

## Engineering geology and remedial works design, Brewery Creek Slide, Clyde Power Project, New Zealand

N.A. Crampton

ECNZ, Clyde Power Project, New Zealand

### ABSTRACT:

Remedial measures at the Brewery Creek Slide are part of works to stabilise a number of large schist landslides along the shores of Lake Dunstan, Clyde Power Project, New Zealand. Remedial measures for part of the slide comprise a low level pumped drainage drive/drillhole network in conjunction with a zoned earthfill blanket and grout curtain. The works were designed to, and have successfully, lowered and controlled groundwater at the toe of the slide. Comprehensive investigations provided data for geological and geohydrological models on which the design was based. The design was independent of model uncertainties yet enabled an area which developed adverse conditions during lake filling to be readily and successfully treated.

### 1 INTRODUCTION

The Clyde Power Project is a hydro-electric development on the Clutha River, South Island, New Zealand. The project which is owned by the Electricity Corporation of New Zealand (ECNZ) comprises a 102m high concrete gravity dam, powerhouse, and a 35km long reservoir up to 60m deep. Approximately 20km (25%) of the shoreline of the reservoir (Lake Dunstan) is bordered by existing large landslides (Figure 1). Extensive stabilisation work was carried out on the Brewery Creek Slide and six of the other landslides to offset the destabilising effects of lake filling. A general overview of the landslides on the project is presented by Gillon and Hancox (1992).

The Brewery Creek Slide, situated 15km upstream from the dam (Figure 1), is approximately 2.4km wide, 1.3km long, up to 150m deep and covers an area of 220 hectares. The slide mass contains an estimated volume of 150Mm<sup>3</sup> of gravitationally displaced material. Reservoir filling has raised the water level at the toe by 35m.

Although the slide was dormant, geological precedent indicated that lake filling would result in a more adverse groundwater regime than that during the last phase of movement (<18,000 years ago). This together with stability analysis and the overall strategy adopted for stabilisation works on the project established the need for remedial works to offset the destabilising effects of lake filling. The works comprise a buttress and gravity drainage drive system at the upstream end (Zone 1) and a low level pumped drainage drive/drillhole network with associated grout curtain and low permeability earthfill blanket across Zones 2 and 3 (Figure 2).

The general nature of remedial works constructed

to stabilise the Brewery Creek Slide have been outlined in previous papers (Graham et al, 1991; Gillon et al, 1992) so this paper focuses on the interaction between engineering geology and the Zone 2/3 remedial works.

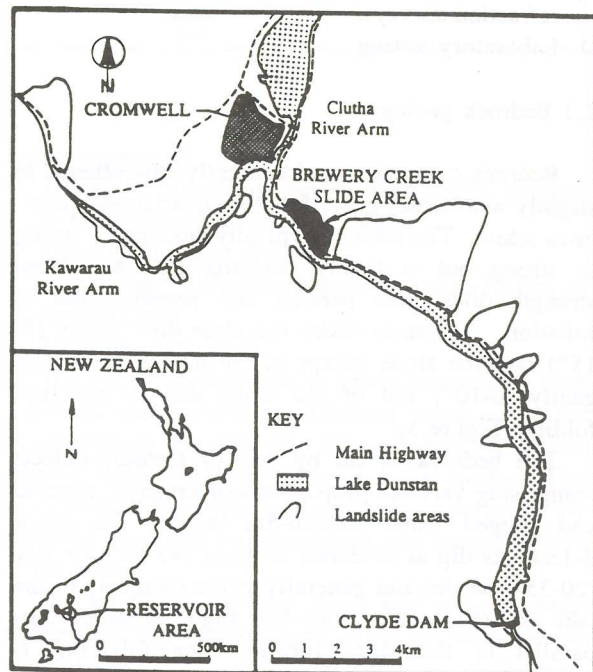


Figure 1. Locality plan.

### 2 GEOLOGY AND GEOHYDROLOGY

At the time of remedial work design the geology and geohydrology models of the landslide were based on a comprehensive investigation programme comprising:

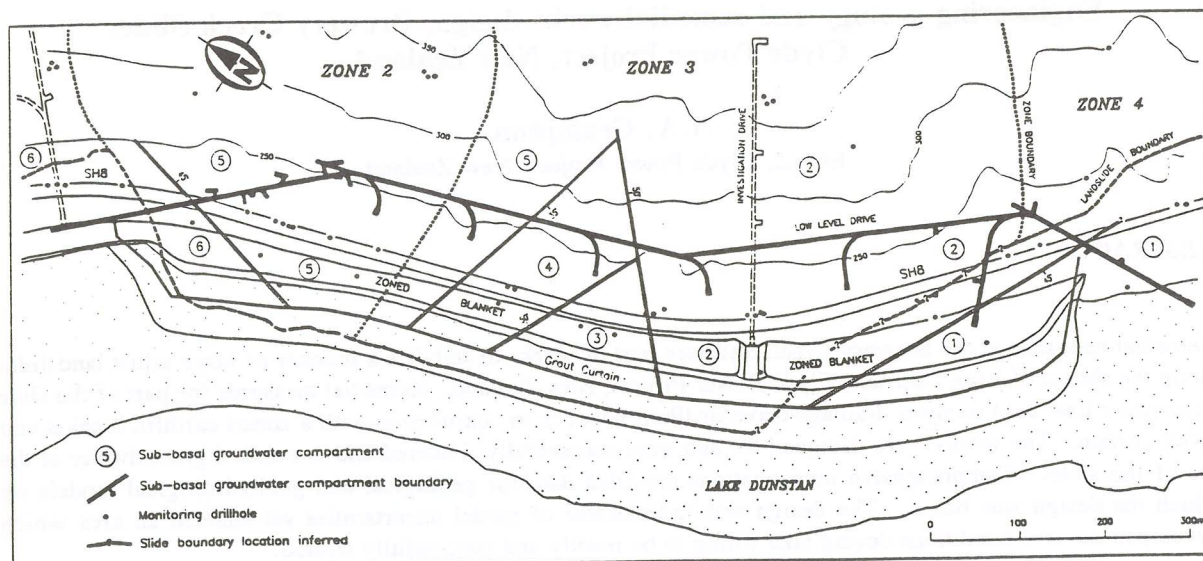


Figure 2. Plan of Zone 2/3 remedial works.

- Engineering geological mapping.
- Trenching.
- 9666m of cored and non-cored drilling.
- Two investigation drives (717m).
- 11.6km of surface and underground seismic refraction surveys.
- Laboratory testing.

### 2.1 Bedrock geology

Bedrock comprises predominantly unweathered to slightly weathered, grey, foliated, quartzofeldspathic mica schist. The schist is typically moderately strong to strong but is highly anisotropic with marked strength differences parallel and perpendicular to foliation. Foliation under the slide dips gently (5-15°) into the slope except in the toe where it dips gently (0-10°) out of the slope due to anticlinal folding (Figure 3).

The bedrock is cut by sets of tectonic defects comprising variable proportions of crushed, sheared and gouged schist 200mm-5m thick. The major defect sets dip at moderate to steep (45-60°) or low (20-35°) angles and generally strike obliquely to the lake axis (Figure 2). One low angle set which dips parallel to the slope (cross-cutting foliation) is inferred to be the major factor controlling landslide initiation and slide base geometry.

### 2.2 Landslide model

Subdivision of the landslide into six zones was based on geomorphological evidence and the nature of the slide mass which varies from highly disrupted "chaotic debris" through less disrupted "blocky debris" to least disrupted "displaced schist". The amount of disruption is inferred to be related predominantly to the amount of downslope movement

the material has undergone.

In the mid and upper slopes the slide base geometry is relatively planar reflecting the nature of the inferred controlling defect. At the toe the slide base forms a broad partly rotational breakout zone which typically dips back into the slope indicating an upthrust component (Figure 3).

Due to the comprehensive investigation programme the model for slide base geometry made available for remedial works design had a high degree of confidence. The main area of uncertainty in the model was the location of the downstream margin of Zone 3 in the area between the river and highway (Figure 2). To facilitate remedial work design in this area the downstream margin was shown as a zone covering the area in which the actual margin could be located. Design was based on the most downstream and deepest (most conservative) possible location.

### 2.3 Groundwater model

At the time of remedial works design the Zones 2/3 groundwater model comprised sub-basal and perched aquifers.

The sub-basal semi-confined aquifer was coincident with river level up to 700m back from the river. The aquifer exerted uplift pressure on the slide base over a relatively small but critical area in the toe of the slide (Figure 3). Further upslope the piezometric level was well below slide base due to the almost flat gradient back from the river. The only subdivision of the semi-confined aquifer possible prior to drainage drawdown was at the upstream end of Zone 2 (later to be identified as Groundwater Compartment 5) where the piezometric level was 6m higher than the remaining area (Figure 2). All other piezometers showed piezometric levels coincident with the river. In addition most piezometers in the toe

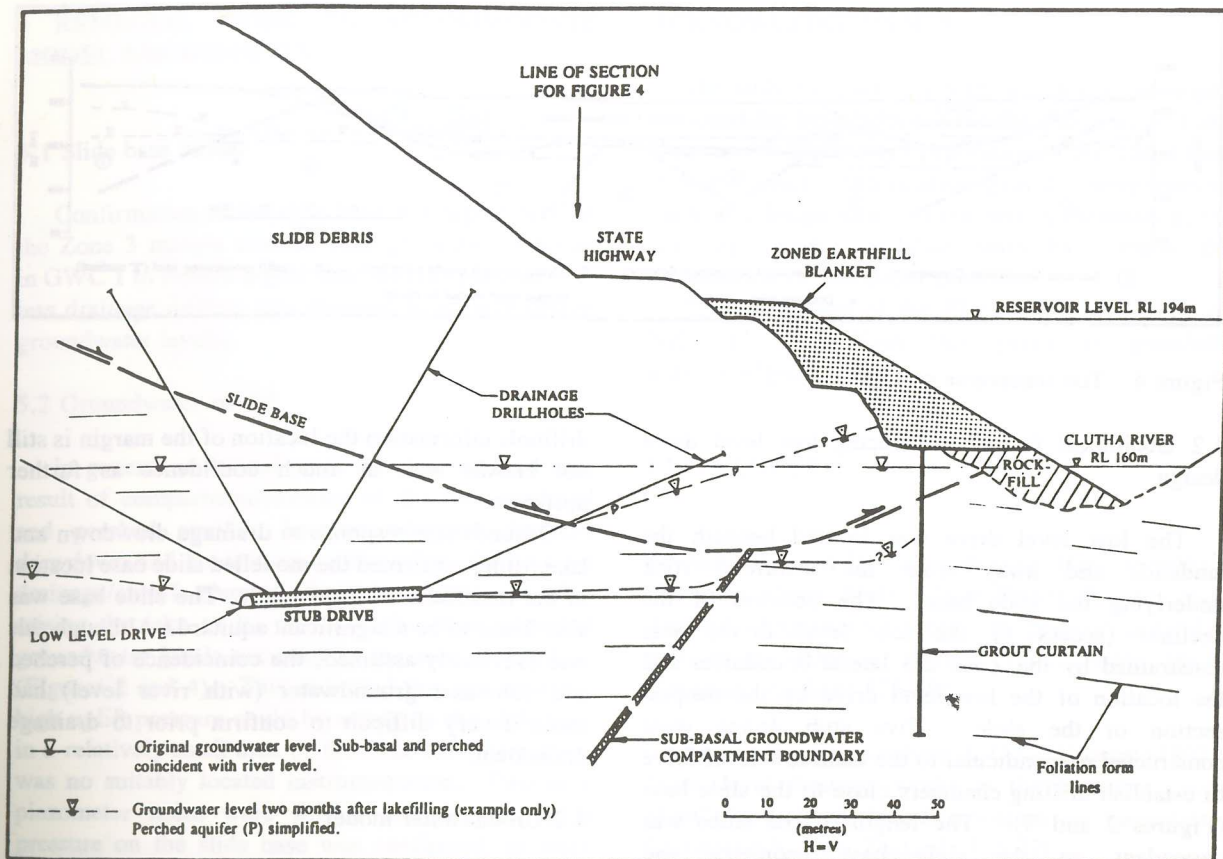


Figure 3. Toe cross section.

and some further upslope showed a rapid and positive response to changes in river level indicating a strong hydraulic connection with the river.

The perched aquifer was mainly restricted to the trough formed by the slide base in the toe of the slide (Figure 3). Like the semi-confined aquifer the perched aquifer was coincident with river level in all but the upstream end of Zone 2 and most piezometers showed a positive response to changes in river level. Due to the paucity of data points the perched aquifer was not subdivided but experience from other landslides indicated it would be highly compartmentalised.

### 3 REMEDIAL WORKS DESIGN

#### 3.1 General

Low level pumped drainage was chosen to stabilise Zones 2/3 of the slide. Gravity drainage to reservoir level was not feasible because there was no drainable head and buttressing was not possible because of the narrow river valley. The chosen option comprises a low level pumped drainage drive/drillhole network together with a zoned earthfill blanket and grout curtain (Figures 2 and 3). These

works consist of:

- 1.9km of tunnelling (up to 30m below original river level) and a 70m deep shaft,
- 12km of drainage drilling,
- 1.3km long, 140,000m<sup>2</sup> grout curtain (100km of drilling), and
- 2Mm<sup>3</sup> of earthworks

The works are designed to lower and control both sub-basal and perched groundwater levels in the toe of the slide so that post lake filling stability is greater than or equal to that prior to remedial works. The key effect of the works is the stabilising thrust of the reservoir generated by drainage at and behind the toe of the slide.

The low level drainage drive acts as a drainage element and provides ongoing access for maintenance and, if necessary, additional drainage drilling or tunnelling. Water collected in the drives is pumped back into the reservoir. The combined effect of the drives and drilling is to increase the rock mass permeability both sub-basally and within the landslide. The low permeability zoned earthfill, which includes core and filter zones, and grout curtain impede flow from the reservoir to the drive/drillhole system.

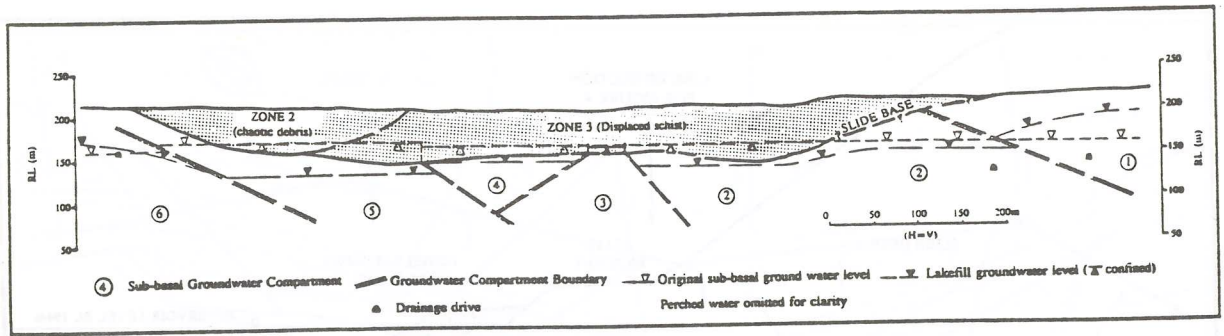


Figure 4. Toe transverse section.

### 3.2 Geological factors influencing low level drive design

The low level drive was located beneath the landslide and away from the disturbed rock underlying the slide base. The position of the declines (access to the low level drive) was constrained by the Zone 2/3 lateral boundaries and the location of the low level drive by the deepest section of the slide. Five stub drives were constructed perpendicular to the main low level drive to establish drilling chambers close to the slide base (Figures 2 and 3). The length of the stubs was dependent on the slide base geometry and optimization of tunnelling and drilling costs. An array of drainage holes was drilled from the stubs to provide drainage beneath and within the landslide. The orientation of the drilling arrays was dependent on slide base geometry in the stub area.

### 3.3 Design and model uncertainties

The remedial works were designed/located to be independent of model uncertainties but also enable unforeseen problem areas to be treated.

A significant advantage of the layout of the low level drive was that it provided a network of easily accessible drives from which additional drilling and/or tunnelling could be carried out if geological and/or groundwater conditions developed which resulted in design objectives not being met.

## 4 MODEL REFINEMENTS FROM CONSTRUCTION AND LAKE FILLING INFORMATION

### 4.1 Slide base model

Excavation of the decline and shaft excavation at the downstream end of the low level drive system enabled the landslide margin in Zone 3 to be more accurately delineated. However due to poor definition of the slide base in this area and conflicting data from

drillhole information the location of the margin is still not known with as much confidence as further upstream.

Groundwater response to drainage drawdown and lake filling confirmed the modelled slide base location in the remainder of Zones 2/3. The slide base was also found to be a significant aquitard. Although this was previously assumed, the coincidence of perched and sub-basal groundwater (with river level) had made it very difficult to confirm prior to drainage drawdown.

### 4.2 Groundwater model

Stressing of the groundwater systems during drainage drawdown and lake filling revealed significantly more compartmentalisation in the sub-basal semi-confined aquifer than had been inferred prior to drawdown (Figure 4).

The semi-confined aquifer groundwater compartments (GWC) were identified by analysing piezometric response to groundwater stress events such as tunnel excavation, drainage drilling and lake filling. These response diagrams often enabled piezometric response in one or many drillholes to be attributed to the penetration of a discrete crushed zone. Response diagrams and other methods used for determining groundwater characteristics on the Clyde Power Project landslides are outlined by Macfarlane, Pattle and Salt (1992)

In contrast to the apparent homogeneity (except for GWC 5) indicated prior to remedial works, the identified compartments of the semi-confined aquifer showed significant variability in drained and post lake filling water levels (Figure 4). The different water levels are due to factors such as:

- Rock mass storativity and transmissivity,
- Length and effectiveness of drainage elements intersecting the GWC's,
- Area of grout curtain frontage vs GWC volume (dictated by GWC boundary defect orientations) and,
- Relationship between grout curtain and drainage element effectiveness per unit area.

## 5 REMEDIAL WORK TO ACCOMMODATE MODEL REFINEMENTS

### 5.1 Slide base model

Confirmation of the slide base at a higher level at the Zone 3 margin enabled final groundwater levels in GWC 1 to remain higher than initially planned (i.e. less drainage drilling was required to achieve design groundwater levels).

### 5.2 Groundwater model

In general additional work was not required as a result of compartmentalisation of the semi-confined and perched aquifers because adequate drainage drawdown and control was achieved by the original drainage/cutoff element design. However after raising the lake to RL 177m higher than expected groundwater levels occurred in the area of GWC 3 (Figures 2 and 4). This indicated that unacceptably high uplift pressure could be acting on the slide base in a relatively small area of the slide toe where there was no suitably located instrumentation. Two new piezometer holes were drilled and 8m of uplift pressure on the slide base was confirmed, as were revised boundary defects for GWC 3. The previously inferred GWC 3 was larger and was intersected by the drive. The newly defined GWC had a large grout curtain "frontage" and minimal drainage element penetration (6 drainage holes and no tunnel) compared to its total volume.

The drive layout enabled additional drainage drilling to be carried out promptly and the GWC 3 groundwater level was lowered 15m with a series of ten holes. If necessary it would also have been possible to extend DR 583 into GWC 3 to provide additional drainage.

## 6 CONCLUSIONS

Comprehensive engineering geological investigations enabled development of geological and geohydrological models with a high degree of confidence on which to base remedial works design for a large schist landslide. The adopted design layout was purposely independent of the identified model uncertainties yet still enabled adverse conditions which developed in one area during lake filling to be readily treated to achieve the overall stabilisation objective. The remedial works have successfully lowered and controlled groundwater levels in the toe of the slide.

## ACKNOWLEDGEMENTS

The author is part of a team which has developed solutions for landslides around the shoreline of Lake Dunstan for Electricity Corporation of NZ Ltd, Clyde Power Project. Information gained, interpretations made and design solutions reached by members of the Brewery Creek Landslide team have made the presentation of this paper possible.

The permission of the Electricity Corporation of NZ Ltd to publish this paper is gratefully acknowledged.

## REFERENCES

- Graham, C.J., M.D. Gillon & G.G. Grocott (1991), "Brewery Creek Slide, Clyde Power Project, New Zealand. Engineering works to prevent instability induced by reservoir filling" Proc. Ninth ISRM Congress, Aachen: 875-880.
- Gillon, M.D., C.J. Graham & G.G. Grocott (1992), "Low level drainage works at the Brewery Creek Slide" Proc. Sixth Int. Symposium on Landslides, Christchurch, New Zealand: 715-720.
- Gillon, M.D & G.T. Hancox (1992), "Cromwell Gorge landslides: a general overview", Proc. Sixth Int. Symposium on Landslides, Christchurch, New Zealand: 83-102.
- Macfarlane, D.F., A.D. Pattle & G. Salt (1992), "Nature and identification of Cromwell Gorge landslides groundwater systems" Proc. Sixth Int. Symposium on Landslides, Christchurch, New Zealand: 509-518.