July 10, 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 S039-I; H03:06, km 12.952 West Brocket Slide
Section C – 2024 Spring Readings

1 GENERAL

Four slope inclinometers (SIs) (SI16-01 and SI16-03) and two vibrating wire piezometers (VWPs) (BH16-02A/B) were read at the S039 site in the Southern Region on May 15, 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 03:06, km 12.95, approximately 1.9 km west of the junction with Hwy 786:02 and approximately 500 m west of Brocket, Alberta. The S039 site is located on the southern slope of the Oldman River Valley, and Hwy 03:06 is routed along the crest of the slope. The approximate site coordinates are 5491976 N, 298990 E (UTM Zone 12, NAD 83). A site plan is presented in Figure 1.

The geohazard at the S039 site consists of a range of instabilities over a total length of approximately 600 m along Hwy 03:06. Two subsites have been identified: S039-I at the west end of the site and S039-II at the east end of the site. Instrumentation is only installed at the S039-I site.

Previous remedial actions at the S039-I site include:

- In 2015, pavement patching, crack filling, and installation of an asphalt curb to limit pavement runoff from flowing onto the slide area was completed. Previously, the Maintenance Contract Inspector (MCI) has dumped loose gravel over the guardrail onto the head of the slide to reduce the height of the head scarp.
- In 2017, pavement patching and repairs to the asphalt curb were completed.
- In 2023, 215 grouted soil nails, 16 m in length each, were installed into the slide backscarp with a metal mesh surface treatment and hydroseeding. The back scarp slope was regraded from approximately 2H:1V to 1.5H:1V during soil nail installation and drainage diversion

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measures were installed at the crest of the slope to keep water from flowing off the highway onto the slope. As part of this work two additional SIs were installed on the mid-slope bench of the landslide area. During construction the contractor damaged the existing SI16-01 at the crest of the slope. This SI was replaced with SI23-03 as part of the construction.

Since completion of the repair, a wet zone on the upper ¾ mark of the east limit of the anchored backscarp slope was first observed during the May 2023 Section B inspection. This wet zone was not observed or encountered during the 2017 drilling investigation, during any Section B inspections, nor during construction. A small, shallow zone of movement developed in 2023 approximately 30 m by 6 m at the east extent of the repair. During the spring 2024 Section B inspection additional slope movement and sloughing was observed across the repair slope. Instrumentation is not in place to monitor the performance of the anchored back slope nor the zone of movement associated with an isolated wet area on the upper east part of the anchored slope.

1.1 Instrumentation

Instrumentation installation details are tabulated in Table 1.1. Instrument locations are shown in Figure 1.

In 2016, five boreholes were drilled at the S039-I site:

- BH16-04A and BH16-04B were drilled through the mid-slope bench so one SI (SI16-04B) and two VWPs (BH16-04A/B) could be installed to monitor depth of movement and groundwater conditions, respectively, within the slide mass. By September 2020, SI16-04B was sheared and the two VWPs were inoperable, likely due to ongoing slide movements.
- BH16-01 and BH16-03 were drilled on either side of the active slide mass so two SIs (SI16-01 and SI16-03) could be installed to monitor if the slide is expanding laterally.
- BH16-02 was drilled on the south side of the highway so two VWPs (BH16-02A/B) could be installed to monitoring groundwater conditions upslope of the highway and slide.

In 2023, three boreholes were drilled at the S039-I site:

- BH23-01 and BH23-02 were drilled at the bench at the base of the repair slope. Two SIs (SI23-01 and SI23-02) were installed to monitor slope movement at the mid-slope bench of the landslide area.
- BH23-3 was drilled at the crest of the slope on the west side. SI23-03 was installed to replace SI16-01 that was damaged during construction.

KCB changed the SI reading equipment in October 2021 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.

Table 1.1 Instrument Installation Details

Instrument ID	Instrument Type	Installation Date	UTM Coordinates[1] (m)		Ground Surface Elevation (m)	Stick Up (m)	Depth (mbgs[2])	Condition
			Northing	Easting				
~~SI16-01~~	~~SI~~	~~Oct. 16, 2016~~	~~5491991~~	~~298936~~	~~1071~~	~~0.9~~	~~22.0~~	~~Inoperable[4]~~
BH16-02A	VWP	Oct. 20, 2016	5491940	598971	1078	N/A	17.4	Operable
BH16-02B	VWP	Oct. 20, 2016	5491940	598971	1078	N/A	22.6	Operable
SI16-03	SI	Oct. 19, 2016	5492020	299047	1065	0.9	19.0	Operable
~~BH16-04A~~	~~VWP~~	~~Oct. 18, 2016~~	~~5492022~~	~~298975~~	1060	N/A	~~7.8~~	~~Inoperable~~
~~BH16-04B~~	~~VWP~~	~~Oct. 19, 2016~~	~~5492022~~	~~298975~~	1060	N/A	~~15.0~~	~~Inoperable~~
~~SI16-04B~~	~~SI~~	~~Oct. 19, 2016~~	~~5492022~~	~~298973~~	1060	~~0.80~~	~~17.4~~	~~Inoperable[3]~~
SI23-01	SI	Feb. 27, 2023	5492004	298993	1061	0.80	14.0	Operable
SI23-02	SI	Feb. 27, 2023	5492003	298962	1061	0.80	15.0	Operable
SI23-03	SI	Feb. 28, 2023	5491993	298930	1070	0.84	21.0	Operable

Notes:

[1] Coordinates were obtained by KCB with a handheld GPS (accuracy of ±5 m) during installation.

[2] Meters below ground surface (mbgs). Bottom reading depth for SIs and tip depth for VWPs.

[3] SI16-04B has sheared at an approximate depth of 5.5 m below ground surface.

[4] SI16-01 was destroyed during construction and replaced with SI23-03

2 INTERPRETATION

2.1 General

For the operable SIs, the cumulative displacement, incremental displacement, displacement-time data was plotted in the A-direction (i.e., the direction of the A0-grooves) and the X-direction (i.e., the direction of maximum movement obtained at a skew angle from the A0-grooves). SI16-01 and SI16-03 have skew angles of 320° and 340° respectively, measured clockwise from the direction of the A0-grooves.

For the operable VWPs, the recorded porewater pressures were converted to an equivalent water/piezometric elevation and plotted relative to ground surface elevation and each instruments tip elevation.

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 TWP007-28-W4.

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.

The SI data obtained in the three new SIs is relatively noisy (despite good data quality) compared to the existing SI (SI16-03) and is difficult to interpret, especially for SI23-02. It is unclear if the noise is due to installation issues (e.g., casing kinked or titled). For example, SI23-01 is tilted approximately 0.8 m over its 14 m depth and SI23-03 is tilted approximately 1 m over its 21 m depth. More data is needed to interpret the data and movement zones.

2.2 Zones of Movement

SI23-03 is located on the west flank of the slide near the crest of the slope. A possible zone of distributed movement has been recorded in SI23-03 between an approximate depth of 10 m and 12 m below ground surface (approximately El. 1062 m to El. 1057 m) in the clay till.

SI16-03 is located on the east flank of the slide near the mid slope. Distributed movement (less than 10 mm) has been recorded in SI16-03 from ground surface to an approximate depth of 8 m below ground surface (approximately El. 1057 m) in the clay till.

More data is needed to interpret the movement zones in SI23-01 and SI23-02, located at the base of the repair slope.

Before shearing in 2020, movement was recorded in SI16-04B from an approximate depth of 6.5 m to 8.0 m below ground surface (approximately El. 1053.5 m to El. 1052.0 m) in the clay till.

Currently there is no instrumentation in place to monitor movement on the repair slope.

Table 2.1 Slope Inclinometer Reading Summary

Instrument ID	Date				Ground Surface Elevation (m)	Depth of Movement (mbgs[1])	Direction of Movement, Skew Angle[2]	Movement (mm)				Rate of Movement (mm/year)		
	Initialized (Re-initialized)	Previous Maximum Cumulative Movement Recorded	Previous Reading	Most Recent Reading				Maximum Cumulative			Incremental Since Previous Maximum Cumulative	Previous Maximum	Most Recent Reading	Change from Previous Reading
								Before Re-Initialization	After Re-Initialization	Total				
SI16-03	Nov. 24, 2016 (Jan. 30, 2017)[3]	Oct. 15, 2018	Sep. 21, 2023	May 15, 2024	1065	0.4 – 7.9	X-Direction, 340°	N/A – no discernible movement recorded	14.2	14.2	5.8	12.5	19.7	23.4
SI23-01	Mar. 10, 2023	N/A	Sep. 21, 2023	May 15, 2024	1061	N/A	N/A	N/A – no discernible movement recorded since initialization						
SI23-02	Jun. 7, 2023	Sep. 21, 2023	Sep. 21, 2023	May 15, 2024	1061	9.0 – 11.0	A-Direction	N/A	8.5	8.5	4.3	14.3	6.7	-7.6
SI23-03	Mar. 10, 2023	Sep. 21, 2023	Sep. 21, 2023	May 15, 2024	1070	10.0 - 12.0	X-Direction, 45°	N/A	6.1	6.1	1.0	13.4	1.6	-4.6

Notes:
[1] Meters below ground surface (mbgs).
[2] Skew angle of X-direction measured clockwise from the A-direction.
[3] Bad data was obtained during the first two readings of these instruments, so they were re-initialized to the January 2017 reading.

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)
BH16-02A	Oct. 20, 2016	Sep. 22, 2022	May 15, 2024	1078	17.4	10.8	10.1	0.7
BH16-02B	Oct. 20, 2016	Sep. 22, 2022	May 15, 2024	1078	22.6	8.3	7.4	0.9

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

2.3 Interpretation of Monitoring Results

Most of the movement recorded in SI16-03 (located east of the slide mass) occurred immediately after installation and could be due to post installation SI casing flexure. Since late-2018, the rate of movement recorded in SI16-03 has been slow (less than 5 mm/year). The spring 2024 reading measured approximately 9 mm of movement in the top 1.5 m of the SI which could indicate the slide is expanding laterally to the east. Additional readings are needed to interpret this data and determine if this is a long term movement trend.

SI23-03 (located west of slide mass) measured distributed movement between depths of approximately 10 m to 12 m below ground level at a skew angle of 45 degrees (northeast) from down slope (perpendicular to the highway). Movement at similar depths was previously measured in SI16-01 (replaced by SI23-03) prior to it being damaged. This elevation is approximately the same as the bench at the base of the slope. More data is required to assess movement zones and trends.

More data is needed to assess movement zones and trends in the newly installed SIs (SI23-01 and SI23-02) located at the base of the repair area. SI23-02 measured distributed movement between depths of approximately 9 m to 11 m below ground level. Based on the installation records, this movement is in the upper bedrock, however the data is difficult to interpret, despite good data quality.

Since fall 2017, water levels recorded in the two VWPs installed in BH16-02A (clay till) and BH16-02B (bedrock) have been relatively steady (up to ±1.0 m). Water level readings completed in spring 2024 increased by 0.7 m and 0.9 m in BH16-02A and BH16-02B, respectively, compared to the fall 2023 readings. This increase could be due to increased precipitation in spring 2024 compared with previous years. At the time of writing this report, rainfall data was only available up to the end of March 2024.

Observed ground water noted on the slope at the eastern extent of the repair slope during the spring 2023 Section B inspection in May 2023 did not correspond with the water levels recorded in the VWPs read in June 2023. During the May 2024 instrument reading there was no wet areas located on the slope. There could be perched water tables within the slope in more permeable seams as noted by Thurber in 1998 “the surficial soils in the area comprise a sequence of medium to high plastic glaciolacustrine silty clays, with occasional lenses or discontinuous beds of sands and gravels. Underlying these surficial soils is a stiff to hard clay till, which overlies clay shale bedrock”. Data loggers should be installed on the VWPs to get more information on how ground water levels fluctuate in relation to snow melt and precipitation events.

3 RECOMMENDATIONS

3.1 Future Work

All operable instruments should continue to be read twice per year (spring and fall). Spring readings should be completed after mid-May, due to the risk of water inside the instrument casings being frozen earlier in the year.

Surveys (ground-based LiDAR or UAV photogrammetry) should be done to complete change detection analysis to monitor movement on the repair slope as there is no instrumentation currently installed.

Additional repair work is required on the slope due to the ongoing sloughing and slope movement. A proposal was submitted to TEC in July 2024 to evaluate additional repair options.

Data logger should be installed on the functioning VWPs upslope of the repair section to monitor groundwater fluctuations throughout the year.

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

3.2 Instrument Repairs and Maintenance

No instruments repairs or maintenance is required.

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.

10 Jul. 2024
ID 141695

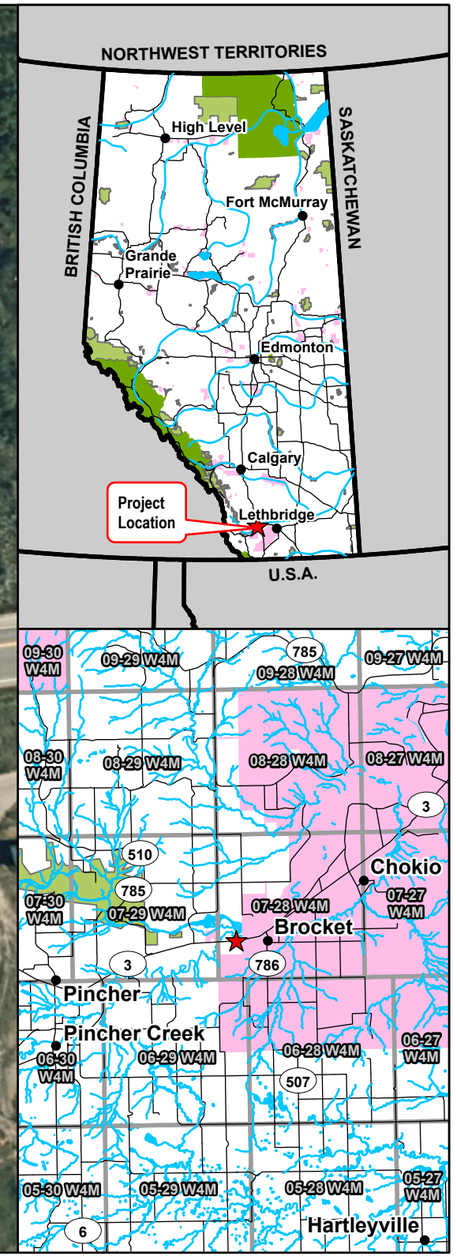
PERMIT TO PRACTICE
KLOHN CRIPPEN BERGER LTD.
RM SIGNATURE: _____
RM APEGA ID #: 58463
DATE: July 12 2024
PERMIT NUMBER: P009196
The Association of Professional Engineers and Geoscientists of Alberta (APEGA)

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
- Soil Nail Repair Area

0 50 Metres

NOTES:
1. HORIZONTAL DATUM: NAD83
2. GRID ZONE: UTM ZONE 12N
3. IMAGE SOURCE: MD OF WILLOW CREEK NO. 26, TOWN OF CARDSTON, TOWN OF PINCHER CREEK, MAXAR
4. STRIKETHROUGH INDICATES INSTRUMENT IS INACTIVE
5. AVAILABLE IMAGERY DOES NOT SHOW EXTENT OF REPAIRS.

CLIENT: Alberta

Klohn Crippen Berger

PROJECT: SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE: Site Plan
S039 - Brocket Slides
Hwy 3.06, km 12.952

SCALE	PROJECT No.	FIG No.
1:1,250	A05116A03	1

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APPENDIX I

Instrumentation Plots

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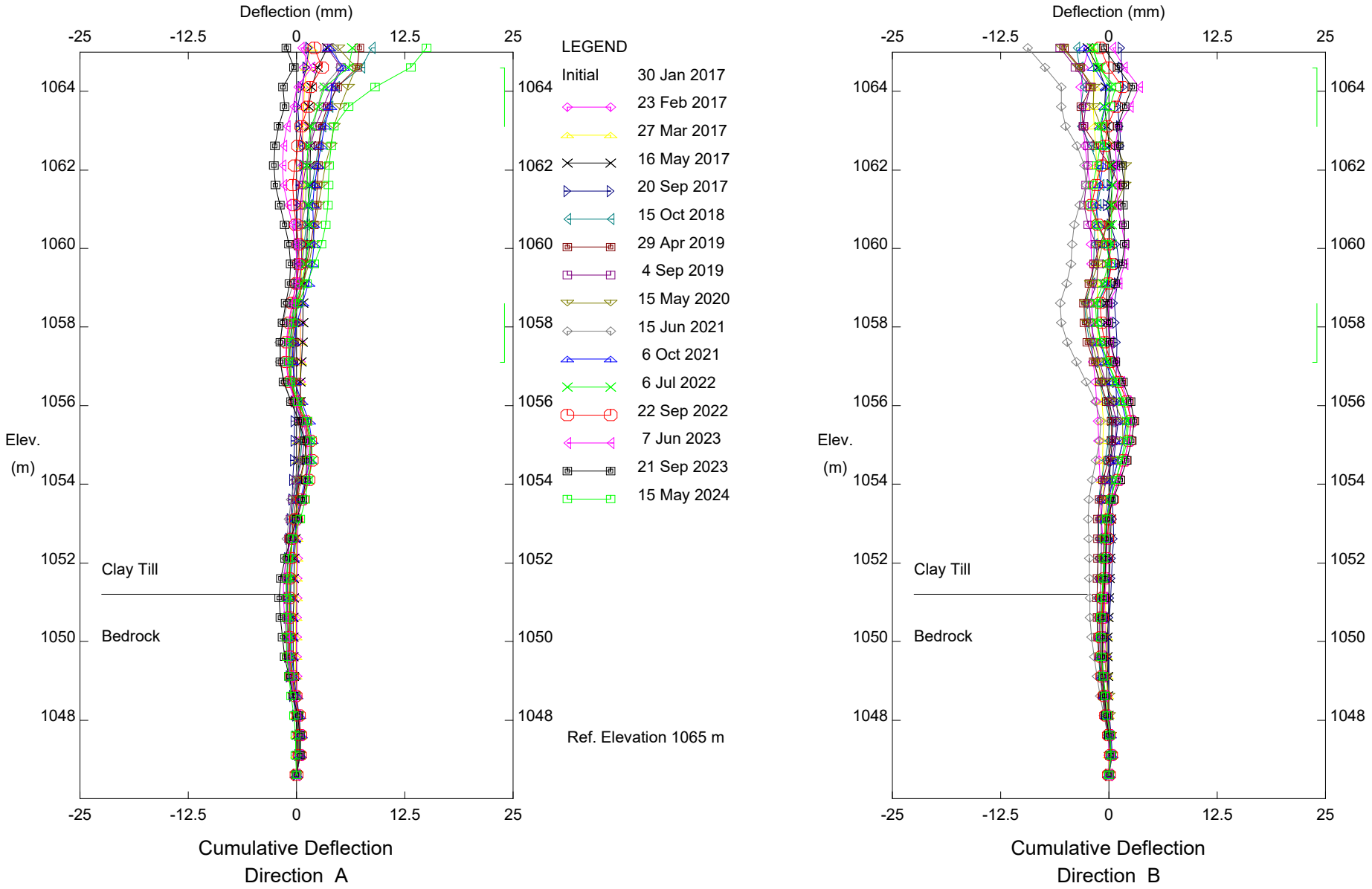

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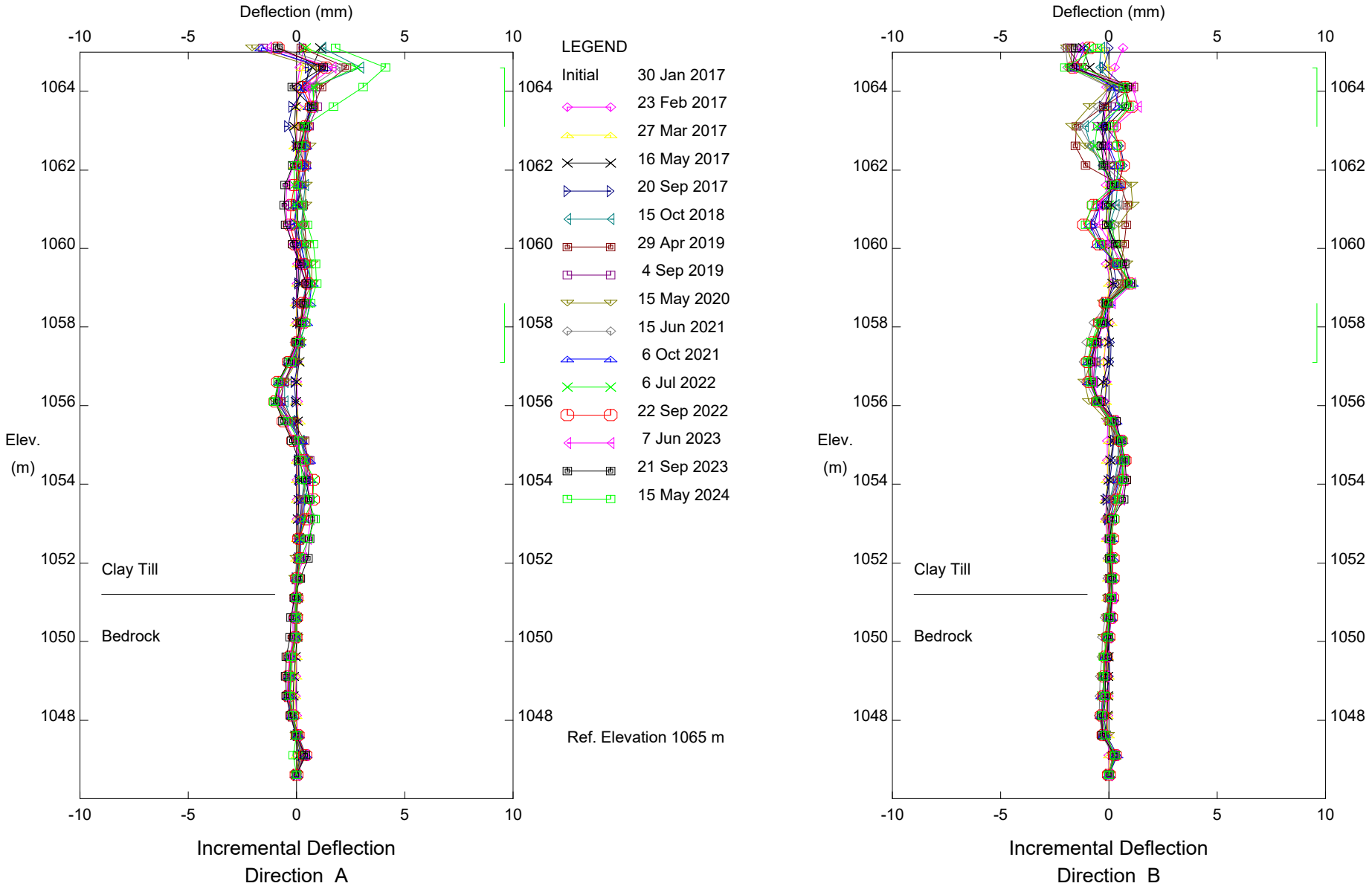

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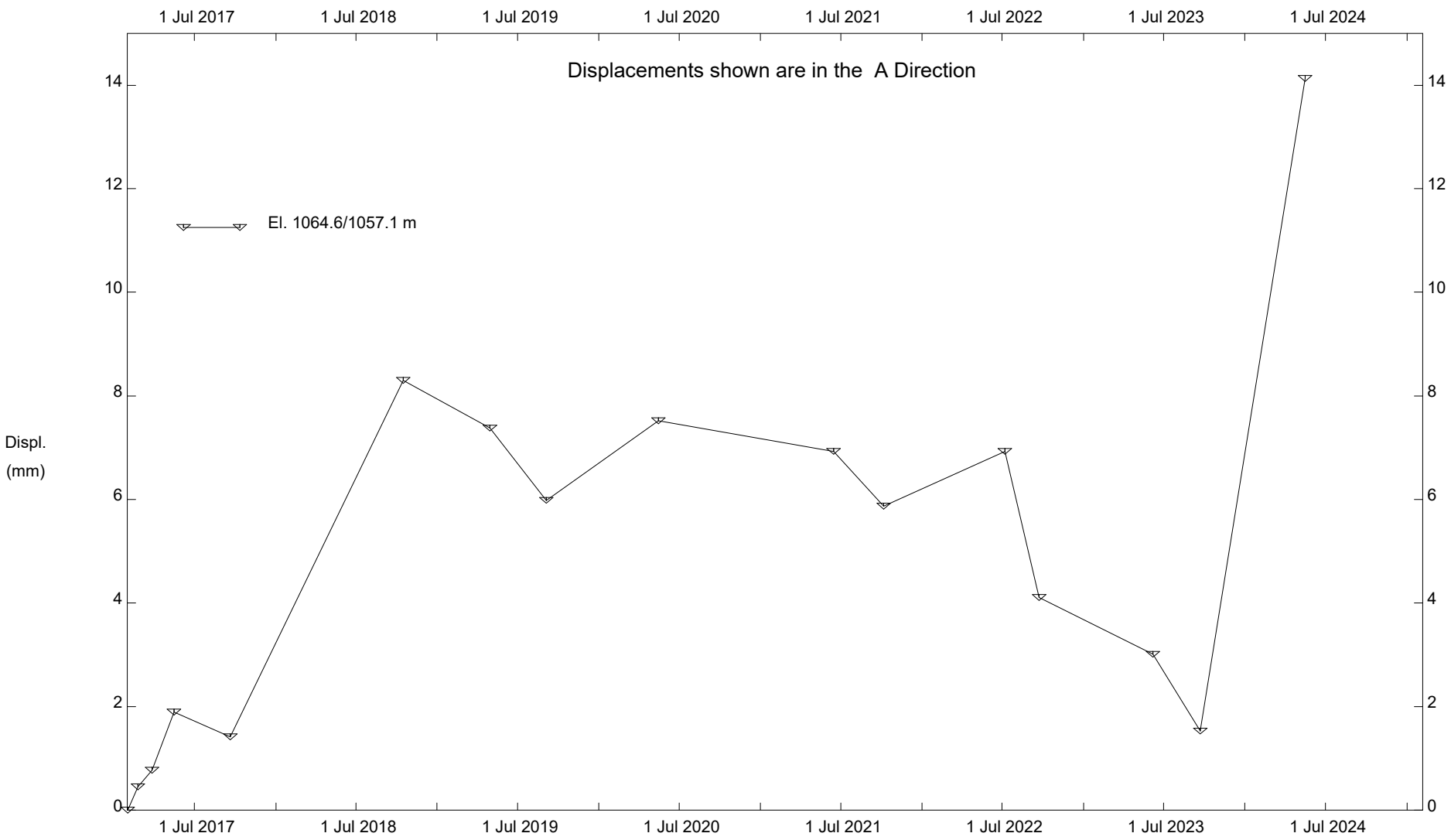

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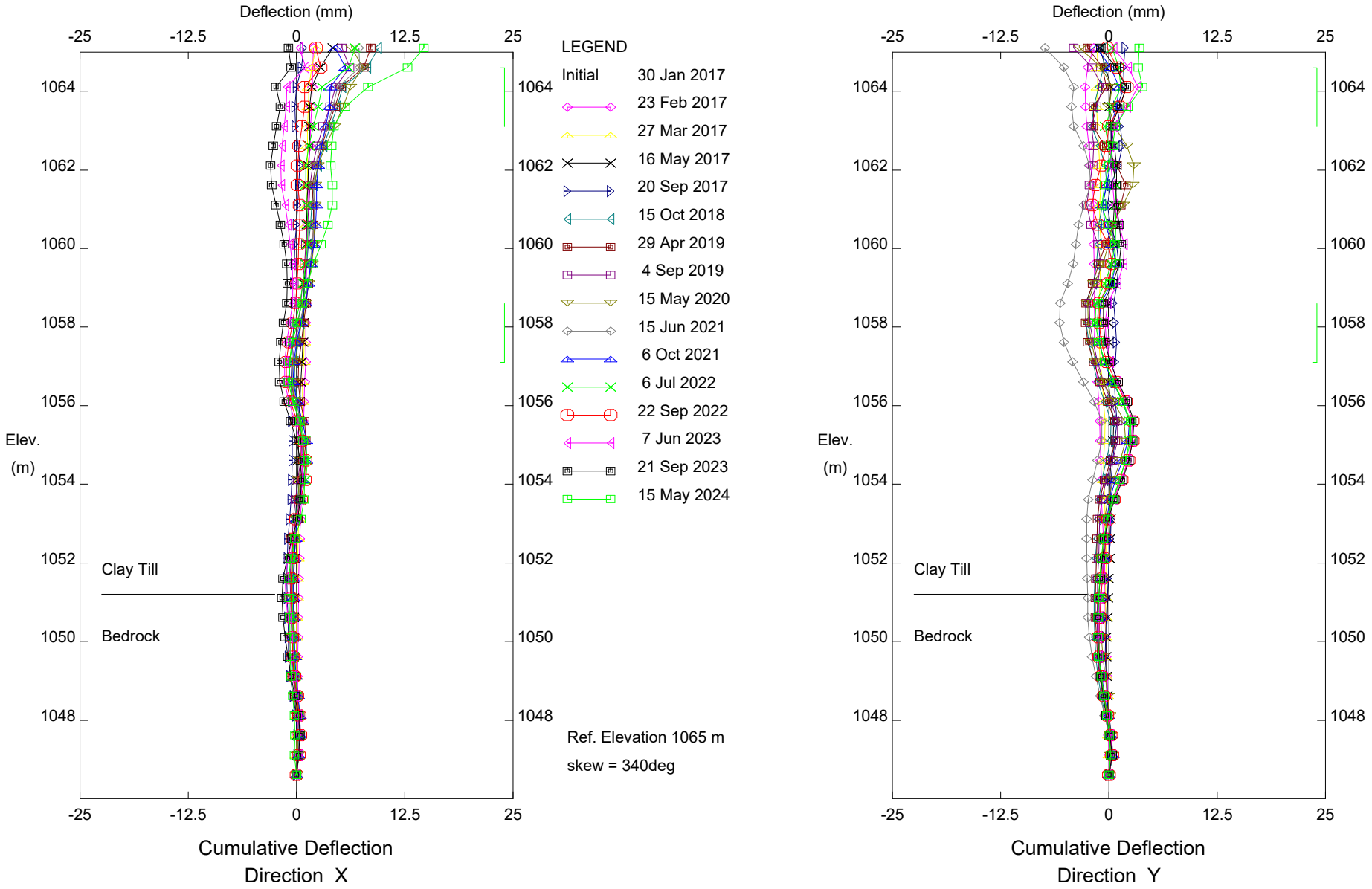

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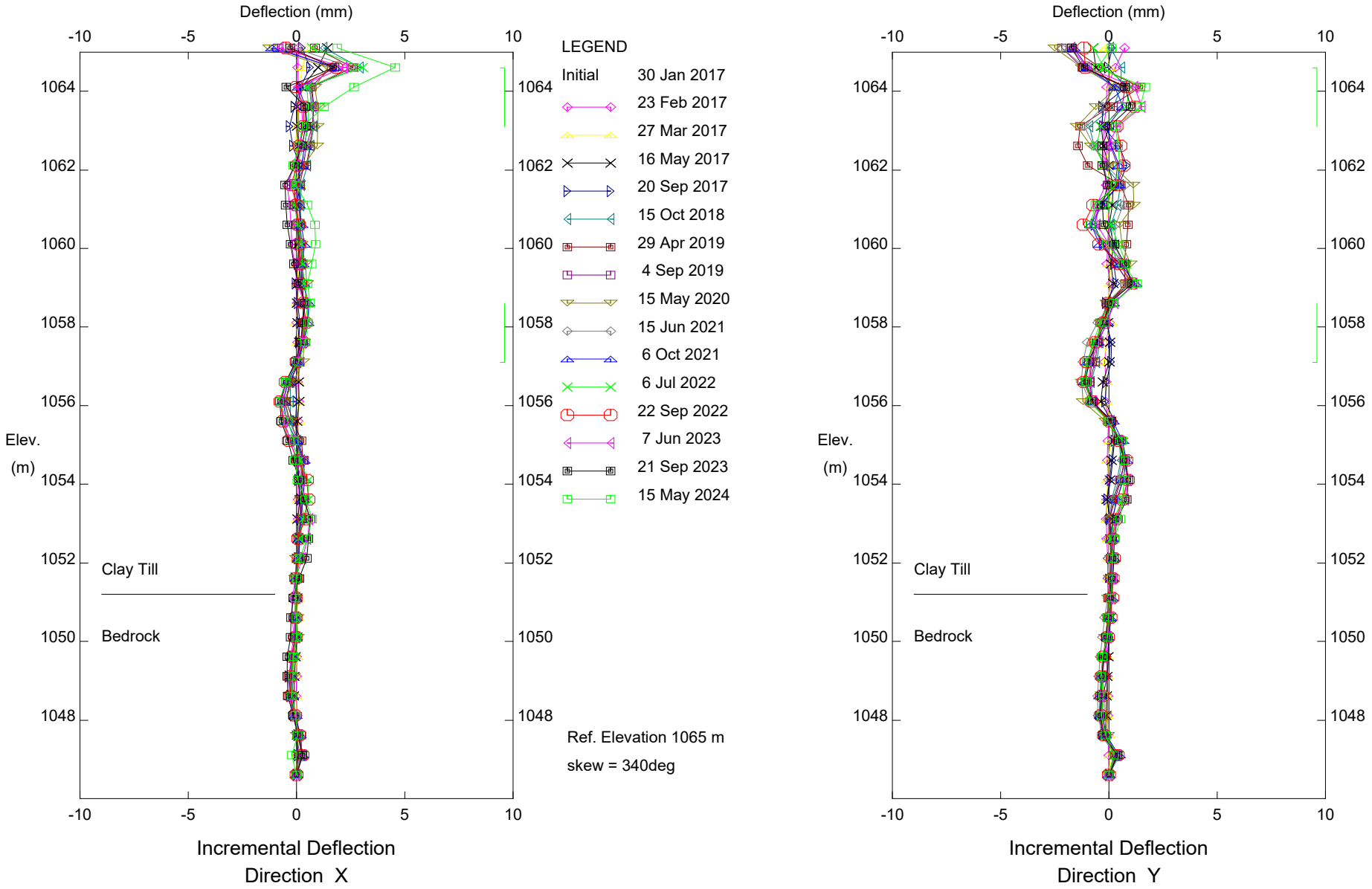

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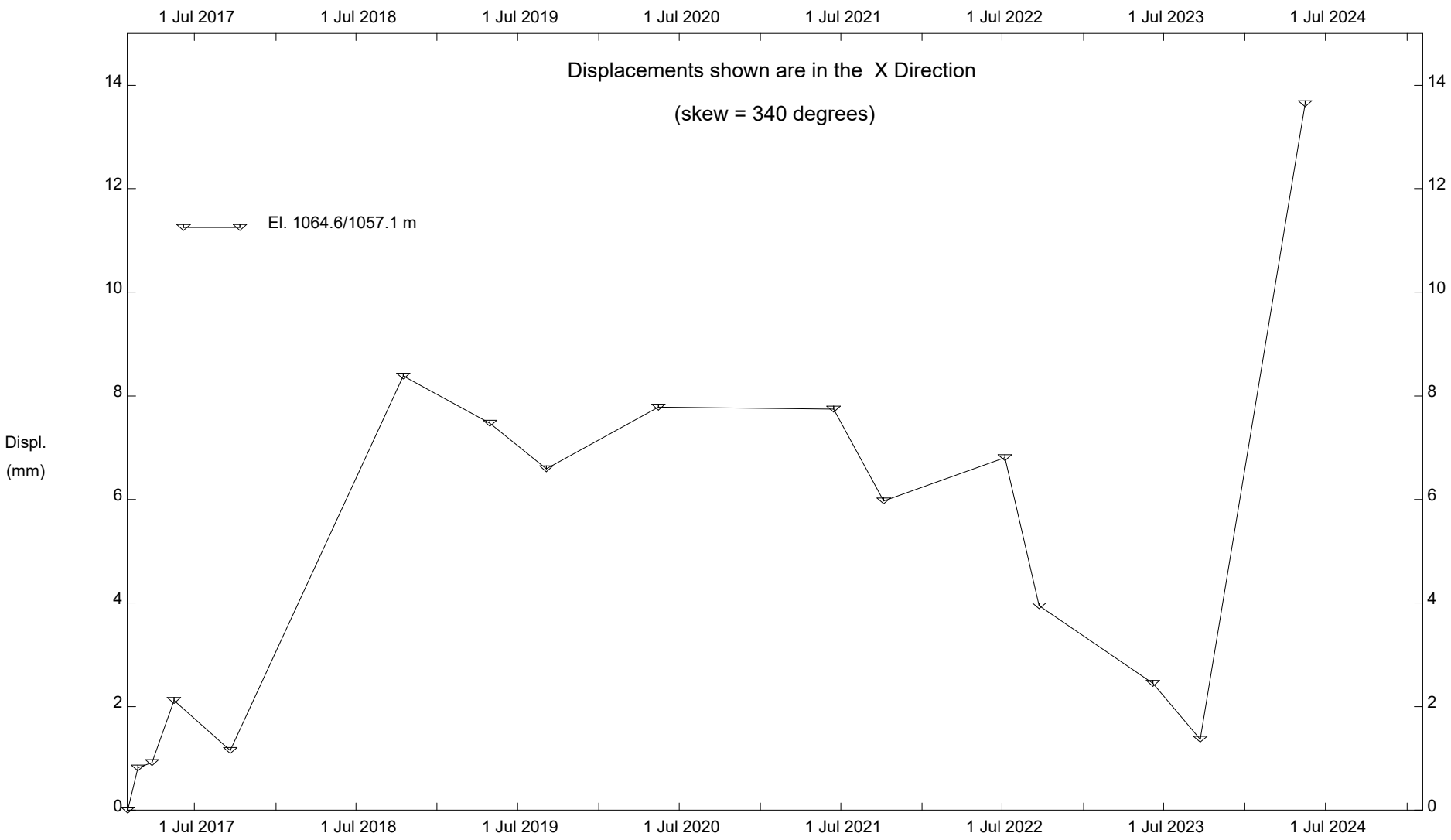

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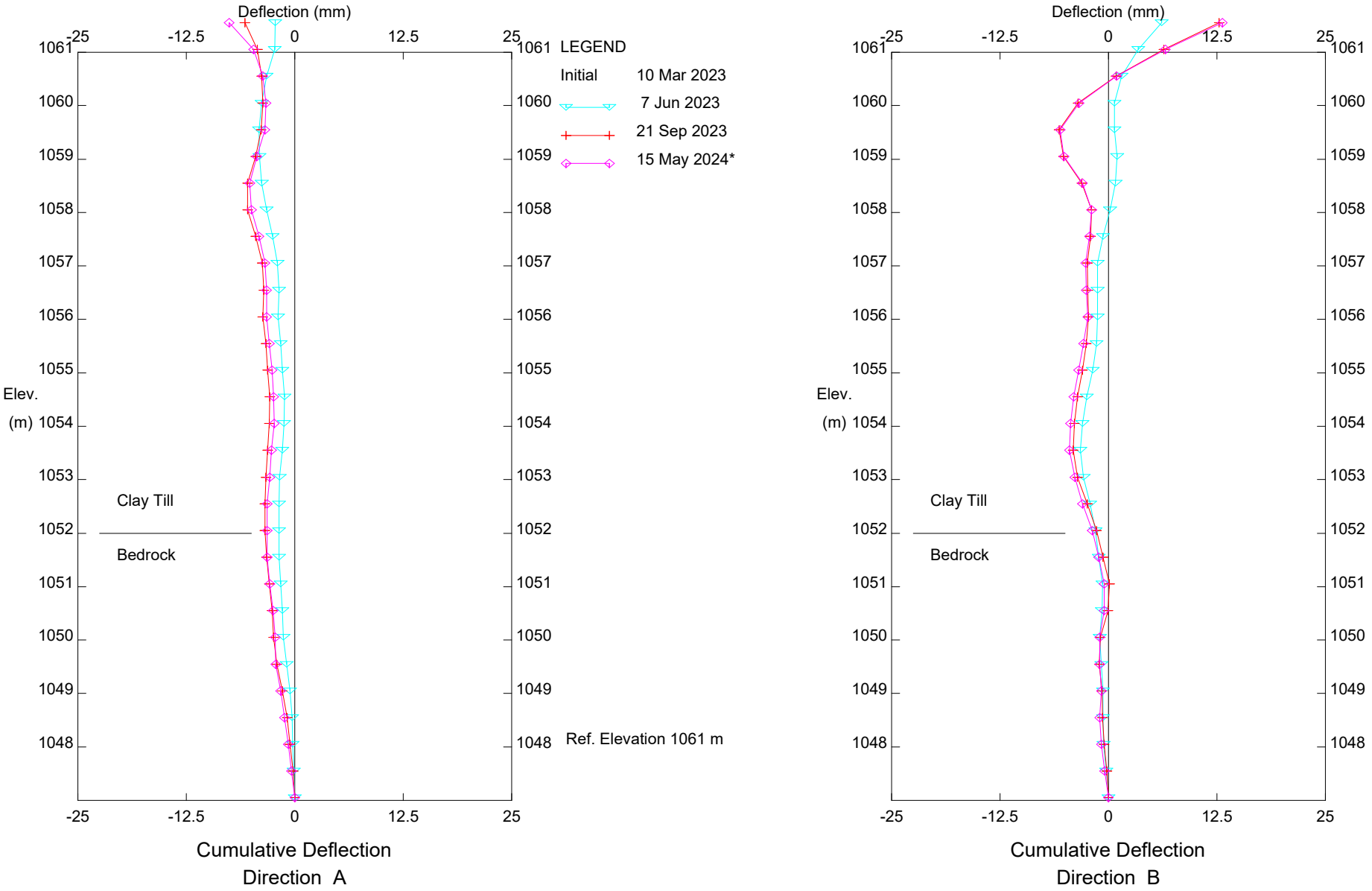

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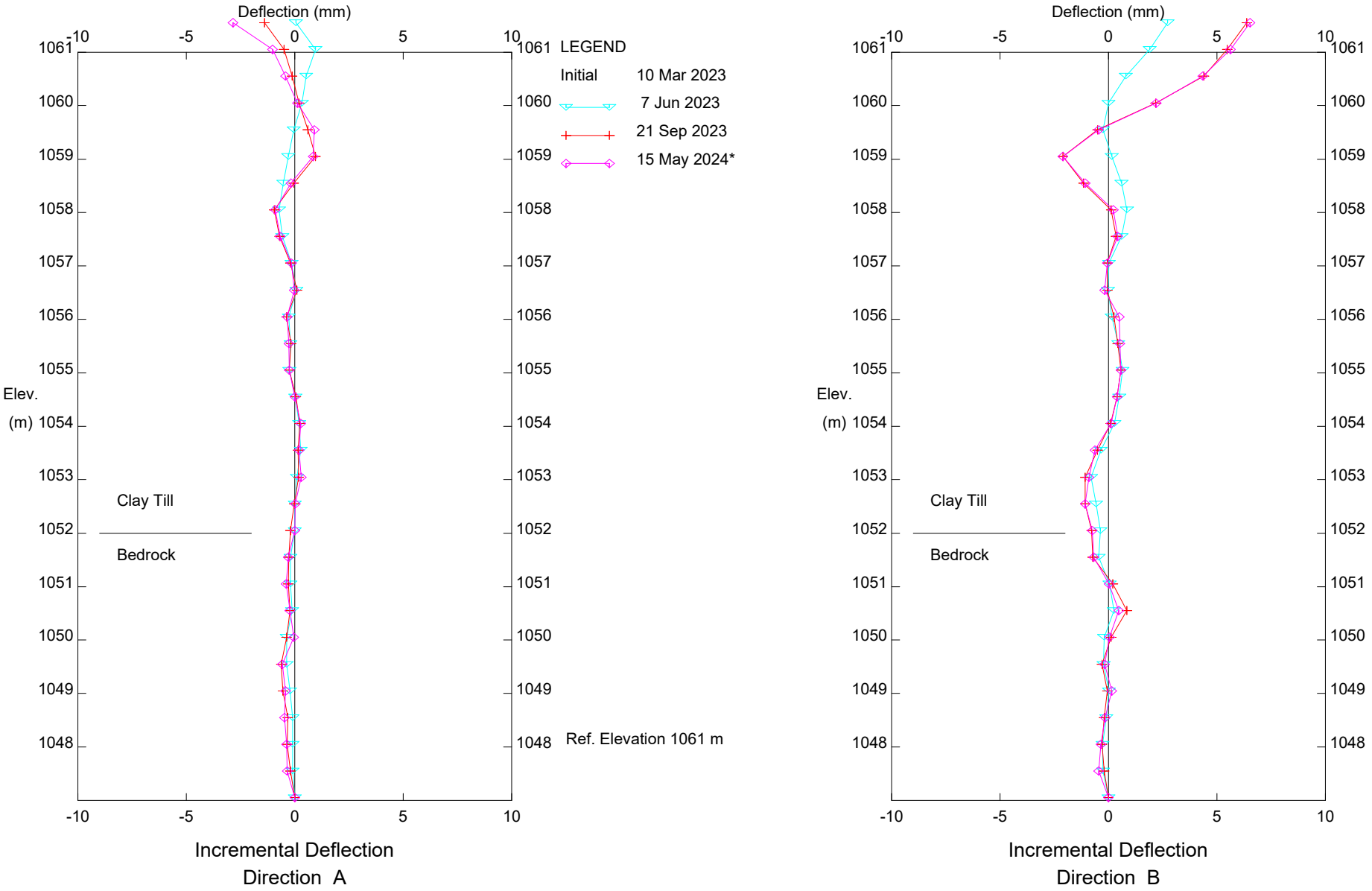

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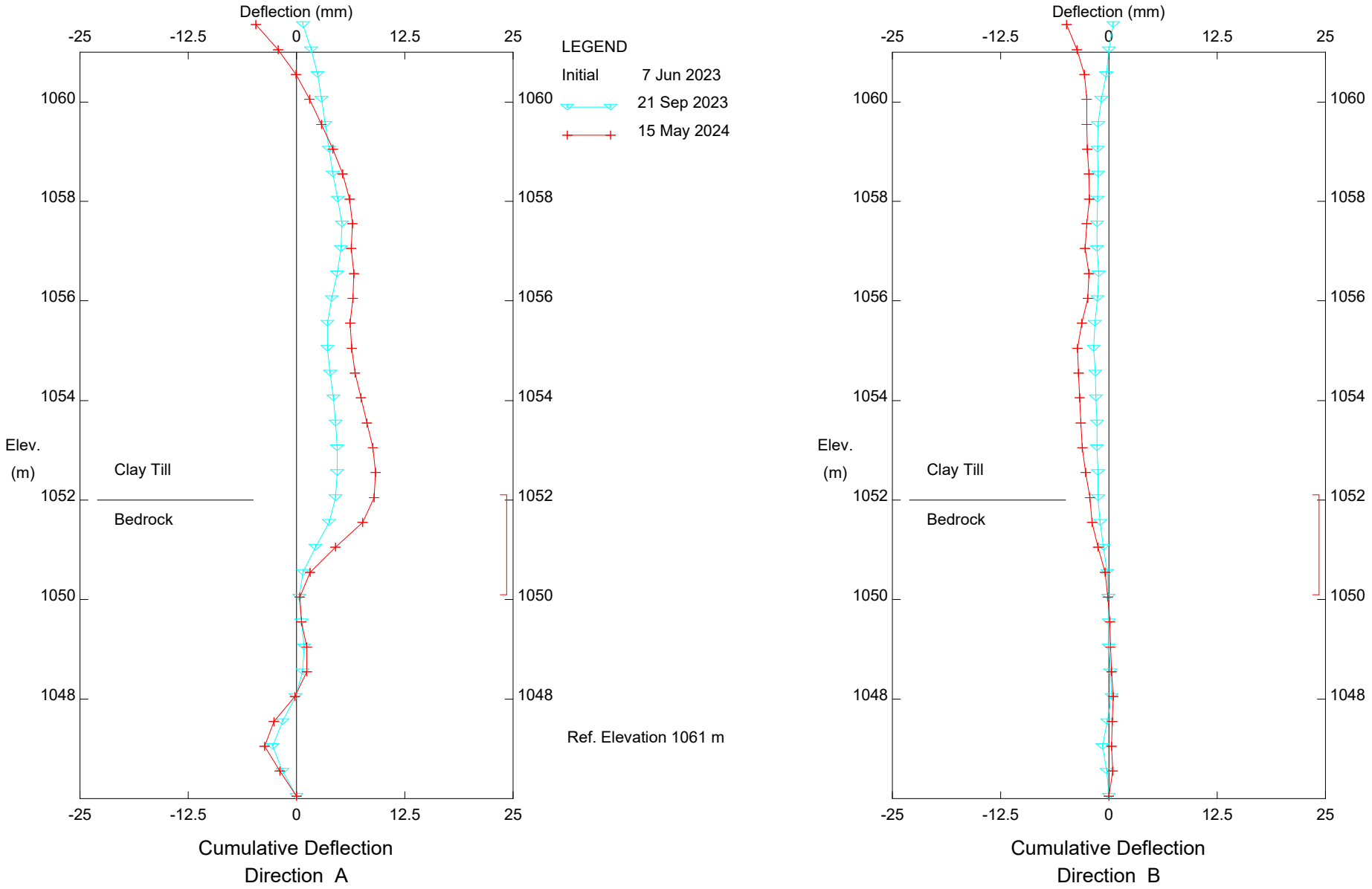

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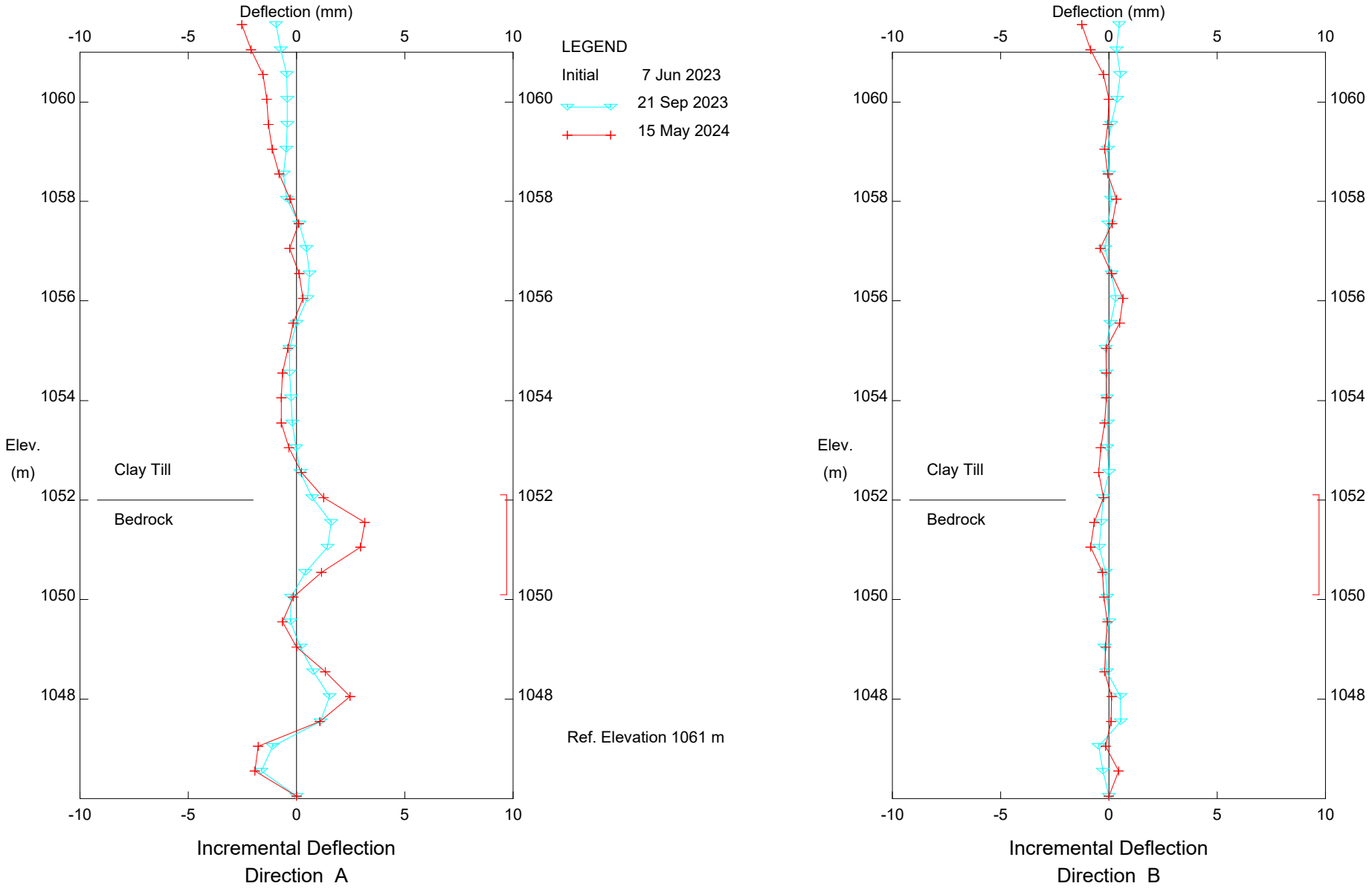

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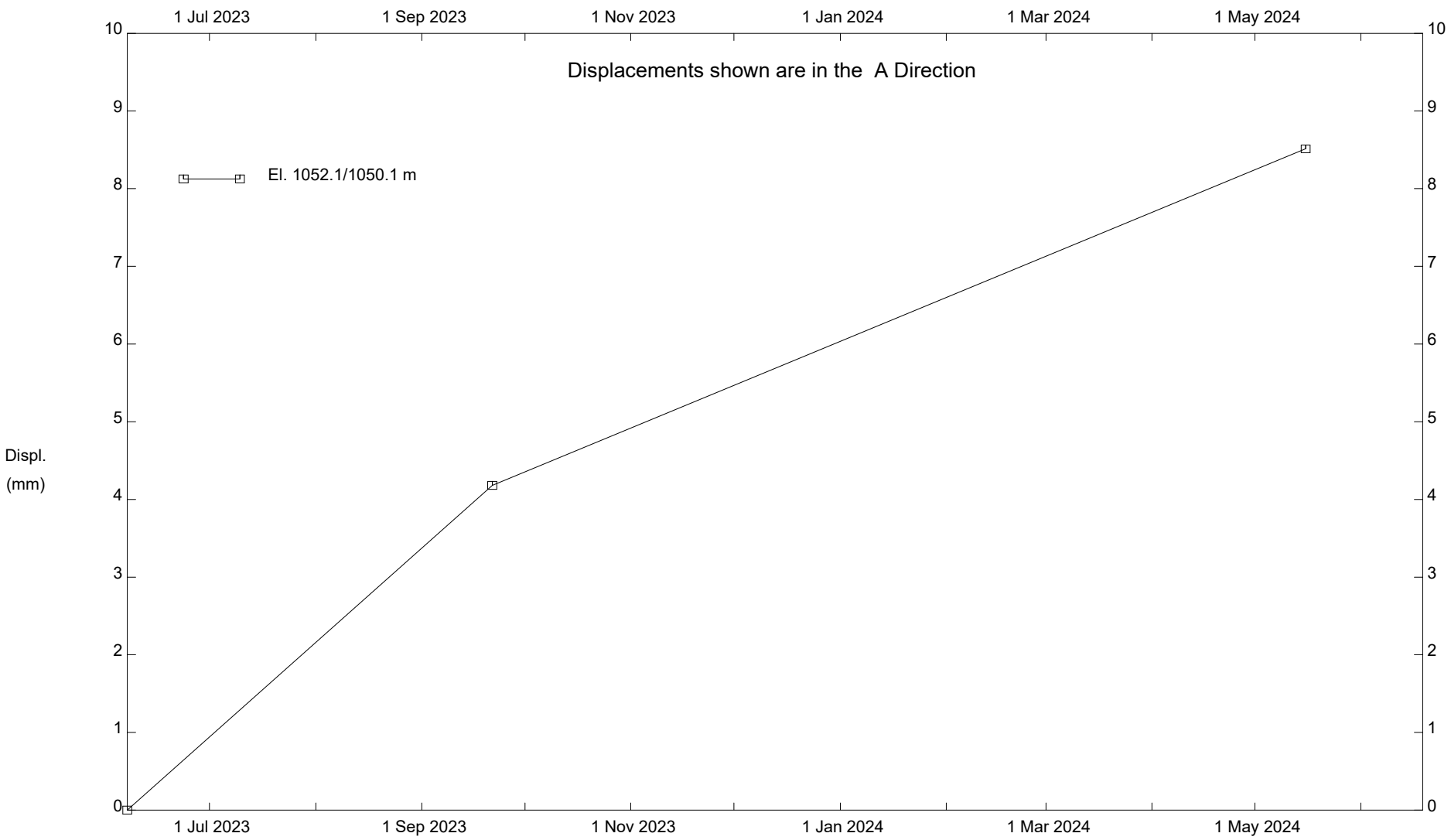

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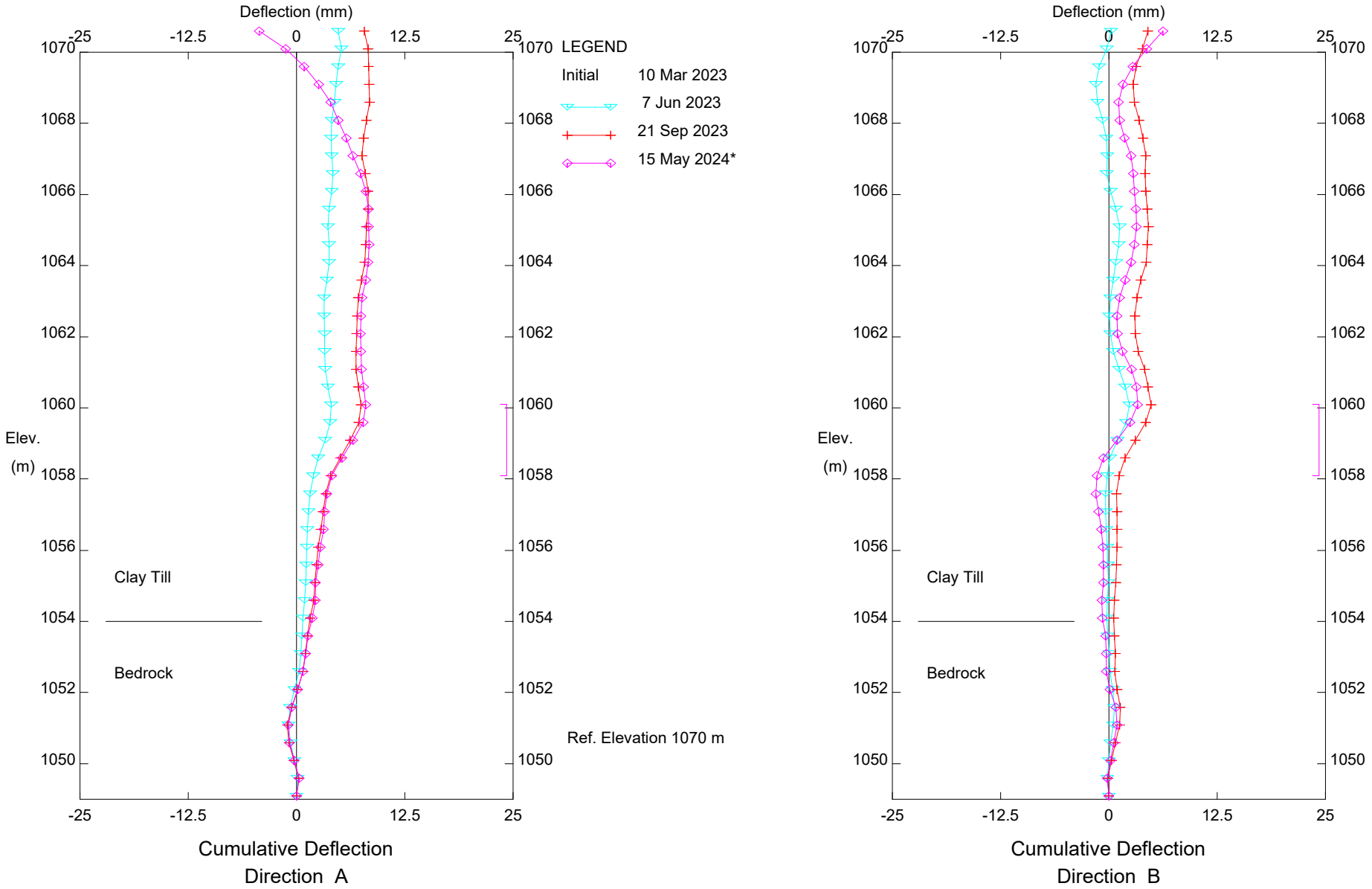

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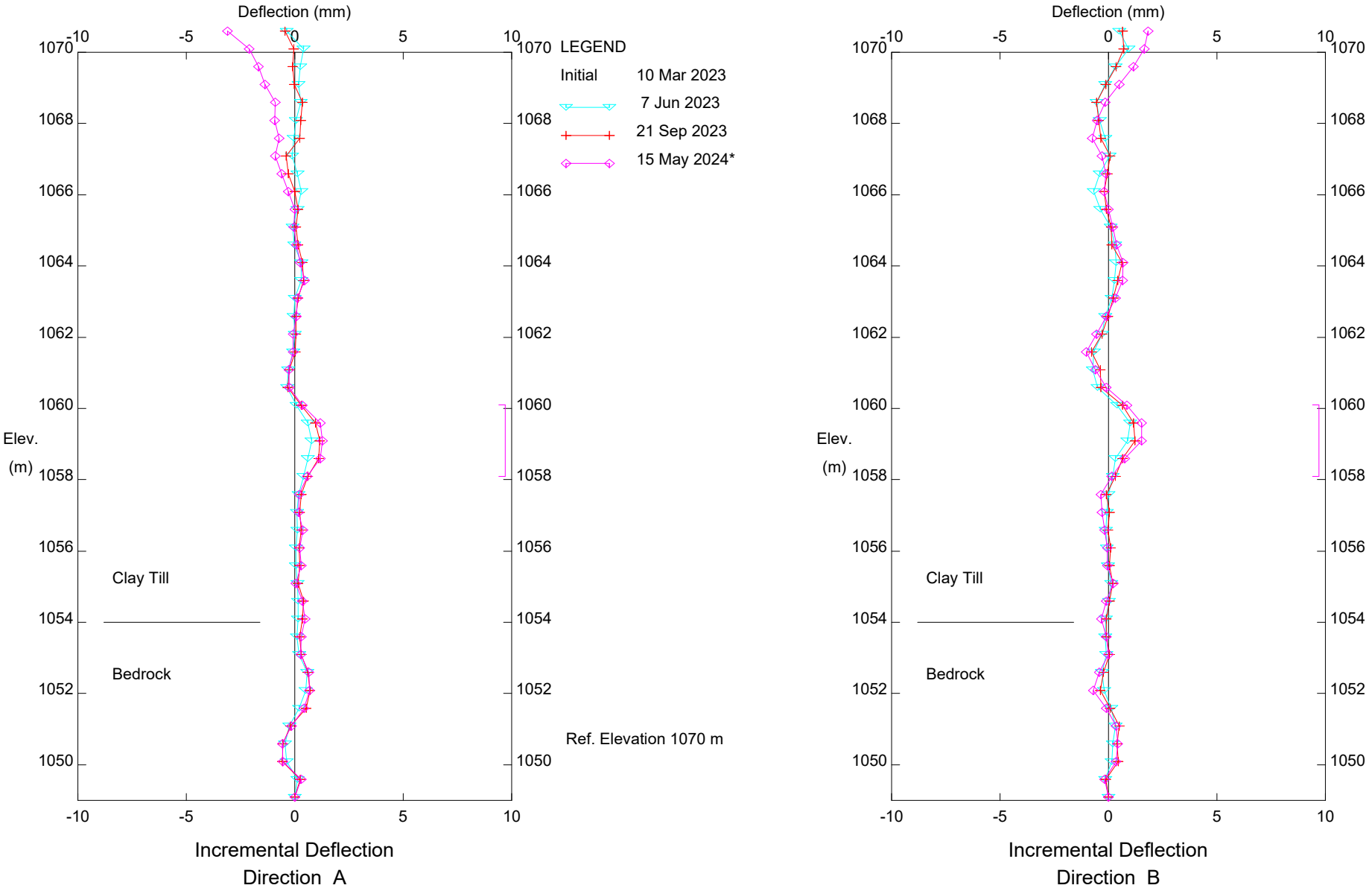

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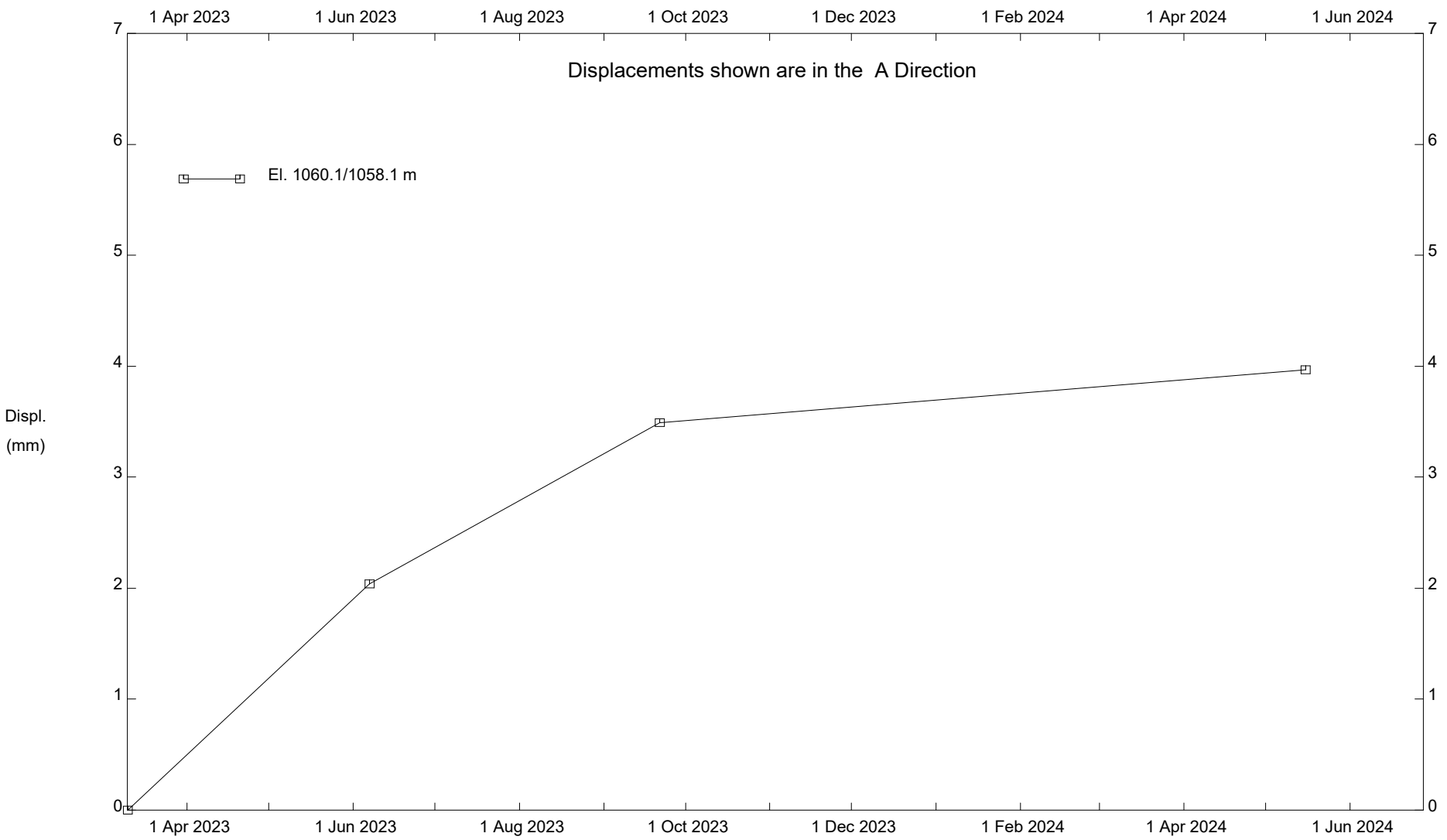
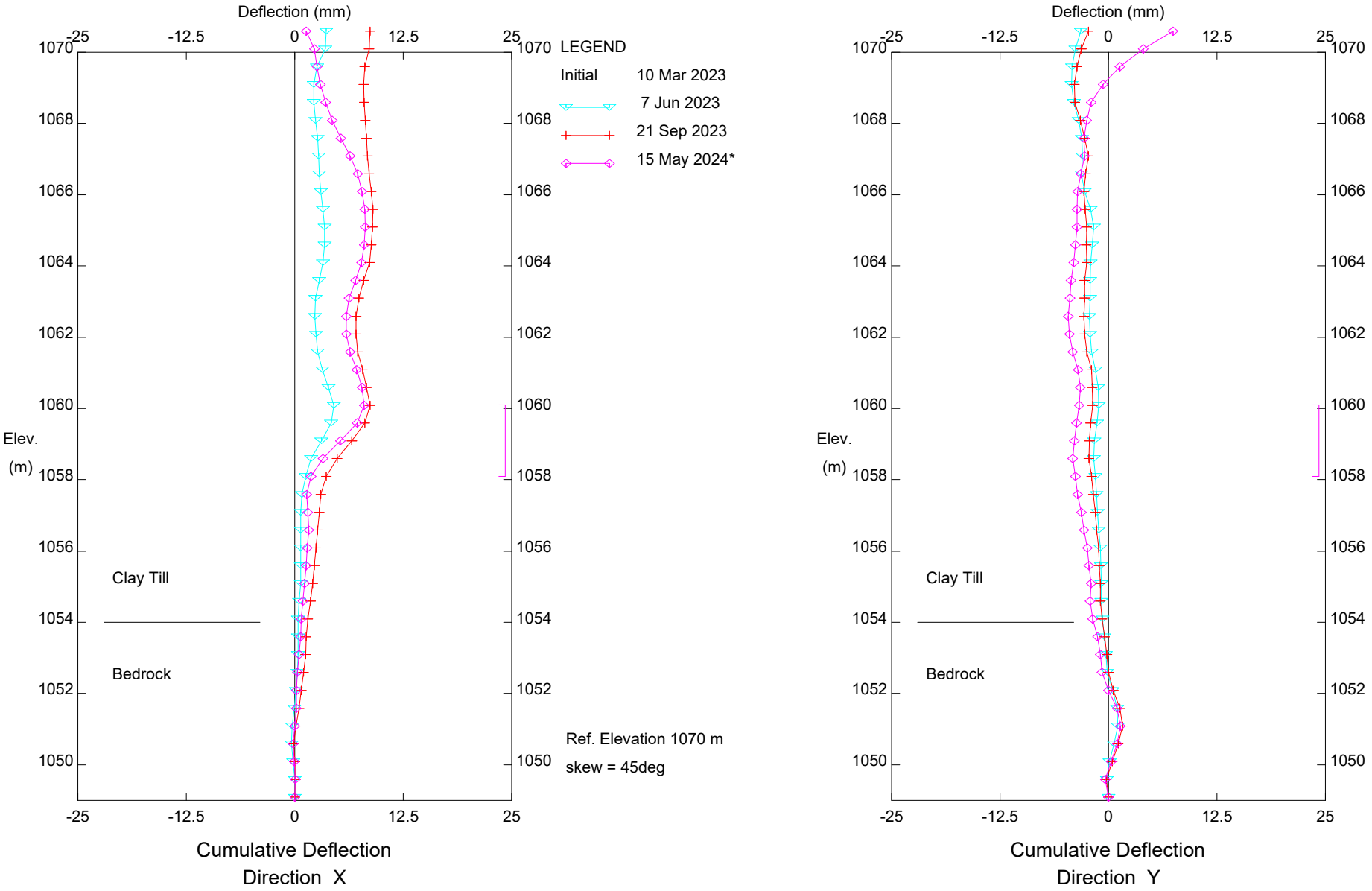
Klohn Crippen Berger Ltd. - Calgary, AB



S039 West Brocket Slide, Inclinometer SI 23-03

Alberta Transportation

Klohn Crippen Berger Ltd. - Calgary, AB



S039 West Brocket Slide, Inclinometer SI 23-03

Alberta Transportation

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

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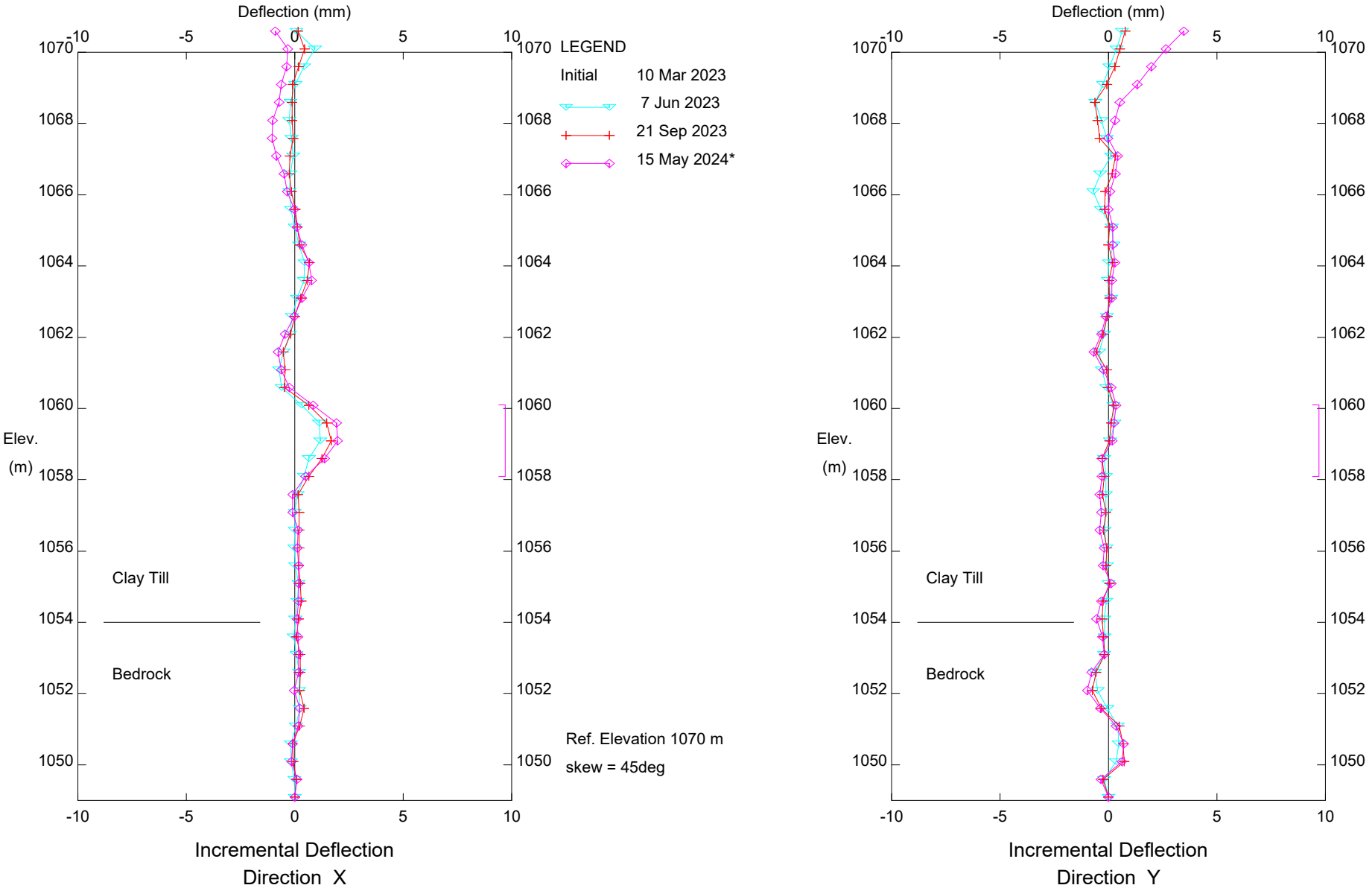
Klohn Crippen Berger Ltd. - Calgary, AB



S039 West Brocket Slide, Inclinometer SI 23-03

Alberta Transportation

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

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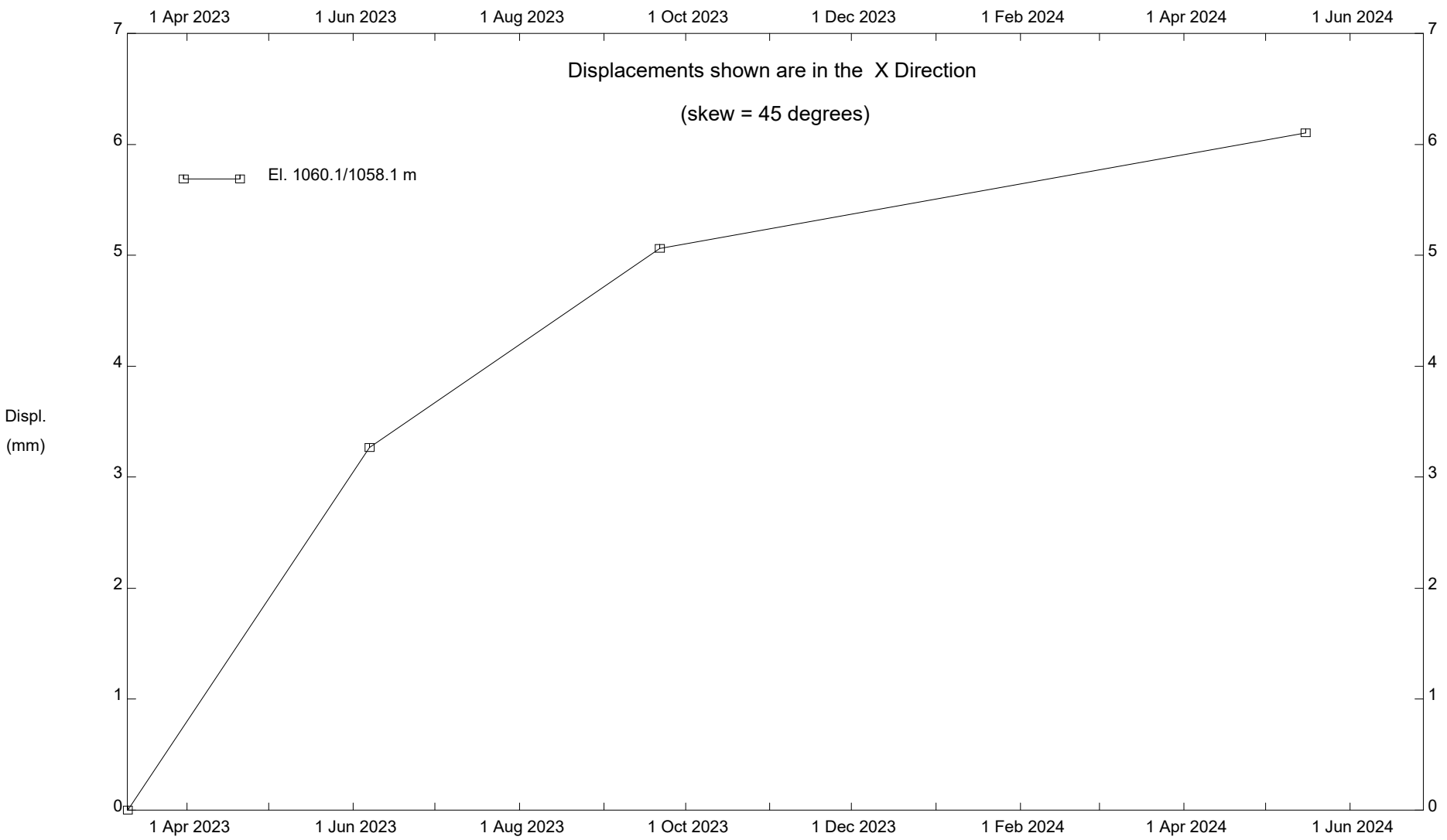
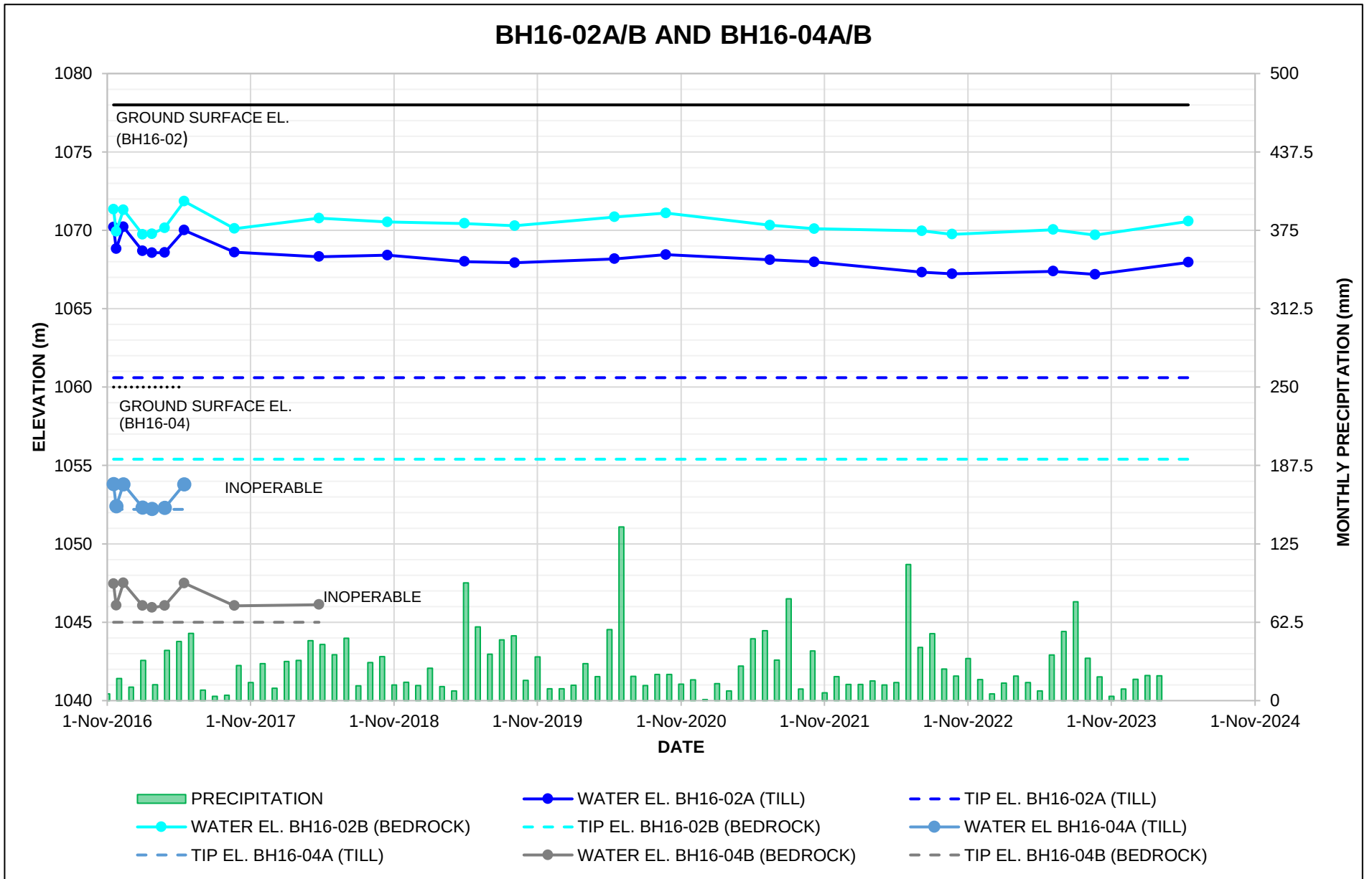


S039 West Brocket Slide, Inclinometer SI 23-03

Alberta Transportation



NOTES:
1. MONTHLY PRECIPITATION DATA OBTAINED FROM THE ALBERTA CLIMATE INFORMATION SERVICE (ACIS) DATABASE, REFERENCING LEGAL SUBDIVISION TWP007-28-W4.

CLIENT
Alberta
Klohn Crippen Berger

PROJECT
SOUTHERN REGION GEOHAZARD RISK MANAGEMENT PROGRAM

TITLE
Piezometer Data
S039 - West Brocket Slide
Hwy 03:06 km 12.952

SCALE	PROJECT No.	FIG No.
	A05116A03	