3.2.3 Surface movement

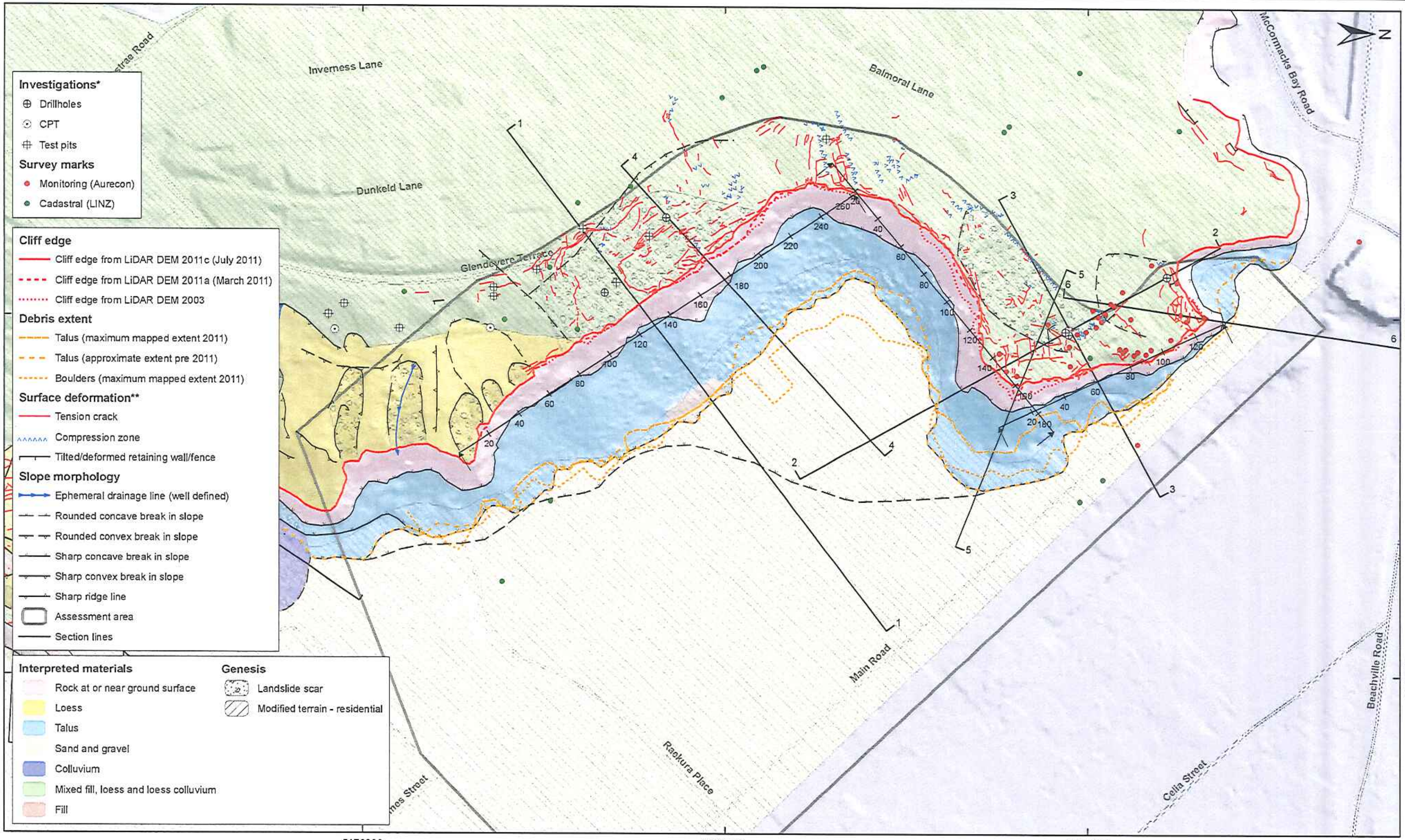
3.2.3.1 Inferred cliff crest displacements from crack apertures

Total displacements of the cliff crest in response to the 2010/11 Canterbury earthquakes have been inferred from the measurement of crack apertures, as there are limited survey data available. Many of the cracks at the slope surface are in loess and fill material. Therefore, the measured crack apertures may not reflect the true displacement of the underlying rock, as the cracks in loess may have formed in response to several different mechanisms, e.g., earthquake induced settlement and or slumping in the loess, as well as permanent displacement of the underlying rock.

The logs from the test pits (Tonkin and Taylor, 2012a) located back from the cliff crest show that cracks in the loess, extend down from the surface, but do not reach bedrock. This would suggest that the presence of cracks in loess do not necessary imply cracking of the underlying rock. However, field mapping of exposures of loess at the cliff crest also show that cracks formed in the bedrock do not always extend into the loess, or to the ground surface.

Two distinct crack patterns were identified in the loess (and fill) at the cliff crest:

- Set 1 indicates mainly extensional (horizontal) displacements across cracks – occurring well back from the cliff edge – and are inferred to be a function of shallow inelastic response of the loess (and fill) above rock head during shaking (e.g., settlement, slumping).
- Set 2 indicates both horizontal and vertical displacement (up to 1.5 m of cumulative vertical displacement measured), and are located closer to the slope crest. In these areas the thickness of the surficial loess/fill cover over rock is only 1–2 m and therefore unlikely to accommodate settlement of the loess due to earthquake shaking. These cracks are therefore inferred to relate to deeper-seated deformation in the underlying rock mass during shaking.



SCALE BAR: 0 50 100 m

EXPLANATION:

* For details refer to site investigation map

** Taken from report 2012/317

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution.
Roads provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM, FDP

GNS SCIENCE TE PŪ AO

ENGINEERING GEOLOGY MAP

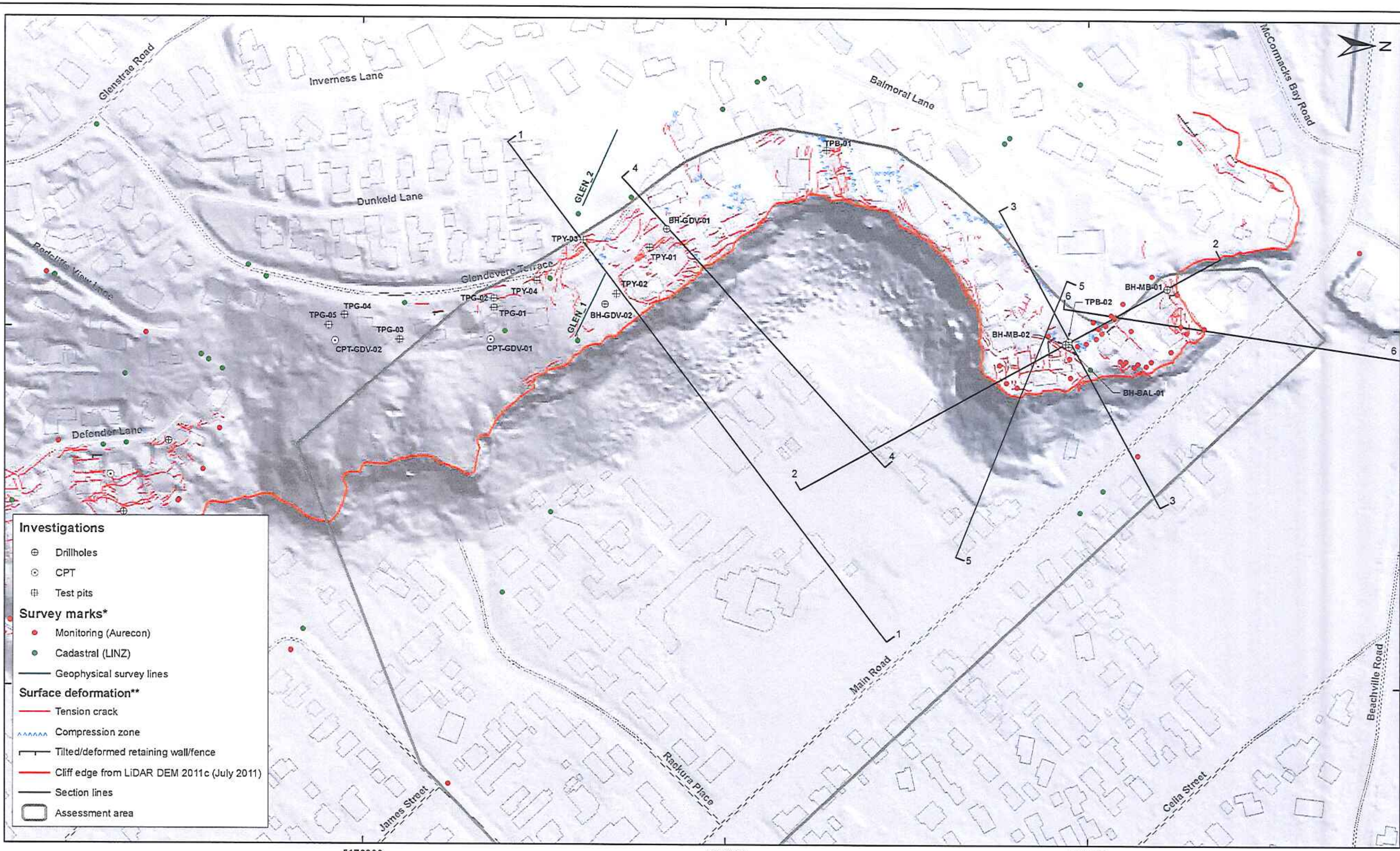
Redcliffs
Christchurch

FIGURE 11

FINAL

REPORT: CR2014/78

DATE: August 2014



SCALE BAR: 0 50 100 m

EXPLANATION:
* For detail refer to Appendix 4
** Taken from report 2012/317

Background shade model derived from NZAM post earthquake 2011c (July 2011) LiDAR survey resampled to a 1 m ground resolution.
Roads and building footprints provided by Christchurch City Council (20/02/2012).
PROJECTION: New Zealand Transverse Mercator 2000

DRW: BL

CHK: CM, FDP

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SITE INVESTIGATION MAP

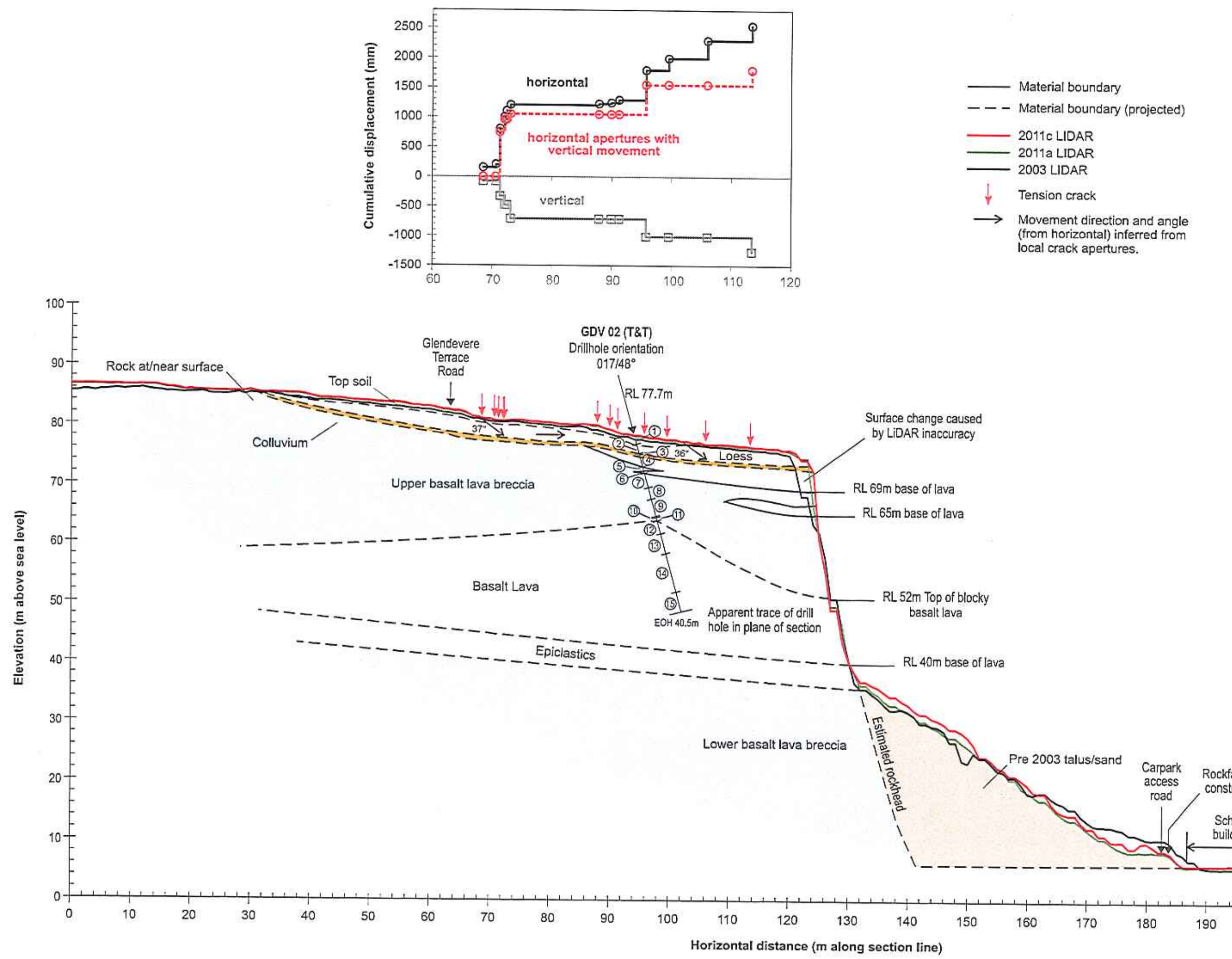
Redcliffs
Christchurch

FIGURE 12

FINAL

REPORT: CR2014/78

DATE: August 2014



GDV 02 (T&T)

	Material type	Weathering	Strength	RQD %
①	Top Soil			
②	Loess			
③	Colluvium			
④	Basalt lava	SW	MS	50-70
⑤	Basalt lava breccia	MW	W	50
⑥	Basalt lava	UW	MS	65-100
⑦	Basalt lava breccia	HW	VW-S	40-80
⑧	Basalt lava breccia	HW	W	50-80
⑨	Basalt lava breccia	HW	VW-W	65-100
⑩	Basalt lava breccia	HW	MS	30-75
⑪	Basalt lava breccia	MW	MS	75
⑫	Basalt lava	SW	S	65
⑬	Basalt lava	SW	S	60-100
⑭	Basalt lava	SW	S	50-90
⑮	Basalt lava	SW	S	60

Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC

CHK: CM/FDP

GNS SCIENCE TE PŪ AO

ENGINEERING GEOLOGY CROSS SECTION R01

Redcliffs
Christchurch

FIGURE 13

FINAL

REPORT: CR2014/78

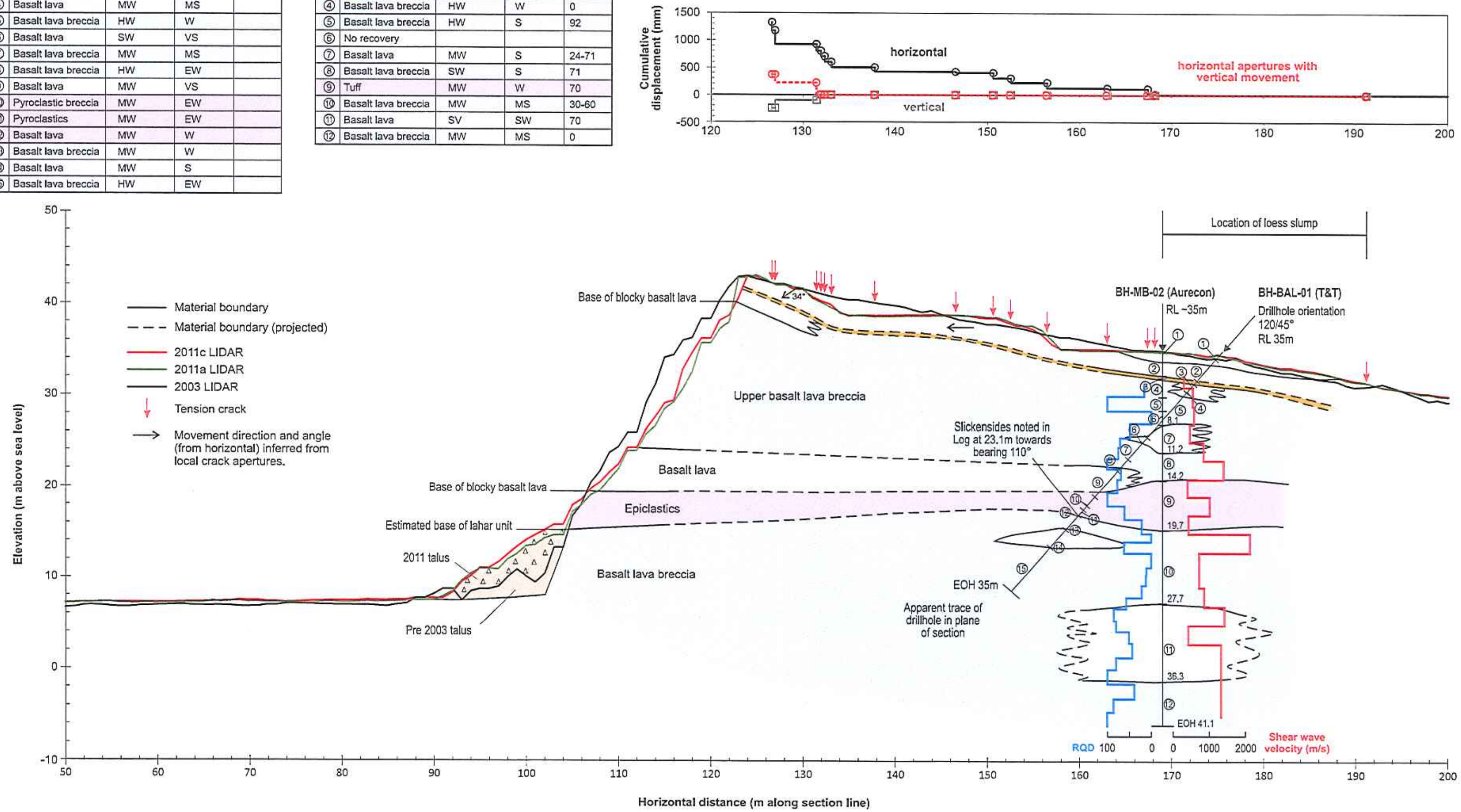
DATE: August 2014

BH-BAL-01 (T&T)

	Material type	Weathering	Strength	RQD %
①	Top Soil			
②	Loess			
③	Basalt lava breccia	HW	W	
④	Basalt lava	MW	MS	
⑤	Basalt lava breccia	HW	W	
⑥	Basalt lava	SW	VS	
⑦	Basalt lava breccia	MW	MS	
⑧	Basalt lava breccia	HW	EW	
⑨	Basalt lava	MW	VS	
⑩	Pyroclastic breccia	MW	EW	
⑪	Pyroclastics	MW	EW	
⑫	Basalt lava	MW	W	
⑬	Basalt lava breccia	MW	W	
⑭	Basalt lava	MW	S	
⑮	Basalt lava breccia	HW	EW	

BH-MB-02 (Aurecon)

	Material type	Weathering	Strength	RQD %
①	Road/Fill			
②	Loess			
③	Colluvium			
④	Basalt lava breccia	HW	W	0
⑤	Basalt lava breccia	HW	S	92
⑥	No recovery			
⑦	Basalt lava	MW	S	24-71
⑧	Basalt lava breccia	SW	S	71
⑨	Tuff	MW	W	70
⑩	Basalt lava breccia	MW	MS	30-60
⑪	Basalt lava	SV	SW	70
⑫	Basalt lava breccia	MW	MS	0



Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC

CHK: CM/FDP

ENGINEERING GEOLOGY CROSS SECTION R02

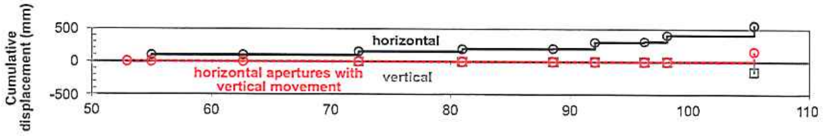
Redcliffs
Christchurch

FIGURE 13

FINAL

REPORT: CR2014/78

DATE: August 2014

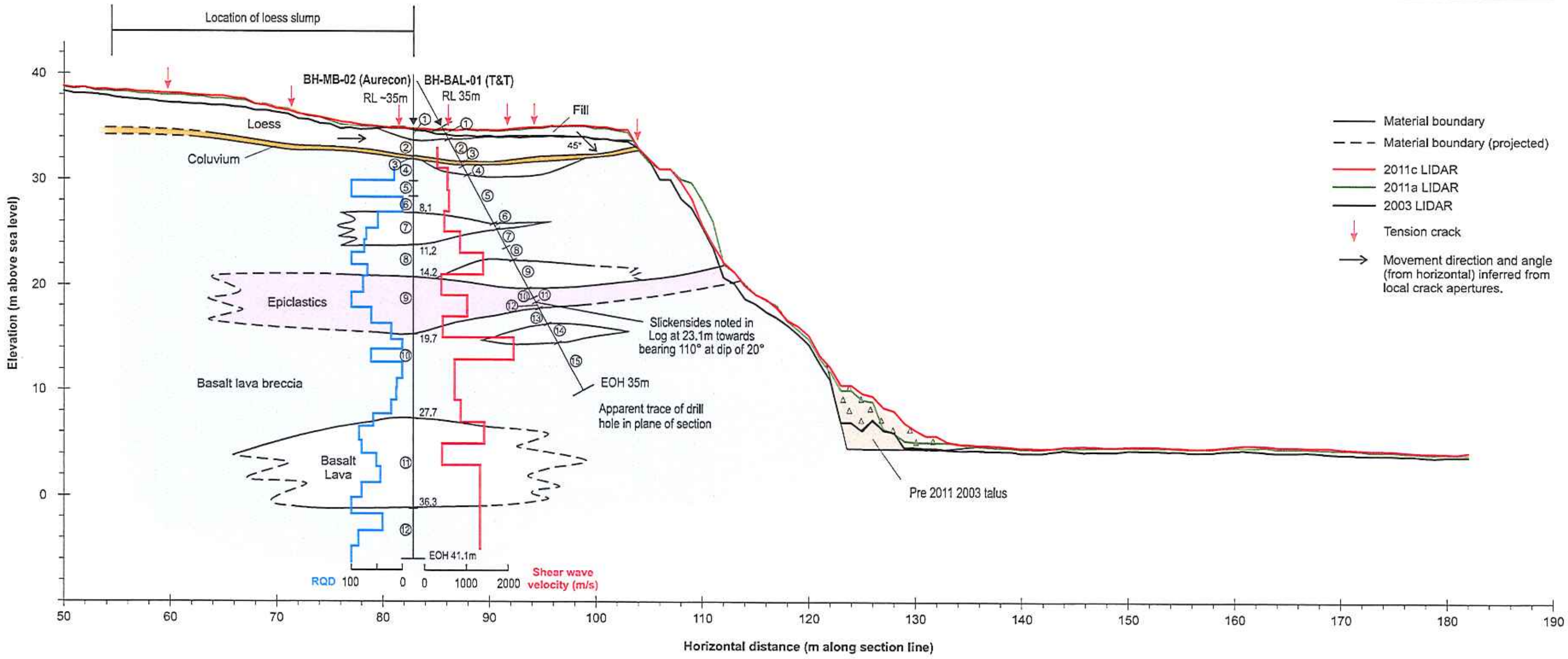


BH-MB-02 (Aurecon)

	Material type	Weathering	Strength	RQD %
①	Road/Fill			
②	Loess			
③	Colluvium			
④	Basalt lava breccia	HW	W	0
⑤	Basalt lava breccia	HW	S	92
⑥	No recovery			
⑦	Basalt lava	MW	S	24-71
⑧	Basalt lava breccia	SW	S	71
⑨	Epiclastics	MW	W	70
⑩	Basalt lava breccia	MW	MS	30-60
⑪	Basalt lava	SV	SW	70
⑫	Basalt lava breccia	MW	MS	0

BH-BAL-01 (T&T)

	Material type	Weathering	Strength	RQD %
①	Top Soil			
②	Loess			
③	Basalt lava breccia	HW	W	
④	Basalt lava	MW	MS	
⑤	Basalt lava breccia	HW	W	
⑥	Basalt lava	SW	VS	
⑦	Basalt lava breccia	MW	MS	
⑧	Basalt lava breccia	HW	EW	
⑨	Basalt lava	MW	VS	
⑩	Epiclastics	MW	EW	
⑪	Epiclastics	MW	EW	
⑫	Epiclastics	MW	W	
⑬	Basalt lava breccia	MW	W	
⑭	Basalt lava	MW	S	
⑮	Basalt lava breccia	HW	EW	



Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC

CHK: CM/FDP

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ENGINEERING GEOLOGY CROSS SECTION R03

Redcliffs
Christchurch

FIGURE 13

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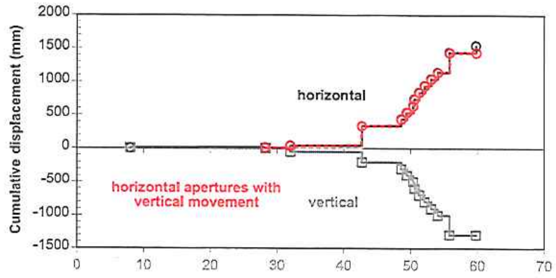
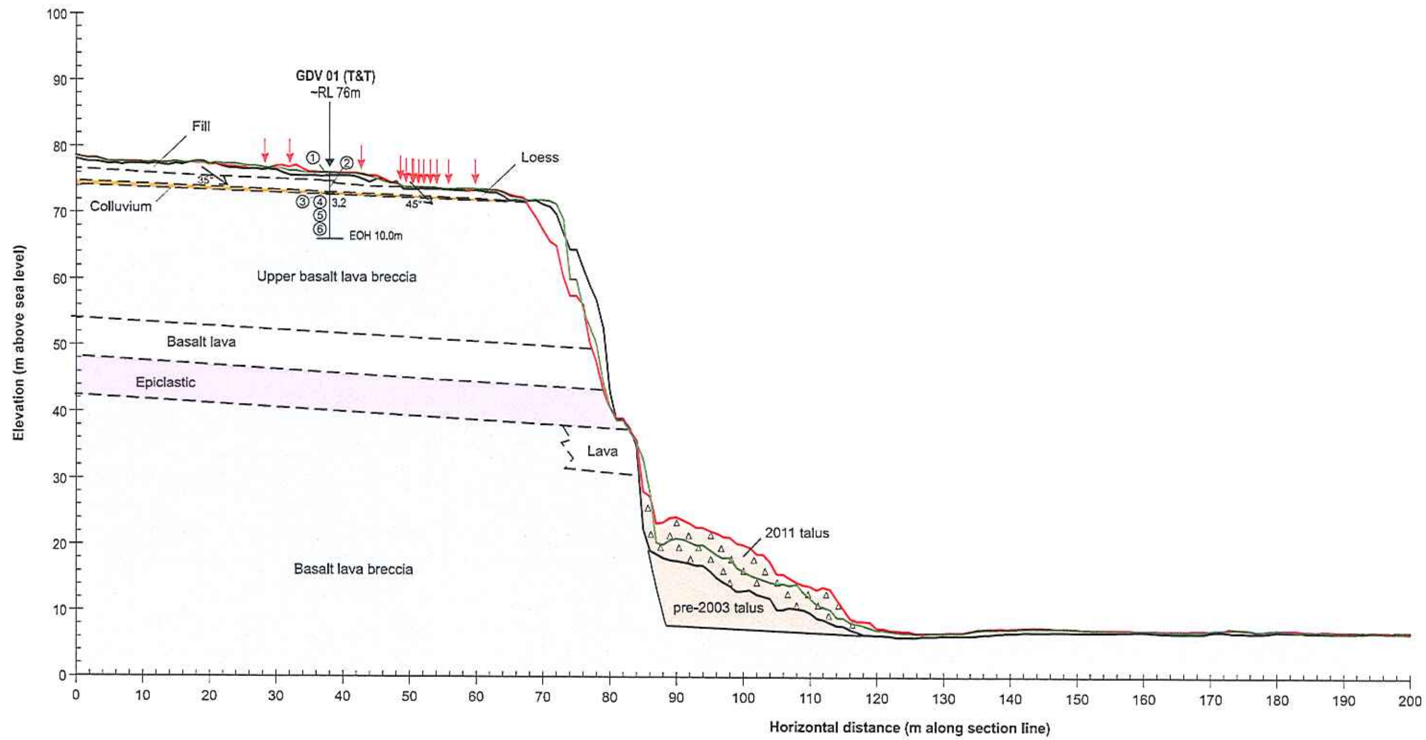
REPORT: CR2014/78

DATE: August 2014



GDV 01 (T&T)

	Material type	Weathering	Strength	RQD %
①	Fill			
②	Loess	M-W		100
③	Colluvium	MW-W	S	100
④	Basalt lava breccia	W	S	100
⑤	Core loss			
⑥	Basalt lava breccia	MW	MS	100



Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC

CHK: CM/FDP

GNS SCIENCE TE PŪ AO

ENGINEERING GEOLOGY CROSS SECTION R04

Redcliffs
Christchurch

FIGURE 13

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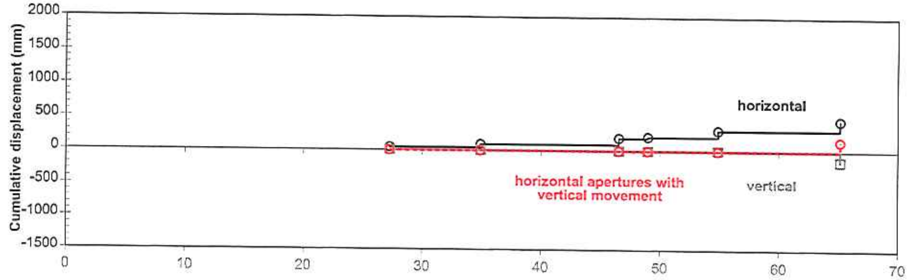
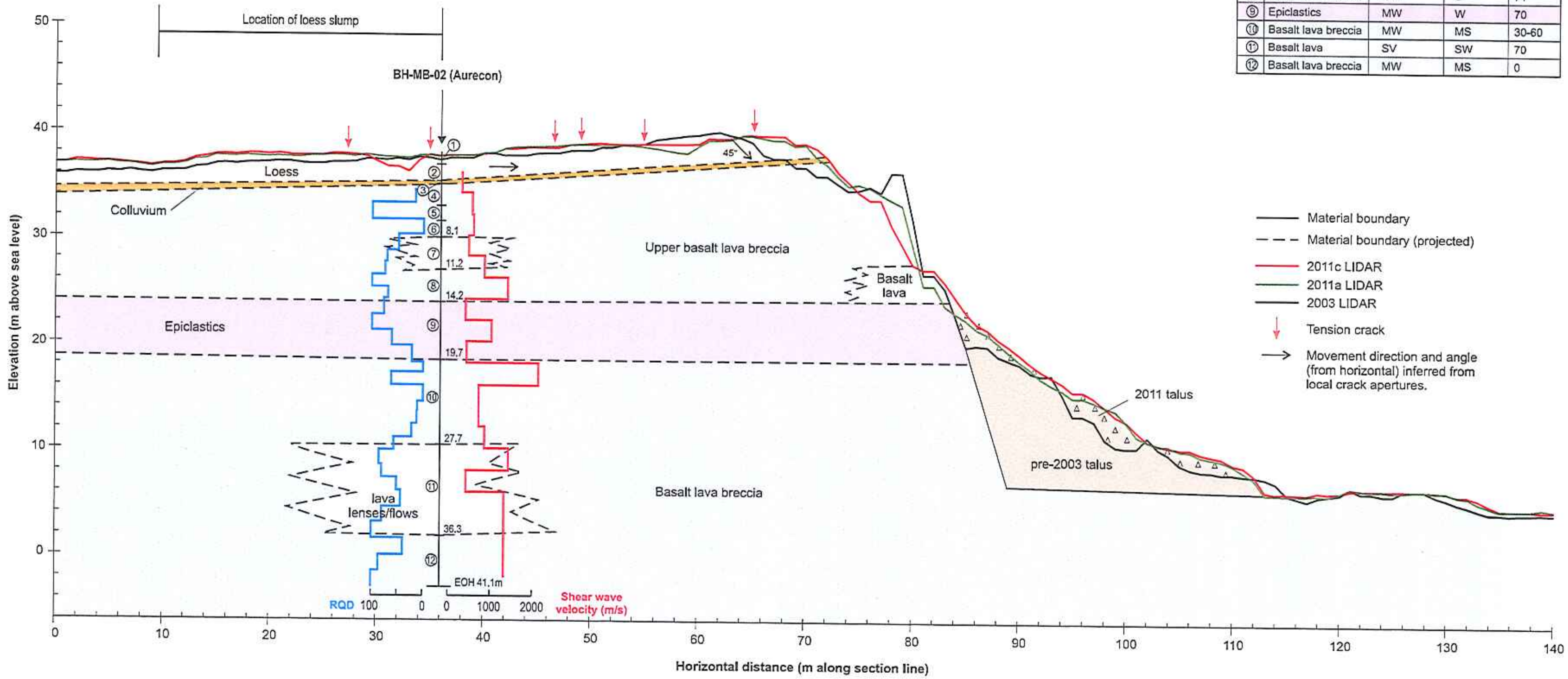
REPORT: CR2014/78

DATE: August 2014



BH-MB-02 (Aurecon)

	Material type	Weathering	Strength	RQD %
①	Road/Fill			
②	Loess			
③	Colluvium			
④	Basalt lava breccia	HW	W	0
⑤	Basalt lava breccia	HW	S	92
⑥	No recovery			
⑦	Basalt lava	MW	S	24-71
⑧	Basalt lava breccia	SW	S	71
⑨	Epiclastics	MW	W	70
⑩	Basalt lava breccia	MW	MS	30-60
⑪	Basalt lava	SV	SW	70
⑫	Basalt lava breccia	MW	MS	0



Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC

CHK: CM/FDP

ENGINEERING GEOLOGY CROSS SECTION R05

Redcliffs
Christchurch

FIGURE 13

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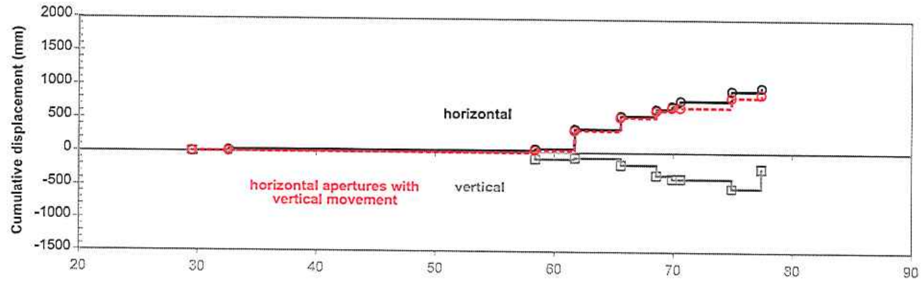
REPORT: CR2014/78

DATE: August 2014

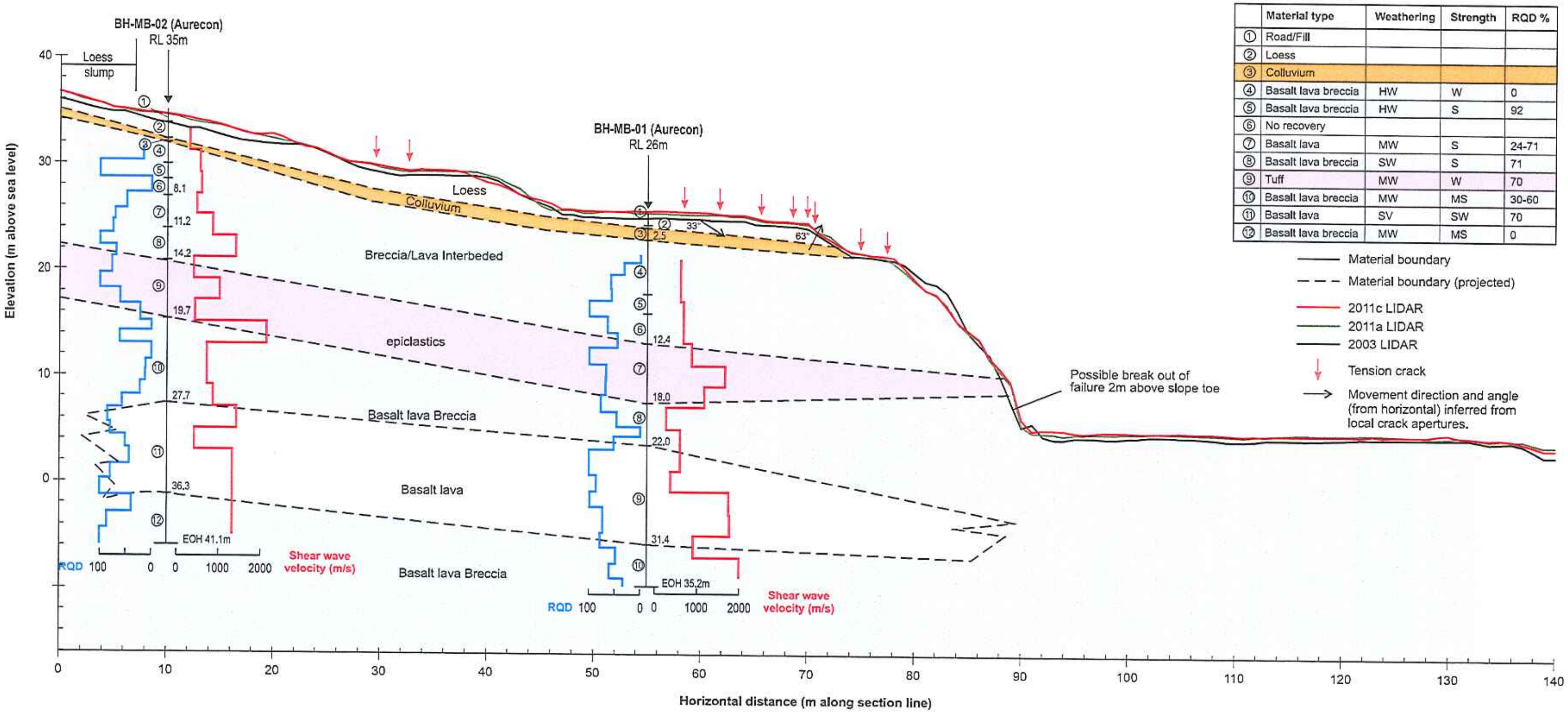


BH-MB-01 (Aurecon)

	Material type	Weathering	Strength	RQD %
①	Road/Fill			
②	Loess			
③	Colluvium			
④	Basalt lava	HW	W-S	0-100
⑤	Tuff	MW	S	60-100
⑥	Basalt lava breccia	HW	S	45-65
⑦	Tuff	HW	W-MS	60-100
⑧	Basalt lava breccia	HW	W-MS	0-50
⑨	Basalt lava	SW	S-VS	100
⑩	Basalt lava breccia	SW-HW	S	30-60

BH-MB-02 (Aurecon)

	Material type	Weathering	Strength	RQD %
①	Road/Fill			
②	Loess			
③	Colluvium			
④	Basalt lava breccia	HW	W	0
⑤	Basalt lava breccia	HW	S	92
⑥	No recovery			
⑦	Basalt lava	MW	S	24-71
⑧	Basalt lava breccia	SW	S	71
⑨	Tuff	MW	W	70
⑩	Basalt lava breccia	MW	MS	30-60
⑪	Basalt lava	SV	SW	70
⑫	Basalt lava breccia	MW	MS	0



Weathering (adopting NZGS (2005) terminology): CW completely weathered; HW highly weathered; MW moderately weathered; SW slightly weathered; UW unweathered.
Rock Strength (field strengths adopting NZGS (2005) terminology): EW extremely weak; VW very weak; W weak; MS moderately strong; S Strong; VS very strong; extremely strong.
Soil strength (field strengths adopting NZGS (2005) terminology): Coarse soils – VL very loose; L loose; MD medium dense; D dense, VD very dense. Cohesive soils – H hard; VSt very stiff; St stiff; F firm; So soft; VSo very soft.
RQD: Rock quality designation

DRW: PC
CHK: CM/FDP

ENGINEERING GEOLOGY CROSS SECTION R06

Redcliffs
Christchurch

FIGURE 13

FINAL

REPORT: CR2014/78

DATE: August 2014

Table 6 shows the total inferred displacement across all cracks relative to each cross-section; the number in brackets represents the displacement calculated using only those components with both horizontal and vertical measurements.

The dip of the resultant vectors from the horizontal – adopting only those components with both vertical and horizontal displacement – suggests that the angle of displacement is significantly steeper than the loess/rock interface, and more consistent with displacement of the underlying rock rather than localised slumping of the loess along the loess/rock interface. Also, the loess thickness is only 1–2 m near the cliff edge, where vertical displacements of greater than 0.5 m have been recorded (e.g., 1.5 m in cross-section 4).

Given these uncertainties, the displacements inferred from crack apertures are thought to represent upper bound estimates of the total permanent displacements of the cliff crest during the 2010/11 Canterbury earthquakes.

Table 6 Measured total cumulate crack apertures (measured normal to the slope), which formed during the 2010/11 Canterbury earthquakes (mainly during the 22 February 2011 earthquakes and less so during the 13 June 2011 earthquakes). Cracks measured by GNS Science and M. Yetton (Geotech Ltd). Displacements are inferred from field mapping of tension crack apertures along survey lines. Errors are nominally estimated as being ±0.01 m (values are rounded to the nearest 10 mm).

Cross-section	Source area	Vertical component (mm)	Horizontal component (mm)	Resultant vector magnitude/dip angle from horizontal (mm)	(°)	Angle of rockhead (loess/rock interface) (°)
1	1	1260 (560)[1]	2540 (750)[1]	2840 (940)	26 (37)	3
2	2	250	1330 (370)	1350 (450)	11 (34)	10
3		150	560 (150)	580 (210)	15 (45)	0
4	1	1300	1540 (1430)	2015 (1930)	40 (42)	4
5		150	460 (150)	480 (210)	18 (45)	3 (into slope)
6	3	230	990 (880)	1010 (910)	13 (15)	5

Values in brackets represent those displacements calculated using only those components with both horizontal and vertical measurements only.

1 Displacement estimate also excludes the first crack, which corresponds to a local feature within the loess, and is not thought to be related to displacement of the larger cliff.