GROUND MOVEMENTS DUE TO UNDERGROUND MINING

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ABOUT THE AUTHOR

KEVIN THOMPSON is Employed as a Registered Surveyor with the Crown Lands Service of the Department of Conservation and Land Management at Maitland.

Kevin commenced work as a Trainee Surveyor with the Central Mapping Authority of N.S.W. in 1975. Upon completion of the Surveying Degree at the University of N.S.W. he continued to work as a geodetic surveyor with the CMA until 1979 when he resigned to enter the private sector workplace.

Kevin worked with private survey firms in Sydney and the Hunter Valley as an articled surveyor and as a registered surveyor. In 1986 Kevin rejoined the public service and was employed by the Department of Mineral Resources in Newcastle. His involvement with the mining industry has lead to an appreciation of various causes of ground movements both by natural and human causes. Being involved with this industry also inspired Kevin to continued his education in the area of land management.

Kevin, being keen to use both his surveying and land management qualifications, commenced his employment with the Crown Lands Service in 1993.

1. INTRODUCTION

The mining of coal from Eastern Australia has enabled the development of one of the most important industries in Australia. In New South Wales the coal industry is the State's largest export earner and it is a major source of employment and income for the mining areas, (Holla, 1987b). Coal is also an important local commodity as an input to the power generation, steel and cement industries. Coal is one of the most valuable resources in New South Wales. It is a non-renewable resource that requires careful management of its recovery so that the maximum benefit to the community is achieved.

In New South Wales, the juxtaposition of coal deposits and urban developments has created conflict in recent years. Mining of coal by underground methods causes subsidence of the overlying land and this can result in ground movements that damage surface structures and can disturb infrastructure. The extraction of coal that provides so many benefits to the community can also prove to be a nightmare for those people directly affected by mine subsidence.

The conflict between land development and underground mining will probably escalate in the near future. As the population continues to grow, the need to expand urban centres forces development of land further into Coal Mining Authorisation Areas and existing leases. Subsidence can be, and is, restricted in some areas to enable surface development to proceed and to protect existing surface developments. The impact of restrictions on mining companies can be severe with the actual viability of existing mines being placed in jeopardy.

2. NATURAL RESOURCES

The planet earth provides the environment in which human beings live. In order to survive, we need land to stand upon, air to breath and food to eat. Based on current technological abilities, the habitable limit of our vast planet is the land surface. The surface area is limited by the physical size of the planet, the climate and the topography. From the land surface we have been able to develop our lifestyles by using far more of the earth than just the part where we live. The earth naturally provides all the resources needed by humans to live. These natural resources can be either organic or inorganic, they can be used for food or as an input to a technological process developed to maintain or enhance our lifestyles.

The overall management of natural resources is a relatively recent concept. Prior to the 1960's little thought was given to the inter-relationships that exist in the natural environment. The use of natural resources depended on attaining the right or licence to carry out the necessary actions to harvest the resource.

Whether it was farming, fishing, mining or building a town, the activity was carried out to satisfy a demand that was current at the time of the activity. Certainly, there were rules and regulations specific to the activity, but it would have been rare for a co-ordinated approach to have been taken to ensure that conflicts of competing resource use were minimised. As a result, some of our country's best agricultural lands are situated under towns, many species of flora and fauna have been either extinguished or reduced to levels threatening extinction and some of our coal authorisation areas and colliery holdings are now being developed, on the surface, as urban areas.

"Resource management is a process of decision-making which allocates resources according to the needs of humanity. This management is confined by humanity's technology, political and social institutions, culture and legal and administrative arrangements. While striving for the best solution, trade-offs must be made." (Dept. of Ecosystem Management 1990, 2).

3. COAL MINING

Coal is a fossil fuel formed from the accumulation of plant debris subjected to intense heat and pressure over millions of years. "Major coal - forming periods commenced about 350 million years ago, and extended to about 180 million years ago" (NSW Coal Association 1989, 3). During this period, layers or seams of coal were laid down in sedimentary basins. In New South Wales the main coal deposits are located predominantly in the Sydney - Gunnedah Basin. The depth below the land surface varies from outcrop to in excess of 2000 metres.

Coal mining in Australia first occurred at Newcastle shortly after its discovery there in 1796. Early coal mining was carried out at shallow depths and became widespread around Newcastle and the Lower Hunter. Early mining was by the "bord and pillar" method of underground mining, using hand tools. The controls upon miners were few in the early years of development and accurate records of workings were not prepared. The Department of Mines was inaugurated in 1874. A report from 1887 stated that at least 40 collieries worked the Newcastle area during the 1880's. (Fryer 1980, 60). It was not surprising that this mining resulted in disasters including severe surface movements.

Royal Commissions following near disasters in 1896 emphasised the need for accurate records of mine workings as basic information. For safety of workers underground and as a precaution to prevent the surface from being disturbed, the location of underground workings relative to the surface and other workings was seen to be very important. Unfortunately, it was not until the introduction of The Coal Mines Regulation Act of 1912 that there was a formal requirement for mine plans to be prepared and regularly updated. The early inhabitants of this district had to accept the hazard of mine subsidence.

The Surveyor of 1890, quoted in Fryer (1980, 60), wrote "to bring under his notice the question of undermining on the part of the Wickham and Linwood collieries, and whilst stating the grievances they (a deputation from the Wickham Municipality and Vigilance Committee), made use of the following hyperbolic language: 'There was no security for persons who had bought land and gone to the expense of building, many of the buildings being of valuable character.' It was considered that it was a reflection on the surveyors for not accurately indicating to the owners whether they were being undermined. " The Minister of Mines in his reply to the deputation, said that " arrangements are now being made for a surveyor to make a thorough survey of the mine to ascertain definitely the extent of undermining." Major Subsidence incidents occurred around Newcastle in 1906, 1908, 1916 and 1925. A Royal Commission into mine subsidence and these events in particular gave rise to the Mine Subsidence Compensation Act of 1928 and the formation of the Mine Subsidence Board (M.S.B.).

Modern mining has advanced with world wide technological improvements. Accurate surveys are now mandatory, they are necessary for both production works and for maintaining various records of workings and related information. The Newcastle Coalfield, consisting of the Lower Hunter areas of Newcastle to Wyong, is predominantly mined by underground techniques. Underground mining has been carried out in Australia for nearly 200 years. It is now fully mechanised with complex machinery performing the work of men, working with picks and shovels as was the case even into the 1950's. There are two stages of mining, first workings or mine development and pillar extraction. First workings are necessary to provide access to the coal seams using vertical shafts and inclined tunnels. They also provide a means of ventilation and transportation throughout the mine, as well as possible access to all the coal within the limits of the holding. Pillar extraction is the operation where a company plans to make some profit. Approximately 30-40% of coal is mined by first workings making development costs very high, especially in the deeper mines. Mine plans are determined so as to develop an area with a series of headings and cut-throughs called a panel. The panel consists of the roadways and the remaining coal pillars. A typical mine layout is shown in Figure 1 with more detail shown in Figure 2.

The size of the coal pillars depends on a number of factors of which mine safety is paramount. The minimum size of pillars is determined on mine safety, there must be enough coal to ensure that pillars do not collapse. There are three methods used to extract pillars within a panel, Bord and Pillar, Longwall and Shortwall. The choice of one of these methods will in part determine the maximum size of the panel pillars. Bord and pillar mining is an extension of first workings, at the completion of the panel the pillars are extracted in a systematic manner while working back to the main access headings. In this way extraction rates of over 80% can be achieved. Longwall and shortwall mining techniques offer greater safety for the operators of the machinery and a more efficient recovery of the coal.

The two methods involve the mining of large pillars of solid coal. With longwall mining the dimensions of the pillar are typically 200 metres wide by a length that can vary from 500 to 2000 metres. Shortwall pillars can be of similar length but are considerably narrower with a width of about 60 metres. With these methods the coal is extracted by shearing layers from the face, hydraulic roof supports across the entire face form a protected area for men and machinery. 100% of the pillar is extracted by these methods in a relatively short period of time.

Mine subsidence is the lowering or settling down of land due to the removal of a section of substrata. When the layer of rock or coal is removed a void is created and the forces within the surrounding rocks are redistributed to allow for the loss of support provided by the material removed as shown in Figure 3. When sufficient material is removed the forces within the rocks are unable to be supported and the strata near the void collapses. This predominantly vertical movement (sagging) is transferred to overlying strata and is reduced with distance to the surface, geology and mining geometry. When a mine extracts coal by any of the methods described above, there can be mine subsidence. The discipline of subsidence engineering has been developed to gain a better understanding of the processes involved both underground and on the surface. The aim of subsidence engineers is to assist with mine planning so that underground safety is maintained and the maximum recovery of coal is achieved with a minimum of surface disturbance.

Subsidence investigations are not new, the origins of scientific subsidence studies stem from Belgium in the 1820's, where a commission investigated surface cracks and damage to buildings in Liege. By 1880 a number of empirically based theories had been developed in Britain, Europe and the U.S.A. In the 1920's these theories were subjected to significant review. By the 1950's, the five basic elements of subsidence of the ground were recognised. They are the vertical displacement (subsidence), the horizontal displacement, slope (tilt), curvature and strains (tension and compression). Figure 4 indicates these elements relative to the extracted seam. Figure 5 indicates the progression of subsidence and its effect on the surface.

In Australia, subsidence engineering techniques were taken directly from British empirical research and applied to Australian mining and geological conditions. It became clear that subsidence characteristics are site specific and the British subsidence trends did not match those observed in Australia. Studies commenced in Australia in 1965 and by 1970 a co-ordinated programme of subsidence investigations was in place in the Newcastle District. Handbooks have been developed for the Newcastle, Southern and Western Coalfields, these assist in predicting and modelling subsidence behaviour. Ongoing research is being applied to the response of surface structures to subsidence. The magnitude of subsidence parameters is dependent on the location of a point above the extracted panel as well as mine geometry, geology, surface topography and so on.

4. MONITORING OF MINE SUBSIDENCE

A co-ordinated program of subsidence monitoring was established by 1970. The investigations involved the frequent repetitive measurement of levels of and distances between ground stations. The ground stations consisted of 1.5 metre lengths of G.I.Pipe driven into the ground and collared by concrete for stability. The top of the pipe was capped to enable a punch mark to be placed for a reference point. Figure 6 shows a typical ground station. The ground stations were placed in lines (gridlines) across the proposed extraction area with each terminal extending beyond the limit of mining movement. Generally, the lines of stations were placed relative to the direction of extraction advance, both parallel and orthogonal directions. After some early investigations, the separation of stations was eventually determined to be a function of the depth of seam below the surface. Generally, for the Newcastle District, the spacing was between 5 and 20 metres.

Monitoring of changes of levels of stations was considered very important and observations were made with first order levelling equipment. Distances between the stations was made with a standardised wire corrected for temperature, tension, sag and slope. Initial computations were made by survey staff and passed on to the engineers for computer analysis of changes in station positions during the period of active mining and post mining settlement. This analysis determined the magnitude of subsidence and ground stains and tilts. Actual horizontal movement of stations was not measured.

More recent trends in monitoring include the use of total station survey instruments for data capture. This process often used by the colliery survey teams is fairly rapid and provides 3 dimensional (3-D) station coordinates. The Department of Mineral Resources, being the "control" and requiring the data for ongoing research, needed to maintain a more rigorous approach to ensure quality results. The Department improvised a modified, precision "second" order levelling with the use of a Wild NA2 and parallel plate micrometer and aluminium staves observed both sides for levelling. Distances were still observed with a standard wire. In addition, observations were taken for horizontal co-ordinates using theodolite and EDM for the control traverse and radiations, offsets from the traverse lines were made to check radiations to stations. Vertical angles and instrument and reflector heights were used to determine levels. Computations and basic analyses were carried out by the surveyors using HP 41CX programs and the results were passed to the engineers for advanced analysis. With the purchase of personal computers and powerful spreadsheet programes, computations and analysis became far quicker and easier. Survey equipment was updated to include Wild NA2000 level and data recorder, Wild T1600 electronic theodolite and DI2002 precision EDM with data recorder. The updated equipment provided rapid down loading of survey observations and minimisation of human error.

5. EXAMPLES OF SUBSIDENCE MONITORING

5.1 Pacific Highway and Vales Road at Wyee

A number of longwall panels were extracted from an area just north of Doyalson. The coal seam mined was about 3.4 metres thick and 205 metres deep. Three panels were below the Pacific Highway and each panel was about 200 metres wide. A continuous pillar of coal about 20 metres wide, was left between the adjacent panels. The Department established a gridline in the nature strip adjacent to the northbound carriageway. Bench marks were placed at each extremity on "stable" ground. The RTA surveyors also placed gridlines across the panels with the stations located in the bitumen roadway and then monitored the 3-D movements. The RTA established a number of survey pillars to assist in their traverse control and numerous radiations. Figure 7 shows the layout and some of the surface features.

Initially the line was monitored only for the first panel and not for 3-D movements. The gridline was later extended to the south beyond the limit of expected movement due to the third panel. Surveys of mining movements due to the second and third panels were total 3-D surveys. A summary of the results of the Departments monitoring of the first panel is that the maximum subsidence observed was 2.23 metres and horizontal ground strains were about 8 mm/m. Figure 8 shows a number of graphs summarising the results of monitoring, the last graph was a calculated horizontal movement assuming the end points were stable and comparing the changes in distances across the gridline. This subsidence was more than that expected for the longwall mining but after investigation it was determined that a previously mined seam at about 180 metres added to the subsidence. Even with the above movement, the highway remained open to traffic, although repairs were required and single lanes were closed to effect the repairs.

Horizontal movements recorded by the RTA were supplied to the Department, a number of charts of the movements of points over time were prepared, but as this was not yet an area of research for the Department, further study was not undertaken. The maximum magnitude of movements was in excess of 100 mm from the initial point position. As a guide, the components of horizontal movements are towards the centre of the extraction panel and parallel to the direction of mining. Points tend to move towards the approaching mining face and then reverse direction as it passes and move back towards the starting point as the face passes and moves further away. This movement is like a wave with the points nearest the centre of the panel being subject to most movement in this parallel to mining direction. Combined with the movement towards the centre, the maximum horizontal movement may be offset from the centre.

The Department extended its control for the second and third panels but certainty of results was not high due to insufficient premining control surveys. A number of cadastral monuments were also measured before and after mining panels 2 and 3, again priorities were such that no time was permitted to analyse the information collected.

5.2 Newstan Colliery Property near Fassifern

Two panels were mined at relatively shallow depth under hilly terrain being part of the land controlled by the Newstan Colliery. The two panels were in fact not adjacent but rather verticcaly separated by about 15 metres. The first panel was at a depth of about 40 to 60 metres, it was about 160 metres wide by 650 metres long with an extracted seam thickness of 3.4 metres. The second seam was below the first with the eastern sides aligning vertically. The second panel was about 210 metres wide by 900 metres long, the thickness of the extraction was 3.2 metres. There was a delay of about 6 months between the mining of the two panels.

The gridline was planned for both panels to be monitored for 3-D movements with substantial control and check measurements. Ground stations were at 10 metres spacings and extended well beyond the expected limits of mining movements. A number of pre-mining surveys were undertaken to ascertain the level of natural ground movements and survey precision. The gridline was placed across the panels perpendicular to the direction of mining advance. The line was located near the top of a ridge and this was not far past a deep valley where the seam was closest to the surface.

Figure 9 shows the layout of the two seams and the surface contours. Figures 10 shows the results of monitoring for the first panel. It can be seen from the graphs that the maximum subsidence was just over 2 metres and horizontal movements were about 0.7 metres. There was considerable surface damage due to this mining. Figure 11 shows the results of monitoring the second panel only, the movements of the first panel were taken as the undisturbed positions. Maximum subsidence was over 3.2 metres and horizontal movements were in the order of 1 metre. The total movements due to both panels being mined were directly observed and are the complement of the individual results.

There was considerable surface disturbance all of which was restored by the coal company. This was a special case of mining and only permitted because of the coal company's ownership of the land. The magnitudes and pattern of horizontal movements are not typical of those to be found in most mining situations. It has been recognised that the surface topography, especially the proximity of the gridline to the deep valley, has had a significant influence on the magnitude and pattern of horizontal ground movement. Whereas it is usual to detect a large amount of elasticity in the ground, in this case there was considerable deformation.

Usually the ground stations usually move out and then back following the passing of the mine face, it is believed that the ground slumped downhill and following the passing of the mine face gravity was too much for the elasticity of the strata. Figure 12 is an attempt to show the effect of surface slope on the horizontal movement.

5.3 Woodrising Estate at Booragul

Two adjacent panels were mined after considerable public debate and inquiry. The panels were designed such that subsidence movements would be tolerated by most surface structures. This did not mean that structures would not be damaged but most repaires would be minor. About 60 structures were damaged out of about 175 that existed at the time of mining and the average repair bill was $1200. A few suffered major damage but all repairs were covered by the Mine Subsidenec Board.

The panels were similar in size, both being about 150 metres wide by about 2.4km in length and about 180 metres deep. The extracted seam thickness was about 2.3 metres. The Department established a network of stations in and around the undermined houses with control marks being well away from mining. The colliery established as much of the standard gridlines as possible with the constraints of roads and houses. From the results of all monitoring, the maximum subsidence was about 550 mm and horizontal movements were about 100 mm.

Mining of the type at Booragul is seen to be acceptable for areas with surface development and subsidence of about 500 mm and horizontal movement of about 100 mm could be encountered. In less developed areas the magnitudes of movements could well be greater although rarely like that at Newstan Colliery.

6. PROBLEMS FOR LAND SURVEYORS

6.1 Survey Control Marks

As an accurate and reliable bench mark with known height on the Australian Height Datum, care must be exercised in the coalfield areas of Newcastle and the Hunter Valley. This point is well known and understood by most if not all surveyors. The Land Information Centre, Survey Control Branch is generally kept informed of where subsidence is anticipated and then records can be modified to reflect the uncertainty of R.L's for a period. Generally, 90% of subsidence occurs shortly after the extraction. The residual settlement can take much longer, over 12 months sometimes, to reach a stable state.

As mentioned above, the ground can also move horizontally due to mining and therefore can affect the recorded easting and northing coordinates in the SCIMs register.

With the increase in use of survey control marks for coordination of the cadastre, as required by the Survey Practice Regulations 1994, there now arises the issue of ground movements due to mining and azimuth stability. Suppose a survey was effected prior to mining and a number of control marks were used with azimuth taken from SCIMs coordinates. Some time after mining, control marks which were affected by horizontal and vertical components of subsidence were used for azimuth for another survey. Are there enough safeguards in place to ensure that the resulting survey will reliable and accurate or maybe a sufficient change in azimuth has occured that at best could provide the surveyor with a considerable headache.

What might be the implication for movement of monuments? Could there be any legal determinations regarding land and the limit of ownership?

6.2 Mean High Water Definitions

When mine subsidence occurs the water level remains stationary however the land drops allowing the water to encroach onto the foreshore. The distance of the encroachment is dependent on the level of subsidence and the gradient of the foreshore.

6.2.1 Chain Valley Bay

An area of land at Chain Valley Bay, on the southern end of Lake Macquarie was undermined by the traditional bord and pillar method in the last decade. After mining was completed in the area, residents awoke one morning to find that there lakeside properties were flooded. After investigation it was determined that mine subsidence was the cause and near the very flat shore it was about 200 mm. The subsidence was due to the supporting pillars being pushed into the soft mudstone lying beneath the extracted coal seam. This had the effect of mining those pillars and considerably increasing the subsidence from that planned. The Mine Subsidence Board coordinated the restoration of the foreshore and properties.

6.2.2 Gwandalan

Again at the southern end of Lake Macquarie, in an area that had been mined well in excess of 20 years earlier, a similar situation to the Chain Valley Bay incident occured. Following investigatiion it was determined that a few, adjacent supporting pillars in an area of extraction again pushed into the floor.

The result was that a small area of Gwandalan suffered subsidence. At the shoreline the level of subsidence was about 500 mm, this figure rose to 800 mm in the centre of the subsided area.

7. CONCLUDING COMMENTS

It can be seen from the above examples that there may be a need to take alittle more care when surveying in the coalfields. I have not tried to present solutions because subsidence movements vary considerably in their development depending on the type of mining, geology, topography and many other variables. Patterns of movements are still being studied by the Department and others in the coal industry. I feel that where subsidence movements are significant the surveyor is in the best position to determine from all available measurements and information about local conditions, to determine how he (she) will effect the survey.

8. ACKNOWLEDGEMENTS

This paper was prepared using information from a number of sources which are gratefully acknowledged, none more so, however, than the Department of Mineral Resources Subsidence Engineering Section.

All responsibility for the ideas presented in this paper lie with the author, they do not necessarily reflect the views of the Department of Mineral Resources or any other agency.

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Figure 1: Typical Mining Layout

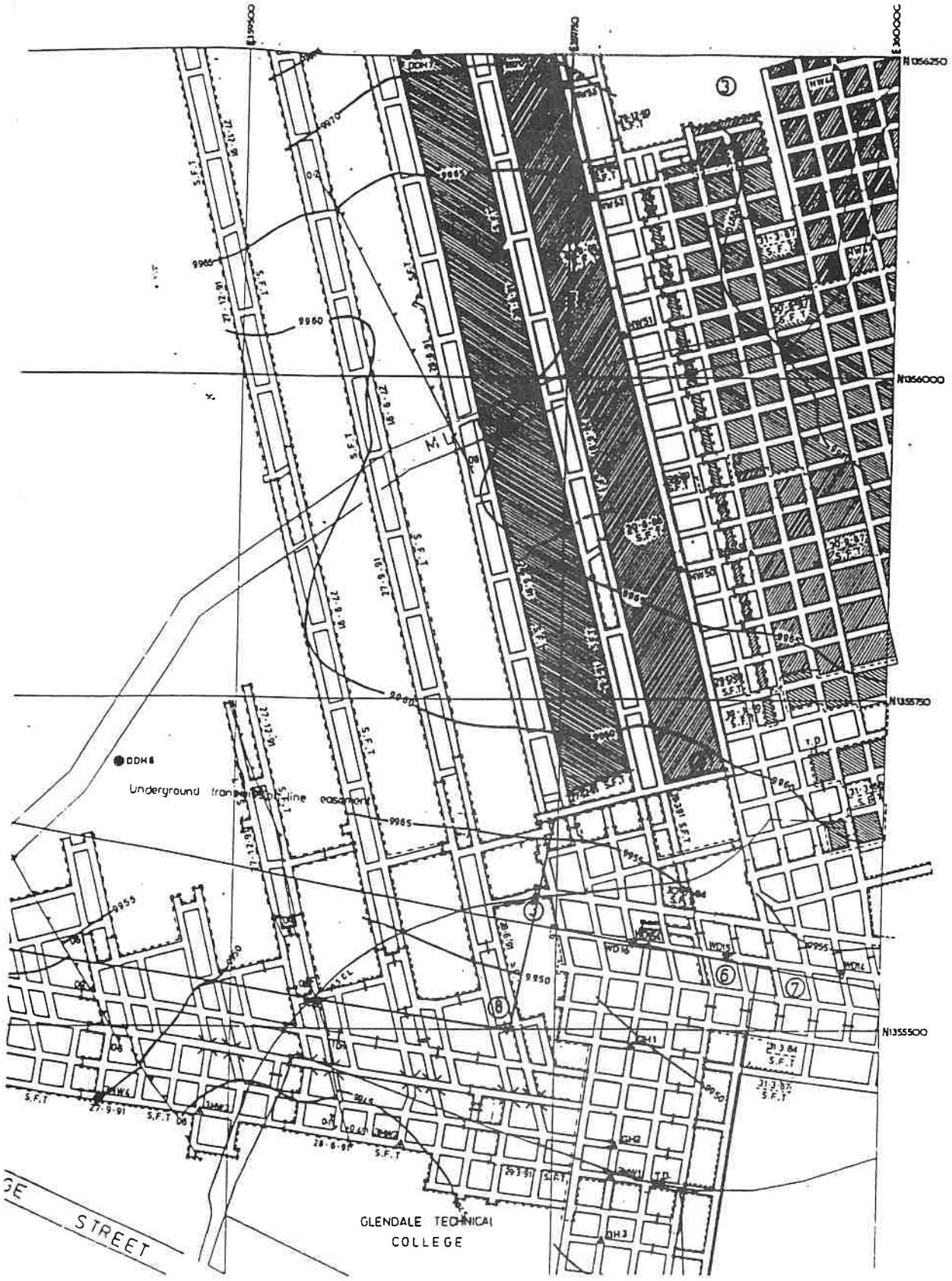


Figure 2: Detail of Mining Layout

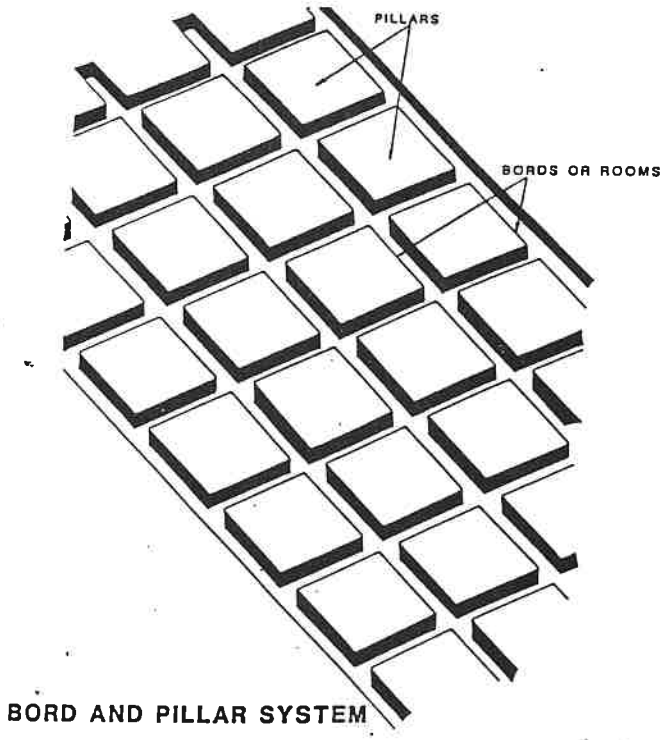
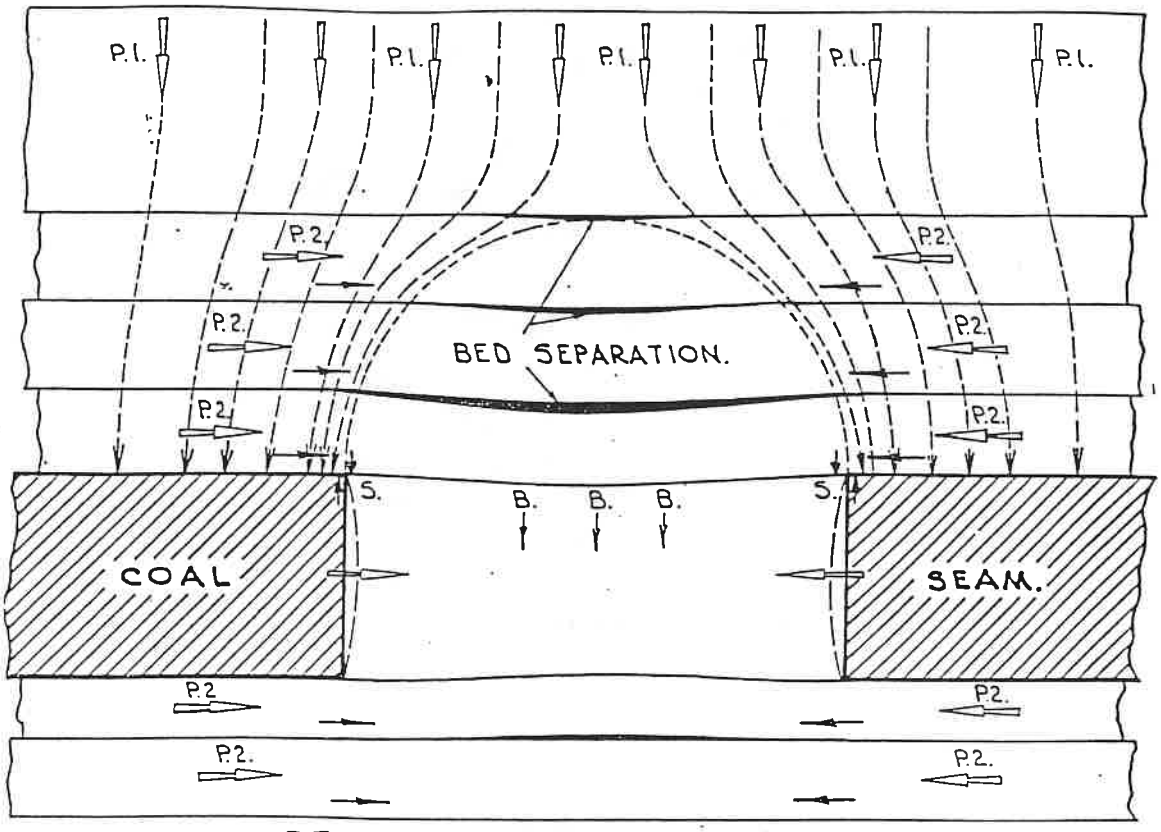


Figure 3: Roof Support in Coal Mines (Menzies, 1972)



RE-DISTRIBUTION OF FORCES AROUND NARROW EXCAVATION.

DIRECTION OF PRESSURE DUE TO OVERBURDEN WEIGHT- P.I.
LATERAL MOVEMENT OF COAL SIDES AND IMMEDIATE ROOF AND FLOOR STRATUM TOWARDS THE OPENING OR VOID. - P.2.
LATERAL HORIZONTAL STRESSES CAUSED BY THE FRICTION BETWEEN THE MOVING COAL AND THE ADJACENT ROCK BEDS.
RE-DISTRIBUTION OF THE VERTICAL FORCES P.I. AROUND THE EXCAVATION IS SHOWN BY DOTTED LINES THUS:-

Fig. 3 Roof Support in Coal Mines (Menzies, 1972)

Figure 4: Characteristics of Subsidence, Vertical & Horizontal Components (Holla, 1987b)

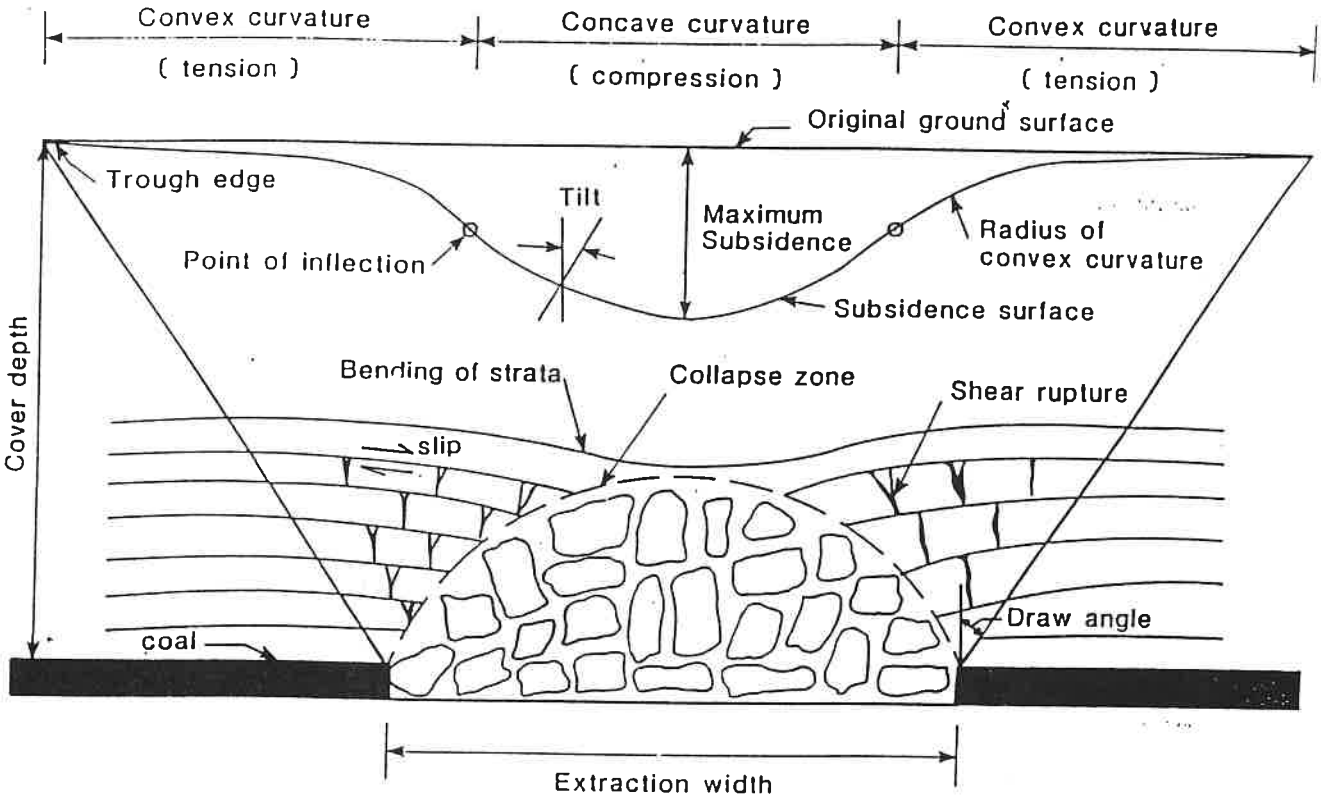


Fig. 4a Subsidence Effect of a Large Underground Extraction (Holla, 1987a)

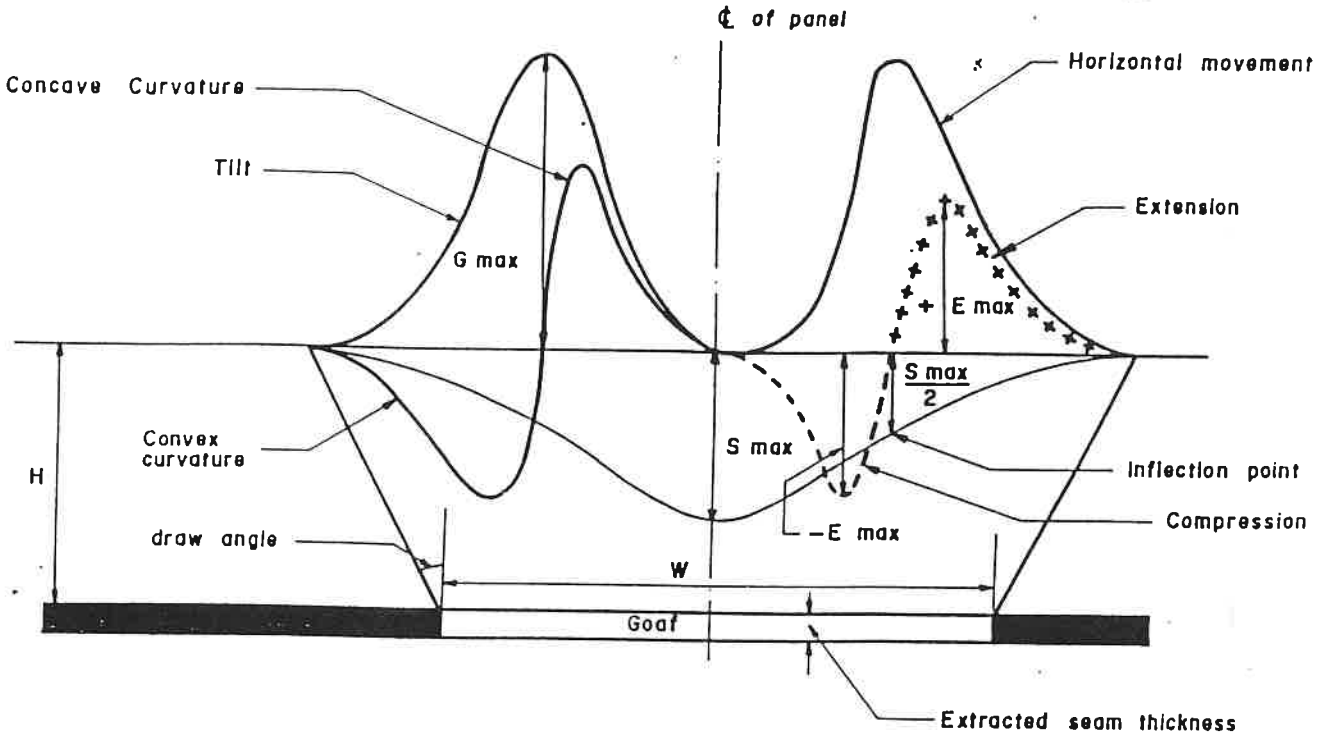
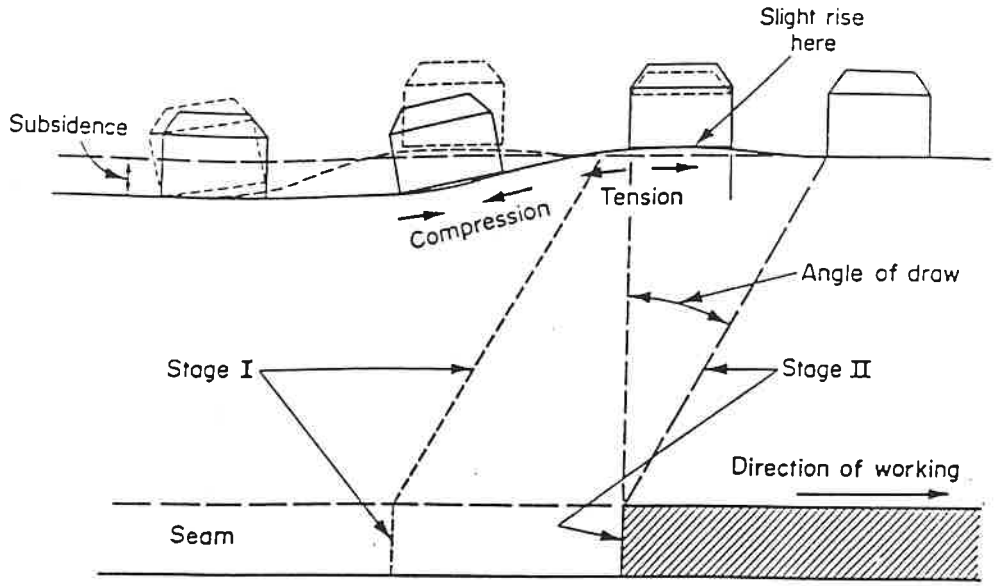


Figure 5: Effects of Subsidence Wave (Nawar, 1985)



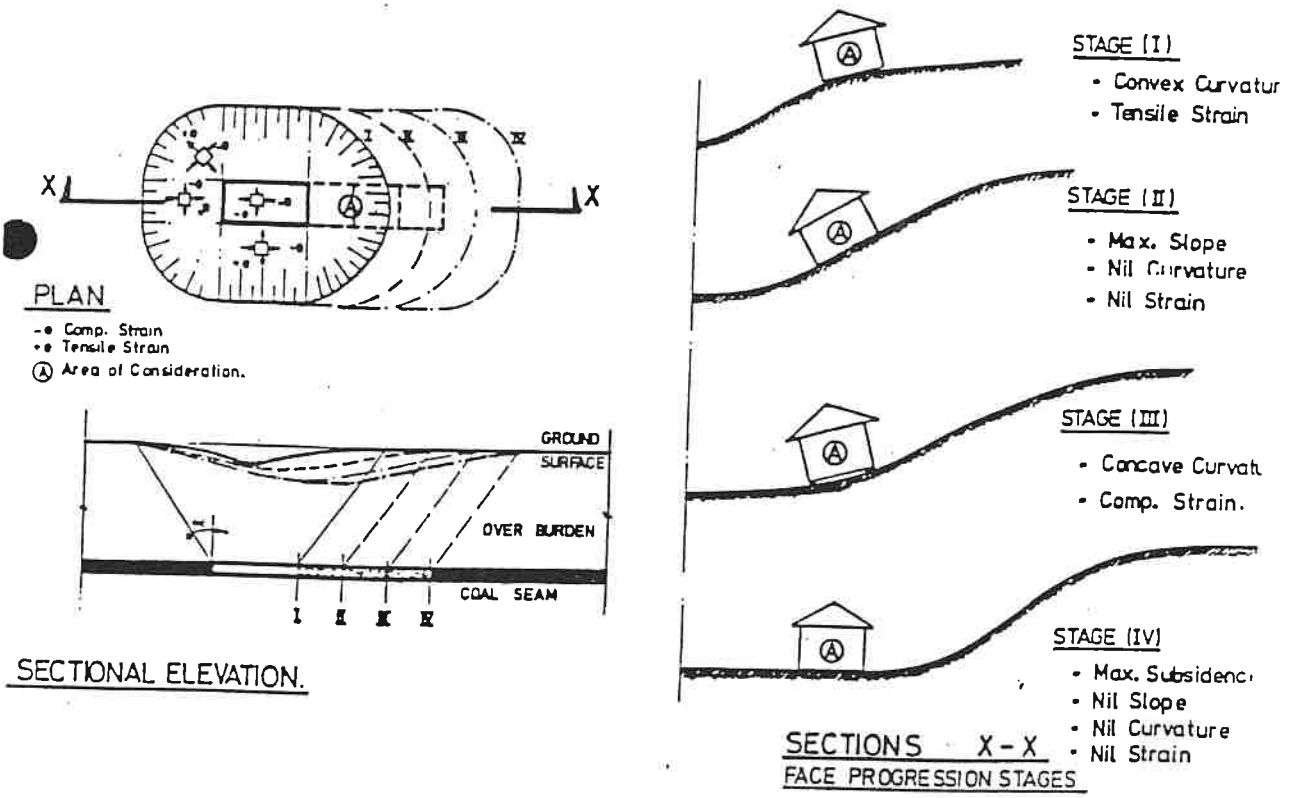


Figure 6a: Details of Subsidence Ground Station (Holla, 1987a)

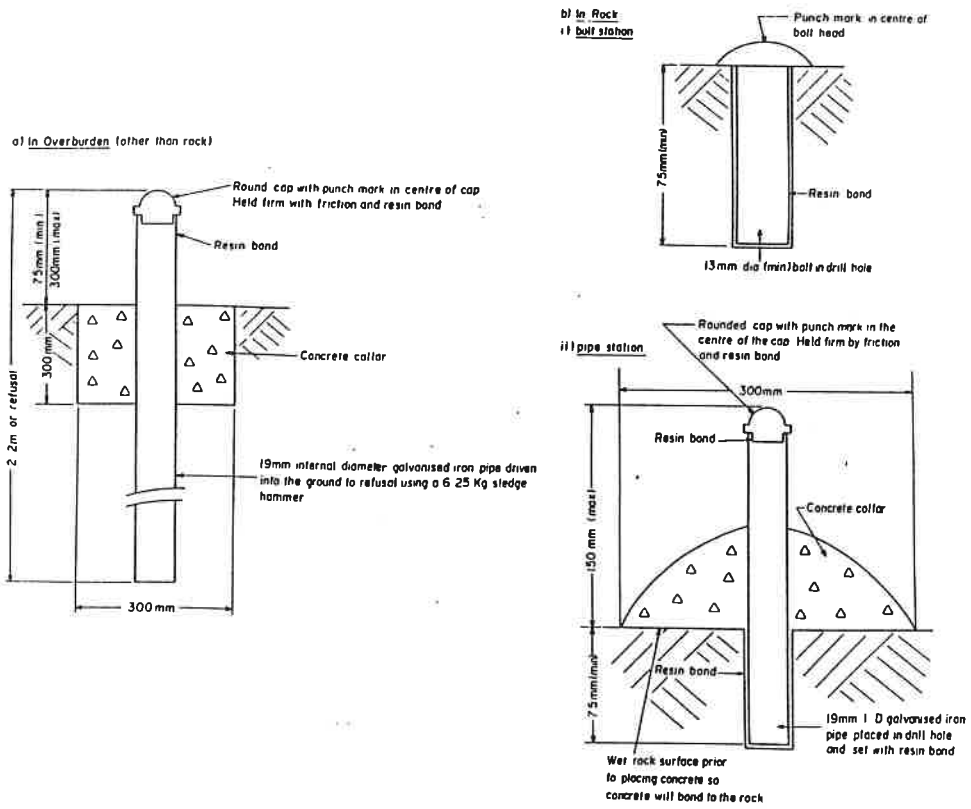


Figure 6b: Typical Layout of a Subsidence Gridline

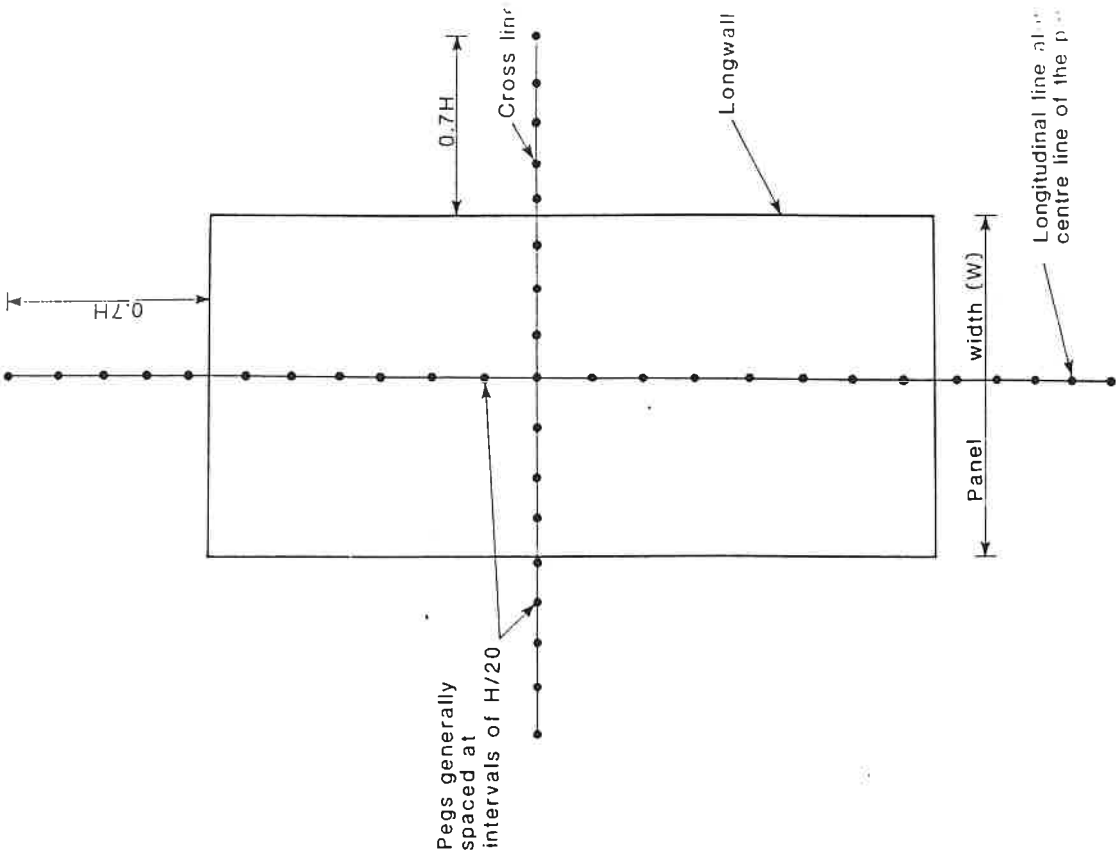


Figure 7: Longwall Extraction at Wyee (Holla & Thompson, 1988)

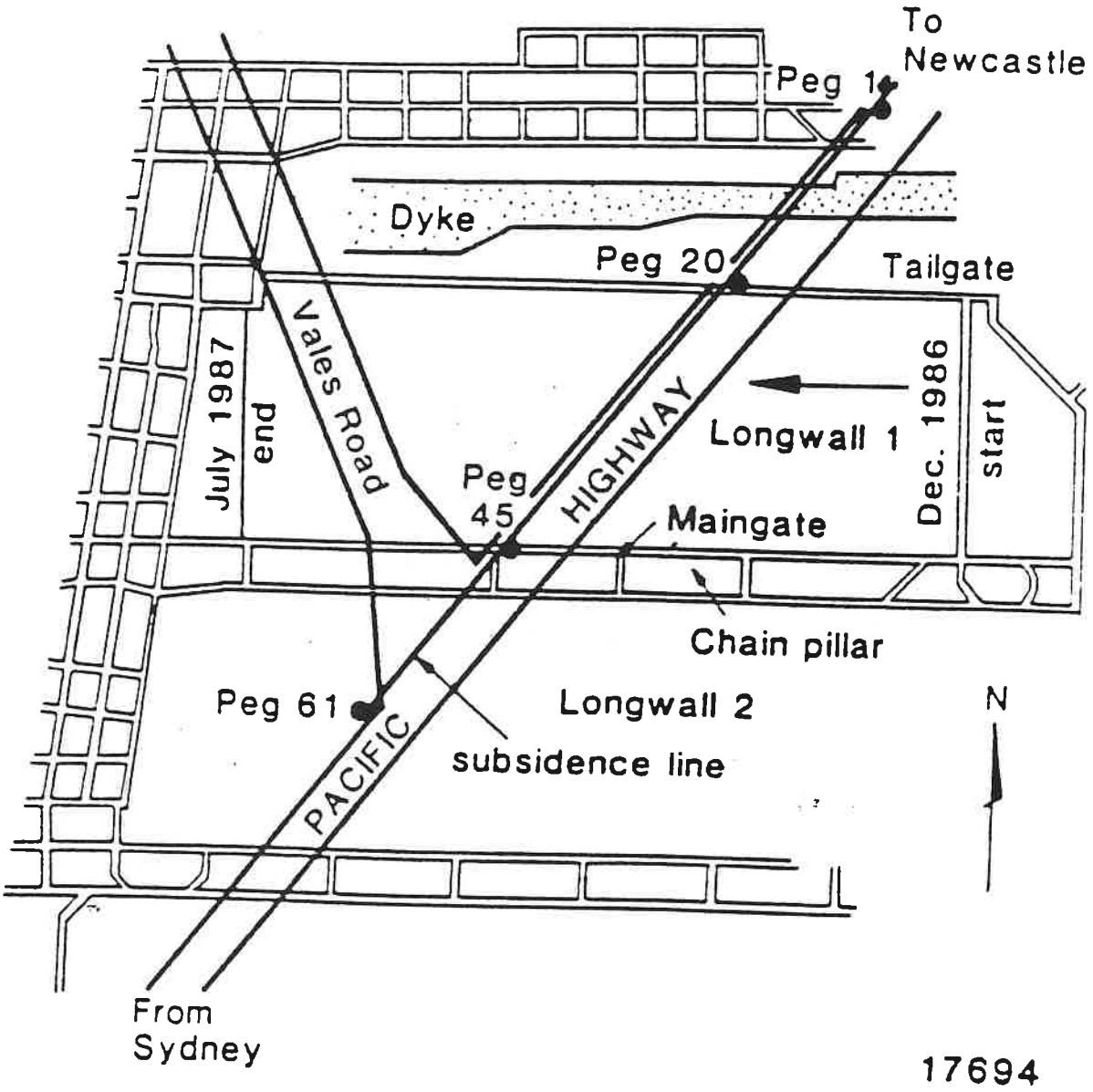


Figure 8: Subsidence Movements along the Highway (Holla & Thompson, 1988)

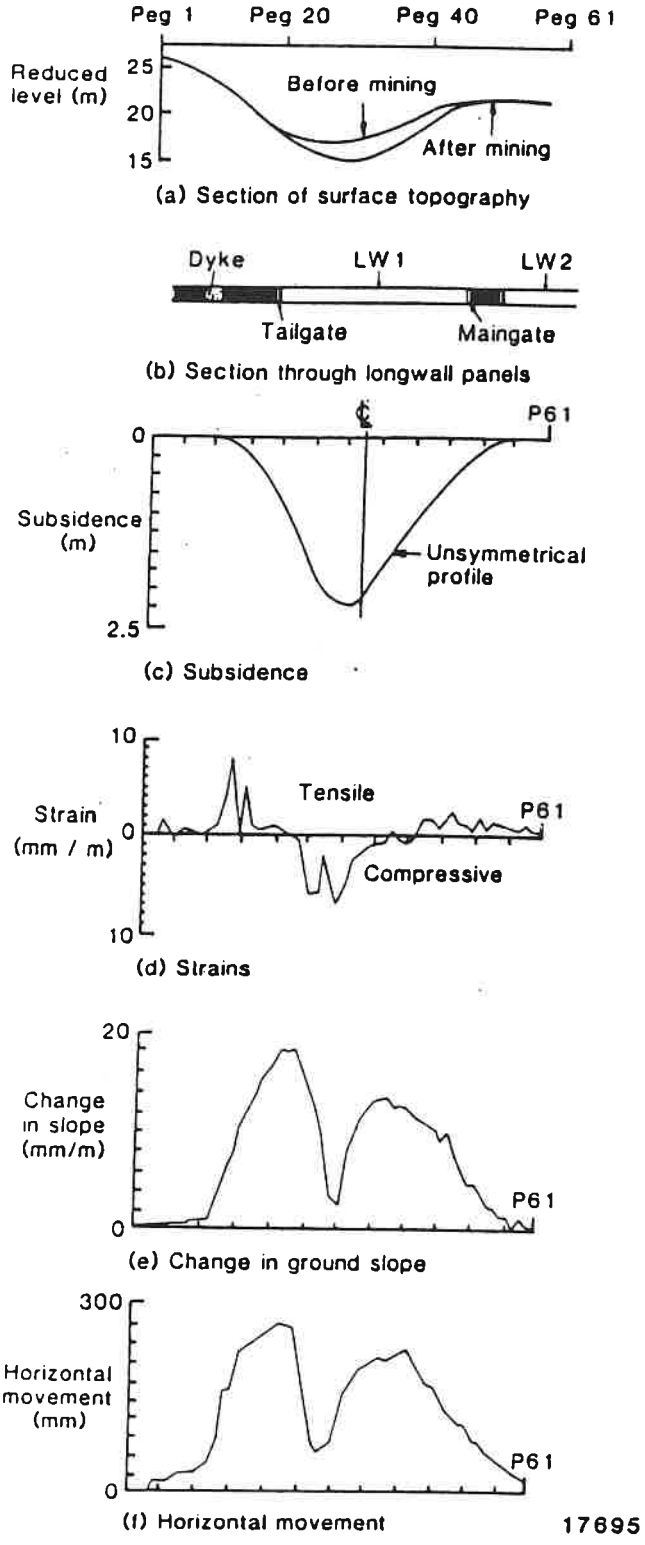


Figure 9: Longwall Extraction at Fassifern (Holla & Thompson, 1992)

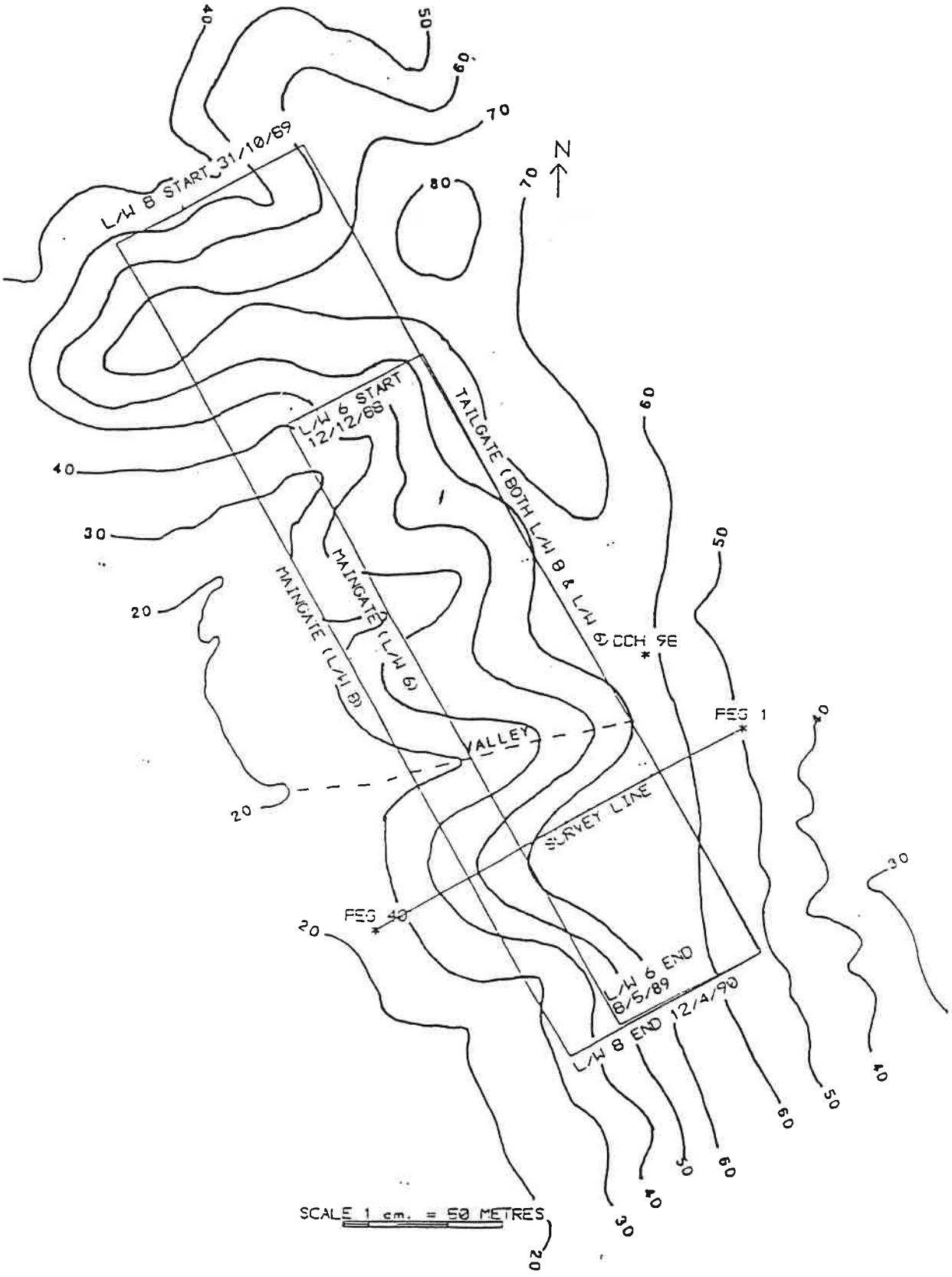


Figure 10: Subsidence movements due to First Panel (Holla & Thompson, 1992)

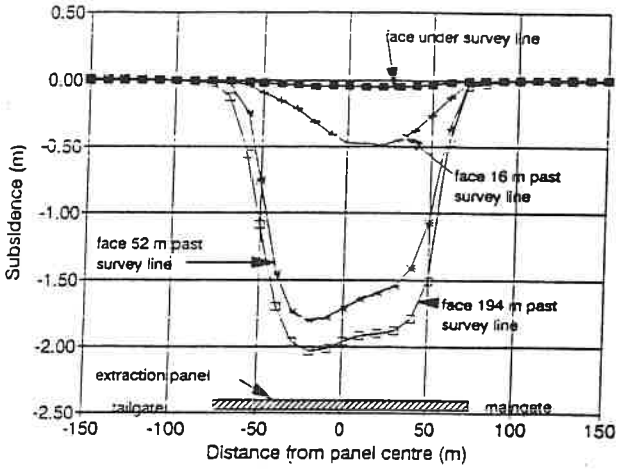


Figure 4. Subsidence due to Mining in LW6

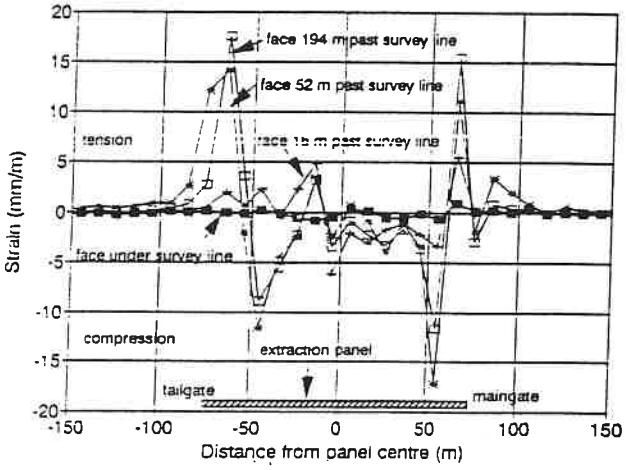
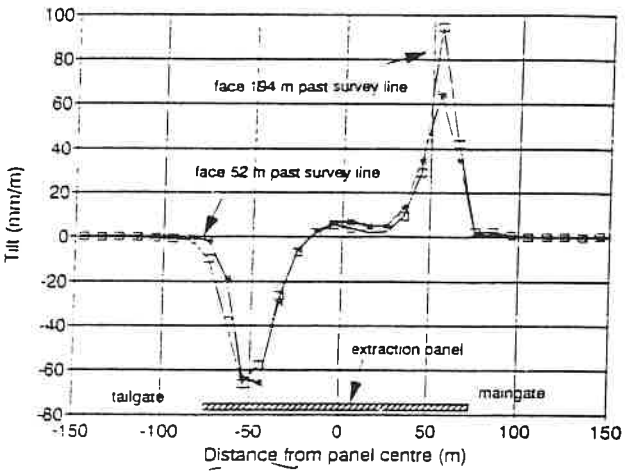


Figure 5. Strains due to Mining in LW6



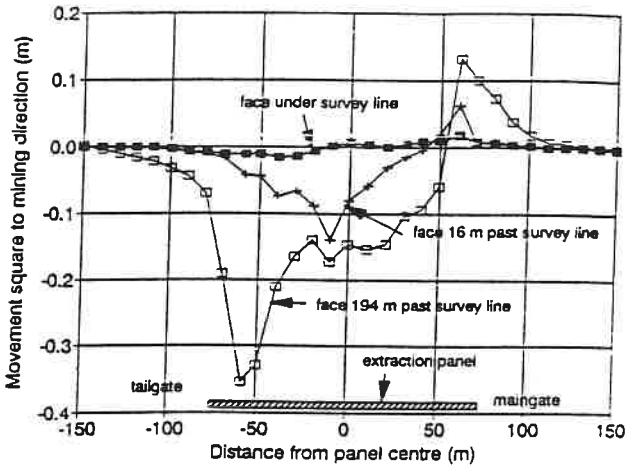


Figure 7. Movement Square to Mining Direction due to Mining in LW6

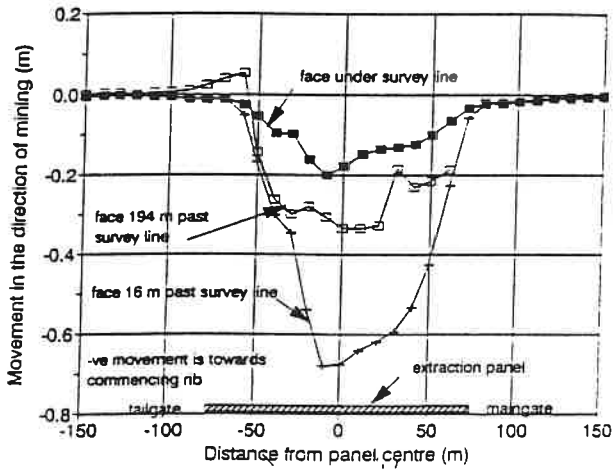


Figure 11: Subsidence movements due to Second Panel (Holla & Thompson, 1992)

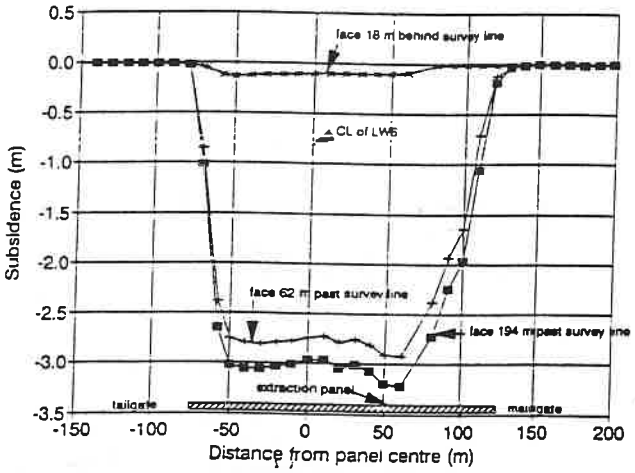


Figure 9. Subsidence due to Mining in LW8

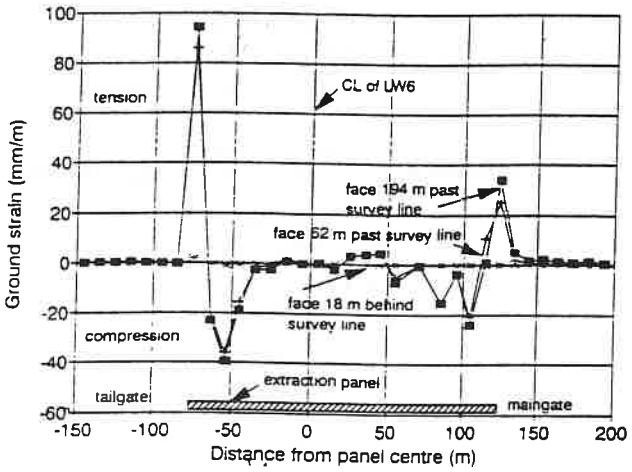
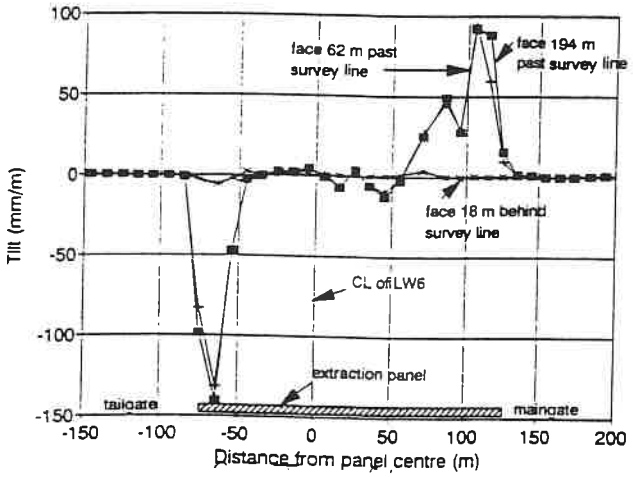


Figure 10. Strains due to Mining in LW8



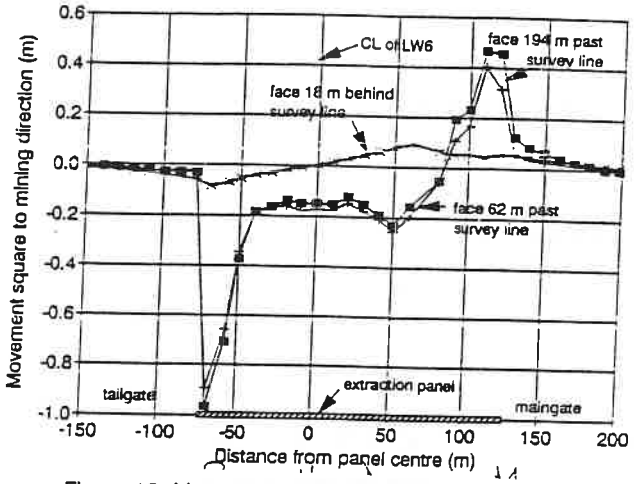


Figure 12. Movement Square to Mining Direction due to Mining in LW6

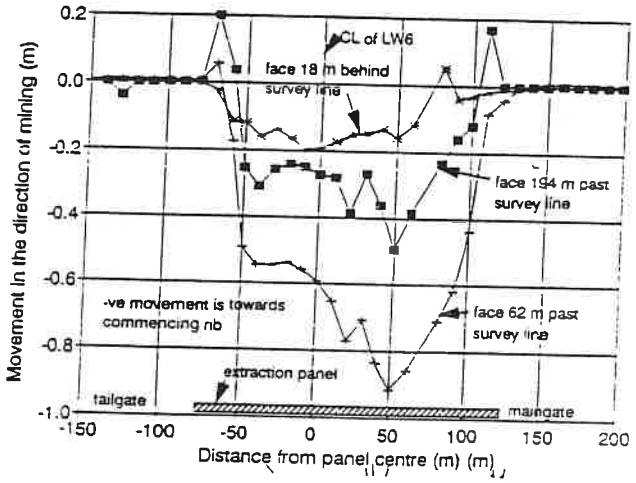
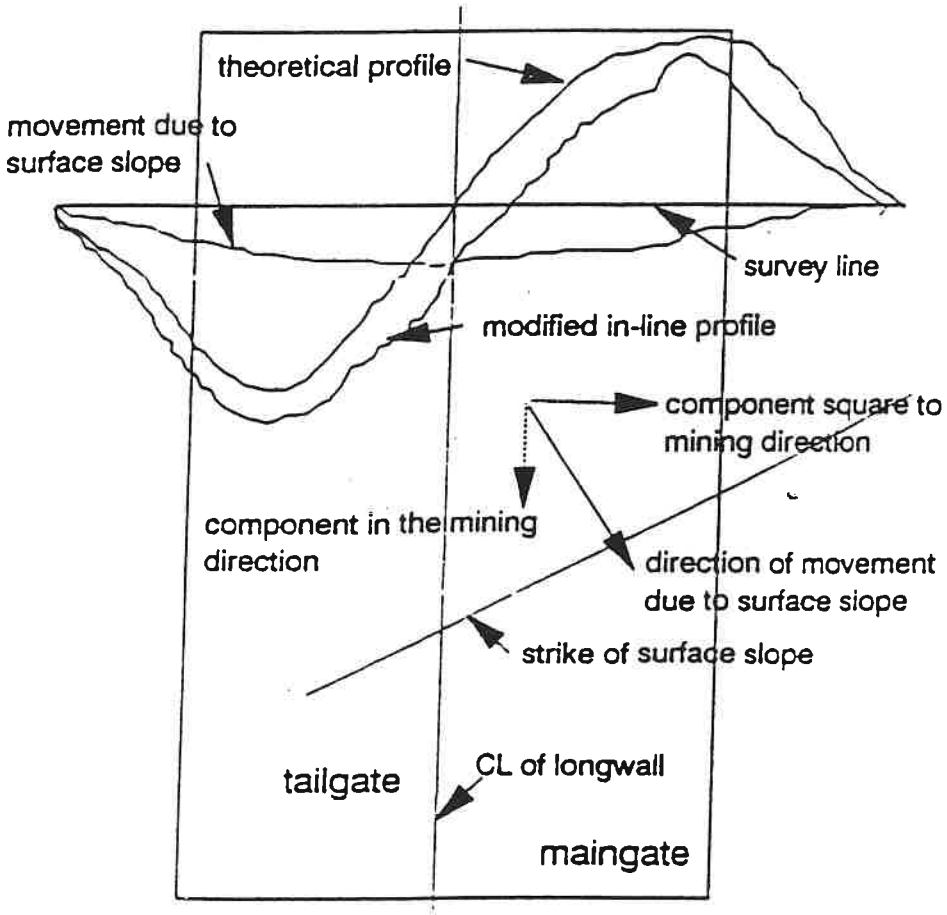



Figure 12: The Effect of Surface Slope on Horizontal Movement (Holla & Thompson, 1992)