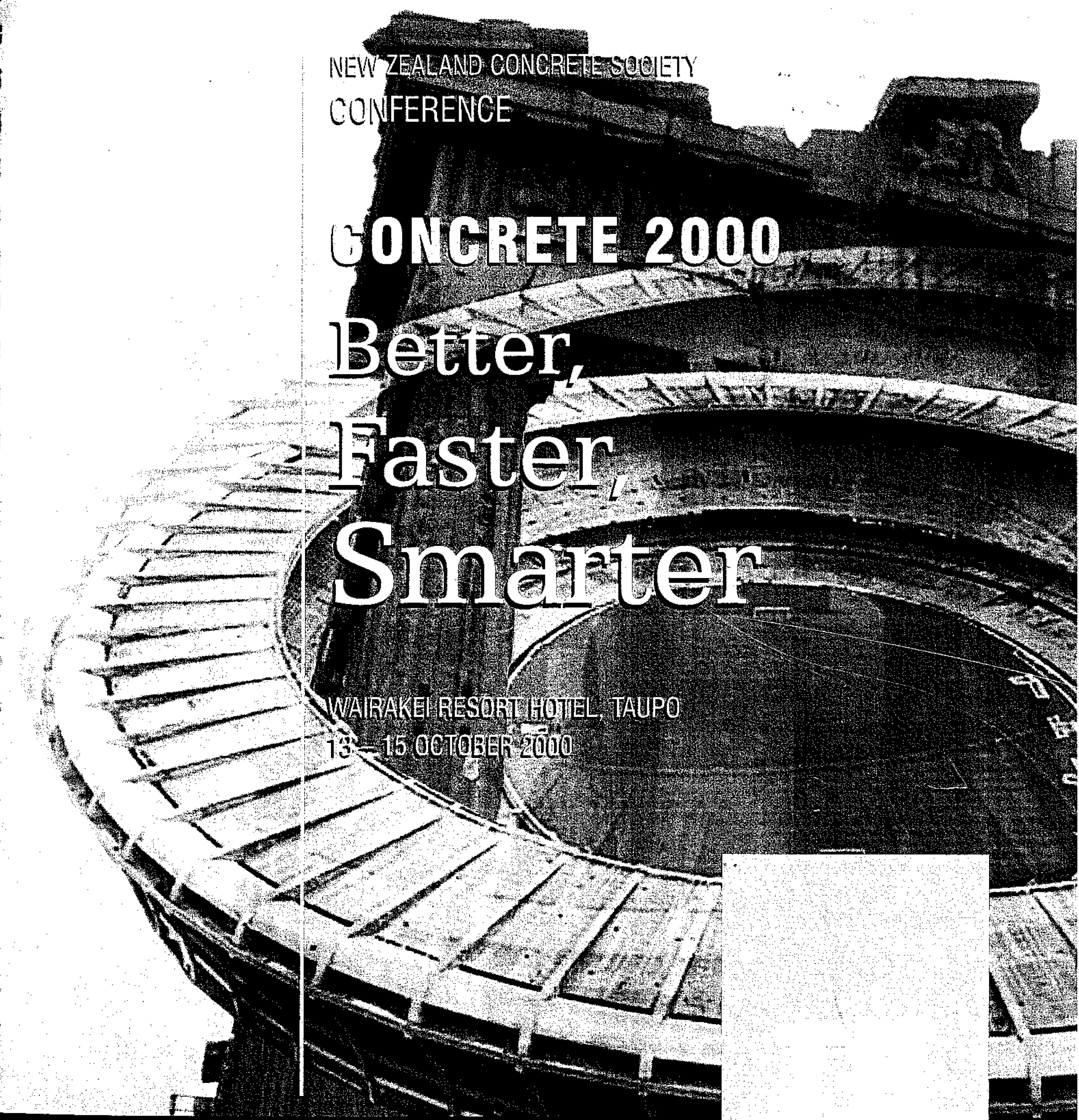

NEW ZEALAND CONCRETE SOCIETY
CONFERENCE

CONCRETE 2000

Better, Faster, Smarter

WAIRAKEI RESORT HOTEL, TAUPO
13 – 15 OCTOBER 2000

Technical Paper

NEW ZEALAND CONCRETE SOCIETY

CONCRETE '00
"BETTER, FASTER, SMARTER"

Technical Conference and AGM
Wairakei Resort Hotel, Taupo
13 – 15 October 2000

Conference Programme and Table of Contents

Further copies of this volume, designated NZCS Technical Report (TR) 23
Price: Members - $45.00 (inclusive GST); Non-Members - $60.00 (inclusive GST)
and are available from: New Zealand Concrete Society, P O Box 12, Beachlands, Auckland, New Zealand
Phone: (09) 536 5410 Fax: (09) 536 5442 Email: toplev@xtra.co.nz

DESIGN ASPECTS – CANDY'S BEND ROAD WIDENING ARTHUR'S PASS

Melvyn Maylin[1]

SUMMARY

The Candy's Bend to Starvation Point project is an 850 metre long road project under construction in the Southern Alps of New Zealand. This paper outlines the design processes used, and solutions developed, to create a cost effective two lane road on an extremely complex and challenging site. The completed design incorporates a number of unusual structures. These include two overhead rockfall protection structures, two half bridge structures (one propped, the other cantilevered), and an existing bridge widened by a half bridge extension. The solutions developed are innovative, unique and focussed on construction practicality.

INTRODUCTION

The Candy's Bend to Starvation Point project is an 850metre length of State Highway 73 in the Arthur's Pass National Park in the Southern Alps of New Zealand. The site has long been prone to rockfall and was single lane for much of its length. This paper outlines the constraints, design processes, and design solutions adopted to improve the safety and efficiency of this section of road for Transit New Zealand. The completed design includes a number of innovative and unique structures to provide cost effective outcomes at an extremely complex and challenging alpine site.

ISSUES AND CONSTRAINTS

Highway Geometry and Traffic Safety

The existing road was single lane for much of its length. It has steep grades (around 16%) tight curves and limited visibility. It was also governed by a bylaw restricting vehicles to 13 metres in length. These factors meant that, as traffic volumes grew, delays and conflicts on the route were occurring with increasing frequency.

Furthermore, the site is immediately downhill of the Otira viaduct. When the viaduct project was completed the site was of a considerably lower standard than the adjacent section and accident migration could be expected if improvements were not made.

Environmental Aspects

This section of State Highway passes through Arthur's Pass National Park. Accordingly environmental considerations and national park values were of paramount importance throughout the design process. The site has been subject to earlier environmental impact assessment procedures and considerable dialogue between Transit New Zealand and the Department of Conservation [1-7].

In terms of design philosophy, guiding principles were:

- Special attention should be paid to visual impact and appearance
- Excavation and embankments would be kept to the minimum practical
- Existing native vegetation should be preserved as much as possible
- Impact on water quality should be minimised
- Impact on birdlife should be minimised

Topography

The site passes through an alpine pass with steep slopes extending several hundred metres above the road and near vertical drops of between 20 and 70 metres to the river below the road. Realigning and widening the existing road is therefore sensitive to comparatively small lateral movements. For example widening of less than one metre out of the hillside can require building new structures while moving into the hillside can require large cut volumes and impose adverse environmental effects associated with large cut faces.

The steep topography and limited width of the existing, single lane, road bench also meant that any construction or widening on the existing alignment would inevitably interfere with traffic flow and require a strong focus on buildability.

Seismicity

The site is located in one of the most seismically active areas of New Zealand: within five kilometres of the active Kakapo fault and within 20 kilometres of the main alpine fault. An earthquake in 1994 dislodged a significant block of material

[1] Principal Consultant, Opus International Consultants

(approximately 7000m3) from above the "Passing Bay".

Climatic Conditions

Its alpine location means that this site experiences extreme weather conditions. These include frequent heavy rainfall events as well as snow and ice during winter. The average annual rainfall is in the range of 4 to 5 metres.

Geology and Rockfall

The steep slopes and fractured rock above the road, combined with freeze /thaw action, extreme rainfall, and seismic events mean that the road is subject to frequent rockfall. This poses a significant safety hazard to traffic and also leads to periodic road closures and ongoing maintenance requirements.

The spacing and orientation of rock bedding defects is quite variable throughout the site and there is potential for unfavourable orientation of defects to combine locally to produce unstable zones in new rock cuttings.

There are also a number of shear zones in the rock. Intersection of several of these formed the basal failure planes of a rock slide initiated at the "Passing Bay" (refer to figure 1) in the 1994 earthquake.

Additionally there are two steeply dipping fault zones 1-2m thick in the rock mass at Starvation Point. This sheared rock is highly weathered which significantly reduces the strength of the rock mass in this area.

Candy's Bend comprises a narrow ridge of greywacke. However, from Candy's Bend to just past the northern end of Candy's bridge the road crosses an open bush covered slope. This is a continuous debris slope extending from the river below to the top of extensive scree deposits at the foot of Hills Peak ridge. Candy's creek follows a very steep slope down the bedrock/slope deposit interface. Debris flows occur in Candy's creek at 5 to 10 year intervals and have damaged the existing bridge many times. In 1988 a debris flow destroyed the bridge deck and covered the bridge in debris up to 5 metres deep.

Budget

Achieving a fundable solution for this project required that construction costs should lie somewhere in the $8 to $10 million range given the need to meet Transfund New Zealand Benefit Cost criteria and the level of benefits which could be realised at the site.

OPTIONS CONSIDERED

Earlier studies [8] identified 5 broad options to improve this section of road. These are shown on figure 1 and include:

- Option 1, following the existing road with a short bridge at Candy's Creek
- Option 2, following the existing road with a long bridge at Candy's Creek.
- Option 3, two bridges and a sidling cut on the true left bank of the river opposite the existing road.
- Option 4, two bridges and a tunnel on the true left bank of the river.
- Option 5, a viaduct along the true left bank of the river.

Following extensive investigation and consultation, option 1 was identified as the preferred alignment. This was because, by staying as close as possible to the existing alignment, environmental impact and construction cost were minimised allowing a fundable project to be developed.

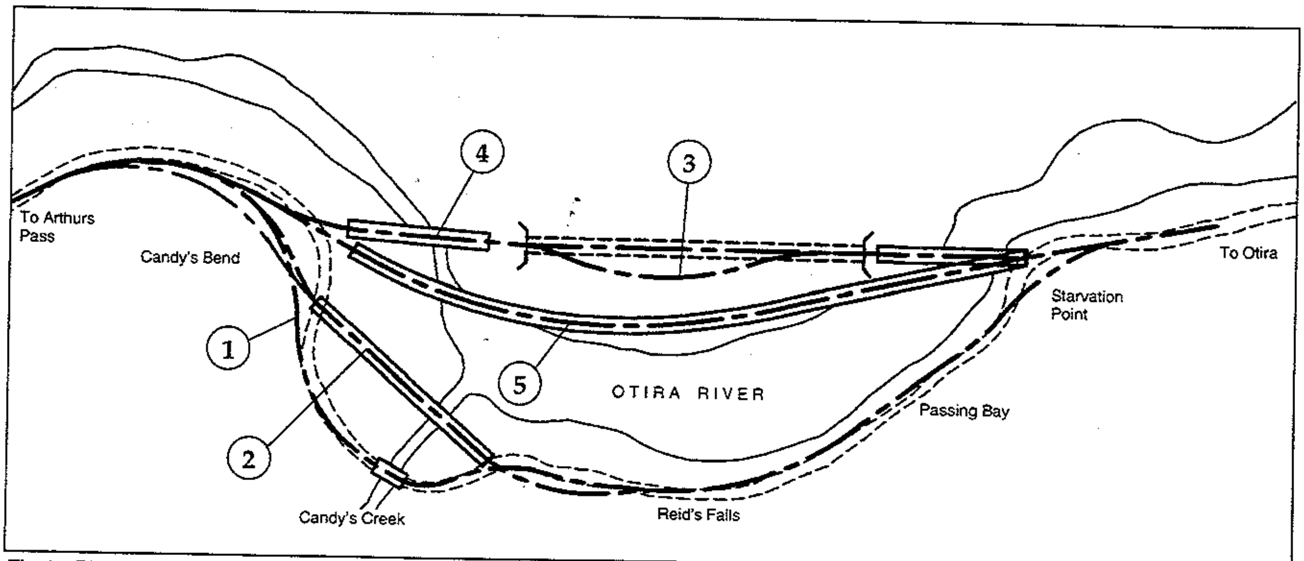

Fig 1 - Plan of Earlier Options

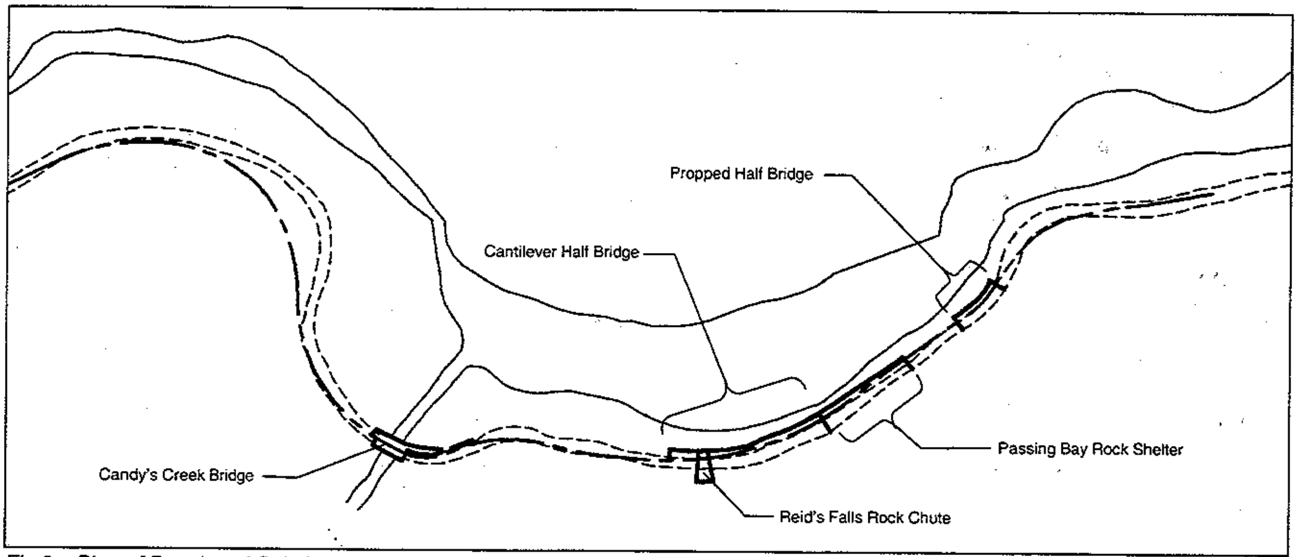

Fig 2 – Plan of Developed Solution

The Solution

The developed solution is shown in plan on figure 2. Key features include:

- Widening of the existing Candy's creek bridge downstream.
- An overhead chute to carry the waterfall and rock debris over the road at Reid's Falls.
- A cantilever half bridge structure between Reid's Falls and the Passing Bay.
- An overhead rockfall protection structure at the Passing Bay.
- A propped half bridge structure between the Passing Bay and Starvation Point.

It should be appreciated that this highway is a low speed environment with curve design speeds of between 50 and 65 km/hr. By comparison, the typically recommended speed environment for mountainous terrain is 70km/hr with design speeds for individual curves of 60 to 65 km/hr [9]. The lower than typical design speed environment is appropriate due to the nature of this site. In particular the topography "closes in" the site. This will be reinforced by the continuous guardrail and the two overhead rock shelters. The combination of these effects will lead to a lower expectation of the speed environment by drivers.

Iterative Design Process

Having determined that option 1 was preferred it was then subjected to an intensive iterative design process to optimise the selection of the alignment. This was essential to fully integrate potentially conflicting requirements while recognising the extreme constraints of the topography. For example a geometric design which resolved an issue at one area by a small movement in or out of the hill could create a more significant problem by requiring a similar or larger magnitude movement elsewhere.

In simple terms, a tradeoff was required between the cost of structural widening and the cost and environmental impact of significant cuts into the hillside.

The key to understanding the various issues and integrating them fully into the final design concept was to understand the site in three dimensions. This understanding was achieved by using detailed 3-D electronic modelling and geometric design in MOSS combined with conceptual structural design and a continuously updated cost plan. The iterative cycle was repeated about a dozen times to refine option 1. Further understanding of the site was also gained by plotting important features onto topographical plans. All plotting was to the same scale and on the same base topographical plans. In this way quite different facets of the problem could be integrated into the design solution. Examples include:

- Mapping of geological defects [10]
- Mapping of 14 distinct areas of vegetation
- Mapping of sources and paths of rock fall [10]
- Development of a risk plan for the site which defined 12 separate areas giving a visual representation of original and residual risk. This was important as it was not economic to mitigate against all risks (such as rock fall) at all areas of this site.

The iterative design process resolved almost all environmental issues. The most cost effective solution met most of the environmental concerns. For example;

- Cut batter heights were minimised
- Investigation ascertained that water quality issues could be managed by care during construction [11]
- Surveys indicated that birdlife was unlikely to be affected
- With the exception of a completely new section of road at Candy's Bend (where traffic safety issues were dominant), vegetation disturbance was minimised.

The principle environmental feature earmarked for further consideration in the detailed design phase was consideration of visual impact of structures. [12] The visual design philosophy being to seek structures which:

- were compatible with pyramids and truncated pyramid forms in the landscape.
- were blocky and robust.
- were honest with the structure obvious.
- Grow out of and batter into the slopes.
- Contain coarse and uneven surfaces finished with line and/or texture compatible with the rock faces.
- were seen as a family and reflect design unity throughout.

Detailed Design

The iterative process defined the preferred solution in considerable detail and largely fixed the road geometry. Subsequent detailed design efforts largely concentrated on design of the structures and slope stabilisation measures.

Buildability

Buildability was a central theme of the whole design process. Common themes during detailed design were:

- Development of piling solutions able to use available drilling equipment on the limited rock bench width.
- Careful consideration of construction methods and in particular crane operation and handling weights.
- Road closures would be necessary to complete the planned construction. It was essential to minimise the number and duration of these. Thus the design focussed on practicality and speed of erection as a key consideration.
- Use of precast elements to limit the quantum of site work in a difficult alpine environment and minimise required road closures.

Consultation and Road Closures

As the conceptual and detailed design processes unfolded, consultation was essential with representatives of all affected parties. This included bodies such as the Department of Conservation, Local Authorities, Road User groups, Iwi, and Tourism interests. The integration of environmental issues into the iterative design process from commencement proved very constructive in understanding and avoiding potential conflicts as the design developed.

Consultation regarding road closures to permit construction led to vigorous debate with affected parties, but a positive approach was maintained throughout. The agreed programme was for a five week block closure of the road immediately after Easter 2000 (from 8:00am on 1 May 2000 to midday on 2 June 2000) followed by "two day" (44 hour) closures from 2 June to 30 September 2000. This allowed 17 two day closures and a significant bonus was offered to encourage the contractor to use less than the permitted number of closures. In the event the contractor only required 5 of the two day closures.

THE STRUCTURES

Seismicity

Site specific seismic studies were undertaken as part of the design of the Otira viaduct immediately uphill of Candy's Bend [13]. Interpretation and application of those studies to the Candy's Bend to Starvation Point Project led to an equivalent static force for design of 0.7g. This is 40% higher than the maximum value normally used.

Design Standards

The guiding design standard was the Transit New Zealand Bridge manual.

The overall carriageway width is typically 8.0 metres between the inside face of the outer guardrail and the outside of the road shoulder.

Materials

Concrete and steel were both considered for all structures but concrete was preferred because:

- Materials were available locally and concrete was cost effective
- Concrete was more compatible aesthetically
- Connection details such as between piles, beams, and tie rods were simpler to achieve with concrete
- Concrete offered a longer life to first maintenance. This is important at such an isolated site in a wet environment. Access to

some structures for maintenance would also be difficult.

- Concrete sections offered more robust solutions less susceptible to damage from rock fall and debris flow impact

Structure Geometry

The structures are built on a curved alignment with a steep longitudinal grade (up to 16%) and a high crossfall (up to 6.6%). Geometry is therefore complex requiring cross beams to be positioned radially and deck slabs to have tapered ends.

Candy's Creek Bridge

The structure is shown on figure 3. The existing bridge and computer generated impression of the completed structure are shown on photographs 1&2.

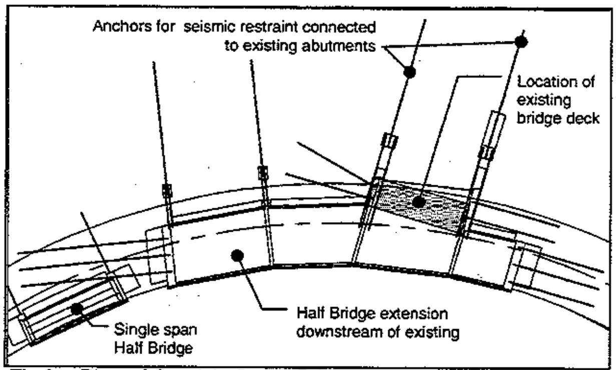

Fig 3 – Plan of Candy's Creek Bridge


Photo 1 - Existing Candy's Creek Bridge

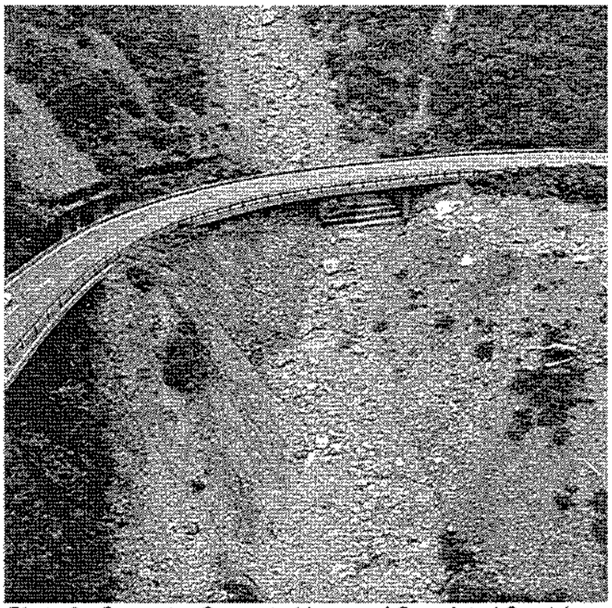
Photo 2 - Computer Generated Image of Completed Candy's Creek Bridge

This bridge crosses a moderately steep slope (30°) comprised of alluvial materials deposited by old landslide events. However the existing abutments have performed satisfactorily during two recent earthquakes and many debris flows. It was resolved to re use these and widen the bridge downstream to avoid constricting the channel further as would occur with widening upstream.

Bored piles were selected and extend 12 metres into the bouldery gravels. These are deep enough to found below scour depths and provide some measure of resistance to deformation in a large earthquake. However, the proximity of the piles to the steep slope below the road and gravelly nature of the slope material meant that ground anchors are also required to resist seismic loads on the structure.
This was one of the easier structures from a buildability perspective as work could proceed off the line of the existing road.

Cantilever Half Bridging

Between Reid's Falls and the Passing Bay, an 88 metre length of half road width was required to extend out over near vertical cliffs below. The design solution was an 11 span cantilevered half bridge. The typical section is shown in figure 4 with photographs 3 & 4 showing the partially built structure.

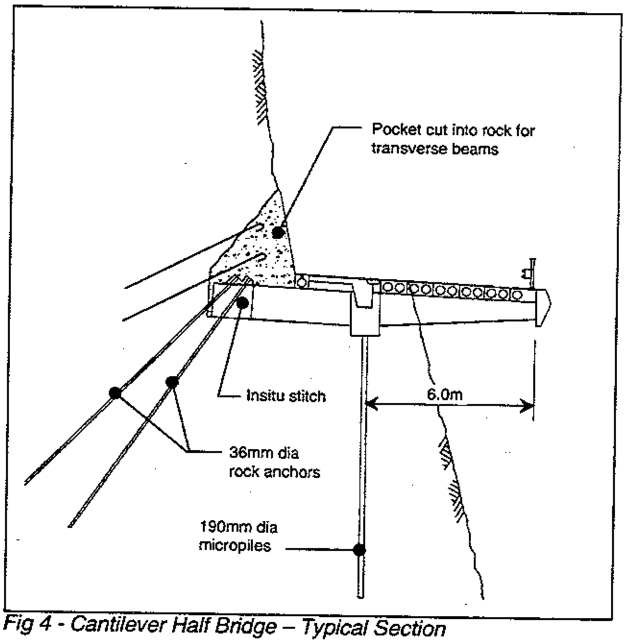

Fig 4 - Cantilever Half Bridge – Typical Section

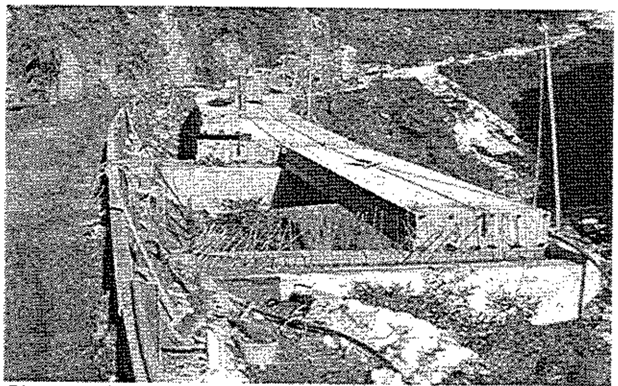

Photo 3 - Cantilever Half Bridge Looking South

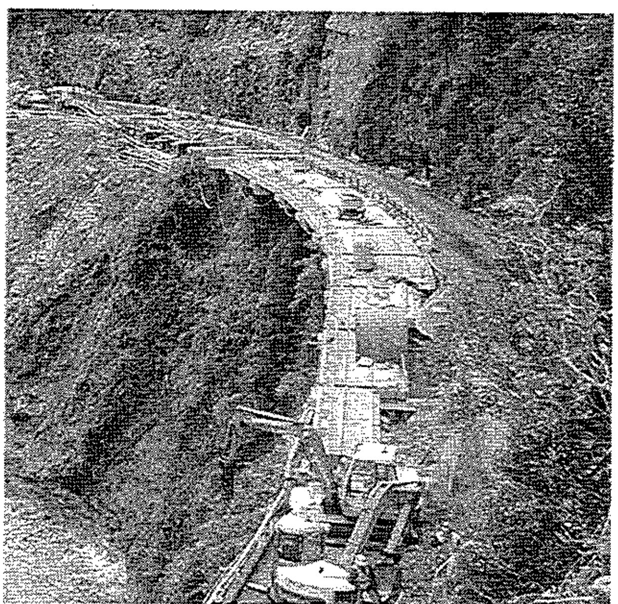

Photo 4 – Cantilever Half Bridge Looking North

Analysis of the defects in rock below the road bench indicated the potential for defects to combine giving stepped planar or wedge failure if excessive loads were applied to the outer edge of the rock bench. Accordingly piled support was required with pile penetration of 15 metres. The selected final design was four 190mm diameter micro piles per transverse beam. While larger piles were considered, this part of the site has very restricted access and thus piling rig size became a limiting factor. Photograph 5 indicates how confined the site is. The top 3 metres of these piles was cased to ensure load transfer to the rock at a lower level.

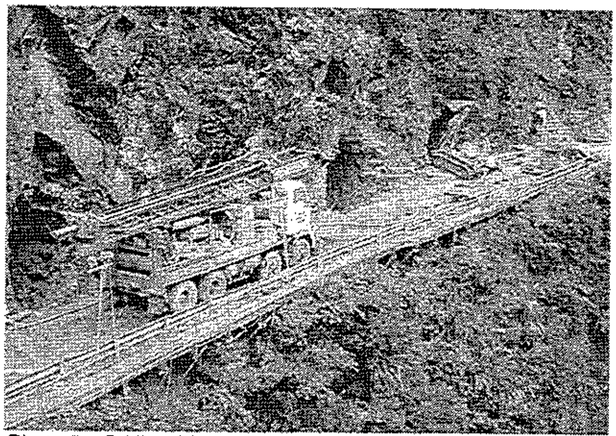

Photo 5 – Drilling Rig on Existing Road

Pockets were required, cut into the rock, at transverse beam locations to provide adequate moment lever arm for the beams. Transverse beams were anchored in these pockets by pairs of rock anchors. These provide moment stability during construction and for the full design loads in addition to providing lateral seismic restraint. As an added precaution, the design also provided to mobilise sufficient rock mass above the anchors to provide overturning stability without reliance on the rock anchors.

Use of pre cast concrete components was maximised. This included transverse beams, deck units, and fascia panels. To meet anticipated handling weight constraints, the transverse beams were designed as pairs of beams rather than single units. This gave a handling weight of approximately 14 tonnes.

Construction of the bridge would give an irregular stepped edge running down the completed road. It was necessary to detail this junction to provide effective edge restraint to the pavement and also to tolerate deflection of the longitudinal beams during traffic loading. To achieve both of these aims, a concrete edge beam and concrete road slab were selected adjacent to the half bridge. The detail is shown in figure 5.

Assessment of rock fall risk in the zone of this half bridge indicated the risk of damage to the bridge deck was comparatively small as most rock was small in diameter and also would most likely first impact on the road bench rather than on the structure. While damage due to rock fall is possible it was considered appropriate to accept the risk and repair the bridge should damage occur.

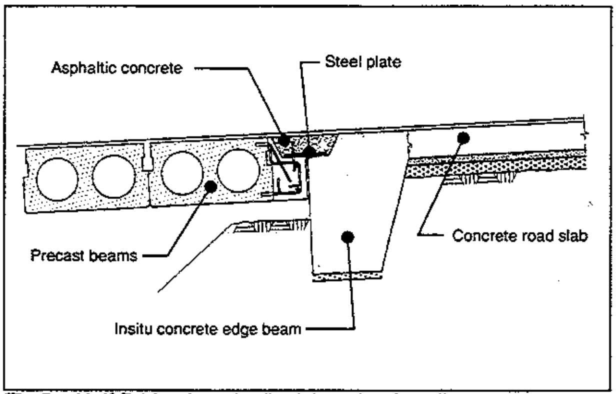

Fig 5 – Half Bridge Longitudinal Junction Detail

Propped Half Bridge

Between the Passing Bay and Starvation Point, a 48 metre length of half road width was required extending out over steep slopes below. However these slopes were less steep than beneath the cantilever half bridge and the design solution was a five span propped half bridge. The typical section is shown in figure 6 with photographs 6 & 7 showing the partially built structure.

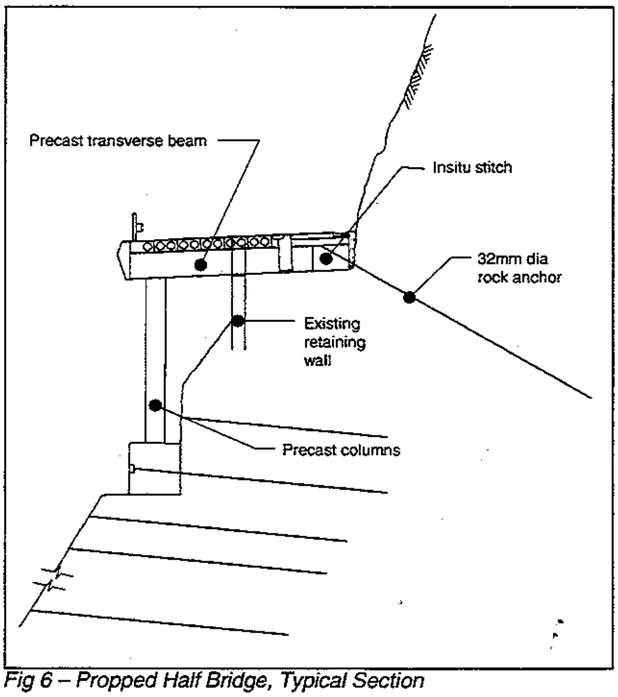

Fig 6 – Propped Half Bridge, Typical Section

Stressed rock anchors feature in two aspects of this design. Firstly the rock slopes below the prop locations were reinforced to ensure stability. Secondly, lateral seismic restraint was provided at deck level by 12 metre long anchors fixed to the transvere beams.

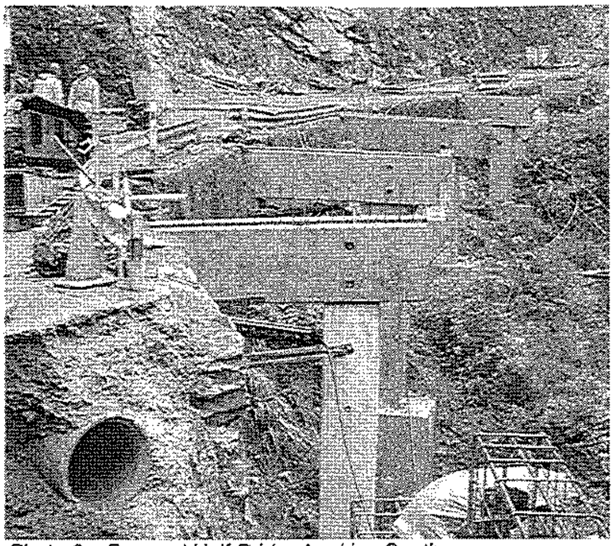
Photo 6 – Propped Half Bridge Looking South

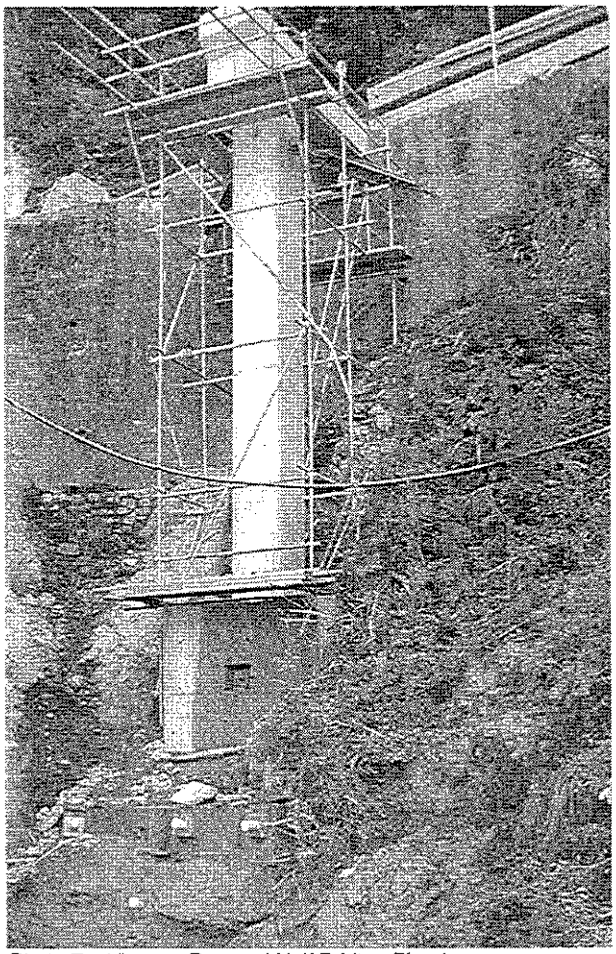
Photo 7 – View on Propped Half Bridge, Pier 4

Design investigations discovered an old debris flow gully above this bridge. This gully has not been active for a number of years and is currently stable. While there is a high probability that this gully will become active again in the next 10 years a probability based economic assessment indicated that additional protection measures (such as overhead structures) could not be justified.

Other design details such as road edge beams, handling weights and emphasis on precast concrete and buildability, were similar to the cantilever half bridge design outlined above.

Passing Bay Rock Shelter

The section of hillside adjacent to the existing passing bay is an open expanse of rock left exposed after a significant block of material (about 7000m^3) was dislodged during the 1994 earthquake event. This slope is quite extensive and the countryside above provides little natural confinement of rock fall that can be initiated considerable distances up the slope above the highway. Thus this section of road suffers the highest frequency of rock fall. The main source of rock fall at this site is debris flows of colluvium (comprising sandy gravel with some boulders) from a debris chute approximately 70 metres above the road. This material has a maximum boulder size of about 1 metre although the predominant size is much less.

The solution to the rock fall safety issue was to provide a 60 metre overhead protection structure along the base of this slope. The general arrangement of that structure is shown in figures 7 and 8 and the area under construction is shown on photograph 8.

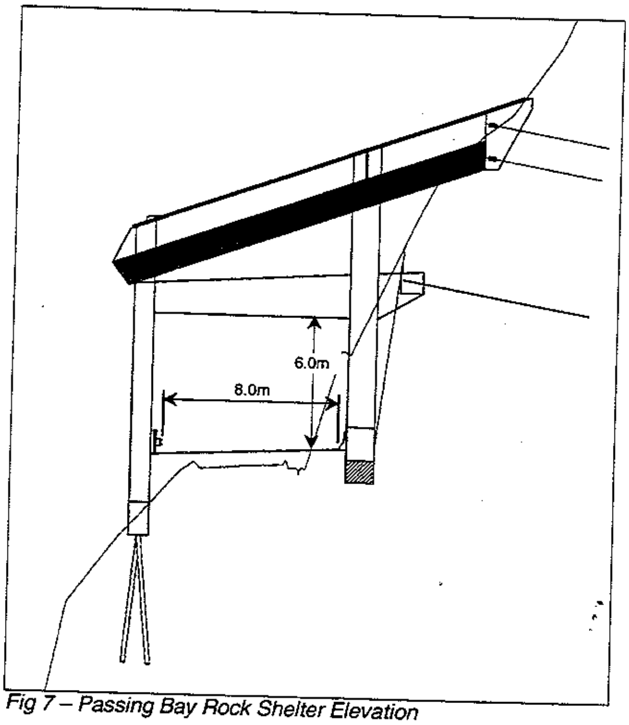

Fig 7 – Passing Bay Rock Shelter Elevation

Rockfall impact design loading is not codified and was derived from a combination of analysis and judgement. The outcome was an impact load based on a 2.5 tonne boulder bouncing down the slope. Energy to be absorbed on impact and withstood by the structure were derived using the CRSP rockfall analysis software package. Reference to design procedures reported in South Africa [14] and Japan [15] led to adoption of a simplified derived design rock impact force, P=2E/d where E is the energy of the falling rock and d is the displacement of the cushion layer. It is assumed that d equals half the radius of the rock.

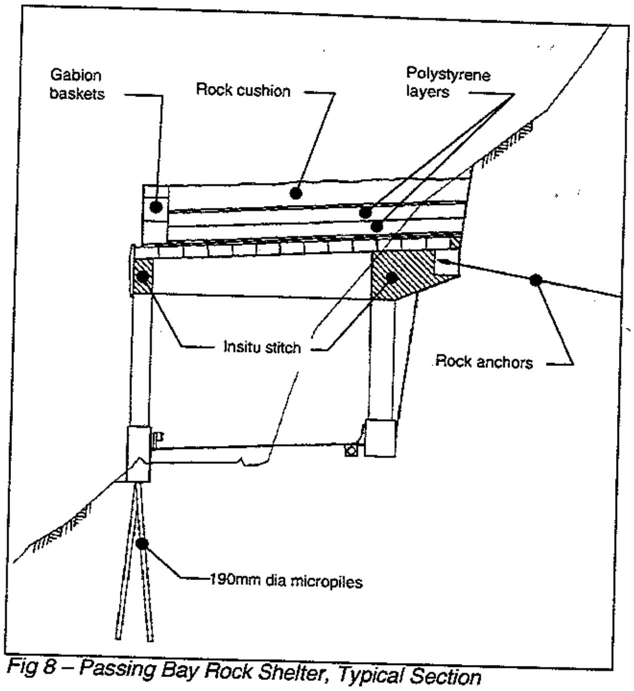

Fig 8 – Passing Bay Rock Shelter, Typical Section

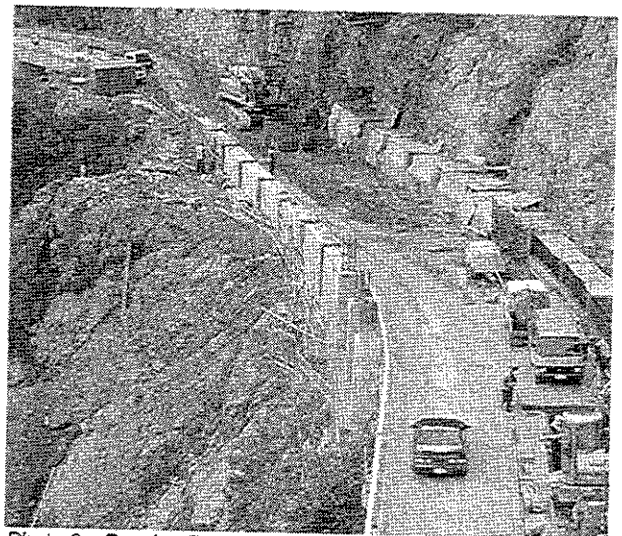
Photo 8 – Passing Bay Rock Shelter Ground Beams

Load combinations also had to be derived. The design combinations allowed for the as built roof cushion with a further 2 metre thick layer (assumed built up over time) combined with the rock impact loads and Earthquake loads. The other important load combination was a build up of loose gravel to an angle of 37° above the as built roof cushion. No dynamic rock fall load or earthquake load was combined with this maximum gravity load.

The implication of the load combination assumptions is that maintenance will be required to limit the gradual build up of rock on the roof to 2 metres above the as built level, and that rock will be removed immediately following a major rock fall event.

The vertical loads to be resisted by the structure are very significant. Hence it was essential that the geometric design moved the road back into the hillside at this location to ensure ability to transfer the loads to the rock bench. Also a 1.2 metre layer of polystyrene was placed above the structure roof. This was to provide load spread capacity to the structure below while minimising the weight supported by the structure. A 1.0 metre energy absorbing gravel cushion is placed above the polystyrene.

The structure comprises transverse frames at 6.0 metre centres with piled foundations to support the front face. These piles were 190mm diameter to match the arrangement used for the cantilever half bridge. A total of 68 piles were required for the 60m long shelter.

End walls were required to contain rock build up and prevent overspill from the chute ends.

Seismic restraint is supplied at roof level by three 15 metre long rock anchors at each frame.

Reid's Falls Rock Chute

The topography of the hills above the road at Reid's Falls provides natural confinement of the rock debris originating in this area. There is a basin approximately 20m above the existing road which collects debris until an extreme rainfall event flushes the basin and deposits as much as 500 m^3 of material on the road below. This poses both a safety hazard and an ongoing maintenance problem. The solution selected at this site was to provide a chute to carry the waterfall and any rock fall debris over the road and into the river below. The general arrangement is shown on figure 9.

This is a very constrained part of the site and this structure overlaps the cantilever half bridge. It was not feasible to move the road into the hillside at this location due to the near vertical faces above the road. However it was essential to carry design loads to the inside face of the rock bench. This dictated the design solution shown which effectively cantilevers the chute over the vertical column and carries the load down to the rock bench via spread footings.

Seismic restraint and static load stability is provided by rock anchors at the upper end of the rock chute.

Railway irons were cast into the chute floor to protect the concrete against abrasion from the continuous passage of rock.

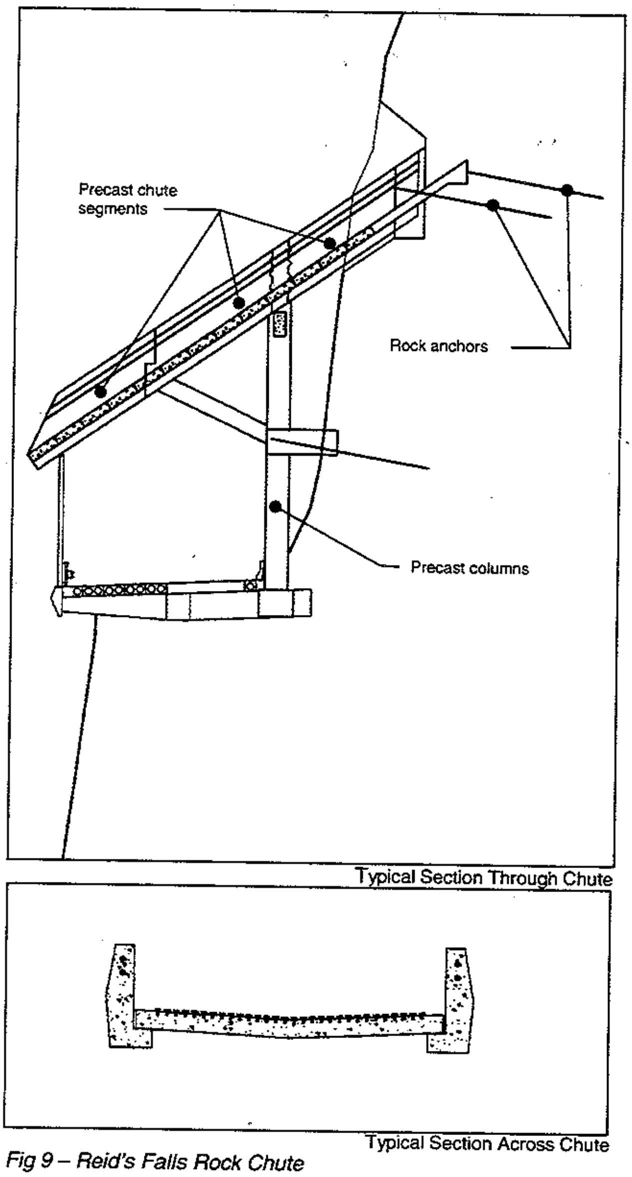

Fig 9 – Reid's Falls Rock Chute

CONCLUSION

The Candy's Bend to Starvation Point project traverses an extremely complex and difficult alpine site. The challenge of this project have been met by a design process which fully integrated environmental, cost, buildability, and engineering issues from conceptual through detailed design phases. The solution incorporates a number of unique concrete structures that are outlined in some detail in this paper. Fulton Hogan Ltd are currently proceeding with construction, and design assumptions have been consistently validated as the works progressed.

The sheer complexity and diversity of this site have necessitated providing only a brief overview of the design. The design incorporates considerable additional risk assessment, geotechnical investigation and rock slope design, structural analysis, and environmental assessment that it is only possible to reference in this paper.

ACKNOWLEDGEMENT

The author wishes to acknowledge the support of Transit New Zealand staff who have contributed significantly to the success of this project.

Equally importantly, a design project as complex as this depends on the considerable commitment of the full design team. I commend the inputs of my whole design team and especially acknowledge the contributions made by my colleagues Geoff Brown (structures) and Greg Saul (geotechnical) both in delivering the design and in reviewing this paper.

REFERENCES

[1] WORKS Consultancy Services, 1987, *SH 73 : Arthur's Pass National Park Roading Project : Environmental Impact Assessment.*

[2] TNZ, *Arthur's Pass National Park SH 73 : Environmental Impact Statement Summary : Summary of Submissions.*

[3] TNZ, *Arthur's Pass National Park SH 73 : Environmental Impact Statement Summary : Issue Analysis By Subject and Transit New Zealand's Response.*

[4] Department of Conservation, *Arthur's Pass National Park Management Plan.*

[5] Department of Conservation, December 1989, *Arthur's Pass National Park Management Plan Review.*

[6] Department of Conservation, 1991, *Arthur's Pass National Park Management Plan : Proposed Roading Review HS 73.*

[7] TNZ, SH 73 : *Arthur's Pass National Park Road Management Plan.*

[8] Ministry of Works and Development, May 1987, *Scheme Assessment Candy's bend to Starvation Point Section.*

[9] Autroads, 1989, *Guide to the Geometric Design of Rural Roads.*

[10] Brian Paterson, August 1998, *SH 73 Candy's Bend : Starvation Point. Otira Gorge Report on Engineering Geological Investigations.*

[11] Alastair Suren NIWA, August 1998, *Biological Assessment of Waterways between Candy's Creek and Starvation Point.*

[12] Earl H Bennett, August 1998, *SH 73 Candy's Bend to Starvation Point. Landscape Information for Highway Improvements.*

[13] Beca Carter Hollings and Ferner, November 1994, *Otira Viaduct and Approaches, Preliminary Design Report – Appendix B.*

[14] H A D Kirsten, Die Siviele Ingenieur in Suid Afrika – September 1982, *Design and Construction of the Konwyn's Pass Rockfall Shelter.*

[15] Japan Railway Civil Engineering Association. *Development of Accident Detection Techniques Research report on Measures against Rock Fall, March 1979.*