Project Number: 6-CD109.55

Landslide Monitoring Report – Albany Street, Dunedin Central

20 May 2022

CONFIDENTIAL

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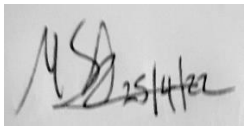

Mark Easton | Principal Geotechnical Engineer

Approved for Release by:

Abdul Obaid | Project Director

Document History and Status

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Revision Details

Revision	Details
A	Final Issue

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Disclaimers and Limitations

This report **('Report')** has been prepared by WSP exclusively for Dunedin City Council **('Client')** in relation to the landslide monitoring at selected sites in Dunedin (Long-Term Landslide Monitoring SoW DCC Reference 9662). The scope of this report is to present the survey monitoring results and recommendations for future surveys for the site **('Purpose')**. The findings in this Report are based on and subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

Executive Summary

A recent survey of the Albany Street site has been undertaken in October 2021 to assess the extent of movements compared with previous surveys. The main findings, where deformations were found to exceed the accuracy of the survey (±10 mm Hz, ±10 mm V), are presented in Table 1 below.

Table 1 Summary of recorded displacements.

	Horizontal	Vertical
Displacements from the previous survey	<10 mm	<10 mm
Displacements from the original survey	8 – 38 mm	0 – 35 mm

The results indicate that horizontal and vertical movement has slowed relative to previous rates and only minor movement has been measured since the previous survey (May 2020). This is likely to have been caused by below average rainfall during 2019 and 2020 (preceded by above average rainfall during 2017 and 2018), demonstrating a potential link between rainfall and deformation rate.

We recommend the next survey to be undertaken in late 2022, with consideration given to an expedited survey should accumulative rainfall be expected to exceed the annual long-term average.

1 Introduction

WSP have been commissioned by Dunedin City Council (DCC) to undertake monitoring of 12 landslide sites around Dunedin. The purpose of monitoring is to identify the trend and magnitude of movements and provide recommendations for future monitoring.

This report presents a summary of the factual survey monitoring results for the Albany Street site, as well as monitoring recommendations. A survey network diagram is provided in Appendix A.

2 Survey Monitoring

2.1 Monitoring History

Survey monitoring of the site began in 2008 but was re-established in 2010 following re-surfacing works on Queen and Albany Streets that destroyed many survey marks.

The 2010 baseline monitoring was carried out using total station and dumpy level. Subsequent surveys appear to have been carried out using total station for both horizontal and vertical measurements. Pin 214 was destroyed after the 2011 monitoring round and replaced with Pin 214A in the subsequent survey. ALP 215 was destroyed following the 2017 survey and has not been replaced.

After the 2018 survey, control survey mark SS9P was destroyed and a new survey mark, Nail 1 was installed nearby in 2020, leaving only two fixed control survey marks from the original survey.

Monitor frequency varies between 1 and 2 years. Survey dates are shown in the cumulative monitoring spreadsheet presented in Appendix C.

2.2 Methodology

This survey monitoring round was undertaken by a WSP Surveyor on 15 October 2021. The equipment used was a 3" Trimble S6 total station and a Leica DNA03 digital level with a fixed 3 m invar staff. Levelling was chosen for this monitor to confirm mark levels to a higher accuracy owing to contract handover.

2.2.1 Field Survey

A closed-loop 3d traverse was carried out by total station traversing around the block holding baseline ALP 5 - SS13G fixed as per the original 2010 coordinates with resulting calculated grid bearing 27° 58' 55" held fixed with a bearing mis-close of 13" observed closing back on the origin baseline. The vertical distance of each traverse leg was measured twice, the average difference was 0.008 m. A vertical mis-close of 0.001 m in the closed loop, although the accuracy of this method of heighting is likely to be 0.010 m. Each monitoring survey mark was measured by mini-prism on left and right face. Monitor marks on Albany St were doubled tied from ALP 4 and Nail A.

A new temporary traverse survey mark was placed uphill from ALP 6 and traversed through on this monitor to avoid loss of bearing control on short traverse lines SS13G – SS 9G – ALP 6. At the time of monitor, the James K Baxter memorial works also created obstructions to observing between ALP 6 – SS9G and prevented access to monitoring survey mark ALP 216, likely destroyed with the works.

Three closed loop level runs were carried out, from SS13G – AP4, AP4 – Nail 1 and AP 4 to monitoring survey mark ALP 210. Survey marks not able to be observed by level due to being below the surrounding ground level were ALP 203 and PIN 205. ALP 211 had a car bumper overhanging the survey mark. All three could be observed by mini-prism.

2.2.2 *Office Processing*

A bearing adjustment was applied to distribute the bearing mis-close of the traverse before being entered into a traverse spreadsheet using 12d software and co-ordinate mis-close adjusted by bow-ditch. A closed loop holding 1 point fixed results in a 0.005 m horizontal mis-close. The horizontal mis-close between the two fixed origin control points is 0.008 m using the observed distance which differed from calculation by 0.001 m. A full listing of the traverse spreadsheet is included in Appendix D.

The level-run mis-closures (Run 1: 0.0006 m, Run 2: 0.0024 m, Run 3: 0.0002 m) were distributed by pro-rata. Monitor marks were double tied during closed level run loops with an average difference / repeatability of 0.0004 m. Comparison between total station measured heights and DNA level heights varied from 0 to -0.004 m with an average of -0.002 m.

Comparison of control marks to the 2020 monitor saw an average difference of +0.003 m, i.e. the DNA level results are split between the two years data. A correction of -0.002 m was applied to monitor marks observed by total station only.

2.2.3 *Geodetic Parameters*

Horizontal Datum: Equipment geodesy settings used during survey and processing are NZGD2000 datum, North Taieri circuit projection. The fixed coordinates and orientation of the survey have been historically determined by marks SS13G – ALP 5 and are maintained regardless of their relationship to NZGD2000.

Vertical Datum: Height datum has been previously reported as Otago Metric Datum, commonly accepted as 100.00 m above Dunedin Vertical Datum 1958.

2.3 Accuracy

The historically reported accuracy of survey is quoted as;

Horizontal position +/- 10 mm
Vertical position +/- 10 mm

The vertical accuracy of 3d heighting is within the above tolerance, as confirmed on this survey by independent check with digital level.

2.4 Future Monitoring

Pin 214 was destroyed after the 2011 monitoring, replaced with Pin 214A in the subsequent survey. ALP 215 was destroyed following the 2017 survey and has not been replaced. ALP 216 could not be accessed during this 2021 survey due to fencing surrounding the construction of the James K Baxter memorial and has likely been destroyed. Additional work will be required during a subsequent monitoring round to install new survey marks to replace 215 and 216 and any others recommended by the Engineer and Client.

3 Monitoring Results

The cumulative results spreadsheet is presented in Appendix C of this report. The monitoring results are discussed below.

Table 2 Summary of deformation monitoring results since the previous and base surveys.

	Deformation since previous survey		Deformation since base survey	
	Horizontal	Vertical	Horizontal	Vertical
Average	<10 mm	<10 mm	25 mm	-16 mm
Maximum	10 mm	-16 mm	38 mm	-35 mm

4 Rainfall Data

A summary of the rainfall data since the previous survey is presented in Figure 1 below. Data was retrieved from the NIWA (National Institute of Water and Atmospheric Research) National Climate Database website (CliFlo.niwa.co.nz) using the Musselburgh Station (Agent ID #15752). Mean monthly rainfall is calculated for the "Dunedin" area between 1981 and 2010 (source: https://niwa.co.nz/education-and-training/schools/resources/climate/meanrain).

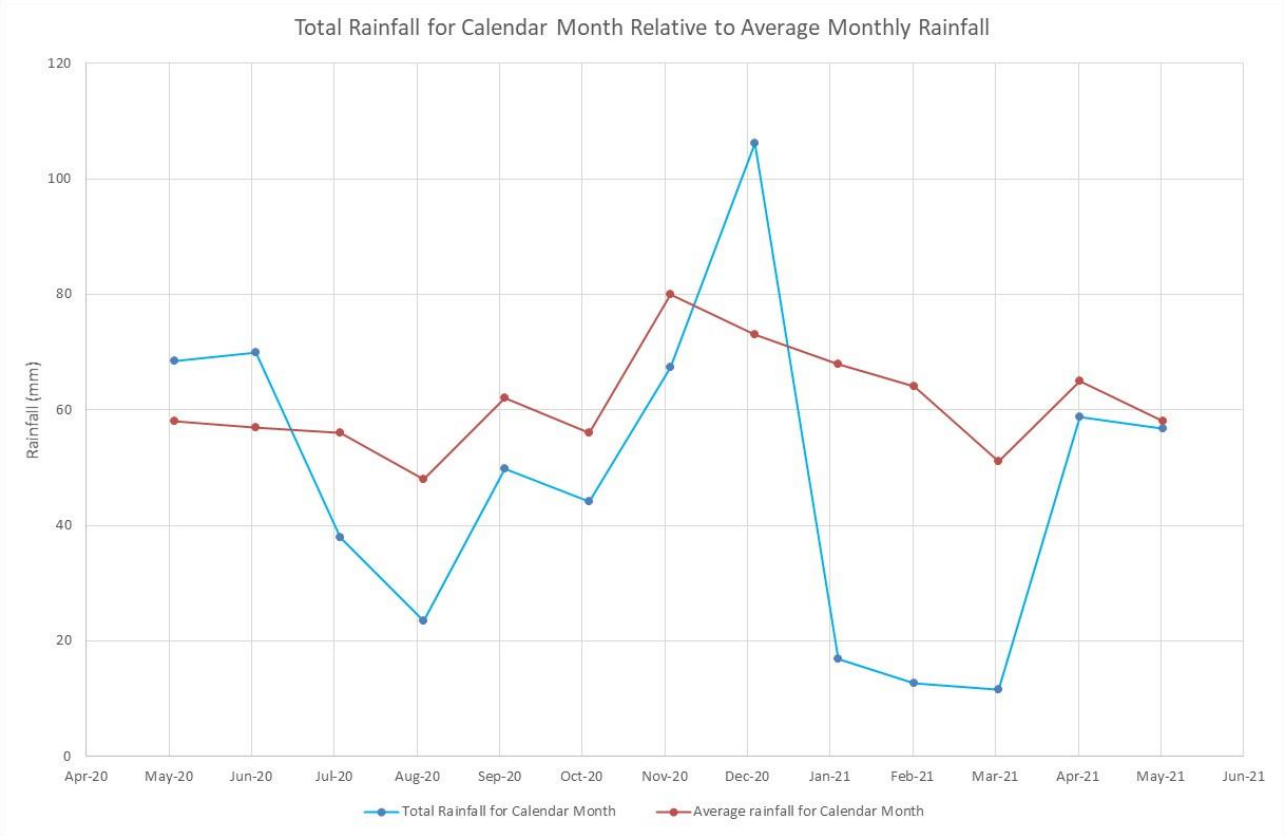


Figure 1 Measured monthly rainfall compared with average monthly rainfall (CliFlo.niwa.co.nz).

5 Conclusions and Recommendations

In conclusion, the maximum displacements recorded since the 2010 base survey are as follows:

- 38 mm in plan,
- -35 mm vertically.

While the average horizontal and vertical deformations since the previous monitor are less than the accuracy of the survey, almost all data indicates a minor deformation consistent with that of landslide movement (downslope and negative vertical directions). Recent results indicate a slower rate of movement from the previous survey relative to that recorded circa 2016 – 2020, a period where deformation appeared to accelerate. Rainfall during this former period was relatively high with 784mm and 823mm having been recorded in 2017 and 2018 respectively (both higher than the long-term average), which is likely to have contributed to the accelerated movement. Recent years have seen below average rainfall (726mm in 2019 and 600mm in 2020) coinciding with a period of slowed deformation, hence demonstrating a potential rainfall-dependent deformation trend.

Overall, the deformation trends recorded are broadly consistent with the long-term record. Due to total deformation equalling roughly 35 mm vertical and horizontal since 2010 (a long-term average of ~3 mm/year), and the number of dwellings affected, we recommend that a follow-up survey is completed on a 12-monthly basis.

In addition, we recommend consideration be given to an additional survey in advance of the scheduled 12-monthly monitoring round when accumulative annual rainfall is expected to exceed the long-term average of approximately 750mm/year (as of 2021). If future surveys reveal adverse deformation trends, we recommend the DCC discuss possible treatment options with WSP.

Appendix A
Network Diagram

NOTES:

COORDINATE DATUM- NZGD2000 (NORTH TAIERI)
LEVEL DATUM- OMD
HORIZONTAL AND VERTICAL ACCURACY +/- 10mm Hz AND Vt
"REFER TO SPREADSHEET FOR SURVEY DATA"

LEGEND

LANDSLIDE - OTAGO REGION (CERTAINTY)

- DEFINITE
- LIKELY
- POSSIBLE
- NOT ASSESSED
- NO INFORMATION

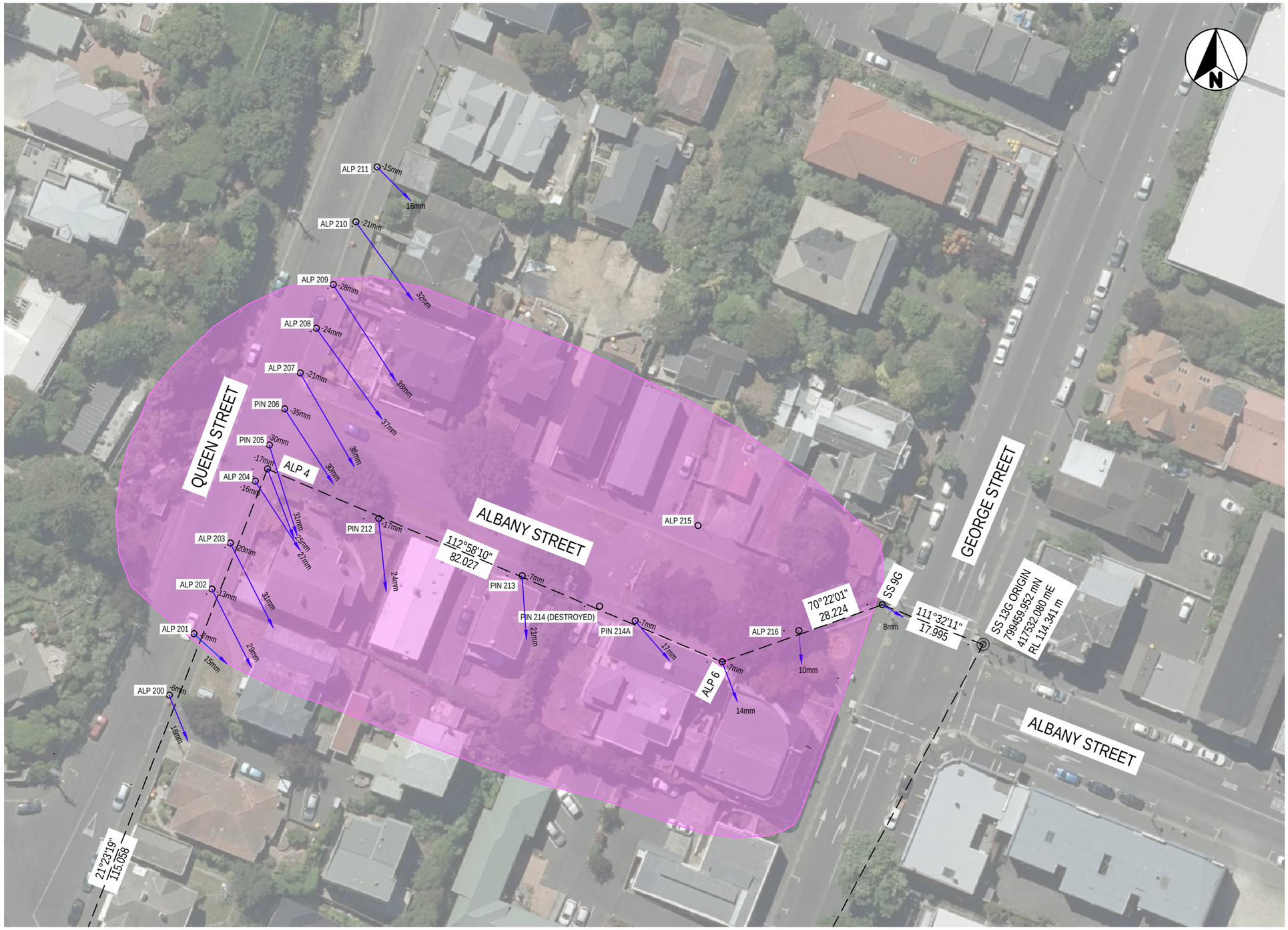
INDICATIVE LANDSLIDE EXTENTS ARE BASED ON "REVISED LANDSLIDE DATABASE FOR THE COASTAL SECTOR OF THE DUNEDIN CITY DISTRICT" BY BARRELL, D.J.A, SMITH LYTTLE, B., GLASSEY, P.J. GNS SCIENCE CONSULTANCY REPORT 2017/41 , JULY 2017, SOURCED FROM THE OTAGO REGIONAL COUNCIL (ORC) NATURAL HAZARDS PORTAL.

OTHER

+/- Xmm = CUMULATIVE VERTICAL DISPLACEMENT

CUMULATIVE HORIZONTAL DISPLACEMENT

SURVEY MARKER



1:100 @ A1
1:200 @ A3
0 1 2 3 4 5 6 7 8 9 10 m

WORK IN PROGRESS

PRINTED 22/04/2022 8:09:08 AM

REVISION	AMENDMENT	APPROVED	DATE

DUNEDIN CITY COUNCIL | kaunihera a-rohe o Ōtepoti

Dunedin Office
+64 3 471 5500
Private Bag 1913
Dunedin 9016
New Zealand

CIVIL

SCALES: N.T.S
ORIGINAL SIZE: A1
DRAWN: J.WILLIAMS
DESIGNED:
APPROVED:
DRAWING VERIFIED:
DESIGN VERIFIED:
APPROVED DATE:

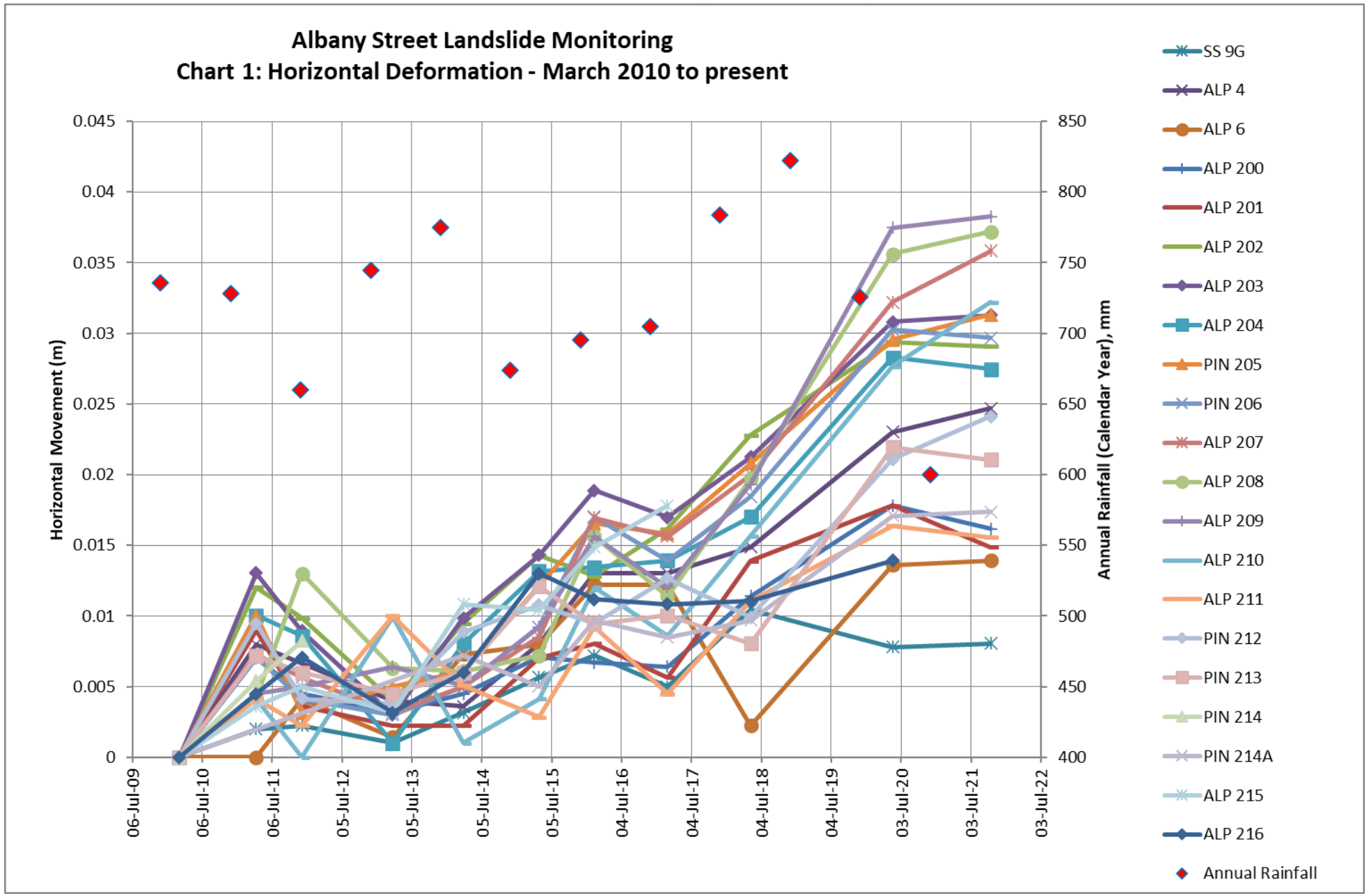
FOR INFORMANTION

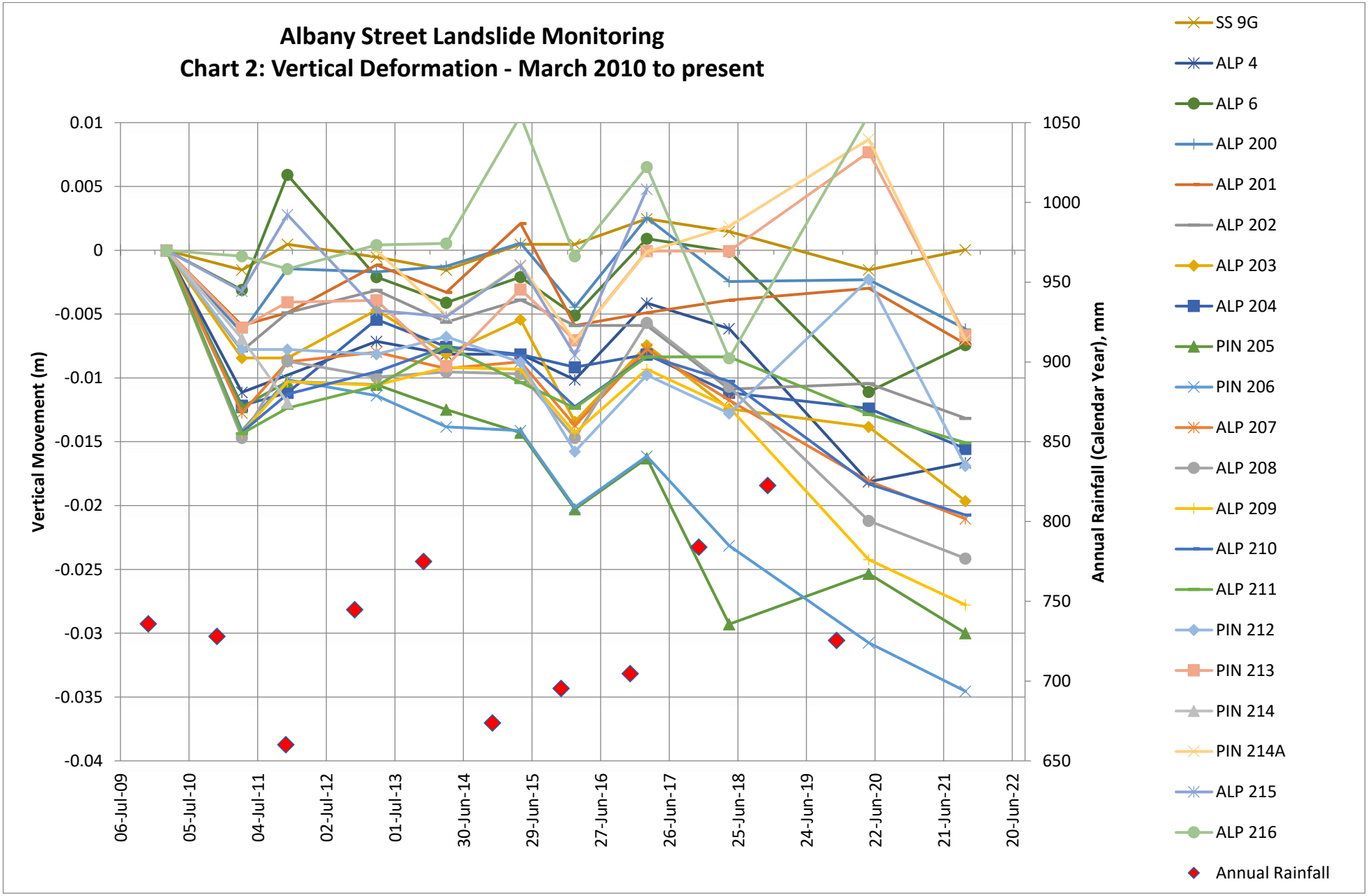
PROJECT: DUNEDIN CITY COUNCIL
LONG TERM LANDSLIDE MONITORING

TITLE: LANDSLIDE MONITORING
ALBANY STREET

WSP PROJECT NO.	PROJ-ORIG-VOL-LOC-TYPE	SHEET NO.	REVISION
6-CD109.55	6-CD109.55	C01	A

Appendix B
Selected Monitoring Charts


Albany Street Landslide Monitoring
Chart 1: Horizontal Deformation - March 2010 to present
Horizontal Movement (m)
Annual Rainfall (Calendar Year), mm
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
850
800
750
700
650
600
550
500
450
400
06-Jul-09
06-Jul-10
06-Jul-11
05-Jul-12
05-Jul-13
05-Jul-14
05-Jul-15
04-Jul-16
04-Jul-17
04-Jul-18
04-Jul-19
03-Jul-20
03-Jul-21
03-Jul-22
SS 9G
ALP 4
ALP 6
ALP 200
ALP 201
ALP 202
ALP 203
ALP 204
PIN 205
PIN 206
ALP 207
ALP 208
ALP 209
ALP 210
ALP 211
PIN 212
PIN 213
PIN 214
PIN 214A
ALP 215
ALP 216
Annual Rainfall


Albany Street Landslide Monitoring
Chart 2: Vertical Deformation - March 2010 to present
Vertical Movement (m)
Annual Rainfall (Calendar Year), mm
0.01
0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
-0.035
-0.04
1050
1000
950
900
850
800
750
700
650
06-Jul-09
05-Jul-10
04-Jul-11
02-Jul-12
01-Jul-13
30-Jun-14
29-Jun-15
27-Jun-16
26-Jun-17
25-Jun-18
24-Jun-19
22-Jun-20
21-Jun-21
20-Jun-22
SS 9G
ALP 4
ALP 6
ALP 200
ALP 201
ALP 202
ALP 203
ALP 204
PIN 205
PIN 206
ALP 207
ALP 208
ALP 209
ALP 210
ALP 211
PIN 212
PIN 213
PIN 214
PIN 214A
ALP 215
ALP 216
Annual Rainfall

Appendix C
Cumulative Monitoring Results Spreadsheet

Date of Survey: 15/10/2021
Datum: Horizontal: NZGD2000, North Taieri Circuit
Vertical: Otago Metric Datum

DCC LANDSLIDE MONITORING
ALBANY STREET 3D CONTROL TRAVERSE

3D network established 8 March 2010
Survey carried out by 3D traverse (S6 robotic)
Marks SS13G and ALP5 are held fixed
Initial heights and 2021 surveyed heights established by levelling
3d traverse accuracy: +/-10mm horizontal
+/-10mm vertical

NOTE: Data is flagged where movement is in excess of 10mm

SURVEY 10

Survey Date: 15/10/2021

				Present to Previous Northing					Present to Original (08/03/2010)				
Pin #	Northing (NZGD2000 Nth Taieri)	Easting	Height (Otago Metric Datum)	dN	dE	Bearing	Dist	dRL	dN	dE	Bearing	Dist	dRL
SS13G	799459.952	417532.080	114.341	0.000	0.000	0	0.000	0.000	0.000	0.000	0	0.000	0.000
ALP 5	799276.250	417434.478	112.217	0.000	0.000	0	0.000	0.000	0.000	0.000	0	0.000	0.000
Nail 1											0		
SS9G	799466.551	417515.345	114.502	-0.001	-0.001	225	0.001	0.002	-0.007	0.004	150	0.008	0.000
ALP4	799489.078	417413.253	136.902	0.004	0.004	45	0.006	0.001	-0.009	0.023	111	**0.025**	**-0.017**
ALP6	799457.070	417488.767	122.910	0.003	0.002	56	0.004	0.004	-0.005	0.013	111	**0.014**	-0.007
200	799451.537	417396.942	134.487	0.008	0.004	63	0.009	-0.004	-0.006	0.015	112	**0.016**	-0.006
201	799461.713	417401.006	135.293	0.003	-0.001	108	0.003	-0.004	-0.011	0.010	138	**0.015**	-0.007
202	799469.128	417404.006	135.718	0.004	0.002	63	0.004	-0.003	-0.013	0.026	117	**0.029**	**-0.013**
203	799476.766	417407.082	136.284	0.004	0.003	53	0.005	-0.006	-0.014	0.028	117	**0.031**	**-0.020**
204	799487.046	417411.200	136.971	0.005	0.003	59	0.006	-0.003	-0.015	0.023	123	**0.027**	**-0.016**
205	799493.077	417413.573	137.181	0.003	0.003	45	0.004	-0.005	-0.009	0.030	107	**0.031**	**-0.030**
206	799499.062	417416.092	137.446	0.001	0.000	90	0.001	-0.004	-0.016	0.025	123	**0.030**	**-0.035**
207	799505.013	417418.694	137.662	0.001	0.005	11	0.005	-0.003	-0.018	0.031	120	**0.036**	**-0.021**
208	799512.420	417421.356	138.429	0.000	0.002	0	0.002	-0.003	-0.022	0.030	126	**0.037**	**-0.024**
209	799519.688	417424.184	139.207	0.006	0.006	45	0.008	-0.004	-0.021	0.032	123	**0.038**	**-0.028**
210	799530.097	417427.902	140.504	-0.001	0.005	349	0.005	-0.002	-0.019	0.026	126	**0.032**	**-0.021**
211	799539.195	417431.461	141.265	0.002	0.001	63	0.002	-0.002	-0.011	0.011	135	**0.016**	**-0.015**
212	799480.859	417431.713	133.518	0.008	0.006	55	**0.010**	**-0.015**	-0.003	0.024	96	**0.024**	**-0.017**
213	799471.364	417455.559	129.523	0.007	0.001	82	0.008	**-0.014**	-0.002	0.021	94	**0.021**	-0.007
214A	799464.567	417472.637	126.603	0.003	0.004	37	0.005	**-0.016**	-0.012	0.013	131	**0.017**	-0.007
216													

Appendix D

Traverse Spreadsheet

Height Checks

Chris Hall
Surveyor

Traverses of: Landslide Monitor
Albany Street

Circuit: North Taieri

Datum: Geodetic 2000

Coords interms of: False Origin
800000.000mN 400000.000mE

Sheet 1 3/12/2021
Field Book:

Plan No:

Land District:
Otago

Line No	Bearing ° ′ ″	Scale Factor 0.99996000 Reduced Dist:	Metres N	Metres E	Survey Mark	Remarks Including Source of Coordinate
1	Scale: Applied		799459.952	417532.080	SS13G	(COORDINATE ORIGIN)
2	207 58 55	208.020	799276.250	417434.478	ALP 5	(COORDINATE ORIGIN)
3	28 57 38	0.008	-0.007	-0.004	RF 1:25514	
4						
5	Scale: Applied		799276.250	417434.478	ALP 5 L2 P1	
6	329 03 57	122.973	799381.731	417371.268	NAIL 1	
7	21 21 37	115.265	799489.078	417413.253	AP 4	
8	111 52 06	70.870	799462.684	417479.022	NAIL A	
9	92 56 56	53.129	799459.952	417532.080	SS13G L1 P1	
10	216 45 15	0.013	0.011	0.008	RF 1:26944	
11						
12	Scale: Applied		799489.078	417413.253	AP 4 L7 P1	
13	203 29 02	40.933	799451.537	417396.942	AP 200	
14	204 06 40	29.981	799461.713	417401.006	AP 201	
15	204 52 04	21.989	799469.128	417404.006	AP 202	
16	206 37 11	13.772	799476.766	417407.082	AP 203	
17	225 17 17	2.888	799487.046	417411.200	AP 204	
18	4 34 54	4.012	799493.077	417413.573	PIN 205	
19	15 52 35	10.381	799499.062	417416.092	PIN 206	
20	18 51 15	16.839	799505.013	417418.694	AP 207	
21	19 08 38	24.710	799512.420	417421.356	AP 208	
22	19 39 07	32.505	799519.688	417424.184	AP 209	
23	19 39 14	43.558	799530.097	417427.902	AP 210	
24	19 58 00	53.324	799539.195	417431.461	AP 211	
25	114 00 38	20.208	799480.855	417431.711	PIN 212	
26	112 43 27	45.866	799471.361	417455.557	PIN 213	
27	112 25 55	64.246	799464.563	417472.635	PIN 214a	
28						
29	Scale: Applied		799462.684	417479.022	NAIL A L8 P1	
30	291 01 12	50.681	799480.862	417431.715	PIN 212	
31	290 18 32	25.017	799471.366	417455.561	PIN 213	
32	286 28 21	6.657	799464.571	417472.639	PIN 214A	
33	119 56 39	11.246	799457.070	417488.767	AP 6	
34						
35	Scale: Applied		799459.952	417532.080	SS13G L1 P1	
36	291 31 07	17.990	799466.551	417515.345	SS9G	
37						

Levels by TS (using DNA level of station)

From	To	dH	RL
SS13G	ALP5	-2.1218	112.2193
SS13G	SS9G	0.1615	114.5025
SS13G	Nail A	10.8980	125.2390
ALP5	SS13G	2.1218	
ALP5	Nail 1	15.0268	
Nail A	SS13G	-10.8875	114.3464
Nail A	AP6	-2.3230	122.9109
Nail A	Pin 212	8.2875	133.5214
Nail A	Pin 213	4.2920	129.5259
Nail A	AP4	11.6725	136.9064
Nail A	Pin 214A	1.3745	126.6084
Nail 1	ALP5	-15.0225	110.2114
Nail 1	AP4	9.6620	134.8959
AP4	Nail 1	-9.6608	127.2408
AP4	Nail A	-11.6690	125.2325
AP4	AP 200	-2.4110	134.4905
AP4	AP 201	-1.6060	135.2955
AP4	AP 202	-1.1835	135.7180
AP4	AP 203	-0.6155	136.2860
AP4	AP 204	0.0695	136.9710
AP4	AP 205	0.2820	137.1835
AP4	AP 206	0.5485	137.4500
AP4	AP 207	0.7630	137.6645
AP4	AP 208	1.5295	138.4310
AP4	AP 209	2.3080	139.2095
AP4	AP 210	3.6045	140.5060
AP4	AP 211	4.3660	141.2675
AP4	Pin 212	-3.3810	133.5205
AP4	Pin 213	-7.3805	129.5210
AP4	AP 214A	-10.3005	126.6010
AP4	Nail A	-11.6690	125.2325

Double ties - averaged

AP 214A	126.605
Pin 213	129.523
Pin 212	133.521

Reciprocal Trig Heighting **Origin** **SS13G**

From	To	dH	From	to	dH	diff	average	Mark	RL
SS13G	ALP5	-2.122	ALP5	SS13G	2.122	0.000	2.122		
SS13G	SS9G	0.162							
SS13G	Nail A	10.898	Nail A	SS13G	-10.888	-0.011	10.893		
Nail A	ALP4	11.673	ALP4	Nail A	-11.669	-0.003	11.671		
ALP4	NAIL 1	-9.661	NAIL 1	ALP4	9.662	0.001	9.661		
Nail 1	ALP5	-15.023	ALP5	Nail 1	15.027	0.004	15.025		
					Avg:	**-0.0084**			

Misclose: **-0.0007**

Control Mark Cross Checks

Mark	RL TS	RL DNA	Diff	RL 2020	DNA - 2020	TS - 2020
Nail A	125.234	125.2339	0.000			
ALP 4	136.905	136.9015	-0.003	136.899	0.002	0.005
Nail 1	127.243	127.2397	-0.003	127.236	0.004	0.007
SS 9G	114.503	114.5016	-0.001	114.501	0.001	0.002
ALP5	112.219			112.217		0.002
ALP6	122.911	122.9097	-0.001	122.906	0.004	0.005
		Avg:	**-0.0017**	**Avg:**	**0.003**	**0.004**

Monitoring Mark RLs

Mark	TS	DNA	Diff	Interp. Corrn.
ALP200	134.491	134.487	-0.003	
ALP201	135.296	135.293	-0.003	
ALP202	135.718	135.718	0.000	
ALP203	136.286	-		136.284
ALP204	136.971	136.971	0.000	
PIN 205	137.184	-		137.181
PIN 206	137.450	137.446	-0.004	
ALP207	137.665	137.662	-0.003	
ALP208	138.431	138.429	-0.002	
ALP209	139.210	139.207	-0.003	
ALP210	140.506	140.504	-0.002	
ALP211	141.268	-		141.265
PIN212	133.521	133.518	-0.003	
PIN213	129.523	129.523	0.000	
PIN214A	126.605	126.603	-0.002	
		Avg:	**-0.0022**	

Marks not measured by DNA were below surrounding ground level,
Pin 211 had a car bumper overhanging the mark, could be obsvd by mini prism

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