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Stability and Earth Movements on the Western Batters of Yallourn Open Cut Mine

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SUMMARY The 90m deep Yallourn Open Cut brown coal mine in the Latrobe Valley, Victoria is developing into an area close to a reverse fault. To maximise coal recovery a major batter stabilisation program has commenced, where the fault is within 100m of the Open Cut, to match on-going operations. The geotechnical investigations and analysis procedures are presented. Horizontal earth movements at the batter crest are predicted to be in the order of 3m with up to 1m recorded to date. Horizontal movement at the toe of the batter is anticipated to be 4.5m. The majority of the movement is attributed to stress relief of regional and local tectonic stresses associated with the monocline/fault structure. Back analysis of these movements with a Boundary Element model has been used to estimate the tectonic stress prior to stress relief. This back analysis information has been used in estimating future stability conditions as the base slope of the coal seam steepens in the area ahead of the current operations. Current earth movements and batter stability conditions are considered satisfactory.

1 INTRODUCTION

Yallourn Open Cut in the Latrobe Valley, Victoria (Figure 1), operated by the State Electricity Commission of Victoria, supplies brown coal for power generation. The 90m deep open cut is currently being developed along its western boundary close to the Yallourn Monocline Fault, where associated geotechnical factors will critically affect open cut operations. The permanent western batter system is being developed on the basis of maximising coal recovery, minimising batter stabilisation costs and maintaining the safety of open cut operations. A key factor in achieving these objectives is the monitoring of earth movements and batter stability conditions in the area.

Yallourn Open Cut commenced operations in the early 1920's and currently produces some 17 Mt of coal and 5 Mm^3 of overburden per annum. Since the early 1980's the open cut has operated in the Hernes Oak Area, some 300m east of the Yallourn Monocline/Fault. The open cut is now developing into the Township Area where the Monocline/Fault is within 100m of the batter crest and will require the construction of major batter stabilization works. Stabilization of the batter involves the removal of 7 Mm^3 of overburden between the open cut and the fault to form a stabilising embankment near the toe of the batter during on-going mining operations (Figure 2). This work commenced in 1987 and will continue up until 1995 to match the coal excavation program. Mining in the Township Area will be completed in 1996.

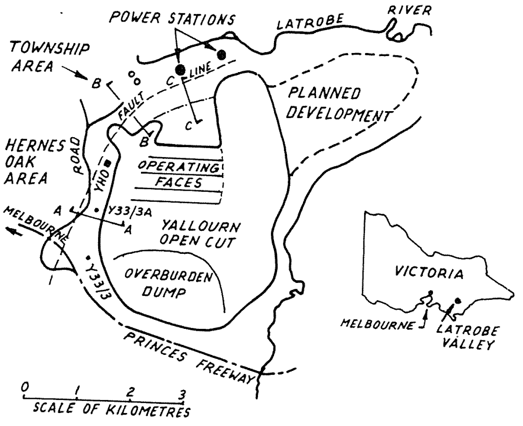

Figure 1 Yallourn Open Cut Locality Plan

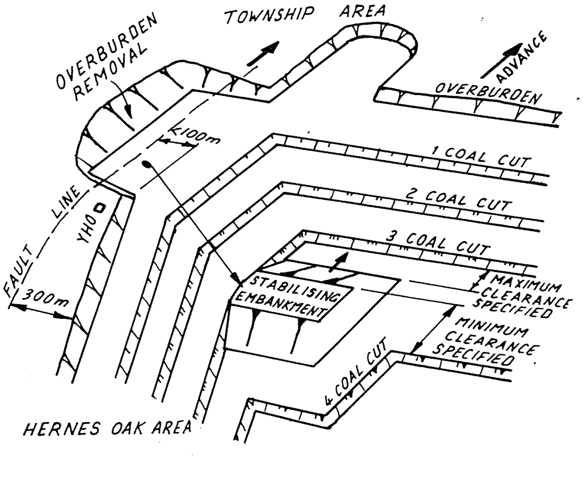

Figure 2 Method of Operation

2 GEOLOGY

The general geology and stratigraphy of the Latrobe Valley Depression is described by Gloe (1976). The Depression, which forms the western part of the Gippsland Basin, contains up to 770m of Tertiary Latrobe Valley Coal Measures lying unconformably on Mesozoic basement rocks. The Latrobe Valley Coal Measures consist of three main Formations of brown coal seams interbedded with clays, sands, silts and minor volcanics. The coal seams are continuous over large areas but the stratigraphy is complicated by numerous splits in the depositional sequence and latter major structural displacements.

The youngest coal measures group is the Yallourn Formation which contains the 70m thick Yallourn seam coal mined at Yallourn Open Cut. The sediments west and north of the open cut have been uplifted by the Yallourn Monocline/Fault and erosion has resulted in removal of the Yallourn coal seam. The Pliocene overburden sediments, typically 20m thick, are clays and sands. The Yallourn coal seam east and south of the Fault is flat lying and strongly jointed with the joint orientation reflecting their tectonic origin (Barton 1981). Major joints are near vertical and fully penetrate the seam. The joints oriented perpendicular to the fault strike are more open than those parallel and are often filled with sand from the overburden. Parallel joints are usually closed because they are still under residual compression associated with the formation of the reverse faulted Yallourn Monocline.

3 GEOTECHNICAL INVESTIGATIONS

3.1 Site Investigation

Although the general geology of the Yallourn Open Cut Western Batter area had been defined, bores were drilled, particularly in the Township Area, for three main reasons: to more accurately locate the subcrop of the fault; to define the local geological model for analysis; and, to recover samples and determine their strength and deformation characteristics. Many of the bores were instrumented to monitor groundwater levels in the coal seam and pore water pressures in the underlying interseam clays and sands. Hydraulic fracturing techniques were employed to determine the minimum insitu horizontal stress within the coal, perpendicular to the major joint set. An average minimum value of 100 kPa was determined, however a value of 50 kPa was adopted allowing for stress relief near the batter surface.

3.2 Material Parameters

3.2.1 Overburden

The overburden mainly consists of stiff sandy clays and minor amounts of fissured clays. Geotechnical investigations undertaken for a nearby road indicated general strength parameters of effective cohesion, $c'=20$ kPa, and effective internal angle of friction, $\phi'=24^{o}$.

3.2.2 Interseam

Experience at Yallourn and Morwell Open Cuts indicates that as coal winning proceeds horizontal movements at the base of coal occur due to stress relief. The coal seams slides over a ligneous interface sediment and reduces the strength to residual values. The initial failure mechanism is controlled by this interface material because it is presheared by tectonic movements and although healed by time is still weaker than the underlying interseam sediments. The long-term stability of the permanent batter system is largely dependent upon the residual strength of this interface.

Direct shear testing of the interseam sediments indicate a multi-nodal distribution of shear strengths. Peak strength lower quartile values for this material are $c' = 58$ kPa and $\phi' = 19^{o}$. The uplifted sediments west of the fault indicate slightly higher strength parameters. Similar interseam strength parameters have been determined at Morwell Open Cut. (Gloe, James and McKenzie, 1973).

Boundary Element modelling of earth movements, Pedler and Skotnicki (1988), at the Yallourn western batters indicates that major relative displacements along the coal/interseam interface occur only after the lower coal cuts are excavated. Accordingly, there is a cohesive component of interface strength applicable during the removal of the upper coal levels.

Analysis of the various interseam strength test data, corresponding to each potential instability mode, led to the adoption of the strength parameters presented in Table 1.

TABLE 1

INTERSEAM STRENGTH PARAMETERS

Notes	Below Coal Seam	West of Fault
A	$c'=50$ kPa $\phi'=13^{o}$	$c'=50$ kPa $\phi'=17^{o}$
B	$c_r=0$ kPa $\phi_r=13^{o}$	$c_r=0$ kPa $\phi_r=17^{o}$
C	$c'=34$ kPa $\phi'=17^{o}$	$c'=43$ kPa $\phi'=17^{o}$

Notes: A : Interface Clay Before No.3 Coal Cut
B : Interface Clay After No. 3 Coal Cut
C : Deep Interseam Clays

3.2.3 Coal

Unconfined and confined triaxial, tensile and direct shear testing of coal samples up to 250mm diameter were undertaken to supplement existing data by Trollope, Rosengren and Brown (1965). Rosengren (1961) indicated a 30% reduction in unconfined compressive strength parallel to bedding. The coal shows a distinct curved shear strength profile at low confining pressures. The strength parameters determined, for the anticipated normal stress range of 0 to 150 kPa, are given in Table II.

TABLE II

YALLOURN SEAM COAL STRENGTH PARAMETERS

FAILURE PLANE	C' (kPa)	ϕ' (degrees)
Mean value perpendicular to bedding	160	40
Lower bound parallel to bedding	100	40
Tight tension joint	0	40
Rough shear or open tension joint	0	33
Smooth shear or bedding plane joint	0	29

Triaxial testing indicated typical values of initial tangent modules of deformation, Ei, and modulus of expansion, Ex, as 60 MPa and 40 MPa, respectively, for samples parallel to bedding at low confining stresses.

3.3 Groundwater Conditions

Monitoring of groundwater levels has indicated a stable phreatic surface within the coal of about 8° rising from the coal batter toe. Horizontal drains (180m long at 30m spacing) are drilled at an angle of 5° into two lower levels, to intersect coal joints. To intersect daylighting sub-horizontal discontinuities in the coal, every second bore is installed at an angle of 10°.

Drainage of the coal results in groundwater in the overburden becoming perched. Extensive monitoring of interface pore water pressures indicates pore water pressure reduction due to stress relief associated with coal excavation. For design purposes, allowance has been made for a 15% reduction in the potentiometric level where coal is removed and a 10% increase where the coal is to be replaced by the stabilising embankment.

4 HERNES OAK AREA

4.1 Stability

The permanent western batter is now fully excavated along most of the Hernes Oak Area. Two types of batter stability analysis are applicable in this area. The first is the potential failure along the interface from the toe of the open cut batter back to the fault. This can be considered as overall stability. The second condition is the potential movement of large vertically jointed blocks of coal, driven by high groundwater levels within the coal. This block movement mechanism can damage conveyors and pipes etc, on the batters (Washusen and Fraser, 1982). The current overall stability factor of safety of about 1.4 is more than adequate, mainly due to low pore water pressures produced by the installation of horizontal drains. Monitoring the pore water pressures and maintenance of these horizontal drains is an important factor in maintaining stability and limiting batter movements. (Figure 3) The block stability analyses indicate that groundwater induced batter movements are unlikely to occur since the coal phreatic surface is effectively reduced.

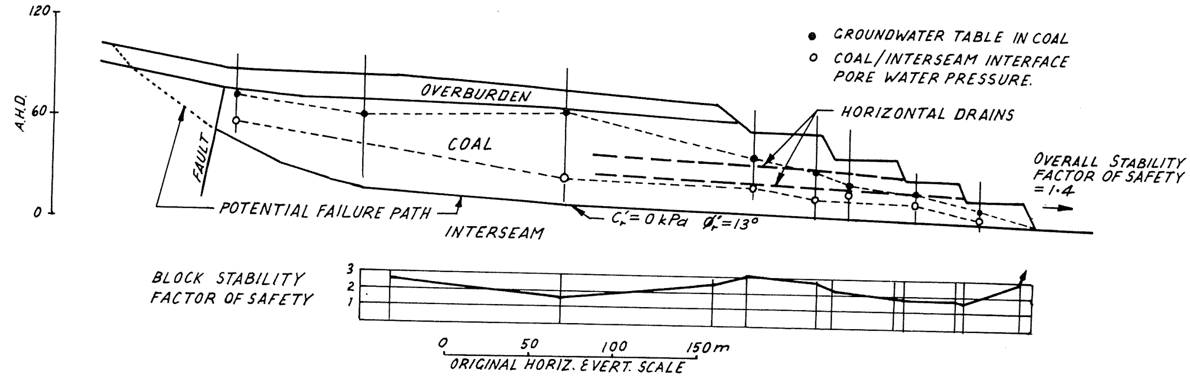

Figure 3 Section A-A Hernes Oak Area

4.2 Earth Movements

A Boundary Element program developed by Crotty, (1984) was employed to mathematically model earth movements in the Hernes Oak Area. Back-analysing of earth movements provided estimates of in-situ horizontal tectonic stresses resulting from folding and faulting. This data was then used to predict earth movements in the Township Area where stability conditions are more critical. Horizontal in-situ stress conditions varying between 100 kPa to 2000 kPa were analysed, with 500 kPa providing the best correlation to actual displacements (Figure 4). The horizontal stress

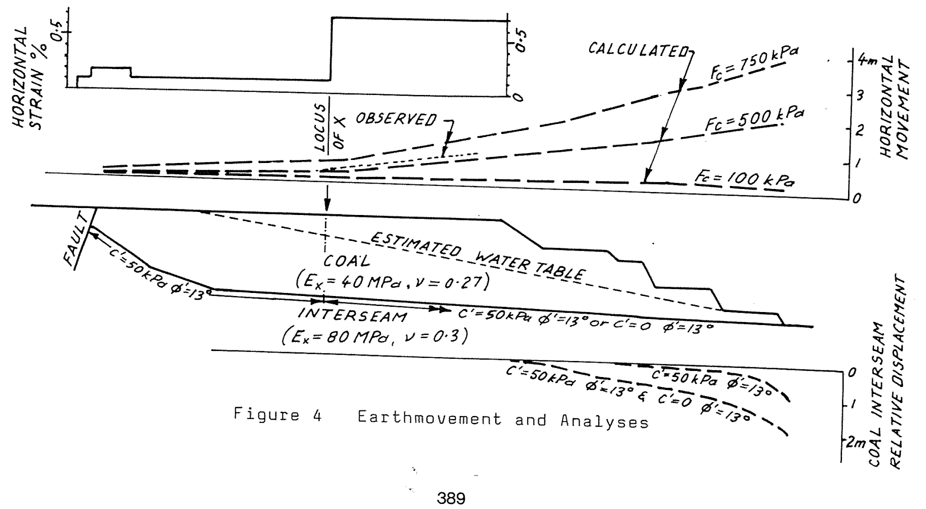

Figure 4 Earthmovement and Analyses

perpendicular to the dominant joint set was estimated at 100 kPa, which correlated closely to the hydraulic fracturing tests.

The analyses reflected the two zones of horizontal movement which have been found to occur beyond the batter crest. At about 150m from the crest a dividing line, called the Locus of X, separates the different slope profiles of horizontal movement versus distance (Figure 4). Between the Locus of X and the crest horizontal strains are five to ten times greater than strains beyond the Locus of X. The maximum horizontal strain to date is 0.7%. Similar movements profiles, resulting from the relief of tectonic stresses, are exhibited at Morwell Open Cut (Hutchings, Fajdiga and Raisbeck, 1977). A small increase in horizontal and vertical strain occurs across the fault. Movements beyond the fault are minor.

The boundary element study indicated that the relative displacement between the coal and interseam is significantly smaller than the surface displacements. The analyses also indicate that beyond Locus of X some cohesive strength above residual parameters remains along the potential failure path.

Horizontal batter crest movements indicate increasing movements as the operating faces moved northward. The maximum movement to date in the Hernes Oak Area is approximately 1m, with an anticipated movement of 1.2m. Horizontal movements versus time plots indicate that the maximum rate of movement occurs as No 3 and 4 coal cuts are excavated. Vertical movements at the crest are approximately half the horizontal movements.

Maximum horizontal movements down the batter face increase exponentially with depth, with horizontal movement near the toe of current operation faces estimated to be 4.5m.

5 TOWNSHIP AREA

5.1 Stability

In a Township Area several potential instability modes have been postulated as shown in Figure 5. The key to the development is the timely excavation of overburden and its subsequent use in the construction of the stabilizing embankment to ensure stability during on-going mining operations. The overburden has to be partly removed prior to excavation of No 2 coal cut, and completely removed prior to the excavation of No 3 coal cut. A quasi three dimensional stability analysis in the area between No 3 cut operating face and the stabilizing embankment, assuming short-term shearing resistance along the coal joints, determines construction clearances (Figure 2). The minimum stabilizing embankment height has been determined for the weather constrained winter operations. Significant drainage will be required beneath the stabilizing embankment to minimise groundwater levels. This includes installation of the following: horizontal drains; geotextile covering No 3 cut; and trench drains in the coal below the embankment.

The required batter stability factor of safety in the Township Area varies depending upon the risk associated with particular types of potential instability. The amount of surveillance has been increased to ensure adequate information is available, thereby limiting the risk and maintaining a minimum acceptable safety margin. For the Overburden and Hillside Stability (Figure 5), where property beyond the open cut could be affected, a Factor of Safety of 1.3 has been adopted. Inside the open cut, a Factor of Safety of 1.2 has been accepted.

In the southern section of the Township Area, where excavation has advanced to No 2 coal cut, monitoring indicates that groundwater conditions are following predicted trends, and stability conditions are acceptable.

5.2 Earth Movements

Boundary element modelling and empirical analysis of earth movements in the Township Area (Section B, Figure 1) indicates that batter crest horizontal movements of approximately 3m should occur. Due to the stabilising embankment, batter toe horizontal movements are estimated at 2m. The Locus of X in the Township Area is expected to coincide with the fault. Similar analyses along the northern batter of the open cut (Pedler and Skotnicki (1988) and Figure 1) indicate operations should not induce earth movements that effect the power station located immediately north of the fault.

6 SURVEILLANCE PROGRAM

A surveillance system has been established to ensure that three basic requirements are achieved: operational and public safety; maximisation of coal recovery; and minimisation of cost.

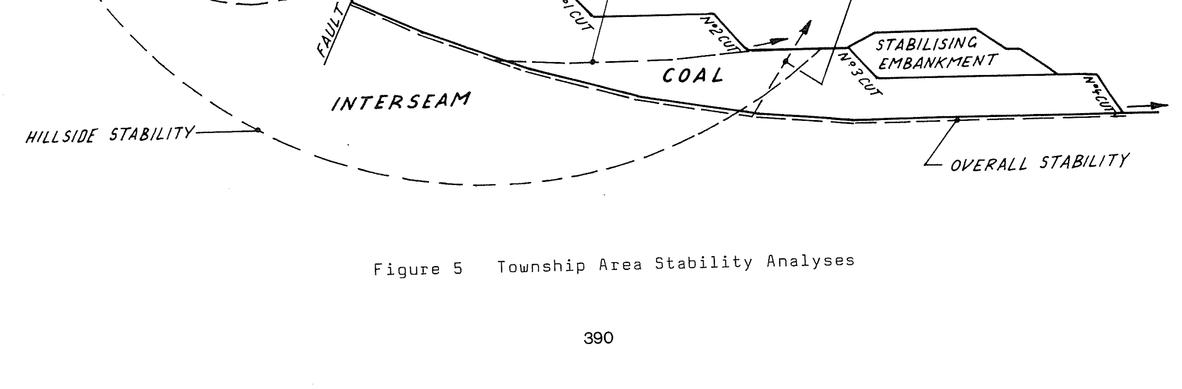

Figure 5 Township Area Stability Analyses

Three methods of monitoring have been developed. The first method consists of regular surveys of surface pins using Electronic Distance Measuring (EDM) equipment, photogrammetry and horizontal extensometers. At present three monthly horizontal movement surveys are undertaken of survey pins in the critical areas of the permanent batter close to No 3 and 4 coal cuts. Less frequent surveys are conducted at locations to the north and south. If batter stability becomes critical as the open cut moves north, an automatic motorized EDM movement monitoring system such as that proposed by Sprent, (1986) would be installed.

The second method involves measurement of sub-surface movements using inclinometers and buried extensometers in the fault area. Several inclinometer bores have been established near the batter crest to monitor sub-surface movements. Horizontal extensometers and vertical shear strips are being established in the vicinity of the fault, as the overburden is removed, in order to indicate the location and extent of movements in this critical area.

The third method provides monitoring of groundwater levels within the batters and interseam pore water pressures using electrical transducers connected to data loggers. This method enables continuous and centralised monitoring to be undertaken if required. The monitoring system will use continuous data logging techniques which will be connected to an alarm system triggered by a threshold velocity of movement.

Regular inspection of the batter system is undertaken by operations geotechnical staff who undertake surveys of joints, and install and maintain the surveillance equipment. Reporting of earth movement is undertaken on a three monthly basis as survey information becomes available. Geotechnical conditions are reviewed annually, taking into consideration any changed operational requirements.

7 CONCLUSIONS

Monitoring and analysis of earth movements and batter stability conditions along the western batters of the Yallourn Open Cut mine indicates satisfactory geotechnical conditions. Information and experience in the Hernes Oak Area has allowed predictions of acceptable geotechnical conditions in the currently developing Township Area where the Yallourn Monocline/Fault is located within 100m of the open cut.

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