Design and Construction of a Large Cut Slope in Sensitive Volcanic Ash Soils

D L Dennison
BSc (Hons)
Principal Geotechnical Engineer, Opus International Consultants Ltd.
N J Edger
BE (Hons), MIPENZ, R Eng
Senior Geotechnical Engineer, Opus International Consultants Ltd.

Abstract: The PJK Expressways Project includes approximately eight kilometres of new roads, seven bridges and more than 1 million m^3 of earthworks. This paper describes the design and construction of one of the larger cut slopes in the project, the J3 Cut. This cut is up to about 20 m high and involves excavation of approximately 50,000 m^3.

Site investigations were carried out in several stages from 1989, including a full scale trial evacuation in 1992, and continued into the construction phase. Soils in the cut area are mainly sensitive fine grained volcanic ash soils.

Analysis demonstrated that control of pore pressures was critical in maintaining the stability of the slope. A variety of drainage measures were used including subsoil drains, bored horizontal drains and counterfort drains.

The excavation extends well below the original ground water table and encountered soils that were too soft or too slippery for standard earthworks equipment. The construction made use of a long reach excavator to dig most of the sensitive soils in a single large lift, working from a bench in the upper more friable soils. Most of the soil excavated was used in non-structural applications, such as stability berms for nearby embankments on soft ground.

A flexible observational approach to construction was successfully applied to deal with the variable soil and groundwater conditions encountered during construction of the J3 Cut.

INTRODUCTION

The PJK Expressways Project was the largest single roading contract in New Zealand when construction began in 1999. The project includes approximately eight kilometres of new roads, seven bridges and more than 1 million m^3 of earthworks.

Tauranga District Council and Transit New Zealand combined their separate projects into one construction contract to maximise flexibility for the contractor's programme. The single contract also simplified project management input from the consultant and clients.

The project comprises the following major components:

- Route K, approximately 4.5 km long, from SH29 to Interchange Area
- Route P, approximately 0.5 km long, from Route K to Takatimu Drive
- Route J, approximately 3.1 km long (including interchange), from SH2 to 15th Avenue.

The layout of the project is shown in Figure 1.

The project faced many challenging geotechnical issues including high embankments on soft compressible soils, placing moisture sensitive fill within a limited corridor, design of pile foundations for bridges, and large cut slopes in sensitive volcanic soils.

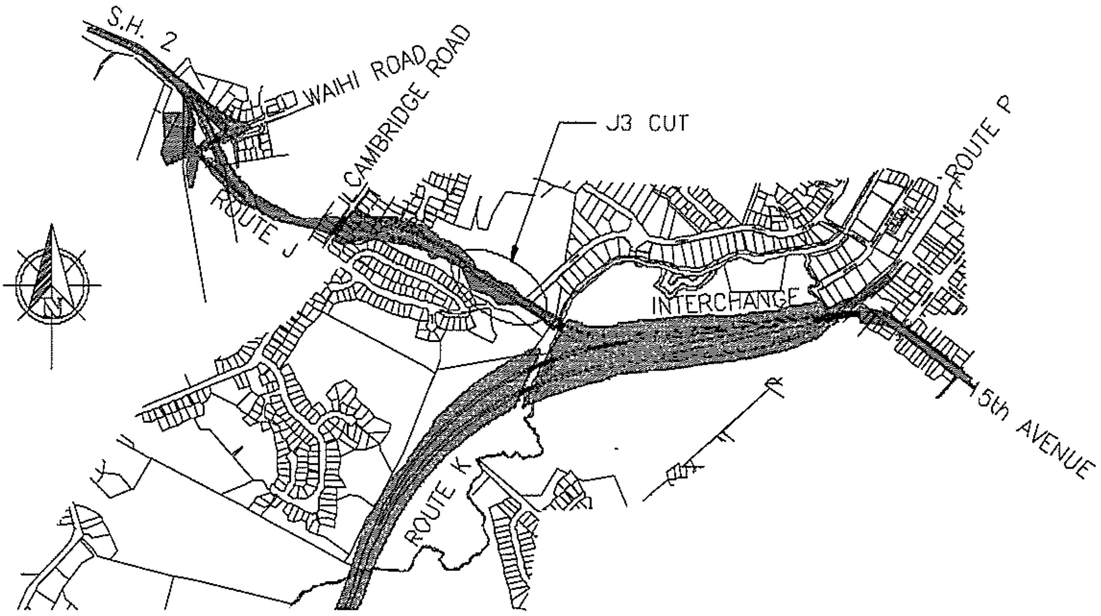

Figure 1. PJK Expressway Site Layout

This paper describes the design and construction of the J3 Cut. The location of the cut is shown on Figure 1. This cut is up to about 20 m high and involves excavation of approximately 50,000 m^3. A general overview of the cut during construction is shown in Figure 2.

Figure 2. Overview of J3 Cut

SITE INVESTIGATION

Site investigation for the cut was carried out in several stages from September 1989, continuing into the construction phase. In the immediate area of the cut there were five cored boreholes, five cone penetration tests (CPTs) and three test pits. In addition, soil conditions were observed directly during the full scale trial excavation described below.

Extensive laboratory testing was carried out on soils from the J3 area including triaxial strength testing for cut slope design, CBR tests to determine pavement subgrade conditions and compaction testing to assess suitability of cut material as structural fill.

SUBSURFACE CONDITIONS

Soils in the cut area are mainly sensitive fine grained volcanic ashes. From the surface downward a typical geologic sequence consists of Younger Ashes, Rotoehu Ash, Hamilton Ash and Matua subgroup soils.

Younger Ashes are generally sandy and suitable for bulk earthworks provided moisture contents are well controlled. Some drying is often necessary to achieve adequate shear strength and workability. Rotoehu Ash is generally a white sandy soil and often has very high moisture content. Brown Hamilton Ash is more clayey, with high moisture contents that required conditioning before use as structural fill.

Underlying the Hamilton Ash is the Matua Sub-group that includes a large variety of soil types, ranging from pumice sands to clayey soils. A particularly sensitive soil, locally known as Pahoia Tephra, is included in the Matua Subgroup. Pahoia Tephra soils were expected to require extensive conditioning over a long period before using as bulk fill, or be cut to a soil disposal area. The Hamilton Ashes and Younger Ashes have an allophane mineral content of 5 to 7 %.

TRIAL EARTHWORKS

The initial investigations showed that the soils in the J3 area were likely to present significant construction difficulties and exhibit variable stability performance. A trial excavation and embankment constructed in 1992 had the following objectives:

- assess slope stability,
- assess suitability of the material from the cut for bulk and subgrade fill,
- determine the degree of construction difficulty associated with the excavation, hauling and placement of the cut soil in fill,
- assess the change in the characteristics of the excavated soil over time after placement in the embankment fill.

The trial excavation comprised a 1H:1V end slope up to 9.5 m high and 1.5H:1V side slopes up to 12 m high (Figure 3). Aside from erosion of some of the less cohesive materials exposed in the cut slopes in the first winter, there was no sign of instability in the trial cut.

Figure 3. Trial Excavation

Hauling and placement in the embankment became significantly more difficult when the more sensitive soils at and below the Hamilton Ash layer were reached in the excavation (Figure 4). Testing indicated that a Pilcon vane strength of about 80 kPa was required to provide passage for trafficking of haul equipment.

Figure 4. Swamp Track Dozer Stuck in Sensitive Ash Fill

As part of the Route J trial fill, an experiment was carried out to assess drying of the soil using light agricultural discs. The equipment repeatedly became bogged down during the trial. A water content reduction of about 6% was achieved in eight days (Figure 5).

Soil sensitivity and moisture content increased with depth in the excavation, making plant movement and material handling increasingly difficult. Below about three to five metres depth the soil exposed in the cut was either too slippery or too soft to allow easy passage of haul traffic. Soils exposed near the base of the excavation remoulded to a viscous fluid consistency when disturbed by excavation and haul equipment.

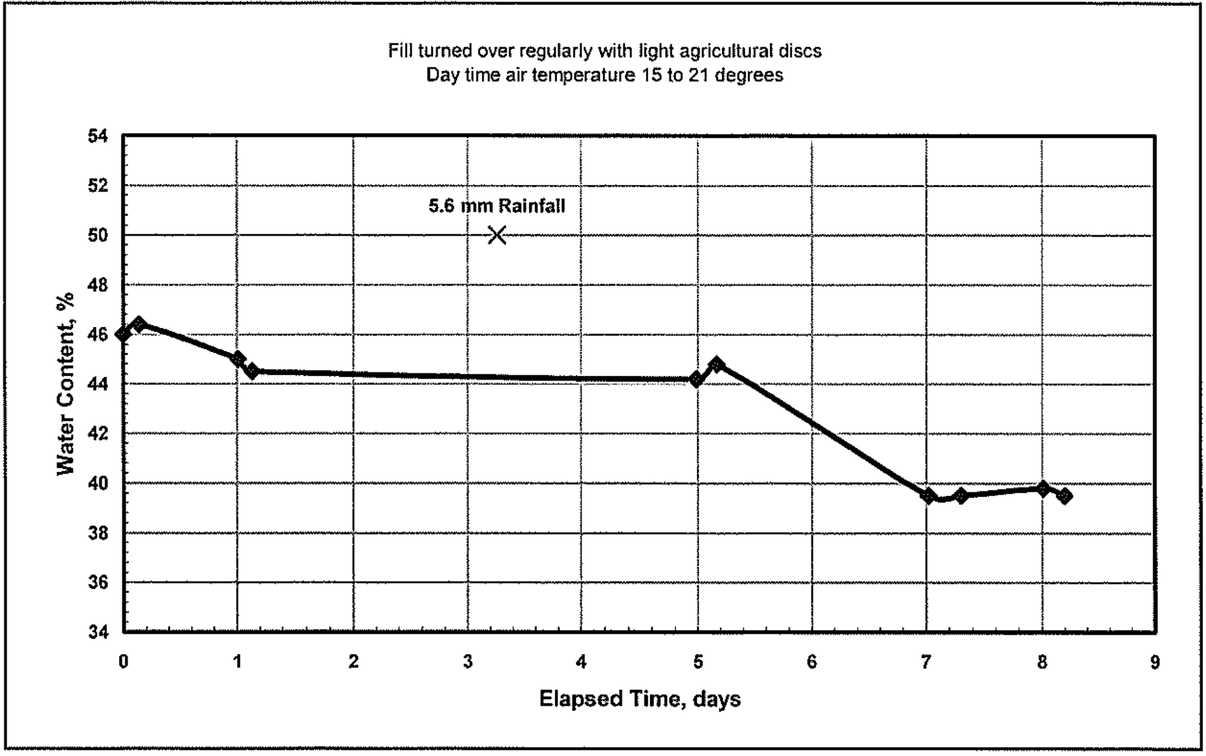

Figure 5. Results of Field Drying Trial

Additional testing was carried out in the trial fill approximately two years after initial placement. Pilcon vane strengths typically increased by about 20 kPa, to 80 kPa, over this time, although water contents were similar. The mechanism for the strength gain is not clear, but may be related to reformation of bonds within the soil.

SLOPE STABILITY

Previous landslips in the hillside to the northwest of the J3 Cut demonstrated the potential for stability problems at the site. Although the subsurface conditions are highly variable, the extensive investigation, lab testing and field trial provided a good indication of the range of soil properties that could be expected at the site. Shear strength properties of c'=15 kPa and $\phi'=25°$ were selected for stability analysis (Figure 6). Possible failure mechanisms include rotational slumping and possible sliding along a soil layer that is lower strength and/or is subject to high pore pressures from a perched water table.

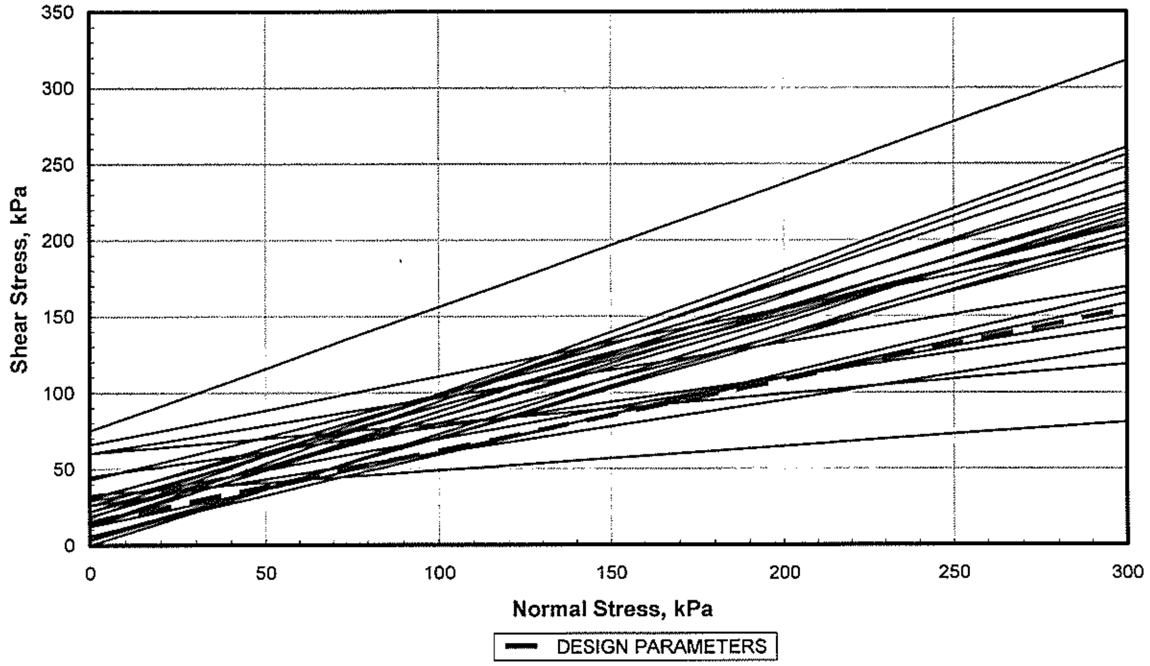

Figure 6. Summary of 24 Triaxial Test Results

The design batter angle is 1.5H: 1V on the left side of the cut and 2H: 1V on the right. The flatter slope on the right is due to the greater overall slope height, higher groundwater levels, and presence of houses at the top. In addition north facing slopes in the Bay of Plenty are often less stable due to increased infiltration caused by desiccation cracking.

Analysis demonstrated that control of pore pressures was critical in maintaining the stability of the slope. The bottom of the excavation was to be below the static groundwater levels measured in the initial investigations, so measures to draw the groundwater level permanently well below the level of the pavement were required. Drainage measures adopted at the site include:

- deep subsoil drains along both sides of the cut, comprising perforated subsoil pipes and clean rockfill,
- counterfort drains running down the slope at regular intervals,
- sub-horizontal drains drilled into the slope.

CONSTRUCTION CONSIDERATIONS

Maximum dry density in the standard compaction test ranges from about 0.95 to 1.20 tonnes/cu m for the soils encountered in J3 Cut. Optimum moisture content is about 40 to 60%. Moisture content of the ash soils is generally about 10% above the optimum moisture content measured in standard compaction tests.

Compaction tests indicate local ash soils are often sensitive to the moisture history of the sample. Samples from similar soils prepared by drying back from the natural moisture content give significantly different results than if they are wetted up from oven dried samples, as shown in Figure 7. Because of this, it can be difficult to control compaction using the standard moisture versus density laboratory test.

Curve	IWC* %	OWC %	$\rho_{d(max)}$ t/m^3
E	<5	45.5	1.07
F	64.5	57.5	0.98
G	75.3	64.0	0.93

*Initial Water Content

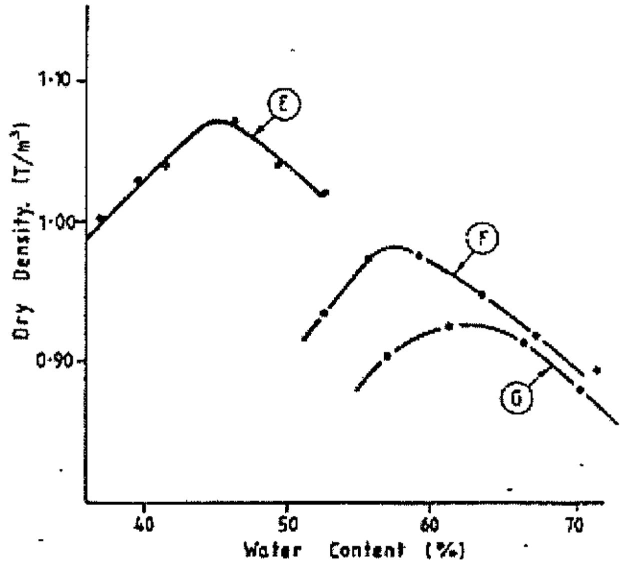

Figure 7. Compaction Curves at Different Initial Water Contents (after Parton & Olsen, 1980)

Moisture content readings by a nuclear densometer were poorly correlated to those measured in the laboratory, with no consistent difference between them. This required nuclear densometer readings to be frequently checked against oven dried moisture contents during construction.

The ash soils do not dry easily and it is generally not practicable to achieve compaction criteria based on optimum moisture contents determined in standard compaction tests. Attempts to dry the fill by disc harrowing may reduce the strength of the soil by remoulding rather than improve the soil by drying.

The compacted density of the ash fills was significantly greater than the original in-situ density. The amount of imported fill required depended partly on this difference in density. The compaction factor varies within the project area and with depth. Average dry densities measured in the trial excavation were not significantly different from dry densities measured in the trial fill. A large trench was excavated in similar soils at the Lakewood borrow area as part of the Route K enabling contract. The surveyed volume of the excavation was 14,750 cu m. The combined volume of the soil stockpiles and fills made from this material was 11,600 cu m, giving a compaction factor of 79%. The soil stockpiles in the enabling contract were compacted only by construction traffic.

The J3 excavation extends well below the original ground water table and encountered soils that were too soft or slippery for standard earthworks equipment. Within the Route J trial excavation a long reach excavator was used to reduce the requirement for construction traffic because of the trafficability problems. The full scale construction also made use of a long reach excavator to dig most of the sensitive soils in a single large lift, working from a bench in the upper more friable soils (Figure 8). Most of the soil excavated was used in non-structural applications, such as stability berms for the embankments in the interchange area.

Figure 8. Single Large Excavation Lift

Because of the problems with water content and trafficability, temporary drainage measures in the cut were carefully maintained to minimise moisture within the excavations. Control of water was important for maintaining the trafficability of the cut surface and for maximising the use of cut materials in embankment fills. Temporary drainage measures in the cut were carefully maintained to maximise the use of cut materials in embankments and to reduce trafficability problems. Drains were needed to handle both surface run-off and groundwater inflows. As the base of the cut could not support even lightweight construction equipment, it was necessary to lay a filter cloth on top of the sensitive soils, and then use thick lifts of rockfill from the ends of the cut.

OBSERVATIONAL APPROACH

It was necessary to adopt a flexible observational approach to the construction because of the variable and difficult conditions. Activities during construction included additional investigation drilling, regular inspections of soil and groundwater conditions updating stability calculations, additional triaxial strength testing, and review of monitoring data (piezometer, inclinometer and survey data). Several changes were made to the design as a result of these activities, including the following:

- reticulated stormwater from the houses nearest to the top of the cut (previously using soakholes),
- additional bored drains, covered by filter fabric, extending deeper into the slope,
- increased number and depth of counterfort drains,
- additional instrumentation,
- changes to the hydro-seed mix,
- widened berm at base of the slope to provide more room for stormwater pipe installation,
- altered design of subsoil drains at the base of the slope,
- deeper subgrade improvement layer under the pavement at the base of the slope.

Flows from the bored drains ranged from nil to approximately 20 l/min. Some drains flowed for a while after installation and then stopped, while others are still flowing. Additional drains were installed in areas where springs were encountered and around initial drains showing significant flow.

An intensive rainstorm caused extensive damage in the Tauranga area in April 2000. Rainfall was estimated at more than 200 mm in a 25 hour period. The timing of the storm caught the J3 Cut at its most vulnerable stage, excavated to full depth but with vegetation not well established on the slope. Although there was some surface erosion at J3 (Figure 9), the drainage system worked well and no signs of serious instability were observed.

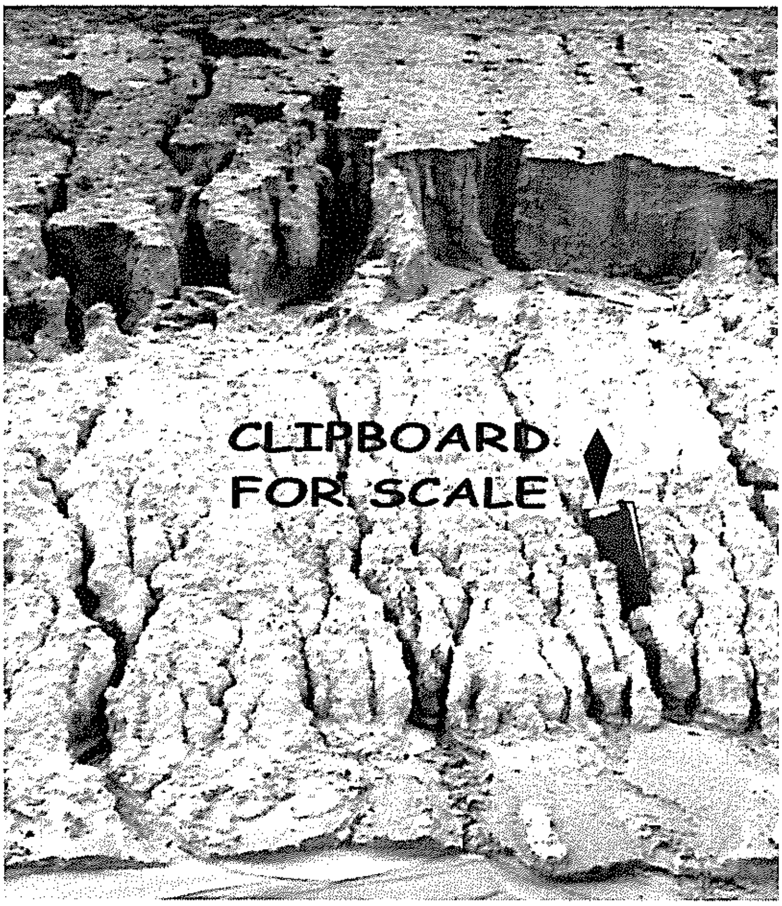

Figure 9. Storm Erosion

CONCLUSION

The sensitivity of the volcanic ash at the site, as well as the variability of soil and groundwater conditions, required extensive investigation work to provide information for cut slope design and earthwork management. The large scale trial excavation and embankment construction were particularly valuable to examine the ground conditions and identify appropriate construction techniques.

An observational approach to construction was required to adapt the design to the range of soil and groundwater conditions encountered. Key aspects to this flexible approach were:

- a reasonably conservative design,
- adequate contingencies in both programme and budget to handle changes,
- allowance in material balance for additional fill and/or waste soil disposal,
- a programme of monitoring, additional testing and design review during construction,
- communicating expected difficulties to other parties, especially those tendering for the work.

ACKNOWLEDGEMENT

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REFERENCES

Parton, I.M., Olsen, A.J., (1980), "Compaction Properties of Bay of Plenty Volcanic Soils, New Zealand", 3rd Australia-NZ Conference on Geomechanics. Vol.1, Wellington, NZ.