

EMERGENCY RESPONSE PROCESS FOR SLIP REMEDIATION ALONG THE STATE HIGHWAY 4, NEW ZEALAND

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ABSTRACT

State Highway 4 (SH4) is an approximately 240 km long, two-lane highway connecting Whanganui in the lower North Island to Te Kuiti in the Waikato, New Zealand. A major storm event in June 2015 led to over 43 landslips affecting an approximately 85 km section of highway between Whanganui and Raetihi. Twelve of these slips resulted in considerable damage to the highway corridor. As part of the Network Outcomes Contract for the Manawatu-Whanganui region, Beca Ltd was commissioned by Higgins Group Holding Ltd and the NZ Transport Agency to provide engineering services, including emergency response, geotechnical investigation, design and construction monitoring of the remedial measures at the slip sites.

Initial emergency response was undertaken to restore access to the affected communities. This was followed by site prioritisation to identify the sites which required in-depth investigation and design for remediation (referred to as 'Category B' sites). Site-specific ground investigations were undertaken at these sites to assess the ground and groundwater conditions and likely failure mechanisms. Remedial options in the form of reinforced, embedded and gravity retaining structures, earth fill buttresses and road re-alignment were developed. Detailed design and construction of the preferred options were undertaken over an approximately 18-month period.

This paper presents the processes adopted to remediate the slip sites through close collaboration between the client, consultant and contractors as well as the local stakeholders. It discusses the geotechnical aspects of the design solutions, and presents the main lessons learnt and recommendations for further improving the collaboration between all parties involved in a NOC delivery model.

1. INTRODUCTION

The NZ Transport Agency (the 'Agency') awarded the Manawatu-Whanganui Network Outcomes Contract (the 'NOC') to Higgins Group Holding Ltd (Higgins) and Beca Ltd (Beca) in July 2015. Regional NOC's are employed across New Zealand to provide maintenance and management of the state highway assets.

A major storm event in June 2015 resulted in multiple slips along the section of SH4 between Whanganui and Raetihi in the lower North Island. The remedial works were undertaken over six phases, commencing from the initial response inspections (phase one) through to site completion and road re-opening (phase six). This paper presents an overview of the steps involved during the process, and discusses a summary of lessons learnt and recommendations for further improving the collaboration between the parties involved in a NOC delivery model. This delivery model is employed to focus on the asset and safety management as well as maintenance and physical works associated with the state highways throughout New Zealand.

2. SITE DESCRIPTION

SH4 is a two-lane state highway connecting Whanganui to Te Kuiti in the Waikato, with an Average Annual Daily Traffic (AADT) of 1000 vehicles per day. The majority of SH4 is classified as a 'primary collector road' by the Agency, defined as a road linking local roads to the arterial network. The section of SH4 affected by the June 2015 storm event was approximately 85 km long between Whanganui and Raetihi. An approximate extent of SH4 and the affected section is presented in Figure 1 below.



Figure 1: Approximate Extent of SH4 in the North Island, New Zealand (indicative only)

3. REGIONAL GEOLOGY

The published geology by Townsend. et al (2008) indicates that SH4 is in the uplifted eastern margin of the Whanganui basin, a sedimentary basin that formed as a result of a major regional subsidence in the Late Pliocene and Pleistocene (known as the Tangahoe pull-down). The basin contains approximately 4 km of predominantly marine (shelf and shallow water) deposits of the Rangitikei Group which is dominated by mudstone with increasing sandstone towards the top of the succession. The geology is regionally tilted, with a shallow south to south west dip due to the uplift in the central North Island having inverted the north-east edge of the basin.

The geomorphology of the area is characterised by dissected hill country. The weak sandstone and mudstone rocks are cut by the south west flowing river systems, including the Whanganui and Managawhero Rivers and their tributaries. Literature that accompanies the published geology map for the region states that the geology within the steep terrain is prone to land sliding during high intensity prolonged rainfall.

The New Zealand Geology Web Map by GNS Science indicates the southern section of SH4 is underlain by the Rangitikei Supergroup, comprising mudstone, siltstone and sandstone interbeds. The northern section is generally underlain by the Tangahoe Formation comprising sandstone and mudstone interbeds. Figure 2 below presents the published geology of SH4.

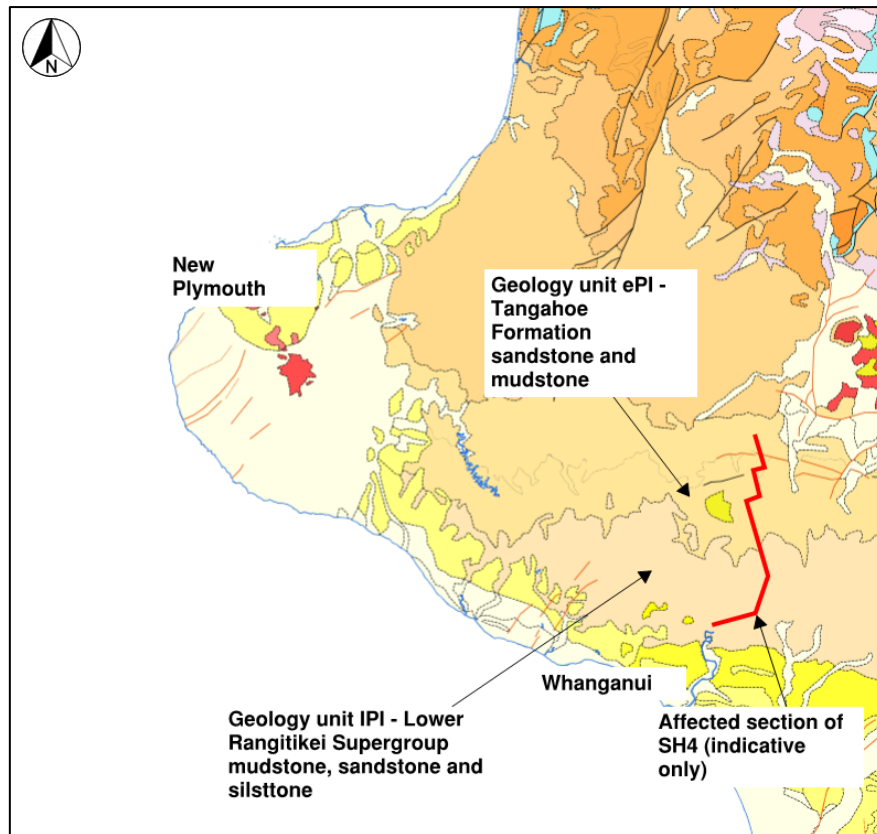


Figure 2: Published Geology of SH4 (courtesy of the New Zealand Geology Web Map by GNS Science)

4. RECOVERY PROCESS

4.1 OVERVIEW

The 20 June 2015 storm resulted in over 43 landslides affecting this section of SH4. Twelve of these slips resulted in considerable damage to the road corridor and partial loss of the north-bound shoulder and traffic lane in several locations. Under-slips occurred in the fill materials supporting the carriageway and rock fall occurred above the carriageway. These resulted in damage, temporary closures and reduced speed limits.

The scale of the storm equated to a 1 in 100 year storm but it is the third time this has occurred in the last 10 years. The event occurred several days prior to awarding the NOC contract and existing remedial processes suitable for an event of this scale were not in place. Throughout the recovery work phases, remedial works processes were continuously developed and refined through collaboration between the involved parties. Remedial works were generally undertaken based on a six-phase process, as shown in Figure 3 below. The steps involved in each phase are described in more details in the Sections 4.2 to 4.7 of this paper.

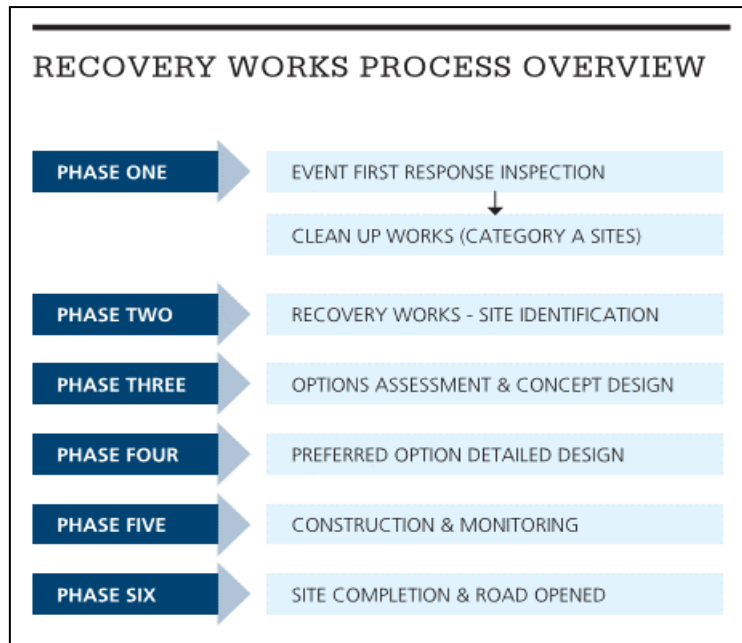


Figure 3: General Overview of the Remedial Works Process

4.2 PHASE ONE: EVENT FIRST RESPONSE INSPECTIONS

The first phase of response included initial efforts to allow access to the affected local communities across the region. This was achieved through the existing relationships that Higgins had developed in the region outside of NOC and resulted in the use of local contract teams to restore access within a very short timeframe. The access was restored by 123 staff working an estimated total of 6000 hours on rotating shifts between 19 June and 29 June 2015.

During this period, site walkovers were undertaken by Beca engineering geologists, and Higgins' representatives to assess the potential causes of the failure and prioritise the slip sites based on the extent of damage.

4.3 PHASE TWO: SITE IDENTIFICATION AND PRIORITISATION

Upon restoring access, the priority shifted to full repair works. The slip sites were divided into two categories:

- **Category A:** These sites could be scoped and approved to proceed within a short time frame (and within the current construction season). The remedial solutions for these sites generally included clearance of slip debris, and repairing blocked drainage features.
- **Category B:** Due to the scale of these slips and the high risk of further instability, detailed investigation and design were planned for these sites. Therefore, these sites were scheduled for construction in the next season, and continuously monitored for further degradation.

Ten slips sites were grouped into Category B, and each slip was assigned an ID. The approximate locations of these slips are shown on Figure 4 below.

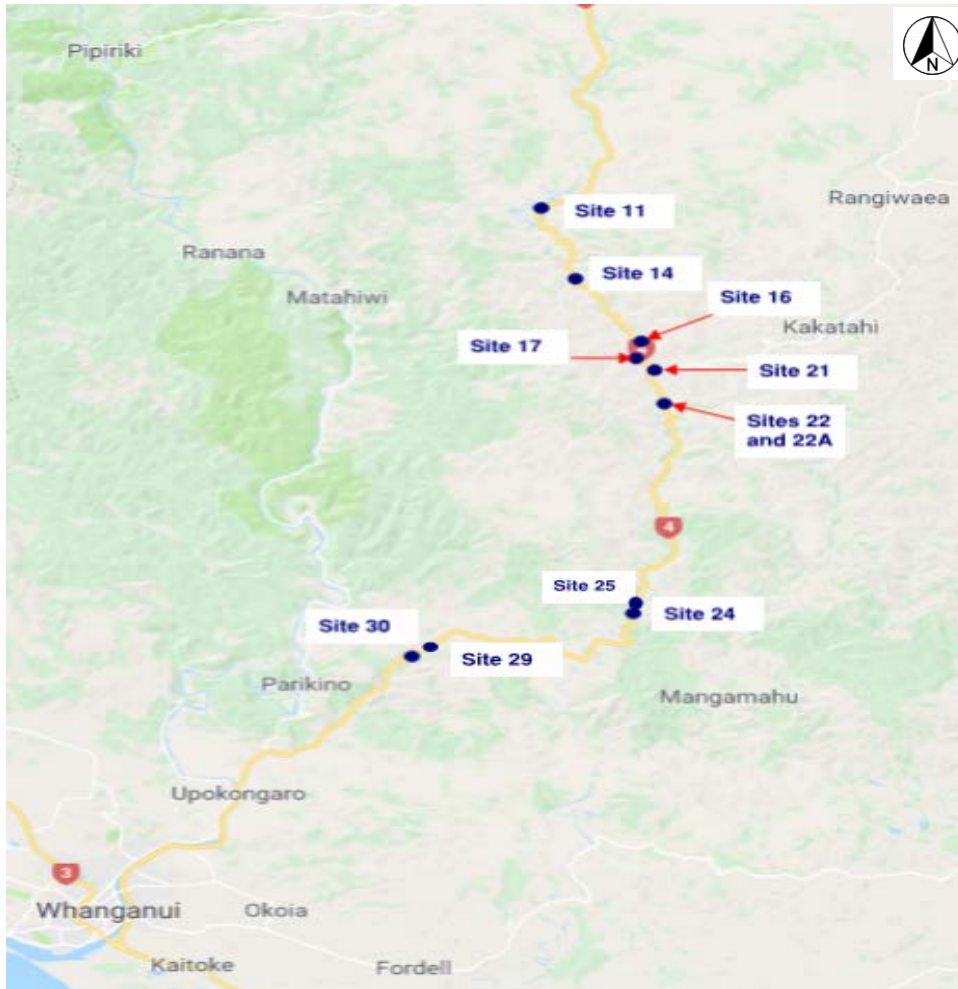


Figure 4: Approximate locations of Category B sites along SH4 (indicative only)

This paper focuses on the remedial measures adopted for the more complex Category B slips only. A summary of the observations made at the Category B slip sites during the initial inspections is summarised in Table 1 below. Selected photographs of the damage observed during the inspections at several sites are presented on Figures 5 and 6.

Table 1: Summary of the Observations at the Slip Sites during the Initial Responses Process

Slip ID	Slip Route Position* (RP)	Approx. width of head scarp (m)	Observed Damage
Site 11	158/7.33	10 – 15	<ul style="list-style-type: none"> • Excessive deformation of an approximately 2 m high crib wall. • Loss of the north bound shoulder. • Tension cracks and ground subsidence.
Site 14	158/11.80	30	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Tension cracks.
Site 16	176/2.46	65	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Tension cracks. • Partial undermining of the north bound lane.
Site 17	176/3.41	25 – 30	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Tension cracks. • Partial undermining of the north-bound lane.

Slip ID	Slip Route Position* (RP)	Approx. width of head scarp (m)	Observed Damage
Site 21	176/4.58	30	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Tension cracks. • Partial undermining of the north-bound lane.
Site 22	176/5.55	28 – 54	<ul style="list-style-type: none"> • Loss of the north-bound shoulder and approximately 1.5 m width of the north-bound lane.
Site 22a	176/11.35	20	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Partial damage to existing MSE wall and barriers. • Tension cracking and partial undermining of the north-bound lane.
Site 24/25	188/5.95	30	<ul style="list-style-type: none"> • Failure of existing tied-back timber pole retaining wall. • Loss of the north-bound shoulder and approx. 0.5 m width of the north bound lane.
Site 29	206/6.39	15	<ul style="list-style-type: none"> • Damage to the existing retaining wall. • Loss of the north-bound shoulder.
Site 30	206/6.54	15	<ul style="list-style-type: none"> • Loss of the north-bound shoulder. • Tension cracking.

* Route position (RP) is defined as the ‘address’ format for describing a linear position along a state highway.



Figure 5: Observed damage at slip sites #14 (left) and #22 (right)



Figure 6: Observed damage at slip sites #24/25 (left) and #22a (right)

4.4 PHASE THREE: OPTIONS ASSESSMENT AND CONCEPT DESIGN

This included the geotechnical investigations, options assessment and concept design of the Category B slip sites. The processes involved during this phase are indicated in Figure 7 below.

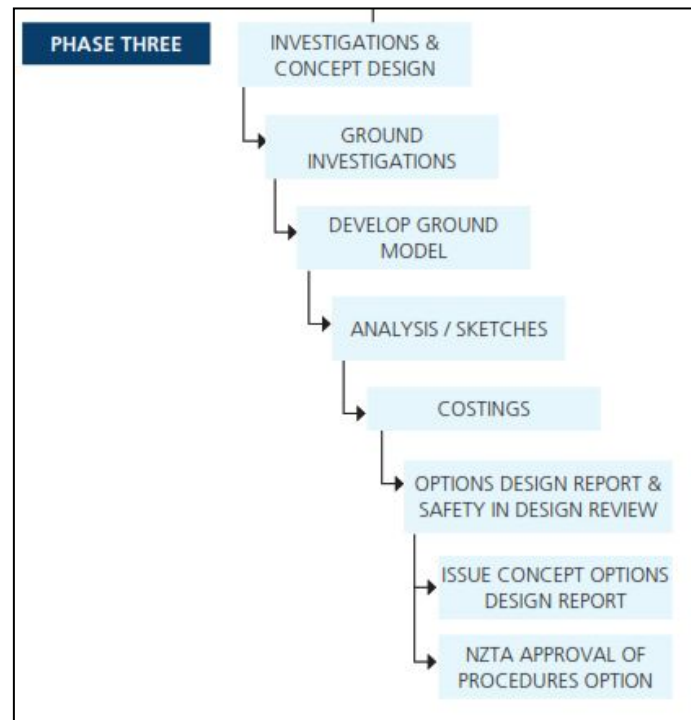


Figure 7: Phase Three Options Assessment Process

4.4.1 GROUND INVESTIGATIONS AND GROUND MODELS

A conceptual ground model was developed for the slip sites based on the review of published geology and observations made during the site walkover. Intrusive ground investigations, including shallow and deep machine boreholes, were undertaken at each of the Category B slip sites to confirm the ground and groundwater conditions and finalise representative ground models to inform the development of remedial measures. Machine boreholes were selected as the preferred investigation technique to recover high quality soil and rock samples.

The machine boreholes were drilled using track-mounted rotary rigs, retrieving HQ-sized core (~63mm in diameter) through both soil and rock strata. The investigations were supervised by an engineering geologist on a full-time basis. Recovered soil and rock core was logged in accordance with the NZGS (2005).

Standard Penetration Tests (SPTs) were typically undertaken at 1.5 m intervals throughout the machine boreholes. Hand-held shear vane testing was undertaken within cohesive materials. Laboratory testing, including Particle Size Distribution, Atterberg Limits and Unconfined Compressive Strength (UCS) testing was undertaken on several disturbed soil and rock samples. Aerial surveys of the slip sites were undertaken by the Beca surveyors using Unmanned Aerial Vehicles (UAV).

Strata encountered at the slip sites were generally consistent with the published geology and consisted of Quaternary landslide deposits and fan alluvium, Tangahoe Mudstone, Paparangi Group and the Upper Okiwa Group. A representative ground model was developed for each slip site to inform the assessment of remedial options. Back analyses were completed using the GeoStudio SLOPE/W software to assess the likely failure mechanisms, and confirm the adopted design parameters. The instigated failure mechanisms are summarised in Table 2 below.

Table 2: Instigated Failure Mechanisms at Category B Slip Sites

Site ID	Likely Failure Mechanism
Site 11	Rotational slide at the interface of the fill behind the existing crib wall and the <i>in-situ</i> landslide deposits.
Site 14	Shallow translational slide within the landslide deposits due to surface water run-off.
Site 16	Shallow translational slide of the fill over the mudstone due to erosion at the toe of the bank.
Site 17	Shallow translational slide of the near surface fill due to surface water run-off resulting in a failure of an existing retaining wall.
Site 21	Shallow translational slide of the near surface fill due to surface water run-off and bank erosion.
Site 22	Rotational slide within the colluvium and overlying fill due to the overland flow pathways created on the above carriageway and adjacent farm paddocks.
Site 22a	Rotational slide of the near-surface fill materials due to surface water run-off.
Site 24/25	Elevated river levels at the base of the existing retaining wall due to heavy rainfall, leading to erosion and undermining. Surface run-off also played a significant factor reducing the strength of the fill and landslide deposits behind the existing wall.
Site 29	Shallow rotational slide of the near surface fill materials due to surface water run-off.
Site 30	Shallow rotational slide of the near surface fill materials due to surface water run-off.

4.4.2 DEVELOPMENT OF REMEDIAL OPTIONS

During this stage, a range of remedial options were developed for each slip site during this stage. These options included the following:

- Fill buttresses.
- Embedded or gravity retaining structures.
- Mechanically stabilised earth (MSE) structures and reinforced slopes.
- Road re-alignment away from the affected slip area.

Concept level assessments were undertaken to provide a rough estimation of the dimensions of each option for costing purposes. The options were then qualitatively compared based on their construction complexity, cost and ability to meet the NZTAs Key Performance Indicators (KPIs).

The proposed remedial options are summarised in Table 3 below. The recommended (and subsequently approved) option for detailed design is indicated in bold.

Table 3: Summary of the remedial options and the recommended option (in bold) for Category B slip sites

Site ID	Remedial Options	Reason for Selection of the Preferred Option
Site 11	1. Do nothing – continue to monitor	<ul style="list-style-type: none"> • Lower construction cost • Ease of construction
	2. Extension of the existing timber crib wall	
	3. Cantilevered timber pole retaining wall	
	4. Gravity retaining wall	
	5. Tied-back timber pole retaining wall	

Site ID	Remedial Options	Reason for Selection of the Preferred Option
Site 14	1. Road re-alignment	<ul style="list-style-type: none"> • Lower construction cost • Re-alignment not considered feasible due to potential instability of upslope materials
	2. Tied-back timber pole retaining wall	
	3. Tied-back steel H-pile retaining wall	
Site 16	1. MSE 'Terramesh' wall	<ul style="list-style-type: none"> • Lower construction cost • Easier to construct compared to MSE Terramesh wall due to space requirements
	2. Cantilever timber pole retaining wall	
	3. Tied-back timber retaining wall	
	4. Cantilever steel H-pile retaining wall	
	5. Fill buttress	
Site 17	1. Do nothing – continue to monitor	<ul style="list-style-type: none"> • Lower construction cost • Ground anchors extended into bedrock, which provided a robust retaining wall option • High risk of continuing movement with the 'do nothing' option
	2. Tied-back timber pole retaining wall	
	3. Cantilevered steel H-pile retaining wall	
Site 21	1. Do nothing – continue to monitor	<ul style="list-style-type: none"> • Lower construction cost • High risk of continuing movement with the 'do nothing' option
	2. Tied-back timber pole retaining wall	
	3. Tied back steel H-pile retaining wall	
Site 22	1. Timber pole retaining wall with or without anchors	<ul style="list-style-type: none"> • Lower construction cost • Gravity wall does not satisfy the design requirements
	2. Steel H-pile retaining wall with or without anchors	
	3. Gravity retaining wall	
Site 22a	1. Tied-back timber pole retaining wall	<ul style="list-style-type: none"> • Lower construction cost • Gravity wall does not satisfy the design requirements
	2. Gravity retaining wall	
Site 24/25	1. MSE 'Terramesh' wall	<ul style="list-style-type: none"> • Lower construction cost • High likelihood of continuing movement with the 'road alignment' option
	2. Retreat	
	3. Tied-back steel H-pile / concrete pile retaining wall	
Site 29	Designed by others	
Site 30	Designed by others	

4.4.3 SAFETY IN DESIGN (SID)

At an early stage of concept design, Safety in Design (SiD) workshops were attended by representatives from Beca Ltd, Higgins and the Agency to assess the likely risks associated with design and construction, and place control measures to minimise the risks, where possible. The identified risks were continuously monitored throughout the design, construction and decommissioning phases of the project.

The risks categorised as ‘high’ generally related to the risk of instability during the removal of existing retaining walls from the sites and potential instability of slopes above and below the construction sites. Mitigation measures generally included monitoring the stability of slopes using spotters and using temporary measures such as sheet piles during staged construction.

4.5 PHASE FOUR: DETAILED DESIGN

Detailed design of the preferred remedial options commenced following approval from the Agency. The main steps adopted for this stage are indicated on Figure 8 below.

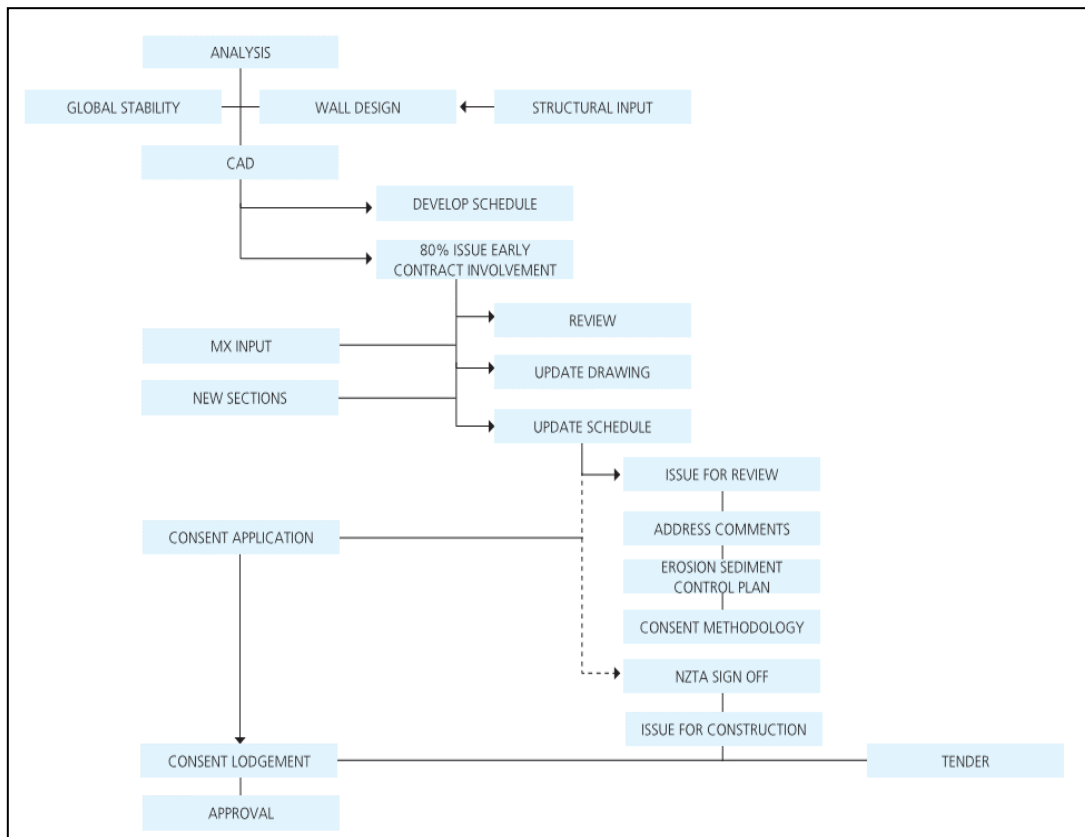


Figure 8: Main Steps involved in Phase 4

Design required inputs from multiple disciplines, including geotechnical, civil, structural engineering and planning. This ensured the provided solution addressed the likely cause(s) of failure, in particular the drainage aspects.

Given the slip sites were in an area subject to continuous instability and flooding, it was agreed to reduce the performance criteria for the geotechnical design of the retaining structures, compared to those proposed in the NZTA Bridge Manual, Third Edition, Amendment 2 (The ‘Bridge Manual’). The main departures included the following:

- Design life of 25 years was adopted for all retaining walls (compared to a 100-year design life recommended by the Bridge manual).
- Importance Level (IL) 2 was adopted for all retaining walls (compared to an IL 3 recommended by the Bridge Manual for retaining walls with heights greater than 5m and face areas greater than 100m³).

The above departures allowed for cost-effective solutions by reducing the seismic demands on the retaining walls. A peak ground acceleration (PGA) of 0.27 g under the Ultimate Limit State (ULS) event was derived for the retaining walls founded on sites with site subsoil class ‘C – Shallow Soils’ (in accordance with NZS1170.5:2004).

Detailed design of the retaining walls generally included global and local stability assessments and ground anchor design for the tied-back solutions. Global stability analysis was undertaken using the GeoStudio SLOPE/W software to ensure the required factors of safety (FoS) were met.

Local stability analyses were undertaken using the Geosolve WALLAP software ('WALLAP') to determine the required wall dimensions and assess the moment and shear demands on the wall members. The factors of safety (FoS) for embedment was determined using the 'Strength Factor Method', and shear force and bending moment demands on the wall were calculated using the 'Subgrade Reaction Model' provided in WALLAP. Ground anchor design and construction was in general accordance with the British Standard BS8081: 2015.

Details of the final design solutions are presented in Table 4 below.

Table 4: Details of the final solutions adopted for the slip sites

Site ID	Detailed Design Solution	Pole/Pile Size (mm)	Nominal Pole/Pile spacing (m)	Pole/Pile Length (m)	Ground Anchor Details
Site 11	Cantilevered timber pole retaining wall	350 SED*	1.0	8.0	Anchors were not installed but allowance provided, subject to annual monitoring results.
Site 14	Tied-back timber pole retaining wall	400 SED	2.0	7.0	15 m long, 32 mm dia. Reid bars
Site 16	Tied-back timber pole retaining wall with rip-rap protection	400 SED	1.0	12.0	10 m long 28 mm dia. Reid bars
Site 17	Tied-back timber pole retaining wall with rip-rap protection	400 SED	2.0	8.0	7.5 m long 32 mm dia. Reid bars
Site 21	Tied-back timber pole retaining wall with rip-rap protection	400 SED	2.0	7.0	8 m long, 25 mm dia. Reid bars
Site 22	Tied-back steel H-pile retaining wall	250UC89 Section	2.0	15.0	14 m long, 32mm dia. Reid bars
Site 22a	Tied-back timber pole retaining wall	400 SED	2.0	7.0	7.5 m long, 25 mm dia. Reid bars
Site 24/25	Tied back steel H-pile retaining wall (two rows of anchors)	250UC89 Section	2.0	13.0	Two row: 16 m long 32 mm dia. Bottom row: 16 m long 25 mm dia. Reid bars
Site 29	Detailed design of the preferred option has not been undertaken to date.				
Site 30	Detailed design undertaken by another consultant.				

*SED: Small End Diameter

4.6 PHASE FIVE: CONSTRUCTION AND MONITORING

Construction of the retaining walls at the Category B slips sites was undertaken concurrently over a 12-month period by Higgins, with support from several local sub-contractors. Some of the challenges faced during the construction included:

- The retaining walls were situated in areas within high risk of instability, particularly rock fall from the upslope side of SH4. This required continuous monitoring of the slopes during both the construction phase of the works. Spotters were regularly employed to monitor the slopes, and temporary measures such as sheet piles and barriers were used during staged construction.
- Adverse weather conditions, such as further heavy rainfall events, led to elevated river levels and delays to the construction.
- Further instability and fretting of slopes adjacent to the initial slips commonly occurred. This resulted in designs being extended or transitions being designed to account for the tie-ins to existing bank.
- Additional storm events during design and construction increased the risk of temporary stability issues of partially constructed walls.
- New slips occurred along SH4 during periods of heavy rain, and resulted in construction delays due to disruptions with access to the sites.

Selected photographs of the retaining walls during construction are presented in Figure 9 and 10 below.



Figure 9: Photographs of Site #16 (left) and Site #22 (right) during construction

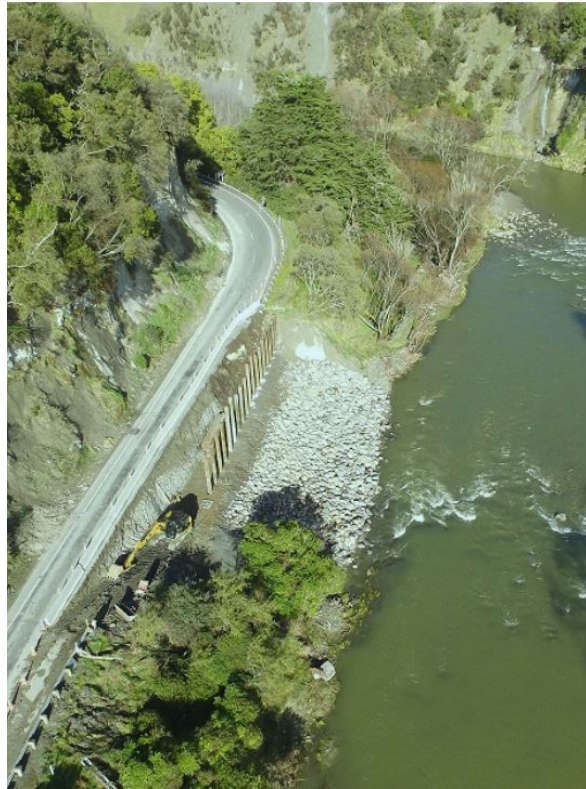


Figure 10: Aerial Photograph of Site #21 during construction

4.7 PHASE SIX: SITE COMPLETION

Construction of nine Category B sites has currently been completed. Selected photographs of the completed retaining walls are presented in Figures 11 and 12 below.



Figure 11: Photograph of completed remedial works at Site #14



Figure 12: Photograph of completed remedial works at Site #24/25

5. CONCLUSIONS AND LESSONS LEARNT

The emergency response for the June 2015 storm event was of a large scale and included initial efforts from Higgins and local subcontractors to restore access to the affected sections of SH4 within a very short timeframe. Once access was restored, a process was developed to prioritise the slip sites, develop remedial options and undertake detailed design and construction monitoring of remedial options.

Some of the lessons learnt from the recovery works process and recommendation for further improvement are summarised below.

- Effective and clear communications between all three parties is pivotal for development of cost-effective remedial solutions in a NOC delivery model. In this case, communications were mainly through regular meetings between the parties involved and use of registers to document correspondence. A software platform, shared by all parties involved, may prove to be an invaluable tool for open and clear communications
- The whole of site, including site access and the wider affected site, should be considered during the early planning of the recovery works. The remedial measures at the slip sites included temporary and permanent access tracks and working platforms to allow construction of the retaining walls from below the carriageway. The elements beyond the immediate slip affected the overall cost of the solutions and should be included in early planning of the recovery works.
- The design performance criteria for the remedial structures should consider the overall region and the likelihood of instability adjacent to the new structures. The retaining walls along SH4 are situated in a region exposed to regular flooding and land instability. Therefore, it will not be practical to achieve a 100-year design life as recommended by the Bridge Manual. Selection of an appropriate design life and importance level, whilst considering the future repairs in extreme events, may lead to more economic design solutions.
- Safety in Design (SiD) workshops at early stages of design were invaluable in assessing the risks (including residual risks) and opportunities to ensure appropriate control measures were placed during the design and construction phases. The risks encountered on site continuously evolved over time. It was therefore crucial to re-visit the risks accordingly throughout the design and construction phases.

The above lessons learnt and recommendations may prove valuable for improving the collaboration amongst the parties involved in NOC's across the country.

6. ACKNOWLEDGEMENTS

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