PATTLE DELAMORE PARTNERS LTD

Waitangi Stream Remediation and Erosion Protection Works – Design Report

Bay of Plenty Regional Council

Waitangi Stream Remediation and Erosion Protection Works – Design Report

Prepared for

Bay of Plenty Regional Council

March 2018

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Limitations:

This report has been prepared by Pattle Delamore Partners Limited (PDP) on the basis of information provided by Bay of Plenty Regional Council and SurveyOne Limited. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the specification. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

This report has been prepared by PDP on the specific instructions of Bay of Plenty Regional Council for the limited purposes described within. PDP accepts no liability if this document is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

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Appendices

1.0 Introduction

Pattle Delamore Partners Ltd (PDP) was engaged by Bay of Plenty Regional Council (BoPRC) in November 2017 to undertake investigations and detailed design of erosion protection works for a 50 m section of Waitangi Stream at 341 Spencer Road, Tarawera.

This report outlines the basis of the design, assumptions, risks and cost estimates and should be read in conjunction with the drawings, schedule of quantities and technical specifications for the works.

1.1 Background

Lake Okareka discharges to the headwater of Waitangi Stream via a pipeline constructed in the 1960s. This pipeline was constructed to mitigate against flooding at Lake Okareka caused by elevated lake levels.

The pipeline has historically discharged up to 240 L/s into the Waitangi Stream. The pipeline was upgraded in 2014 to discharge up to 360 L/s, and since June 2017 a temporary above ground pumped system has increased the discharge flowrate to 500 L/s.

Since increasing the flow from Lake Okareka to the Waitangi Stream, BoPRC has been monitoring the stream for hydraulic, ecological and erosion effects. BoPRC have identified approximately a 50 m section where the stream bed has been eroding. This section is immediately downstream of a 1,050 mm diameter culvert over a shared right-of-way at Waitangi Bay, accessed from Spencer Road. The streambank is steeply incised in this section, with banks up to 6.0 m high. Stream bed degradation is also impacting on the stability of the stream banks. The house and garage at 341 Spencer Road are in close proximity to this section of the stream on the true left bank, with some of the residential dwelling structures coming within 1 to 2 m of the top of the streambank.

2.0 Investigations

2.1 Topographical Survey

A site survey has been carried out by SurveyOne Ltd on 13 November 2017. This data has been utilised in the design and incorporated into the drawings.

2.2 Geotechnical Investigation

A geotechnical investigation at the site was carried out by PDP on 14 December 2017.

This investigation included a walkover of the site, five hand-augured investigation boreholes and 10 Dynamic Cone (Scala) Penetrometer tests.

The field work identified existing instability and slippage on both sides of the stream bank. Subsequent slope stability modelling utilising results from the onsite investigation and detailed topographical survey indicated that the 6.0 m high streambank below the buildings at 341 Spencer Road was marginally stable, with a factor of safety of approximately 1.0 (which is below the generally accepted safe range of 1.4 to 1.6).

Further details of the geotechnical investigation and modelling are presented in a technical memorandum dated 21 December 2017 included as Appendix A. Further details of subsequent geotechnical modelling and analysis of the proposed slope stabilisation works are outlined in Section 3.3.

3.0 Design

3.1 Concept Design Development

PDP developed an initial concept design for stream bank and bed erosion protection works which was issued to BoPRC for discussion on 21 December 2017. However, following completion of the geotechnical investigation and slope stability analysis, PDP identified that the existing dwelling at 341 Spencer Road was at risk of slope instability and the stream bank protection works proposed at that time did not satisfactorily mitigate this risk.

Therefore, following further discussion with BoPRC including a teleconference on 10 January 2018 with Andy Bruere and Niroy Sumeran from BoPRC, Darrell Holder from Rotorua Lakes Council (RLC) and the landowner of 341 Spencer Road, Richard Armstrong, PDP was instructed by BoPRC to modify the design to incorporate slope stabilisation works to mitigate risk of slope failure and damage to the existing dwelling and outbuildings. The design outlined in the following sections has been undertaken on this basis.

3.2 Design Criteria

Based on discussion with BoPRC staff, key design criteria and controls which have been adopted are outlined as follows:

a) Provide erosion protection to the toe of the stream bank to prevent further erosion of the stream bed and adjacent banks;

b) Provide for stream bed protection to eliminate further stream bed degradation;

c) Stabilise the slope of the stream banks to provide an adequate Factor of Safety against potential slope failure in the long term (i.e. 1.4 to 1.6);

d) Utilise rip-rap and gabion baskets, if possible, in preference to a culvert extension, concrete structure or sheet piling; and

e) Access to the site is difficult and consideration must be given for access for machinery, placement of materials and temporary flow management during construction.

3.3 Geotechnical and Slope Stability Assessment

Stabilising the slope either side of the stream has been achieved by a combination of the following:

a) Raising the stream bed to support the erodible bed and flattening the steepness of the stream channel; and

b) Placement of gabions baskets against the steep slopes to provide a gravity retaining structure.

The proposed design has increased the Factor of Safety against slope failure across the extent of the proposed works from around 1.0, to around 1.4 to 1.6.

Details of the slope stability modelling for the proposed completed stream bank remediation works is outlined in Appendix B.

3.4 Hydraulic Design

The erosion protection works have been designed in accordance with the Bay of Plenty Regional Council Hydrological and Hydraulic Guidelines (2012) (BoPRC Guidelines). In accordance with Section 4.5 of the BoPRC Guidelines, the design requires that a passage for the 20 year Average Recurrence Interval (ARI) flow must be maintained. In addition, an allowance for climate change effects has been made in the calculation of this design flow.

3.4.1 Design Flow

A design flow of 3 m^3/s (20 year ARI event) was calculated using the modified Rational Method in accordance with Section 5.5.3 of the BoPRC Guidelines. This flow was calculated for the section of Waitangi Stream downstream of the private road at Waitangi Bay. Calculation of this design flow is included in Appendix E.

Under most conditions discharge from Lake Okareka will contribute most of the flow in Waitangi Stream. BoPRC has nominated a maximum flow of 500 L/s for the discharge from Lake Okareka. It is expected that base flow in the Waitangi Stream will be in the order of 5 L/s in summer and 30 L/s in winter (River Lake Ltd, 16 October 2017). A conservative maximum baseflow of 100 L/s has been assumed for design purposes.

A 1D hydraulic model was developed to assess velocity, flow depth and flow regime in the Waitangi Stream in the location of the contract works. This model was developed using the Hydrologic Engineering Center’s River Analysis System (HEC-RAS) software (Version 5.0), produced by the US Army Corps of Engineers.

The results of this analysis were checked using manual calculations based on energy grade methods. HEC RAS outputs for velocity, flow depth and other parameters are included in Appendix E.

3.4.2 Rip Rap Sizing

Rock rip-rap has been designed to line the channel bed. This rip rap layer has been sized in accordance with Figure 7.1, Section 7.5.2 of the BoPRC Guidelines. 300 mm median diameter (D_{50}= 300 mm) and 400 mm median diameter rip rap (D_{50}= 400 mm) has been used for the base of the channel.

The depth of rock rip rap in the base of the channel as specified on the drawings is 1.5 times the median diameter. Rip rap is to be placed on a Bidim A44 geotextile, overlying compacted aggregate to minimise erosion of fine grained material.

3.4.3 Erosion Protection at Bends

There is a slight bend in the channel at or about Cross Section B in the Drawings. In accordance with section 7.5.2 of the BoPRC guidelines, a factor of 4/3 has been applied to calculated velocities for this section, and rip rap sizing carried out accordingly for additional protection (Figure 7.1, Section 7.5.2 of the BoPRC Guidelines).

3.4.4 Drop Structure

As outlined in Section 3.1 the channel invert has been raised to the order of 2.0 m above the original stream invert to increase slope stability and reduce hydraulic grade in the section of the stream adjacent to the buildings at 341 Spencer Road. A drop structure has been designed to return flows to the base level of the downstream channel without causing scour erosion at the base of the drop, or further downstream. This drop is approximately 2.1 m.

The drop structure has been designed using the methodology outlined in the US Department of Transportation publication ‘Hydraulic Design of Energy Dissipators for Culverts and Channels’ (Third Edition, July 2006). Two successive drops have been used.

Design calculations for this structure are included in Appendix E.

3.5 Flow Management during Construction

As shown on the drawings, a 450 mm diameter StormBoss™ polypropylene pipe is to be installed in the channel. This pipe will be used to carry flows during the construction period, and shall be blocked-off following. It will remain in-situ to provide bypass flows during maintenance work if required.

The inlet arrangement to this pipeline, and shut-off system will need to be confirmed during construction.

3.6 Draft Construction Sequence

The contractor will be required to prepare a detailed construction sequence and methodology to be approved by the Engineer.

The following draft construction sequence may be used by the Contractor as a guide as to the construction sequence.

1. Bypass stream flows around the Work Site:
   - Request that the Principal closes the valve on the Lake Okareka Pipeline to shut off the majority of the flow in Waitangi Stream for a period to be agreed with the Principal which they will determine based on current lake level and forecast rainfall;
   - Install the 450 mm diameter polypropylene bypass pipeline as shown on Sheet 102 of the Drawings (T01552501 – DWG-102) and establish erosion proofing at outlet;
   - Remove temporary erosion controls (i.e. plywood and steel warratahs) from the waterway immediately prior to bulk filling;
   - Carry out bulk filling of the streambed (compacted GAP65 aggregate) to establish the foundation for the gabion structures and rip rap.
2. Maintain the bypass system for a period of 2 weeks to allow for settlement of the placed fill.
3. Check finished levels and carry out any further filling following settlement of the placed aggregate.
4. Construct the drop structure as shown on Sheet 205 of the Drawings. This will include excavation using small excavator (approximately 1.5 tonne) and backfilling with compacted aggregate to form the lower drop structure.
5. Work upstream to construct the cross sections as shown on the Drawings.
   - Level and prepare the surface and lay geotextile.
   - Place, adjust and secure gabions.
   - Fill gabions with specified gabion rock. Where the adjoining gabion has not yet been placed, the end diaphragm should be left empty and open to allow joining to be carried out once the next gabion is in place. Close and secure rock filled structures using stainless steel rings (maximum 150 mm centres).
6. Carry out remaining compacted backfilling behind gabions.
7. Place rip rap in channel.

8. Construct the culvert headwall as shown on Sheet 206 of the Drawings.
9. Block-off/decommission temporary flow bypass pipeline.

4.0 Project Risks

Project risks are outlined in the Risk Register included in Appendix C. Key project risks are:

a) **Health and Safety risks during construction.** This risk will be mitigated by careful Contractor selection and ensuring that appropriate safety plans are in place and all method statements are carefully planned. Monitoring of the Contractor's health and safety systems during the project will also mitigate this risk. Access to the existing dwelling at 341 Spencer Road will also need to be restricted while the works are undertaken.

b) **Damage to private property during construction.** This risk will be mitigated by clear delineation of the Contractor's working area.

c) **Short term slope stability failure during construction.** This risk will be mitigated through project sequencing (carrying out filling of the streambed first), minimising to excavation in design and during construction, and monitoring of slope stability and protection measures during construction.

d) **Long term slope stability failure.** The contract works have been designed to provide a suitable long term factor of safety against slope failure. This aspect is outlined in Section 3.0.

e) **Fill material mobilised by flow and transported downstream.** All channel linings have been designed to avoid mobilisation of material during design flood flows. If fill/rip rap material is mobilised, deep pools have been included in the drop structure at the downstream end of the contract works which will collect a volume of mobilised material. The stream should be inspected by BOPRC periodically and after high flow events for erosion damage and mobilisation of material, and repairs/reinstatement carried out as required.

f) **Erosion downstream of works.** An engineered drop structure has been designed to ensure downstream flow velocities are minimised.

g) **Stream vanishes at low flows – flows through rip rap and gabions on stream bed.** Given the size of bed material required for erosion protection to accommodate flood flows, low flows in the Waitangi Stream may flow through the rock/gabions and not be visible as surface flow. If this occurs regularly, and is problematic, weirs could be constructed to raise the water level during low flows.

h) **Continued eroding of stream bed under placed rip rap.** If streambed erosion persists in some locations due to changing flow conditions or other factors, rip rap can be replaced with reno mattresses to provide increased protection where required.

i) **Difficulty sourcing larger boulders and rip-rap material.** If suitable large boulders cannot be sourced locally these may need to be imported at additional cost. If this occurs, there may be scope to substitute gabion baskets in place of large boulders in some locations.

j) **Future access for maintenance.** The works will not compromise existing machinery access to this section of Waitangi Stream; however will not improve maintenance access.

k) **Resource consenting and Iwi support.** BoPRC has applied for resource consent for the works under Section 330 of the Resource Management Act (Emergency works). BoPRC understand that they are undertaking the works prior to securing resource consent(s) at their own discretion and risk.

5.0 Safety in Design

A safety in design register for the works is included in Appendix D. Key safety in design aspects include:

- Positive identification of services prior to commencing work;
- Carrying out bulk filling of streambed initially to increase slope stability before carrying out any works on the slopes;
- Monitoring of slope stability during construction; and
- Engineer review of Contractors Health and Safety Plan and Construction Methodology.

6.0 Programme

- March 2018 – Tender and award of contract.
- Early March 2018 – Contractor to commence bulk filling in streambed.
- April 2018 – Completion of works.

7.0 Cost Estimates

An Engineer's Estimate for the works is included in Appendix F. All costs are exclusive of GST.

It should be noted that actual construction costs may vary from this estimate on the basis of competitive bidding, market conditions, inflation of bids, and other factors. It should also be noted that in this case the site constraints (limited access, working areas and other challenges) could further influence actual construction costs.

The Engineers estimate for the contract works is **$315,000 excl. GST**. This estimate includes a 10% contingency sum.

8.0 References

River Lake Limited, Memorandum from Keith Hamill to Andy Woolhouse, Subject: Lake Ōkāreka overflow, Waitangi Stream: Ecology effects of increased flow. Resource consent application CH17-00717, dated 16 October 2017.

US Department of Transportation, 'Hydraulic Design of Energy Dissipators for Culverts and Channels'. Hydraulic Engineering Circular No. 14, Third Edition, (Publication No. FHWA-NHI-06-086, July 2006).

Appendix A

Geotechnical Assessment of Existing Slopes

Pattle Delamore Partners Limited

TECHNICAL MEMORANDUM

INVESTIGATION	Geotechnical Investigation	**PROJECT**	Waitangi Stream Erosion Protection
CLIENT	Bay of Plenty Regional Council	**PROJECT NO**	T01552501
CLIENT CONTACT	Andy Bruere	**PREPARED BY**	Noel Kelly
CLIENT WORK ORDER NO/ PURCHASE ORDER		**SIGNATURE**	NKelly
		DATE	21 December 2017

1.0 Introduction

Pattle Delamore Partners Limited (PDP) have been engaged by Bay of Plenty Regional Council (BOPRC) to carry out detailed design of erosion protection for a section of Waitangi Stream at Waitangi Bay, Lake Tarawera. Waitangi Stream is steeply incised with streambanks up to 6.0 m high in the location of the proposed erosion protection works. There is a house and garage in close proximity to this section of the stream on the true left bank, with the structure coming within 1-2 m of the eastern bank of the stream at its closest point. The site layout is shown on Figure 1, Appendix A.

PDP has carried out a preliminary desktop study, including an initial slope stability assessment of the streambanks in accordance with their scope of work (outlined in Section 2.0). Based on this assessment, it was determined that a geotechnical site investigation was required to further investigate the slope stability of the stream banks, and the associated risk to the proposed contract works and adjacent property.

2.0 Preliminary (Desktop) Analyses

Preliminary slope stability analysis outputs are included in Appendix B. These preliminary analyses examined the existing stability of the bank at both sides applying parameters relevant to the soil indicated to be present on site.

Analyses indicated that both sides of the bank were marginally stable, both exhibiting a Factor of Safety (FoS) of approximately 1.0 (the typically acceptable FoS for long term stability of a slope is 1.5 to 1.6). Further analyses, examining the effects of erosion protection at the toe indicated only marginal improvement to the stability of the slopes, an insufficient improvement to infer satisfactory long term performance.

3.0 Site Walkover and Investigation

Following the preliminary analysis findings, a site investigation was deemed necessary to provide confidence in any further analysis and design of erosion protection and remediation measures. The ground investigation was subsequently scoped and carried out alongside a walkover survey on December 14th 2017. Works on this day comprised the following:

- A walkover survey of the site noting any existing instability and slippage;
- Five hand-augured investigation holes (“Hand Augers”) to depths of between 1.0 m bgl and 4.0 m bgl to investigate soil types and depths on site; and
- 10 Dynamic Cone or ‘Scala’ Penetrometers (DCP) to depths of up to 4.0 m bgl to investigate soil density.

An annotated site plan is included in Appendix A and draft investigation logs are included in Appendix C.

Results of the walkover survey are shown on Figure 1, with sketch cross-sections A-A’, B-B’ and C-C’ also enclosed. The most pertinent points to note from the investigation are as follows:

- A significant proportion of the existing banks are currently experiencing instability, with shallow slips noted on both sides of the stream. In particular, a significant area of slippage has been noted approaching the crest of the slope, immediately behind the adjacent residential property.
- The existing slopes adjacent to the property and elsewhere are steep, approaching 65° - 85° in places.

The layout of the intrusive soil investigation is shown on Figure 1. The investigation encountered the following:

- Alluvium and debris: Typically light grey silt with varying content of fine sand and trace gravel. Encountered up to 1.6 m.
- Volcanic Ash: Typically yellow brown fine sandy silt, encountered as soft or loose. Ash was encountered from surface or underlying alluvial layers to end of hole (EoH) at all Hand Auger locations.
- DCPs were also carried out at locations along the stream bed to establish the depth of loose or soft material overlying a competent bearing stratum. These encountered soft material to depths of between 600 mm and 2.10 m bgl.

4.0 Conclusions and Recommendations

- A preliminary slope stability analysis of the existing slope banks, applying estimated soil parameters, concluded that slopes at either side of the stream are currently marginally stable. This analysis indicated a less than acceptable Factor of Safety for long term stability of the slopes.
- Soil information and testing carried out during the subsequent investigation confirmed that the parameters applied during the preliminary investigation were appropriate to the soils in question.
- The conclusion of the preliminary analysis and site investigation is confirmed by the observation of numerous shallow slips on the banks of Waitangi Stream. The age of the observed failures is unknown. The age/timeframe of slope failures is often difficult to assess accurately without historical survey information, photographs or other references.
- Of particular note are the risks and possible implications for the property to the east of the stream (true left bank). As the slope currently stands, there is a possibility of further slope failure which may progress towards and possibly undercut the structure(s).
- While proposed erosion protection measures at the toe of the slopes may prevent any further de-stabilising removal of toe material, such measures will not significantly improve the overall long-term stability of the slopes.

On this basis, PDP recommend the following:

- To mitigate risk of instability due to excavations at the toe of the slopes, any toe erosion measures shall be installed in a sequential manner, as outlined in the Technical Specification for the works.
- The implication of long-term instability of the banks should be considered. The risk of instability may be acceptable at locations removed from any structures; but less so adjacent to the residential property to the east of the stream.
- On this basis, it is recommended that adjacent to the residential property, retaining measures (such as sheet piling, significant gabion structure, mass-blocks etc.) or alternative solution (such as raising of the stream bed, construction of a culvert structure or slope re-profiling) be incorporated into the erosion protection works.
- Such remedial measures will require further feasibility assessment and design. Following assessment, a combination of such measures may be deemed appropriate.

Limitations

This memorandum has been prepared by PDP on the specific instructions of Bay of Plenty Regional Council for the limited purposes described in this memorandum. PDP accepts no liability to any other person for their use of or reliance on this memorandum, and any such use or reliance will be solely at their own risk.

The findings in this memorandum are based on field observations and a series of hand auger holes and Scala Penetration testing at the site. Engineering geological conditions at the site have been interpolated based on this information using engineering geological experience. The interpolated conditions and parameters cannot be guaranteed to be accurate.

Slope stability analyses and subsequent recommendations have been made on the basis of preliminary information and should not be relied upon for detailed design of retaining structures. The final designer(s) may consider further investigation to be necessary to inform detailed design and construction.

Appendix A: Site Plan and Sections

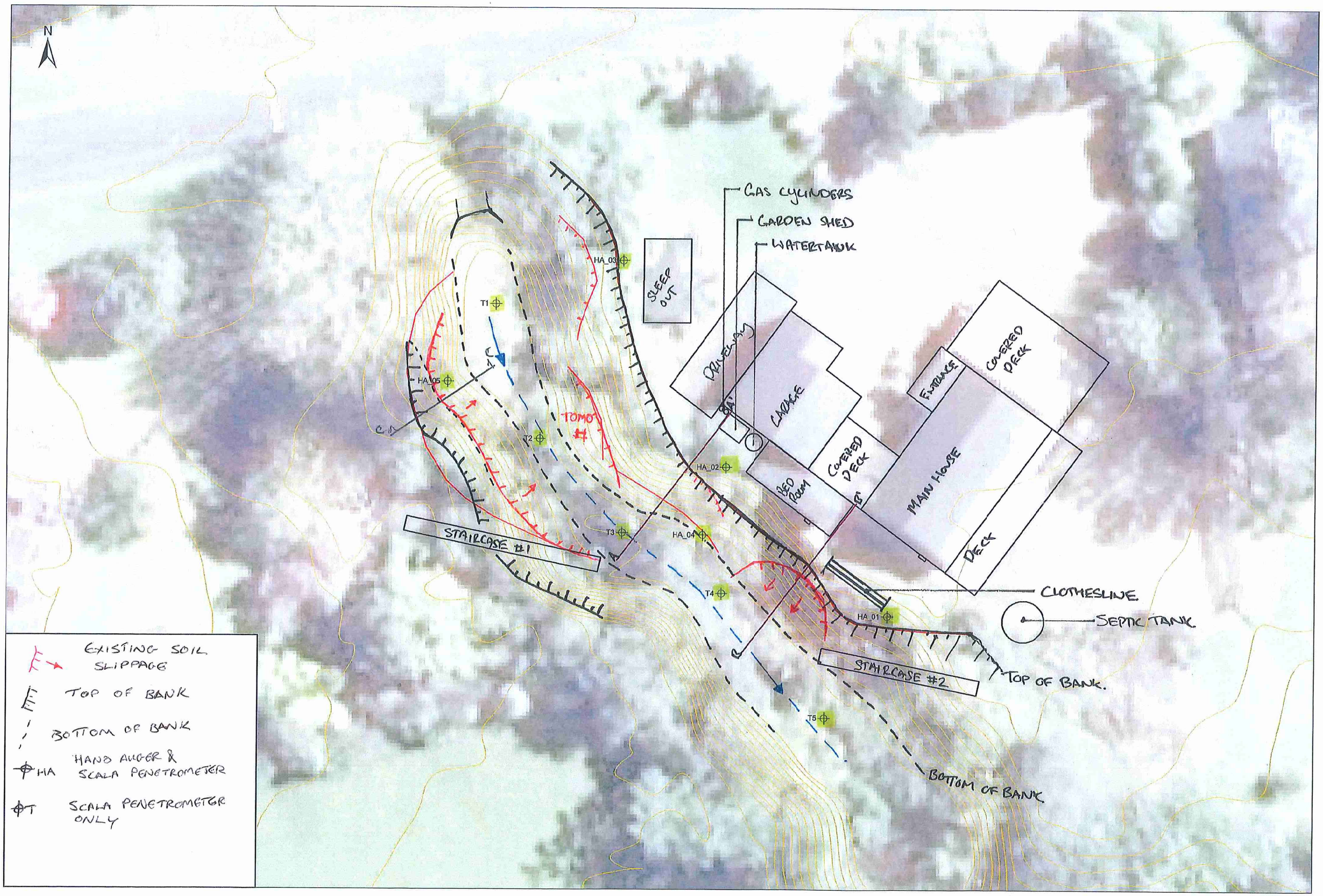

FIGURE 1: ENGGEOL SKETCH PLAN

SCALE: 1:250 (A3)

0 2.5 5 10
METRES

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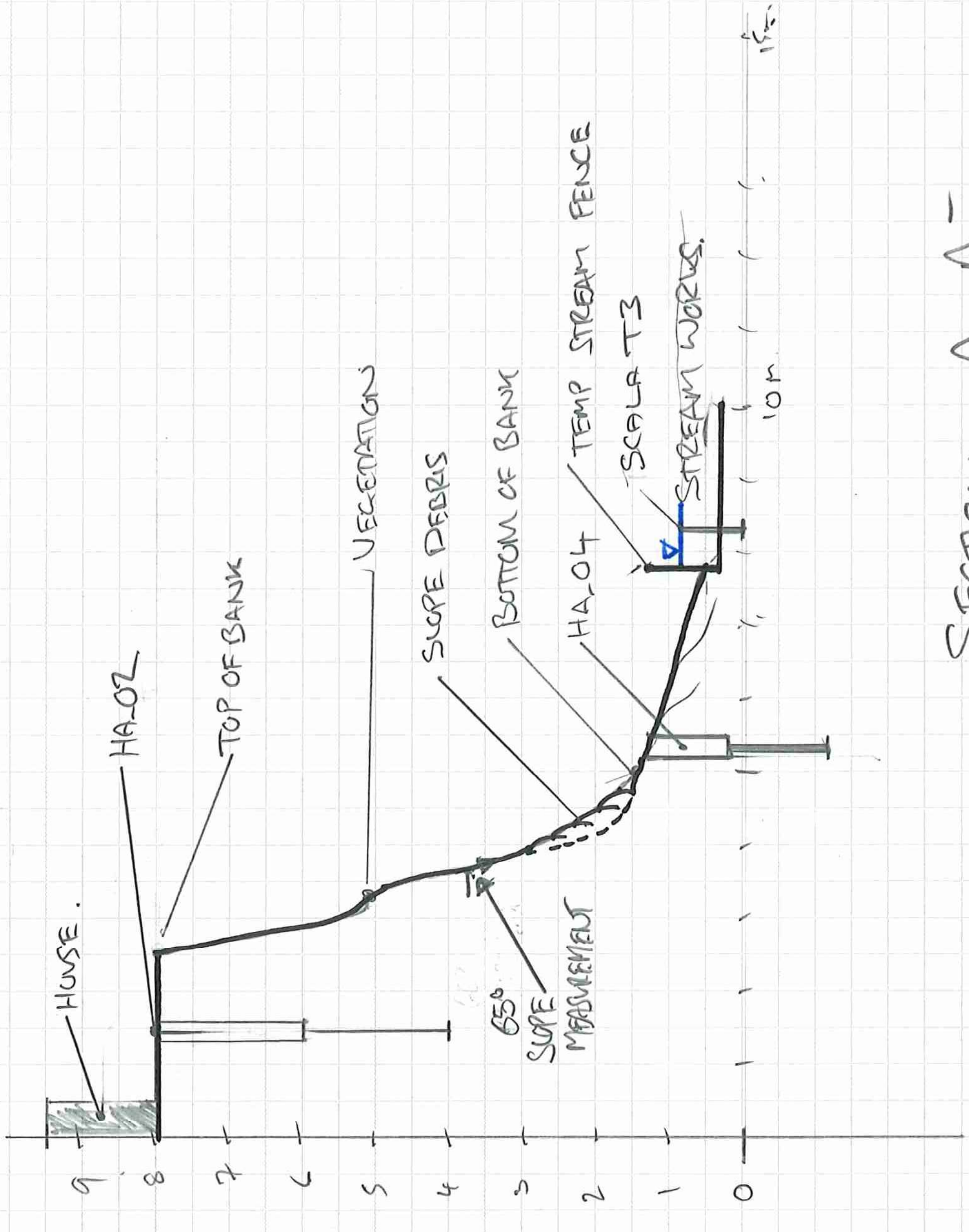
JOB NAME		PAGE No.
WAITANGI STREAM		1/3
JOB No: T01552501	DESIGNED CF	
DATE 15/12/17	CHECKED	



SECTION A-A'

SCALE 1:100

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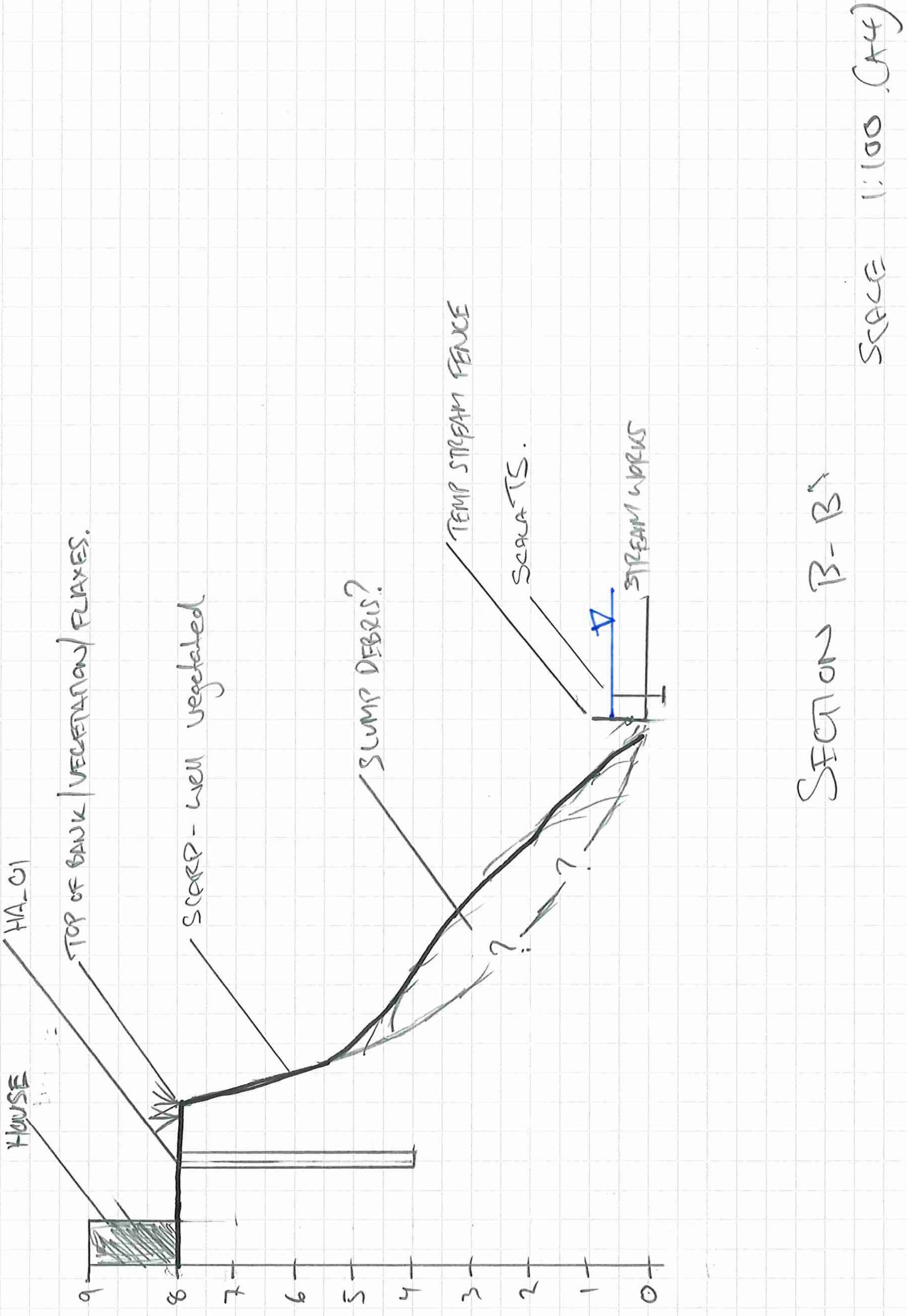
JOB No: TO1552501	**DESIGNED** CE.	
DATE 15/12/17	**CHECKED**	



SECTION B-B'

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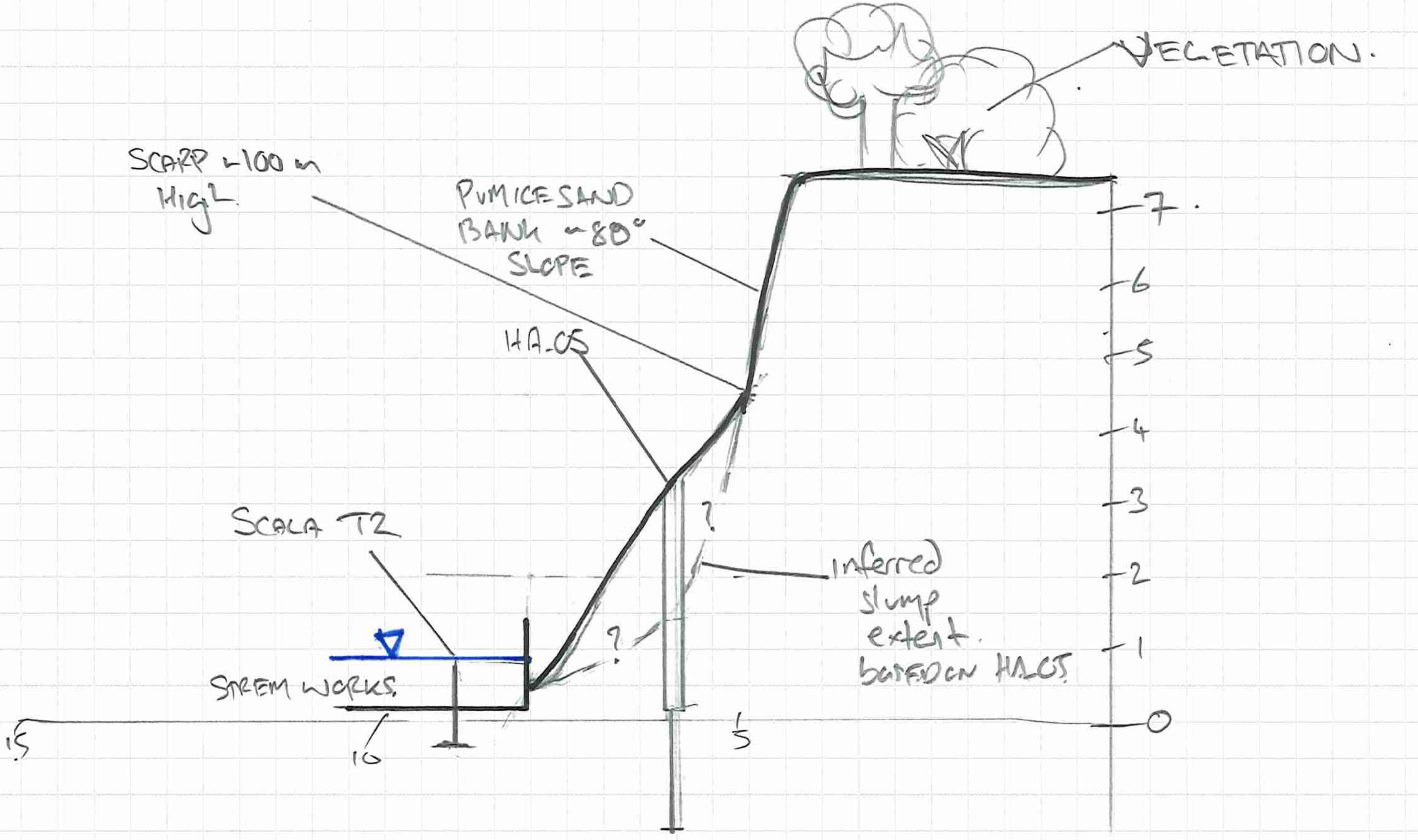
DATE	19/12/17	**CHECKED**	



SECTION C-C1

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Appendix B: Slope Outputs

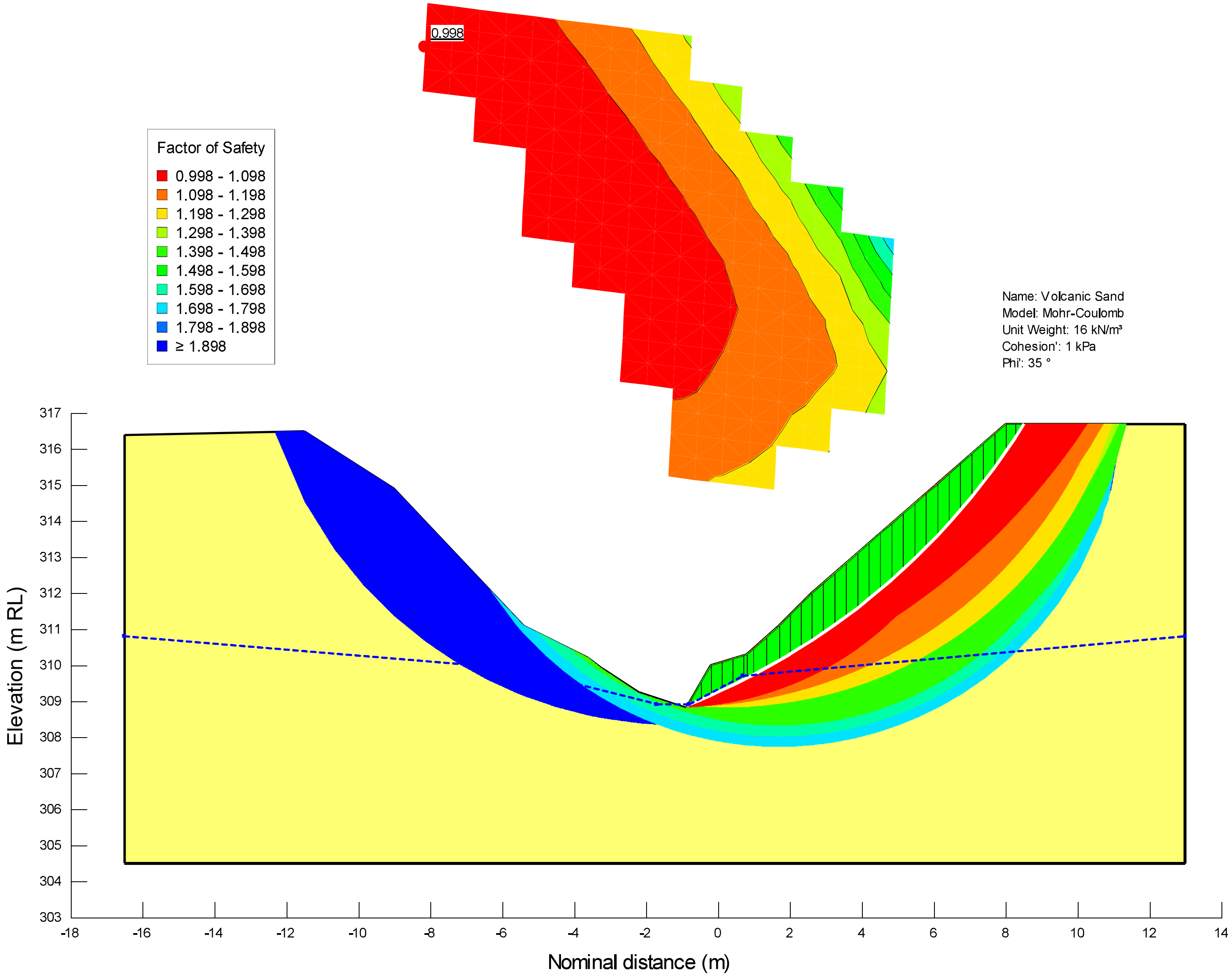

FIGURE 2: WAITANGI STREAM: PRELIMINARY SOPE STABILITY ANALYSIS [EAST]

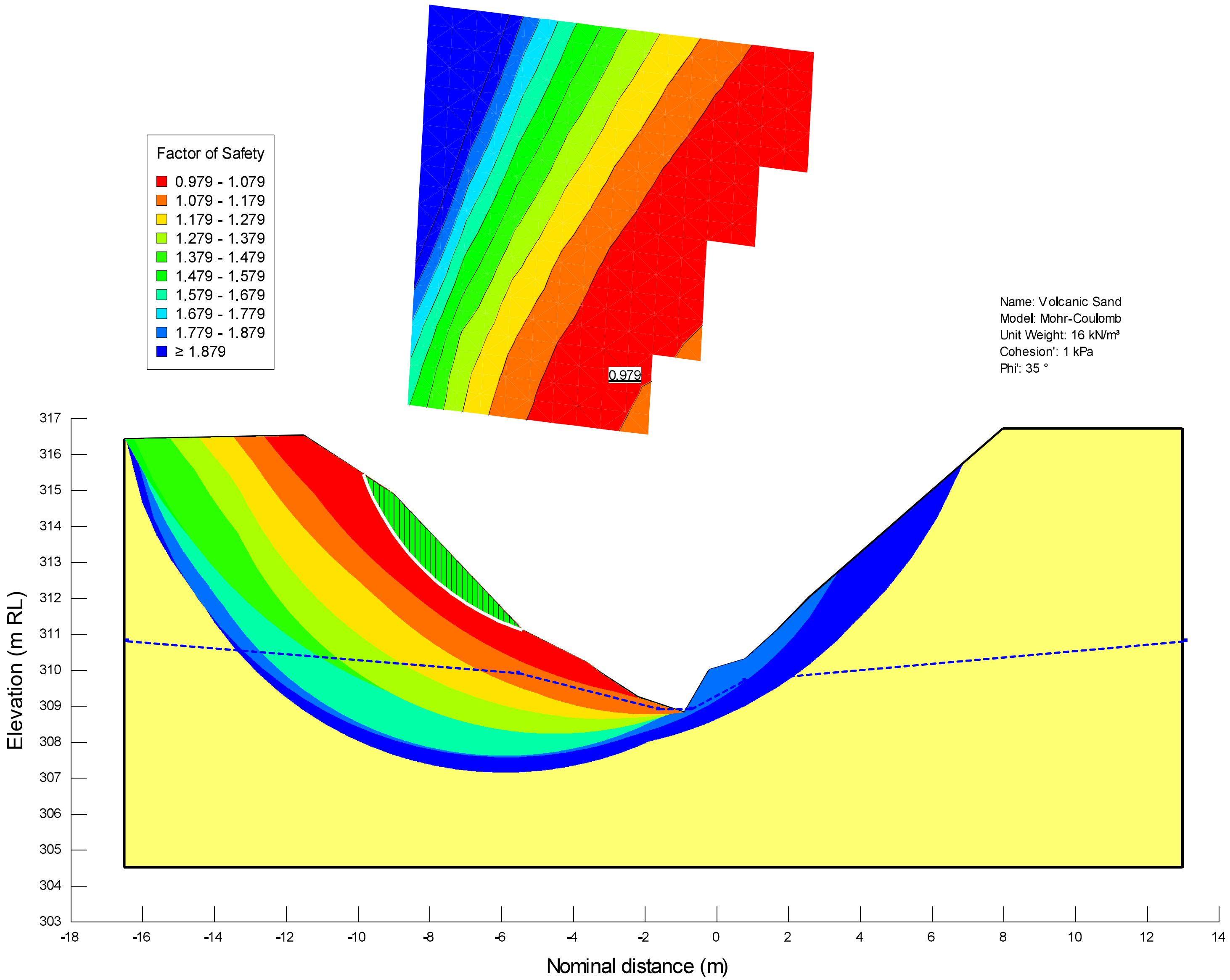

FIGURE 3: WAITANGI STREAM: PRELIMINARY SOPE STABILITY ANALYSIS [WEST]

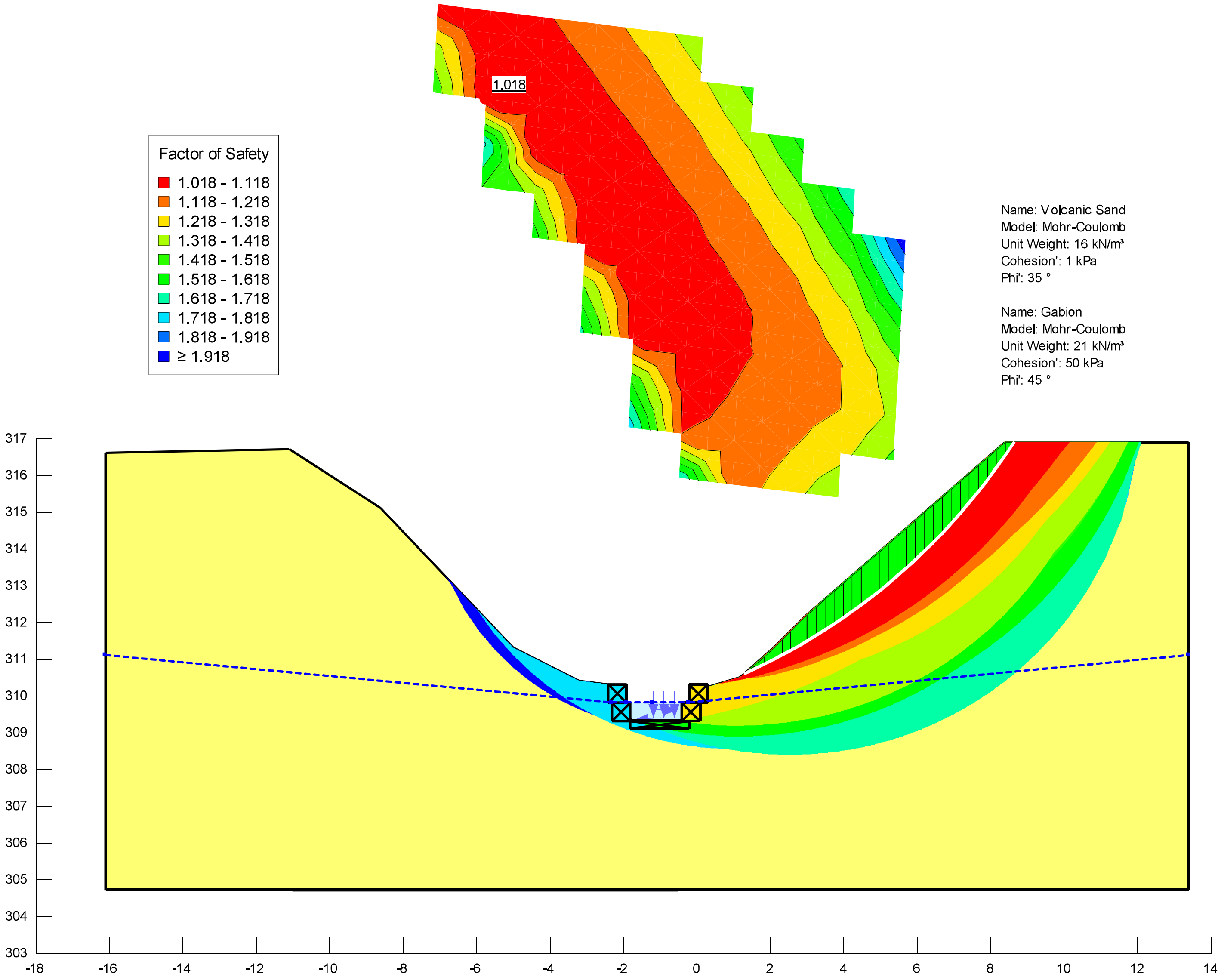

FIGURE 4: WAITANGI STREAM: PRELIMINARY SOPE STABILITY ANALYSIS [EAST – WITH TOE PROTECTION]

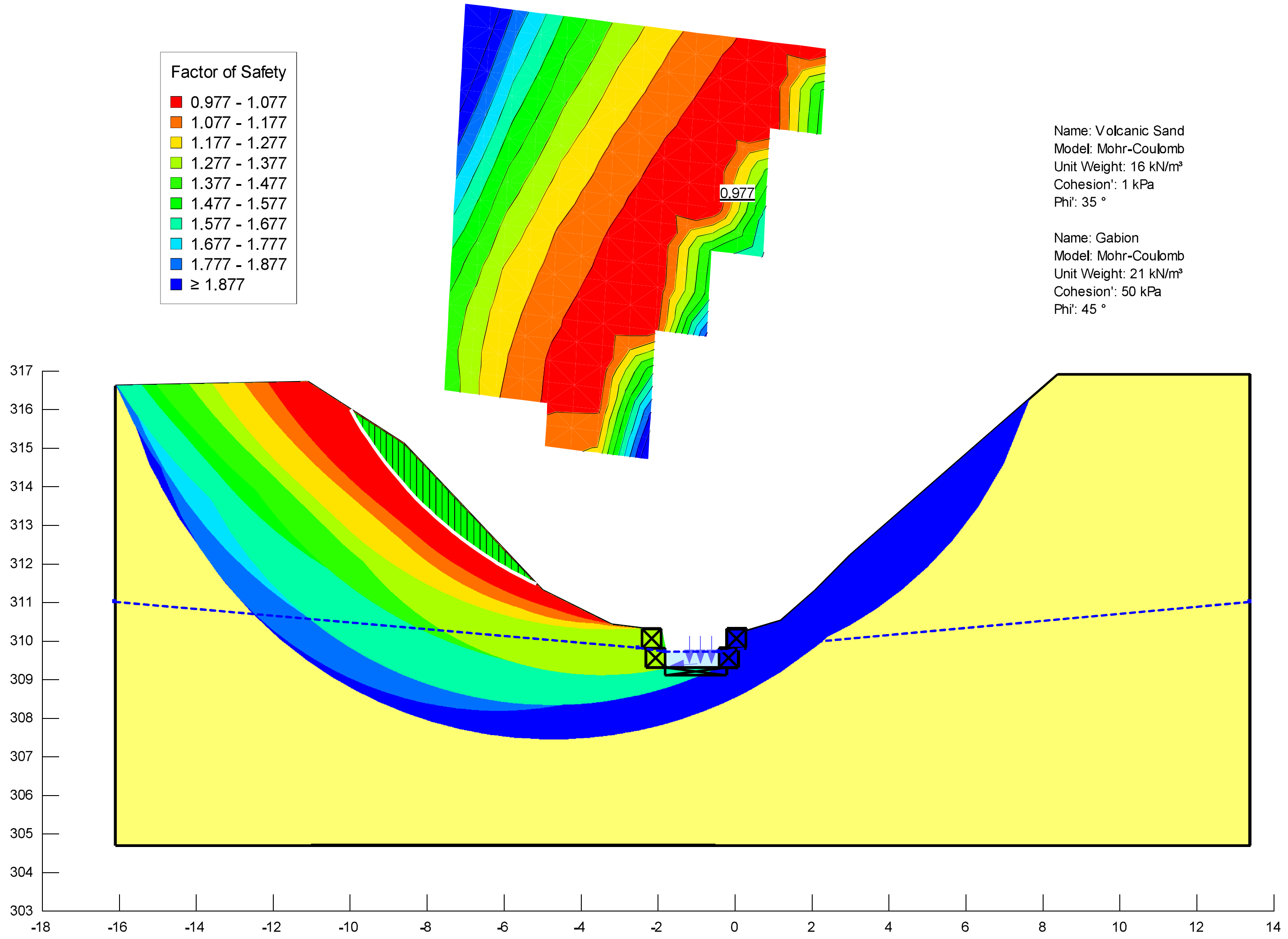

FIGURE 5: WAITANGI STREAM: PRELIMINARY SOPE STABILITY ANALYSIS [WEST – WITH TOE PROTECTION]

Appendix C: Investigation Results

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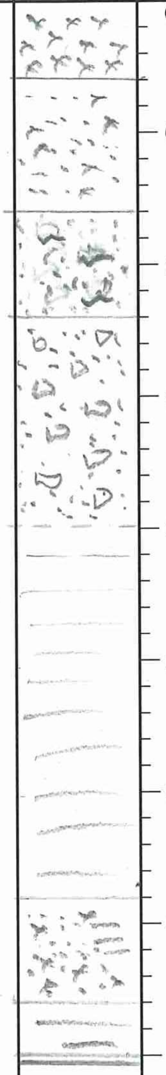
LOG OF HAND AUGER

PIT NO. HA_01
JOB NO:

CLIENT: BOPRC
LOCATION: Corner House
DATE: 14/12/17
DATE BACKFILLED:
LOGGED BY:
SHEET 1 OF 1

	DESCRIPTION OF SOIL	GRAPHIC LOG	DEPTH (m)	SAMPLE DETAILS	TESTS	WATER OBSERVATIONS
0	SILT; light grey. Firm; dry. ash.		0.0			
0.3	fine sandy SILT; dark grey. Firm-stiff dry ~~[illegible]~~ non-cohesive		0.5			
0.8	M-C SAND; black. LP dry. contains pumice gravels M-C.					
1.1	1.1m increasing gravel content.		1.0			
1.2	Gravelly SAND; ~~orange~~ yellow orange, LP moist gravels are pumice - subrounded weak & quartz. Sand is pumice & quartz M-C size		1.5			
1.6	Colour change to light grey.					
2.0	intermittent layers of (200mm) × M-C SAND; dark grey. × Fine SANDY SILT light grey × Fine sand yellow orange - Layers are dry-moist non cohesive		2.0 2.5 3.0			
3.4	fine sandy SILT with some clay; yellow brown. Firm; Moist-wet slightly plastic		3.5			
3.8	As per 2.0m.		4.0			
	EOH @ 4.0m TD GWNF.		4.5 5.0			



Notes: Scala 0-4m.

KEY
Groundwater level
Seepage inflow
Grab sample
× PID Reading (ppm)

Method: Hand Auger
Datum:
Ground Level: --
Coordinates:
Filename: Hand Auger (5m)

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

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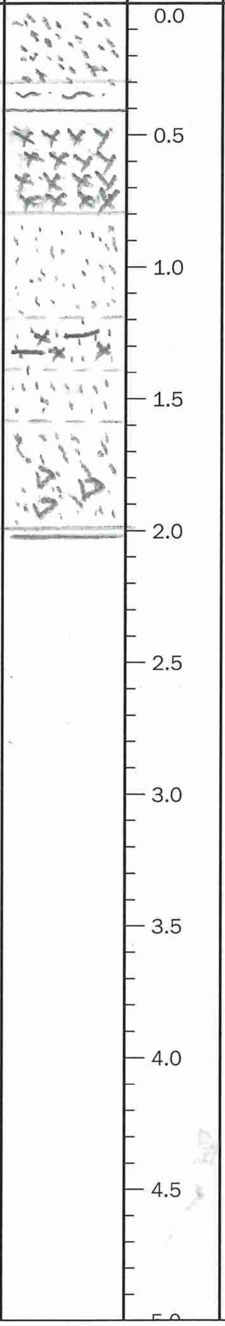
LOG OF HAND AUGER

CLIENT: BOPRC		LOCATION: Behind garden shed	PIT NO. JOB NO: HA_02
DATE: 14/12/17	DATE BACKFILLED:	LOGGED BY: CF	SHEET 1 OF 1

DESCRIPTION OF SOIL	GRAPHIC LOG	DEPTH (m)	SAMPLE DETAILS	TESTS	WATER OBSERVATIONS



0 FINE-MEDIUM SAND; orange brown speckled black; loosely packed; dry.

0.2 silty sand; black organic as per HA_01

0.3 SILT; light grey. soft; moist [ASH]

0.8 fine sand; light grey loosely packed. dry non-cohesive.

1.2 fine-medium sandy silt with some clay. Firm-soft; moist, slightly plastic dilatant

1.4 SAND. medium. light grey. dense pumice

1.6 SAND (F-Medium) light grey streaked orange. Loosely packed; moist-wet

1.9 1.9m Colour change to light grey.

eoh @ 2.0m TD

GWNE

Notes:

KEY
- Groundwater level
- Seepage inflow
- Grab sample
- × PID Reading (ppm)

Method: Hand Auger
Datum:
Ground Level: --
Coordinates:
Filename: Hand Auger (5m)

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

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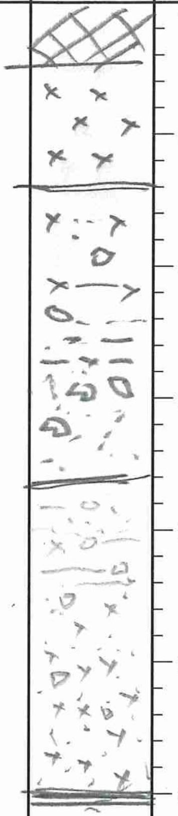
LOG OF HAND AUGER

PIT NO. HA-03
JOB NO:

CLIENT: BOPRC		LOCATION: Behind Sleepout	
DATE: 14/12/17	DATE BACKFILLED:	LOGGED BY: CF + NJ.	SHEET 1 OF 1

DESCRIPTION OF SOIL	GRAPHIC LOG	DEPTH (m)	SAMPLE DETAILS	TESTS	WATER OBSERVATIONS
0 Fill white chip 0.2 Silt with some fine sand; brown. Soft; dry; friable (non cohesive). Slightly organic. 0.3m Firm consistency 0.7 SILT with minor fine sand & fine gravel. light grey. Firm. stiff; dry. non cohesive, gravels are fine angular andesite [ALLUVIUM]. 1.5 soft horizon (300mm) 1.8 Sandy silt with some gravel; white streaked orange brown. stiff, dry-moist. ~~Grave~~ non-cohesive. Gravels are subrounded pumice m-15mm. Sand is fine-med pumice. [TEPHRA] 2.1 as 0.7 but more sand. 2.4 Minor horizons of sf clayey fine-med sand; orange brn. streak white. Dense, moist. Sand is pumice 100mm. e.h @ 3.0m T.D.		0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0			

Notes: CWMF.
Hole collapse between 1.5-2.0m.

KEY
Groundwater level
Seepage inflow
Grab sample
× PID Reading (ppm)

Method: Hand Auger
Datum:
Ground Level: --
Coordinates:
Filename: Hand Auger (5m)

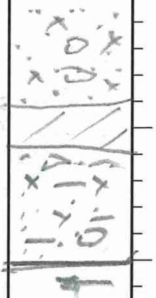
Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

pdp solutions for your environment
PATTLE DELAMORE PARTNERS LTD

LOG OF HAND AUGER

PIT NO. HA-04
JOB NO:

CLIENT: BOPRC
LOCATION: BANK TOE
DATE: 14/12/17
DATE BACKFILLED:
LOGGED BY: CF+NJ.
SHEET 1 OF 1

DESCRIPTION OF SOIL	GRAPHIC LOG	DEPTH (m)	SAMPLE DETAILS	TESTS	WATER OBSERVATIONS
0 Silty fine sand with minor gravel; pinkish grey speckled black. Firm; saturated; non plastic. Sand is fine-medium pumice; gravels are fine pumice. 0.4-0.6 difficult to recover core 0.8 Color change to pinkish grey speckled orange & white; minor clay eoh @ 1.0m Too difficult to auger further. running sands/hole collapse GW @ 0.3m bgl at end of auger.		0.0	▽		
		0.5			
		1.0			
		1.5			
		2.0			
		2.5			
		3.0			
		3.5			
		4.0			
		4.5			
		5.0			

Notes:

KEY
▽ Groundwater level
● Seepage inflow
● Grab sample
× PID Reading (ppm)

Method: Hand Auger
Datum:
Ground Level: --
Coordinates:
Filename: Hand Auger (5m)

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

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LOG OF HAND AUGER

PIT NO. HA_05
JOB NO:
CLIENT: BOPRC
LOCATION: North bank Slumps
DATE: 14/12/17
DATE BACKFILLED:
LOGGED BY: CE
SHEET 1 OF 1

DESCRIPTION OF SOIL

0 fine sandy silt ~~SILT~~, light grey streaked orange brown. Firm. dilatant moist, Contains pumice

1.2 1.2m Saturated slightly plastic

1.6 M-C SAND with some silt; white grey. Loose; Saturated. pumice

1.8 F-M SAND with ~~tr~~ trace silt; graded light grey streaked orange yellow and black, Tightly packed; Moist, Gravelly ore pumice subrounded - coarse med range.

2.1 SILT; light grey; orange lenses. Firm. wet saturated. dilatant soft.

2.3

2.5 F-M SAND with some silt; yellow brown. firm; moist

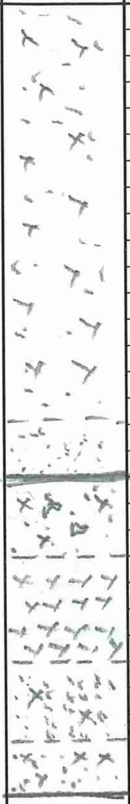
2.7 Fine sandy SILT; yellow grey. Soft; saturated, dilatant

2.9 SAND as per 2.5.

eoh @ 3.0m TD.

x GWNE Hole sse is wet, Soils wet through

GRAPHIC LOG



DEPTH (m)

DEPTH (m)	SAMPLE DETAILS	TESTS	WATER OBSERVATIONS
0.0	DESND (0.0–1.8)		
0.5			
1.0			
1.5		←	Failure
2.0			
2.5			
3.0			
3.5			
4.0			
4.5			
5.0			

Notes:

KEY
- Groundwater level
- Seepage inflow
- Grab sample
- × PID Reading (ppm)

Method: Hand Auger
Datum:
Ground Level: --
Coordinates:
Filename: Hand Auger (5m)

Logs based on New Zealand Geomechanics Society Field Description Guidelines (2005)

Scala Recording Sheet
Waitangi Stream 14/12/2017

Location	HA_03	03	HA_04	04	T4	T3	T5	HA_01	HA_07	HA_02	HA_0L	T2	T1.
Start m bgl	0	2m	0	2m	-	-	-	0	2	0	2	-	
0	—	2	0	5	-	-	-	—	—	—	1	-	
50	1	1	1	5	-	-	-	3	1	2	1	-	
100	↓	2	1	5	-	-	-	2	2	1	1	-	
150	1	2	1	6	-	-	-	2	2	4	1	-	
200	2	2	1	7	-	-	-	1	1	1	1	-	
250	2	2	1	9	-	-	-	1	1	1	1	-	
300	1	2	1	10	-	-	-	2	2	1	1	-	
350	↓	2	1	10	-	-	-	2	2	1	1	-	
400	2	2	1	10	-	-	-	1	2	1	1	-	
450	1	2	2		1	-	-	2	2	2	1	-	
500	1	1	1		2	-	6	2	2	1↓	1	2	1
550	1	1	1		2	-	2	2	2	↓	1	2	1
600	1	2	1		2	1	5	2	4	1	1	3	1
650	2	1	3		2	1	6	2	3	↓	1	7	↓
700	2	1	2		2	2	4	2	3	1	1	5	1
750	1	1	1		3	1	6	1	4	1	1	4	1
800	2	1	3		4	2		1	3	1	1	6	1
850	1	2	3		4	1		2	3	1	1	4	1
900	1	2	2		4	1		0.5	2	↓	1	4	1
950	1	1	1		5	1		0.5	3	1	1	5	5
1000	2	1	3			2		1	2	1	1	5	3
1050	2	2	2			8		1	2	2	1		5
1100	4	2	3			5		1	2	2	1		2
1150	5	1	3			5		1	2	1	1		3
1200	7	2	3					2	1	2	2		3
1250	5	2	4					3	1	2	3		5
1300	6	4	3					2	2	1	2		
1350	8	5	3					2	1	2	3		
1400	4	5	6					2	1	2	3		
1450	3	4	6					2	1	2	3		
1500	2	4	5					2	1	2	3		
1550	2	3	5					2	1	1	6		
1600	3	3	5					2	1	1	3		
1650	4	3	6					1	1	↓	2		
1700	4	2	5					1	2	1	1		
1750	4	2	6					1	2	2	1		
1800	4	2	5					2	3	1	1		
1850	3	4	4					1	3	↓	1		
1900	3	2	3					1	3	1	5		
1950	4	2	3					2	3	1	1		
2000	4	1	2					2	3	2	1		

Exposed in stream bank

— = Stream

SILT minor fsand + clay. yellow orange/light grey. Firm; dilatant. saturated.

Scala Recording Sheet
Waitangi Stream 14/12/2017

Location	HA_05	HA_05											
Start m bgl	On	2m											
0	1	4											
50		1											
100		1											
150		2											
200		3											
250		4											
300		3											
350		3											
400		4											
450		3											
500		2											
550		2											
600		1											
650		2											
700		2											
750		2											
800		2											
850		2											
900		2											
950		2											
1000	↓	4											
1050	1	5											
1100		6											
1150		6											
1200		5											
1250		4											
1300	↓	5											
1350	1	5											
1400		4											
1450		5											
1500	↓	5											
1550	1	5											
1600	↓	4											
1650	1	5											
1700	1	4											
1750	2	4											
1800	2	5											
1850	1	5											
1900	2	4											
1950	2	3											
2000	1	3											

Appendix B

Geotechnical Assessment of Proposed Remediation Works

Pattle Delamore Partners Limited

TECHNICAL MEMORANDUM

INVESTIGATION	Waitangi Stream Stabilisation and Erosion Protection	**PROJECT**	
CLIENT	Bay of Plenty Regional Council	**PROJECT NO**	T01552501
CLIENT CONTACT	Andy Bruere	**PREPARED BY**	Noel Kelly
CLIENT WORK ORDER NO/ PURCHASE ORDER		**SIGNATURE**	NKelly
		DATE	16 March 2018

Introduction

A geotechnical investigation and assessment carried out by Pattle Delamore Partners Ltd (PDP) along a section of Waitangi Stream at Lake Tarawera (Dated December 2017) concluded that that the existing slope gradients along the stream currently possess a significant risk of movement or failure.

Following discussions with Bay of Plenty Regional Council (BOPRC), PDP have designed a remedial solution to address the instability risk, while maintaining flow through the stream.

Geotechnical Design

To satisfy the geometrical, hydrological and environmental constraints of the site, a retaining solution has been proposed which combines the following components:

- Raising the elevation of the existing river bed with rockfill;
- Shoulder reinforcement (regrading) of the existing slopes using granular backfill; and
- Retention of slope reinforcement using filled gabion baskets.

The above components required geotechnical design to ensure economy and safety of the solution.

The geotechnical investigation and assessment carried out by PDP provided an indication of the nature and strength of the soils at Waitangi Stream. A summary of the encountered ground conditions is presented below:

- Alluvium and debris: Typically light grey silt with varying content of fine sand and trace gravel. Encountered up to 1.6 m; and
- Volcanic Ash: Typically yellow brown fine sandy silt, encountered as soft or loose. Ash was encountered from surface or underlying alluvial layers to end of hole (EoH) at all hand auger locations.

Geotechnical parameters for the above materials were applied to analyses and calculations based on a combination of in-situ testing, back analyses of existing slope movements, literature derived values and professional judgement.

Material	Unit Weight (kN/m^3)	Apparent cohesion, c' (kPa)	Friction Angle (°)	*Undrained Shear Strength (c_u)
Alluvium	17	1	32	-
Volcanic Ash	16	1	35	-
Rockfill and Granular Fill	19	0	36	-

Note: The alluvial and volcanic material is predominantly granular and very unlikely to exhibit undrained conditions

Slope Stability

In order to ensure the stability of the remedial solution, a number of analyses and calculations were carried out, including slope stability analyses, sliding and overturning calculations. To satisfy seismic design requirements, a design horizontal seismic coefficient (a_{max}) was derived applying the methods outlined by *Earthquake geotechnical engineering practice, Module 6: Earthquake resistant retaining wall design* (MBIE, 2016) and the *NZTA Bridge Manual* (2016), assuming a 1/1000 year return period seismic event. The derivation of a_{max} is provided Appendix A.

A series of slope stability analyses were carried out to assess the stability of the gabion structure against global (rotational) failure and the stability of the backfill sloped behind the gabion structure. Both were examined for a range of conditions, namely average stream flow, (design flood flow 20 year average recurrence interval) and in response to the prescribed seismic event. Graphical outputs of these analyses are presented in Appendix B.

Results of these slope stability analyses are presented in Table 1. Achieved Factors of Safety (FoS) are presented alongside 'target' values, which are based on industry standard guidelines.

Table 1: Summary of slope stability analysis results

Section	Analysis	Factor of Safety – Static Normal GWL		Factor of Safety – Static High GWL		Factor of Safety Earthquake*	
		Target	Actual	Target	Actual	Target	Actual
B - North	Global stability	1.5	1.550	1.2	1.489	1.1	1.173
	Upper slope stability	1.5	1.531	1.2	1.531	1.1	1.129
B - South	Global stability	1.5	1.587	1.2	1.517	1.1	1.177
	Upper slope stability	1.5	1.667	1.2	1.667	1.1	1.220
C - North	Global stability	1.5	1.831	1.2	1.768	1.1	1.454
	Upper slope stability	1.5	1.482	1.2	1.482	1.1	1.147
C - South	Global stability	1.5	1.482	1.2	1.44	1.1	1.150
	Upper slope stability	1.5	1.447	1.2	1.447	1.1	1.081
D - North	Global stability	1.5	1.656	1.2	1.594	1.1	1.252
	Upper slope stability	1.5	1.770	1.2	1.770	1.1	1.290
D - South	Global stability	1.5	1.558	1.2	1.533	1.1	1.211
	Upper slope stability	1.5	1.699	1.2	1.699	1.1	1.255
	Global stability	1.5	1.877	1.2	1.771	1.1	1.280

G - North	Upper slope stability	1.5	1.994	1.2	1.994	1.1	1.496
G - South	Global stability	1.5	1.779	1.2	1.692	1.1	1.249
	Upper slope stability	1.5	1.985	1.2	1.807	1.1	1.394
* Design horizontal seismic ground acceleration value of 0.15, applying a 1:1000 year return period event and allowing some movement of the gabion structure.							

It is evident that all but four analyses achieve target values. Of the four which do not meet the criteria, the maximum deviation is 3.5% from the target value. Given the conservatism inherent in the analysis method, such a marginal non-compliance is very unlikely to affect the safety and stability of the retaining wall. Slope stability of the proposed solution is therefore considered satisfactory.

Gabion Stability

The proposed gabion structures were also checked for sliding, overturning and bearing failure. These analyses, presented in Appendix C; a summary of results is presented in Table 2.

Table 2:Summary of gabion static stability analysis results

Section	Degree of Utilisation (=Achieved FOS/Target FOS, %)		
	Overturning	Sliding	Bearing*
Section B	22%	66%	13%
Section C, North	15%	75%	23%
Section C, South	15%	66%	26%
Section D	10%	53%	13%
Section G	5%	31%	14%
*Assuming an allowable bearing pressure of 300kPa (rockfill)			

The Degree of Utilisation (DOU) is well below 100% for all cases under static loading. The overall design is therefore considered satisfactory in terms of gabion sliding, bearing and overturning under static loading conditions.

In addition to static loading conditions, an assessment of the safety of the design in response to seismic loading was carried out. This assessment examined the critical case under static conditions (Section C, North), applying a design horizontal seismic acceleration coefficient of 0.15, as applied to the above slope stability analysis. Table 3 presents a summary of the results of the seismic analysis of the design at Section C (North):

Table 3: Summary of gabion seismic stability analysis results

Section	Degree of Utilisation (=Achieved FOS/Target FOS, %)		
	Overturning	Sliding	Bearing
Section C, North, wall tilted at 6 degrees	83%	70%	99% (fail in eccentricity)
Section C, North, wall tilted at 8 degrees	74%	60%	63%

As shown, adjusting the gabion wall tilt to 8 degrees increases the DoU against bearing failure due to seismic loading to acceptable values. Therefore, a gabion tilt of 8 degrees is required in the vicinity of Section C (North), while a tilt of 6 degrees has been demonstrated to provide sufficient stability elsewhere.

Long term settlement

It is noted that the investigation encountered loose alluvial deposits up to 2 m below the existing stream bed level. Should some cohesive material be present below the stream bed, there may be a small risk of long term (post construction) minor settlement of the gabion structure. A typical measure to manage this risk would be to excavate this loose/soft material and replace with rockfill; however, the potential benefits of such a measure are likely to be outweighed by the risk of excavation inducing slope failure during construction.

Conclusions and Recommendations

Previous analyses have shown that the slopes at Waitangi stream are currently marginally stable, exhibiting an unacceptable Factor of Safety against long term movement or failure. A remedial solution incorporating rockfill, gabion walls and slope reinforcement has been proposed in order to provide adequate long-term safety and stability of the slopes.

The set of analyses outlined in this document have examined the suitability of these measures. These analyses have concluded that, subject to the conditions contained in this report, that the measures provide adequate safety against failure for both static conditions and for a 1/1000 year return period prescribed seismic loading.

The measures shall be constructed in accordance with Drawings T01552501; 201 - 207 and the specification. In particular, the contractor shall note the following:

- To minimise the risk of excessive long-term settlement of the gabion structures, it would be advisable to place the rockfill bedding (i.e. the raising of the stream bed) over the entire length of the scheme and then to allow some time for consolidation before construction of the gabion structures.
- Gabions shall generally be tilted at 6 degrees from horizontal; and 8 degrees from horizontal around Section C (north), the area of and almost vertical slope face.
- Backfill behind the gabions shall be placed in a sequential and layered fashion. Backfill lifts shall be placed in no more than 200 mm layers and shall be compacted prior to placement of the subsequent layer.
- The layers are to be compacted to achieve a CBR of 6%.
- The slope angle of backfill behind/above the Gabion baskets shall not exceed 1(v):2(h).
- Lightweight rock such as pumice shall **not** be acceptable as a filling material for Gabion baskets. Fill for the Gabion baskets shall be approved by the designer prior to construction.

TECHNICAL MEMORANDUM

This memorandum has been prepared by Pattle Delamore Partners (PDP) on the specific instructions of **Bay of Plenty Regional Council** for the limited purposes described in the memorandum. PDP accepts no liability if the memorandum is used for a different purpose or if it is used or relied on by any other person. Any such use or reliance will be solely at their own risk.

This memorandum has been prepared by PDP on the basis of information provided by Bay of Plenty Regional Council. PDP has not independently verified the provided information and has relied upon it being accurate and sufficient for use by PDP in preparing the memorandum. PDP accepts no responsibility for errors or omissions in, or the currency or sufficiency of, the provided information.

Appendix A: Calculations

JOB NAME WAITANGI STREAM			**PAGE No.** 1/1
JOB No. T01552501		**DESIGNED** NR	
DATE 22/01/18		**CHECKED**	

CALCULATE PEAK GROUND ACCELERATION (PGA) MBIE; MOD 1

$$a_{max} = C_{0,1000} \frac{R}{1.3} f g$$

$C_{0,1000}$ = UNWEIGHTED PGA, 1000 YR EVENT
= 0.38 (CLASS C SOIL)

R = RETURN PERIOD FACTOR NZS 1170.5
= 1.3 (IMPORTANCE LEVEL 2, 1/1000 T_R)

$a_{max} = (0.38) \times \frac{1.3}{1.3} \times 1.33\ g$
= 0.51 (1000 YR RETURN PERIOD)
= 0.39 (500 YR RETURN PERIOD)

DESIGN HORIZONTAL ACCELERATION

$k_h = a_{max} A_{topo} W_d$ MBIE, MODULE 6

A_{topo} = 1.0 (NO CLIFFS < 30m)
W_d = 0.3 ('Case 6') (TABLE 4.1, 5.2)
[HOUSE PILED - ALLOW SOME MOVEMENT]

$k_h = (0.51 \times 1.0 \times 0.3)$ EQUATION 5.1
= 0.15 FOR 1/1000 YR EVENT

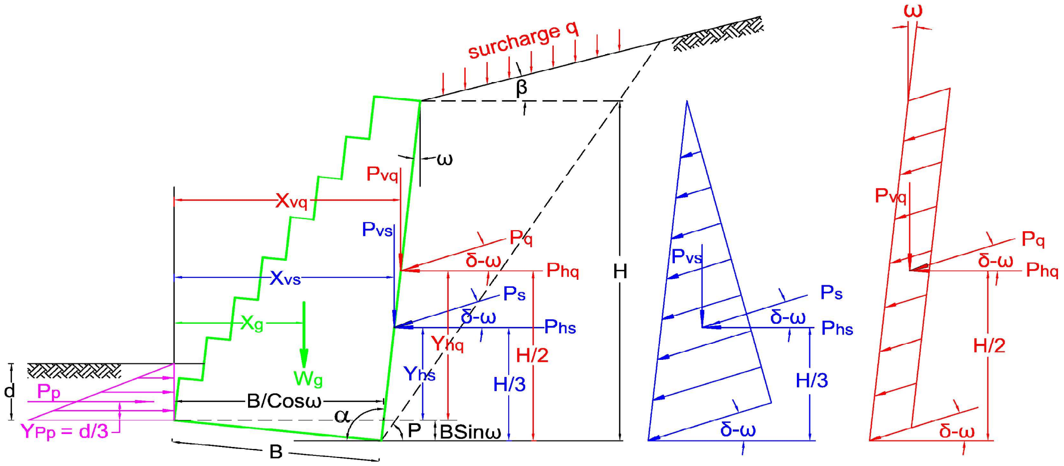
Appendix B: Gabion Check Outputs

GABION WALL DESIGN

STATIC LOADING

PROJECT NAME:	Waitangi Stream Stabilisation	**PROJECT #:**	T015501
LOCATION:	Waitangi Stream, Lake Tarawera	**SECTION:**	Cross Section B
DESIGNED BY	Noel J Kelly	**CHECKED BY**	

NOTES: Stability assessed in accordance with the Load Factor Resistance Design Method as recommended by the NZ Building code



Descriptions	**symbols**	**Input Values**	**Units**	**Notes**
Backfill slope angle above wall	β	27.000	°	< Φ
Angle of internal friction	Φ	36.000	°	
Wall friction reduction by geotextile	f_r	33.000	%	Back of wall
Angle of wall friction	δ	24.120	°	$\Phi(100-f_r)/100$
Inclination angle to vertical plane	ω	6.000	°	for wall with straight back (no offsets)
Back of wall angle to horizontal	α	96.000	°	90+ω
Cohesion	c	0	psf	Ignore cohesion
Surcharge	q	5.000	**kPa**	
Soil density	γ_s	19.635	**kN/m3**	
Rock density	γ_r	20.500	**kN/m3**	
Void in gabion	v	20.000	%	
Gabion density	γ_g	16.400	**kN/m3**	$\gamma_r(100-v)/100$
Actual height of wall	H	2.088	**m**	(hCosω) Corrected for inclination
Embedment	d	0.000	**m**	0m to ignore passive thrust
Width of base	B	1.5	**m**	
Allowable soil bearing capacity	q_a	300.000	kPa	

Retaining wall is:	**SATISFACTORY**	in overturning	22%
	SATISFACTORY	in sliding	66%
	SATISFACTORY	in eccentricity	
	SATISFACTORY	in bearing	13%

DESIGN PROFILE

Row #	Width (m)	Height (m)	offset (from toe) (m)	Area (m²)	X (m)	Moment (m³)	Y (m)	Moment (m³)
15				0.000	0.000	0.000	0.000	0.000
14				0.000	0.000	0.000	0.000	0.000
13				0.000	0.000	0.000	0.000	0.000
12				0.000	0.000	0.000	0.000	0.000
11				0.000	0.000	0.000	0.000	0.000
10				0.000	0.000	0.000	0.000	0.000
9				0.000	0.000	0.000	0.000	0.000
8				0.000	0.000	0.000	0.000	0.000
7				0.000	0.000	0.000	0.000	0.000
6				0.000	0.000	0.000	0.000	0.000
5				0.000	0.000	0.000	0.000	0.000
4				0.000	0.000	0.000	0.000	0.000
3	0.1	0.1	0.50	0.010	0.550	0.006	2.050	0.021
2	1.0	1.0	0.50	1.000	1.000	1.000	1.500	1.500
1	1.5	1.0	0.00	1.500	0.750	1.125	0.500	0.750
	h=	2.1		2.510	0.849	2.131	0.905	2.271

LFRD PARAMETERS		
ϕbc	Resistance factor for bearing capacity	0.5
ϕsl	Resistance factor for sliding	0.8
ϕp	Resistance factor for passive earth pressure	0.5
αG_stab	Load factor for self weight (stabilising)	0.9
αG_desta	Load factor for self weight (destabilising)	1.2
αEP_des	Load factor for earth pressure (destabilising)	1.5

CALCULATIONS

COULOMB'S THEORY

BACK

Active earth pressure coefficient K_a =

$$K_a = \frac{\sin^2(\alpha+\Phi)}{\sin^2\alpha \;\; \sin(\alpha-\delta) \left[1+\sqrt{\frac{\sin(\Phi+\delta) \;\; \sin(\Phi-\beta)}{\sin(\alpha-\delta) \;\; \sin(\alpha+\beta)}}\right]^2}$$

$$\frac{0.552}{0.989 \;\; 0.950 \left[1+\sqrt{\frac{0.867 \;\; 0.156}{0.950 \;\; 0.839}}\right]^2}$$

$$\frac{0.552}{1.876} = 0.294$$

Active soil thrust P_s = $0.5K_a\gamma_s \; H^2$

= 12.609 **kN/m3**

Active surcharge thrust P_q = $\frac{\sin\alpha}{\sin(\alpha+\beta)} \; K_a qH$

= $\frac{0.995}{0.839}$ 3.075

= 3.646 **kN/m**

Horizontal active soil thrust P_{hs} = $P_s\cos(\delta-\omega)$

= 11.984 **kN/m**

Horizontal active surcharge thrust P_{hq} = $P_q\cos(\delta-\omega)$

= 3.465 **kN/m** arallel comp

Vertical active soil thrust P_{vs} = $P_s\sin(\delta-\omega)$

= 3.922 **kN/m** pen component

Vertical active surcharge thrust P_{vq} = $P_q\sin(\delta-\omega)$

= 1.134 **kN/m**

FRONT

Inclination angle to vertical ω_p = 0.000

Front face angle to horizontal α_p = $90-\omega_p$

= 90.000

Backfill slope β_p = 0.000

Angle of wall friction δ_p = 0.000

Passive earth pressure coefficient K_p =

$$K_p = \frac{\sin^2(\alpha-\Phi)}{\sin^2\alpha \;\; \sin(\alpha+\delta) \left[1-\sqrt{\frac{\sin(\Phi+\delta) \;\; \sin(\Phi+\beta)}{\sin(\alpha+\delta) \;\; \sin(\alpha+\beta)}}\right]^2}$$

$$\frac{0.655}{1.000 \;\; 1.000 \left[1-\sqrt{\frac{0.588 \;\; 0.588}{1.000 \;\; 1.000}}\right]^2}$$

$$\frac{0.655}{0.170} = 3.852$$

Passive soil thrust P_p = $0.5K_p\gamma_s \; d^2$

= 0.000 **kN/m**

Check Overturning:

Vertical distance to P_{hs} Y_{hs} = $H/3-BSin\omega$ = 0.539 **m**

Vertical distance to P_{hq} Y_{hq} = $H/2-BSin\omega$ = 0.887 **m**

Overturning moment $\sum M_o$ = $(Y_{hs}P_{hs} + Y_{hq}P_{hq}))*\alpha EP\_destab$

= 4.613 **kNm/m**

Weight of Gabion W_g = $\sum A\ \gamma_g$

= 41.164 **kN/m**

Horizontal distance to W_g X_g = $Ysin\omega + XCos\omega$

= 0.939 **m**

Horizontal distance to P_{vs} X_{vs} = $B/Cos\omega + (H/3-BSin\omega)Tan\omega$

1.565 **m**

Horizontal distance to P_{vq} X_{vq} = $B/Cos\omega + (H/2-BSin\omega)Tan\omega$

1.602 **m**

Vertical distance to P_p Y_{Pp} = d/3

= 0.000

Resisting moment $\sum M_r$ = $(W_g X_g)*\alpha G\_stab + P_{vs} X_{vs} + P_{vq} X_{vq} + P_pY_{Pp}$

= 42.730 **kNm/m**

Overturning factor of safety SF_o = $\frac{\sum M_r}{\sum M_o}$

9.263 ≥ 2.000 **O.K**

Check Sliding

Total Normal forces $\sum W$ = $(W_gCos\omega)*\alpha G\_stab + (P_sSin\delta + P_qSin\delta) - P_pSin\omega$

= 47.624 **kN/m**

Frictional force F_f = $\sum W$ *TanΦ * φsl

= 47.624 0.727 0.800

= 27.681

Total Resisting Forces $\sum F_r$ = $F_f + Cos\omega P_p$

= 27.681

Total Driving Forces at base $\sum F_d$ = $P_sCos\delta + P_qCos\delta)*\alpha EF$ - $W_gSin\omega)*\alpha G$

18.382

Siding factor of safety SF_s = $\frac{\sum F_r}{\sum F_d}$

1.506 ≥ 1.000 **O.K**

Check the Eccentricity of Resultant Force

(Resultant is in middle one third)

Eccentricity	e	=	0.5 B	-	($\sum M_r$	- $\sum W$	M_o)
		=	0.750	-	0.800		
		=	-B/6	≤	e	≤	+B/6
			-0.250	≤ **O.K**	-0.050	≤ **O.K**	0.250

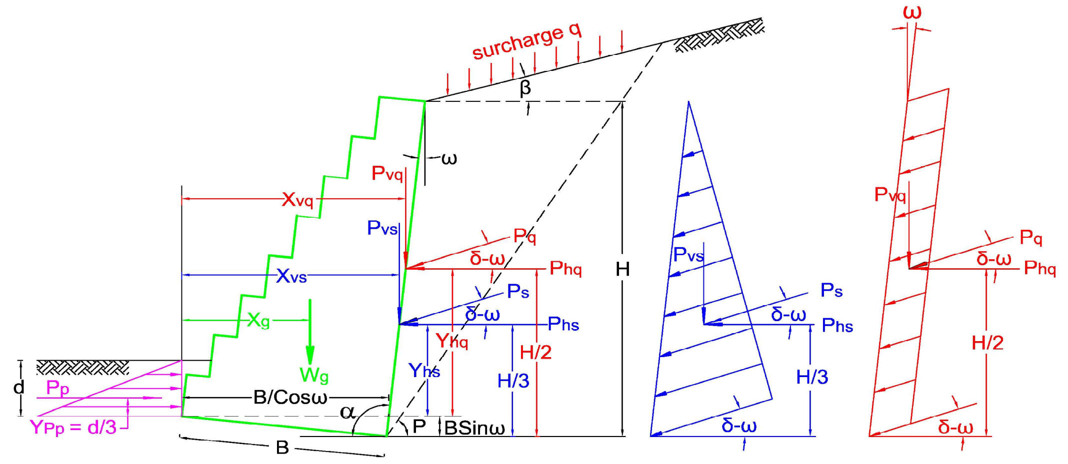
Check Bearing

Applied bearing pressure	P	=	$\sum W$ B	(1±	6e/B)		
		=	31.749	(1±	0.201	)	
Right		=	38.147	psf	≤	300.000	**O.K**
Left		=	25.352	psf	≤	300.000	**O.K**

GABION WALL DESIGN

STATIC LOADING

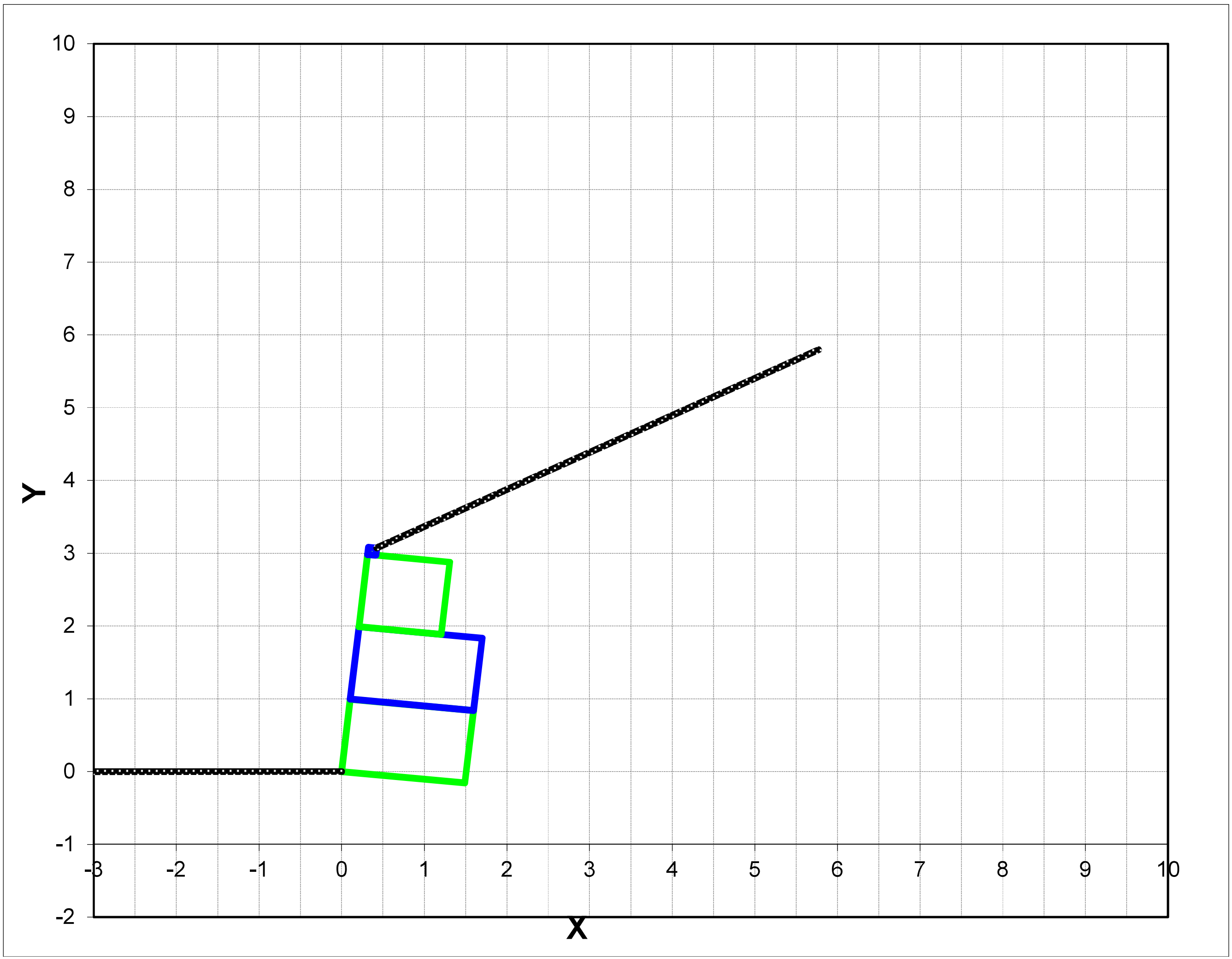
PROJECT NAME:	Waitangi Stream Stabilisation	**PROJECT #:**	T015501
LOCATION:	Waitangi Stream, Lake Tarawera	**SECTION:**	Cross Section C
DESIGNED BY	Noel J Kelly	**CHECKED BY**	
NOTES:	Stability assessed in accordance with the Load Factor Resistance Design Method as recommended by the NZ Building code		



Descriptions	**symbols**	**Input Values**	**Units**	**Notes**
Backfill slope angle above wall	β	27.000	º	< Φ
Angle of internal friction	Φ	36.000	º	
Wall friction reduction by geotextile	fr	33.000	%	Back of wall
Angle of wall friction	δ	24.120	º	Φ(100-fr)/100
Inclination angle to vertical plane	ω	6.000	º	for wall with straight back (no offsets)
Back of wall angle to horizontal	α	96.000	º	90+ω
Cohesion	c	0	psf	Ignore cohesion
Surcharge	q	5.000	**kPa**	
Soil density	γs	19.635	**kN/m3**	
Rock density	γr	21.666	**kN/m3**	
Void in gabion	v	15.000	%	
Gabion density	γg	18.416	**kN/m3**	γr(100-v)/100
Actual height of wall	H	3.083	**m**	(hCosω) Corrected for inclination
Embedment	d	0.000	**m**	0m to ignore passive thrust
Width of base	B	1.5	**m**	
Allowable soil bearing capacity	qa	300.000	kPa	

Retaining wall is:	**SATISFACTORY**	in overturning	15%
	SATISFACTORY	in sliding	75%
	SATISFACTORY	in eccentricity	
	SATISFACTORY	in bearing	23%

DESIGN PROFILE



Row #	Width (m)	Height (m)	offset (from toe) (m)	Area (m²)	X (m)	Moment (m³)	Y (m)	Moment (m³)
15				0.000	0.000	0.000	0.000	0.000
14				0.000	0.000	0.000	0.000	0.000
13				0.000	0.000	0.000	0.000	0.000
12				0.000	0.000	0.000	0.000	0.000
11				0.000	0.000	0.000	0.000	0.000
10				0.000	0.000	0.000	0.000	0.000
9				0.000	0.000	0.000	0.000	0.000
8				0.000	0.000	0.000	0.000	0.000
7				0.000	0.000	0.000	0.000	0.000
6				0.000	0.000	0.000	0.000	0.000
5				0.000	0.000	0.000	0.000	0.000
4	0.1	0.1		0.010	0.050	0.001	3.050	0.031
3	1.0	1.0		1.000	0.500	0.500	2.500	2.500
2	1.5	1.0	0.00	1.500	0.750	1.125	1.500	2.250
1	1.5	1.0	0.00	1.500	0.750	1.125	0.500	0.750
	h=	3.1		4.010	0.686	2.751	1.379	5.531

	LFRD PARAMETERS	
ϕbc	Resistance factor for bearing capacity	0.5
ϕsl	Resistance factor for sliding	0.8
ϕp	Resistance factor for passive earth pressure	0.5
αG_stab	Load factor for self weight (stabilising)	0.9
αG_desta	Load factor for self weight (destabilising)	1.2
αEP_des	Load factor for earth pressure (destabilising)	1.5

CALCULATIONS

COULOMB'S THEORY

BACK

Active earth pressure coefficient K_a =

$$\frac{\mathrm{Sin}^2(\alpha+\Phi)}{\mathrm{Sin}^2\,\alpha \quad \mathrm{Sin}(\alpha-\delta) \quad \left[1+\sqrt{\frac{\mathrm{Sin}(\Phi+\delta)}{\mathrm{Sin}(\alpha-\delta)} \quad \frac{\mathrm{Sin}(\Phi-\beta)}{\mathrm{Sin}(\alpha+\beta)}}\right]^2}$$

$$\frac{0.552}{0.989 \quad 0.950 \quad \left[1+\sqrt{\frac{0.867}{0.950} \quad \frac{0.156}{0.839}}\right]^2}$$

$$\frac{0.552}{1.876} = 0.294$$

Active soil thrust P_s = $0.5K_a\gamma_s$ H^2

= 27.477 **kN/m3**

Active surcharge thrust P_q = $\frac{\mathrm{Sin}\alpha}{\mathrm{Sin}(\alpha+\beta)}$ K_aqH

= $\frac{0.995}{0.839}$ 4.539

= 5.383 **kN/m**

Horizontal active soil thrust P_{hs} = $P_s\mathrm{Cos}(\delta-\omega)$

= 26.115 **kN/m**

Horizontal active surcharge thrust P_{hq} = $P_q\mathrm{Cos}(\delta-\omega)$

= 5.116 **kN/m** arallel comp

Vertical active soil thrust P_{vs} = $P_s\mathrm{Sin}(\delta-\omega)$

= 8.546 **kN/m** pen component

Vertical active surcharge thrust P_{vq} = $P_q\mathrm{Sin}(\delta-\omega)$

= 1.674 **kN/m**

FRONT

Inclination angle to vertical ω_p = 0.000

Front face angle to horizontal α_p = $90-\omega_p$

= 90.000

Backfill slope β_p = 0.000

Angle of wall friction δ_p = 0.000

Passive earth pressure coefficient K_p =

$$\frac{\mathrm{Sin}^2(\alpha-\Phi)}{\mathrm{Sin}^2\,\alpha \quad \mathrm{Sin}(\alpha+\delta) \quad \left[1-\sqrt{\frac{\mathrm{Sin}(\Phi+\delta)}{\mathrm{Sin}(\alpha+\delta)} \quad \frac{\mathrm{Sin}(\Phi+\beta)}{\mathrm{Sin}(\alpha+\beta)}}\right]^2}$$

$$\frac{0.655}{1.000 \quad 1.000 \quad \left[1-\sqrt{\frac{0.588}{1.000} \quad \frac{0.588}{1.000}}\right]^2}$$

$$\frac{0.655}{0.170} = 3.852$$

Passive soil thrust P_p = $0.5K_p\gamma_s$ d^2

= 0.000 **kN/m**

Check Overturning:

Vertical distance to P_{hs} Y_{hs} = H/3-BSinω = 0.871 **m**

Vertical distance to P_{hq} Y_{hq} = H/2-BSinω = 1.385 **m**

Overturning moment $\sum M_o$ = $(Y_{hs}P_{hs}$ + $Y_{hq}P_{hq}))$*αEP_destab

= 10.626 **kNm/m**

Weight of Gabion W_g = ∑A γg

= 73.849 **kN/m**

Horizontal distance to W_g X_g = Ysinω + XCosω

= 0.826 **m**

Horizontal distance to P_{vs} X_{vs} = B/Cosω + (H/3-BSinω)Tanω

1.600 **m**

Horizontal distance to P_{vq} X_{vq} = B/Cosω + (H/2-BSinω)Tanω

1.654 **m**

Vertical distance to P_p YP_p = d/3

= 0.000

Resisting moment $\sum M_r$ = $(W_g X_g)$*αG_stab + $P_{vs} X_{vs}$ + $P_{vq} X_{vq}$ + $P_p Y P_p$

= 71.360 **kNm/m**

Overturning factor of safety SF_o = $\dfrac{\sum M_r}{\sum M_o}$

6.716 ≥ 1.000 **O.K**

Check Sliding

Total Normal forces ∑W = (WgCosω)*αG_stab + $(P_s\text{Sin}\delta$ + $P_q\text{Sin}\delta)$ - $P_p\text{Sin}\omega$

= 86.949 **kN/m**

Frictional force F_f = ∑W *TanΦ * φsl

= 86.949 0.727 0.800

= 50.538

Total Resisting Forces $\sum F_r$ = F_f + CosωP_p

= 50.538

Total Driving Forces at base $\sum F_d$ = PsCosδ +PqCosδ)*αEF - VgSinω)*αG

38.039

Siding factor of safety SF_s = $\dfrac{\sum F_r}{\sum F_d}$

1.329 ≥ 1.000 **O.K**

Check the Eccentricity of Resultant Force

(Resultant is in middle one third)

Eccentricity	e	=	0.5 B	**-**	($\sum M_r$	**-** $\sum W$	M_o)
		=	0.750	**-**	0.699		
		=	-B/6	≤	e	≤	+B/6
			-0.250	≤ **O.K**	0.051	≤ **O.K**	0.250

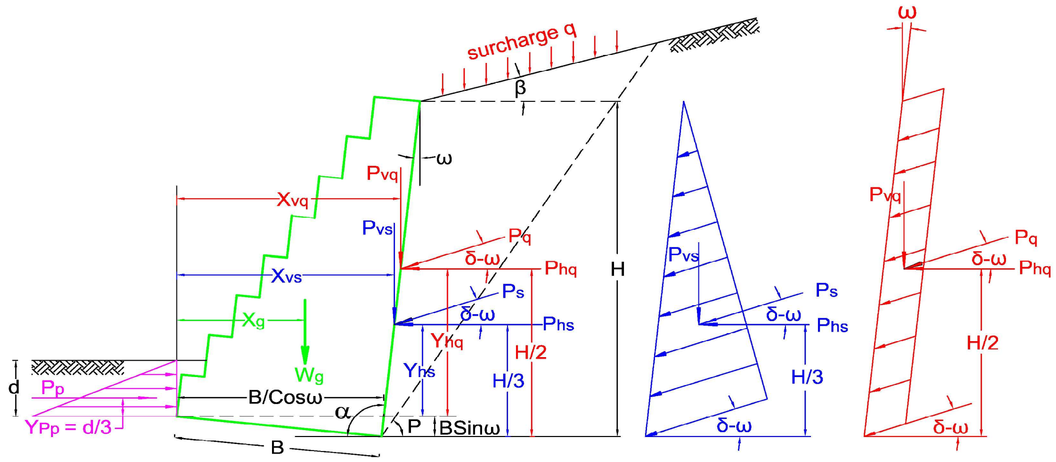
Check Bearing

Applied bearing pressure	P	=	$\sum W$ B	(1±	6e/B)		
		=	57.966	(1±	0.206	)	
Left		=	69.906	psf	≤	300.000	**O.K**
Right		=	46.026	psf	≤	300.000	**O.K**

GABION WALL DESIGN

STATIC LOADING

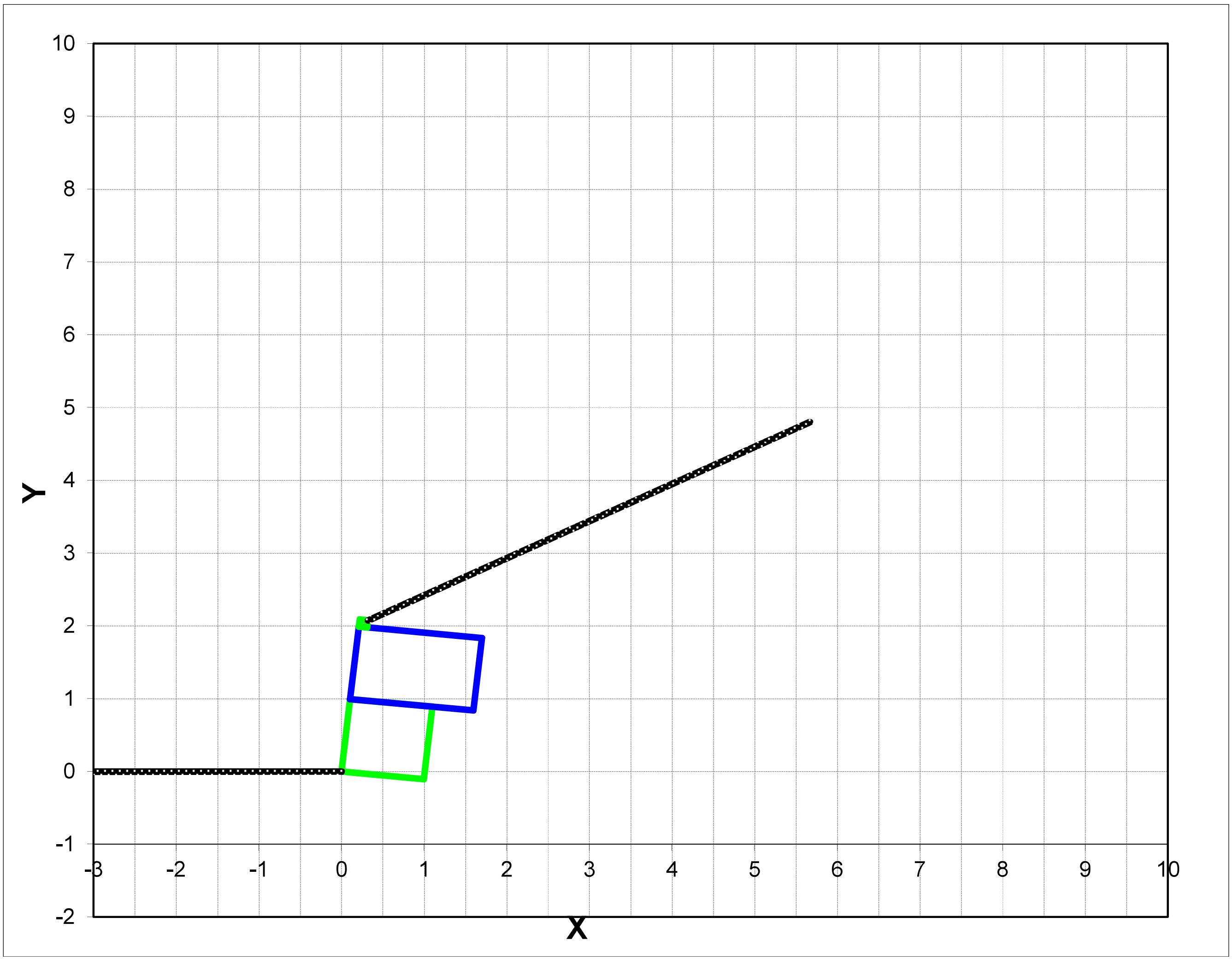
PROJECT NAME:	Waitangi Stream Stabilisation	**PROJECT #:**	T015501
LOCATION:	Waitangi Stream, Lake Tarawera	**SECTION:**	Cross Section C
DESIGNED BY	Noel J Kelly	**CHECKED BY**	
NOTES:	Stability assessed in accordance with the Load Factor Resistance Design Method as recommended by the NZ Building code		



Descriptions	**symbols**	**Input Values**	**Units**	**Notes**
Backfill slope angle above wall	β	27.000	º	< Φ
Angle of internal friction	Φ	36.000	º	
Wall friction reduction by geotextile	fr	33.000	%	Back of wall
Angle of wall friction	δ	24.120	º	Φ(100-fr)/100
Inclination angle to vertical plane	ω	6.000	º	for wall with straight back (no offsets)
Back of wall angle to horizontal	α	96.000	º	90+ω
Cohesion	c	0	psf	Ignore cohesion
Surcharge	q	5.000	**kPa**	
Soil density	γ_s	19.635	**kN/m3**	
Rock density	γ_r	20.500	**kN/m3**	
Void in gabion	v	20.000	%	
Gabion density	γ_g	16.400	**kN/m3**	γ_r(100-v)/100
Actual height of wall	H	2.088	**m**	(hCosω) Corrected for inclination
Embedment	d	0.000	**m**	0m to ignore passive thrust
Width of base	B	1.0	**m**	
Allowable soil bearing capacity	q_a	300.000	kPa	

Retaining wall is:	**SATISFACTORY**	in overturning	15%
	SATISFACTORY	in sliding	66%
	SATISFACTORY	in eccentricity	
	SATISFACTORY	in bearing	26%

DESIGN PROFILE



Row #	Width (m)	Height (m)	offset (from toe) (m)	Area (m²)	X (m)	Moment (m³)	Y (m)	Moment (m³)
15				0.000	0.000	0.000	0.000	0.000
14				0.000	0.000	0.000	0.000	0.000
13				0.000	0.000	0.000	0.000	0.000
12				0.000	0.000	0.000	0.000	0.000
11				0.000	0.000	0.000	0.000	0.000
10				0.000	0.000	0.000	0.000	0.000
9				0.000	0.000	0.000	0.000	0.000
8				0.000	0.000	0.000	0.000	0.000
7				0.000	0.000	0.000	0.000	0.000
6				0.000	0.000	0.000	0.000	0.000
5				0.000	0.000	0.000	0.000	0.000
4				0.000	0.000	0.000	0.000	0.000
3	0.1	0.1	0.00	0.010	0.050	0.001	2.050	0.021
2	1.5	1.0	0.00	1.500	0.750	1.125	1.500	2.250
1	1.0	1.0	0.00	1.000	0.500	0.500	0.500	0.500
	h=	2.1		2.510	0.648	1.626	1.104	2.771

LFRD PARAMETERS

ϕbc	Resistance factor for bearing capacity	0.5
ϕsl	Resistance factor for sliding	0.8
ϕp	Resistance factor for passive earth pressure	0.5
αG_stab	Load factor for self weight (stabilising)	0.9
αG_desta	Load factor for self weight (destabilising)	1.2
αEP_des	Load factor for earth pressure (destabilising)	1.5

CALCULATIONS

COULOMB'S THEORY

BACK

Active earth pressure coefficient K_a

$$K_a = \frac{\sin^2(\alpha+\Phi)}{\sin^2\alpha \quad \sin(\alpha-\delta) \quad \left[1+\sqrt{\frac{\sin(\Phi+\delta)}{\sin(\alpha-\delta)} \quad \frac{\sin(\Phi-\beta)}{\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{0.552}{0.989 \quad 0.950 \quad \left[1+\sqrt{\frac{0.867}{0.950} \quad \frac{0.156}{0.839}}\right]^2}$$

$$= \frac{0.552}{1.876} = 0.294$$

Active soil thrust $P_s = 0.5K_a\gamma_s \quad H^2$

$= 12.609$ **kN/m3**

Active surcharge thrust

$$P_q = \frac{\sin\alpha}{\sin(\alpha+\beta)} \quad K_aqH$$

$$= \frac{0.995}{0.839} \quad 3.075$$

$= 3.646$ **kN/m**

Horizontal active soil thrust $P_{hs} = P_s\cos(\delta-\omega)$

$= 11.984$ **kN/m**

Horizontal active surcharge thrust $P_{hq} = P_q\cos(\delta-\omega)$

$= 3.465$ **kN/m** arallel comp

Vertical active soil thrust $P_{vs} = P_s\sin(\delta-\omega)$

$= 3.922$ **kN/m** pen component

Vertical active surcharge thrust $P_{vq} = P_q\sin(\delta-\omega)$

$= 1.134$ **kN/m**

FRONT

Inclination angle to vertical $\omega_p = 0.000$

Front face angle to horizontal $\alpha_p = 90-\omega_p$

$= 90.000$

Backfill slope $\beta_p = 0.000$

Angle of wall friction $\delta_p = 0.000$

Passive earth pressure coefficient K_p

$$K_p = \frac{\sin^2(\alpha-\Phi)}{\sin^2\alpha \quad \sin(\alpha+\delta) \quad \left[1-\sqrt{\frac{\sin(\Phi+\delta)}{\sin(\alpha+\delta)} \quad \frac{\sin(\Phi+\beta)}{\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{0.655}{1.000 \quad 1.000 \quad \left[1-\sqrt{\frac{0.588}{1.000} \quad \frac{0.588}{1.000}}\right]^2}$$

$$= \frac{0.655}{0.170} = 3.852$$

Passive soil thrust $P_p = 0.5K_p\gamma_s \quad d^2$

$= 0.000$ **kN/m**

Check Overturning:

Vertical distance to P_{hs}	Y_{hs}	=	H/3-BSinω	=	0.592	**m**
Vertical distance to P_{hq}	Y_{hq}	=	H/2-BSinω	=	0.940	**m**
Overturning moment	$\sum M_o$	=	($Y_{hs}P_{hs}$ +	$Y_{hq}P_{hq}$))*αEP_destab		
		=	4.885	**kNm/m**		
Weight of Gabion	W_g	=	$\sum A\ \gamma_g$			
		=	41.164	**kN/m**		
Horizontal distance to W_g	X_g	=	Ysinω +	XCosω		
		=	0.759	**m**		
Horizontal distance to P_{vs}	X_{vs}	=	B/Cosω +	(H/3-BSinω)Tanω		
			1.068	**m**		
Horizontal distance to P_{vq}	X_{vq}	=	B/Cosω +	(H/2-BSinω)Tanω		
			1.104	**m**		
Vertical distance to P_p	YP_p	=	d/3			
		=	0.000			
Resisting moment	$\sum M_r$	=	(W_g X_g)*αG_stab +	P_{vs} X_{vs} +	P_{vq} X_{vq} +	P_pYP_p
		=	33.575	**kNm/m**		
Overturning factor of safety	SF_o	=	$\frac{\sum M_r}{\sum M_o}$			
			6.873	≥	1.000	**O.K**

Check Sliding

Total Normal forces	$\sum W$	=	(W_gCosω)*αG_stab +	(P_sSinδ +	P_qSinδ) -	P_pSinω
		=	47.624	**kN/m**		
Frictional force	F_f	=	$\sum W$	*TanΦ	* φsl	
		=	47.624	0.727	0.800	
		=	27.681			
Total Resisting Forces	$\sum F_r$	=	F_f + CosωP_p			
		=	27.681			
Total Driving Forces at base	$\sum F_d$	=	P_sCosδ +P_qCosδ)*αEI	-	N$_g$Sinω)*αG	
			18.382			
Siding factor of safety	SF_s	=	$\frac{\sum F_r}{\sum F_d}$			
			1.506	≥	1.000	**O.K**

Check the Eccentricity of Resultant Force
(Resultant is in middle one third)

Eccentricity $e = 0.5\,B - \frac{(\sum M_r - M_o)}{\sum W}$

$= 0.500 - 0.602$

$= -B/6 \leq e \leq +B/6$

$-0.167 \leq -0.102 \leq 0.167$

O.K **O.K**

Check Bearing

Applied bearing pressure $P = \frac{\sum W}{B} (1 \pm 6e/B)$

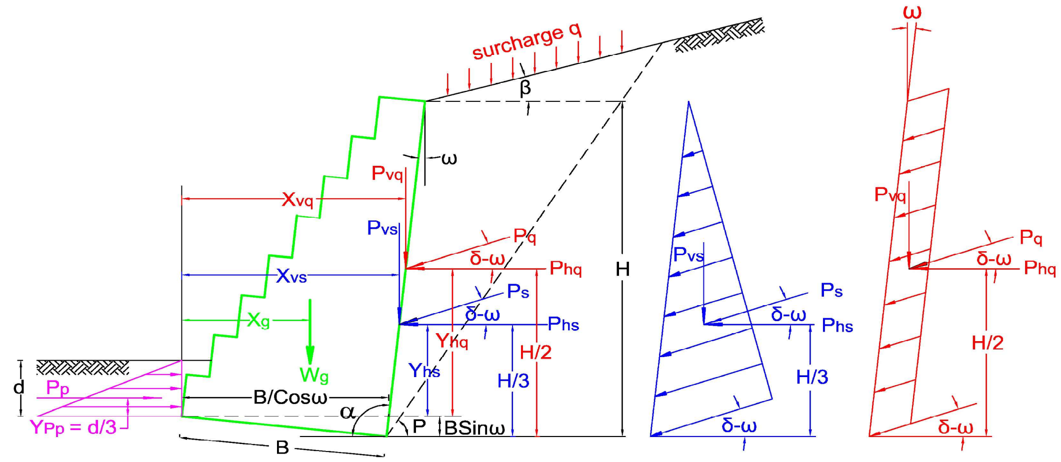
$= 47.624 (1 \pm 0.615)$

Right	=	🟩 76.891	psf	≤	300.000	**O.K**
Left	=	🟩 18.357	psf	≤	300.000	**O.K**

GABION WALL DESIGN

STATIC LOADING

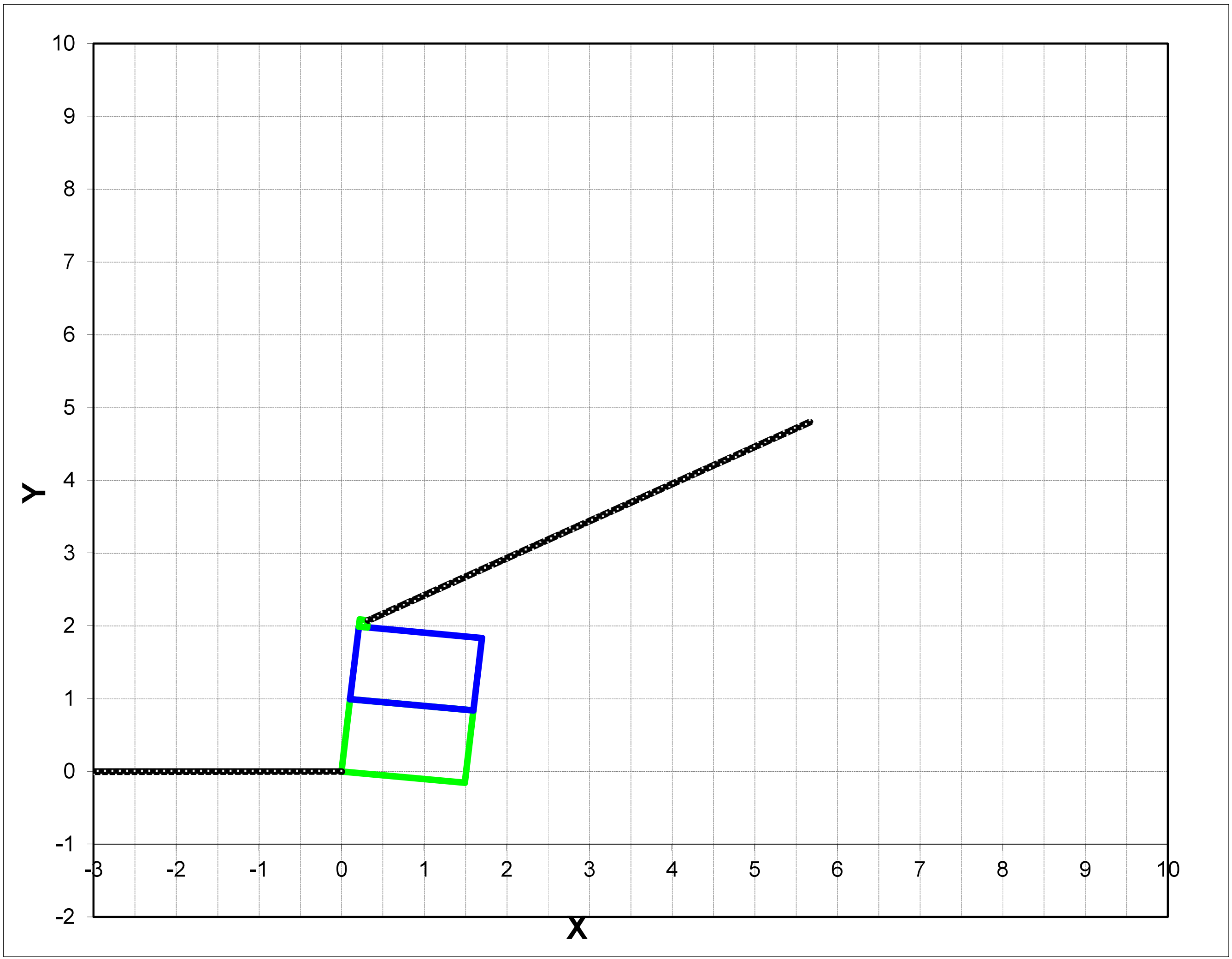
PROJECT NAME:	Waitangi Stream Stabilisation	**PROJECT #:**	T015501
LOCATION:	Waitangi Stream, Lake Tarawera	**SECTION:**	Cross Section D
DESIGNED BY	Noel J Kelly	**CHECKED BY**	
NOTES:	Stability assessed in accordance with the Load Factor Resistance Design Method as recommended by the NZ Building code		



Descriptions	**symbols**	**Input Values**	**Units**	**Notes**
Backfill slope angle above wall	β	27.000	°	< Φ
Angle of internal friction	Φ	36.000	°	
Wall friction reduction by geotextile	fr	33.000	%	Back of wall
Angle of wall friction	δ	24.120	°	Φ(100-fr)/100
Inclination angle to vertical plane	ω	6.000	°	for wall with straight back (no offsets)
Back of wall angle to horizontal	α	96.000	°	90+ω
Cohesion	c	0	psf	Ignore cohesion
Surcharge	q	5.000	**kPa**	
Soil density	γ_s	19.000	**kN/m3**	
Rock density	γ_r	20.500	**kN/m3**	
Void in gabion	v	20.000	%	
Gabion density	γ_g	16.400	**kN/m3**	γ_r(100-v)/100
Actual height of wall	H	2.088	**m**	(hCosω) Corrected for inclination
Embedment	d	0.000	**m**	0m to ignore passive thrust
Width of base	B	1.5	**m**	
Allowable soil bearing capacity	q_a	300.000	kPa	

Retaining wall is:	**SATISFACTORY**	in overturning	10%
	SATISFACTORY	in sliding	53%
	SATISFACTORY	in eccentricity	
	SATISFACTORY	in bearing	13%

DESIGN PROFILE



Row #	Width (m)	Height (m)	offset (from toe) (m)	Area (m²)	X (m)	Moment (m³)	Y (m)	Moment (m³)
15				0.000	0.000	0.000	0.000	0.000
14				0.000	0.000	0.000	0.000	0.000
13				0.000	0.000	0.000	0.000	0.000
12				0.000	0.000	0.000	0.000	0.000
11				0.000	0.000	0.000	0.000	0.000
10				0.000	0.000	0.000	0.000	0.000
9				0.000	0.000	0.000	0.000	0.000
8				0.000	0.000	0.000	0.000	0.000
7				0.000	0.000	0.000	0.000	0.000
6				0.000	0.000	0.000	0.000	0.000
5				0.000	0.000	0.000	0.000	0.000
4				0.000	0.000	0.000	0.000	0.000
3	0.1	0.1	0.00	0.010	0.050	0.001	2.050	0.021
2	1.5	1.0	0.00	1.500	0.750	1.125	1.500	2.250
1	1.5	1.0	0.00	1.500	0.750	1.125	0.500	0.750
	h=	2.1		3.010	0.748	2.251	1.003	3.021

LFRD PARAMETERS

ϕbc	Resistance factor for bearing capacity	0.5
ϕsl	Resistance factor for sliding	0.8
ϕp	Resistance factor for passive earth pressure	0.5
αG_stab	Load factor for self weight (stabilising)	0.9
αG_dest	Load factor for self weight (destabilising)	1.2
αEP_des	Load factor for earth pressure (destabilising)	1.5

CALCULATIONS

COULOMB'S THEORY

BACK

Active earth pressure coefficient K_a =

$$\frac{\sin^2(\alpha+\Phi)}{\sin^2\alpha \quad \sin(\alpha-\delta) \quad \left[1+\sqrt{\frac{\sin(\Phi+\delta) \quad \sin(\Phi-\beta)}{\sin(\alpha-\delta) \quad \sin(\alpha+\beta)}}\right]^2}$$

$$\frac{0.552}{0.989 \quad 0.950 \quad \left[1+\sqrt{\frac{0.867 \quad 0.156}{0.950 \quad 0.839}}\right]^2}$$

$$\frac{0.552}{1.876} = 0.294$$

Active soil thrust P_s = $0.5K_a\gamma_s \quad H^2$

= 12.201 **kN/m3**

Active surcharge thrust P_q = $\frac{\sin\alpha}{\sin(\alpha+\beta)} \quad K_aqH$

= $\frac{0.995}{0.839} \quad 3.075$

= 3.646 **kN/m**

Horizontal active soil thrust P_{hs} = $P_s\cos(\delta-\omega)$

= 11.596 **kN/m**

Horizontal active surcharge thrust P_{hq} = $P_q\cos(\delta-\omega)$

= 3.465 **kN/m** arallel comp

Vertical active soil thrust P_{vs} = $P_s\sin(\delta-\omega)$

= 3.795 **kN/m** pen component

Vertical active surcharge thrust P_{vq} = $P_q\sin(\delta-\omega)$

= 1.134 **kN/m**

FRONT

Inclination angle to vertical ω_p = 0.000

Front face angle to horizontal α_p = $90-\omega_p$

= 90.000

Backfill slope β_p = 0.000

Angle of wall friction δ_p = 0.000

Passive earth pressure coefficient K_p =

$$\frac{\sin^2(\alpha-\Phi)}{\sin^2\alpha \quad \sin(\alpha+\delta) \quad \left[1-\sqrt{\frac{\sin(\Phi+\delta) \quad \sin(\Phi+\beta)}{\sin(\alpha+\delta) \quad \sin(\alpha+\beta)}}\right]^2}$$

$$\frac{0.655}{1.000 \quad 1.000 \quad \left[1-\sqrt{\frac{0.588 \quad 0.588}{1.000 \quad 1.000}}\right]^2}$$

$$\frac{0.655}{0.170} = 3.852$$

Passive soil thrust P_p = $0.5K_p\gamma_s \quad d^2$

= 0.000 **kN/m**

Check Overturning:

Vertical distance to P_{hs}	Y_{hs}	=	H/3-BSinω	=	0.539	**m**
Vertical distance to P_{hq}	Y_{hq}	=	H/2-BSinω	=	0.887	**m**
Overturning moment	$\sum M_o$	=	($Y_{hs}P_{hs}$ +	$Y_{hq}P_{hq}$))*αEP_destab		
		=	4.613	**kNm/m**		
Weight of Gabion	W_g	=	$\sum A\ \gamma_g$			
		=	49.364	**kN/m**		
Horizontal distance to W_g	X_g	=	Ysinω +	XCosω		
		=	0.848	**m**		
Horizontal distance to P_{vs}	X_{vs}	=	B/Cosω +	(H/3-BSinω)Tanω		
			1.565	**m**		
Horizontal distance to P_{vq}	X_{vq}	=	B/Cosω +	(H/2-BSinω)Tanω		
			1.602	**m**		
Vertical distance to P_p	Y_{Pp}	=	d/3			
		=	0.000			
Resisting moment	$\sum M_r$	=	($W_g X_g$)*αG_stab +	$P_{vs} X_{vs}$ +	$P_{vq} X_{vq}$ +	P_pY_{Pp}
		=	45.450	**kNm/m**		
Overturning factor of safety	SF_o	=	$\frac{\sum M_r}{\sum M_o}$			
			🟩 9.852	≥	1.000	**O.K**

Check Sliding

Total Normal forces	$\sum W$	=	(W_gCosω)*αG_stab +	(P_sSinδ +	P_qSinδ) -	P_pSinω
		=	55.621	**kN/m**		
Frictional force	F_f	=	$\sum W$	*TanΦ	* φsl	
		=	55.621	0.727	0.800	
		=	32.329			
Total Resisting Forces	$\sum F_r$	=	F_f + CosωP_p			
		=	32.329			
Total Driving Forces at base	$\sum F_d$	=	P_sCosδ +P_qCosδ)*αE	-	W_gSinω)*αG	
			17.052			
Siding factor of safety	SF_s	=	$\frac{\sum F_r}{\sum F_d}$			
			🟩 1.896	≥	1.000	**O.K**

Check the Eccentricity of Resultant Force
(Resultant is in middle one third)

Eccentricity $e = 0.5\,B - \dfrac{(\sum M_r - M_o)}{\sum W}$

$= 0.750 - 0.734$

$= -B/6 \leq e \leq +B/6$

$-0.250 \leq 0.016 \leq 0.250$

O.K **O.K**

Check Bearing

Applied bearing pressure $P = \dfrac{\sum W}{B}(1 \pm 6e/B)$

$= 37.081\,(1 \pm 0.063\ )$

Left = 39.424 psf ≤ 300.000 **O.K**

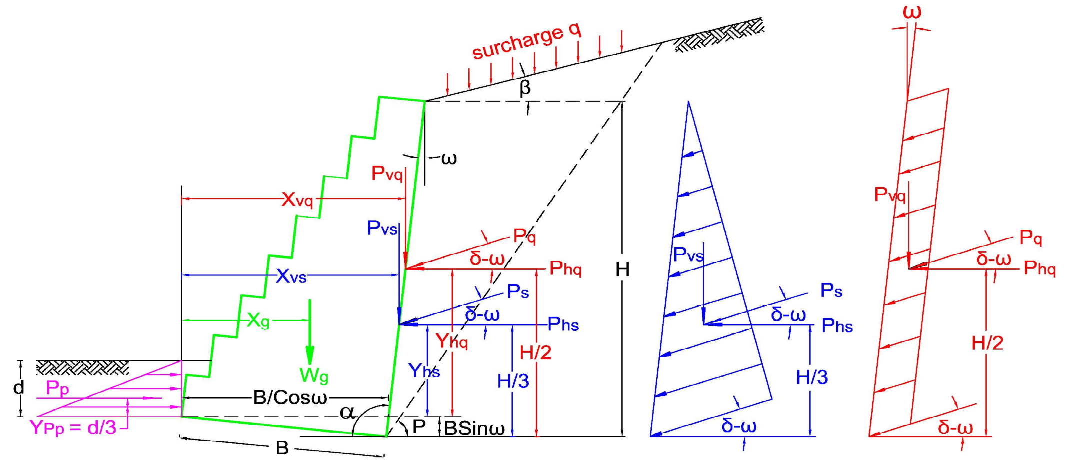
Right = 34.738 psf ≤ 300.000 **O.K**

GABION WALL DESIGN

STATIC LOADING

PROJECT NAME:	Waitangi Stream Stabilisation	**PROJECT #:**	T015501
LOCATION:	Waitangi Stream, Lake Tarawera	**SECTION:**	Cross Section G
DESIGNED BY	Noel J Kelly	**CHECKED BY**	

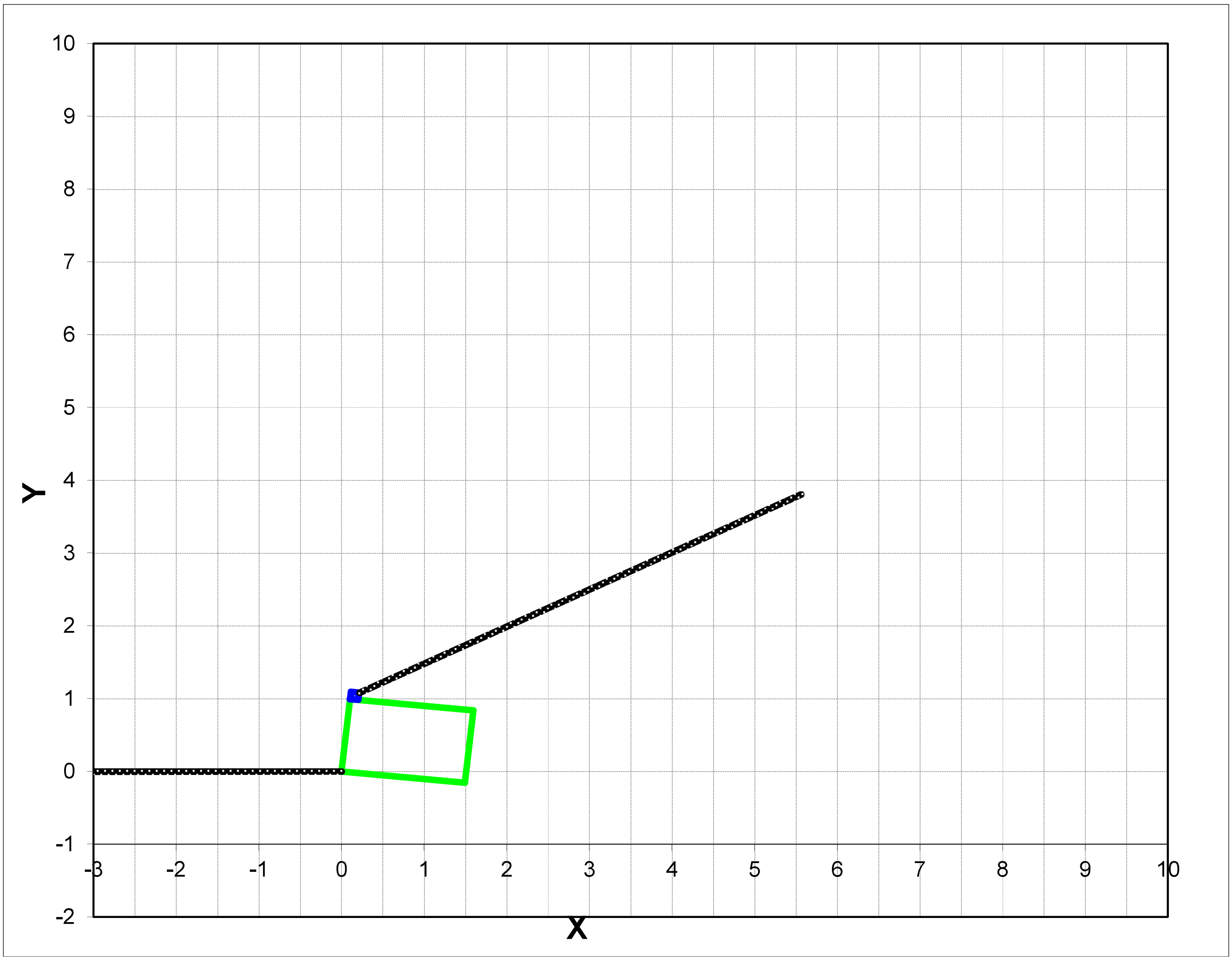
NOTES: Stability assessed in accordance with the Load Factor Resistance Design Method as recommended by the NZ Building code



Descriptions	**symbols**	**Input Values**	**Units**	**Notes**
Backfill slope angle above wall	β	27.000	º	< Φ
Angle of internal friction	Φ	36.000	º	
Wall friction reduction by geotextile	fr	33.000	%	Back of wall
Angle of wall friction	δ	24.120	º	Φ(100-fr)/100
Inclination angle to vertical plane	ω	6.000	º	for wall with straight back (no offsets)
Back of wall angle to horizontal	α	96.000	º	90+ω
Cohesion	c	0	psf	Ignore cohesion
Surcharge	q	5.000	**kPa**	
Soil density	γs	19.000	**kN/m3**	
Rock density	γr	20.500	**kN/m3**	
Void in gabion	v	20.000	%	
Gabion density	γg	16.400	**kN/m3**	γr(100-v)/100
Actual height of wall	H	1.094	**m**	(hCosω) Corrected for inclination
Embedment	d	0.000	**m**	0m to ignore passive thrust
Width of base	B	1.5	**m**	
Allowable soil bearing capacity	qa	**150.000**	kPa	

Retaining wall is:	**SATISFACTORY**	in overturning	5%
	SATISFACTORY	in sliding	31%
	SATISFACTORY	in eccentricity	
	SATISFACTORY	in bearing	14%

DESIGN PROFILE



Row #	Width (m)	Height (m)	offset (from toe) (m)	Area (m²)	X (m)	Moment (m³)	Y (m)	Moment (m³)
15				0.000	0.000	0.000	0.000	0.000
14				0.000	0.000	0.000	0.000	0.000
13				0.000	0.000	0.000	0.000	0.000
12				0.000	0.000	0.000	0.000	0.000
11				0.000	0.000	0.000	0.000	0.000
10				0.000	0.000	0.000	0.000	0.000
9				0.000	0.000	0.000	0.000	0.000
8				0.000	0.000	0.000	0.000	0.000
7				0.000	0.000	0.000	0.000	0.000
6				0.000	0.000	0.000	0.000	0.000
5				0.000	0.000	0.000	0.000	0.000
4				0.000	0.000	0.000	0.000	0.000
3				0.000	0.000	0.000	0.000	0.000
2	0.1	0.1	0.00	0.010	0.050	0.001	1.050	0.011
1	1.5	1.0	0.00	1.500	0.750	1.125	0.500	0.750
	h=	1.1		1.510	0.745	1.126	0.504	0.761

LFRD PARAMETERS

ϕbc	Resistance factor for bearing capacity	0.5
ϕsl	Resistance factor for sliding	0.8
ϕp	Resistance factor for passive earth pressure	0.5
αG_stab	Load factor for self weight (stabilising)	0.9
αG_desta	Load factor for self weight (destabilising)	1.2
αEP_des	Load factor for earth pressure (destabilising)	1.5

CALCULATIONS

COULOMB'S THEORY

BACK

Active earth pressure coefficient K_a =

$$K_a = \frac{\sin^2(\alpha+\Phi)}{\sin^2\alpha \quad \sin(\alpha-\delta) \quad \left[1+\sqrt{\frac{\sin(\Phi+\delta)}{\sin(\alpha-\delta)}\frac{\sin(\Phi-\beta)}{\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{0.552}{0.989 \quad 0.950 \quad \left[1+\sqrt{\frac{0.867}{0.950}\frac{0.156}{0.839}}\right]^2}$$

$$\frac{0.552}{1.876} = 0.294$$

Active soil thrust P_s = $0.5K_a\gamma_s$ H^2

= 3.348 **kN/m3**

Active surcharge thrust P_q = $\frac{\sin\alpha}{\sin(\alpha+\beta)}$ K_aqH

= $\frac{0.995}{0.839}$ 1.611

= 1.910 **kN/m**

Horizontal active soil thrust P_{hs} = $P_s\cos(\delta-\omega)$

= 3.182 **kN/m**

Horizontal active surcharge thrust P_{hq} = $P_q\cos(\delta-\omega)$

= 1.815 **kN/m** arallel comp

Vertical active soil thrust P_{vs} = $P_s\sin(\delta-\omega)$

= 1.041 **kN/m** pen component

Vertical active surcharge thrust P_{vq} = $P_q\sin(\delta-\omega)$

= 0.594 **kN/m**

FRONT

Inclination angle to vertical ω_p = 0.000

Front face angle to horizontal α_p = $90-\omega_p$

= 90.000

Backfill slope β_p = 0.000

Angle of wall friction δ_p = 0.000

Passive earth pressure coefficient K_p =

$$K_p = \frac{\sin^2(\alpha-\Phi)}{\sin^2\alpha \quad \sin(\alpha+\delta) \quad \left[1-\sqrt{\frac{\sin(\Phi+\delta)}{\sin(\alpha+\delta)}\frac{\sin(\Phi+\beta)}{\sin(\alpha+\beta)}}\right]^2}$$

$$= \frac{0.655}{1.000 \quad 1.000 \quad \left[1-\sqrt{\frac{0.588}{1.000}\frac{0.588}{1.000}}\right]^2}$$

$$\frac{0.655}{0.170} = 3.852$$

Passive soil thrust P_p = $0.5K_p\gamma_s$ d^2

= 0.000 **kN/m**

Check Overturning:

Vertical distance to P_{hs} Y_{hs} = H/3-BSinω = 0.208 **m**

Vertical distance to P_{hq} Y_{hq} = H/2-BSinω = 0.390 **m**

Overturning moment $\sum M_o$ = $(Y_{hs}P_{hs}$ + $Y_{hq}P_{hq}))$*αEP_destab

= 1.062 **kNm/m**

Weight of Gabion W_g = ∑A γg

= 24.764 **kN/m**

Horizontal distance to W_g X_g = Ysinω + XCosω

= 0.794 **m**

Horizontal distance to P_{vs} X_{vs} = B/Cosω + (H/3-BSinω)Tanω

1.530 **m**

Horizontal distance to P_{vq} X_{vq} = B/Cosω + (H/2-BSinω)Tanω

1.549 **m**

Vertical distance to P_p YP_p = d/3

= 0.000

Resisting moment $\sum M_r$ = $(W_g X_g)$*αG_stab + $P_{vs} X_{vs}$ + $P_{vq} X_{vq}$ + P_pYP_p

= 20.208 **kNm/m**

Overturning factor of safety SF_o = $\frac{\sum M_r}{\sum M_o}$

19.021 ≥ 1.000 **O.K**

Check Sliding

Total Normal forces ∑W = (WgCosω)*αG_stab + (PsSinδ + PqSinδ) - P_pSinω

= 26.803 **kN/m**

Frictional force F_f = ∑W *TanΦ * φsl

= 26.803 0.727 0.800

= 15.579

Total Resisting Forces $\sum F_r$ = F_f + CosωP_p

= 15.579

Total Driving Forces at base $\sum F_d$ = PsCosδ +PqCosδ)*αE - WgSinω)*αG

4.868

Siding factor of safety SF_s = $\frac{\sum F_r}{\sum F_d}$

3.200 ≥ 1.000 **O.K**

Check the Eccentricity of Resultant Force

(Resultant is in middle one third)

Eccentricity	e	=	0.5 B	-	(∑M_r	-	M_o)
						∑W	
		=	0.750	-	0.714		
		=	-B/6	≤	e	≤	+B/6
			-0.250	≤	0.036	≤	0.250
				O.K		**O.K**	

Check Bearing

Applied bearing pressure	P	=	∑W	(1±	6e/B)		
			B				
		=	17.868	(1±	0.143	)	
	Left	=	20.419	psf	≤	150.000	**O.K**
	Right	=	15.318	psf	≤	150.000	**O.K**

Appendix C: Slope Outputs

T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_North_Gabion_Global Stability

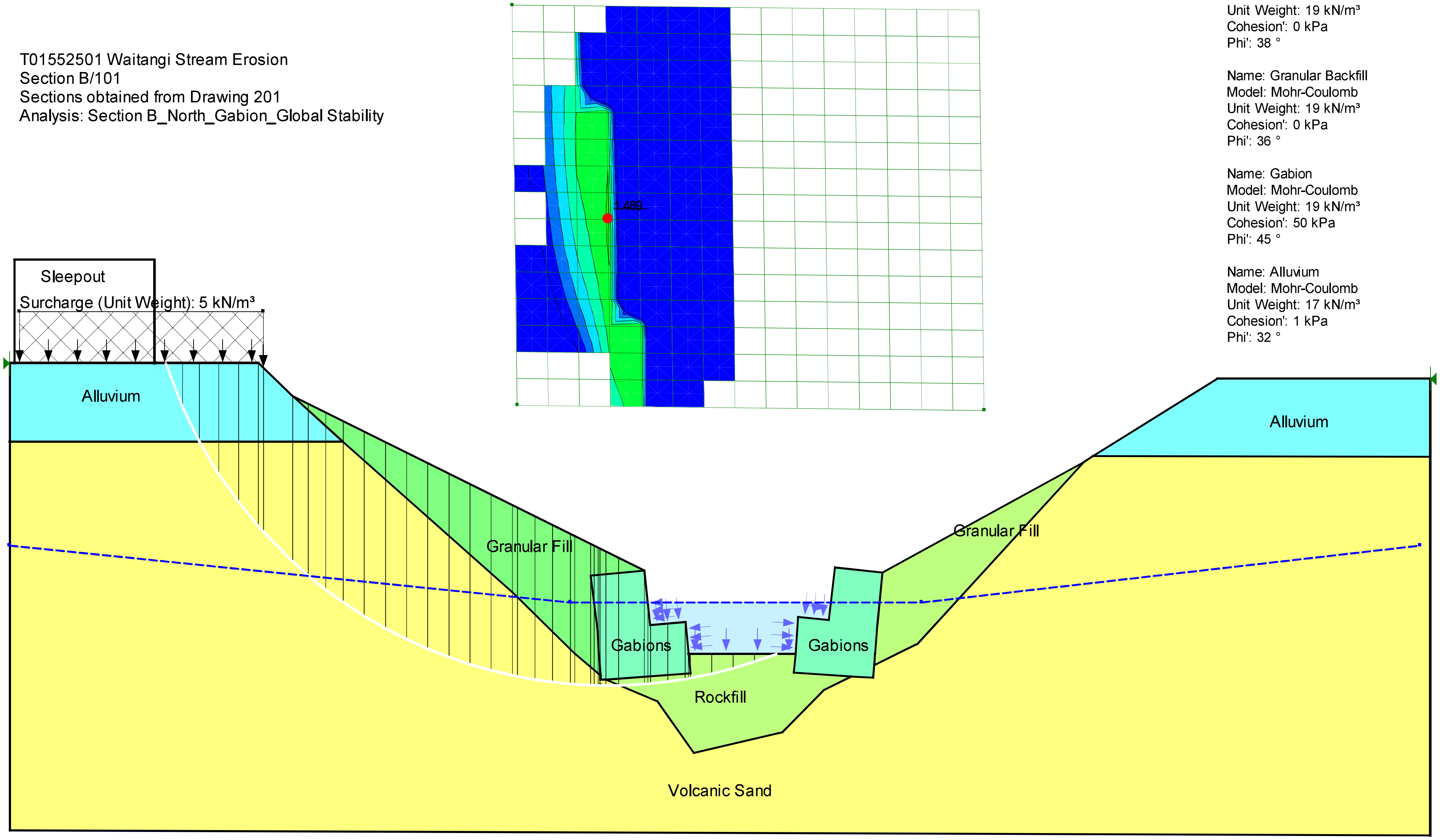
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_North_Gabion_Upper Stability

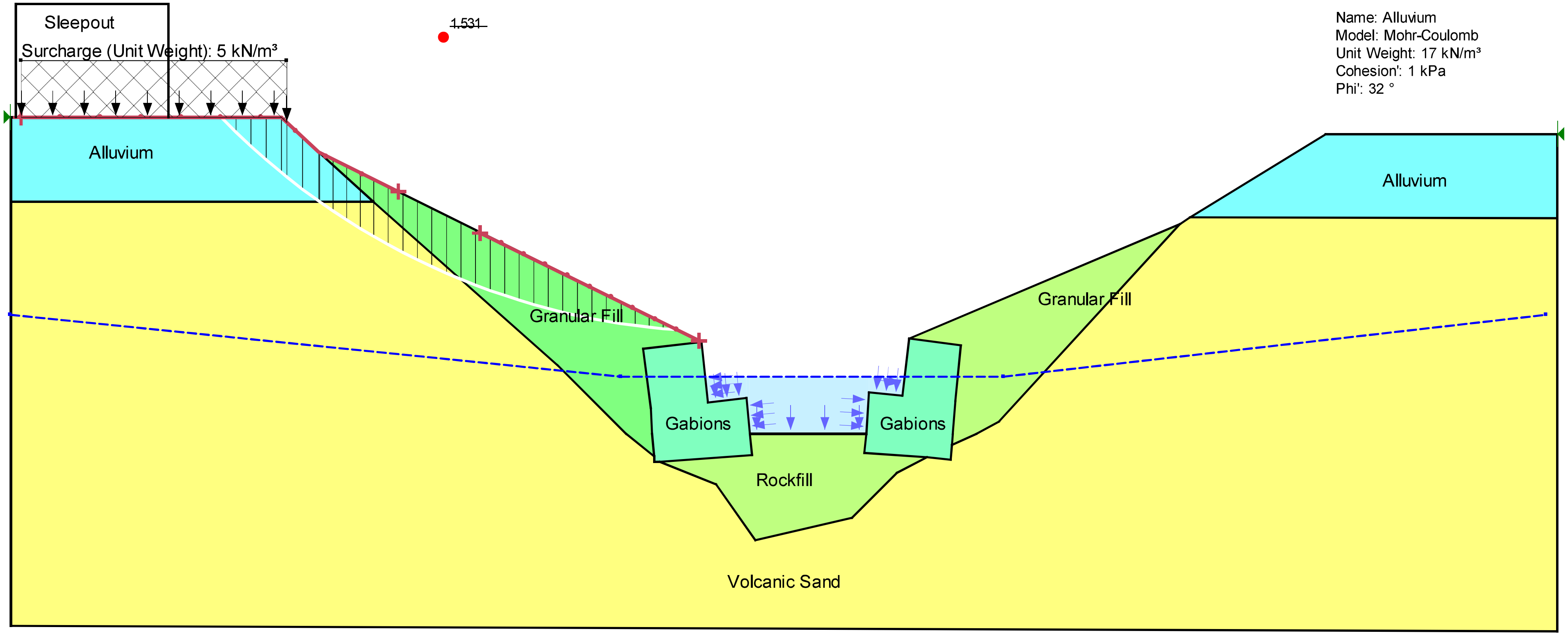
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_North_Gabion_Global Stability

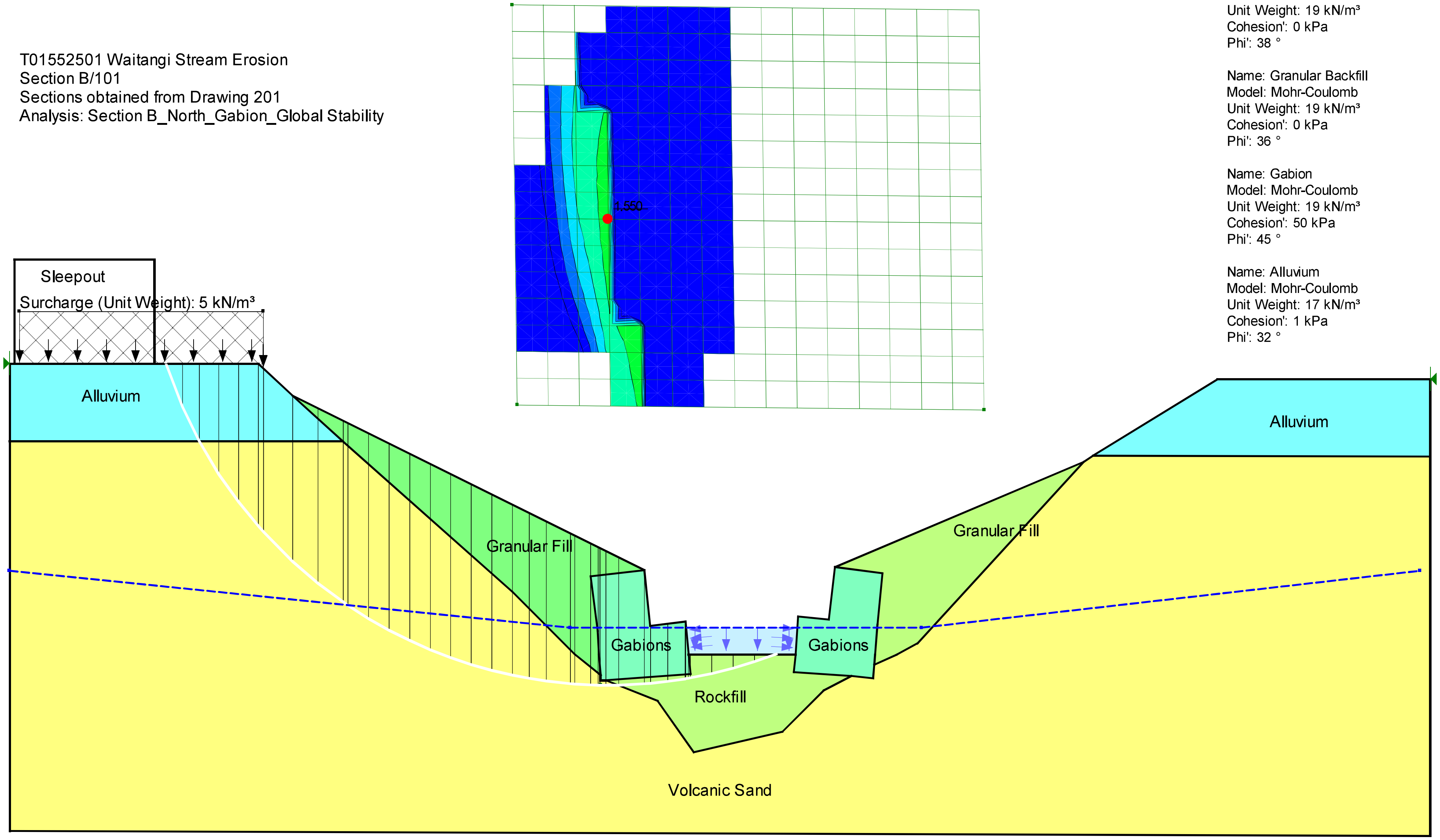
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

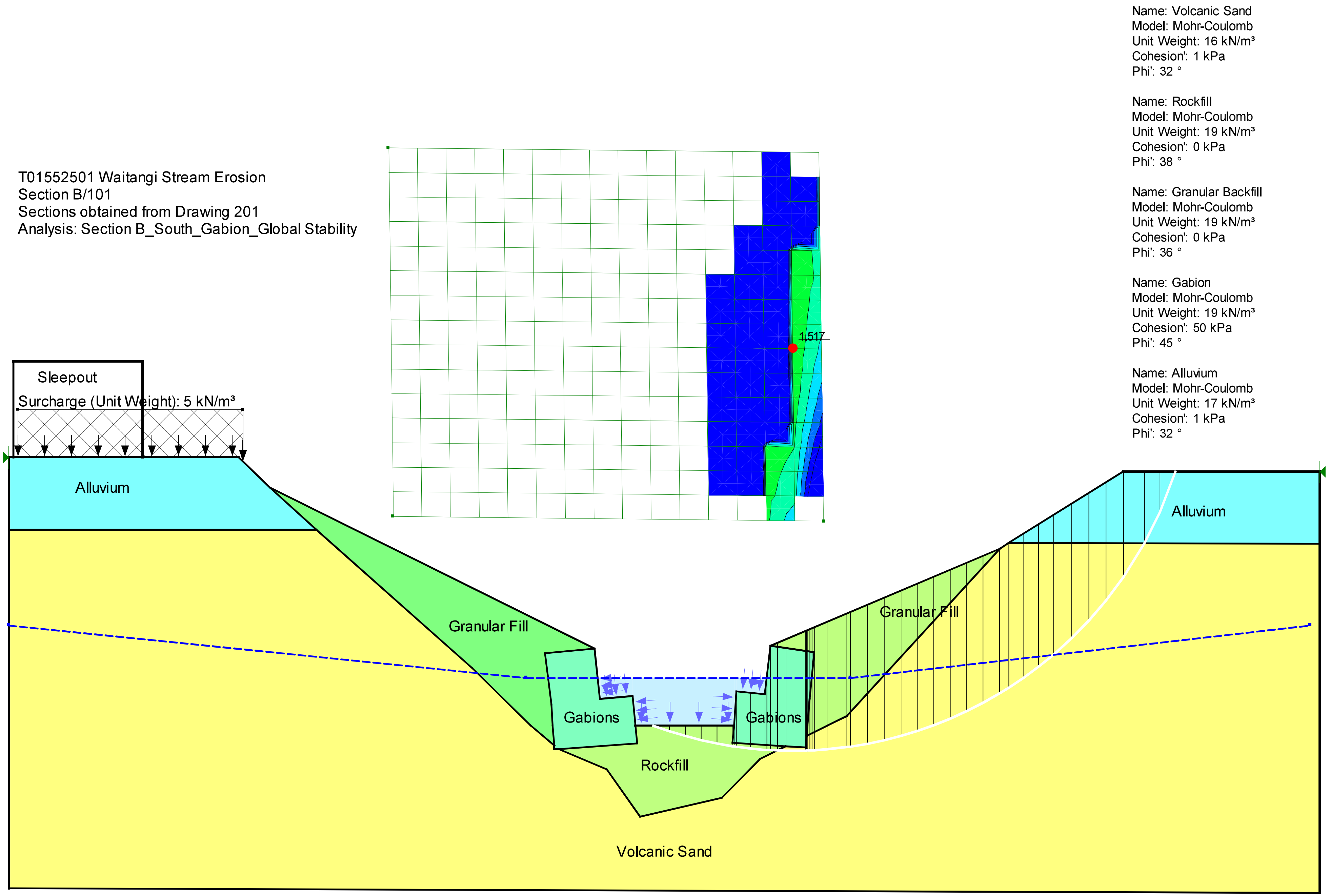
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Gabion_Global Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Gabion_Upper Stability

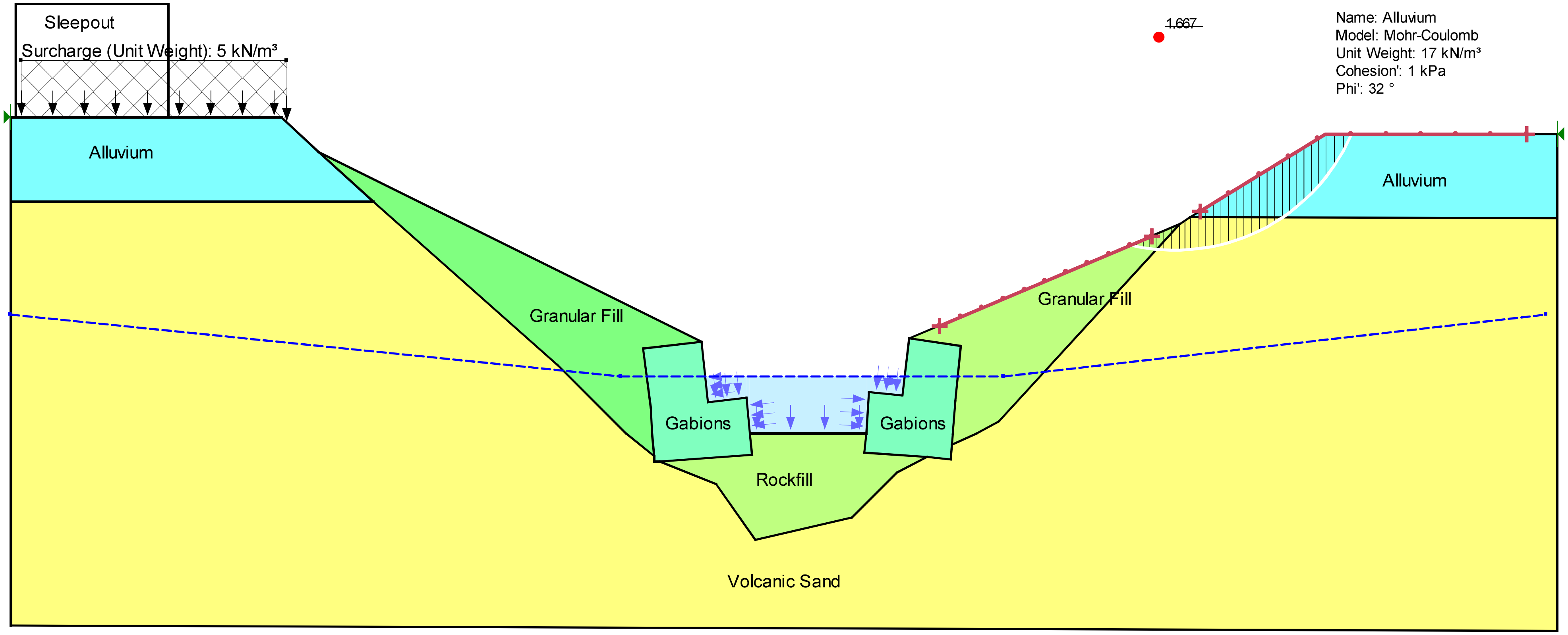
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

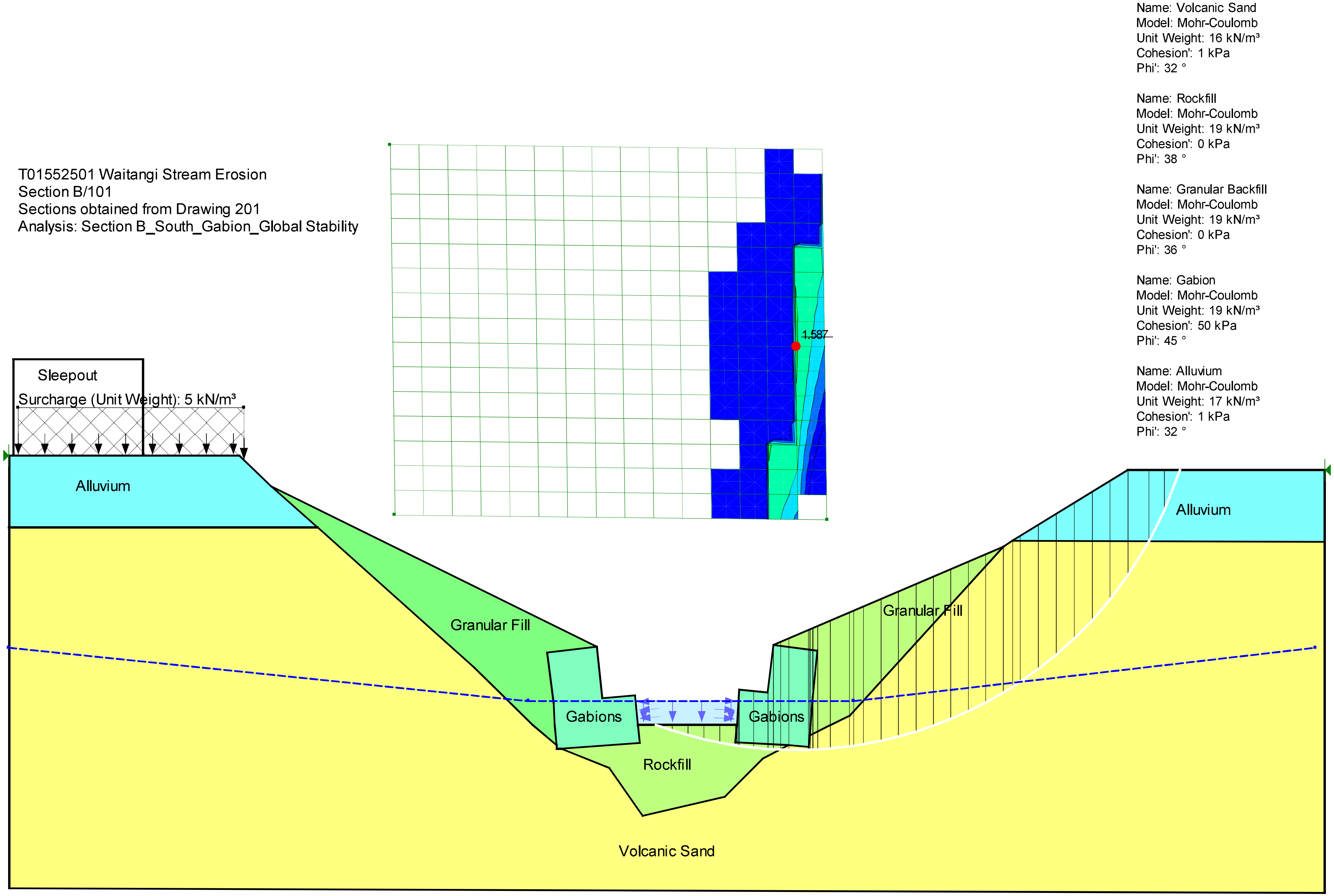
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Gabion_Global Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Gabion_Upper Stability

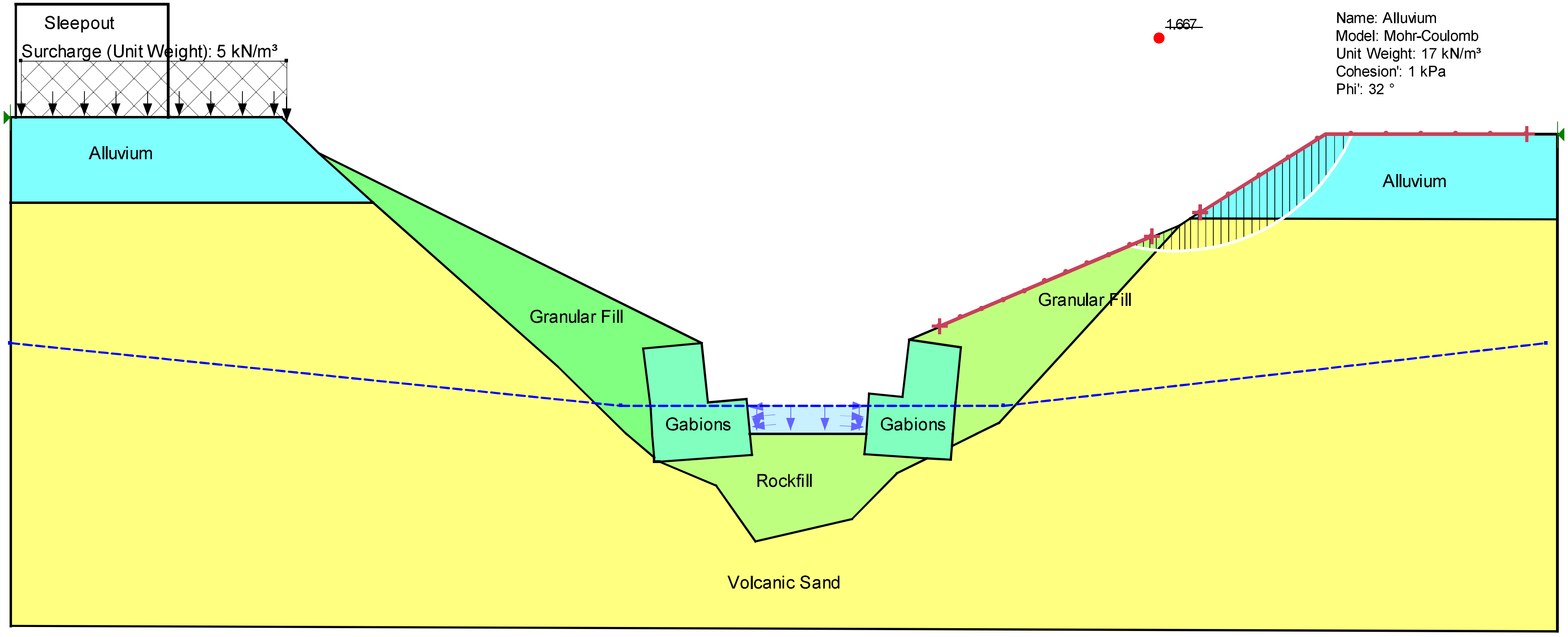
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_North_Gabion_Global Stability

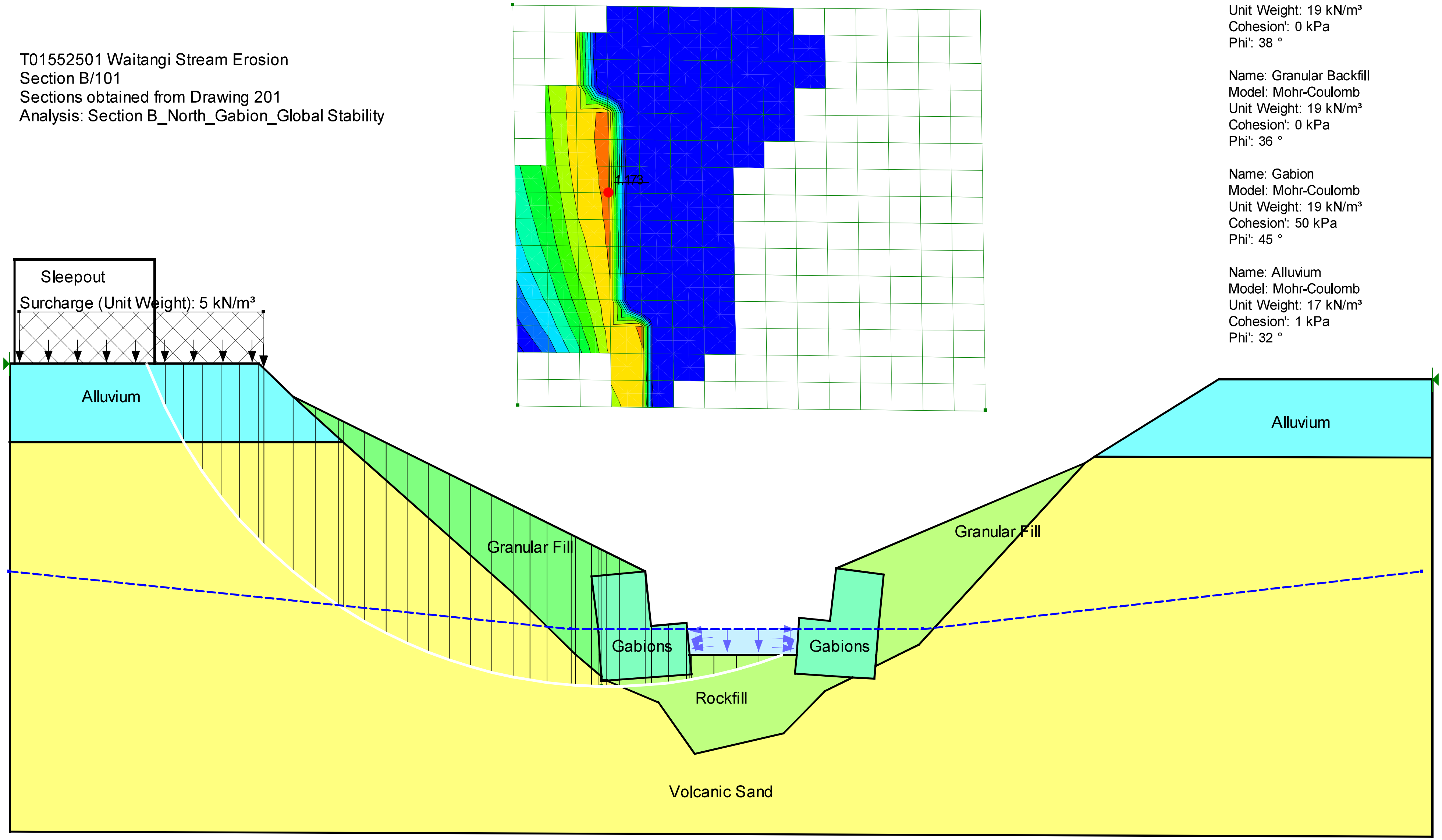
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

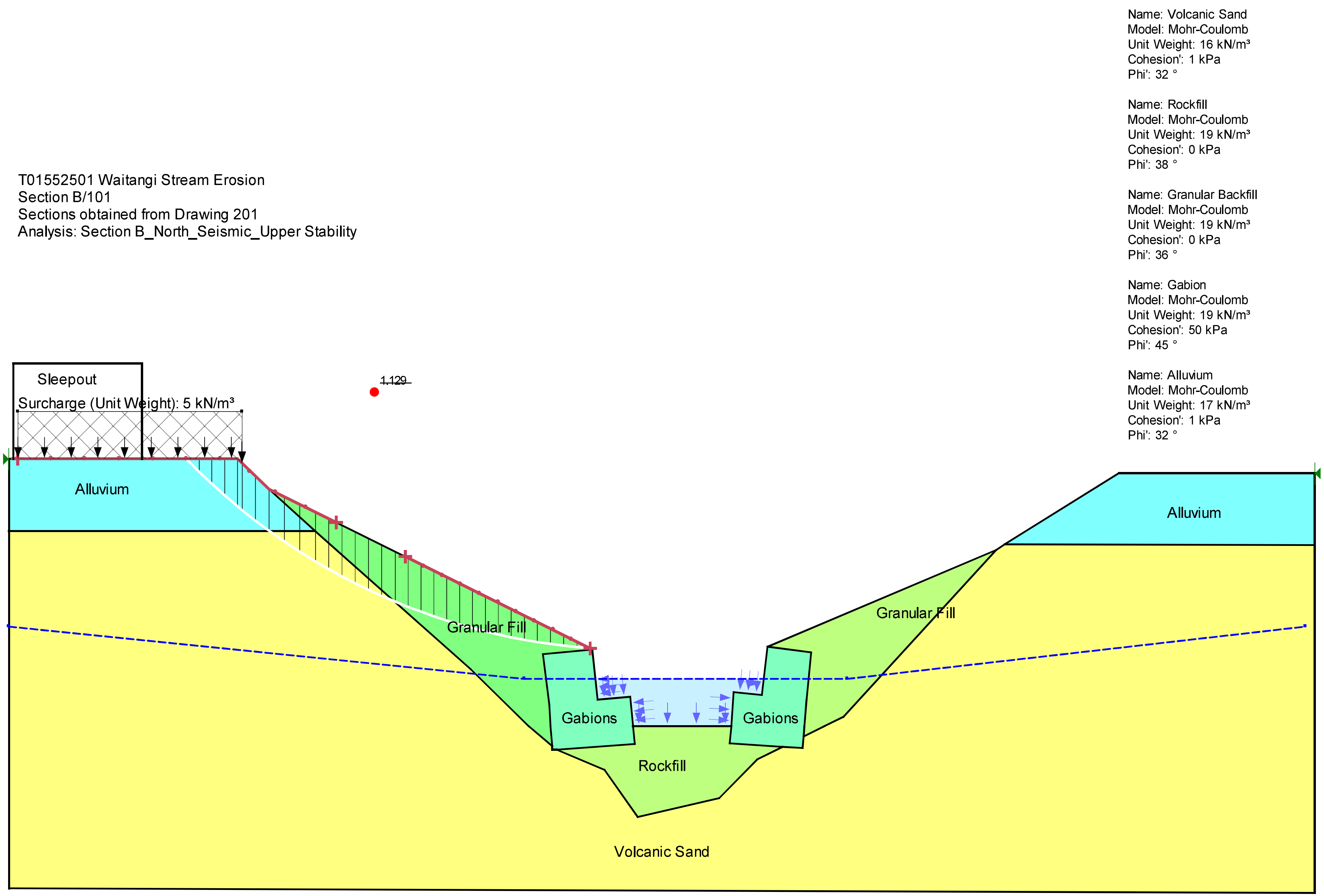
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_North_Seismic_Upper Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Seismic_Global Stability

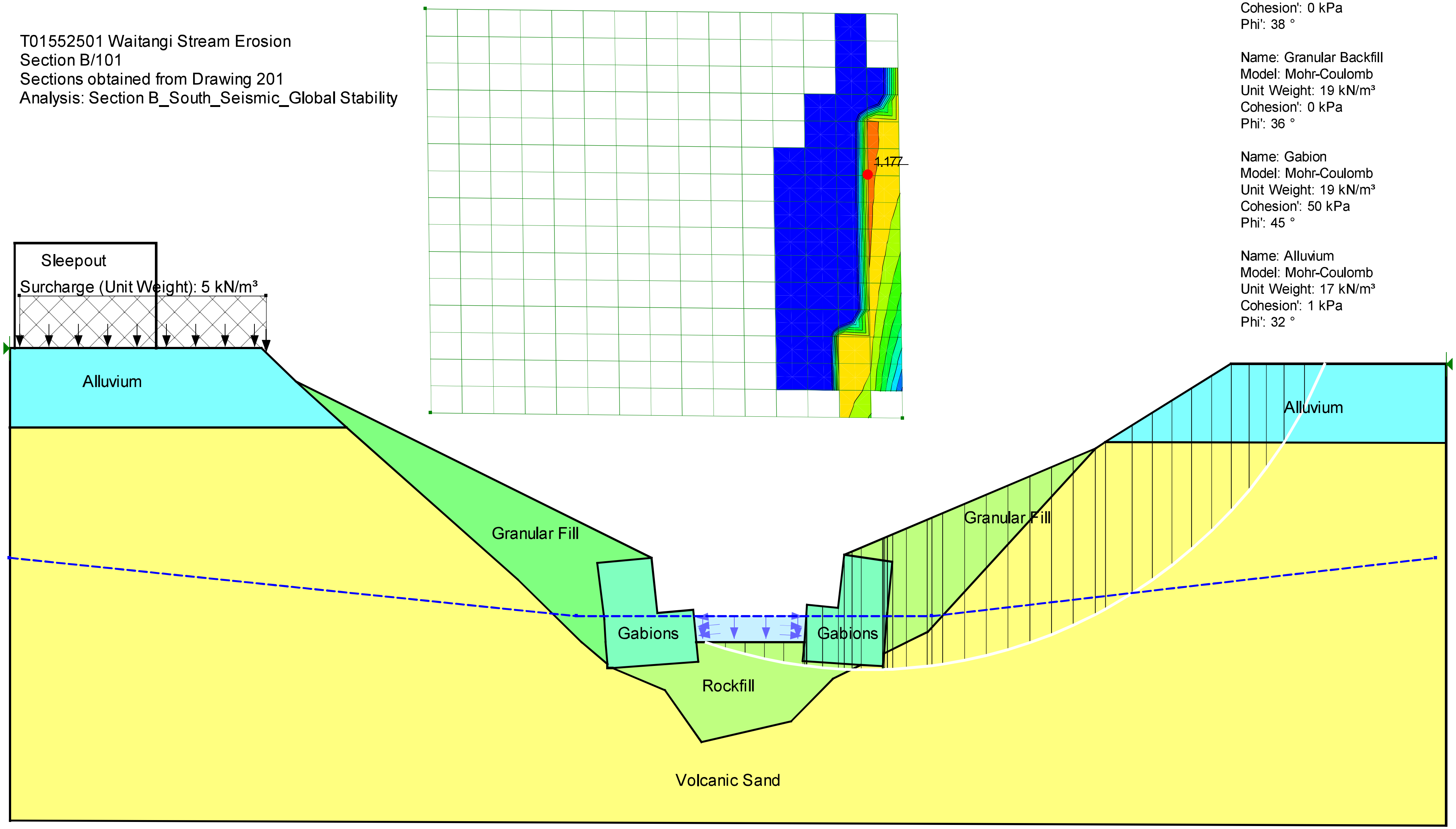
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section B_South_Seismic_Upper Stability

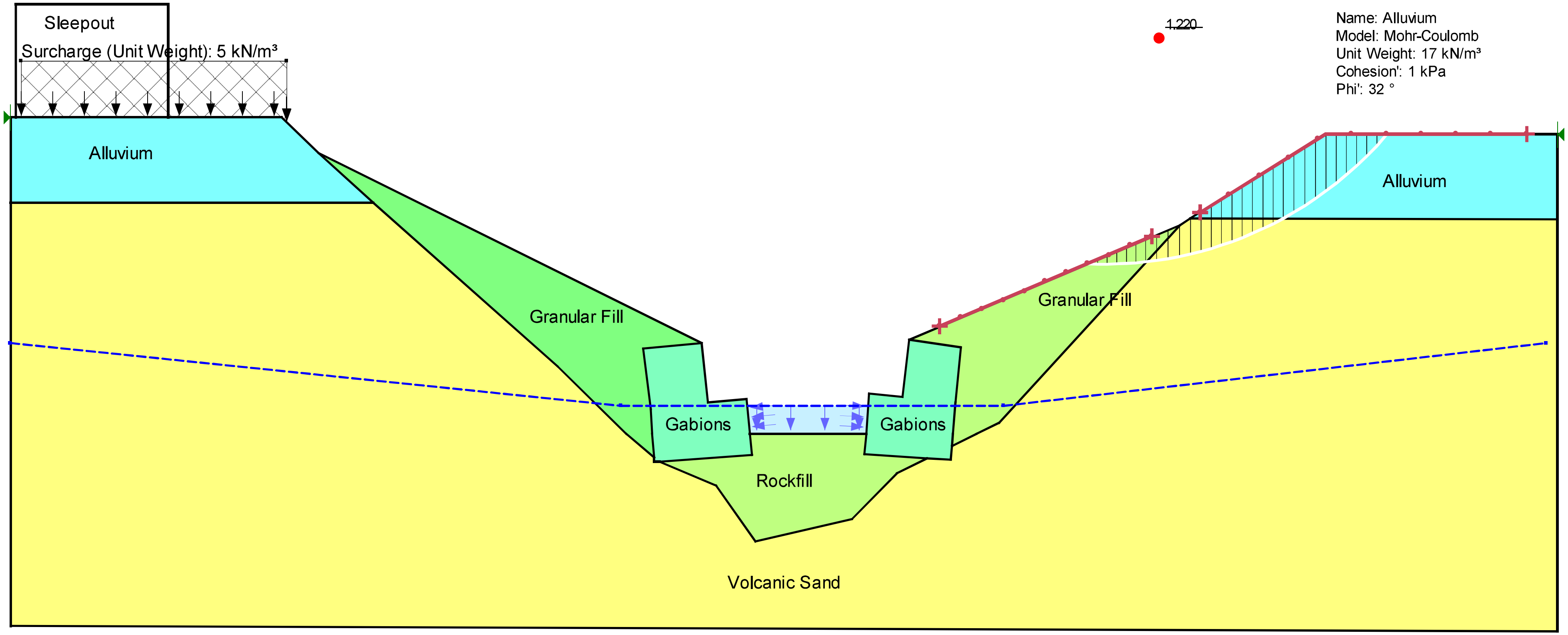
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

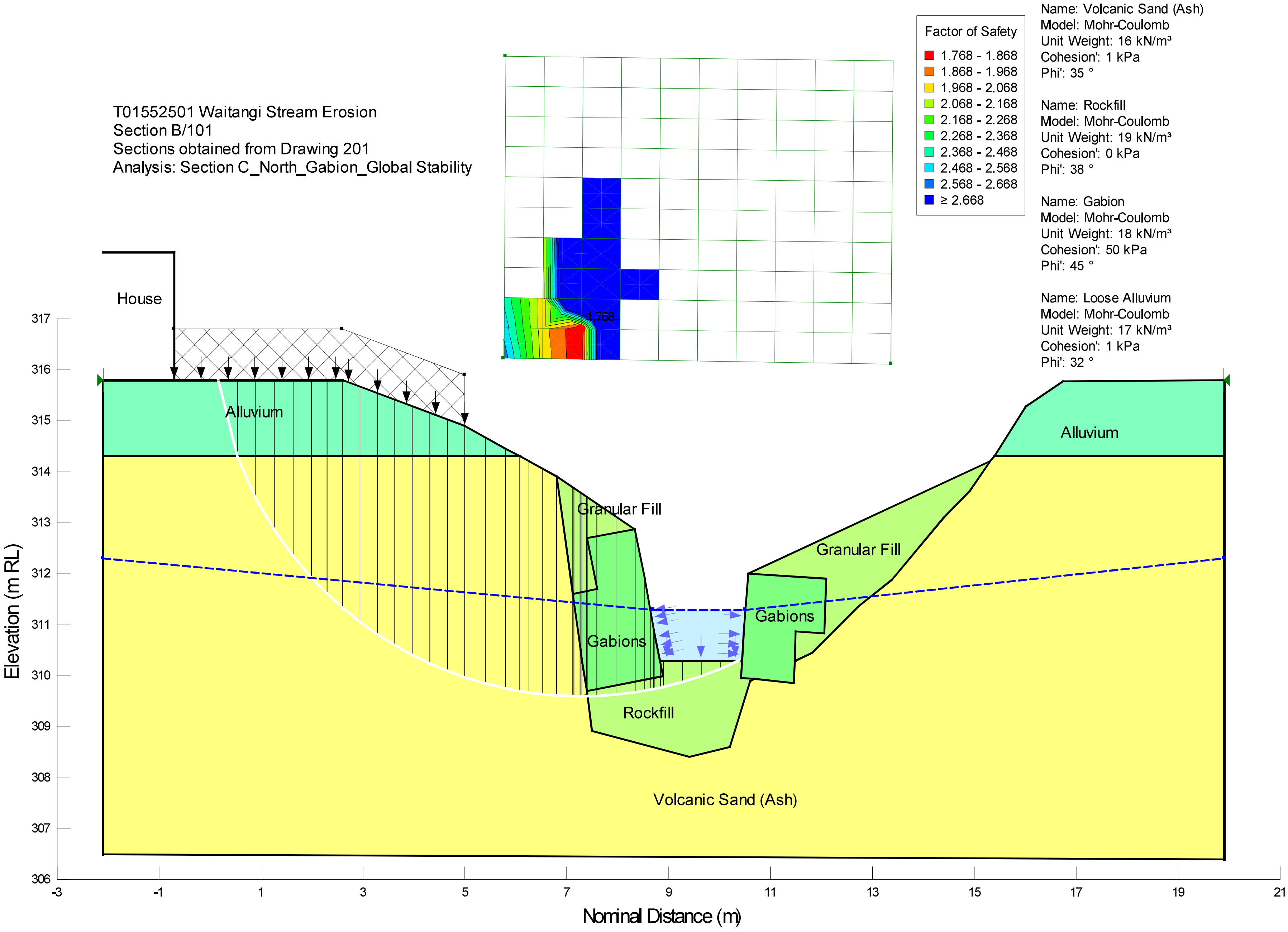
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Granular Backfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

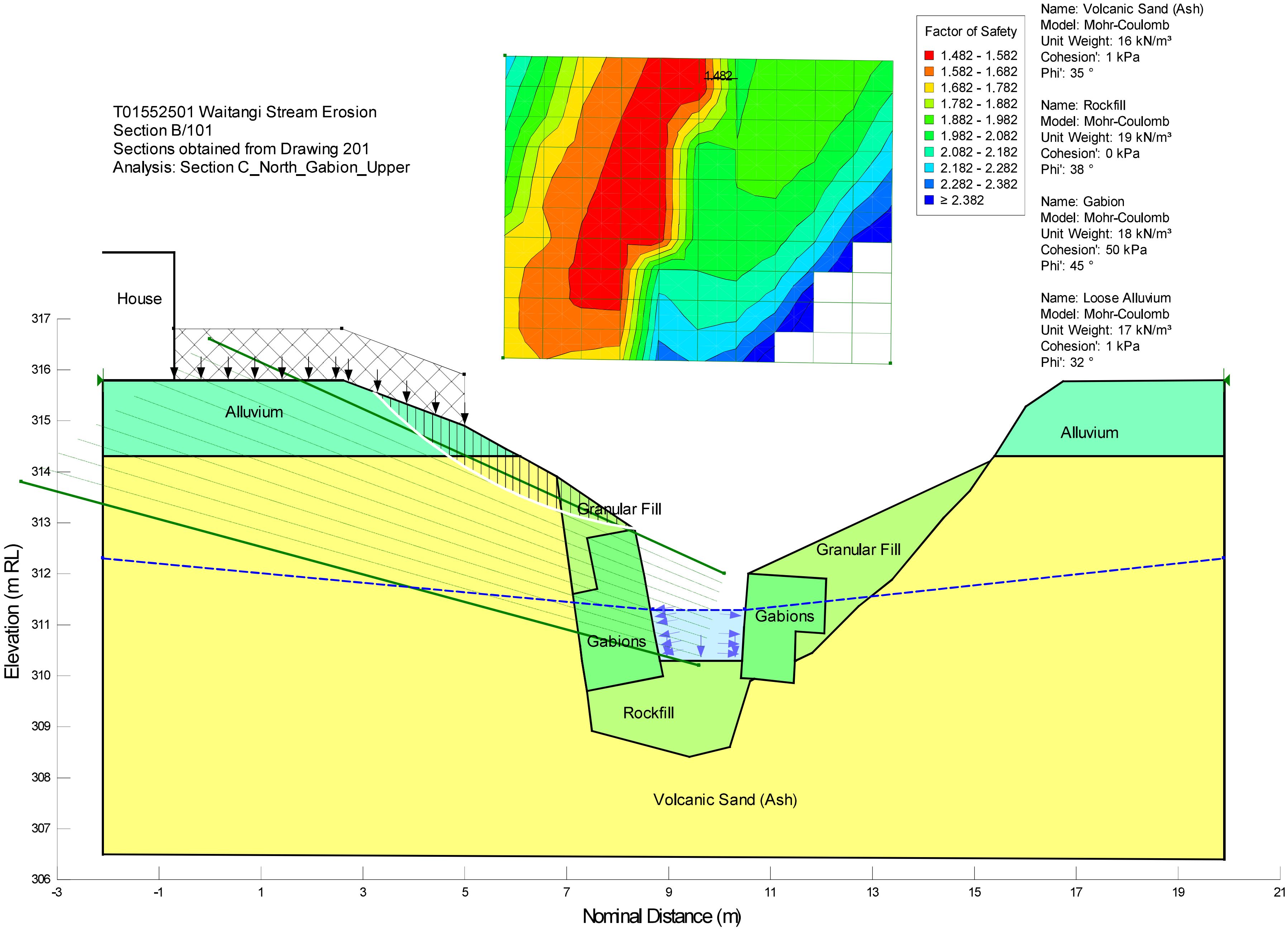
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 50 kPa
Phi': 45 °

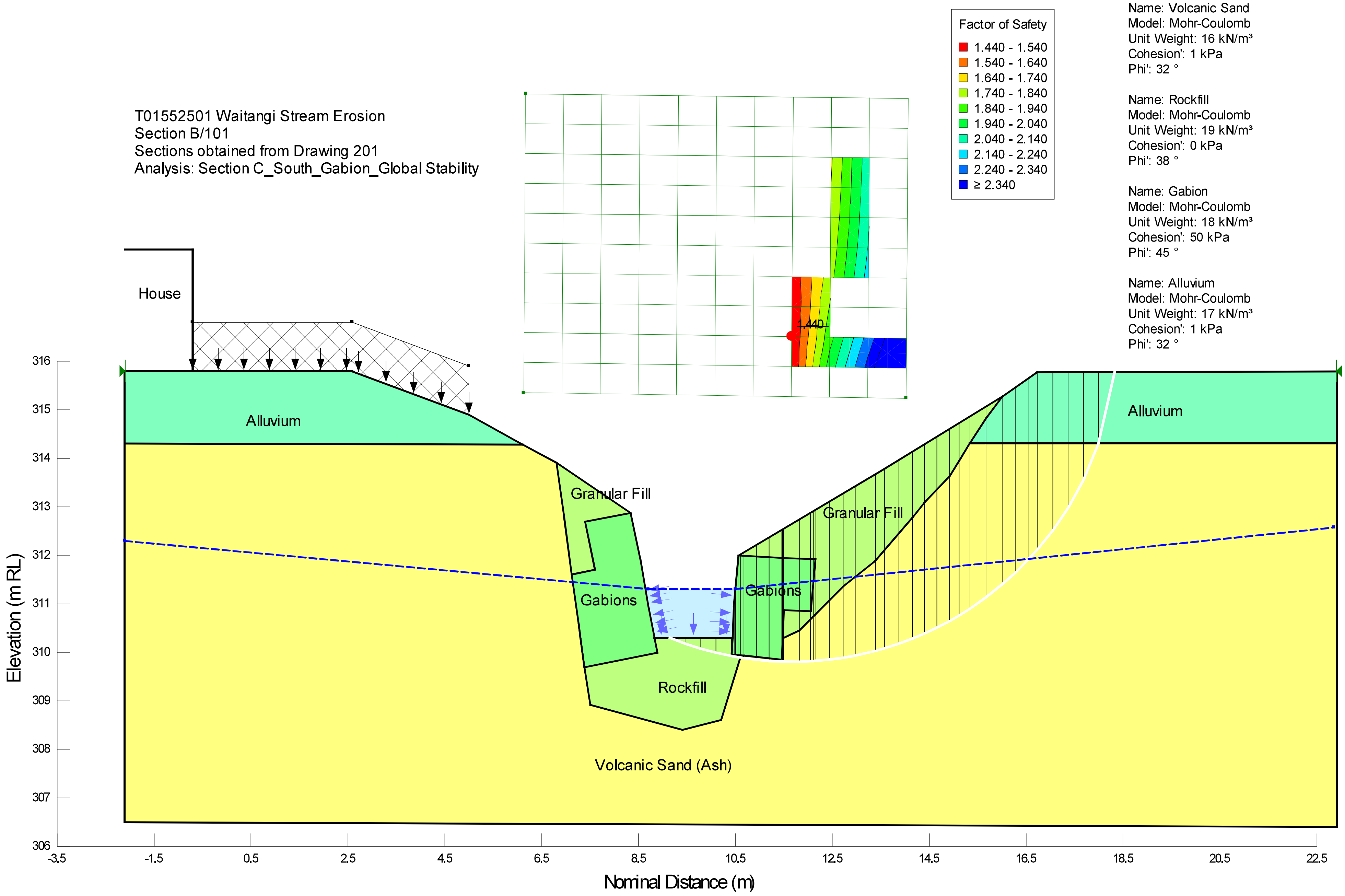
Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Gabion_Global Stability


T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Gabion_Upper
1.482
Factor of Safety
🟥 1.482 - 1.582
🟧 1.582 - 1.682
🟨 1.682 - 1.782
🟩 1.782 - 1.882
🟩 1.882 - 1.982
🟩 1.982 - 2.082
🟩 2.082 - 2.182
🟦 2.182 - 2.282
🟦 2.282 - 2.382
🟦 ≥ 2.382
Name: Volcanic Sand (Ash)
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °
Name: Loose Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House
Alluvium
Alluvium
Granular Fill
Granular Fill
Gabions
Gabions
Rockfill
Volcanic Sand (Ash)
Elevation (m RL)
317
316
315
314
313
312
311
310
309
308
307
306
Nominal Distance (m)
-3
-1
1
3
5
7
9
11
13
15
17
19
21



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Gabion_Global Stability

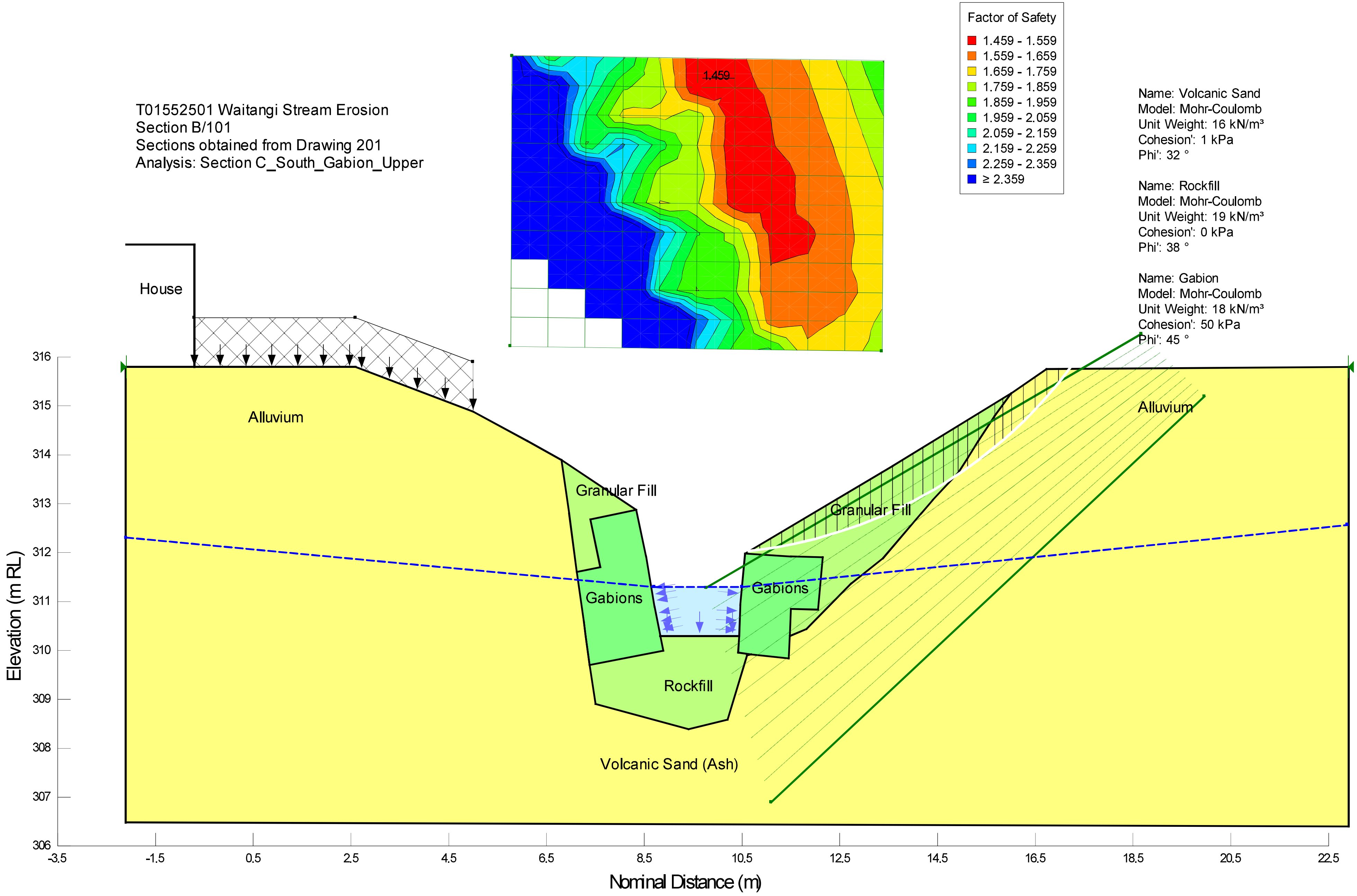
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

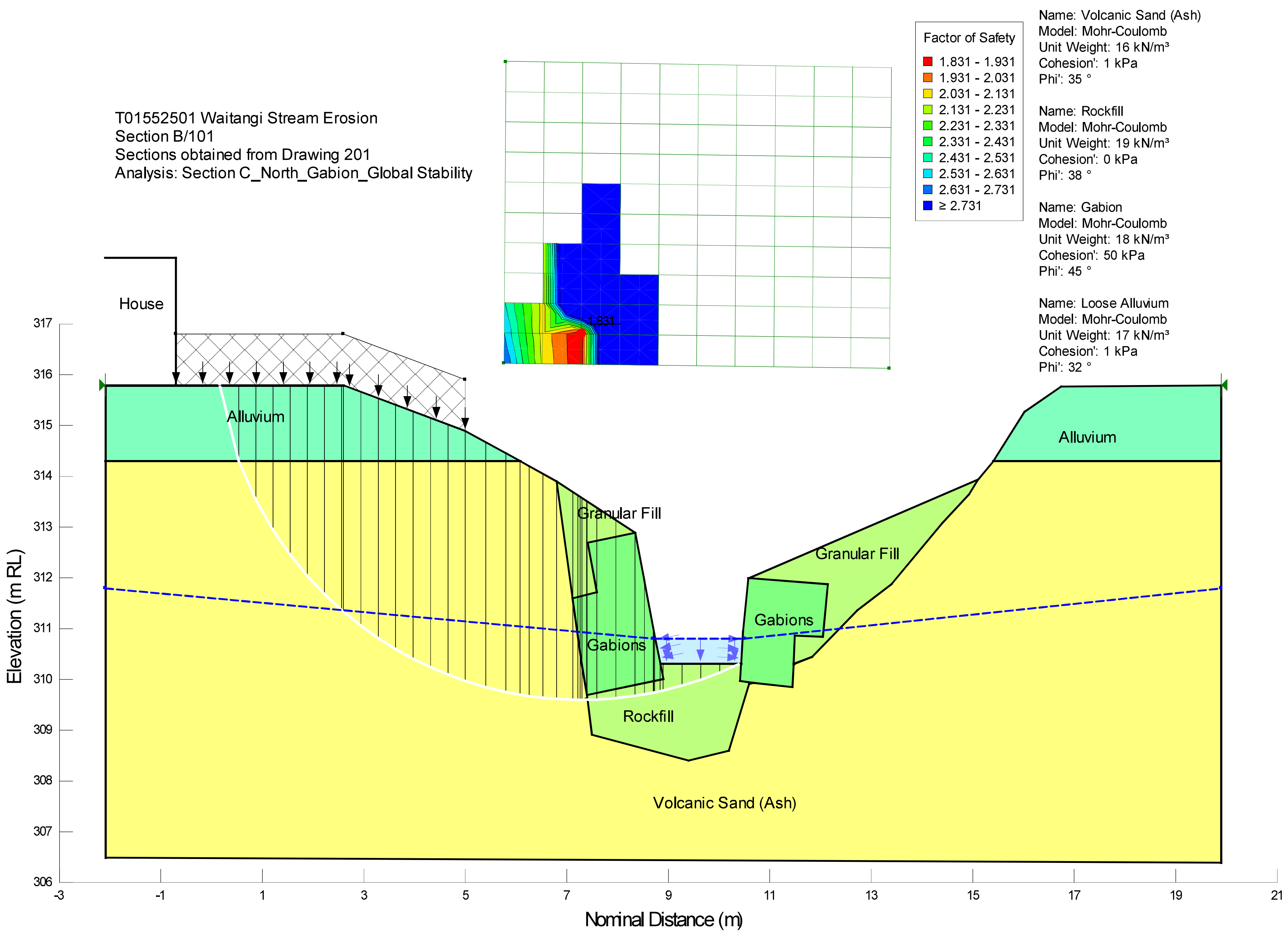
T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Gabion_Upper



Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °



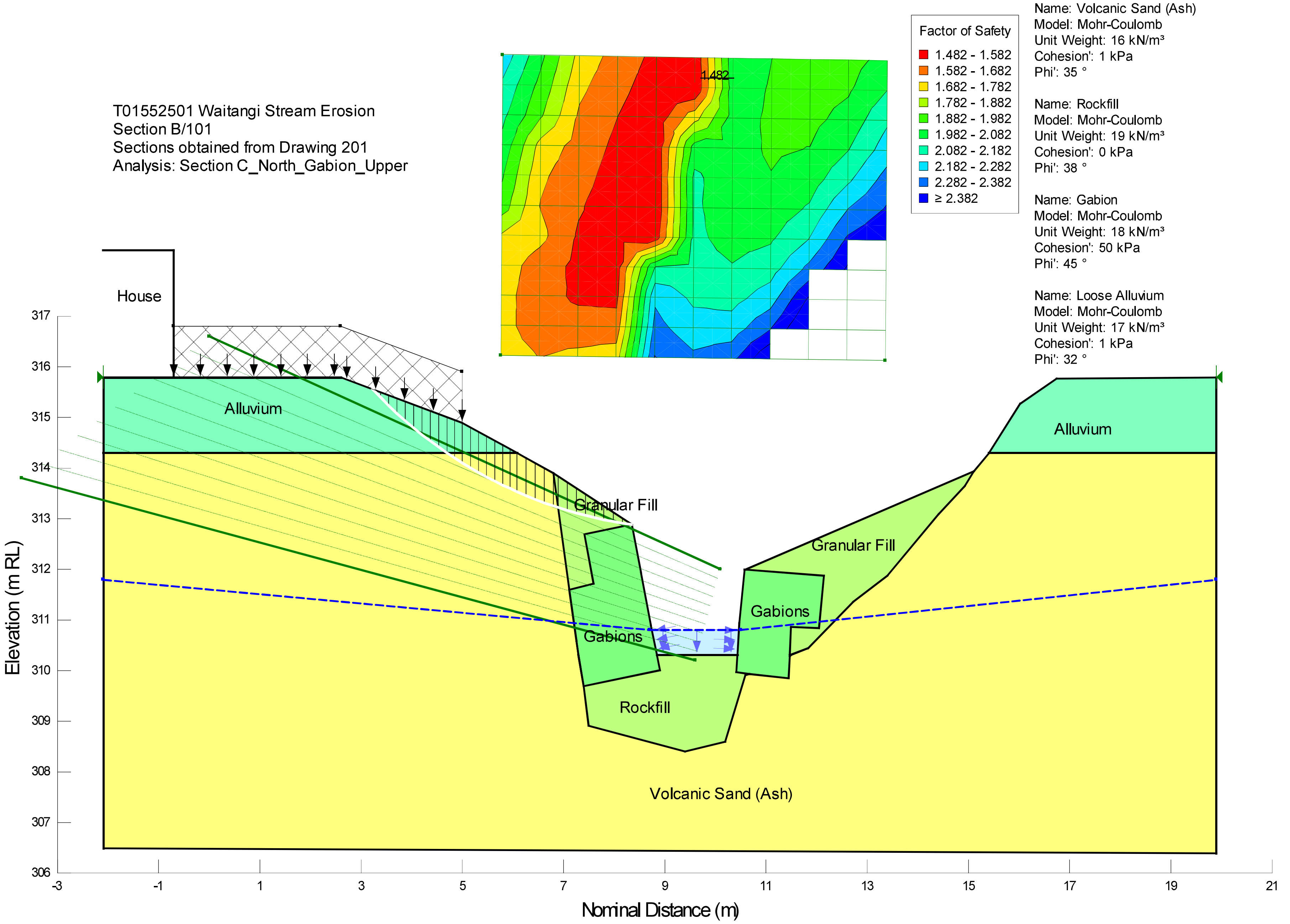
T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Gabion_Global Stability

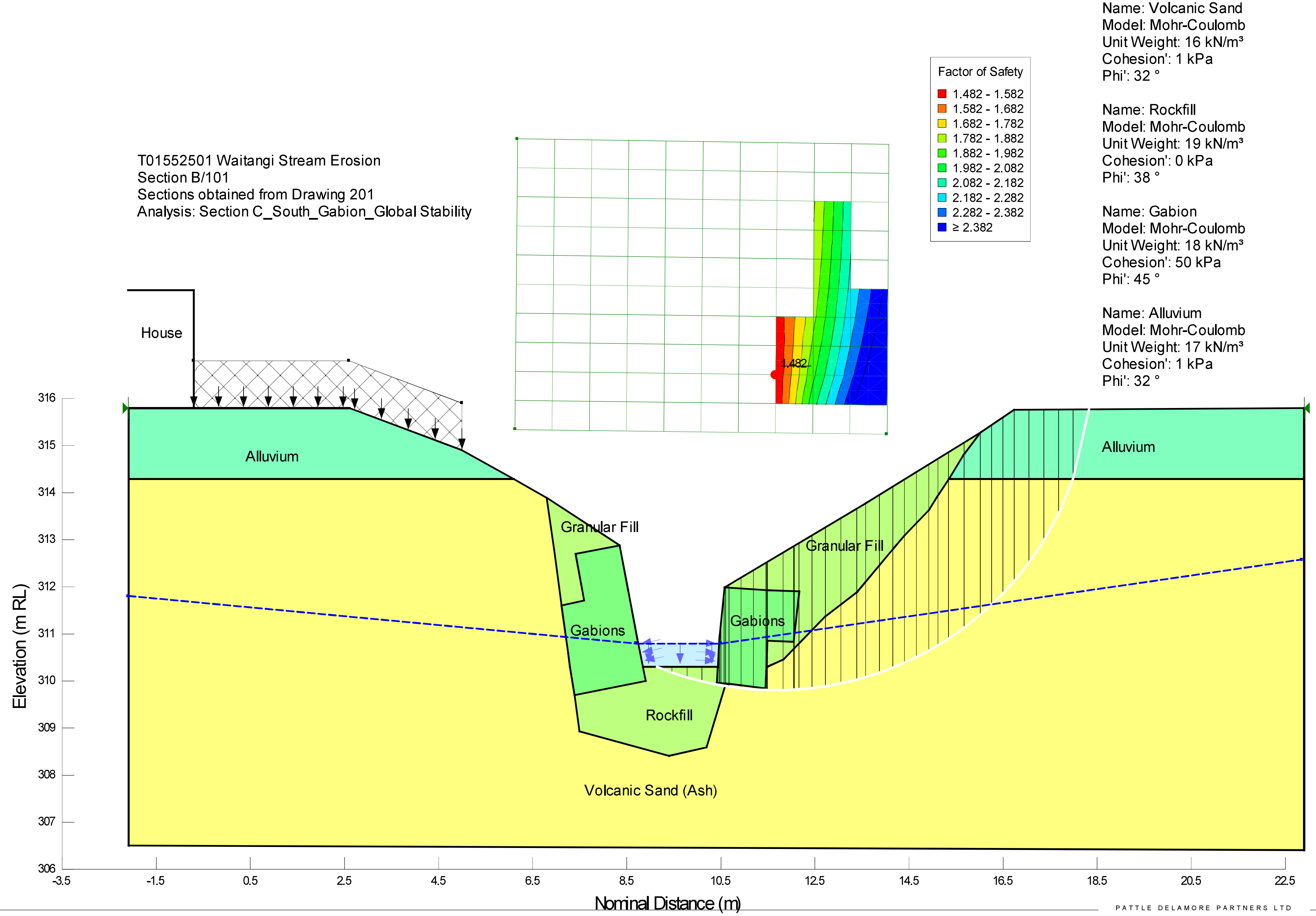
Name: Volcanic Sand (Ash)
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

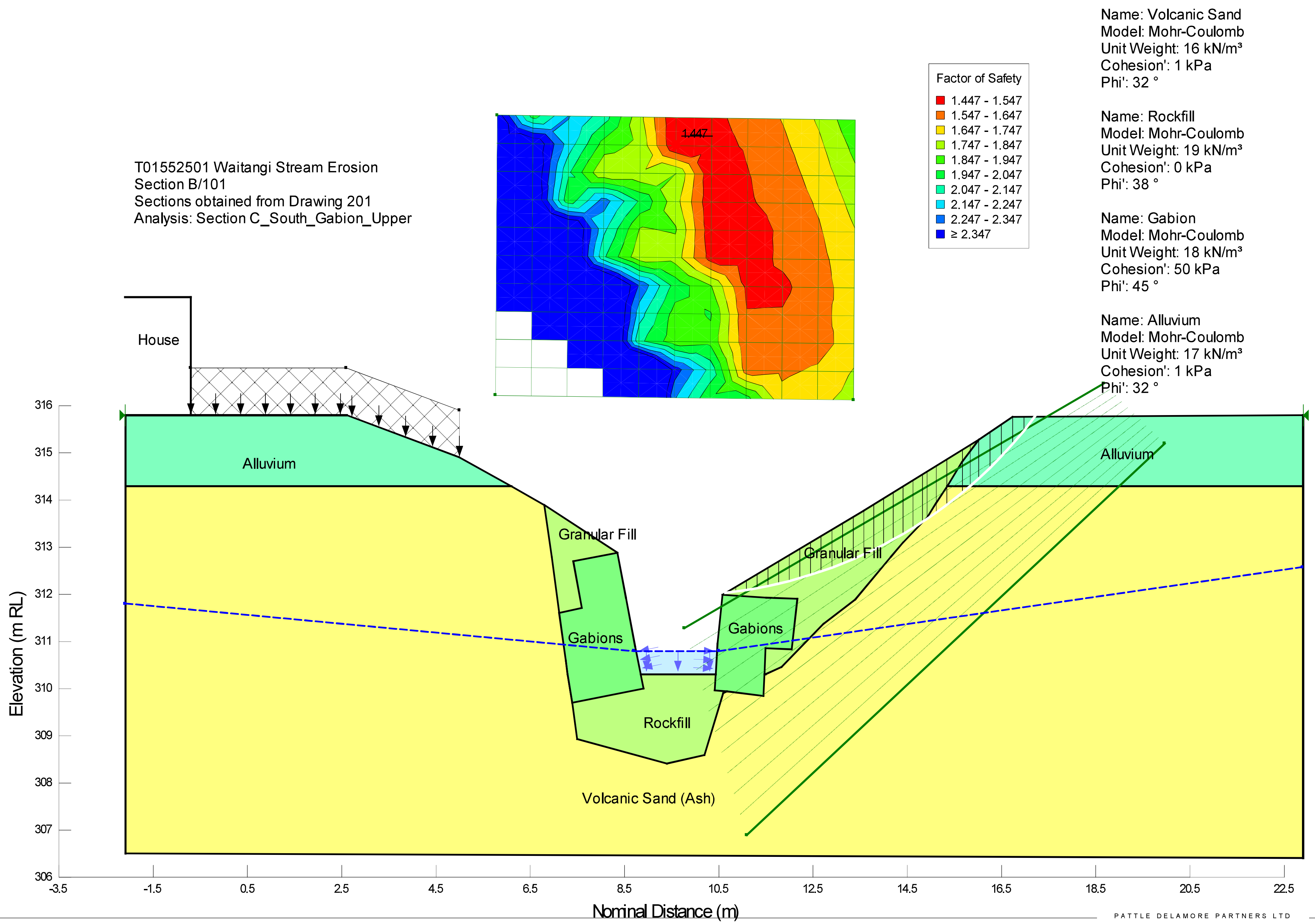
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

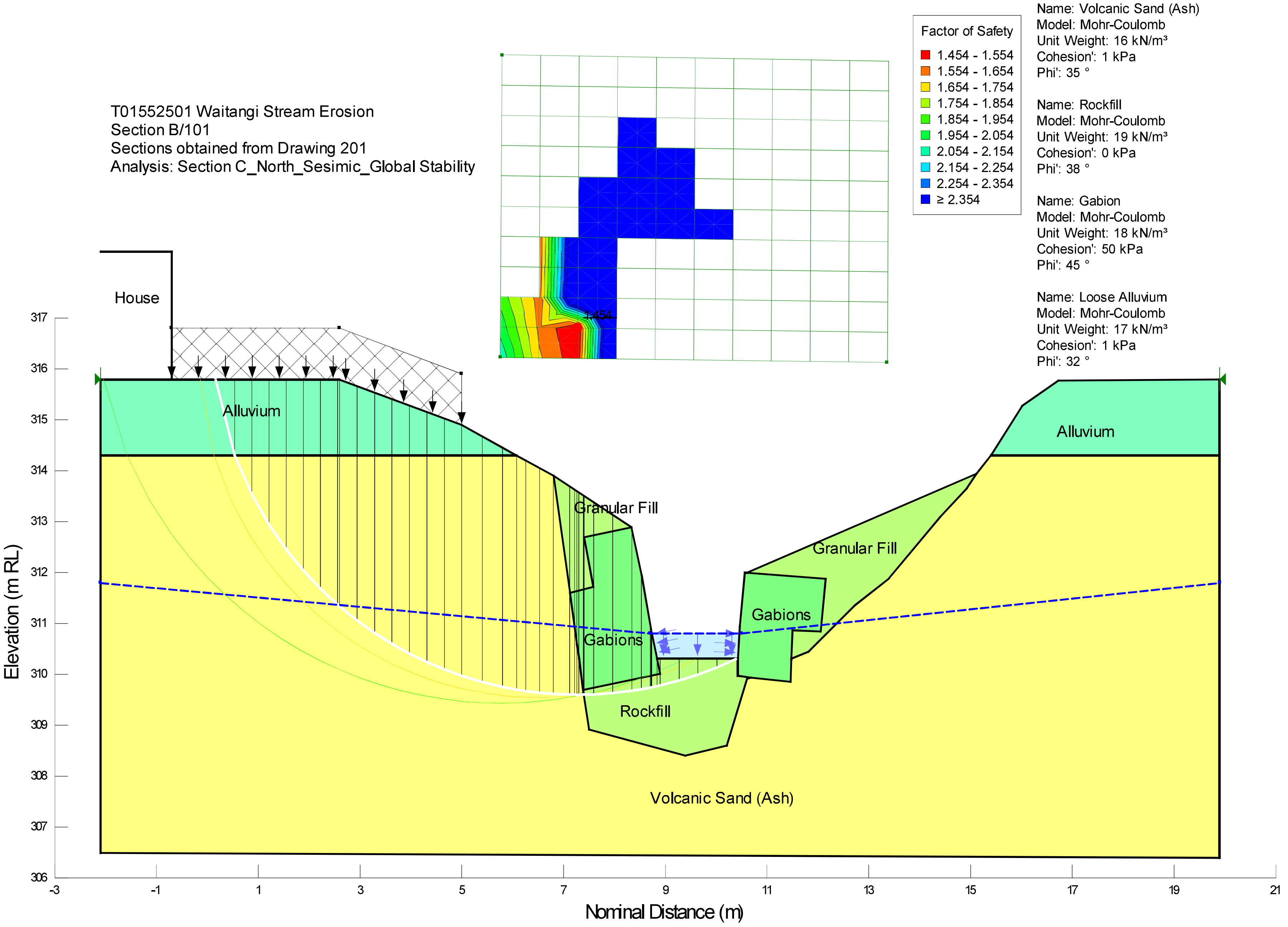
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Loose Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °


T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Gabion_Upper
Factor of Safety
🟥 1.482 - 1.582
🟧 1.582 - 1.682
🟨 1.682 - 1.782
🟩 1.782 - 1.882
🟩 1.882 - 1.982
🟩 1.982 - 2.082
🟩 2.082 - 2.182
🟦 2.182 - 2.282
🟦 2.282 - 2.382
🟦 ≥ 2.382
1.482
Name: Volcanic Sand (Ash)
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °
Name: Loose Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House
Alluvium
Granular Fill
Gabions
Rockfill
Volcanic Sand (Ash)
Granular Fill
Gabions
Alluvium
Elevation (m RL)
317
316
315
314
313
312
311
310
309
308
307
306
-3
-1
1
3
5
7
9
11
13
15
17
19
21
Nominal Distance (m)


T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Gabion_Global Stability
Factor of Safety
🟥 1.482 - 1.582
🟧 1.582 - 1.682
🟨 1.682 - 1.782
🟩 1.782 - 1.882
🟩 1.882 - 1.982
🟩 1.982 - 2.082
🟩 2.082 - 2.182
🟦 2.182 - 2.282
🟦 2.282 - 2.382
🟦 ≥ 2.382
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °
Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
1.482
House
Alluvium
Alluvium
Granular Fill
Granular Fill
Gabions
Gabions
Rockfill
Volcanic Sand (Ash)
Elevation (m RL)
316
315
314
313
312
311
310
309
308
307
306
Nominal Distance (m)
-3.5
-1.5
0.5
2.5
4.5
6.5
8.5
10.5
12.5
14.5
16.5
18.5
20.5
22.5


T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Gabion_Upper
Factor of Safety
🟥 1.447 - 1.547
🟧 1.547 - 1.647
🟨 1.647 - 1.747
🟩 1.747 - 1.847
🟩 1.847 - 1.947
🟩 1.947 - 2.047
🟩 2.047 - 2.147
🟦 2.147 - 2.247
🟦 2.247 - 2.347
🟦 ≥ 2.347
1.447
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °
Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House
Alluvium
Granular Fill
Gabions
Rockfill
Volcanic Sand (Ash)
Granular Fill
Gabions
Alluvium
Elevation (m RL)
316
315
314
313
312
311
310
309
308
307
306
Nominal Distance (m)
-3.5
-1.5
0.5
2.5
4.5
6.5
8.5
10.5
12.5
14.5
16.5
18.5
20.5
22.5



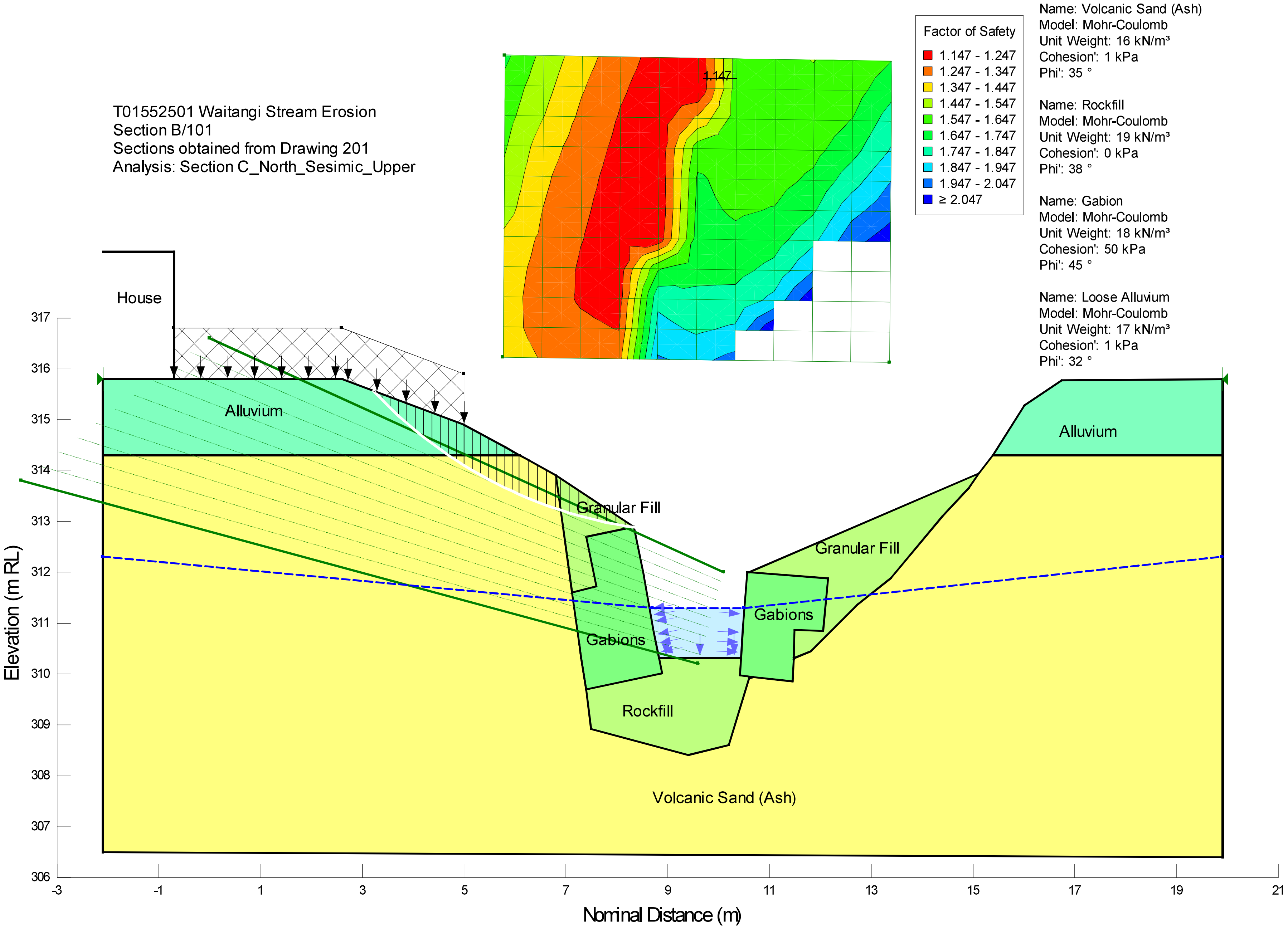
T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Sesimic_Global Stability

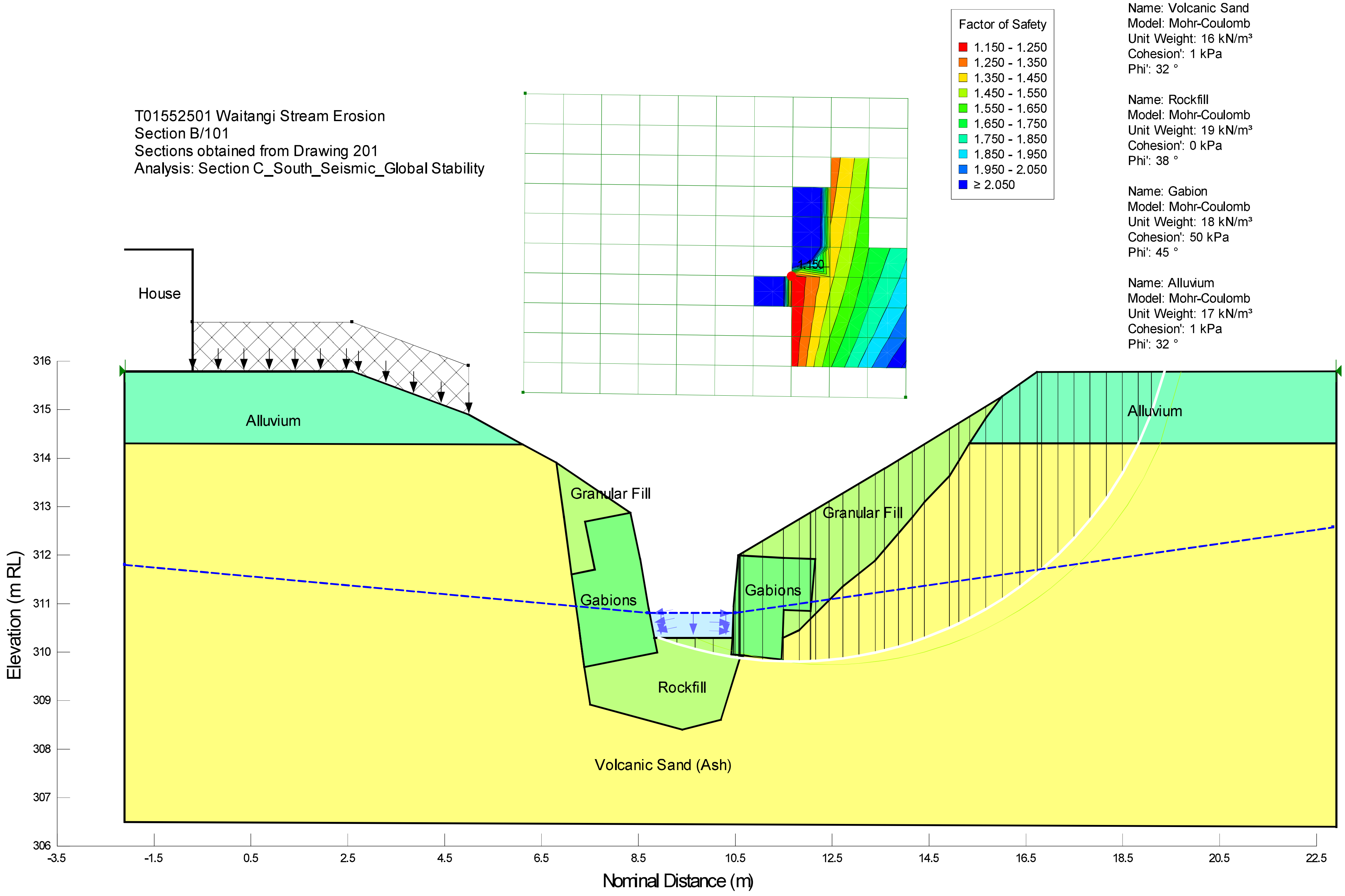
Name: Volcanic Sand (Ash)
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Loose Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °


T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_North_Sesimic_Upper
Factor of Safety
🟥 1.147 - 1.247
🟧 1.247 - 1.347
🟨 1.347 - 1.447
1.447 - 1.547
🟩 1.547 - 1.647
1.647 - 1.747
1.747 - 1.847
1.847 - 1.947
🟦 1.947 - 2.047
≥ 2.047
1.147
Name: Volcanic Sand (Ash)
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °
Name: Loose Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House
Alluvium
Alluvium
Granular Fill
Granular Fill
Gabions
Gabions
Rockfill
Volcanic Sand (Ash)
Elevation (m RL)
317
316
315
314
313
312
311
310
309
308
307
306
-3
-1
1
3
5
7
9
11
13
15
17
19
21
Nominal Distance (m)



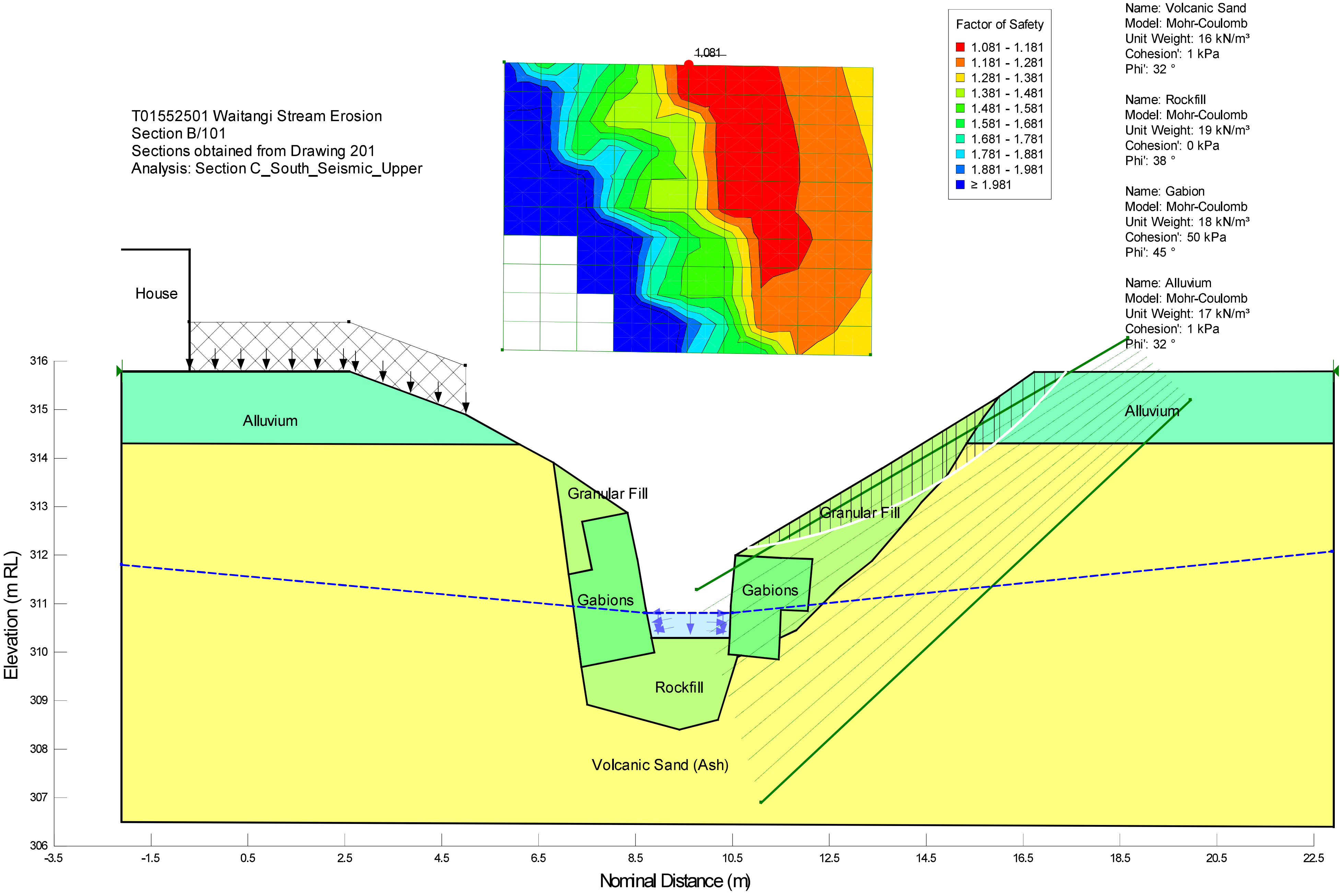
T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Seismic_Global Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



T01552501 Waitangi Stream Erosion
Section B/101
Sections obtained from Drawing 201
Analysis: Section C_South_Seismic_Upper

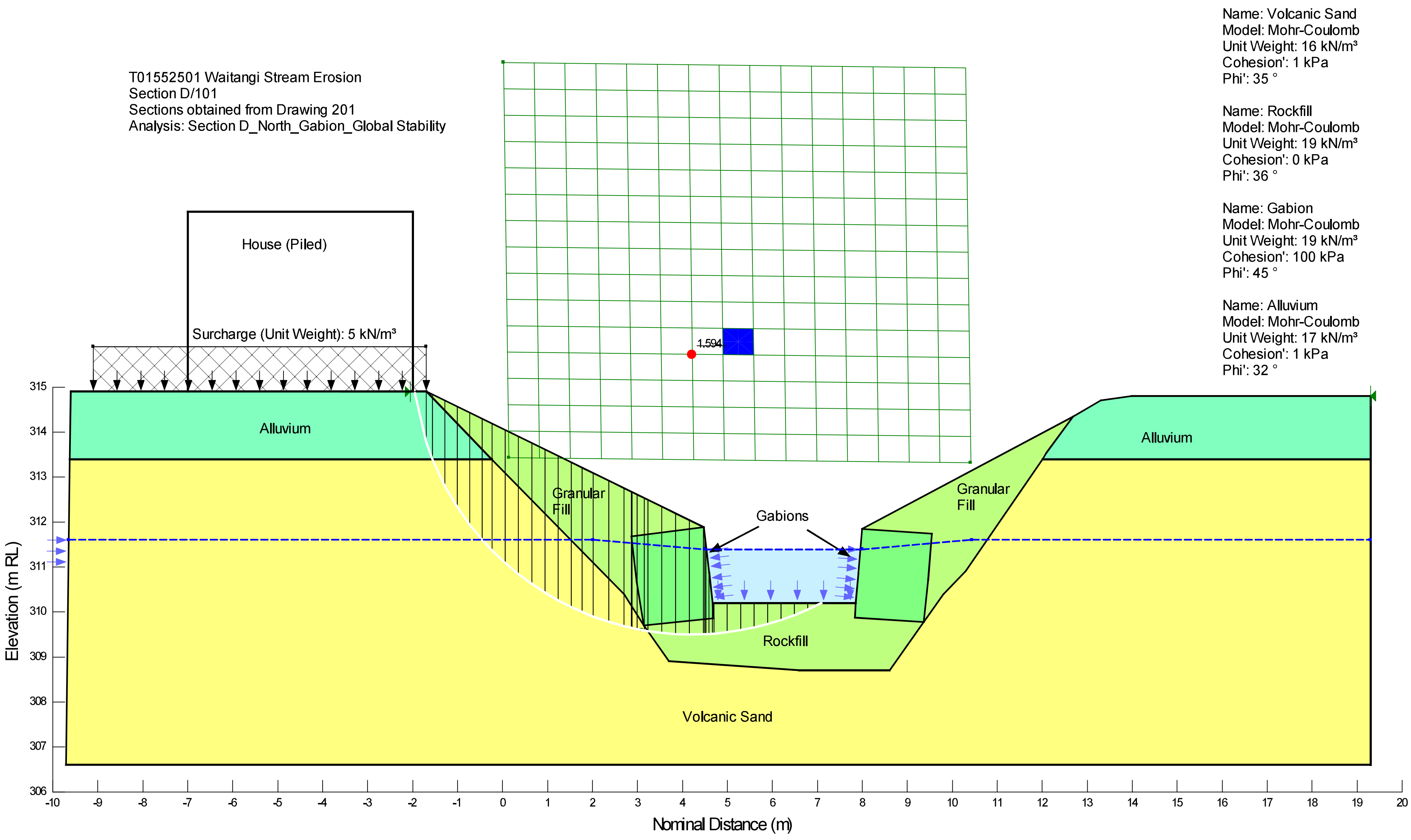
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 32 °

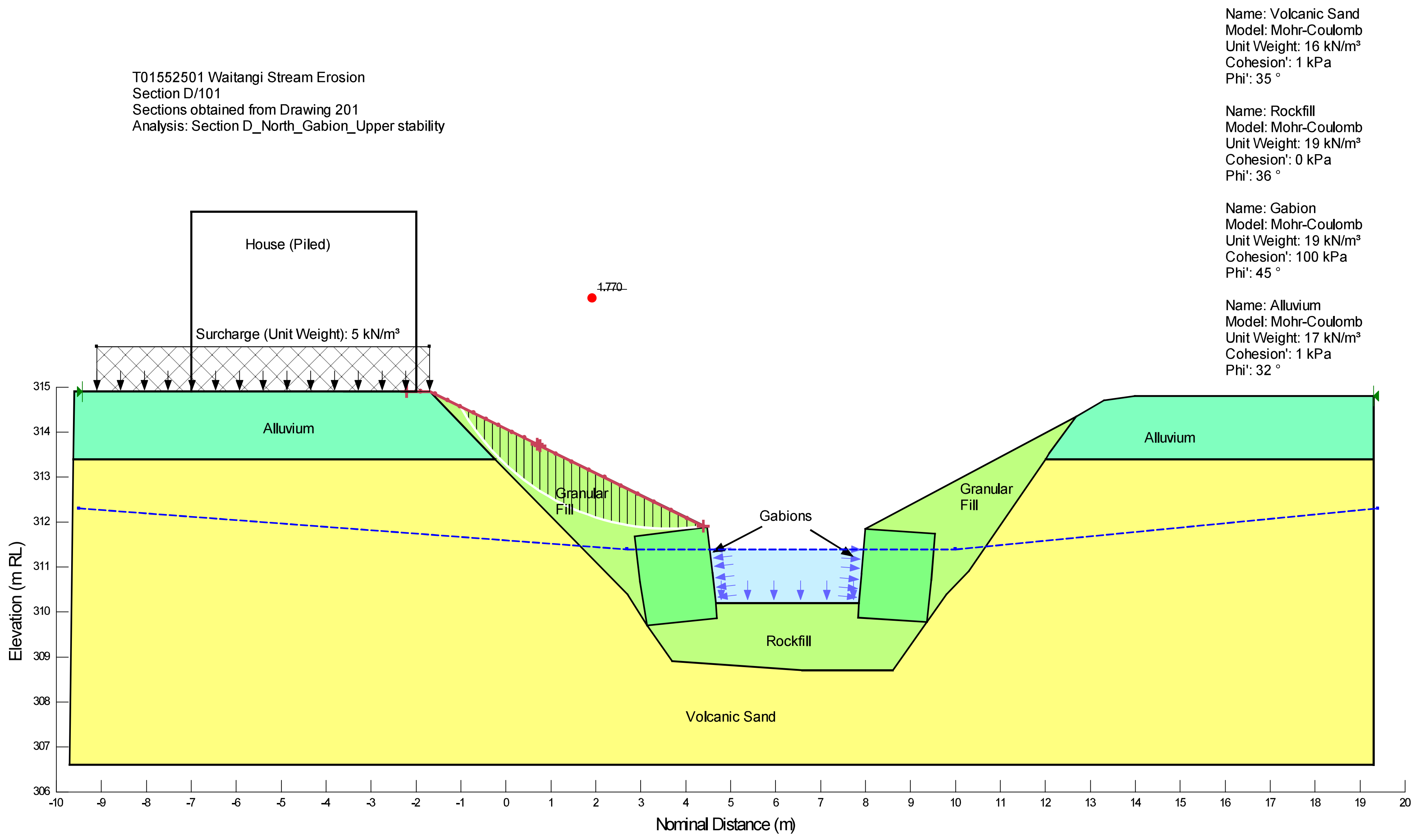
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 38 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 18 kN/m³
Cohesion': 50 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

Factor of Safety
🟥 1.081 - 1.181
🟧 1.181 - 1.281
🟨 1.281 - 1.381
🟩 1.381 - 1.481
🟩 1.481 - 1.581
🟩 1.581 - 1.681
🟩 1.681 - 1.781
🟦 1.781 - 1.881
🟦 1.881 - 1.981
🟦 ≥ 1.981


T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_North_Gabion_Global Stability
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °
Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °
Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House (Piled)
Surcharge (Unit Weight): 5 kN/m³
1.594
Alluvium
Granular Fill
Gabions
Granular Fill
Alluvium
Rockfill
Volcanic Sand
Elevation (m RL)
315
314
313
312
311
310
309
308
307
306
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Nominal Distance (m)



T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_North_Gabion_Upper stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

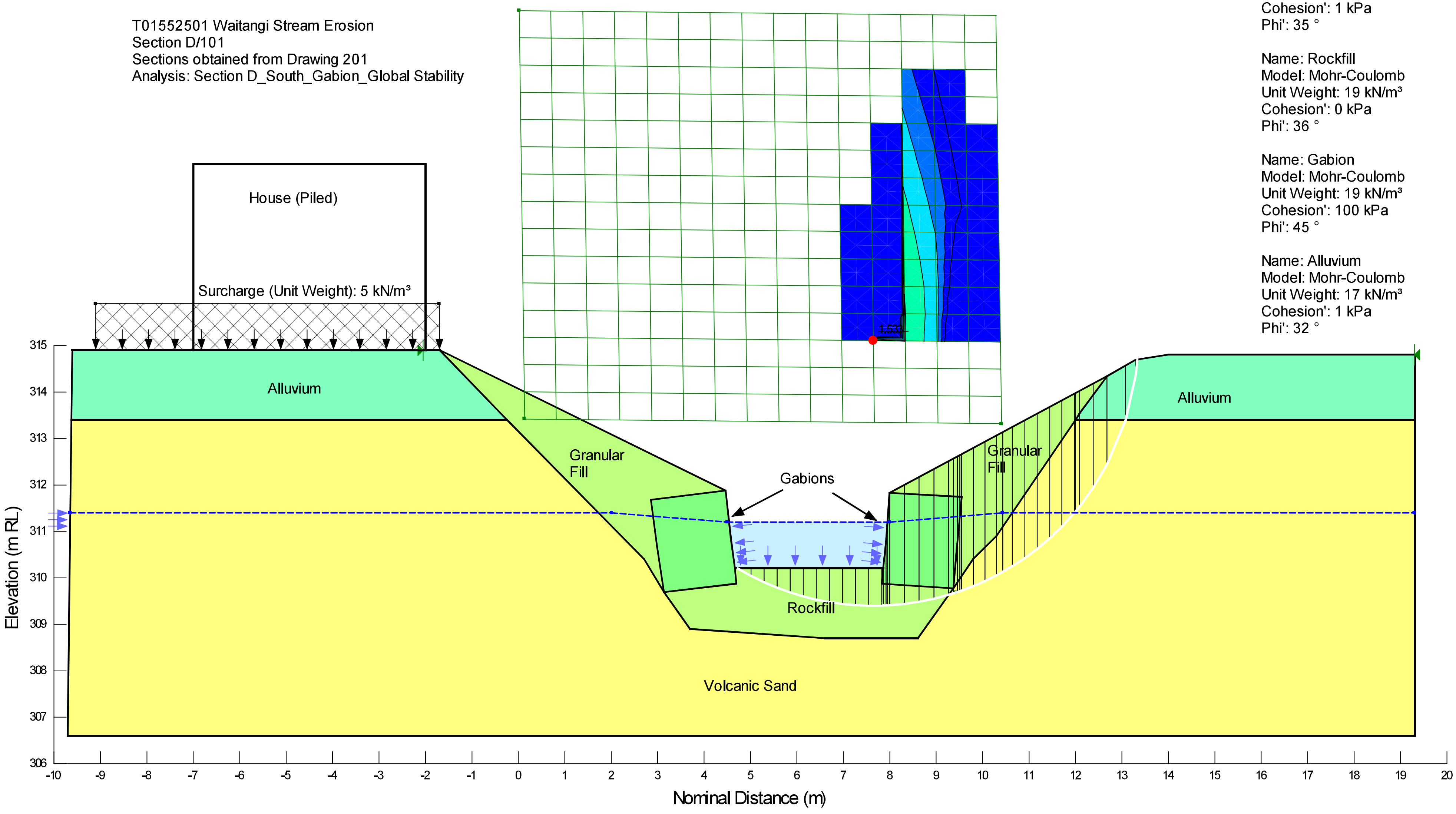
T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_South_Gabion_Global Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



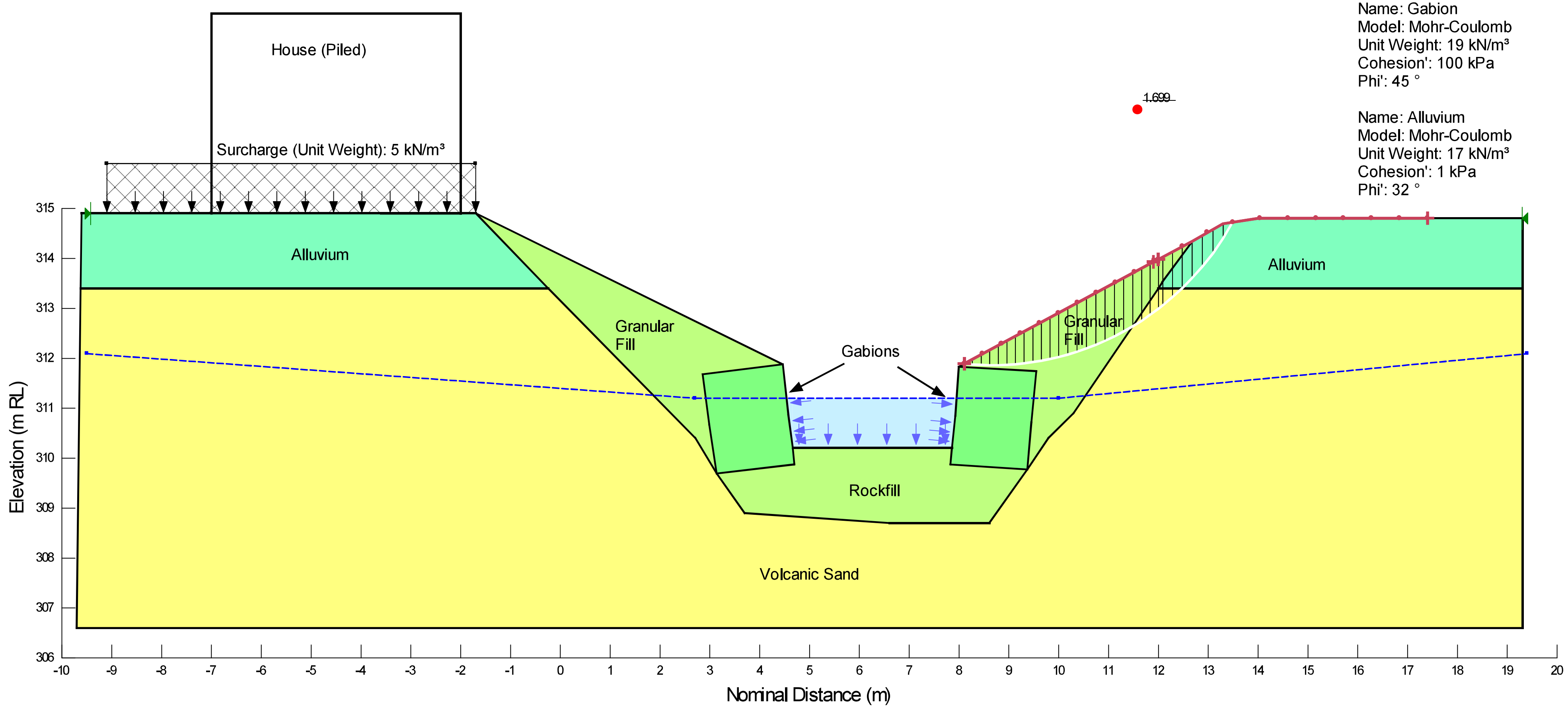
T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_South_Gabion_Upper stability

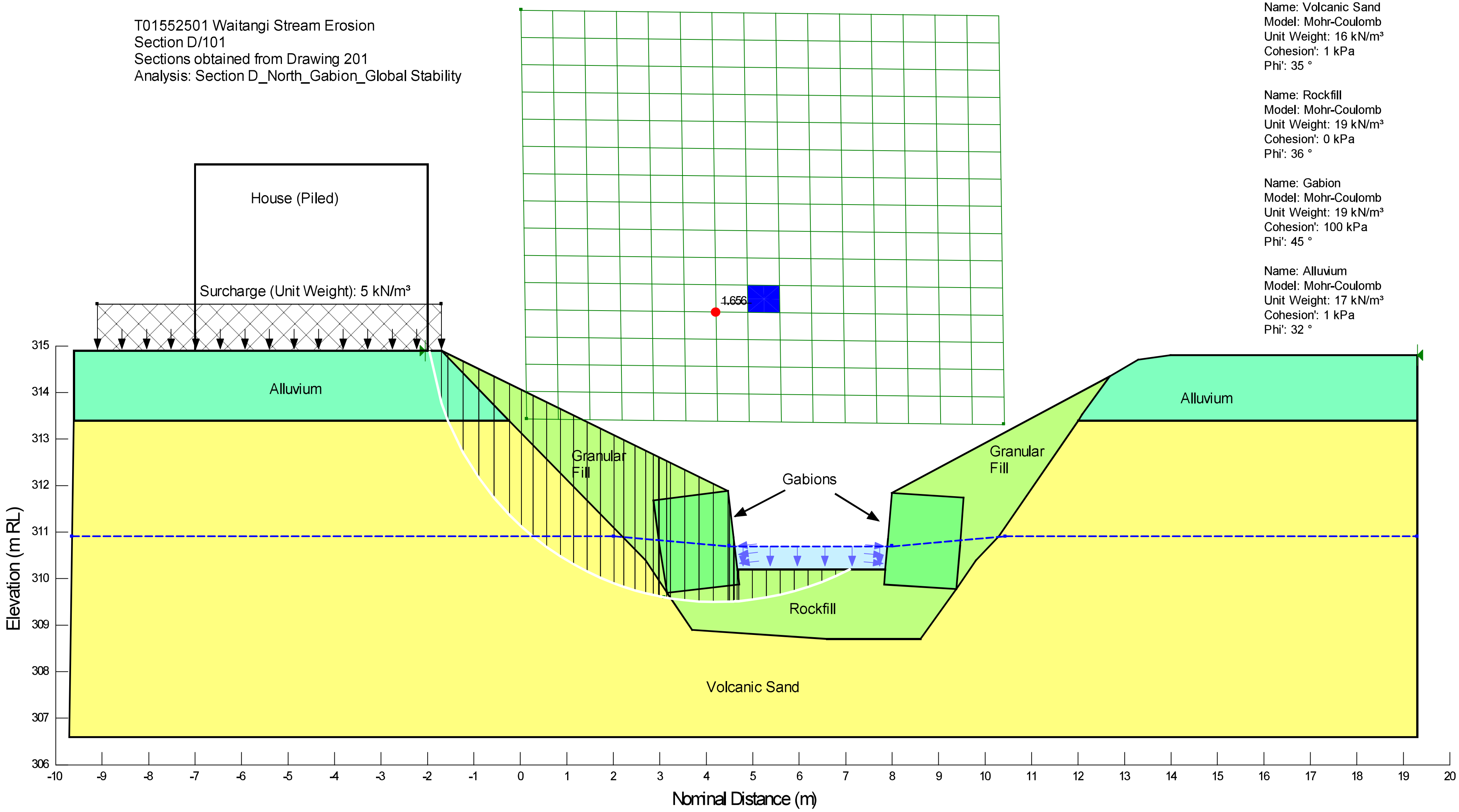
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_North_Gabion_Global Stability

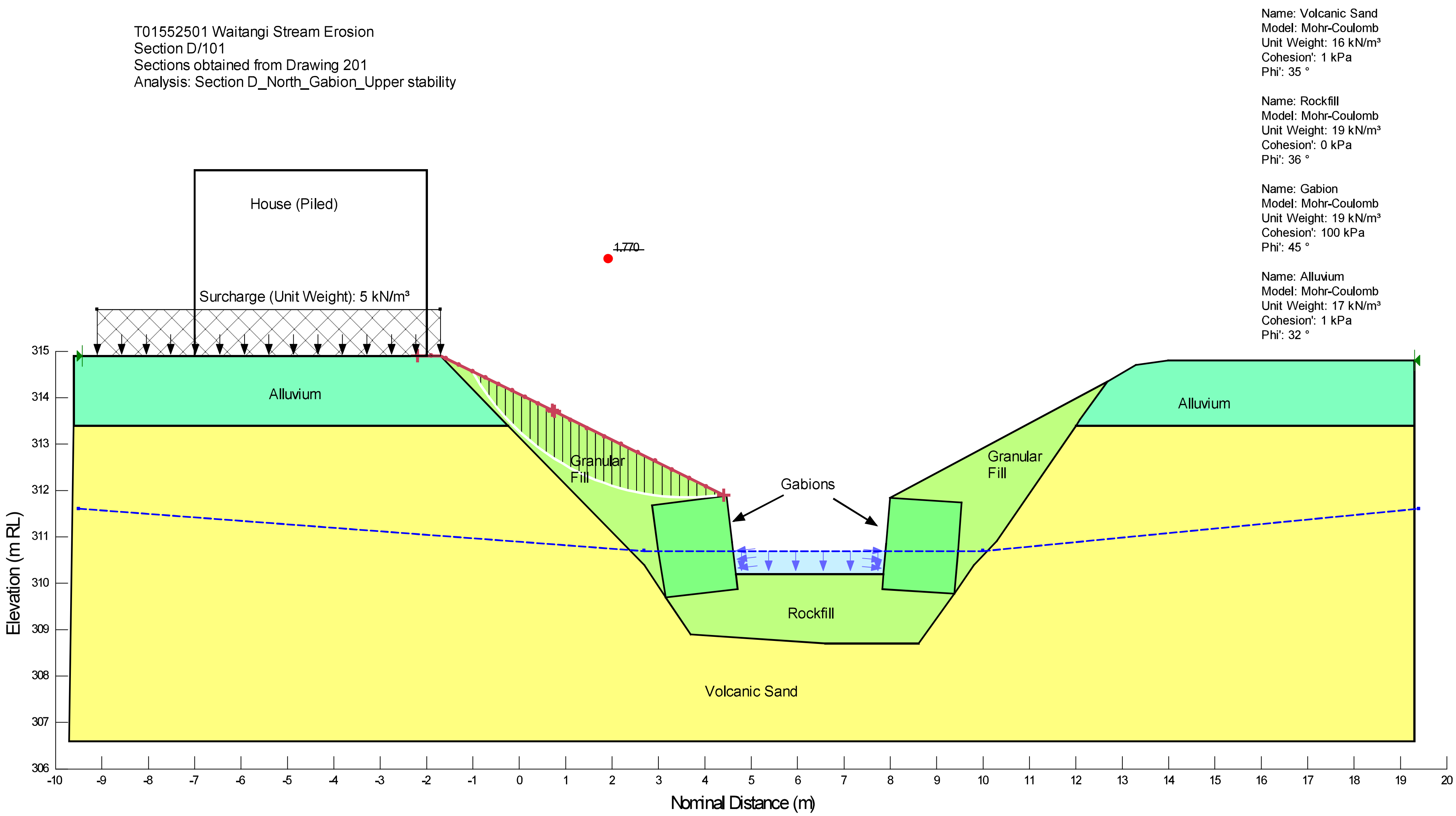
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °

T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_North_Gabion_Upper stability

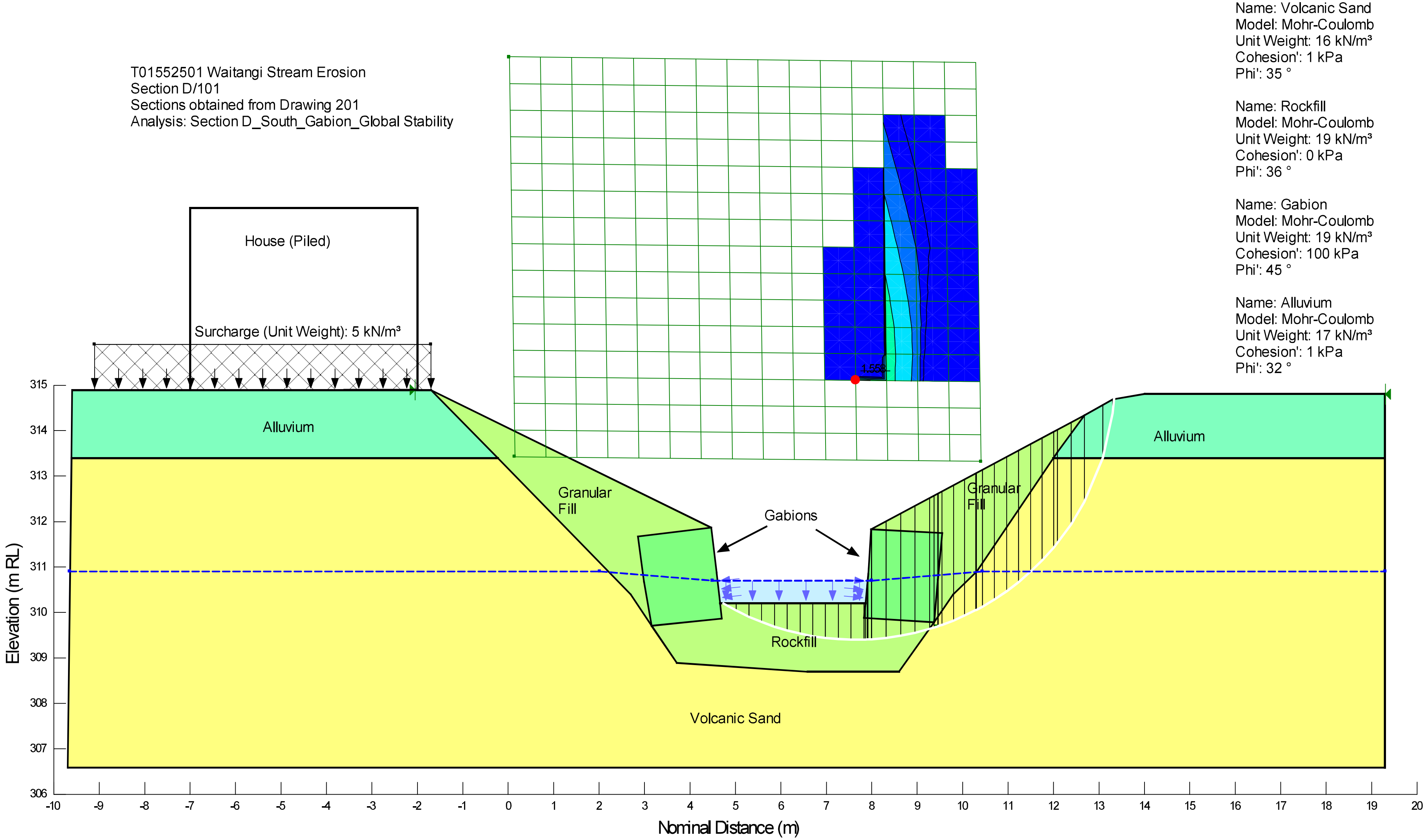


Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



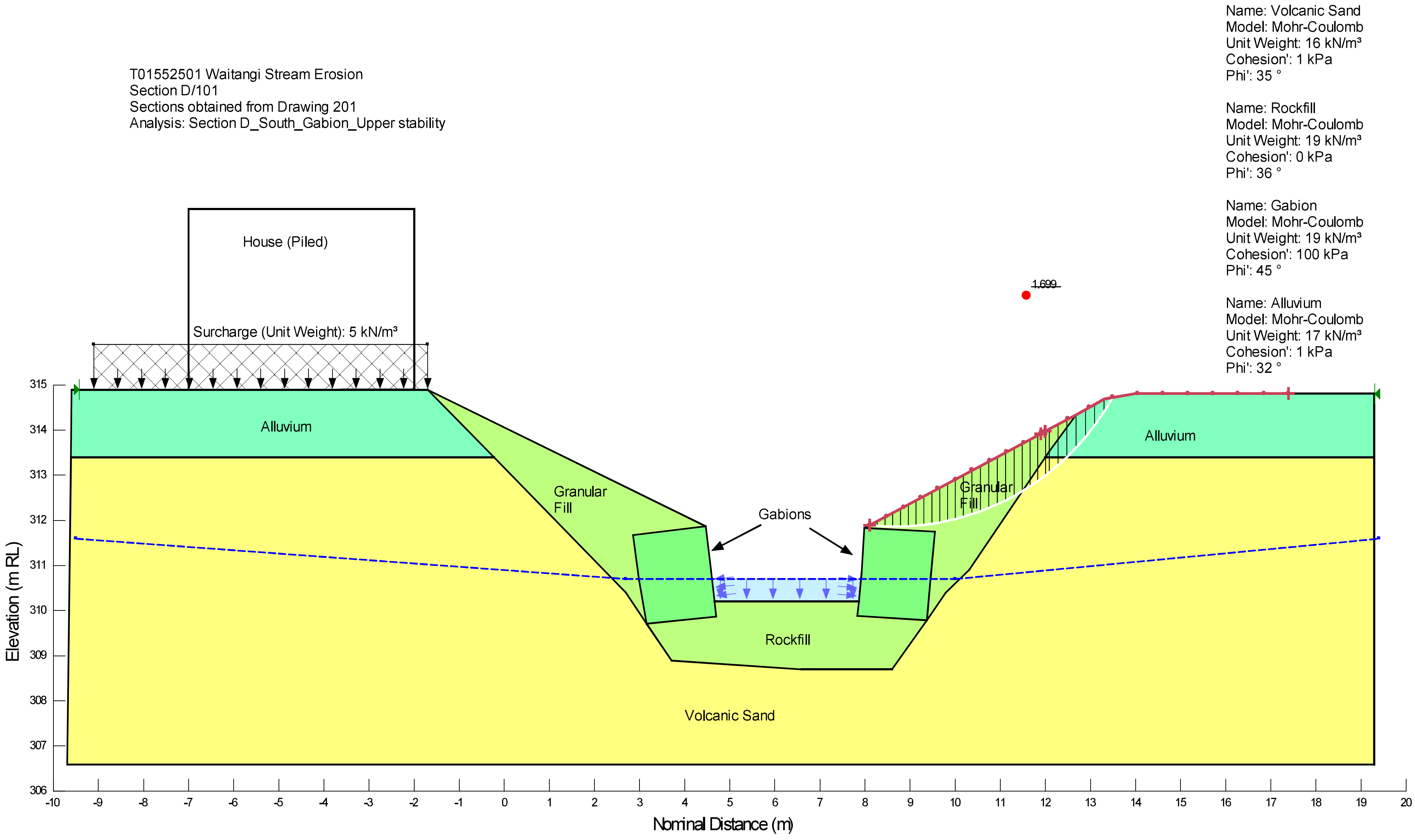
T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_South_Gabion_Global Stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °



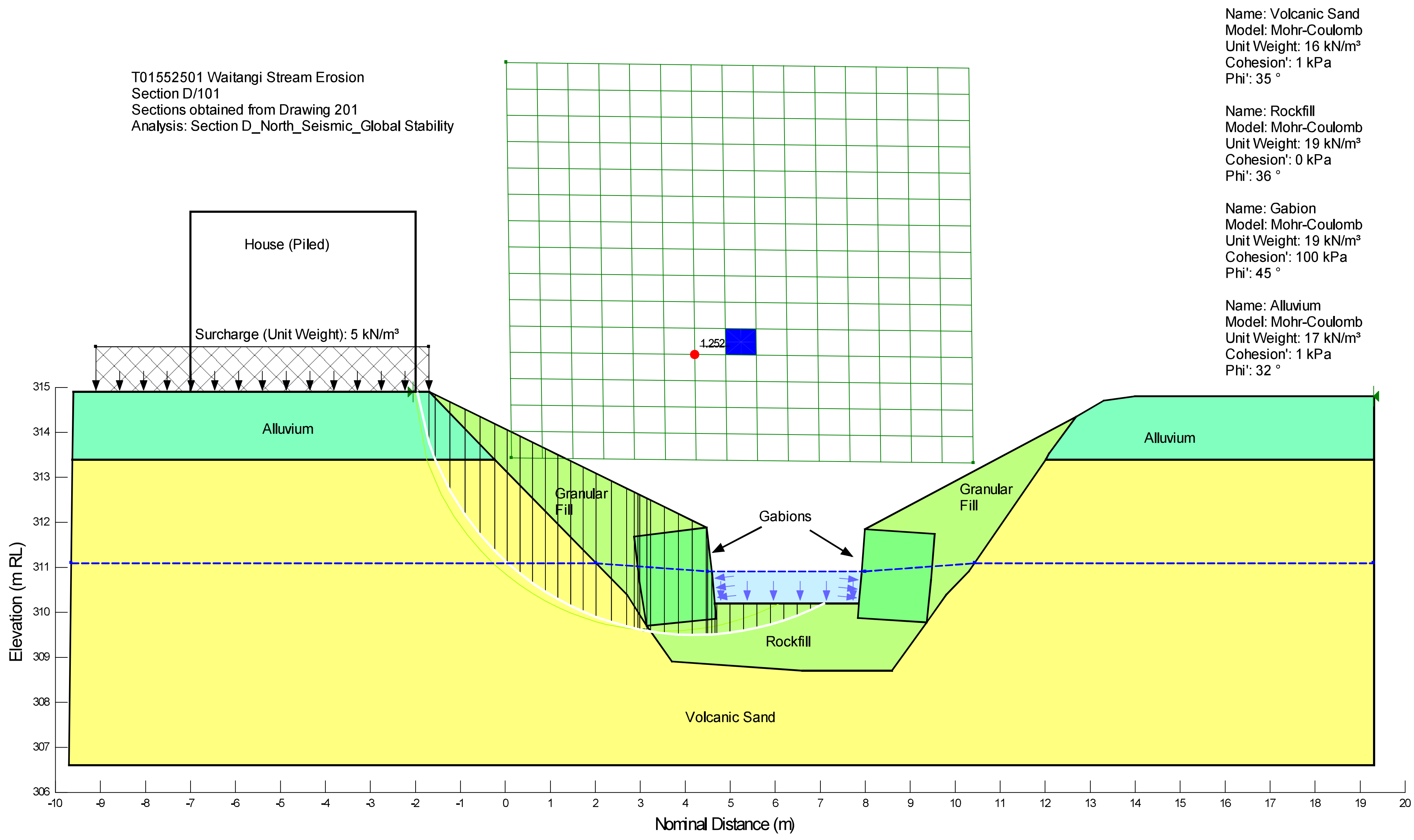
T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_South_Gabion_Upper stability

Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °

Name: Rockfill
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °

Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °

Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °


T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section D_North_Seismic_Global Stability
Name: Volcanic Sand
Model: Mohr-Coulomb
Unit Weight: 16 kN/m³
Cohesion': 1 kPa
Phi': 35 °
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Unit Weight: 19 kN/m³
Cohesion': 0 kPa
Phi': 36 °
Name: Gabion
Model: Mohr-Coulomb
Unit Weight: 19 kN/m³
Cohesion': 100 kPa
Phi': 45 °
Name: Alluvium
Model: Mohr-Coulomb
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °
House (Piled)
Surcharge (Unit Weight): 5 kN/m³
1.252
Alluvium
Granular Fill
Gabions
Granular Fill
Alluvium
Rockfill
Volcanic Sand
Elevation (m RL)
315
314
313
312
311
310
309
308
307
306
-10
-9
-8
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Nominal Distance (m)

T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
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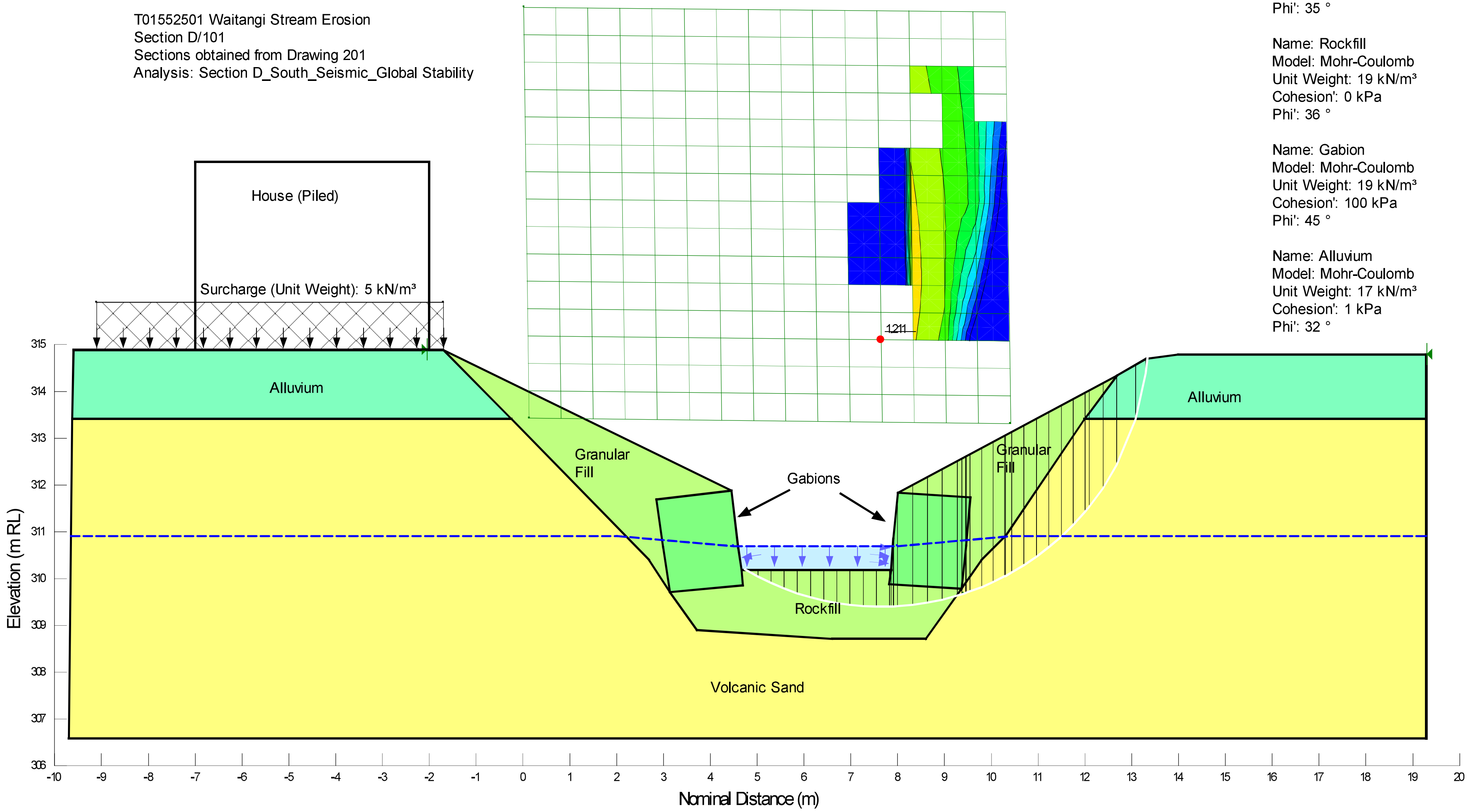
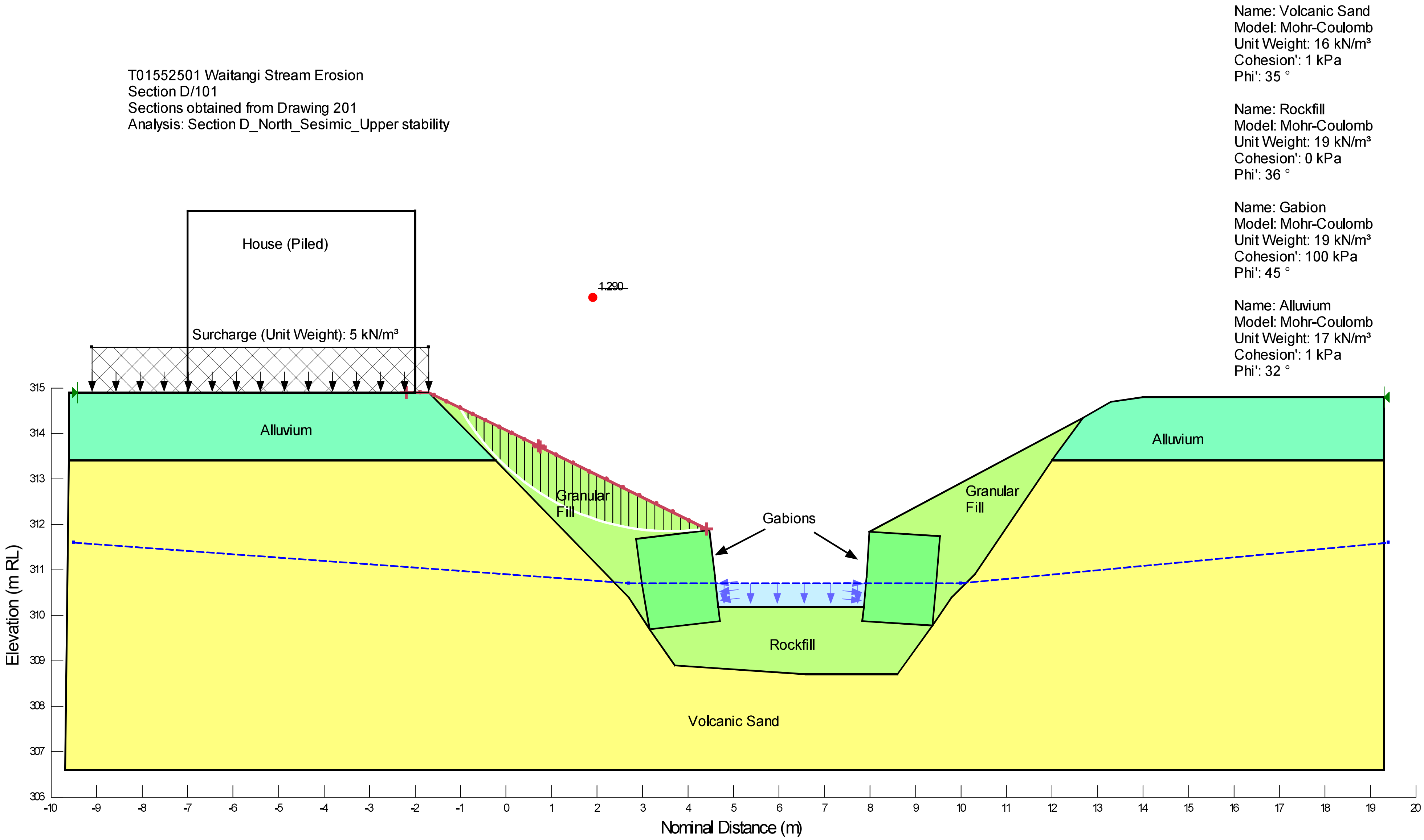
Unit Weight: 17 kN/m³
Cohesion': 1 kPa
Phi': 32 °





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Section D/101
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Analysis: Section D_North_Sesimic_Upper stability

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Unit Weight: 17 kN/m³
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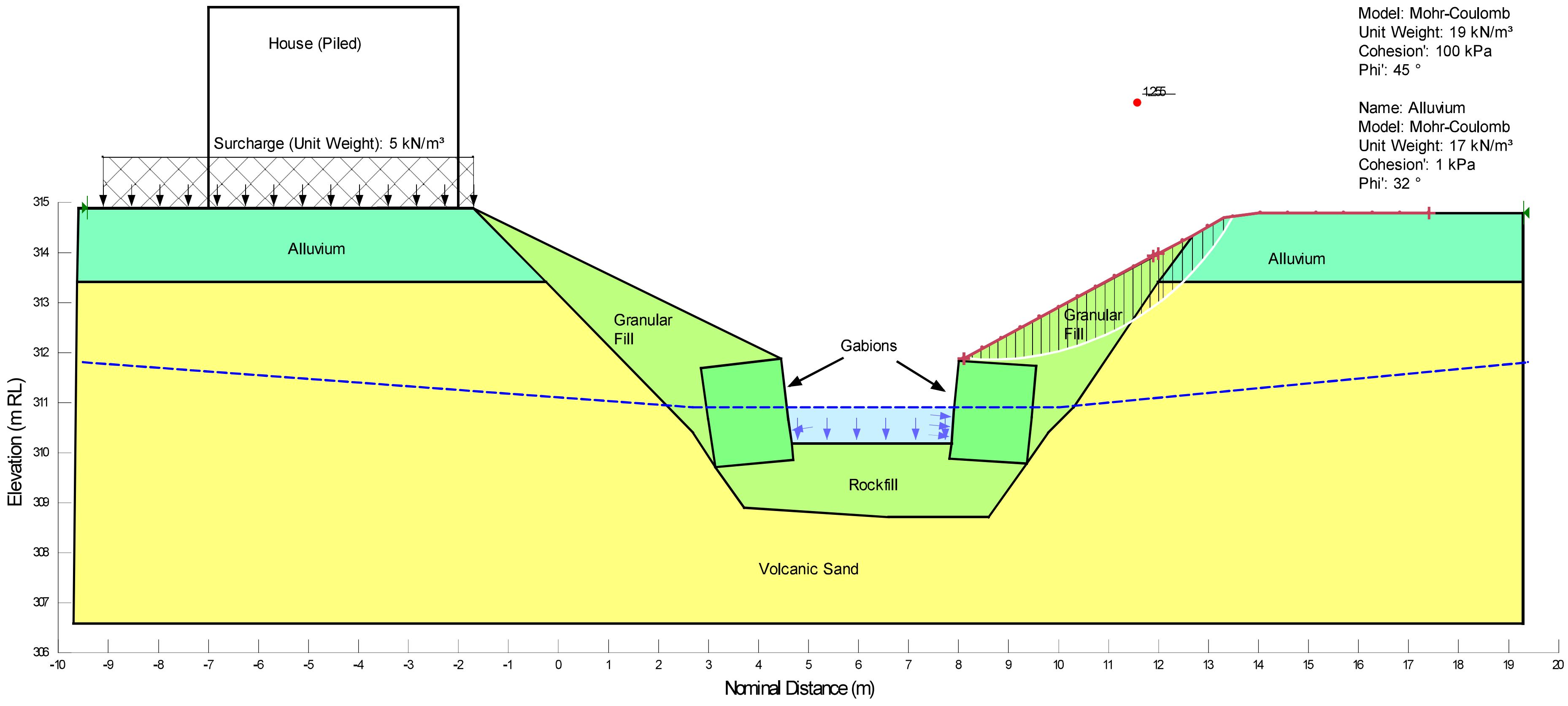
Phi': 32 °



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Sections obtained from Drawing 201
Analysis: Section G_North_Gabion_Global Stability

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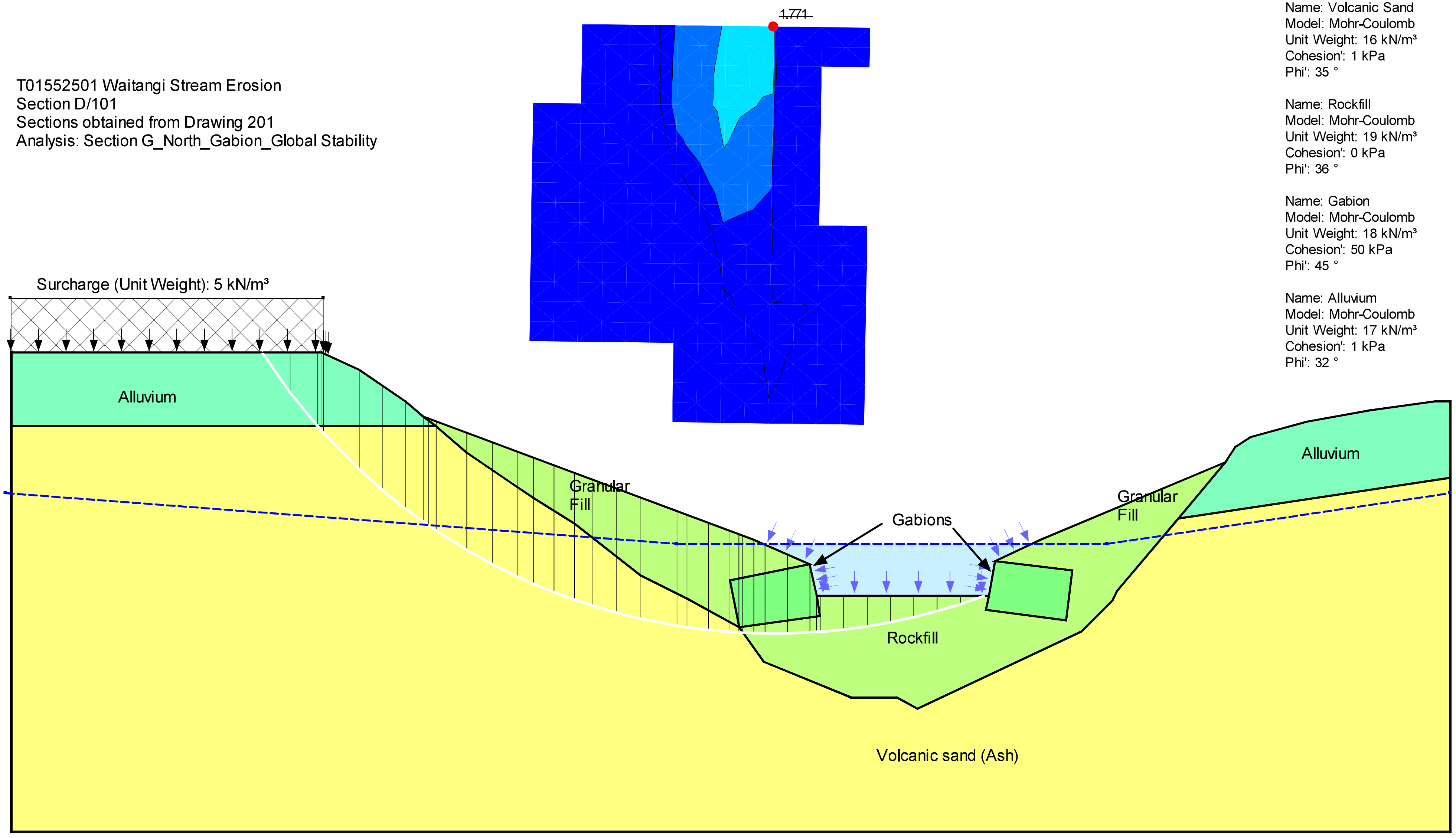

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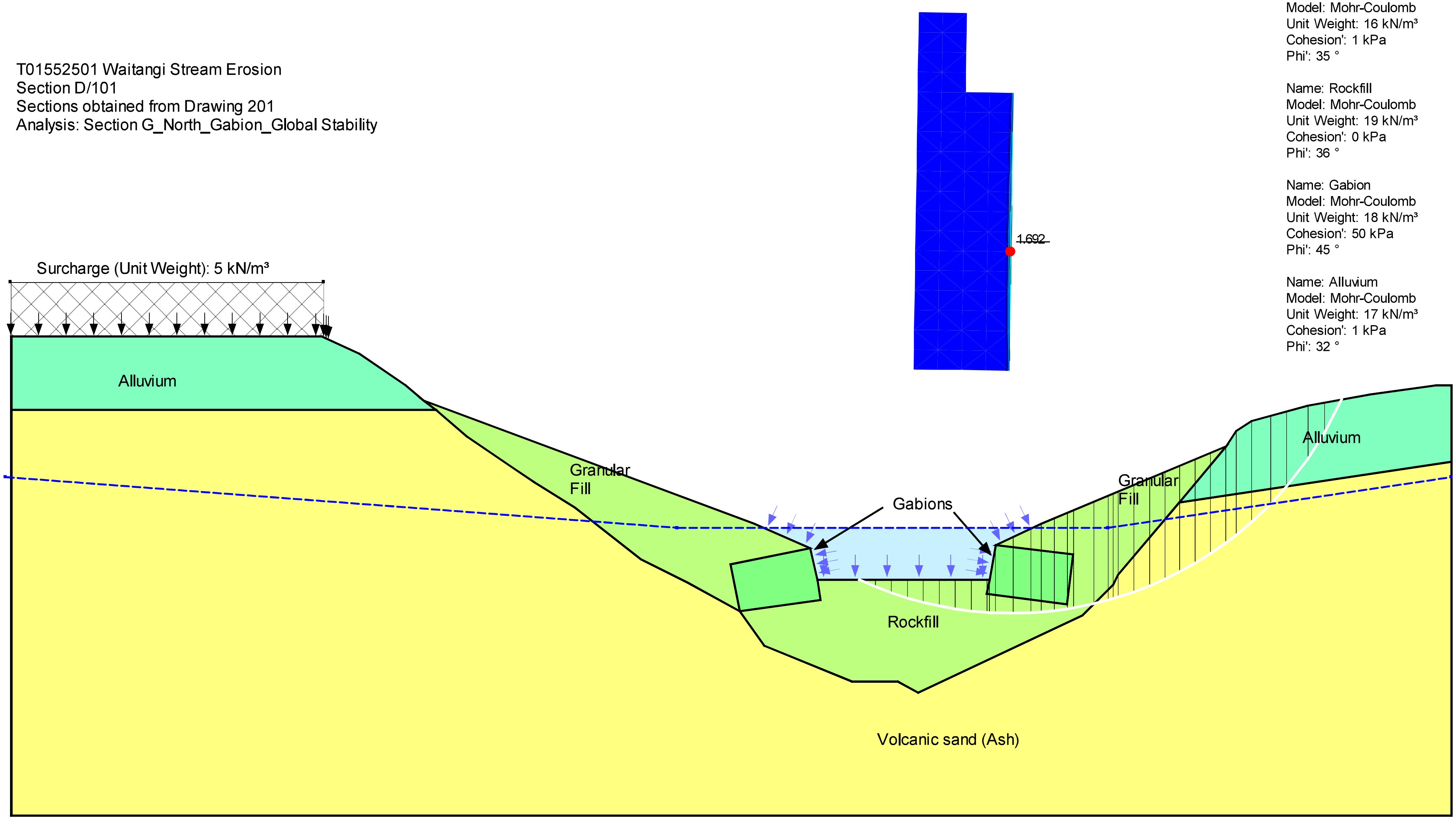

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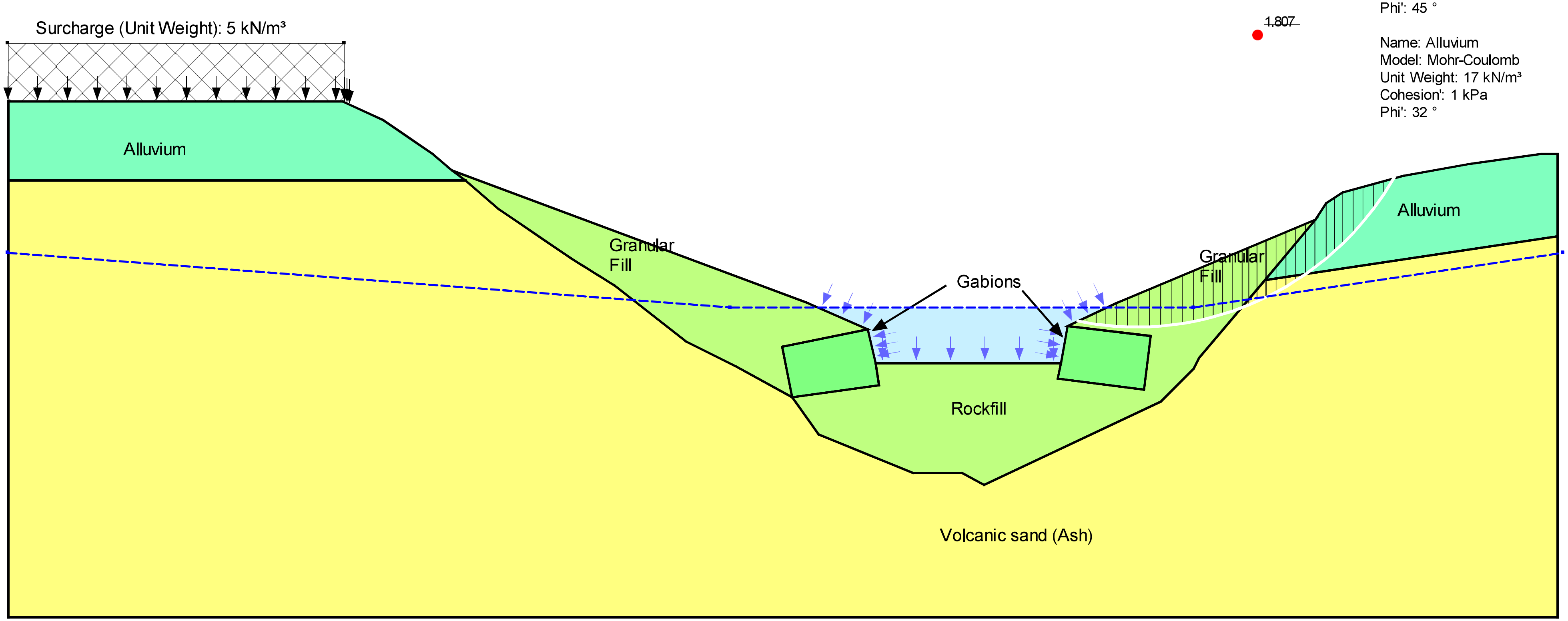

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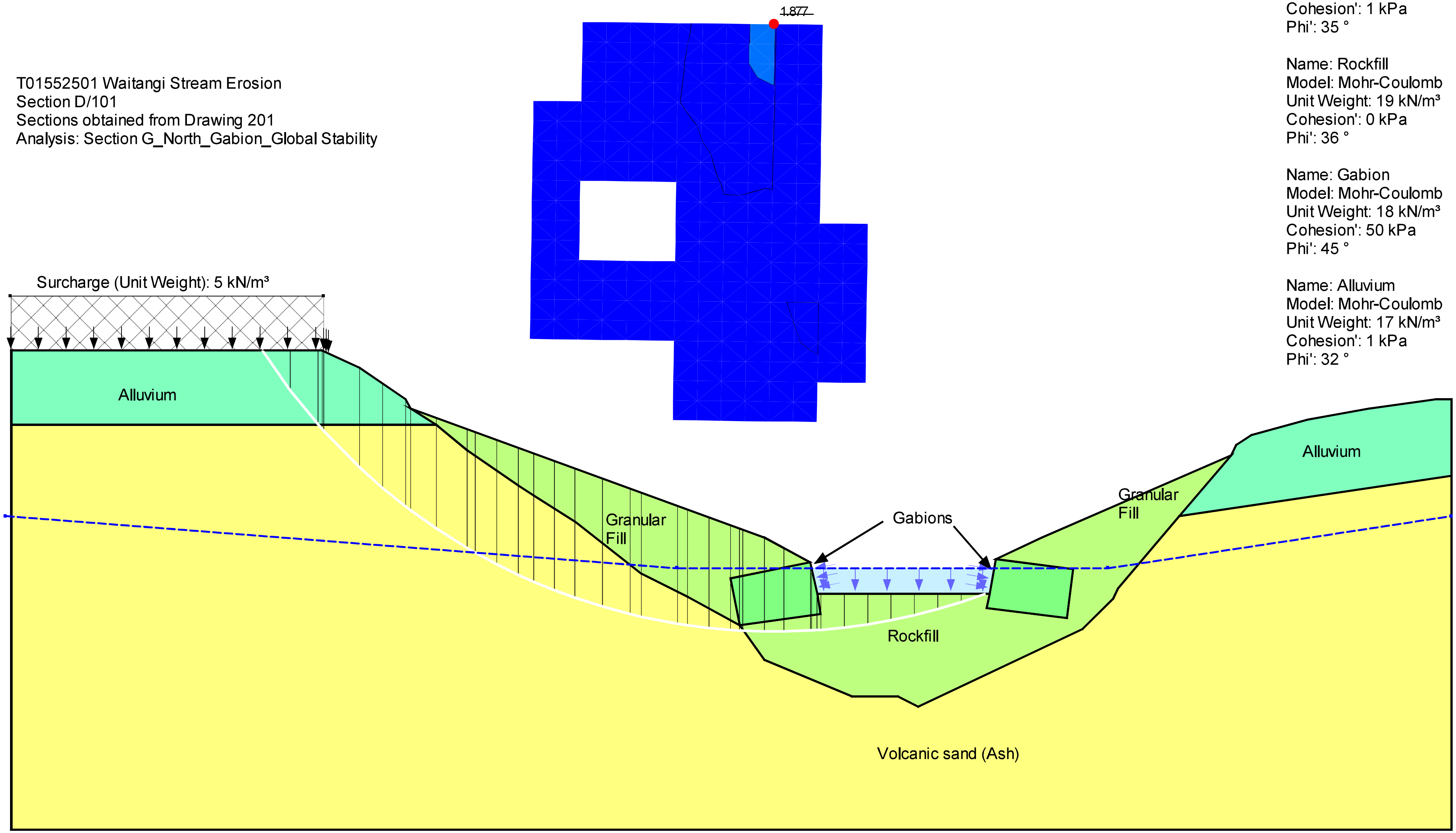

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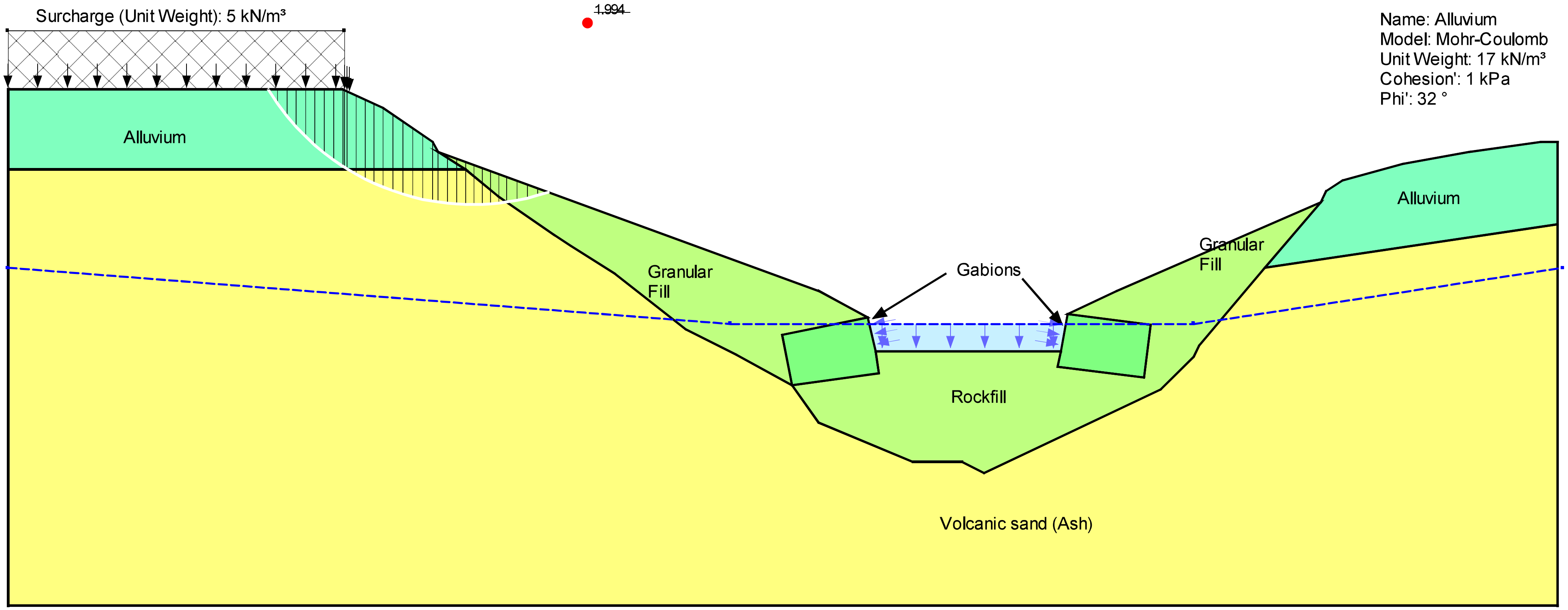

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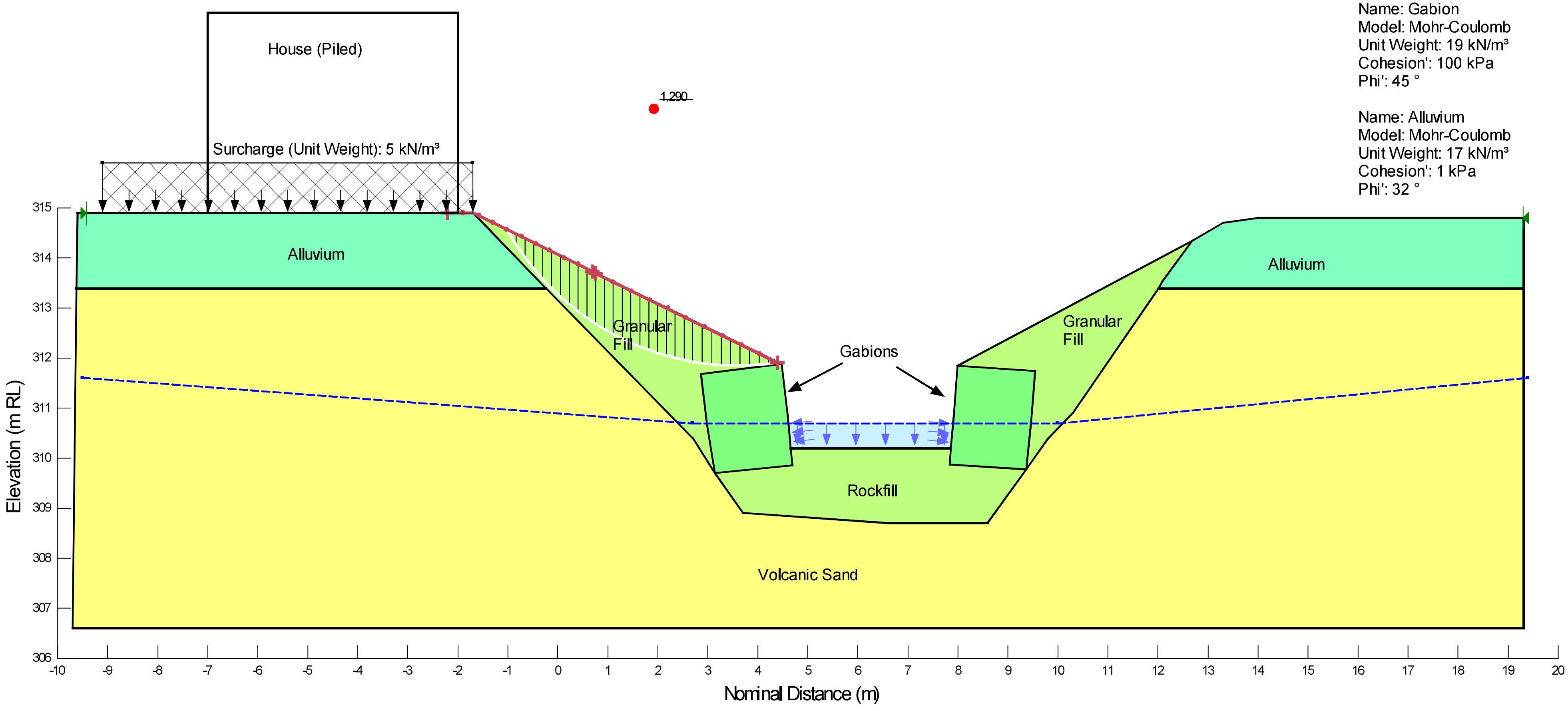

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Section D/101
Sections obtained from Drawing 201
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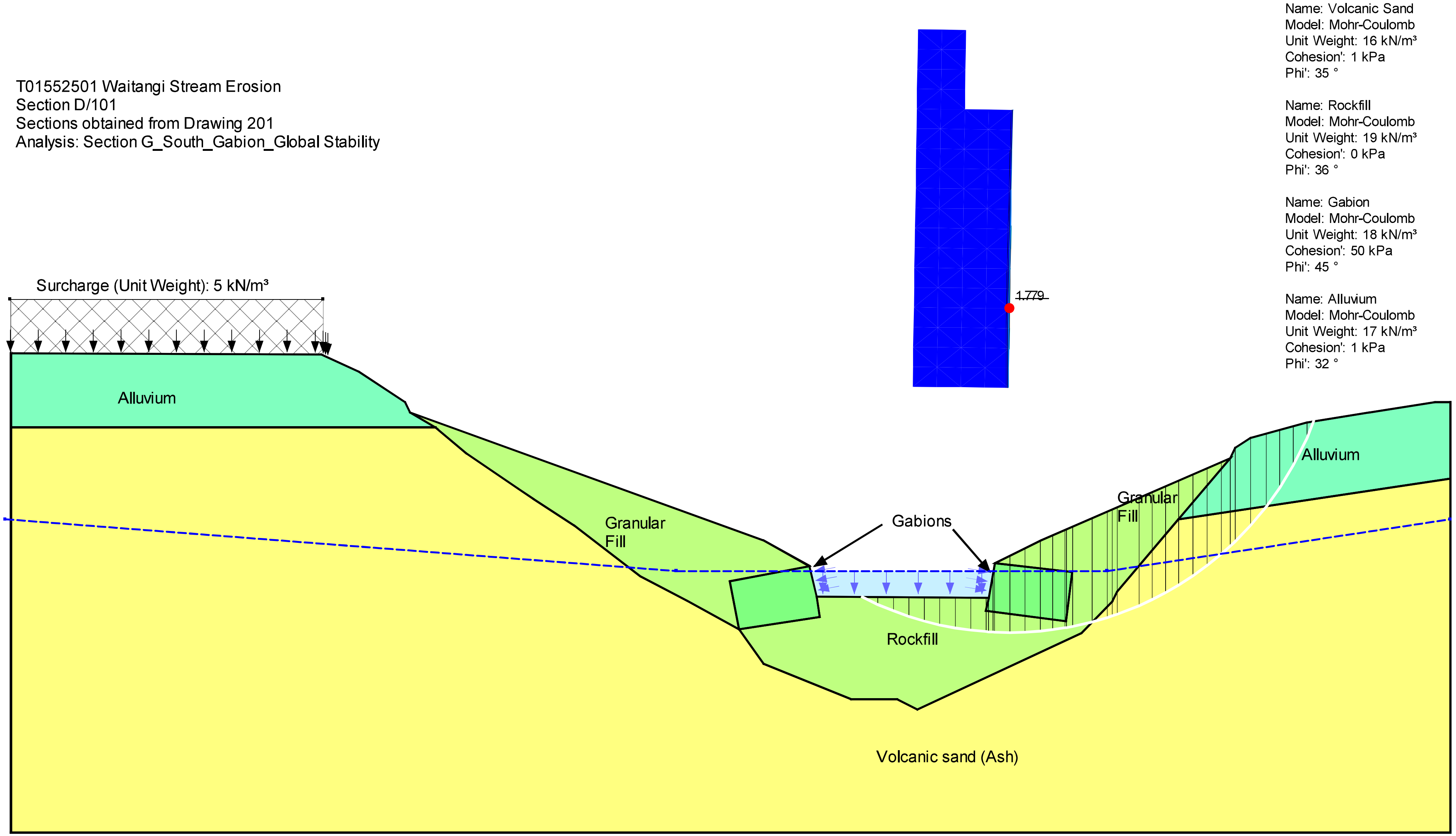

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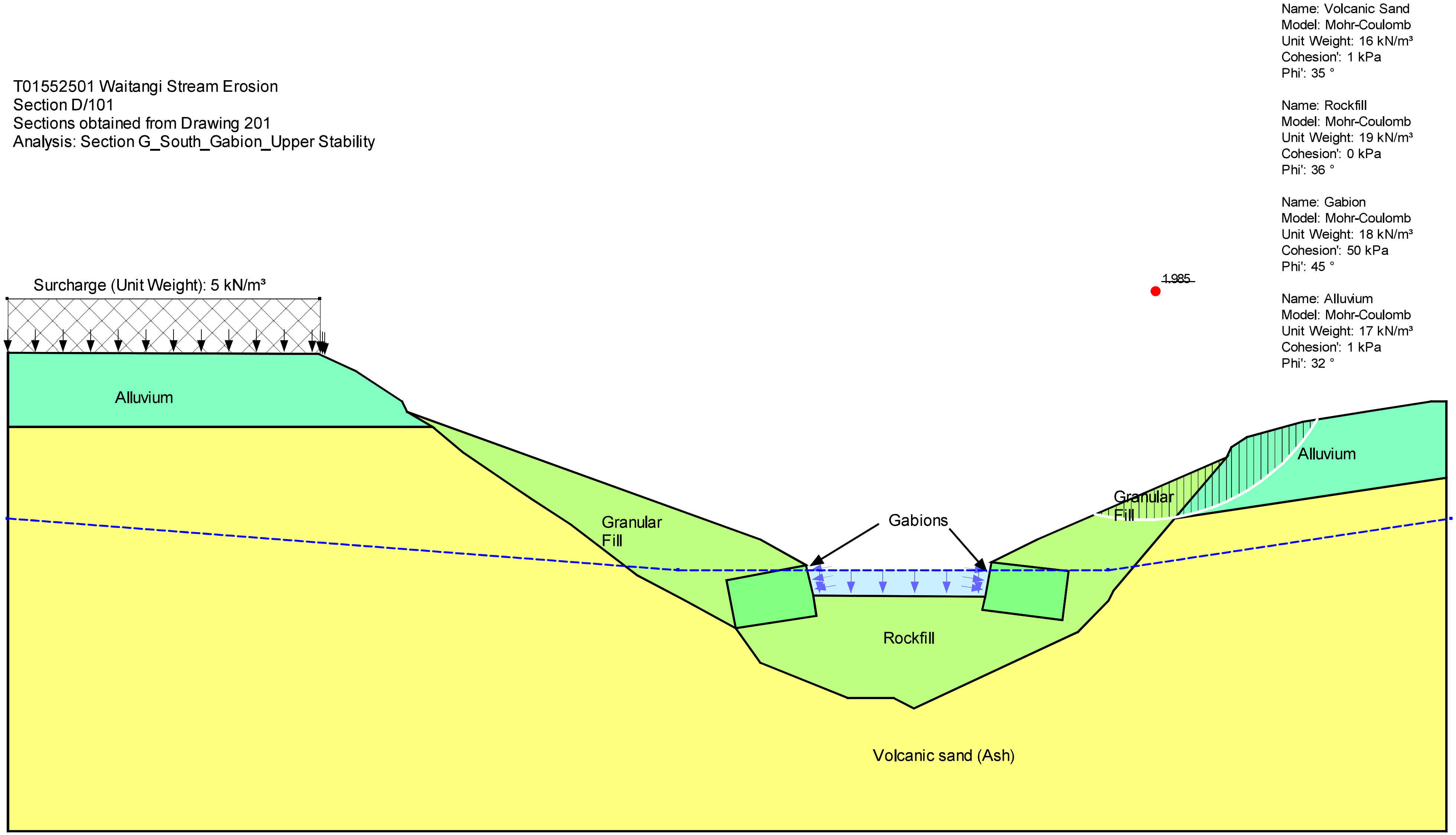
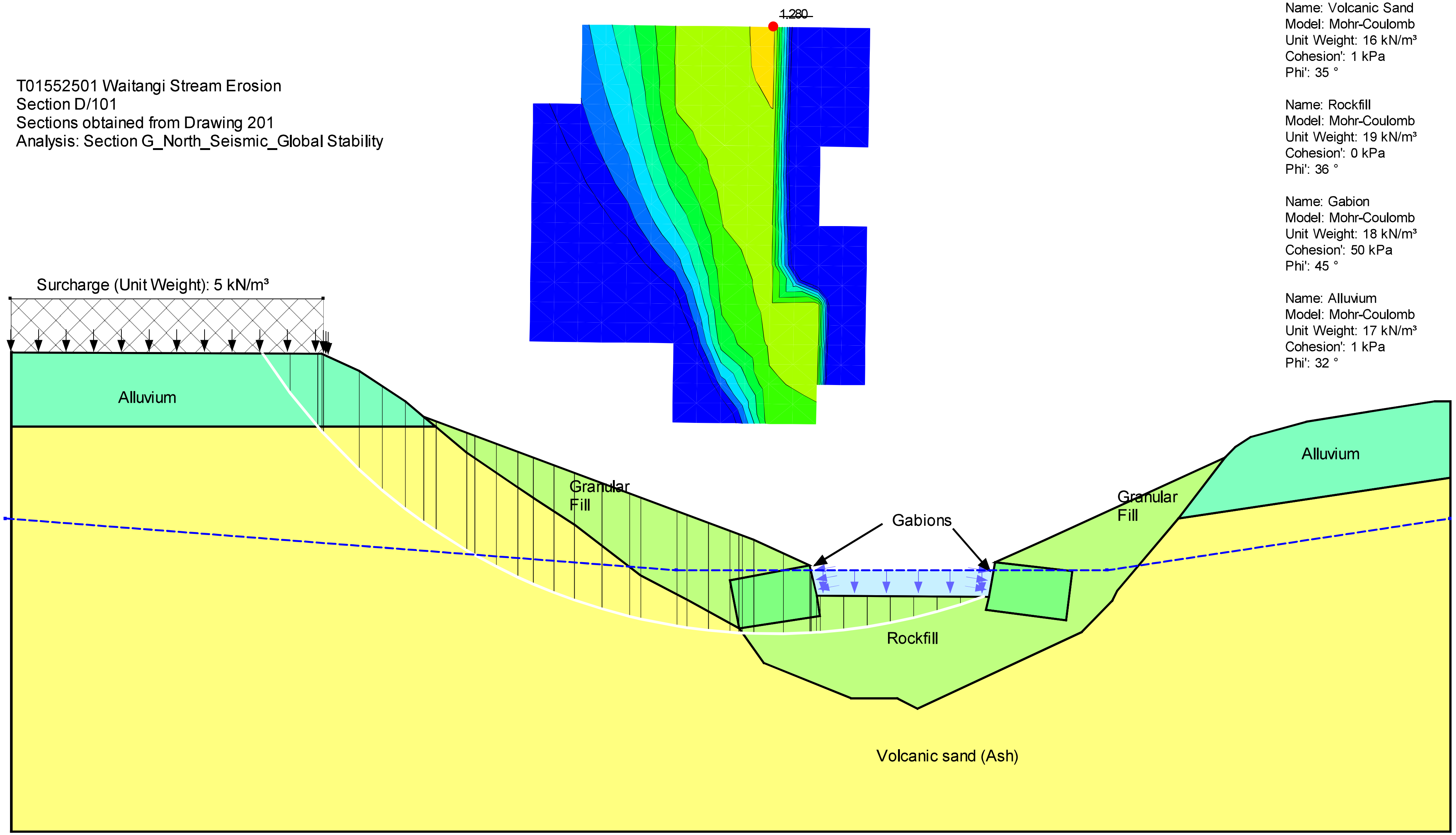


T01552501 Waitangi Stream Erosion
Section D/101
Sections obtained from Drawing 201
Analysis: Section G_North_Seismic_Global Stability



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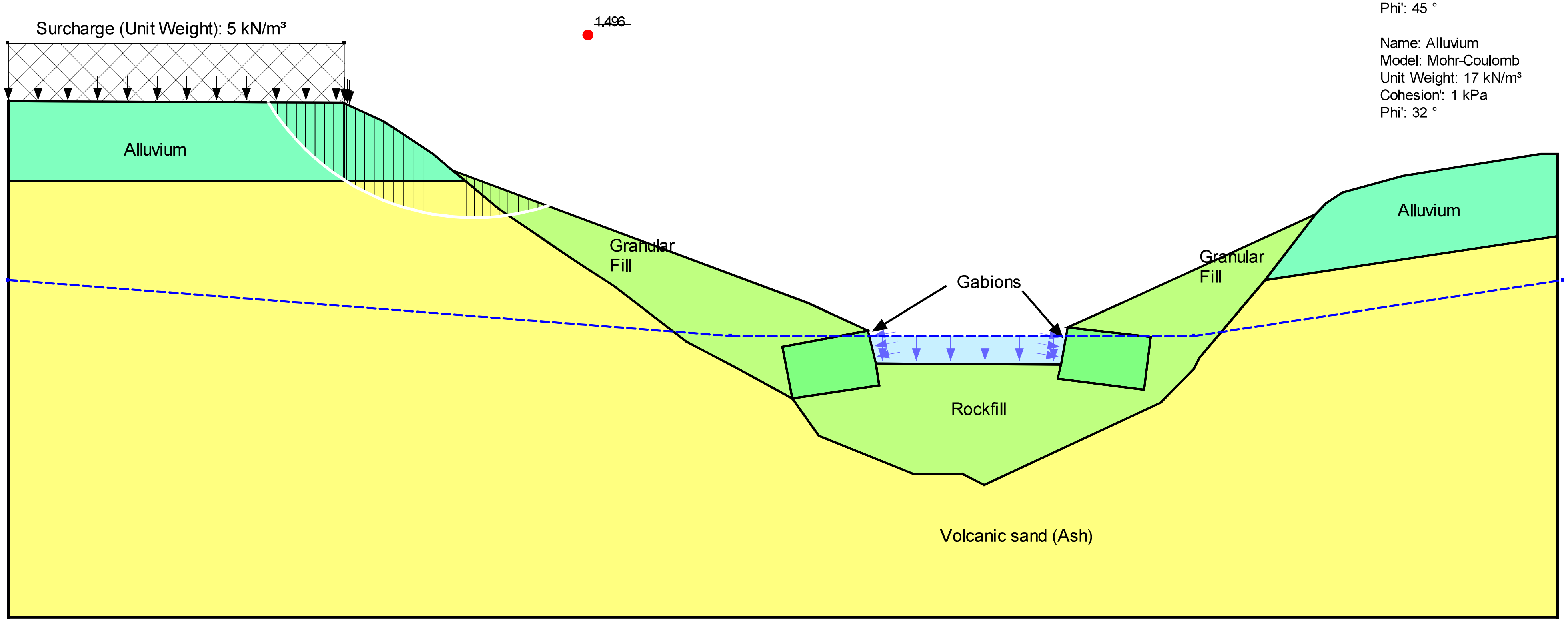

T01552501 Waitangi Stream Erosion
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Sections obtained from Drawing 201
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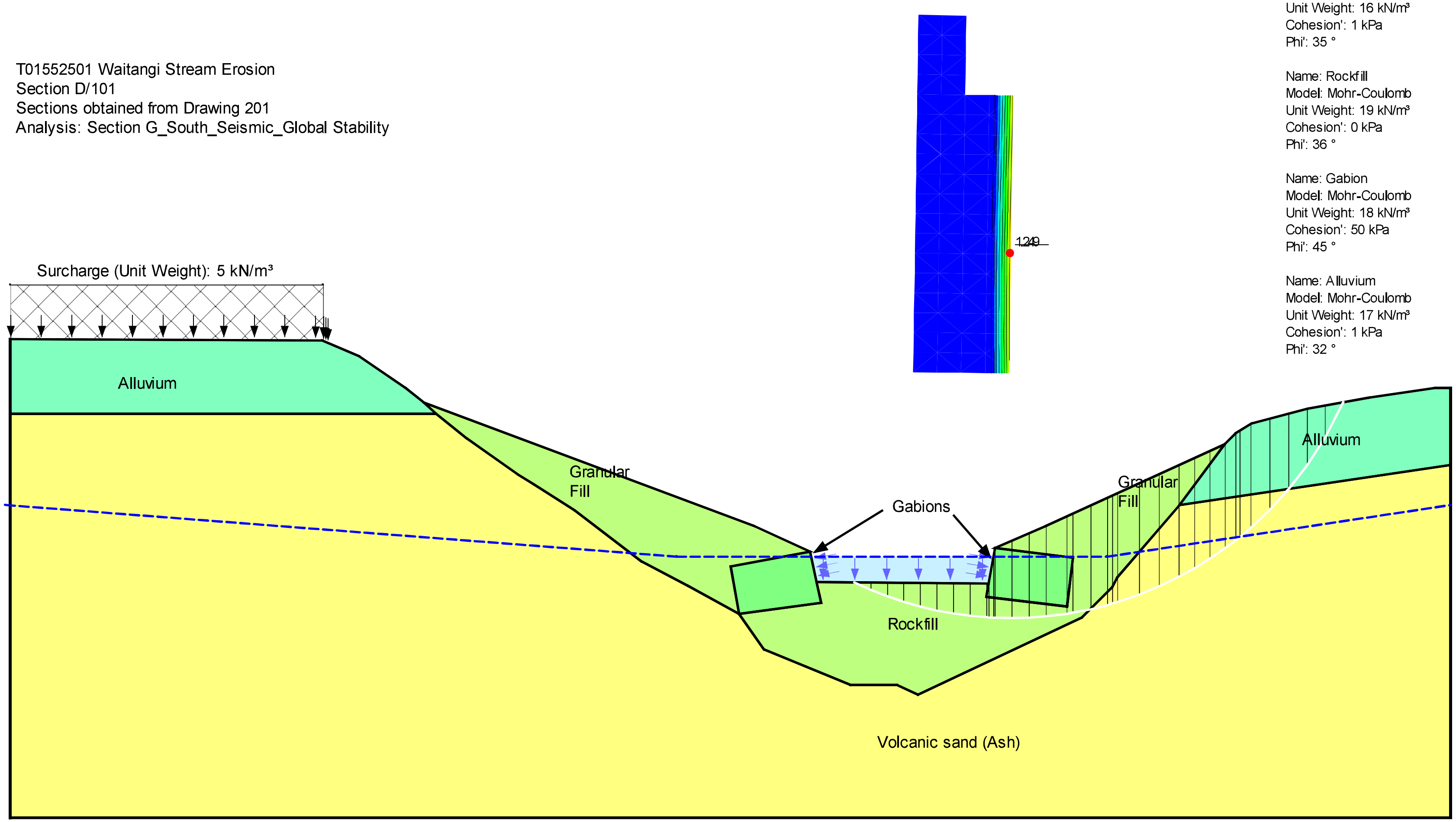

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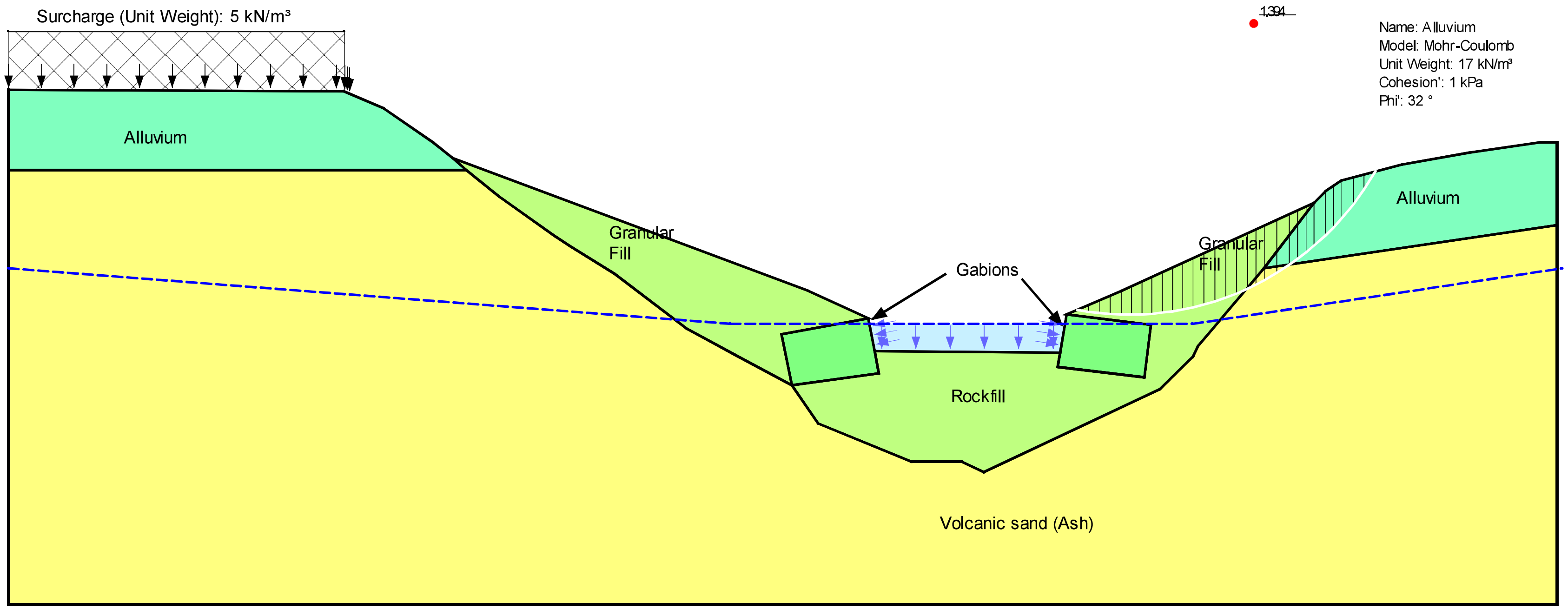


Appendix C

Risk Register

Waitangi Stream Erosion Protection Risk Register

Item	Description	Consequences	Mitigation Method	Likelihood	Risk owner
Geotechnical					
1	Slope failure during construction.	Major hazard for workers. Potential failure of building foundation.	⁖ Safety in design measures. ⁖ Construction sequencing. ⁖ Monitoring of slopes/failures.	Low/Moderate	Contractor
2	Slope failure following construction.	Potential failure of building foundation.	⁖ Geotechnical analysis and design.	Low	Landowner/BOPRC/ PDP
3	Poor ground conditions/inadequate bearing capacity.	More work for the contractor resulting in additional costs and time delays.	⁖ Geotechnical investigation results provided to contractor. ⁖ Filling of streambed to provide foundation.	Low	BOPRC
Natural Hazards (Erosion and Flooding)					
4	Gabion and rip rap solution not adequate for long term erosion protection in Waitangi Stream.	Continued erosion of streambed/streambanks.	⁖ Full hydraulic engineering design of channel section in line with BOPRC hydrological and hydraulic guidelines.	Moderate	BOPRC/PDP
5	Erosion occurring in other sections of the waterway not within scope of works.	Erosion of streambed/streambanks.	⁖ Not accounted for in existing scope of works.	Low	BOPRC
6	High flow/flood event(s) during construction interrupting construction programme.	Damage to partially completed works. Delay of completion. Additional costs due to mobilisation of plant, re-work, site re-establishment.	⁖ Good environments control measures in place including erosion and sediment control plan. ⁖ Ensure contractor has "dry area" well above channel for establishment of site and storage of equipment. ⁖ Include high flow/flood contingency planning in contract.	Moderate	BOPRC

Waitangi Stream Erosion Protection Risk Register

Item	Description	Consequences	Mitigation Method	Likelihood	Risk owner
7	Significant flood event (in excess of design flood flow) damaging erosion protection following completion.	Erosion of streambed/streambanks.	⁖ Beyond control for very large events. ⁖ Can undertake more extensive works by altering scope. ⁖ Design is to BOPRC guidelines (20 year ARI event for erosion protection).	Moderate	BOPRC
8	Erosion Downstream of works.	Erosion of streambed/streambanks.	⁖ Engineered Drop Structure	Low/Moderate	Landowners
Financial & Delivery					
9	Health and safety risks during construction.	Injury	⁖ Safety in design ⁖ Contractor selection ⁖ Contract requirements	Low	Contractor
10	Insufficient funding resources to proceed with project in early 2018.	Delay in project delivery.	⁖ PDP engineers estimate to be delivered to BOPRC prior to tender. ⁖ Early discussion with selected tenderers required to determine likely costs.	Residual to be managed	BOPRC
11	Stream vanishes at low flow.	Ecological and aesthetic impacts.	⁖ Weirs in streambank.	Low	BOPRC
12	Difficulty sourcing necessary size and quality rock.	Additional cost.	⁖ Conservative estimation of material costs.	Low	BOPRC
13	Damage to private property during construction.	Financial liability.	⁖ Delineation of contractors working area.	Low	Contractor/BOPRC

Waitangi Stream Erosion Protection Risk Register

Item	Description	Consequences	Mitigation Method	Likelihood	Risk owner
14	Contractors' tender inflated prices due to nature of work/high demand during construction season.	Insufficient project budget resulting in project put on hold or taking longer to deliver.	⁖ Beyond control. ⁖ Review recent contract rates to assist in confirming budget.	Residual to be managed	BOPRC
15	Programme delays owing to contractor performance/nature of work.	Possible additional costs and delayed completion.	⁖ Select proven contractors. ⁖ Tight contract administration.	Moderate	Contractor
Consenting					
16	Resource consent is not granted for current design.	Additional time and costs associated with redesign, programme delays.	⁖ Early consultation with resource consent authority.	Low	BOPRC
17	Works not carried out as specified in design.	Potential for project failure.	⁖ Ensure contractor reads and understands technical drawings and specifications. Inspect works when necessary. ⁖ Keep in contact with contractor during construction.	Low	Contractor

Appendix D

Safety in Design Risk Register

TITLE:	Safety in Design - Designer Identified Hazards	PROCEDURE NUMBER:	APPROVED BY:
		F15.01 Form 01	ROB DOCHERTY
		DATE RELEASED:	REVISION NUMBER:
		16/11/2016	Rev B

Details

Project Name:	**Waitangi Stream Erosion Protection**	
Project No.:		
	Name	Date
Prepared by:	A. Dean	8/02/2018
Checked By:	D. Garden	9/02/2018
Approved by:		

Definitions

Ref	Reference Number for each item	**Activity**	An identified activity associated with the construction work
Hazard	An object, substance or set of circumstances with the potential to cause harm to personnel and/or the wider public	**Risk**	**Risk** = ***consequence*** of hazard X ***likelihood*** of occurrence
Design Control Measure	Control measure employed by the Designer to eliminate, minimise or control the risk	**Document Ref**	Reference to additional documentation (e.g. tender dwgs or specifications) detailing the control measures

This Safety in Design Hazard assessment is to capture safety related hazards associated with the construction, commissioning, operation and maintenance of the proposed works. The identified hazards will be considered during the design process and appropriate mitigations will be included in the design and contract documentation where appropriate and described in the Design Report, as noted in the table below.

This Hazard assessment should not include other project hazards unrelated to personnel/public safety. Other non-health and safety related project hazards need to be identified separately in the Project Risk Register.

General H &S issues controlled by normal practices are not included in this assessment, e.g. hygiene hazards associated with working within a WWTP, working within an operational plant, standard construction risks etc. The Contractor should provide Risk Assessments (RA) and Method Statements (MS) for all high risk construction activities.

Examples have been included in the following table as a guide. The example project around which this hazard assessment has been based is an underground wastewater pumpstation. The example has been prepared by the engineering design team (including both civil and electrical engineers) to specifically address electrical hazards throughout the 'life' of the structure.

Ref	Activity	Hazard Description	Consequence	Likelihood	Initial Risk			Design Control Measure	Residual Risk			Document Ref.
					L	M	H		L	M	H	
1. Construction												
1.1	Excavation and below ground construction	Strike unmarked existing buried electrical services	Electric shock, death	Medium		M		Positively identify all known services on drawings, specify pot-holing/service locations as part of construction works prior to work commencing.	L			Drawings and specification including construction methodology
1.2	Works at the base of streambank slopes	Slope failure	Entrapment, personal injury, death	Medium			H	Initial filling of streambed to improve stability, no undercutting of streambanks, monitoring of slopes required during construction		M		Drawings and specification including construction methodology
1.3	Transport of materials on site	Accident or injury from moving materials under site constraints (steep, narrow, labour intensive, small machinery only)	Strain injury, machinery overturning	High			H	Contractor to provide construction methodology and health and safety plan to be approved by the Engineer, Gabions to be placed empty.	L			Specification including construction methodology
1.4	Overhead lifts	Falling material	Personal injury, death	Low			H	Contractor to provide construction methodology and health and safety plan to be approved by the Engineer, Gabions to be placed empty.	L			Specification including construction methodology
1.5	Flooding	Fast moving water	Personal injury, death	Medium			H	Contractor to monitor weather forecast and maintain contact with BOPRC operations staff on Okareka discharge. Planning for mobilisation of site.	L			Specification including construction methodology
1.6	Excluding public and residents	Construction site hazards	Personal injury, death	Low		M		Contractor to secure site including appropriate signage.	L			Drawings and specification
1.7	Machinery at top of slope	Slope failure	Personal injury, death	Medium			H	Specified set-back from top of slope for machinery.	L			Specification
1.8	Slips/trips/falls	Slippery steep and uneven ground in streambed	Personal injury	High		M		Contractor to provide construction methodology and health and safety plan to be approved by the Engineer.	L			Specification

1.9	Transport of materials on site	Accident or injury from moving materials under site constraints (steep, narrow, labour intensive, small machinery only)	Strain injury, machinery overturning	High	H	Contractor to provide construction methodology and health and safety plan to be approved by the Engineer, Gabions to be placed empty.	L	Specification including construction methodology
3. Maintenance Works								
3.1	As per construction hazards and controls							

Appendix E

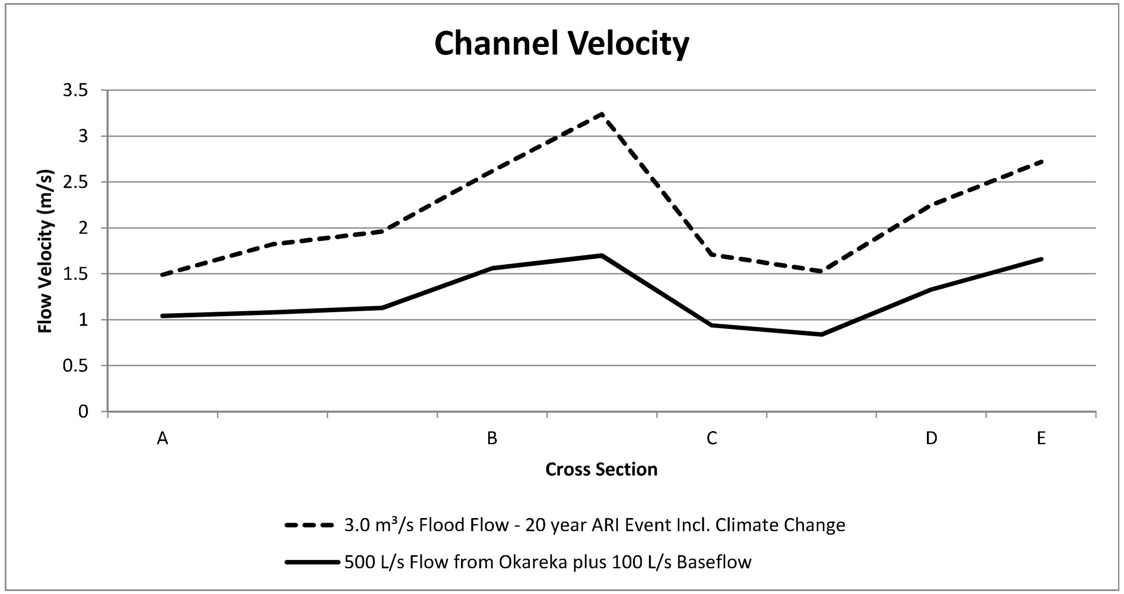
Hydraulic and Hydrologic Calculation Sheets

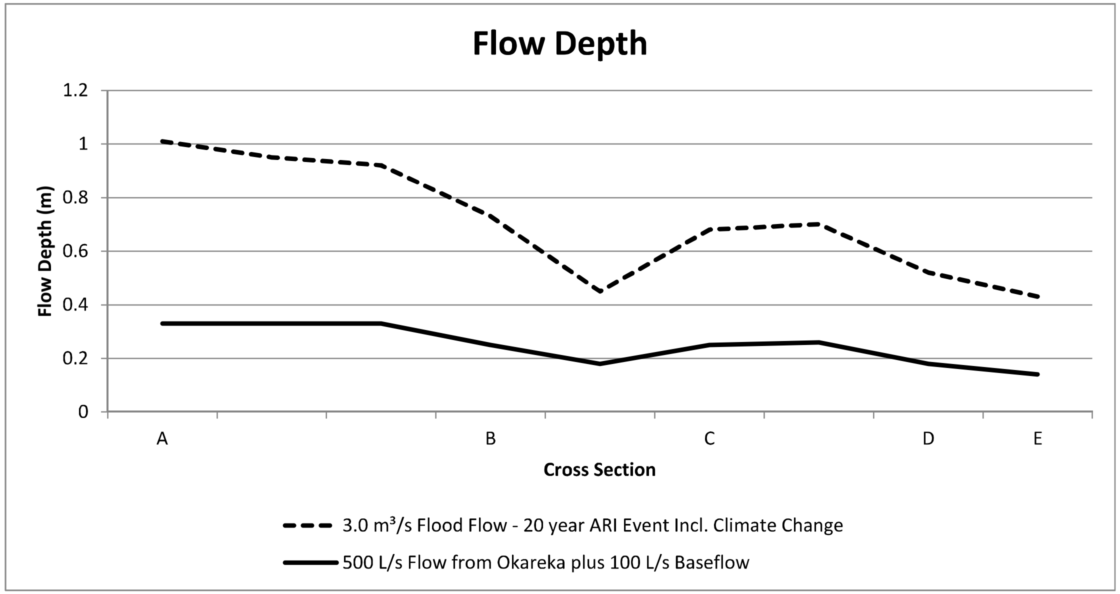
500 L/s Flow from Okareka plus 100 L/s Baseflow

Reach	Cross Section	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Flow Depth (m)	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)		(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
DS of ROW		80		Inl Struct										
DS of ROW	A	45	PF 1	0.6	310.4	310.73	0.33		310.79	0.0064	1.04	0.58	1.77	0.58
DS of ROW		41.000*	PF 1	0.6	310.37	310.7	0.33		310.76	0.0070	1.08	0.56	1.7	0.6
DS of ROW		37.000*	PF 1	0.6	310.33	310.66	0.33		310.73	0.0078	1.13	0.53	1.64	0.63
DS of ROW	B	33	PF 1	0.6	310.3	310.55	0.25	310.55	310.68	0.0199	1.56	0.38	1.55	1
DS of ROW		29.000*	PF 1	0.6	310.25	310.43	0.18	310.46	310.57	0.0324	1.7	0.35	2.04	1.3
DS of ROW	C	25	PF 1	0.6	310.2	310.45	0.25	310.38	310.5	0.0063	0.94	0.64	2.55	0.6
DS of ROW		20.000*	PF 1	0.6	310.17	310.43	0.26		310.47	0.0049	0.84	0.71	2.8	0.53
DS of ROW	D	15	PF 1	0.6	310.15	310.33	0.18	310.33	310.42	0.0186	1.33	0.45	2.54	1.01
DS of ROW	E	10	PF 1	0.6	310	310.14	0.14	310.18	310.28	0.0377	1.66	0.36	2.53	1.4

3.0 m^3/s Flood Flow - 20 year ARI Event Incl. Climate Change

Reach	Cross Section	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Flow Depth (m)	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)		(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
DS of ROW		80		Inl Struct										
DS of ROW	A	45	PF 1	3	310.4	311.41	1.01		311.52	0.0041	1.49	2.2	2.93	0.48
DS of ROW		41.000*	PF 1	3	310.37	311.32	0.95		311.49	0.0082	1.82	1.65	1.84	0.61
DS of ROW		37.000*	PF 1	3	310.33	311.25	0.92		311.45	0.0101	1.96	1.53	1.76	0.67
DS of ROW	B	33	PF 1	3	310.3	311.03	0.73	311.03	311.38	0.0219	2.62	1.15	1.65	1.01
DS of ROW		29.000*	PF 1	3	310.25	310.7	0.45	310.85	311.24	0.0436	3.24	0.93	2.1	1.56
DS of ROW	C	25	PF 1	3	310.2	310.88	0.68	310.72	311.03	0.0076	1.71	1.75	2.65	0.67
DS of ROW		20.000*	PF 1	3	310.17	310.87	0.7		310.99	0.0057	1.53	1.96	2.9	0.59
DS of ROW	D	15	PF 1	3	310.15	310.67	0.52	310.67	310.93	0.0168	2.25	1.33	2.61	1.01
DS of ROW	E	10	PF 1	3	310	310.43	0.43	310.52	310.81	0.0295	2.72	1.1	2.59	1.33


Channel Velocity
Flow Velocity (m/s)
3.5
3
2.5
2
1.5
1
0.5
0
A
B
C
D
E
Cross Section
3.0 m³/s Flood Flow - 20 year ARI Event Incl. Climate Change
500 L/s Flow from Okareka plus 100 L/s Baseflow


Flow Depth
Flow Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
A
B
C
D
E
Cross Section
3.0 m³/s Flood Flow - 20 year ARI Event Incl. Climate Change
500 L/s Flow from Okareka plus 100 L/s Baseflow

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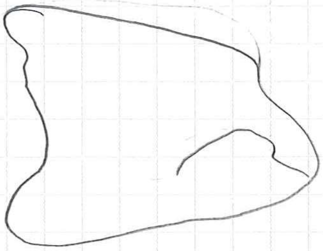
solutions for your environment

JOB NAME Waitangi Stream Erosion Protection	**PAGE No.** 1
JOB No. T01~~0~~552501	**DESIGNED** JG
DATE 1/12/17	**CHECKED** AD

Total catchment area = 260,000 m^2 (~~260~~ ha) ~~26,000,000 ha~~
upstream of Waitangi Bay Right of way culvert 26 ha

(from Bay explorer GIS software)

Area of: - Bush = 230,000 m^2
- Road = 5,000 m^2 (incl. all impermeable surfaces)
- Pasture = 25,000 m^2



Proportion of: - Bush = 0.88
- Road = 0.02
- Pasture = 0.10

~~Modified~~ Rational Method

Using SMAP Online -> Soil type: Well drained Loam w rapid permeability

∴ use high soakage gravel, sandy & volcanic soil types

From table 5.2 of BOPRC 11/12 Hydrological and Hydraulic Guidelines 2012

Bush: C = 0.15
Road: C = 0.9
Pasture: C = 0.2

$C_{weighted} = (0.88 \times 0.15) + (0.02 \times 0.9) + (0.1 \times 0.2)$
$= 0.17$

~~Assume slope 5-10% (no adjustment for slope)~~
include effect of slope: S = 0.2 -> C = 0.17 + 0.1 = 0.27

$Q_p = \frac{1}{360}$ C.I.A (eq. from Guidelines 11/12 BOPRC)
~~$= \frac{1}{360}$~~

$\frac{rise}{run} = \frac{214}{770} = 0.28$ (from pg. 2)
214 (Height drop)
770 (Direct length)

I = ? From HIRDs, (T = 5yr) 20% AEP, (T = 20yr) 5% AEP, (T = 50yr) 2% AEP

~~T = 5 yr. { Rainfall depth = , , }~~
~~{ Intensity = , , }~~

ARI

~~T = 20yr { Depth =~~
~~Int. = }~~
~~T = 50yr { Depth =~~
~~Int. = }~~

Find I

For 20% AEP, 5% AEP, 2% AEP (T = 5, 20, 50yr)

Duration = t_c

t_c -> Use Bransby-Williams Method & check w US Soil Conservation Service (from TM61)

B-W Method

$$t_c = \frac{0.953 L^{1.2}}{A^{0.1} H^{0.2}}$$

$$= \frac{0.953 \times 770}{260 \times 214^{0.2}}$$

$$= 0.137 \text{ hrs}$$

$0.137 \times 60 = 8.22$ min

A = ~~260 km²~~ 26 ha
H = 529 - 315 = 214 m
L = 770 m
(longest straight line distance from outlet to catchment edge)

Check using US Soil Conservation Service

$$t_c = \left(\frac{0.87 L^3}{H}\right)^{0.385}$$

$$= \left(\frac{0.87 \times 0.77^3}{214}\right)^{0.385}$$

$$= 0.089 \text{ hrs}$$

$0.089 \times 60 = 5.34$ min

Checked using Ramser-Kirpich & TP108 method. Results are 13 min ✓✓ OK

Note that only TP108 accounts for soil type directly (by CN). (Free Draining in this case)

Both less than smallest duration on HIRDs
∴ use duration = 10 mins (smallest)

$\frac{1}{360} \times C \times I \times A$

Indicates T_c = 10 min for CN = 25

From HIRDS

AEP	I (mm/hr)	Q_p (m³/s)
20%	79.2	$\frac{1}{360} \times 0.27 \times 79.2 \times 26$ = 1.54 m³/s
~~5%~~		
~~2%~~. 5%	109.8 +2.0°C (2090 cc) ⇒ 127.2	$\frac{1}{360} \times 0.27 \times 109.8 \times 26$ = 2.14 m³/s = 2.46 m³/s
2%	135	$\frac{1}{360} \times 0.27 \times 135 \times 26$ = 2.63

DUDFIELD BRYCE

Try duration = 30 min

From HIRDS

AEP	I (mm/hr)	Q_p (m^3/s)
20%	46.6	0.91
5%	64.6 +CC = 74.4	1.26 1.45
2%	79.2	1.54

Try duration = 60 min

From HIRDS

AEP	I (mm/hr)	Q (m^3/s)
20%	33.3	0.65
5%	46.1 +CC = 52.9	0.9 1.03
2%	56.6	1.10

Base flow estimated to range from 5 → 30 l/s (BOPRC Ecology report).

Design outflow from Lake Okareka is 500 l/s.

$2.48\ m^3/s + 0.5\ m^3/s + 0.03\ m^3/s = 3.01\ m^3/s$

$1.45\ m^3/s + 0.5\ m^3/s + 0.03\ m^3/s = 1.98\ m^3/s$

So flow is likely to be in the 2-3 m^3/s range for a 20 year event when the pipeline is operational & allowing for CC effects.

Design of Drop Structure

Project Name:	Waitangi Stream Erosion Protection	
Project Number:	T01552501	
Designed by and on:	JG	24/01/2018
Checked by and on:	JL	30/01/2018

DESIGN GUIDELINE: Hydraulic Engineering Circular No. 14, Third Edition Hydraulic Design of Energy Dissipators for Culverts and Channels, Chapter 11

KEY INPUTS

Peak Design Flow (20 ARI storm)	Q=	3	m^3/sec
Height of drop	H=	2.1	m
Average width of channel	B=	3	m
Number of drops		2	

KEY OUTPUTS

For a straight drop structure with blocks and an end sill,

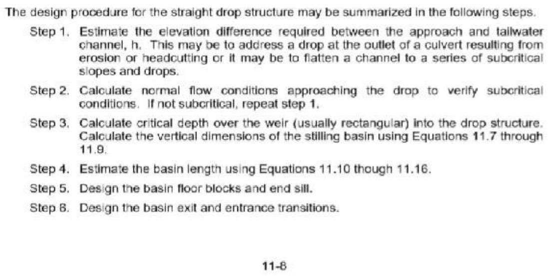
Length of each basin	L_B=	3.02	m
Height from crest to bottom of each basin	h_0=	1.50	m
Sill heights		0.19	m
Block heights		0.37	m
Block width and spacing		0.19	m
Length between first sill and second drop		3.00	m

Use Design 2 as it inlcudes a sill (which allows sediment to collect and not be carried further downstream)

From Sheet 1 (Design 1),

Unit discharge	q=	1	m^3/sec/m
Acceleration due to gravity	g=	9.81	m/sec^2

Design of Straight Drop Structure (with floor blocks and an end sill)



The design procedure for the straight drop structure may be summarized in the following steps.

Step 1. Estimate the elevation difference required between the approach and tailwater channel, h. This may be to address a drop at the outlet of a culvert resulting from erosion or headcutting or it may be to flatten a channel to a series of subcritical slopes and drops.

Step 2. Calculate normal flow conditions approaching the drop to verify subcritical conditions. If not subcritical, repeat step 1.

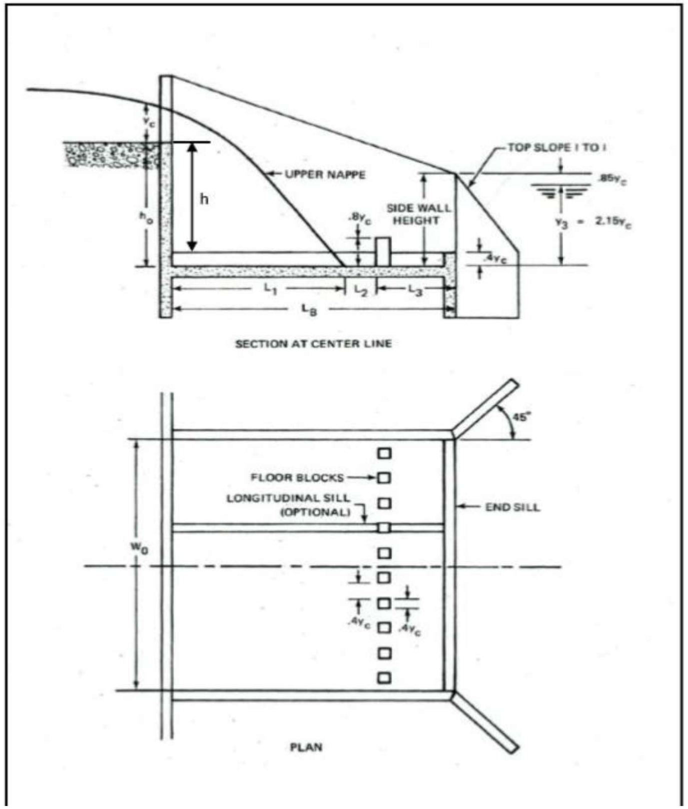
Step 3. Calculate critical depth over the weir (usually rectangular) into the drop structure. Calculate the vertical dimensions of the stilling basin using Equations 11.7 through 11.9.

Step 4. Estimate the basin length using Equations 11.10 though 11.16.

Step 5. Design the basin floor blocks and end sill.

Step 6. Design the basin exit and entrance transitions.

11-8



For a rectangular weir and assuming approximately rectangular upstream and downstream channel
Assume crest length is same as the average channel width

Crest length	W_0=	3	m	
Slope	S_0=	0.01	m/m	(after providing for drop)
Mannings n	n=	0.03		(assumption for rip-rap roughness - Page 8-A-6 of ODOT Hydraulics Manual Appendix A)

Drop 1

Step 1 : Elevation difference required between the approach and tailwater channel (h)

Height of each drop h= 1.05 m

Step 2 : Normal flow conditions approaching the drop to verify subcritical conditions

Use Mannings equation to find y_0

$$Q = \frac{1}{n} A m^{2/3} S^{1/2}$$

Guess y_0 0.55 m

Q found from Mannings 3.00 m^3/sec

Q should be 3.00 m^3/sec

y_0= 0.55 m

V_0= 1.82 m/sec V=Q/A

Fr_0= 0.78 $Fr_1 = \frac{V_1}{\sqrt{gy_1}}$

Flow is subcritical. Proceed to step 3

Figure 11.3. Straight Drop Structure (Rand, 1955)

11-5

Step 3 : Critical depth over the weir into the drop structure and the vertical dimensions of the stilling basin

Critical Depth

$$y_c = \left(\frac{q^2}{g}\right)^{1/3} \qquad (11.5)$$

where,

y_c = critical depth, m (ft)

q = unit discharge (Q/B), m (ft)

y_c= 0.47 m

Tailwater depth above floor

$$y_3 = 2.15y_c \qquad (11.7)$$

where,

y_3 = tailwater depth above the floor of the stilling basin, m (ft)

y_3= 1.00 m

Vert distance of tailwater below crest

$$h_2 = -(h - y_e) \qquad (11.8)$$

where,

h_2 = vertical distance of the tailwater below the crest, m (ft)

h = vertical drop between the approach and tailwater channels, m (ft)

y_e = normal depth in the tailwater channel (equals normal depth in approach channel assuming same channel characteristics), m (ft)

h_2= -0.50 m negative as crest is datum

Drop from crest to basin floor

$$h_o = h_2 - y_3 \qquad (11.9)$$

where,

h_o = drop from crest to stilling basin floor, m (ft)

h_0= -1.50 m negative as crest is datum

Distance of floor to be depressed 0.45 m

Step 4 : Basin length

$$L_t = \left(-0.406 + \sqrt{3.195 - 4.368\frac{h_2}{y_c}}\right)y_c \qquad (11.14)$$

L_t= 1.18 m

$$L_f = \left(-0.406 + \sqrt{3.195 - 4.368\frac{h_o}{y_c}}\right)y_c \qquad (11.12)$$

$$L_s = \frac{\left(0.691 + 0.228\left(\frac{L_t}{y_c}\right)^2 - \left(\frac{h_o}{y_c}\right)\right)y_c}{0.185 + 0.456\left(\frac{L_t}{}\right.} \qquad (11.13)$$

$0.185 + 0.456\left(\frac{}{y_c}\right)$

L_f= 1.79 m
L_s= 1.88 m

Distance of headwall to nappe strike

L_1 is given by:

$$L_1 = \frac{L_f + L_s}{2} \qquad (11.11)$$

where,
L_f = length given by Equation 11.12, m (ft)
L_s = length given by Equation 11.13, m (ft)

L_1= 1.83 m

L_2 and L_3 are determined by:

$$L_2 - 0.8y_c \qquad (11.15)$$
$$L_3 \geq 1.75y_c \qquad (11.16)$$

Distance from nappe strike to blocks L_2= 0.37 m
Distance from blocks to end of basin L_3= 0.82 m (minimum)

Total basin length

$$L_B = L_1 + L_2 + L_3 \qquad (11.10)$$

where,
L_B = stilling basin length, m (ft)
L_1 = distance from the headwall to the point where the surface of the upper nappe strikes the stilling basin floor, m (ft)
L_2 = distance from the point where the surface of the upper nappe strikes the stilling basin floor to the upstream face of the floor blocks, m (ft)
L_3 = distance from the upstream face of the floor blocks to the end of the stilling basin, m (ft)

L_B= 3.02 m

Step 5 : Basin floor blocks and end sill

Height of floor blocks 0.37 m (refer to pg 11-8 for equations)
Width of floor blocks 0.19 m (refer to pg 11-8 for equations)
Spacing of floor blocks 0.19 m (refer to pg 11-8 for equations)

End sill height 0.19 m (refer to pg 11-8 for equations)

Step 6 : Basin exit and entrance transitions

Sidewall height above tailwater elevation 0.37 m (refer to pg 11-8 for equations)

Final Check of Design Limits

The recommended design is limited to the following conditions:

1. Total drop, h_o, less than 4.6 m (15 ft) with sufficient tailwater.
2. Relative drop, h_o/y_c, between 1.0 and 15.
3. Crest length, W_o, greater than $1.5y_c$.

pg 11-6

h_0= -1.50 m
This is less than 4.6m so OK

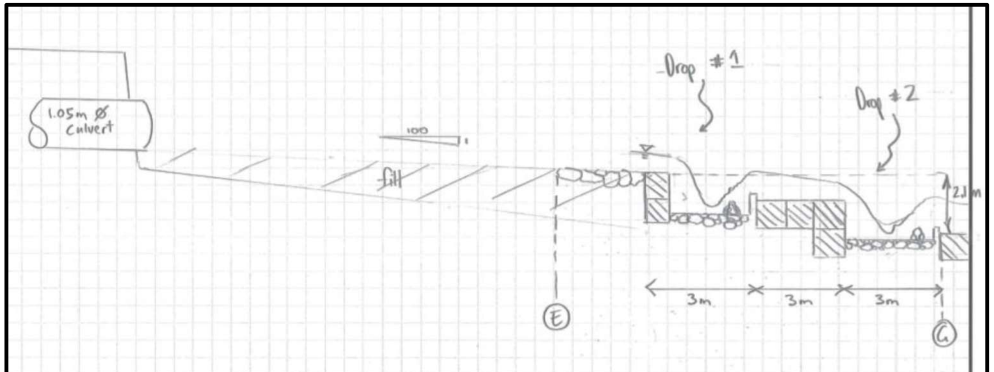
$h0/y_c$= 3.22
Between 1.0 and 15 so OK

W_0= 3 m
Greater than $1.5y_c$ so OK

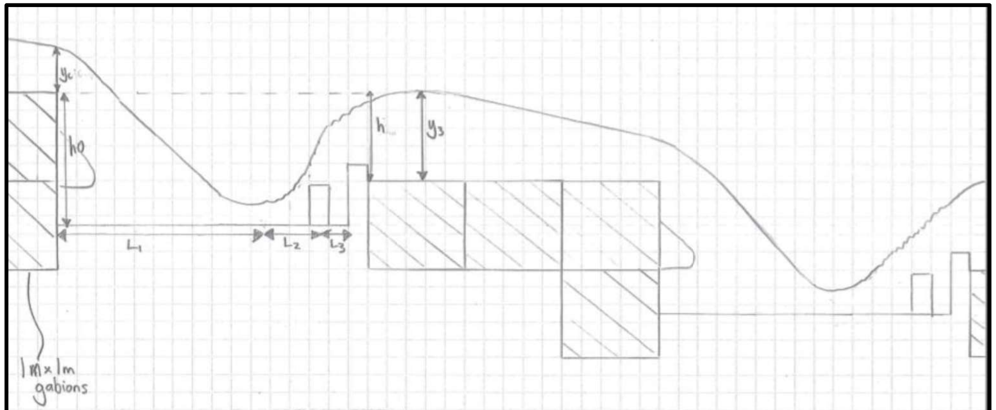
Drop 2

Use same dimensions for drop 2, with 3m length between sill of first basin and crest of scond drop (to allow normal flow conditions to resume.

Drawings



Drop Structure
Long Section



Drop Structure
Detailed Long Section