November 29, 2024

Alberta Transportation and Economic Corridors
2nd Floor, 803 Manning Road N.E.
Calgary, Alberta
T2E 7M8

Alex Frotten, P.Eng.
Construction Engineer – Delivery Services Division (Southern Region)

Dear Mr. Frotten:

CON0022161 Southern Region GRMP Instrumentation Monitoring
Site S003; H22:16 km 9.9 Cochrane
Section C – 2024 Fall Readings

1 GENERAL

Five slope inclinometer (SI) (SI18-01), and three vibrating wire piezometers (VWPs) (VW18-01 through VW18-03) were read at the S003 site in Southern Region on September 16, 2024, by Mr. Bradley Lawson, E.I.T. of Klohn Crippen Berger Ltd. (KCB). These instruments were read as part of the Southern Region Geohazard Risk Management Program (GRMP). The site is located on Hwy 22:16 km 9.9, south of Cochrane, Alberta, approximately 1 km south of the Bow River bridge. The approximate site coordinates are 5672089 N, 676024 E (UTM Zone 11, NAD 83), and the legal land description for the site is SW 34-25-4-W5. A site plan is presented in Figure 1.

The geohazard at the S003 site consists of a landslide along the south slope of the Bow River valley. The landslide encroaches approximately 3 m into the northbound lane of Hwy 22:16. Previous remedial actions at this site include construction of a ditch berm (date unknown) in the northeast (northbound lane) ditch to reduce surface water runoff from discharging onto the landslide. However, in late-2020, ongoing movement of the slide area had caused settlement of the ditch berm such that ditch flows were directed onto the slide area. In fall 2023 a pile wall consisting of 133 piles, spaced at 0.72 m, center to center, was constructed on the east side of the highway in the slide zone to stabilize the slope. The ditch across the slide area was also repaired so that water did not flow out of the ditch onto the slide mass.

Geotechnical site investigations, which included installing instruments, were conducted at the S003 site in 1991, 1994, 2007, and 2009 by the previous consultants. In March 2018, KCB conducted a geotechnical site investigation during which instruments were installed to monitor movement and groundwater conditions, respectively. Drilling was completed by Mayfield Drilling and Environmental Service Ltd. The encountered stratigraphy during the 2018 investigation was as follows: medium-

Klohn Crippen Berger Ltd.
7315 – 8 Street NE ▪ Calgary AB T2E 8A2 ▪ Canada
t 403.274.3424 ▪ f 403.274.5349 ▪ www.klohn.com

plastic clay, overlying medium-plastic clay till. As part of the 2023 construction, 4 SI where installed in the pile wall to monitor movement as the pile wall takes load from the slide mass.

1.1 Instrumentation

KCB has been reading the instruments at this site since 2016. Instrumentation installation details are tabulated in Table 1.1.

Instrument locations are shown in Figure 1. Any instruments not included in Table 1.1 or shown in Figure 1 are assumed to be inoperable and are not presented or discussed herein.

Between 1991 and 2007, 11 SIs and two piezometers were installed at the site by the previous consultants to monitor movement and groundwater conditions, respectively. By May 2020, most of these instruments were inoperable (e.g., destroyed, sheared, or lost). The pneumatic piezometer was found to be inoperable after the pile wall construction was completed, which could have been caused by slope movement observed downslope of the pile wall during construction activities.

In fall 2023, 4 SIs were installed along the newly constructed pile wall (SI23-XX).

The remaining operable instruments, including those installed by KCB in 2018 and 2023, are protected by either a flush-mounted or an above-ground casing protector.

KCB changed the SI reading equipment in May 2022 after the previous equipment became inoperable. Currently, KCB is reading the SIs with a metric RST Digital MEMS Inclinometer System.

The VWPs were read using an RST VWP readout box and Water Level Meter, respectively.

Table 1.1 Instrumentation Installation Details

Instrument ID	Instrument Type	Date Installed[1]	UTM Coordinates[2] (m)		Ground Surface Elevation (m)	Stick Up (m)	Depth (mbgs[3])	Condition
			Northing	Easting				
~~SI#1~~	~~SI~~	~~Sep. 1991~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable~~
~~SI#2~~	~~SI~~	~~Sep. 1991~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable~~
~~SI#3~~	~~SI~~	~~Sep. 1991~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable~~
~~SI#2~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~23.7~~	~~Inoperable~~
~~SI#3A~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable[4]~~
~~SI#4~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable[4]~~
~~SI#5~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~28.6~~	~~Inoperable~~
~~SI#6~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Inoperable[4]~~
~~SI#7~~	~~SI~~	~~Sep. 1994~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~20.2~~	~~Inoperable~~
~~SI2007-1~~	~~SI~~	~~Mar. 2007~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~19.7~~	~~Inoperable[4]~~
~~SI2007-3~~	~~SI~~	~~Mar. 2007~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~14.9~~	~~Inoperable~~
~~SI2009-1~~	~~SI~~	~~Jul. 2009~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~Unknown~~	~~19.0~~	~~Inoperable[4]~~
SI18-01	SI	Mar. 2018	5672120	676028	1174.0	0.8	21.3	Operable
SI23-01	SI	Sept. 2023	5672156	675976	1171.0	1.3	15.0	Operable
SI23-02	SI	Sept. 2023	5672141	675990	1171.0	1.3	15.0	Operable
SI23-03	SI	Sept. 2023	5672108	676015	1171.0	1.1	15.0	Operable
SI23-04	SI	Sept. 2023	5672083	676035	1171.0	1.4	14.0	Operable
VW18-01	VWP	Mar. 2018	5672120	676028	1174.0	N/A	13.7	Operable
VW18-02	VWP	Mar. 2018	5672056	676047	1176.0	N/A	10.1	Operable
VW18-03	VWP	Mar. 2018	5672048	676027	1176.5	N/A	4.6	Operable
~~BH2007-02~~	~~PN~~	~~Mar. 2007~~	~~5672117~~	~~676020~~	~~1173.8~~	~~N/A~~	~~5.6~~	~~Inoperable~~

Notes:
[1] Instrument installation details taken from reports and data files prepared or provided by the previous consultant(s) or Alberta Transportation and Economic Corridors.
[2] Coordinates confirmed by KCB with a handheld GPS. The handheld GPS had a horizontal accuracy of +/- 5 m.
[3] Meters below ground surface (mbgs). Bottom casing depth for SIs and tip depth for piezometers.
[4] SI#3A, SI#4, SI#6, SI2007-1, and SI2009-1 have all sheared at depths between approximately 1.8 m and 4.0 m, respectively.

2 INTERPRETATION

2.1 General

For the operable SI, the cumulative displacement, incremental displacement, and displacement-time data was plotted in the A-direction (i.e., the direction of the A0-groove) and X-direction (i.e., the direction of maximum movement obtained at a skew angle from the A0-grooves).

For the piezometers, the recorded porewater pressures were converted to an equivalent water/piezometric elevation and plotted relative to ground surface elevation of each instrument's tip elevation.

The SI and piezometer data plots are included in Appendix I, and a summary of the SI and piezometer data is provided in Table 2.1 and Table 2.2, respectively. Monthly precipitation data is also plotted

with the piezometer data. The data was obtained from the Alberta Climate Information Service (ACIS) database, referencing legal subdivision TWP026-04-W5.

2.2 Zones of Movement

Movement was previously recorded in the now inoperable SIs at depths between 1.0 m and 4.0 m below ground surface (approximately El. 1172.5 m to El. 1170.0).

Distributed movement is being recorded in SI18-01 from ground surface to an approximate depth of 2.3 m below ground surface (approximately El. 1173.6 m to El. 1171.7), and possible discrete movement between 2.3 m and 3.8 m (approximately El. 1171.7 m to El. 1170.2). The casing also appears to be settling or buckling between an approximate depth of 3.8 m and 8.8 m as discussed below. SI18-01 is located near the middle of the slide on the downslope side of the highway.

Distributed movement has started to be recorded in the SIs installed in the pile wall (SI23-01, SI23-02, and SI23-03) in the top 4 m to 6 m below ground surface, indicated that the pile wall has begun to take load from the slide mass.

2.3 Interpretation of Monitoring Results

The settlement or buckling observed in SI18-01 (from approximately 3.8 m and 8.8 m below ground surface) could be an indication that the instrument is poorly grouted with a possible grout void. The readings along this segment also do not stabilize, which further indicates a possible issue with the grout or damage to the casing. The movements of the slide mass and interpretation of the SI data is complicated by the potential for settlement or buckling of the SI casing in the poorly grouted casing segment.

Approximately 331 mm of cumulative movement has been recorded in SI18-01 since installation from a depth of 3.8 mbgs to ground surface. We expect this instrument may shear soon. SI18-01 was installed to support the design of an H-pile wall and drainage improvements to mitigate the impacts of the slope movement on Hwy 22:16.

Approximately 104 mm of movement was measured in SI18-01 between the spring 2023 reading and the reading taken post pile wall construction (November 2023) from a depth of 3.8 mbgs to surface. During construction, survey monitoring pins installed downslope of the pile wall measured horizontal movement up to 67 mm in the downslope direction in the slide zone at surface. This movement is believed to be due to added weight on the slope during pile installation from the piling rig, potential excess pore pressures in the slope due to pile installation and vibrations due to pile installation.

Cumulative movement in SI18-01 between the November 2023 (post construction) and the spring 2024 readings measured an additional 4 mm of cumulative movement in the upper 3.8 m. An additional 20 mm of cumulative movement was measured between spring 2024 and fall 2024 in the upper 3.8 m.

The four SIs installed during construction were initialized in November 2023 once construction was completed. The new SIs were installed inside the H-Pile flanges in steel channels and backfilled with sand. Small amounts of distributed movement (up to approximately 2.5 mm) are starting to be measured in the top 4 to 6 mbgs in SI23-01, SI23-02 and SI23-03, indicating that the pile wall has begun to take load from the slide mass. Additional readings will be needed to provide further interpretation of the pile wall movement as it continues to take load from the slide mass. Readings taken since installation in SI23-04 have had poor data quality and have been re-read several additional times to try and get consistent readings. The issue with SI23-04 will need to be investigated further as the readings to date do not have consistent check sum values, resulting in displacement plots that are unable to be interpreted.

The initial readings for the VWPs (VW18-01 through VW18-03) were taken immediately following grouting operations, and KCB believes that the initial water levels recorded in the VWPs were artificially high due to grouting. Water levels recorded in these instruments decreased up to 12 m within a month of installation.

Excluding the first reading, water levels recorded in VW18-01 located within the slide mass, downslope from the highway) have varied from 8.8 m and 13.4 m below ground surface, and water levels in VW18-02 (located within the slide mass, on the east shoulder of the highway) have varied from approximately 7.7 m and 10.1 m below ground surface. These water levels are below the depth of movement recorded in the SI (between ground surface and 4.0 m below ground surface). The data indicates slide movements are likely in response to periods of increased precipitation when surface water infiltrates into the top few meters, destabilizing the slope.

Water levels recorded in VW18-03 (located in the west highway ditch) have been within 0.4 m of ground surface since 2021. The fall 2024 was recorded at 0.2 m below ground surface. Rainfall data past August 31, 2024 was not available at the time of writing this report, further discussion on how the piezometers respond to increased rainfall will be discussed in subsequent reports once the data is available.

Overall, the September 2024 readings for the VWPs were consistent with historical trends observed in these instruments. More data is needed to assess long-term trends for the piezometers installed in 2018.

Table 2.1 Slope Inclinometer Reading Summary

Instrument ID	Date				Ground Surface Elevation (m)	Depth of Movement (mbgs[1])	Direction of Movement, Skew Angle	Movement (mm)			Rate of Movement (mm/year)		
	Initialized[3]	Previous Maximum Cumulative Movement Recorded	Previous Reading	Most Recent Reading				Previous Maximum Cumulative	Incremental Since Previous Maximum Cumulative	Total	Previous Maximum	Most Recent Reading	Change from Previous Reading
SI18-01	Oct. 23, 2018	May 8, 2024	May 8, 2024	Sep. 16, 2024	1174	0.5 – 2.5	A-Direction	68.0	6.7	70.7	57.3	7.4	0.3
						2.5 – 3.8	A-Direction	243.5	17.2	260.8	263.2	48.0	47.0
SI23-01	Nov. 28, 2023	N/A	May 8, 2024	Sep. 16, 2024	1171	N/A	A-Direction	1.5	0.5	2.0	3.4	1.5	-1.9
SI23-02	Nov. 28, 2023	N/A	May 8, 2024	Sep. 16, 2024	1171	N/A	A-Direction	N/A	2.2	2.2	N/A	9.4	9.4
SI23-03	Nov. 28, 2023	N/A	May 8, 2024	Sep. 16, 2024	1171	0 – 6.0	A-Direction	N/A	2.4	2.4	N/A	7.1	7.1
SI23-04	Nov. 28, 2023	N/A	May 8, 2024	Sep. 16, 2024	1171	N/A	A-Direction	N/A – More readings needed to provide movement trends					

Note:
[1] Meters below ground surface (mbgs).
[2] Skew angle of X-direction measured clockwise from the A-direction.
[3] Initialized on October 23, 2018, due to an anomalous upslope deformation after installation.

Table 2.2 Vibrating Wire Piezometer Reading Summary

Instrument ID	Date			Ground Surface Elevation (m)	Tip Depth (mbgs[1])	Water Level		
	Installed	Previous Reading	Most Recent Reading			Previous Reading (mbgs[1])	Most Recent Reading (mbgs[1])	Change from Previous Reading (m)
VW18-01	Mar. 5, 2018	May 8, 2024	Sep. 16, 2024	1174.0	13.7	12.6	12.5	0.1
VW18-02	Mar. 5, 2018	May 8, 2024	Sep. 16, 2024	1176.0	10.1	9.8	9.7	0.1
VW18-03	Mar. 5, 2018	May 8, 2024	Sep. 16, 2024	1176.6	4.7	0.2	0.2	0.0

Note:
[1] Meters below ground surface (mbgs).

3 RECOMMENDATIONS

3.1 Future Work

All instruments should be read twice per year (spring and fall).

The site should continue to be inspected by the Maintenance Contract Inspector (MCI) and as part of the Central Region GRMP Section B inspections.

3.2 Instrument Repairs and Maintenance

Readings in SI23-04 to date have been providing poor quality data that is not useable.

It is possible that some of the sand backfill around the SI23-04 casing has migrated out from the welded channel on the H-pile, causing the SI casing to be loose in the pile. KCB is working with the contractor who completed the pile wall construction to determine if the SI sand backfill can be checked and additional material added around the SI casing as part of the construction warranty.

4 CLOSURE

This report is an instrument of service of Klohn Crippen Berger (KCB). The report has been prepared for the exclusive use of Alberta Transportation and Economic Corridors (Client) for the specific application to the Southern Region Geohazard Risk Management Program (Contract No. CON0022161), and it may not be relied upon by any other party without KCB's written consent.

KCB has prepared this report in a manner consistent with the level of care, skill and diligence ordinarily provided by members of the same profession for projects of a similar nature at the time and place the services were rendered. KCB makes no warranty, express or implied.

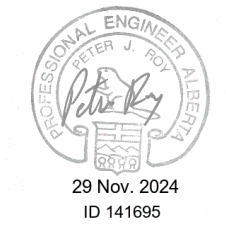
Use of or reliance upon this instrument of service by the Client is subject to the following conditions:

1. The report is to be read in full, with sections or parts of the report relied upon in the context of the whole report.
2. The observations, findings and conclusions in this report are based on observed factual data and conditions that existed at the time of the work and should not be relied upon to precisely represent conditions at any other time.
3. The report is based on information provided to KCB by the Client or by other parties on behalf of the client (Client-supplied information). KCB has not verified the correctness or accuracy of such information and makes no representations regarding its correctness or accuracy. KCB shall not be responsible to the Client for the consequences of any error or omission contained in Client-supplied information.
4. KCB should be consulted regarding the interpretation or application of the findings and recommendations in the report.
5. This report is electronically signed and sealed, and its electronic form is considered the original. A printed version of the original can be relied upon as a true copy when supplied by the author or when printed from its original electronic file.

Please contact the undersigned if you have any questions or comments regarding this report.

Yours truly,

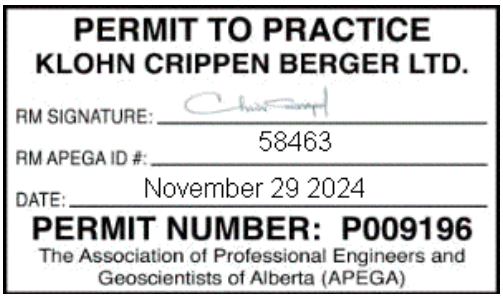
KLOHN CRIPPEN BERGER LTD.



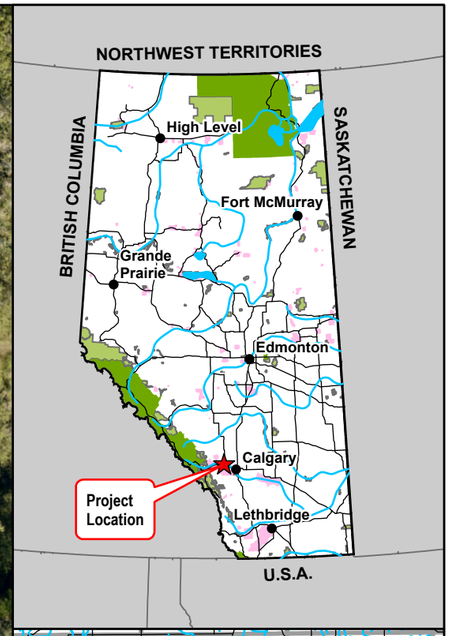
Peter Roy, P.Eng.
Civil Engineer

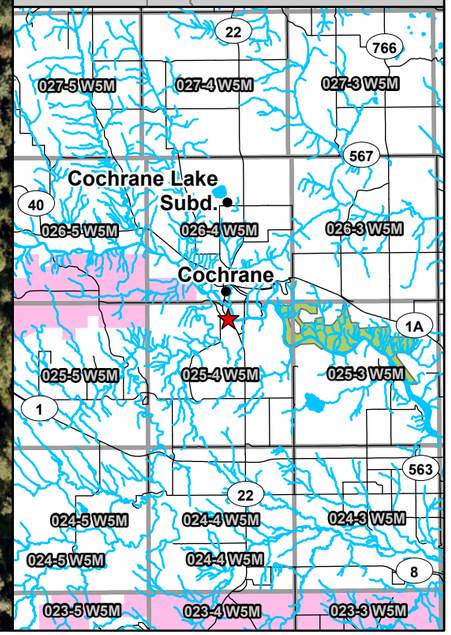
PR:kb

ATTACHMENTS
Figure
Appendix I Instrumentation Plots



FIGURE





Legend

- Slope Inclinometer (SI)
- Vibrating Wire Piezometer (VW)
- Flow Direction
- Scarp
- Crack

0 45 Metres

NOTES:
1. HORIZONTAL DATUM: NAD83
2. GRID ZONE: UTM ZONE 11N
3. IMAGE SOURCE: TOWN OF COCHRANE, AB

CLIENT: Alberta

Klohn Crippen Berger

PROJECT: SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

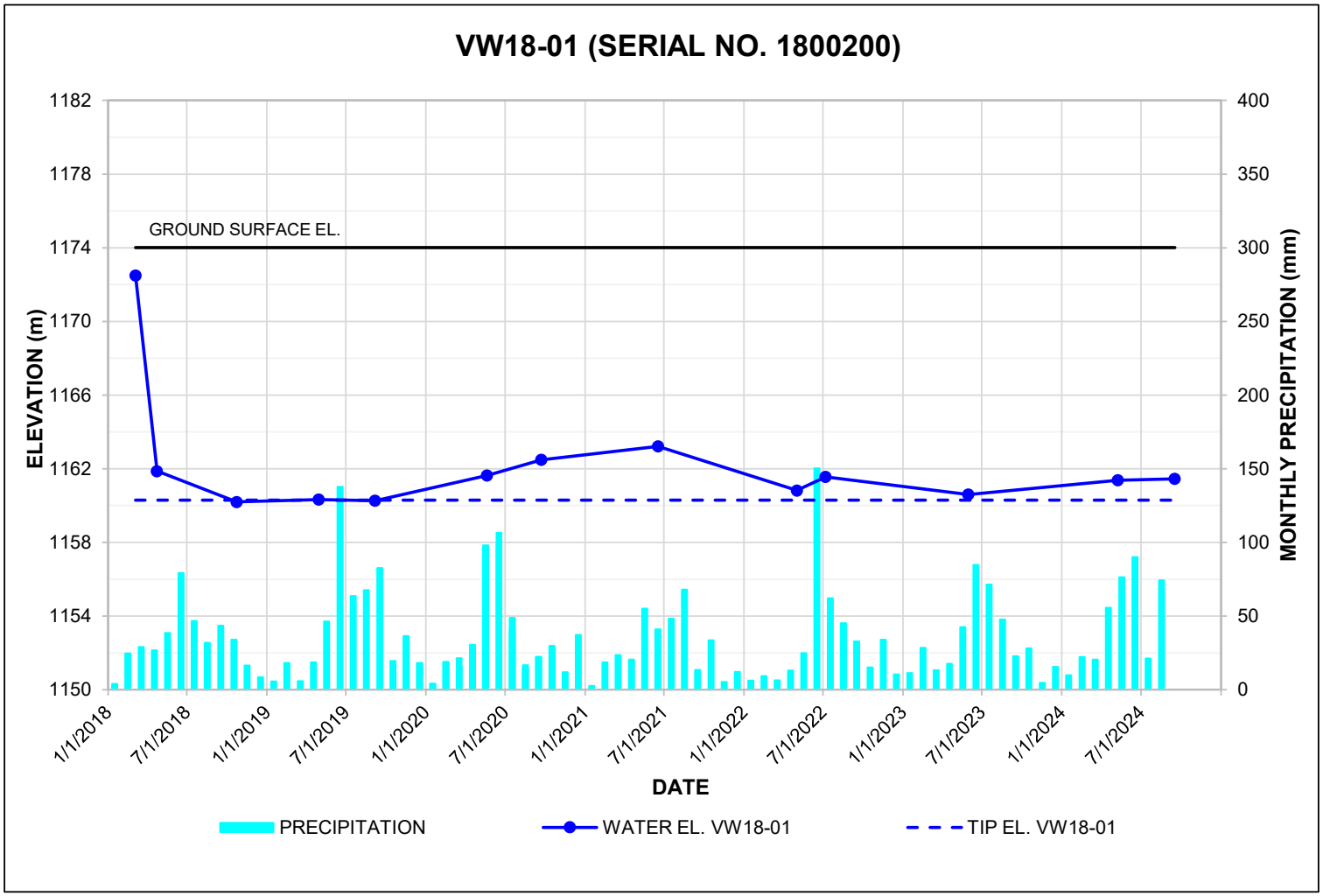
TITLE: Site Plan
S003 - Cochrane
Hwy 22:16, km 9.875

SCALE	PROJECT No.	FIG No.
1:1,000	A05116A03	1

File: \\int.klohn.com\ProjData\A\CGY\Alberta\A05116A03 ABT Southern Region GRMP\400 Drawings\2024\Section C\Section_C_2024\Section_C_2024.aprx Date: Time: Creator: : EQuine

APPENDIX I

Instrumentation Plots



NOTES:
1. MONTHLY PRECIPITATION DATA OBTAINED FROM THE ALBERTA CLIMATE INFORMATION SERVICE (ACIS) DATABASE, REFERENCING LEGAL SUBDIVISION T026R04W5.

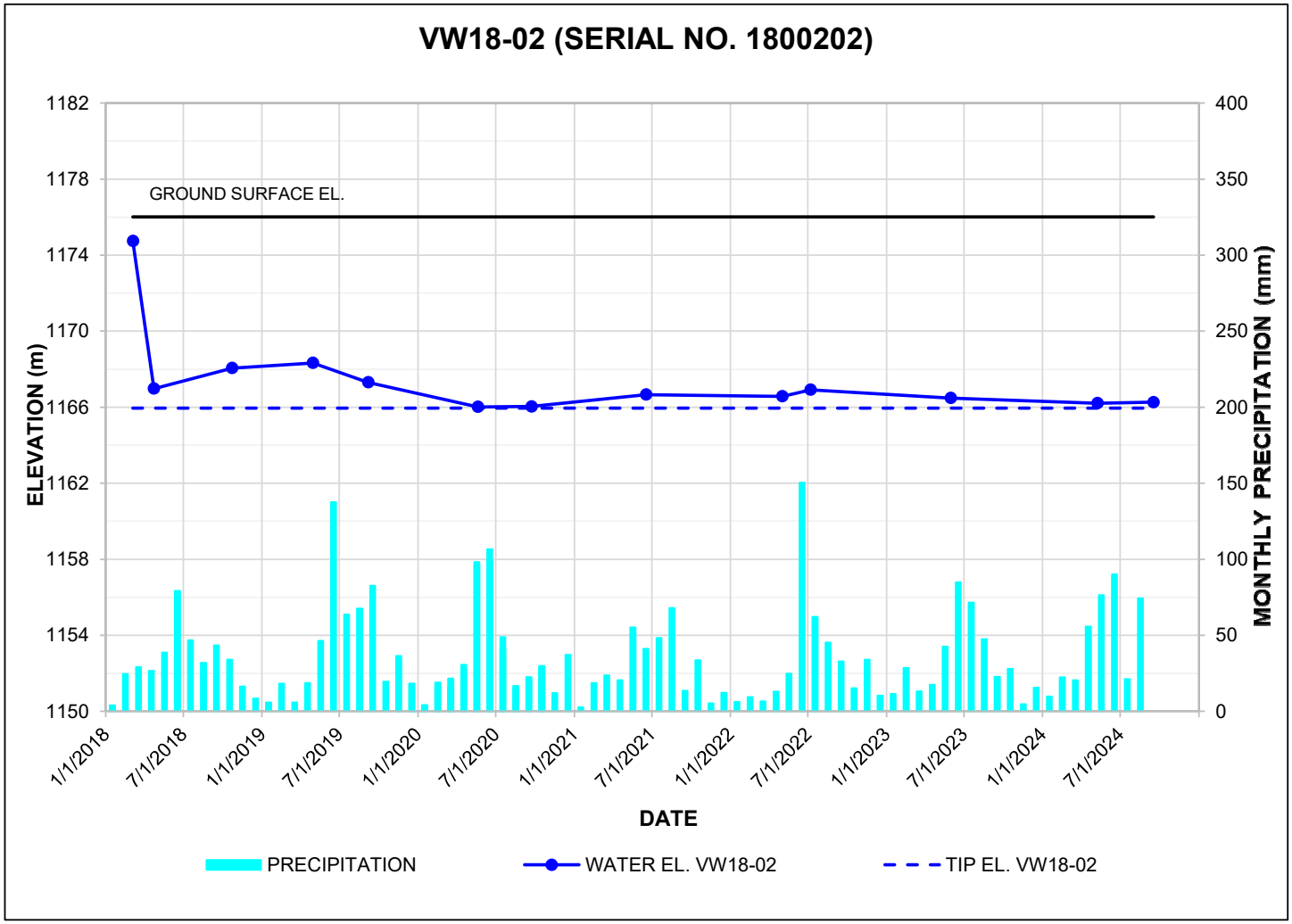
CLIENT: Alberta

Klohn Crippen Berger

PROJECT: SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE: Vibrating Wire Piezometer Data
S003 - Cochrane
Hwy 22:16, km 9.9

SCALE	PROJECT No.	FIG No.
	A05116A03	



NOTES:
1. MONTHLY PRECIPITATION DATA OBTAINED FROM THE ALBERTA CLIMATE INFORMATION SERVICE (ACIS) DATABASE, REFERENCING LEGAL SUBDIVISION T026R04W5.

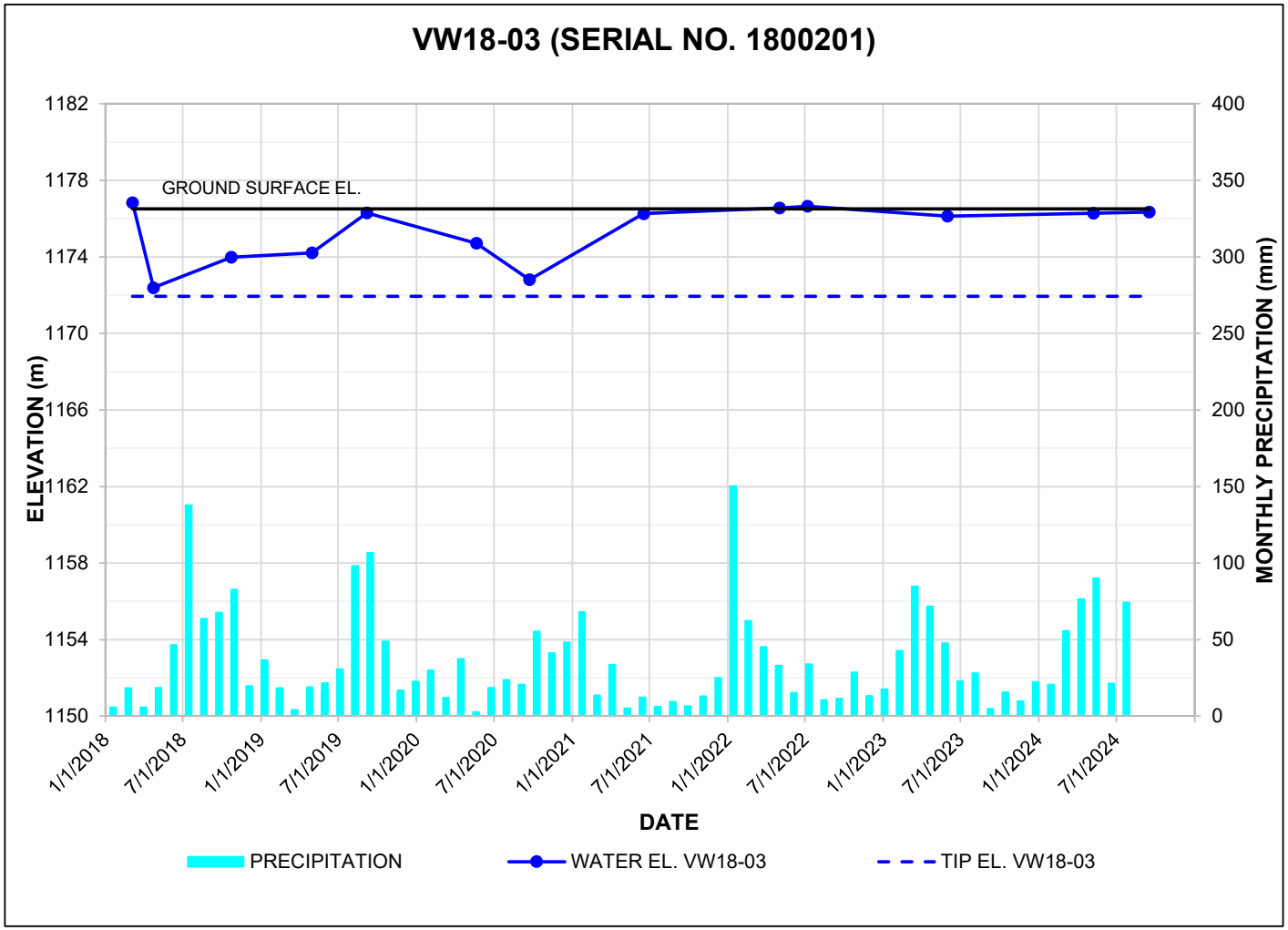
CLIENT: Alberta

Klohn Crippen Berger

PROJECT: SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE: Vibrating Wire Piezometer Data
S003 - Cochrane
Hwy 22:16, km 9.9

SCALE	PROJECT No.	FIG No.
	A05116A03	



NOTES:
1. MONTHLY PRECIPITATION DATA OBTAINED FROM THE ALBERTA CLIMATE INFORMATION SERVICE (ACIS) DATABASE, REFERENCING LEGAL SUBDIVISION T026R04W5.

CLIENT: Alberta

Klohn Crippen Berger

PROJECT: SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

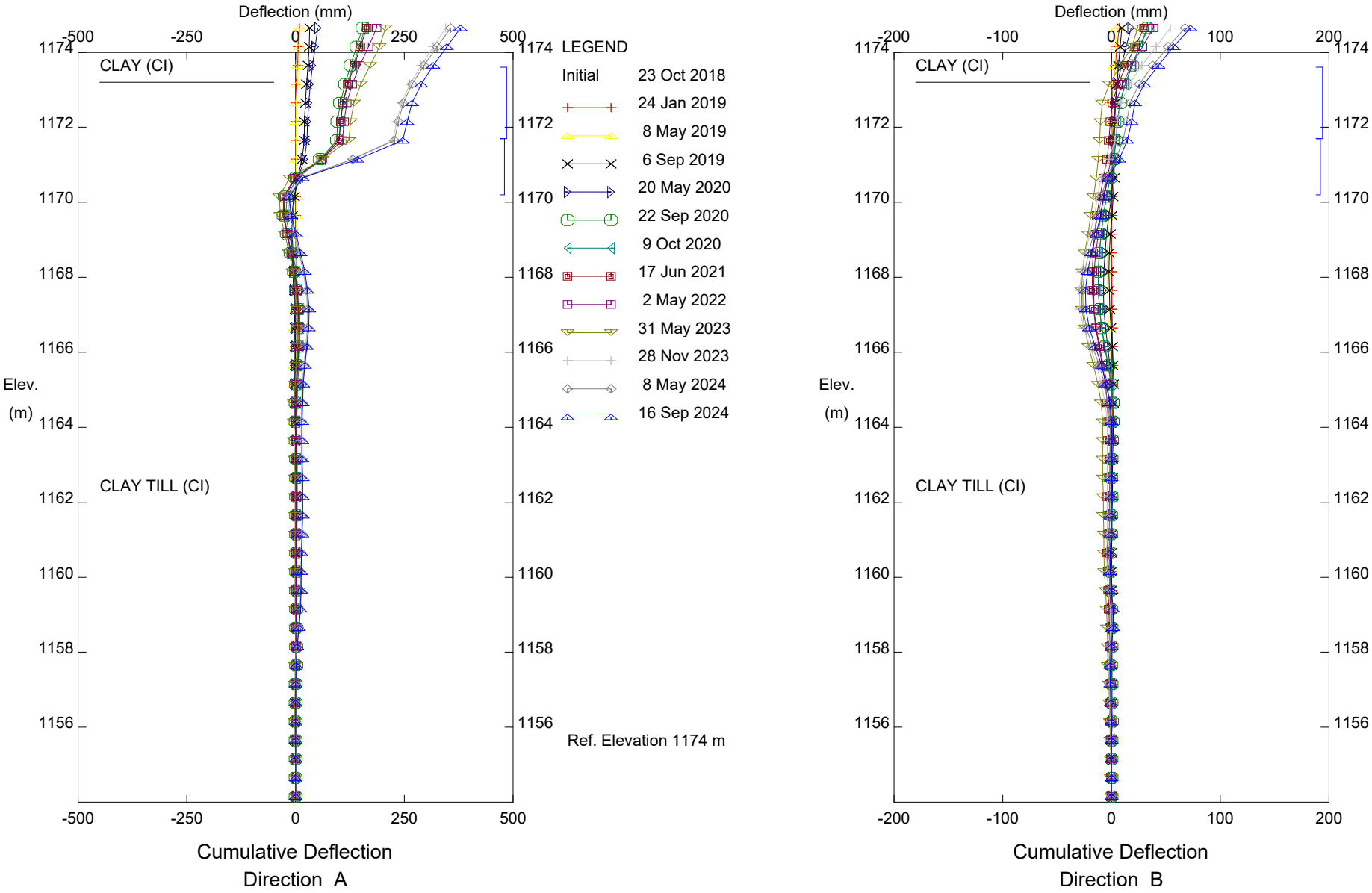
TITLE: Vibrating Wire Piezometer Data
S003 - Cochrane
Hwy 22:16, km 9.9

SCALE

PROJECT No. A05116A03

FIG No.

Klohn Crippen Berger Ltd. - Calgary, AB

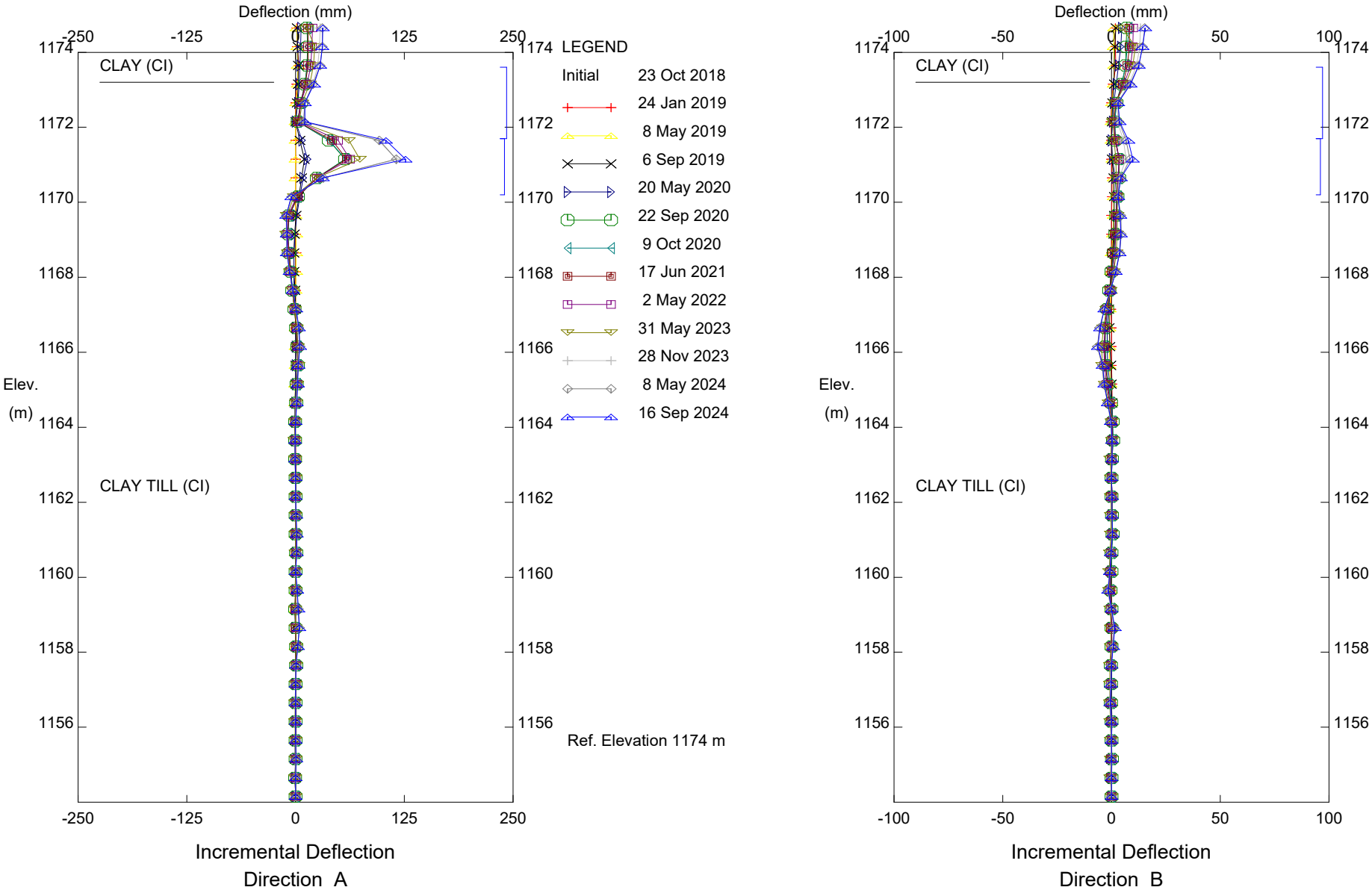


S003; H22:16, Cochrane, Inclinometer SI18-01

Alberta Transportation

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI18-01.GTL

Klohn Crippen Berger Ltd. - Calgary, AB

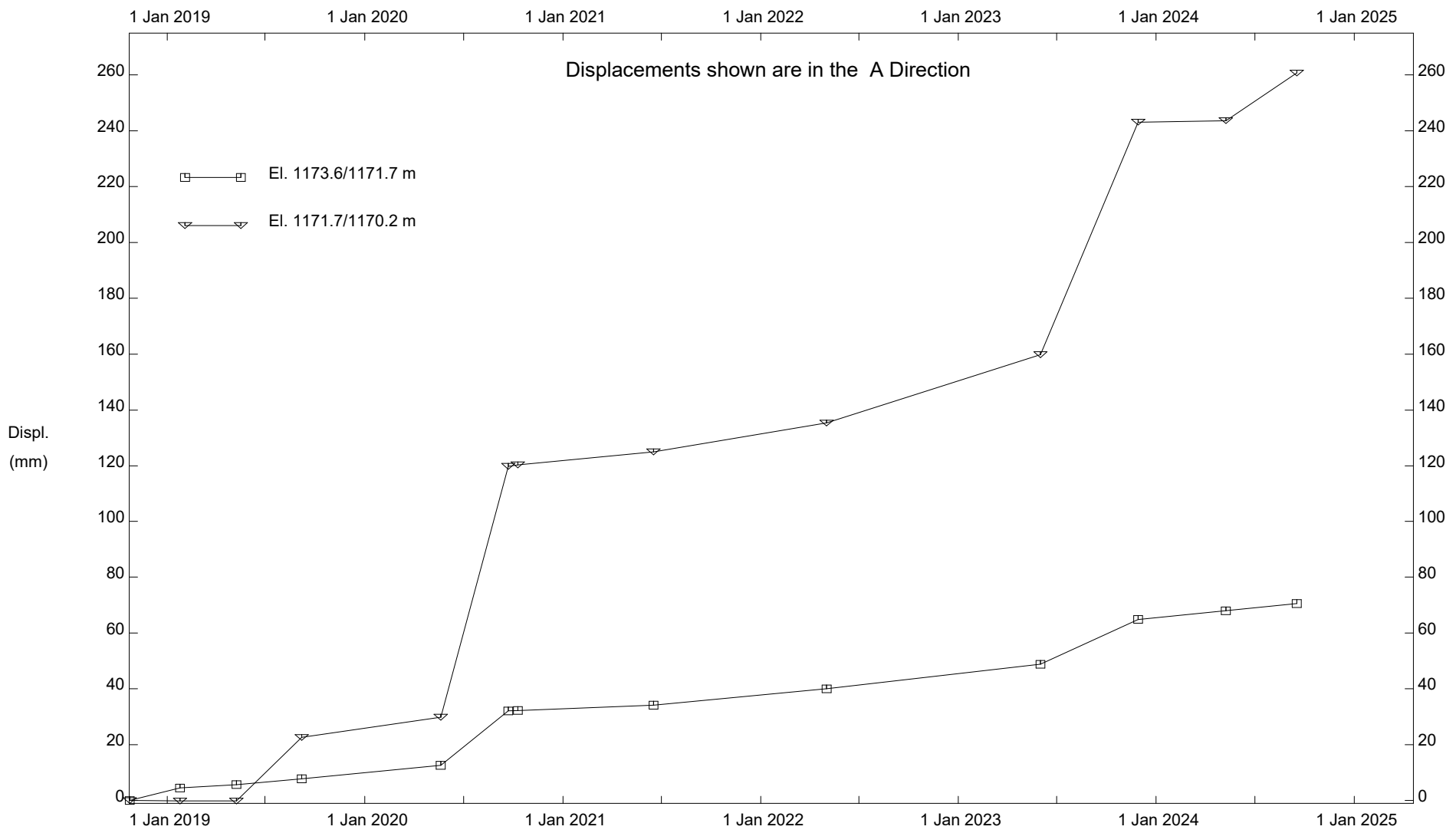


S003; H22:16, Cochrane, Inclinometer SI18-01

Alberta Transportation

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI18-01.GTL

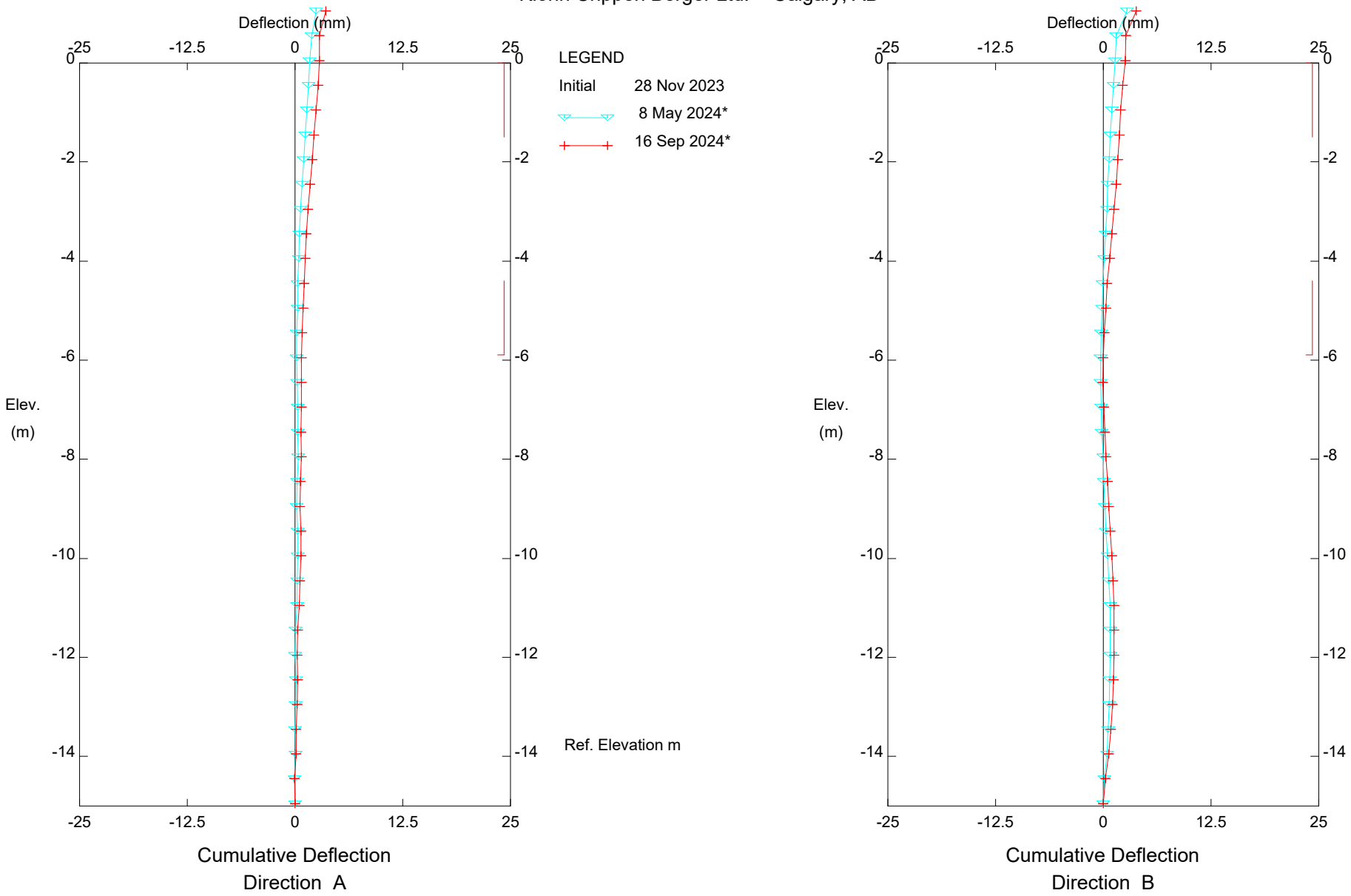
Klohn Crippen Berger Ltd. - Calgary, AB



S003; H22:16, Cochrane, Inclinometer SI18-01

Alberta Transportation

Klohn Crippen Berger Ltd. - Calgary, AB

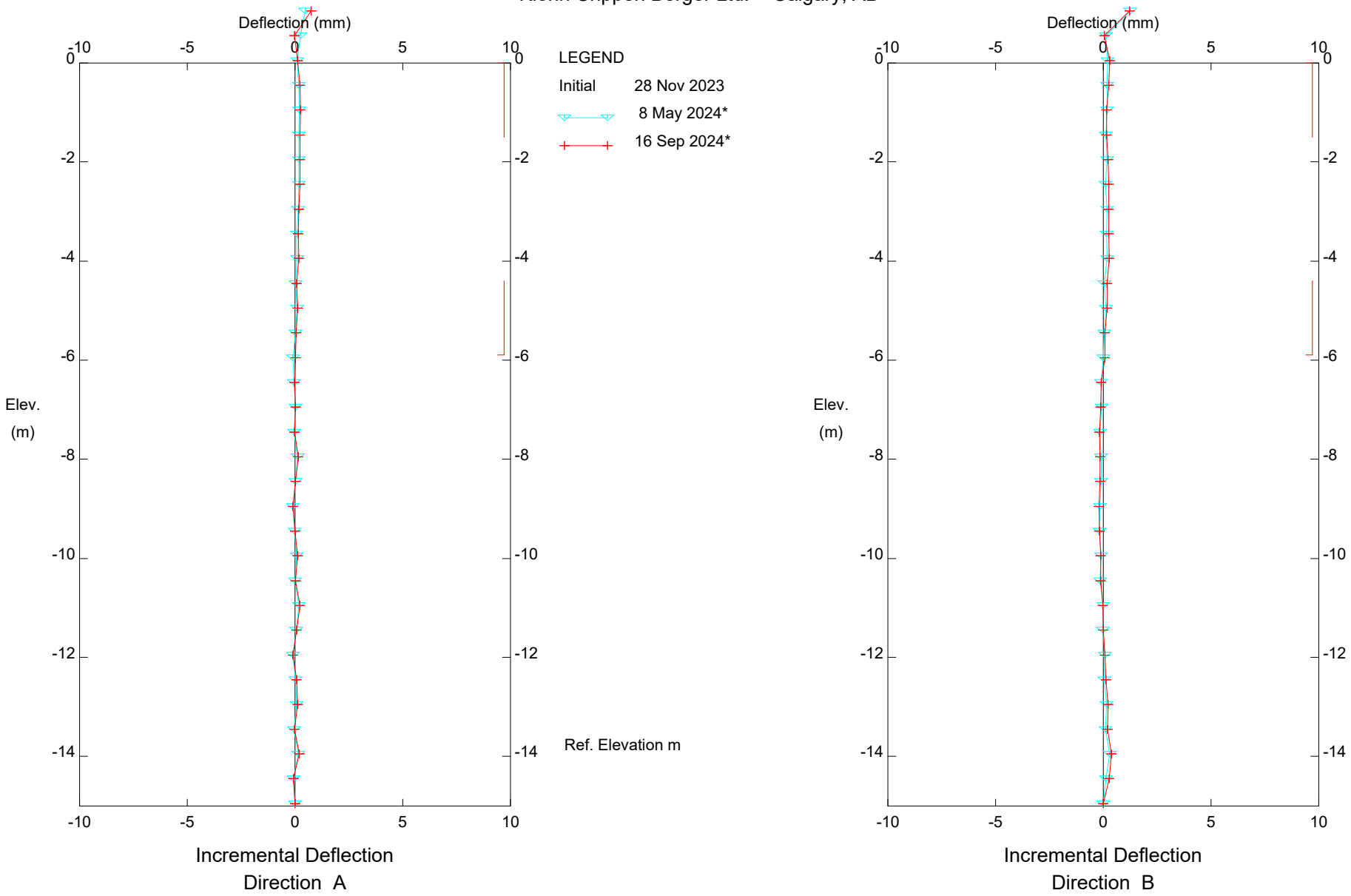


Cochrane, Inclinometer 23-01

Sets marked * include zero shift and/or rotation corrections.

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-01.GTL

Klohn Crippen Berger Ltd. - Calgary, AB

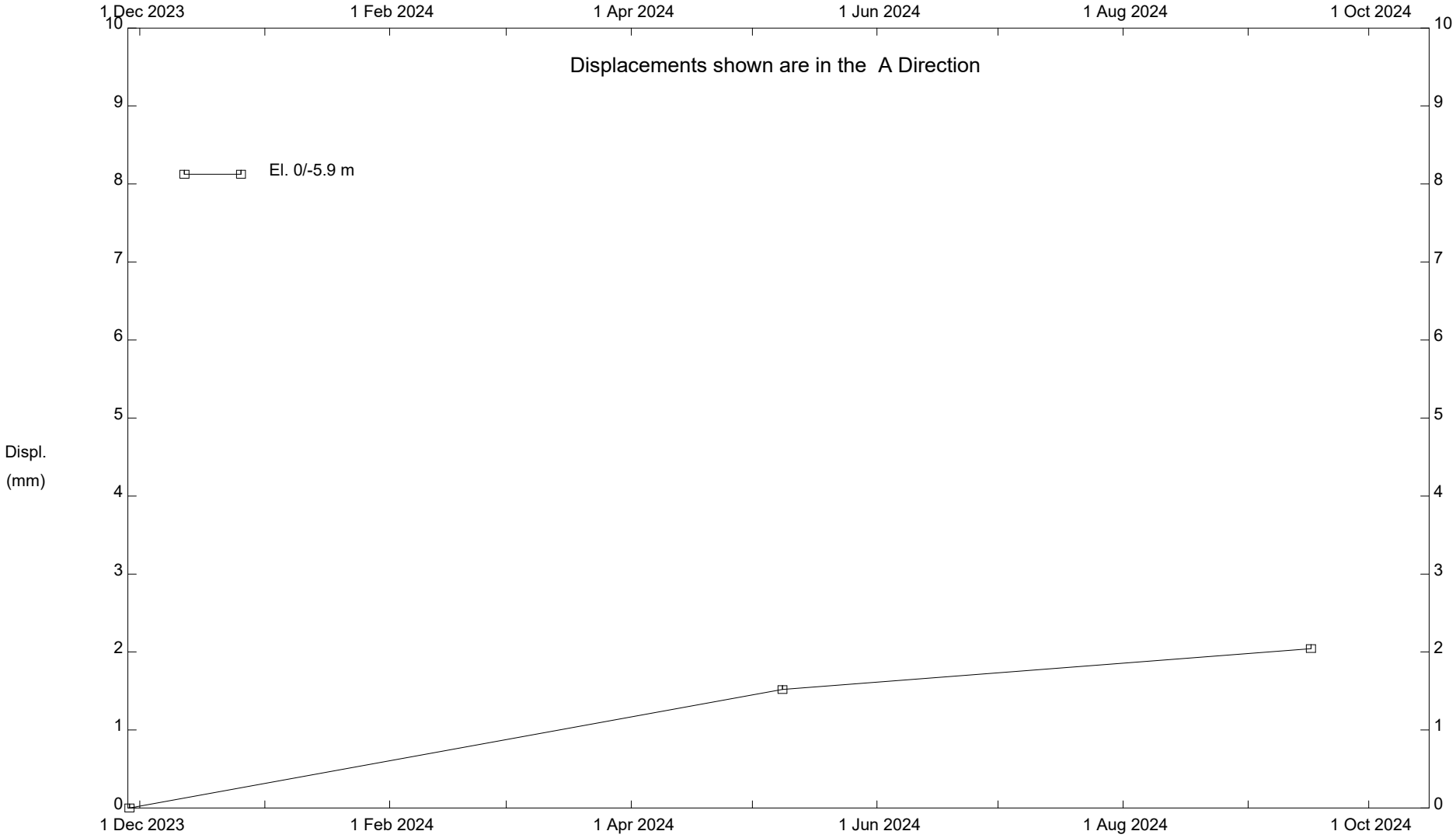


Cochrane, Inclinometer 23-01

Sets marked * include zero shift and/or rotation corrections.

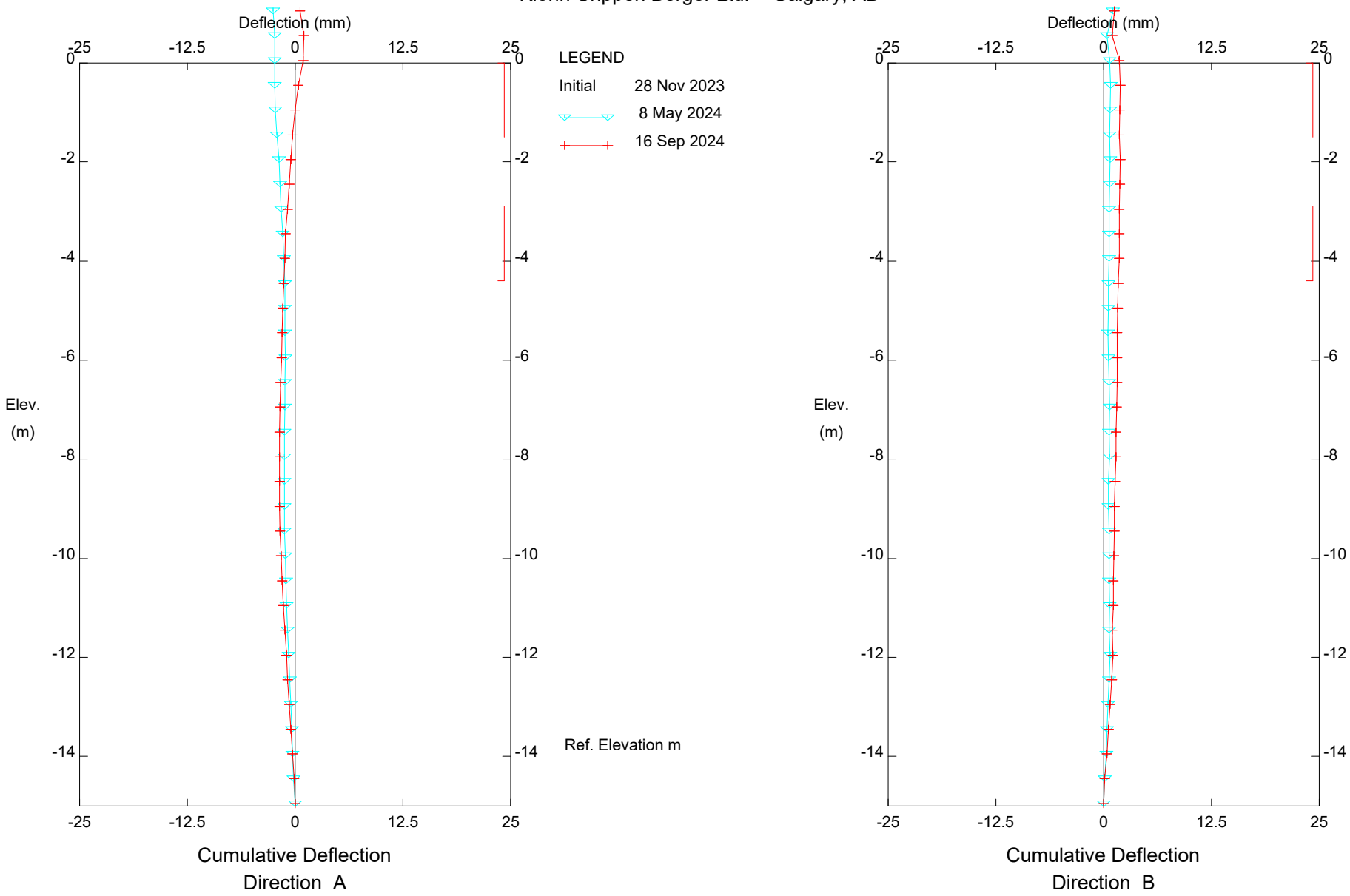
Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-01.GTL

Klohn Crippen Berger Ltd. - Calgary, AB



Cochrane, Inclinometer 23-01

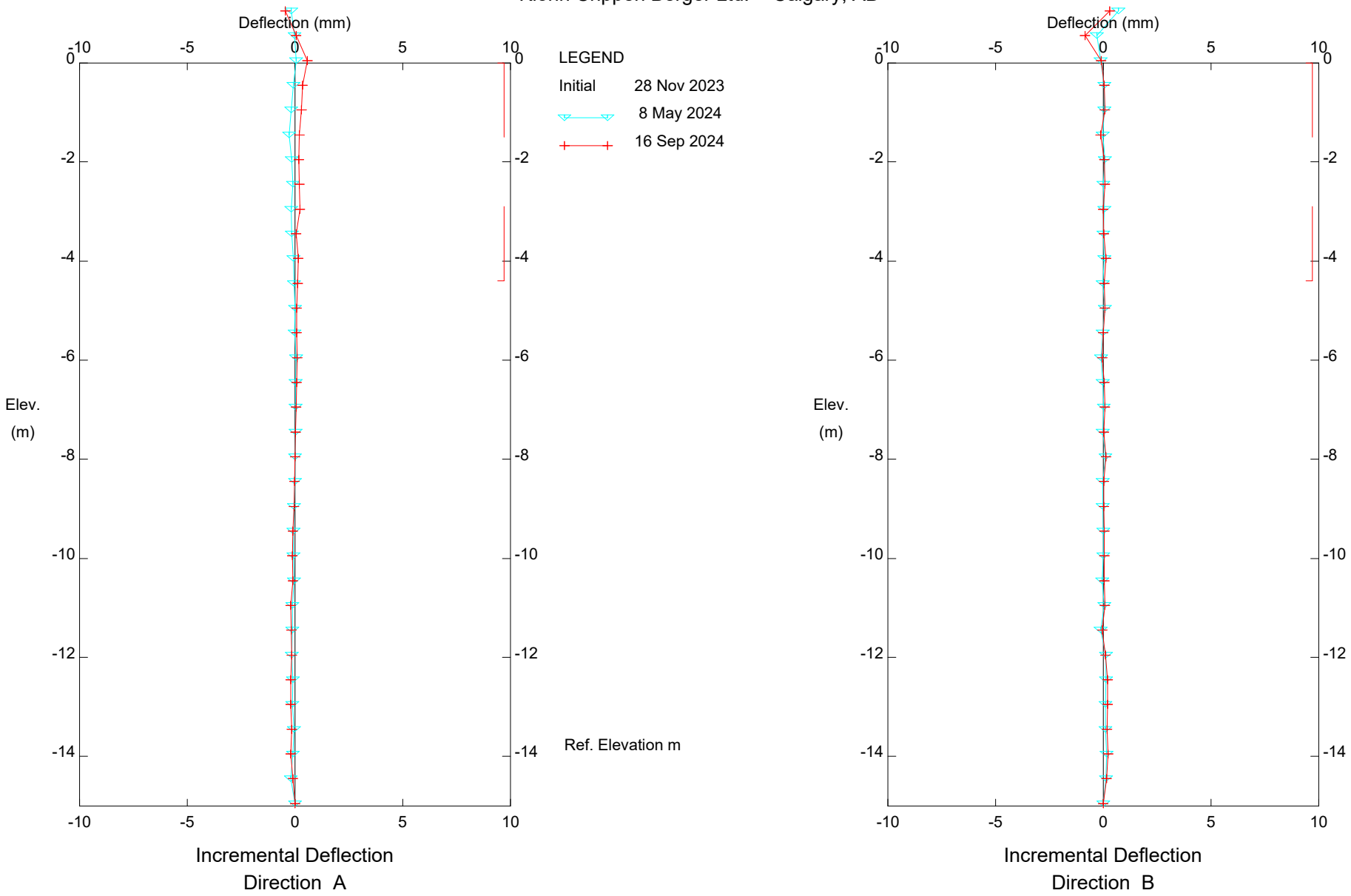
Klohn Crippen Berger Ltd. - Calgary, AB



Cochrane, Inclinometer 23-02

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-02.GTL

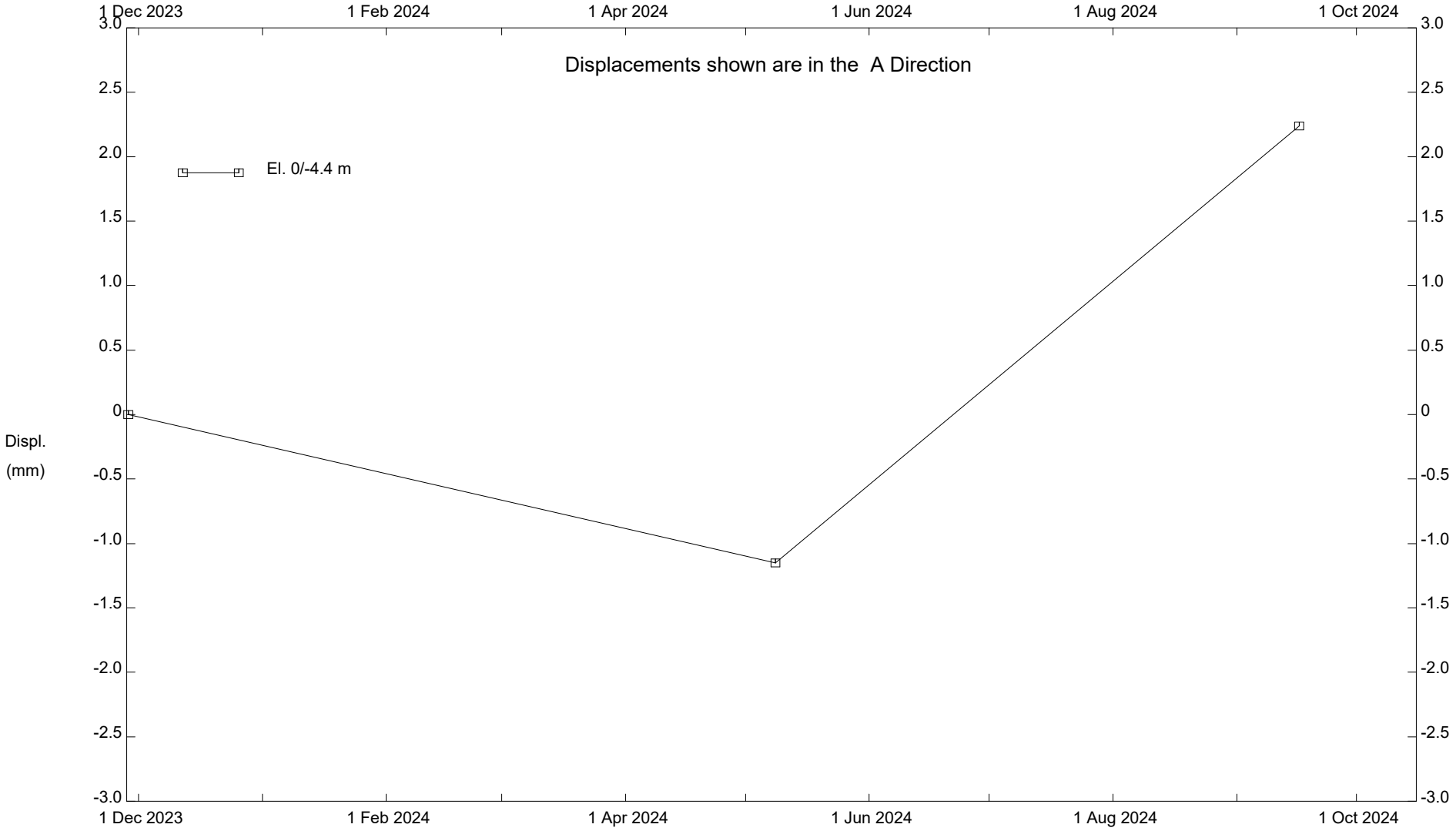
Klohn Crippen Berger Ltd. - Calgary, AB



Cochrane, Inclinometer 23-02

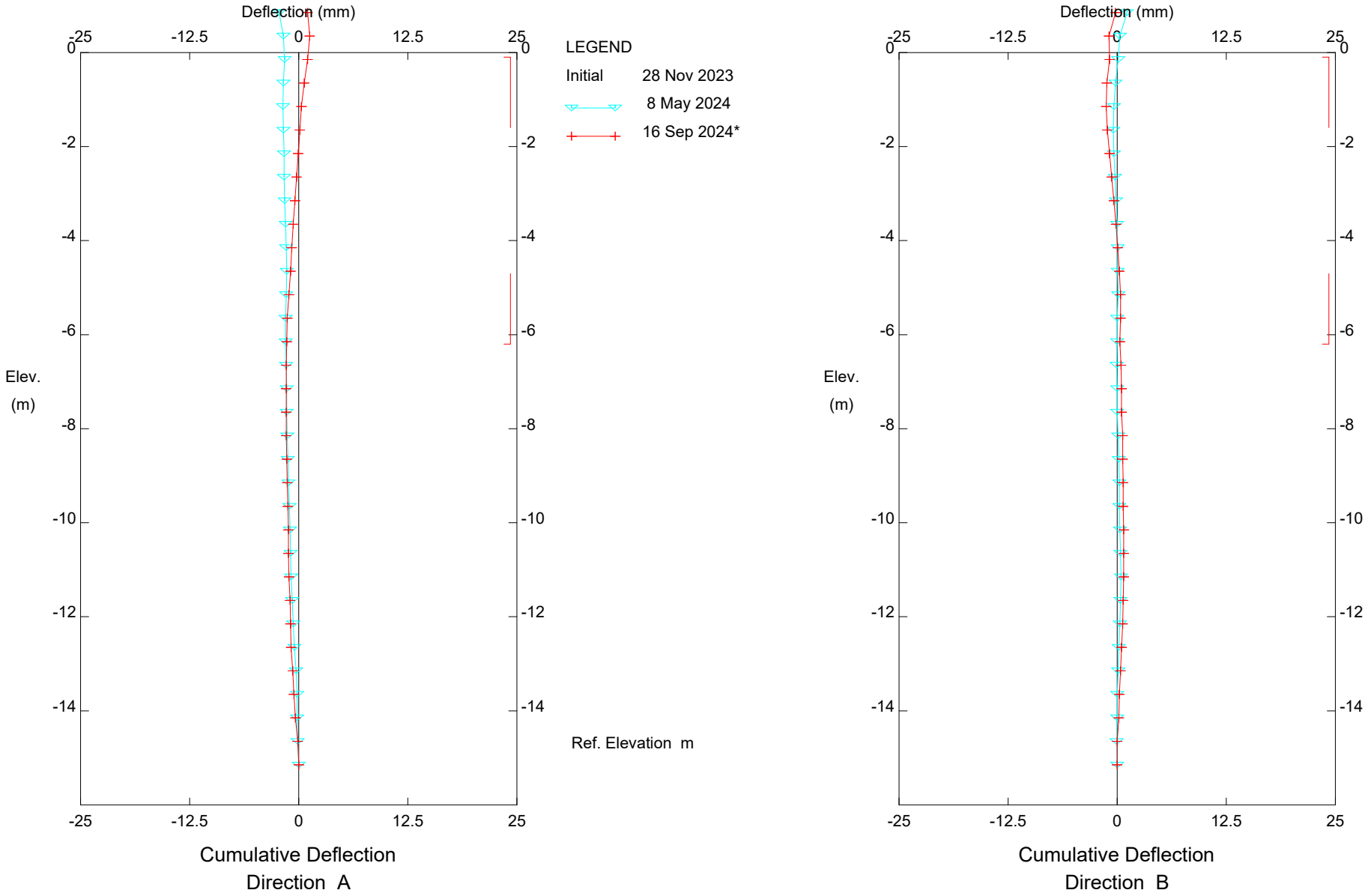
Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-02.GTL

Klohn Crippen Berger Ltd. - Calgary, AB



Cochrane, Inclinometer 23-02

Klohn Crippen Berger Ltd. - Calgary, AB

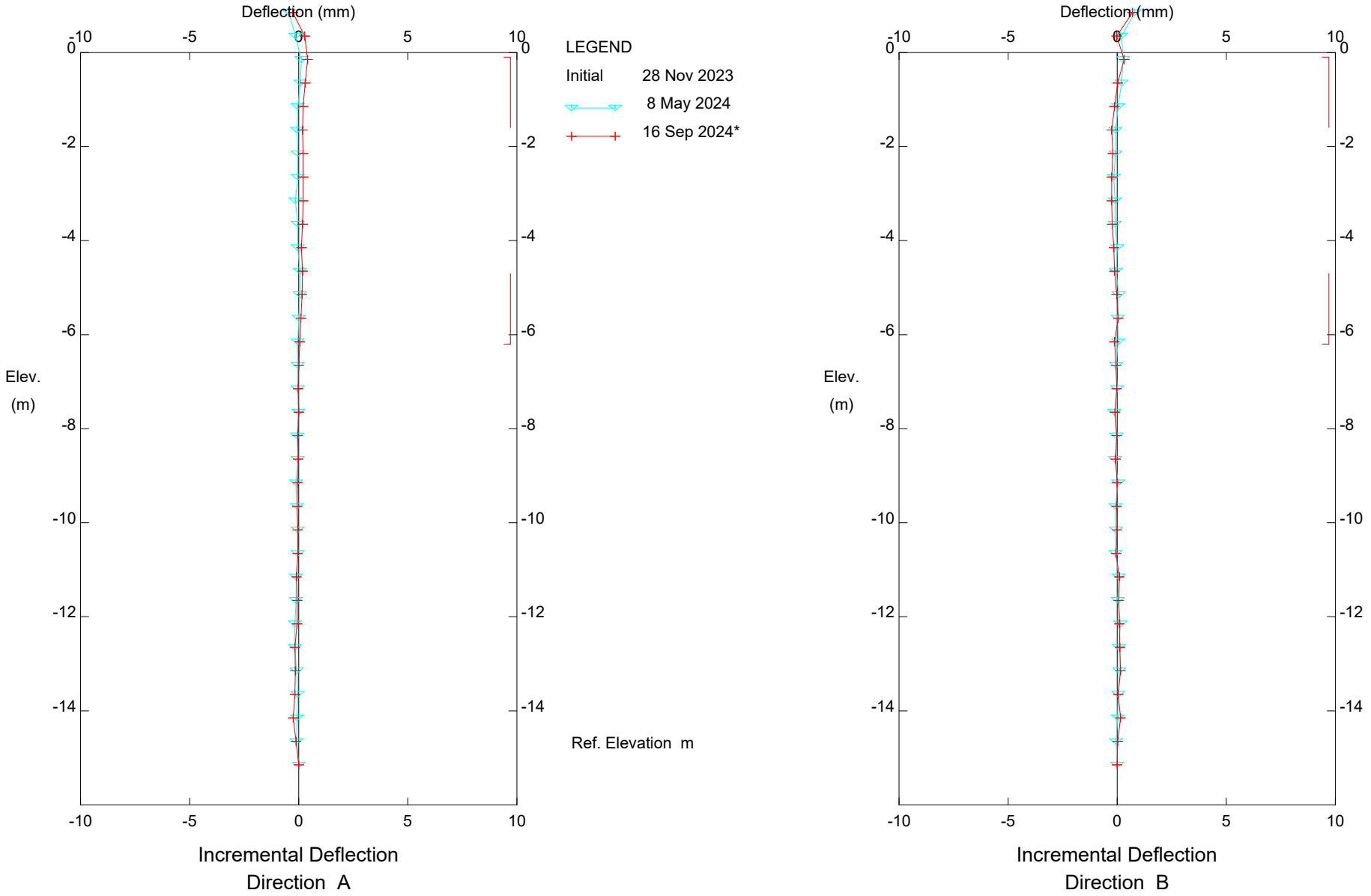


Cochrane, Inclinometer 23-03

Sets marked * include zero shift and/or rotation corrections.

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-03.GTL

Klohn Crippen Berger Ltd. - Calgary, AB

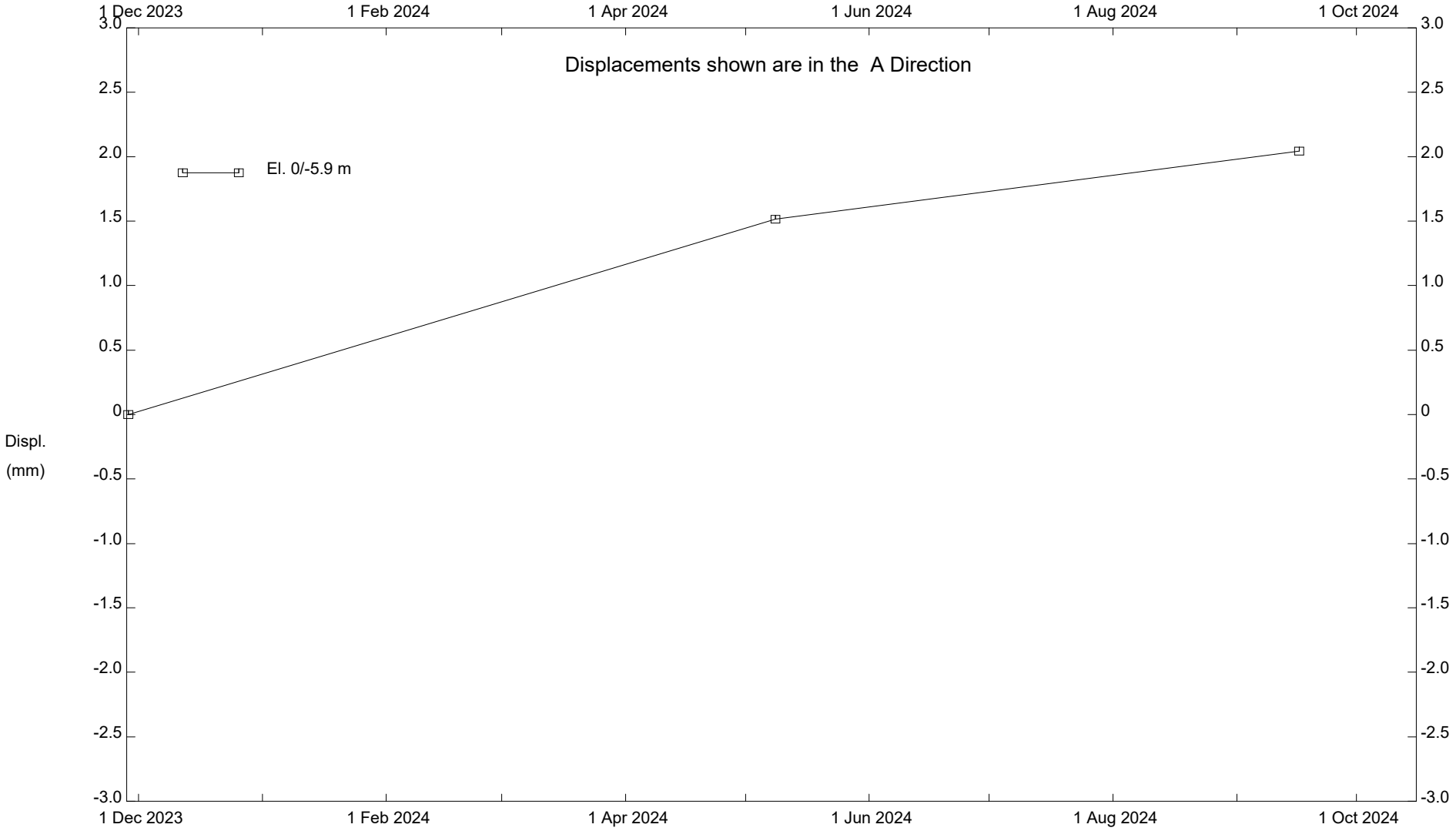


Cochrane, Inclinometer 23-03

Sets marked * include zero shift and/or rotation corrections.

Z:\A\CGY\ALBERTA\A05116A03 ABT SOUTHERN REGION GRMP\300 DESIGN\2024\SECTION C\04 INSTRUMENTATION\2. FALL\S003 - COCHRANE\SIS\ABT S003 SI23-03.GTL

Klohn Crippen Berger Ltd. - Calgary, AB



Cochrane, Inclinometer 23-01