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Highwall Design for a New Zealand Opencast Coal Mine

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SUMMARY The development stages and the highwall design of the No. 16 opencast coal mine in the Ohai coal field are described. The factors which were considered in the design of the 100 m high batters for the mine are discussed. Of particular concern was the nature of the overburden in the highwall where old underground workings were recorded as having been pillared out. Careful consideration was given to the selection of appropriate factors of safety, representative strength parameters and piezometric conditions for design.

1 INTRODUCTION

The Ohai Coalfield located in the South Island (Figure 1) is one of the main coalfields in New Zealand. Within the field, coal is recovered from both underground and opencast mines. In recent years opencast coal has been utilised to meet the winter peak demands and several opencast pits have been worked over the last 40 years.

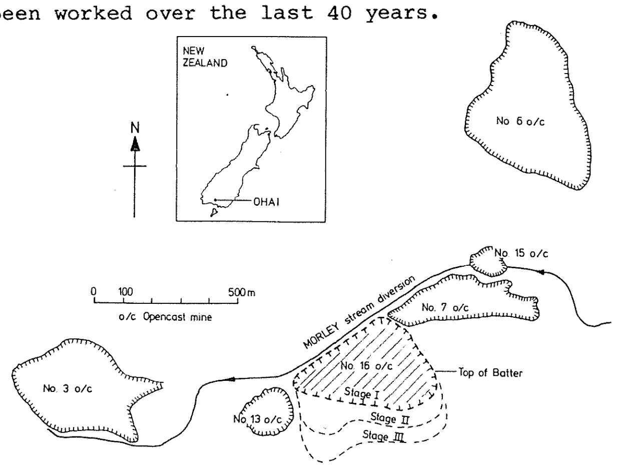

Figure 1. OHAI COALFIELD

In 1977 the Mines Division of the Ministry of Energy proposed the development of a new open pit (No. 16). The aim was to recover 650 000 tonnes of coal from a seam previously worked by underground methods, at a rate of 110 000 tonnes pa. Excavation of this open pit was designed also to facilitate the development of a new underground mine (Wairaki) and provide the coal necessary to meet demands until the new Wairaki mine was in production (the Wairaki mine is to produce 8 000 000 tonnes over a 30 year period).

The Ministry of Works and Development (MWD) was commissioned by Mines Division to:

(i) prepare an environmental impact assessment (EIA) for the No. 16 mine;

(ii) implement pollution control measures for the Ohai coalfield;

(iii) rehabilitate old workings and spoil heaps in the Ohai coalfield;

(iv) investigate and design the No. 16 open pit.

This paper discusses work undertaken for objective (iv) above. The work associated with (ii) and (iii) is described by Hawkins and Thompson (1981). Pit design and slope stability analyses required the consideration of the following factors:

(i) it was intended to construct the entrance to the new Wairaki underground mine at the base of the highwall;

(ii) sections of the highwall were located over old underground workings which were recorded as having been pillared out;

(iii) the mine would be developed in stages with a short lead time for Stage I but with the opportunity to refine the highwall design in subsequent stages as additional data was collected.

2 COALFIELD LOCATION

The Ohai coalfield lies in western Southland in the south of the South Island (Figure 1). The location of the No. 16 open pit and the other principal features within the Ohai field are shown on Figure 1.

3 GEOLOGY

The Ohai coalfield consists of mostly marine Tertiary rocks (Bowen 1964). In the upper part of the sequence known as the Morley Coal Measures, sandstones and siltstones overly the Morley No. 2 coal seam which was the target of the No. 16 Opencast mine. Sandstone forms the predominant lithology.

The No. 16 open pit is on the crest of the Ohai anticline which plunges gently to the Southwest. The Morley No. 2 seam is some 10 m thick and contains old underground workings which Mines Division records indicated had been pillared in some areas (Figure 2, Figure 3).

4 DEVELOPMENT STAGES

The investigation and design for the No. 16 open pit has proceeded in stages on an interactive basis with refinements being made as more information has become available. These stages are broadly defined as:

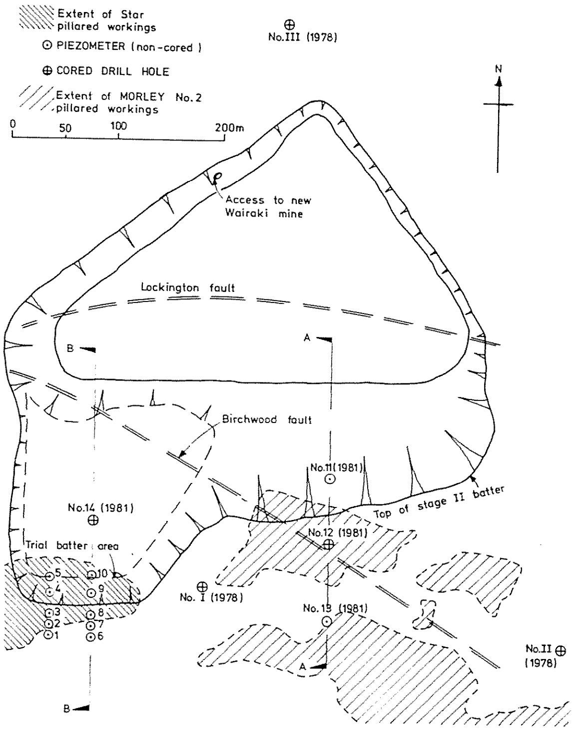

Figure 2: PLAN OF No. 16 OPENCAST MINE

Stage I 1979 design for first stripping contract (Highwall up to 50 m)

Stage II 1981 design for second stripping contract (Highwall up to 90 m above pillaring)

Stage III 1982 design for third stripping contract (Highwall up to 100 m above pillaring)

Investigation and design activities are discussed in relation to preparation of guidelines for the contract drawings for the development stages outlined.

5 INVESTIGATIONS AND DESIGN

5.1 Stage I

5.1.1 Investigation

The time available for investigations and design of the Stage I development of the No. 16 open pit following approval of the EIA was limited. Although no ground had been broken on the No. 16 pit site extensive exposures of coal measures overburden existed in the adjacent No. 3 and 6 pits. Three investigation holes (holes I, II and III, Figure 2) were drilled to identify the overburden materials and their distribution. A comparison of the core materials from the drill holes with the materials in No. 3 and No. 6 open pits indicated general similarities. On this basis block samples of representative materials were selected from No. 3 and No. 6 pits for laboratory strength testing.

The materials recovered comprised alternating sandstones (70%) and mudstones (30%). Typically the mudstone material had a LL about 40 and PI about 20 and core samples indicated a high slake potential (this had been observed in other Ohai pits). The sandstone materials varied in strength often being described as soft. Structural features (joints, shears, etc.) were not apparent in the cores recovered.

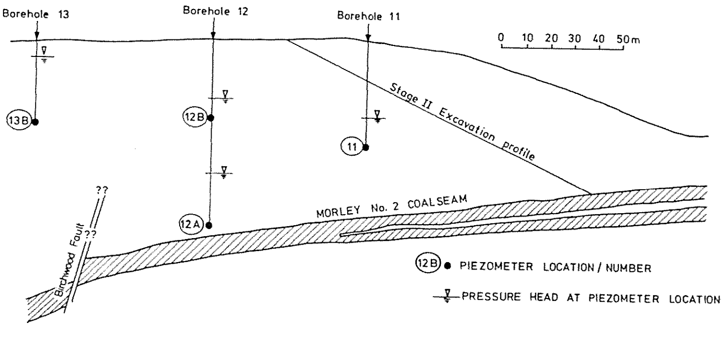

Figure 3: CROSS SECTION A – A

Effective stress results of the laboratory simple shear tests are presented in Figure 4.

Only limited groundwater data was collected during these investigations.

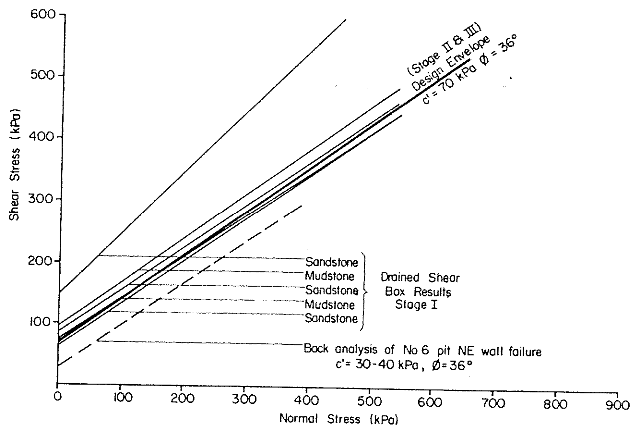

FIGURE 4 OHAI COAL MINES - TEST STRENGTH PARAMETERS - COAL MEASURES

5.1.2 Design

The design of the first stage involved slopes up to 50 m high which were not affected by pillaring. Strength parameters were available for the overburden but groundwater conditions had not been recorded. At this stage it was proposed to construct the access to the new Wairaki underground mine within the pit. A conservative design approach was considered appropriate because of the need to ensure the safety of the underground mine access. (It was recognised that batters could be steepened in later stages if justified). Overburden strength parameters c' = 95 kPa, ϕ' = 36^{o} were used and the following conditions considered:

(i) Piezometric surface 1 m below ground level, Permanent batters F.S. = 1.8

(ii) Piezometric surface 1 m below ground level, Temporary batters F.S. = 1.5

These conservative piezometric conditions and factors of safety reflect the concern for the safety of the underground mine access and the limited knowledge of the overburden materials.

The resulting slope height curves are presented in Figure 5.

Following this design a trial batter was contemplated over a section of pillared workings in the shallow Star seam (above the Morley No. 2 seam) and piezometers (1-10) and inclinometers (2, 4, 7

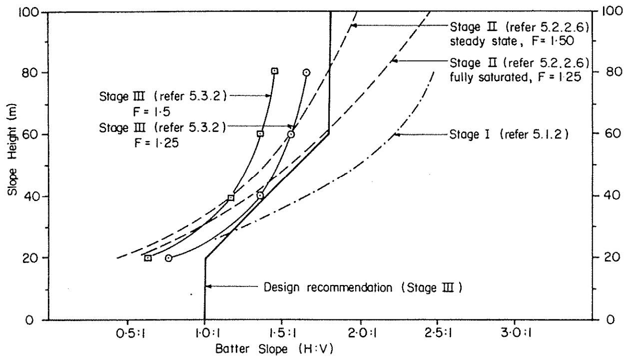

FIGURE 5 BATTER SLOPES IN UNDISTURBED MATERIAL

and 9) (Figure 2, Figure 7) were installed in anticipation. The trial excavation did not proceed until Stage II development.

5.2 Stage II

As the Stage I overburden stripping advanced investigations were initiated to provide information, particularly on groundwater, and to confirm overburden material properties. This enabled a more refined design to be made of the Stage II highwall which was significantly higher (up to 100 m) and would encroach on areas of pillared underground workings. Five features were identified as requiring careful consideration in the analysis and design:

(i) geological structure and its influence on stability

(ii) strength parameters (for the undisturbed overburden and the overburden in the pillared areas which was assumed to be disturbed)

(iii) groundwater

(iv) tension cracks

(v) factors of safety

5.2.1 Investigations

Four boreholes were drilled to allow piezometers (11, 12, 13 and 14, Figure 2 and Figure 3) to be installed. Extensive core losses in borehole 12 some 15 m above the Morley No. 2 seam suggested disturbance due to pillaring. The piezometers suggested a series of perched water tables in the coal measures overburden (Figure 3).

An engineering geological appraisal of exposures in the Stage I excavation confirmed that natural joints were not common and the overburden could be assumed 'homogeneous' for analytical purposes. Exceptions to this were assumed in the pillared areas (Figure 2). Sandstone materials of varying degrees of compaction and cementing were observed to predominate over the silt/mudstone strata. In general the overburden materials were considered more competent than the No. 3 and No. 6 materials selected for strength testing. No further testing was undertaken as the test results held were considered to be representative of the No. 16 materials.

5.2.2 Design

5.2.2.1 Strength parameters

To complement and confirm the strength test data for the overburden, back analysis of failures in No. 3 and No. 6 pits was attempted. This indicated, for are fully saturated ground conditions assumed (as the failures occurred in mid winter), mobilised strengths of c' = 30-45 kPa, $\phi' = 36^o$. On the basis of this, and the observation that the No. 16 materials were generally more competent, strength parameters for the undistrubed No. 16 overburden of c' = 70 kPa, $\phi' = 36^o$ (Figure 4) were adopted. (These are marginally lower than for Stage I design but were considered appropriate in the light of the back analysis results (No. 3 and 6 pits) and the more competent No. 16 materials).

Investigations had indicated that overburden disturbance associated with pillaring was a real possibility (BH 12, Figure 3). It was not possible to define the extent of pillaring disturbance but the Stage II highwall excavation was to encroach on areas identified from the Mines Division records as having been pillared. Overburden was considered to have collapsed into the workings and it was reasoned that progressive failure could disturb the remaining undisturbed overburden where the underlying support had been removed. Due to the difficulties in defining the nature and degree of disturbance this material was conservatively assumed to behave as cohesionless ('fully softened') material with c' = 0, $\phi' = 36^o$. Envelope curvature was considered qualitatively in the design analysis and this removed problems with critical shallow failures.

Because of the uncertainties in assessing strength parameters in 'disturbed' overburden it was decided to proceed with the construction of a trial batter in an area where disturbed overburden was thought to exist (see Section 5.2.2.6).

Coal strength parameters were not measured. The intact coal was assumed to have a bulk strength, including the effect of workings, at least as strong as the overburden. Excavation of coal in Stage I confirmed that no weak seat earth existed under the coal seam.

5.2.2.2 Groundwater

Initial readings of the piezometers (Figure 3) suggested that the groundwater regime consisted of discrete perched water tables associated with individual strata within the coal measures. Only summer readings were available at the time of design. Groundwater behaviour through a wet Ohai winter had not been observed.

It was considered that the data was not sufficiently conclusive to justify using perched water tables in design. This was particularly so in the pillared areas where disturbance could be expected to produce a 'homogeneous' mass and uniform groundwater conditions.

A 'steady state' draw down profile was adopted giving a conservative model of piezometric conditions for deep seated failure surfaces (as associated with slope heights of 80-100 m).

It was expected that pore pressures would decrease with the unloading associated with overburden excavation but the time response was considered to be too uncertain to allow a short term/long term slope design philosophy to be adopted.

5.2.2.3 Factors of safety

The assessment of appropriate factors of safety for the design of the No. 16 highwall was given very careful consideration. Consequences of highwall failure were identified as:

(i) lost/buried coal;

(ii) injury to operating personnel;

(iii) obstruction/loss of haul roads.

Factors of safety were evaluated in a qualitative sense. An acceptable factor of safety reflects the confidence placed in the design parameters, the risks and consequences associated with a batter failure and the time of exposure. The degree of risk accepted in a mining operation must be weighed against the costs associated with a higher factor of safety and a flatter highwall slope (costs are proportional to the volume of overburden excavated).

Some typical factors of safety reported in the literature were reviewed (Table I).

TABLE I: Typical Factors of Safety

Reference	Factors of Safety
Hoek and Bray (1977)	1.3-1.5
Canmet (1977)	>1.0 (reliability approach)
Piteau (1977)	1.2-1.5
National Coal Board (1970) (Spoil Heaps)	1.2-1.5 (risk to person and property) 1.1-1.2 (no danger to property)

After the Stage I design Mines Division relocated the access for the new Wairaki underground mine high on the low wall and this removed an important design risk.

On consideration of the points discussed above and the indicated range of factors safety in Table I, the following design cases were adopted for the No. 16 highwall:

(a) Steady state groundwater profile (Probable normal) F.S = 1.5

(b) Steady state groundwater profile with water filled tension crack (Probable in the life of the mine) F.S = 1.4

(c) Saturated ground with water filled tension crack (Possible in the life of the mine) F.S = 1.25

Situation (c) was considered to represent winter periods of substantial rainfall and at such times earthworks operations would not be possible. Monitoring of highwall slopes with piezometers was expected to indicate the development of this critical condition.

5.2.2.4 Analysis

Stability calculations for the No. 16 highwall were carried out in two stages: stability charts (Hoek and Bray) were used initially and then more detailed limit equilibrium analyses were performed using ICES LEASE (Bishop (1955) and Sarma (1973) methods) and an MWD in house program GPS1 (Janbu (1972) method).

5.2.2.5 Results

A uniform highwall slope was adopted contrary to the more conventional practice of incorporating benches. Based on the observed performance of uniform slopes at Ohai and, in some cases, the variable success of benches, planar slopes appeared to be preferable. The highwall design indicated 2.5:1 slopes for the 100 m high batters in undisturbed material and 3:1 slopes, independent of height, over the pillared areas. The recommendations for the highwall are summarised in Figure 5. Two operational considerations were identified in the design which would assist stability during the mining operation:

(i) a toe berm (Figure 6) should be incorporated and only removed when necessary to allow the underlying coal to be recovered (this could give a 10% increase in stability).

(ii) the toe of the slope should not be undercut during coal recovery as this reduces stability (approximately 10%).

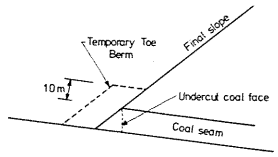

Figure 6: TOE BERM GEOMETRY

In areas of pillaring a design highwall slope of 3:1, independent of height, was adopted.

5.2.2.6 Trial batter

In the design for Stage II there was still uncertainty associated with the highwall design over the pillared areas and the degree of overburden disturbance. With a view to improving this situation for future mine development a trial batter was designed, over the shallow pillared out Star seam workings (Figure 7), to be excavated during the Stage II development. Disturbance was considered highly likely because of the typically hummocky terrain overlying the area.

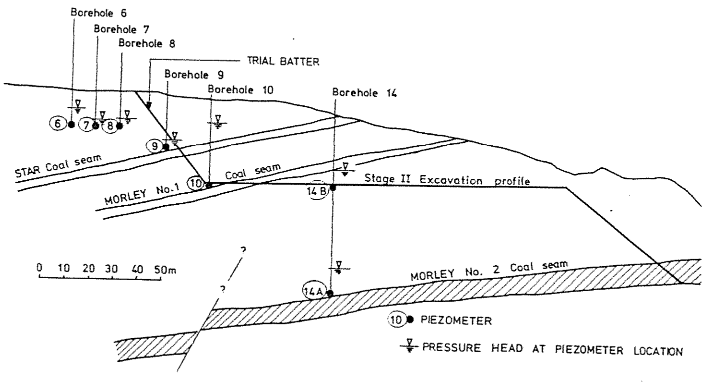

Figure 7: CROSS SECTION B - B

The trial batter was designed to a factor of safety of 1.1 for strength parameters of $c' = o$, $\phi = 36^{o}$ and the measured piezometric profile (Figure 7). It was designed as a staged excavation with the possibility of top loading if the survey, inclinometer and piezometric monitoring did not indicate critical stability.

In the event the whole exercise was unsuccessful as there was no evidence of pillaring and overburden disturbance upon excavation of the batter.

(Consequently the trial batter design was very conservative).

5.3 Stage III

5.3.1 Investigations

No new investigations were initiated. Monitoring of piezometers and the trial batter had continued in the 6 months since Stage II design.

5.3.2 Design

For this design piezometric data for the No. 16 highwall through the critical winter season was available. This confirmed a series of perched water tables with a head of approximately 10 m (Figure 3) and a seasonal variation generally less than 1 m. Even though the 1981 winter was relatively dry it was considered that in a wet year the proportion of run off to infiltration would be higher and water levels were unlikely to change significantly.

A design model of 10 m layers (Figure 8) with two perched water table conditions 'A' and 'B' (Figure 8). Condition 'A' represents steady state seepage and condition 'B' was considered a possible extreme state. These conditions were considered similar to the Stage II cases 5.2.2.3 (a) and (c).

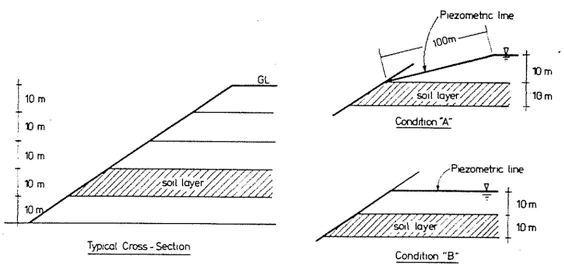

Figure 8. STAGE III DESIGN PIEZOMETRIC MODEL

A reconsideration of failures in No. 3 and No. 6 pits with the above piezometric condition 'B' gave factors of safety of 0.99 ($c' = 70$ kPa, $\phi' = 36^{\circ}$) and 1.06 ($c' = 35$ kPa, $\phi' = 36^{\circ}$) respectively. This indicated that the piezometric model was reasonably representative of the field behaviour.

Design of the Stage III highwall was performed as for Stage II (5.2.2) with the modified piezometric model discussed above. The results are presented in Figure 5.

No change was made to the disturbed overburden design slope of 3:1.

6 CONCLUSIONS

This paper has outlined the evolution of the highwall design for the No. 16 opencast coal mine development at Ohai. The design has been an interactive process with refinements as the quality of the design data has increased with time. Old underground workings in the basal Morley No. 2 seam and pillar robbing activities during retreat have created problems with the assessment of the overburden strength parameters.

(1) The technique of back analysis of failures has been found to be very useful in establishing representative parameters for the No. 16 open pit, even with the difficulties associated with assessing piezometric conditions at the time of failure.

(2) It has not been possible to assess the influence of pillaring on the overburden materials in the No. 16 open pit prior to excavation. Excavation indicates that the materials are undisturbed.

(3) The use of fully softened strength parameters $c' = 0$, $\phi' = 36^{\circ}$ in the pillared areas has resulted in satisfactory highwall stability although this has probably been conservative.

(4) Piezometers have indicated perched water tables in the Ohai coal measures.

(5) The literature does not contain definitive design factors of safety and the assessment of these requires very careful consideration.

(6) Trial batter investigations require careful planning and the full co-operation of construction personnel.

ACKNOWLEDGEMENTS

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