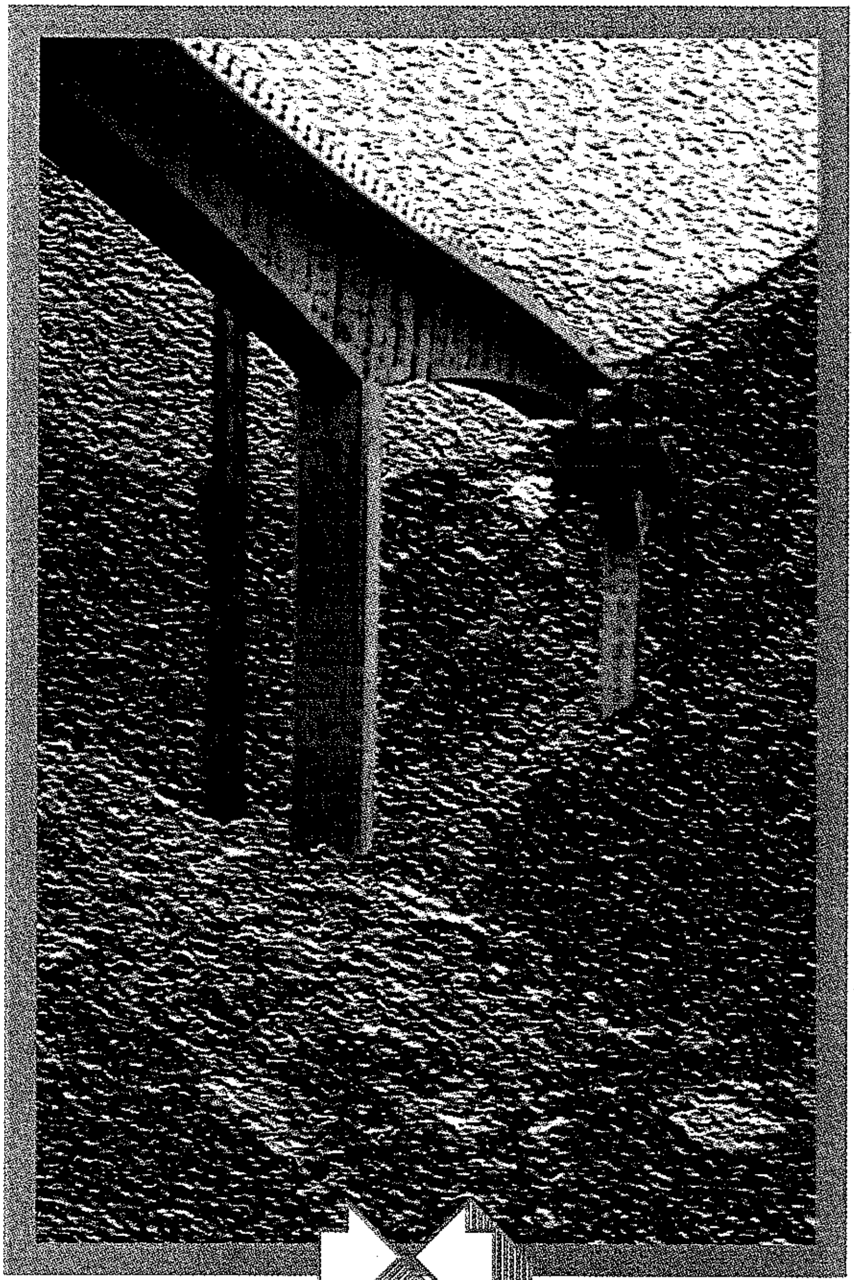

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"CREATING IN CONCRETE– ARCHITECTURAL AND ENGINEERING PERSPECTIVE"

WAIRAKEI RESORT HOTEL, TAUPO
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CONSTRUCTION OF THE OTIRA VIADUCT - A CONSULTANT'S PERSPECTIVE

Richard J Holyoake [1]

SUMMARY

The Otira Viaduct is 445 m long prestressed concrete box girder bridge under construction in the Southern Alps of New Zealand. The viaduct will allow State Highway 73 to bypass an actively eroding and retreating rock avalanche generated scree slope. The bridge lies within Arthur's Pass National Park, an area of obvious ecological and aesthetic value. This paper describes aspects of the construction of this balanced cantilever bridge that has spans up to 134m and piers constructed deep into avalanche material, and looks at some of the challenges presented during the construction from a consultant's perspective.

INTRODUCTION

The Otira Viaduct is a 445 metre long prestressed concrete box girder bridge being constructed for Transit New Zealand to bypass an actively eroding hillside threatening to cut a main highway. The site is located high in the Southern Alps in Arthur's Pass National Park and presents many challenges. This paper describes some of the challenges for the Construction team of this project.

ISSUES AND CONSTRAINTS

The conditions at this site are unusually complex and challenging. The key issues and constraints are described below.

Environmental Issues

The effect of the project on the environment is critical, and control of the impact on the landscape, vegetation, and wildlife and on the river itself is vital. Environmental issues have formed an important part of the design and construction process.

Geological Issues

The spur that marks the Deaths Corner is a huge rock avalanche which 2000 years ago dammed the valley, and ran well up the western bank. The river has subsequently cut a V notch in this dam. The original river valley under the bridge has been in filled with the rock avalanche material.

The rock avalanche material is very hard and abrasive and ranges in size from a silty sand matrix up to blocks of greywacke many metres in size.

The ground water conditions are extremely variable, and complex, with artesian conditions prevalent at the toe of the Deaths Corner landslide dam.

The presence of unstable rock outcrops on either side of the valley means that the road and the viaduct are prone to rockfall. The design and construction of the viaduct have both been affected by the variable foundation conditions and the rockfall – both predicted and real.

Seismicity

The project is located in an area recognised as the most seismically active in New Zealand. A site specific seismic hazard study carried out showed response levels 30 to 40% higher than the normal bridge code values and the bridge has been designed accordingly.

Hydraulics

The high rainfall in the Otira catchment means that the Otira River can rise very rapidly in flood conditions and has caused significant erosion in the project area in the past. The present major erosion of the east bank that is threatening the highway is thought to have been initiated by river lateral erosion and down cutting of the toe of the slope by the river. Loss of control of the river could seriously affect the project and special measures have been taken in the design and construction to counter this attack.

Climatic Conditions

The alpine terrain and its location in the middle of the South Island mean this section of the highway

[1] Senior Engineer, Beca Carter Hollings & Ferner

is subject to extreme weather conditions. In the winter, snow and ice make negotiating the road difficult – and also affect construction progress.

Cultural Significance

Consideration of cultural issues has been fundamental through every stage of development, including extensive consultation with the relevant iwi. Long before Europeans set foot on the Otira Gorge, Maori had been using it as an alternative to their favoured track over the Southern Alps at the head of the Waimakariri River. Kaitiaki (marker stones at places of special significance) are located through the gorge, marking the historical trail which led Maori to the greenstone-rich West Coast. Iwi input was requested in order to ensure the spiritual importance of the area was not compromised.

Aesthetics

Aesthetic considerations have played a significant part in the shaping of the new Otira Viaduct. In particular, a curved viaduct was recommended and subsequently adopted to ensure the structure blended into the surrounding landscape. Special attention has been paid to the form of the bridge, including the use of sloping sides to the box girder superstructure. The connection between pier and superstructure was another key detail studied carefully in the design phase.

Geometrics

Geometrics are constrained by the topography. In particular the viaduct has a gradient of 11.7%.

CONSTRUCTION

Introduction

The contract for construction of the viaduct was won by McConnell Smith Ltd, and the 36 Month contract period commenced in January 1997.

Project Control Group

The concept of a Project Control Group (PCG) was central to the consultant's (Beca) methodology for the project. This system promoted a spirit of partnership which allowed interested groups to be kept informed of project progress throughout the long design phase of the project, through regular meetings. This group included representatives of iwi, Department of Conservation (DOC), Regional and District Councils, Transit New Zealand, Beca and subconsultants.

The PCG commenced at the start of design and continued through into the construction phase of the project with the addition of the contractor to the group. Meetings of this group are held at eight weekly intervals throughout the three year project period, giving the opportunity for continued input from the involved parties into the project. This forum has proved particularly successful with regard to flow of project information, resolution of issues, such as variations to consents or approvals, where alternative construction methods or activities to those envisaged have occurred.

Within this wider group a close and co-operative relationship has been maintained between the client, consultant and contractor. All parties have achieved this through an open approach.

The spirit of partnership has been well in place since the onset of construction and a formal partnering charter has been in place since late 1998. (Figure 2). DOC has taken particular interest in the project due to its location in the National Park, and communication between site staff and DOC has been frequent.

Contractor Quality System

The contract specification requires that the contractor operate a high level quality system throughout the contract containing procedures for self monitoring of compliance with technical specification requirements, environmental management procedures and a Health and Safety management system. At the time of award the contractor was required to provide evidence that he had started working towards a TQS1 compliant quality system. This is along similar lines to ISO 9002 but is less stringent. Implementation was required by mid 1997, and hence development of the system occurred as the contract started to move along. In effect the contractor was required to take a greater ownership of the project quality, rather than the more traditional approach of relying on the engineer to check compliance with drawings etc. The specification identified hold points for various critical phases of the project.

Construction Engineering

The contractor was required to obtain construction engineering services for the design and checking of temporary works, and to prepare and monitor a construction procedure for the viaduct. This included geometry control and preparation of methodologies for critical aspects of the works (piling, cantilevers and closures). Geometry control profiles and expertise were provided to the contractor by Finley McNary Engineers Inc of USA.

The consultant's role was to review the methodologies for compliance with the specification, particularly with regard to any likely effects on the permanent works.

Temporary Works

The responsibility for design of all temporary works lay with the contractor. The specification stated that the permanent works had been designed to withstand solely the specified environmental and traffic loads. No allowance was made for loads that may be imposed on the permanent works by temporary works with the exception of specified traveller and out of balance loads on the superstructure.

The contractor was required to supply to the consultant a summary of the significant forces imposed on the permanent works by the temporary works signed off by his design engineer and independent checking engineer.

Foundations

The difficult foundation conditions dictated a long span bridge. Deep 4m diameter single cylinder foundations up to 25m long, under each pier position were found to be the most appropriate solution. Construction of the cylinders into the rock avalanche debris in the conditions previously described has been a major challenge for this project.

The contractor devised a method of construction that met the demanding conditions and minimised ground relaxation and environmental impacts. This involved the use of state of the art down the hole hammer drilling technology.

The methodology was reviewed and updated a number of times to ensure that consideration had been given to minimising the risk of problems, contingency measures, and to monitoring the performance of the proposed method during construction.

The refined method involves the construction of a concrete pile secant wall with 762 mm diameter 17 MPa concrete piles around the outside of the permanent pile footprint allowing later excavation inside the concrete pile coffer dam for lowering of the permanent steel liner and reinforcement. (Figure 3). As dewatering was not possible most of the work was below water.

The temporary works associated with the construction of the piles varied - different methods were used for each of the 3 pier foundations to improve efficiency and match site conditions.

The possibility of flowing groundwater in the porous avalanche debris caused concern about the integrity of the secant pile ring due to the washing of cement. For this reason core drilling of piles at Pier 2 and 1 was undertaken by the contractor to determine the integrity of the piles. One pile in each of Piers 1 and 2 was drilled and both cores indicated intact concrete full depth.

Following excavation the permanent 4 metre diameter casings were lowered in to the excavation and located prior to tremie concreting the plug and later the annulus outside the steel casing. The steel casings were dewatered to allow placement of the reinforcement and pile concrete in the dry.

Superstructure

The bridge superstructure comprises a four span 445m long balanced cantilever concrete box girder with central spans of 134 metres. The cantilever cables for the box girder comprise twenty 19/12.7mm strand cables and the continuity cables up to eighteen 12/12.7mm strand cables. (Figure 4)

The superstructure was typically built in 4 metre segments, each cantilever being 16 segments either side of the pier, equating to a cantilever length of 66.5m.

The endspans adjacent to the abutments were built on ground supported falsework, and are connected to the superstructure with continuity tendons. Similarly the cantilevers are joined at midspan by a series of continuity tendons.

Concrete

In the early stages of the project the contractor was required to devise a mix design that would become the standard mix design for the remainder of the project. Consistency throughout the project was seen as a key issue, not just with regard to high early strengths allowing prompt stressing and a quick segment turnaround but also for consistency of colour in the completed structure. Mix trials were undertaken in the early pours, the south endspan and the pier 2 foundation pile. The mix adopted proved to be slightly denser than the design assumed and led to a design review of the dead load capacity of the structure during construction. To provide for this and other dead load variations 2 additional 12/12.7mm cantilever cables were added to each cantilever.

The specified 40 MPa concrete was supplied from a batch plant outside the National Park in Otira. This plant was a Special grade plant and was set up especially for the project. Delivery of concrete to the site was undertaken in Readymix trucks, and the concrete typically skipped into place.

The contractor opted to use heated and insulated forms on Pier 2 to provide assistance in the curing of concrete in particularly cold weather.

Methodologies

Construction of the superstructure was undertaken using cantilever carriages. The contractor designed and manufactured his own travellers for supporting hanging formwork for each cantilever. The traveller beams are stressed down to the deck at the rear with Dywidag bars cast into the webs of the viaduct. The travellers were self launching using hydraulic rams to push the support beams out onto the next segment with the frame following.

Commencing cantilever construction at the pier table was time consuming due to the limited space available on the pier tables. At pier 2 the first cantilever segment was constructed on falsework supported off the pier. The opposite segment was constructed in traveller supported forms. After construction of the first cantilever segment each side, erection of both carriages was possible and cantilever construction progressed rapidly. This approach was modified further at pier 1 to pour the first cantilever segments on ground supported falsework.

At pier 2 The contractor needed to satisfy the consultant that the soffit of the first pour was capable of supporting the wet webs given the much higher soffit stiffness than falsework stiffness. Similarly where ground support was proposed he submitted calculations showing the settlement of the falsework would not result in excessive stresses in the walls and soffit of the first segment.

The superstructure forms required adjustable wall heights and base widths to cope with the changing cross section and changing superelevation of the bridge. The bridge is curved in plan and the traveller was therefore slightly offset at an angle for each new segment.

Two sets of carriages were designed and constructed. The first set of travellers and forms weighed around 70 tonne, some 25 tonne heavier than allowed for in the viaduct design. A method of use was agreed with the consultant where removal of significant sections of the forms would be required prior to construction of the last few segments so that the limits of the structure were not exceeded. The second set of carriages was designed after operation of the first set had been observed, and were significantly lighter than the first, as well as being easier to operate.

The design of the bridge allowed for out of balance loads equivalent to one segment to 60 metres from the pier table. Rather than constructing half segments at the ends of the cantilevers the contractor chose to maintain balance with counterweights.

Construction of cantilever segments was targeted at a weekly cycle, with stressing occurring on day 2 at a concrete strength of greater than 25 MPa. During the construction of the Pier 1 and Pier 3 cantilevers cycle times of 7 to 9 days were typically achieved.

Geometry

The geometry control profiles were calculated based on the loading information provided by the contractor and their proposed method of construction. The analysis also accounted for the predicted cycle time for the construction of the cantilevers.

Geometry control checks were made to ensure that the forms were in the correct target location and to allow some correction if required. Geometry control measurements were made particularly difficult due to the variable and often unpleasant weather conditions on the site. Prior to pouring each segment concrete pour check sheets were checked off by the contractor. These checks included the measurement of the profile and dimensions of the previous segments. These results were forwarded to Finley McNary as a check on any of their assumptions and also to the consultant to check against the design assumptions and allow adjustment of the stressing level in the additional 12 strand tendons.

The tolerances on the profile of the viaduct were +/- 25mm in position or level, and a straightness of +/- 20mm over 8 metres (or 2 segments). Deviations outside this range were treated as serious and as hold points, requiring the input of the consultant in assessing the means of correction, and whether any structural corrective actions were required.

Stressing

Post tensioning of the superstructure was undertaken by Construction Techniques Ltd as a subcontractor. Friction testing was specified for a number of specific tendons to check against the assumed friction losses in design.

All stressing results were forwarded to the consultant. These results typically indicated that the friction losses occurring in the ducts were less than those assumed in the design of the viaduct. This information along with the measured section dimensions (recorded on concrete pour cards) was used in assigning the level of stress to be put into the additional 12 strand tendons. In addition the contractor had to alter the target level of prestress slightly on Pier 3 to ensure that the viaduct was not being overstressed.

Closure

Prior to continuity the spans were jacked apart. This was to help counteract the long term effects of creep and shrinkage in the superstructure. The specified displacement to be locked in to each of spans 2 and 3 was 40mm. Because the viaduct is curved the centre for jacking was eccentric, and the cantilevers would tend to move laterally and vertically during the jacking operation. To counteract this action kentledge was specified. The contractor methodology included a set of closure beams with Teflon sliding joints to hold the cantilevers in position vertically, and chain blocks or turfers were used to laterally restrain the tips.

Rockfall Protection Structures

To mitigate against rockfall damage to the bridge piers a rockfall protection structure was designed above Pier 1 and a rock bund deflection mound provided at Pier 2. During the contract, particularly as work started in the area of Pier 3 it became clear that this slope too, had the potential to unravel and release large rocks, potentially endangering the pier. In 1999 design of a rockfall protection structure for Pier 3 commenced, utilising details from the pier 1 structure and contractor feedback on the constructability of the pier 1 structure.

Site disturbance and revegetation

Limiting the size of work areas to small, clearly-marked and fenced sites is one of the measures being taken during the construction phase to help minimise the overall effect on local ecology. Most of the working areas were specified in the consent application documents. It was realised early in the project that access would be required from the south end of the site as well as the north end, particularly due to restrictions at the north end caused by the construction of pier 3, the north gully bridge and the reinforced walls. TNZ applied for variation to these consents requesting approval for a construction access down the true right bank of the river from Death's Corner. A variation was granted. In addition numerous other minor variations have been granted for the temporary storage of materials outside designated working areas.

Revegetation is an important part of the construction process and will reflect existing plant species and communities, to ensure natural patterns are restored as quickly as possible and to minimise erosion by restoring plant cover.

The bulk of the plant material comes from over 100,000 seeds and cuttings collected from plants on the site and grown at a specialised nursery. There are clear differences in plant communities between the north and south ends of the project, and this is reflected in the plants to be used. The integrity of the local ecosystem is dependent on the use of local material.

Wildlife

Meeting the needs of native wildlife has also played an important part in the project. The waters of the Otira River and the nearby hillsides are home to many species of bird - including the kea, blue duck and great spotted kiwi. The Otira River supports invertebrates and algae that are important food for blue duck and, in the lower reaches, for fish and other birds. During construction, the river has been protected from pollution generated by construction equipment, and regular compliance monitoring has taken place.

Surveys undertaken prior to construction commencing established the numbers of blue duck and great spotted kiwi in the immediate vicinity.

Monitoring programmes continued throughout the construction period to measure the effects, if any, on these native species, and to mitigate any adverse effects detected. These monitoring programmes will add valuable information to the national Department of Conservation database.

To date, no Blue Duck have been observed in the vicinity of the construction site. However, four kiwi (two male and 2 female) are resident in the vicinity, compared to 2 kiwi recorded at the start of the project

Publicity

The construction of the Otira Viaduct has enjoyed a high public profile. This is a project that is seen as a much needed improvement to a section of road that most travellers remember. Furthermore most people who have experienced conditions at the site are aware that the rainfall is of the order of 6 – 7 metres per year, and that the wind is often blowing. The project is respected as an outstanding engineering and construction achievement. This profile is largely due to the efforts of TNZ in providing regular media releases, and holding media days on site.

Programme and Budget

Construction of the bridge and approach works is now largely complete, some 4 weeks ahead of the revised schedule and the viaduct is to be officially opened on 6 November this year. The Contract award value was approximately $22.5M.

CONCLUSION

The Otira Viaduct has been constructed to bypass the most vulnerable section of SH 73, the ZigZag, This piece of road has failed historically and has the potential to fail imminently, with the result of losing the road. The location of the project within a National Park has highlighted environmental issues and particular attention has been paid to aesthetics, cultural significance, existing wildlife and revegetation. These issues were addressed during the design phase of the project, and have provided a continuing focus during construction.

The structure itself is challenging, being the longest span reinforced concrete bridge in New Zealand, with 134 m spans and built in difficult conditions. Features of the project include the use of state of the art drilling technology for foundation construction and balanced cantilever type construction for the superstructure.

Throughout the construction there has been a significant requirement for engineering design and analysis work by the contractor, and review of methodologies and procedures by the consultant.

Significant effort has been put into a partnering culture between the client, contractor and consultant, and with other parties involved with the project.

ACKNOWLEDGMENT

The author wishes to acknowledge the support of Transit New Zealand, McConnell Smith Ltd, Department of Conservation and other parties who have contributed to the success of this project.

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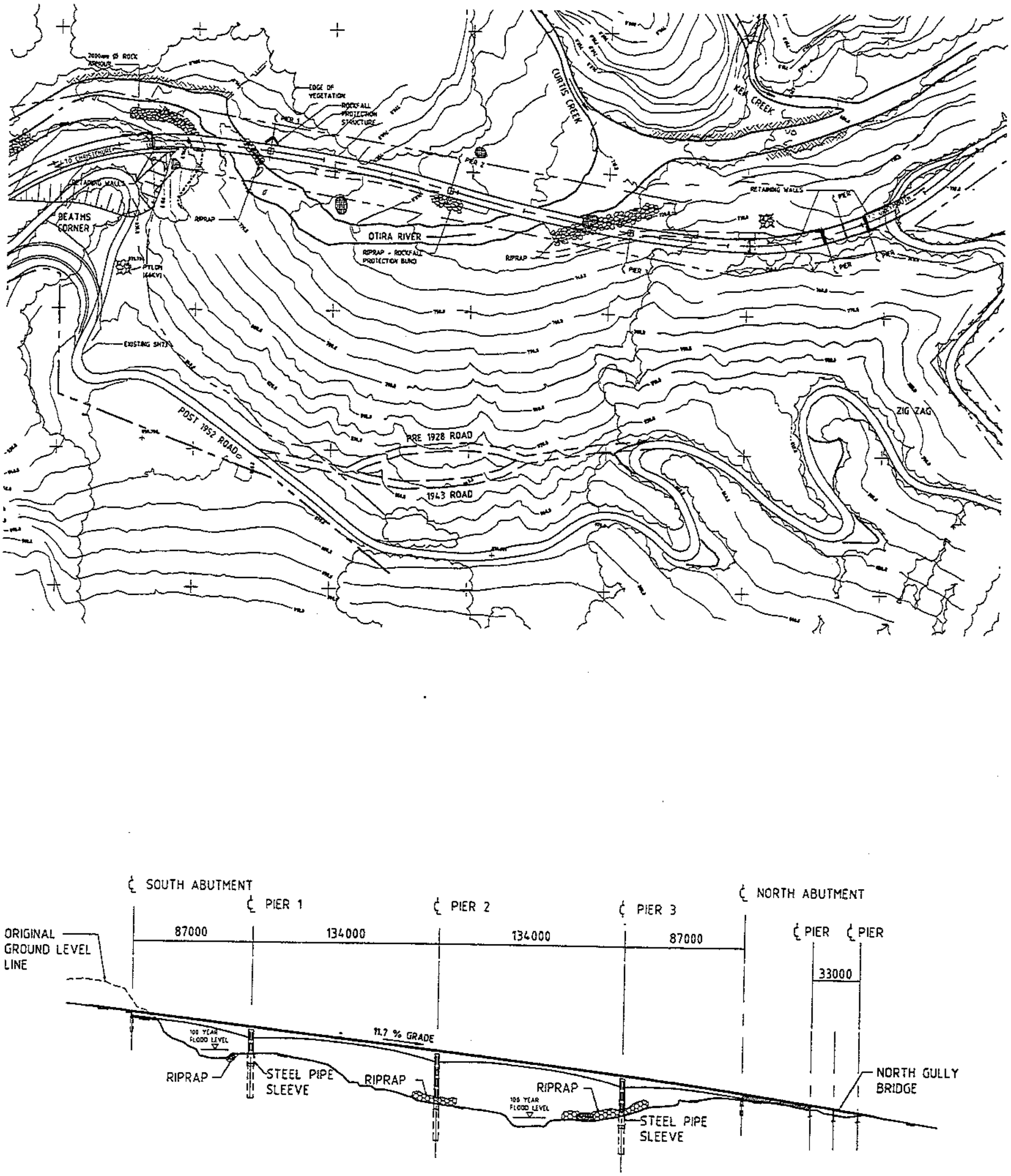

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FIGURE 1

OTIRA VIADUCT AND APPROACHES

PARTNERING CHARTER

Between

THE MAJOR STAKEHOLDERS

Transit New Zealand
McConnell Smith Ltd
Department of Conservation
West Coast Regional Council
Westland District Council
Beca Carter Hollings & Ferner Ltd
Boffa Miskell Ltd
Tangata Whenua

MISSION

We are committed to work together within the spirit of partnering to complete a mutually successful project

GOAL

To implement / complete a successful project

SHARED OBJECTIVES

Ensure a Safe Project
- Create and maintain a safe project site
- Manage public access to the site
- Minimise potential for injury to the travelling public and construction workforce

Encourage Teamwork and Commitment to Partnering
- Set and hold regular formal partnering meetings through out the project
- Encourage informal discussions and partnering meetings at all levels
- Focus upon achieving joint goals and objectives
- Agree and comply with a response / action timeframe
- Elevate issues not resolved within agreed timeframe
- Publicise the Partnering Charter
- Advise promptly upon encountering unforeseen conditions (no surprises)

Enhance Reputation and Capability
- Use sound management practices and resources
- Minimise rework
- Create and implement a public communication strategy
- Complete the project within the budget and the requirements of the quality, safety, traffic management and environmental plans
- Ensure staff are co-operative and well presented
- Incorporate alternatives - value improvements
- Maintain a tidy site

Maximise Returns to all Parties
- Incorporate alternatives - value improvements
- Avoid disputes
- Minimise rework
- Create and maintain a "win/win" environment - partnering, good working relationships
- Monitor costs and productivity
- Identify and manage risks
- Use sound management practices and resources

Maximise Value
- Implement a good Quality plan
- Encourage innovation to maximise value at all levels
- Strive to balance quality with price
- Encourage the concept of sharing risk

Avoid Disputes
- Empower project staff to make decisions at appropriate levels
- Take a reasonable approach to claim resolution
- Identify and communicate issues early - no surprises
- Understand each party's objectives for each issue/proposal
- Consider the achievement of all parties' objectives
- Hold special meetings to focus on identified issues and problems

Enhance Personal Satisfaction and Enjoyment
- Maintain a well managed project
- Adopt partnering principles at all levels
- Avoid rework, conflict and disputes
- Reward initiatives and innovation

Communicate with the Public
- Prepare and implement communication strategy
- Provide up to date information on project development at Visitor Centre and Death's Corner lookout

Retain Intrinsic Values
- Recognise that the project is within Arthur's Pass National Park
- Recognise the values placed on the site by tangata whenua
- Recognise the importance of high quality water in the Otira River

Minimise Disruption
- Recognise the strategic importance of the project to West Coast communities
- Thoroughly plan in consultation with affected parties
- Advertise our plans
- Remain committed to the public interest
- Work as a team
- Address problems and issues quickly

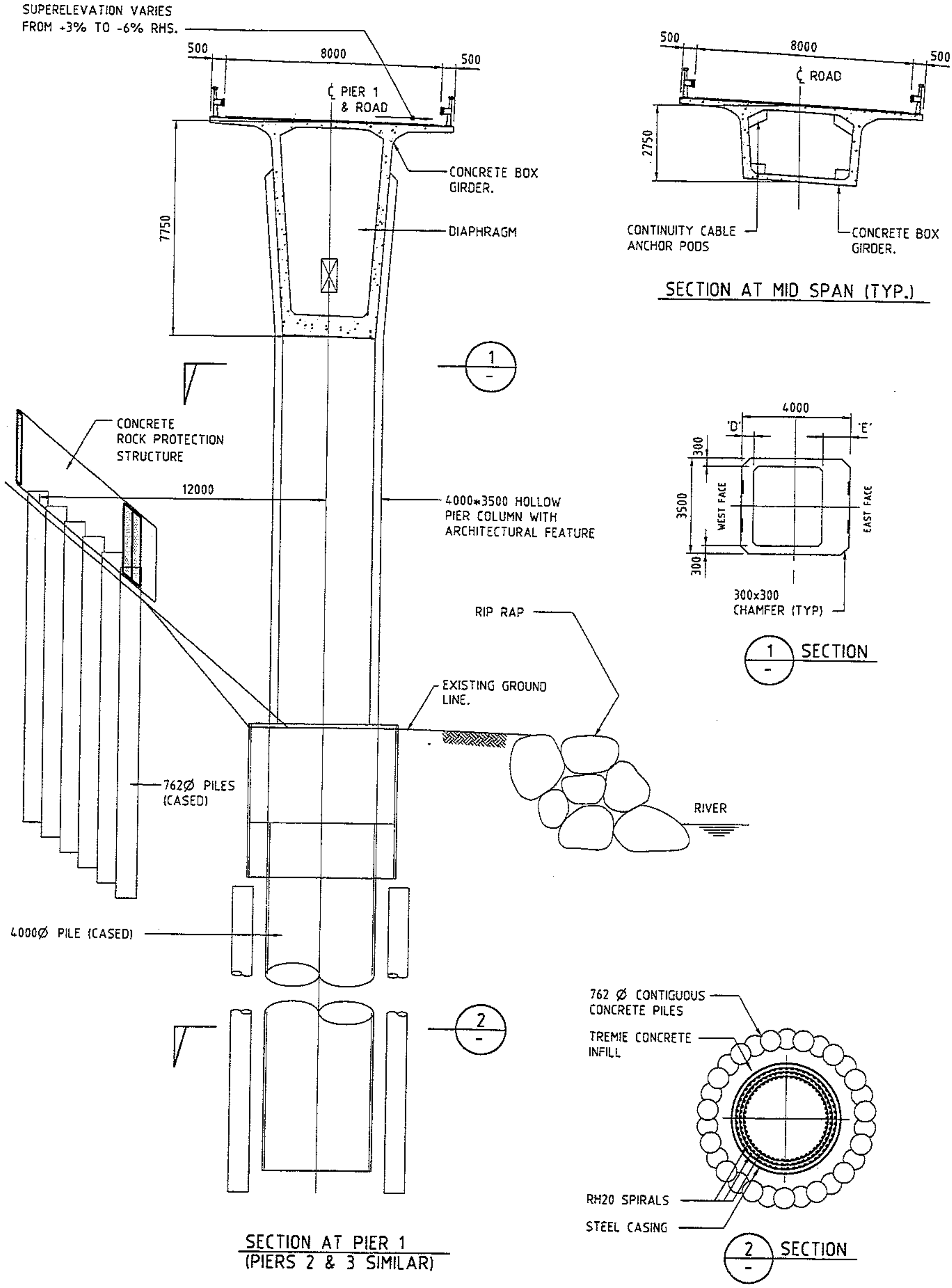

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FIGURE 3

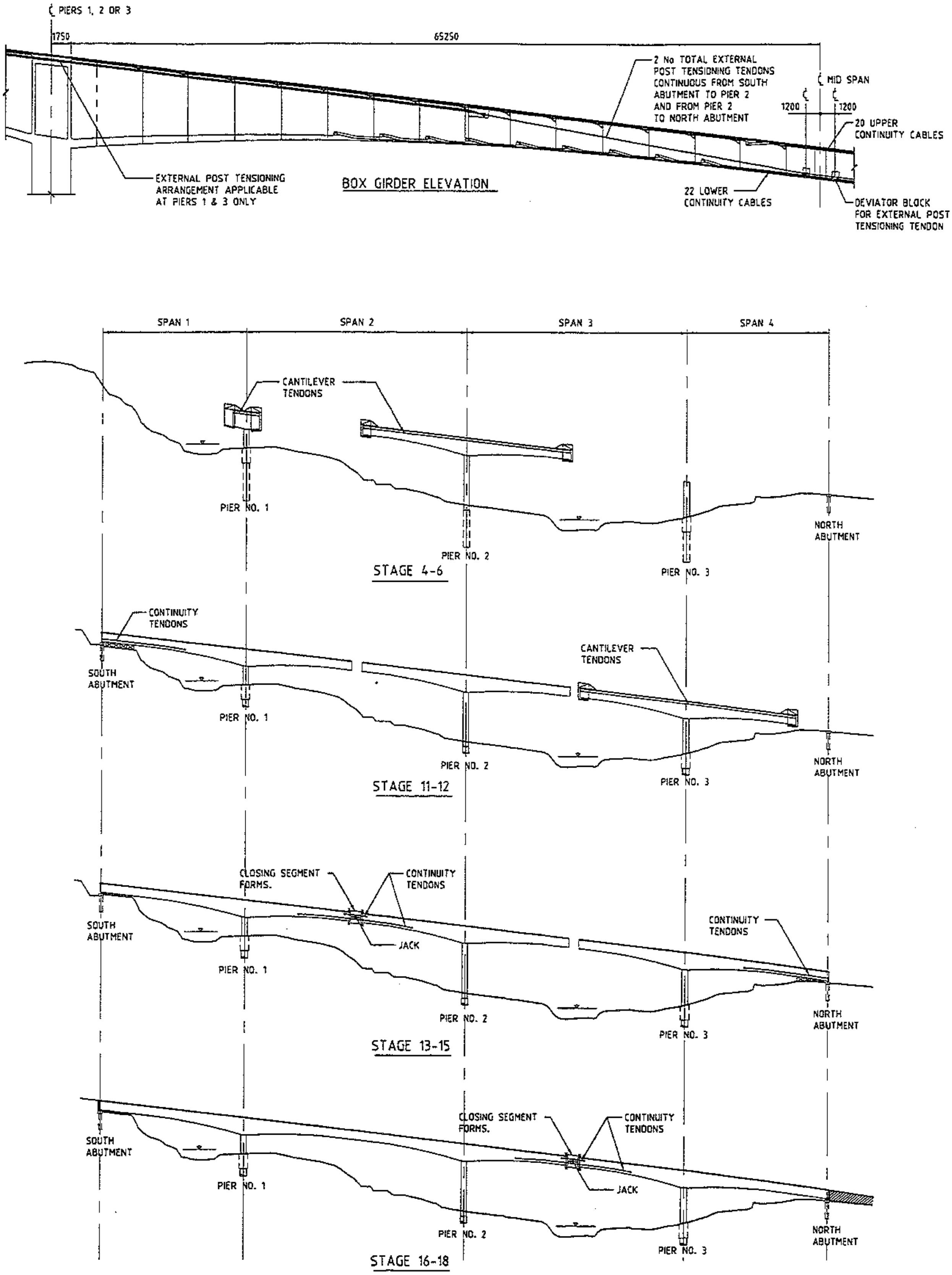

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FIGURE 4