J&&giÈu^èfotënsiv& Computer Paépifè'^3 Ground Movement and Subsidence Studies

Arazi Hareketleri ve Tasman Tahmin ÇàÈsrnaMm 4& Geliştirilmiş Bir-Bilgisayar Programı

*X.L. mo**
*Dj.m>Dm***
*R.K, DVMim****

ABSTRACT

This **paper** describes several computer packages developed at the University of **Nottingham** to study ground movement and subsidence due to underground mining. The packages include four computer programs: FEP, SEHSPP, SWIFT and ESDAS. FEP is a non-linear finite element package that allows a two-dimensional analysis of the displacement, stress and strain behaviour around longwall panels. SEHSPP is a computerised version of the Subsidence Engineers' Handbook. SWIFT is an influence function based surface subsidence prediction package capable of predicting displacements and strains over complex three-dimensional excavations. ESDAS is an expert system capable of assessing a broad range of mining, geological and structural information in terms of subsidence risk.

ÖZET

Bu bildiride, yeraltı madenciliği sonucu oluşan arazi haraketleri ve tasmanın tahmin edilebilmesi için Nottingham Üniversitesi'nde geliştirilen çeşitli bilgisayar paket programları tanıtılmaktadır. Bu programlar FEP, SEHSPP, SWIFT ve ESDAS olarak adlandırılmıştır. İki boyutlu doğrusal olmayan sonlu elemanlar programı (FEP), uzunayak panoları çevresindeki kayaçlarda üretim çalışmaları sonucu oluşan yerdeğiştirmelerin, deformasyonların ve gerilmelerin analizlerini yapabilmektedir. SEHSPP, Tasman Mühendisliği El Kitabı'nda önerilen çözümlemelerin bilgisayara

uyarlanmış şeklidir. Karmaşık yeraltı açıklıkları üzerinde oluşan yerdeğiştirmeler ve deformasyonlar bir etki fonksiyonu yardımı ile tasman açısından SWIFT aracılığı ile tahmin edilebilmektedir. Tasman sonucu yeryüzü yapılarında meydana gelebilecek hasar riskleri, temel faktörler (üretim metodları, jeolojik ve yapısal faktörler) gözönûne alınarak geliştirilmiş bir Uzman Sistem (ESDAS) programı ile tahmin edilebilmektedir.

(*) Research Fellow, Department of Mineral Resources Engineering, University of Nottingham, NG7 2RD, U.K.
(**) Lecturer in Geotechnical Engineering., Department of Mineral Resources Engineering, University of Nottingham, NG7 2RD, U.K.
(***) Head and Professor of Rock Mechanics., Department of Mineral Resources Engineering, University of Nottingham, NG7 2RD, U.K.

1. INTRODUCTION

Surface subsidence is recognised as a problem when significant mining and other underground extraction activity take place. The underground mining will result in ground movement both below and at the surface if the extent of the excavation is sufficently large.

In the sub-surface, longwall mining encourages large scale stress redistribution by inducing the overburden to massively cave. The caving process involves fracturing of the overburden above the longwall extraction. These potentially large fractures can allow aquifer horizons or subsurface water bodies a route of access to the workings. The degree and nature of the fractures, the aquifers character and the detailed geology ultimately control the water inflow. Numerical modelling techniques, such as FEP, will allow die engineer a fuller understanding of the fracturing and stress behaviour over longwall panels, and thus with further consideration of the aquifers physical characteristics and geological setting, a meaningful risk assessment can be conducted.

At the surface, displacement and strain result from underground mining. The significant effect of surface subsidence occurrence is damage to surface structures. Therefore, it is important to have a reliable prediction model, such as ESDAS, to determine the damage levels that can be expected at the surface in order to minimise subsidence cost. In order to accurately predict displacement and strain produced at the surface, computer programs, such as SEHSPP and SWIFT, should be used to pre-calculate ground movement, based on which the risk to surface structures can be reasonably assessed.

Fig.l illustrates the relationships between the various prediction packages.

It should be stressed that research on ground movement must combine both theory and practice. Any theory developed for ground movement must be refined with field validation. The four computer programs described in the paper have been developed by combining developmental theories and field validation. It is believed that all these computer programs could be used in any Coalfield worldwide by recalibration of the programs based on locally measured subsidence data.

2. FEP - FINITE ELEMENT PROGRAM

The finite element program, FEP, developed at the University of Nottingham, can be used to determine the distributions of displacement, induced principal stress, and strain for the ground between the mining horizon and the surface that is effected by the longwall extraction. It is important to note that the areas of high strain magnitude

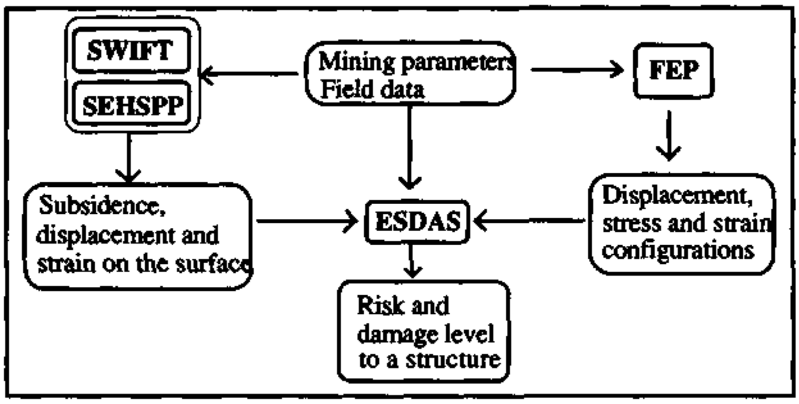


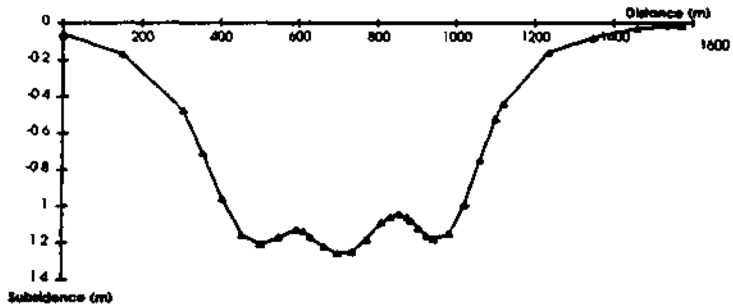
Fig.1 The purpose of each program

coincide with areas of fracturing, and more important, the major principal tensile strains are orientated at right angles to the fractures whilst the minor principal compressive strains are orientated with the fractures. Based on this knowledge, the strain patterns predicted by this kind of model can be interpreted in terms of their influence upon potential water inflow into the mining excavations.

The background to the non - linear finite element model FEP for subsidence research has been discussed by previous researchers (1,2). The basic computational procedure of this model has been given by Whittaker and Reddish (3). In practice, the program is run twice for each situation in order to subtract the results obtained through gravity loading of the intact strata from those in the mined - out case. This is to enable the results of mining alone to be obtained.

As an example, recently this FEP has been successfully used to investigate the interaction effects due to multi-panel extraction in a North American coal mine. The extracted seam height varies between 1.5m and 3.0m with face length between 100 and 250m at depth between 200m and 550m. The seam dip is 12°. Figs.2a, 2b, 2c illustrate the predicted subsidence profile, displacement vectors and major principal strain levels from three panels extraction respectively. Figure 2b shows that the pillars partially punch into the strata, above and below themselves. This has resulted in the three subsidence profiles combining into a single, large, wide, flat-bottomed profile, with a maximum subsidence of 1.18 m and, a few gentle humps over the pillars, which are indicated in Fig.2a. The Fig.2b also clearly illustrates large scale floor heave in the three panels. Fig.2c indicates the following features:

a. The outer edges of the extraction district in the seam suffer the greatest strains, in terms of magnitude and extent with a maximum strain of 16 mm/m. The middle panel shows a reduced strain condition. This effect is due to the pillars providing a softer edge to the excavation.



Fig,2a Surface subsidence profile predicted from FEP

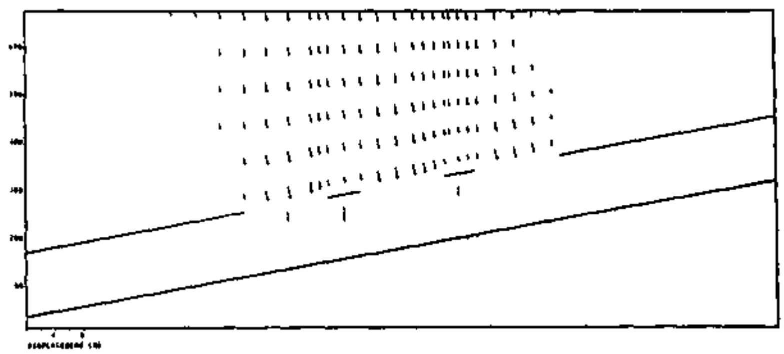


Fig.2b Displacement vectors from three panels extraction

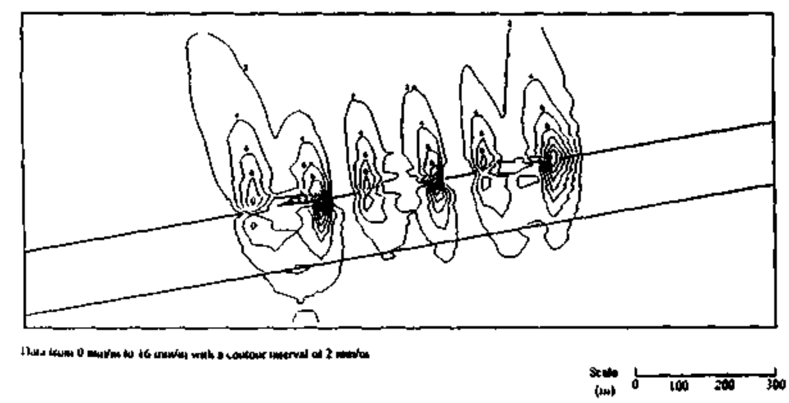


Fig 2c Major pnncipal strain levels from three panels extraction

b. The strains on the rise side of the excavations are far more intense but less extensive than those on the dip side. The dip side tensile strains extend further above the excavation but are less intense.

c. The high tensile strains are clearly associated with the region just inside the panel edges, and can be easily likened to fracture areas observed on physical models.

3. SEHSPP - SUBSIDENCE ENGINEERS HANDBOOK SUBSIDENCE PREDICTION PROGRAM

The original computer program, SEHSPP, for the calculation of subsidence, displacements and surface ground strains arising from longwall mining extraction has been described by Whittaker and Reddish (3). The program essentially uses a series of graphs and tables of data from SEH (4) to form the basis of the calculation for obtaining subsidence and horizontal strain profiles for the transverse and longitudinal directions of the longwall workings. The input parameters of panel width, depth, distance of travel, thickness of extraction and dip of seam are interactively checked by the program to see if they are within the range of the program. These basic parameters are used to calculate the maximum subsidence and strains, from which the subsidence and strain profiles are subsequently determined.

The treatment of the longitudinal profiles has been described by Whittaker and Reddish (3) in detail. The program is capable of calculating horizontal displacement from strain, generating grids of data over whole surface area of influence and predicting principal strains produced on the surface.

The original program was developed in a Pascal environment. In order to ensure its flexibility, a Visual Basic package (5) has been used to design a menu system for the program, and to produce the graphical outputs in a single environment by calling the commercially available EXCEL (6) and SURFER (7) packages from within the Visual Basic package itself.

This menu-driven user-friendly package, developed on an IBM PC, has the following facilities:-

a. Output of standard longitudinal and transverse profiles as text or graphics;

b. Ability to calculate and graphically display subsidence, and horizontal displacements over the whole of a panel using contour diagrams;

c. Ability to display graphically displacements as vector diagrams;

d. Ability to calculate principal strains and display them as a vector diagram;

An example of a case study is given to demonstrate some facilities of this package. Details can also be found in **Help** menu in the package. Case details are as foUowings: width = 200m, depth = 400m, thickness = 2.0m, length = 1000m and dip of seam = 0°.

Table 1 shows the sub-menu of **Graphical Output.** For example, if the user clicks the first one, **Transverse Profiles,** a form will appear. After following **the** instruction in the form, Figs.3a, 3b, and 3c will be produced automatically showing the transverse profiles of subsidence, displacement and strain for the case. Fig.4 illustrates the principal strain vectors predicted from the package by clicking **Principal Strains** in the **Vectors** menu.

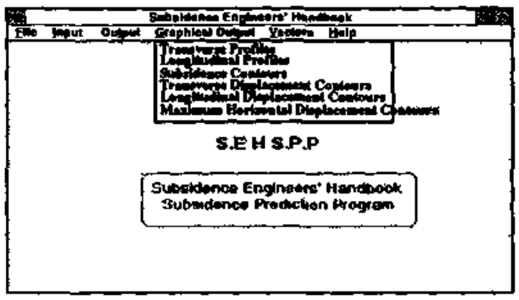


Table 1 Sub-menu of **Graphical Output**

4. SWIFT - SUBSIDENCE WITH INFLUENCE FUNCTION TECHNIQUE

SWIFT is a subsidence prediction program, developed for the IBM PC type machine, which uses the stochastic influence function method as a basis for calculation. More details of this method have been given by Ren, Reddish and Whittaker (8). Its application in subsidence prediction in other associated geotechnical problems such as in oil and gas fields is being explored currently. This program has the following major advantages:

a. It is capable of predicting ground movements, such as subsidence, displacement and strain, from regular and irregular-shaped mining layouts, including multi-seam and multi-panel layouts with the facility to also consider steep seam excavations;

b. It can predict ground movement for a Point, Line or Grid;

c. The program can be readily re - calibrated to conditions in any Coalfield worldwide by utilising local subsidence data;

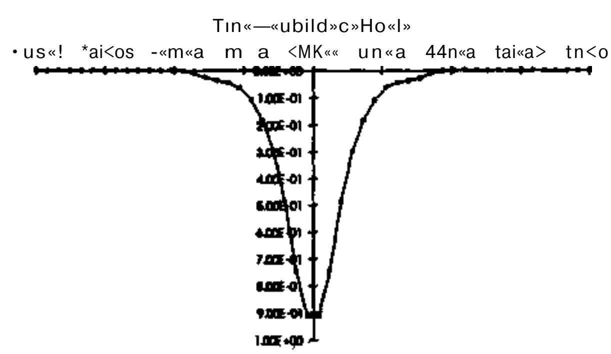


Fig.3a Subsidence profile from **Transverse Profiles in Graphical Output**

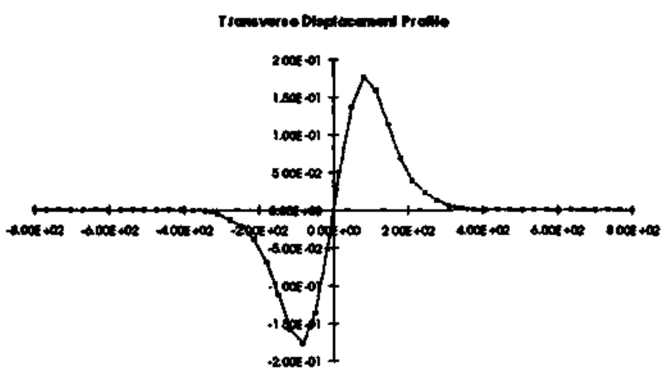
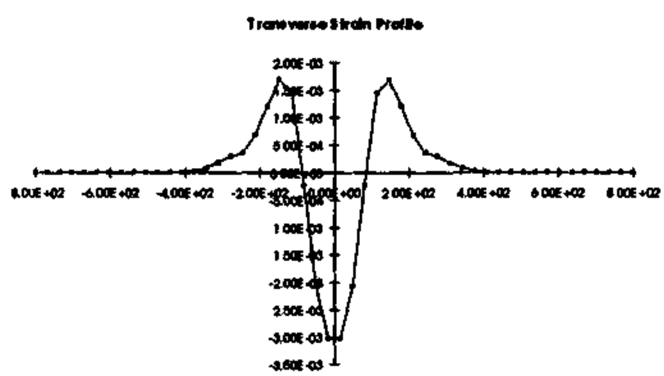
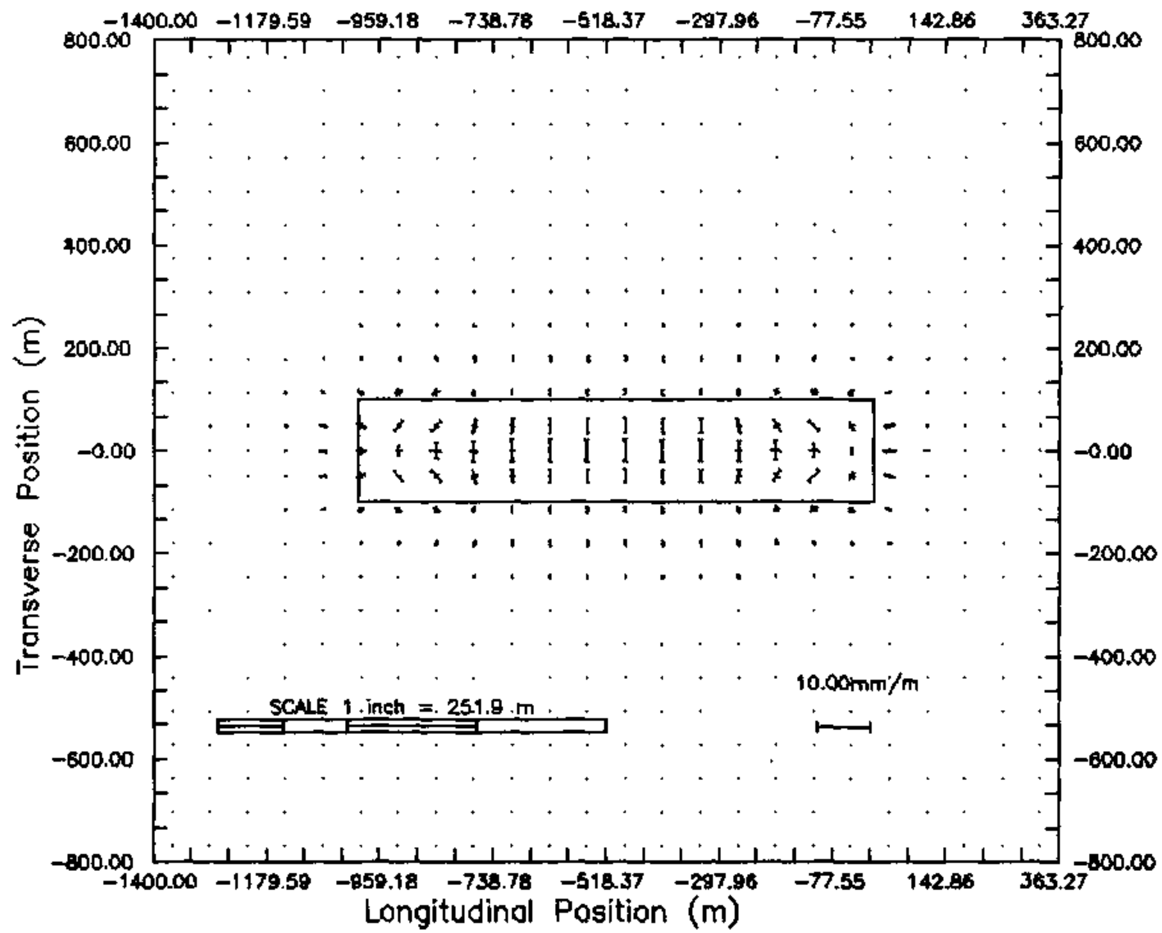


Fig.3b Displacement profile from **Transverse Profiles in Graphical Output**



Fie.3c Strain profile from Transverse Profiles in Graphical Output

Fig.4 Principal Strains Vectors



This program has been integrated into the expert system (ESDAS), which will be discussed later, to allow the strain profile along the structure to be predicted, so that the damage level from strain effects can be determined.

An example is given to demonstrate the application of SWIFT in a complex mining condition. Fig. 5a shows the plan view of 10 panels extracted underground. Fig.5b illustrates the predicted subsidence profile along the survey line.

5. ESDAS - EXPERT STRUCTURAL DAMAGE ASSESSMENT SYSTEM

ESDAS is a rule - based expert system to assess the risk to surface structures subjected to underground mining. This system was developed to embody statistical data from case histories of damage in the UK coal fields, and knowledge and experience from previous researchers' results (4,9,10,11,12).

This system is designed to have three main knowledge bases, which have been discussed by Yao (13). Fig.6 illustrates the general structure of the three knowledge bases of this system. In each of these knowledge bases, a number of sub - parameters has been taken into consideration. By using the certainty factor risk assessment technique (13) , the final damage risk level can be evaluated by the calculation and combination of all the certainty factors from each of these sub - parameters. For a particular surface structure, the system also presents the contributing factors leading to the damage, a description of likely damage and possible measures to be taken to reduce **the** damage to the particular structure. An example is given in the following section.

6. AN INTEGRATED COMPUTER APPROACH - COMBINATION OF ESDAS AND SWIFT

The expert system, ESDAS, forms the heart of this approach and functions as an adviser in response to user-initiated consultations. When the user reaches the Mining factors knowledge base, the external program, SWIFT, is called, and the user is required to provide the mining data. After the mining data has been given, the system displays the predicted strain profile along the structure, which indicates the position of maximum strains. Demonstration of this integrated approach can be seen in the case study described later. Fig.7 illustrates the structure of this integrated approach to assess surface structural damage due to mining subsidence.

An example is shown to demonstrate the potential of this integrated system being applied to assess surface structural damage under complex mining conditions.

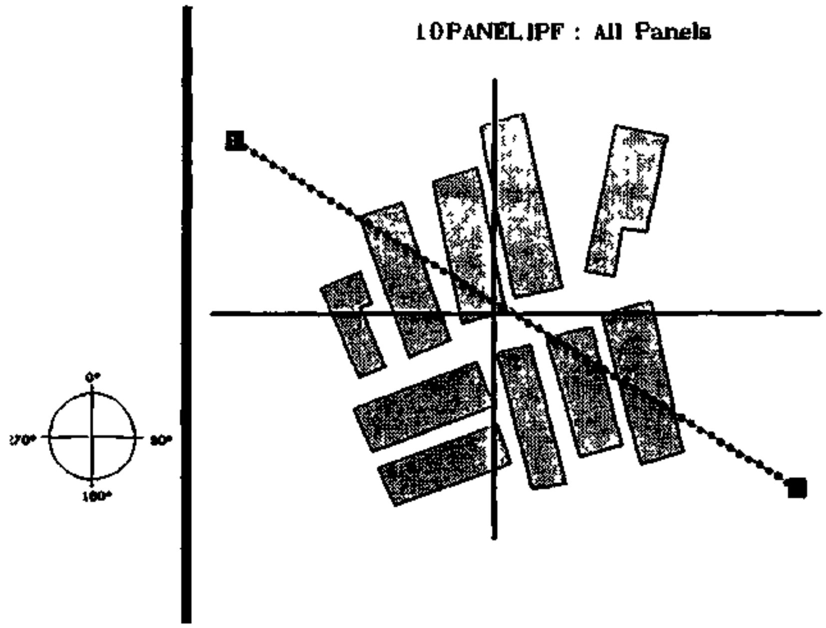


Fig.5a Plan View of 10 panels

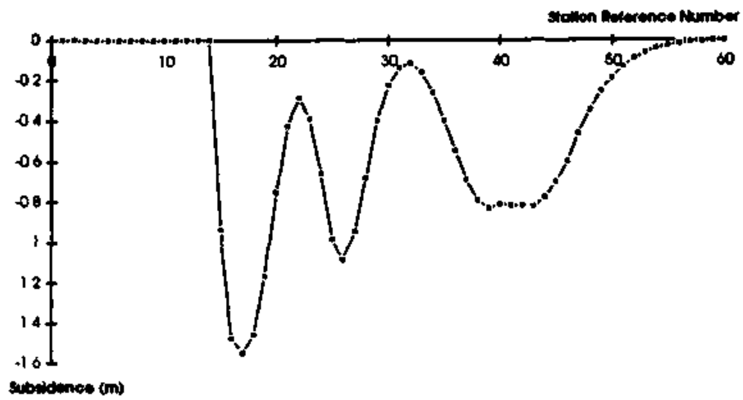
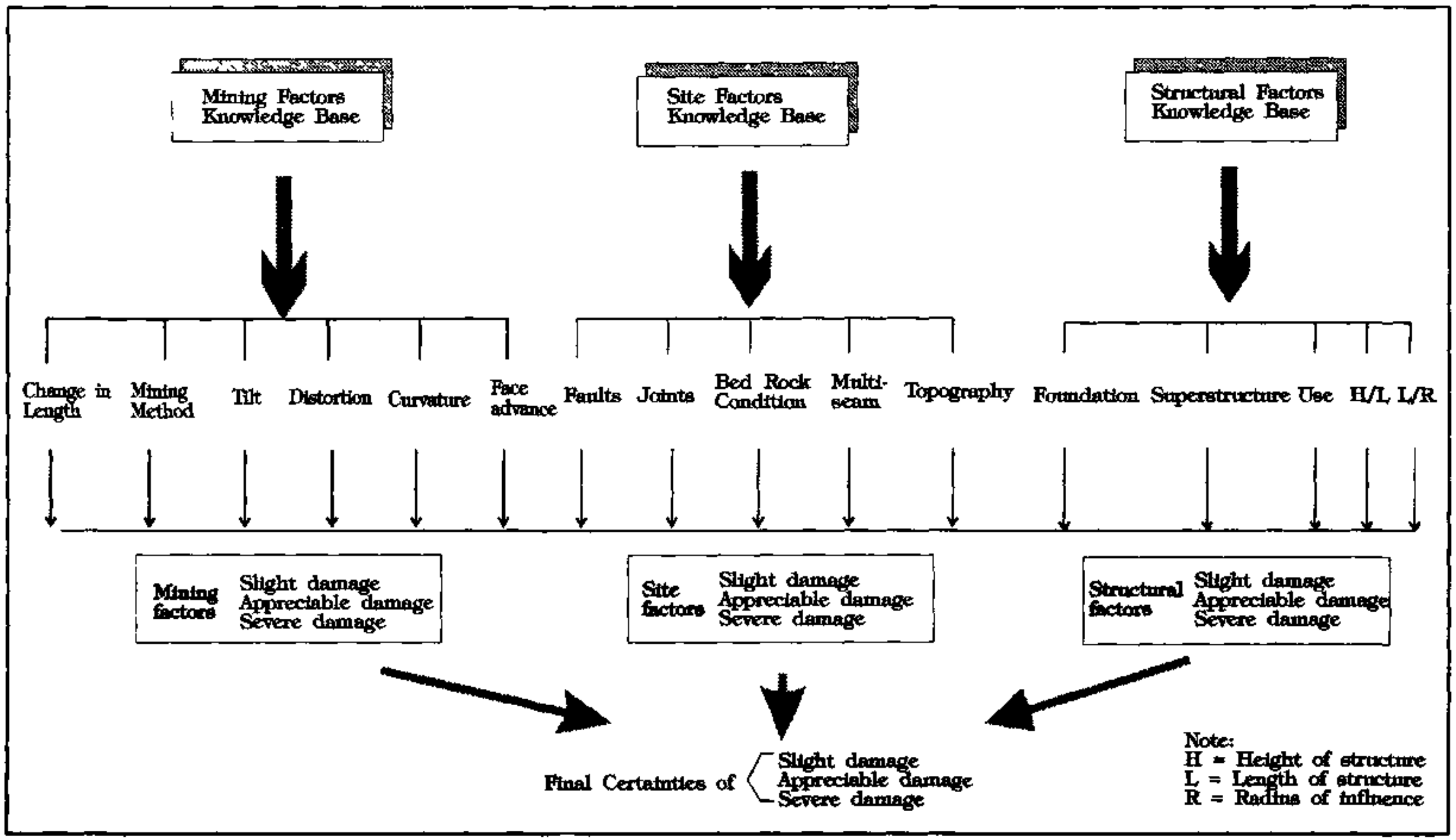


Fig. 5b Predicted subsidence profile along the survey line



Flg.6 Structure of three main knowledge base» far Bipert Stxacttae Damage Assessment System

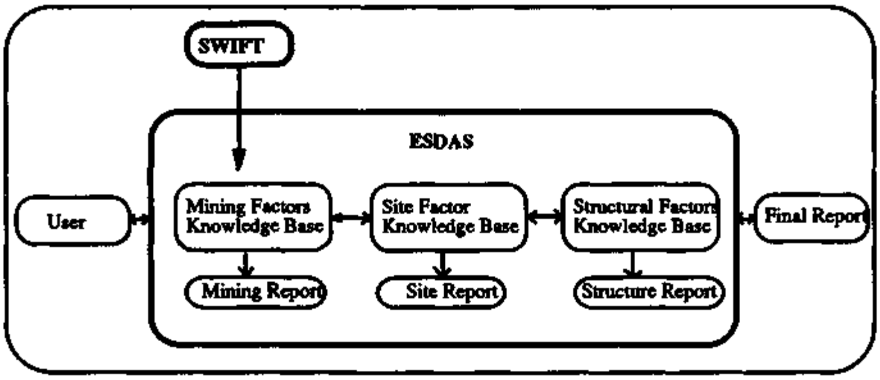


Fig.7 Structure of the integrated computer approach

Fig. 8 illustrates the site condition for this case study. The coal seam has an average dip of 5°. The two panels were separated by a 25-30 m wide pillar. The shape of each panel is formed by connecting each corner, which has its coordinate, along the panel boundary. The depth was 170 m, extracted seam height 1.17 m and the mean panel width for these two panels was 125 m and 90 m respectively. The surface structure, 85 m x 30 m, was located at the edge of panel No.2, as illustrated in Fig.8.

The consultation starts in the Mining factors knowledge base. SWIFT is called, and the user is required to provide such input data as: the mining data described above, subsidence factor (0.9 used), coordinates of the corners for each panel, survey type (line for this case), etc. After inputting this data, SWIFT will predict the subsidence profile, displacement profile and strain profile along the line AB. Fig. 9 indicates the subsidence and strain profiles predicted from SWIFT for line AB. As shown in Fig.9, the structure covers both compressive and tensile zones. One part of the structure, 48 m, is subjected to average tensile strain of 0.8 mm/m, while the other part, 37 m, is subjected to average compressive strain of 0.7 mm/m. Based on this data, the change in length of the two parts can be calculated. The maximum value between these two is selected for the evaluation of the effects of strain on the damage level. Further questions in the mining factors knowledge base are then processed. At the end of this procedure, the individual certainty factors from each of the rules are combined to obtain the final degree of slight, appreciable or severe damage due to mining factors. A report of this result is presented.

In a similar way, questions associated with site factors and structural factors are asked. After finishing all the questions, the system moves in to the Conclusion knowledge base. By combining the mining, site and structural certainty factors, the overall damage degree of slight, appreciable or severe damage can be obtained. The system finally selects the largest certainty factor as the final assessment of damage to the structure. Meanwhile the main contributing factors leading to the damage and recommendations for damage control are stored in two different text files, which can be presented to the user at the end of the consultation. The final conclusion reached and a

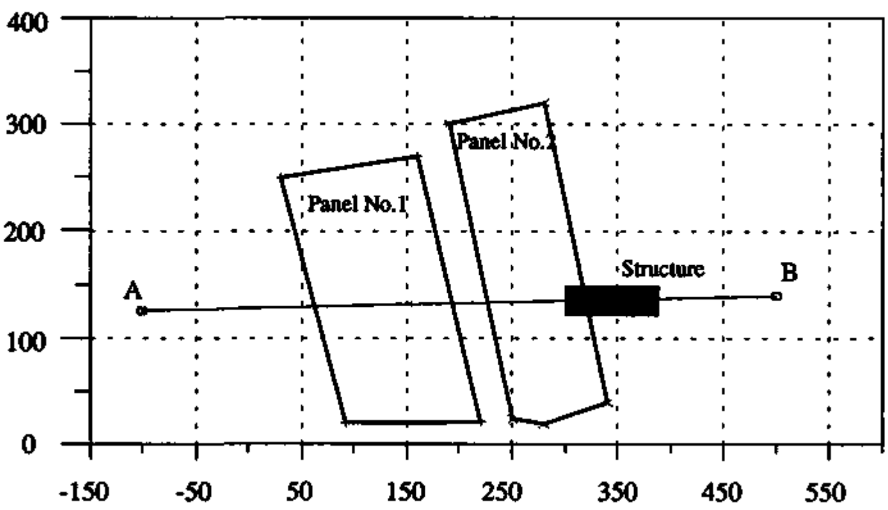


Fig.8 Two panels' layouts and line AB in relation to a surface structure for the case study

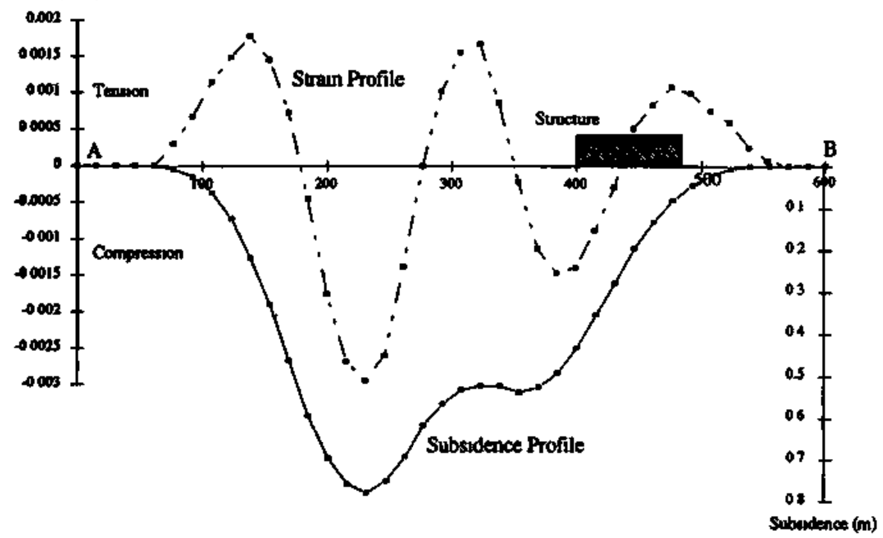


Fig.9 Subsidence and strain profiles for line AB, predicted from SWIFT

Final Repart

Slight damage risk is	**-0.88**
Appreciable damage risk is	**0.93**
***Severe* damage risk is**	**0.86**

Conclusion

The structure will suffer Appreciable damage with certainty of 0.93

Description of typical damage

Slight fracture showing on outside of the building, doors and windows sticking, service pipes may fracture.

Main factors leading to damage

Mining method; face advance; strain effects; site location; joint existence; multi-seam mining

Measures suggested to be taken

Change mining method to partial or full retreating extraction;
Reduce face advance if possible;
Keep building from joint systems.

Table 2 Final report for the case study

description of damage to the structure are also presented at the end of the consultation. Table 2 shows the final report for this case study.

7. CONCLUSIONS

This papei has described four computer programs developed at the University of Nottingham for mining-induced ground movement and subsidence studies. The numerical model, FEP, is capable of evaluating strains, stresses and failure over a wide range of geological and mining conditions. The stress and strain patterns predicted by this model can be interpreted in terms of their direct influence upon potential water flow into the mining excavation. The package can also be used to assess the interaction effects due to multi- panel or multi-seam mining. Although SEHSPP was developed based on the SEH, the principals can be applied to any Coalfield, if the local subsidence data is available. SWIFT is a powerful ground movement prediction package which can deal with any complex mining condition. The combination of SWIFT with ESDAS forms an integrated computer approach, which can be used to assess and control mining subsidence damage risks in any Coalfield.

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