---

```
&RDPARAMS
&
```

LIM ANGLE	WIDTH FAC	EDGE SUBS FAC	CHAR TIME	PITCH FAC
55.0000	0.2800	0.0	0.0	0.6500

--- SUBSIDENCE PARAMETERS ---

--- TASK &RDPARM HAS BEEN COMPLETED ---

```
&CMPSUBS
SPGFID=2;
DATES=0,300;
&
```

--- TASK &CSUB HAS BEEN COMPLETED ---

```
&CMPSUES                                                                 00002150
SPGRID=2;                                                                00002200
DATES=0,300;                                                             00002250
&                                                                        00002300
```

--- TASK &CSUB HAS BEEN COMPLETED ---

```
&PRTDISPL                                                                00002350
'TITLE=DISPLACEMENTS ALONG X-AXIS;                                       00002400
&                                                                        00002450
```

DISPLACEMENTS ALONG X-AXIS

GRID LOCN E	GRID LOCN N	VERTICAL DISPLACEMENT	HORIZONTAL DISPLACEMENTS E-COMPONENT	N-COMPONENT	MAGNITUDE	DIRECTION
1	1	1.8064	-0.0000	0.0000	0.0000	0.0
1	2	1.8031	-0.0000	-0.0103	0.0103	-179.76
1	3	1.7910	-0.0000	-0.0265	0.0265	-179.92
1	4	1.7618	-0.0000	-0.0557	0.0557	-179.97
1	5	1.6888	-0.0000	-0.1070	0.1070	-179.99
1	6	1.5094	-0.0000	-0.1833	0.1833	-179.99
1	7	1.1660	-0.0000	-0.2505	0.2505	-180.00
1	8	0.7303	-0.0000	-0.2577	0.2577	-180.00
1	9	0.3581	-0.0000	-0.1995	0.1995	-180.00
1	10	0.1471	-0.0000	-0.1211	0.1211	-180.00
1	11	0.0584	-0.0000	-0.0642	0.0642	-180.00

--- SUBSIDENCE GRID NUMBER= 1 SURFACE GRID NUMBER= 2 ---
--- SURFACE DISPLACEMENTS BETWEEN DATES 0.0 AND 300.00 ---

--- TASK &PDISPL HAS BEEN COMPLETED ---

```
&TERMINATE                                                               00002500
TAPE=11;                                                                 00002550
&                                                                        00002600
```

SUBSIDENCE GRID DIRECTORY

GRID NBR	SURF GRID	GRID SIZE EAST	GRID SIZE NORTH	DIMS OF GRID ELEMENT EAST	DIMS OF GRID ELEMENT NORTH	# TIME INTVLS	DATUM TIME	FINISH TIME
1	2	1	11	0.0	20.00	1	0.0	300.00

--- TASK &TERMIN HAS BEEN COMPLETED ---

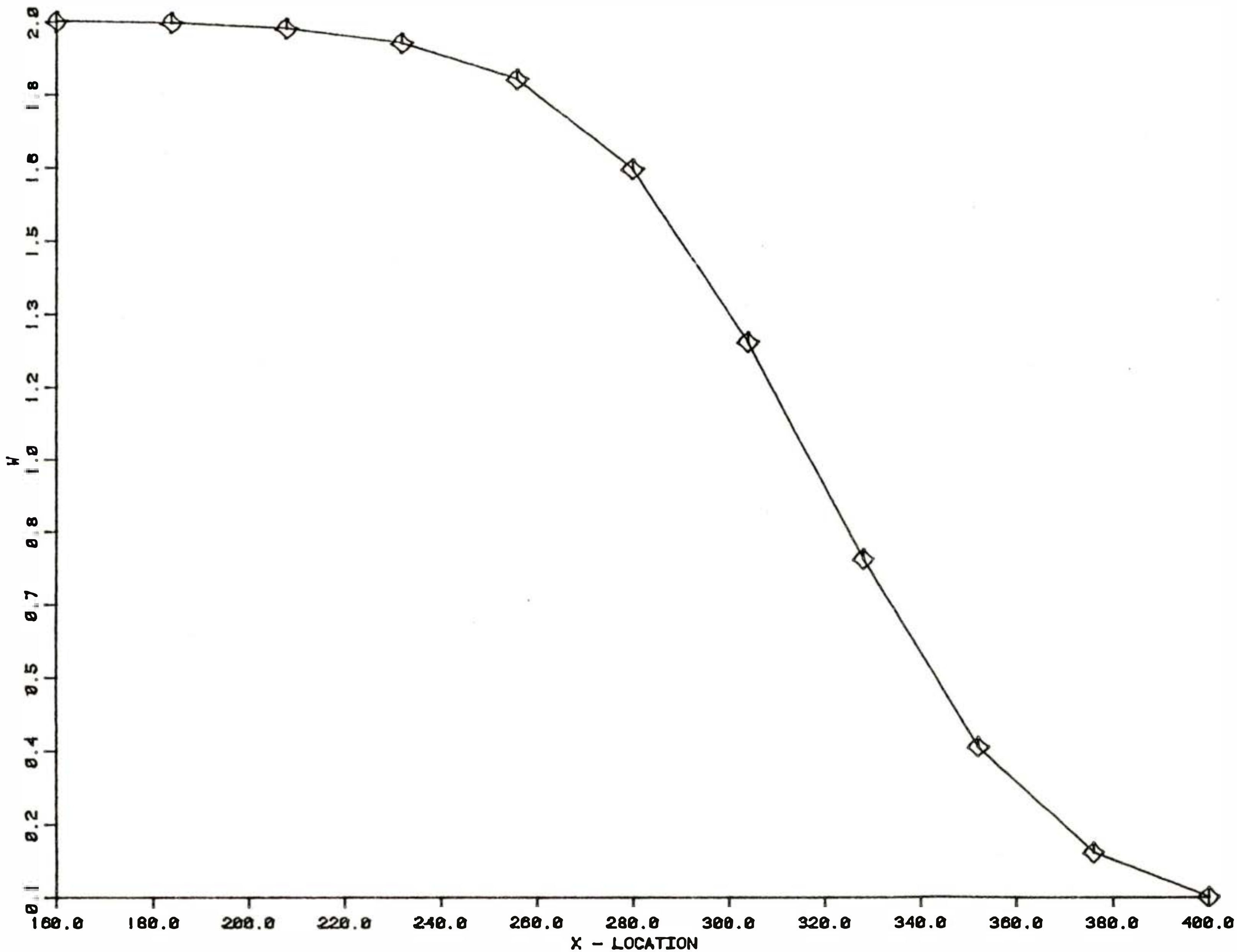
D.6 Postprocessor Run

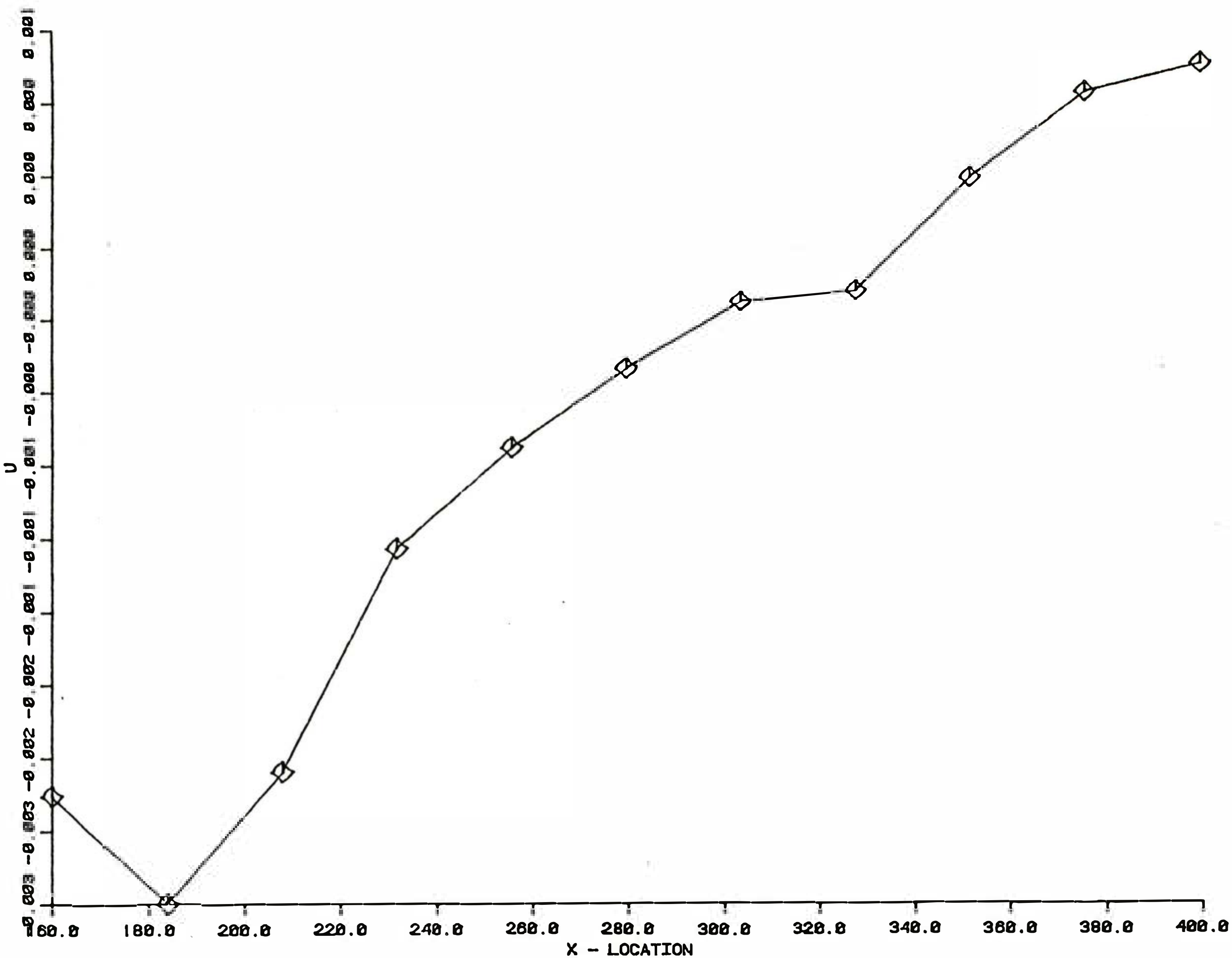
The Postprocessor was run to plot the graphs presented in the Postprocessor Module Output section. Five X-Y plots were generated on a 4662 Tektronix plotter using default parameters for the plotting options. Since the test data set contained only slices from the Subsidence Module, only X-Y plots could be generated from this information.

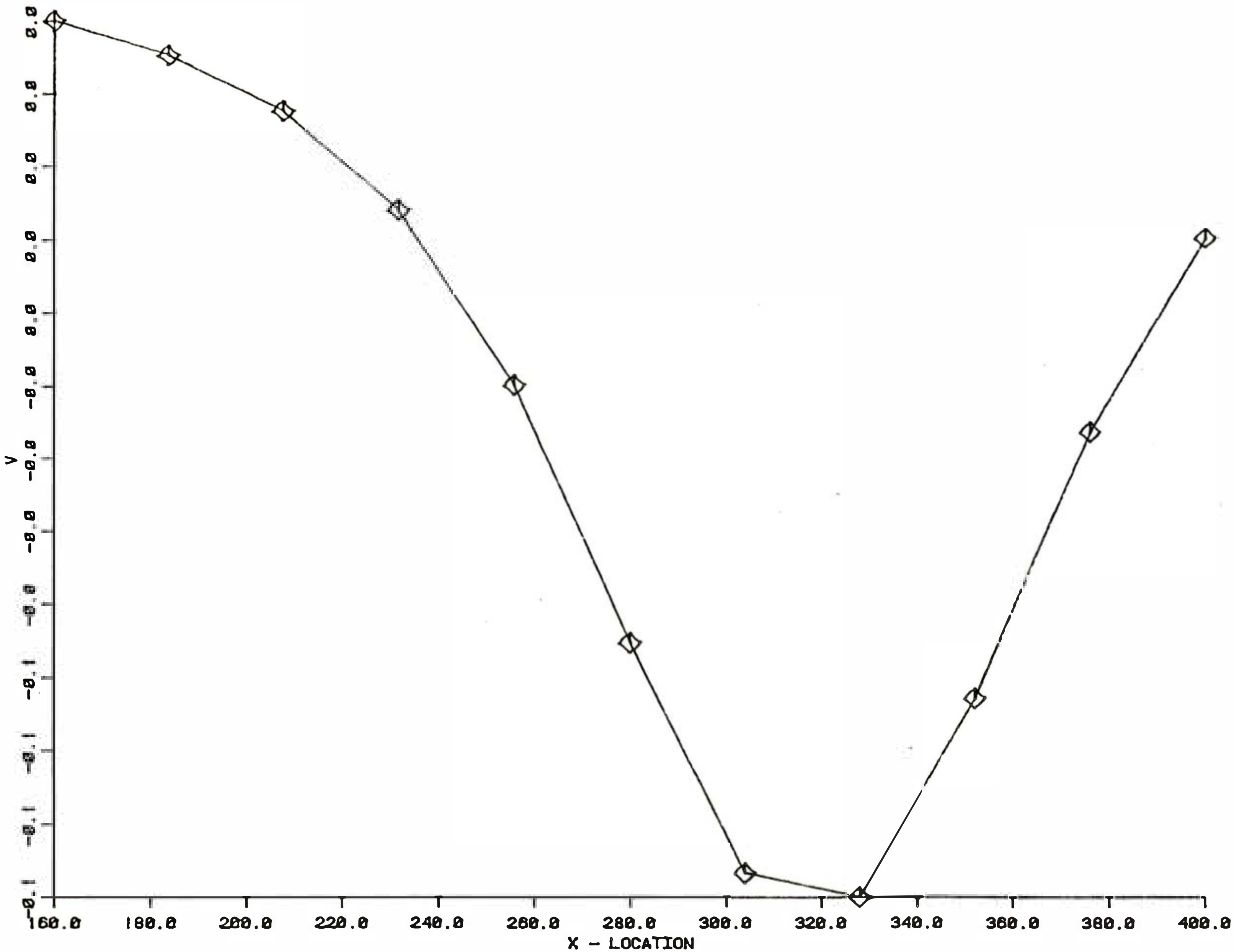
In order to demonstrate the perspective and contour packages, a test surface was generated and used to provide data for these two routines. The surface from the Preprocessor is very uninteresting - it is a flat 5 x 5 grid and therefore would show no features for the plotting routines to display.

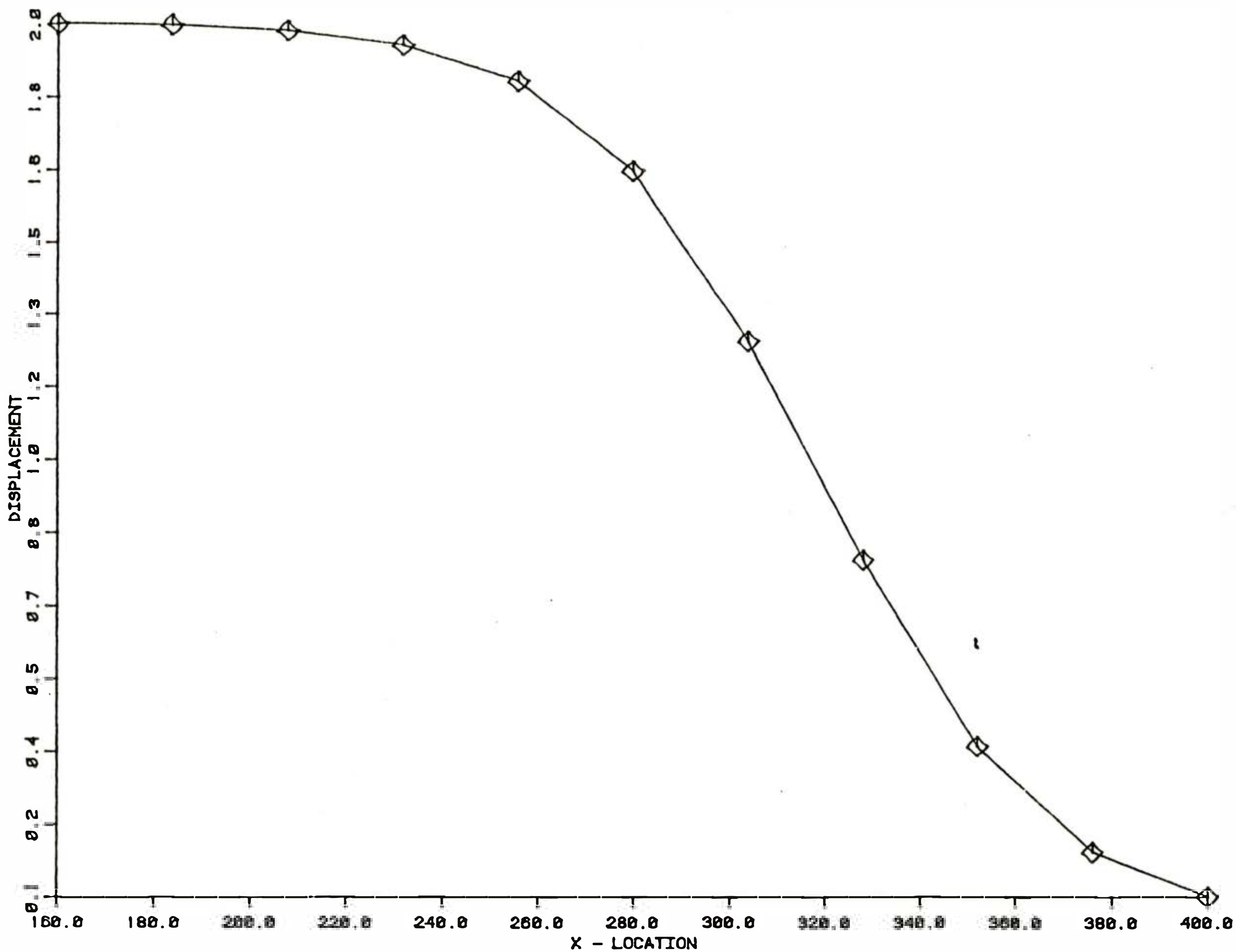
The contour package was set for fourteen levels and minimum character cell size. Although the output at this level may not seem sufficiently detailed enough to be useful, the contour map package can automatically generate multiple strip maps so that more detail may be included. At large character cell to grid cell ratios the detail is quite good, and of course is still a function of the number of contour intervals and the actual shape of the surface.

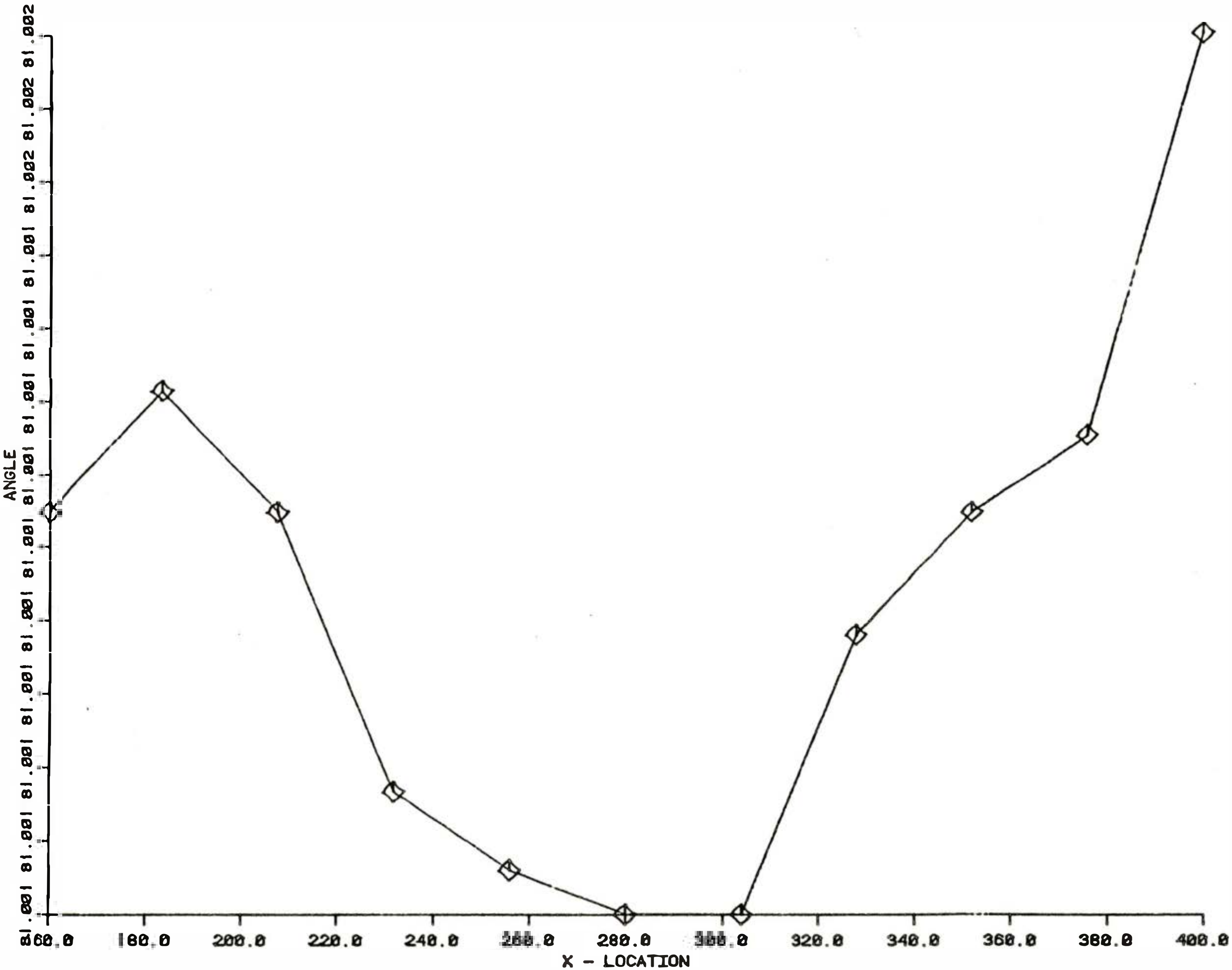
The perspective plot was produced entirely with default settings using the same test grid generated for the contour map.


W
X - LOCATION
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0


U
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
X - LOCATION

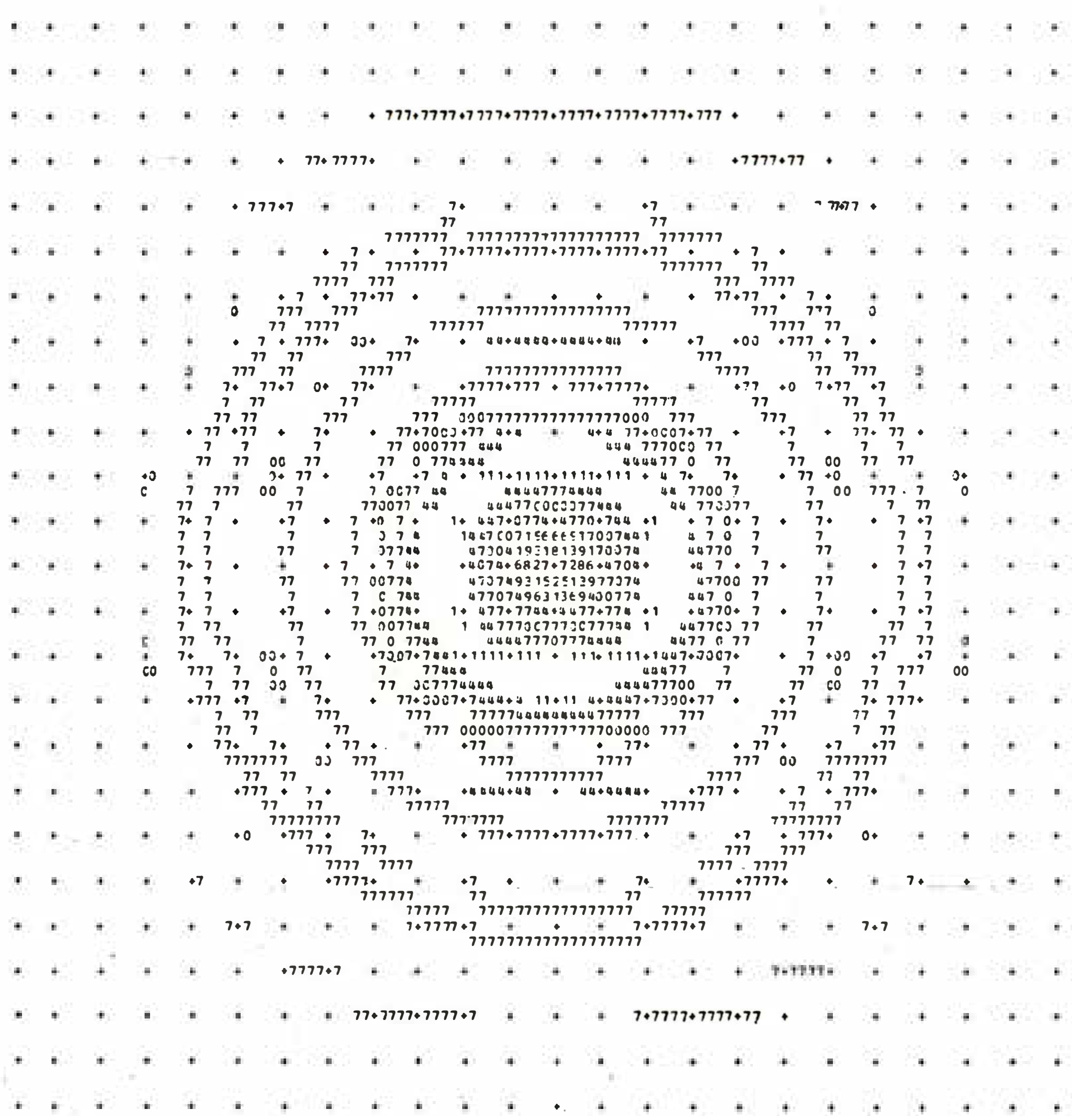

V
X - LOCATION
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0

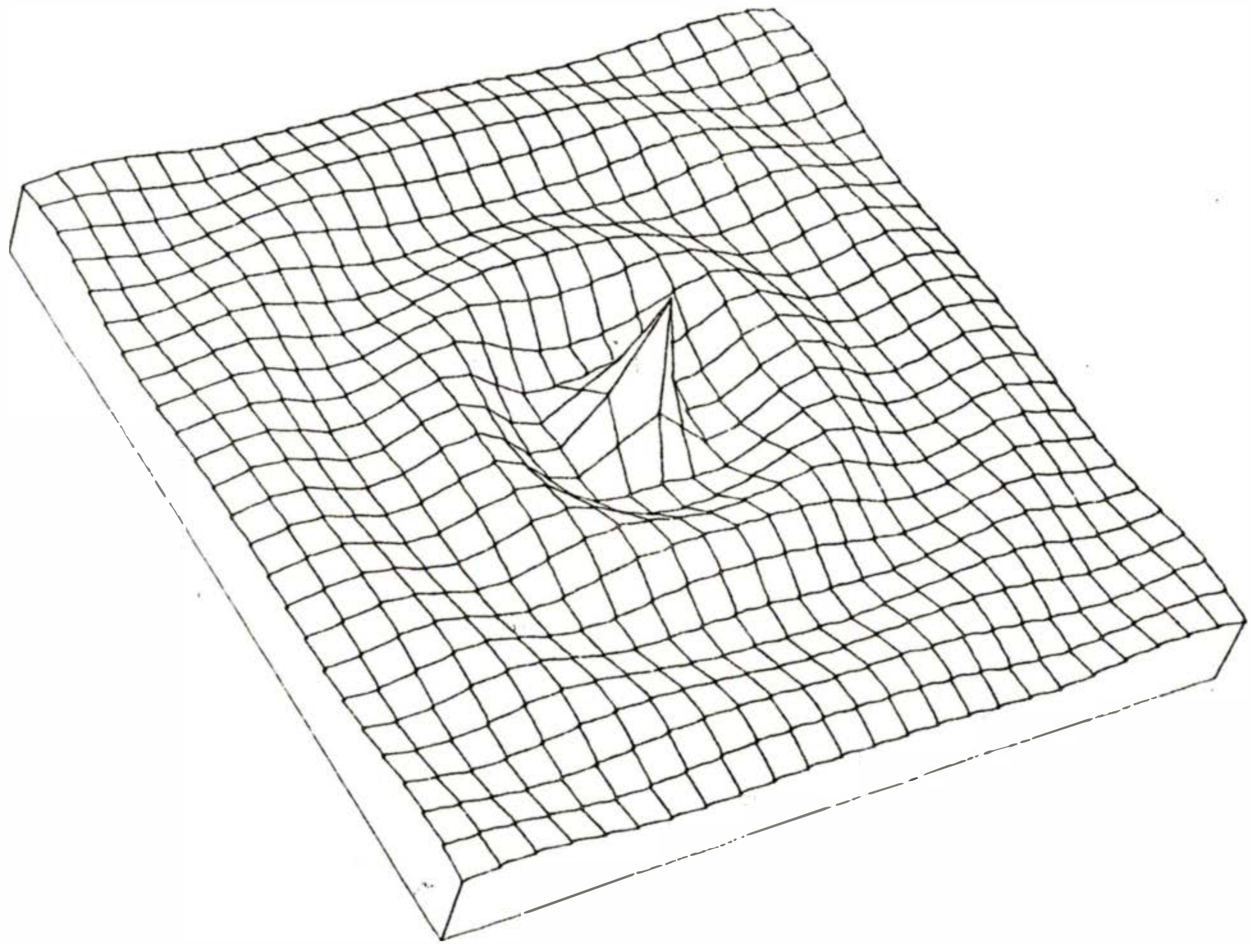

DISPLACEMENT
X - LOCATION
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0


ANGLE
81.001
81.002
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0
340.0
360.0
380.0
400.0
X - LOCATION

CONTOUR MAP WITH 14 LEVELS OF 7.2979 EACH
GRID MINIMUM =-22.1701 GRID MAXIMUM = 80.0000

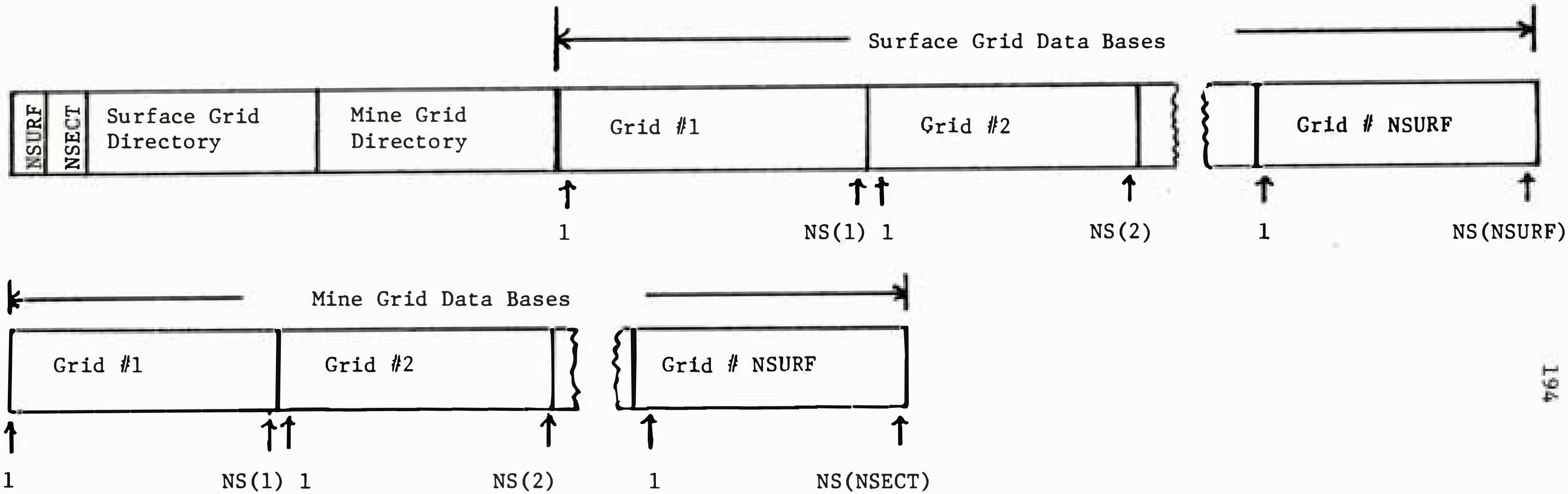
THIS IS A TEST SURFACE USING PROGRAM DEFAULTS





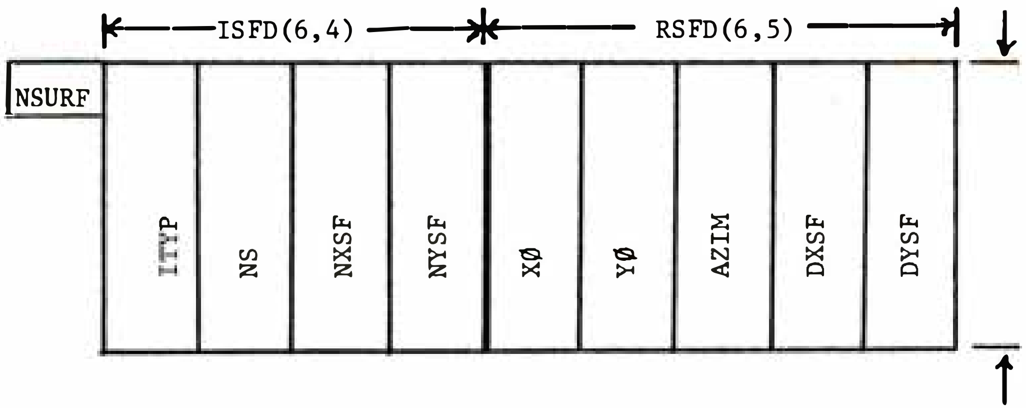
APPENDIX E DATA BASE ORGANIZATION

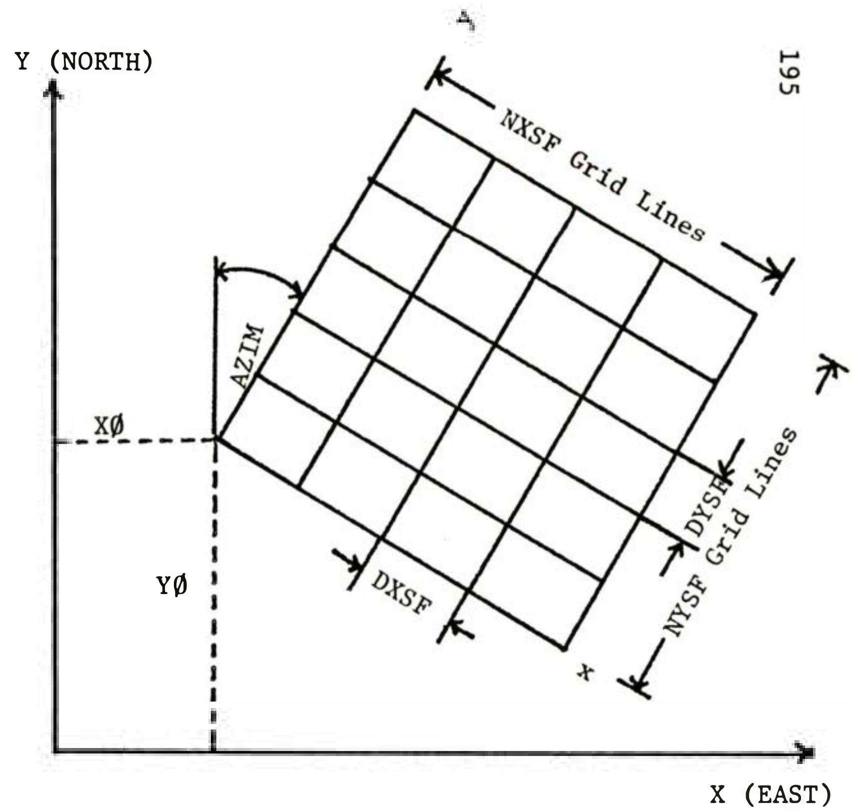
Organization of tape "ITAPE"



Surface and Mine Grid Data

Surface Grid Directory Organization





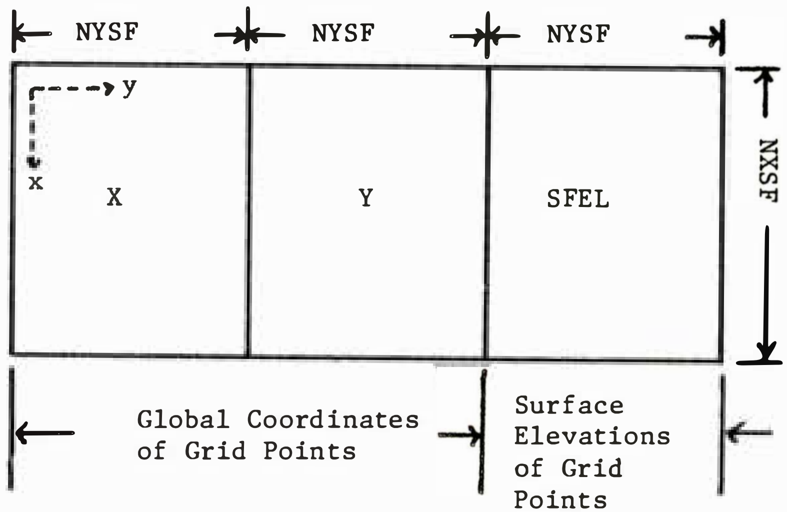
ITYP = Grid Type:

1: Rectangular Grid (as shown)
2: Irregular collection of points; Grid Data Base stored as one-dimensional array.

X, Y = Global Coordinates
x, y = Local (Grid) Coordinates

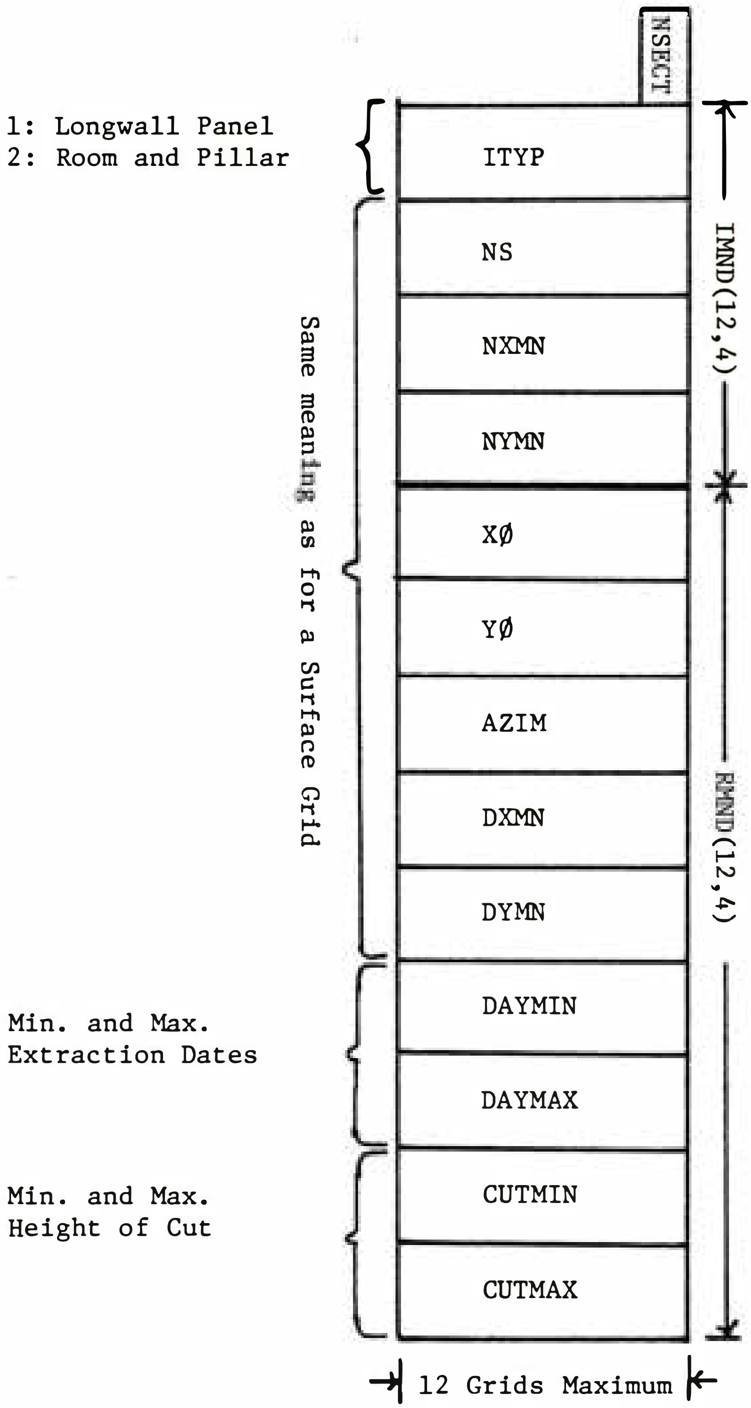
NS = number of records (numbers) in the grid data base. Facilitates reading and writing of entire data base.

Surface Data Base

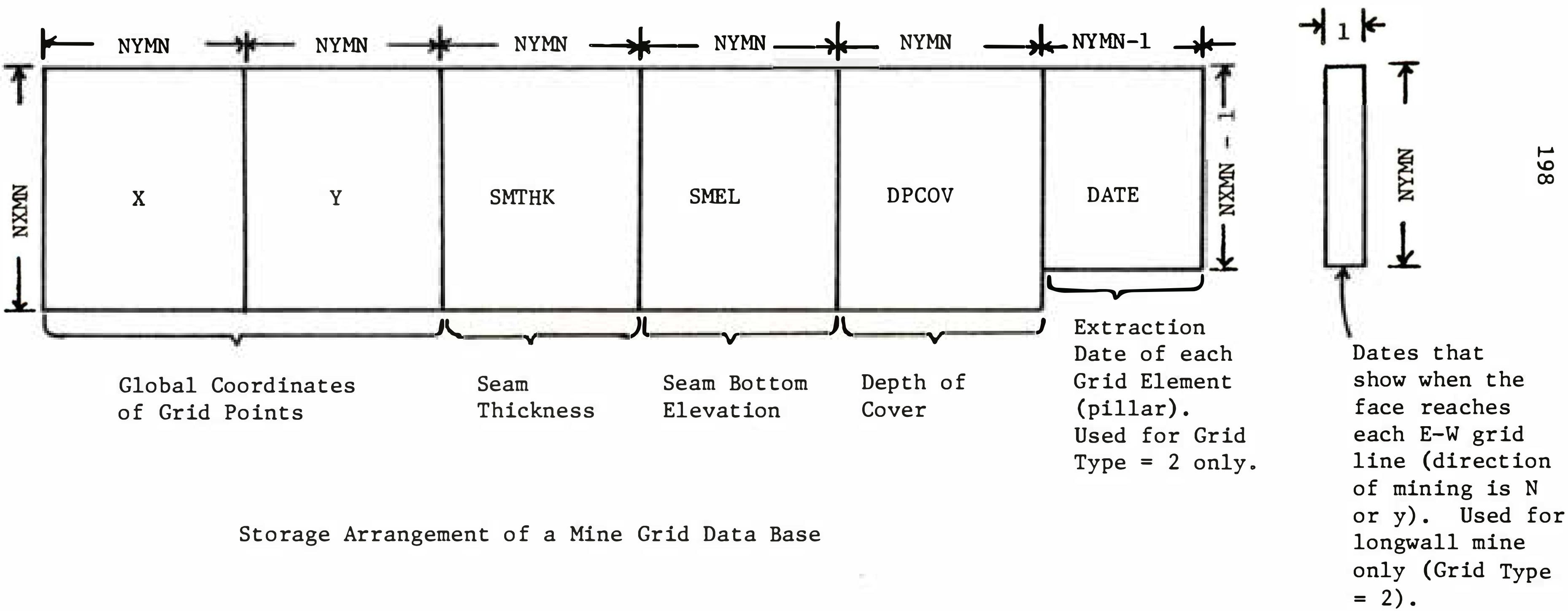


Storage Arrangement of Surface Grid Data Base

Mine Grid Directory Organization

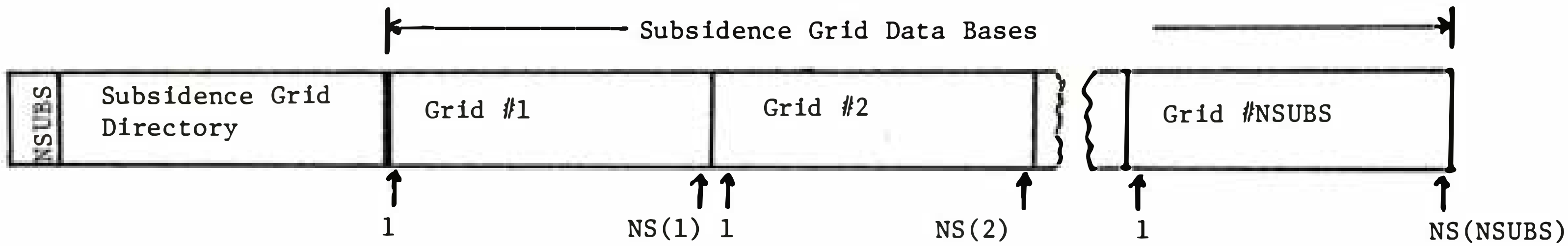


Mine Data Base Organization

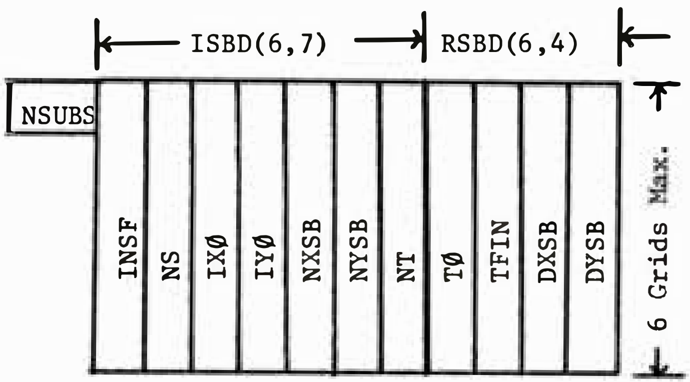


Storage Arrangement of a Mine Grid Data Base

Subsidence Grid Data Base

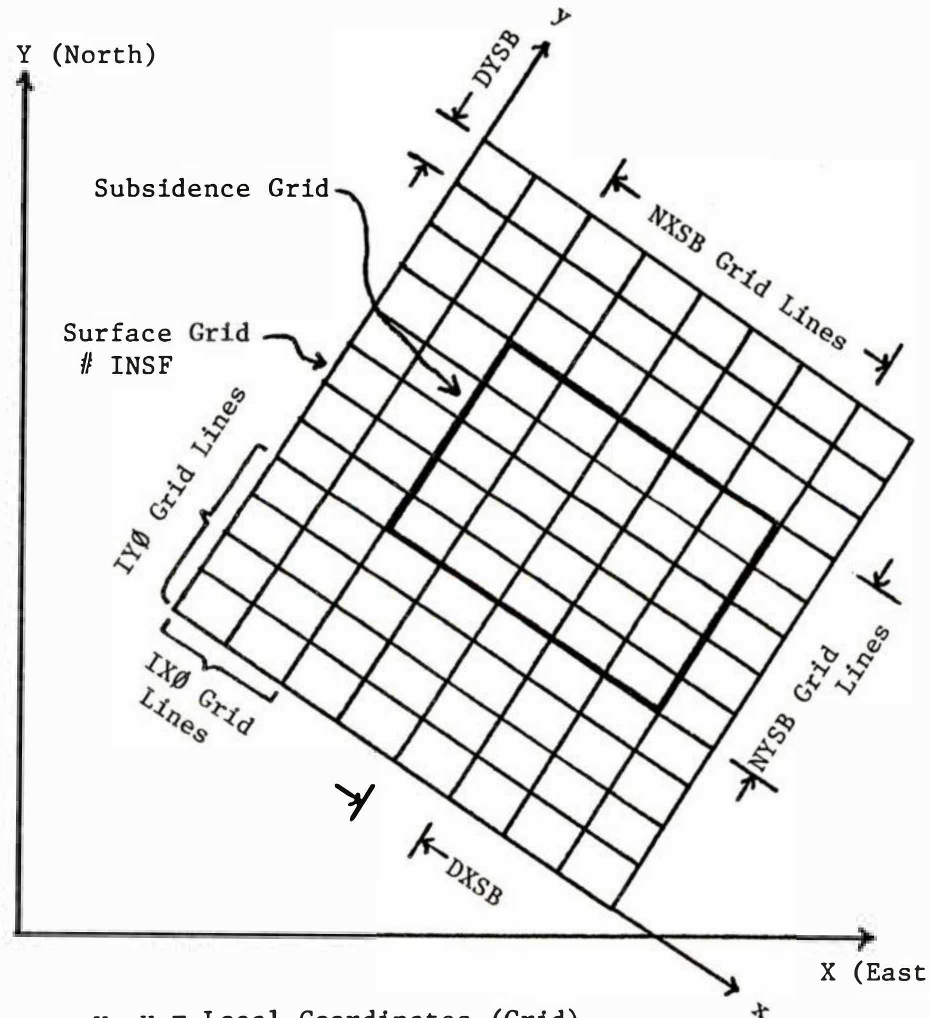


Subsidence Grid Directory



TØ
TFIN - Subsidence that occurs between these dates is computed at NT equal time increments (e.g. if NT = 1, subsidence at time = TFIN only will be calculated).

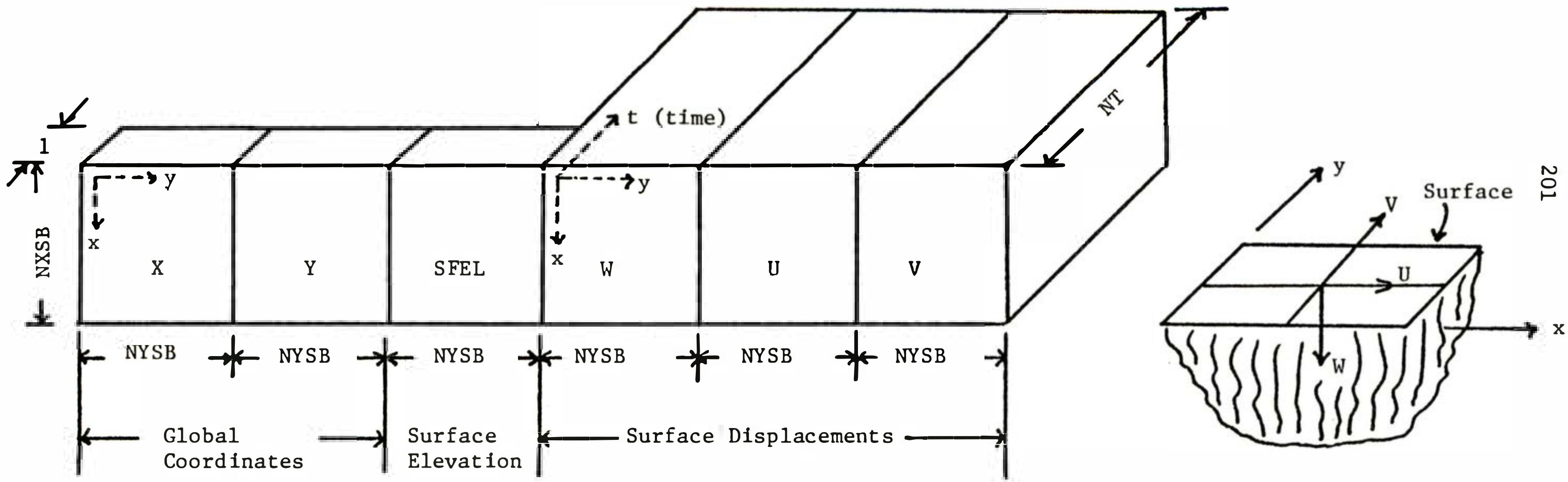
NS = Same meaning as for Surface and Mine Grids



x, y = Local Coordinates (Grid)

X, Y = Global Coordinates

Subsidence Data Base Organization



Positive Displacements of a surface point are in direction of <u>local</u> (grid) <u>coordinates.</u>