Monitoring Close Out Report
Docklands Light Railway (DLR) Asset: DLR/12 Woolwich Tunnels
Contract C310 Drive H Thames Tunnel

Document Number: C310-XRL-C-RGN-CR146-50001

Document History:

Version:	Date:	Prepared by:	Checked by:	Approved by:	Reason for Issue:
1.0	21/03/14	[redacted]			For DLR Approval

Contents

Executive Summary

Overview

This report summarises the monitoring data and observations of the Docklands Light Railway (DLR) Woolwich Tunnels during the construction of the Crossrail westbound and eastbound tunnels.

The first Crossrail TBM drive overpassed the DLR tunnels between 1st and 3rd May 2013 while the second TBM drive overpassed between 31st July and 1st August 2013.

Instrumentation and Monitoring

Monitoring of the DLR Woolwich Tunnels comprised a combination of automated and manual in-tunnel system of Hydrostatic Levelling Cells (HLC), rail monitoring using track trolleys and laser scanning. The HLCs were automated while the track trolley and laser scanning were carried out manually at prescribed frequencies.

The track trolley monitoring was carried out between 2/5/12 and 10/11/13, HLCs between 27/6/13 and 28/10/13 and laser scanning between 14/8/12 and 17/1/14.

Observations

No discernible movement or trends were detected from the various sensors arising from the construction of the Crossrail tunnels.

The HLCs displayed small temperature related movement trends while some sporadic anomalies, attributed to monitoring equipment, was observed in the laser scanning and track monitoring data. Nonetheless, the recent monitoring data generally indicated good convergence with the initial baseline readings to suggest no untoward movement.

Visual observations of the DLR tunnels during construction of the Crossrail tunnels did not indicated anomalies in the tunnel lining which could have potentially arisen from the TBM slurry pressures and tunnel construction activity (e.g. grouting).

Conclusion

Based on the monitoring data and observations, the impact of the Crossrail works on the DLR tunnels is considered to be low – negligible.

The monitoring has been carried out for the minimum period post completion of construction in accordance with the specifications. The HCLs and track monitoring remained in place for at least 3 months after the second TBM drive while the laser scanning was carried out until January 2014, almost 6 months after completion.

All monitoring data display an acceptably small rate of change (i.e. within the accuracies of the respective instruments) and satisfies the decommissioning requirements.

As such, in view of the monitoring and observations to date in conjunction with the current phase of construction, it considered that there are no further residual risks on the DLR tunnels arising from the Crossrail works.

1 Introduction

This report summarises the monitoring data and observations of the Docklands Light Railway (DLR) Woolwich Tunnels during the construction of the Crossrail westbound and eastbound tunnels. The objective of this is to assess the impact of the Crossrail works on the DLR tunnels and evaluate the potential residual risks to the DLR tunnels.

Specifically, this report will aim to:

- Summarise monitoring data and observed movements
- Demonstrate that the rate of change in the monitoring data has reached the acceptable decommissioning requirements
- Provide an impact assessment on the DLR tunnels and an evaluation of residual risks

For completeness, this report should be read in conjunction with the corresponding baseline monitoring report titled "Baseline Monitoring Report –Docklands Light Railway (DLR) Asset: DLR/12 Woolwich Tunnels" (C310-XRL-C2-RGN-CR148-50001) which presents an overview of background movements and the contractor's monitoring plan "HMJV Construction Monitoring Plan (CMP) (C310-HTM-C4-STP-CR146_ST004-50012).

1.1 Crossrail Contract C310

The Crossrail works at this location will be carried out under Contract C310 Drive H Thames Tunnels. The Crossrail running tunnels comprises twin bore single track tunnels constructed with precast concrete segmental linings. The internal diameter of the tunnels will be 6.2m with a segment thickness of 300mm. The tunnels were constructed using 2 Slurry Tunnel Boring Machines (TBM) with an external diameter of 7.1m. The TBMs were launched from Plumstead Portal, driven westwards towards Woolwich Station.

The date of the overpassing of both TBMs are indicated in Table 1.as follows.

Activity	Overpass date*
TBM1 – Westbound Tunnel Drive	1st May 2013 – 3rd May 2013
TBM2 – Eastbound Tunnel Drive	31st July 2013 – 1st August 2013

Table 1 – Construction of westbound and eastbound tunnel drives within the vicinity of the DLR Tunnels.

**The over pass dates listed in Table 1 are the dates for when the TBM was directly over the DLR Up and Down tunnels. This does not include the extent of influence zones before and after the TBMs. The achieved (average) advance rate for TBM1 and TBM2 when they overpassed the DLR tunnels were 10rings / day and 13 rings / day respectively.*

1.2 Related Documents and References

In line with schedule 4 of the Works Agreement (WA) between Crossrail (CRL) and DLR, the following documents have been produce and have been approved by DLR.

- Technical Interface Statement (TIS) – DLR Woolwich Interface (DLR/12) (C122-OVE-C4-XST-CR148-00001) Rev. 3.0
- Design Interface Statement (DIS) – DLR12 – Woolwich Interface (C122-OVE-Z-XST-CR001-50001) Rev. 5.0
- Construction Interface Statement (CIS) – Construction of Crossrail Running Tunnels over the Dockland Light Rail Thames Tunnels at Woolwich (C310-HTM-C4-RGN-CR146_ST004-50052)
- Instrumentation & Monitoring Plans: Docklands Light Railway Assets: DLR/12 (C122-OVE-C2-RGN-CR140-50004) Rev. 5.0
- HMJV Construction Monitoring Plan (CMP) (C310-HTM-C4-STP-CR146_ST004-50012) Rev 4.0
- Baseline Monitoring Report –Docklands Light Railway (DLR) Asset: DLR/12 Woolwich Tunnels (C310-XRL-C2-RGN-CR148-50001) Rev 3.0

2 Overview of DLR Interface and Crossrail Works

2.1 Interface

At the location of the interface, the proposed Crossrail tunnels traverse approximately in the east – west direction crossing over the DLR tunnels which run in the north – south direction. The clearance between the Crossrail and DLR tunnels (extrados to extrados) ranges between 2.3m and 3.2m. The site location is shown and general arrangement of the interface is shown on Figure 1 below.

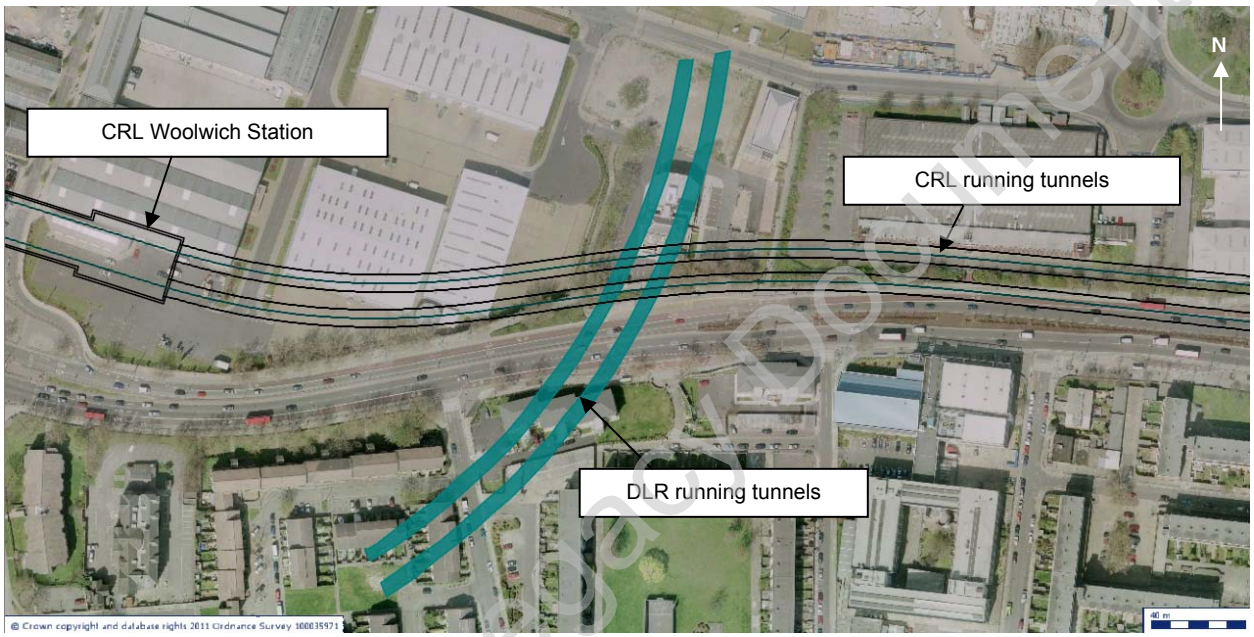


Figure 1 – Overview of DLR – Crossrail Interface

2.2 DLR Assets

The DLR Interface comprise twin tunnels constructed from precast concrete segments with an internal diameter of 5.3m and external diameter of 5.8m.

A detailed description of the DLR Woolwich Tunnels are provided in the respective TIS and DIS documents referenced in Section 1.2.

3 Instrumentation and Monitoring (I&M)

The I&M of the DLR tunnels are provided in Table 2 and 3 below.

Element / Structure	**I&M Activity / Installation**	**Monitoring objective**	**Monitored period** (including baseline)	
			Start	**End**
Track	Manual track trolley runs	Track deformation, e.g. track cant and twist.	2/5/12	10/11/13
Tunnel Lining	Hydrostatic levelling cells (HLC) 8 no. HLCs in the Up and Down Tunnel respectively. These are installed at 8m intervals over a distance of 56m.	Tunnel lining deformation. Vertical and or horizontal displacements leading to changes in tunnel shape (ovalisation)	27/6/12	28/10/13
	Laser scanning to obtain tunnel transects		14/8/12	17/01/14

Table 2 – I&M installation and monitoring period

Element / Structure	**I&M Activity / Installation**	**Frequency**			
		Baseline	During Tunnel Drive(s)	Between Tunnel Drives	Post Completion
Track	Track Trolley	Monthly	Nightly	Fortnightly then monthly	Monthly
Tunnel Lining	Hydrostatic levelling cells (HLC)	Real time / data logged			
	Laser scanning	Monthly	Nightly	Fortnightly then monthly	Monthly

Table 3 – I&M monitoring frequency

The laser scanning used to establish the baseline was carried out at each location of the hydrostatic levelling cells, spaced at 8m intervals along the Up and Down DLR tunnels.

The interval between laser scans was narrowed (i.e. brought closer) to every DLR tunnel ring during the construction of the Crossrail westbound and eastbound tunnels. The aim of this was to specifically focus on the section of DLR tunnel immediately within the influence zone of the respective TBMs. The laser scanning regime adopted during passage of TBM1 and TBM2 is indicated in Table 4 and Figure 2. See Appendix A for the C310 I&M drawing.

TBM Drive	Laser scanning location / rings		
	Baseline Monitoring / Post Construction	TBM1 (Westbound) passage	TBM2 (Eastbound) passage
DLR Down Line Tunnel	HLC 1001 – 1008	977 – 984, 988	966, 968 – 974, 977
DLR Up Line Tunnel	HLC 1011 – 1018	961, 964 – 971	950, 953 – 959, 961

Table 4 – Laser scanning during passage of TBM1 and 2

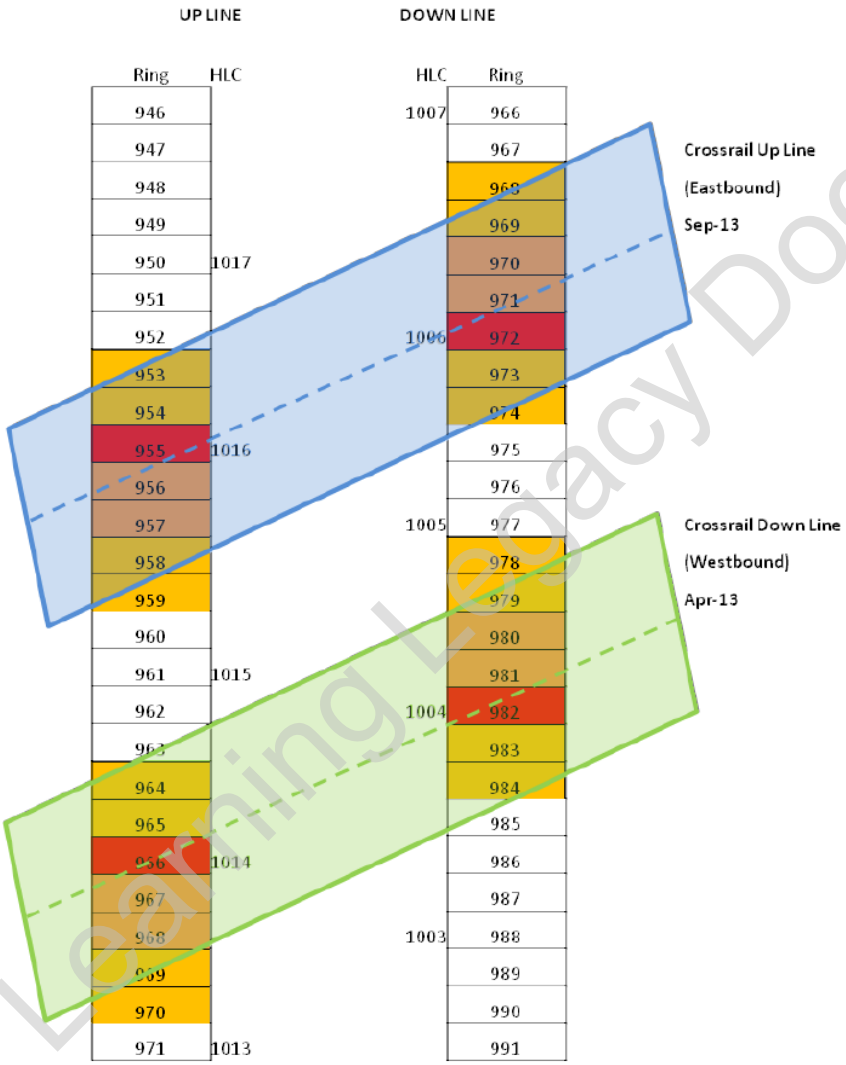


Figure 2 – Laser scanning during passage of TBM1 and 2

4 Monitoring and Observations

4.1 Hydrostatic Levelling Cells (HLC)

Over a period of 16 months between June 2012 – October 2013, the maximum movement range is 1.4mm, between +0.5mm and -0.9mm across all sensors in both tunnels. The range of HLC movement is indicated in Table 5 while detailed HLC monitoring data is provided in Appendix B.

	DLR Down Line Tunnel	DLR Up Line Tunnel
Maximum (mm)	+0.5	+0.2
Minimum (mm)	-0.7	-0.9
Range (mm)	1.2	1.1
Average Range (mm)	0.98	0.56

HLCs have an accuracy of ±0.2mm.

Table 5 – HLC movement range in the DLR Up and Down Tunnels.

In general, the fluctuations in the HLC data are more apparent in the Down tunnel in comparison to the Up tunnel. Sensors in the Up tunnel data indicate a lower average movement range although the peak fluctuation range between the sensors in both tunnels are similar.

There were no discernible movement trends in the HLCs as a result of the construction of the Crossrail tunnels. No trigger levels were breached over the monitored period.

4.2 Track Monitoring

The track cant monitoring indicated a general movement range of approximately 3mm. On the DLR Up Line, the general movement envelope ranged between -1mm to 2mm with an average range between -0.6mm and 0.6mm. On the DLR Down Line, the general movement envelope ranged between -1.2mm and 1.7mm with an average range between -0.3mm and 0.7mm. See Appendix C for details of the track monitoring data.

The monitoring data indicates a scatter of data between ±2mm with the exception of sporadic minor anomalous readings. This is consistent with the baseline monitoring observations albeit with greater scatter since. A comparison between the general movement envelope and data averages indicates a tendency of the monitoring data to display positive fluctuations (i.e. increase in cant).

There are no discernible trends in the data during over passing of both TBMs although there is apparently more 'noise' in the monitoring data with time. There appears to be a consistent gradual translational shift in the data of between 1 – 2mm over the length of the monitored section which is thought to be a systemic error. In comparison, the track twist data is stable and more consistent, suggesting little movement.

Notwithstanding, the observed movement range of the data is largely in line with the sensitivity and accuracy limits of the equipment which is ±2mm. No trigger levels were breached over the monitored period.

4.3 Laser Scanning

In summary, from the most recent set of scans carried out in January 2014, almost 6 months after passage of TBM2 and 9 months after TBM1, no discernible movement or trends were identified to indicate any deviation or distortion in the DLR tunnel lining.

While the laser scanning indicated good consistency during consecutive blocks of repeated scanning, particularly during both periods of tunnel construction, there was notable 'steps' and deviation in between these blocks of consecutive scanning. These blocks of consecutive scanning were, baseline monitoring, first tunnel drive, in between drives, second tunnel drive and post construction monitoring.

While the profiles within each block are consistent and repeatable, the discrepancies between blocks of consecutive scanning are generally 5mm where it occurs, occasionally up to 10mm in some profiles. See Appendix D, D1 and D2 for details of the laser scanning data.

The reason for this observed discrepancy is thought to be due to instrumentation error although the actual mechanics which caused this is not immediately clear. Possible deviations in the scanned profile may have been caused by:

i. Variance in site practice / setup as monitoring was carried out by different site teams (positioning of instrument is down manually)

ii. Different laser scanning instruments were used being used

iii. Deviations in position and alignment of the laser scanner on the track trolley during scanning

iv. Potential changes in conditions in the tunnel *(The laser reflection and detection can be affected by atmospheric changes in the tunnel such as humidity, moisture and 'dark areas' on the scanned surface).*

No discernible changes in tunnel conditions have been observed during the scanning and the irregular profiles produced from some scans were not observed during monitoring suggesting erroneous readings.

Nonetheless, the 2 most recent scans, taken in December 2013 and January 2014 indicate good convergence with the initial baseline profiles suggesting that there has been no notable movement in the DLR tunnels during passage of both Crossrail TBMs.

4.4 Summary

The HLCs displayed small temperature related movement trends while some anomalies, attributed to monitoring equipment, was observed in the laser scanning and track monitoring data.

Nonetheless, no discernible movement or trends were detected from the various sensors arising from the construction of the Crossrail tunnels.

The monitoring has been carried out over the minimum period post completion of construction in accordance with the specification. The HCLs and track monitoring remained in place for at least 3 months after the second TBM drive while the laser scanning was carried out until January 2014, almost 6 months after completion of tunnel construction.

All monitoring data display an acceptably small rate of change (i.e. within the accuracies of the respective instruments) and satisfies the decommissioning requirements.

5 Predicted impact on DLR Tunnels

Prior to construction, an assessment of the impact of ground movements arising from the Crossrail works on DLR assets was carried out and presented in the DIS as referenced in Section 1.2.

The main conclusions from the DIS were:

- The estimated deformations of the DLR tunnels are ≤ 1mm.
- The estimated maximum track twist is 1:10000 which is well below the lowest alert level

Therefore, the impact of ground movements arising from the Crossrail works on the DLR tunnels was considered to be very low.

While the predicted impact of ground movements were low - negligible, there were potential risks arising from the construction works which may have impacted on the DLR tunnels. This relates to the usage of a Slurry Tunnel Boring Machines and the slurry pressures used to stabilise the tunnel excavation face during construction. The risk mitigation measures against this during tunnelling operations were detailed in the CIS.

6 Conclusion

No discernible movement or trends were detected from the various sensors during the construction of the Crossrail tunnels. This is consistent with the initial assessment (DIS) which predicted negligible movements of the DLR tunnels

Observations of the DLR tunnels during construction of the Crossrail tunnels did not indicated anomalies in the tunnel lining which could have potentially arisen from the TBM slurry pressures and tunnel construction activity (e.g. grouting).

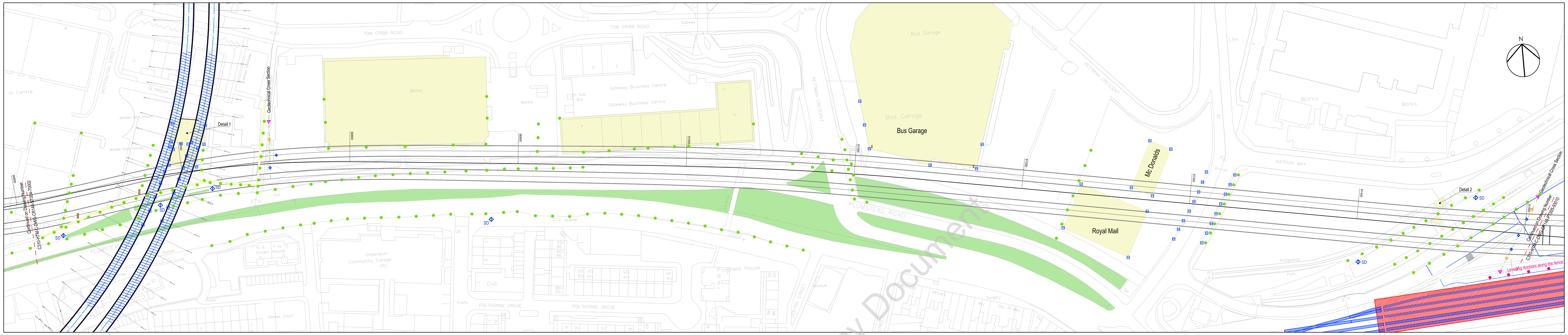
Based on the monitoring data and observations, the impact of the Crossrail works on the DLR tunnels is considered to be low – negligible.

The monitoring has been carried out for the minimum period post completion of construction in accordance with the specifications. The HCLs and track monitoring remained in place for at least 3 months after the second TBM drive while the laser scanning was carried out until January 2014, almost 6 months after completion.

All monitoring data display an acceptably small rate of change (i.e. within the accuracies of the respective instruments) and satisfies the decommissioning requirements.

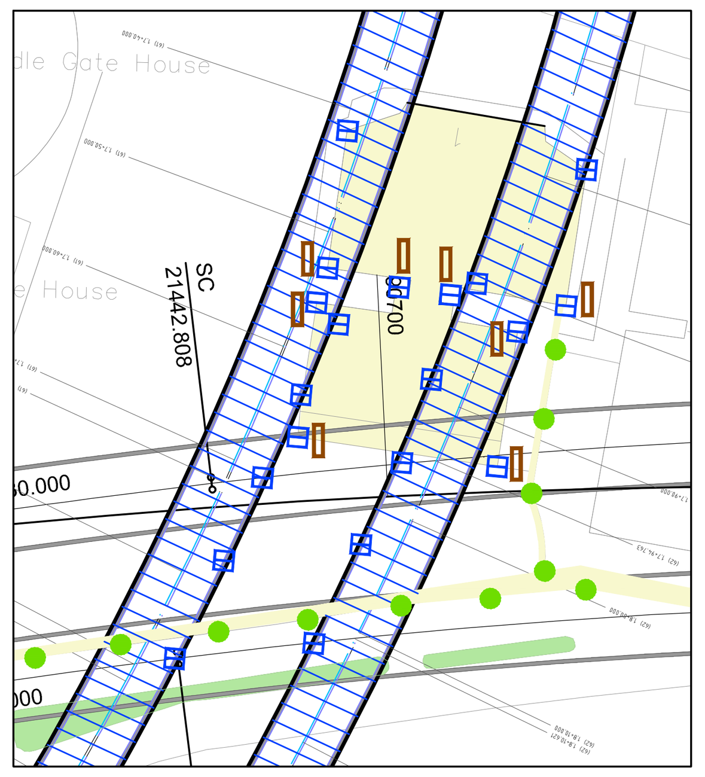
As such, in view of the monitoring and observations to date in conjunction with the current phase of construction, it considered that there are no further residual risks on the DLR tunnels arising from the Crossrail works.

Appendix A C310 Instrumentation and Monitoring Drawings

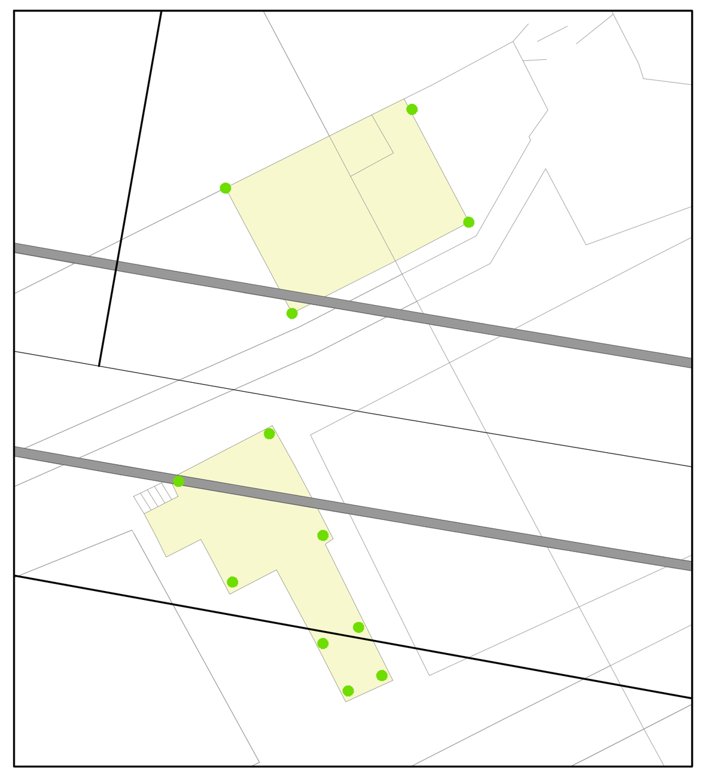


GENERAL LAYOUT MONITORING

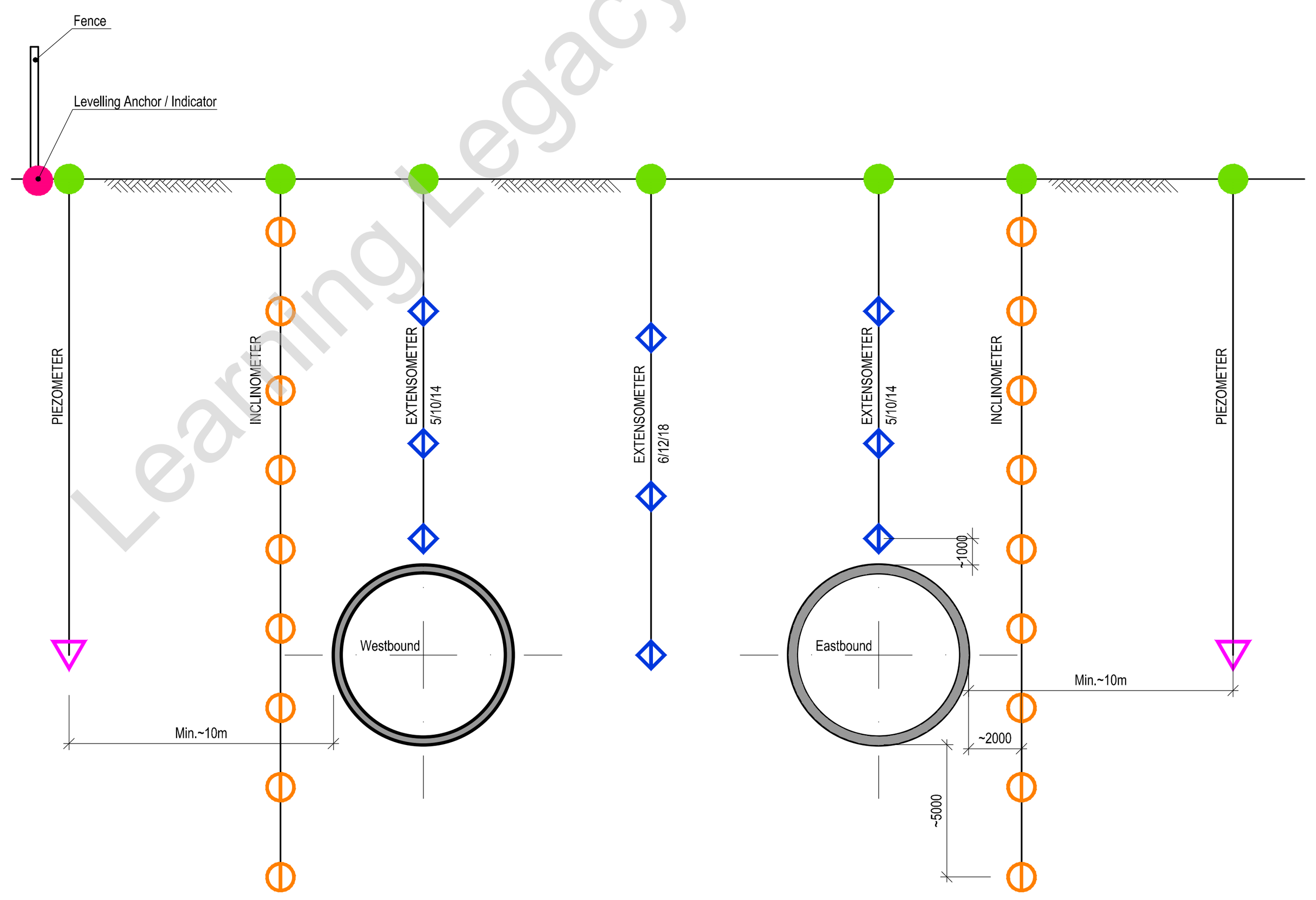
SCALE 1:1000



DETAIL 1 - MIDDLEGATE HOUSE



DETAIL 2 - THAMES WATER PUMP HOUSE AND CHAMBER SOUTHERN OUTFALL SEWER



TYPICAL GEOTECHNICAL CROSS SECTION

NTS

MONITORING DETAILS TABLE

Line No.	Symbol	Installation Type	Monitoring Method	Monitoring Details	Location	Prior to Works	during works / TBM drive nearby	Post Works	Long Term	General note to monitoring frequencies
01		C701 3D prisms and area measured from automated total stations	real time	data transfer via FTP server from C701	on Network Rail lines and siding 3, all along Plumstead Portal to east of Southern Outfall Sewer	permanent, real time	permanent, real time	permanent, real time	permanent, real time	
02		Extensometer (3 type, 5m, 10m, 14m) ending 1m above tunnel crown	manual	with digital gauge	geotechnical cross section east of Southern Outfall Sewer	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	All frequencies are to be increased / decreased according prior results and the use of indicator points. Indication for increase or decrease of monitoring frequencies are to be determined using the results from real time/ permanent monitoring, work progress, condition surveys and /or other requirements
03		Extensometer (3 type, 6m, 12m, 18m) up to depth of tunnel centreline	manual	with digital gauge	geotechnical cross section east of Southern Outfall Sewer	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	
04	SD	Shallow Datum point/ single rod extensometer	manual	with digital gauge	for monitoring of TWUL assets to invert level of the asset	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	
05		below tunnel invert, 2m outside tunnels	manual	probe, 1m steps	geotechnical cross section east of Southern Outfall Sewer	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	
06		Inclinometer, up to bottom of d-wall	manual	probe, 1m steps, backup for SAA's	in d-wall, beside SAA's at 6 locations, from top to bottom of d-wall	baseline reading after installation	daily in TBM influence area	weekly (*1)	monthly (*2)	
07		Piezometer, vibrating wire, in sufficient distance to tunnels (min. 10m)	automated, real time	via datalogger	geotechnical cross section east of Southern Outfall Sewer	prior to TBM, permanent	permanent, real time	permanent, real time	permanent, real time	
08		levelling studs	manual	precise levelling, studs welded to APB posts, 2.5m deep foundation	along at Asset Protection Barrier (APB) posts, 12m c/c, use as early indicator for displacements	baseline before start of d-wall excavation and piling	daily in work zones	weekly (*1)	monthly (*2)	
09		levelling anchors	manual	precise levelling	at sections in loose material	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	
10		levelling studs / bolts	manual	precise levelling	at hard standing surfaces, roads, pavements	baseline reading before arrival of TBM	daily in TBM influence area	weekly (*1)	monthly (*2)	
11		levelling studs / bolts / sockets	manual	precise levelling	at structures and buildings	baseline readings before arrival of TBM and before start of other works	daily in TBM influence area	weekly (*1)	monthly (*2)	
12		Tiltmeters	real time	dual axis tilt measurements	at structures and buildings, at main bearings	baseline readings before start of portal bulk excavation / TBM drive	permanent, real time	permanent, real time	permanent, real time	
13		hydrostatic pressure water cells	real time	0.1mm accuracy, fast reaction real time system	at structures and buildings, at main bearings and important corners	baseline readings before start of portal bulk excavation / TBM drive	permanent, real time	permanent, real time	permanent, real time	
14		3D prisms	manual	manual with automated total station from control points	at top of d-wall and piles at Plumstead portal, next to inclinometer and/or SAA's	baseline readings when d-wall / piling is finished	weekly (*1)	weekly (*1)	monthly (*2)	
15		Shape Accelerator Arrays (SAA)	real time	3D displacements 0.5m steps	built in d-walls and piles, from top to bottom of portal walls	baseline readings when d-wall / piling is finished	permanent, real time	permanent, real time	permanent, real time	
16		track trolley runs	manual, integrated storage for measurement and immediate valuation	cross levels and twist levels in 1m c/c, backup to C701 prism values	along Network Rail track(s) and siding(s)	baseline readings prior to work	weekly with start of bulk excavation - or acc. stand. proced.(*2)	weekly (*1) / monthly (*2)	monthly (*2)	

(*1) - Until no significant movement detected

(*2) - Determination if required with PFE on site

	***Crossrail* Review and Acceptance Decal** This decal is to be used for submitted documents requiring acceptance by *Crossrail*.	
☐	Code 1. Accepted. Work May Proceed	
☐	Code 2. Not Accepted. Revise and resubmit. Work may proceed subject to incorporation of changes indicated	
☐	Code 3. Not Accepted. Revise and resubmit. Work may ☐ot proceed	
☐	Code 4. Received for information only. Receipt is confirmed	
Reviewed/Accepted by:(signature)		
Print Name		
Position:		Date:

Acceptance by *Crossrail* does not relieve the designer/supplier from full compliance with their contractual obligations and does not constitute *Crossrail* approval of design, details, calculations, analyses, test methods or materials developed or selected by the designer/supplier

NOTES:

- Locations shown are generally for information only, final locations are subject to agreement acc. local conditions. Spacing of studs in arrays are 2.5m./5.0m., adopted to local conditions.
- Frequencies shown in table are basically. Actual frequencies are to be determined acc. work progress and indicator values.
- Specific requirements to readings, depths, and others are to be agreed according work progress.
- real time 3D ATS/prism monitoring of rail tracks is acc. C701 (see Legend and Detail table, line 1)

Rev.	Date	Description	By	Chkd	App	Auth
7.0	08.02.2013	Revised According To RFI 693	CMK	CER	DSG	ARE
6.0	08.02.2013	Comments Incorporated According To RFI 667 And PMI 218	CMK	CER	DSG	ARE
5.0	16.01.2013	Comments Incorporated According TWUL meeting minutes from the 11/12/2012	CMK	CER	DSG	ARE
4.0	08.08.2012	Crossrail Comments Incorporated According meeting minutes from the 31/07/2012	CCS	CER	DSG	ARE
3.0	10.07.2012	Crossrail Comments Incorporated According with RFI 319 and 352	CCS	CER	DSG	ARE
2.0	31.05.2012	Thames Water Comments Incorporated	CCS	CER	DSG	ARE
1.0	11.05.2012	For Approval	CCS	CER	DSG	ARE

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Originator : HOCHTIEF MURPHY Joint Venture

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White Hart Avenue Business Park, Off A2016
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Contract : C310 - Thames Tunnel Construction (Plumstead to North Woolwich)

Location : Southern Outfall Sewer to Middlegate House

Title : Monitoring Details
Southern Outfall Sewer, Thames Water Pump House and Chamber
Southern Outfall Sewer, Pettman Crescent Bridges, Bus Garage,
Middlegate House and DLR Tunnels.

By : CCS
Chk : CER
App : DSG
Auth : ARE

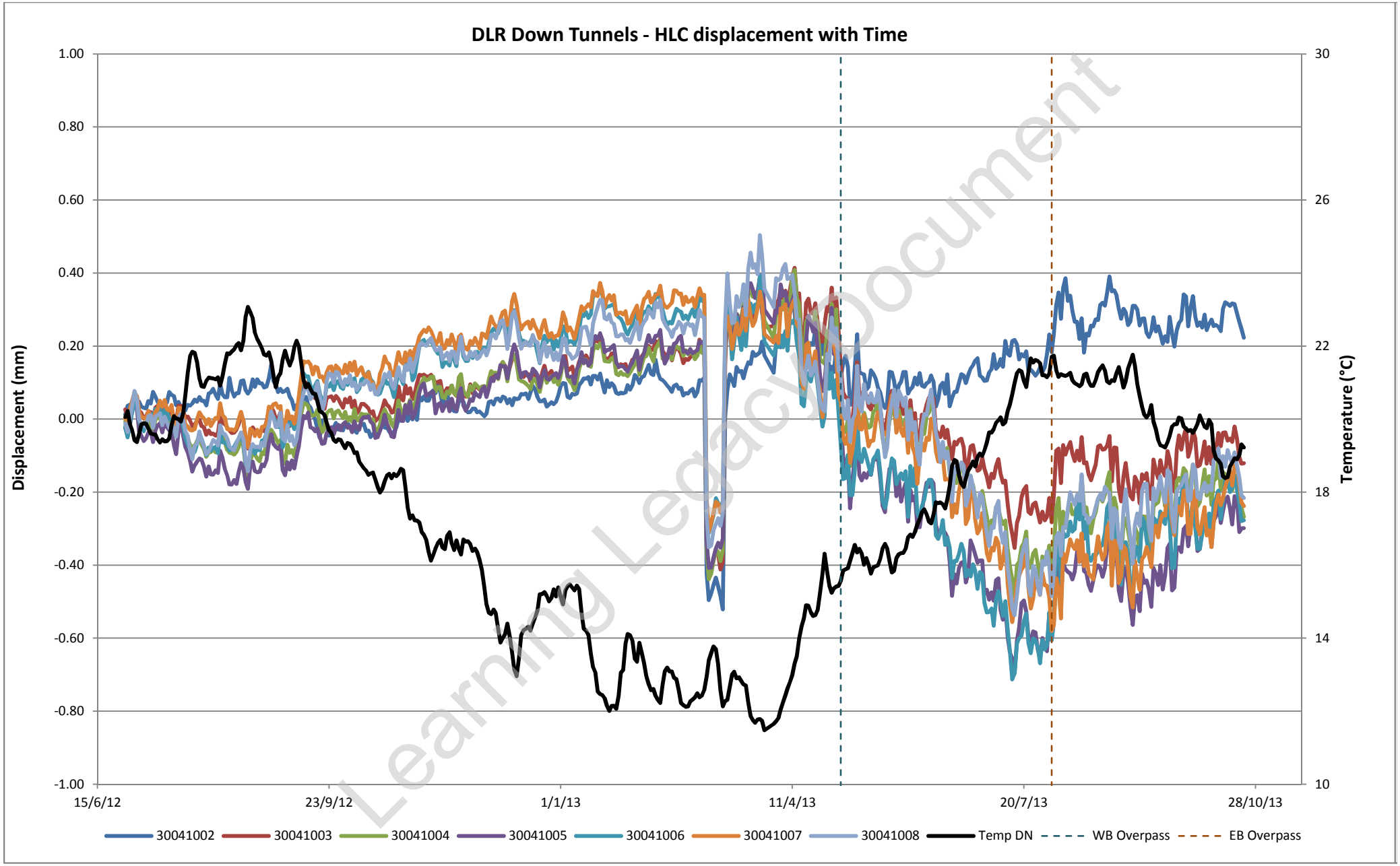
Scale : VARIOUS @ A1

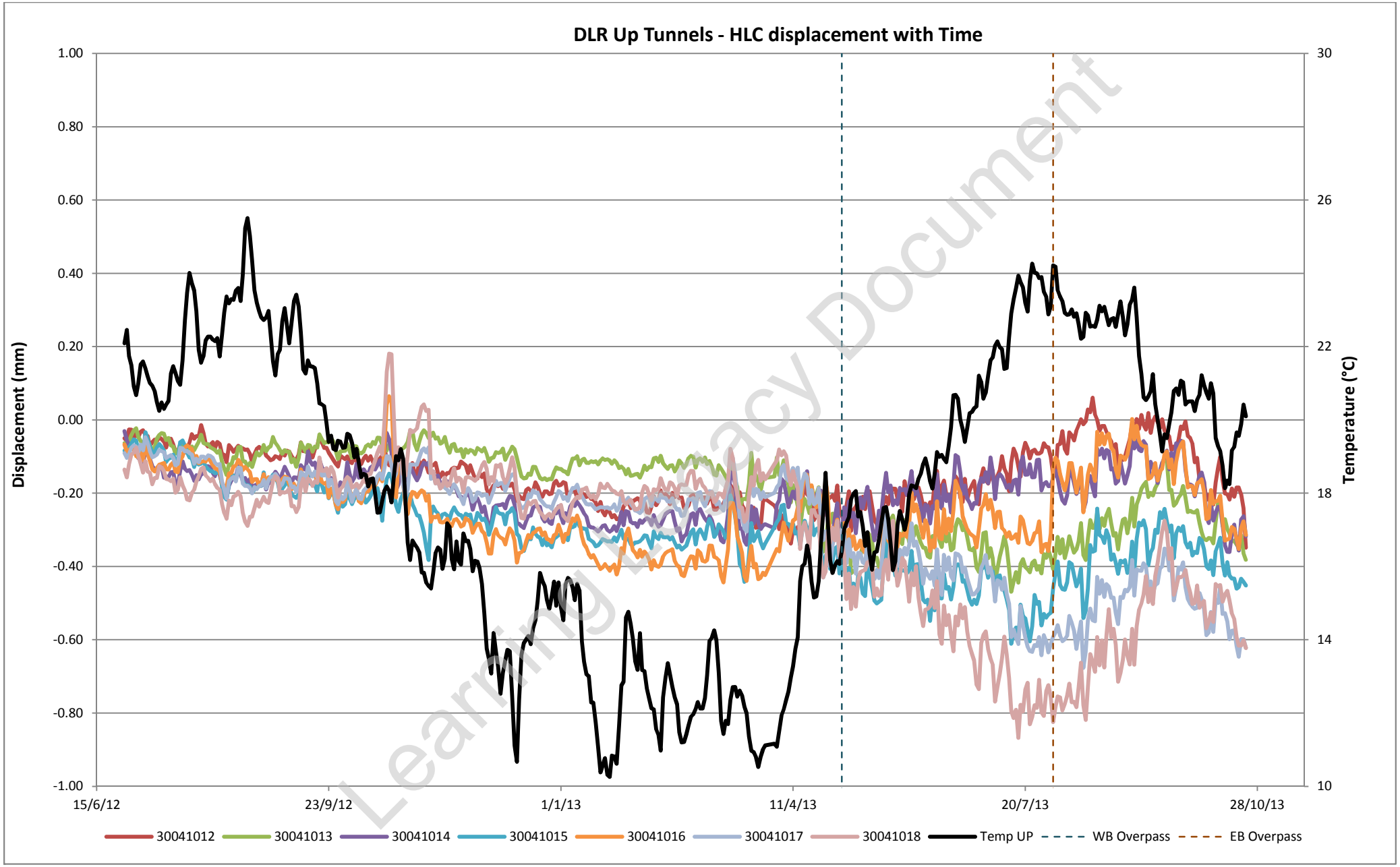
Drawing and CAD file No : C310-HTM-C-DWG-CR146-ST004-70001

Rev : 7.0

Suitability :

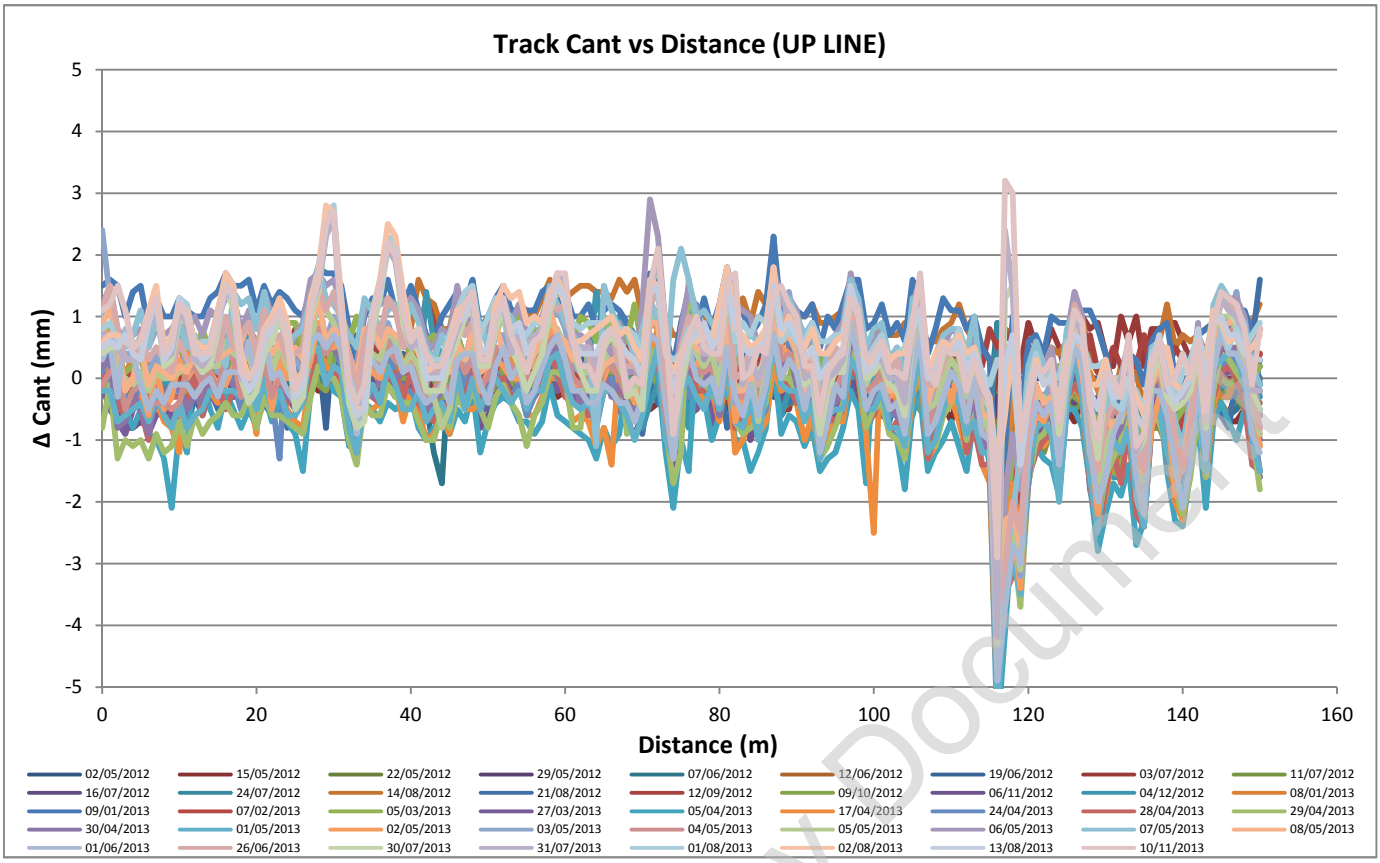
Appendix B Monitoring Results – Hydrostatic Levelling Cells

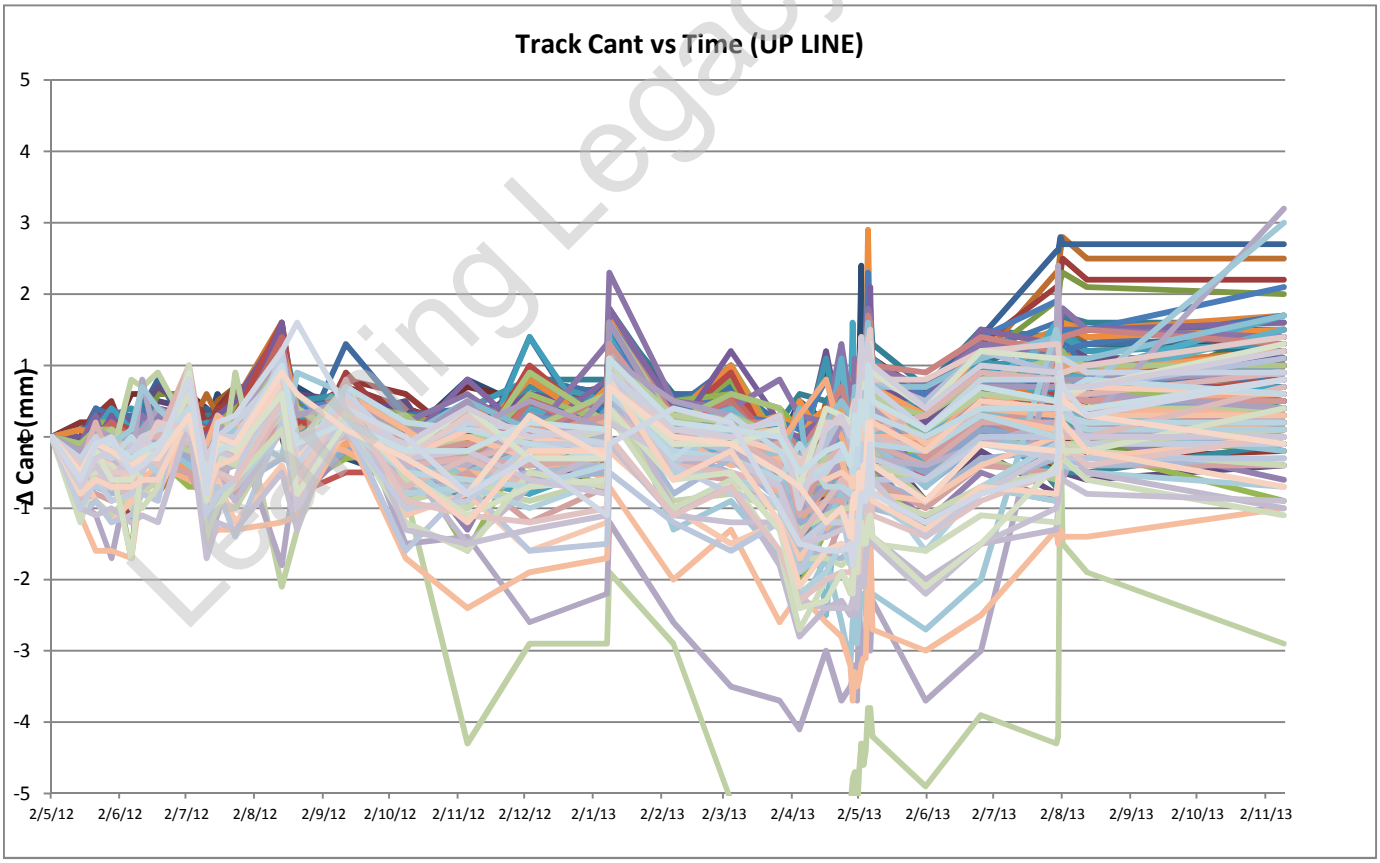




Appendix C Monitoring Results – Track Monitoring

DLR LINE: UP



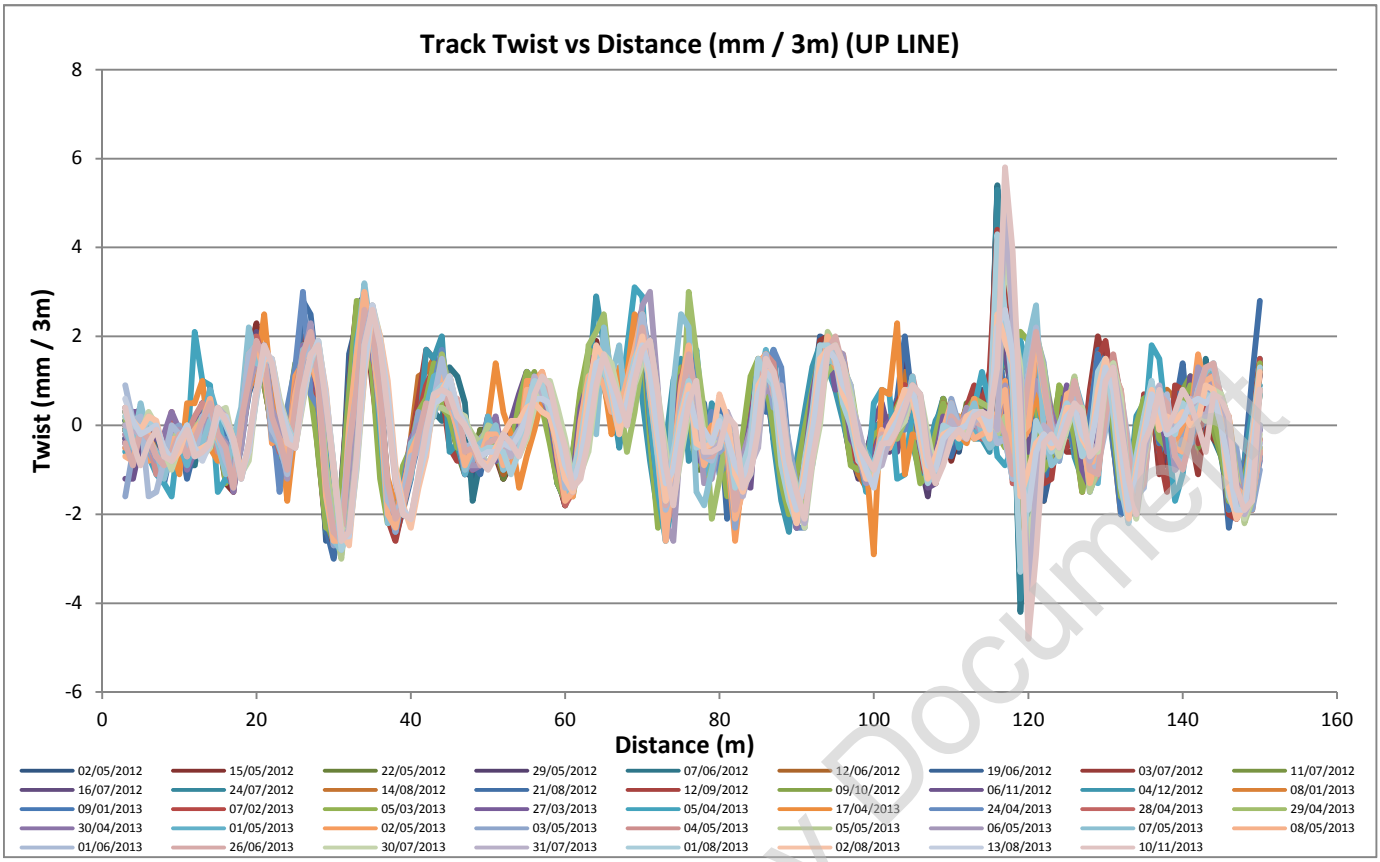


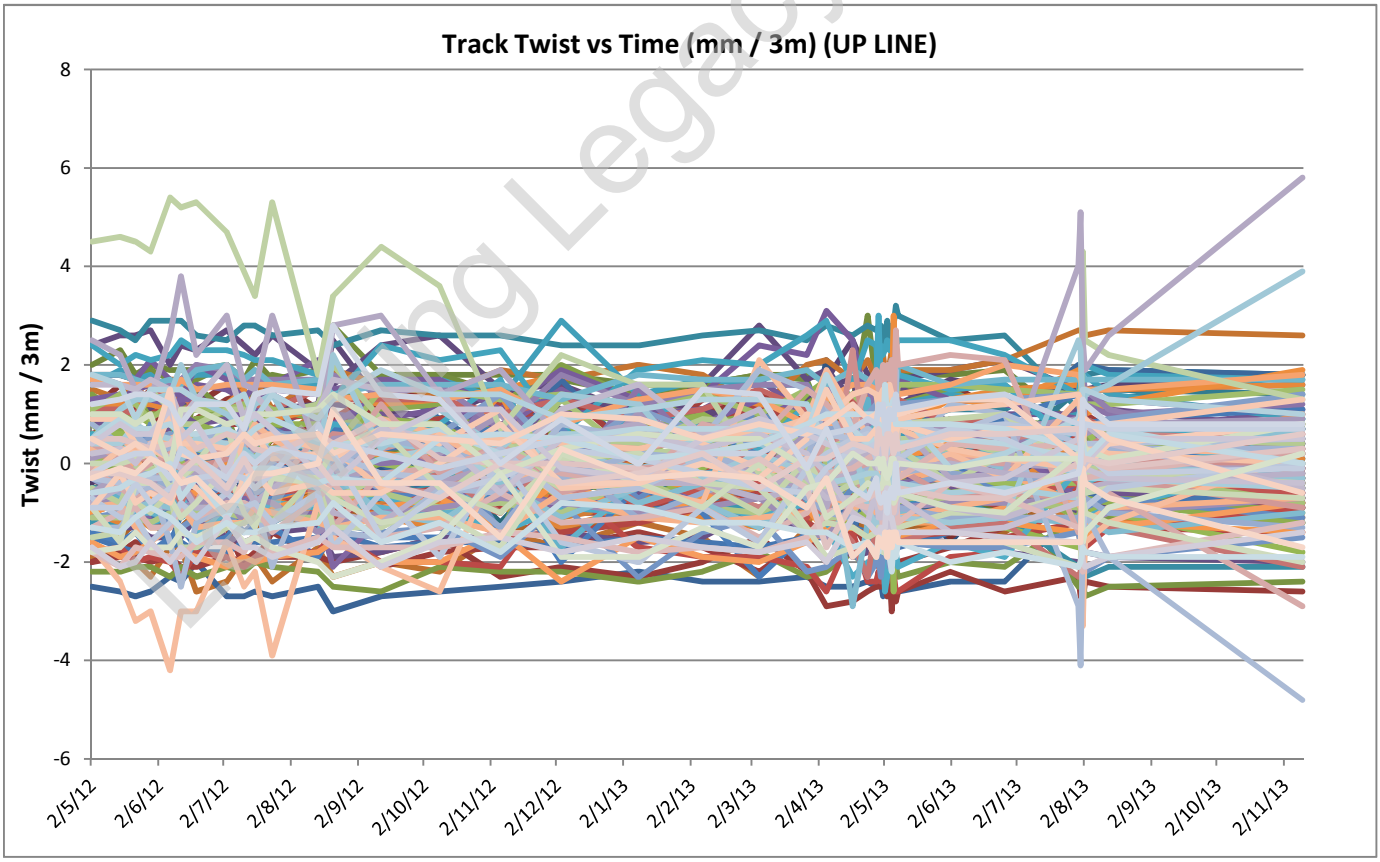
*Graphs indicate change in cant from baseline taken on 02/05/2012. It is assumed that the DLR tracks were constructed as designed and that there are no existing track faults.

*Trigger levels are as that indicated in DLR I&M Plan (Doc Ref. C122-OVE-C2-RGN-CR140-50004)

CANT TRIGGER LEVELS		
	Green	± 8mm
	Amber	± 12mm
	Red	± 15mm

DLR LINE: UP



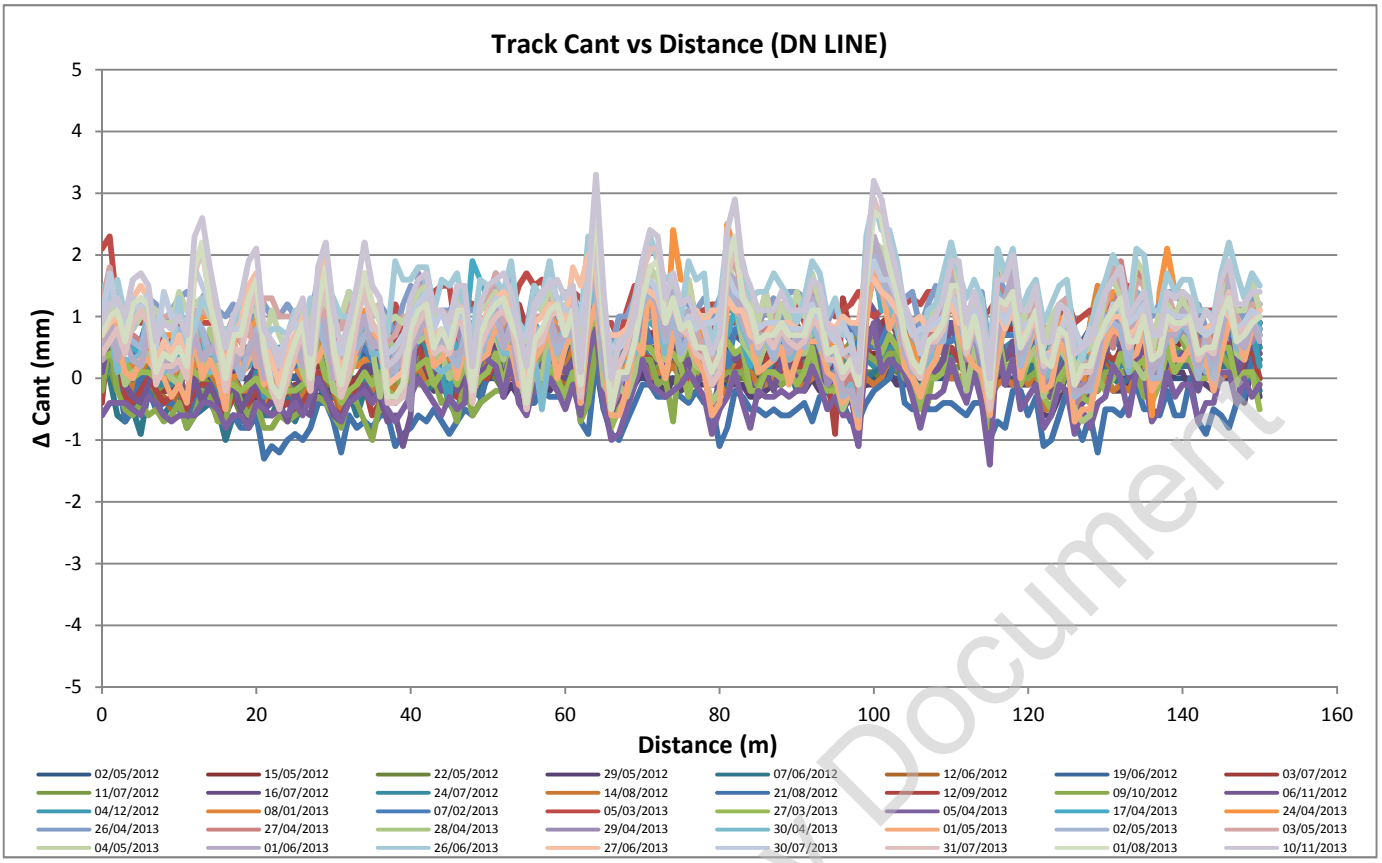


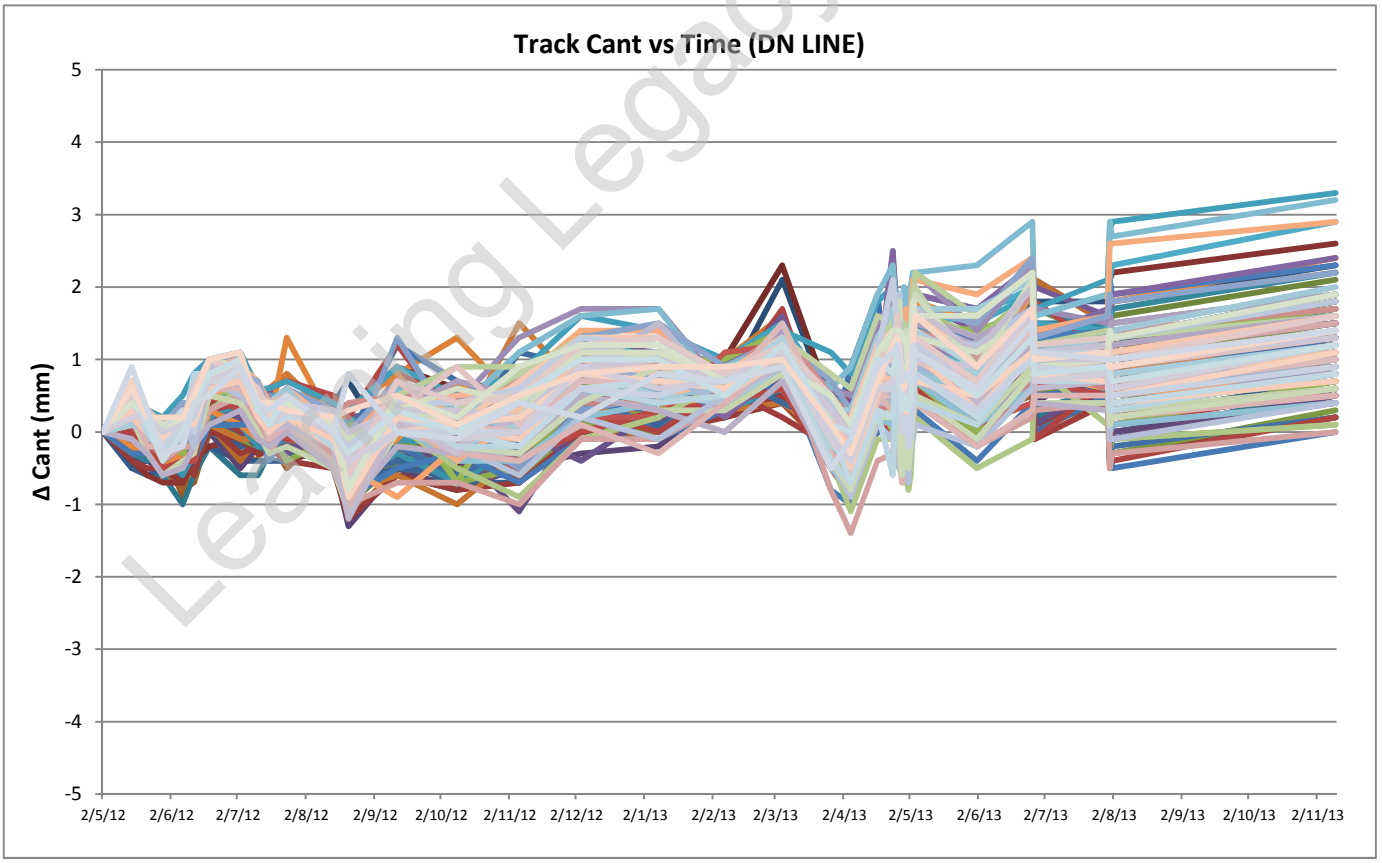
*Graphs indicate change in twist from baseline taken on 02/05/2012.

*Trigger levels are as that indicated in DLR I&M Plan (Doc Ref. C122-OVE-C2-RGN-CR140-50004)

CANT TRIGGER LEVELS			
	Green	1:399 - 1:300	7.5 - 10 (mm / 3m)
	Amber	1:299 - 1:201	10 - 14.9 (mm/ 3m)
	Red	1:200 - 1:134	15 - 22.4 (mm/3m)

DLR LINE: DN



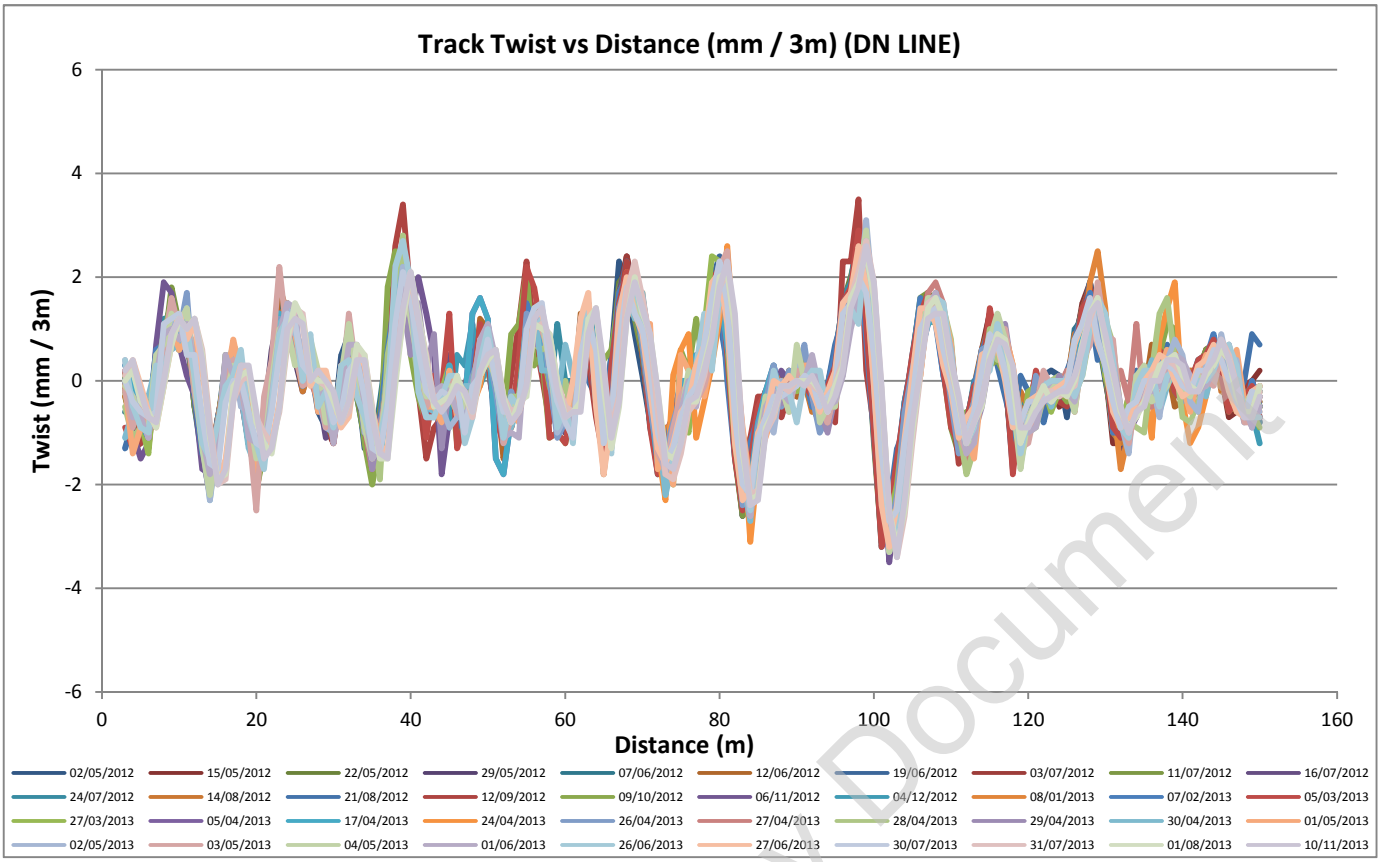


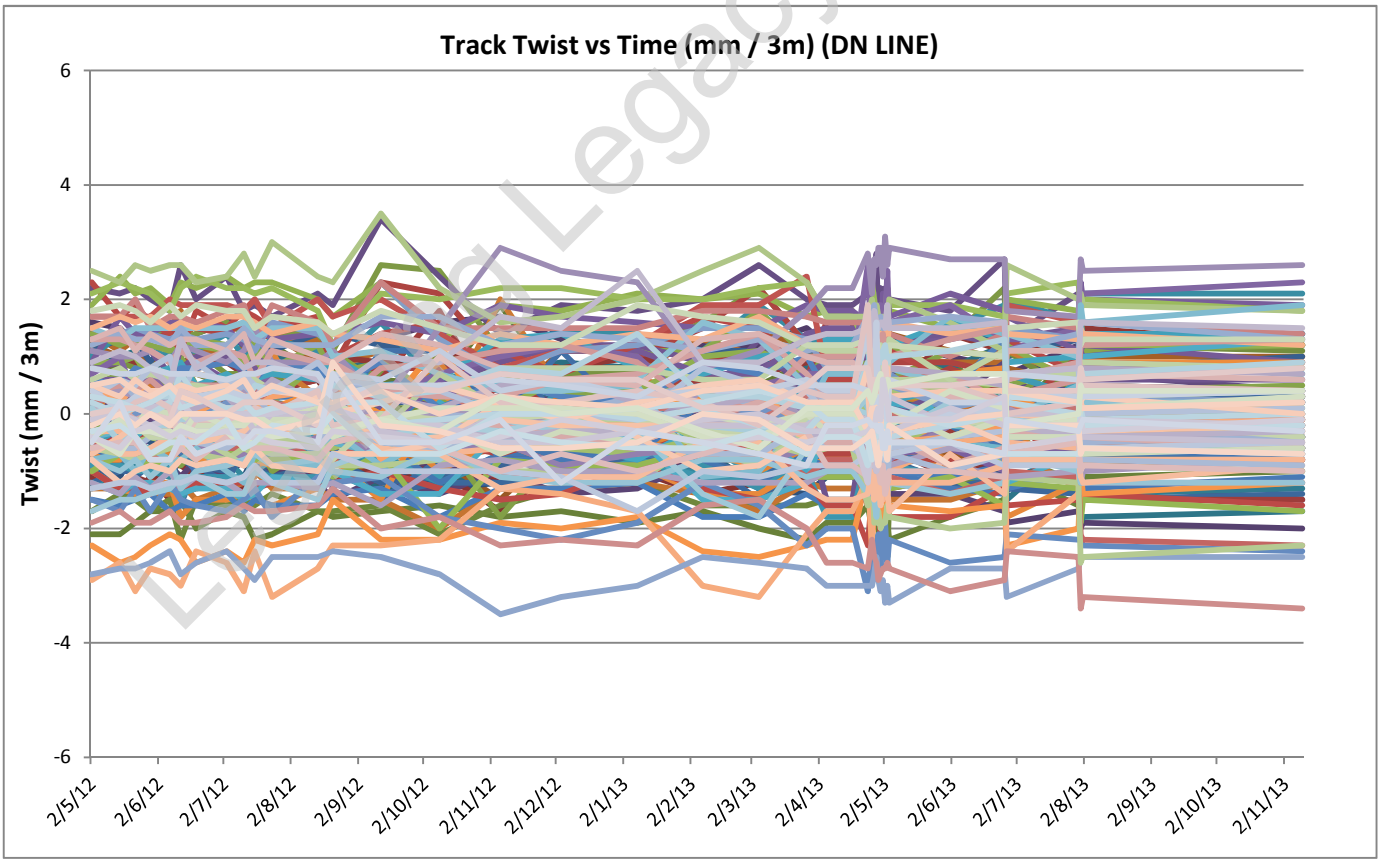
*Graphs indicate change in cant from baseline taken on 02/05/2012. It is assumed that the DLR tracks were constructed as designed and that there are no existing track faults.

*Trigger levels are as that indicated in DLR I&M Plan (Doc Ref. C122-OVE-C2-RGN-CR140-50004)

CANT TRIGGER LEVELS		
	Green	± 8mm
	Amber	± 12mm
	Red	± 15mm

DLR LINE: DN





*Graphs indicate change in twist from baseline taken on 02/05/2012.

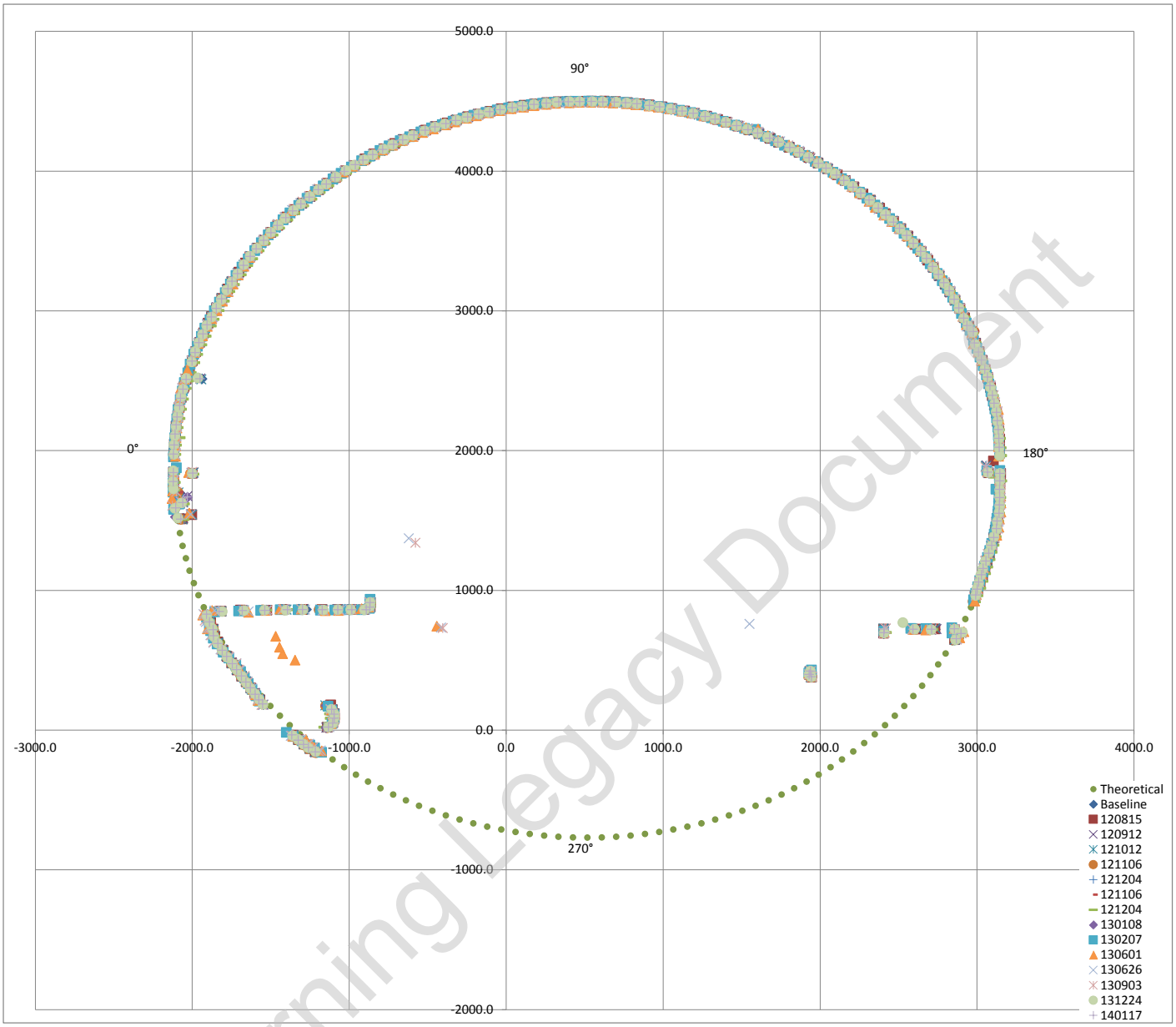
*Trigger levels are as that indicated in DLR I&M Plan (Doc Ref. C122-OVE-C2-RGN-CR140-50004)

CANT TRIGGER LEVELS			
	Green	1:399 - 1:300	7.5 - 10 (mm / 3m)
	Amber	1:299 - 1:201	10 - 14.9 (mm/ 3m)
	Red	1:200 - 1:134	15 - 22.4 (mm/3m)

Appendix D Monitoring Results – Laser Scanning (HLC Locations)

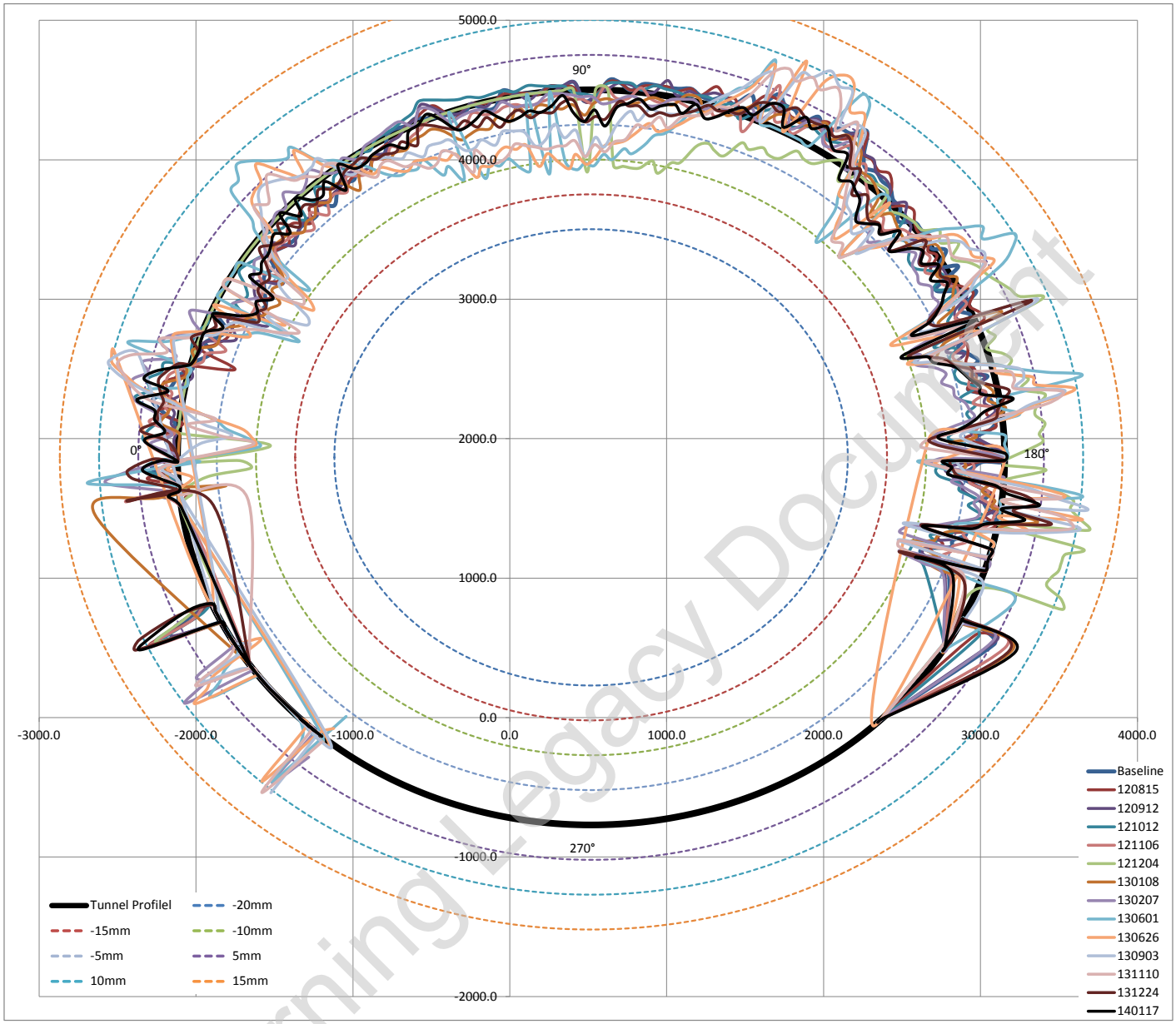
DLR LINE: DN **SECTION: 1001**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1001**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5271.61	mm
Estimated best fit as built diameter	**5272.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00747%	

i.e. Average surveyed diameter varies on -0.007% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

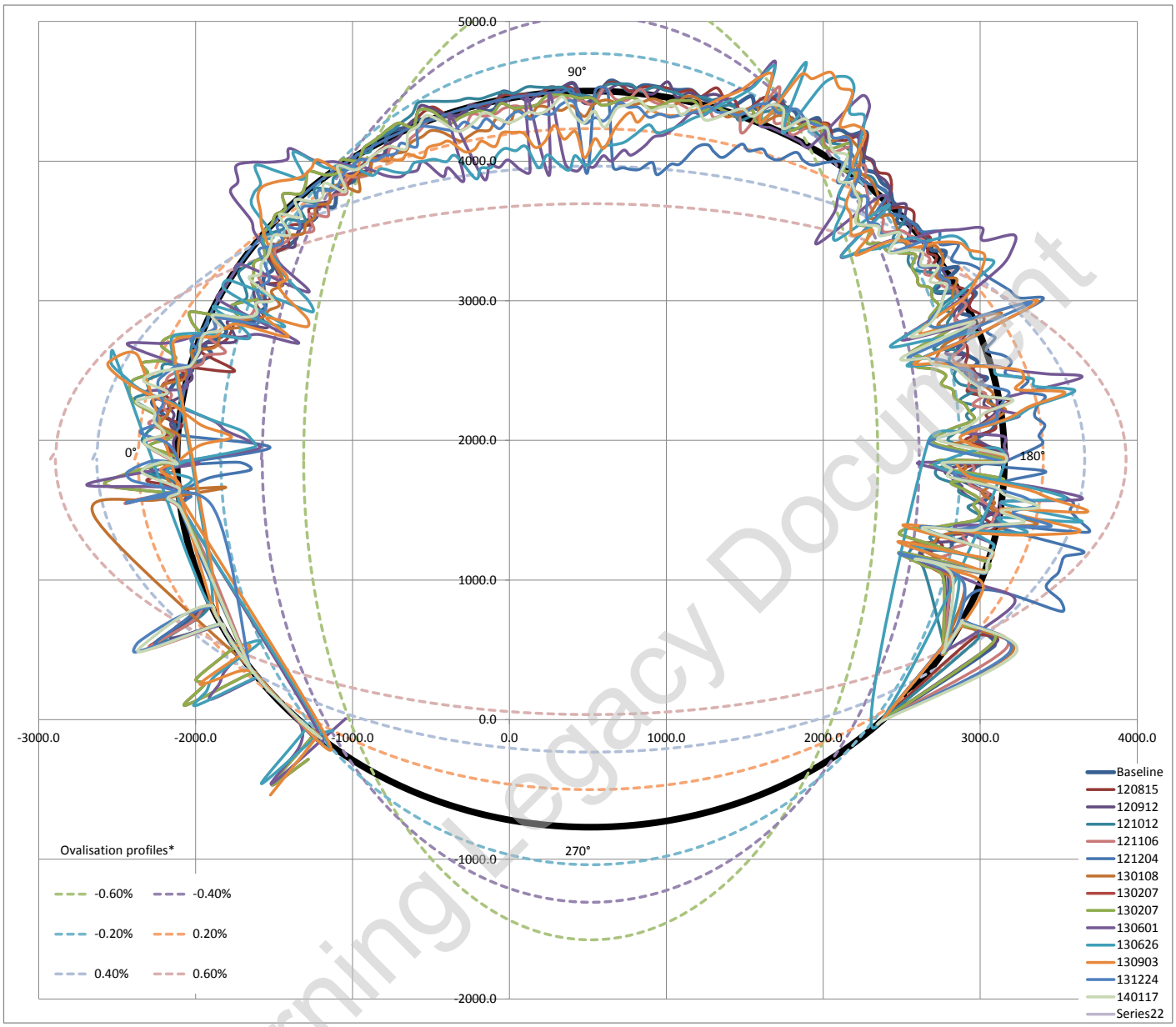
Axis	X	518
	Y	1866
Radius		2636

Max radial difference (+ve) / (-ve) (mm)	**10.2**	**-10.2**
Max / Min deviation % to estimated dia	**0.39%**	**-0.39%**

Estimated best fit as built diameter	5272	mm
Designed diameter	5300	mm
Average diameter difference	**-28**	mm
Average radial difference	**-14**	mm
Average difference%	**-0.53%**	

DLR LINE: **DN** **SECTION:** **1001**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

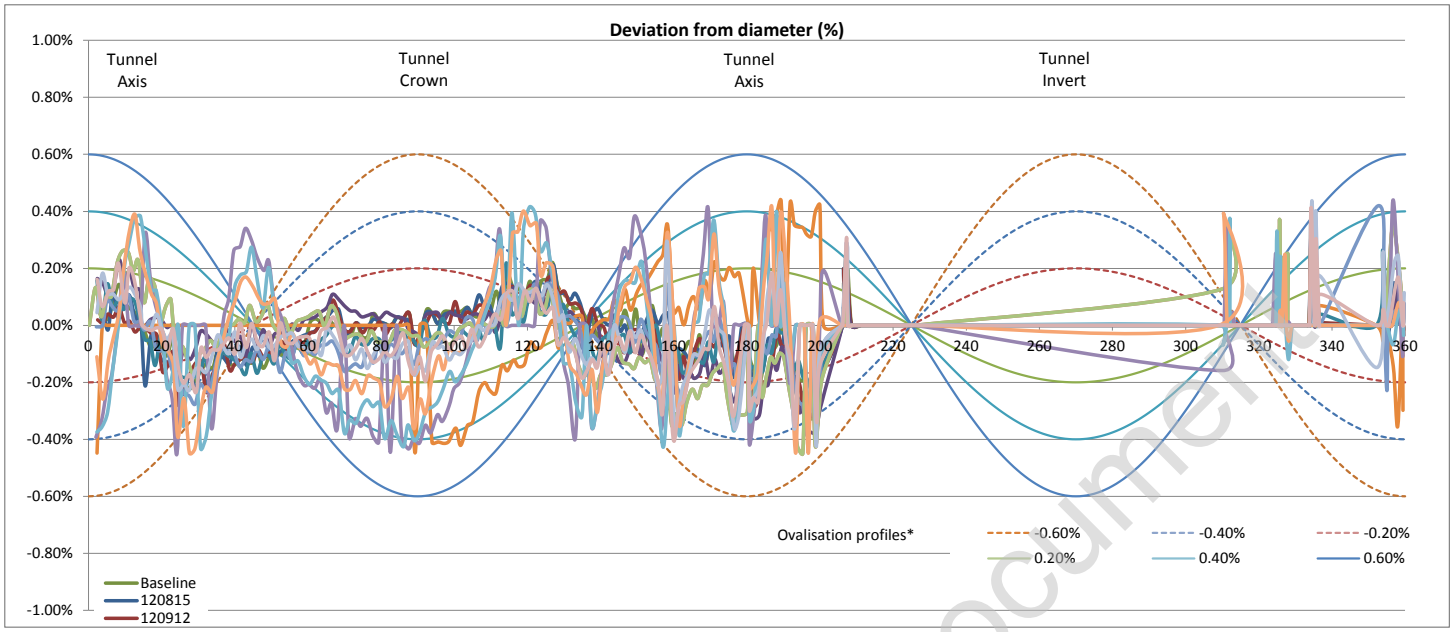
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5269.19	mm
Estimate of vertical diameter at crown, Dv	5273.46	mm
Dh / Dv	0.9992	

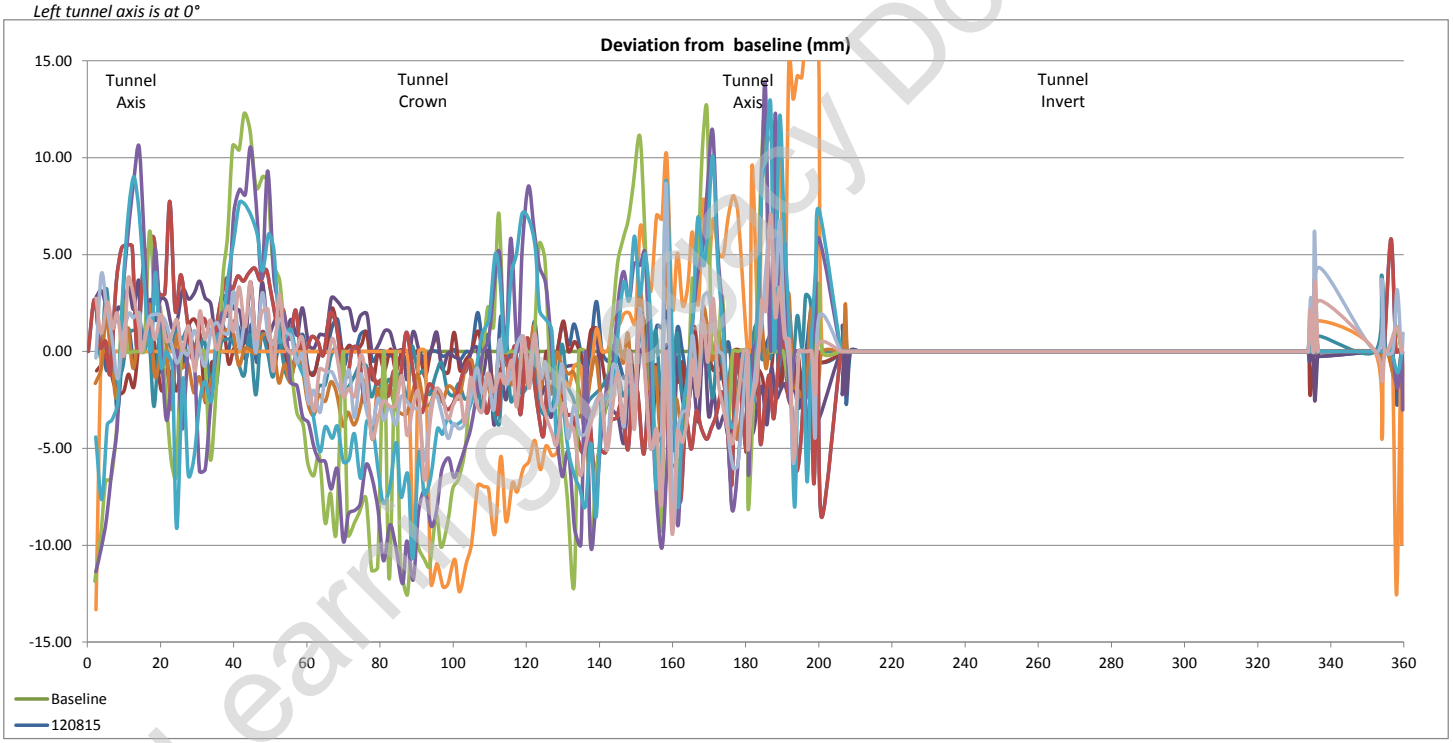
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1001**

Deviation vs Profile

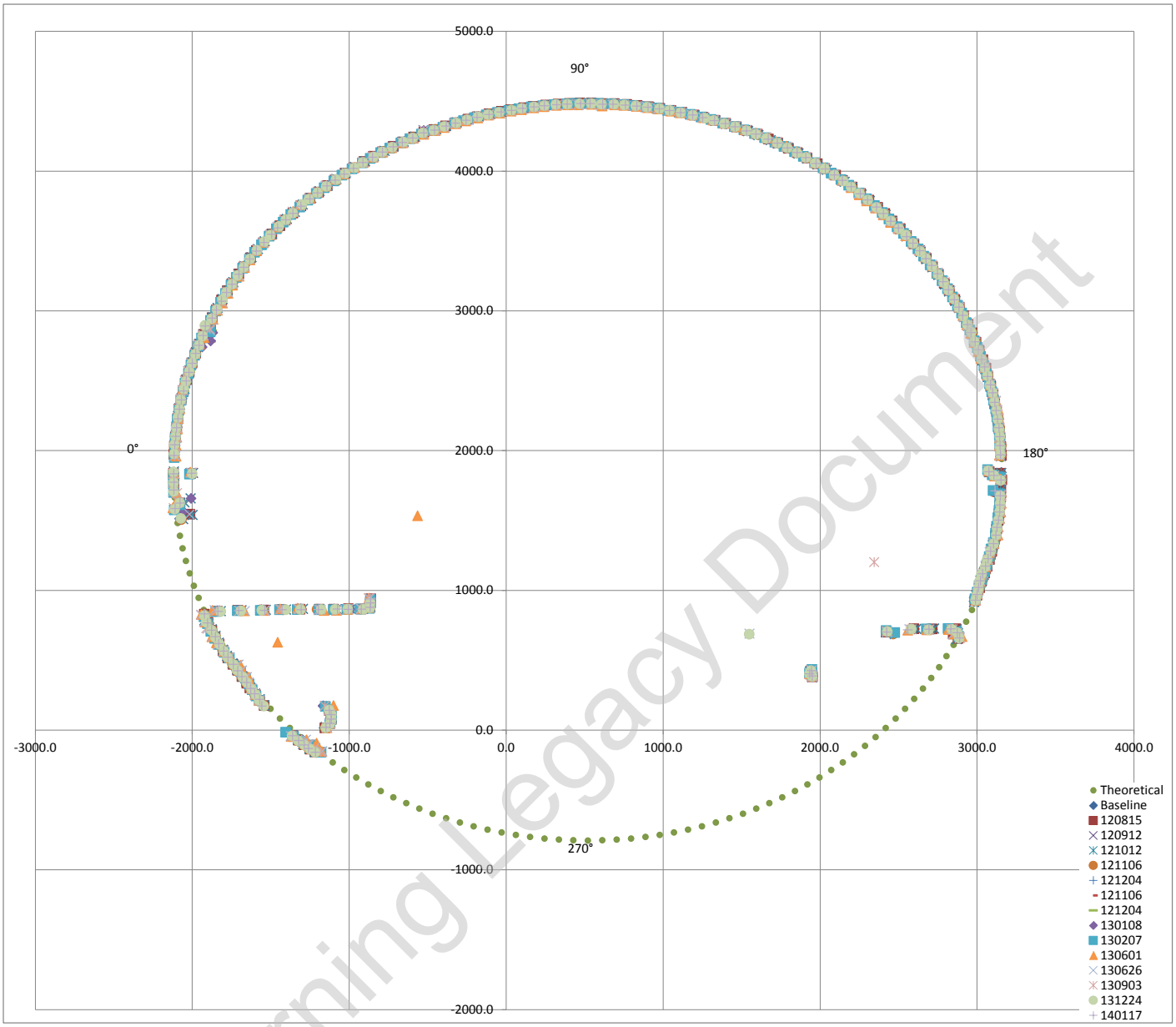


Left tunnel axis is at 0°



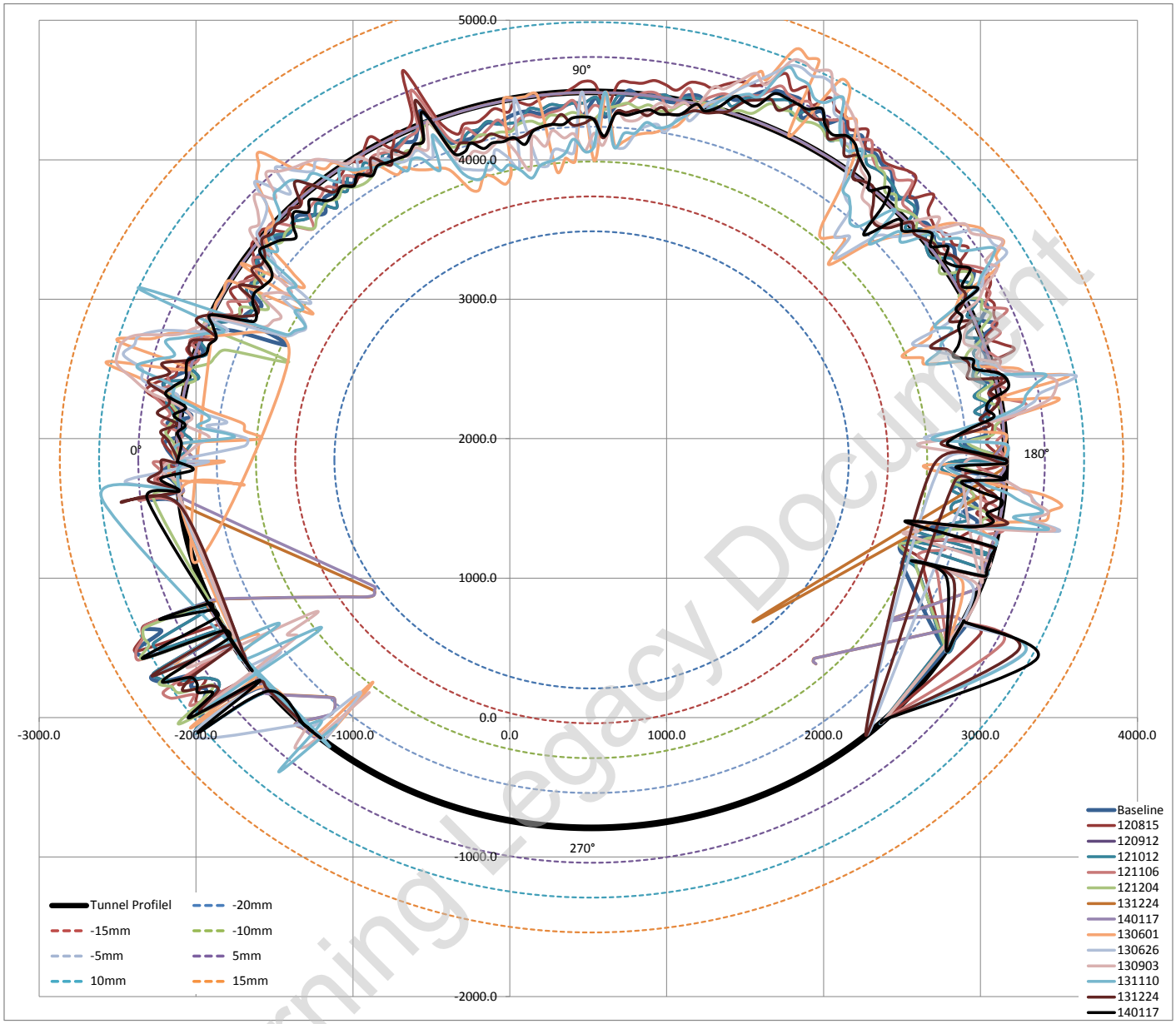
DLR LINE: DN **SECTION: 1002**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1002**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5277.84	mm
Estimated best fit as built diameter	**5278.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00303%	

i.e. Average surveyed diameter varies on -0.003% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

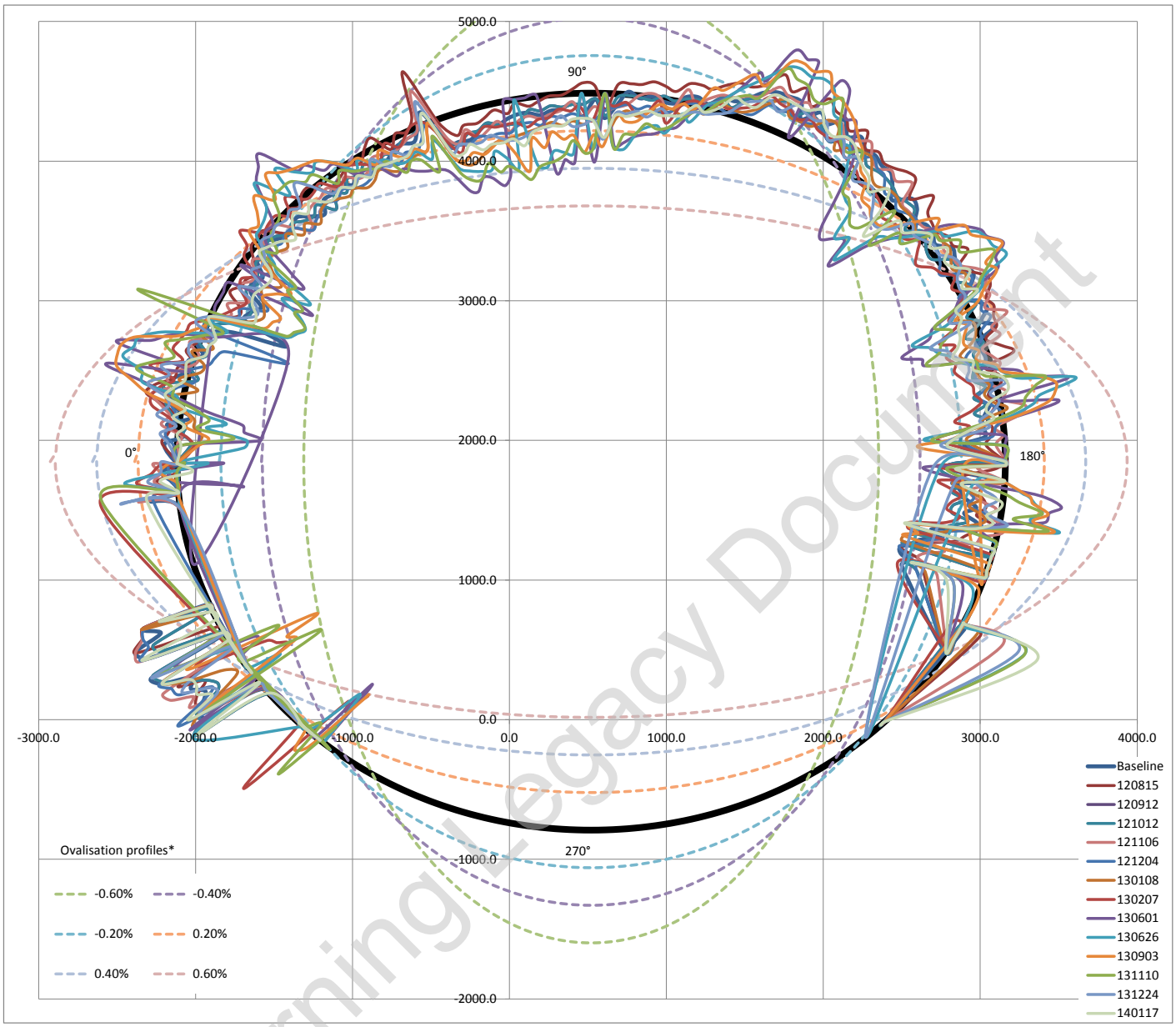
Axis	X	521
	Y	1848
Radius		2639

Max radial difference (+ve) / (-ve) (mm)	**11.2**	**-11.4**
Max / Min deviation % to estimated dia	**0.42%**	**-0.43%**

Estimated best fit as built diameter	5278	mm
Designed diameter	5300	mm
Average diameter difference	**-22**	mm
Average radial difference	**-11**	mm
Average difference%	**-0.42%**	

DLR LINE: **DN** **SECTION:** **1002**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

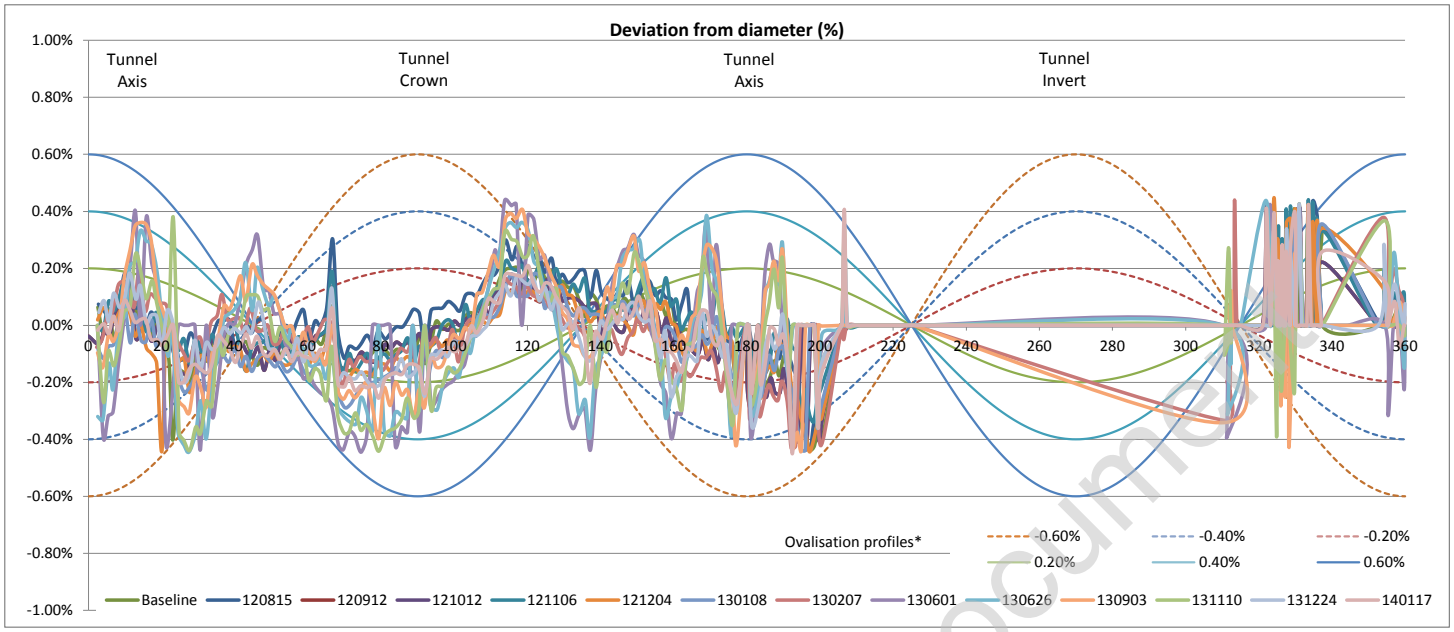
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5272.37	mm
Estimate of vertical diameter at crown, Dv	5274.47	mm
Dh / Dv	0.9996	

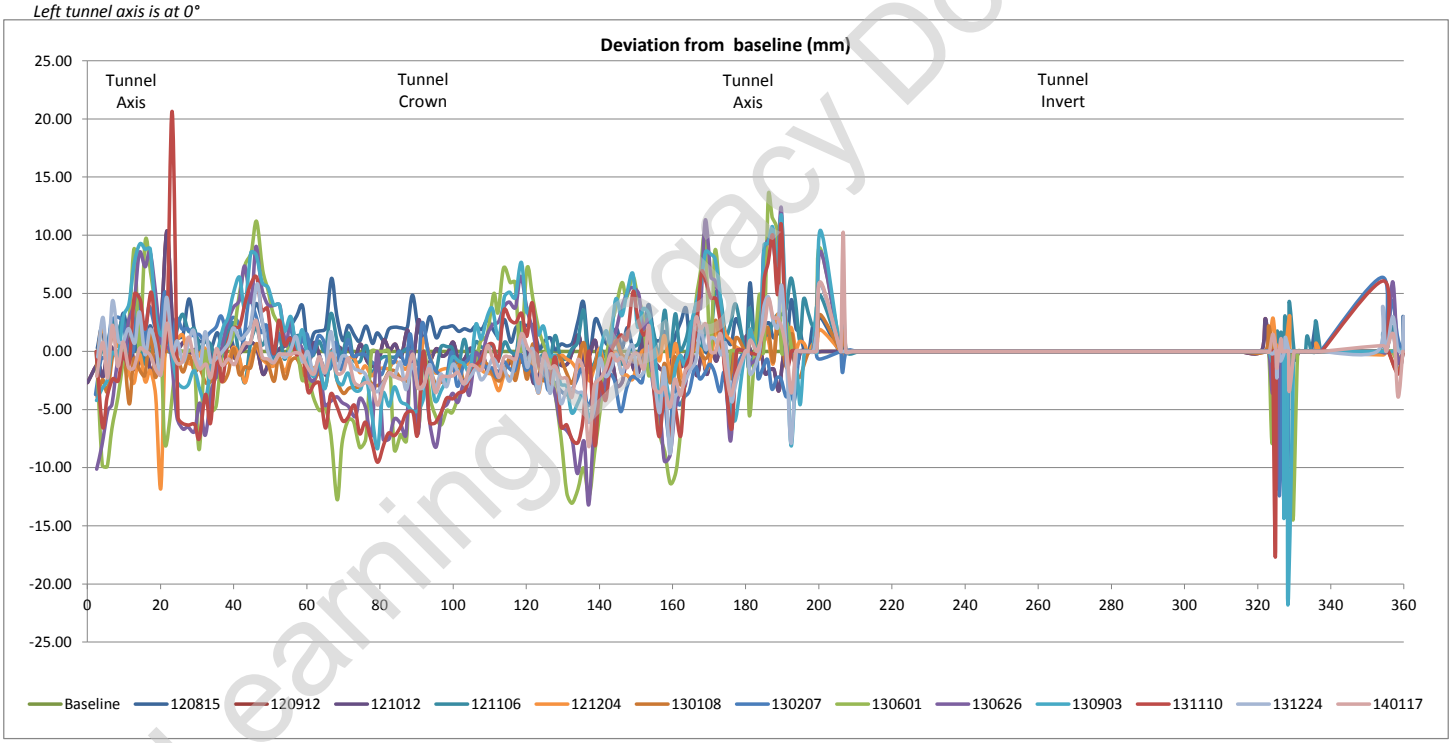
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1002**

Deviation vs Profile

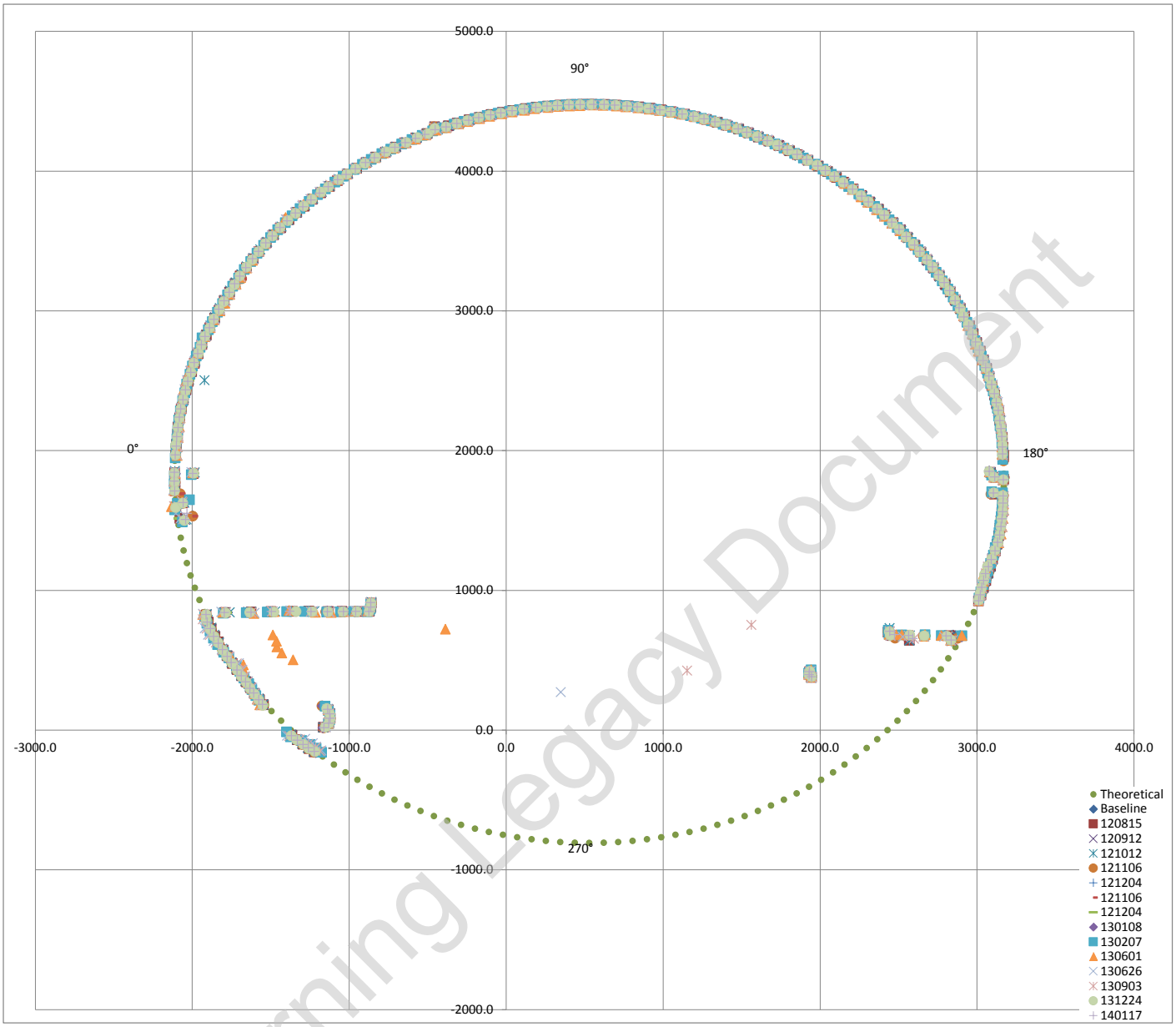


Left tunnel axis is at 0°



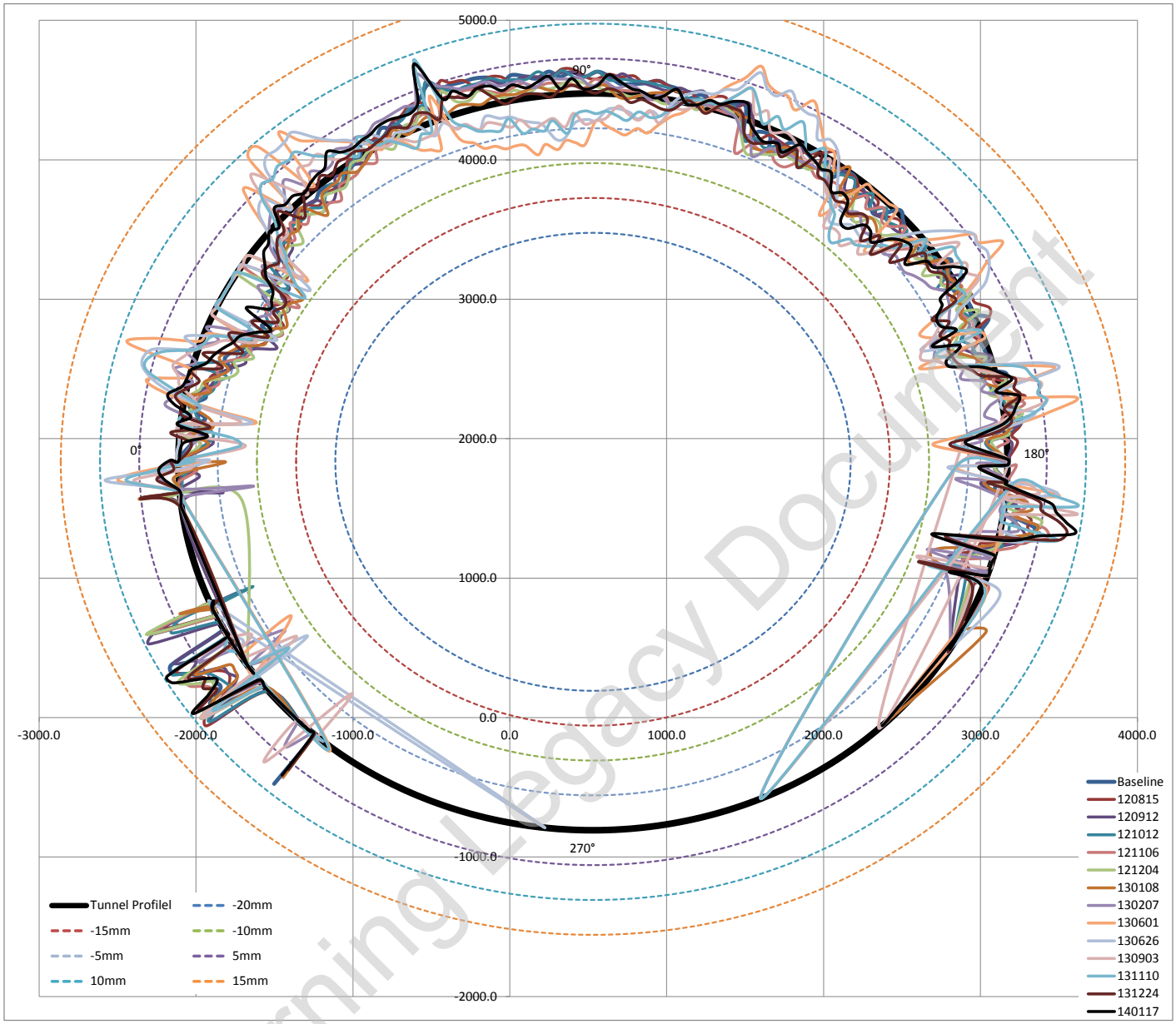
DLR LINE: DN **SECTION: 1003**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1003**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5282.92 mm
Estimated best fit as built diameter	**5284.00 mm**
Difference between average surveyed diameter and best fit diameter	-0.02052%

i.e. Average surveyed diameter varies on -0.02% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

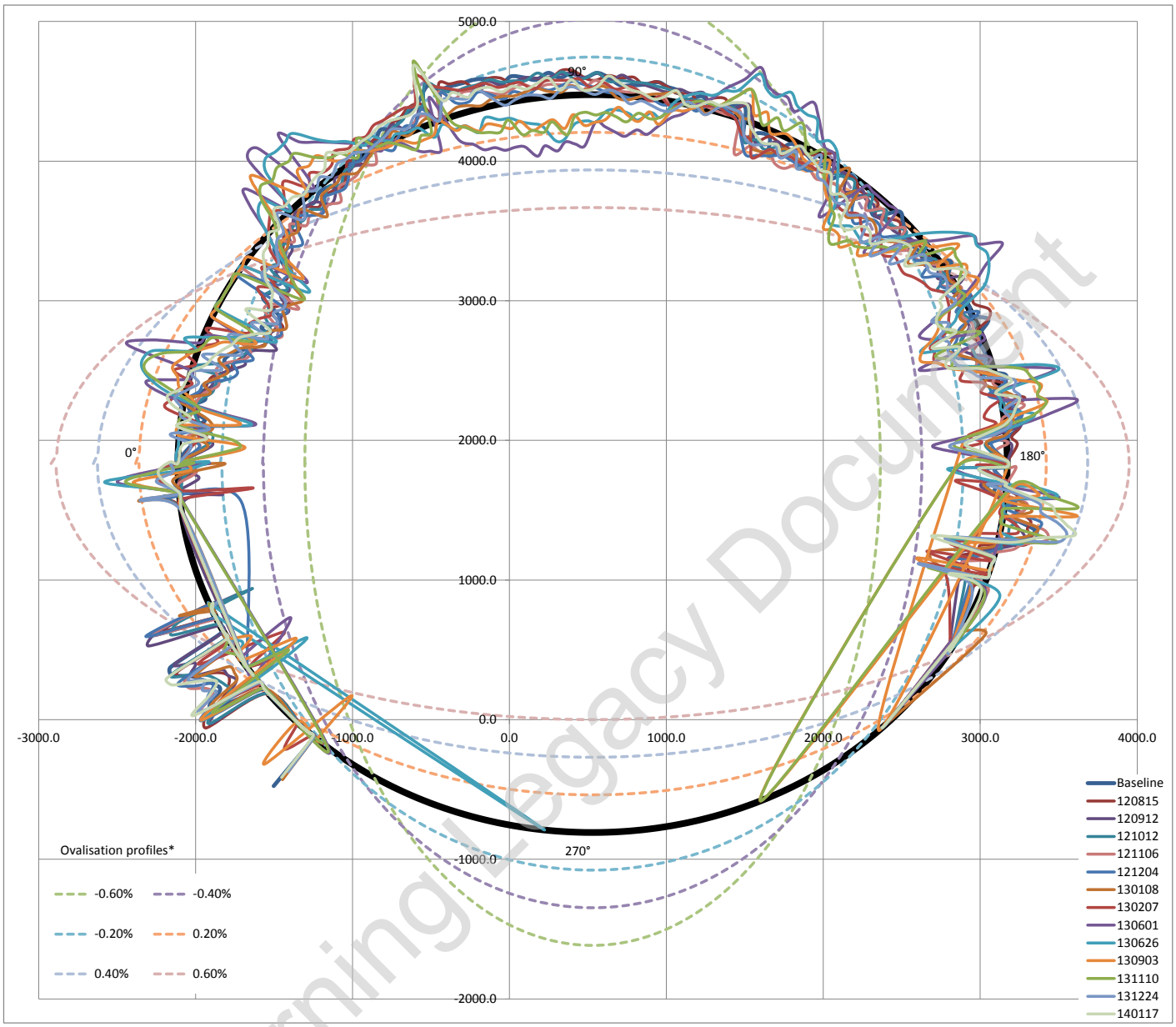
Axis	X	530
	Y	1834
Radius		2642

Max radial difference (+ve) / (-ve) (mm)	**8.9**	**-8.9**
Max / Min deviation % to estimated dia	**0.34%**	**-0.34%**

Estimated best fit as built diameter	5284 mm
Designed diameter	5300 mm
Average diameter difference	**-16** mm
Average radial difference	**-8** mm
Average difference%	**-0.30%**

DLR LINE: **DN** **SECTION:** **1003**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

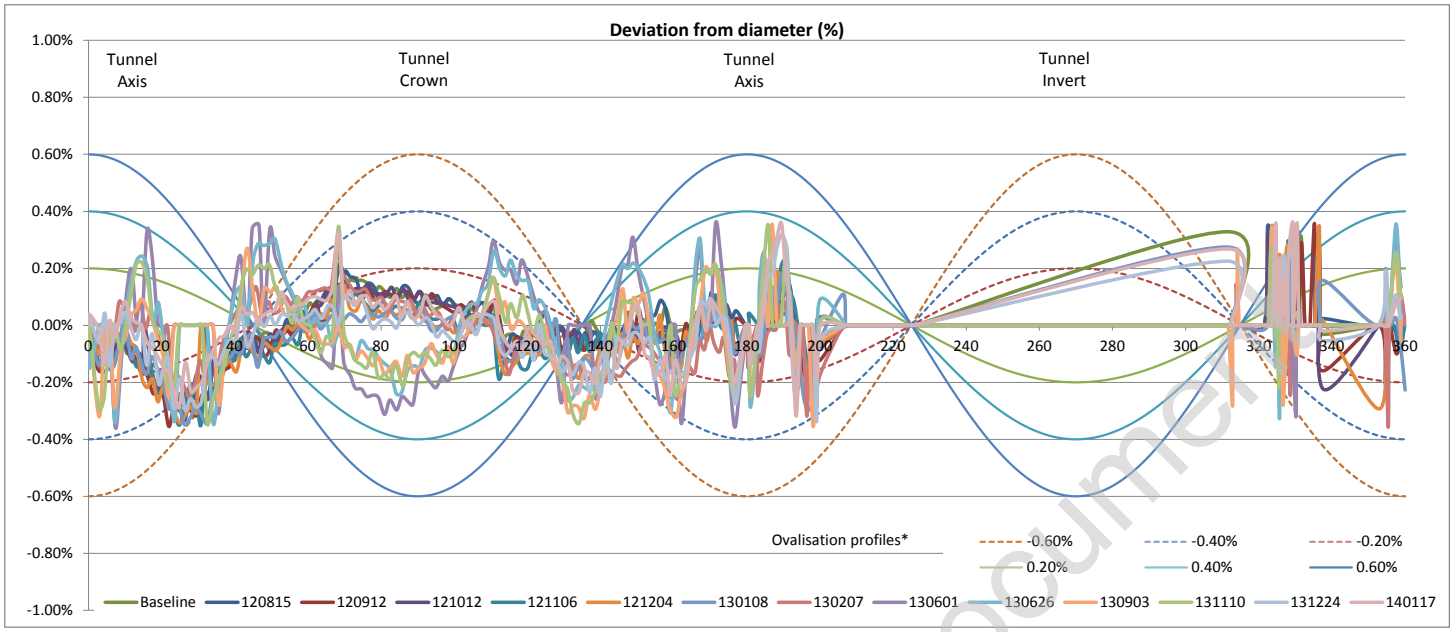
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5279.37 mm
Estimate of vertical diameter at crown, Dv	5287.12 mm
Dh / Dv	0.9985

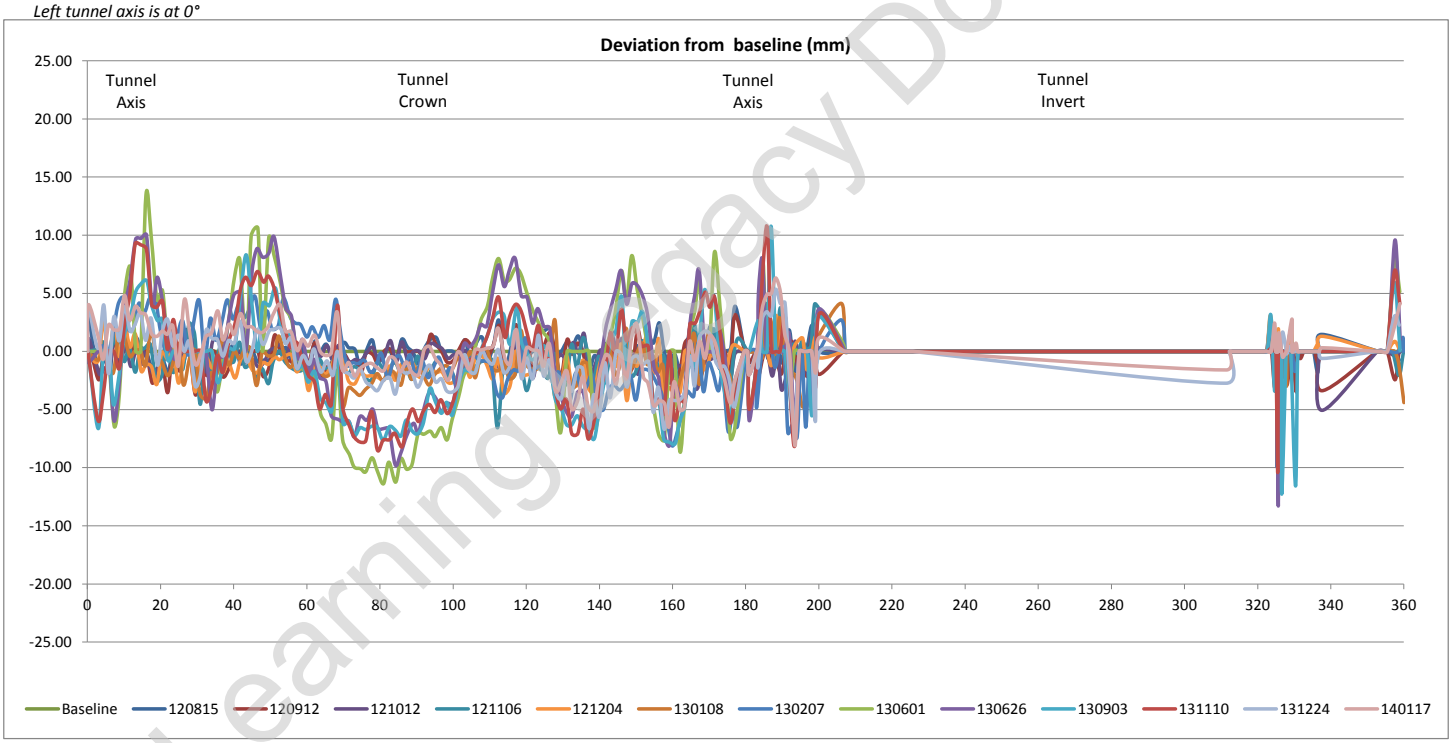
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1003**

Deviation vs Profile

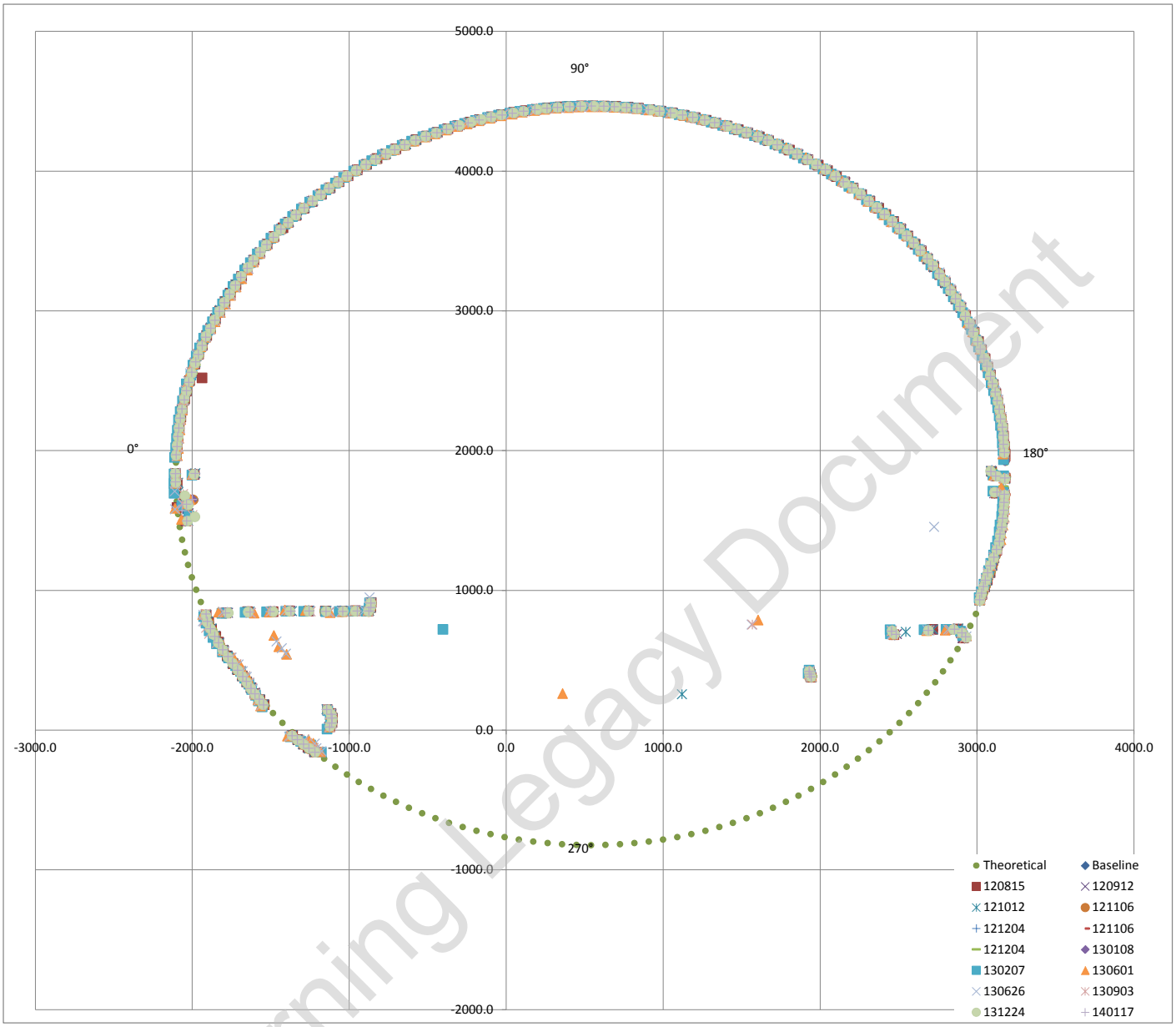


Left tunnel axis is at 0°



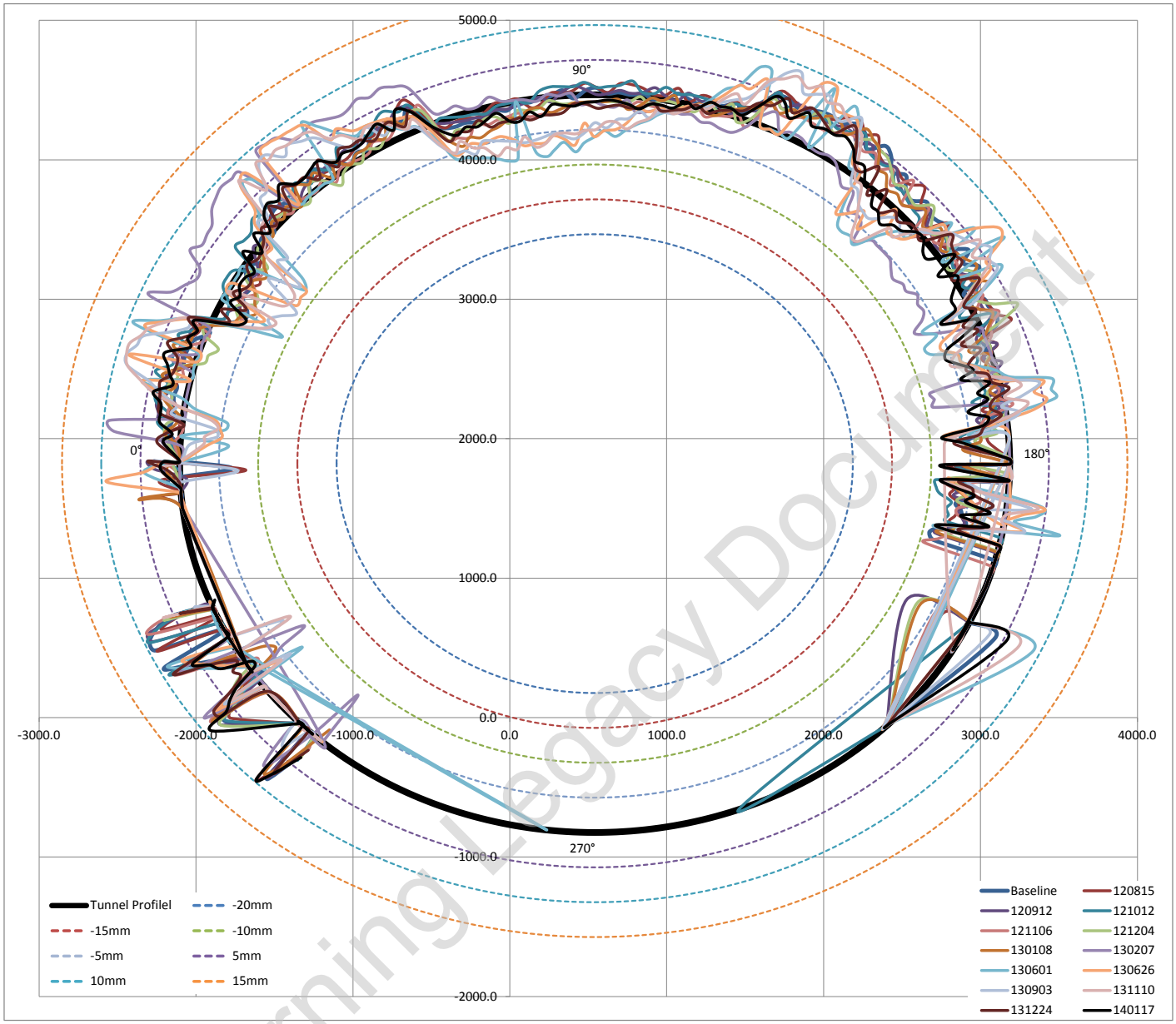
DLR LINE: DN **SECTION: 1004**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1004**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5290.06 mm	
Estimated best fit as built diameter	**5290.00 mm**	
Difference between average surveyed diameter and best fit diameter	0.00112%	
i.e. Average surveyed diameter varies on 0.001% (ave) from estimated best fit as built diameter		
Max radial difference (+ve) / (-ve) (mm)	**9.0**	**-8.8**
Max / Min deviation % to estimated dia	**0.34%**	**-0.33%**

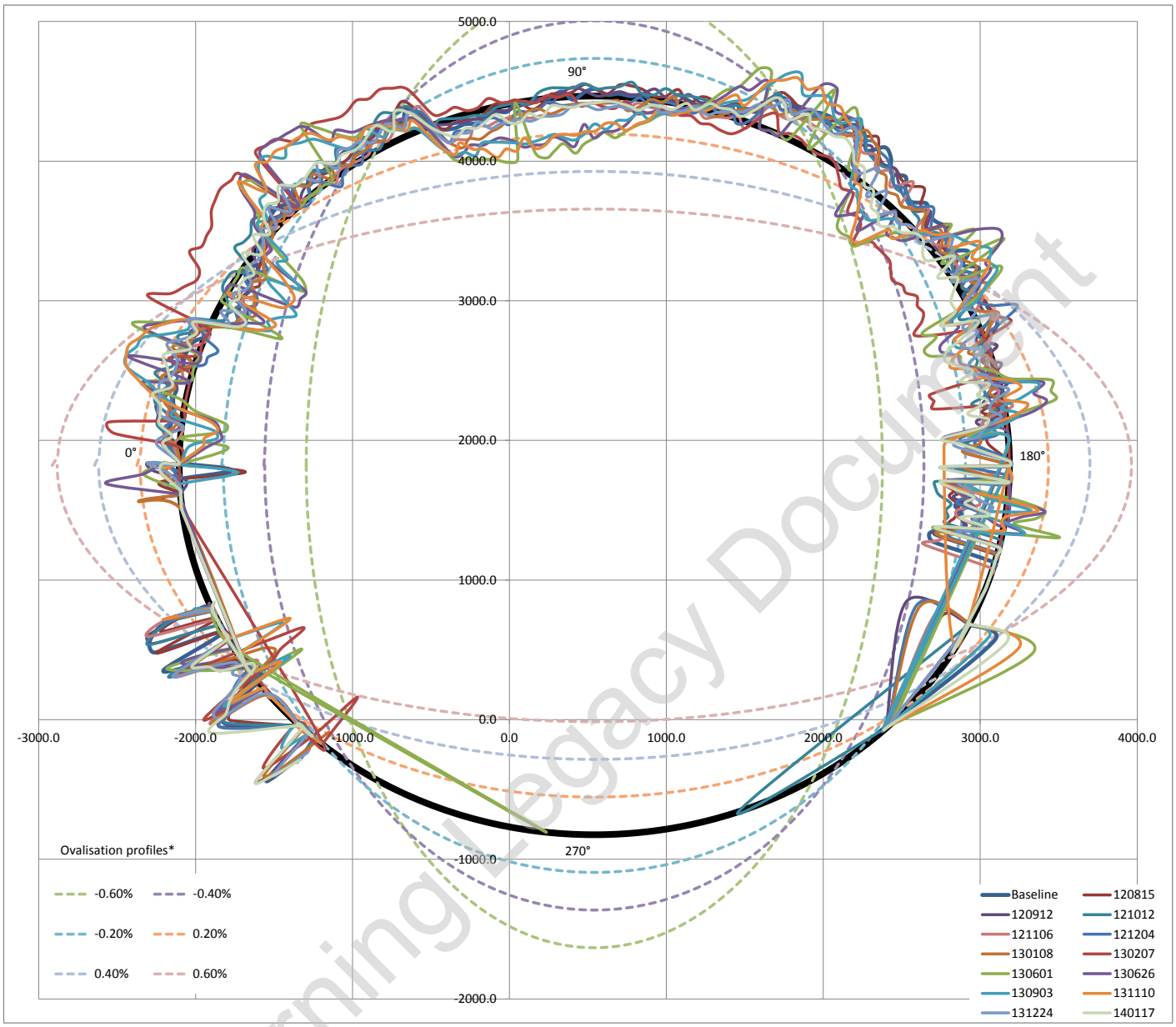
Fitted Circle Coordinates

Axis	X	541
	Y	1821
Radius		2645

Estimated best fit as built diameter	5290 mm
Designed diameter	5300 mm
Average diameter difference	**-10** mm
Average radial difference	**-5** mm
Average difference%	**-0.19%**

DLR LINE: **DN** **SECTION:** **1004**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

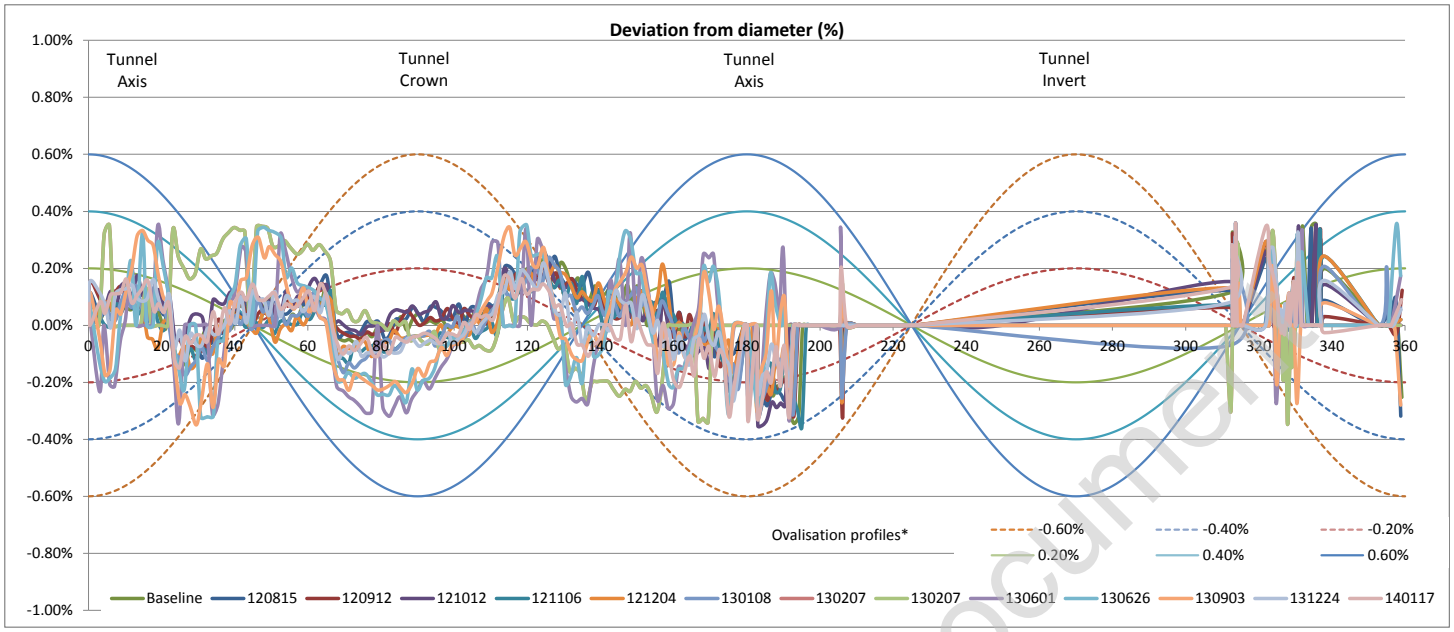
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5284.16 mm
Estimate of vertical diameter at crown, Dv	5291.01 mm
Dh / Dv	0.9987

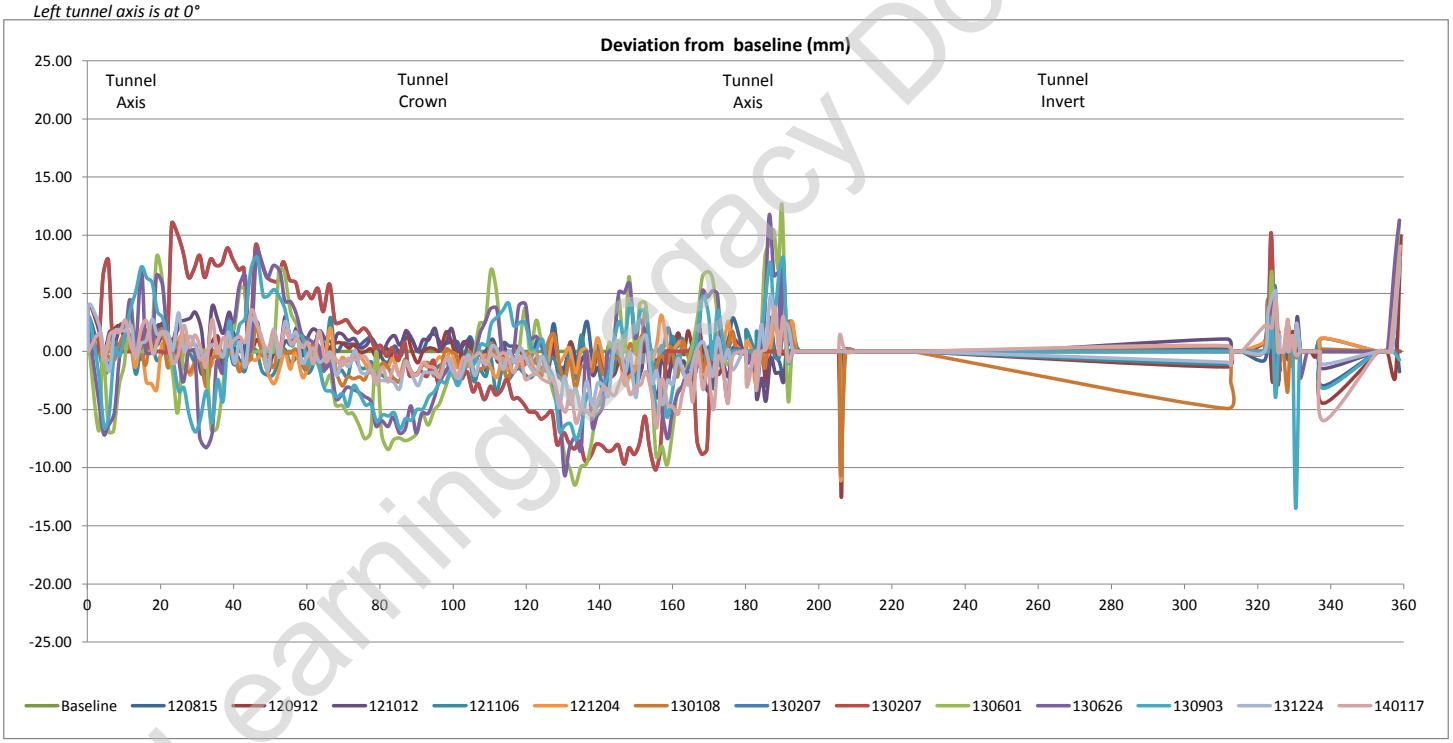
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1004**

Deviation vs Profile

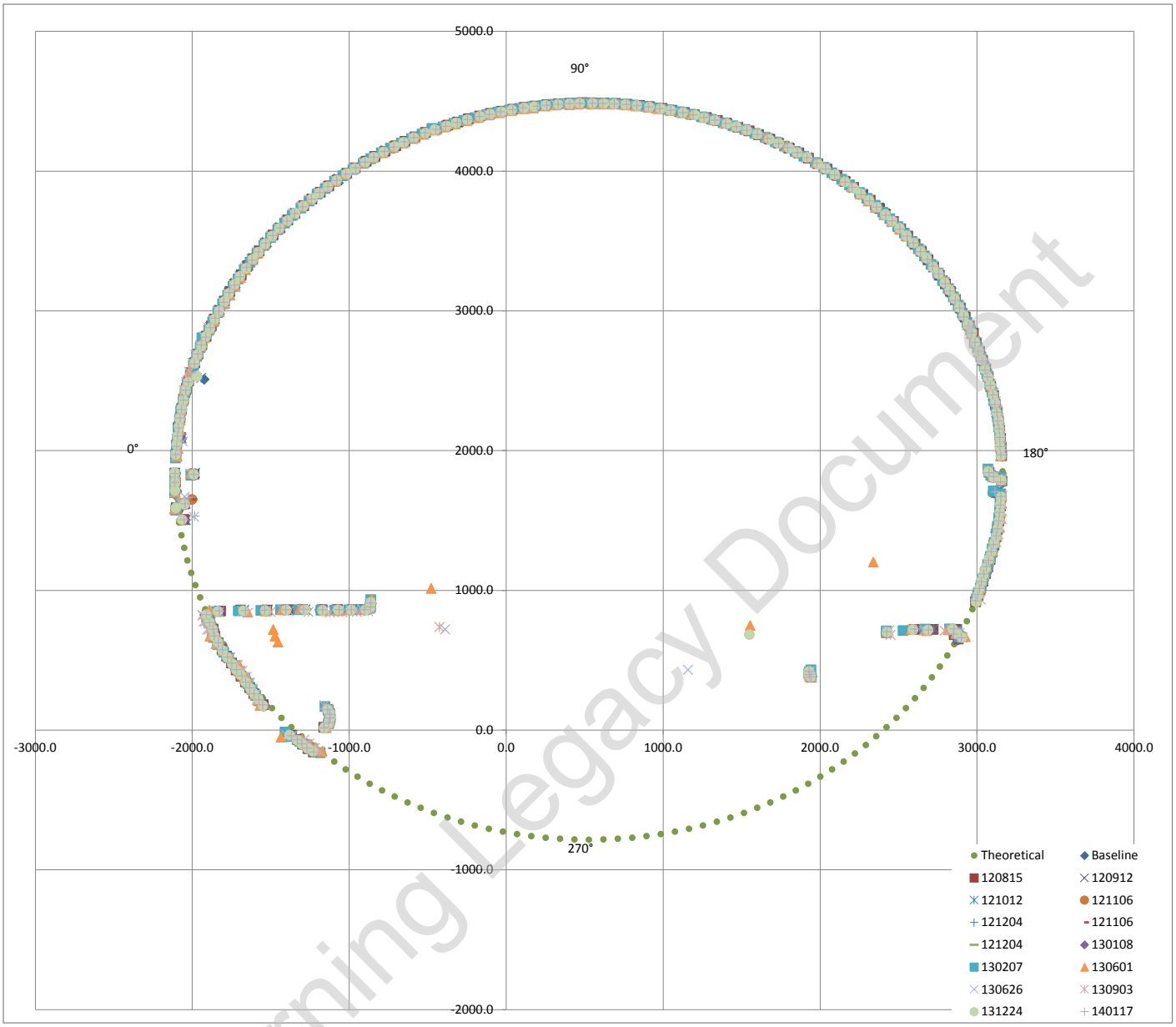


Left tunnel axis is at 0°



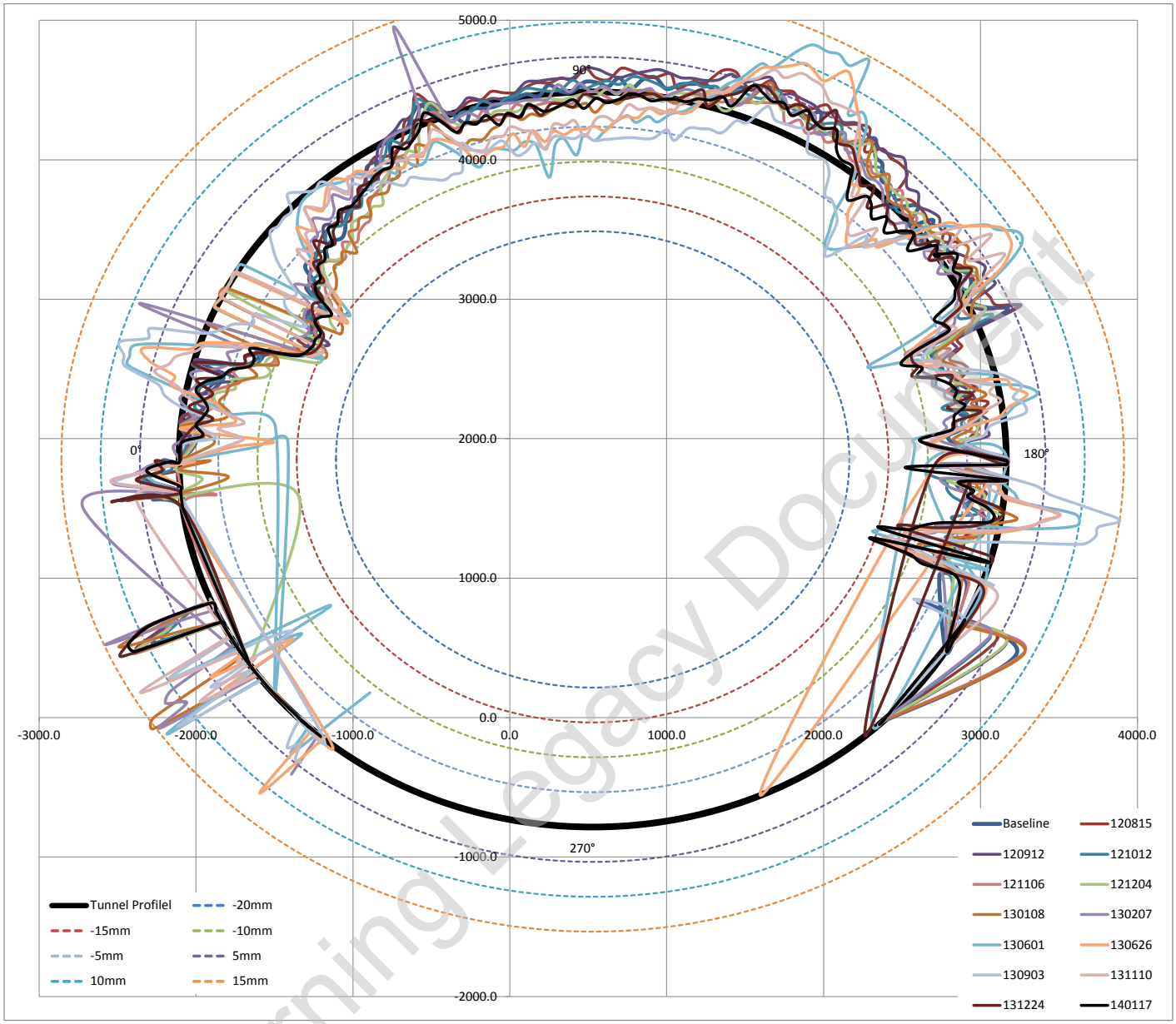
DLR LINE: DN **SECTION: 1005**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1005**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5267.28	mm
Estimated best fit as built diameter	**5272.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.08948%	

i.e. Average surveyed diameter varies on -0.089% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

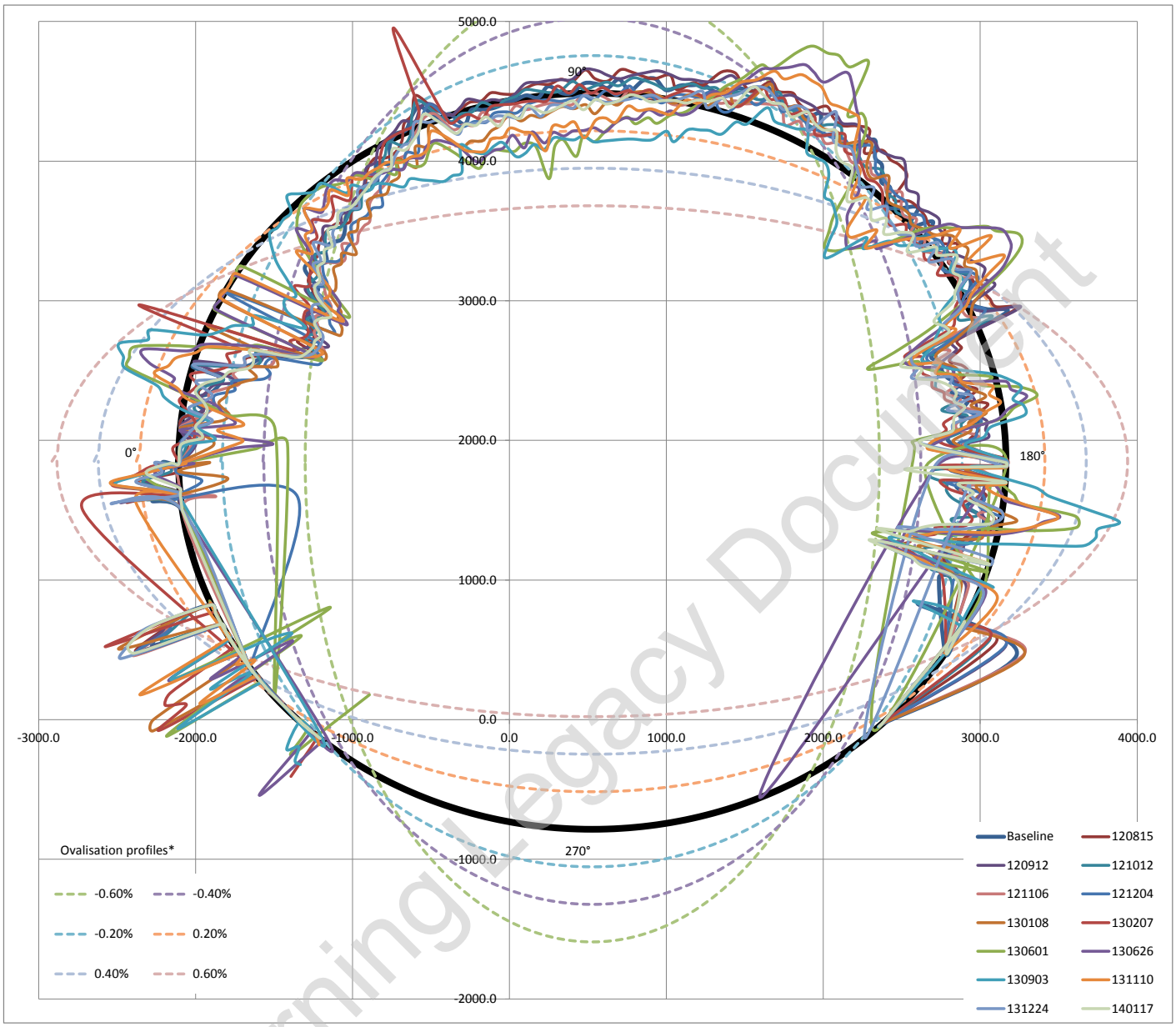
Axis	X	528
	Y	1851
Radius		2636

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-14.7**
Max / Min deviation % to estimated dia	**0.47%**	**-0.56%**

Estimated best fit as built diameter	5272	mm
Designed diameter	5300	mm
Average diameter difference	**-28**	mm
Average radial difference	**-14**	mm
Average difference%	**-0.53%**	

DLR LINE: **DN** **SECTION:** **1005**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

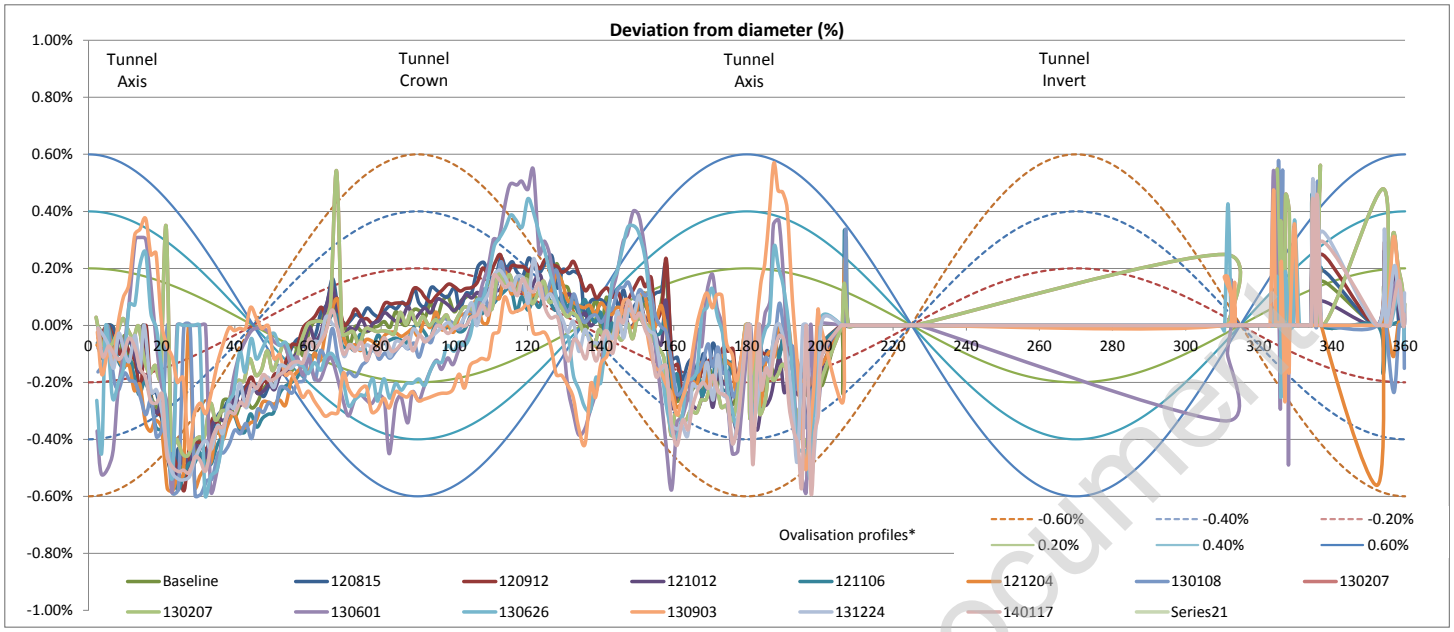
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5259.09	mm
Estimate of vertical diameter at crown, Dv	5274.10	mm
Dh / Dv	0.9972	

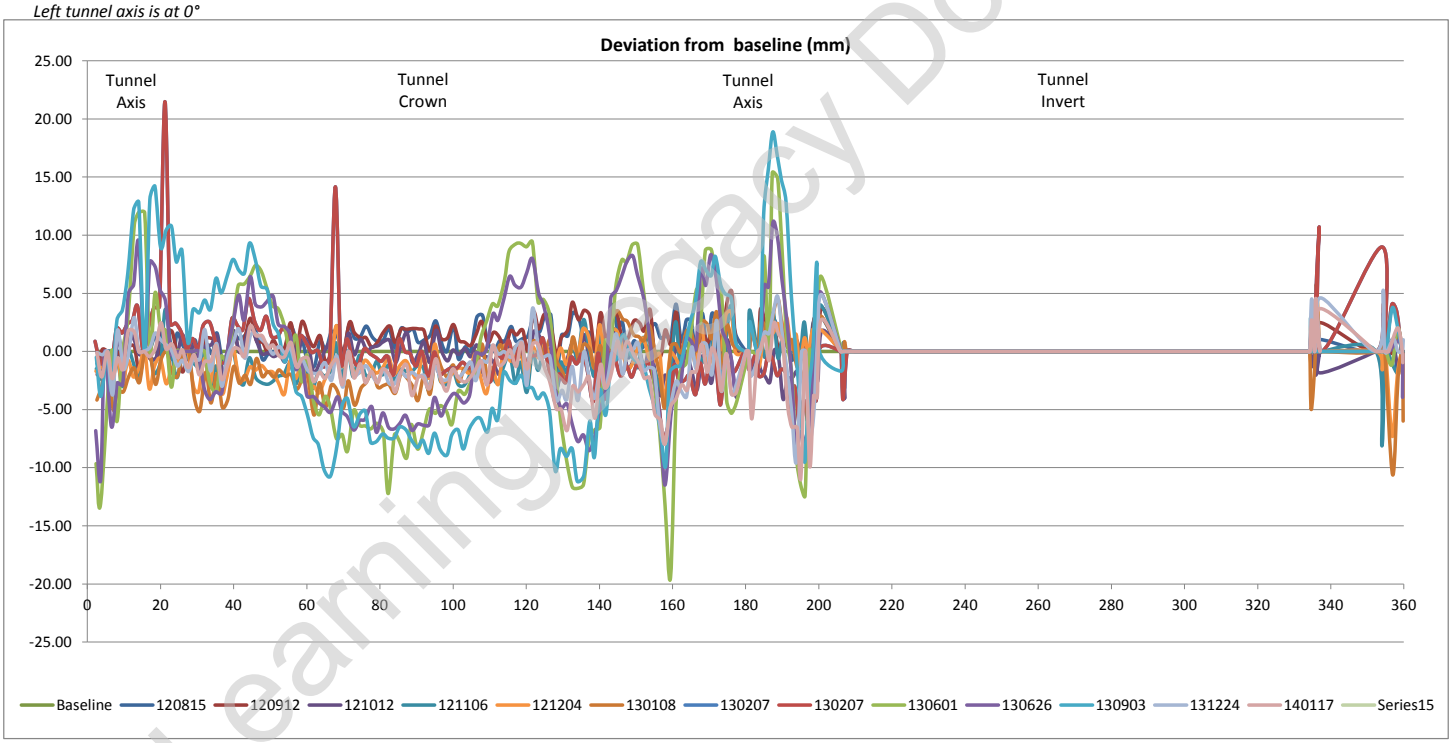
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1005**

Deviation vs Profile

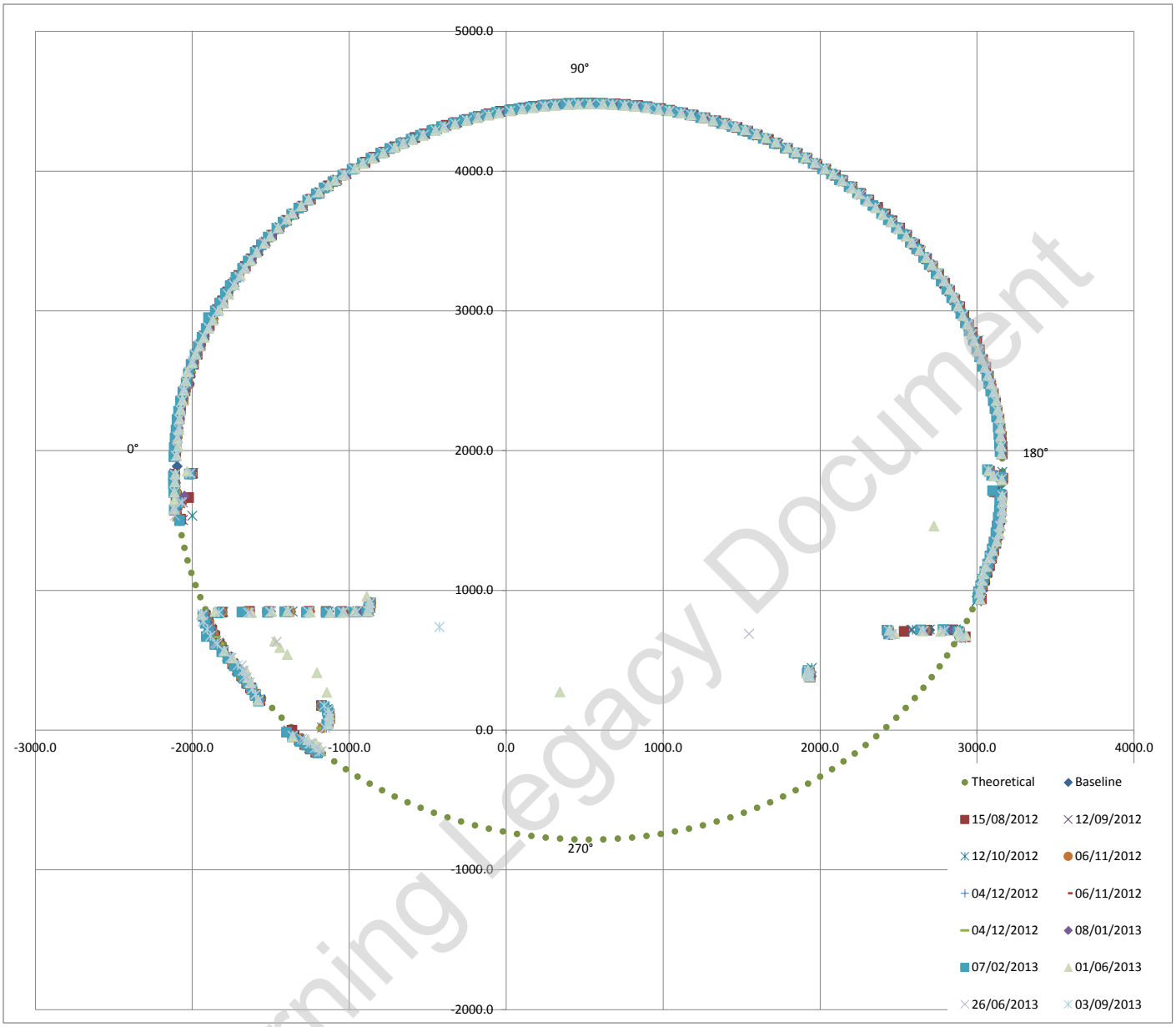


Left tunnel axis is at 0°



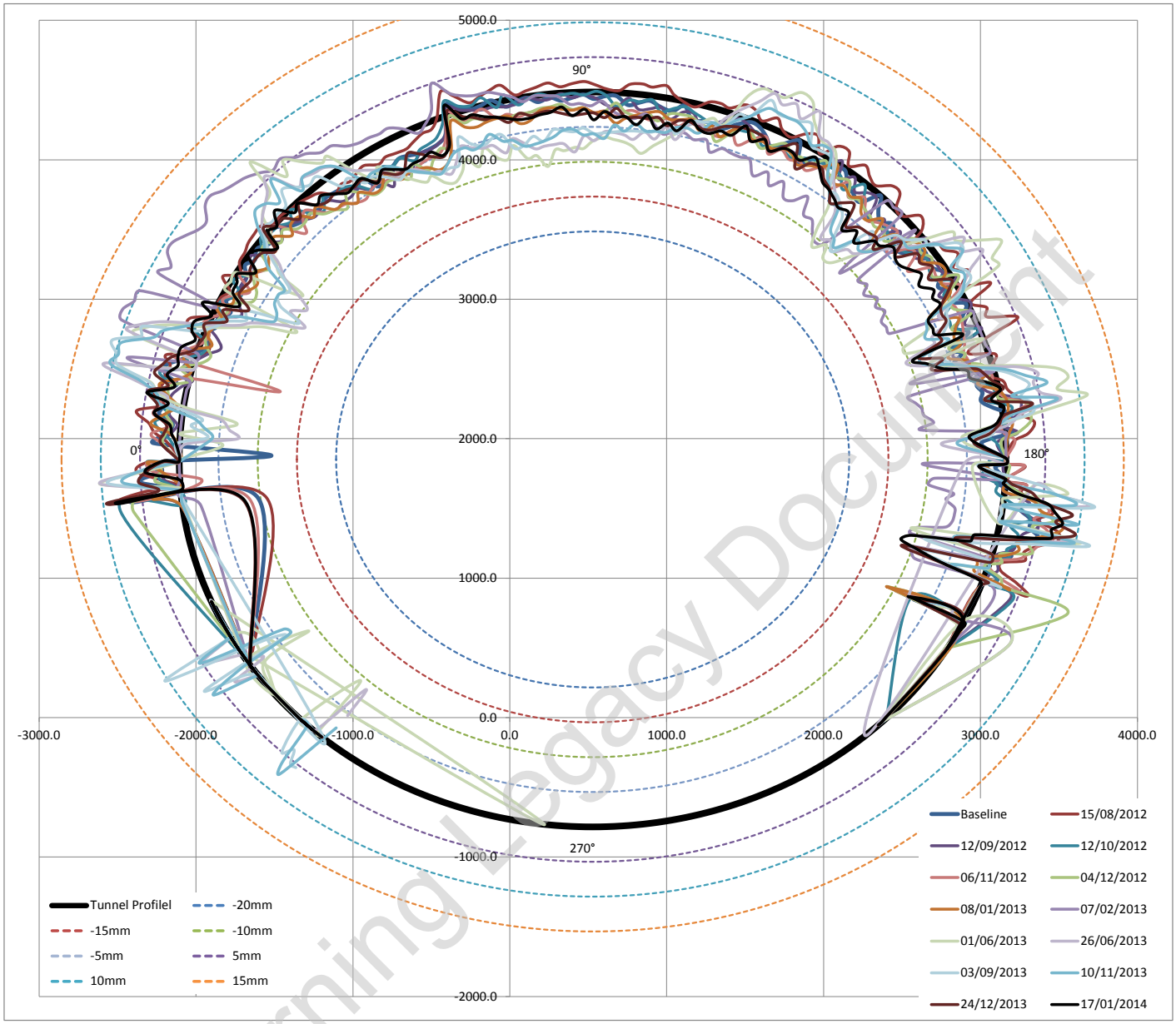
DLR LINE: DN **SECTION: 1006**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1006**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5272.73 mm
Estimated best fit as built diameter	**5270.00 mm**
Difference between average surveyed diameter and best fit diameter	0.05185%

i.e. Average surveyed diameter varies on 0.051% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

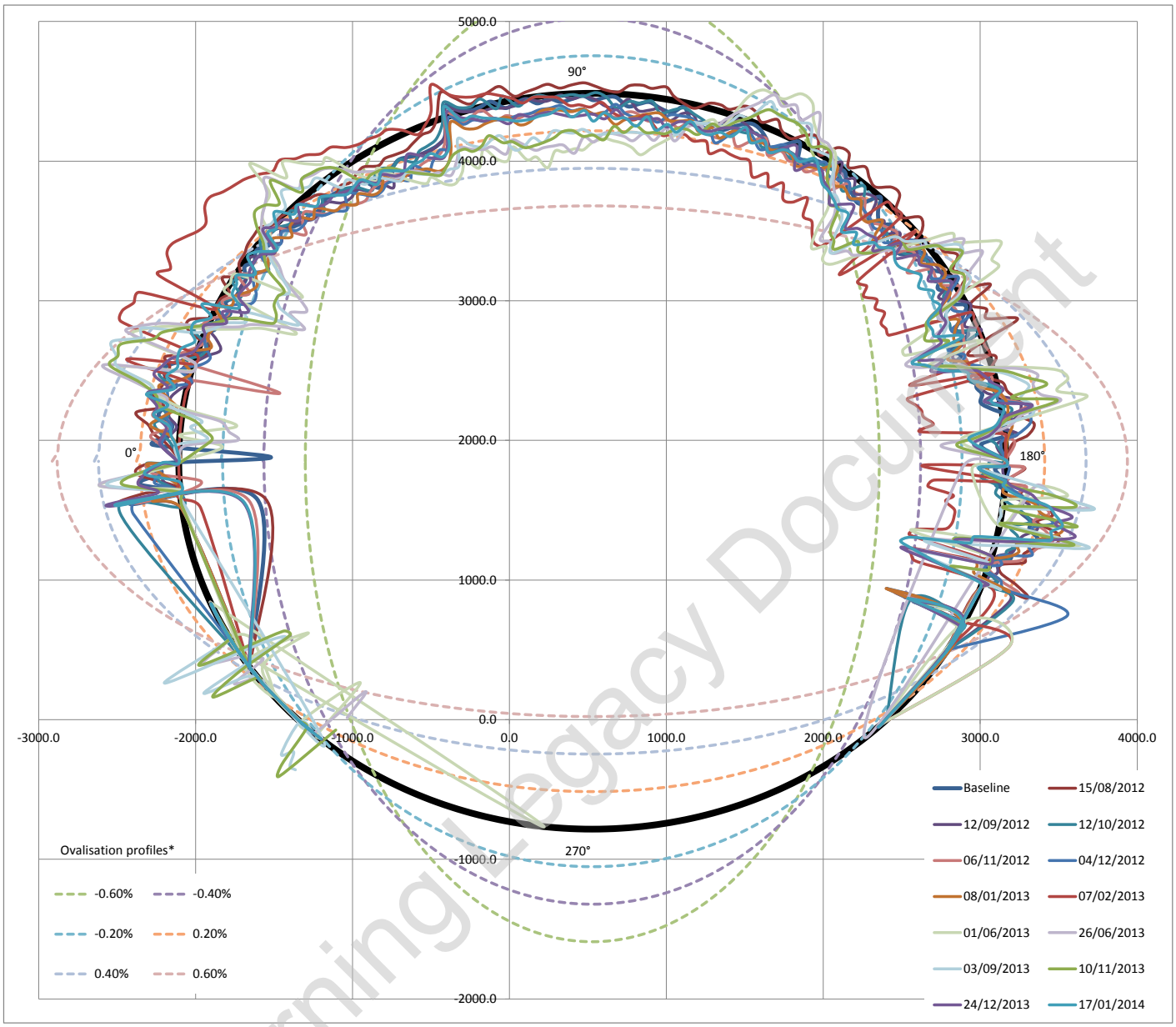
Axis	X	528
	Y	1851
Radius		2635

Max radial difference (+ve) / (-ve) (mm)	**9.0**	**-10.7**
Max / Min deviation % to estimated dia	**0.34%**	**-0.41%**

Estimated best fit as built diameter	5270 mm
Designed diameter	5300 mm
Average diameter difference	**-30** mm
Average radial difference	**-15** mm
Average difference%	**-0.57%**

DLR LINE: **DN** **SECTION:** **1006**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

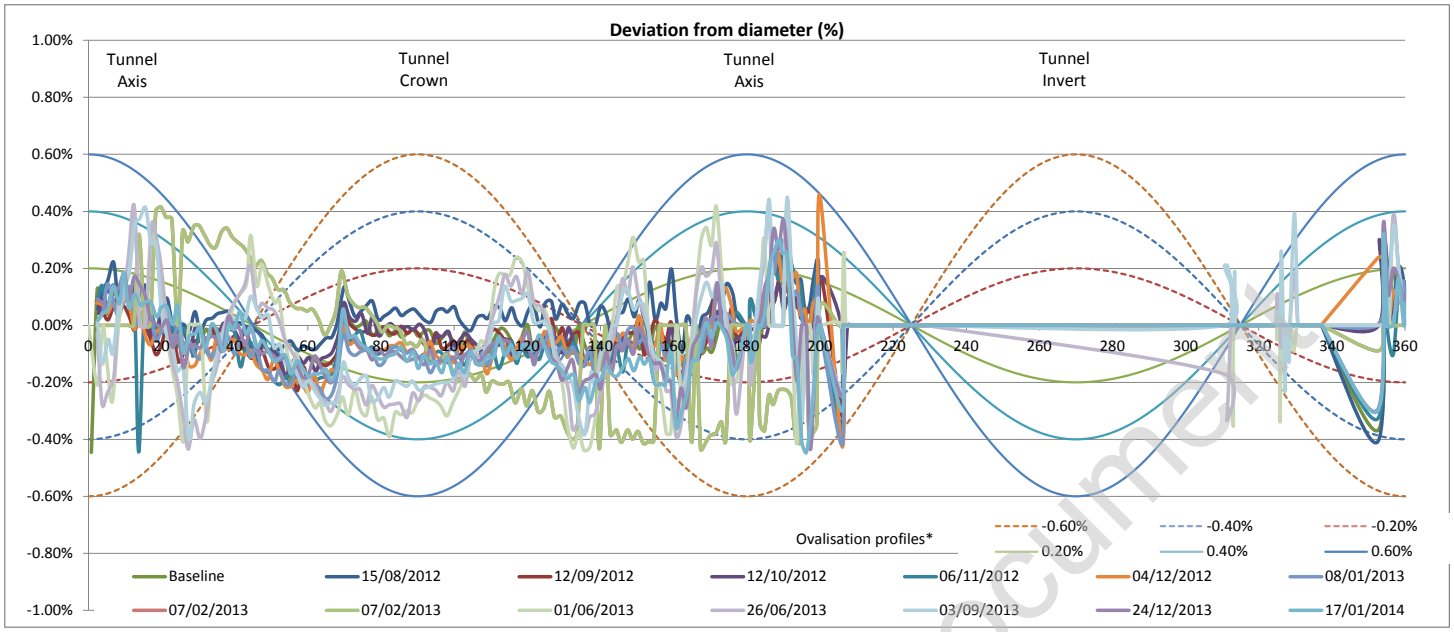
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5256.86 mm
Estimate of vertical diameter at crown, Dv	5269.01 mm
Dh / Dv	0.9977

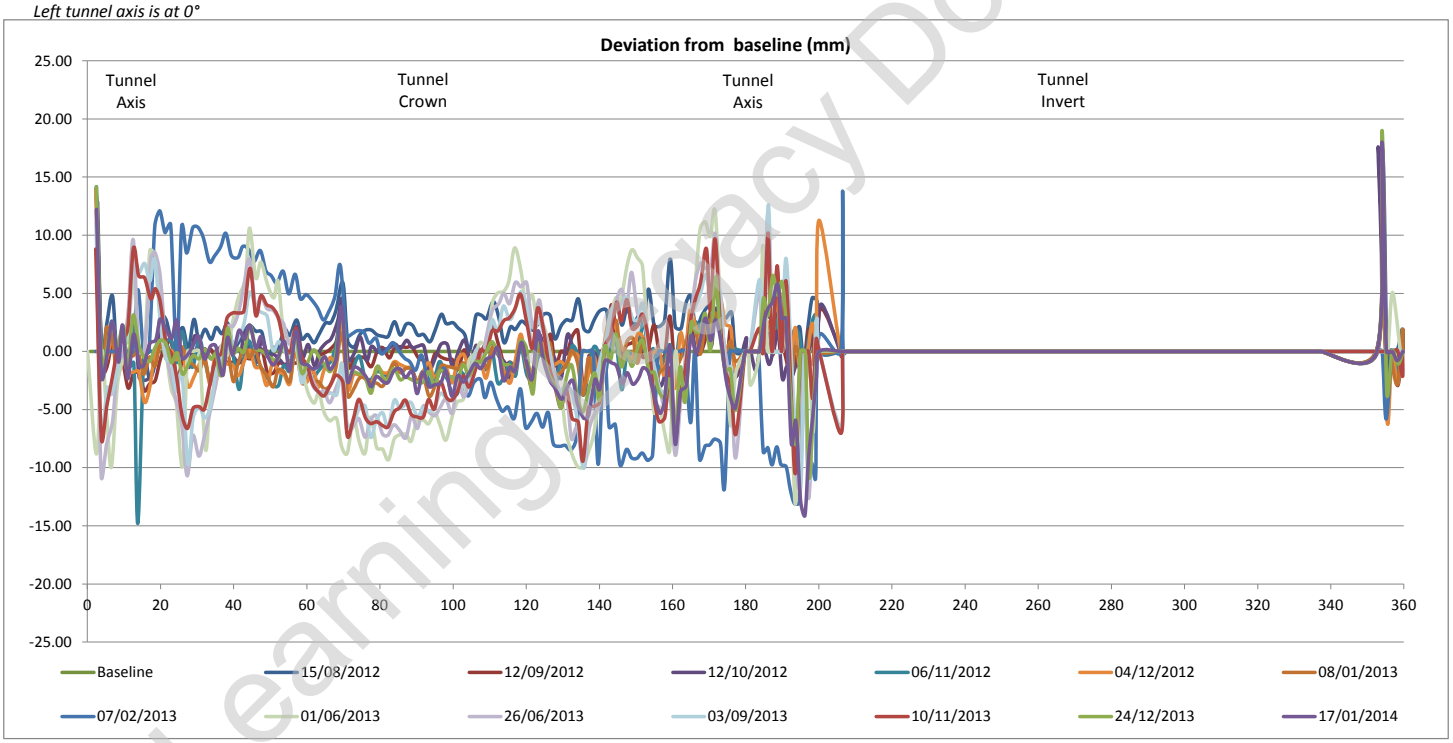
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1006**

Deviation vs Profile

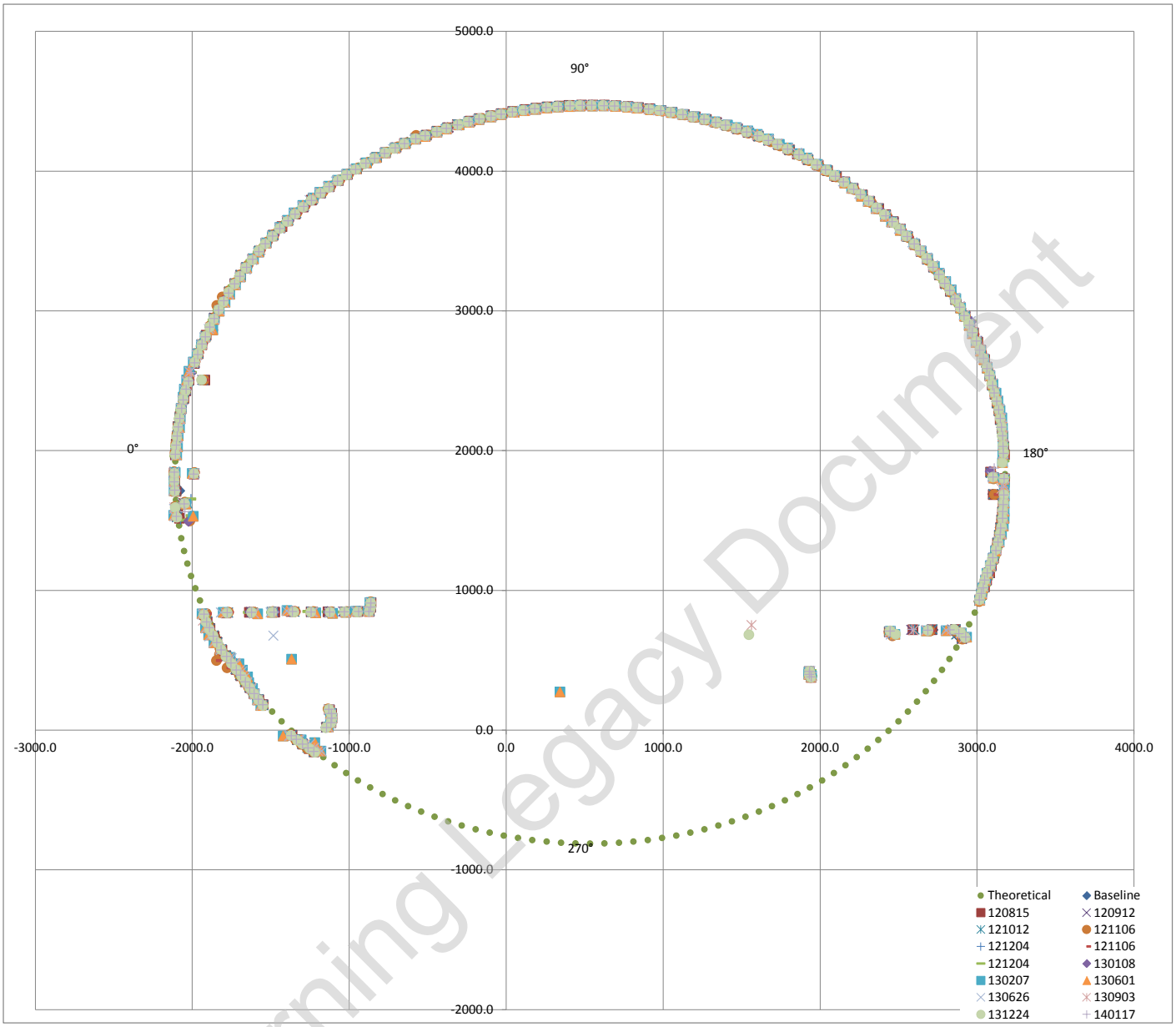


Left tunnel axis is at 0°



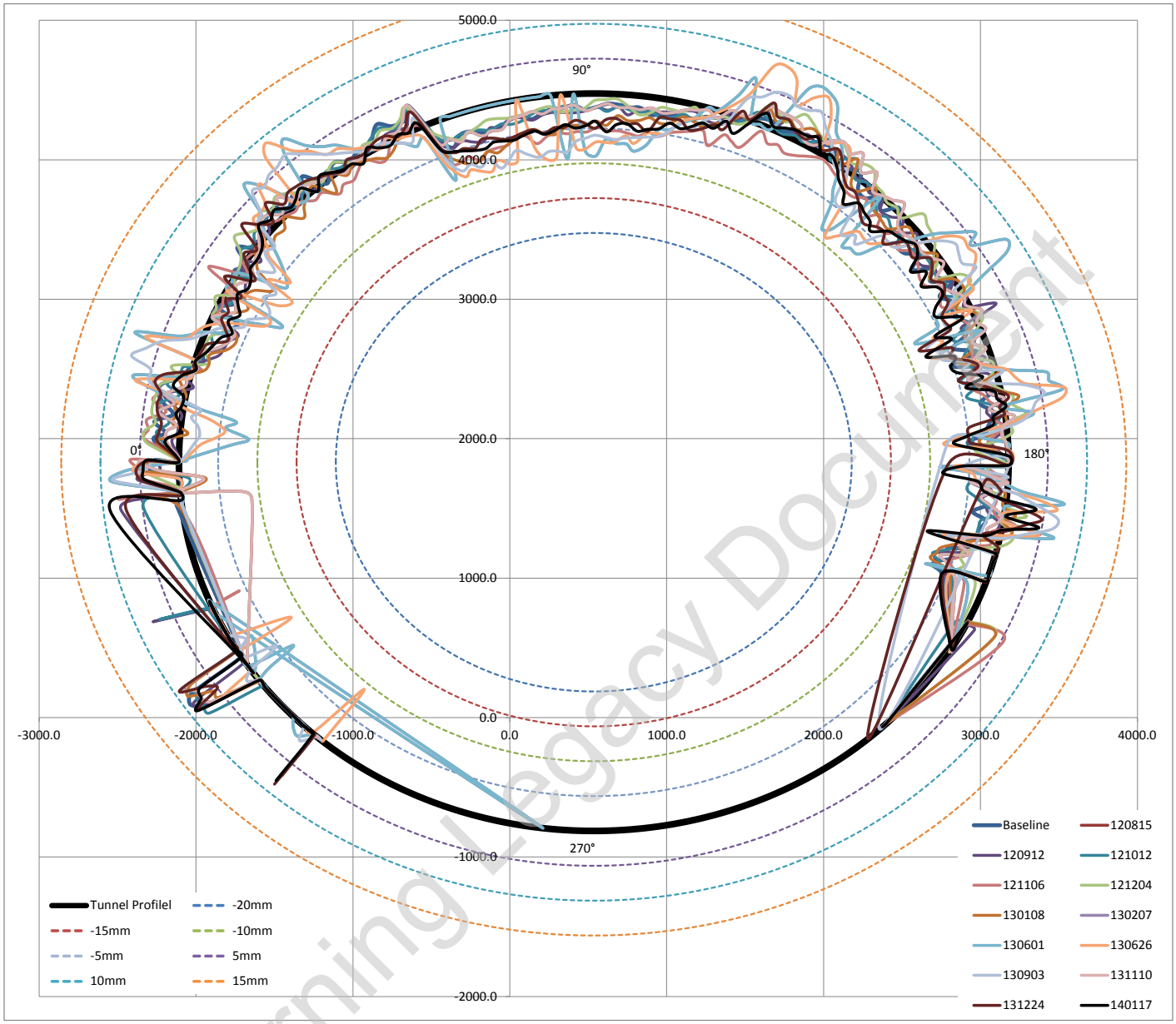
DLR LINE: DN **SECTION: 1007**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1007**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5287.66 mm
Estimated best fit as built diameter	**5288.00 mm**
Difference between average surveyed diameter and best fit diameter	-0.00642%

i.e. Average surveyed diameter varies on -0.006% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

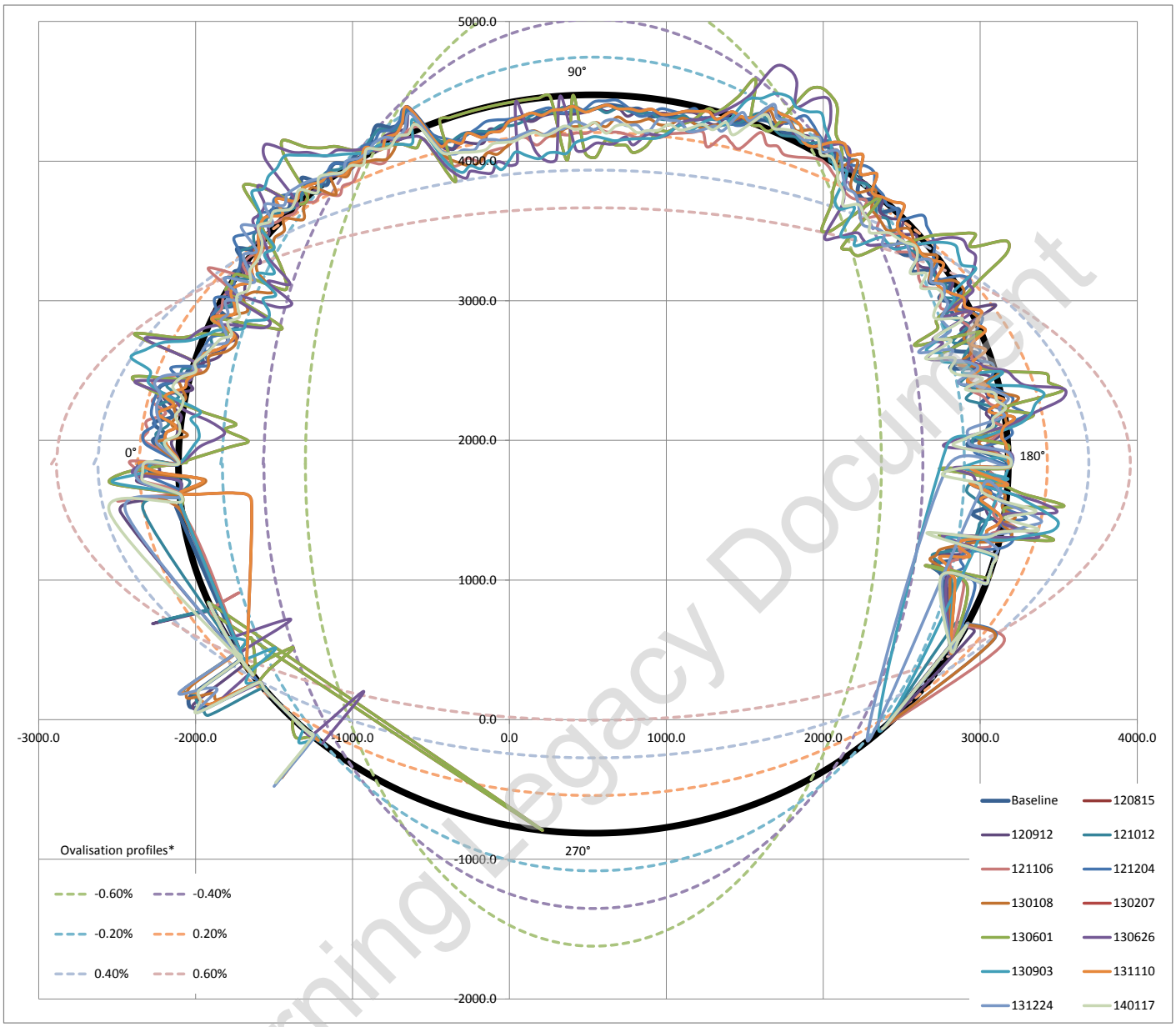
Axis	X	535
	Y	1831
Radius		2644

Max radial difference (+ve) / (-ve) (mm)	**8.5**	**-8.2**
Max / Min deviation % to estimated dia	**0.32%**	**-0.31%**

Estimated best fit as built diameter	5288 mm
Designed diameter	5300 mm
Average diameter difference	**-12** mm
Average radial difference	**-6** mm
Average difference%	**-0.23%**

DLR LINE: **DN** **SECTION:** **1007**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

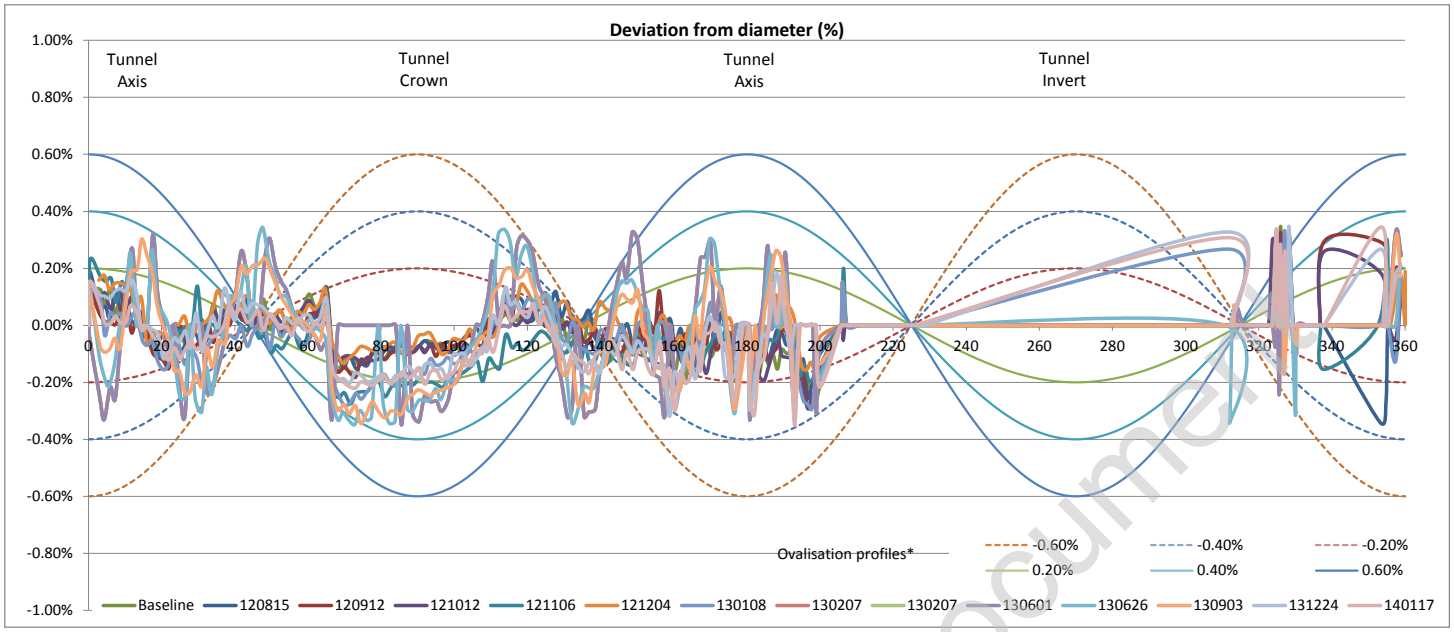
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5286.30	mm
Estimate of vertical diameter at crown, Dv	5286.03	mm
Dh / Dv	1.0001	

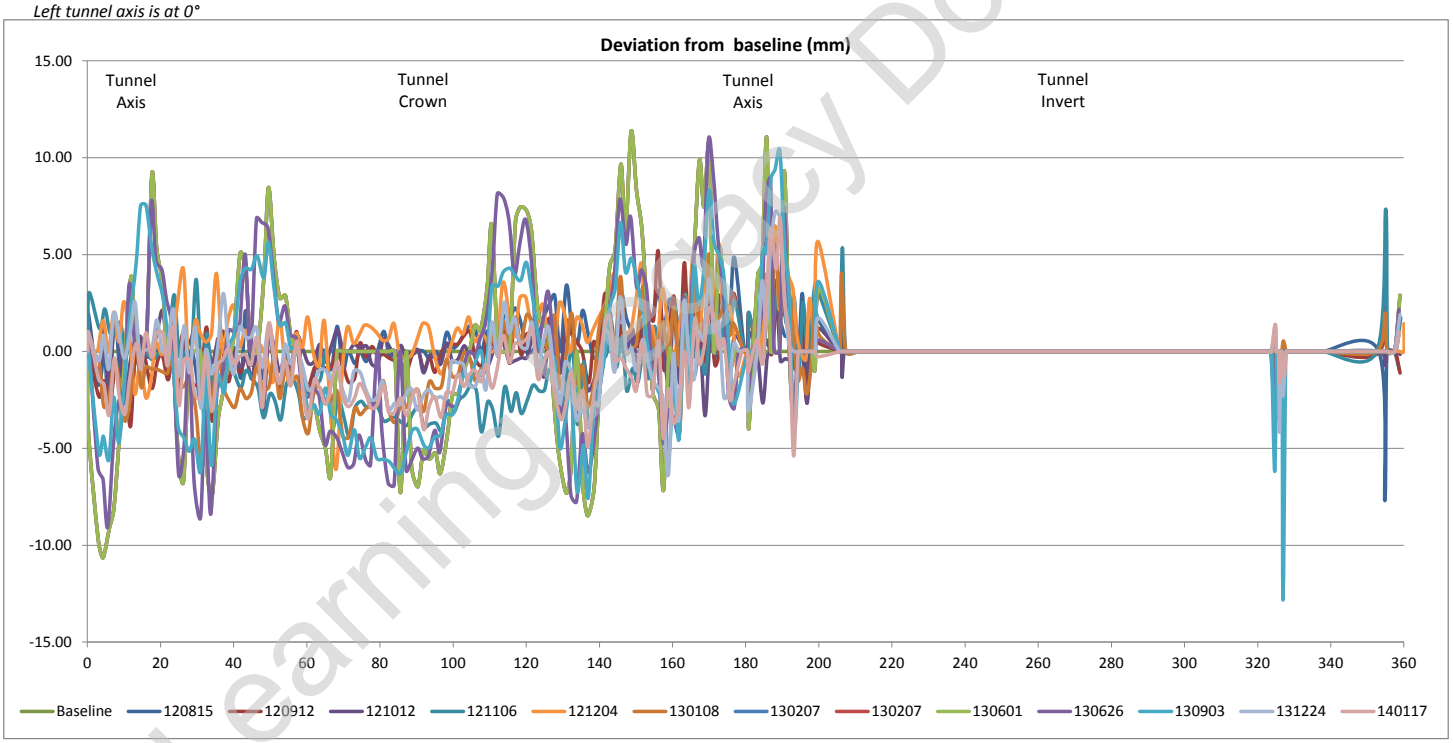
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 1007**

Deviation vs Profile

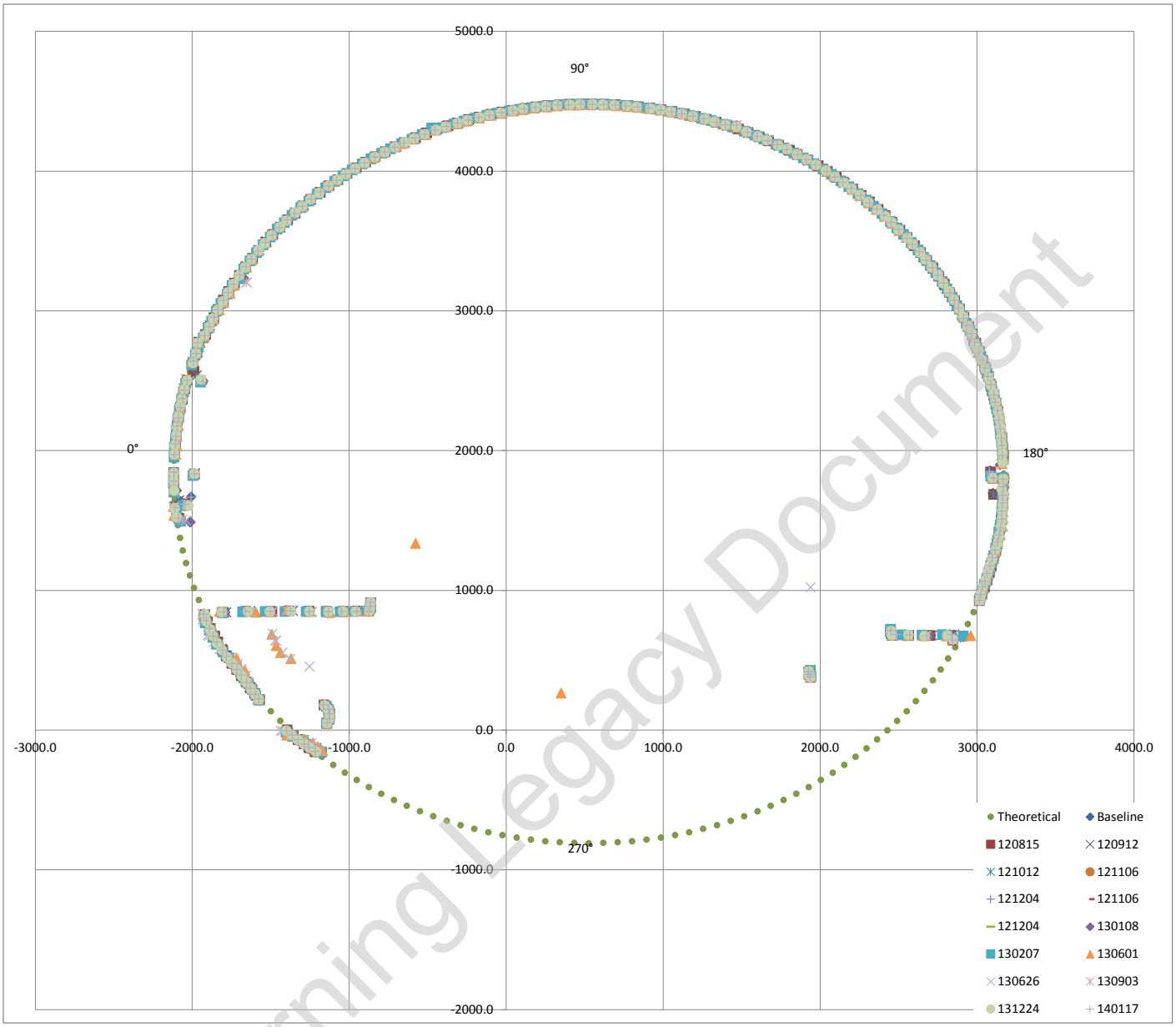


Left tunnel axis is at 0°



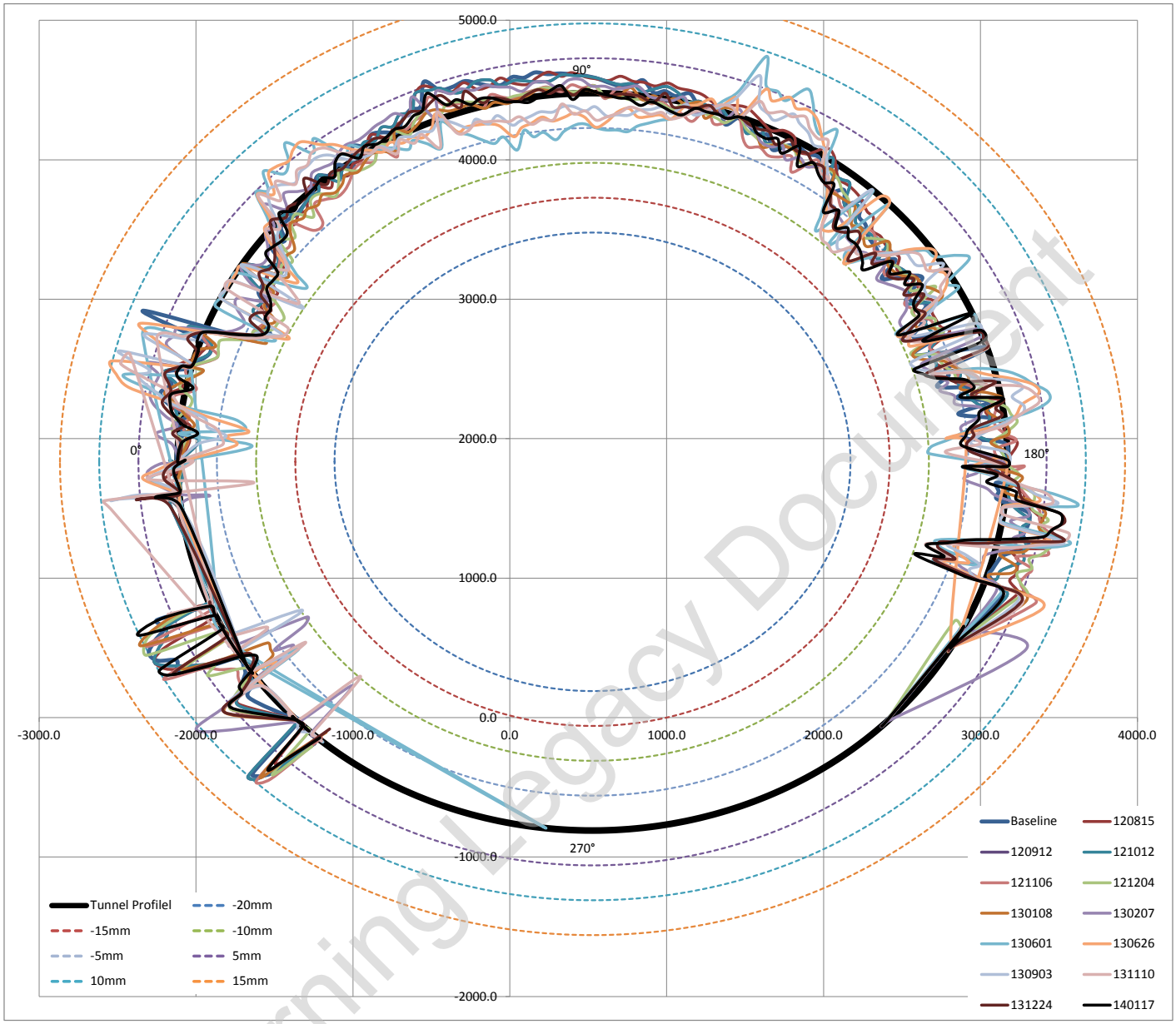
DLR LINE: DN **SECTION: 1008**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **1008**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5288.34 mm	
Estimated best fit as built diameter	**5288.00 mm**	
Difference between average surveyed diameter and best fit diameter	0.00634%	
i.e. Average surveyed diameter varies on 0.006% (ave) from estimated best fit as built diameter		

Fitted Circle Coordinates

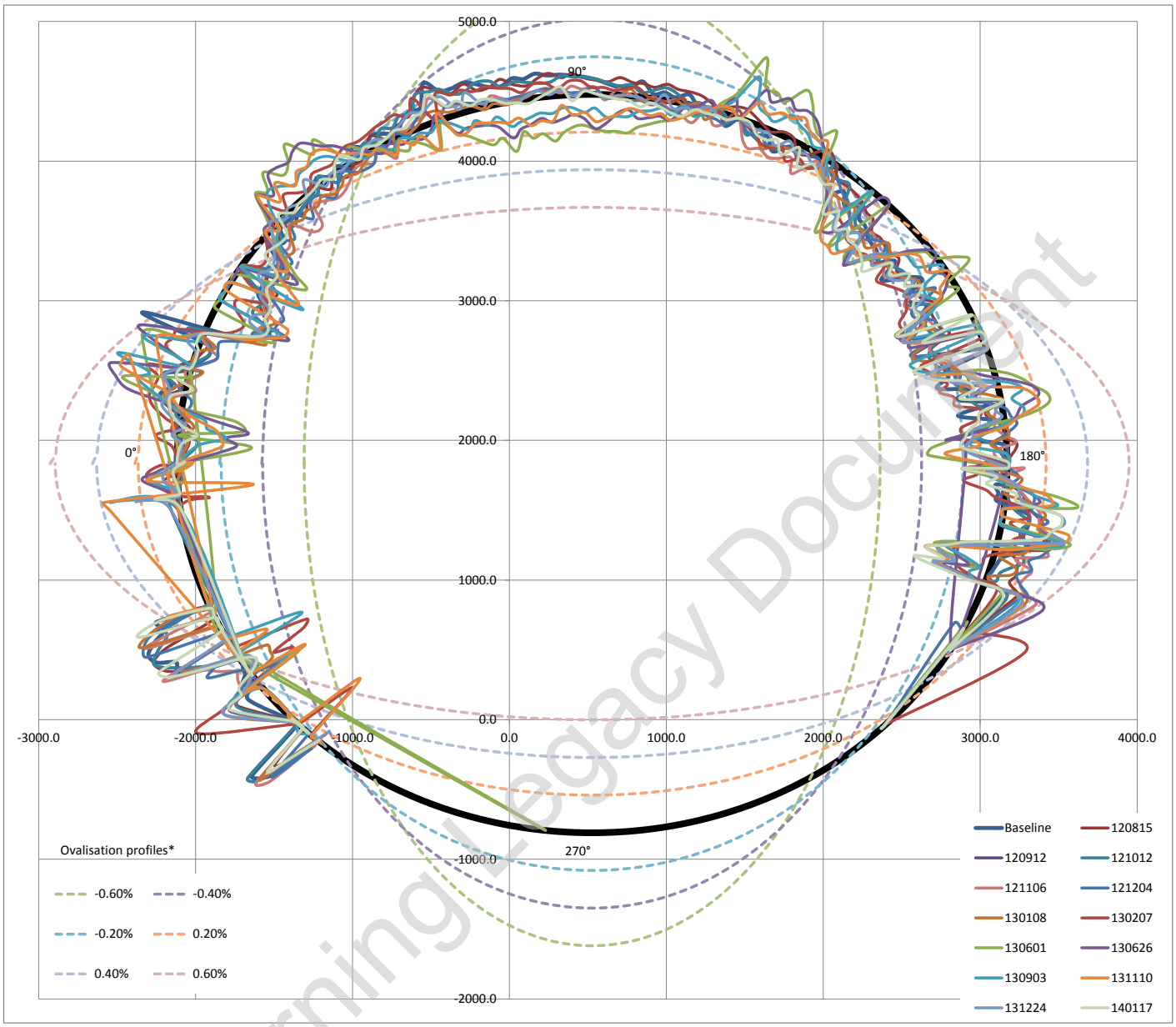
Axis	X	527
	Y	1834
Radius		2644

Max radial difference (+ve) / (-ve) (mm)	**9.9**	**-9.0**
Max / Min deviation % to estimated dia	**0.37%**	**-0.34%**

Estimated best fit as built diameter	5288 mm
Designed diameter	5300 mm
Average diameter difference	**-12** mm
Average radial difference	**-6** mm
Average difference%	**-0.23%**

DLR LINE: **DN** **SECTION:** **1008**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

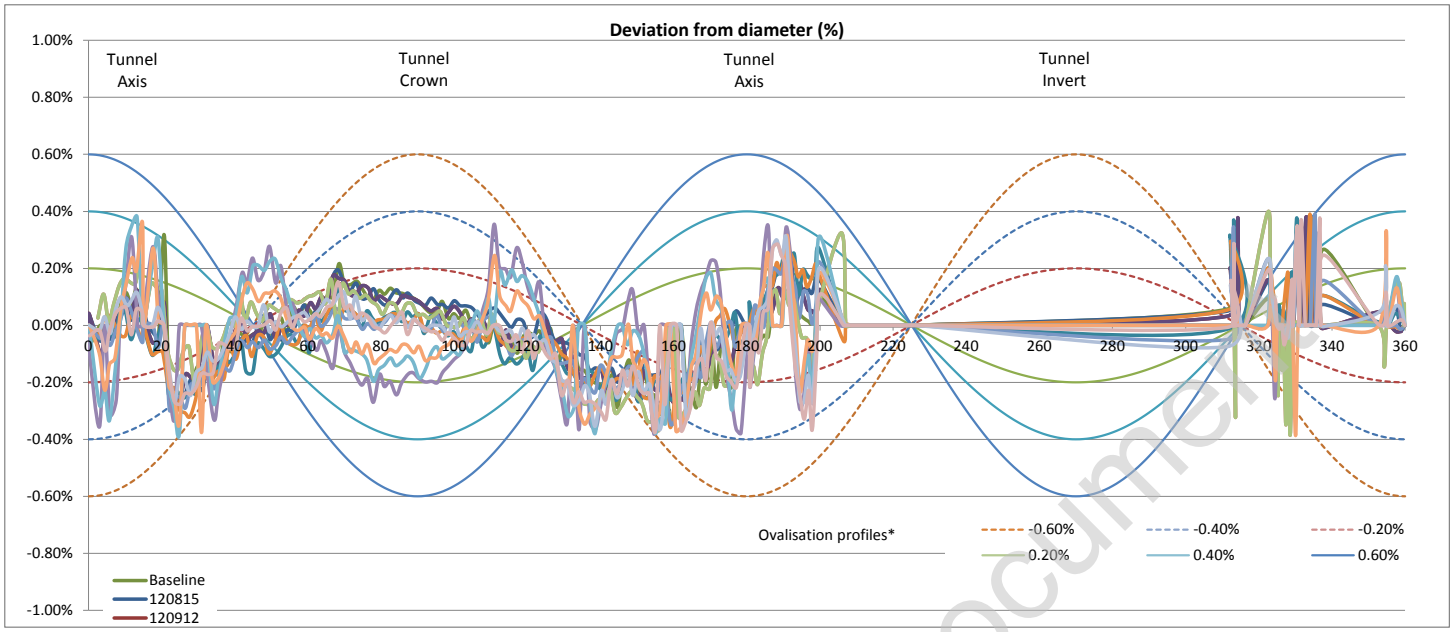
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5284.31	mm
Estimate of vertical diameter at crown, Dv	5290.13	mm
Dh / Dv	0.9989	

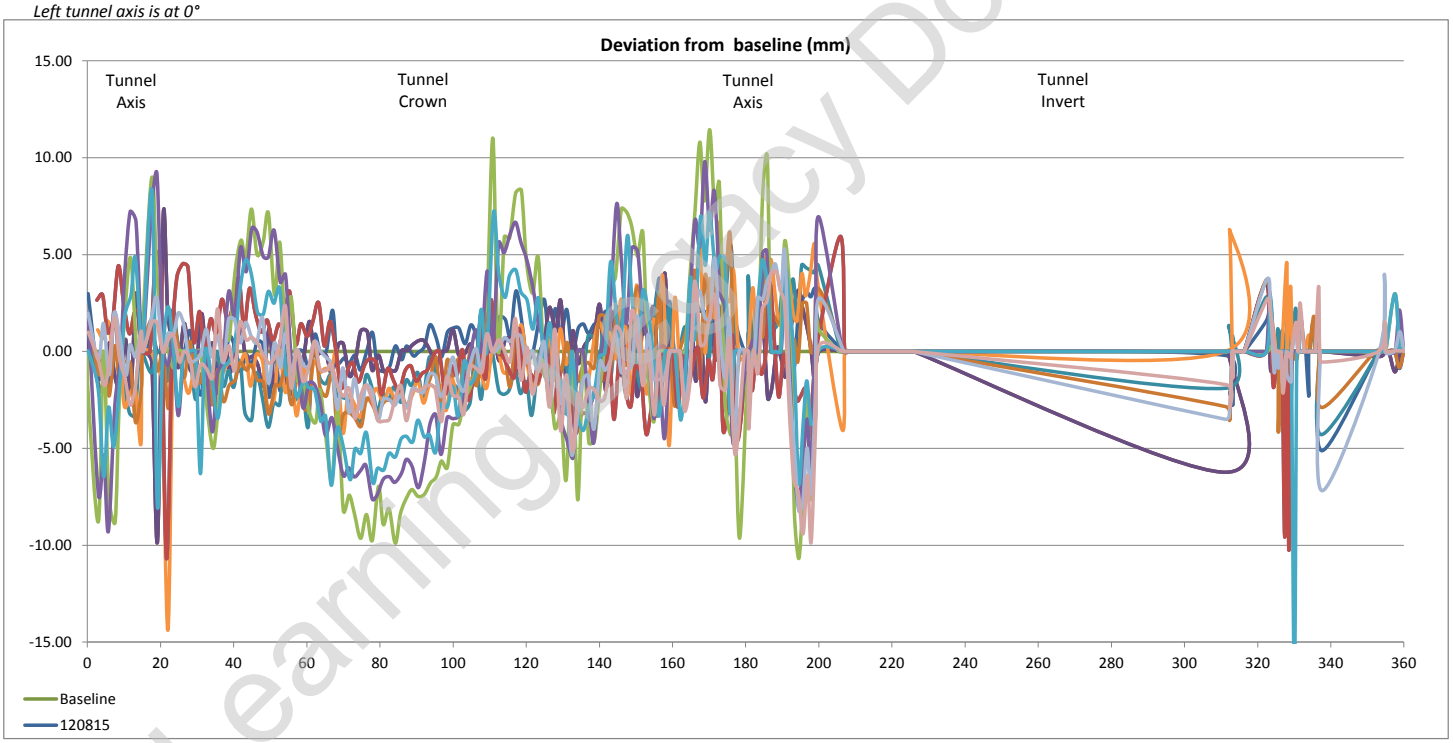
Best fit ovalsation profile: **Negative**

DLR LINE: DN **SECTION: 1008**

Deviation vs Profile

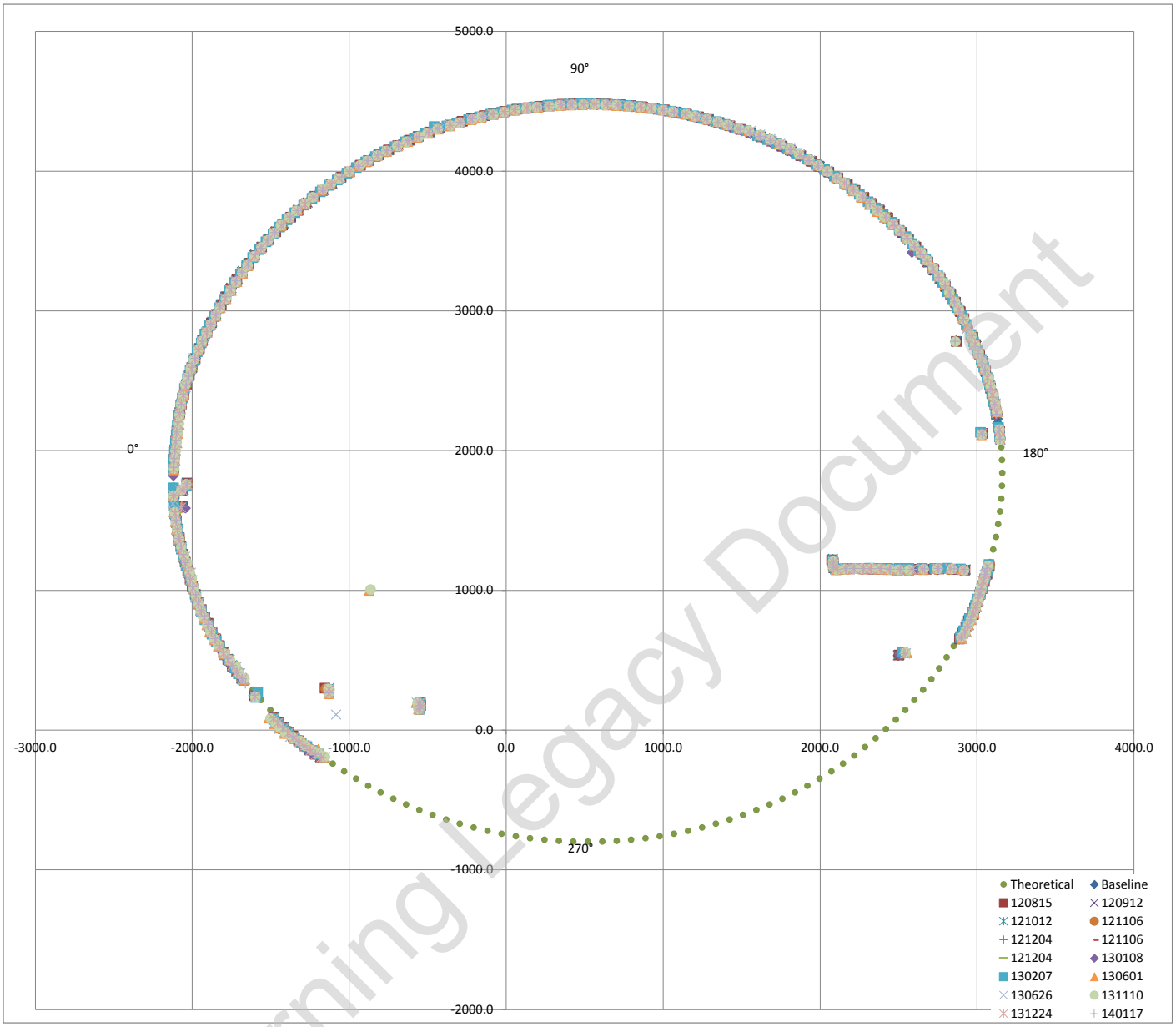


Left tunnel axis is at 0°



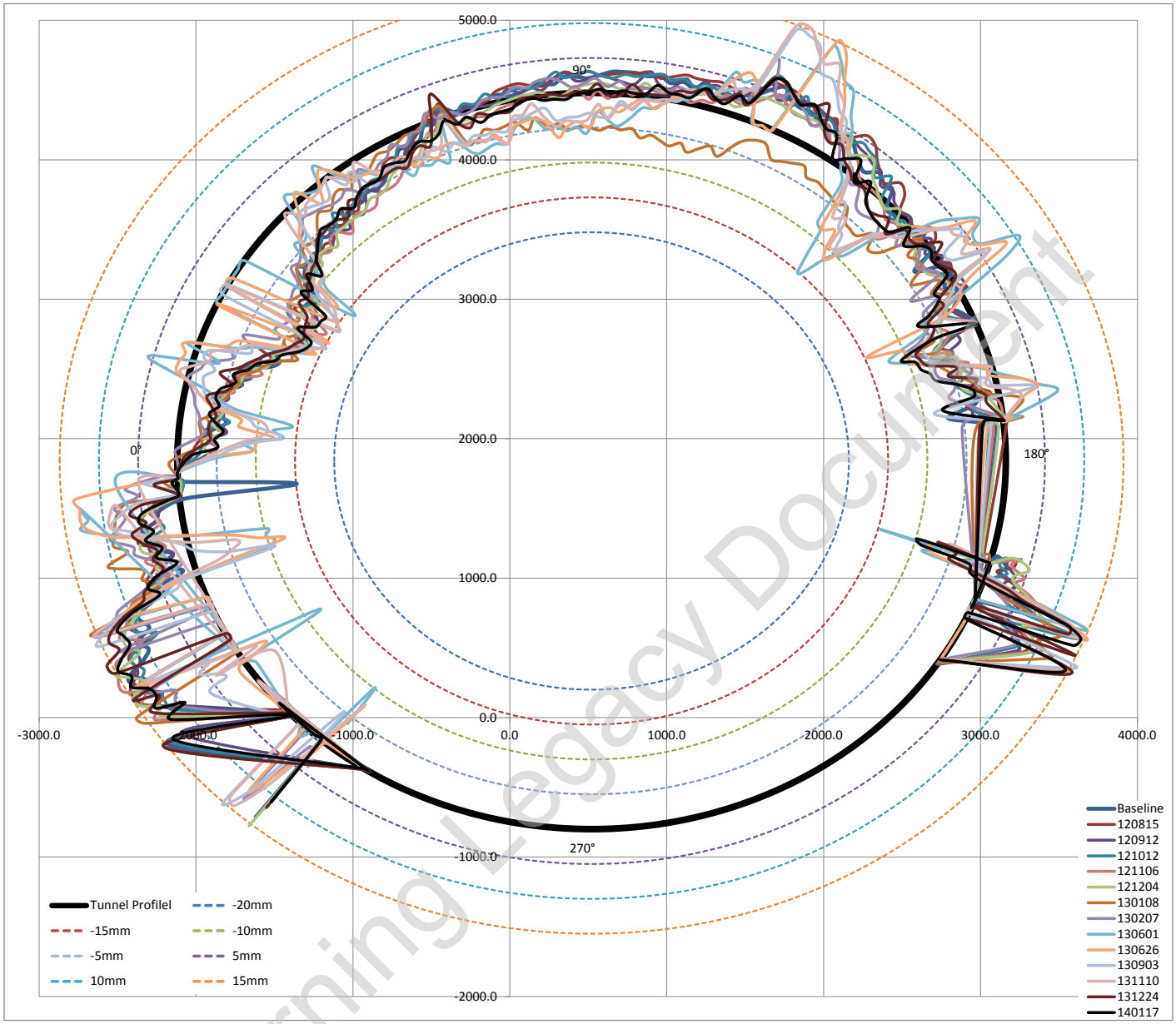
DLR LINE: UP **SECTION: 1011**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1011**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5280.36 mm
Estimated best fit as built diameter	**5280.00 mm**
Difference between average surveyed diameter and best fit diameter	0.00686%

i.e. Average surveyed diameter varies on 0.006% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

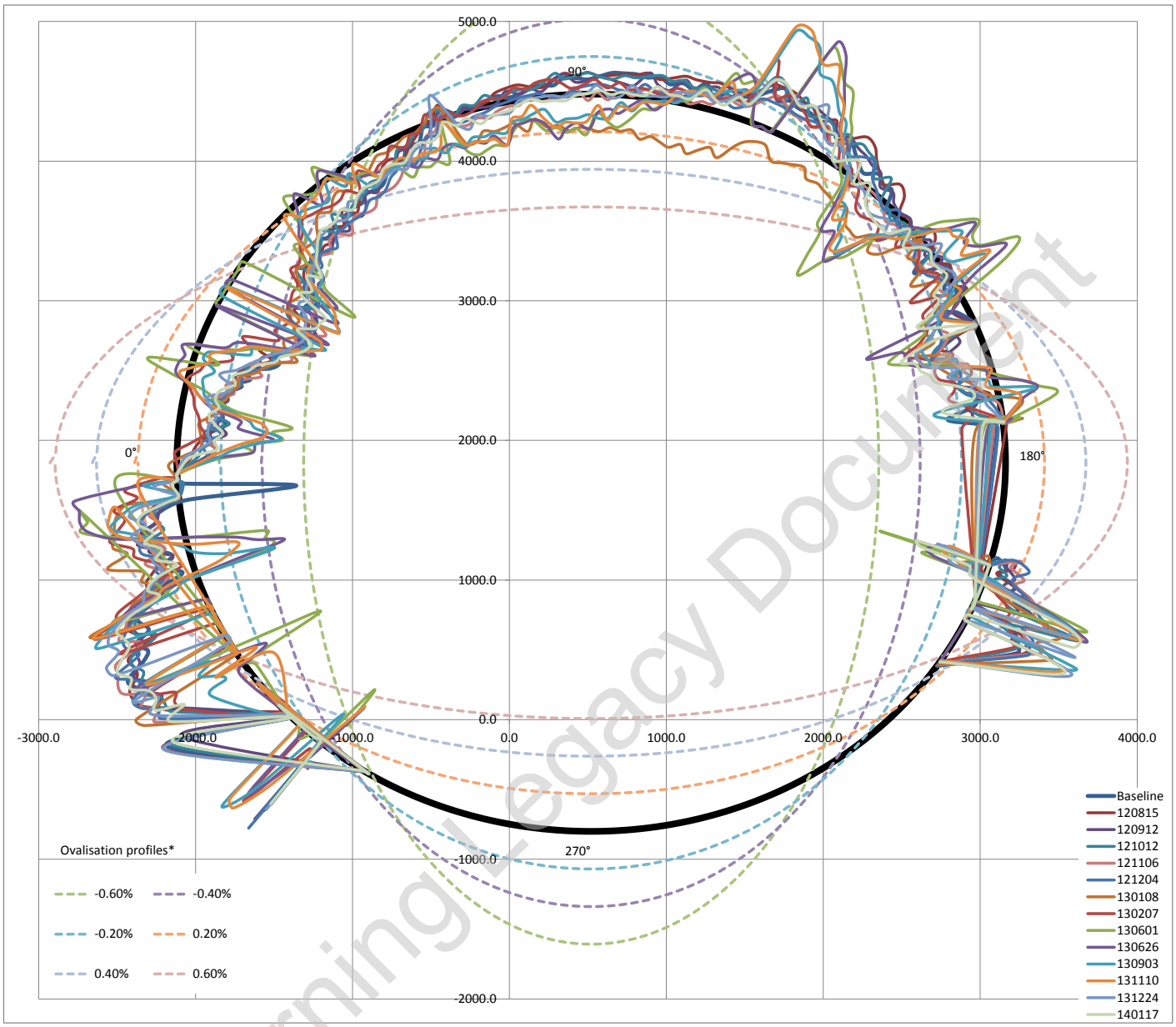
Axis	X	521
	Y	1840
Radius		2640

Max radial difference (+ve) / (-ve) (mm)	**15.0**	**-13.7**
Max / Min deviation % to estimated dia	**0.57%**	**-0.52%**

Estimated best fit as built diameter	5280 mm
Designed diameter	5300 mm
Average diameter difference	**-20** mm
Average radial difference	**-10** mm
Average difference%	**-0.38%**

DLR LINE: **UP** **SECTION:** **1011**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

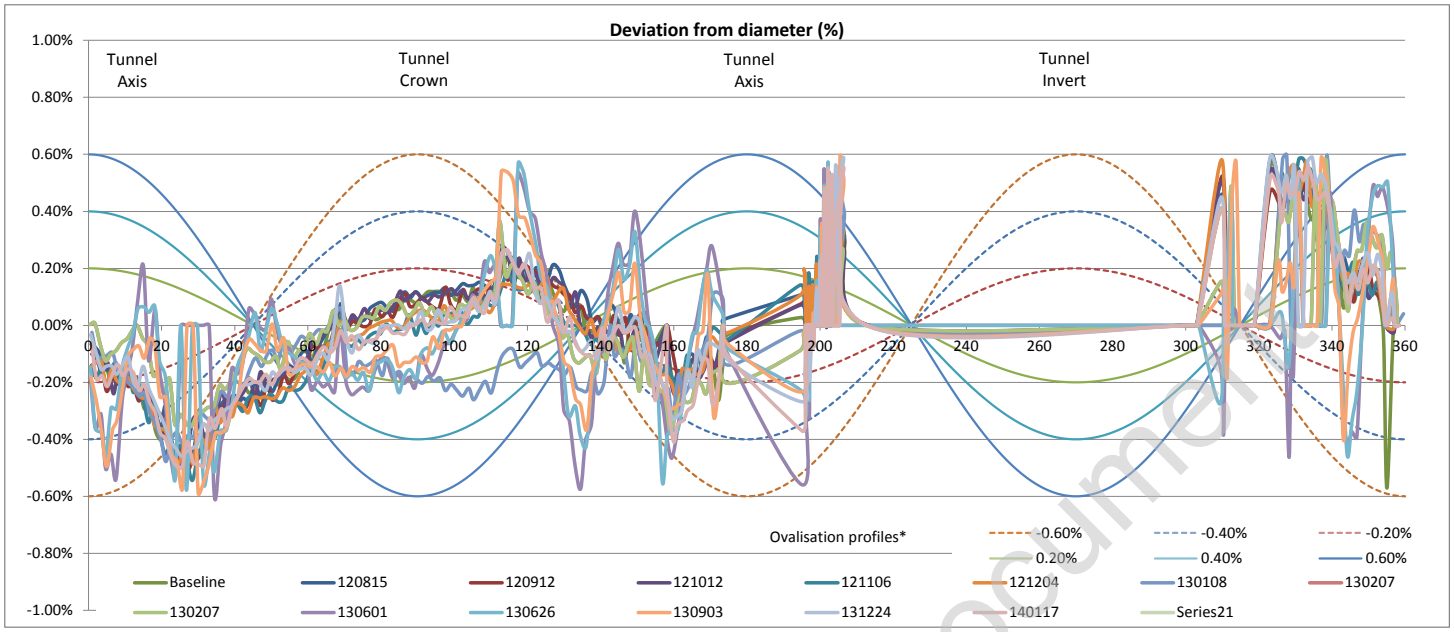
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5263.50 mm
Estimate of vertical diameter at crown, Dv	5282.59 mm
Dh / Dv	0.9964

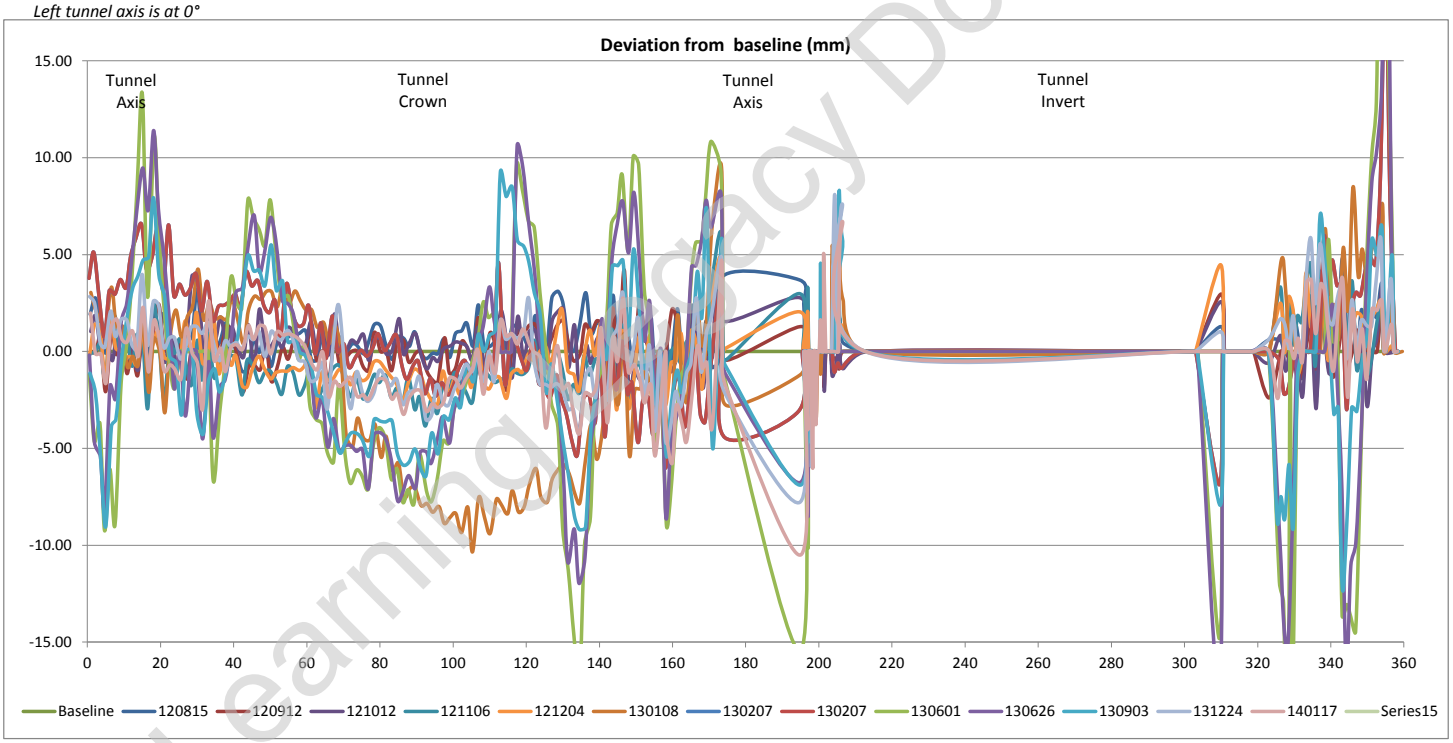
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 1011**

Deviation vs Profile

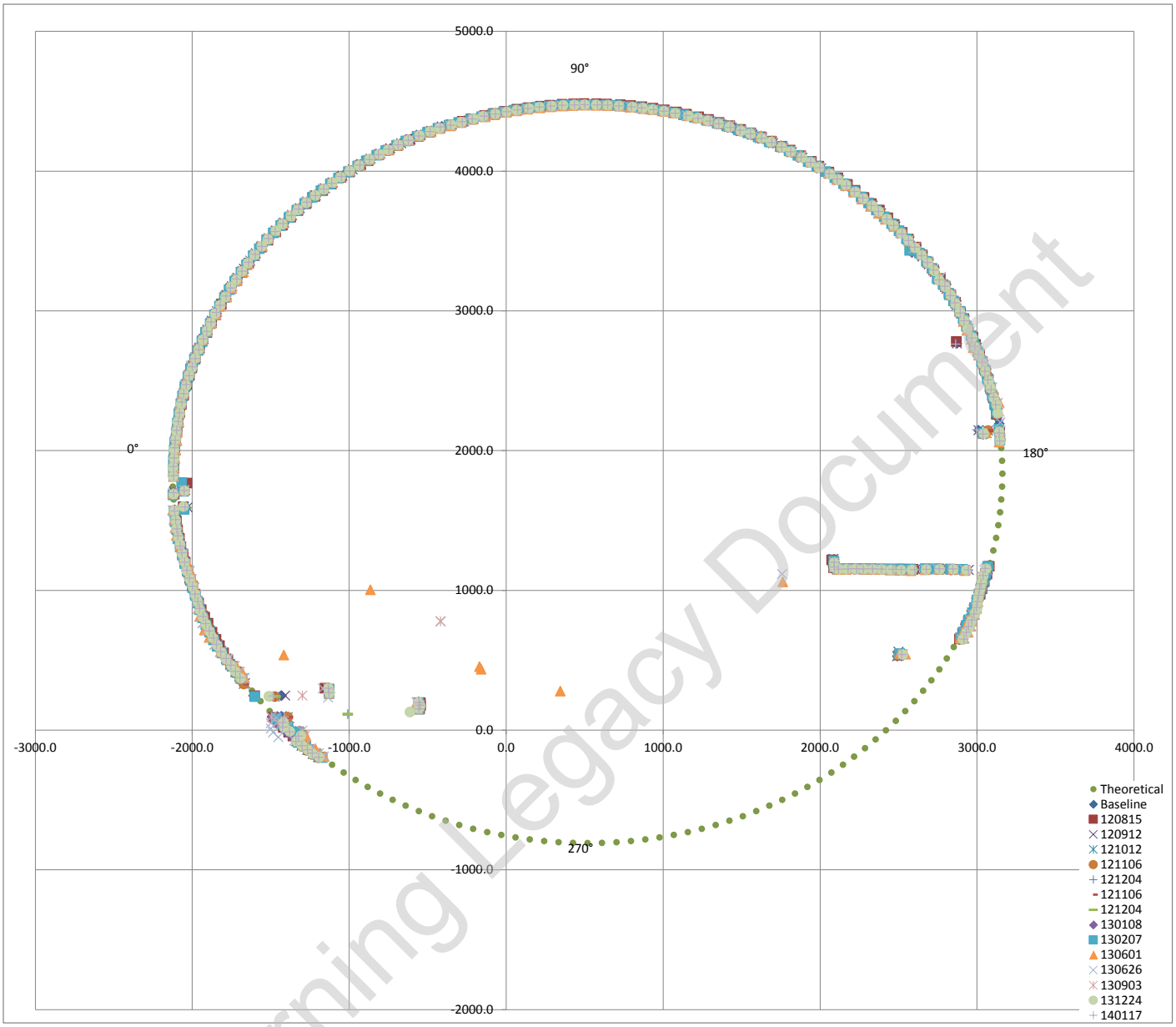


Left tunnel axis is at 0°



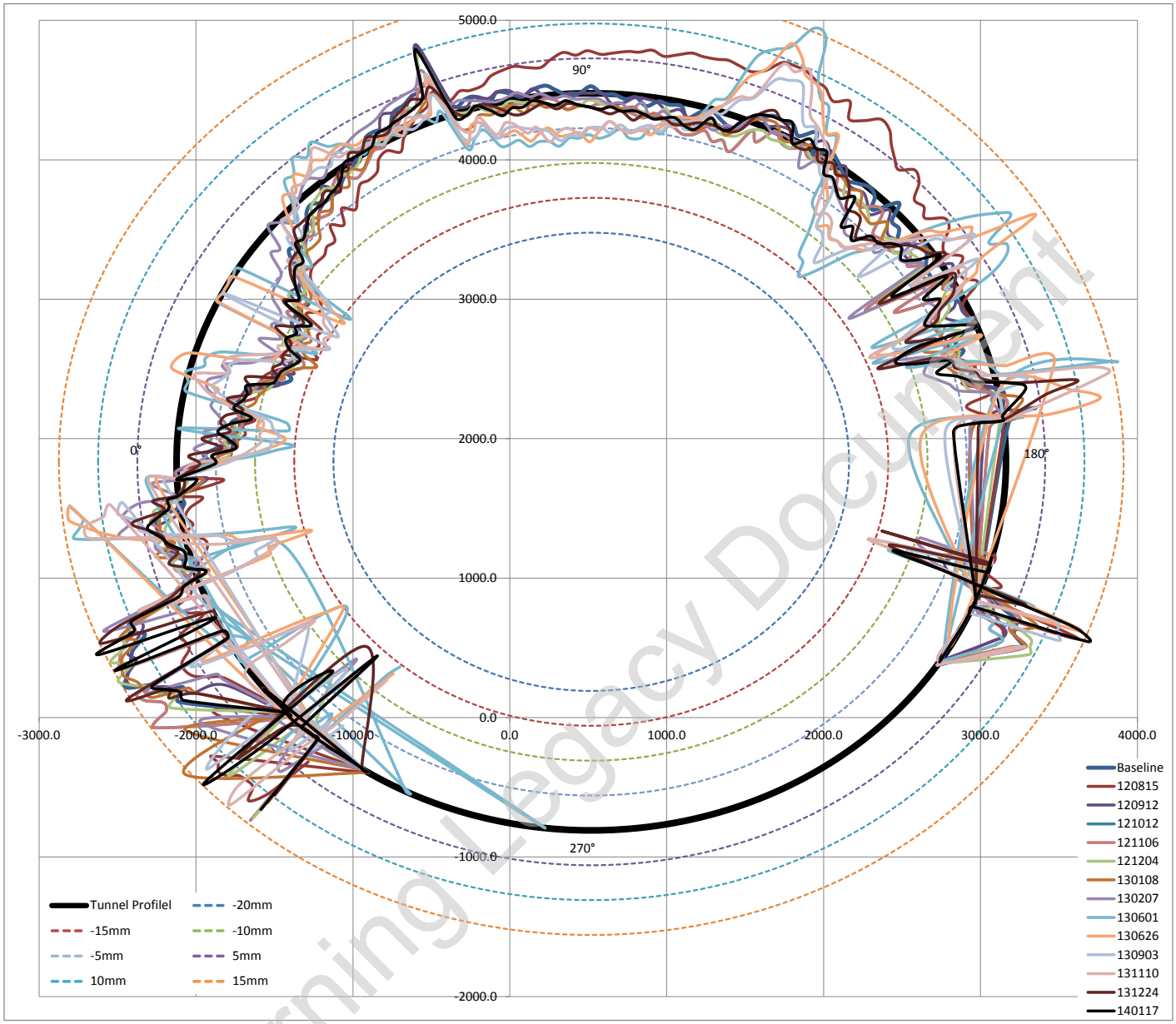
DLR LINE: UP **SECTION: 1012**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1012**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5282.07 mm
Estimated best fit as built diameter	**5286.00 mm**
Difference between average surveyed diameter and best fit diameter	-0.07444%

i.e. Average surveyed diameter varies on -0.074% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

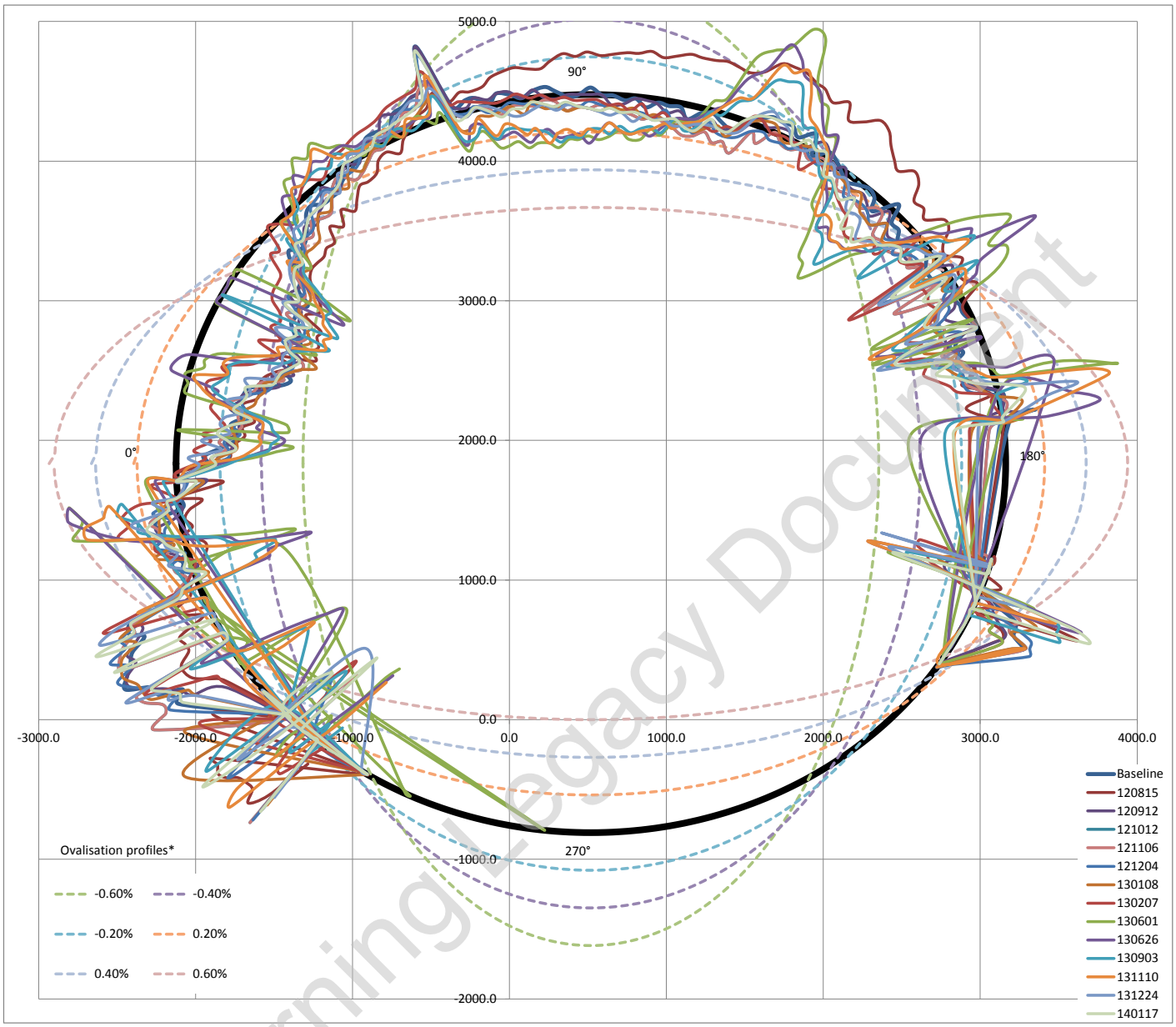
Axis	X	519
	Y	1834
Radius		2643

Max radial difference (+ve) / (-ve) (mm)	**14.6**	**-14.3**
Max / Min deviation % to estimated dia	**0.55%**	**-0.54%**

Estimated best fit as built diameter	5286 mm
Designed diameter	5300 mm
Average diameter difference	**-14** mm
Average radial difference	**-7** mm
Average difference%	**-0.26%**

DLR LINE: **UP** **SECTION:** **1012**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

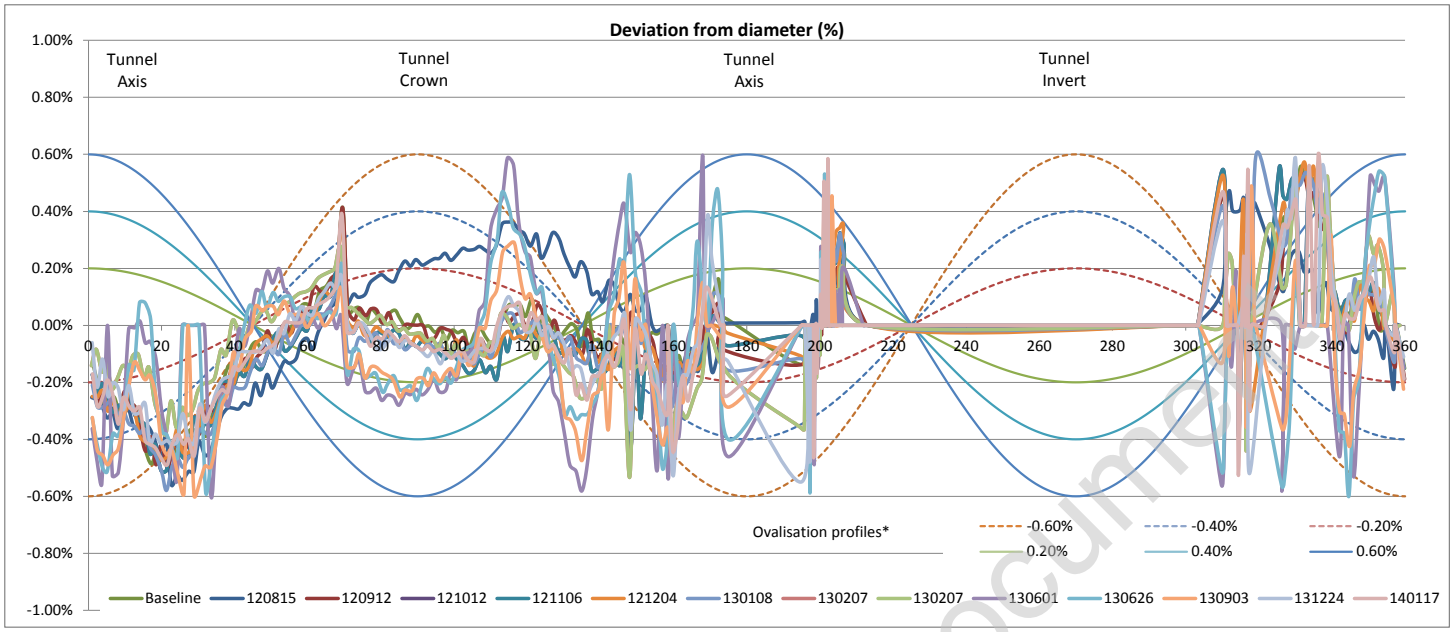
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5283.27 mm
Estimate of vertical diameter at crown, Dv	5285.95 mm
Dh / Dv	0.9995

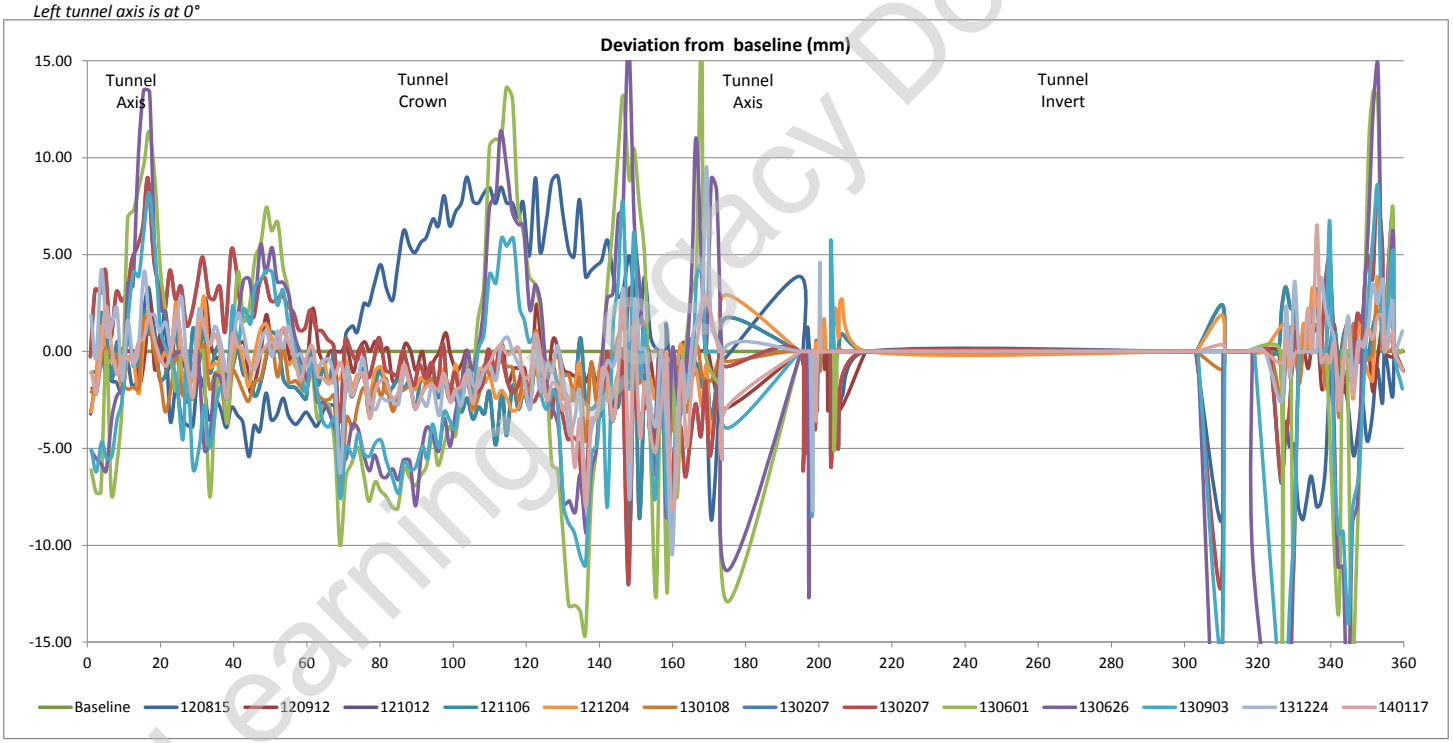
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 1012**

Deviation vs Profile

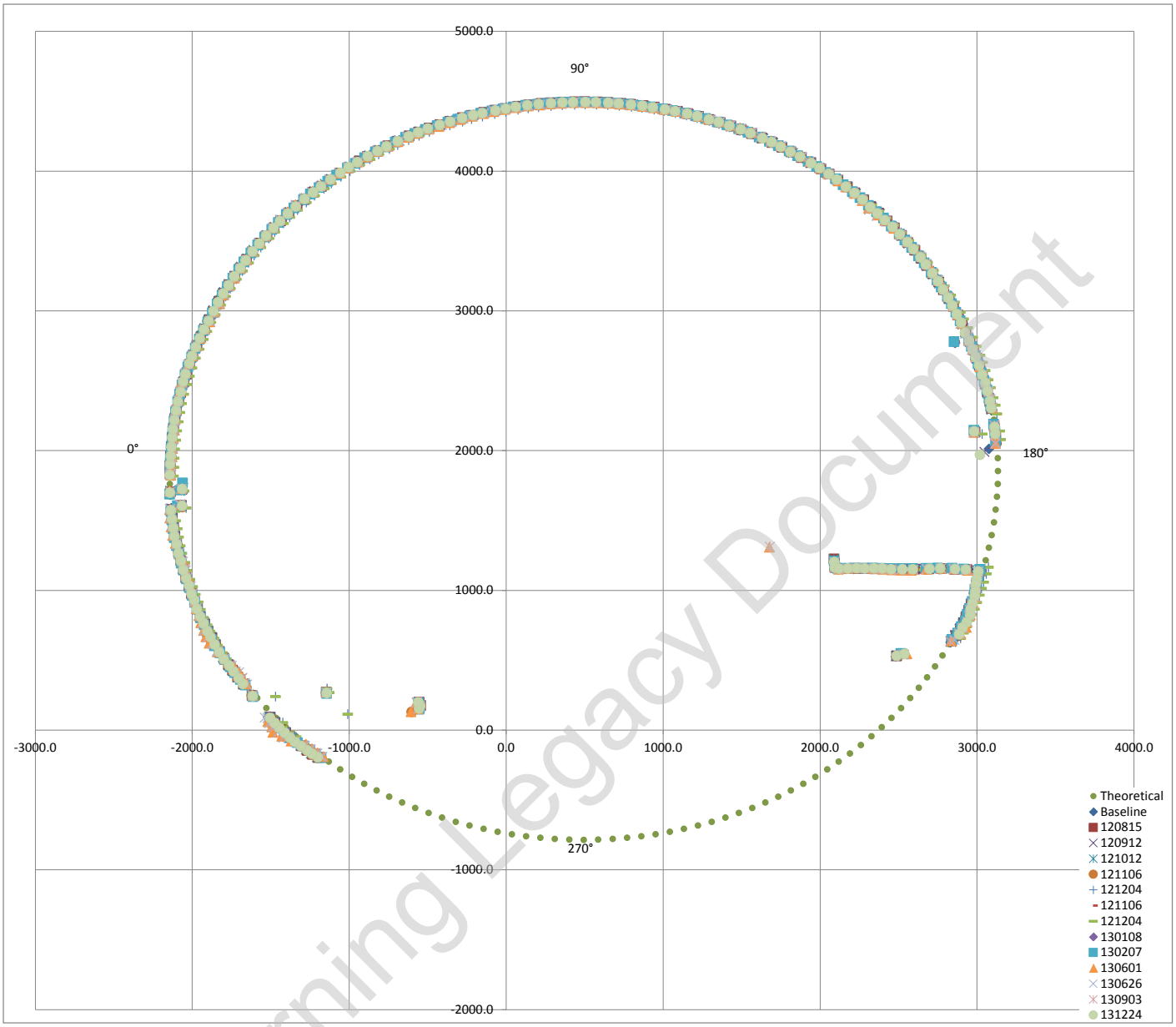


Left tunnel axis is at 0°



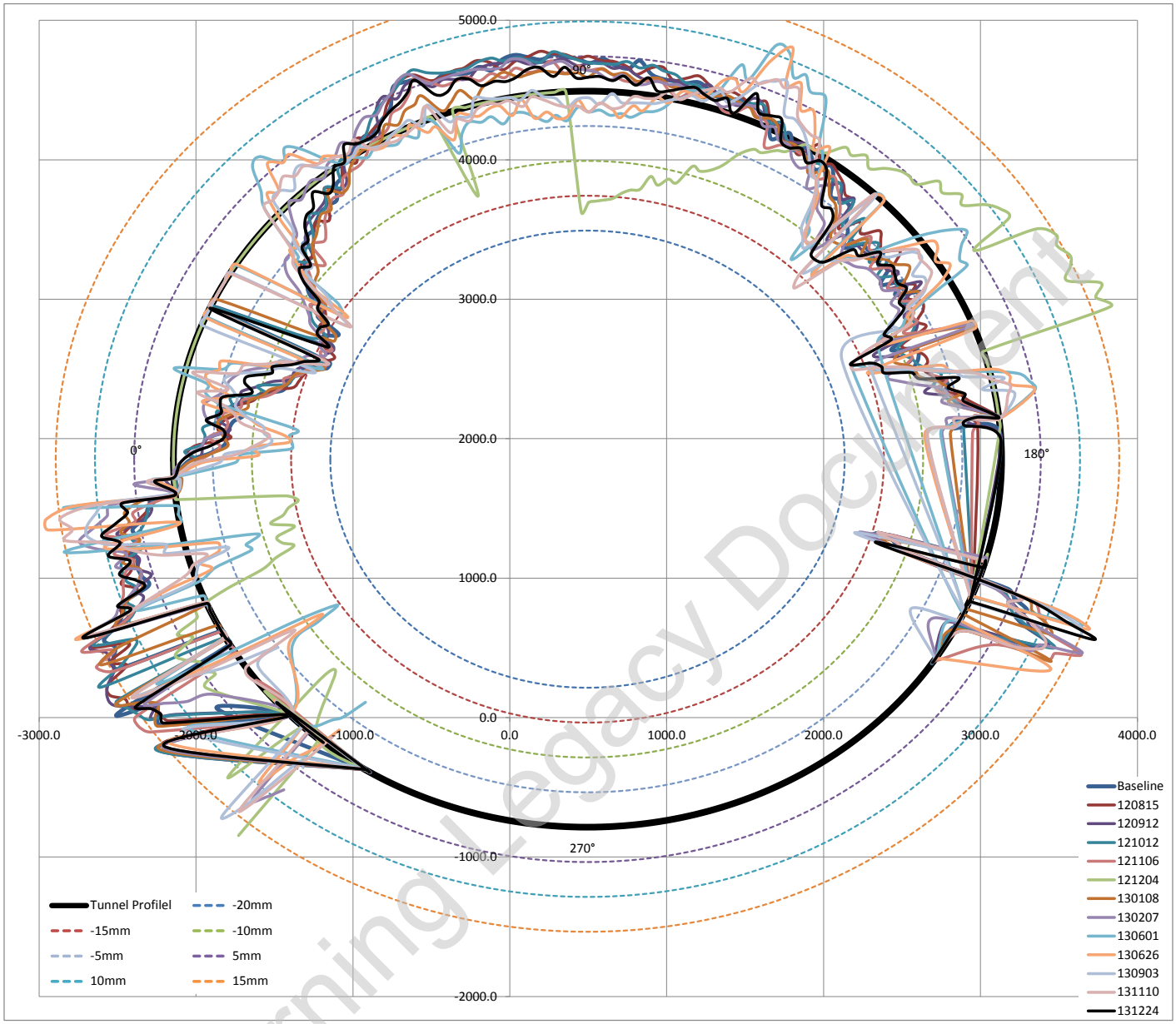
DLR LINE: UP **SECTION: 1013**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1013**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5275.25	mm
Estimated best fit as built diameter	**5278.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.05202%	

i.e. Average surveyed diameter varies on -0.052% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

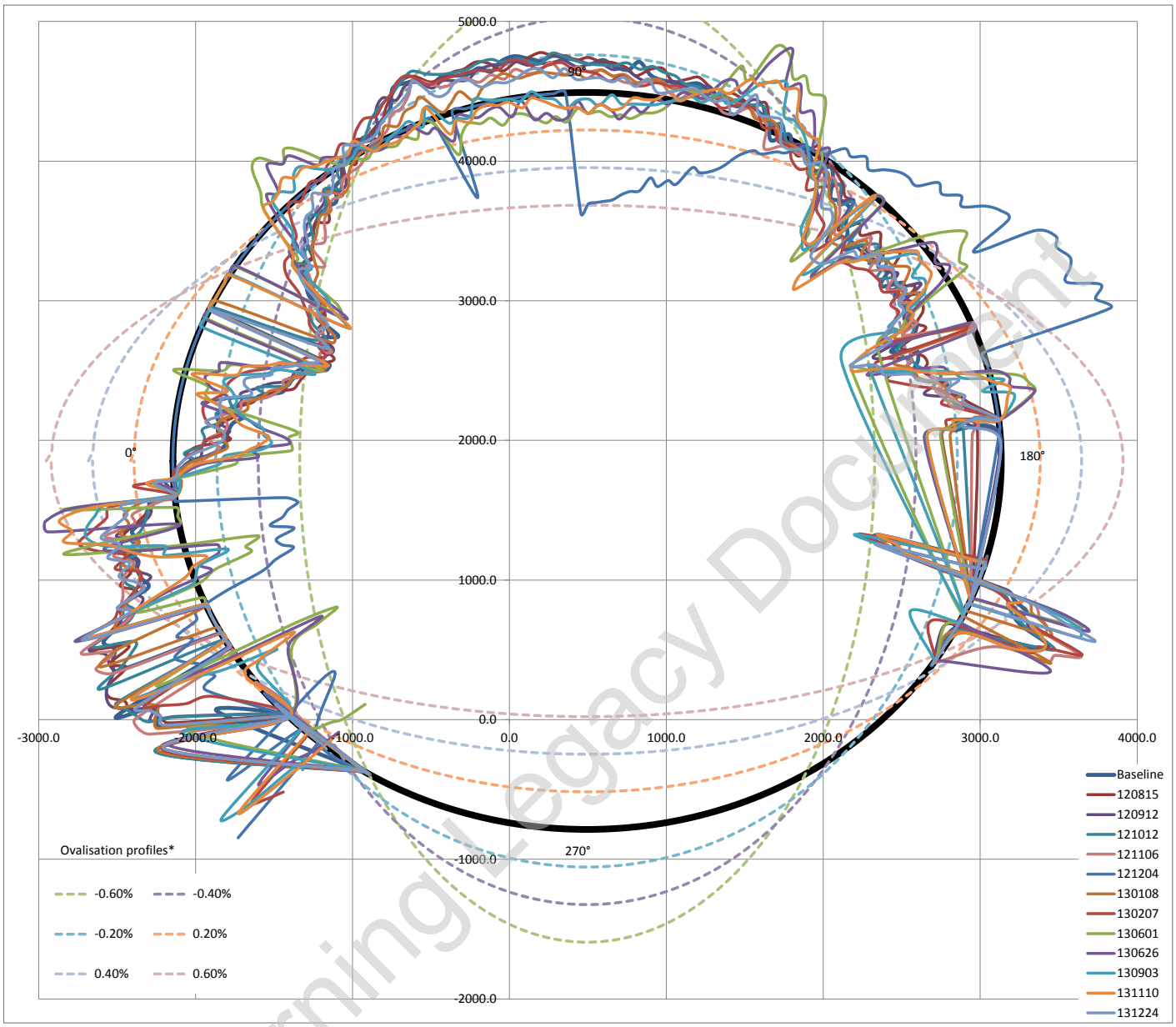
Axis	X	495
	Y	1853
Radius		2639

Max radial difference (+ve) / (-ve) (mm)	**16.7**	**-16.8**
Max / Min deviation % to estimated dia	**0.63%**	**-0.64%**

Estimated best fit as built diameter	5278	mm
Designed diameter	5300	mm
Average diameter difference	**-22**	mm
Average radial difference	**-11**	mm
Average difference%	**-0.42%**	

DLR LINE: **UP** **SECTION:** **1013**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

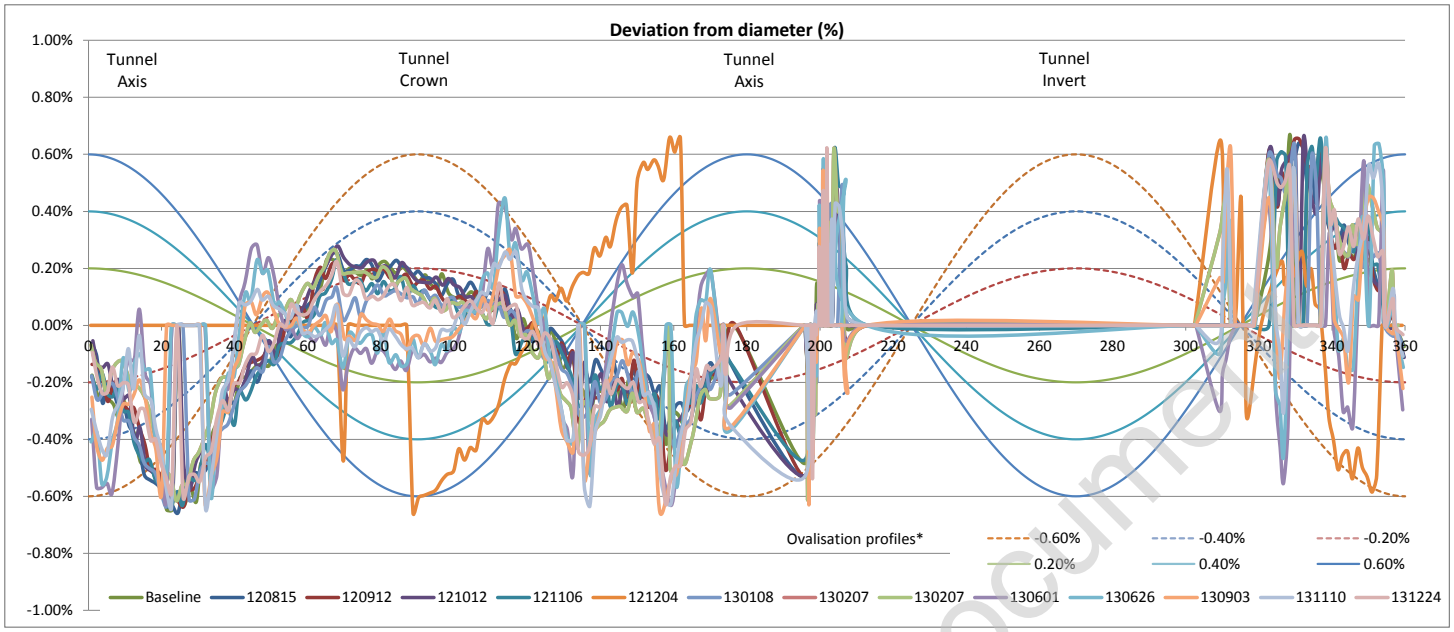
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5269.04 mm
Estimate of vertical diameter at crown, Dv	5282.04 mm
Dh / Dv	0.9975

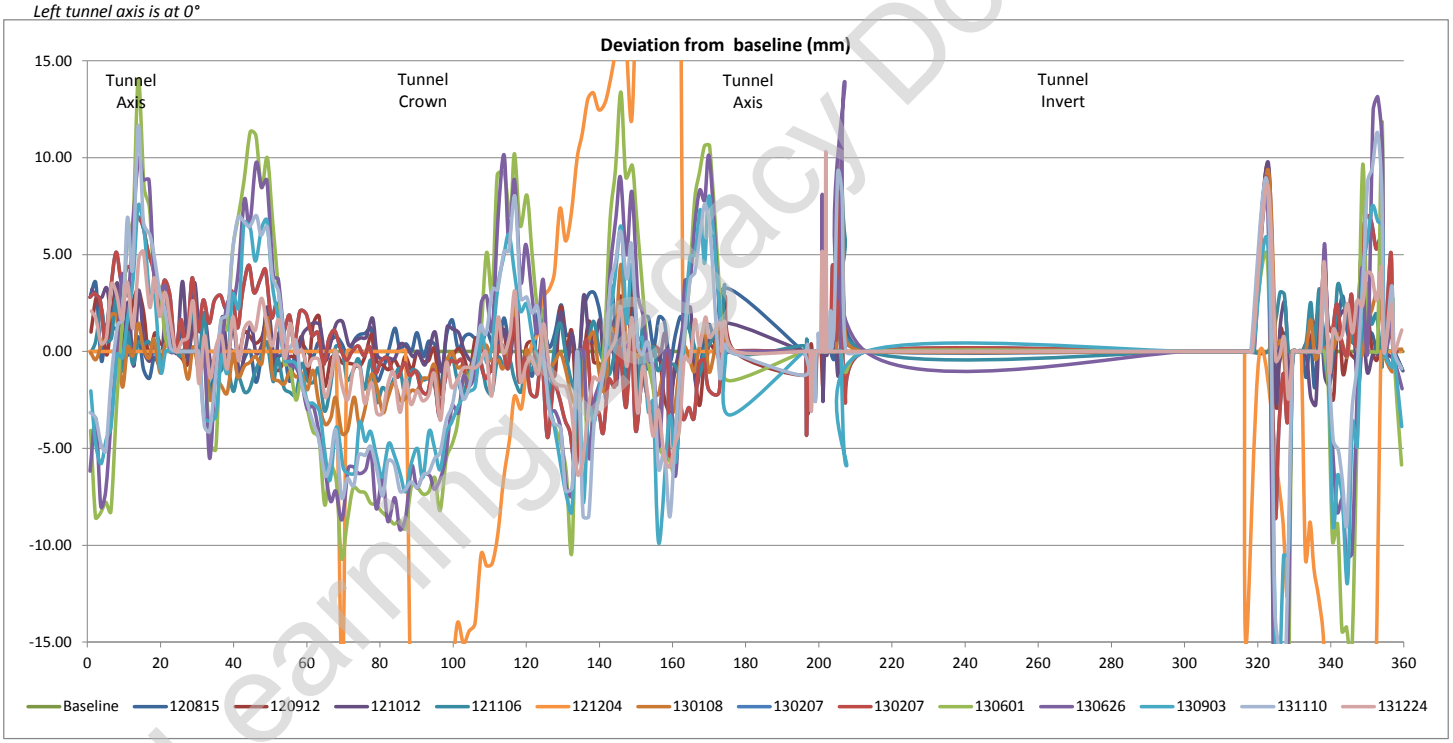
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 1013**

Deviation vs Profile

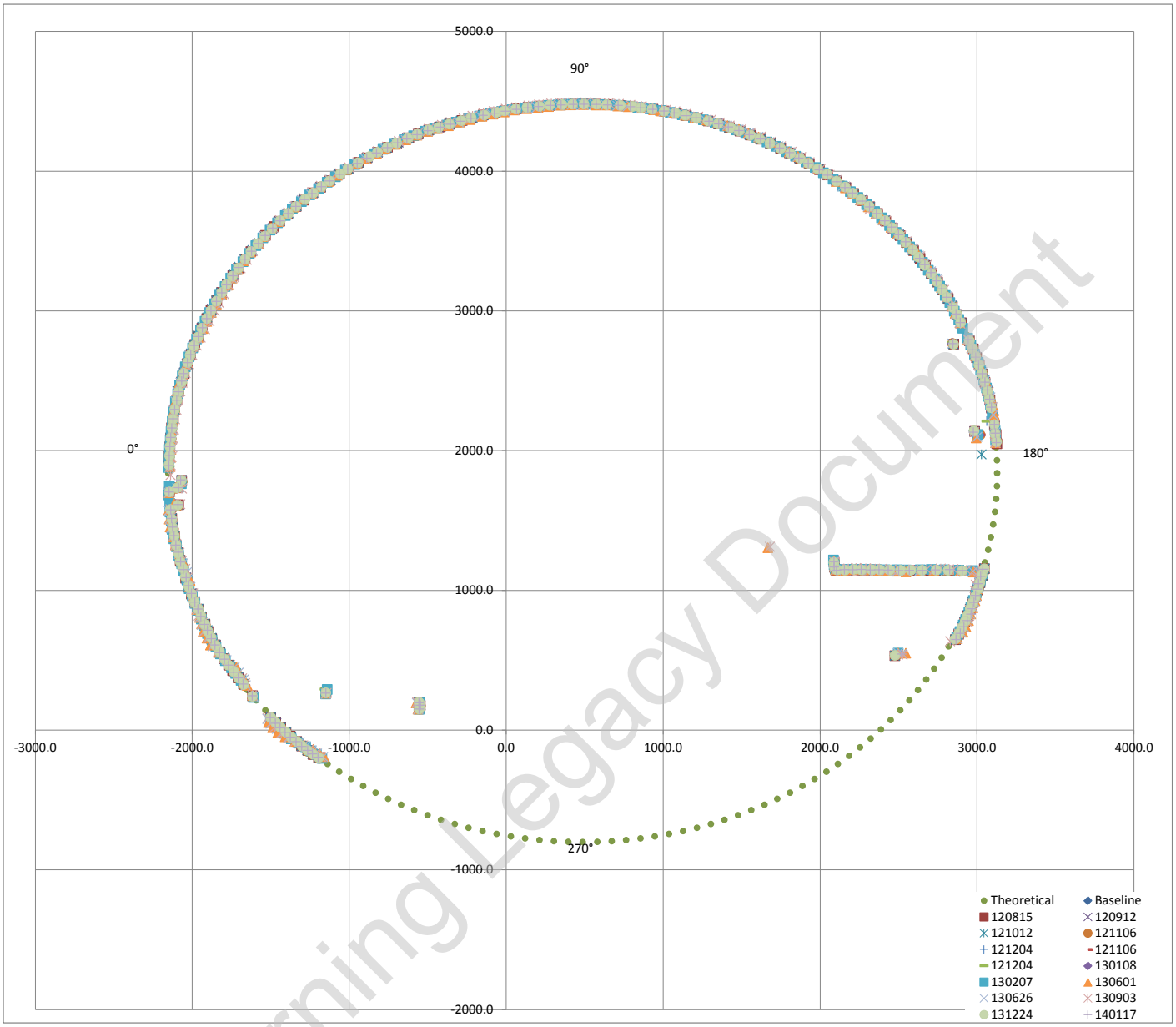


Left tunnel axis is at 0°



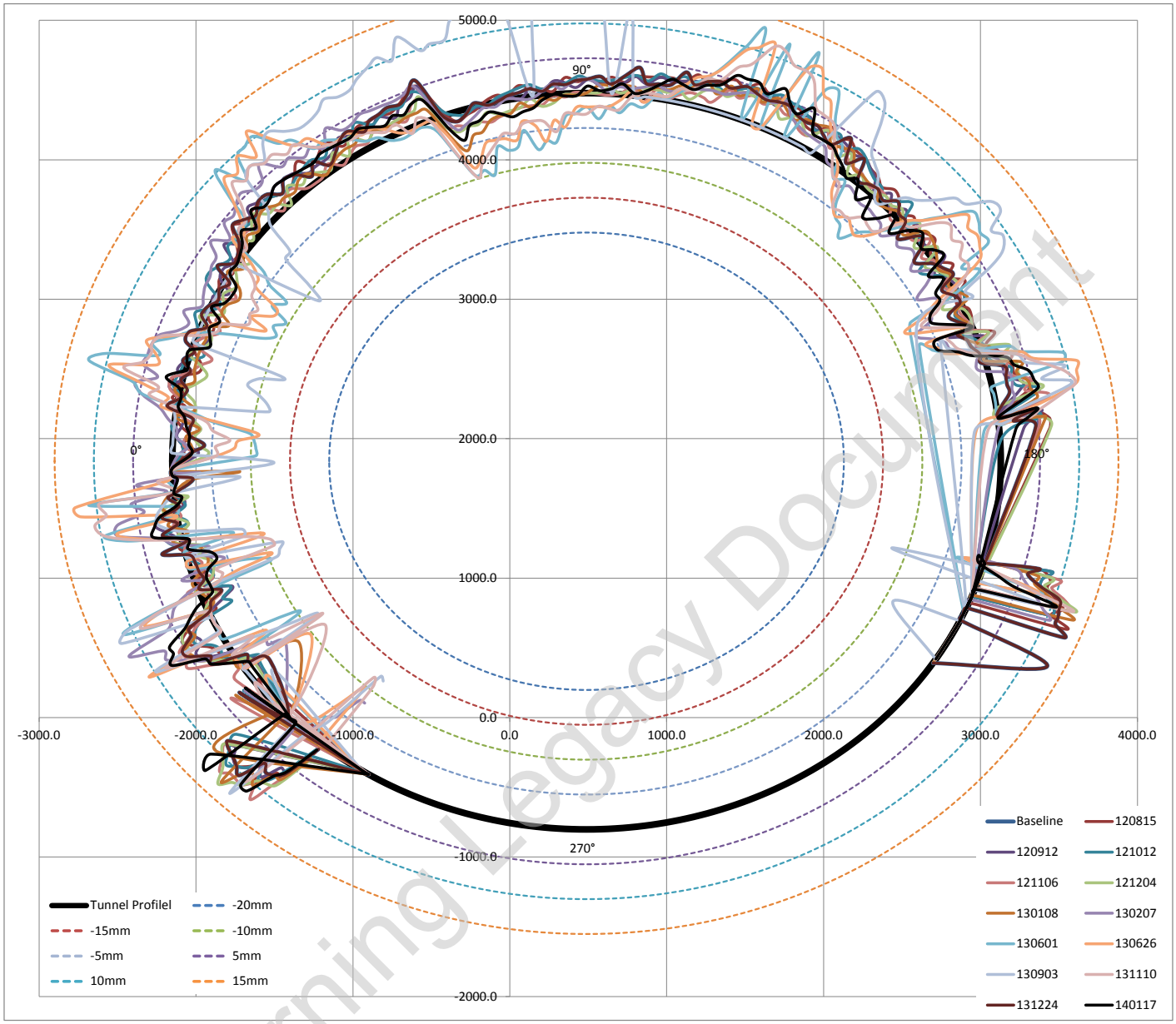
DLR LINE: UP **SECTION: 1014**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1014**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5282.28	mm
Estimated best fit as built diameter	**5280.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.04309%	

i.e. Average surveyed diameter varies on 0.043% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

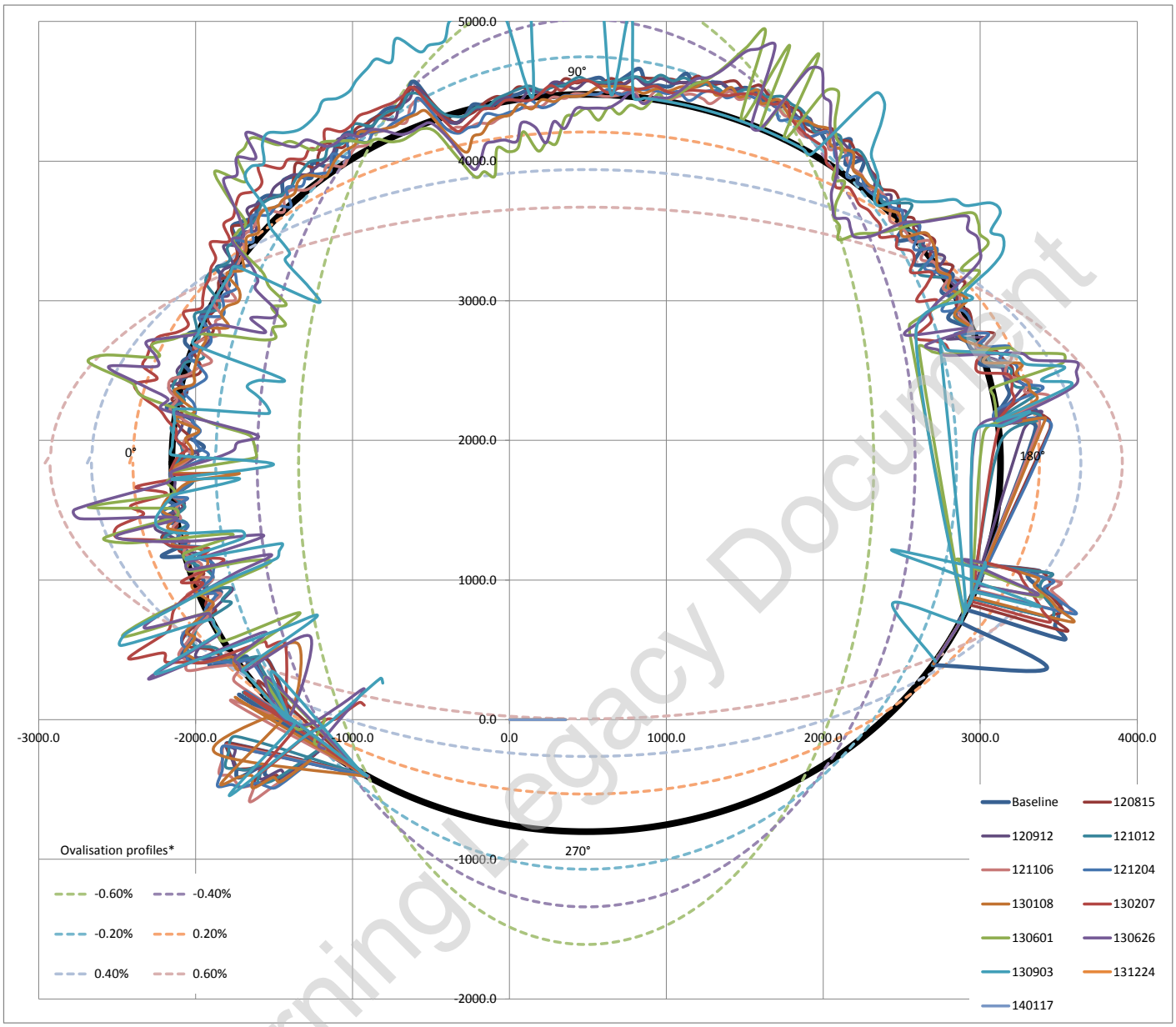
Axis	X	489
	Y	1838
Radius		2640

Max radial difference (+ve) / (-ve) (mm)	**12.5**	**-6.9**
Max / Min deviation % to estimated dia	**0.47%**	**-0.26%**

Estimated best fit as built diameter	5280	mm
Designed diameter	5300	mm
Average diameter difference	**-20**	mm
Average radial difference	**-10**	mm
Average difference%	**-0.38%**	

DLR LINE: **UP** **SECTION:** **1014**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

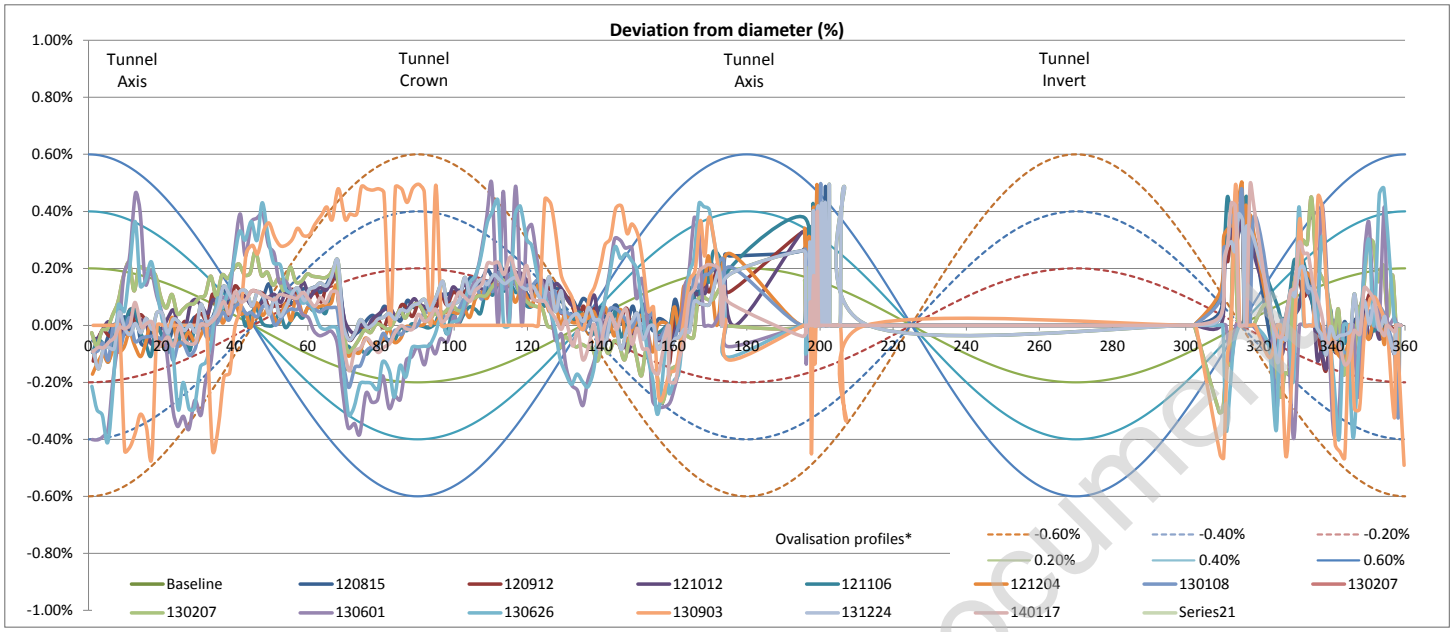
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5282.36	mm
Estimate of vertical diameter at crown, Dv	5282.40	mm
Dh / Dv	1.0000	

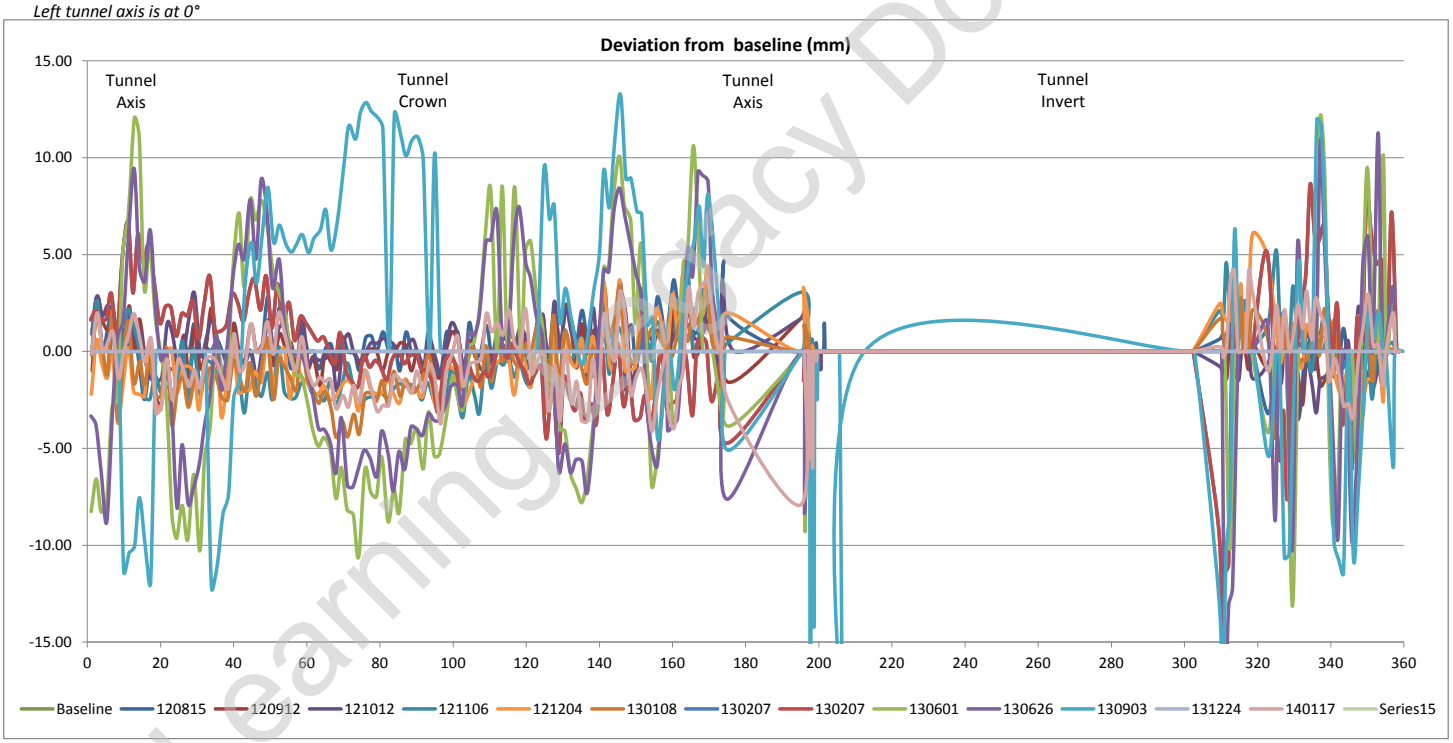
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 1014**

Deviation vs Profile

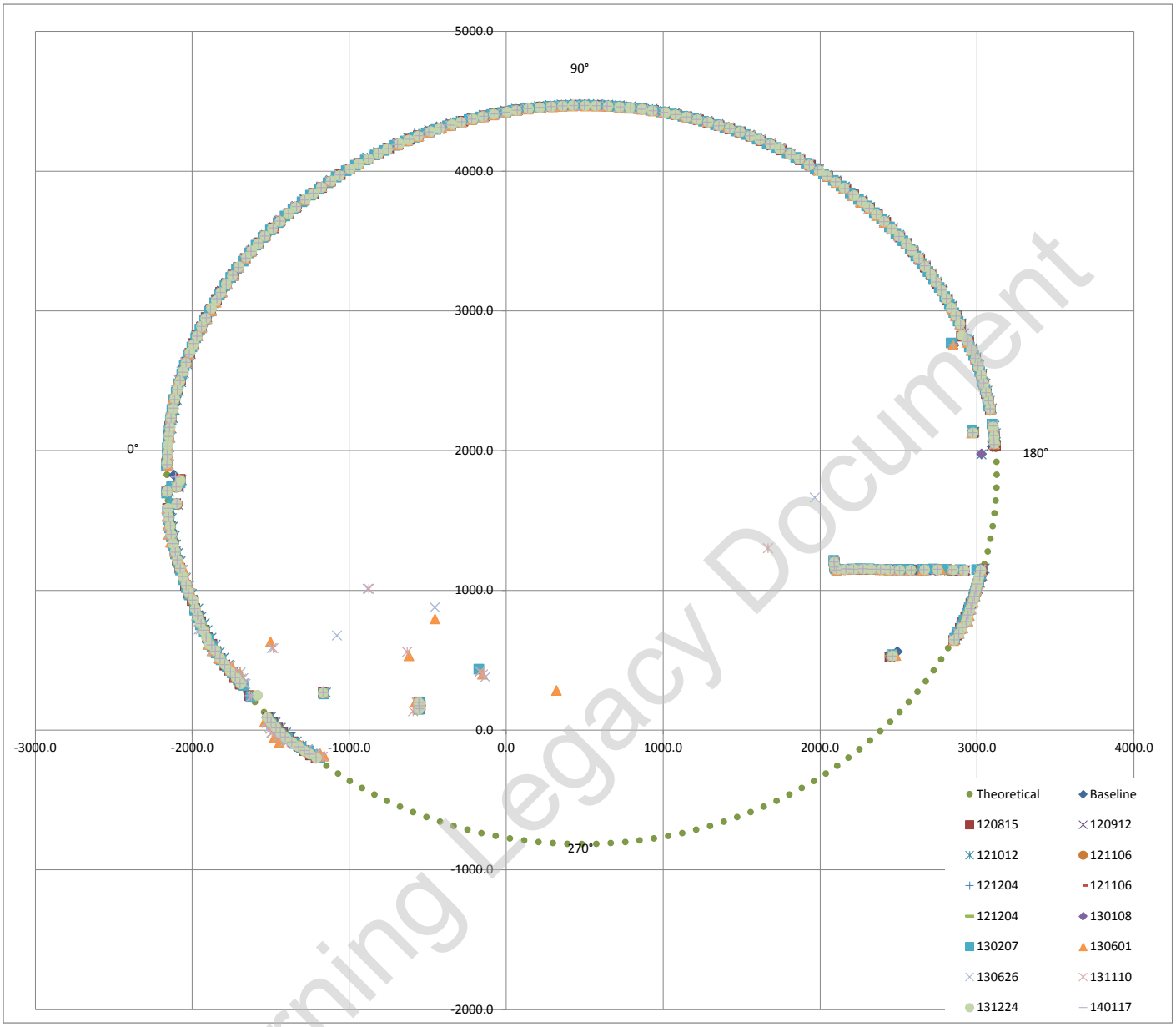


Left tunnel axis is at 0°



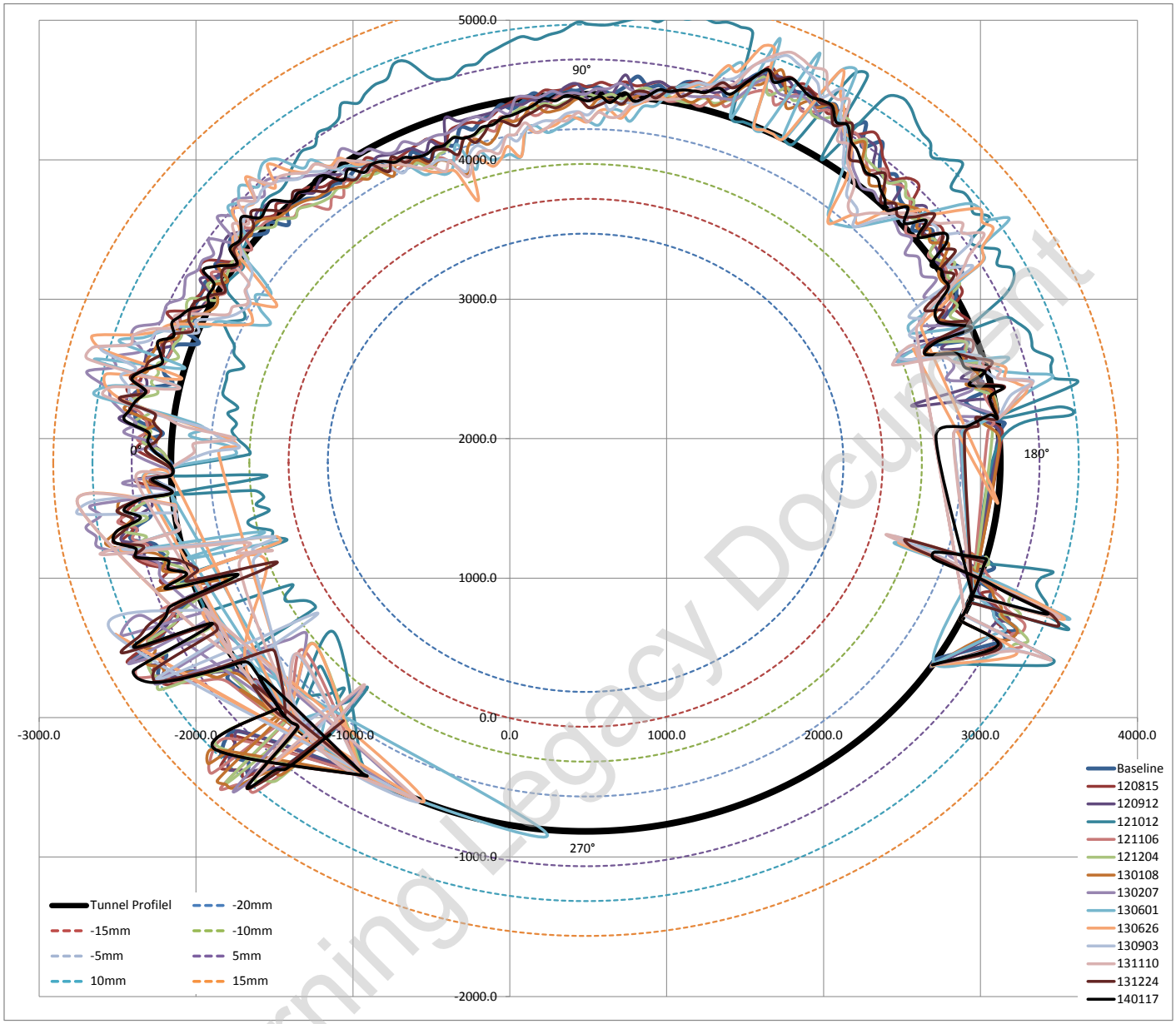
DLR LINE: UP **SECTION: 1015**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1015**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5288.61	mm
Estimated best fit as built diameter	**5286.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.04929%	

i.e. Average surveyed diameter varies on 0.049% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

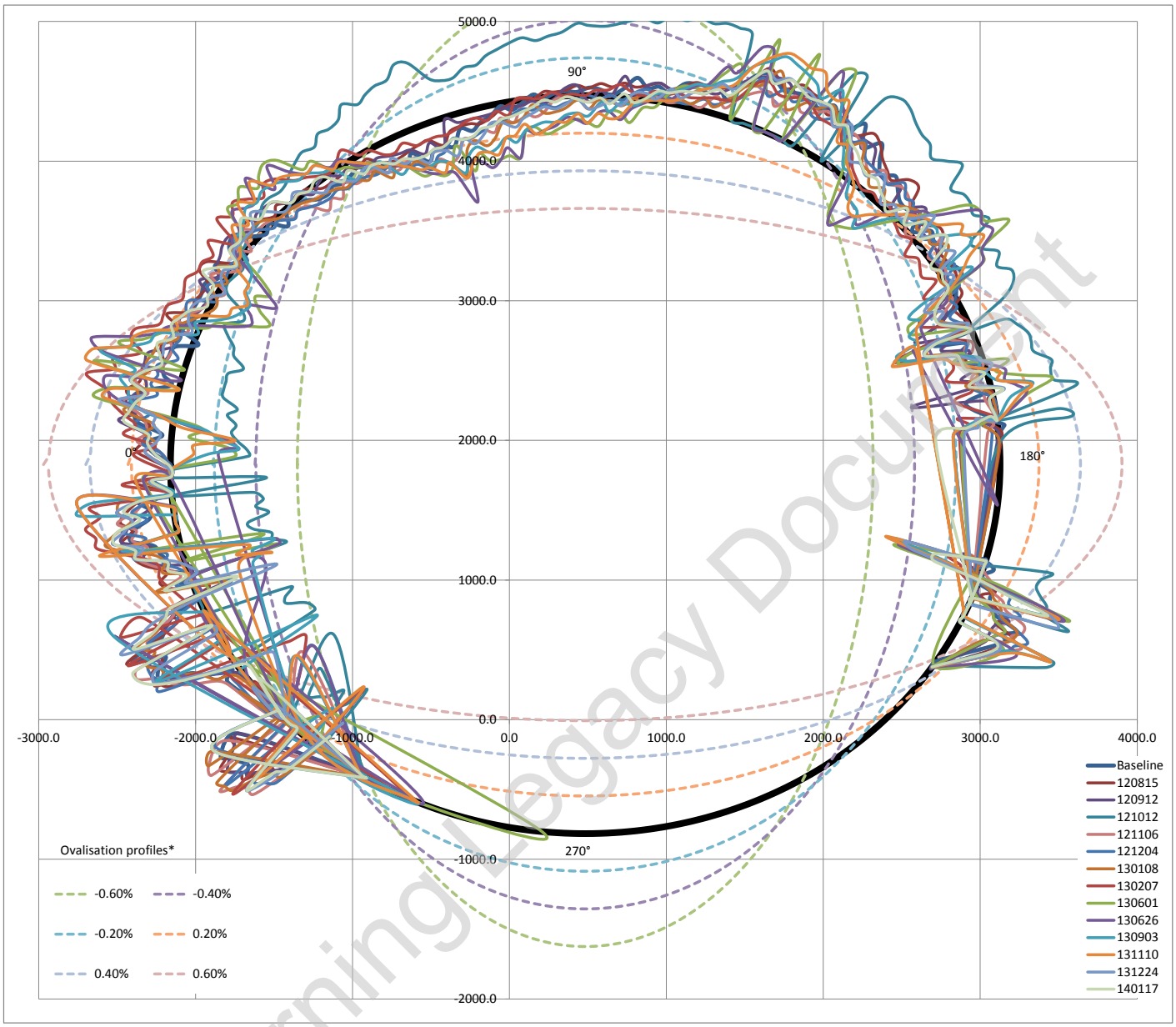
Axis	X	483
	Y	1827
Radius		2643

Max radial difference (+ve) / (-ve) (mm)	**12.3**	**-9.9**
Max / Min deviation % to estimated dia	**0.47%**	**-0.38%**

Estimated best fit as built diameter	5286	mm
Designed diameter	5300	mm
Average diameter difference	**-14**	mm
Average radial difference	**-7**	mm
Average difference%	**-0.26%**	

DLR LINE: **UP** **SECTION:** **1015**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

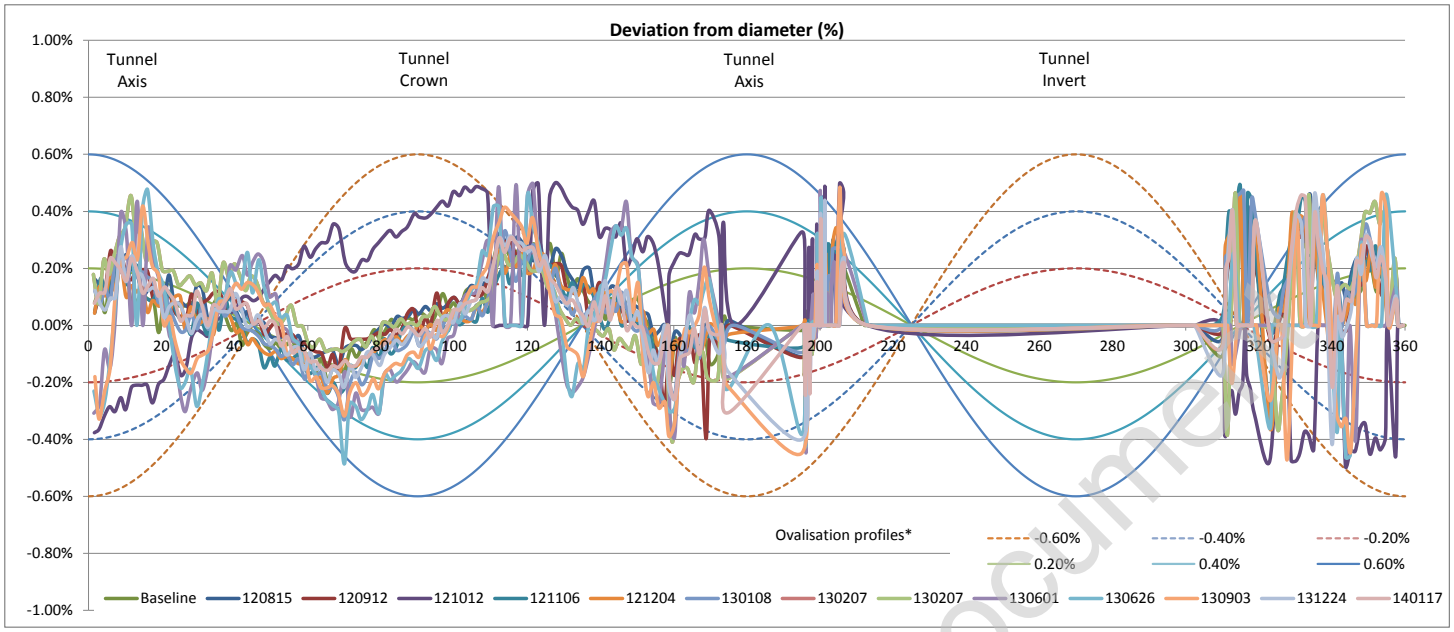
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5284.52 mm
Estimate of vertical diameter at crown, Dv	5286.85 mm
Dh / Dv	0.9996

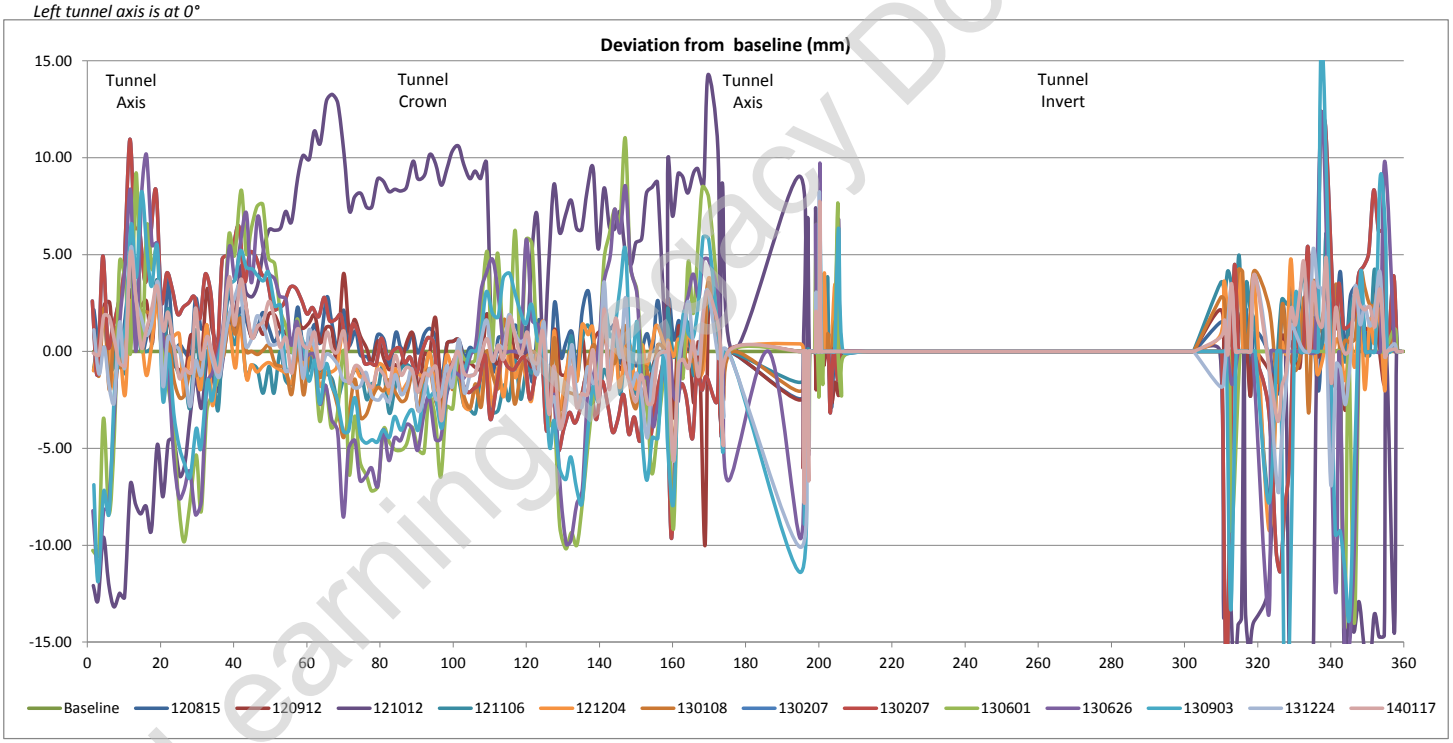
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 1015**

Deviation vs Profile

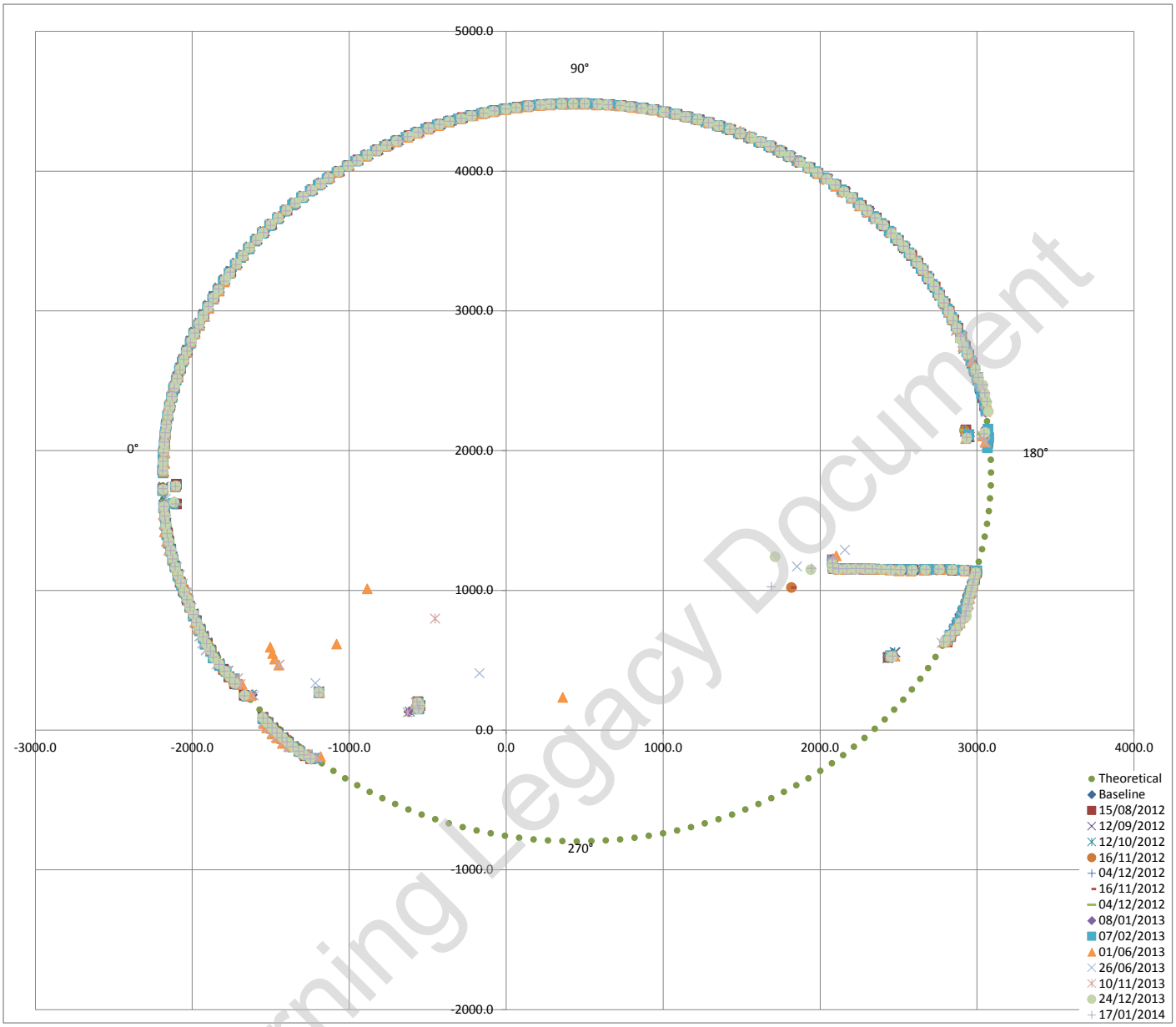


Left tunnel axis is at 0°



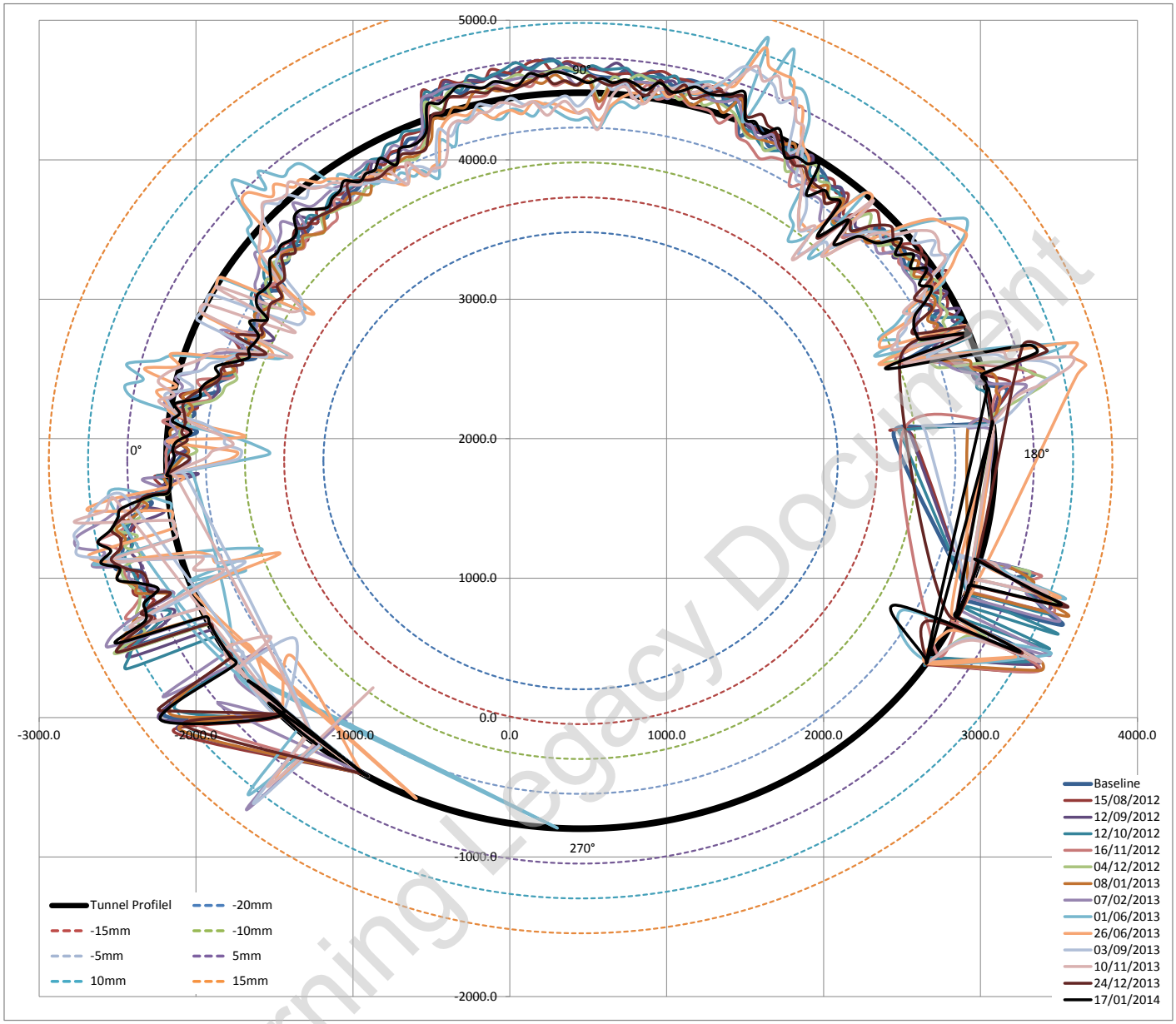
DLR LINE: UP **SECTION: 1016**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1016**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5278.26 mm
Estimated best fit as built diameter	**5278.00 mm**
Difference between average surveyed diameter and best fit diameter	0.00494%

i.e. Average surveyed diameter varies on 0.004% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

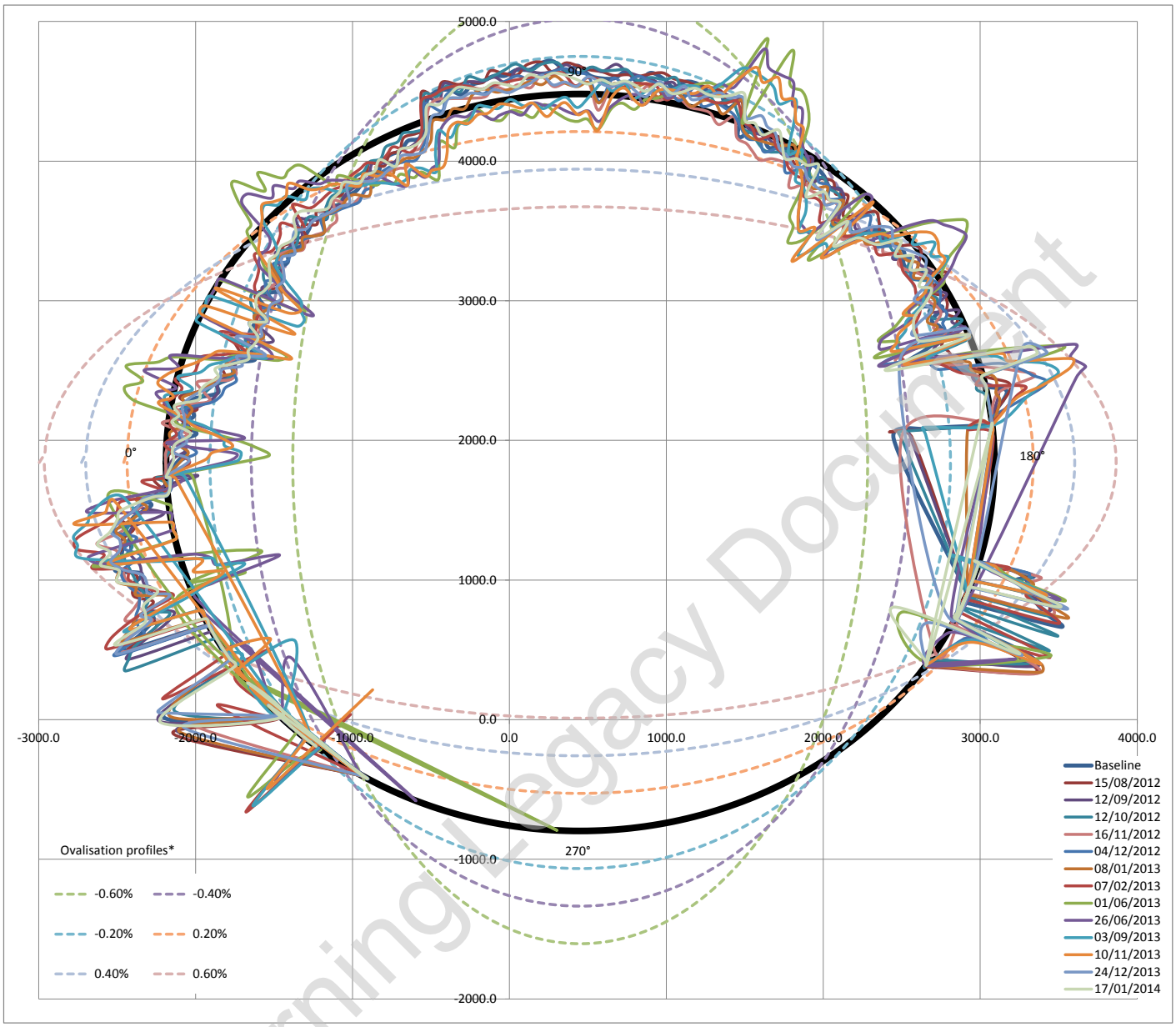
Axis	X	451
	Y	1842
Radius		2639

Max radial difference (+ve) / (-ve) (mm)	**12.8**	**-11.6**
Max / Min deviation % to estimated dia	**0.49%**	**-0.44%**

Estimated best fit as built diameter	5278 mm
Designed diameter	5300 mm
Average diameter difference	**-22** mm
Average radial difference	**-11** mm
Average difference%	**-0.42%**

DLR LINE: **UP** **SECTION:** **1016**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

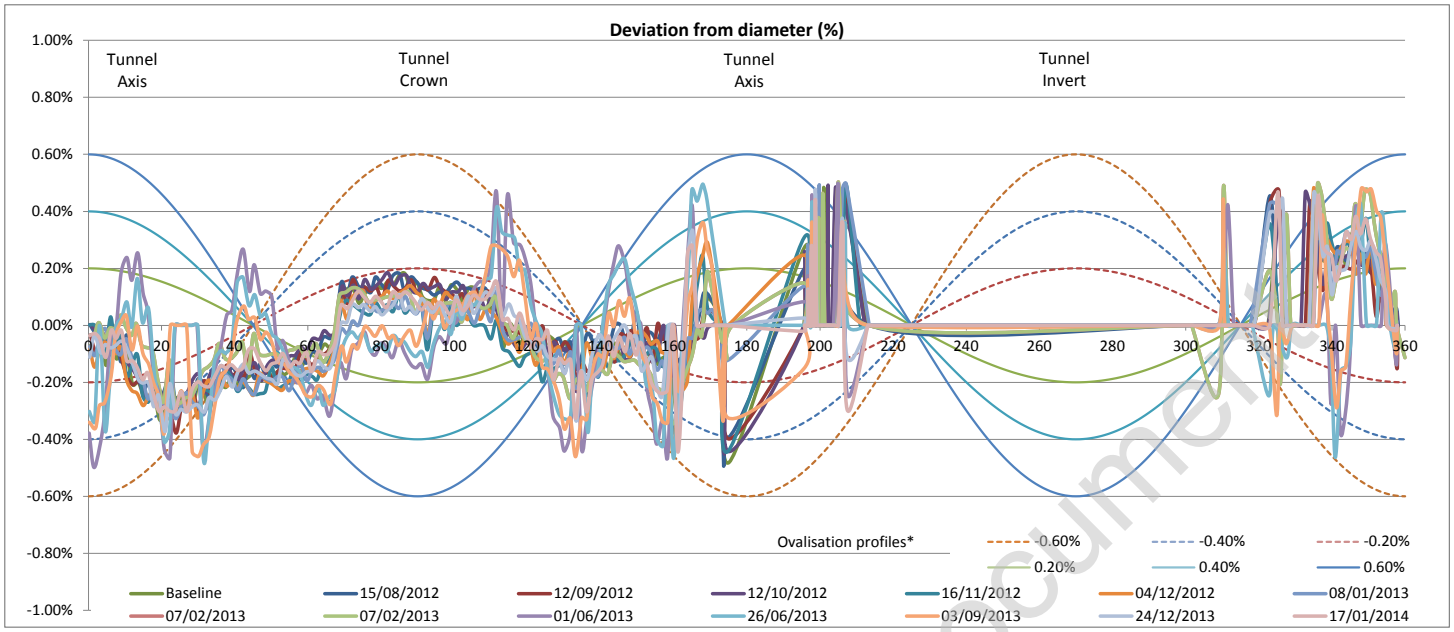
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5278.70 mm
Estimate of vertical diameter at crown, Dv	5280.66 mm
Dh / Dv	0.9996

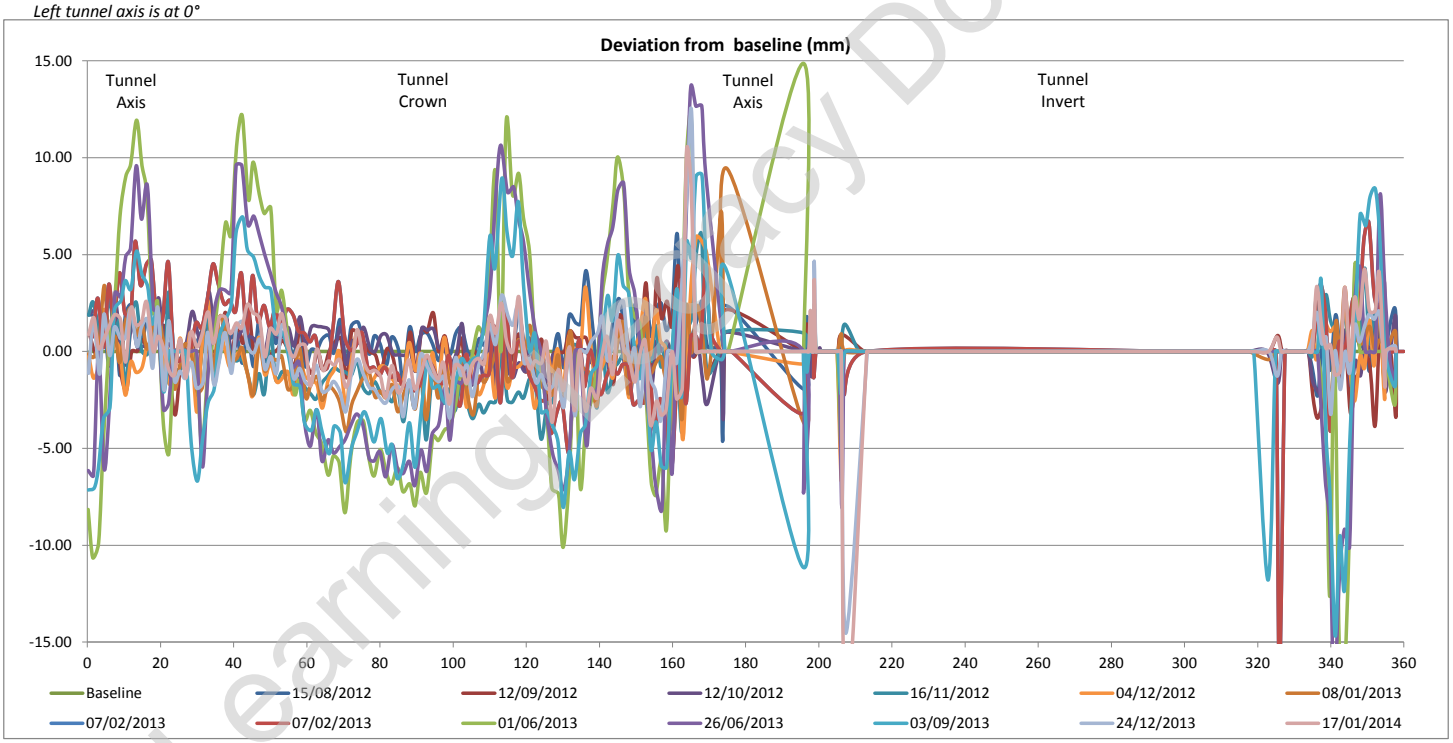
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 1016**

Deviation vs Profile

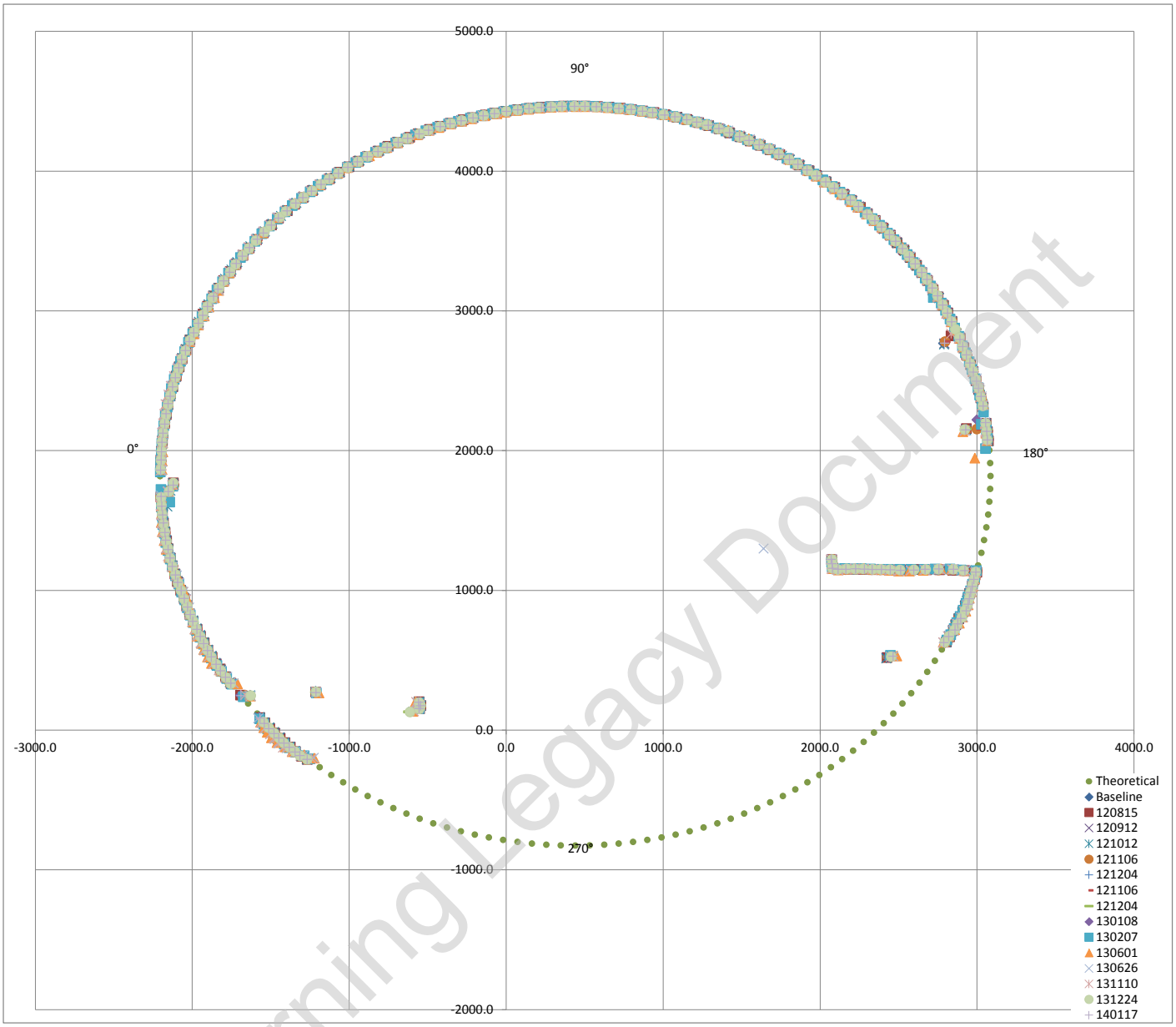


Left tunnel axis is at 0°



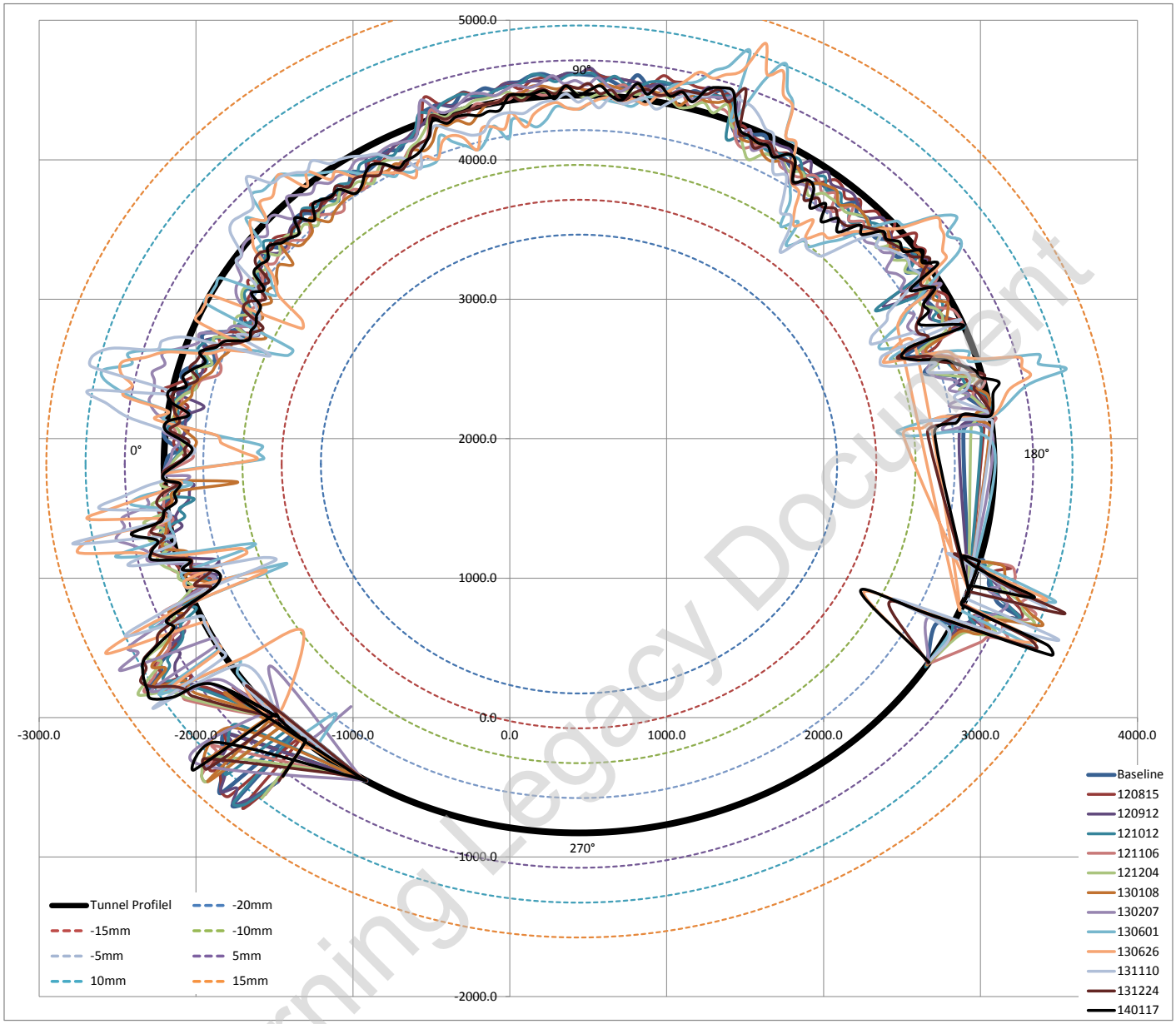
DLR LINE: UP **SECTION: 1017**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1017**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5288.34	mm
Estimated best fit as built diameter	**5290.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.03139%	

i.e. Average surveyed diameter varies on -0.031% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

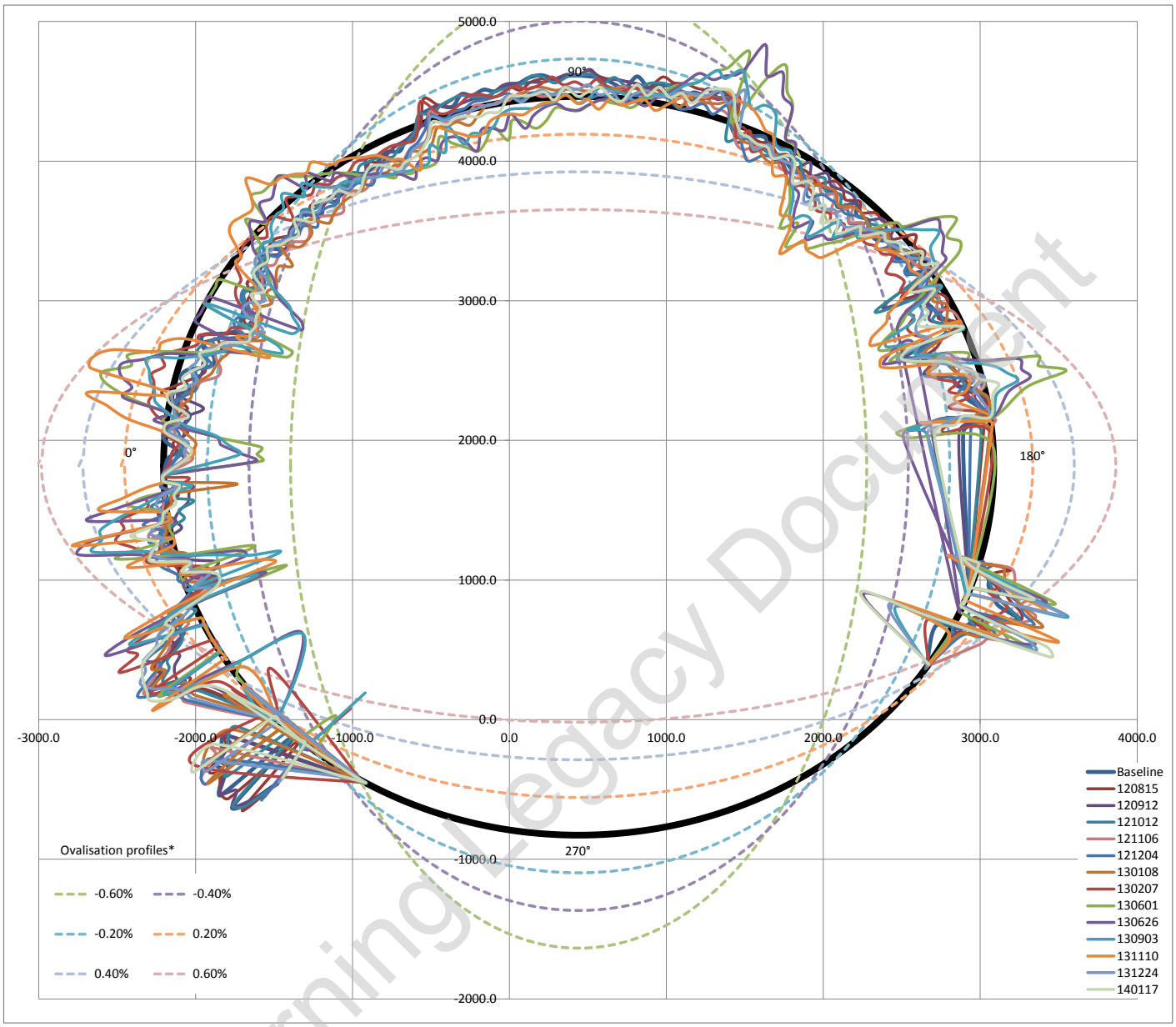
Axis	X	441
	Y	1818
Radius		2645

Max radial difference (+ve) / (-ve) (mm)	**12.7**	**-10.0**
Max / Min deviation % to estimated dia	**0.48%**	**-0.38%**

Estimated best fit as built diameter	5290	mm
Designed diameter	5300	mm
Average diameter difference	**-10**	mm
Average radial difference	**-5**	mm
Average difference%	**-0.19%**	

DLR LINE: **UP** **SECTION:** **1017**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

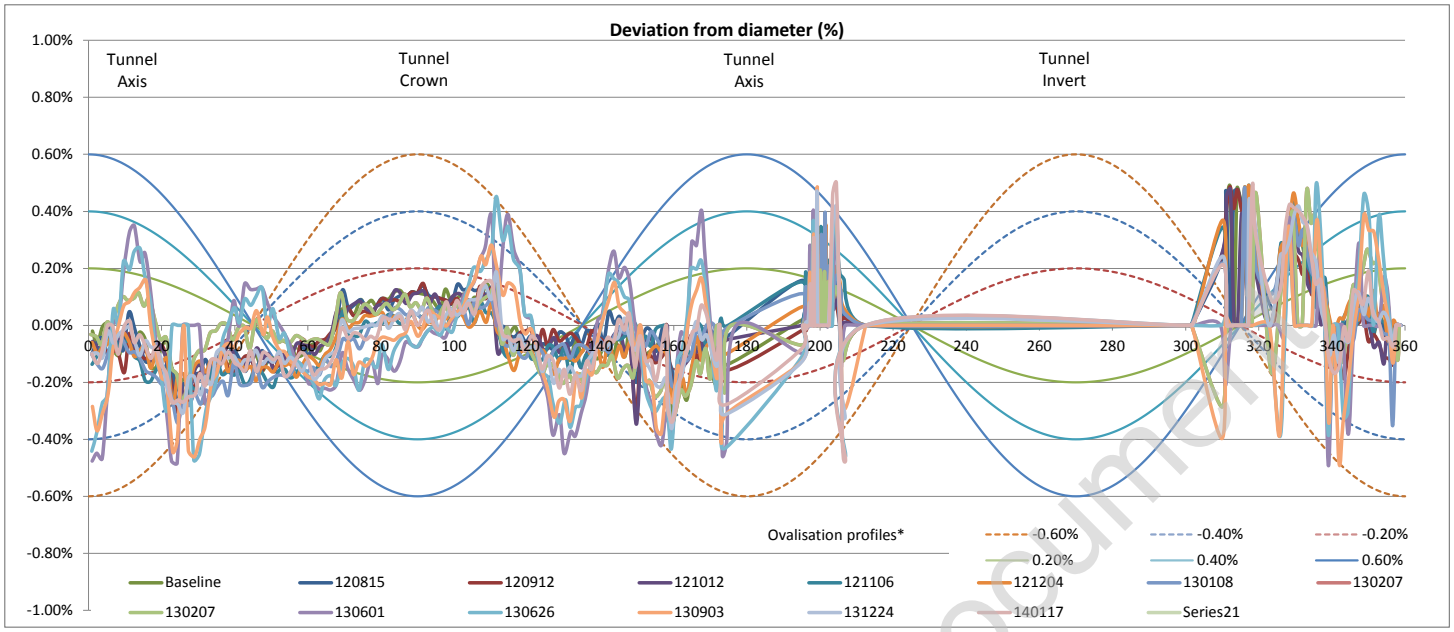
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5286.98	mm
Estimate of vertical diameter at crown, Dv	5292.90	mm
Dh / Dv	0.9989	

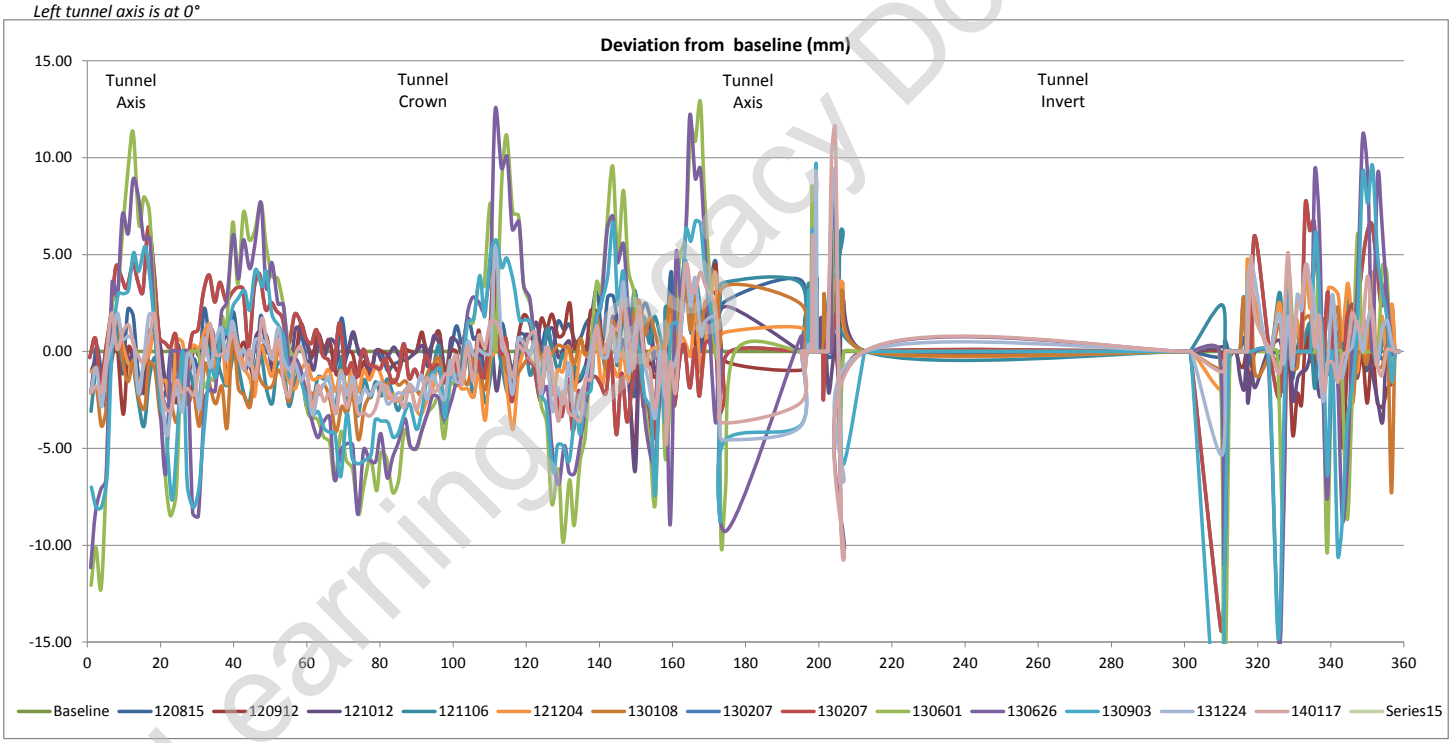
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 1017**

Deviation vs Profile

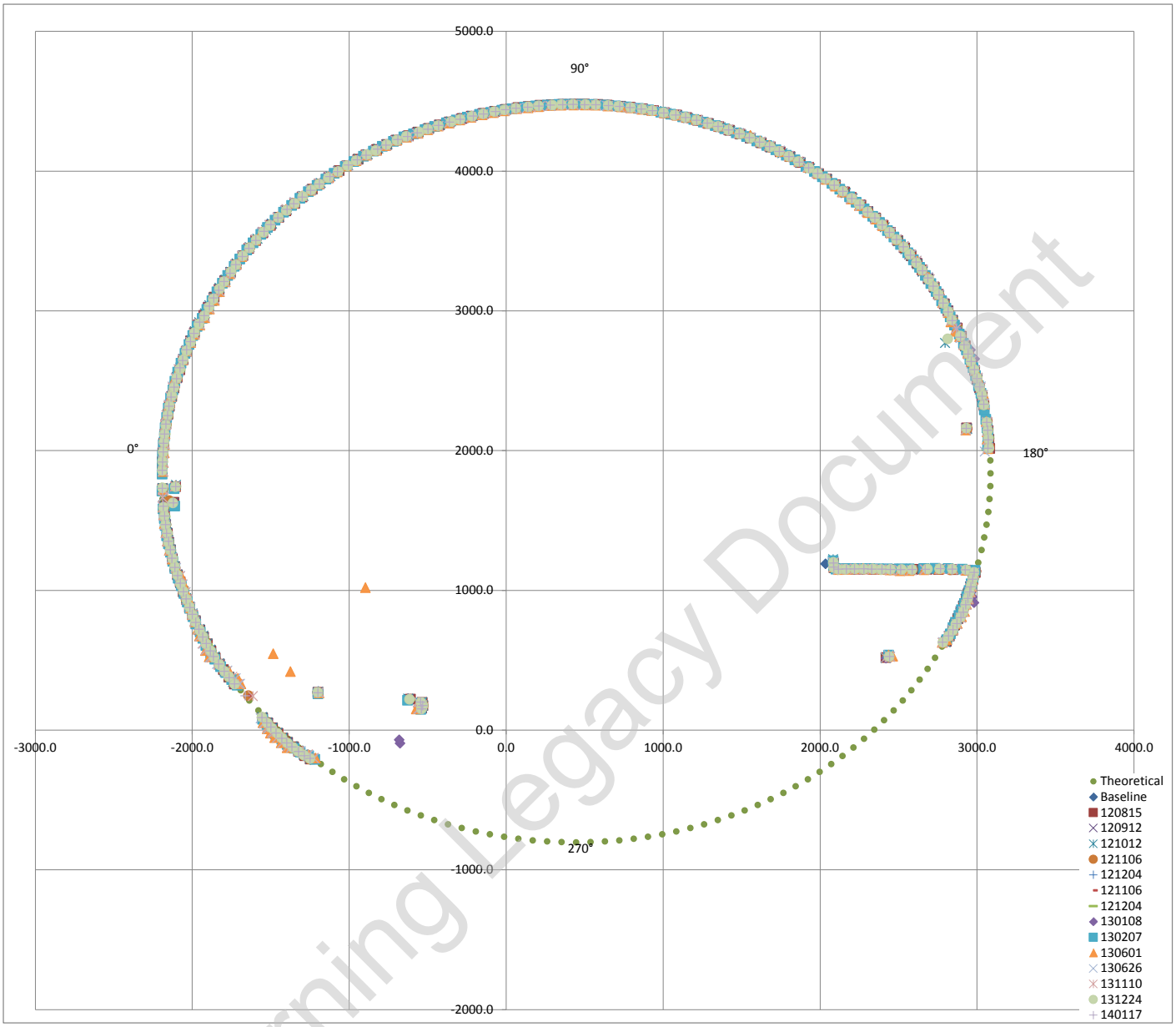


Left tunnel axis is at 0°



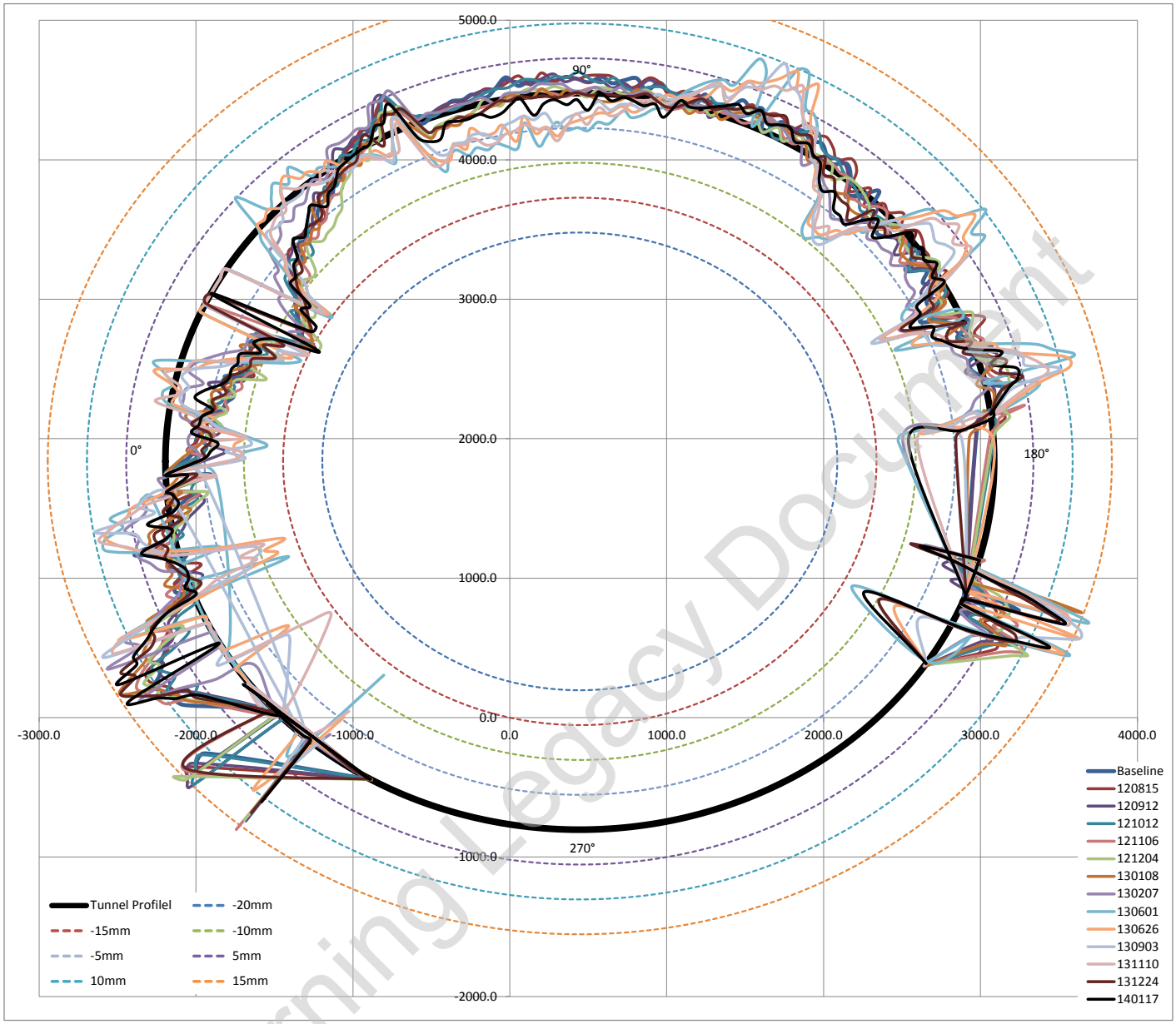
DLR LINE: UP **SECTION: 1018**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **1018**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5280.05	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.03688%	

i.e. Average surveyed diameter varies on -0.036% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

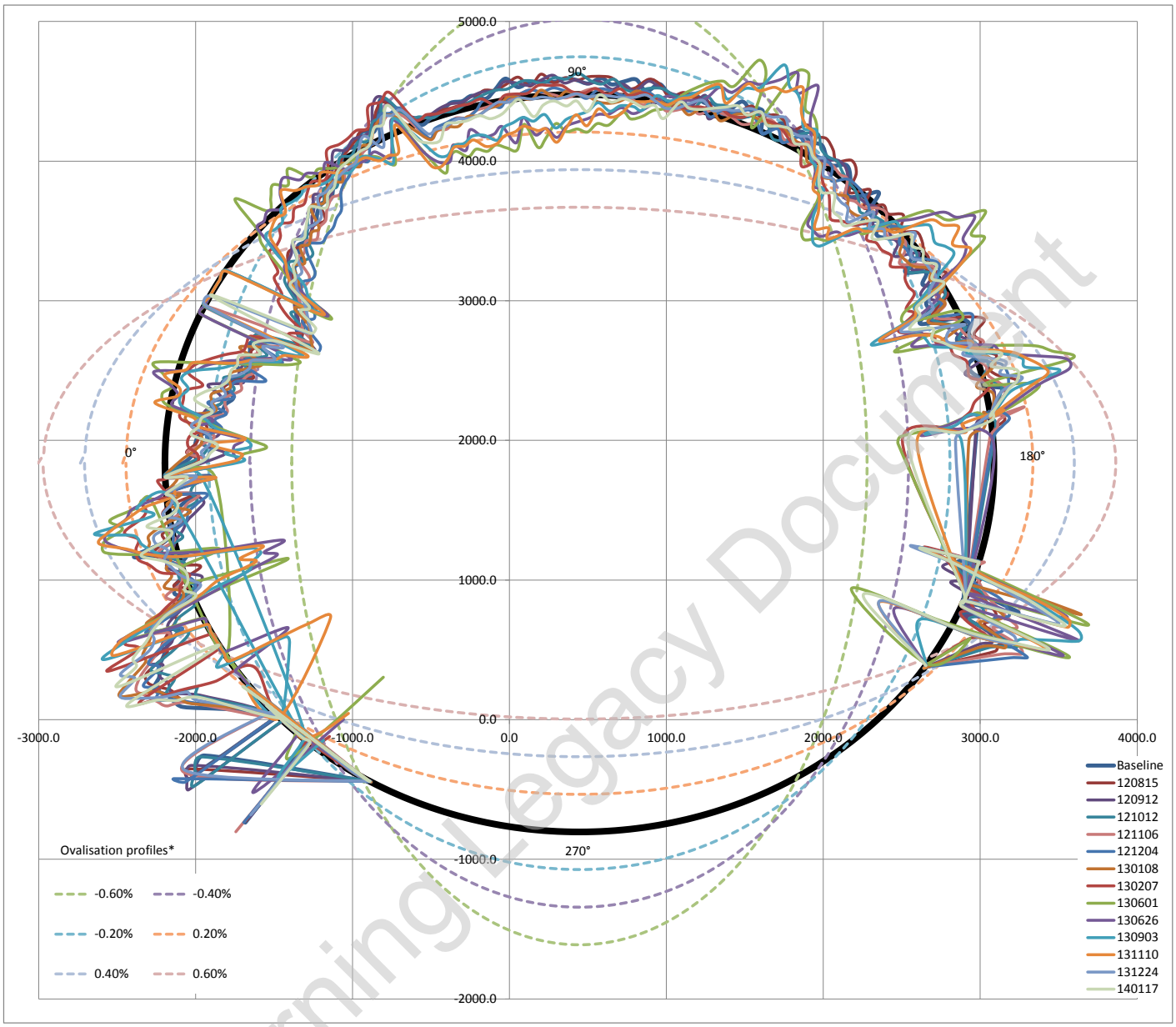
Axis	X	446
	Y	1837
Radius		2641

Max radial difference (+ve) / (-ve) (mm)	**14.9**	**-14.5**
Max / Min deviation % to estimated dia	**0.56%**	**-0.55%**

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **UP** **SECTION:** **1018**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

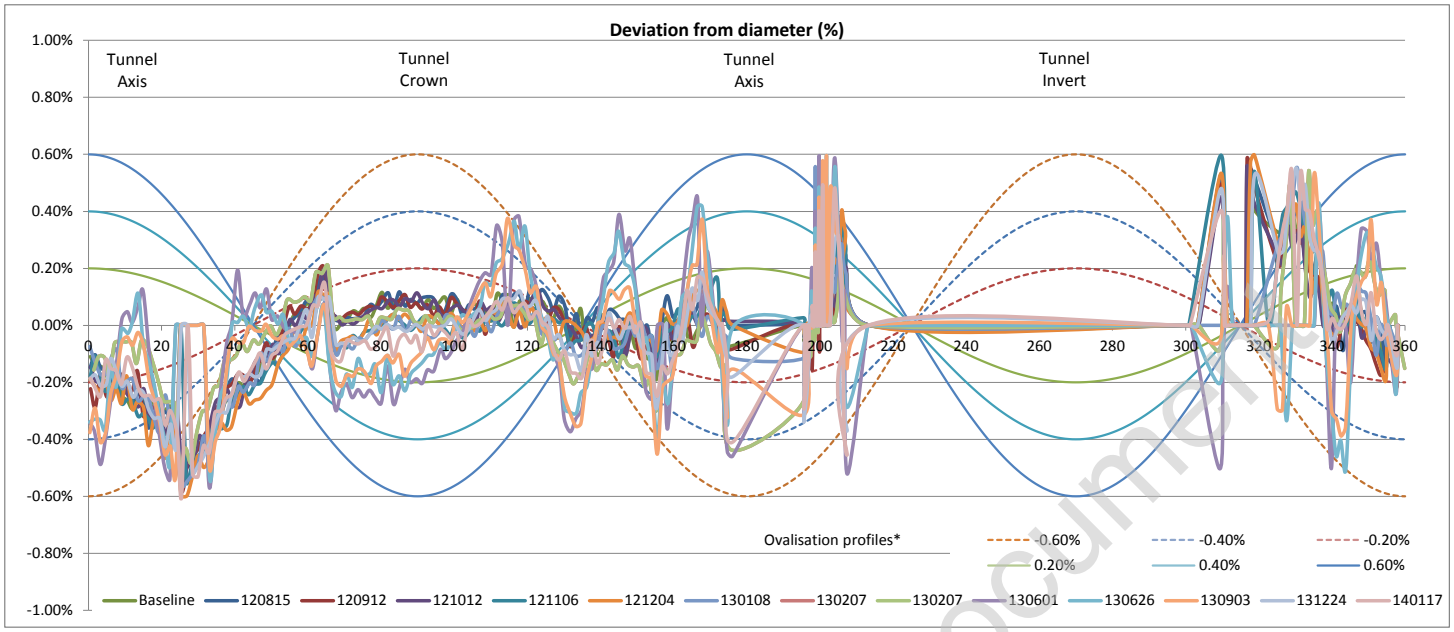
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5281.68 mm
Estimate of vertical diameter at crown, Dv	5283.57 mm
Dh / Dv	0.9996

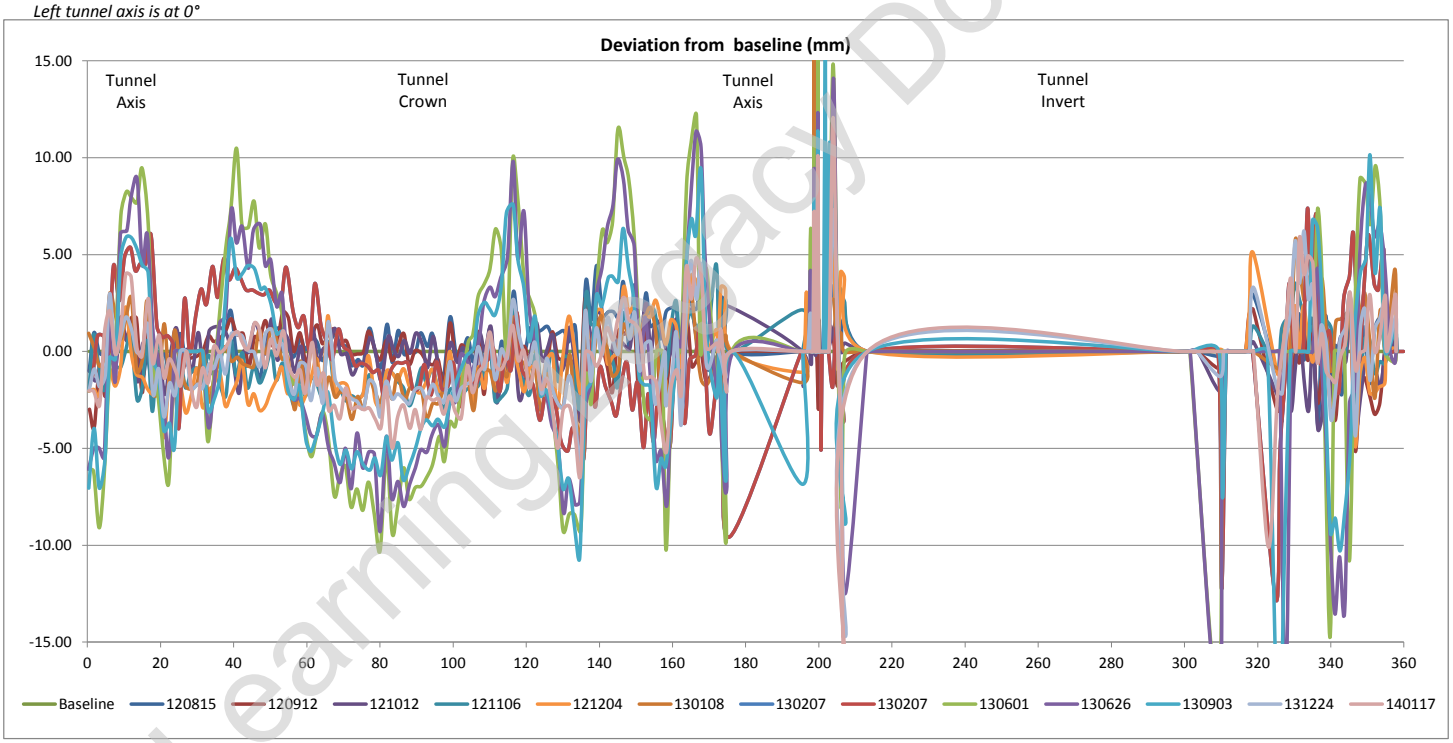
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 1018**

Deviation vs Profile



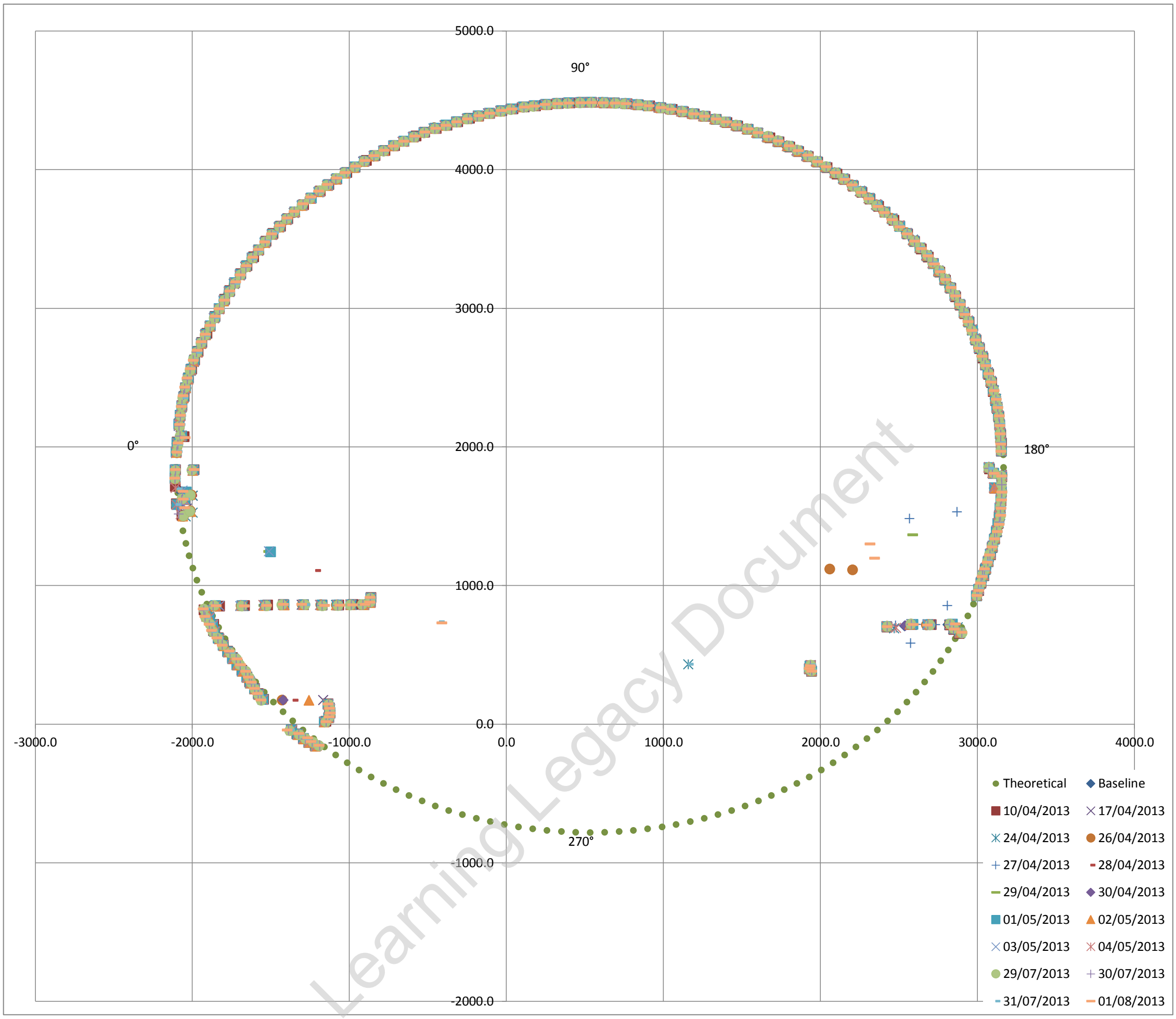
Left tunnel axis is at 0°



Appendix D1 Monitoring Results – Laser Scanning (TBM1 overpassing)

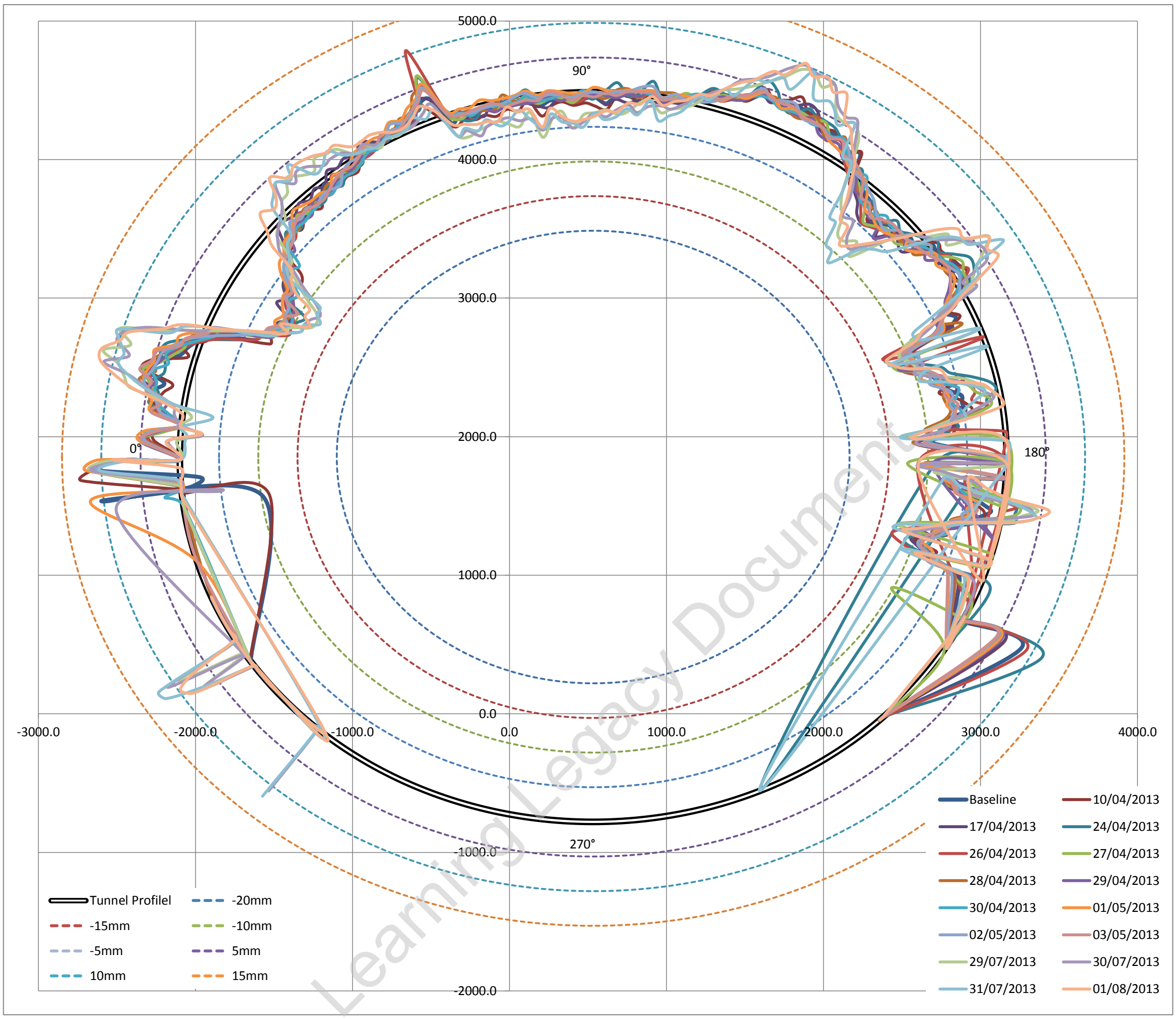
DLR LINE: DN **SECTION: 977**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **977**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5264.30	mm
Estimated best fit as built diameter	**5266.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.03225%	

i.e. Average surveyed diameter varies on -0.032% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.2**	**-11.6**
Max / Min deviation % to estimated dia	**0.43%**	**-0.44%**

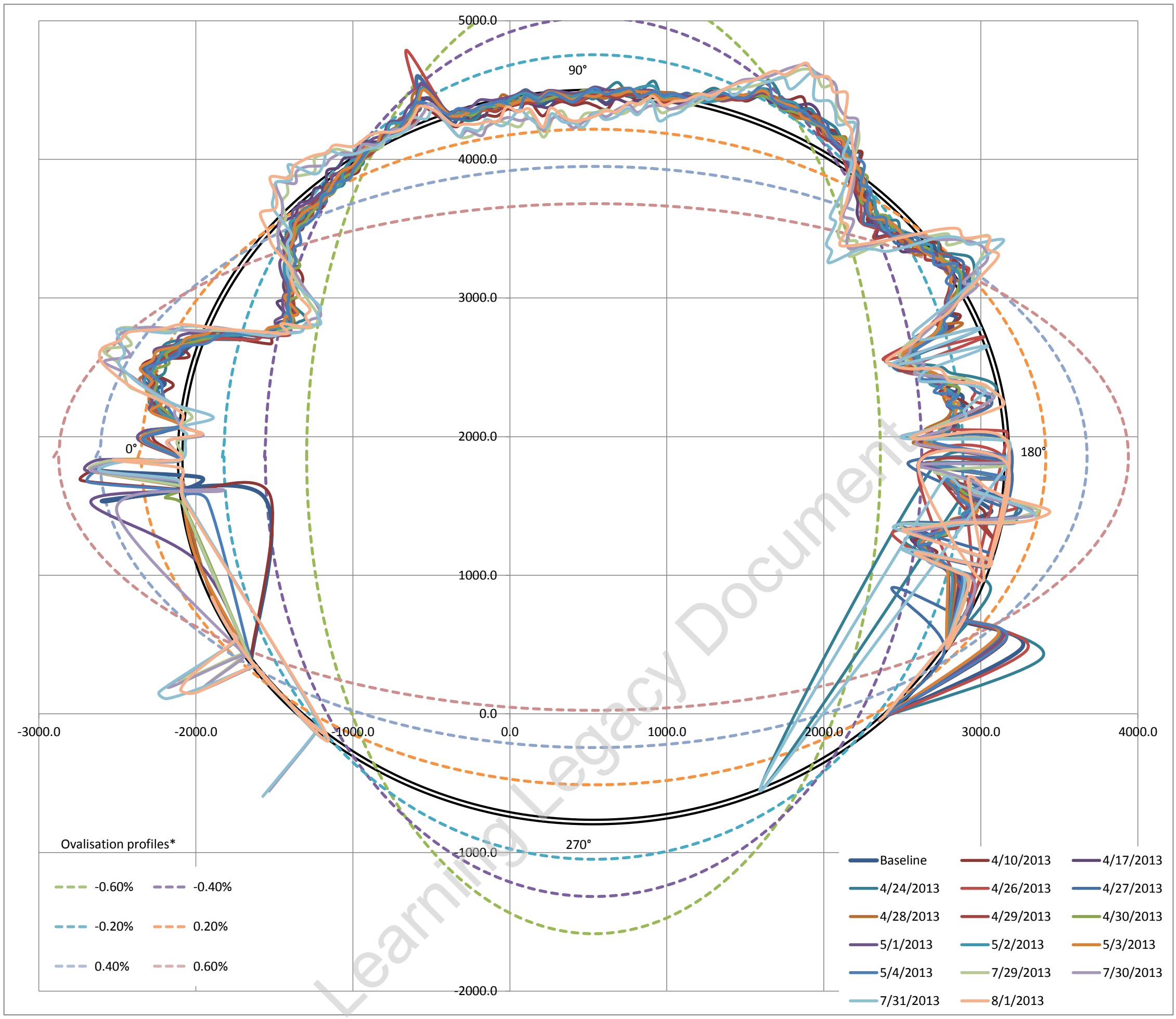
Fitted Circle Coordinates

Axis	X	533
	Y	1853
Radius		2633

Estimated best fit as built diameter	5266	mm
Designed diameter	5300	mm
Average diameter difference	**-34**	mm
Average radial difference	**-17**	mm
Average difference%	**-0.64%**	

DLR LINE: **DN** **SECTION:** **977**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

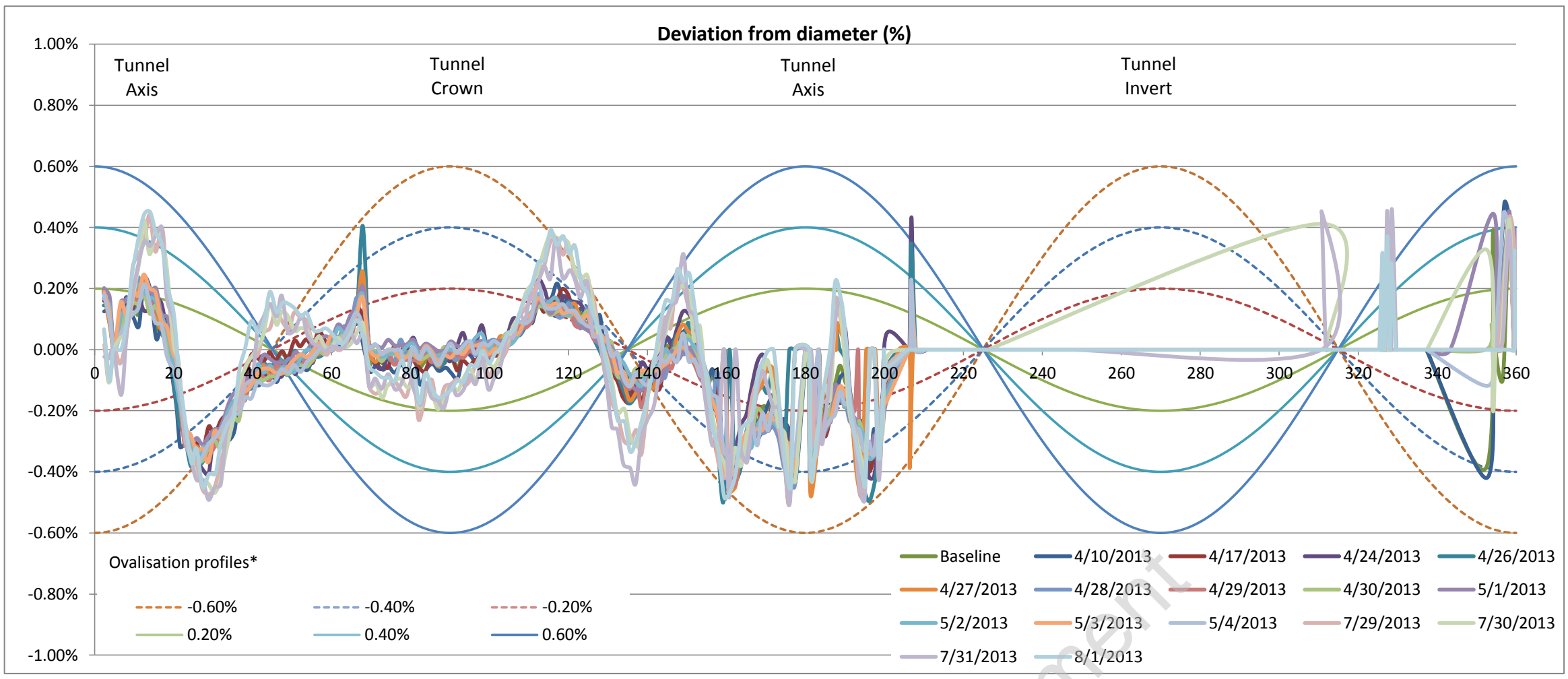
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5261.70 mm
Estimate of vertical diameter at crown, Dv	5264.40 mm
Dh / Dv	0.9995

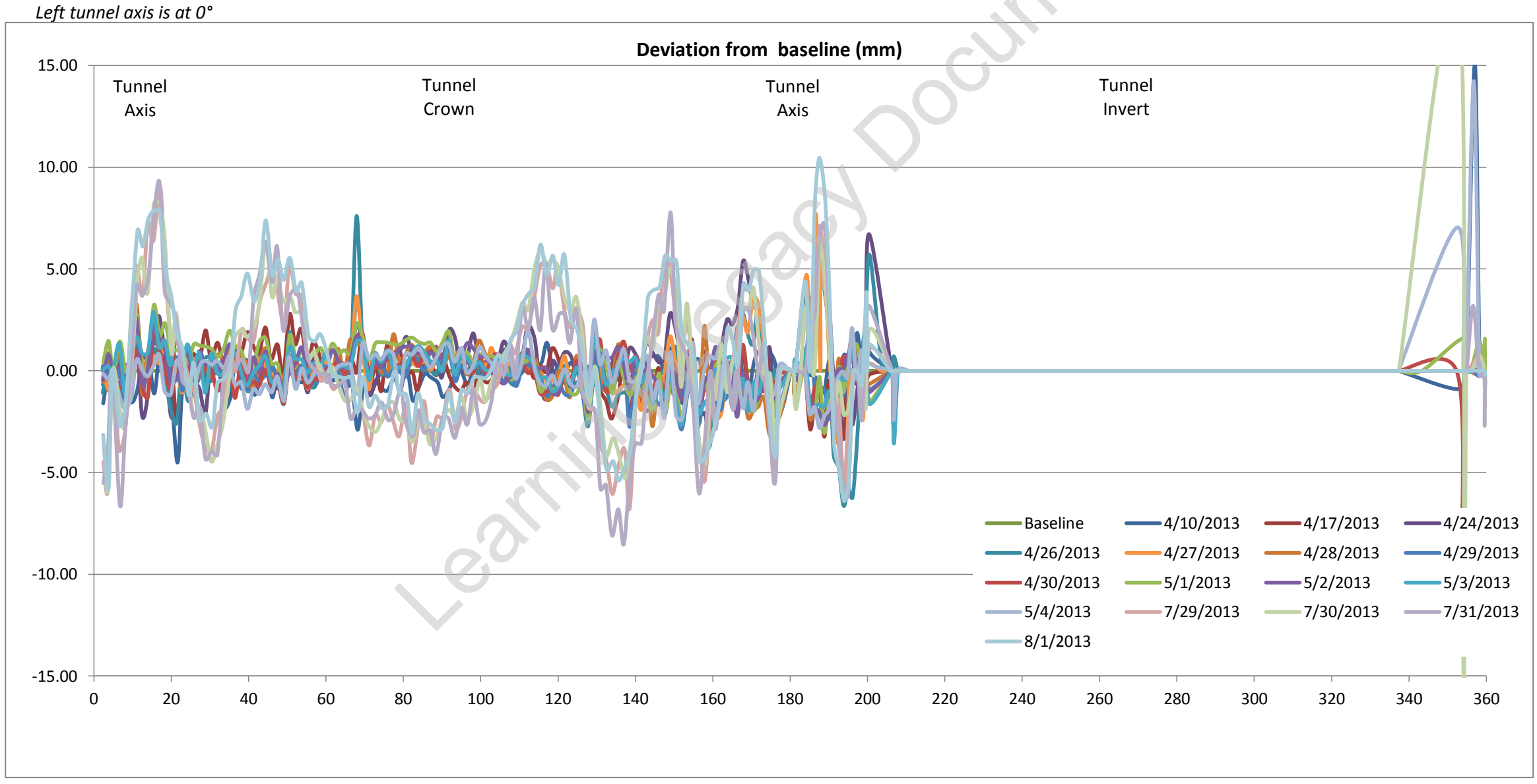
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 977**

Deviation vs Profile

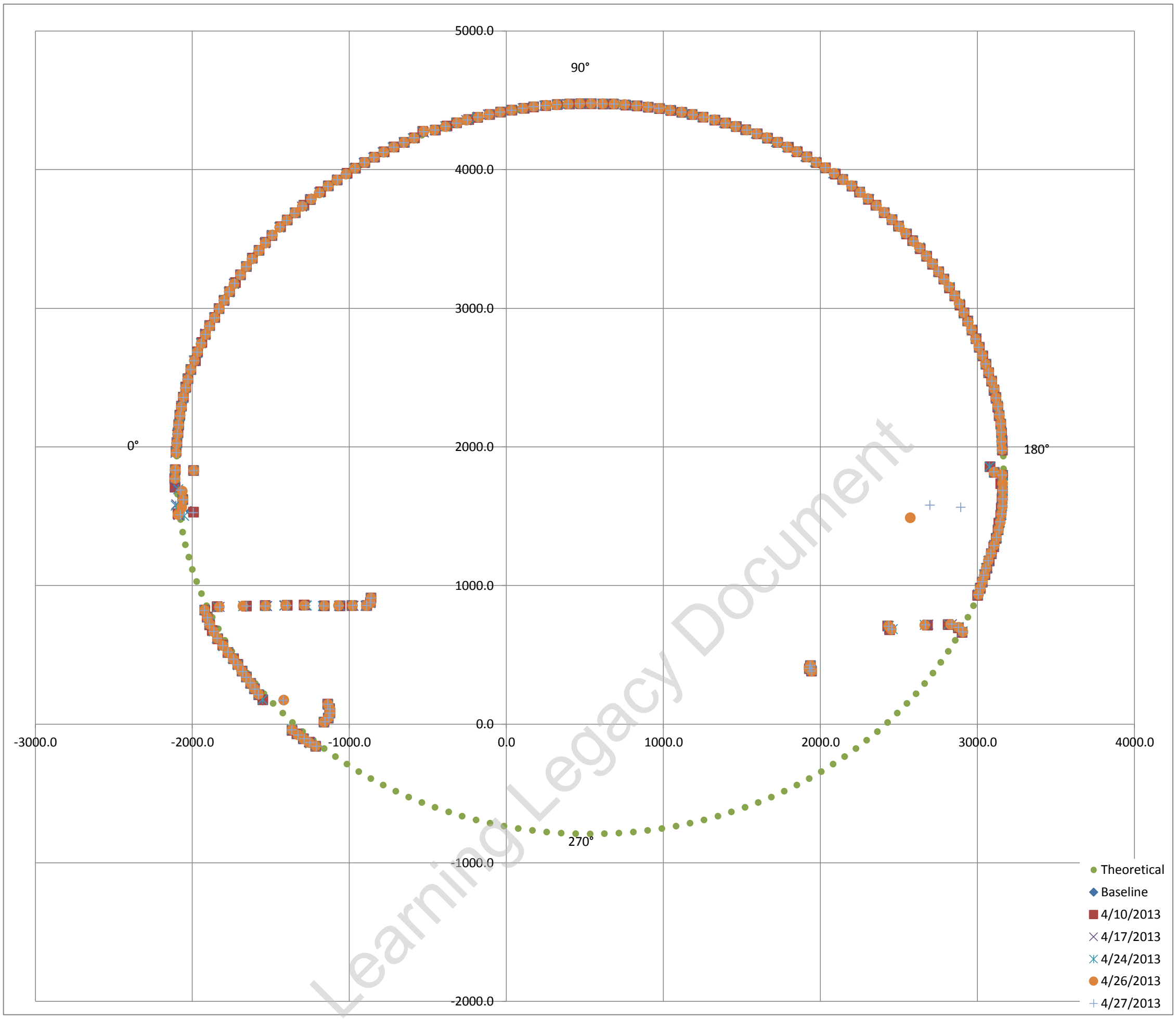


Left tunnel axis is at 0°



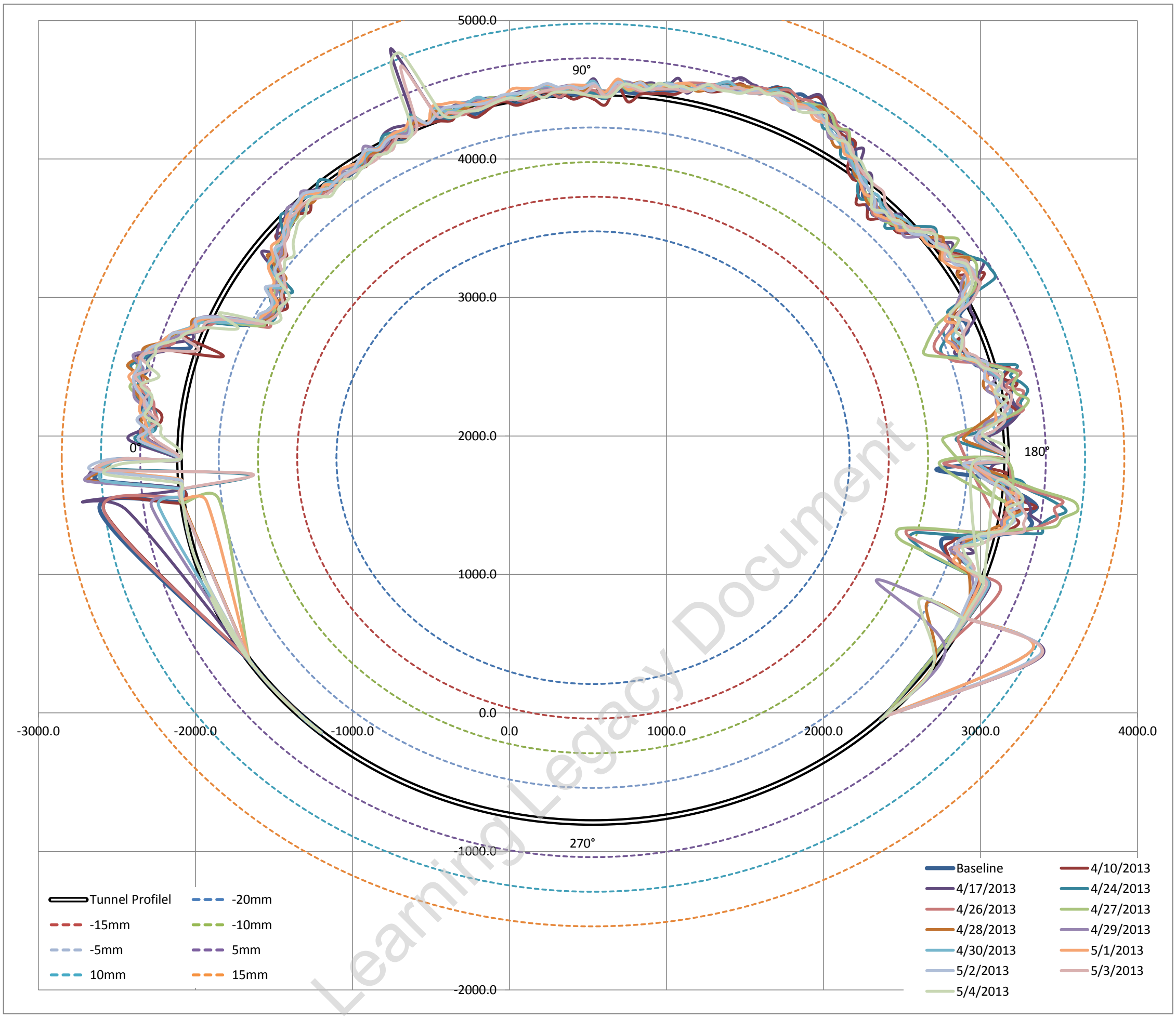
DLR LINE: DN **SECTION: 978**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **978**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5271.00	mm
Estimated best fit as built diameter	**5268.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.05703%	

i.e. Average surveyed diameter varies on 0.057% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

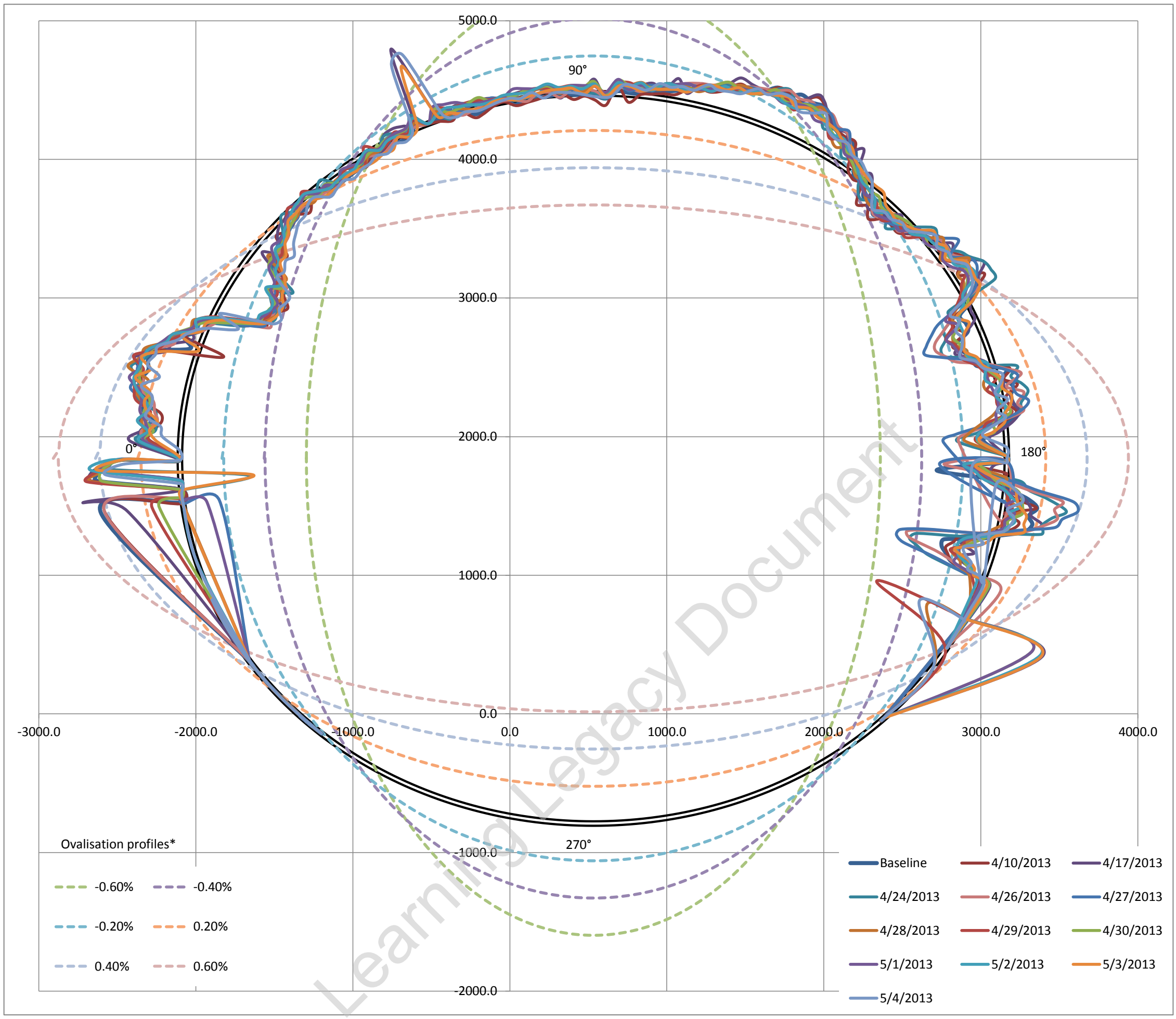
Axis	X	532
	Y	1843
Radius		2634

Max radial difference (+ve) / (-ve) (mm)	**10.8**	**-8.9**
Max / Min deviation % to estimated dia	**0.41%**	**-0.34%**

Estimated best fit as built diameter	5268	mm
Designed diameter	5300	mm
Average diameter difference	**-32**	mm
Average radial difference	**-16**	mm
Average difference%	**-0.60%**	

DLR LINE: **DN** **SECTION:** **978**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

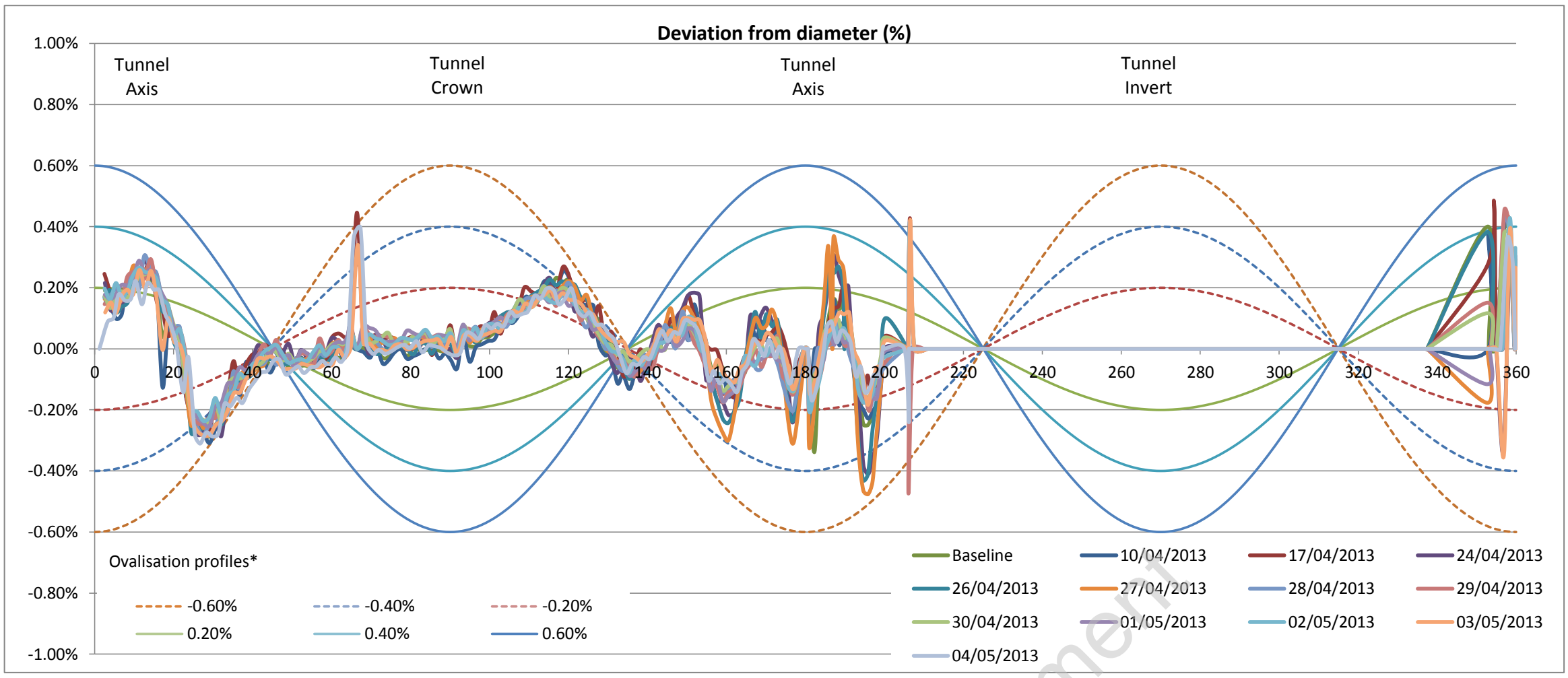
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5264.13 mm
Estimate of vertical diameter at crown, Dv	5267.26 mm
Dh / Dv	0.9994

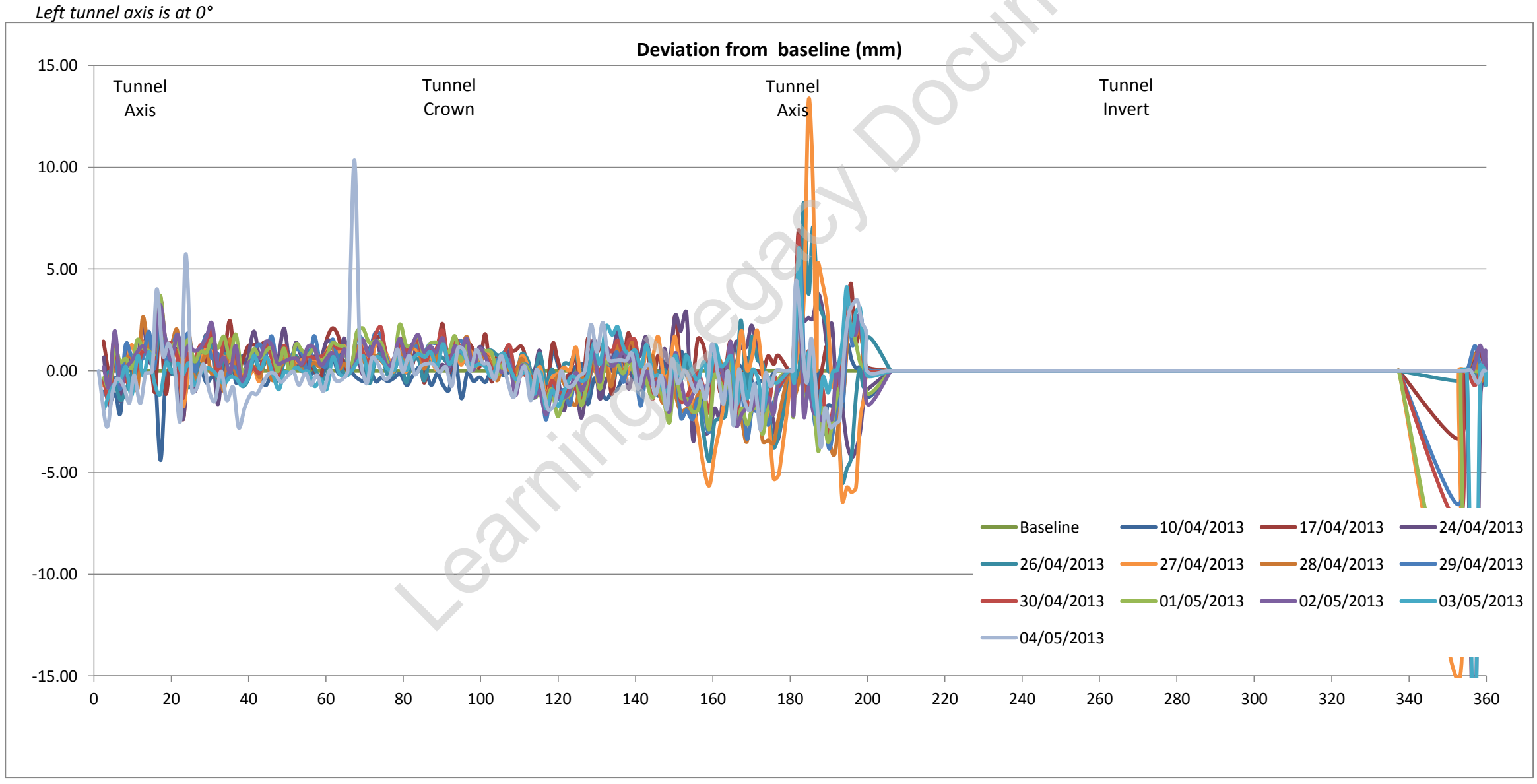
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 978**

Deviation vs Profile

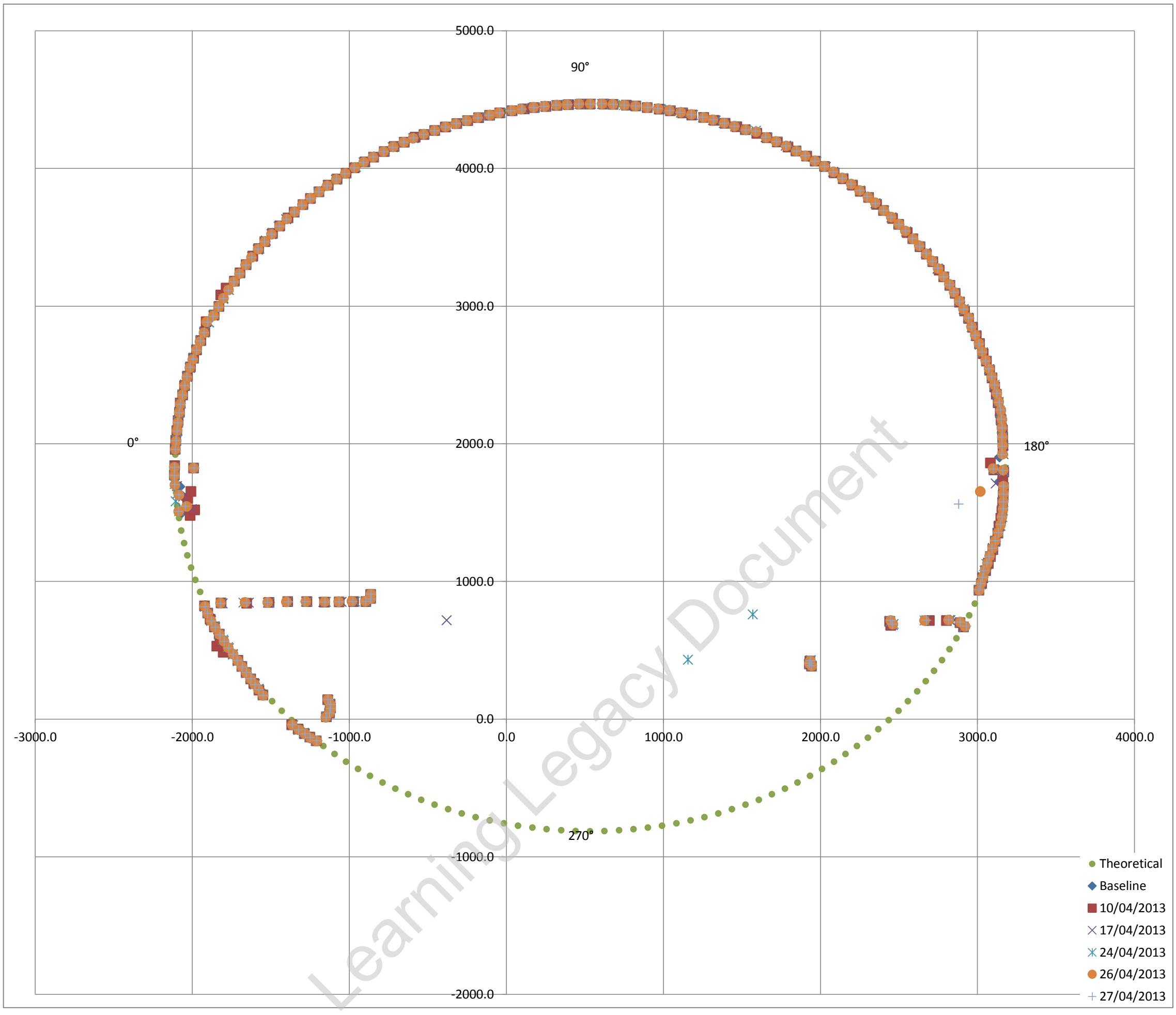


Left tunnel axis is at 0°



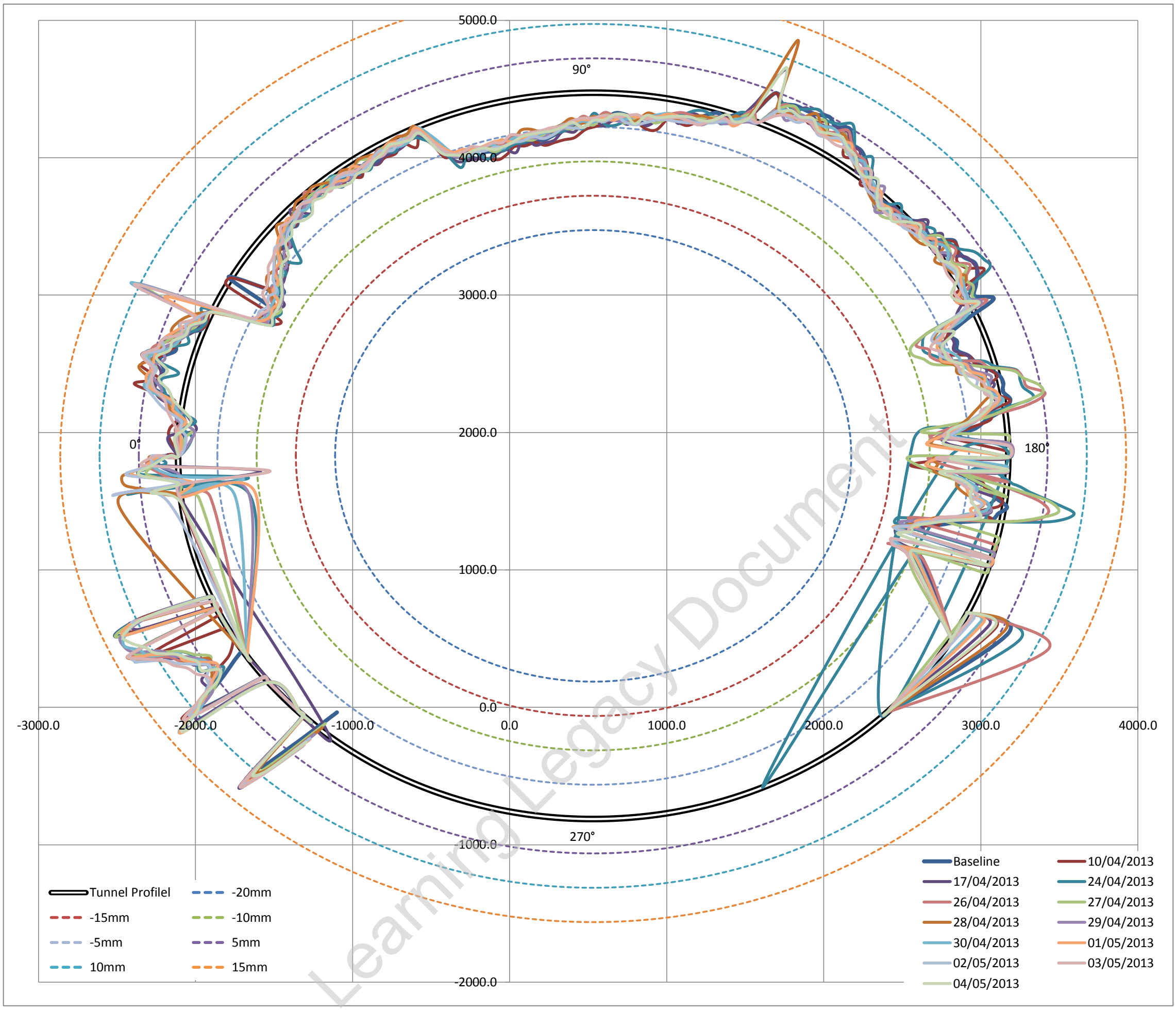
DLR LINE: DN **SECTION: 979**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **979**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5287.04	mm
Estimated best fit as built diameter	**5286.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.01969%	

i.e. Average surveyed diameter varies on 0.019% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.9**	**-12.7**
Max / Min deviation % to estimated dia	**0.49%**	**-0.48%**

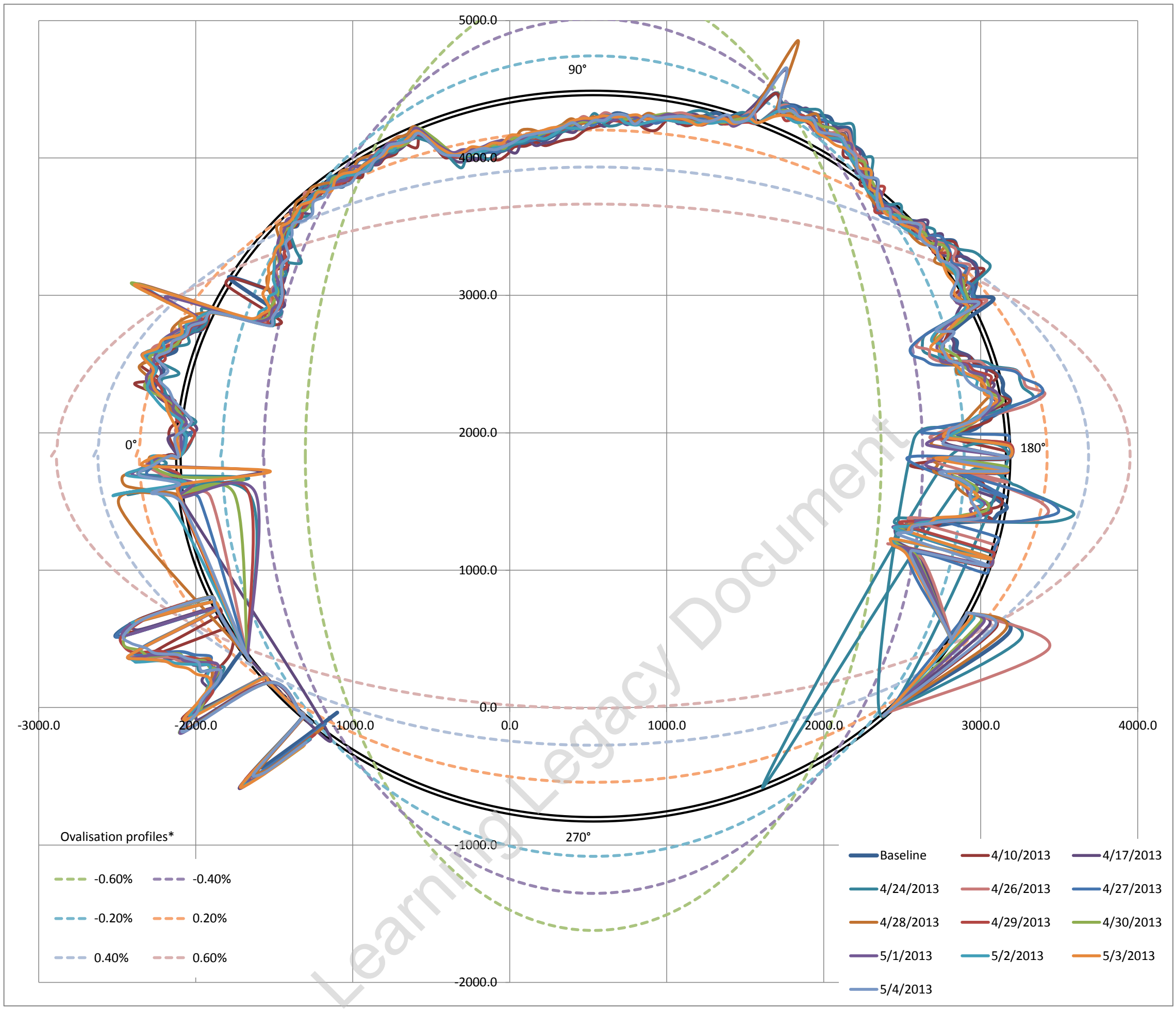
Fitted Circle Coordinates

Axis	X	532
	Y	1830
Radius		2643

Estimated best fit as built diameter	5286	mm
Designed diameter	5300	mm
Average diameter difference	**-14**	mm
Average radial difference	**-7**	mm
Average difference%	**-0.26%**	

DLR LINE: **DN** **SECTION:** **979**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

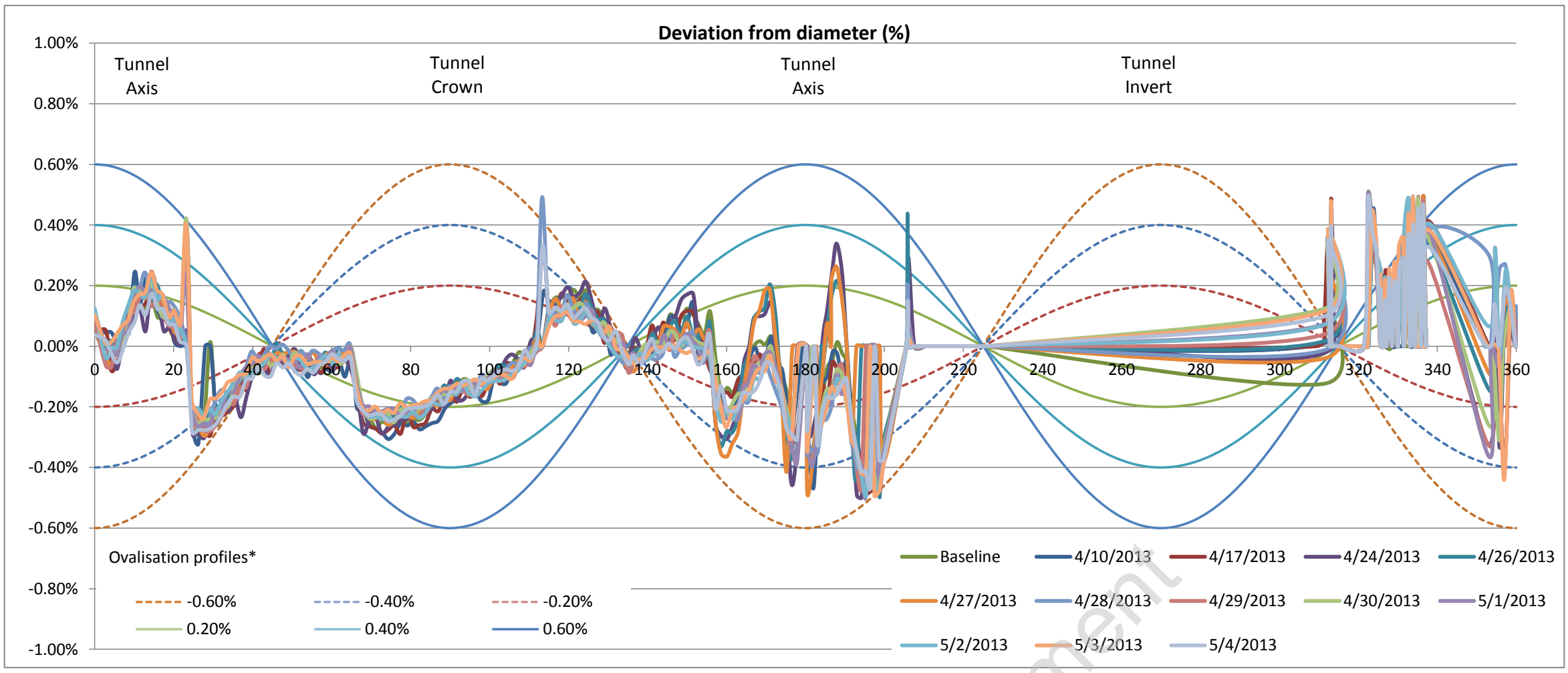
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5281.17 mm
Estimate of vertical diameter at crown, Dv	5281.70 mm
Dh / Dv	0.9999

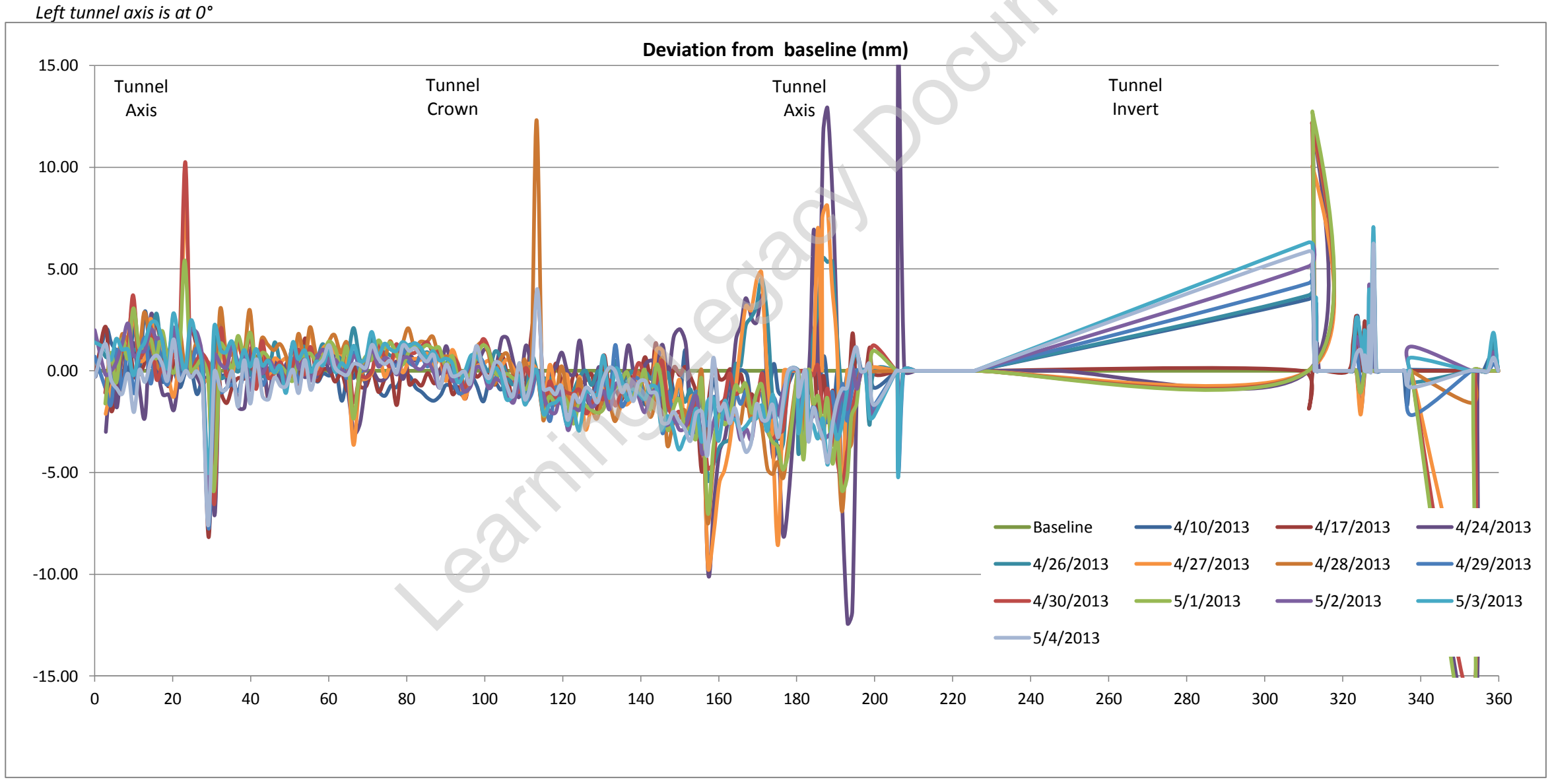
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 979**

Deviation vs Profile

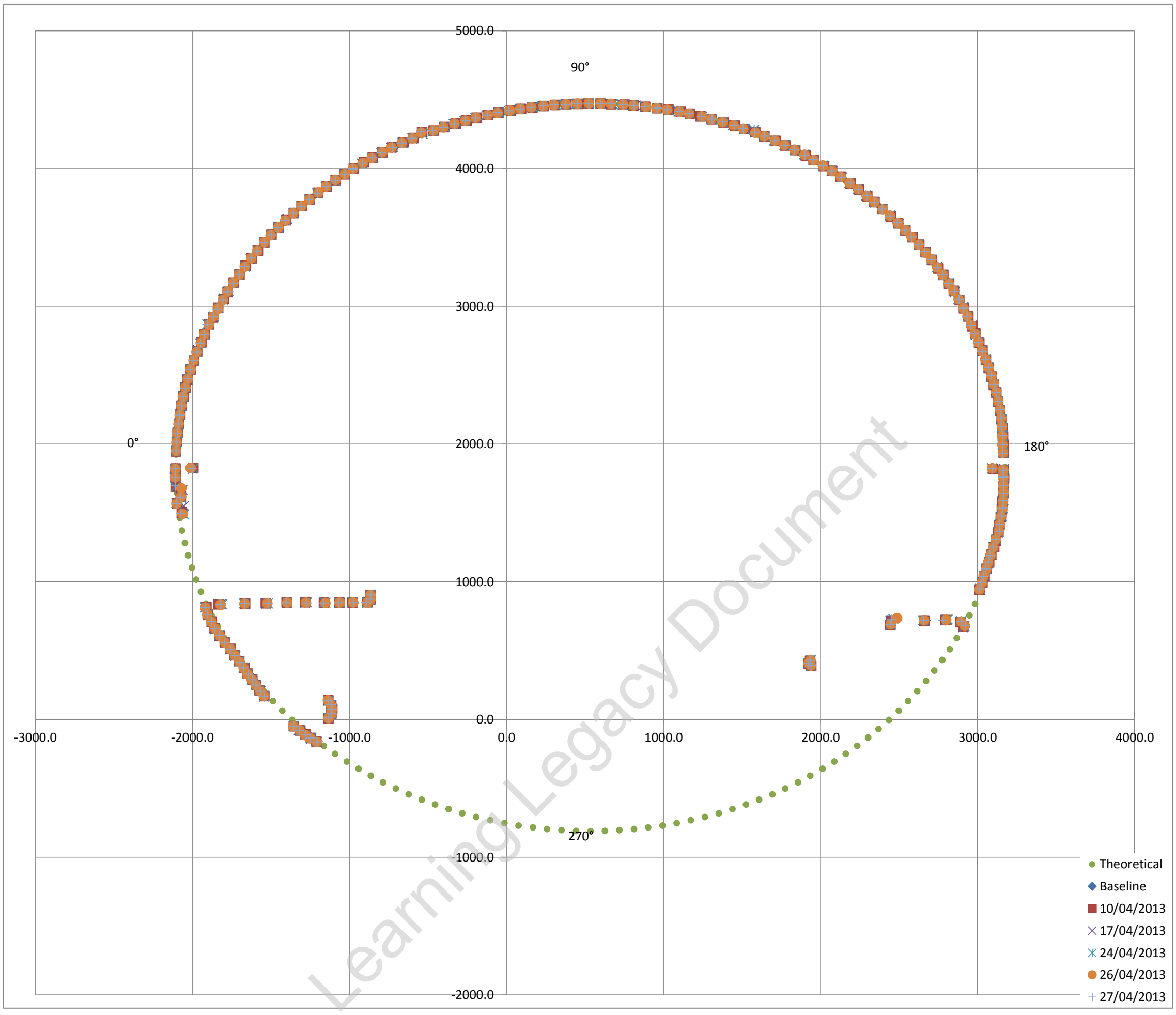


Left tunnel axis is at 0°



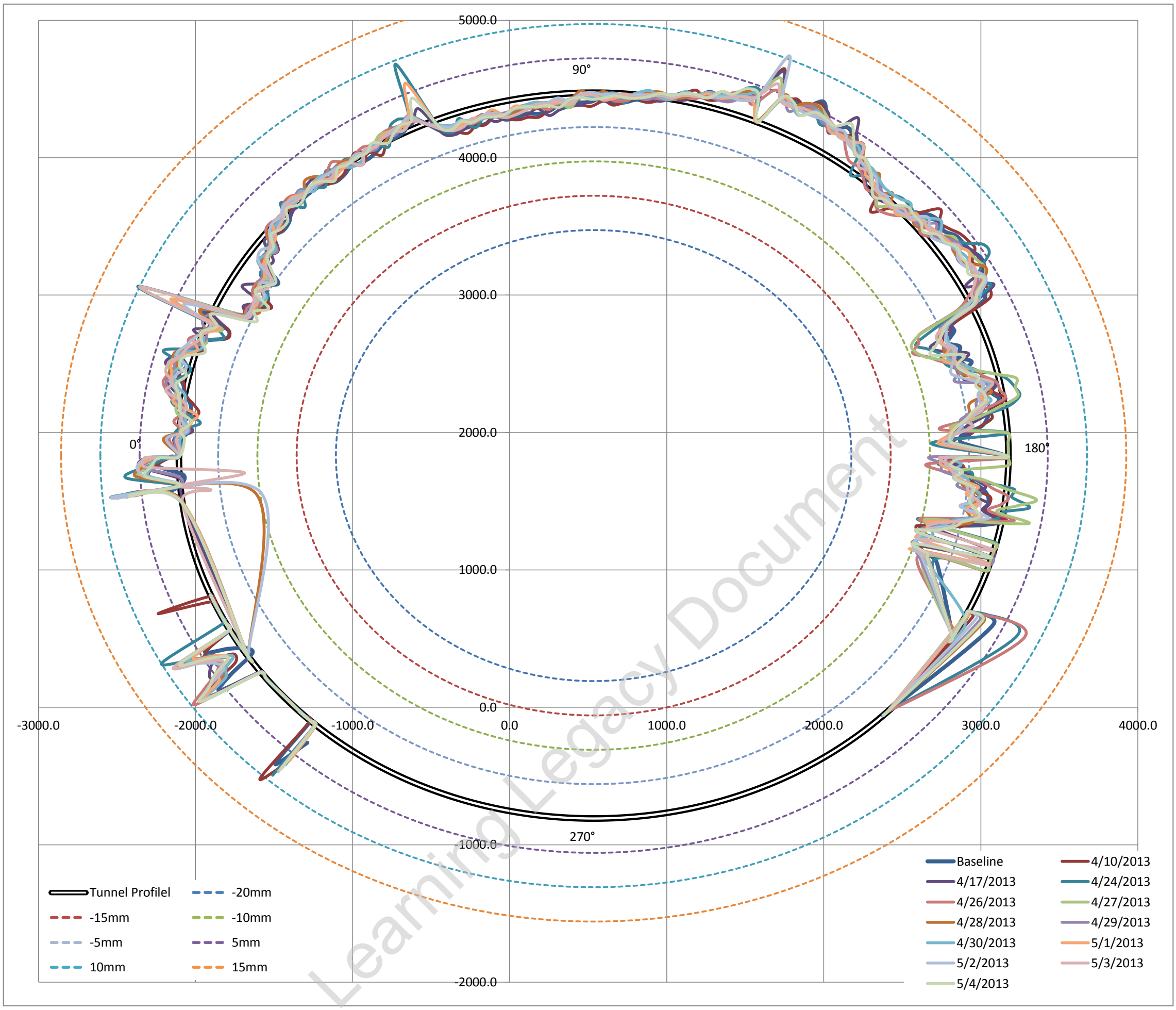
DLR LINE: DN **SECTION: 980**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **980**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.10	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.01711%	

i.e. Average surveyed diameter varies on -0.017% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**9.1**	**-10.0**
Max / Min deviation % to estimated dia	**0.34%**	**-0.38%**

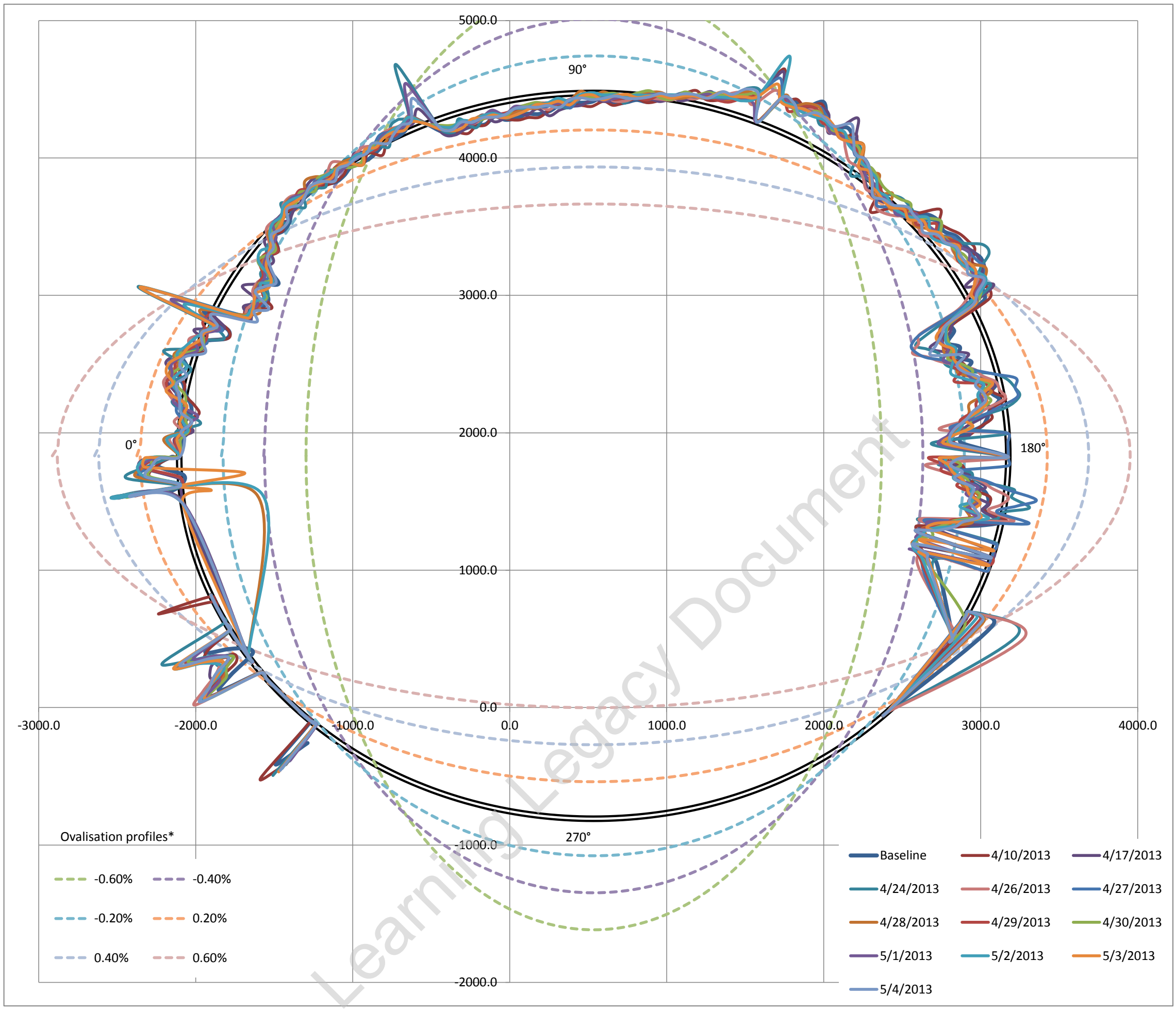
Fitted Circle Coordinates

Axis	X	535
	Y	1832
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **980**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

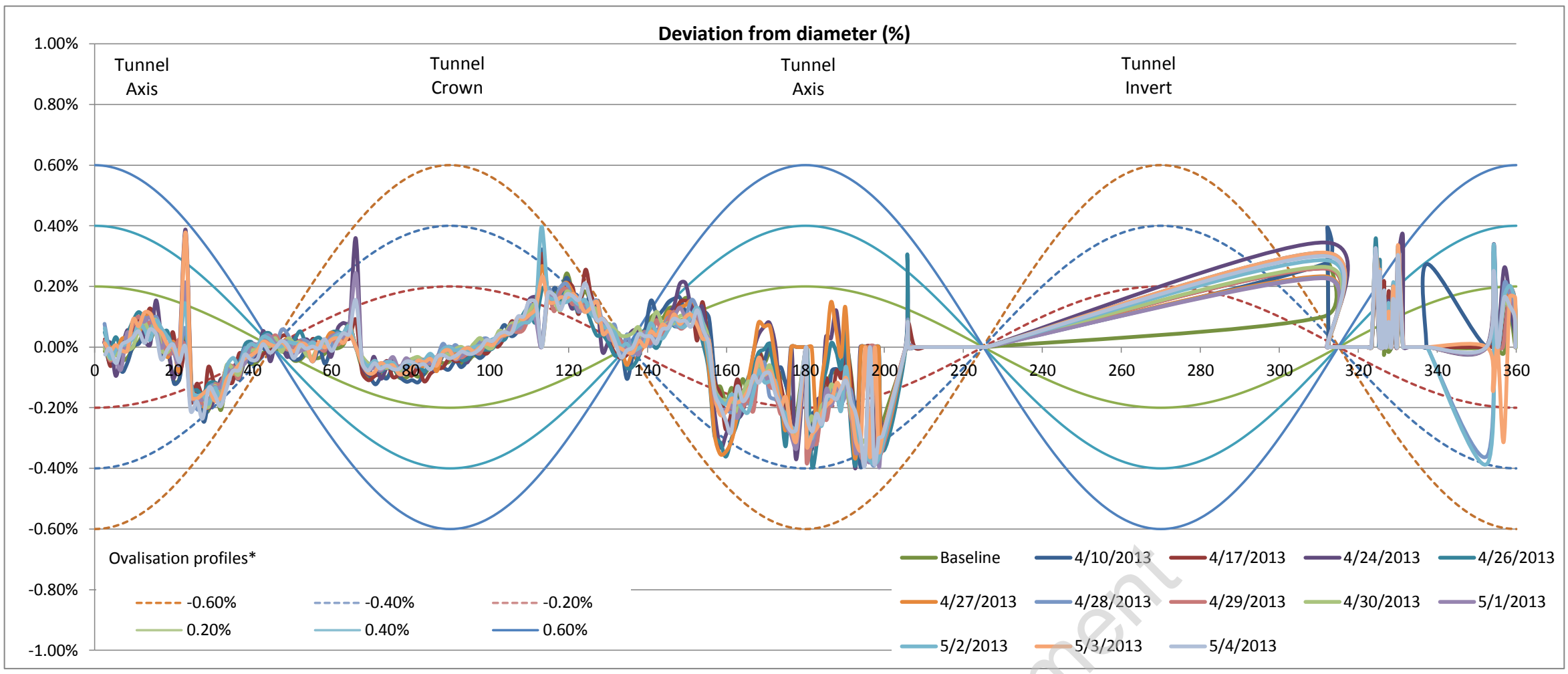
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5276.88 mm
Estimate of vertical diameter at crown, Dv	5280.54 mm
Dh / Dv	0.9993

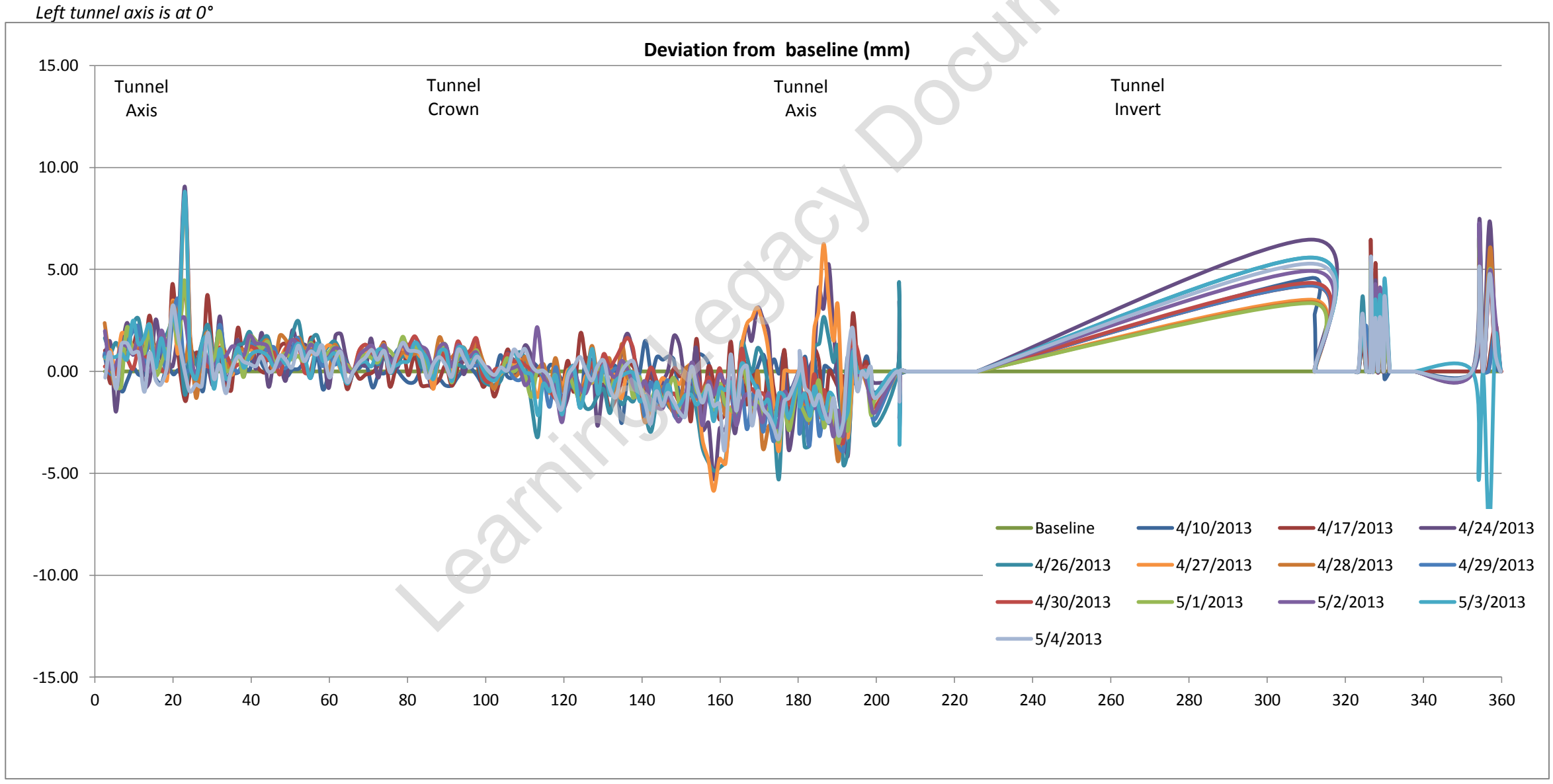
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 980**

Deviation vs Profile

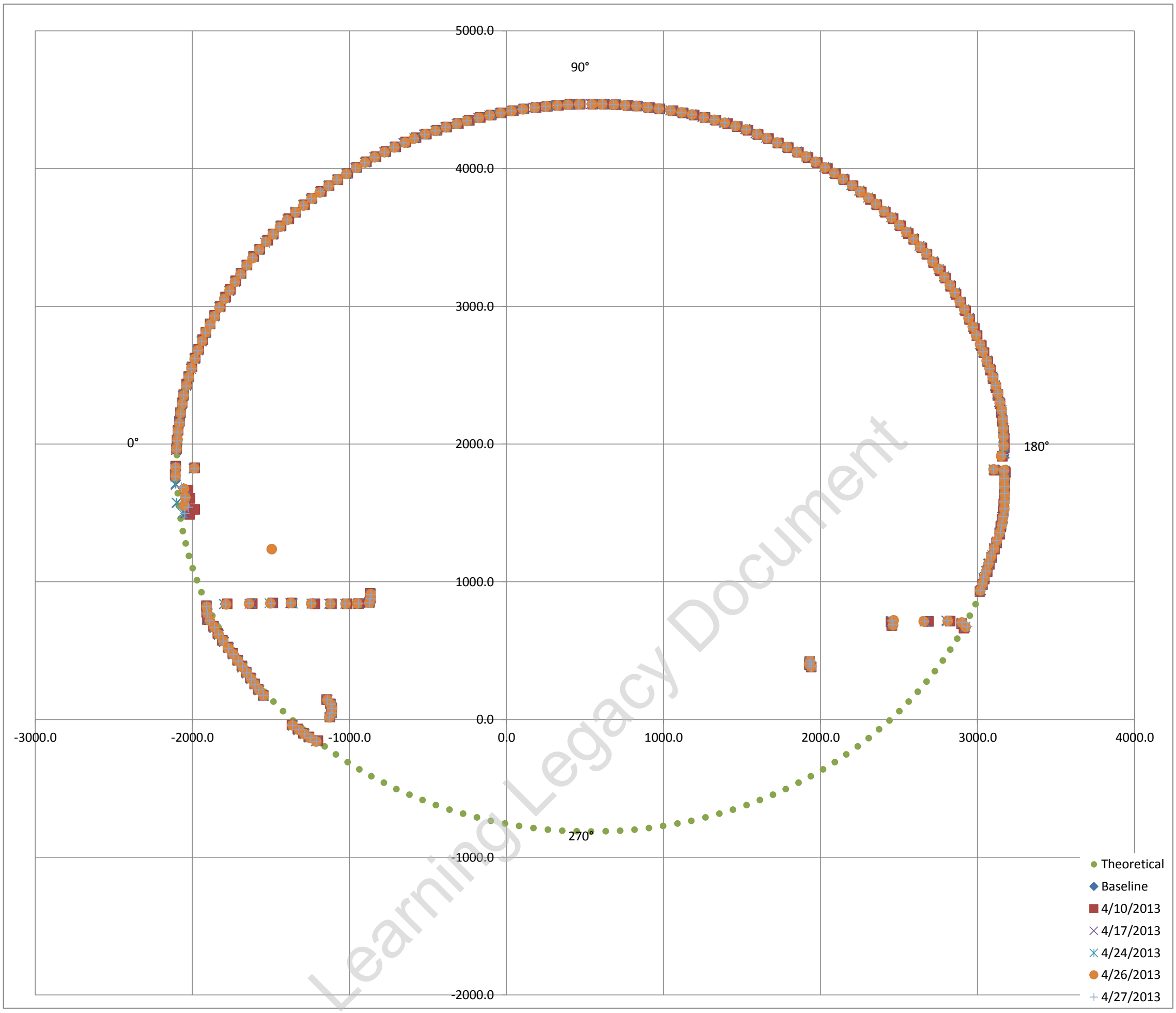


Left tunnel axis is at 0°



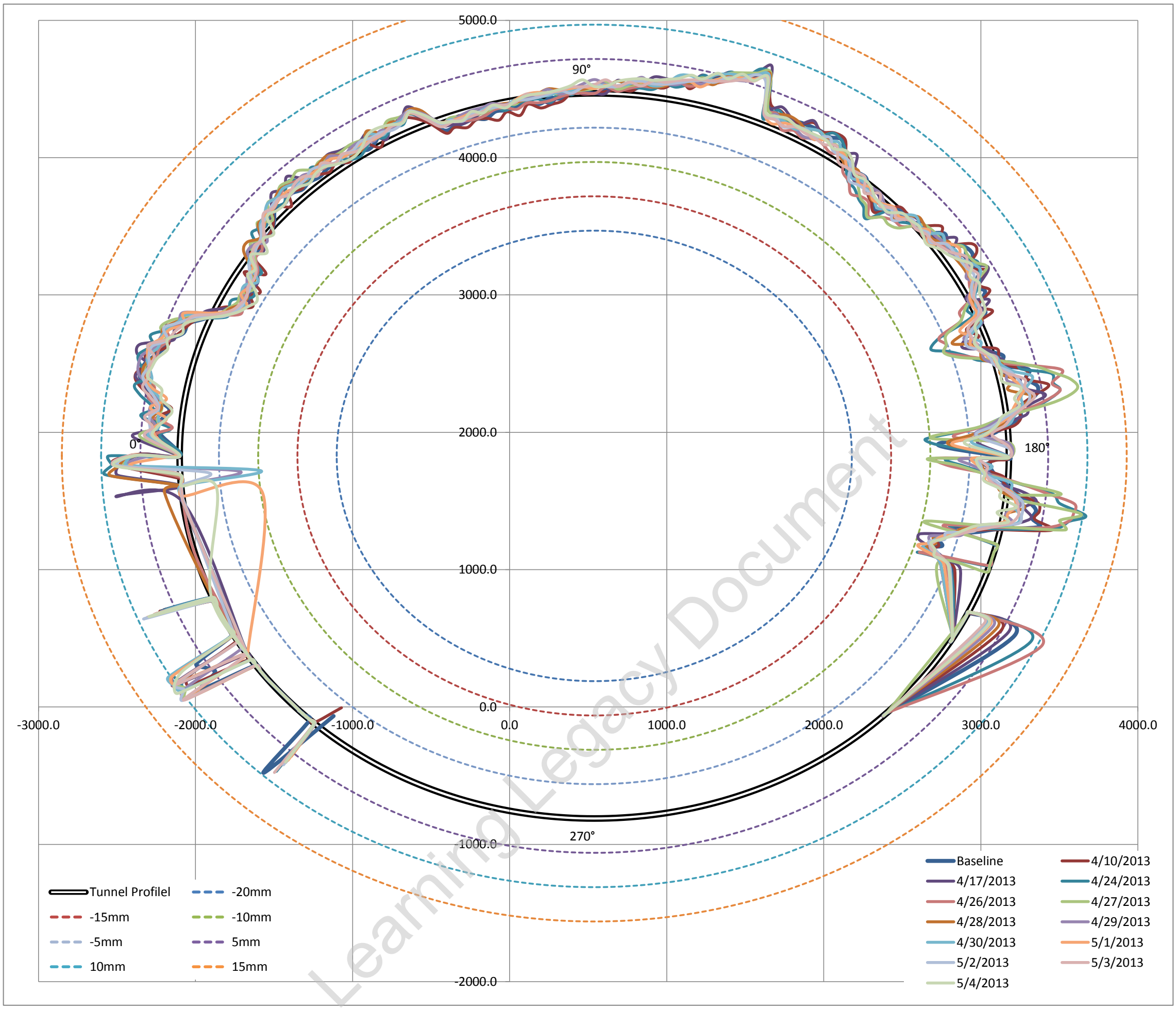
DLR LINE: DN **SECTION: 981**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **981**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5283.47	mm
Estimated best fit as built diameter	**5280.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.06571%	

i.e. Average surveyed diameter varies on 0.065% (ave) from estimated best fit as built diameter

Fitted Circle Coordinates

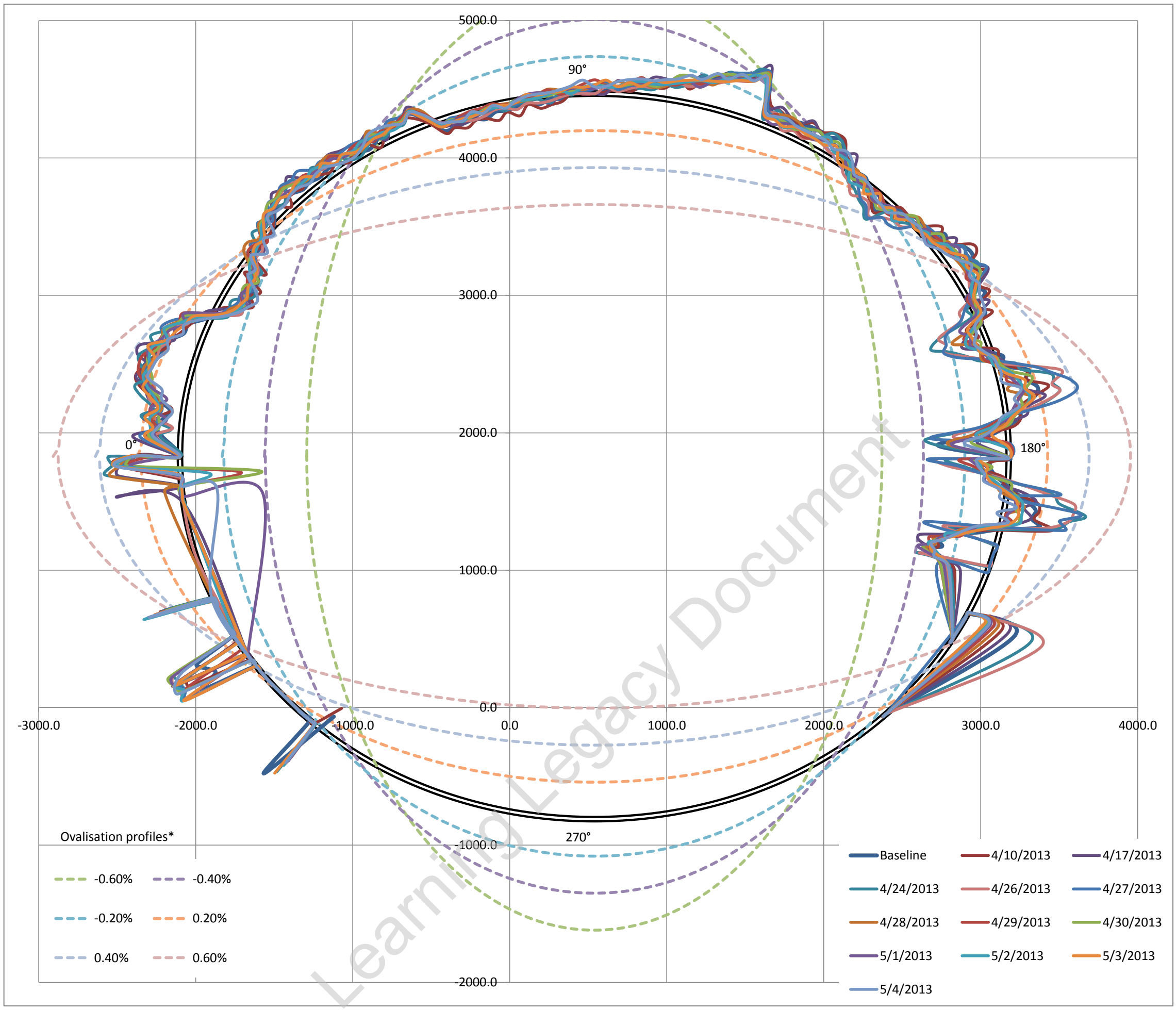
Axis	X	539
	Y	1828
Radius		2640

Max radial difference (+ve) / (-ve) (mm)	**10.1**	**-9.1**
Max / Min deviation % to estimated dia	**0.38%**	**-0.35%**

Estimated best fit as built diameter	5280	mm
Designed diameter	5300	mm
Average diameter difference	**-20**	mm
Average radial difference	**-10**	mm
Average difference%	**-0.38%**	

DLR LINE: **DN** **SECTION:** **981**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

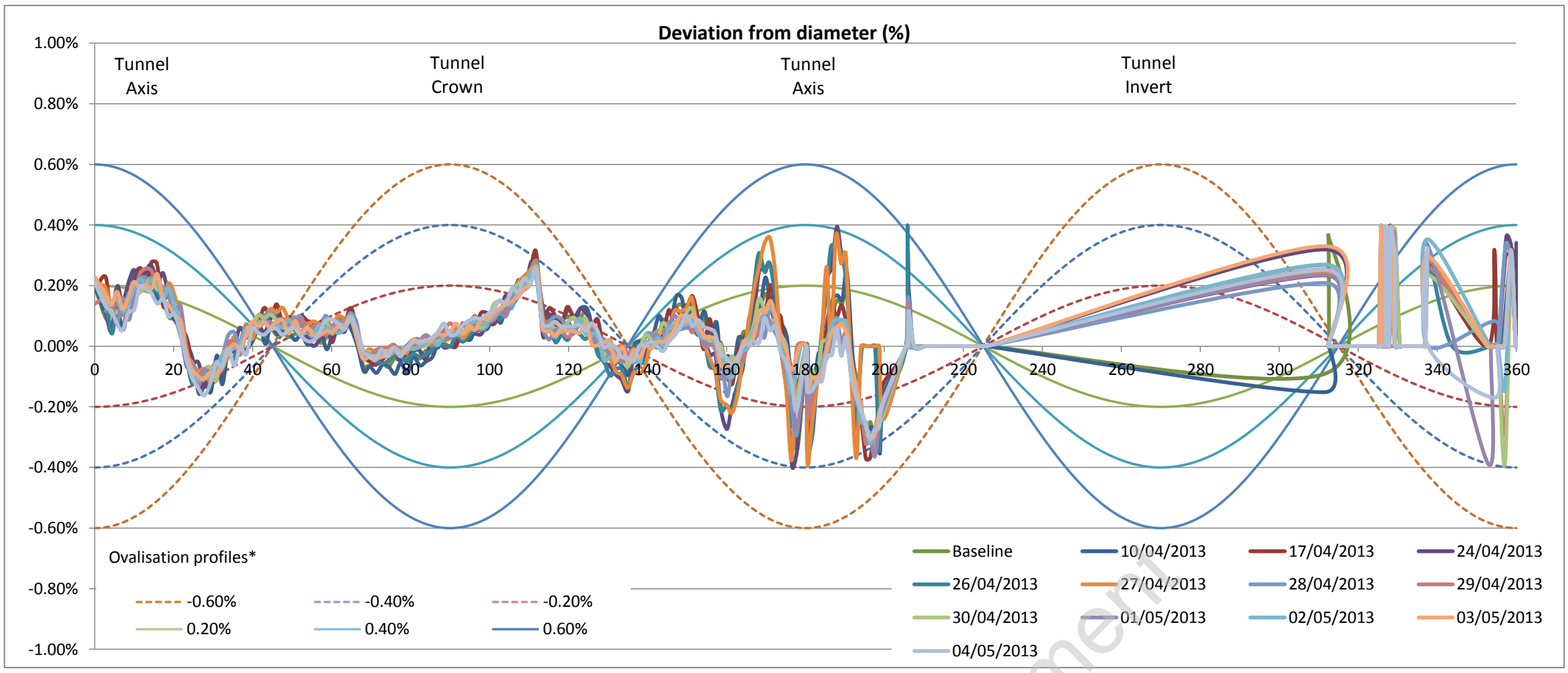
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5282.88 mm
Estimate of vertical diameter at crown, Dv	5280.00 mm
Dh / Dv	1.0005

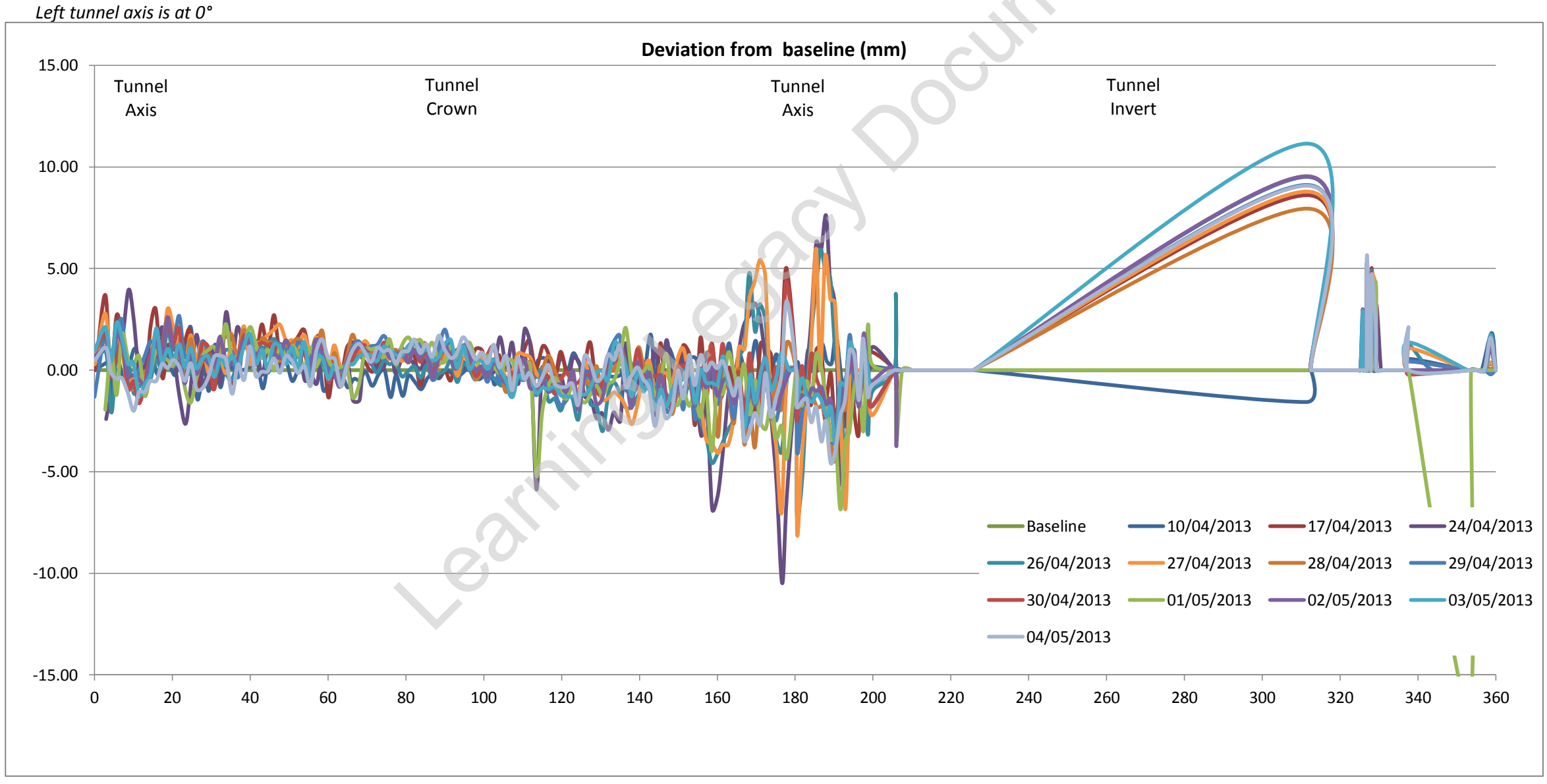
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 981**

Deviation vs Profile

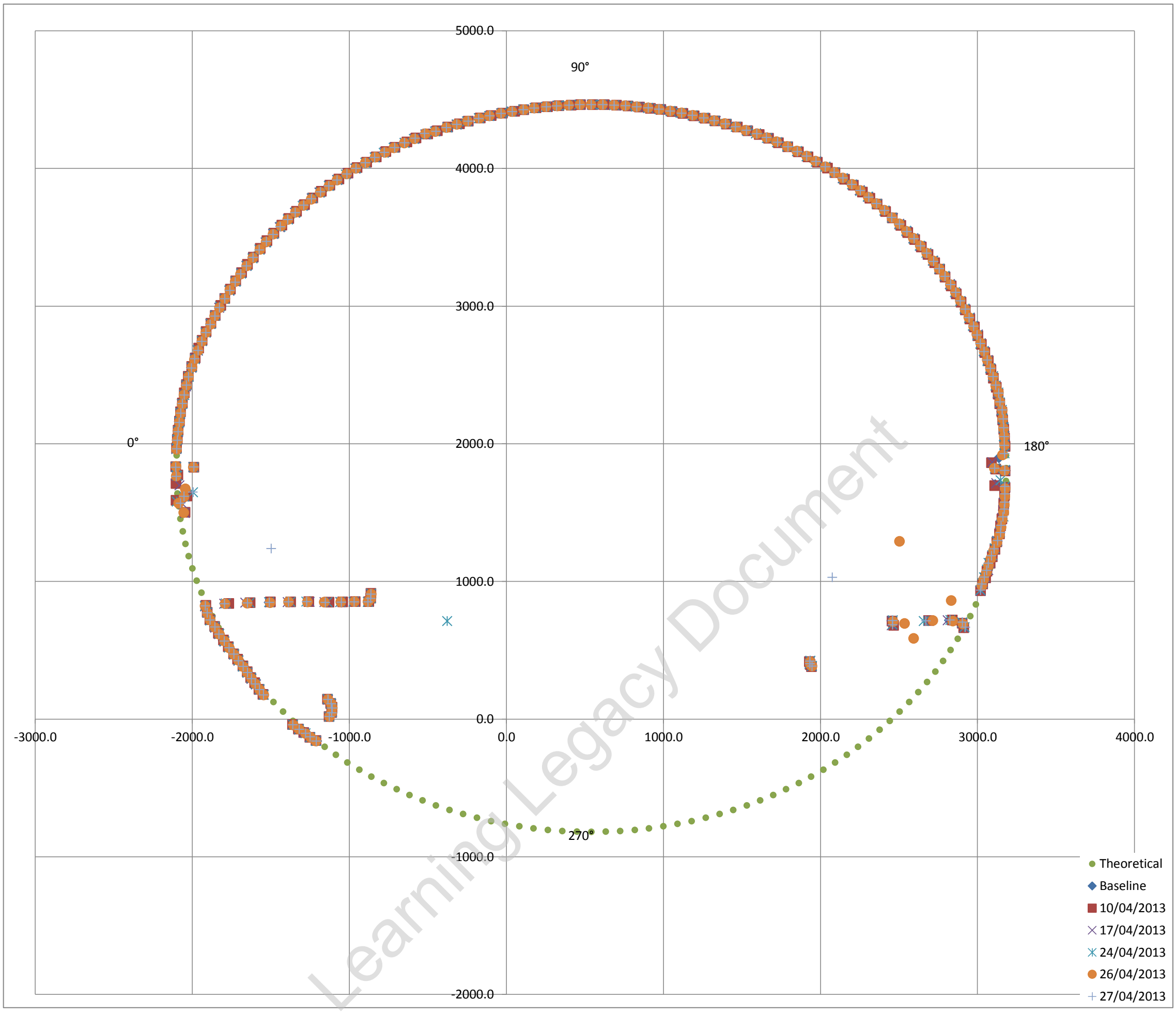


Left tunnel axis is at 0°



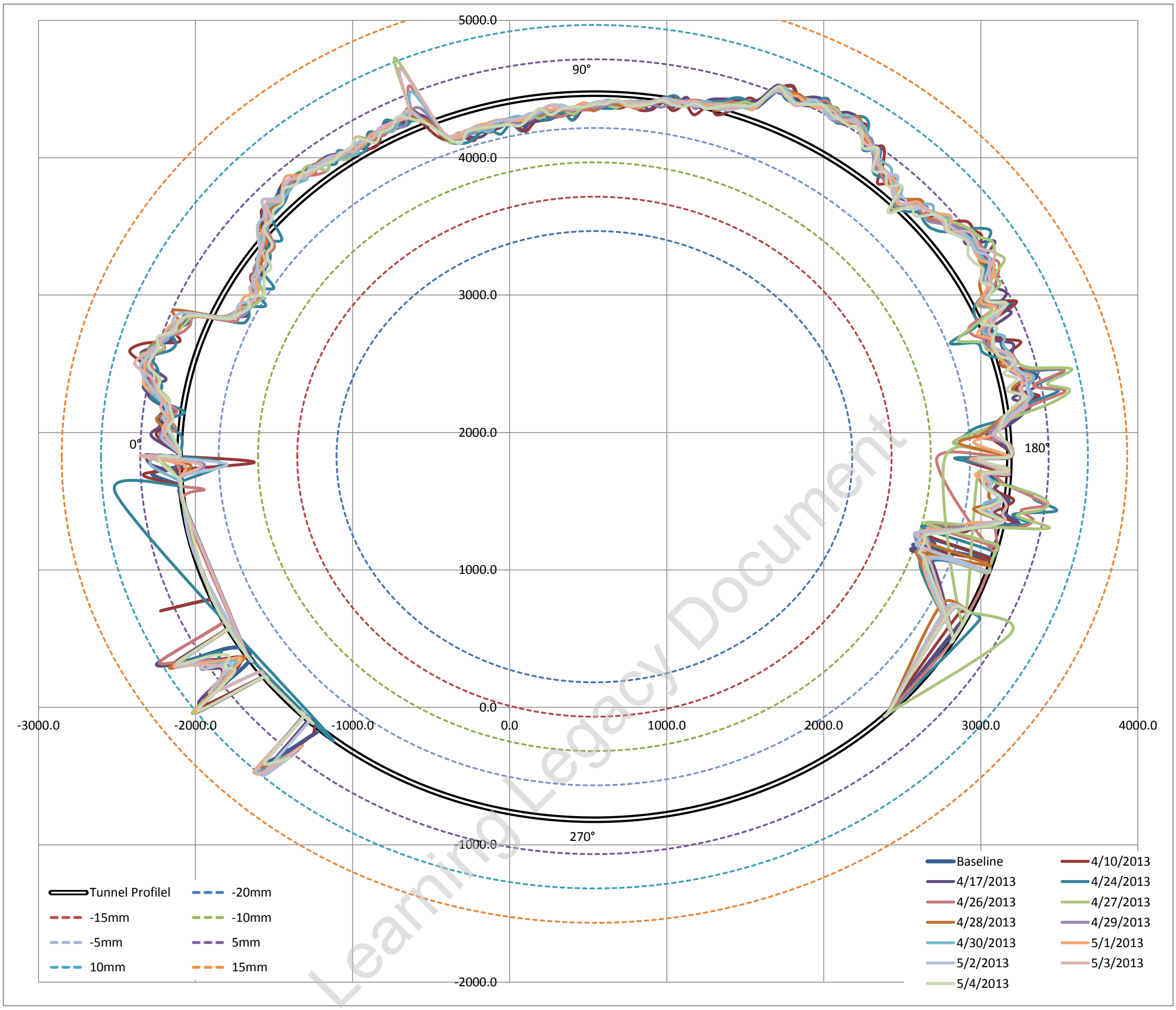
DLR LINE: DN **SECTION: 982**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **982**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5286.12	mm
Estimated best fit as built diameter	**5284.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.04015%	

i.e. Average surveyed diameter varies on 0.04% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**9.9**	**-9.9**
Max / Min deviation % to estimated dia	**0.37%**	**-0.37%**

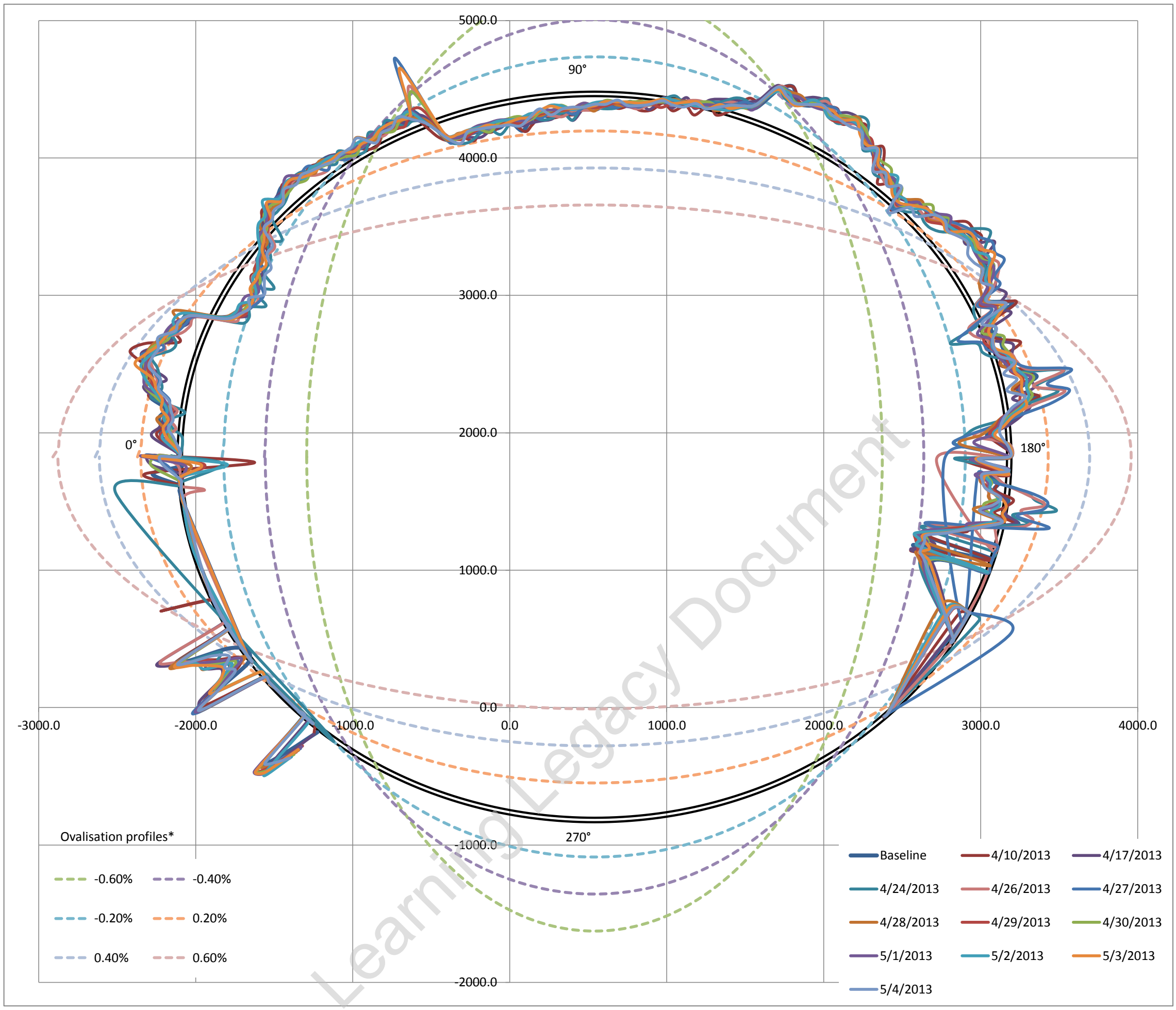
Fitted Circle Coordinates

Axis	X	540
	Y	1824
Radius		2642

Estimated best fit as built diameter	5284	mm
Designed diameter	5300	mm
Average diameter difference	**-16**	mm
Average radial difference	**-8**	mm
Average difference%	**-0.30%**	

DLR LINE: **DN** **SECTION:** **982**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

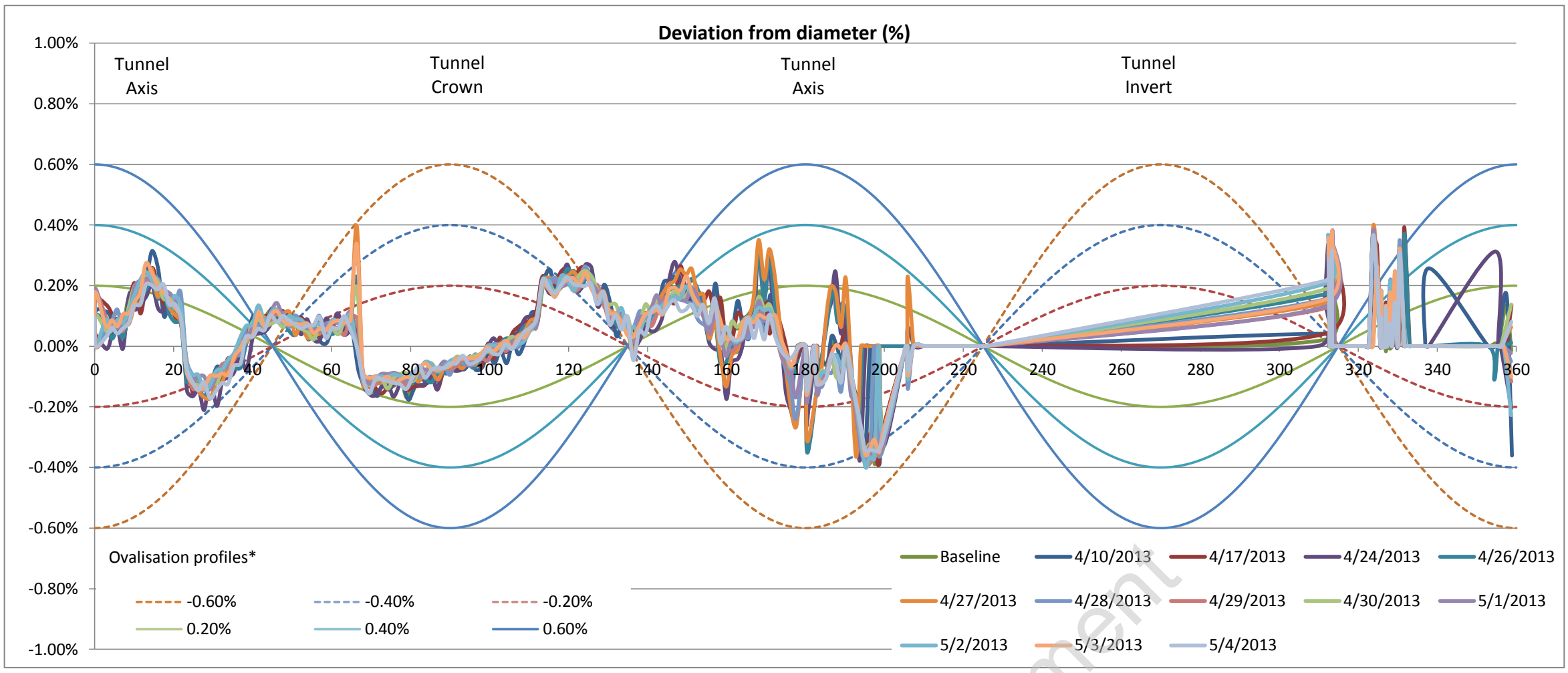
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5283.39 mm
Estimate of vertical diameter at crown, Dv	5281.70 mm
Dh / Dv	1.0003

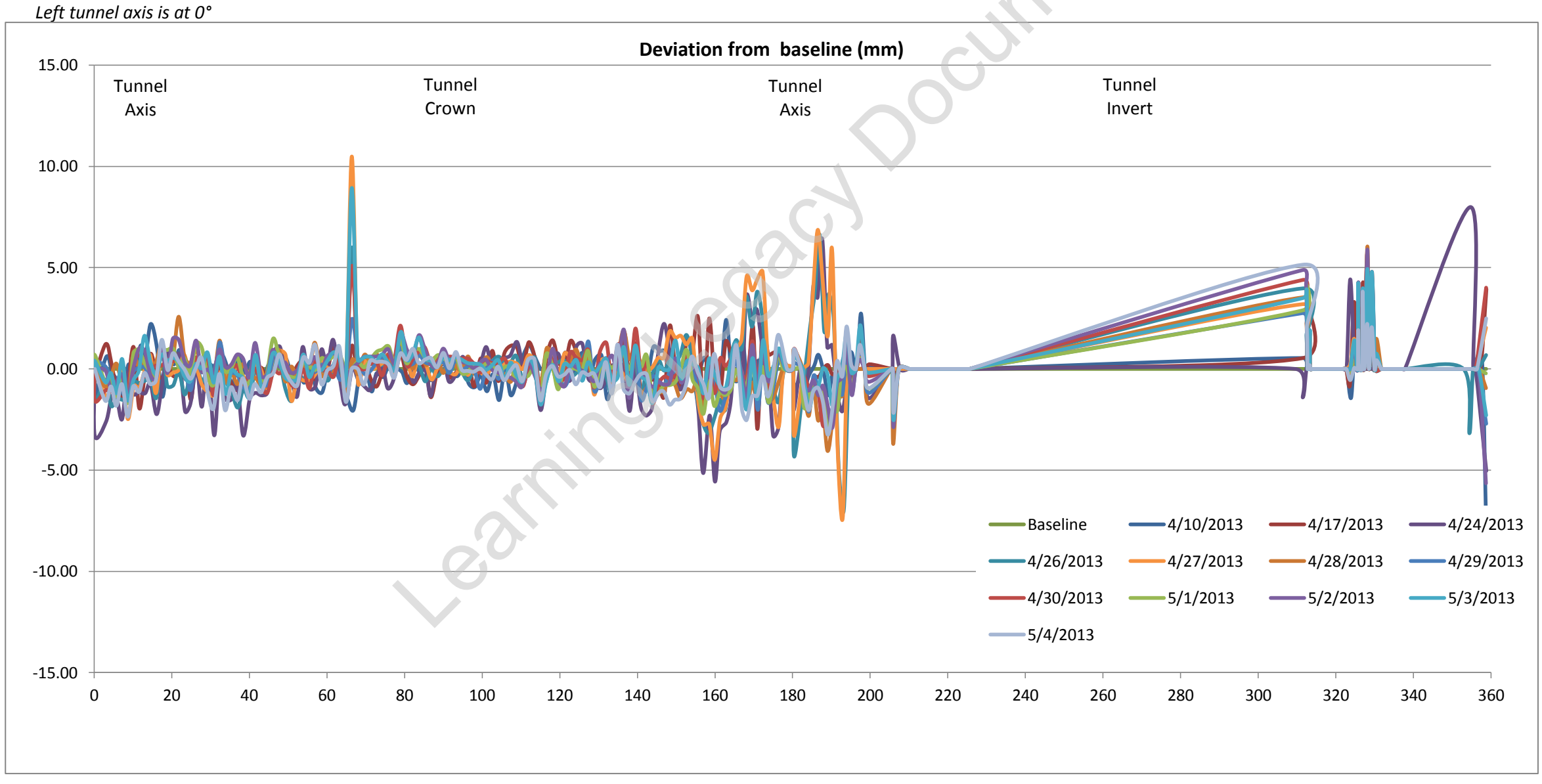
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 982**

Deviation vs Profile

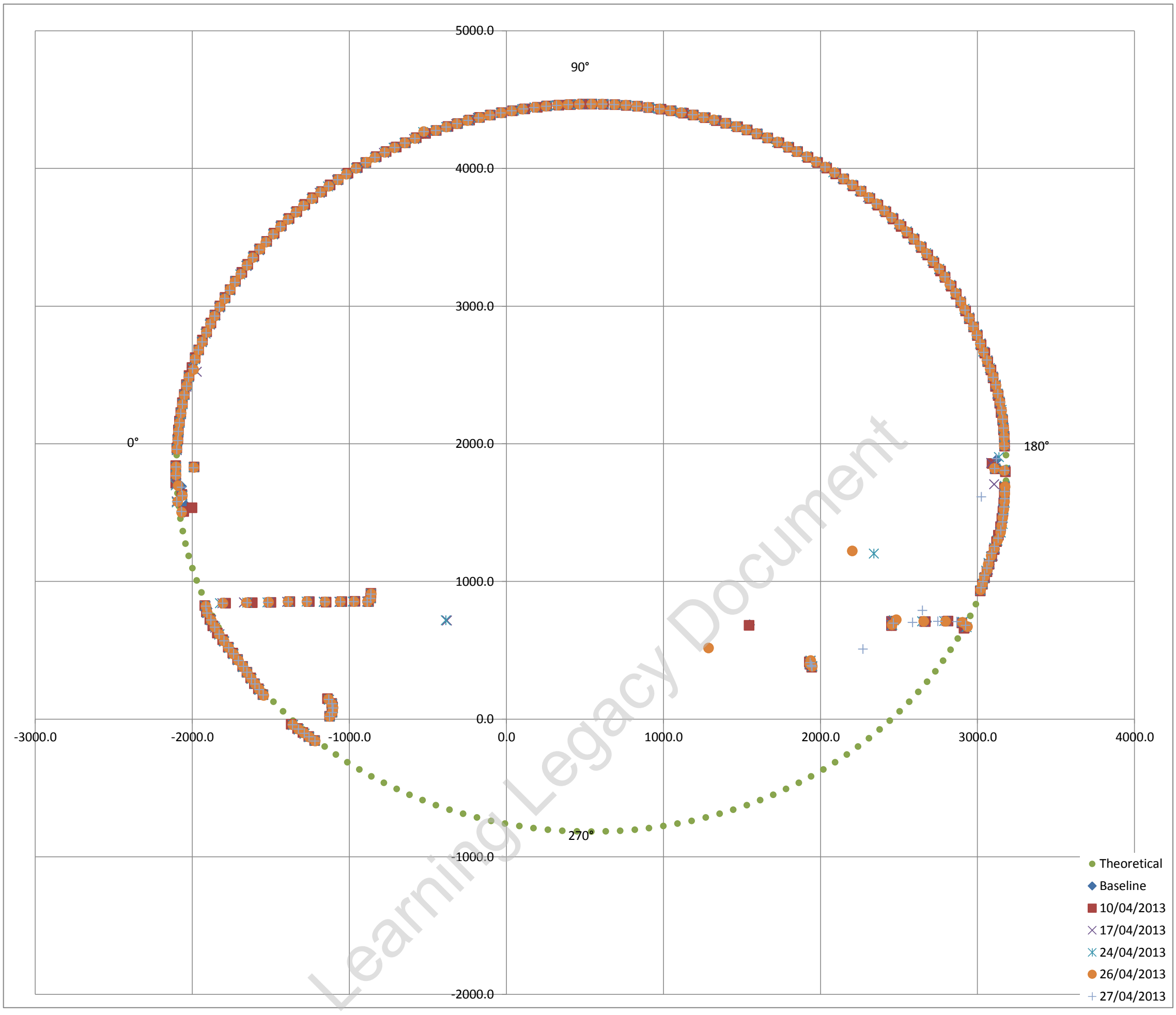


Left tunnel axis is at 0°



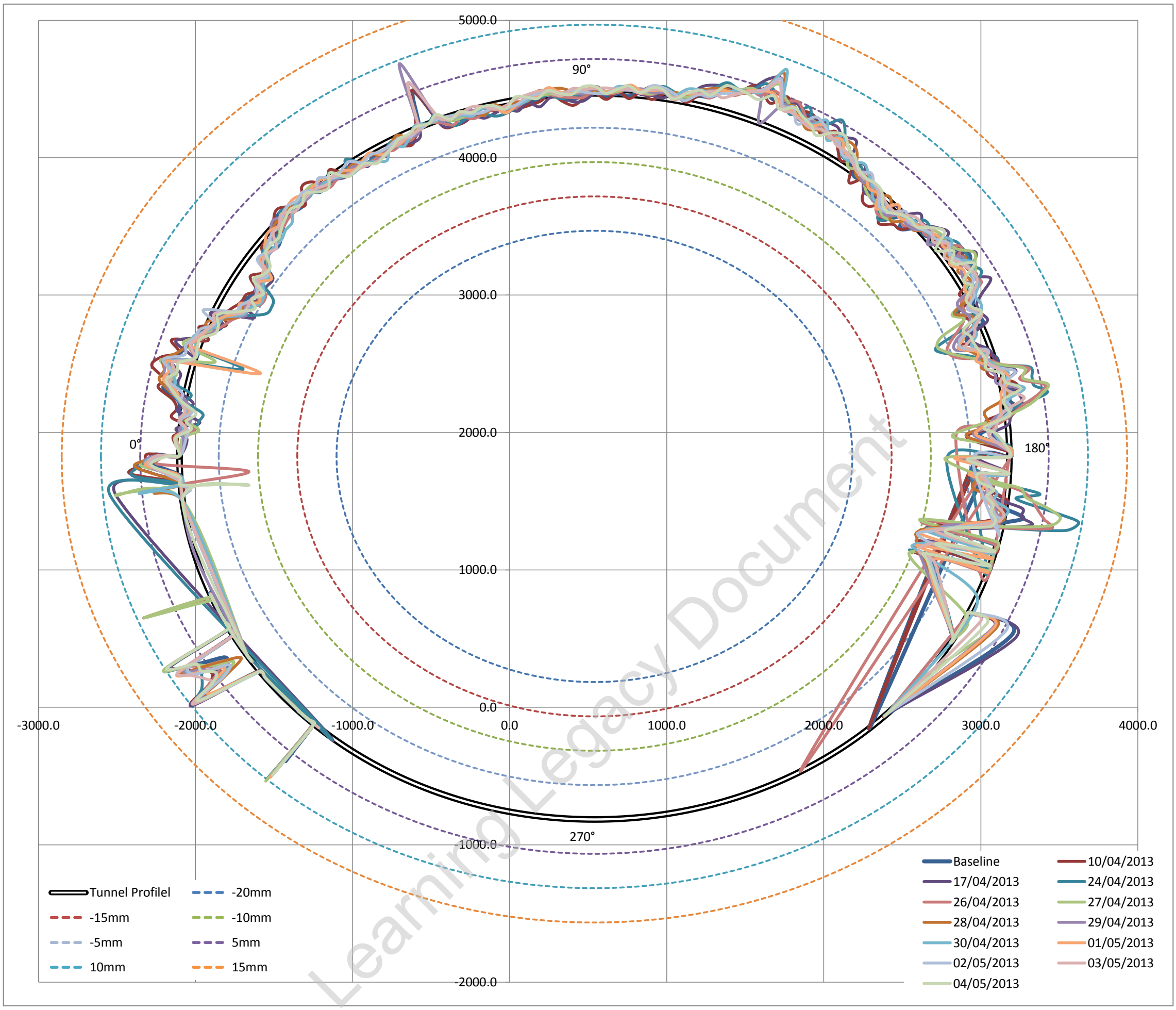
DLR LINE: DN **SECTION: 983**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **983**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5284.68	mm
Estimated best fit as built diameter	**5284.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.01283%	

i.e. Average surveyed diameter varies on 0.012% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**9.6**	**-9.8**
Max / Min deviation % to estimated dia	**0.36%**	**-0.37%**

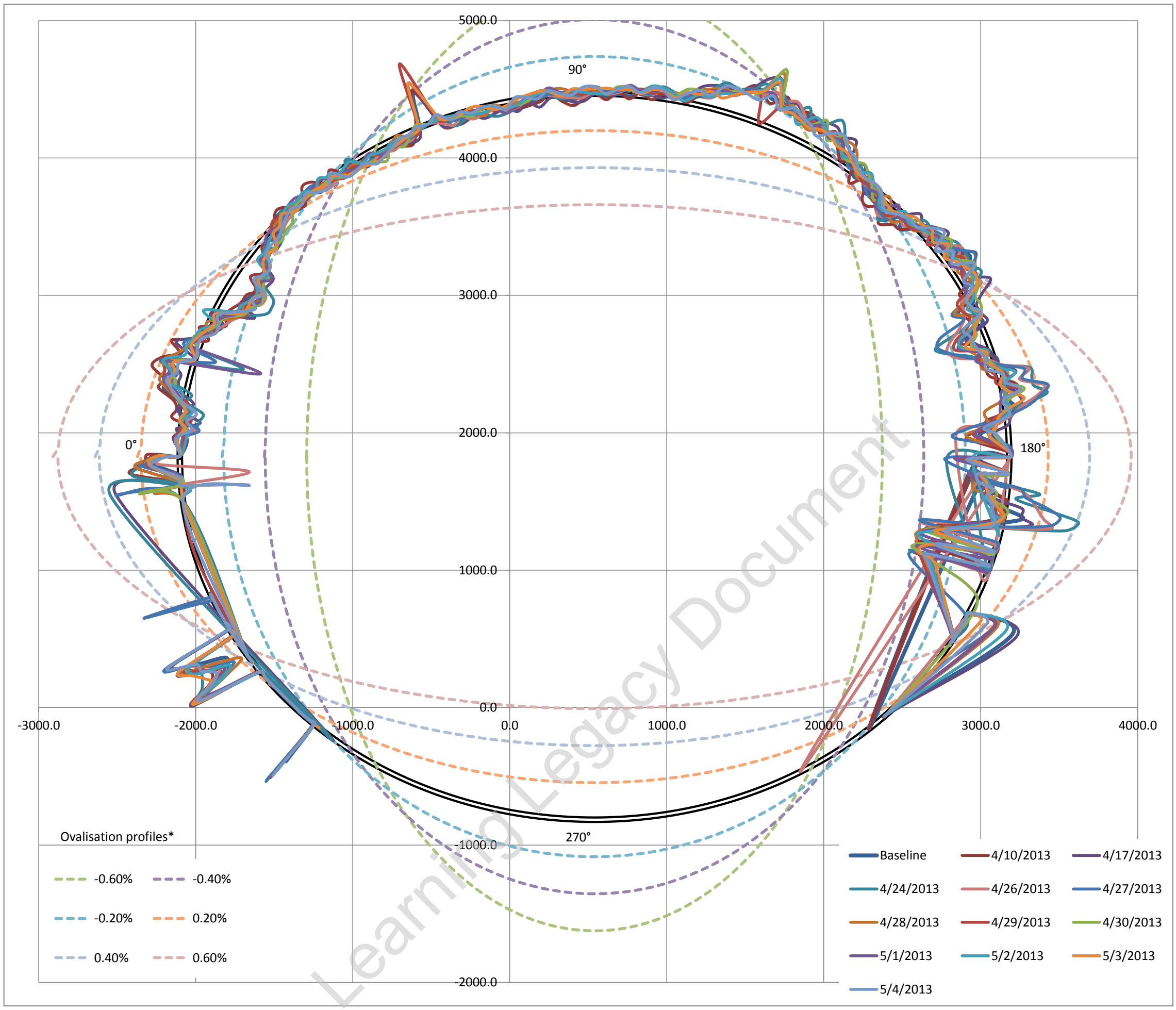
Fitted Circle Coordinates

Axis	X	540
	Y	1826
Radius		2642

Estimated best fit as built diameter	5284	mm
Designed diameter	5300	mm
Average diameter difference	**-16**	mm
Average radial difference	**-8**	mm
Average difference%	**-0.30%**	

DLR LINE: **DN** **SECTION:** **983**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

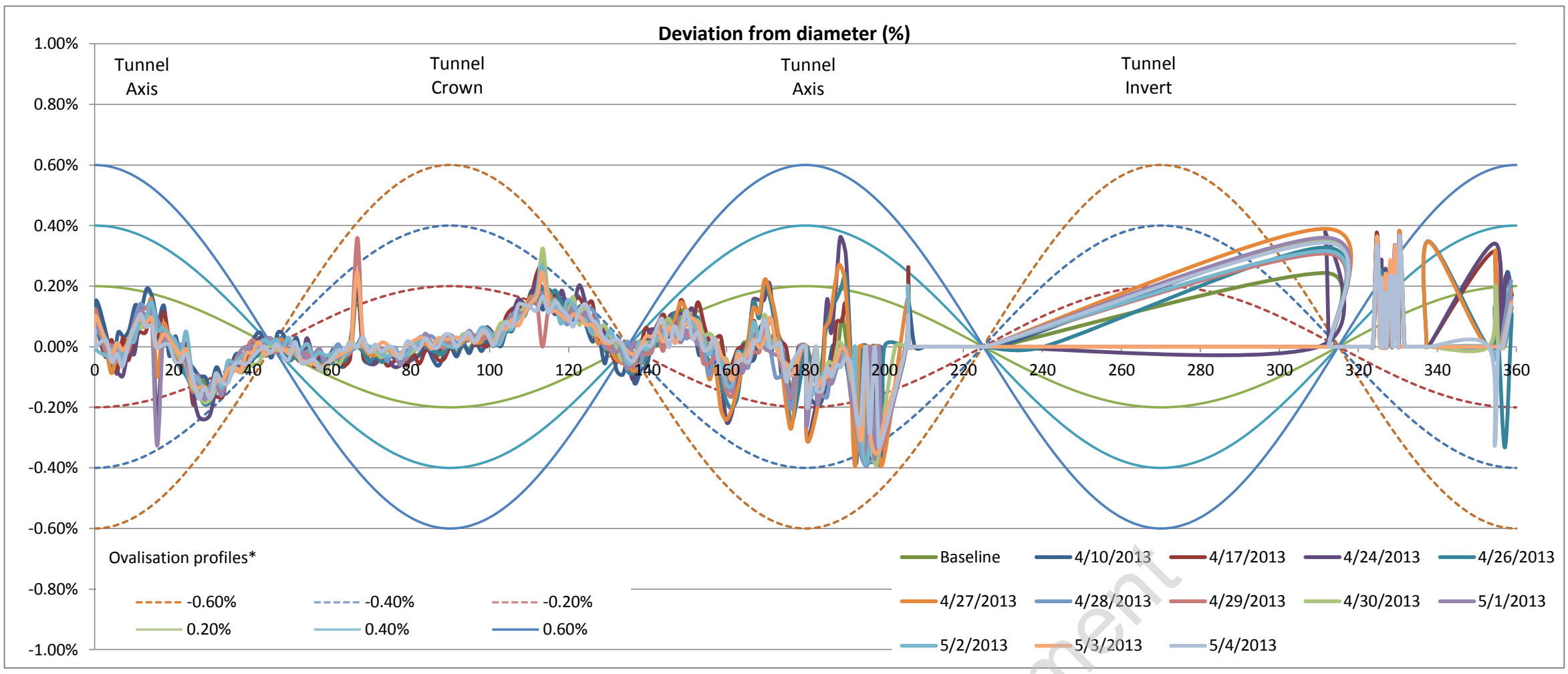
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5283.13 mm
Estimate of vertical diameter at crown, Dv	5284.01 mm
Dh / Dv	0.9998

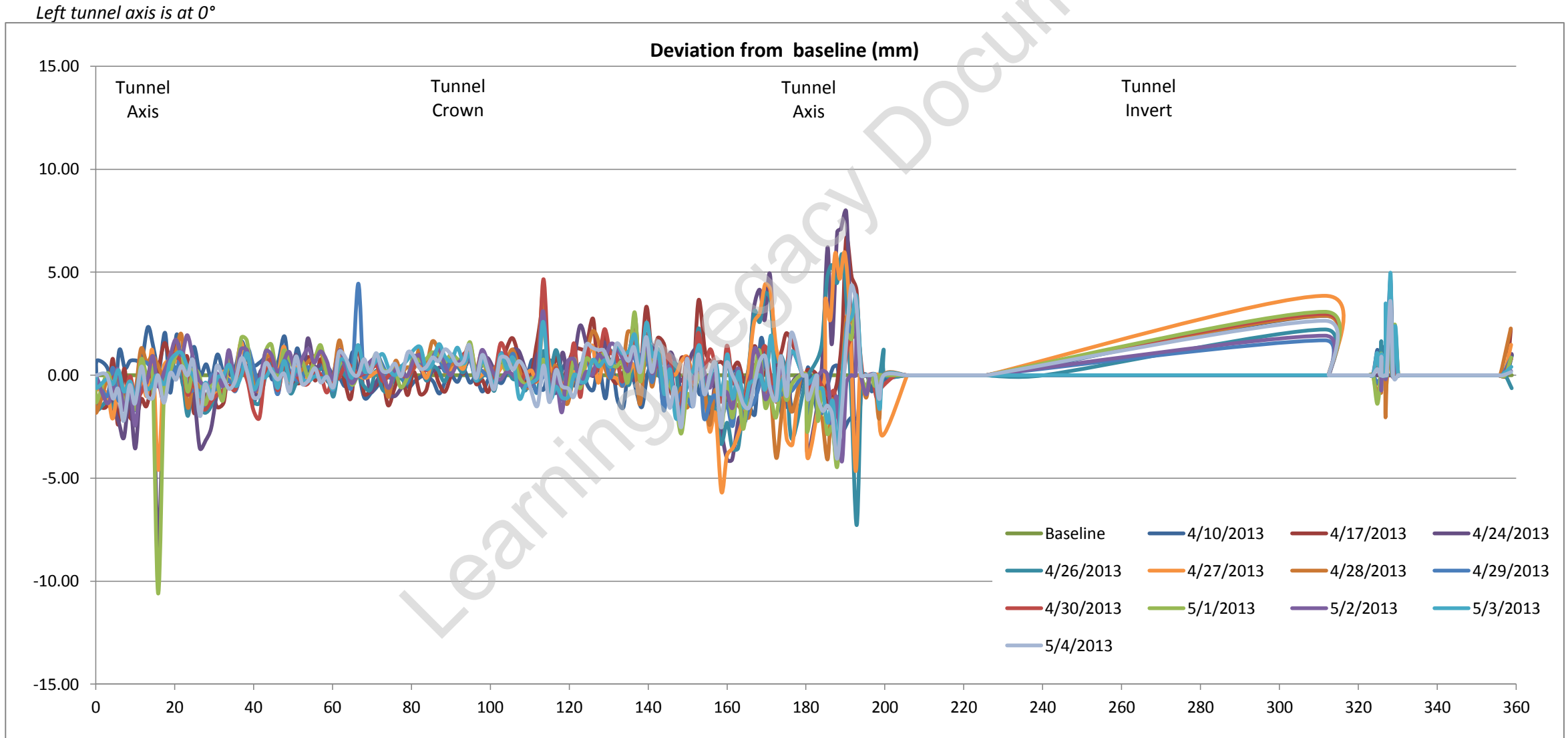
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 983**

Deviation vs Profile

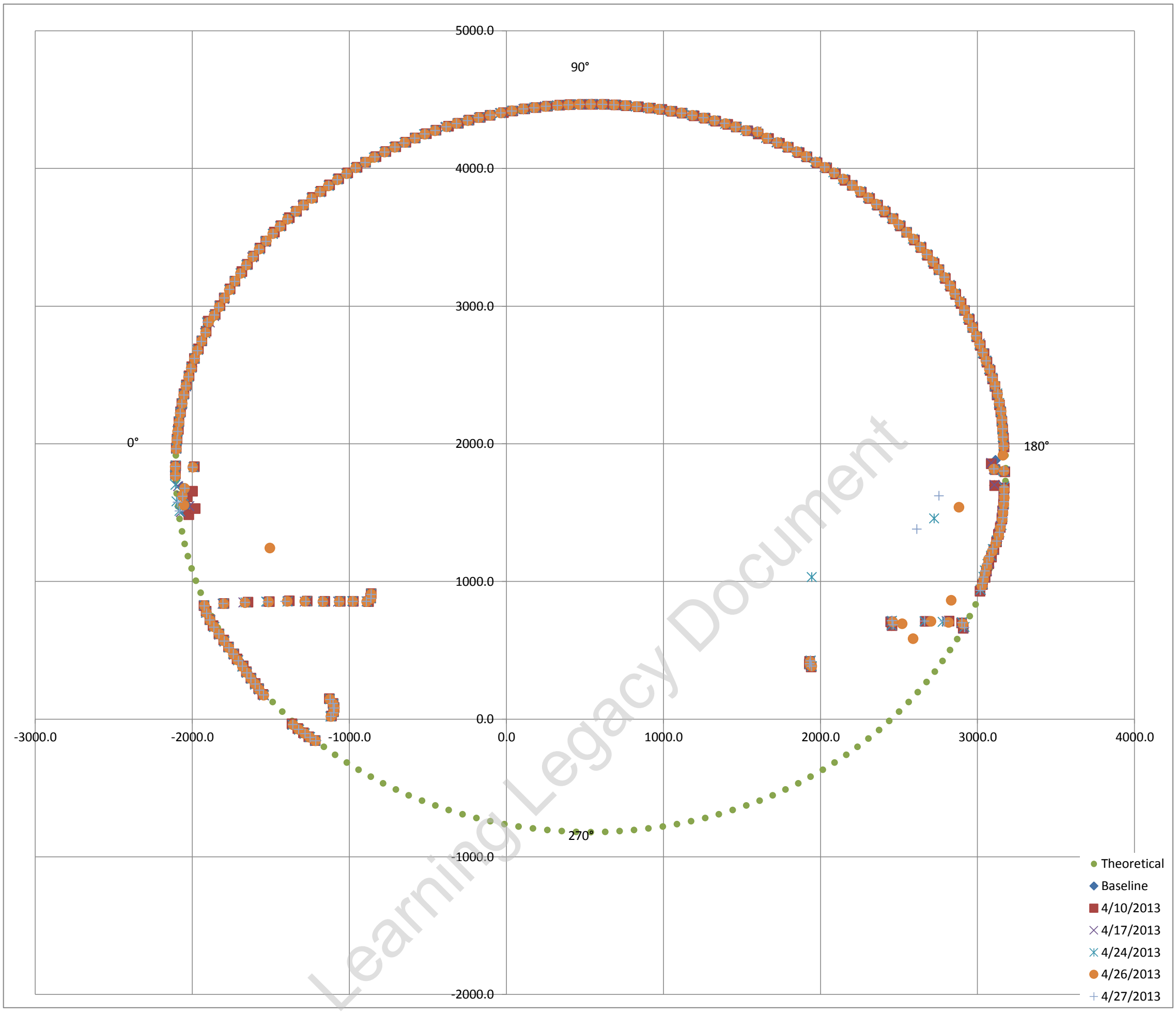


Left tunnel axis is at 0°



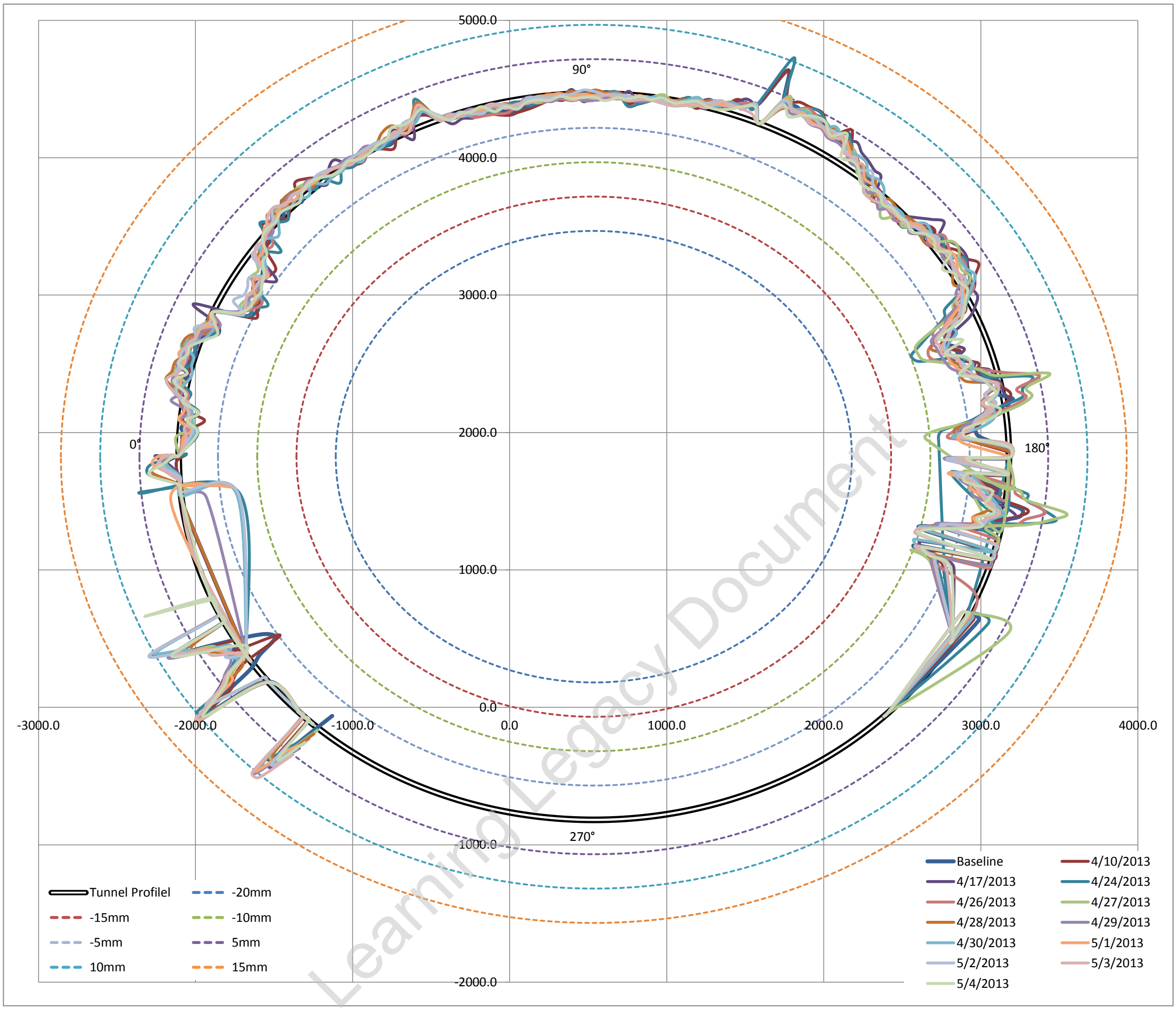
DLR LINE: DN **SECTION: 984**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **984**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5285.94	mm
Estimated best fit as built diameter	**5286.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00108%	

i.e. Average surveyed diameter varies on -0.001% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**10.0**	**-9.5**
Max / Min deviation % to estimated dia	**0.38%**	**-0.36%**

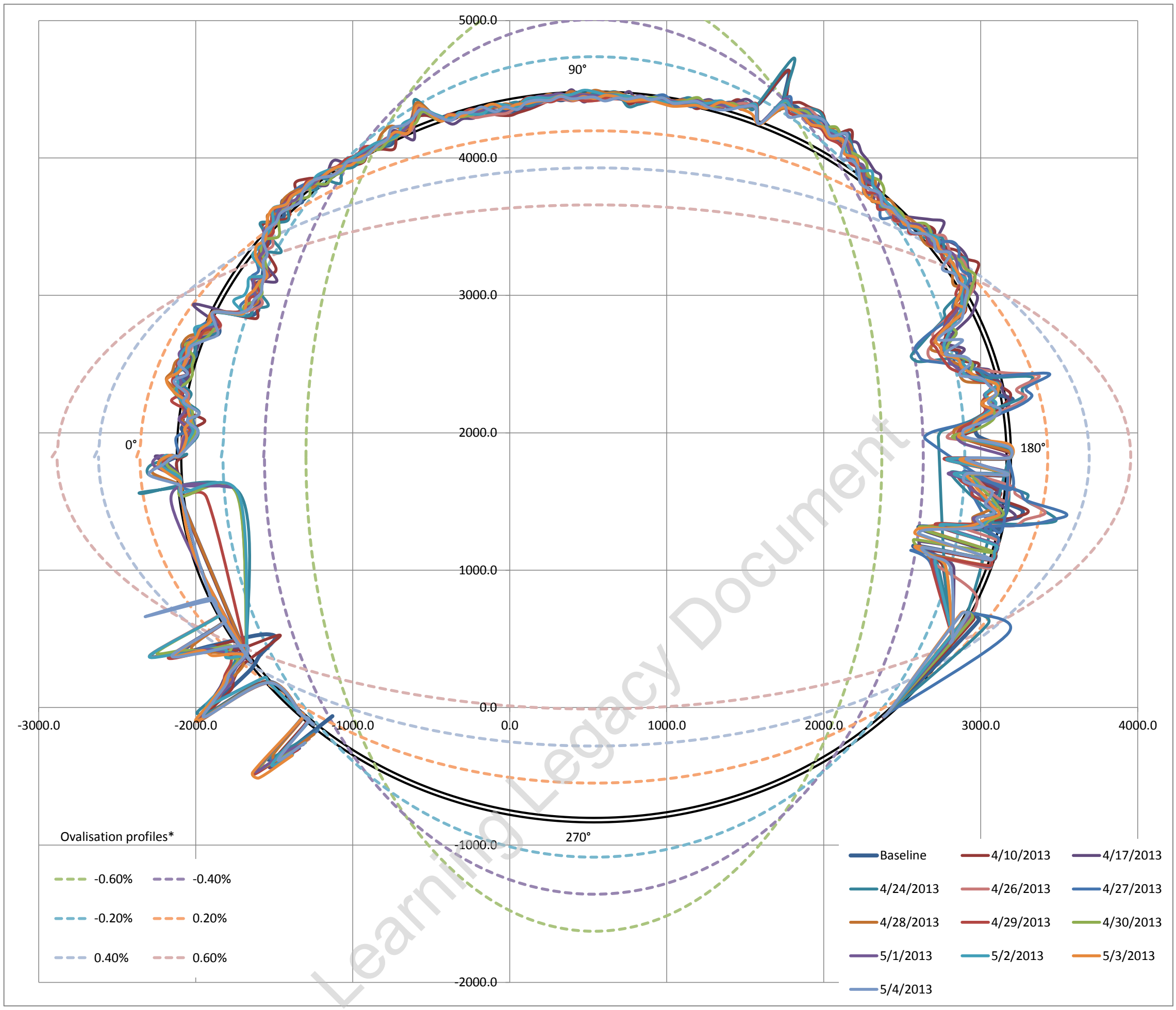
Fitted Circle Coordinates

Axis	X	536
	Y	1824
Radius		2643

Estimated best fit as built diameter	5286	mm
Designed diameter	5300	mm
Average diameter difference	**-14**	mm
Average radial difference	**-7**	mm
Average difference%	**-0.26%**	

DLR LINE: **DN** **SECTION:** **984**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

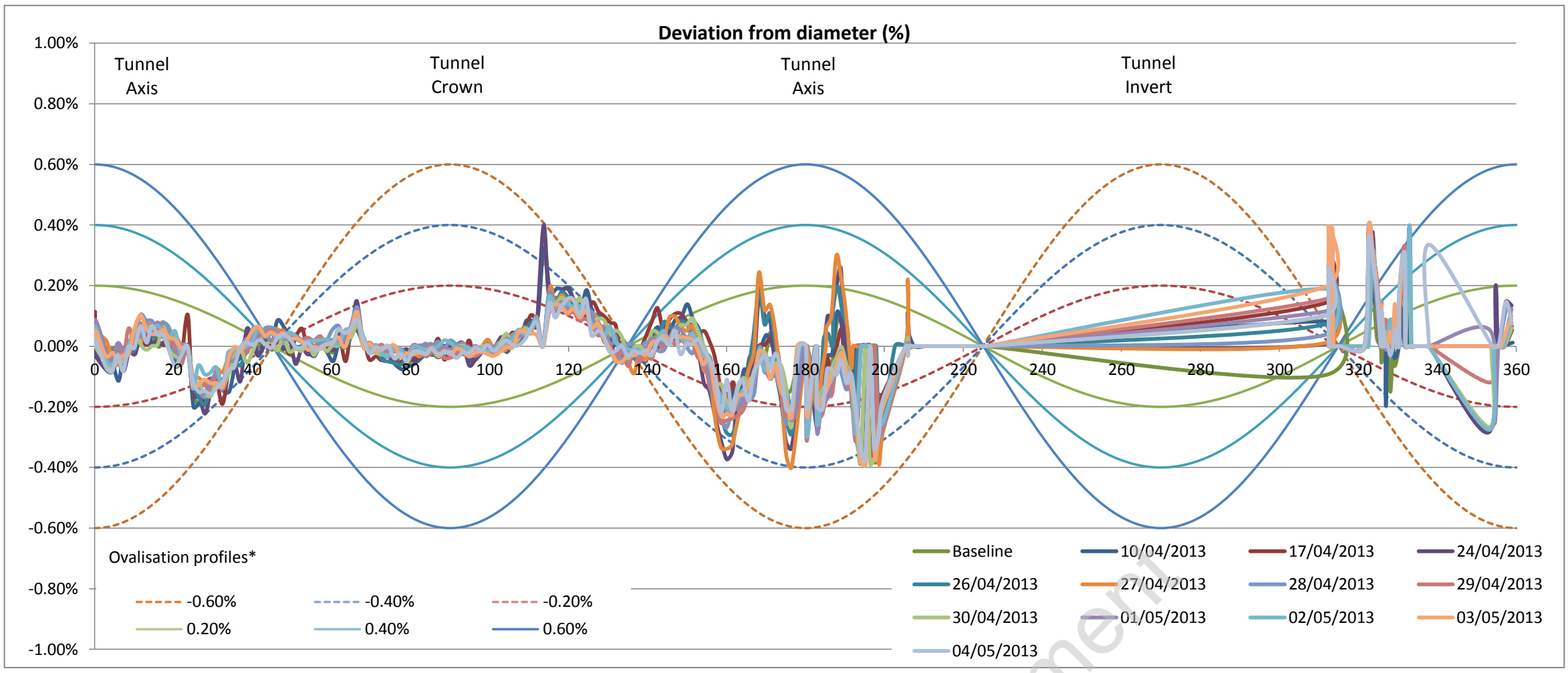
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5279.84 mm
Estimate of vertical diameter at crown, Dv	5285.72 mm
Dh / Dv	0.9989

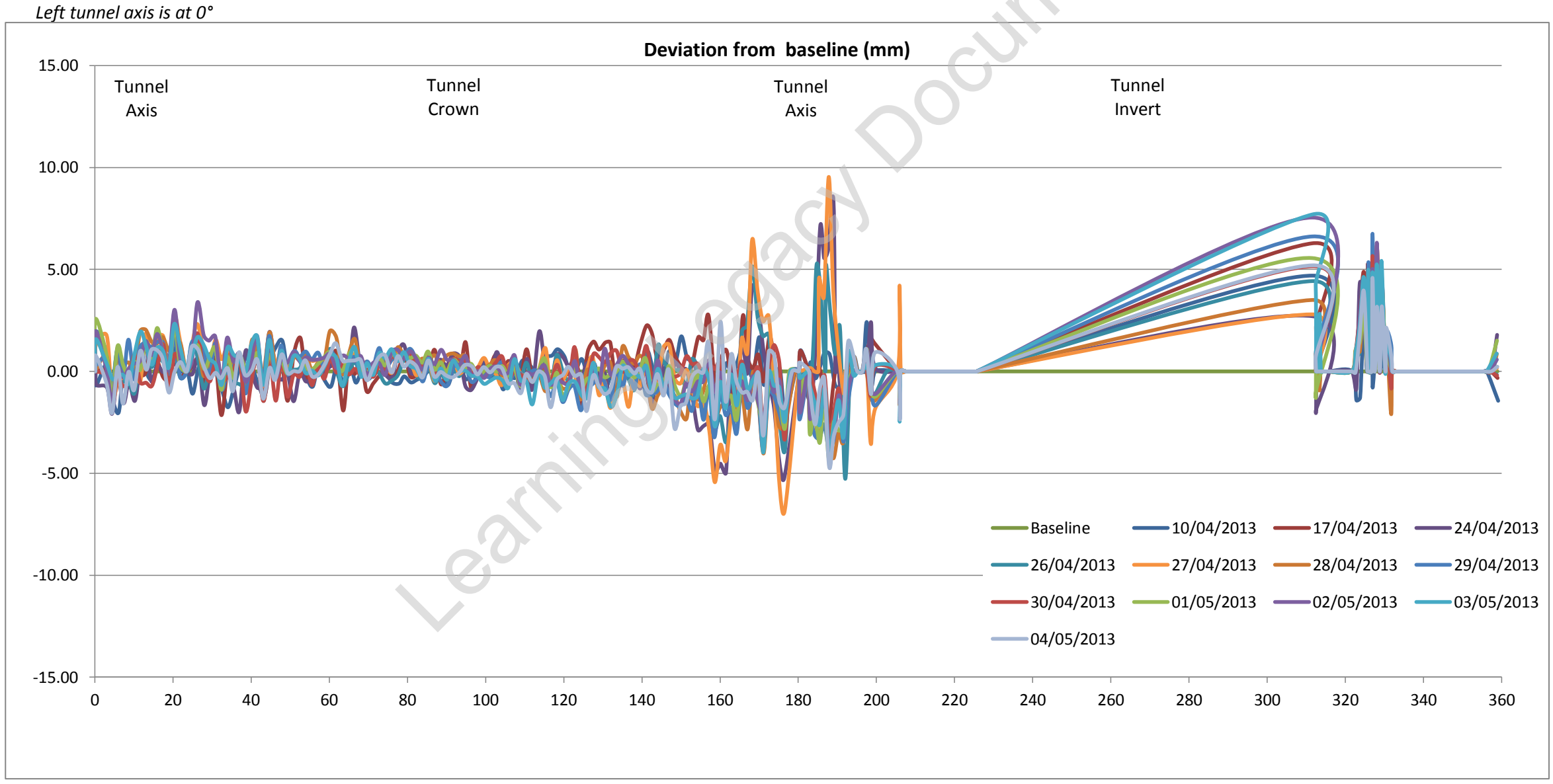
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 984**

Deviation vs Profile

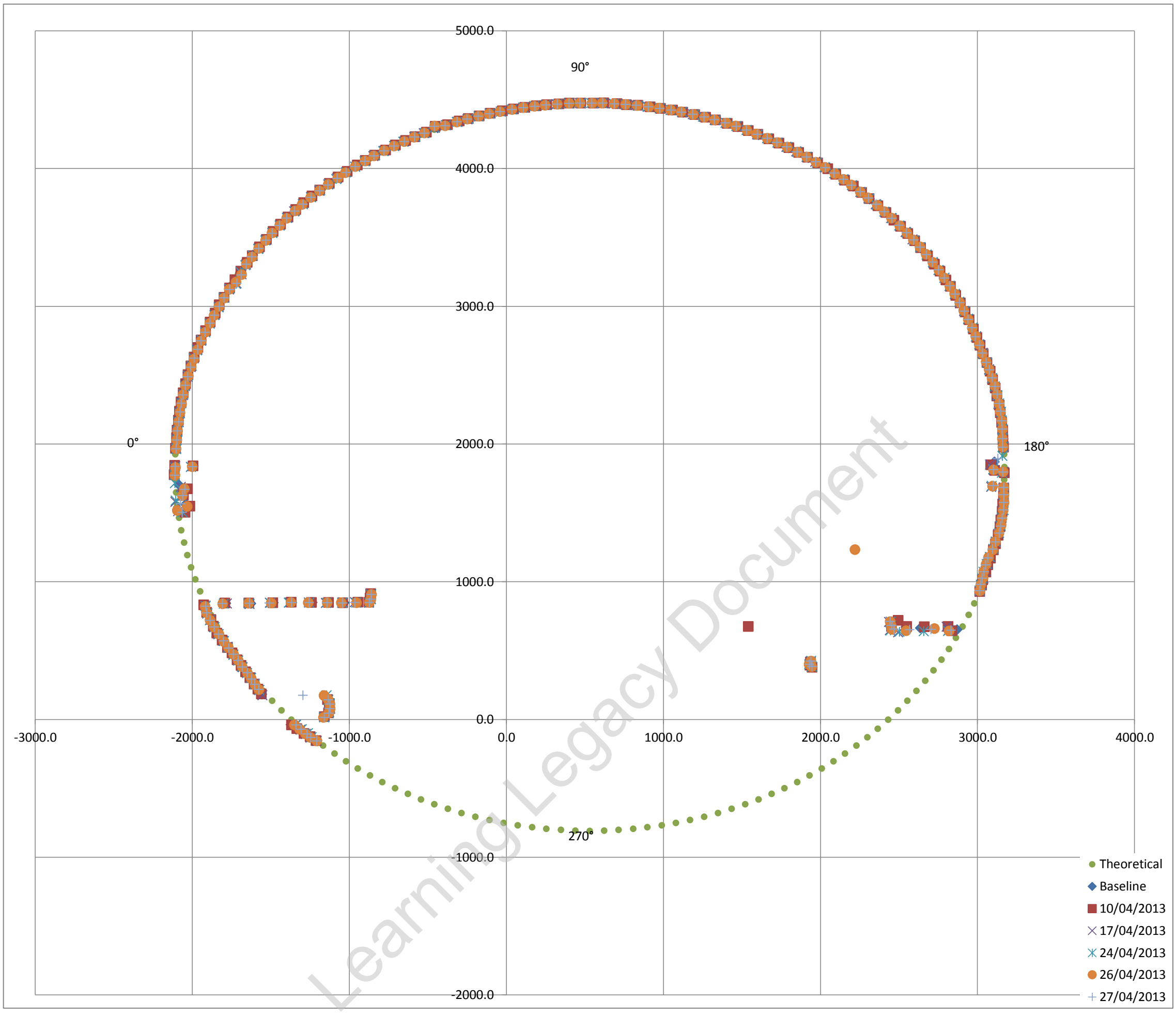


Left tunnel axis is at 0°



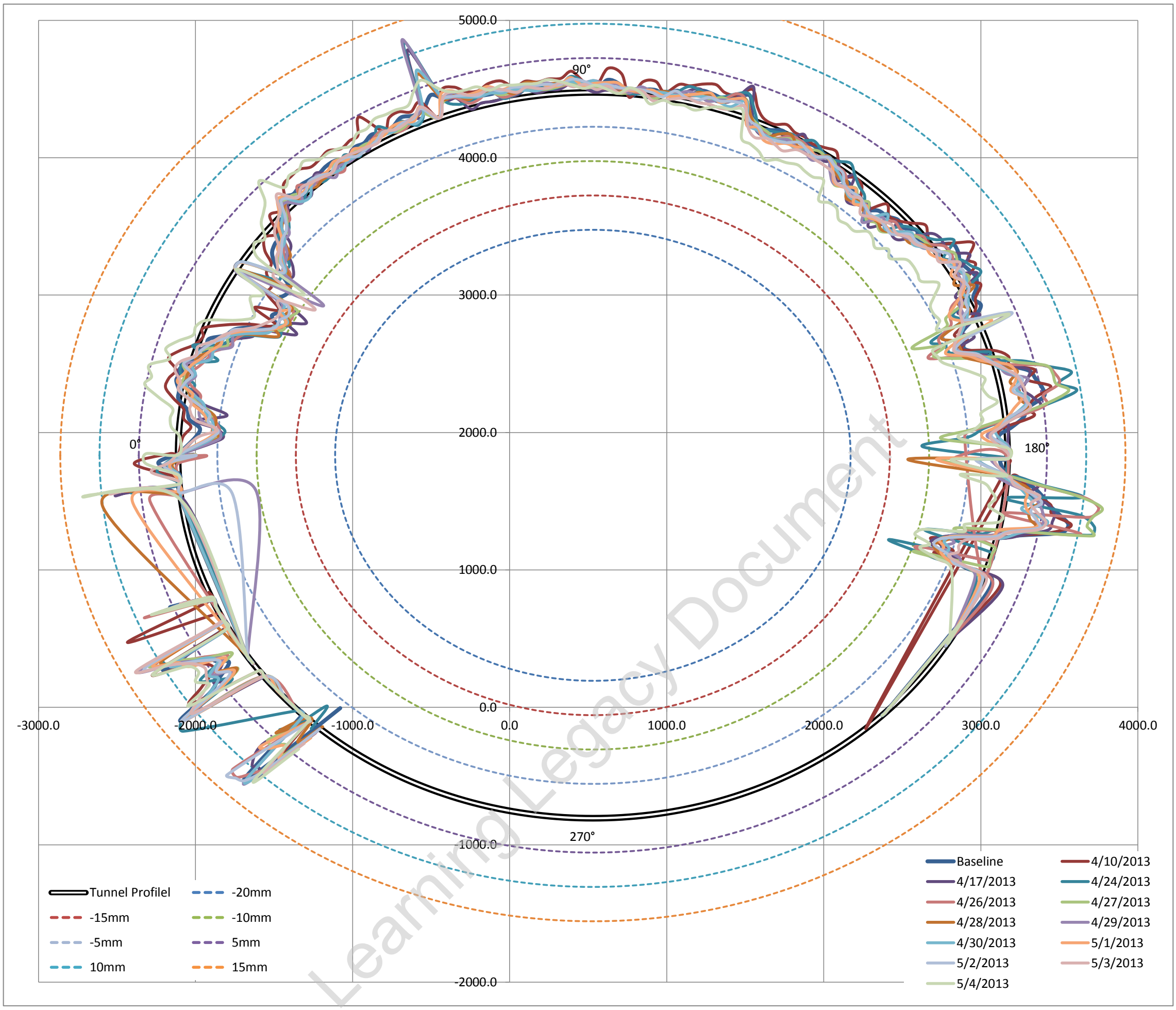
DLR LINE: DN **SECTION: 988**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **988**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5282.94	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.01772%	

i.e. Average surveyed diameter varies on 0.017% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.3**	**-10.4**
Max / Min deviation % to estimated dia	**0.47%**	**-0.39%**

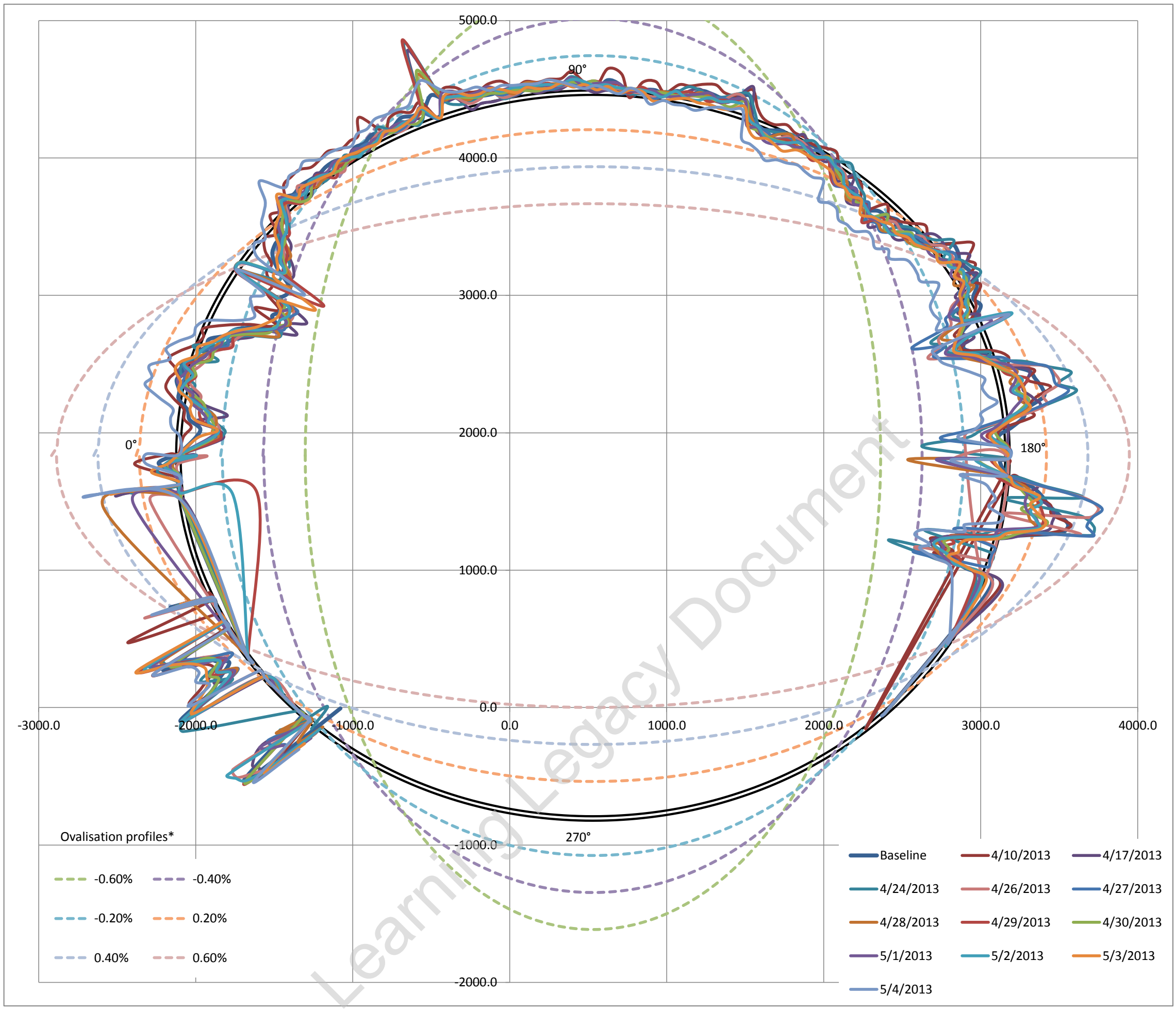
Fitted Circle Coordinates

Axis	X	530
	Y	1834
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **988**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

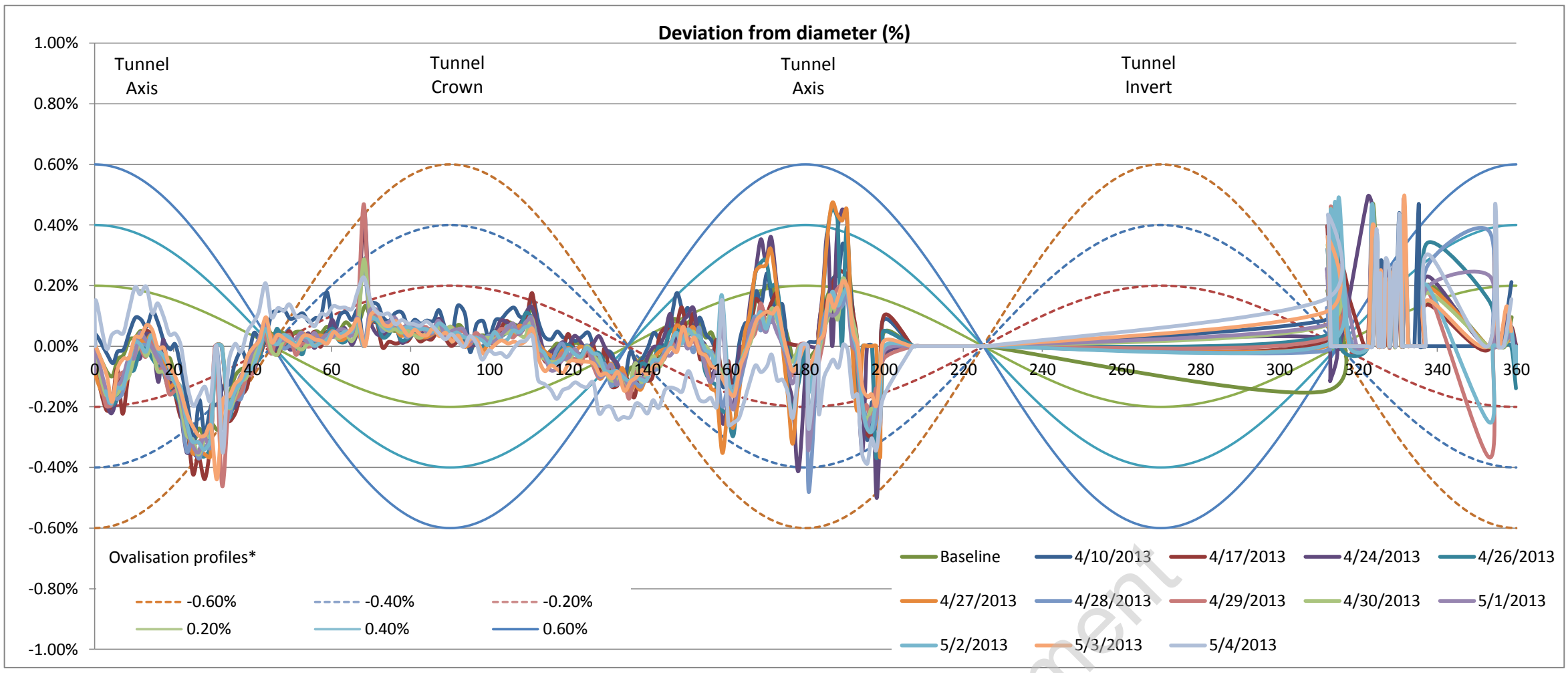
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5281.05 mm
Estimate of vertical diameter at crown, Dv	5282.41 mm
Dh / Dv	0.9997

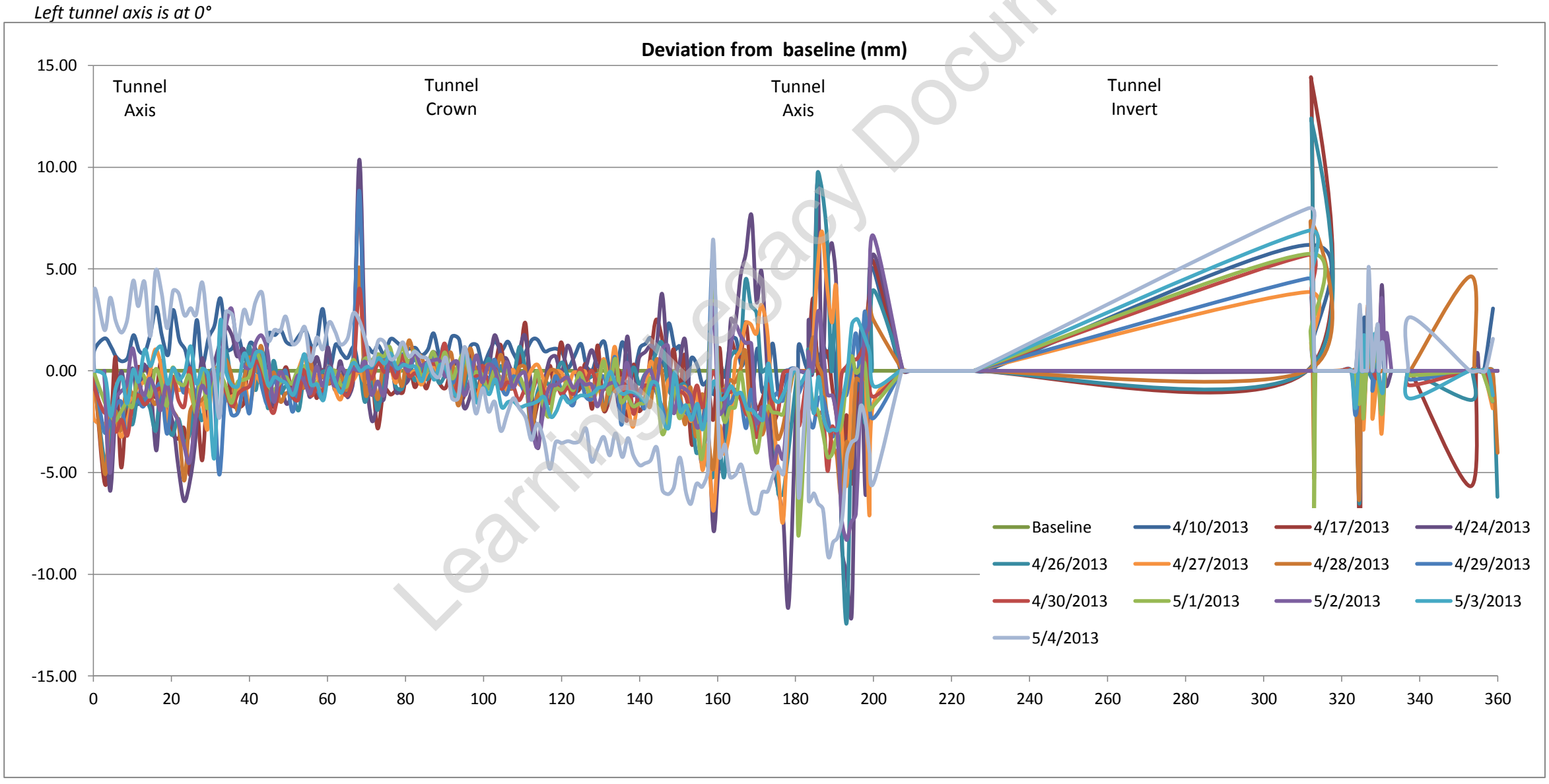
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 988**

Deviation vs Profile

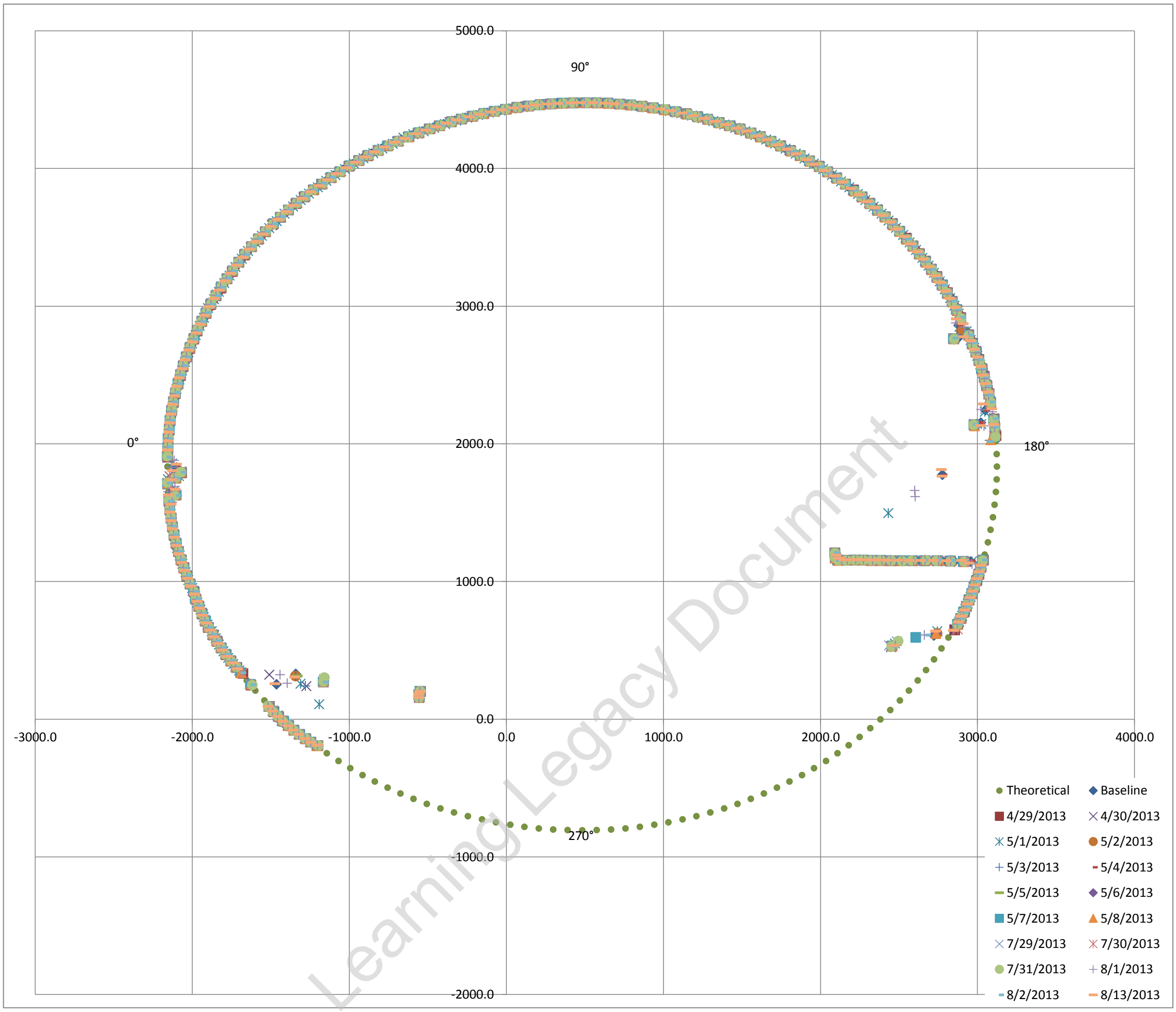


Left tunnel axis is at 0°



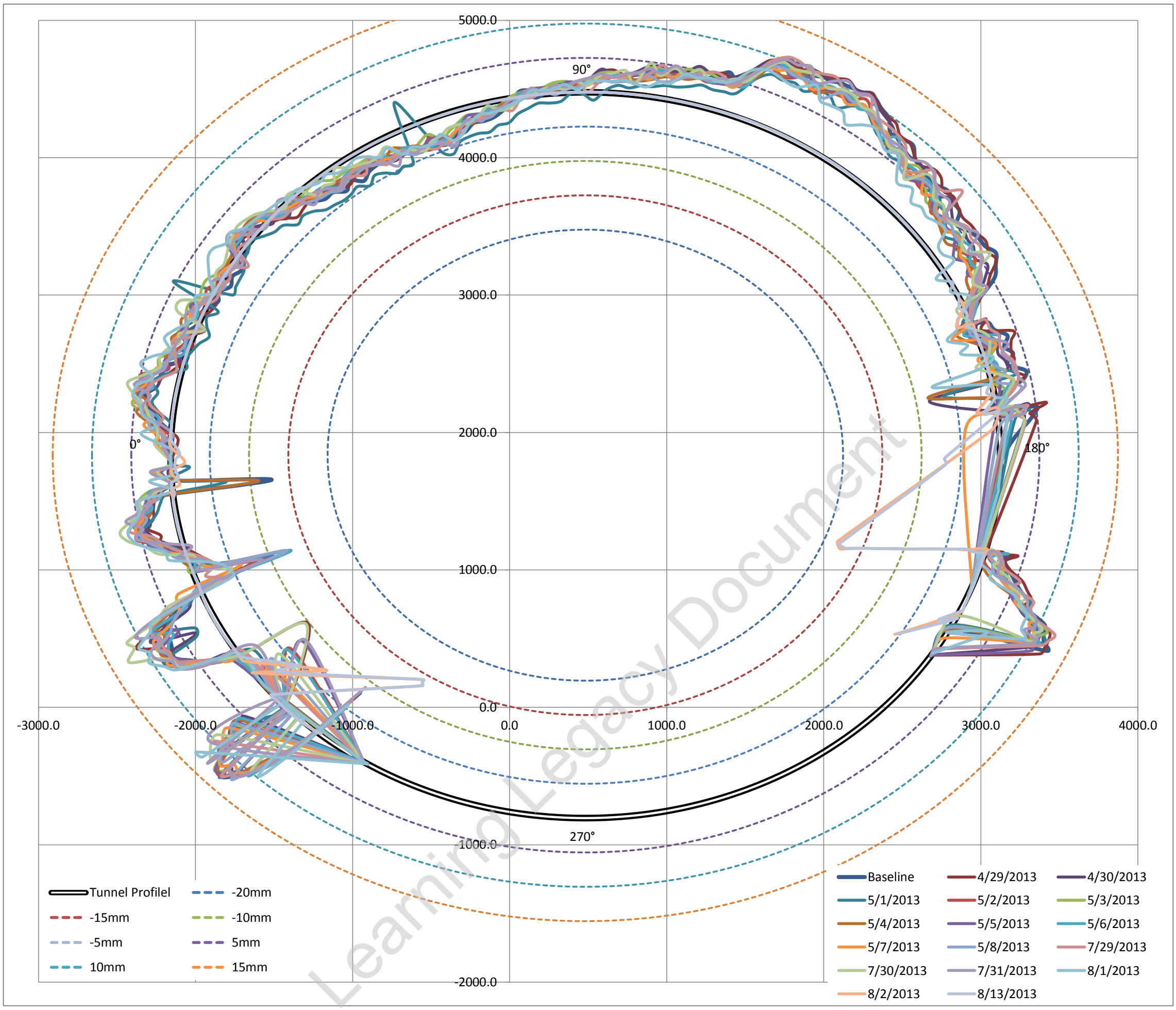
DLR LINE: UP **SECTION: 961**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **961**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5288.31	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.11948%	

i.e. Average surveyed diameter varies on 0.119% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-9.3**
Max / Min deviation % to estimated dia	**0.47%**	**-0.35%**

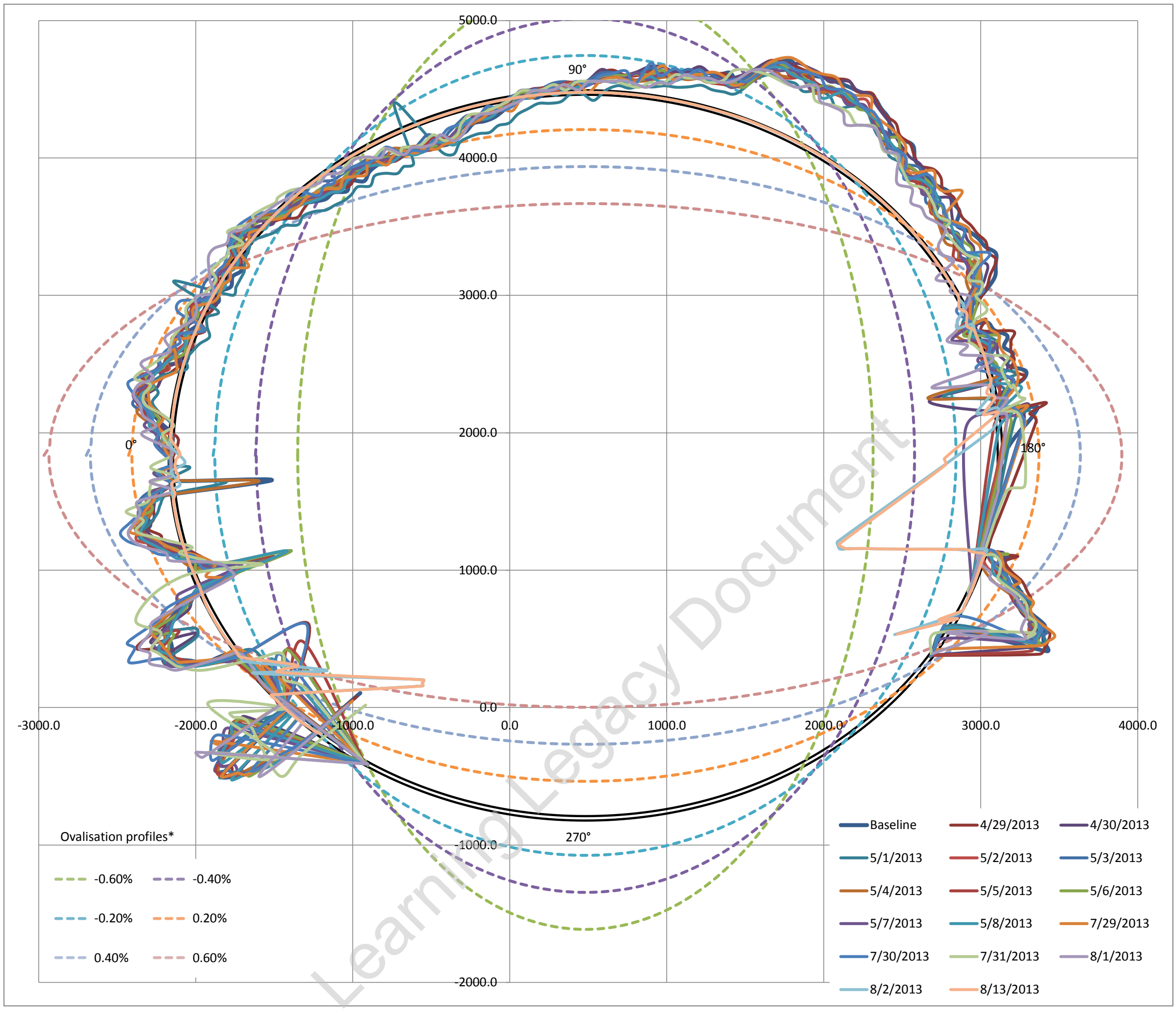
Fitted Circle Coordinates

Axis	X	482
	Y	1835
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **UP** **SECTION:** **961**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

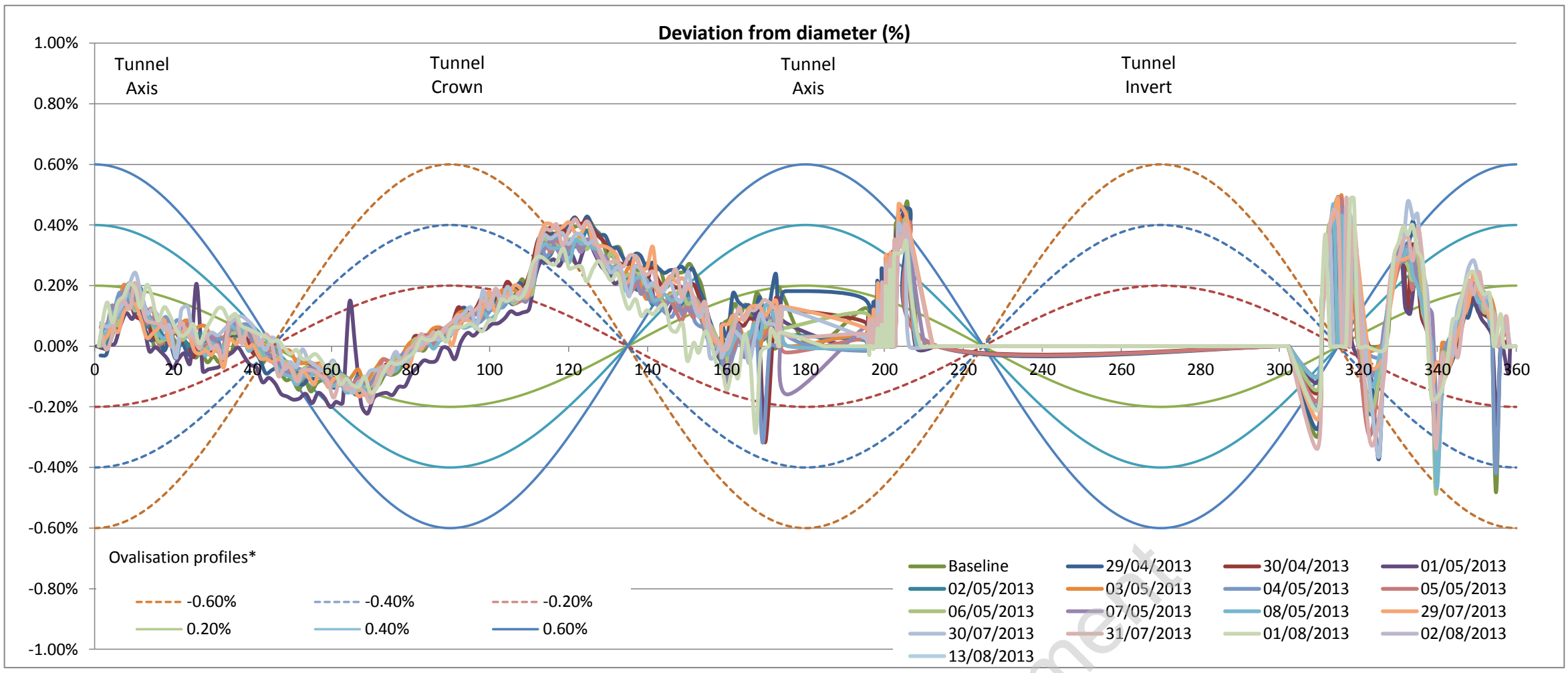
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5285.84 mm
Estimate of vertical diameter at crown, Dv	5283.86 mm
Dh / Dv	1.0004

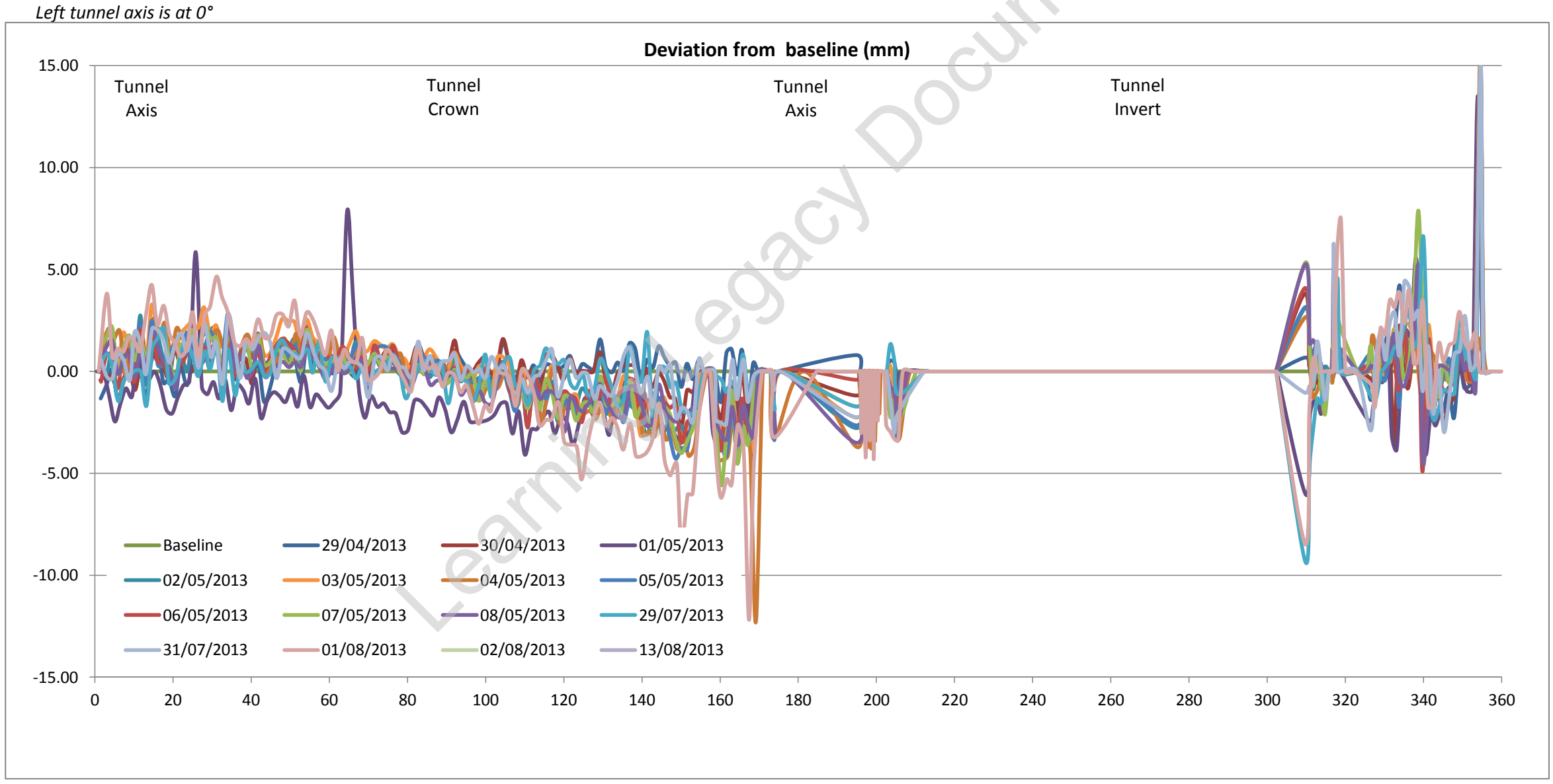
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 961**

Deviation vs Profile

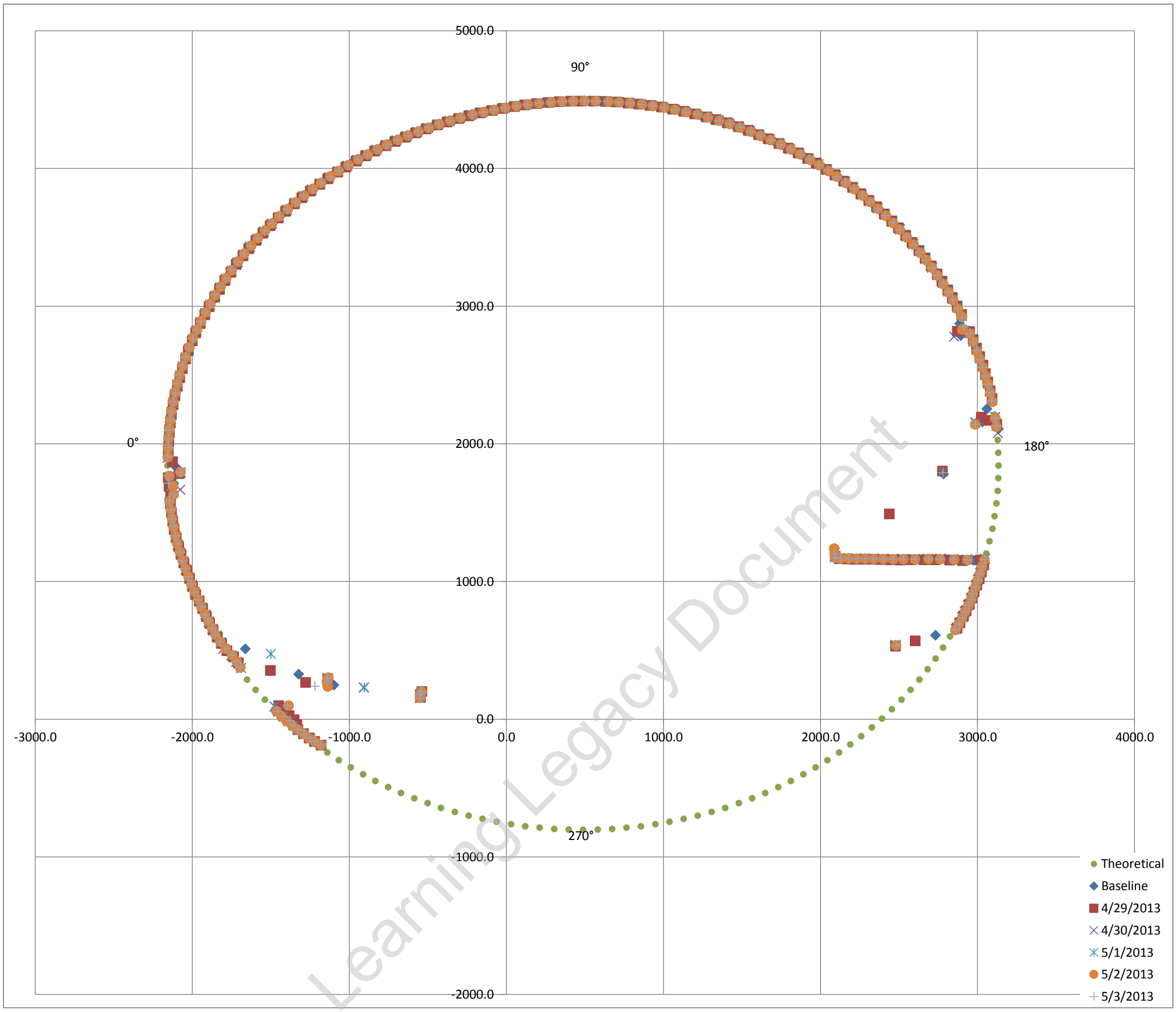


Left tunnel axis is at 0°



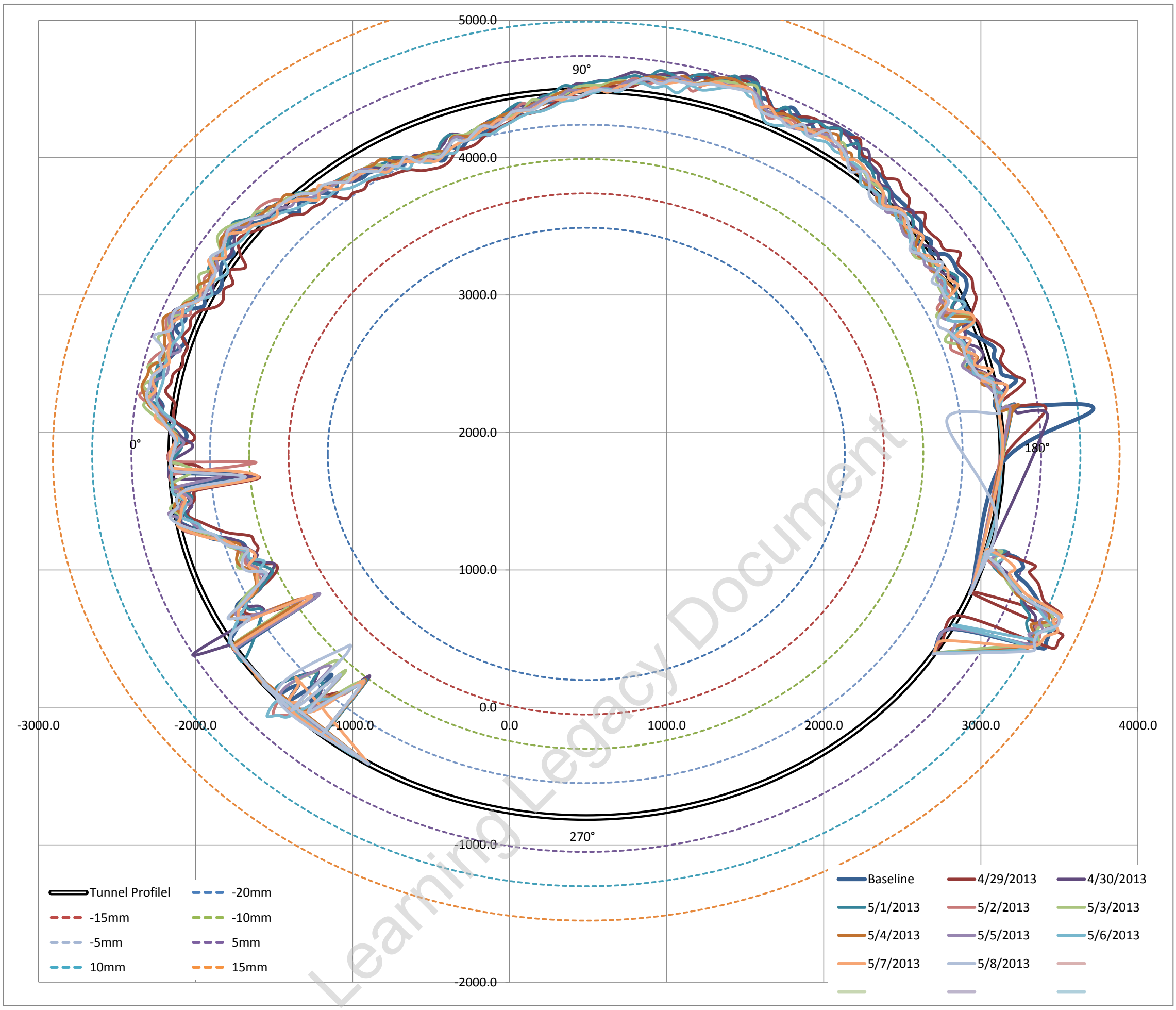
DLR LINE: UP **SECTION: 964**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **964**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5291.79	mm
Estimated best fit as built diameter	**5292.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00398%	

i.e. Average surveyed diameter varies on -0.003% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.5**	**-11.1**
Max / Min deviation % to estimated dia	**0.43%**	**-0.42%**

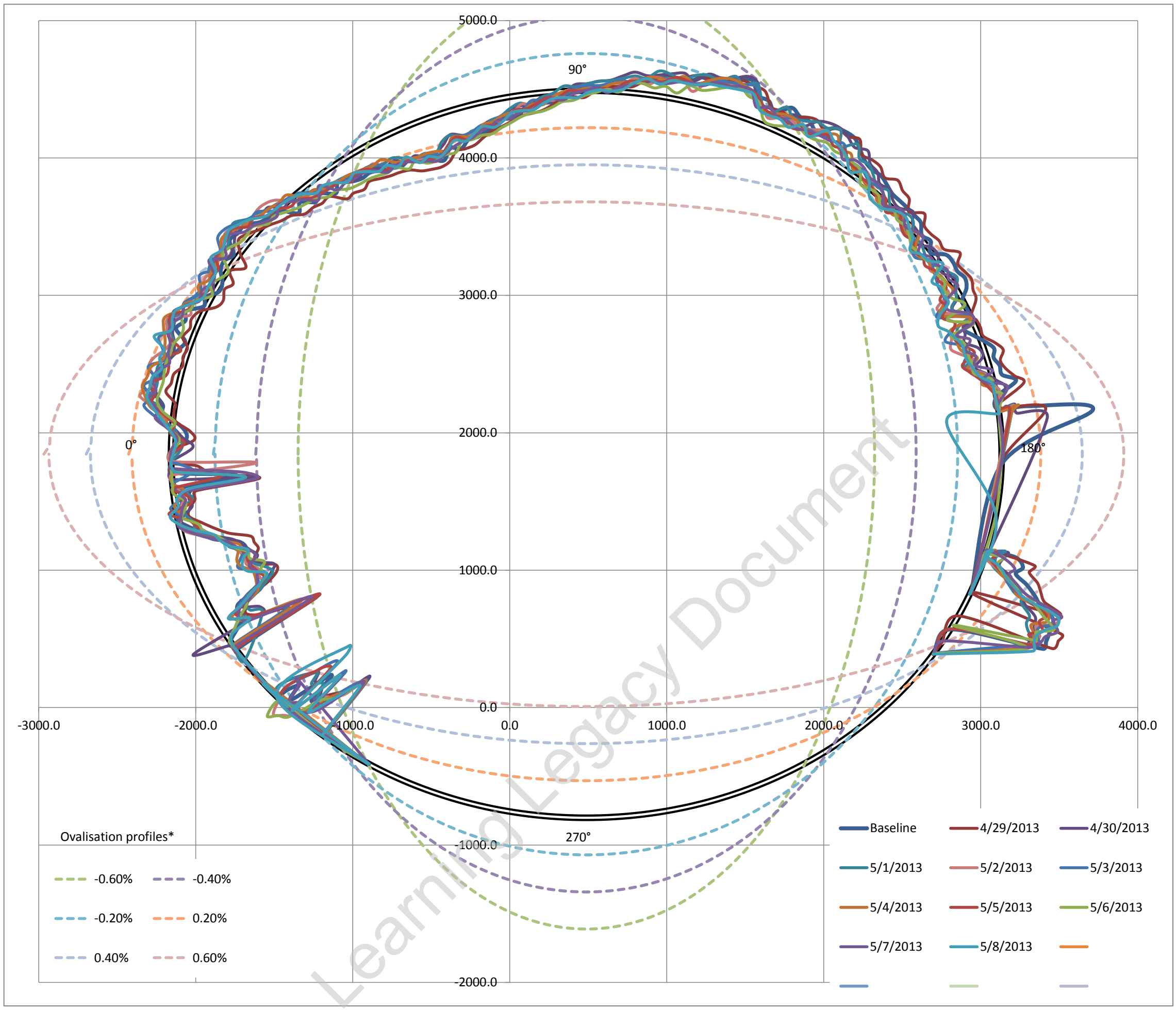
Fitted Circle Coordinates

Axis	X	488
	Y	1844
Radius		2646

Estimated best fit as built diameter	5292	mm
Designed diameter	5300	mm
Average diameter difference	**-8**	mm
Average radial difference	**-4**	mm
Average difference%	**-0.15%**	

DLR LINE: **UP** **SECTION:** **964**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

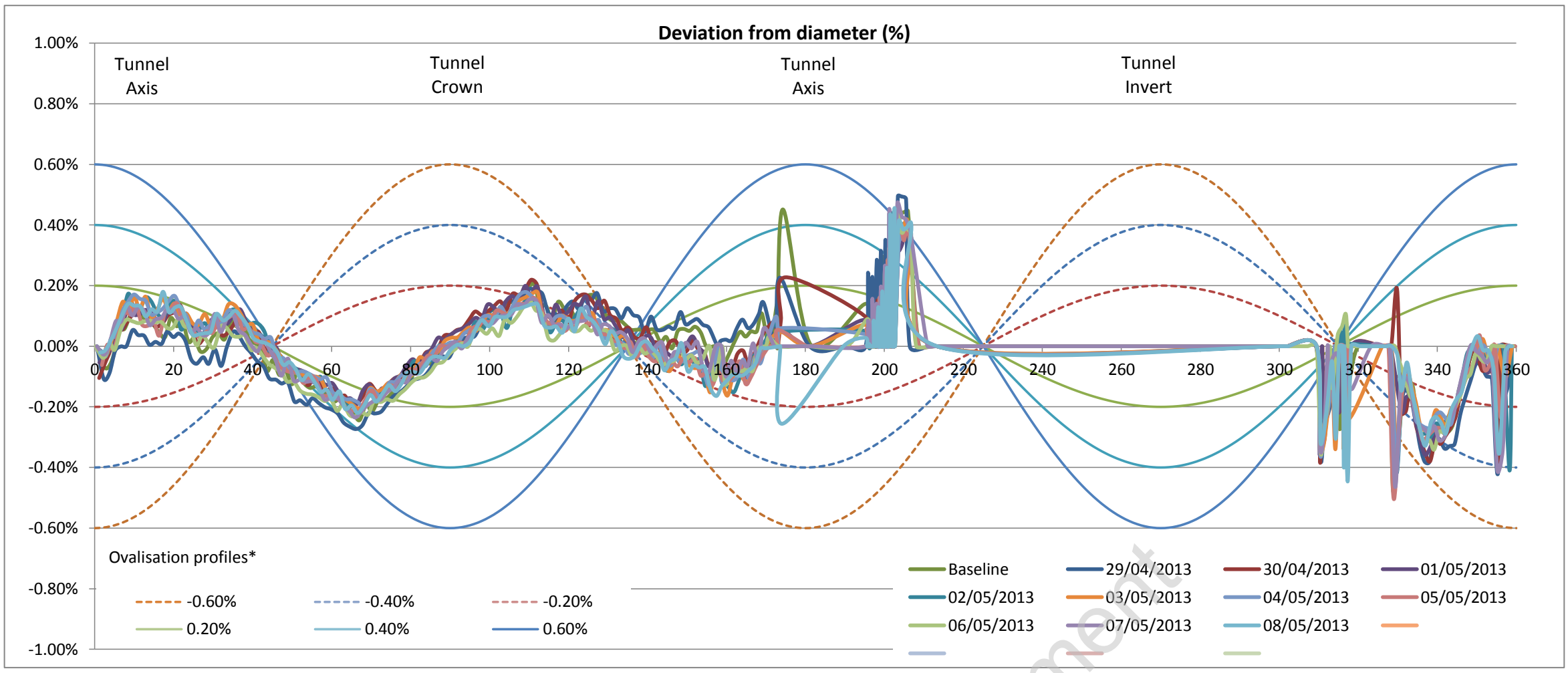
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5294.09 mm
Estimate of vertical diameter at crown, Dv	5292.25 mm
Dh / Dv	1.0003

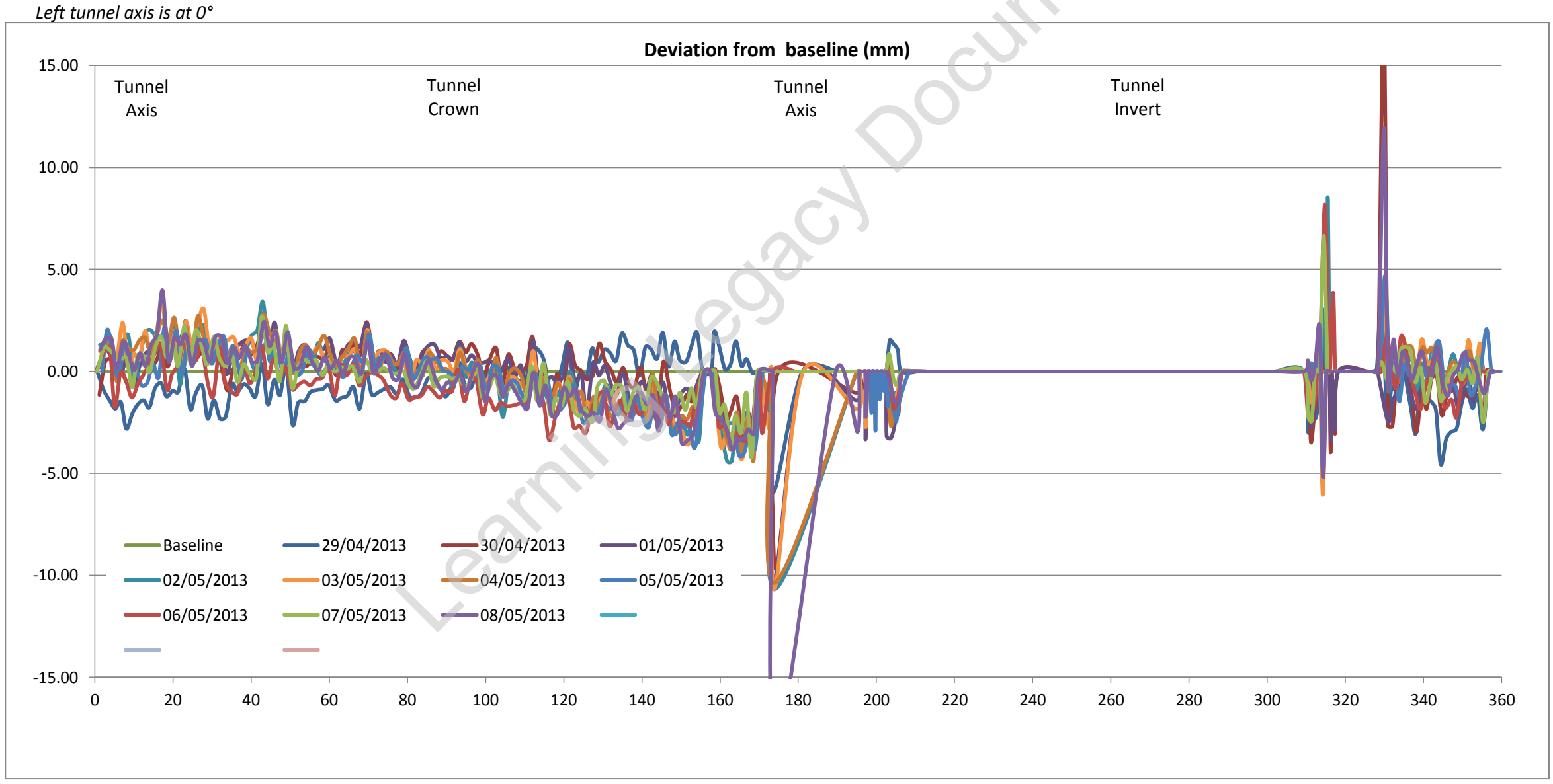
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 964**

Deviation vs Profile

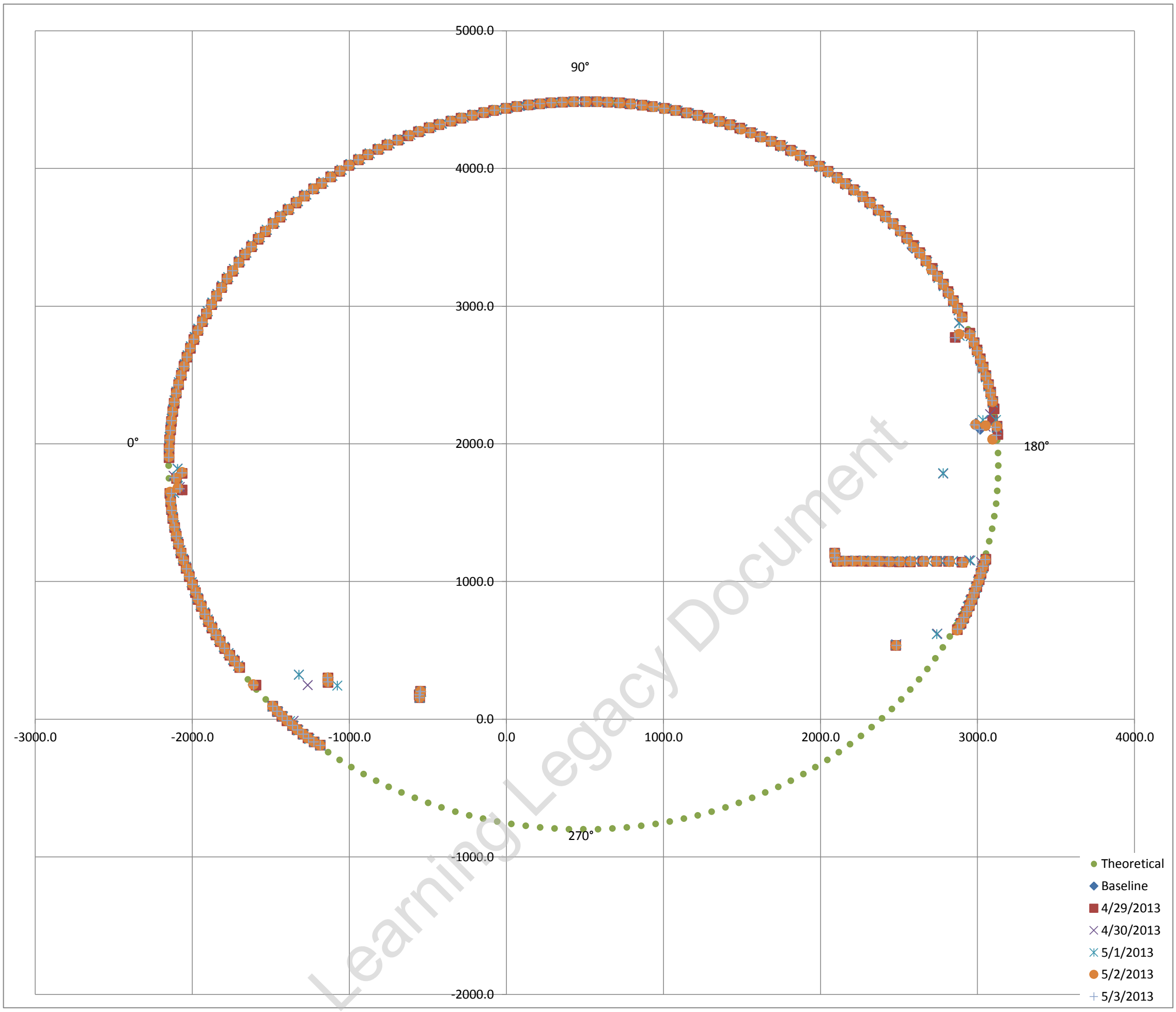


Left tunnel axis is at 0°



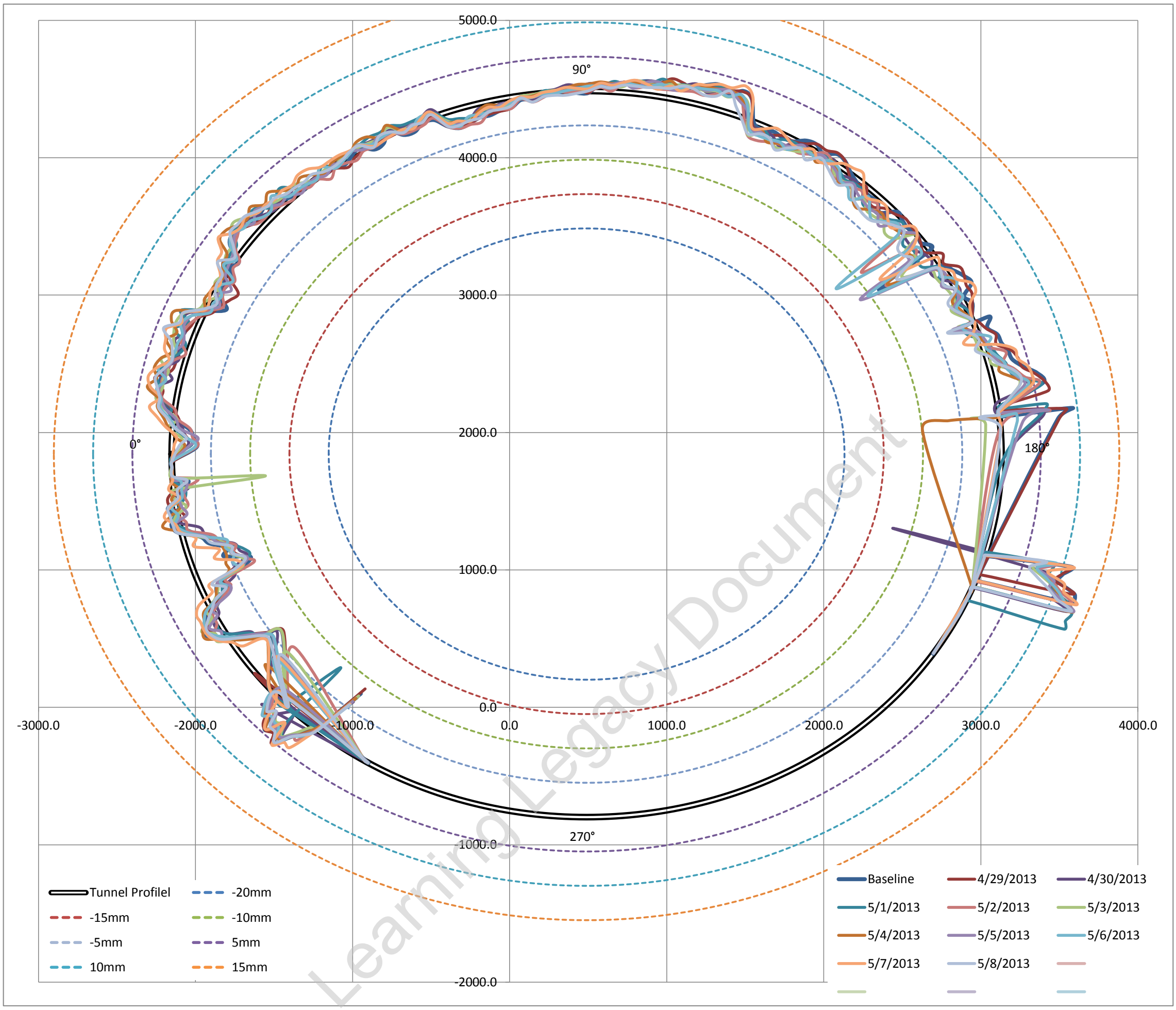
DLR LINE: UP **SECTION: 965**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **965**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5284.43	mm
Estimated best fit as built diameter	**5284.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.00813%	

i.e. Average surveyed diameter varies on 0.008% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.7**	**-9.8**
Max / Min deviation % to estimated dia	**0.48%**	**-0.37%**

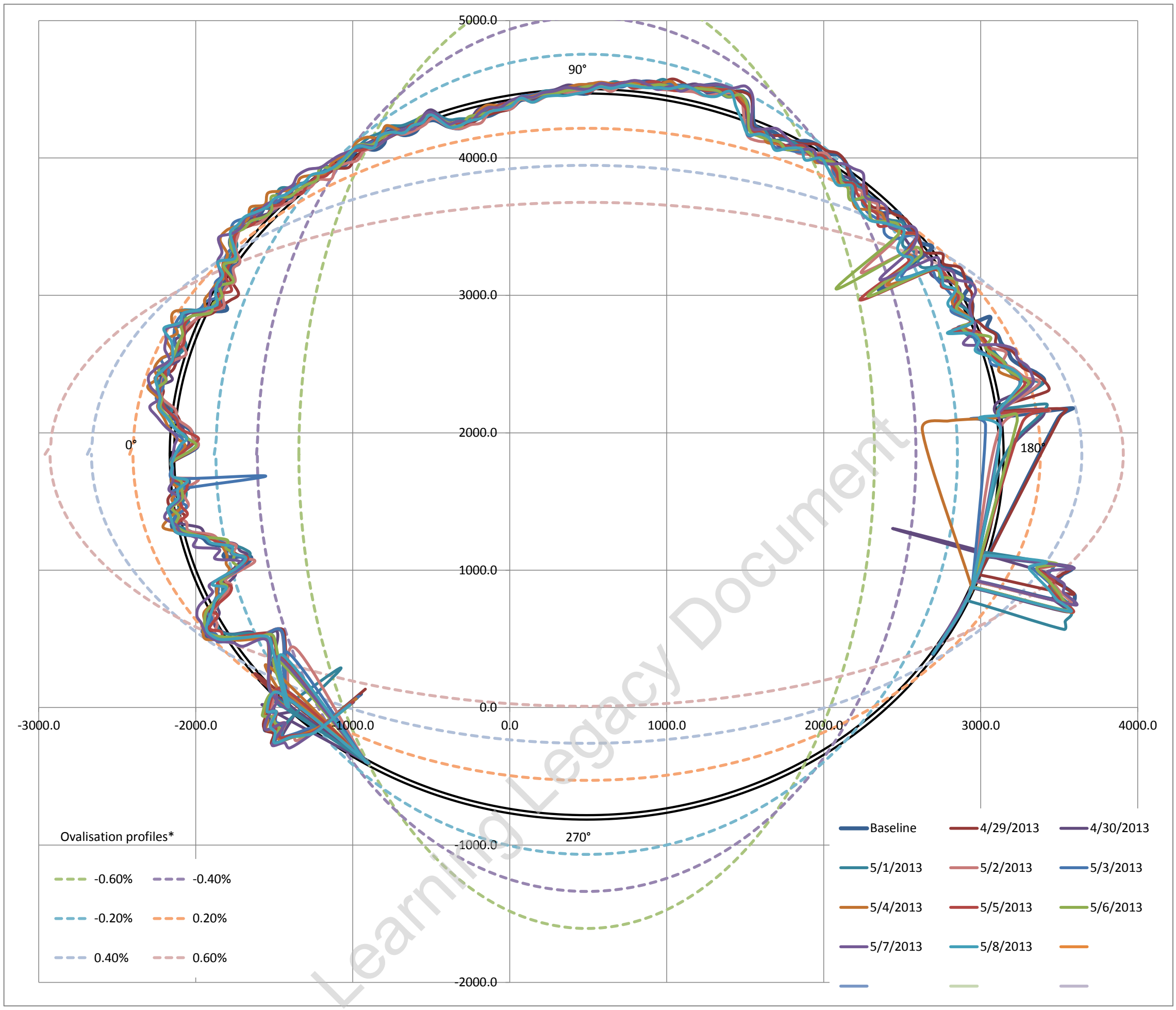
Fitted Circle Coordinates

Axis	X	490
	Y	1843
Radius		2642

Estimated best fit as built diameter	5284	mm
Designed diameter	5300	mm
Average diameter difference	**-16**	mm
Average radial difference	**-8**	mm
Average difference%	**-0.30%**	

DLR LINE: **UP** **SECTION:** **965**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

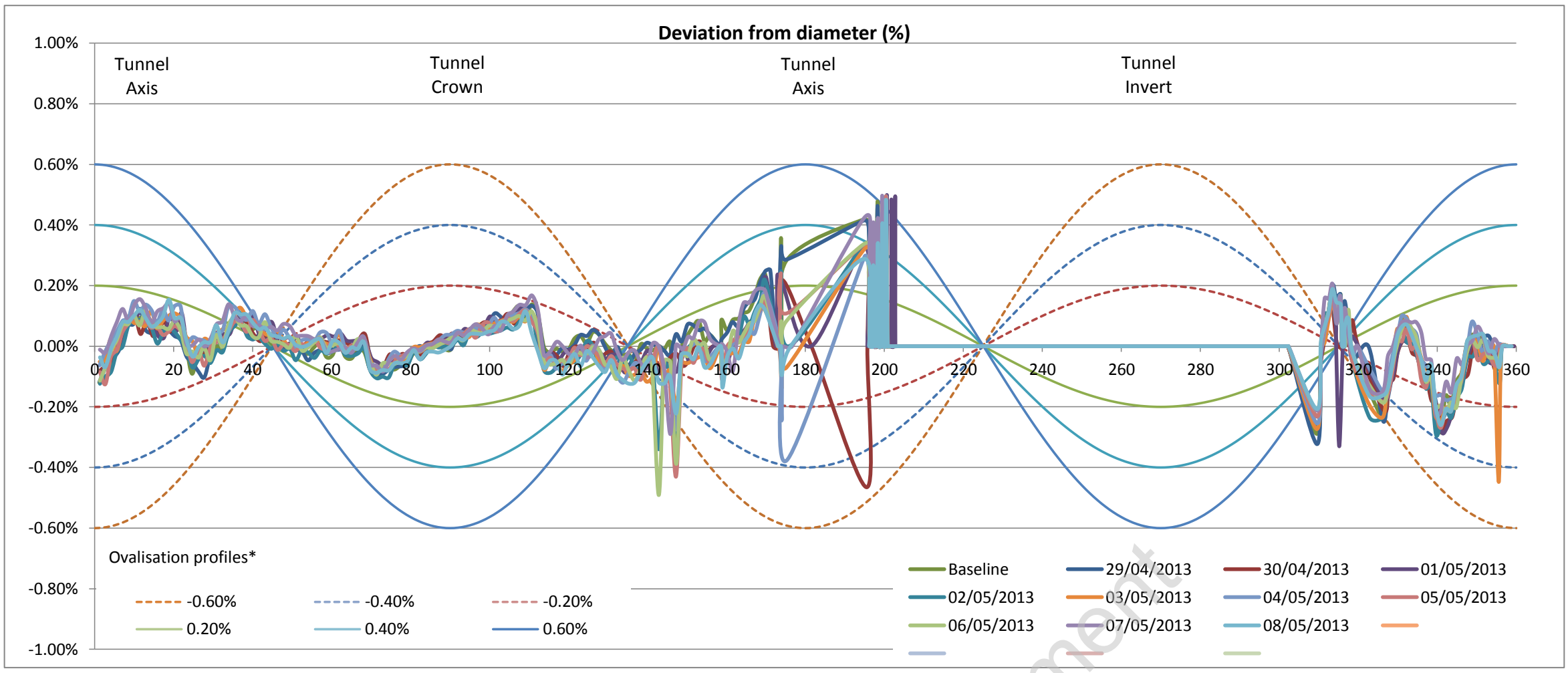
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5291.13 mm
Estimate of vertical diameter at crown, Dv	5284.94 mm
Dh / Dv	1.0012

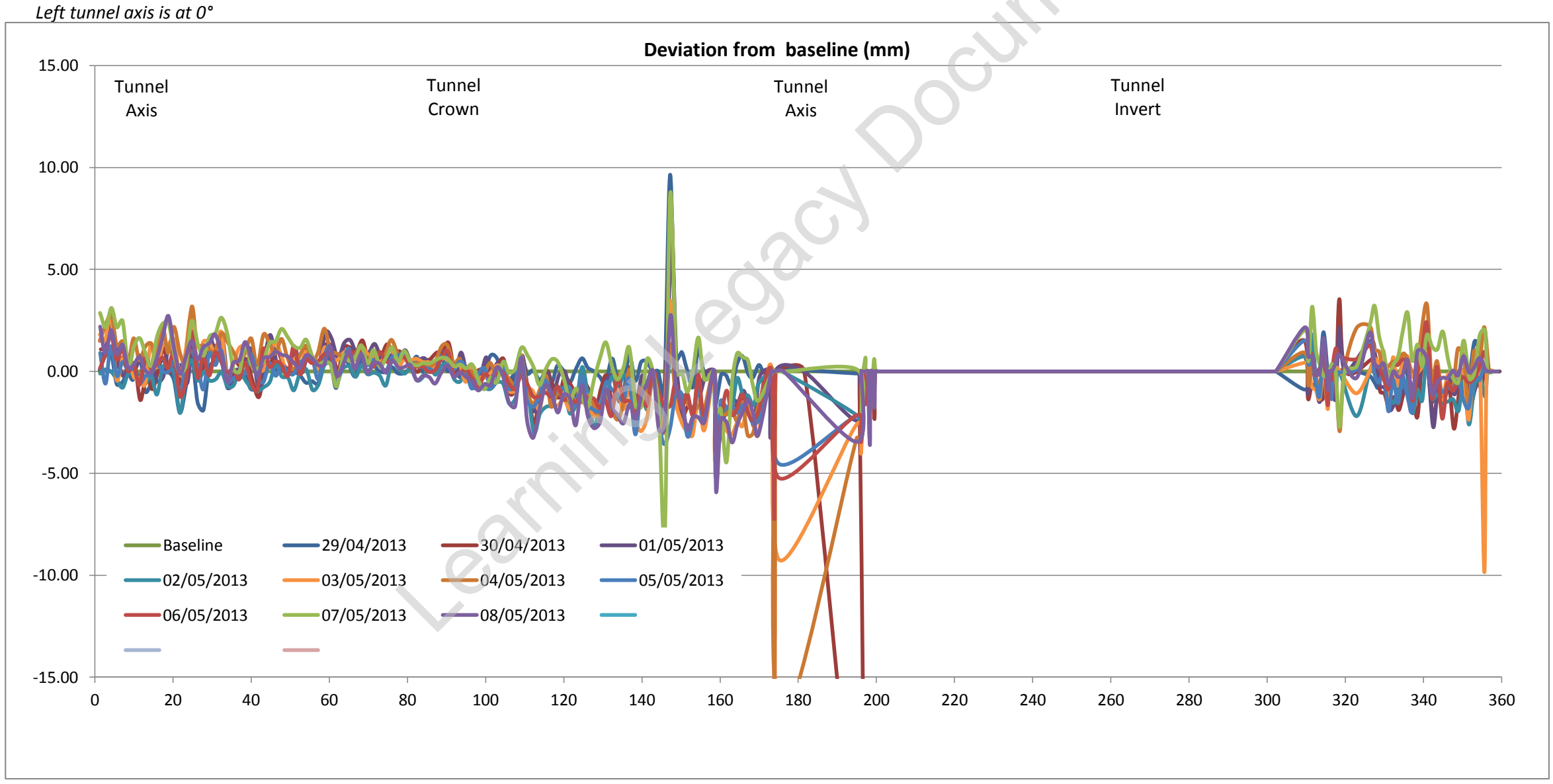
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 965**

Deviation vs Profile

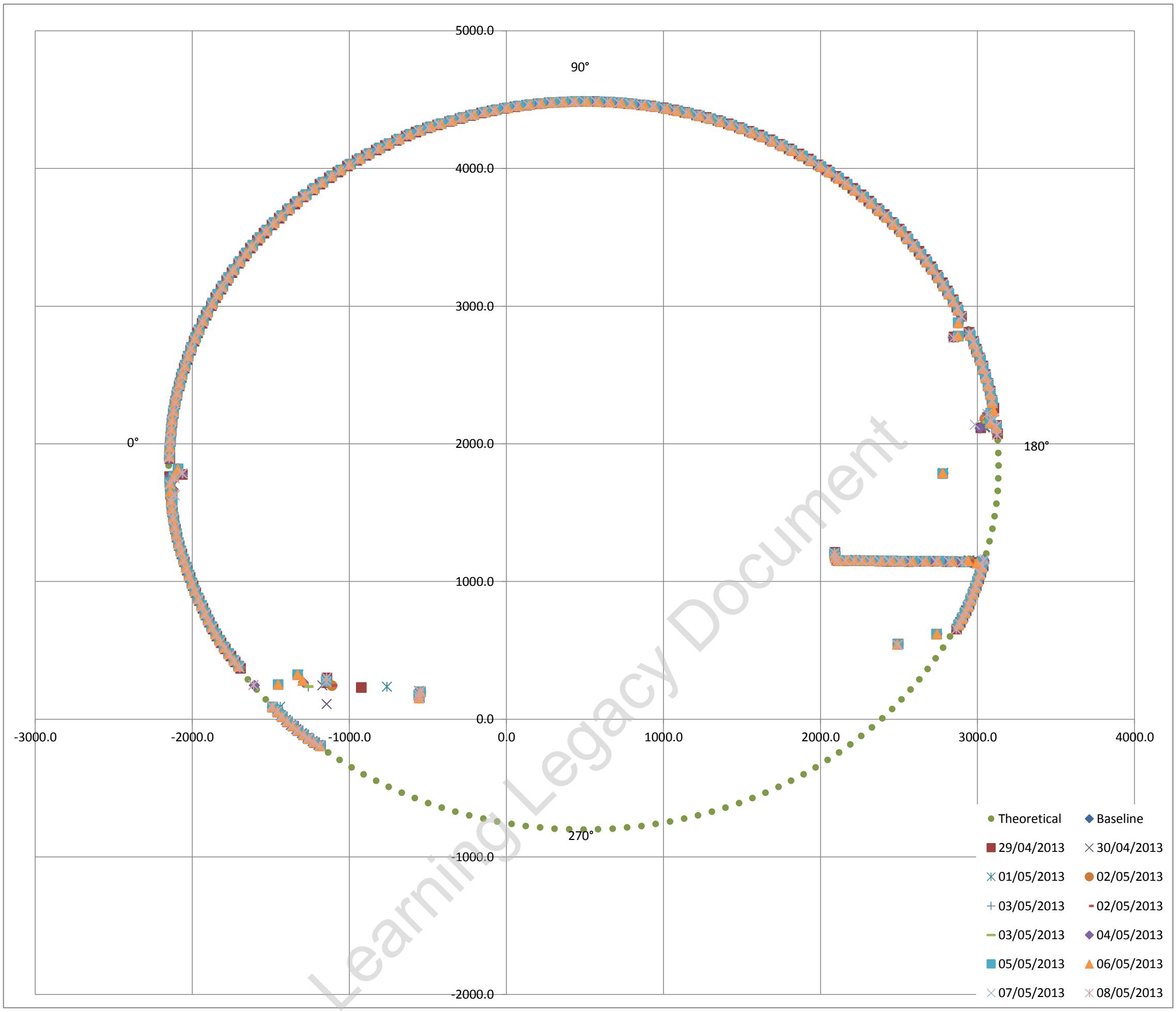


Left tunnel axis is at 0°



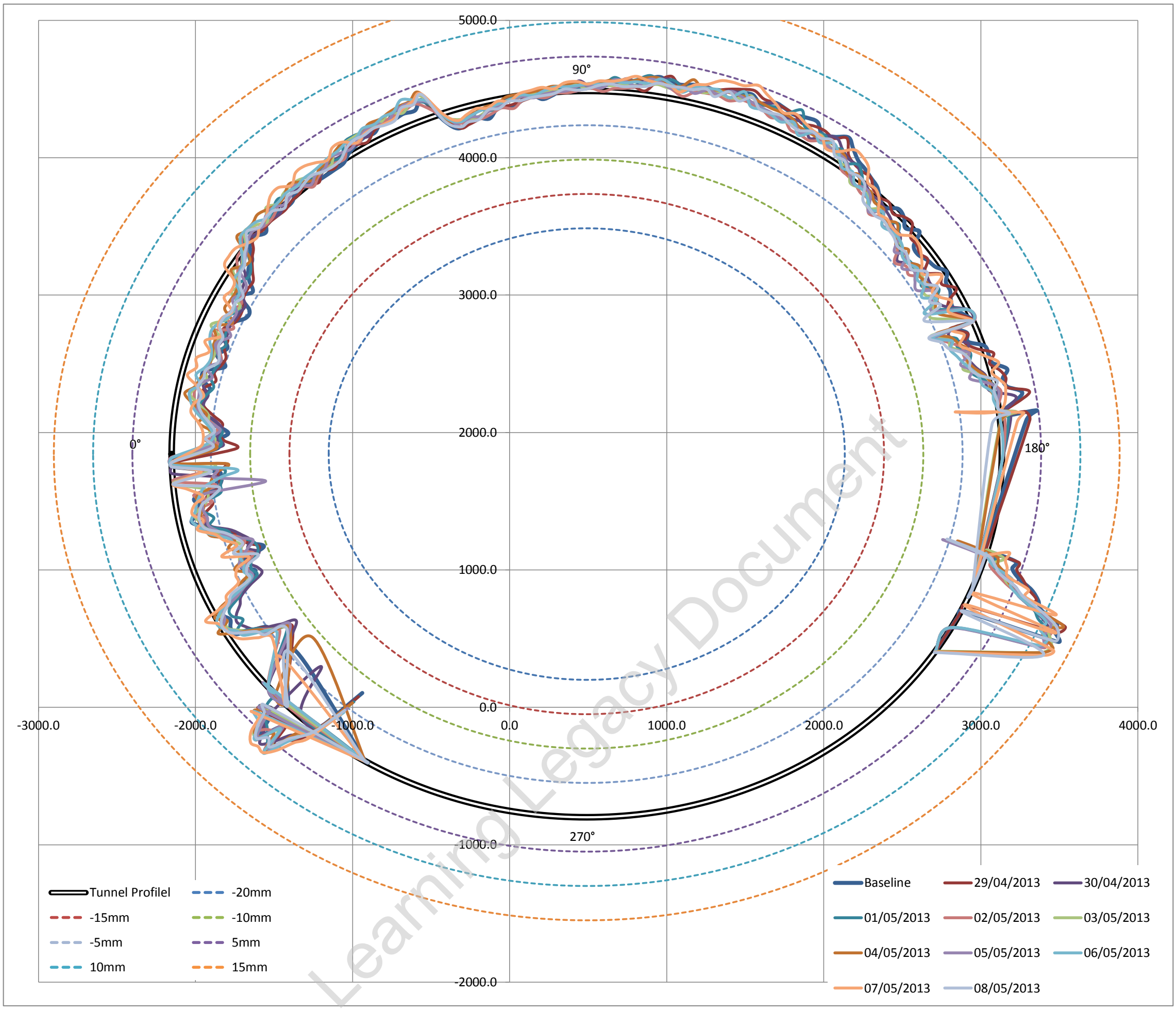
DLR LINE: UP **SECTION: 966**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **966**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5283.69	mm
Estimated best fit as built diameter	**5286.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.04375%	

i.e. Average surveyed diameter varies on -0.043% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-8.7**
Max / Min deviation % to estimated dia	**0.47%**	**-0.33%**

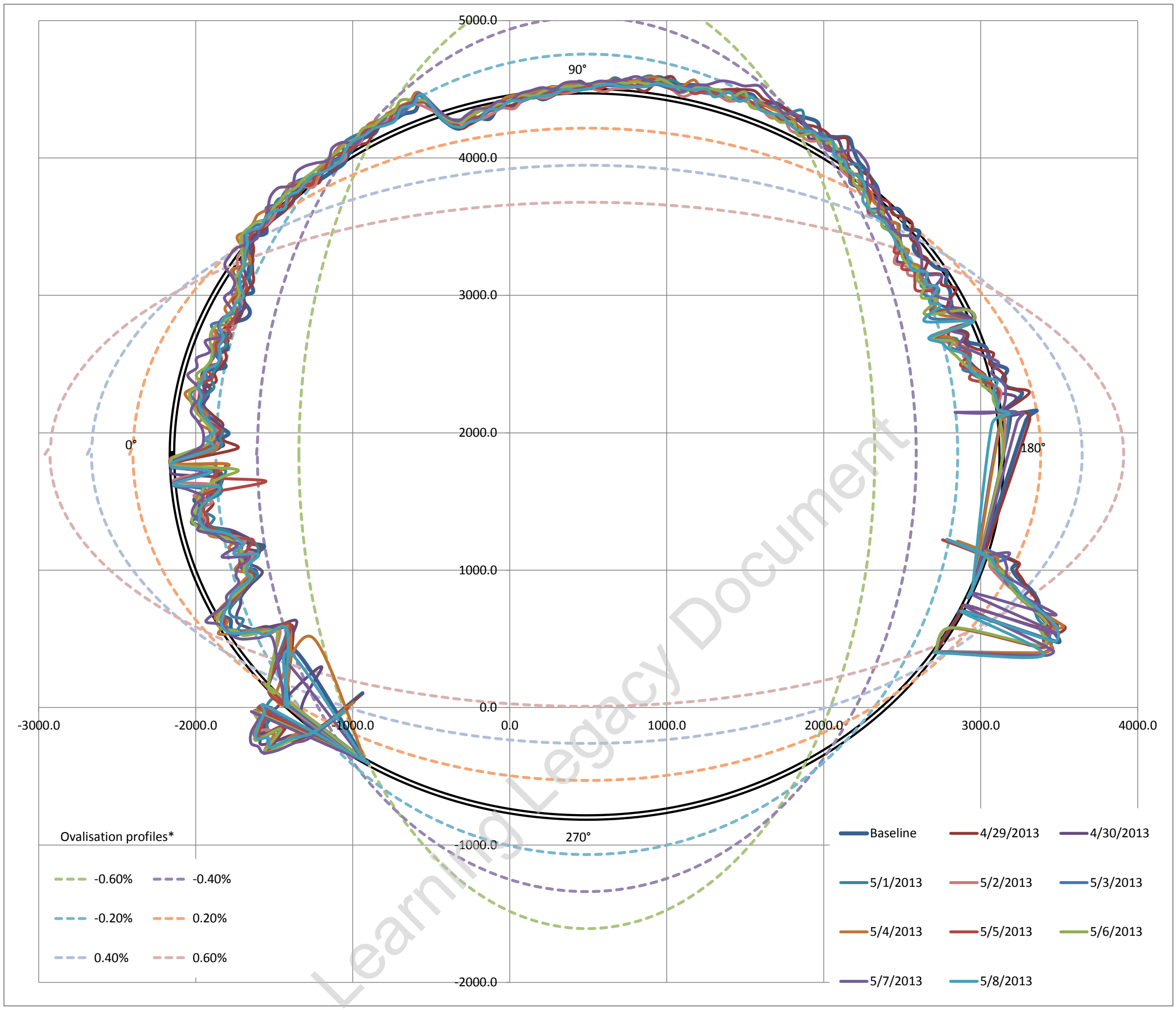
Fitted Circle Coordinates

Axis	X	491
	Y	1843
Radius		2643

Estimated best fit as built diameter	5286	mm
Designed diameter	5300	mm
Average diameter difference	**-14**	mm
Average radial difference	**-7**	mm
Average difference%	**-0.26%**	

DLR LINE: **UP** **SECTION:** **966**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

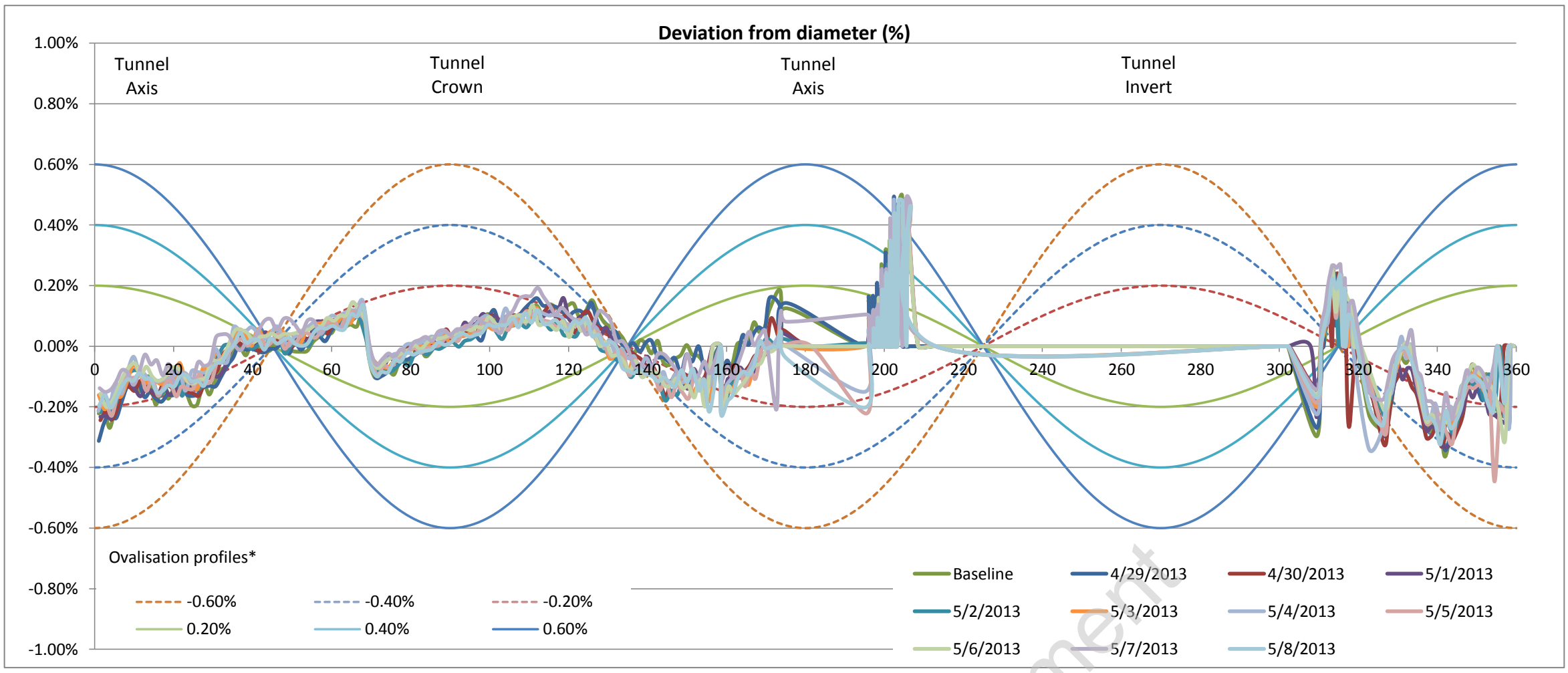
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5284.12 mm
Estimate of vertical diameter at crown, Dv	5286.76 mm
Dh / Dv	0.9995

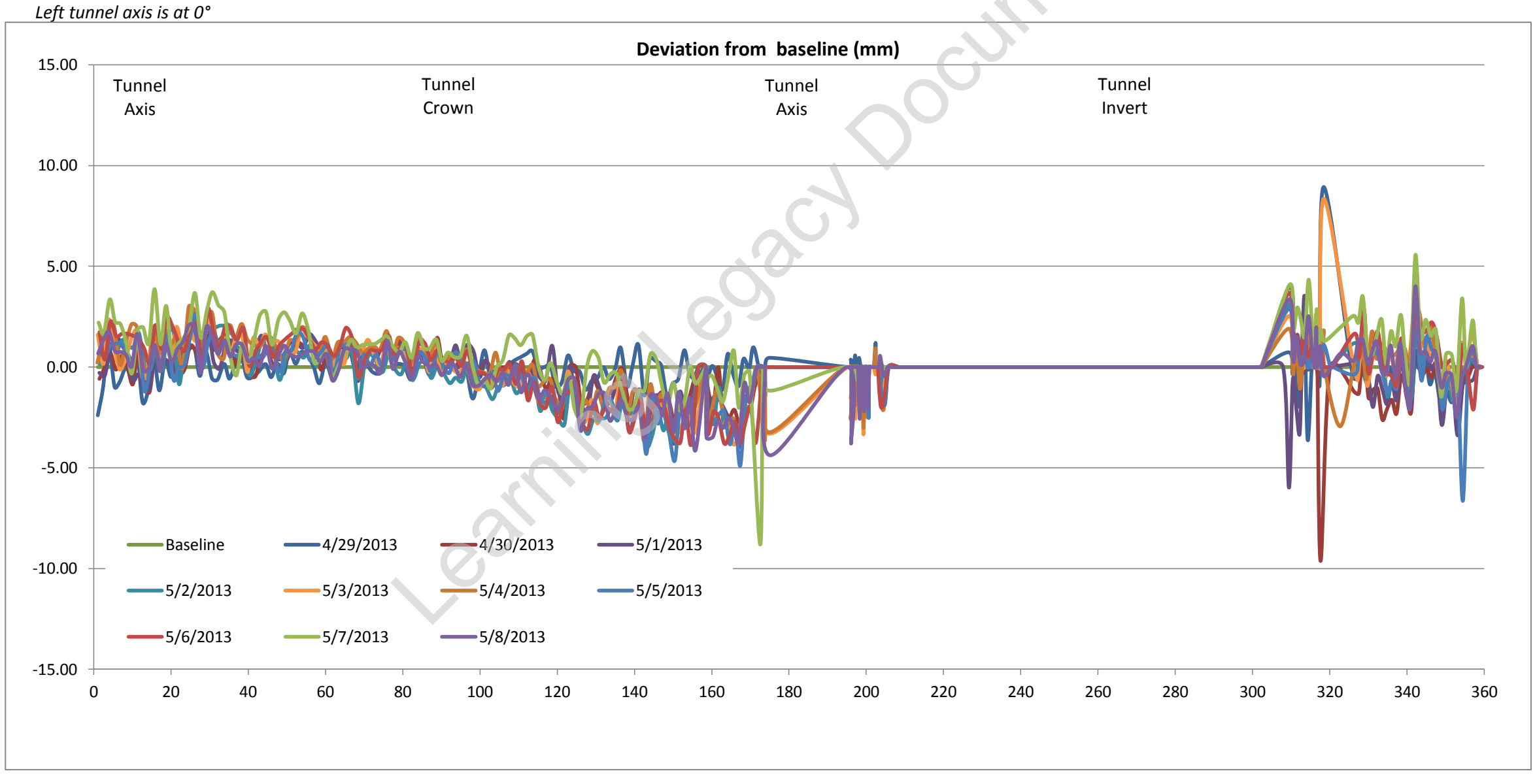
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 966**

Deviation vs Profile

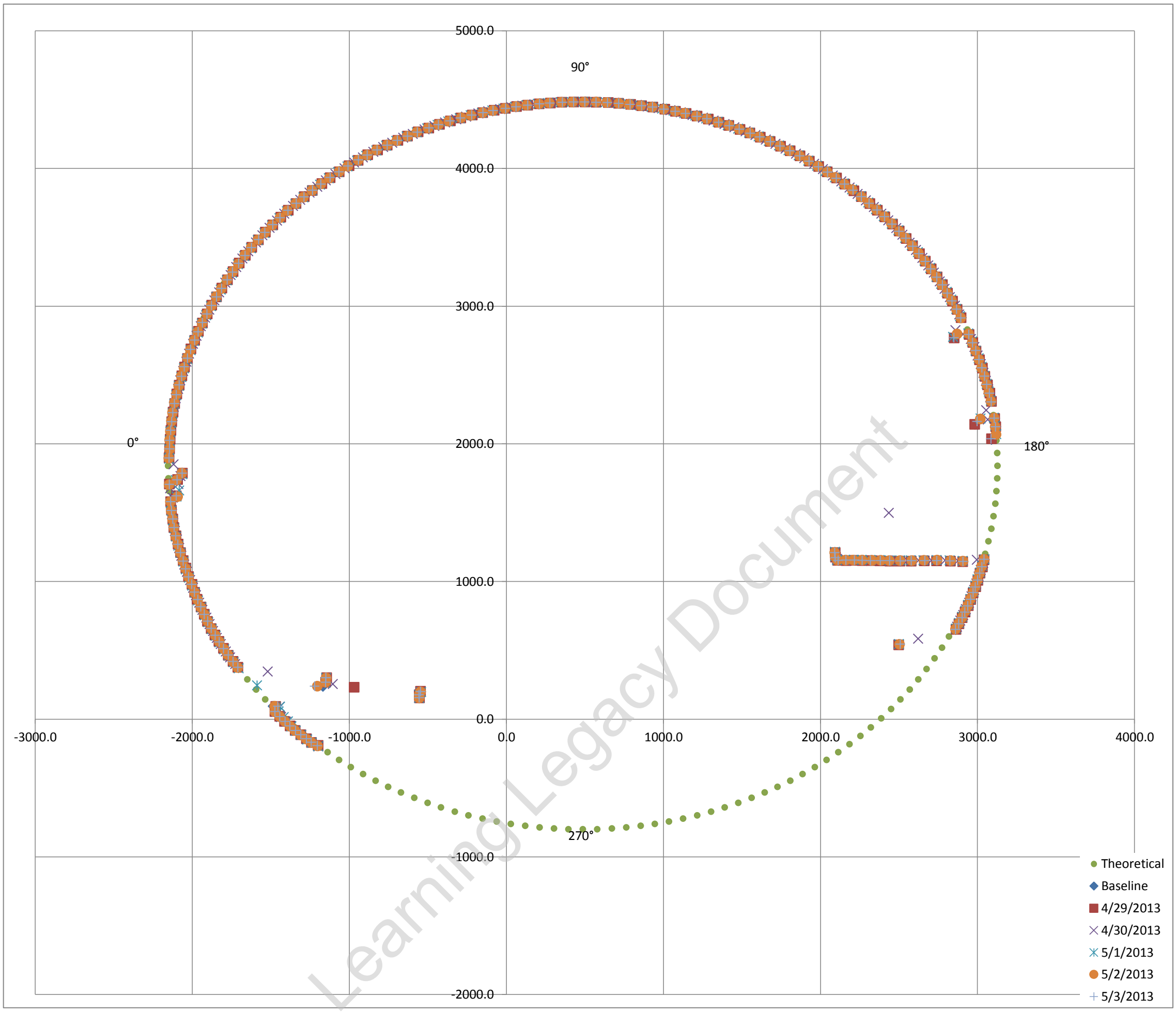


Left tunnel axis is at 0°



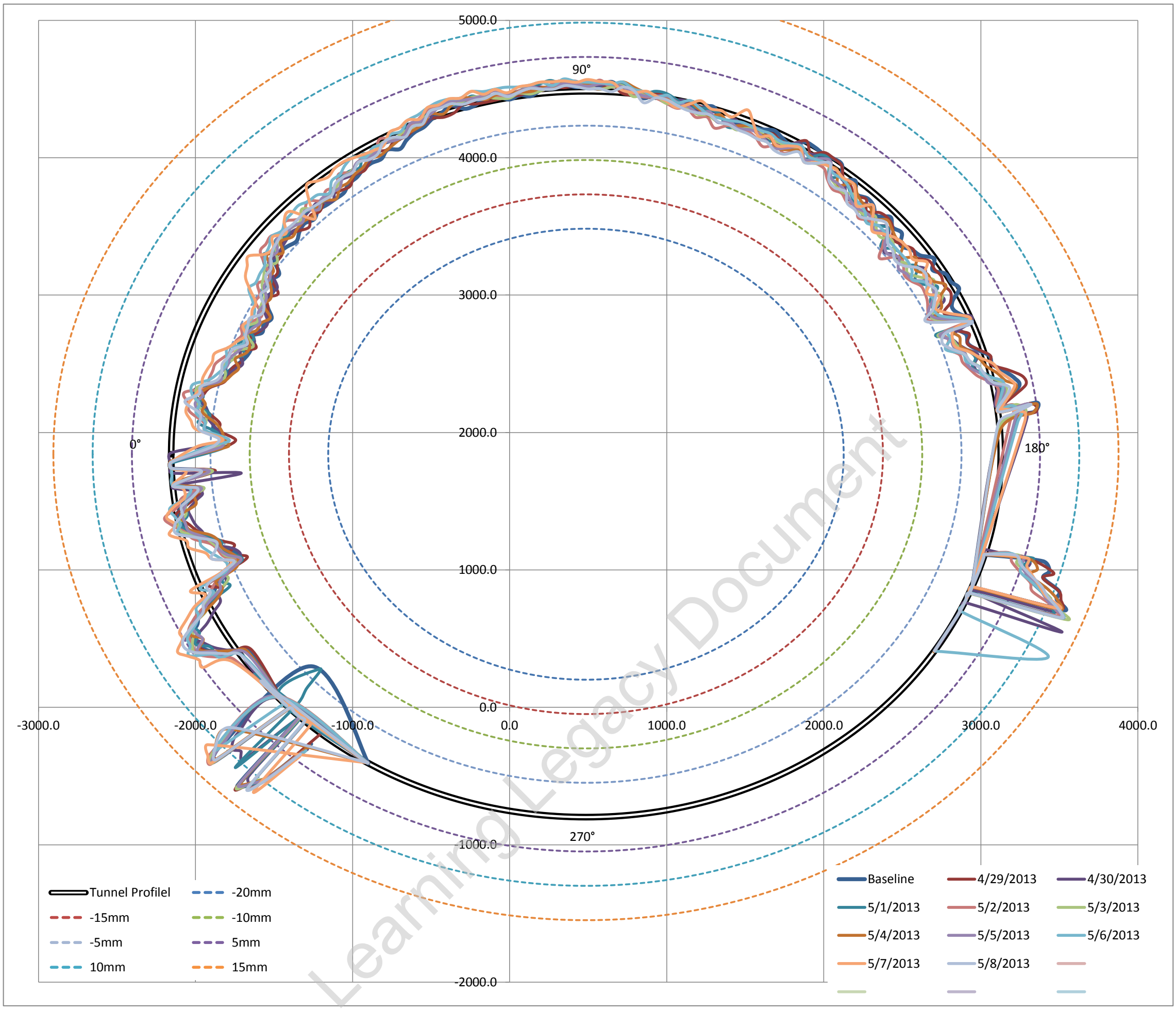
DLR LINE: UP **SECTION: 967**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **967**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.41	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.01113%	

i.e. Average surveyed diameter varies on -0.011% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.7**	**-7.6**
Max / Min deviation % to estimated dia	**0.48%**	**-0.29%**

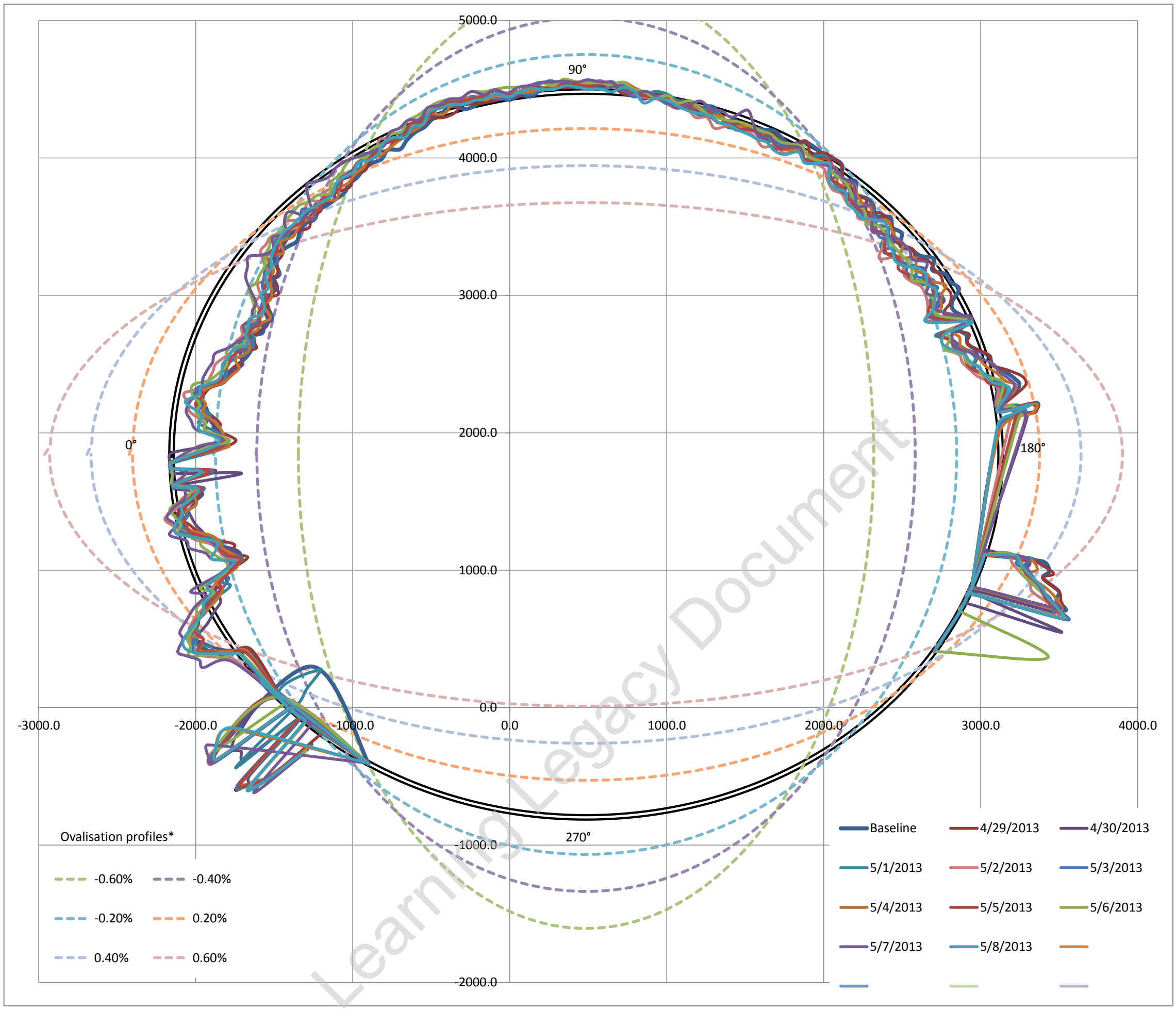
Fitted Circle Coordinates

Axis	X	486
	Y	1842
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **UP** **SECTION:** **967**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

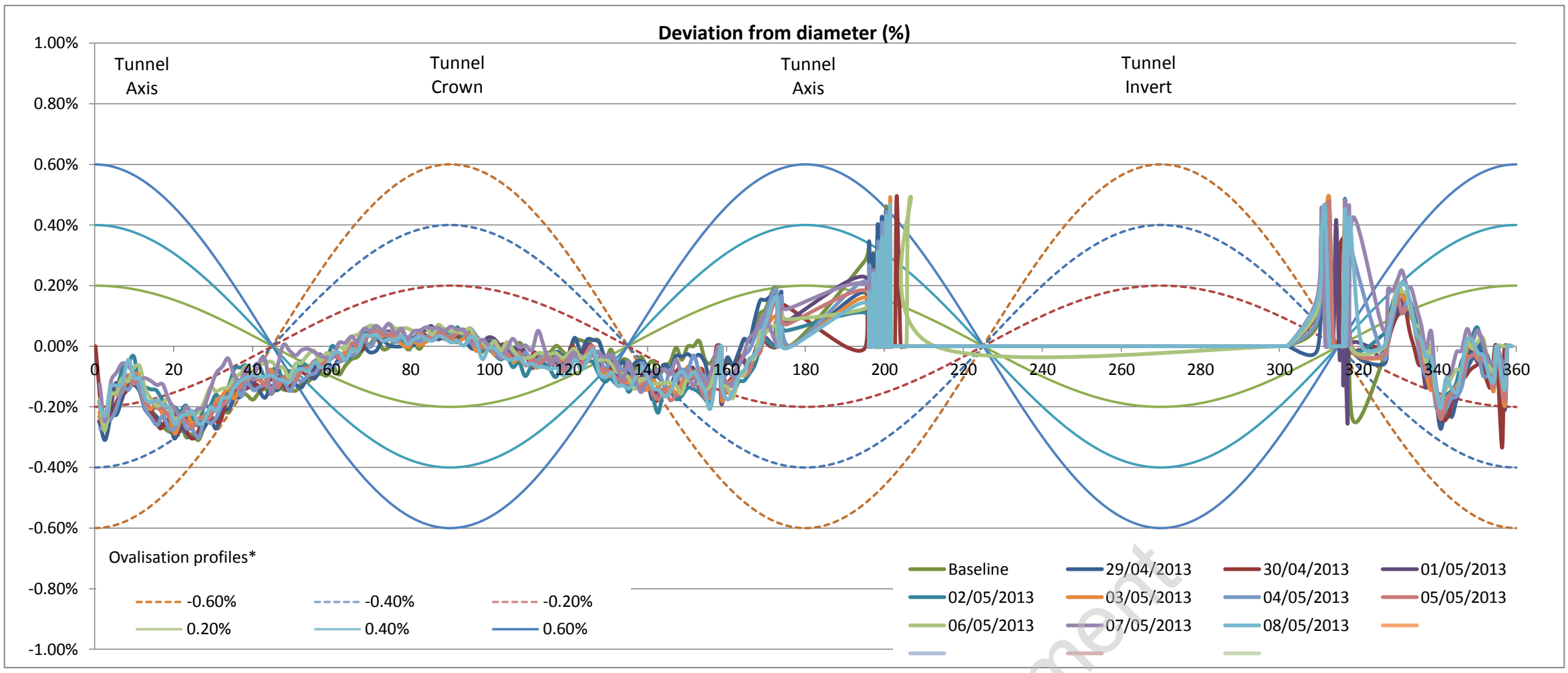
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5280.44 mm
Estimate of vertical diameter at crown, Dv	5283.05 mm
Dh / Dv	0.9995

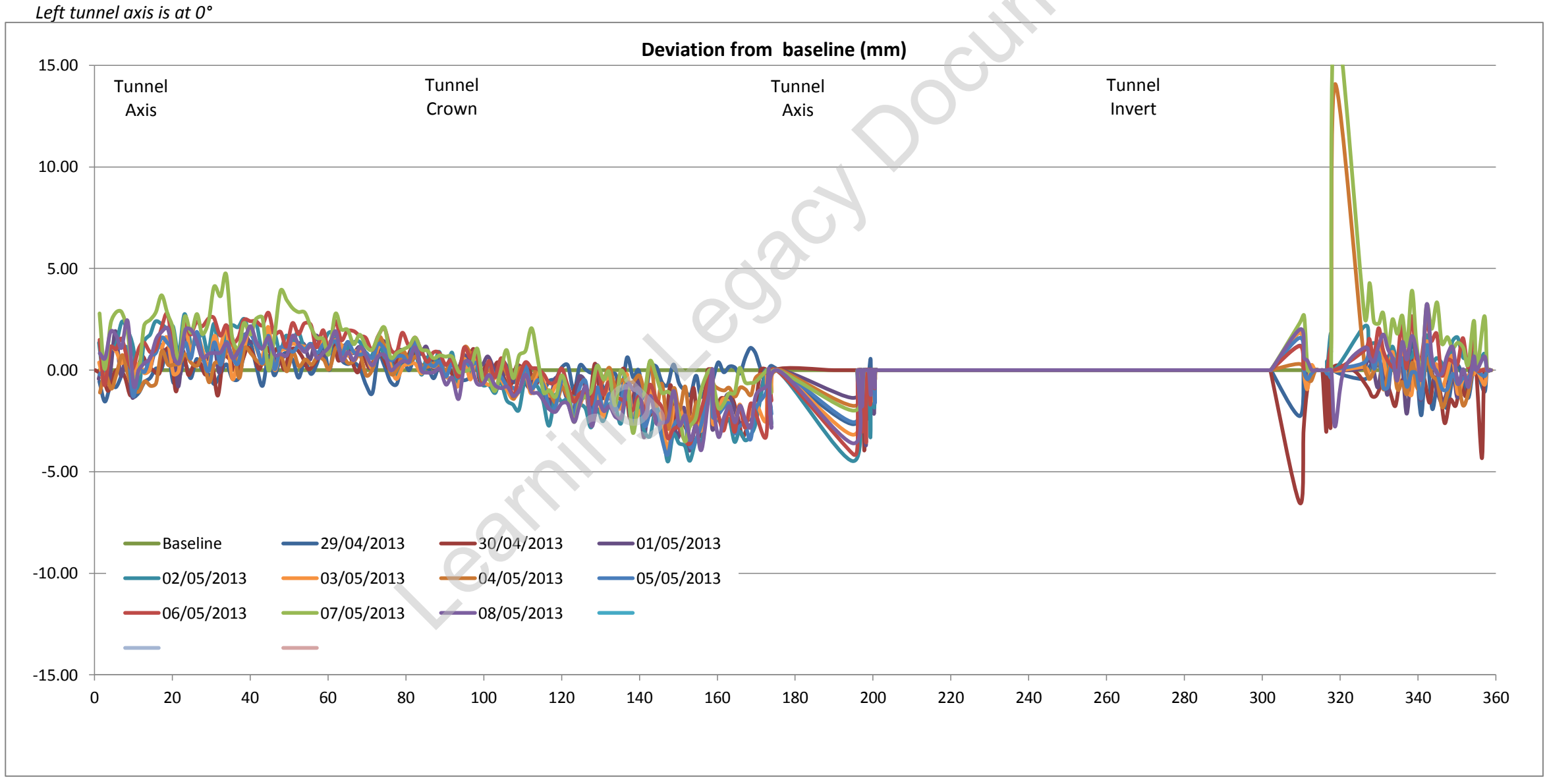
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 967**

Deviation vs Profile

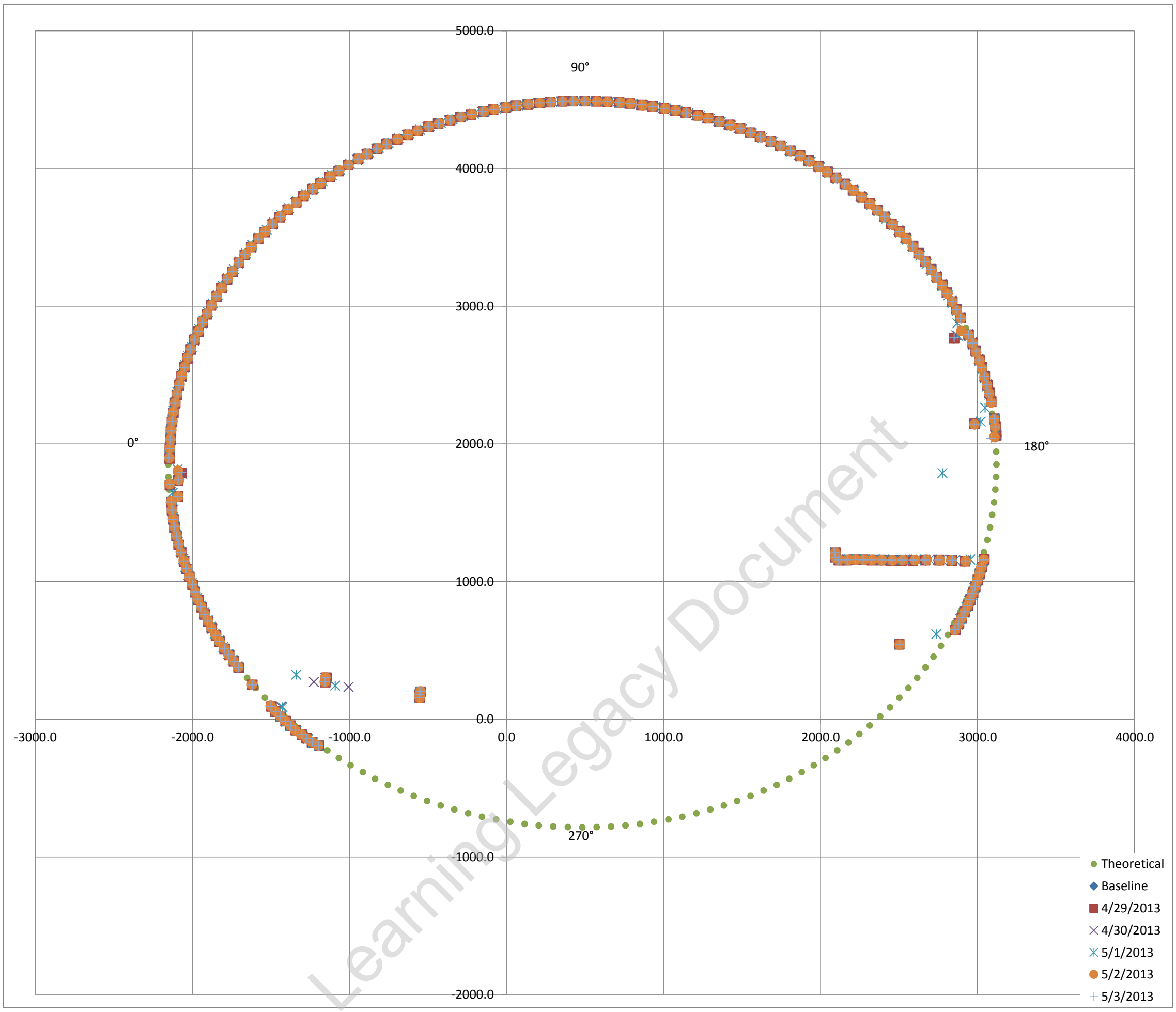


Left tunnel axis is at 0°



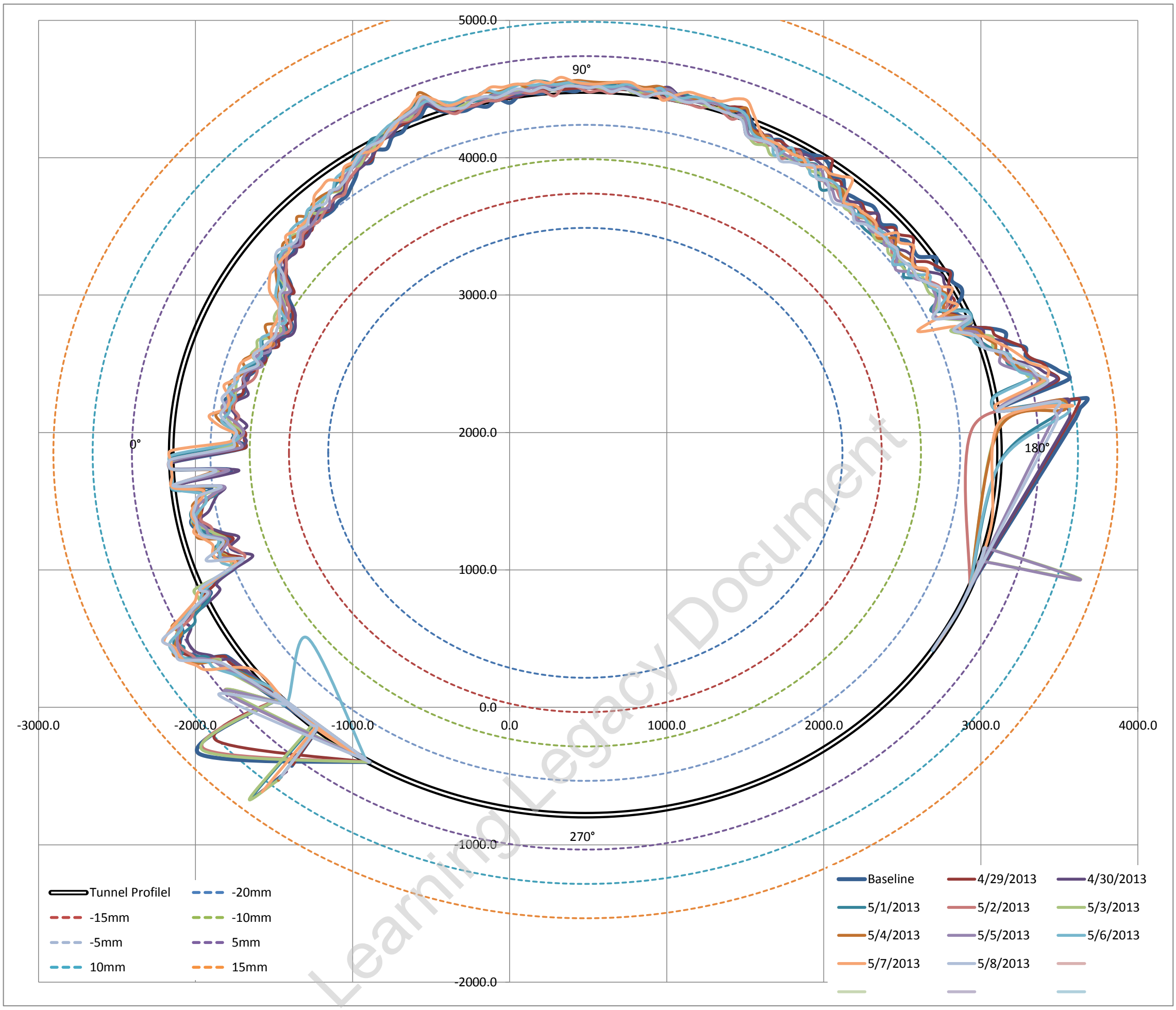
DLR LINE: UP **SECTION: 968**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **968**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5274.34	mm
Estimated best fit as built diameter	**5274.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.00652%	

i.e. Average surveyed diameter varies on 0.006% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.4**	**-10.5**
Max / Min deviation % to estimated dia	**0.43%**	**-0.40%**

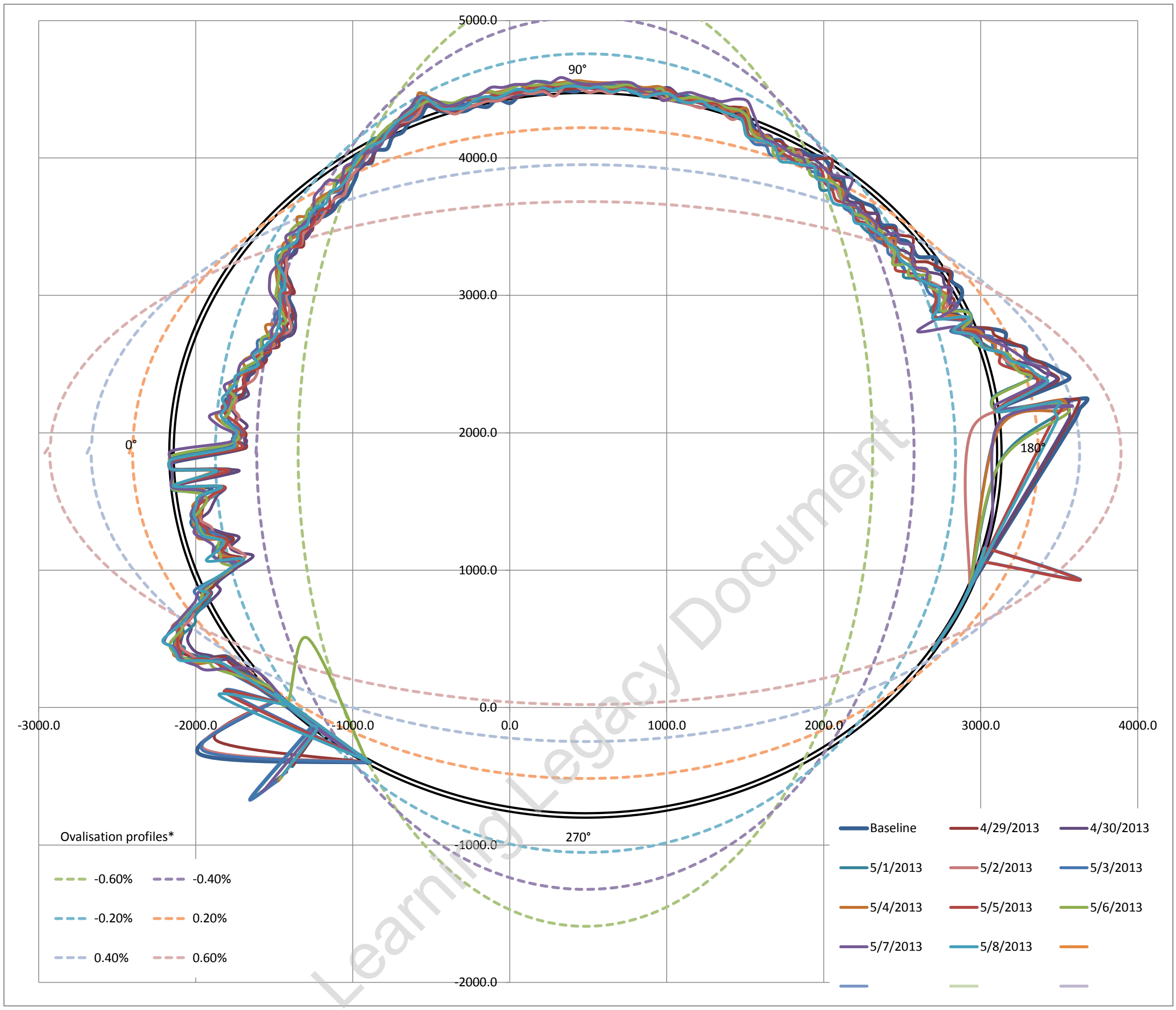
Fitted Circle Coordinates

Axis	X	482
	Y	1852
Radius		2637

Estimated best fit as built diameter	5274	mm
Designed diameter	5300	mm
Average diameter difference	**-26**	mm
Average radial difference	**-13**	mm
Average difference%	**-0.49%**	

DLR LINE: **UP** **SECTION:** **968**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

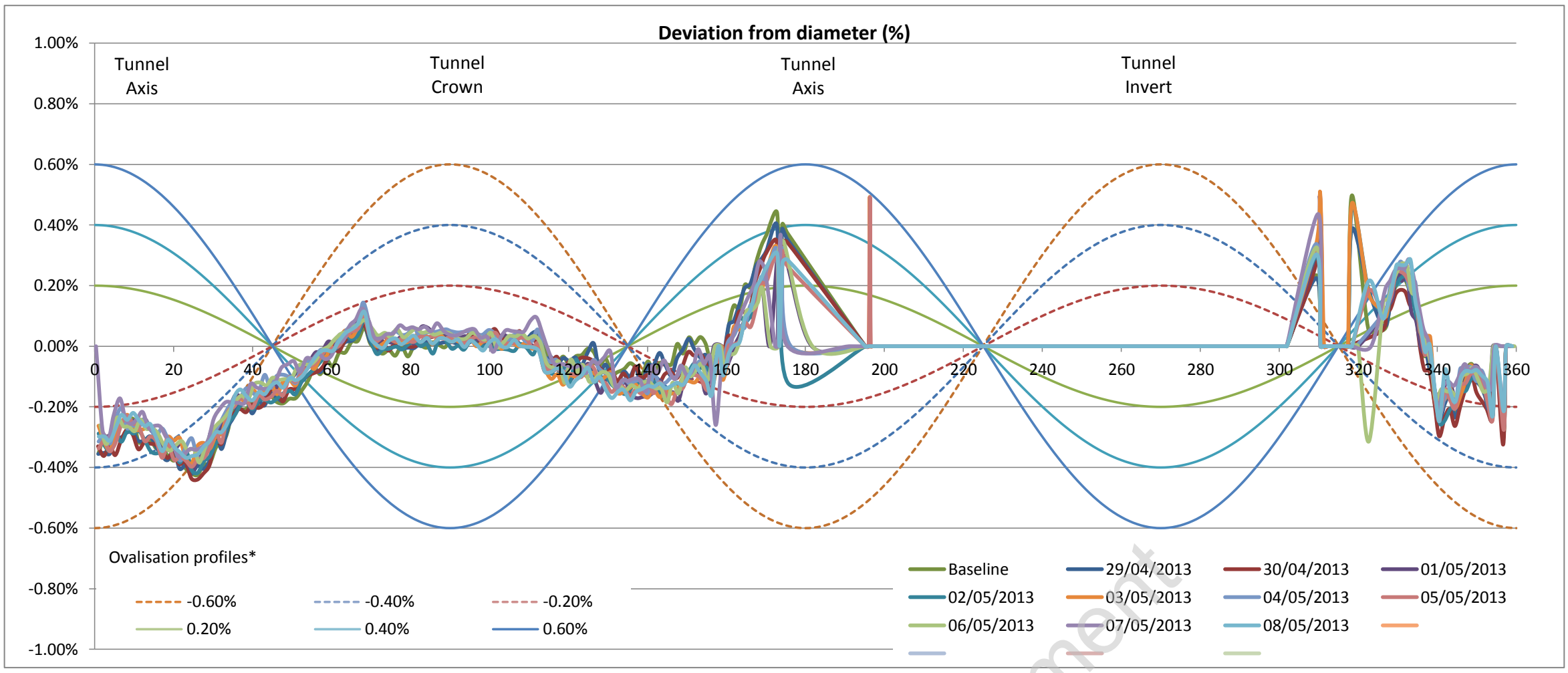
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5274.49 mm
Estimate of vertical diameter at crown, Dv	5274.76 mm
Dh / Dv	0.9999

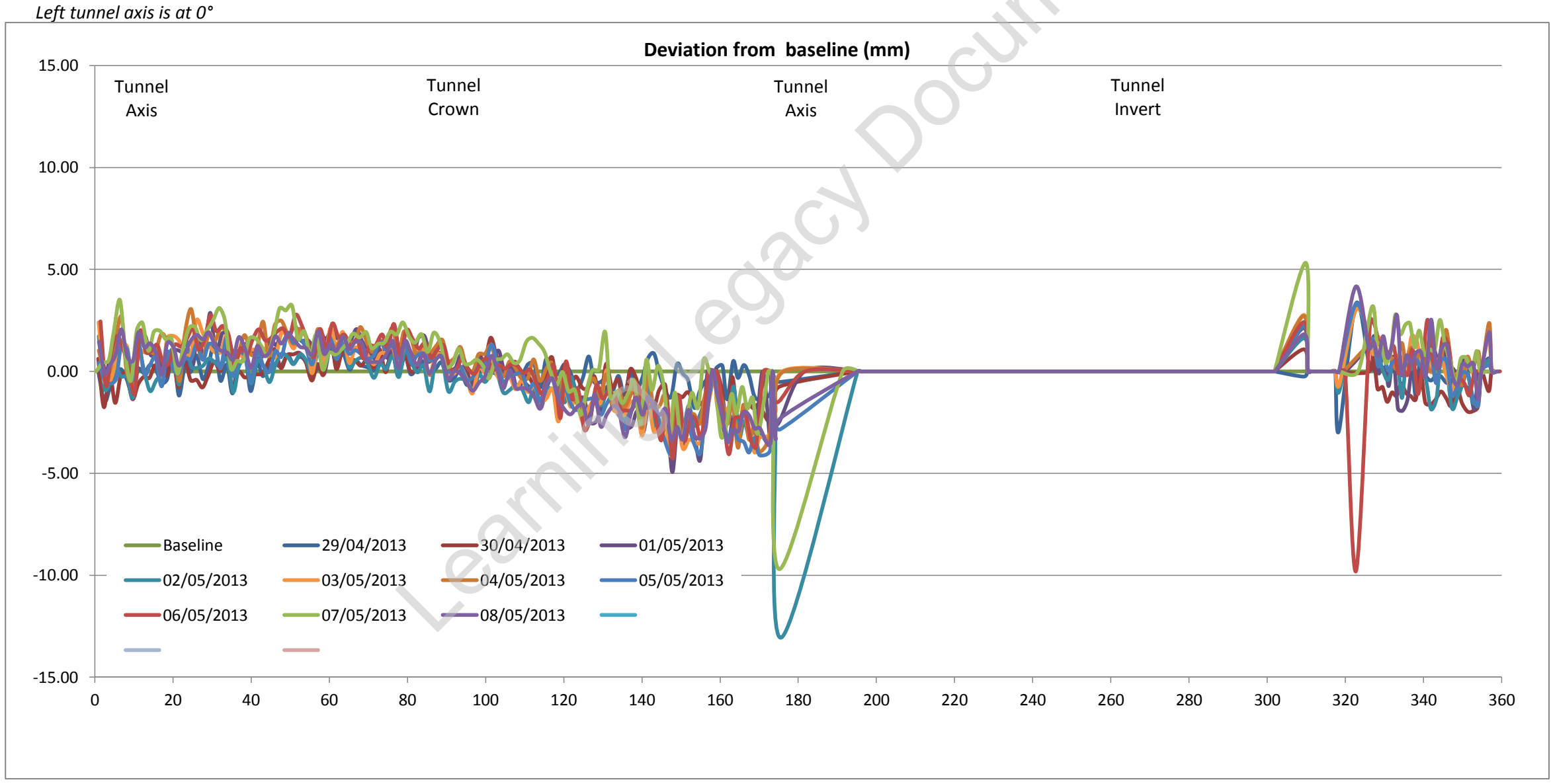
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 968**

Deviation vs Profile

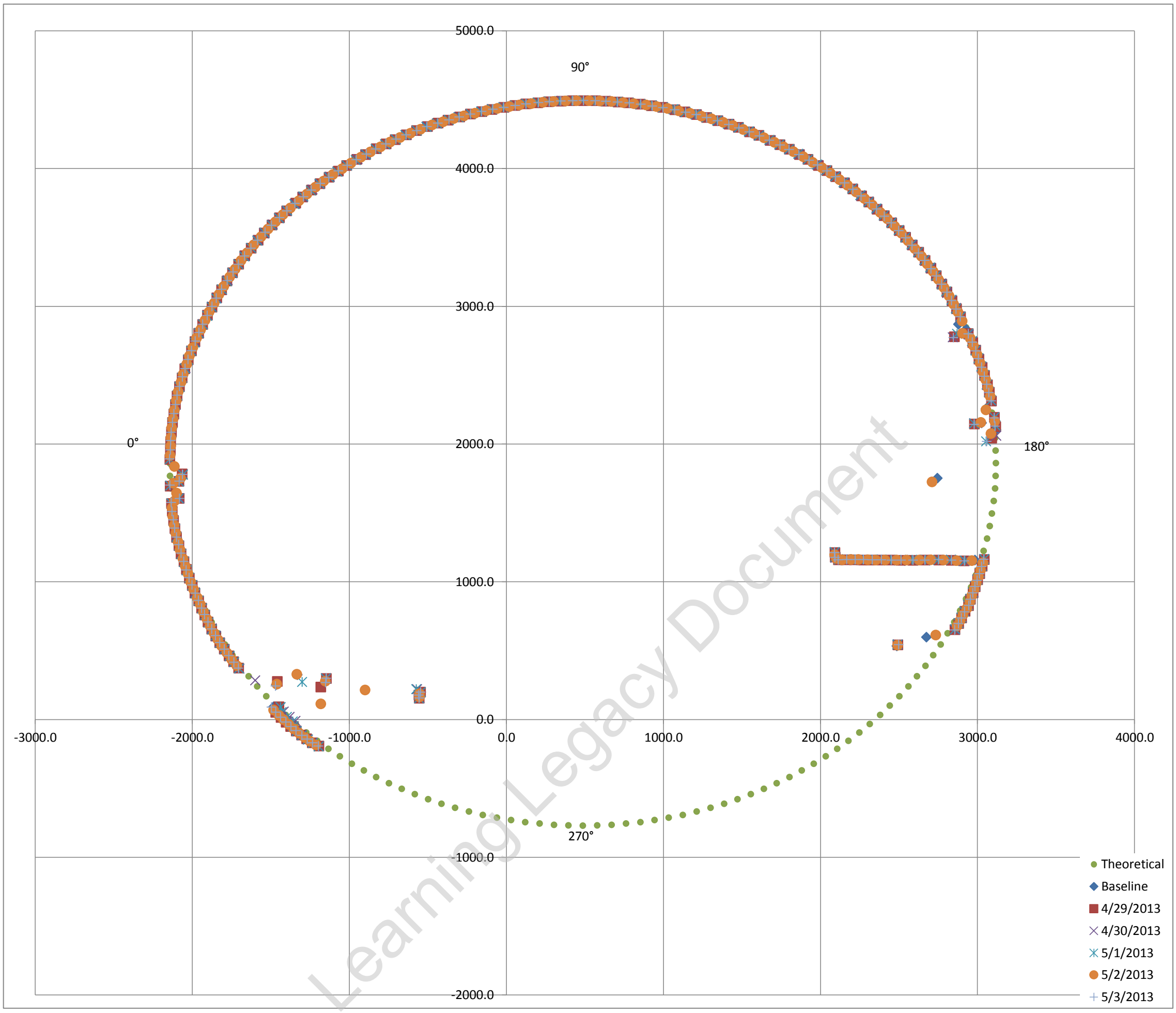


Left tunnel axis is at 0°



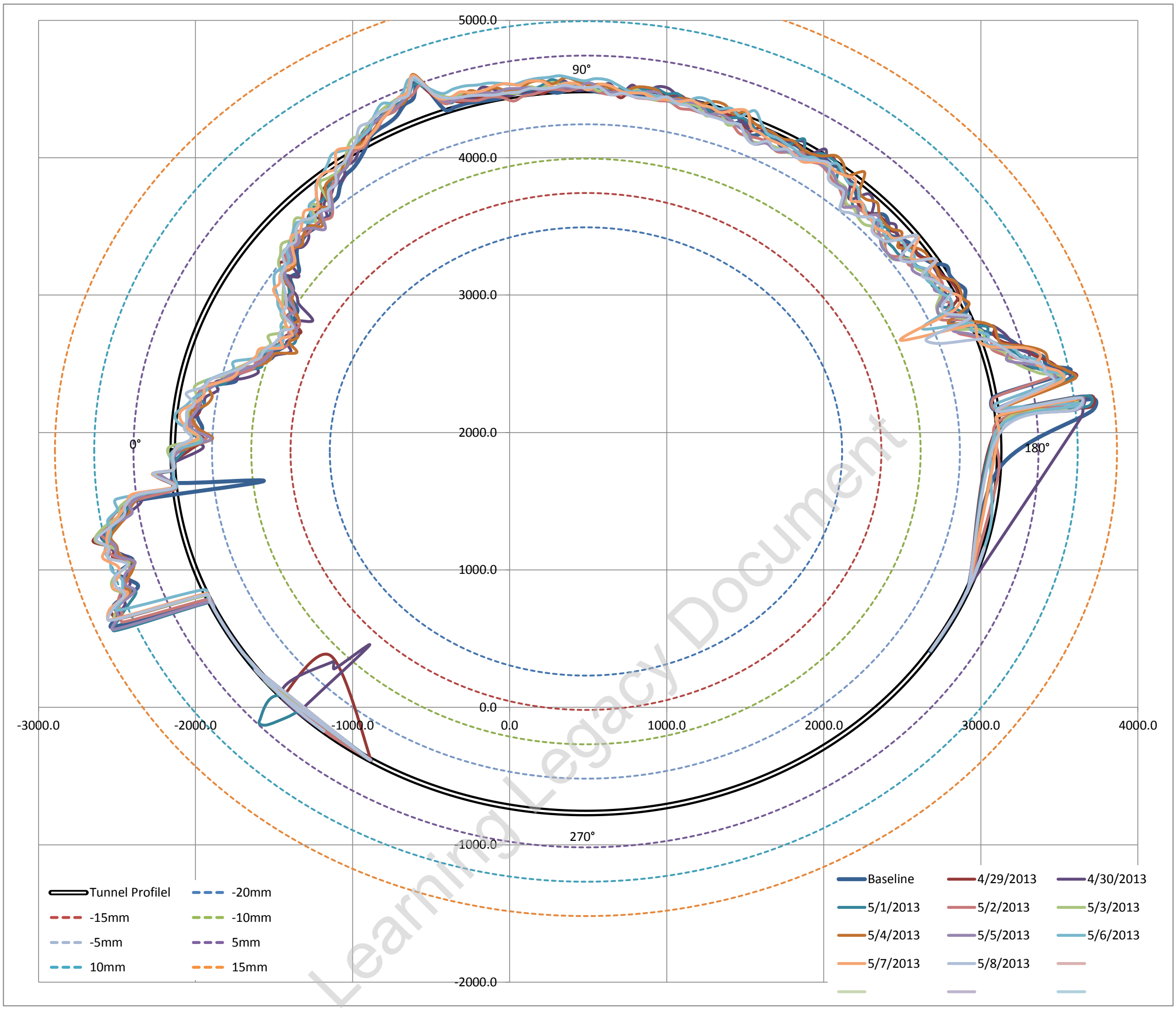
DLR LINE: UP **SECTION: 969**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **969**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5274.40	mm
Estimated best fit as built diameter	**5262.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.23561%	

i.e. Average surveyed diameter varies on 0.235% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.2**	**-11.8**
Max / Min deviation % to estimated dia	**0.46%**	**-0.45%**

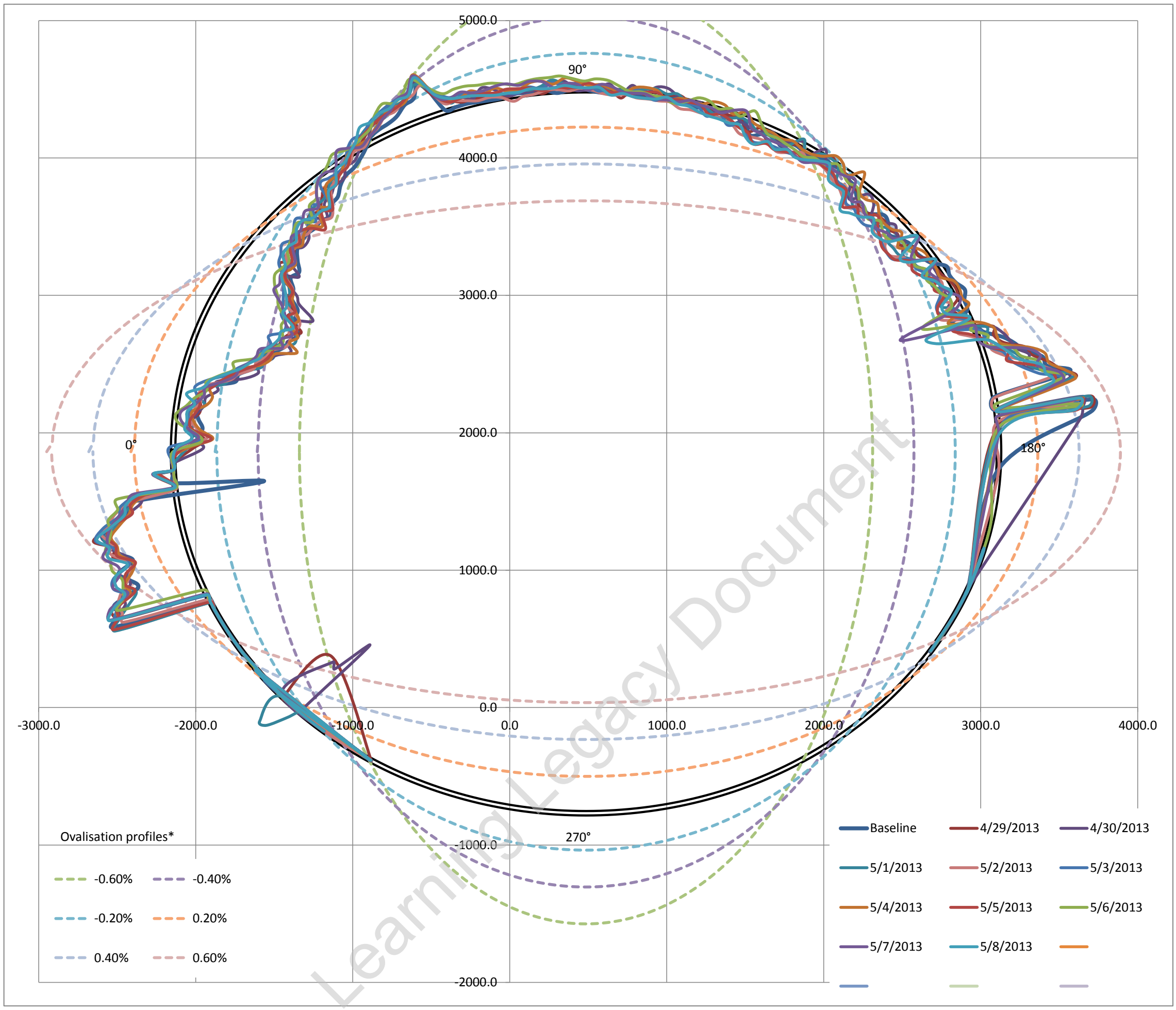
Fitted Circle Coordinates

Axis	X	486
	Y	1862
Radius		2631

Estimated best fit as built diameter	5262	mm
Designed diameter	5300	mm
Average diameter difference	**-38**	mm
Average radial difference	**-19**	mm
Average difference%	**-0.72%**	

DLR LINE: **UP** **SECTION:** **969**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

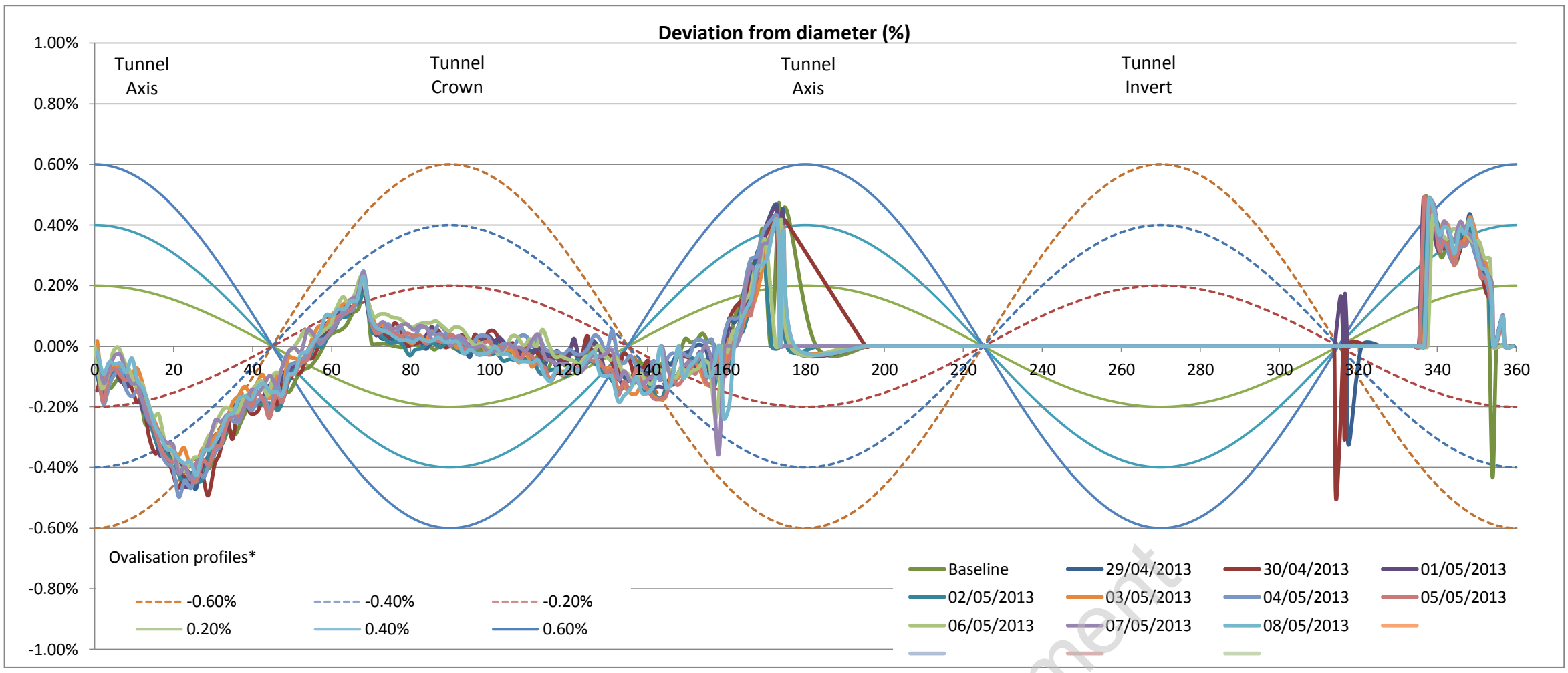
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5271.36 mm
Estimate of vertical diameter at crown, Dv	5261.90 mm
Dh / Dv	1.0018

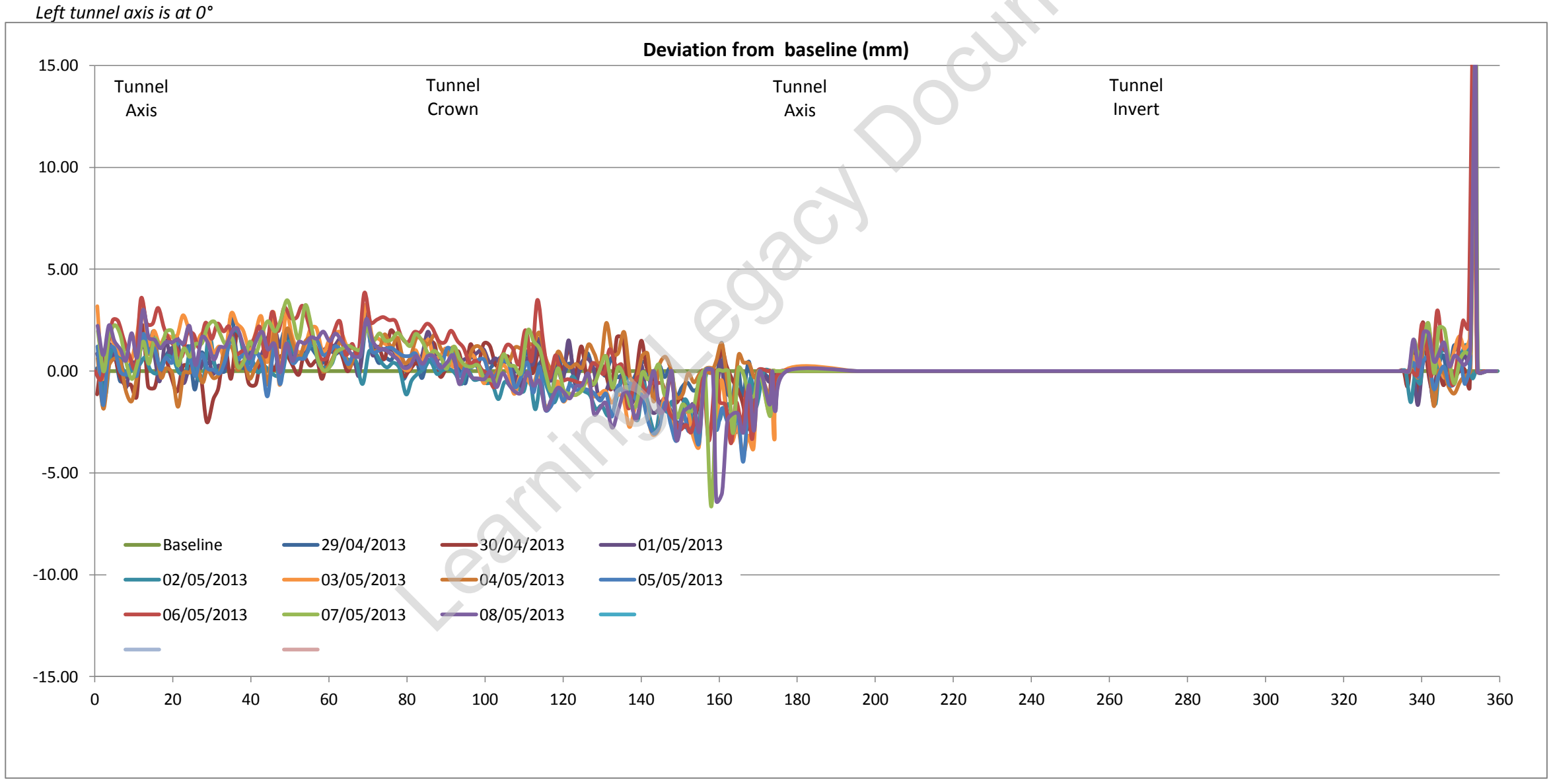
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 969**

Deviation vs Profile

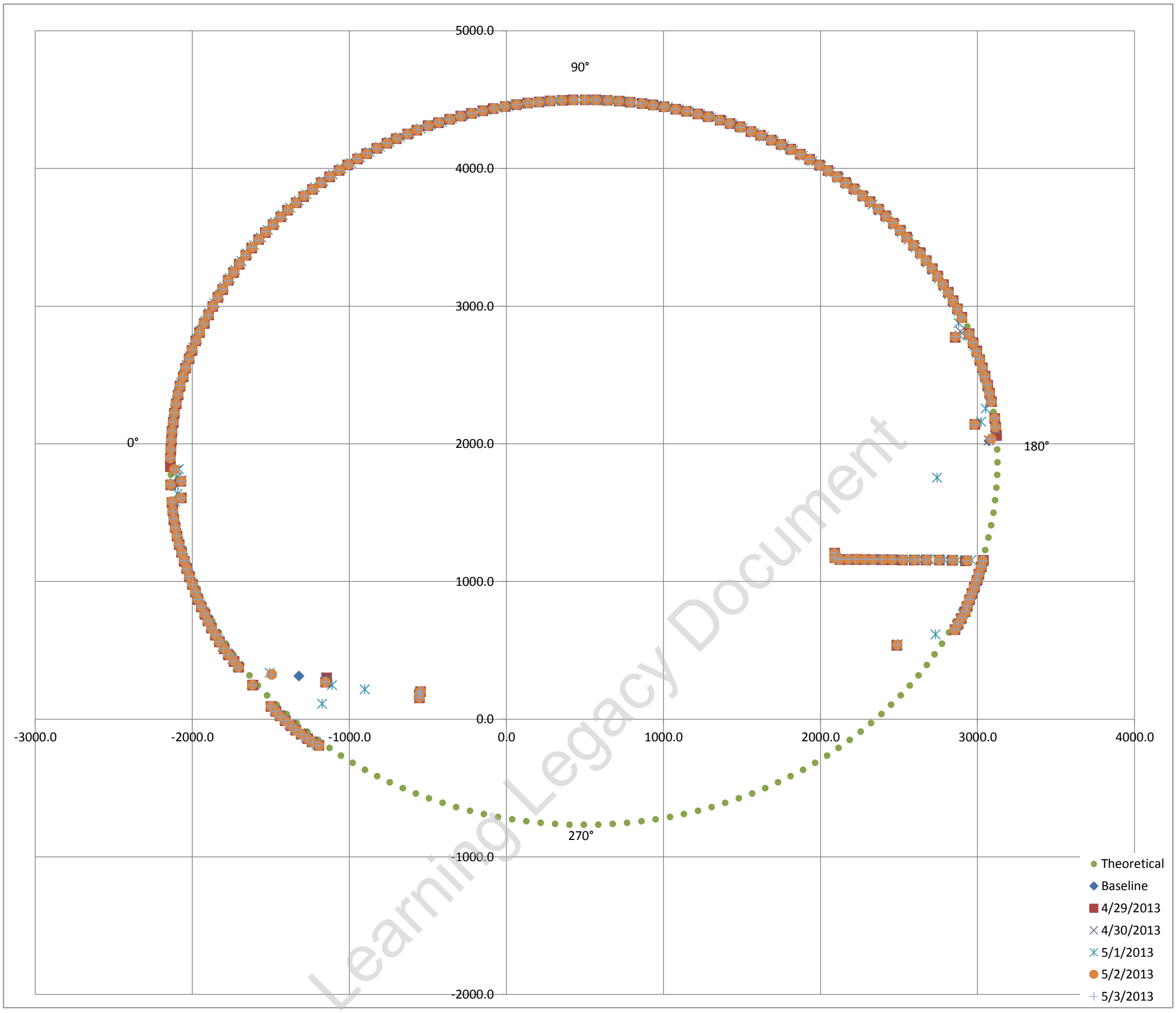


Left tunnel axis is at 0°



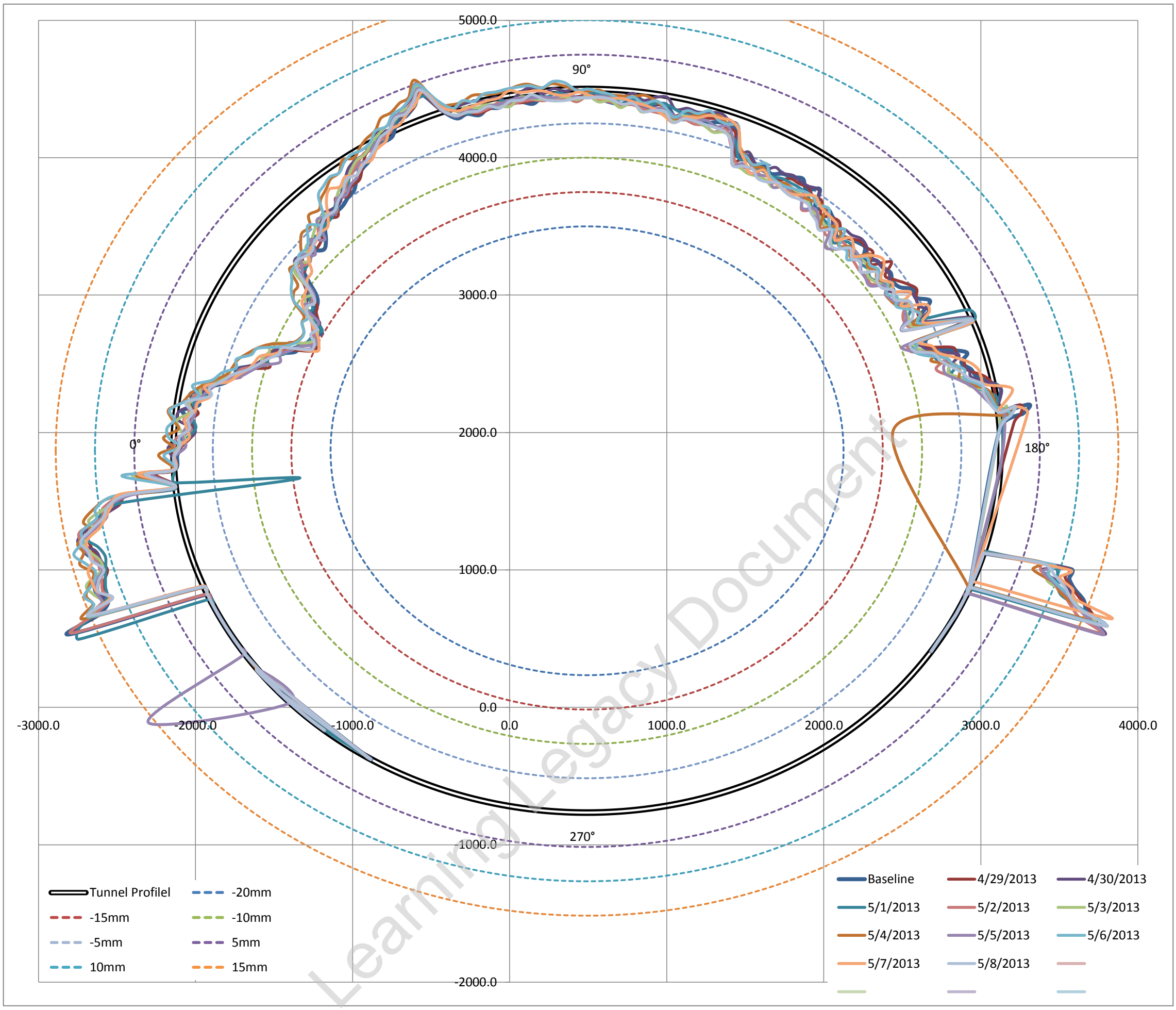
DLR LINE: UP **SECTION: 970**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **970**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5271.23	mm
Estimated best fit as built diameter	**5266.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.09938%	

i.e. Average surveyed diameter varies on 0.099% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**17.5**	**-14.6**
Max / Min deviation % to estimated dia	**0.67%**	**-0.55%**

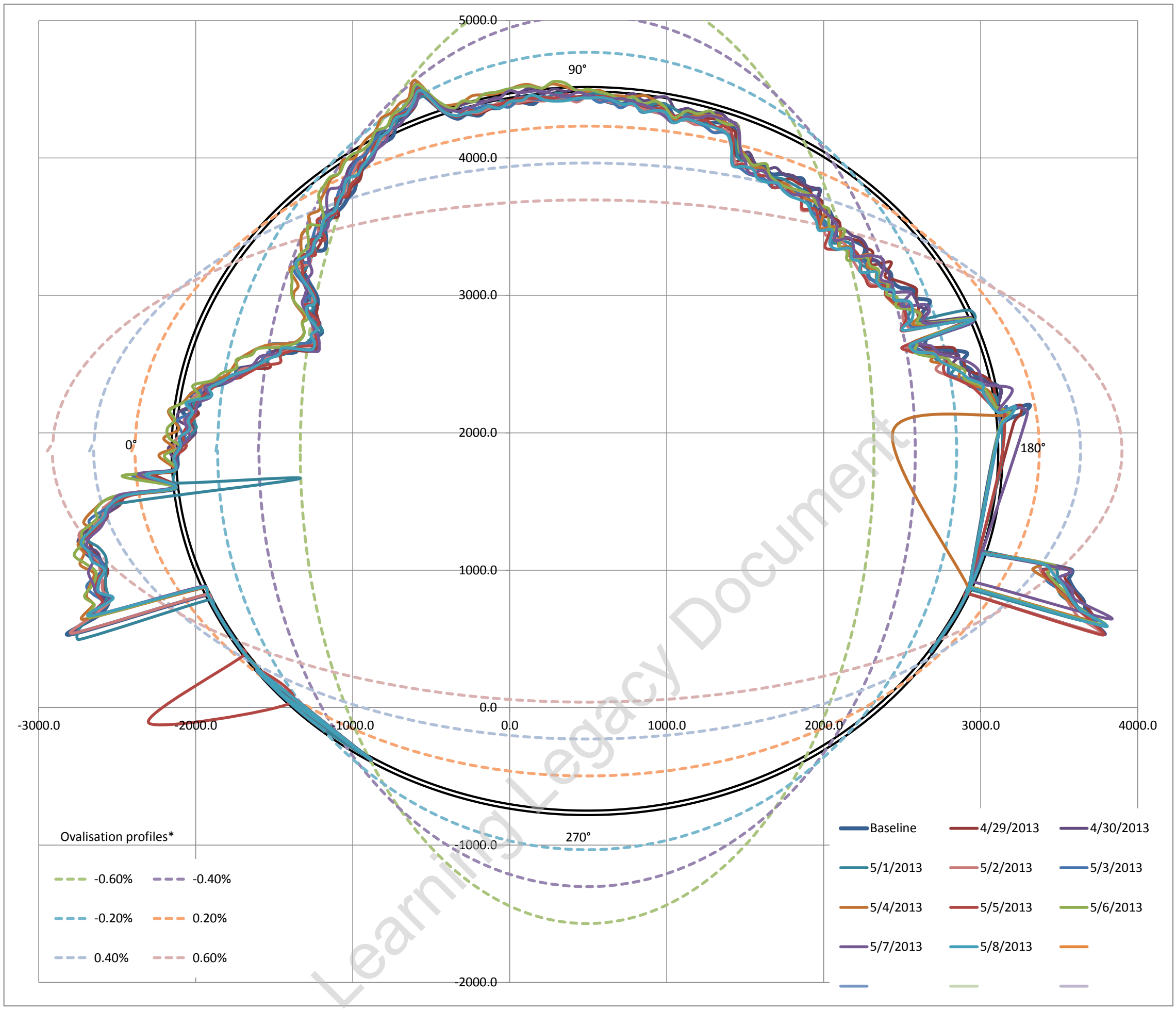
Fitted Circle Coordinates

Axis	X	493
	Y	1867
Radius		2633

Estimated best fit as built diameter	5266	mm
Designed diameter	5300	mm
Average diameter difference	**-34**	mm
Average radial difference	**-17**	mm
Average difference%	**-0.64%**	

DLR LINE: **UP** **SECTION:** **970**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

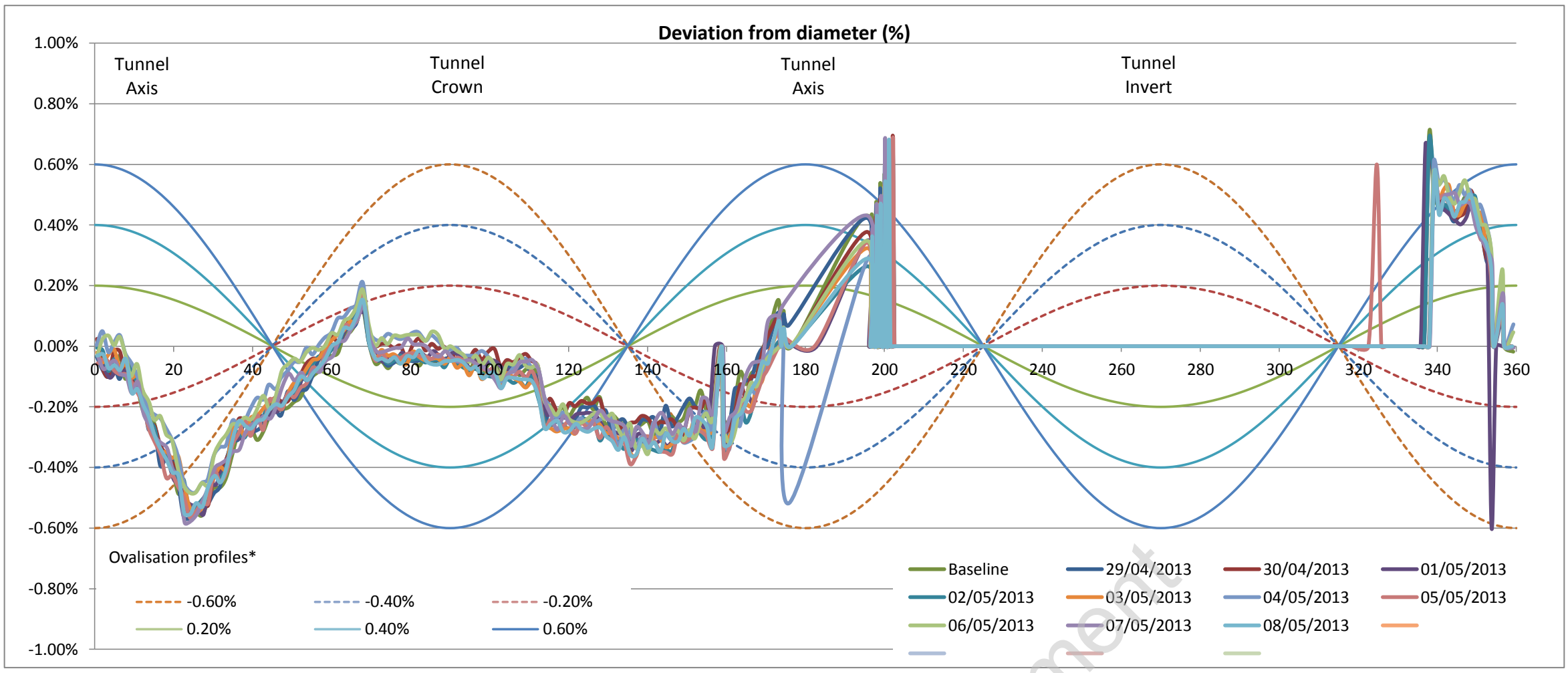
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5268.20 mm
Estimate of vertical diameter at crown, Dv	5265.01 mm
Dh / Dv	1.0006

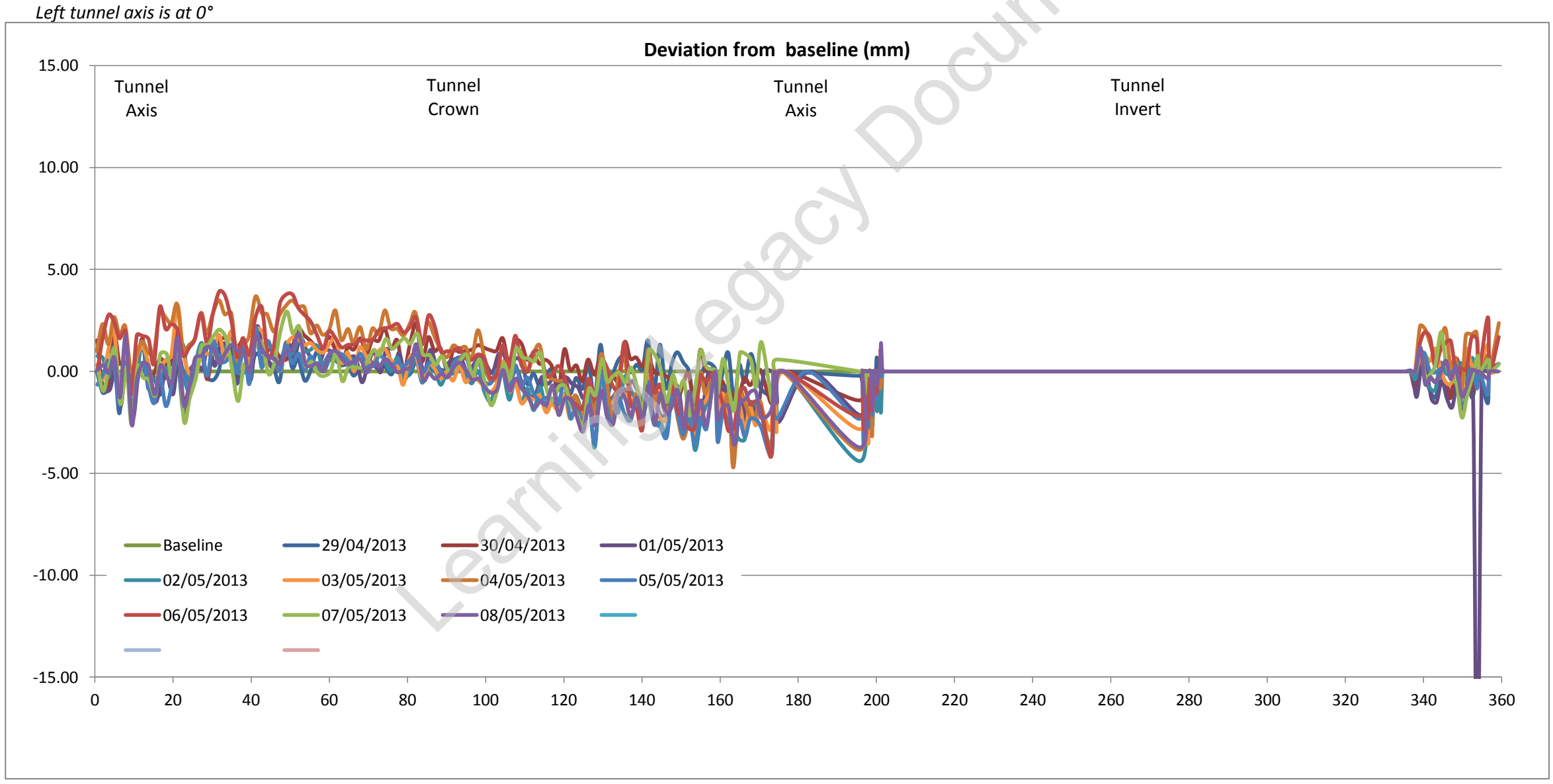
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 970**

Deviation vs Profile

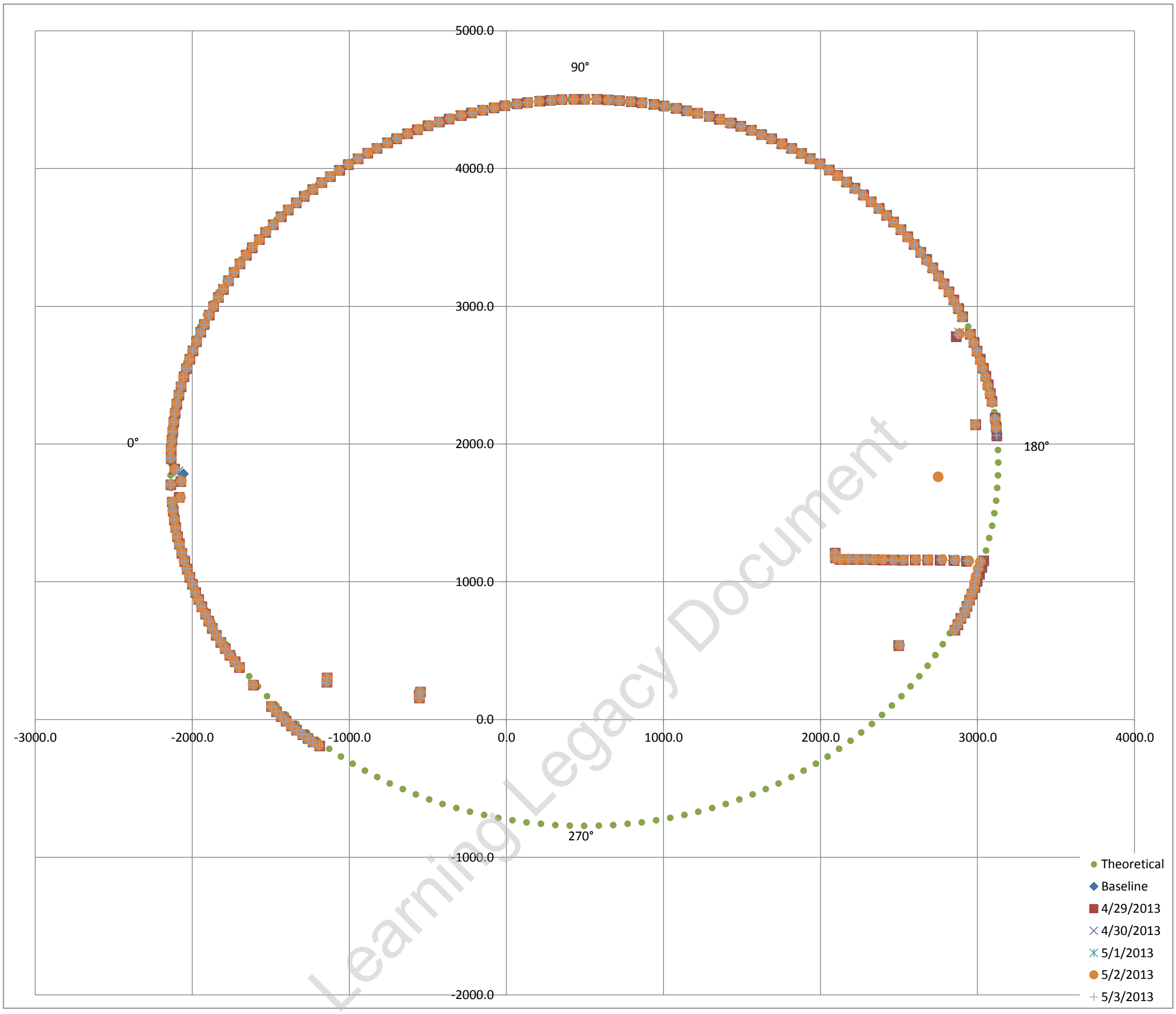


Left tunnel axis is at 0°



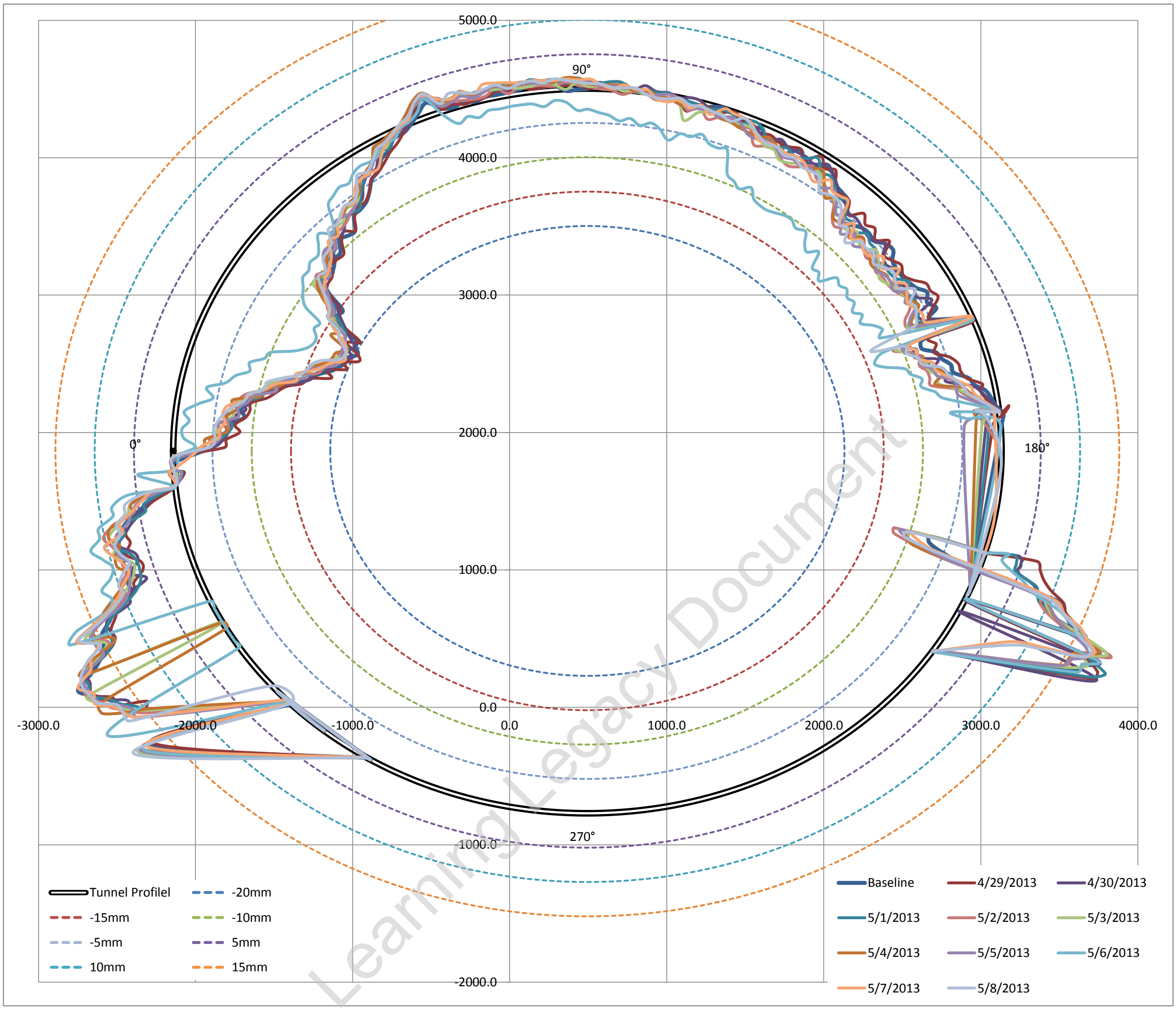
DLR LINE: UP **SECTION: 971**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **971**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5274.23	mm
Estimated best fit as built diameter	**5274.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.00437%	

i.e. Average surveyed diameter varies on 0.004% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**20.4**	**-18.8**
Max / Min deviation % to estimated dia	**0.77%**	**-0.71%**

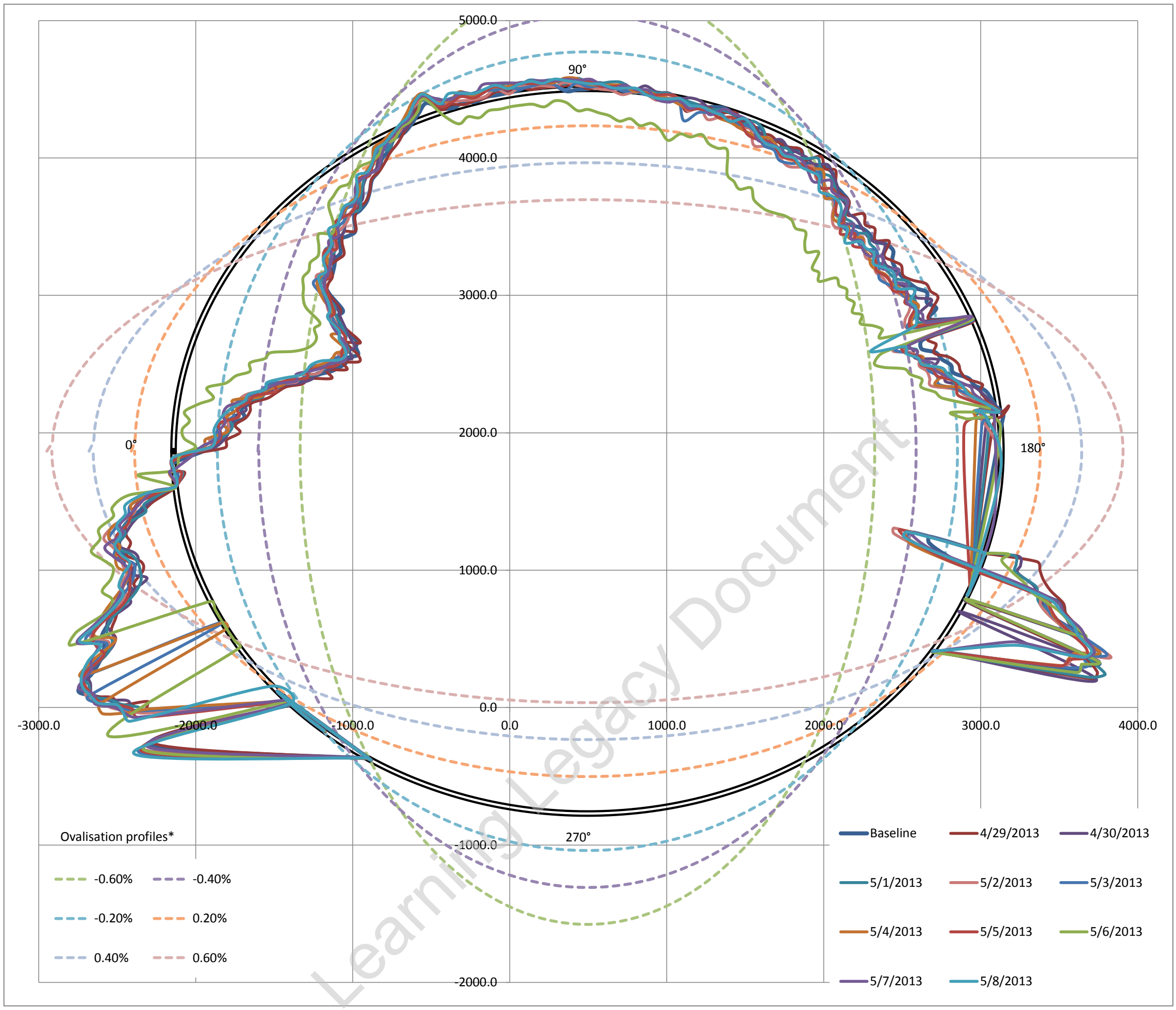
Fitted Circle Coordinates

Axis	X	495
	Y	1866
Radius		2637

Estimated best fit as built diameter	5274	mm
Designed diameter	5300	mm
Average diameter difference	**-26**	mm
Average radial difference	**-13**	mm
Average difference%	**-0.49%**	

DLR LINE: **UP** **SECTION:** **971**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

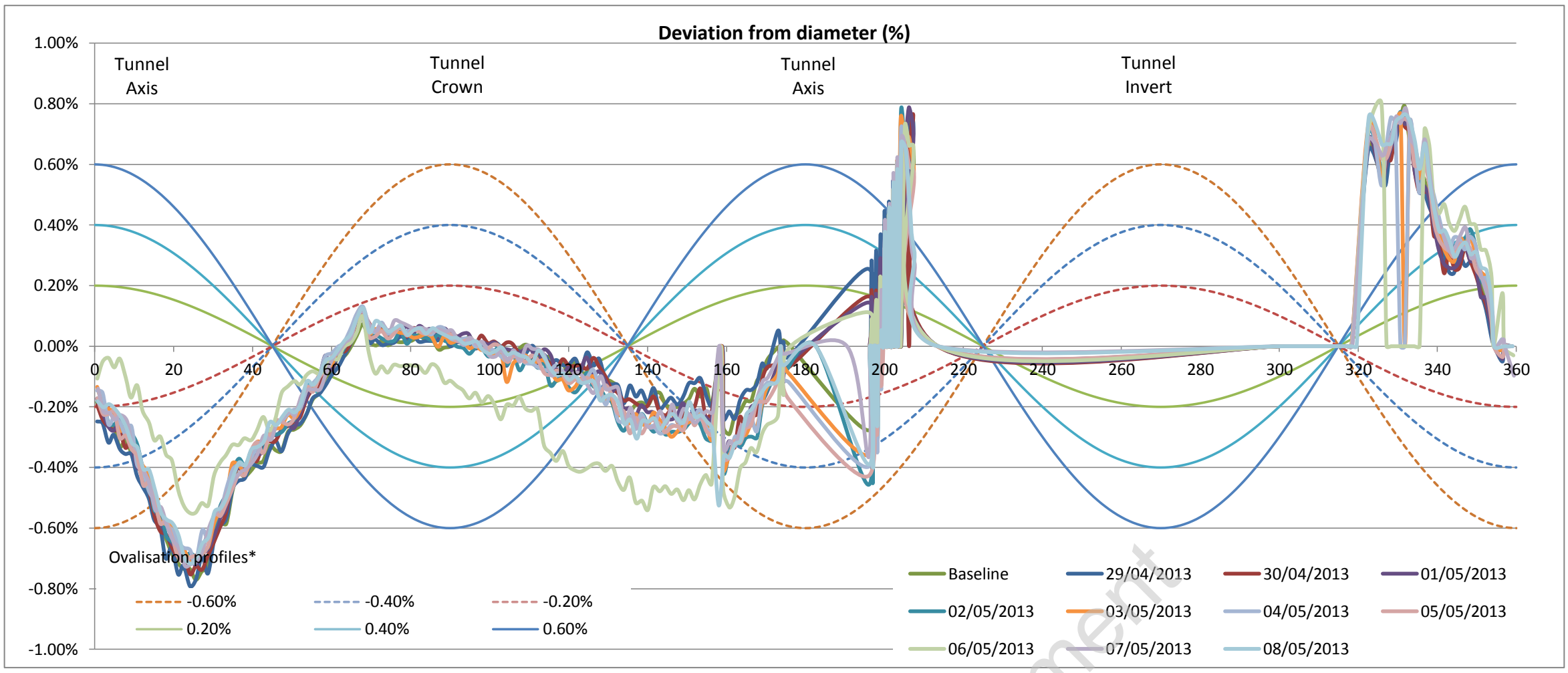
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5269.65 mm
Estimate of vertical diameter at crown, Dv	5274.03 mm
Dh / Dv	0.9992

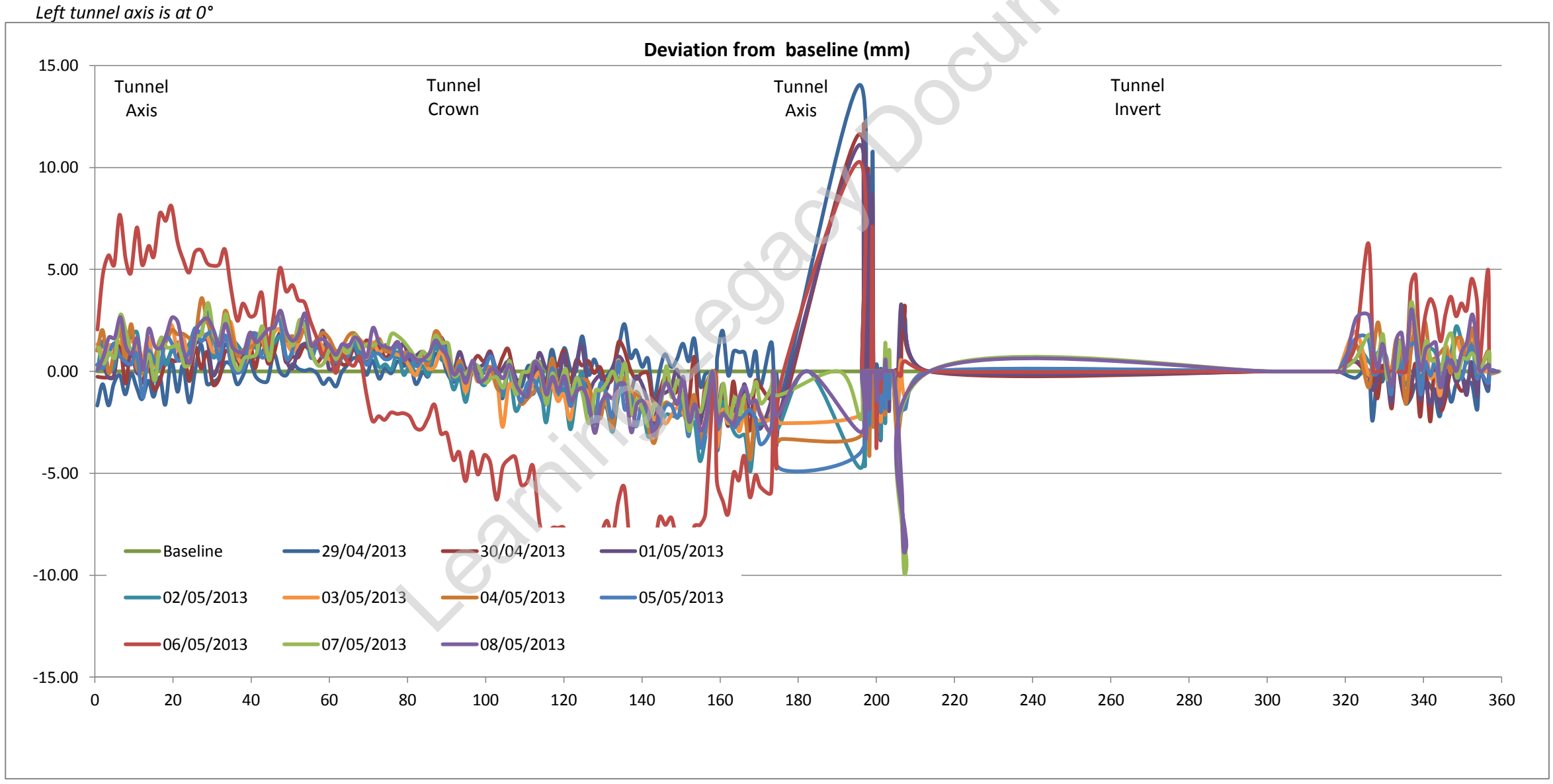
Best fit ovalsation profile: **Negative**

DLR LINE: UP **SECTION: 971**

Deviation vs Profile



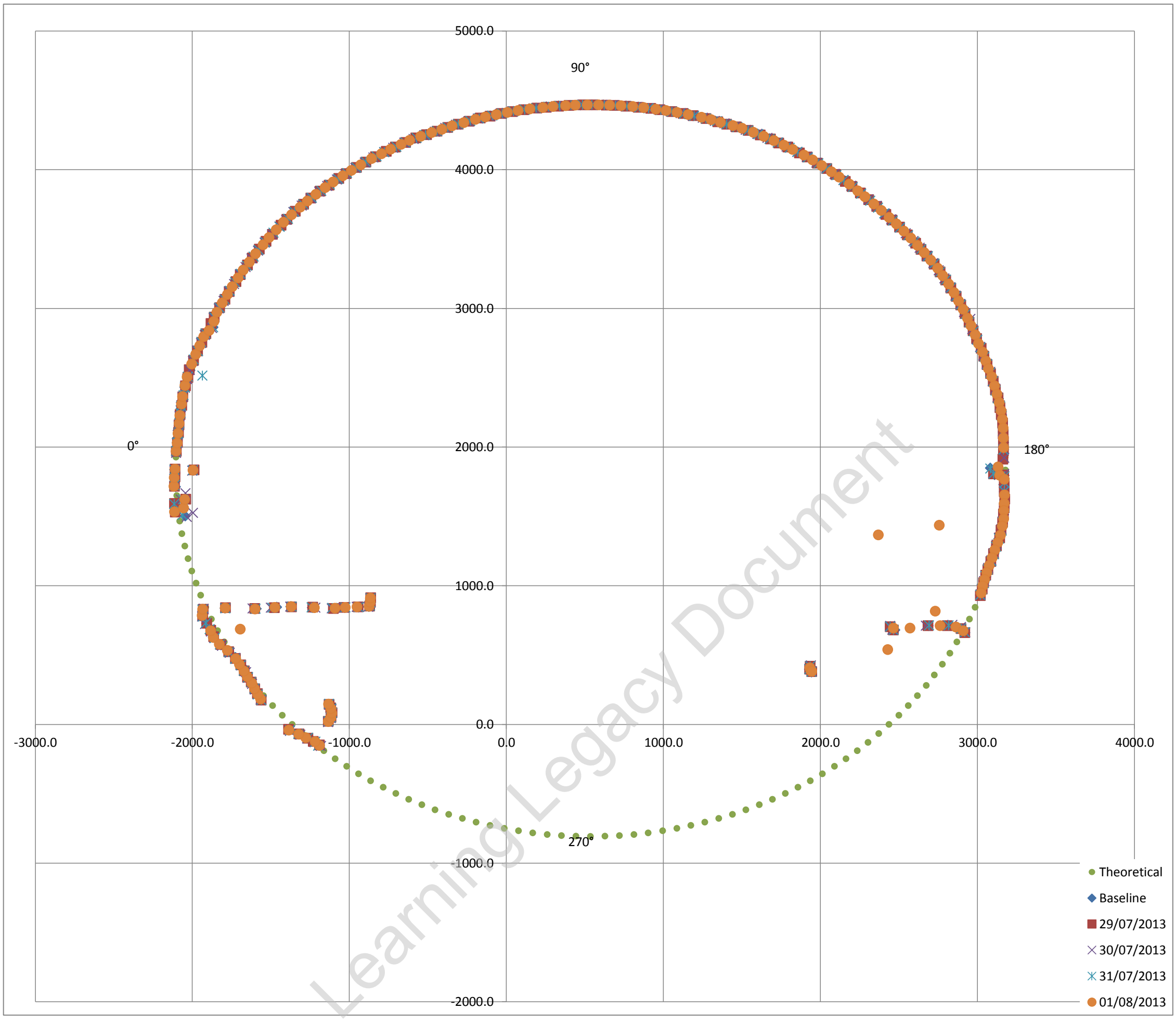
Left tunnel axis is at 0°



Appendix D2 Monitoring Results – Laser Scanning (TBM2 overpassing)

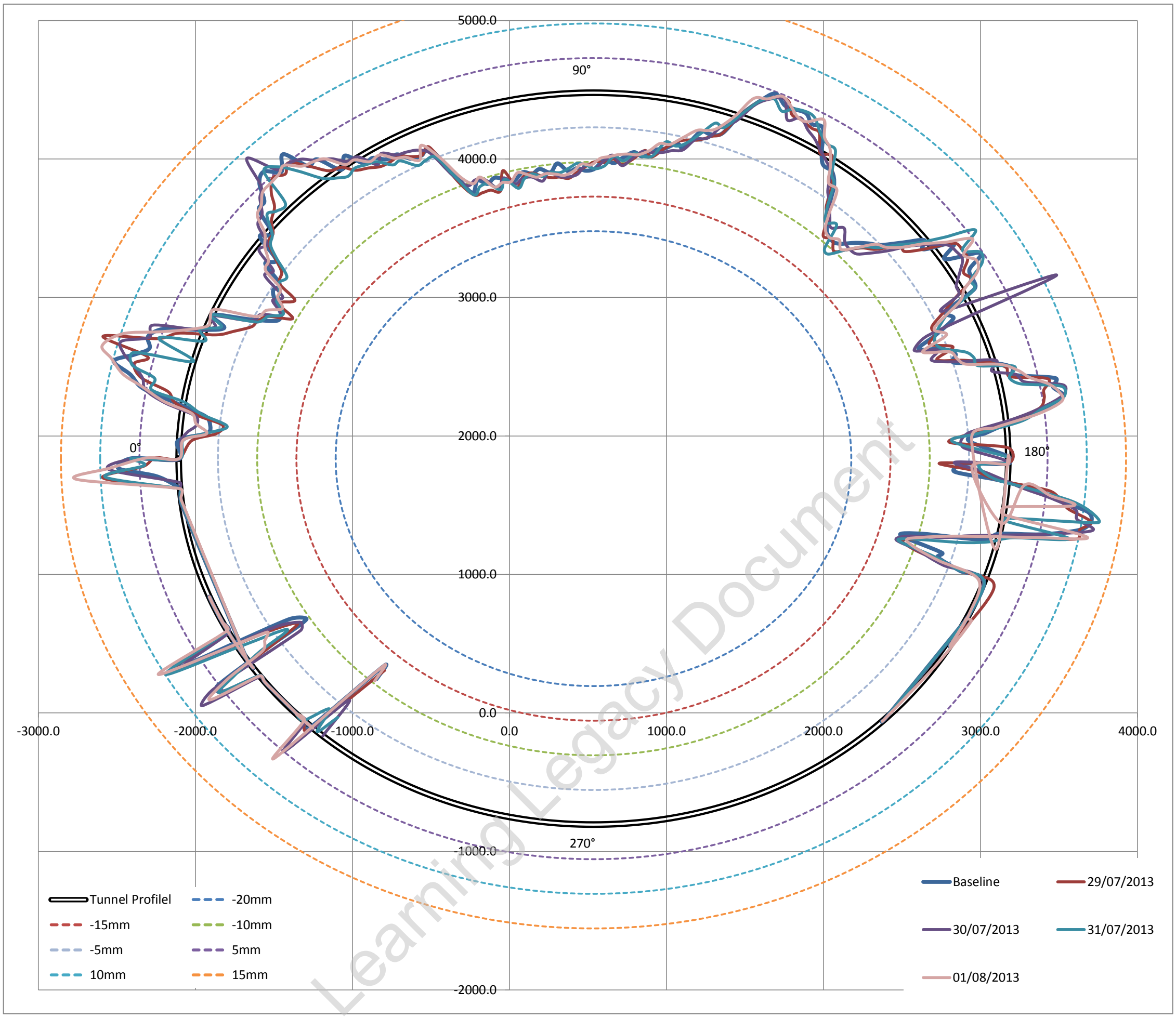
DLR LINE: DN **SECTION: 966**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **966**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5285.14	mm
Estimated best fit as built diameter	**5284.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.02153%	

i.e. Average surveyed diameter varies on 0.021% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.1**	**-12.7**
Max / Min deviation % to estimated dia	**0.46%**	**-0.48%**

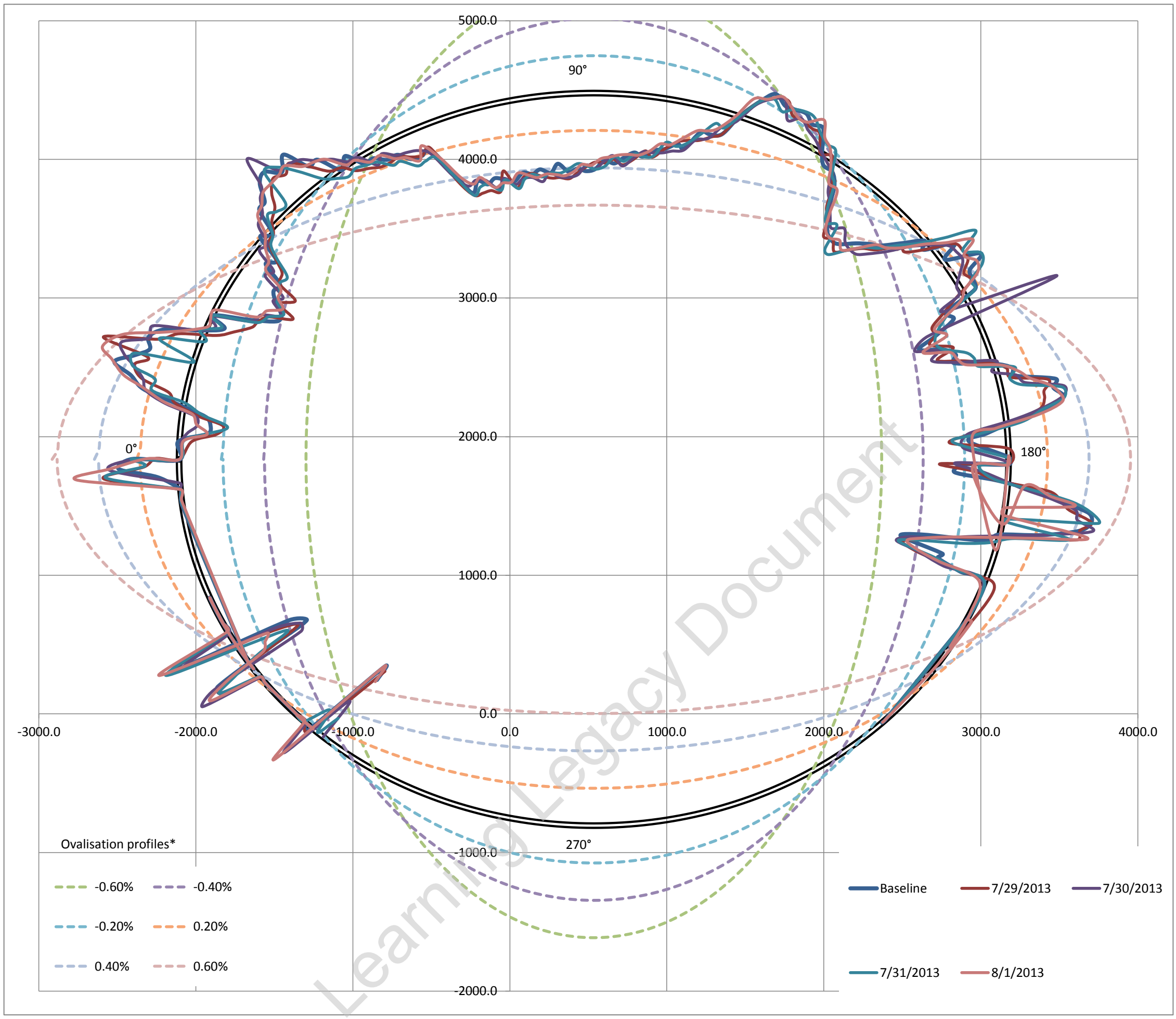
Fitted Circle Coordinates

Axis	X	535
	Y	1836
Radius		2642

Estimated best fit as built diameter	5284	mm
Designed diameter	5300	mm
Average diameter difference	**-16**	mm
Average radial difference	**-8**	mm
Average difference%	**-0.30%**	

DLR LINE: **DN** **SECTION:** **966**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

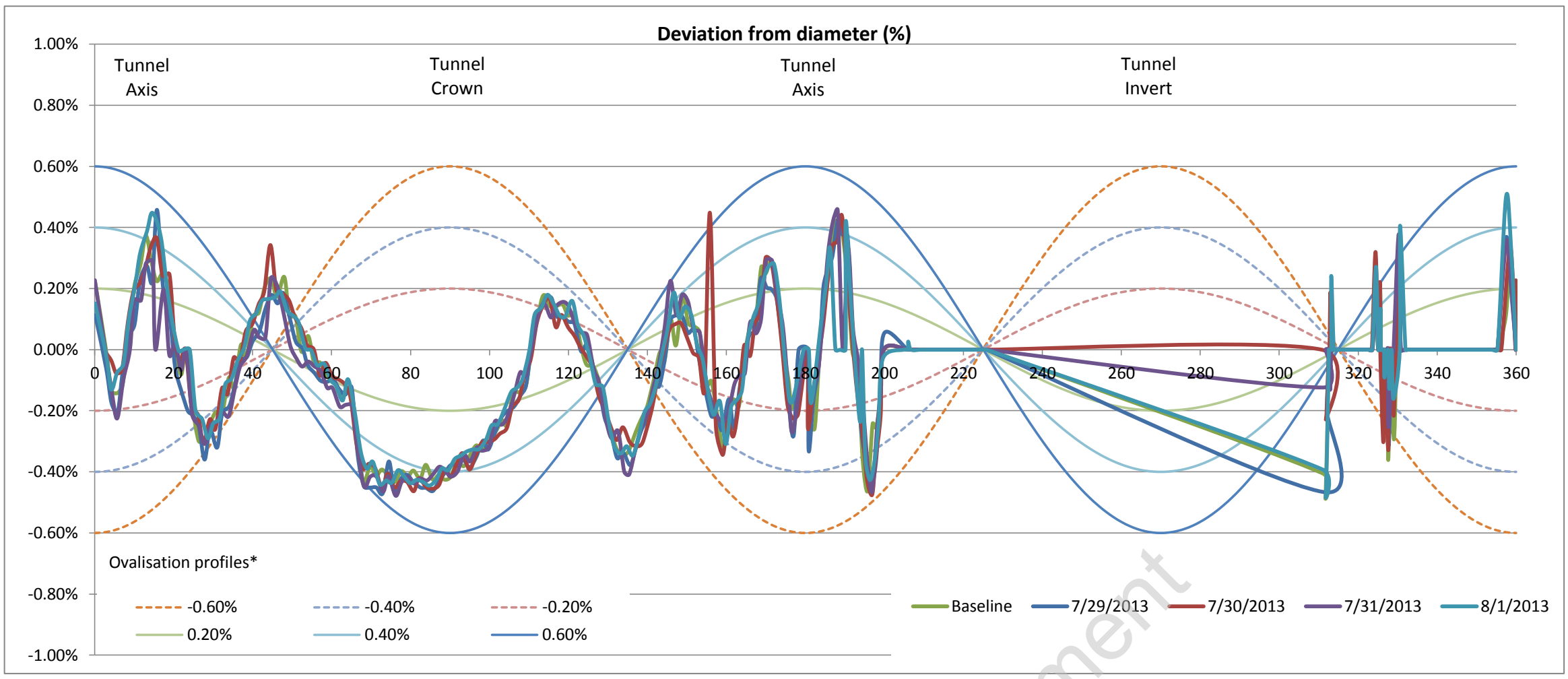
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5272.75	mm
Dh / Dv	#VALUE!	

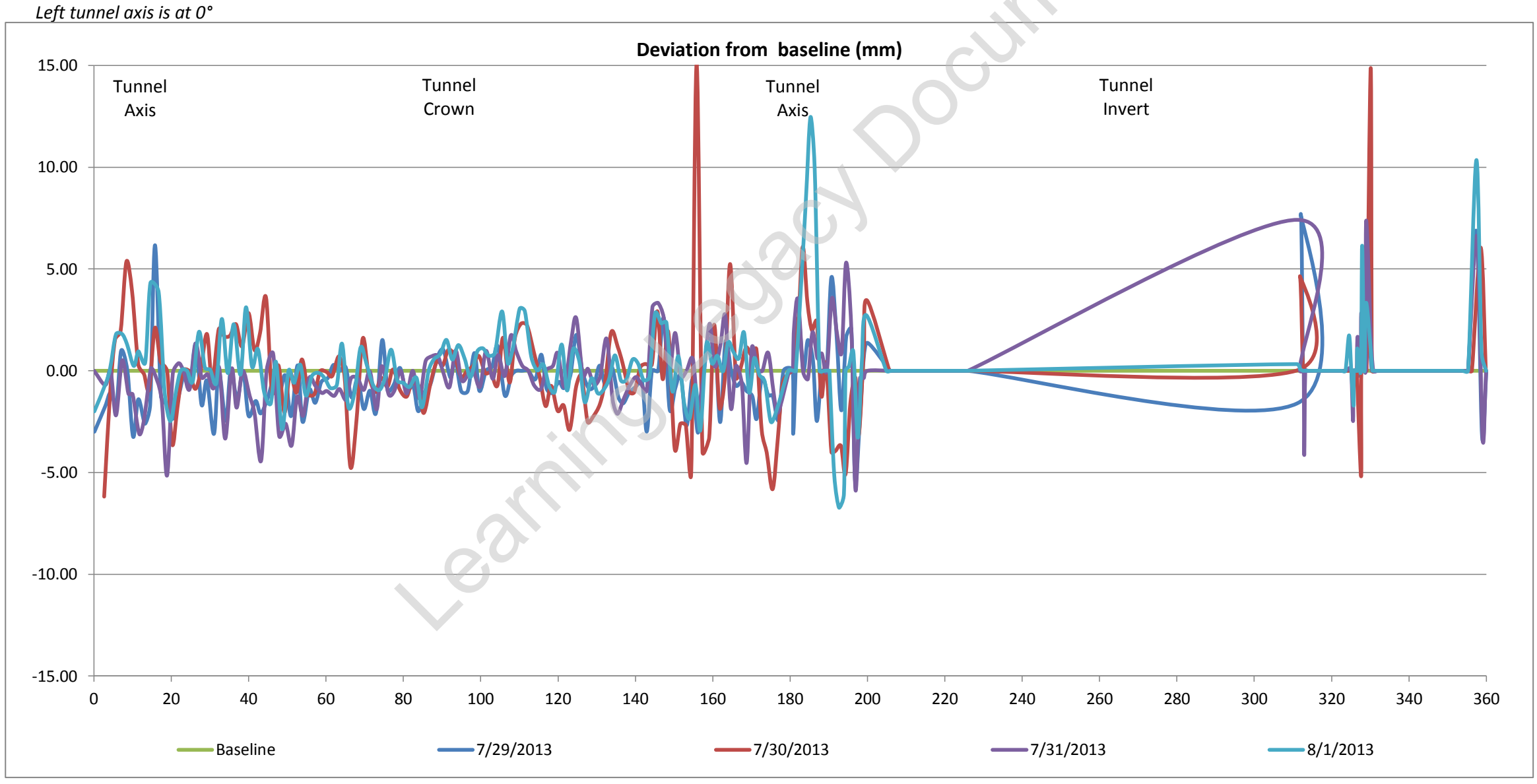
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 966**

Deviation vs Profile

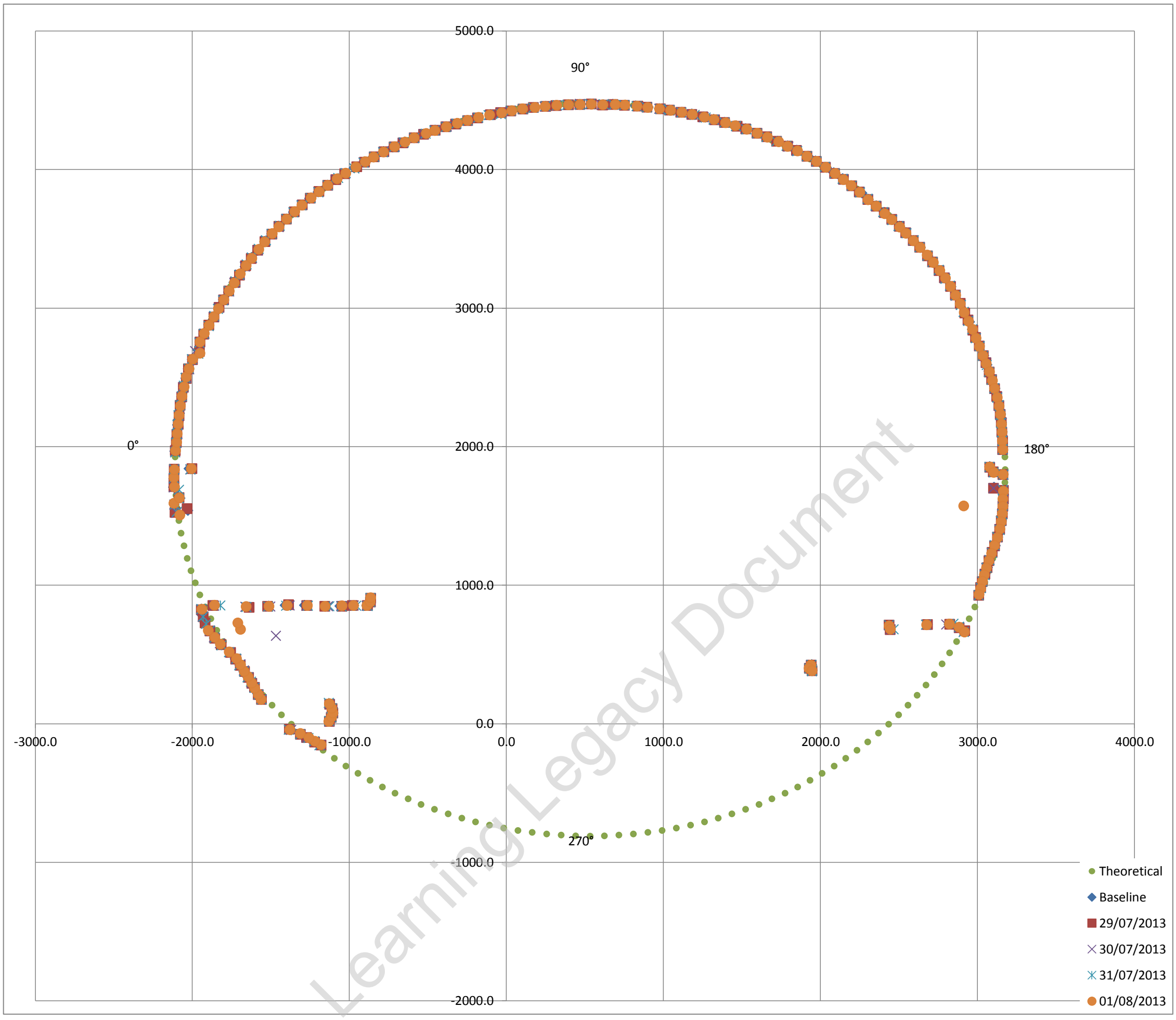


Left tunnel axis is at 0°



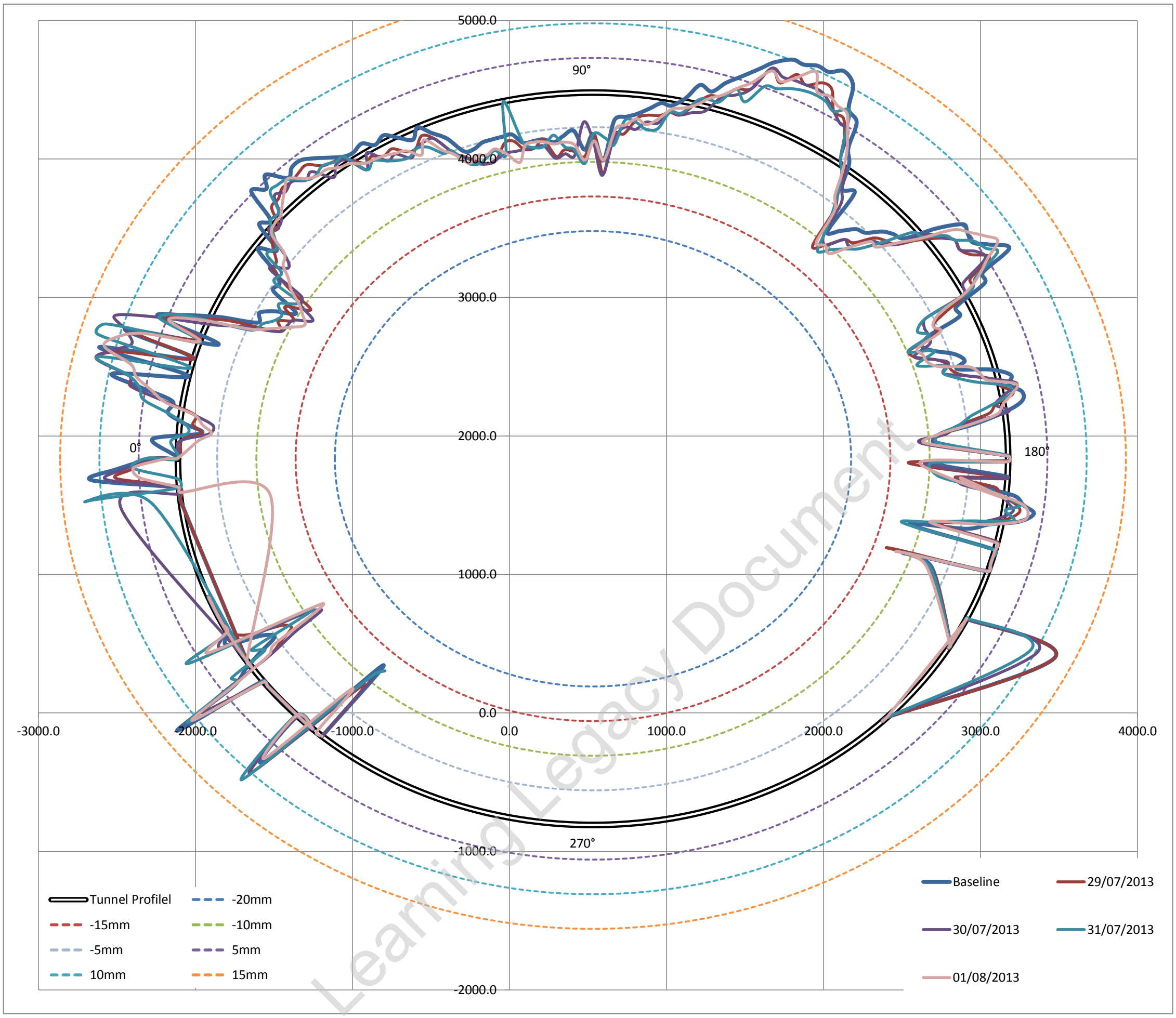
DLR LINE: DN **SECTION: 968**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **968**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5287.92	mm
Estimated best fit as built diameter	**5288.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00160%	

i.e. Average surveyed diameter varies on -0.001% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-12.6**
Max / Min deviation % to estimated dia	**0.47%**	**-0.48%**

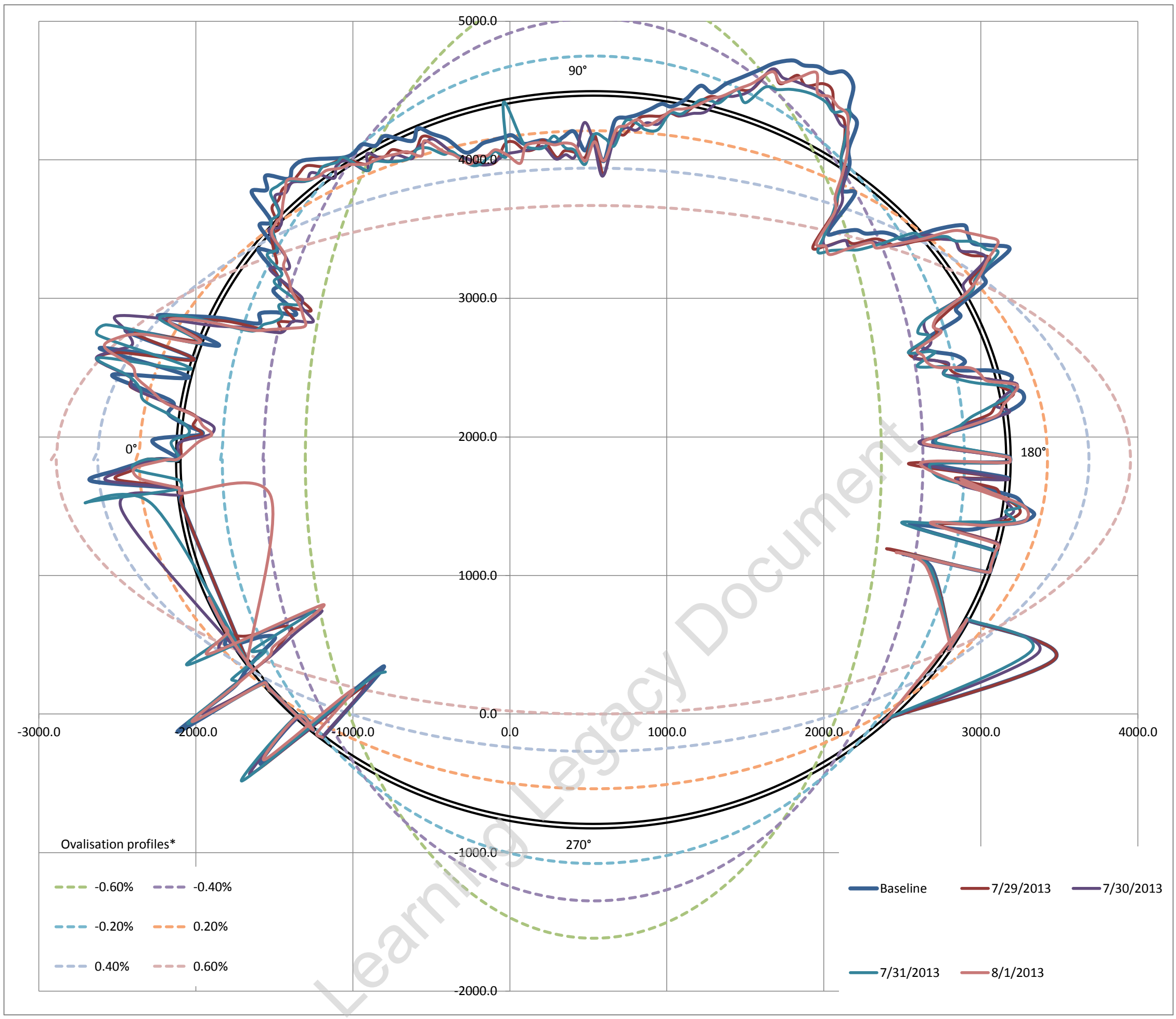
Fitted Circle Coordinates

Axis	X	532
	Y	1835
Radius		2644

Estimated best fit as built diameter	5288	mm
Designed diameter	5300	mm
Average diameter difference	**-12**	mm
Average radial difference	**-6**	mm
Average difference%	**-0.23%**	

DLR LINE: **DN** **SECTION:** **968**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

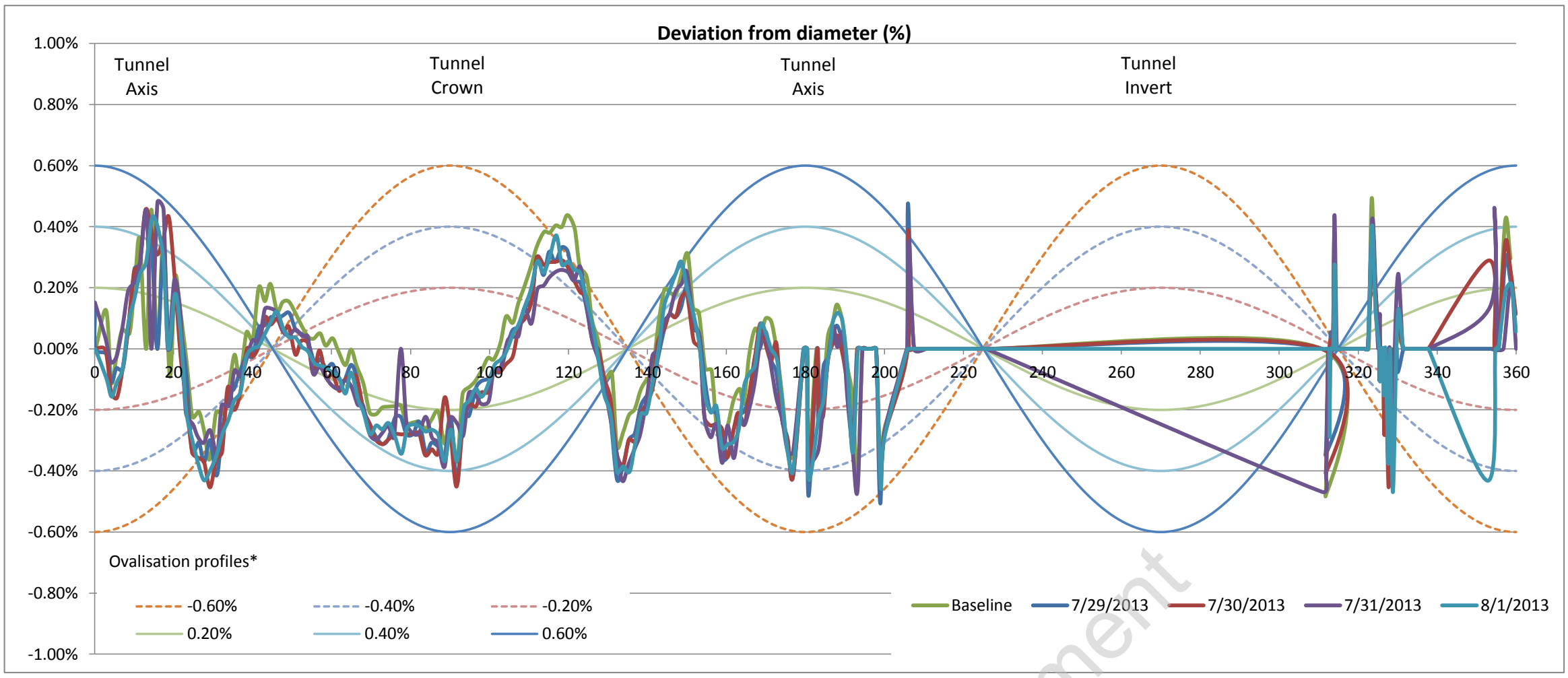
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5279.78	mm
Dh / Dv	#VALUE!	

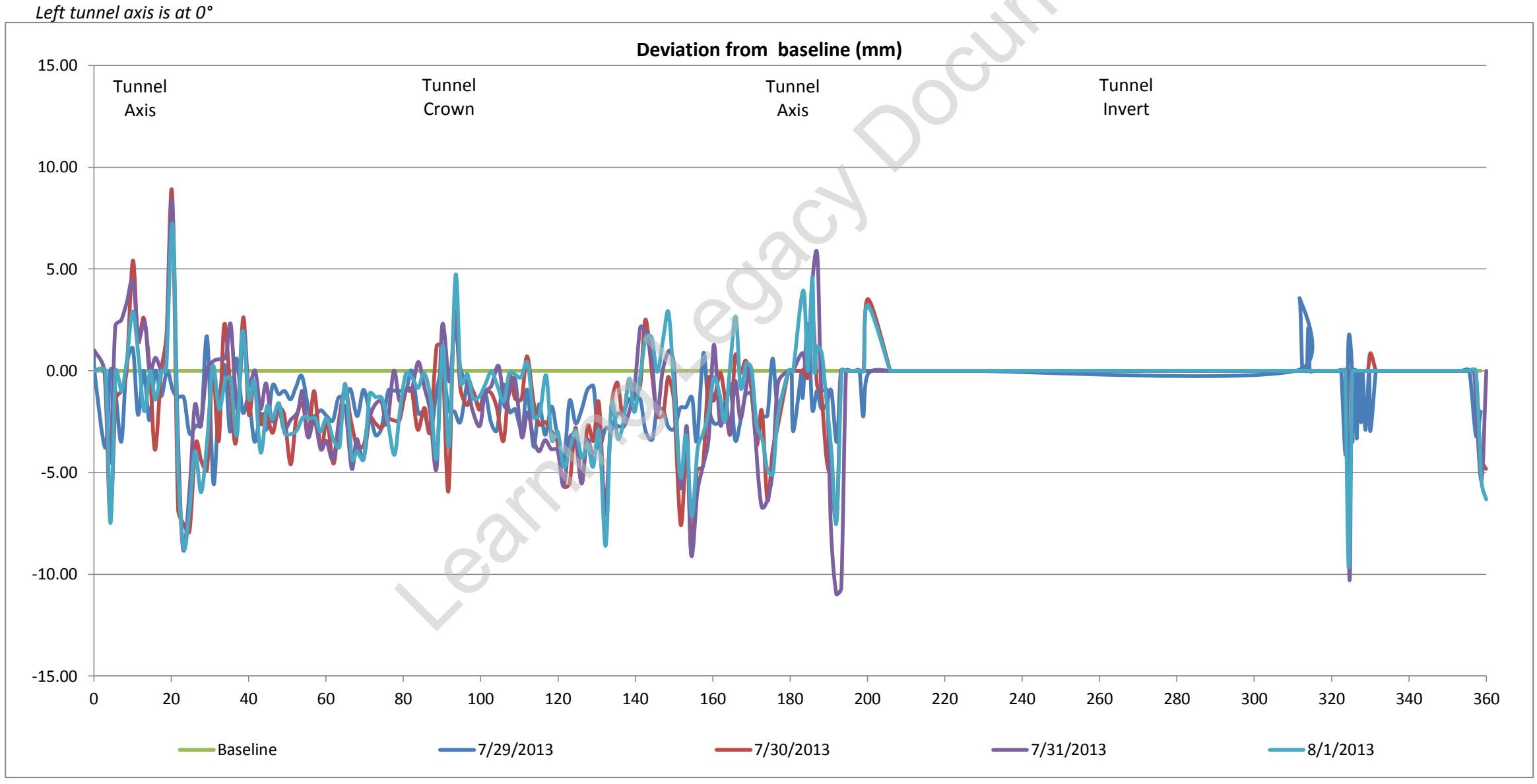
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 968**

Deviation vs Profile

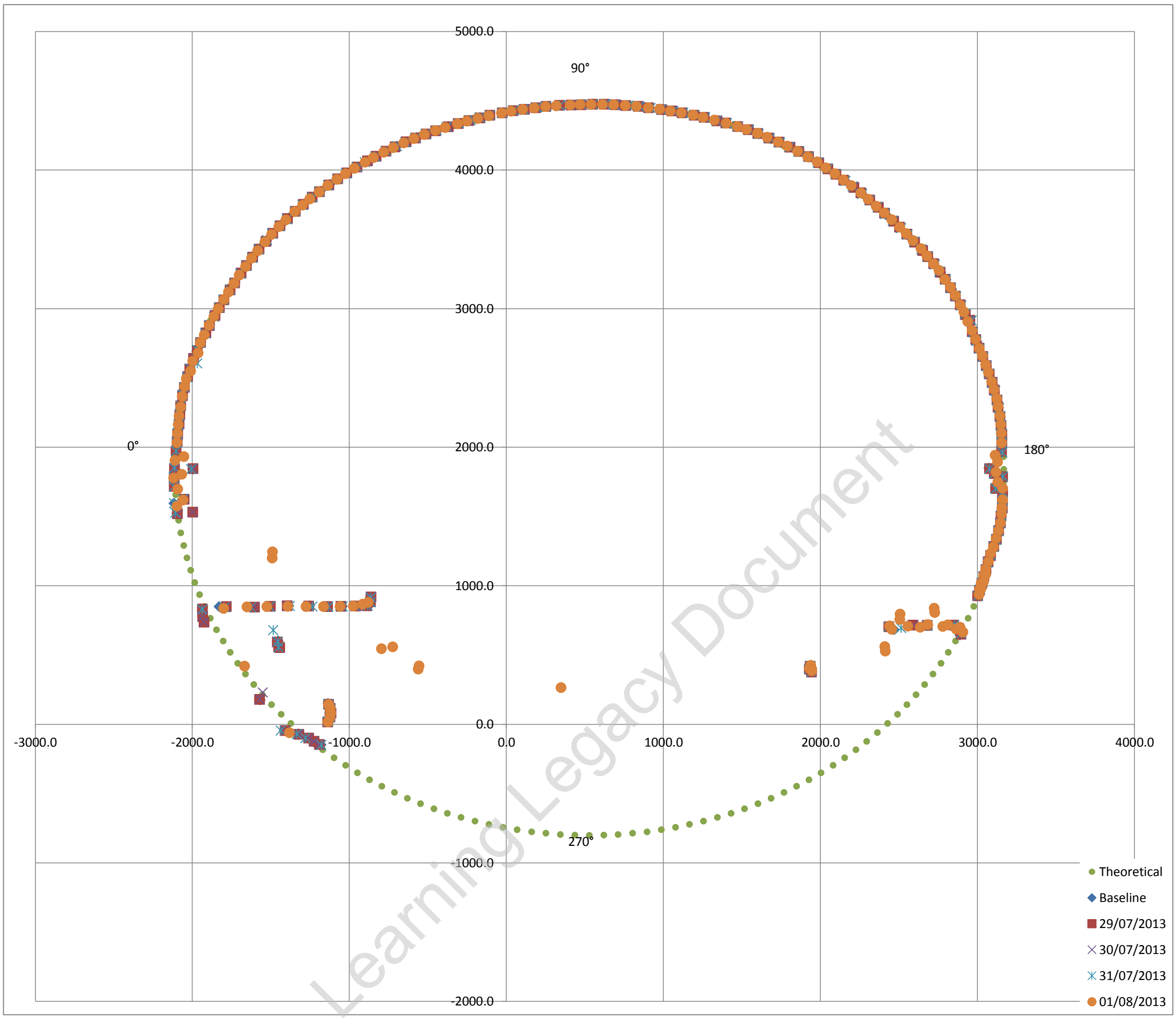


Left tunnel axis is at 0°



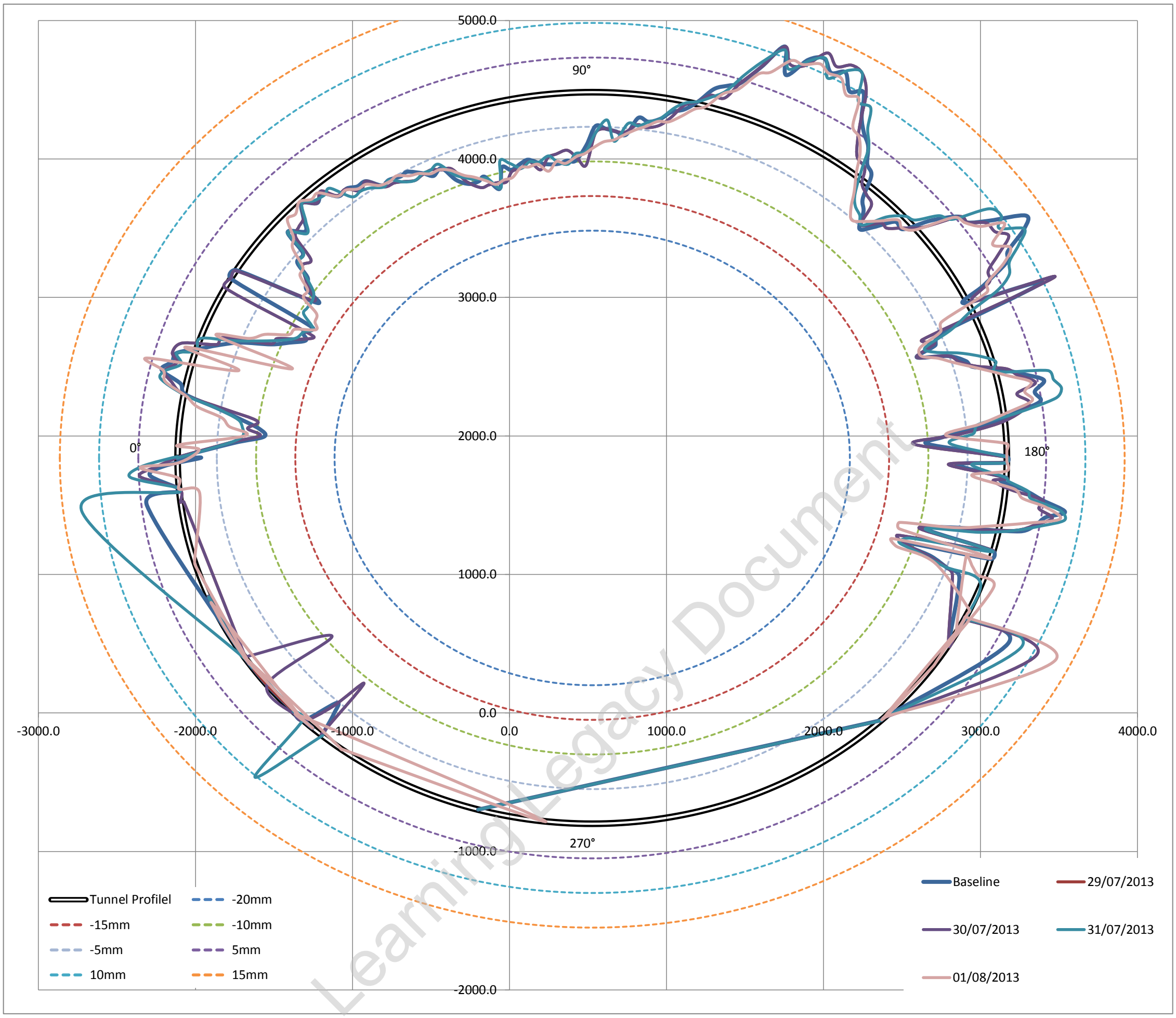
DLR LINE: DN **SECTION: 969**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **969**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5277.64	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.08262%	

i.e. Average surveyed diameter varies on -0.082% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.8**	**-12.9**
Max / Min deviation % to estimated dia	**0.48%**	**-0.49%**

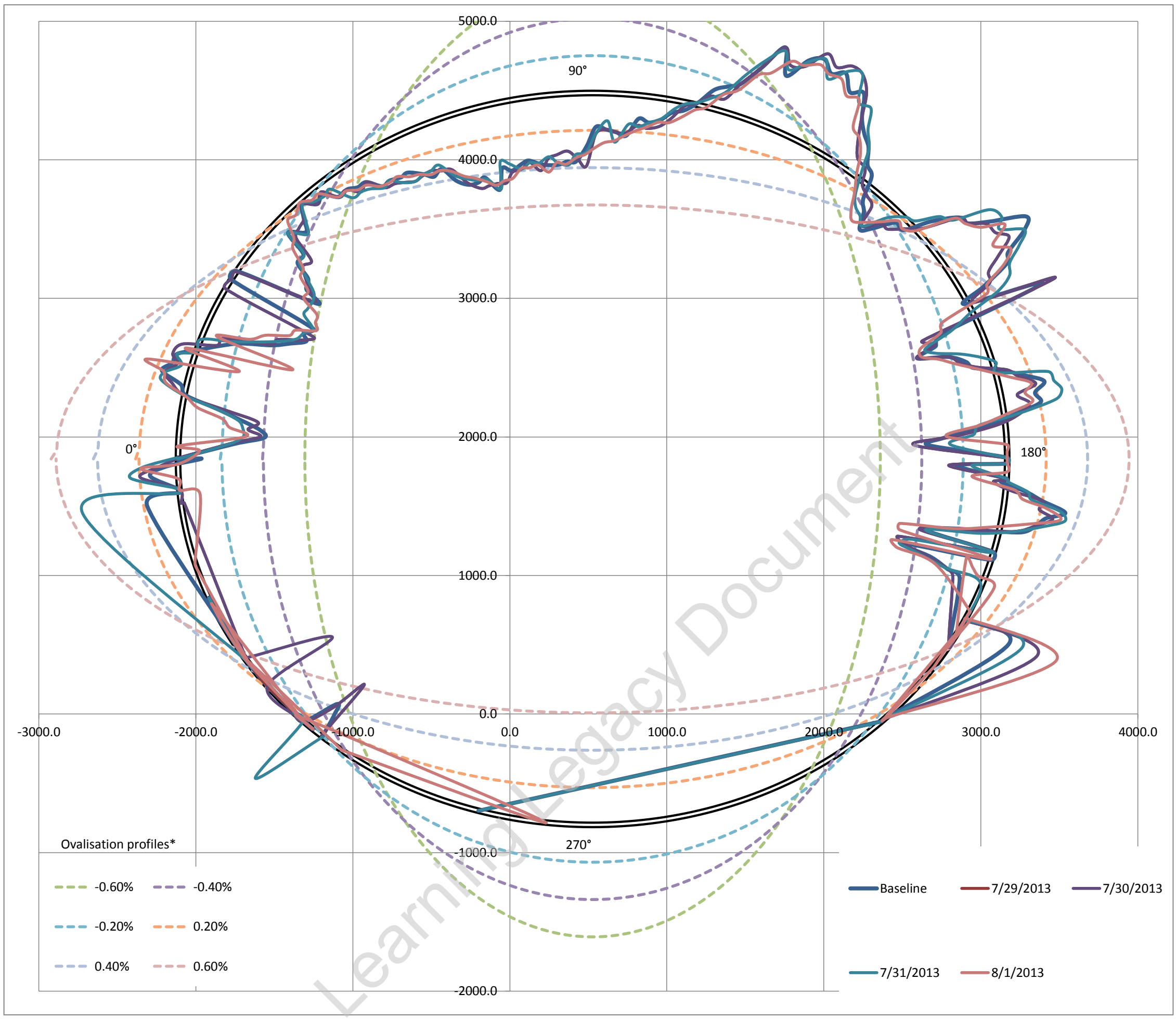
Fitted Circle Coordinates

Axis	X	527
	Y	1841
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **969**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

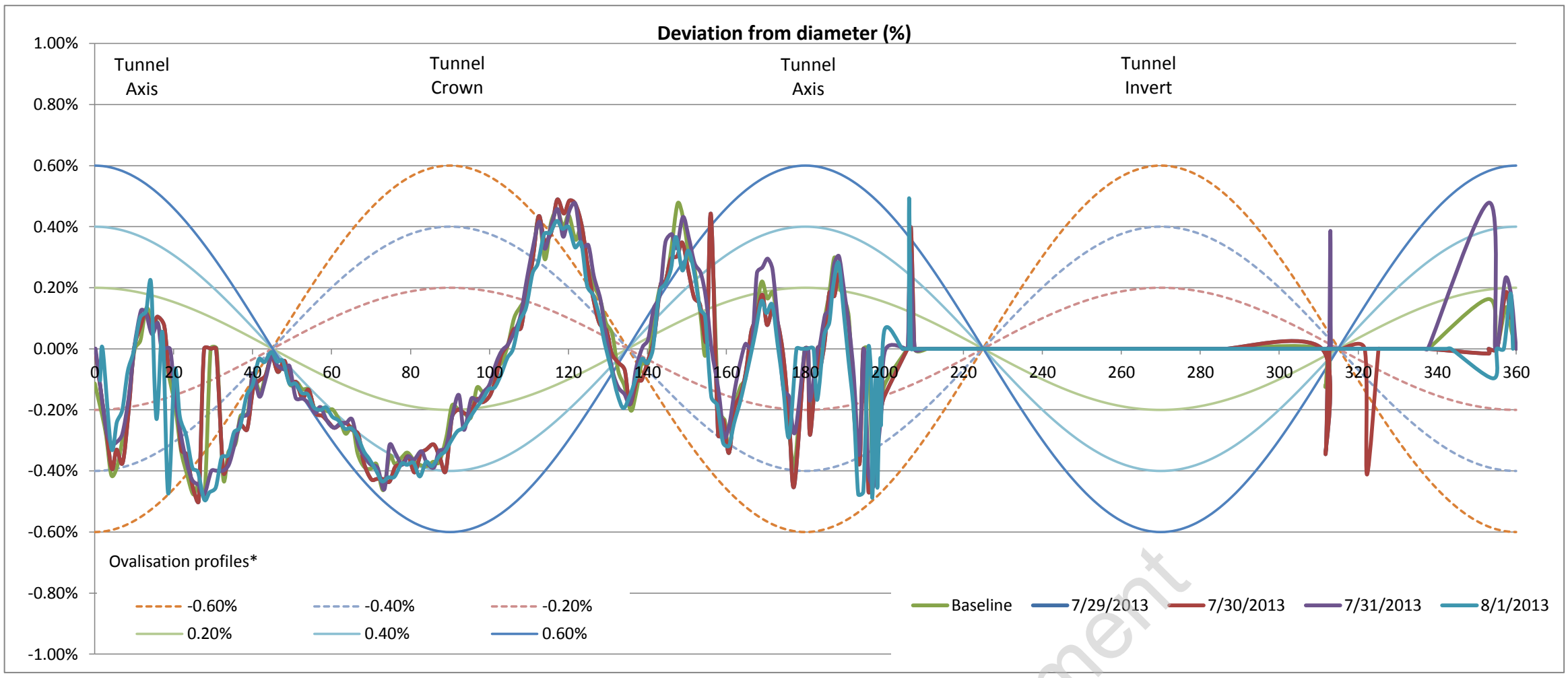
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5274.35	mm
Dh / Dv	#VALUE!	

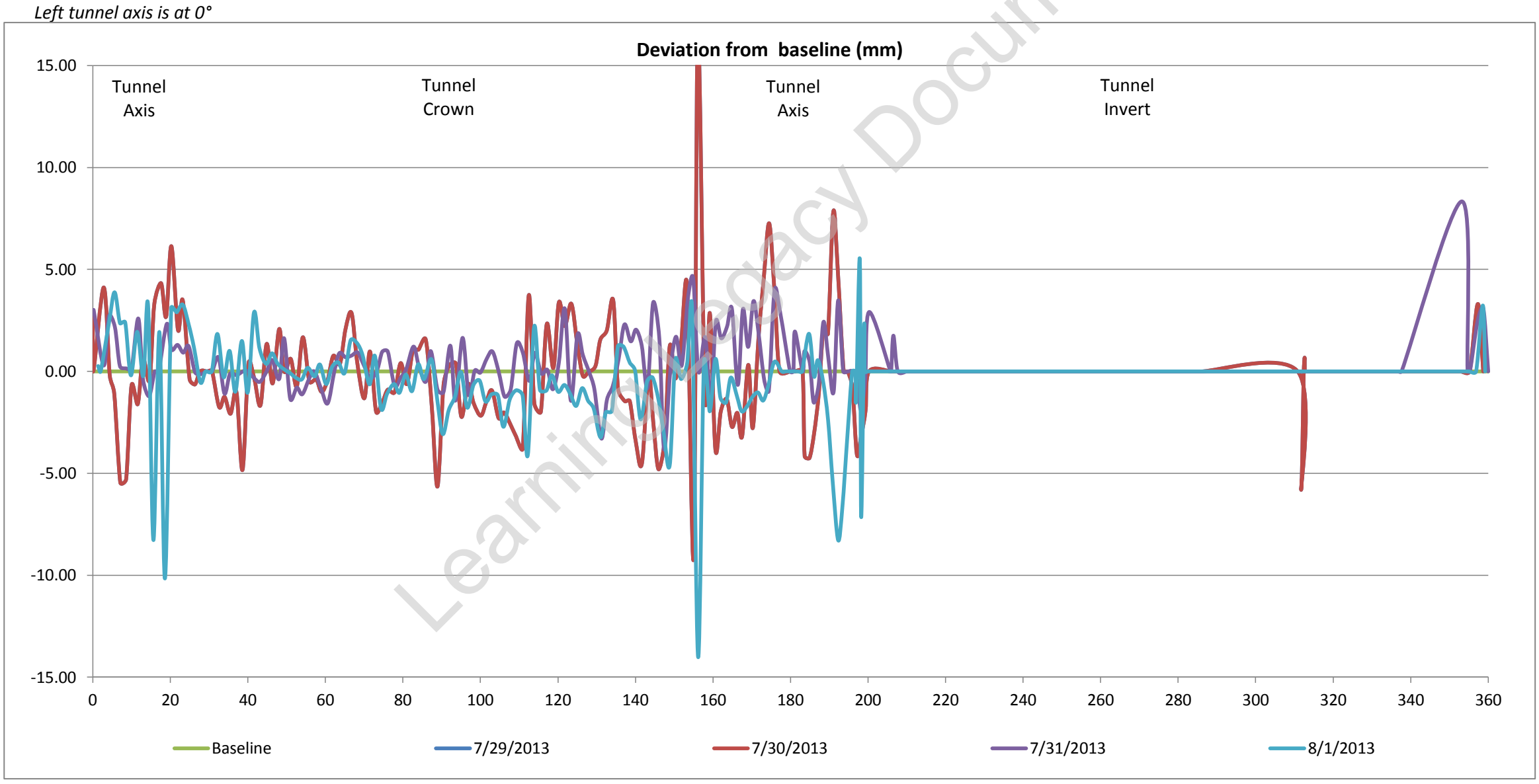
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 969**

Deviation vs Profile

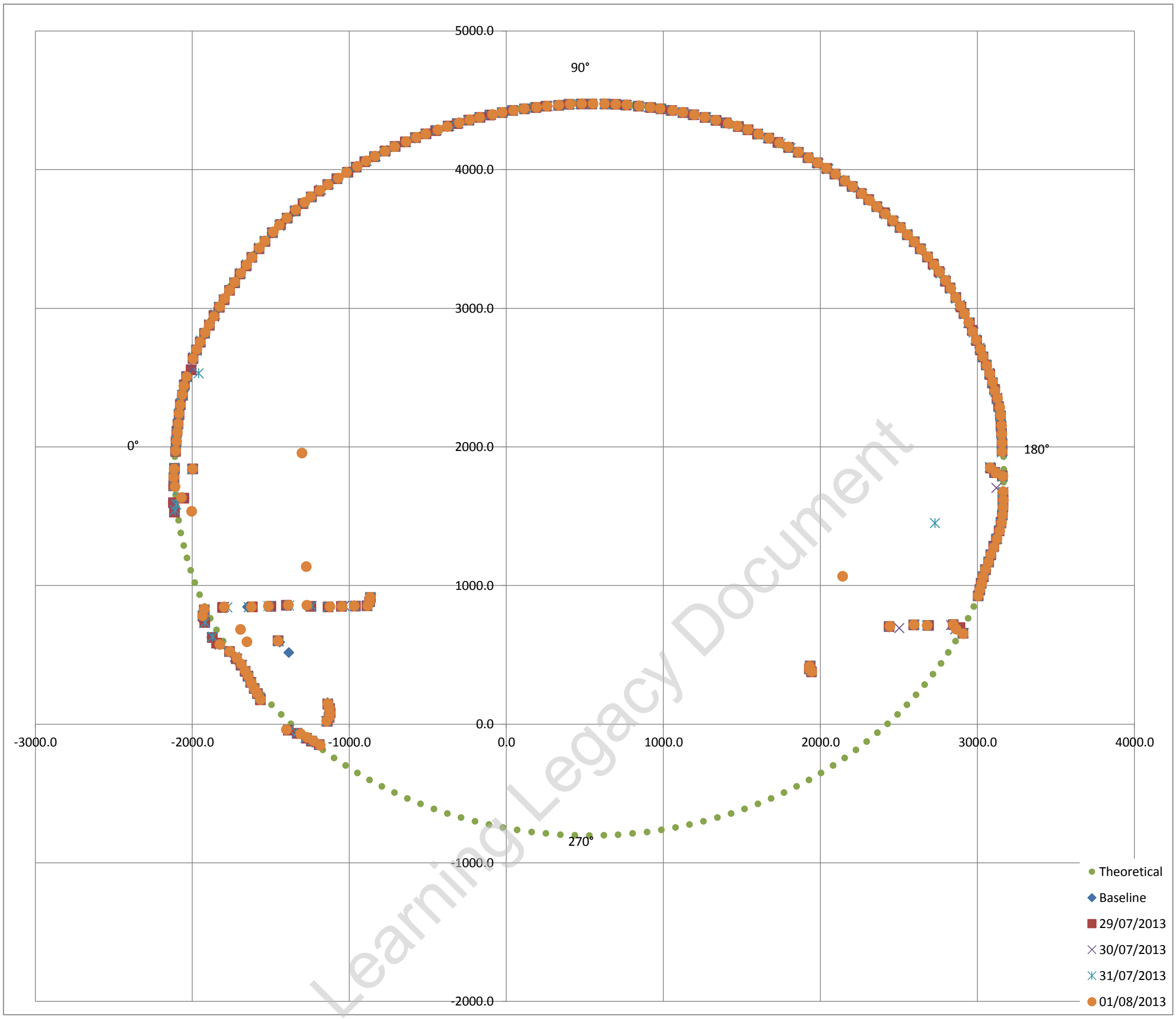


Left tunnel axis is at 0°



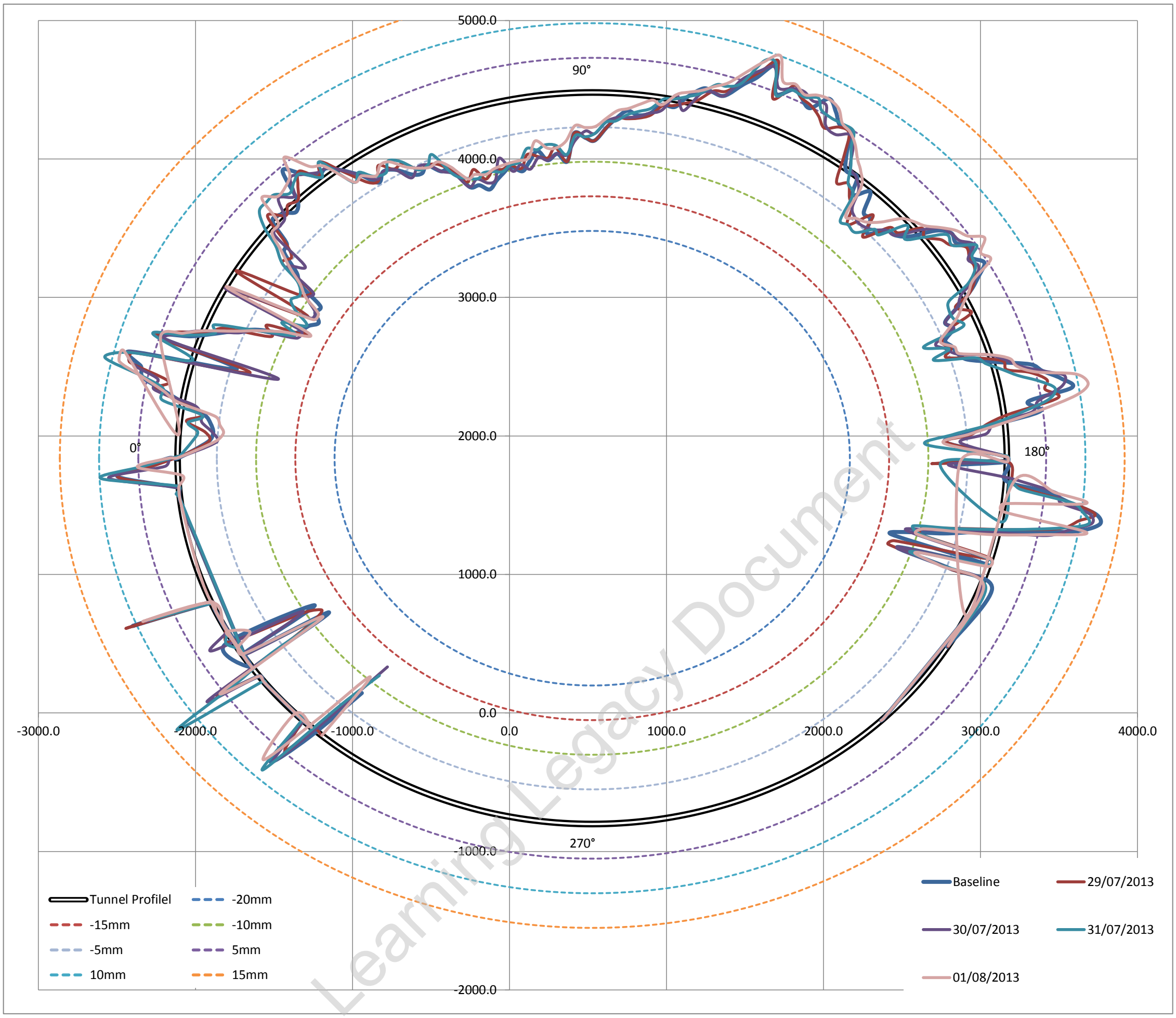
DLR LINE: DN **SECTION: 970**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **970**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.88	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00225%	

i.e. Average surveyed diameter varies on -0.002% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.0**	**-12.7**
Max / Min deviation % to estimated dia	**0.45%**	**-0.48%**

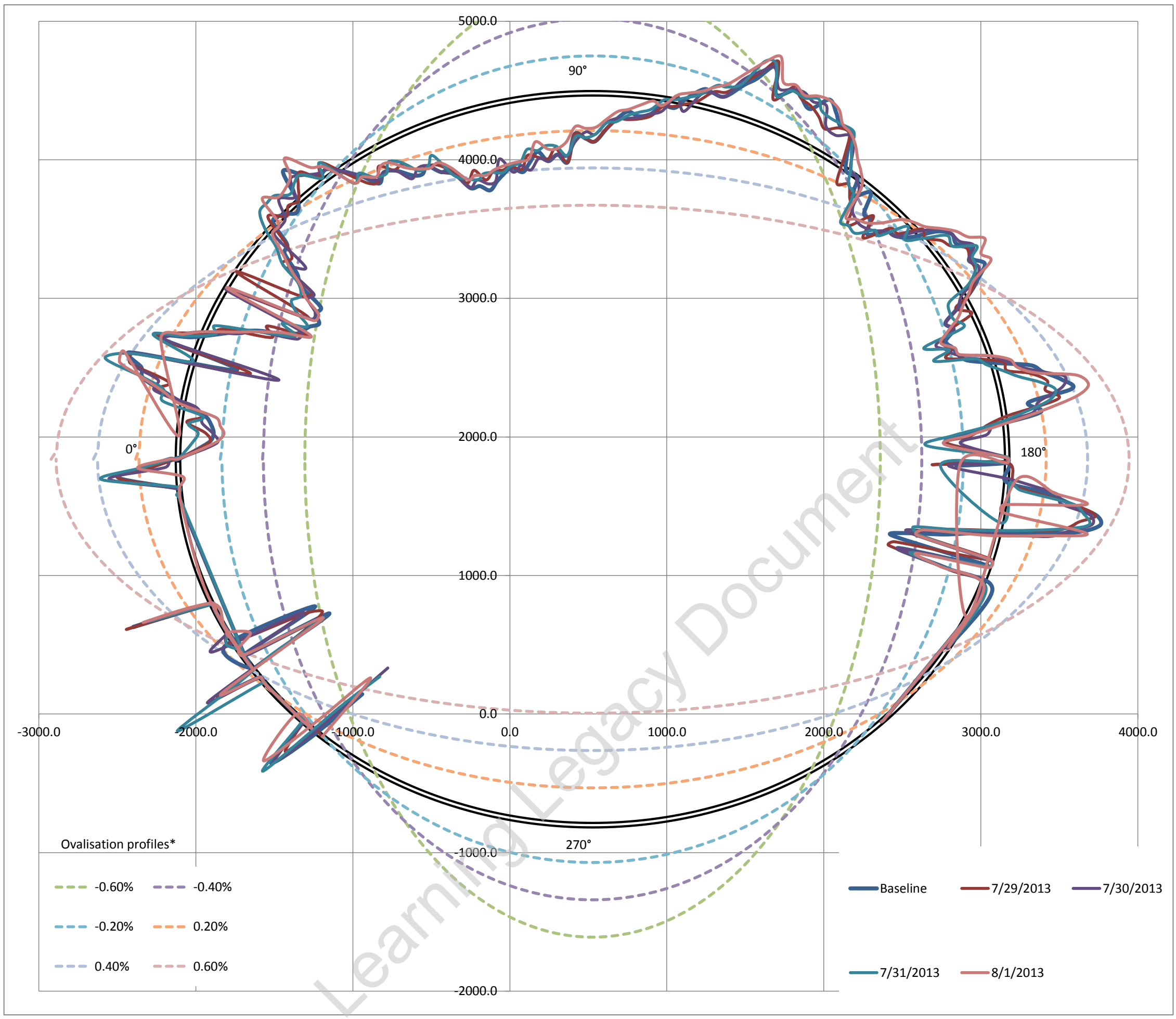
Fitted Circle Coordinates

Axis	X	527
	Y	1839
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **970**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

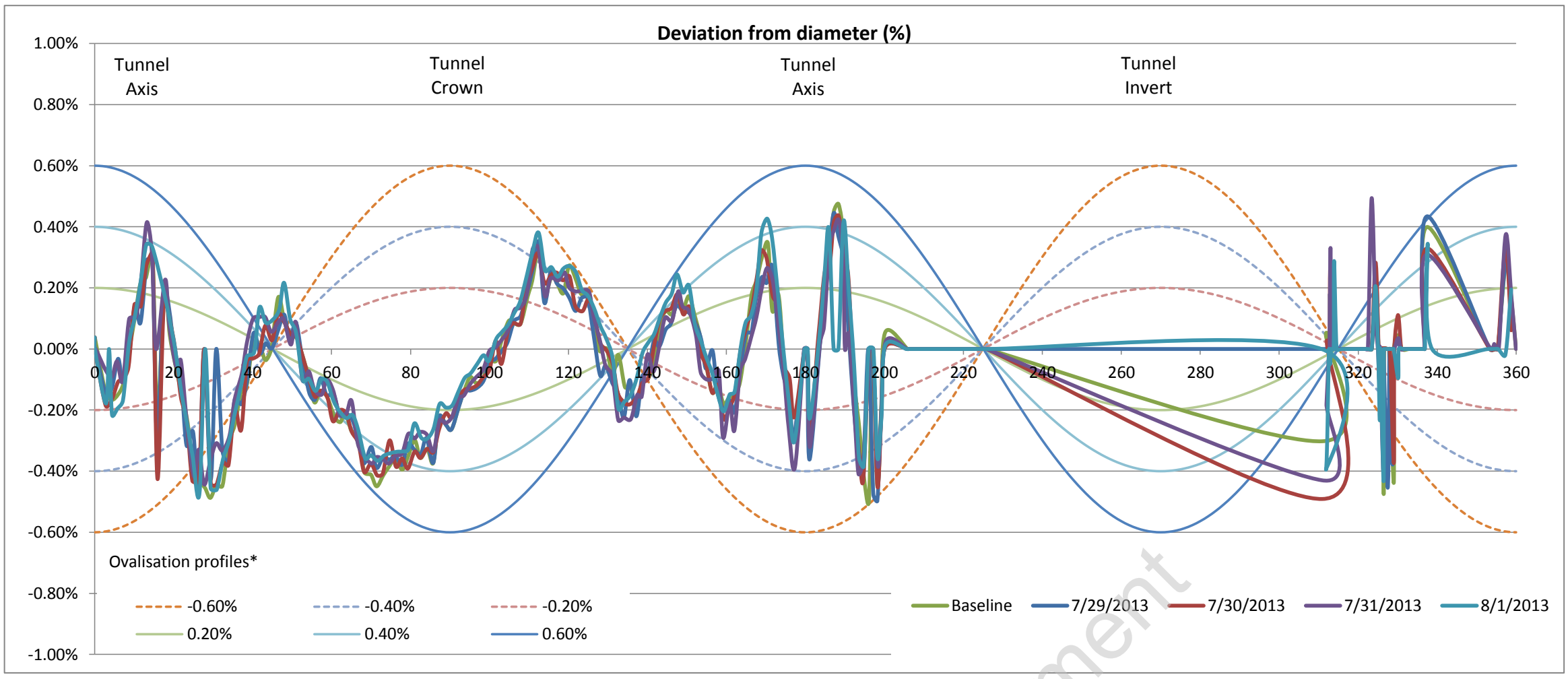
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5275.46	mm
Dh / Dv	#VALUE!	

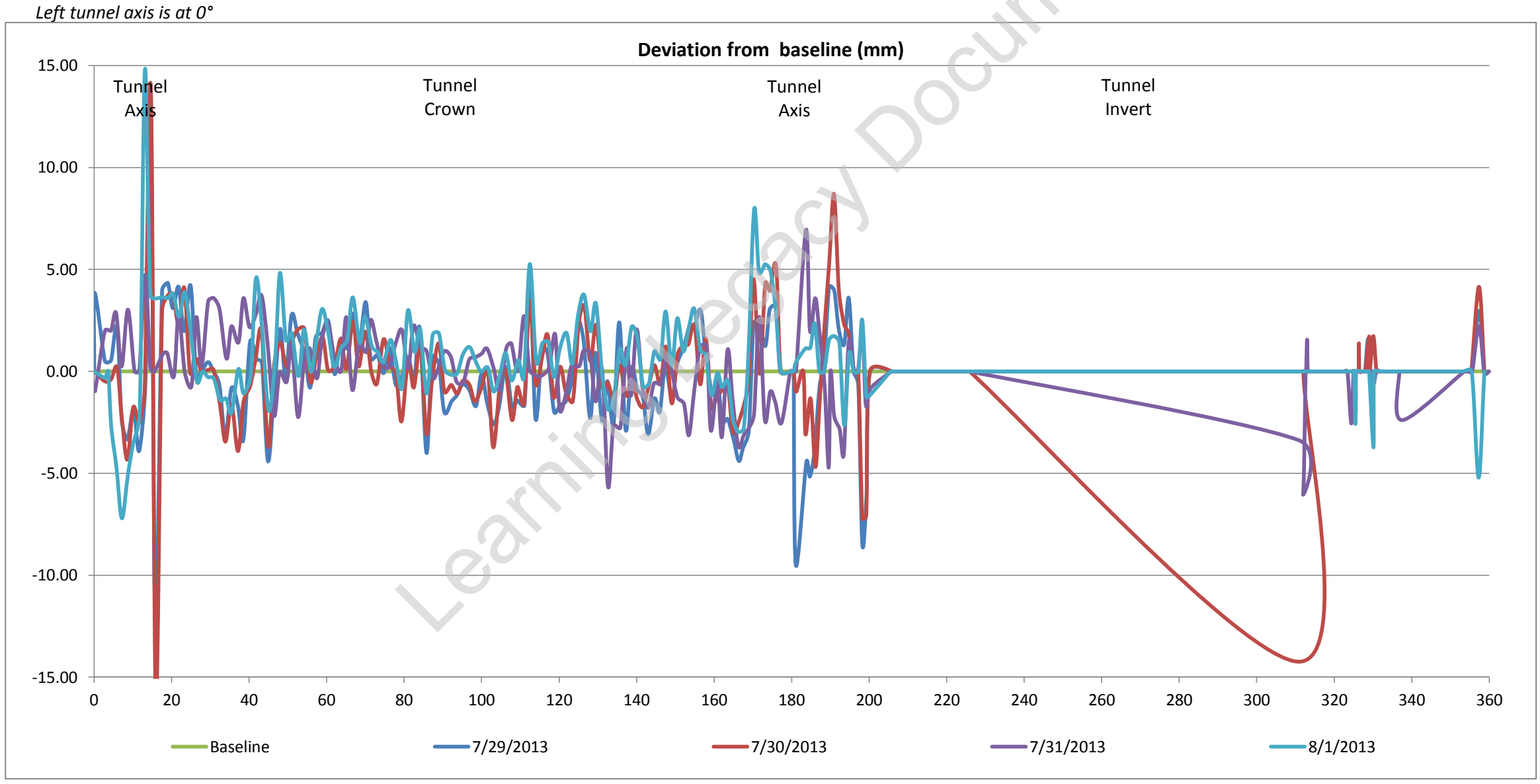
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 970**

Deviation vs Profile

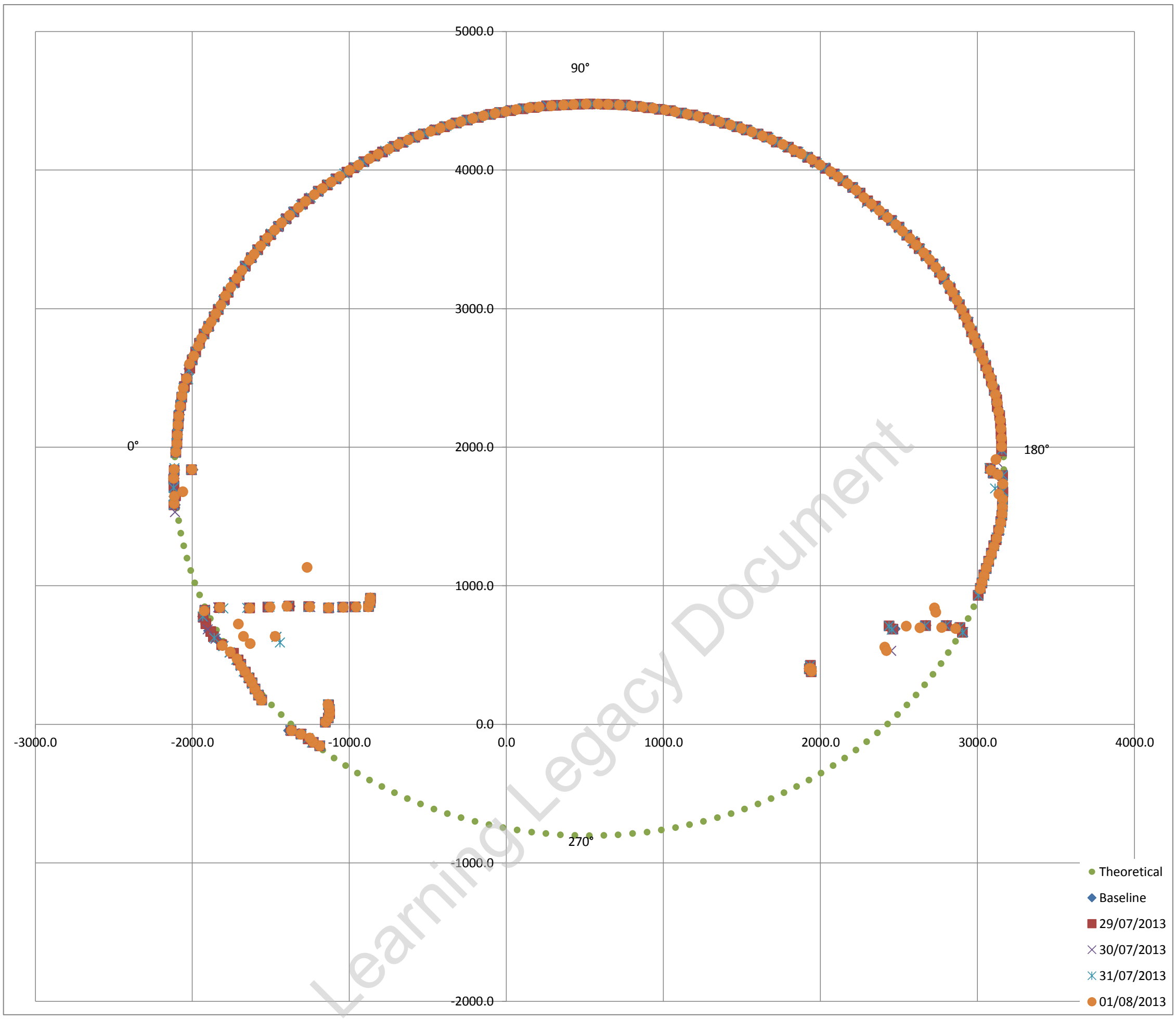


Left tunnel axis is at 0°



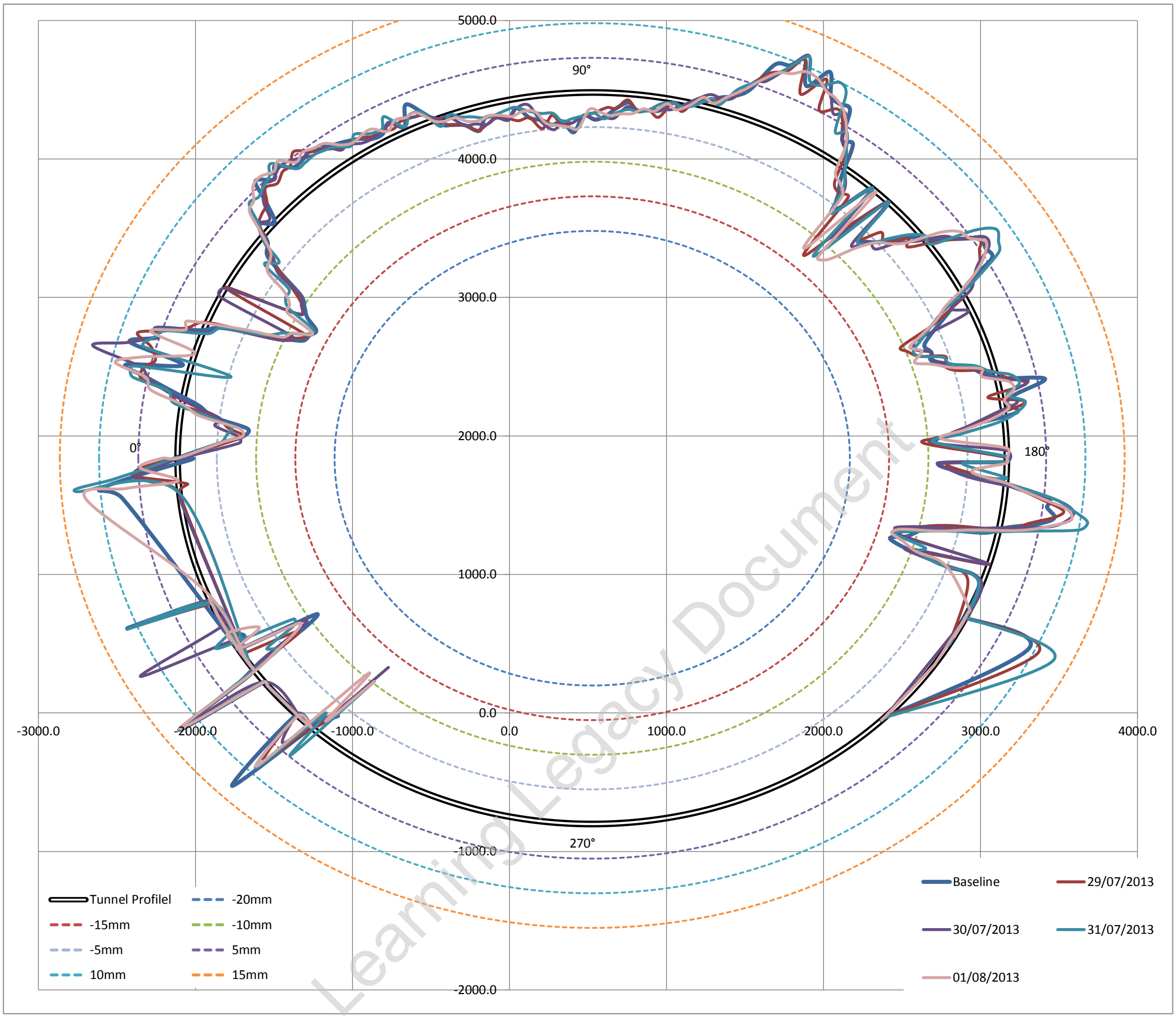
DLR LINE: DN **SECTION: 971**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **971**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.48	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00986%	

i.e. Average surveyed diameter varies on -0.009% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.7**	**-13.0**
Max / Min deviation % to estimated dia	**0.48%**	**-0.49%**

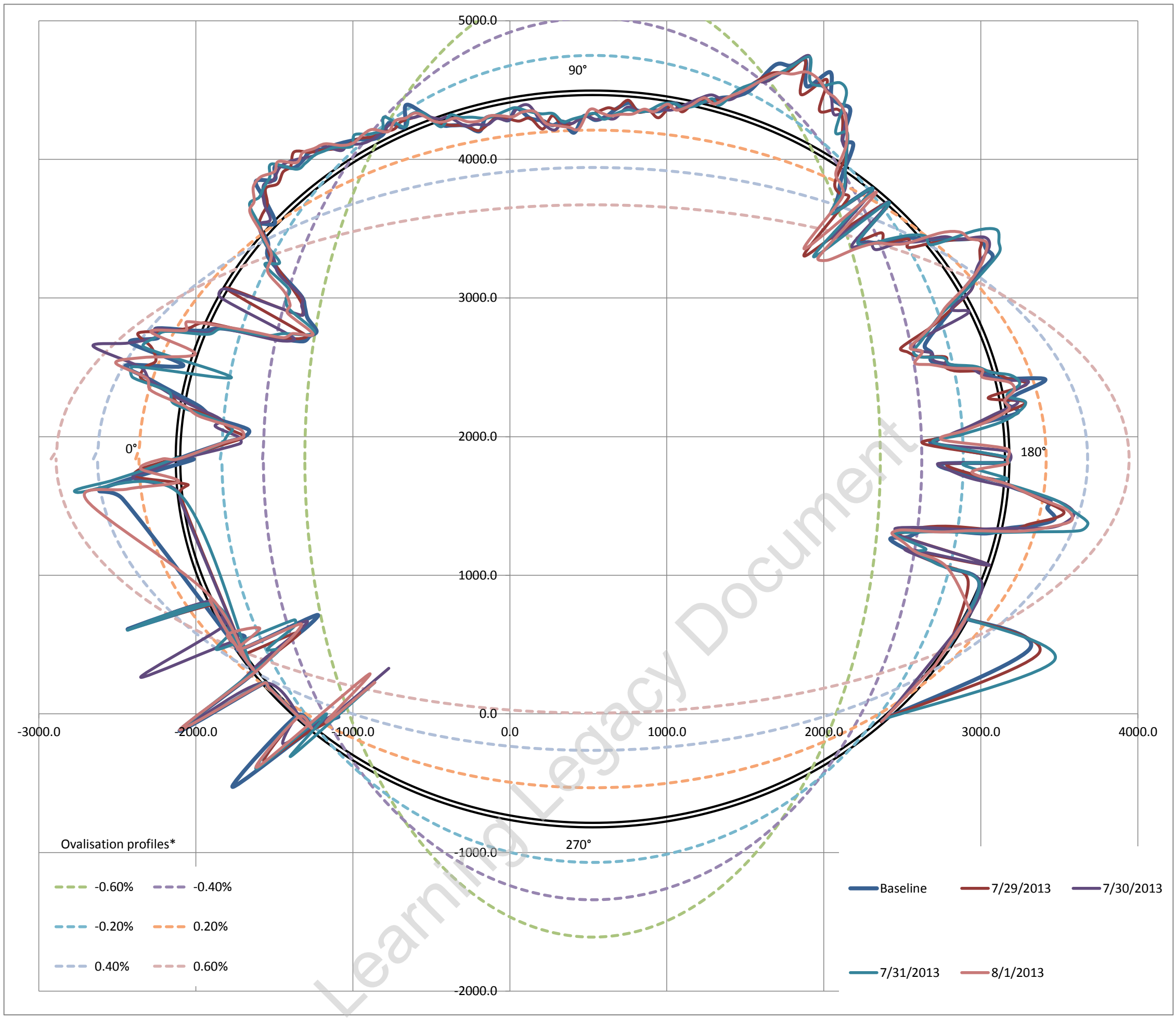
Fitted Circle Coordinates

Axis	X	527
	Y	1839
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **971**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

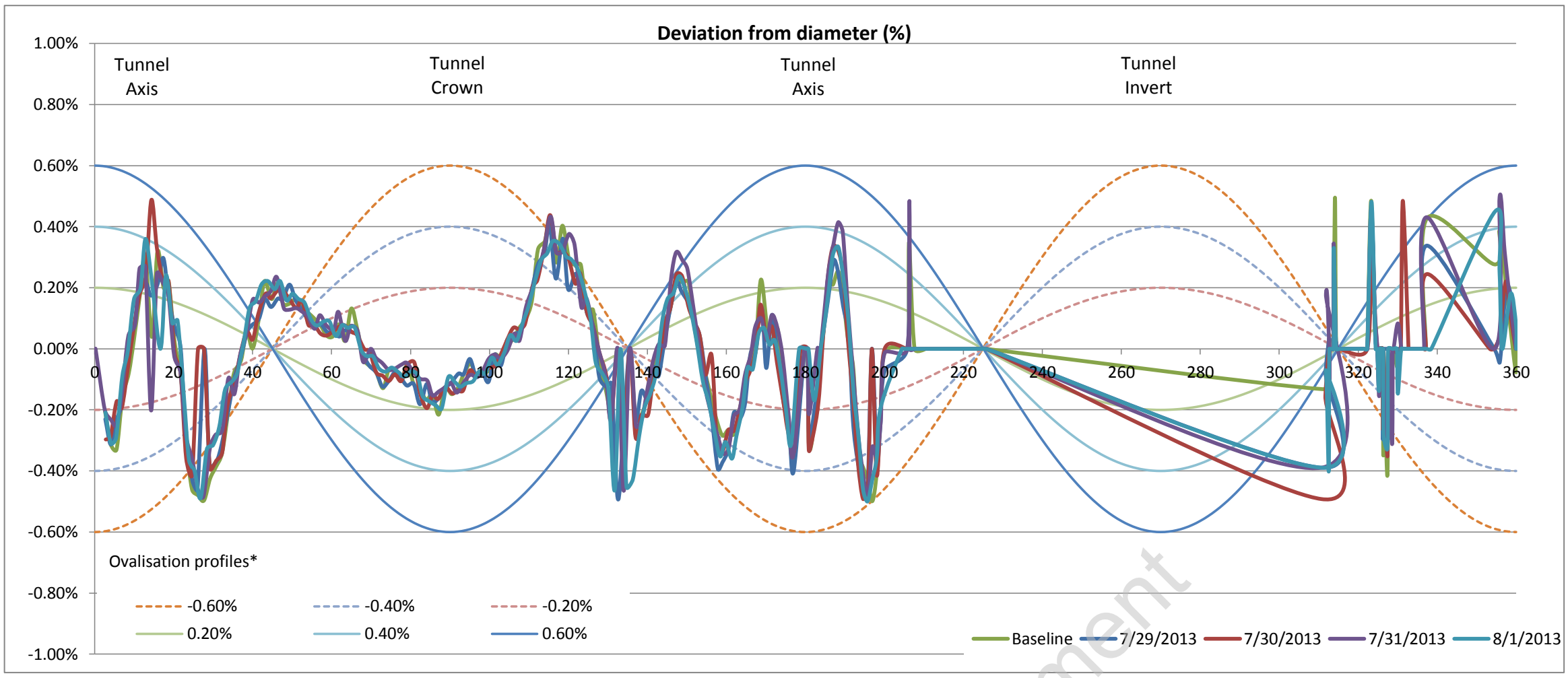
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5268.06 mm
Estimate of vertical diameter at crown, Dv	5278.64 mm
Dh / Dv	0.9980

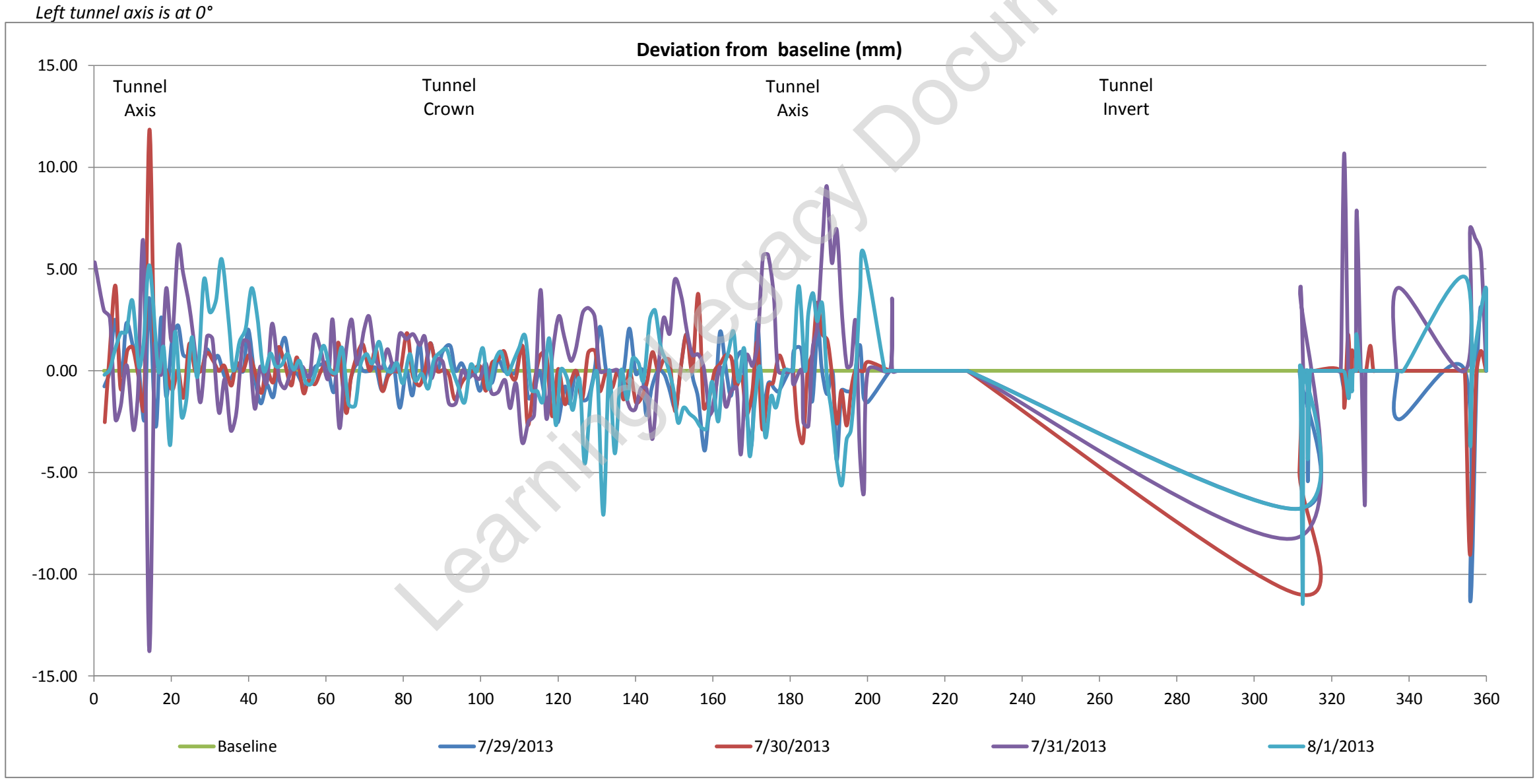
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 971**

Deviation vs Profile

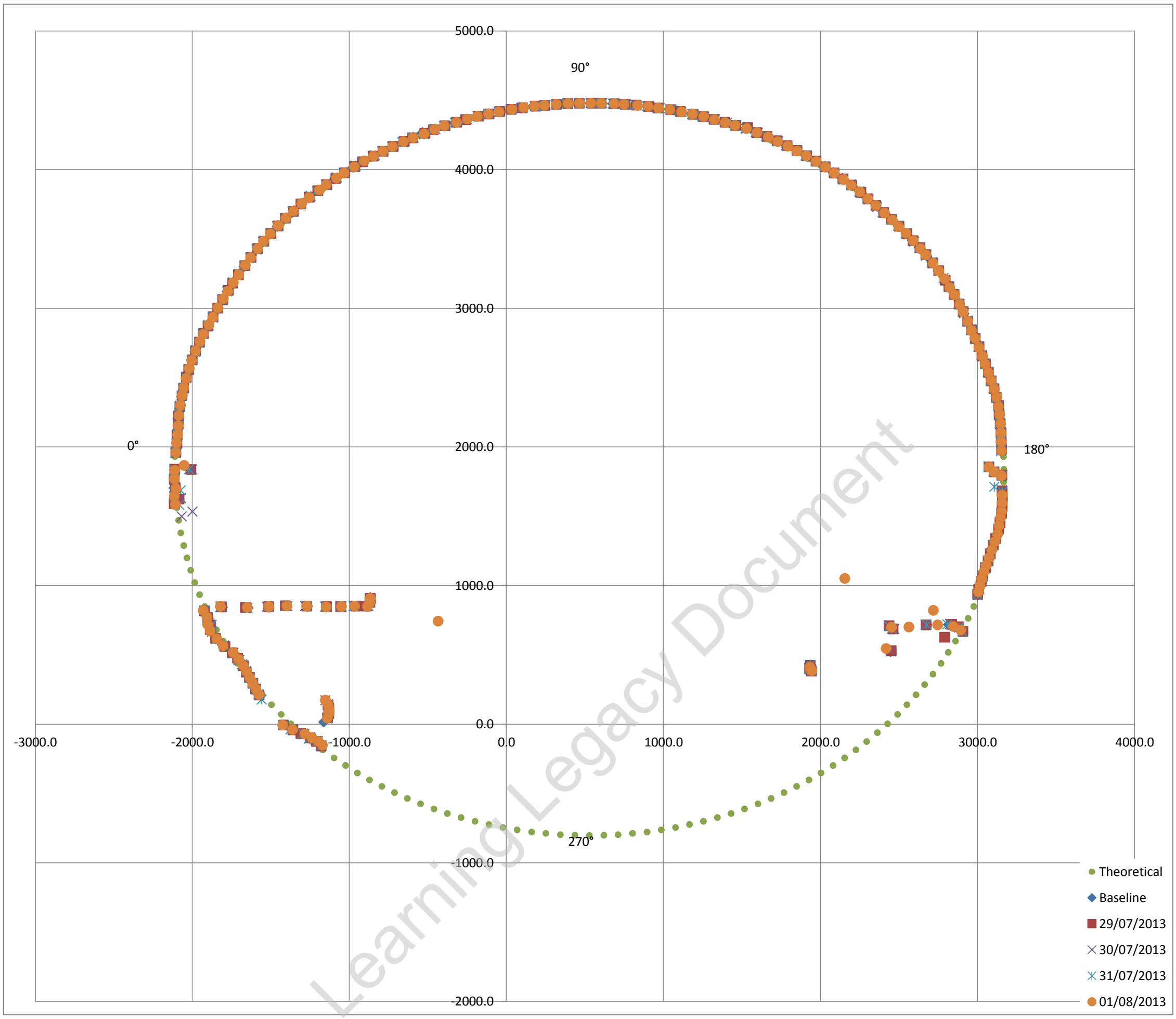


Left tunnel axis is at 0°



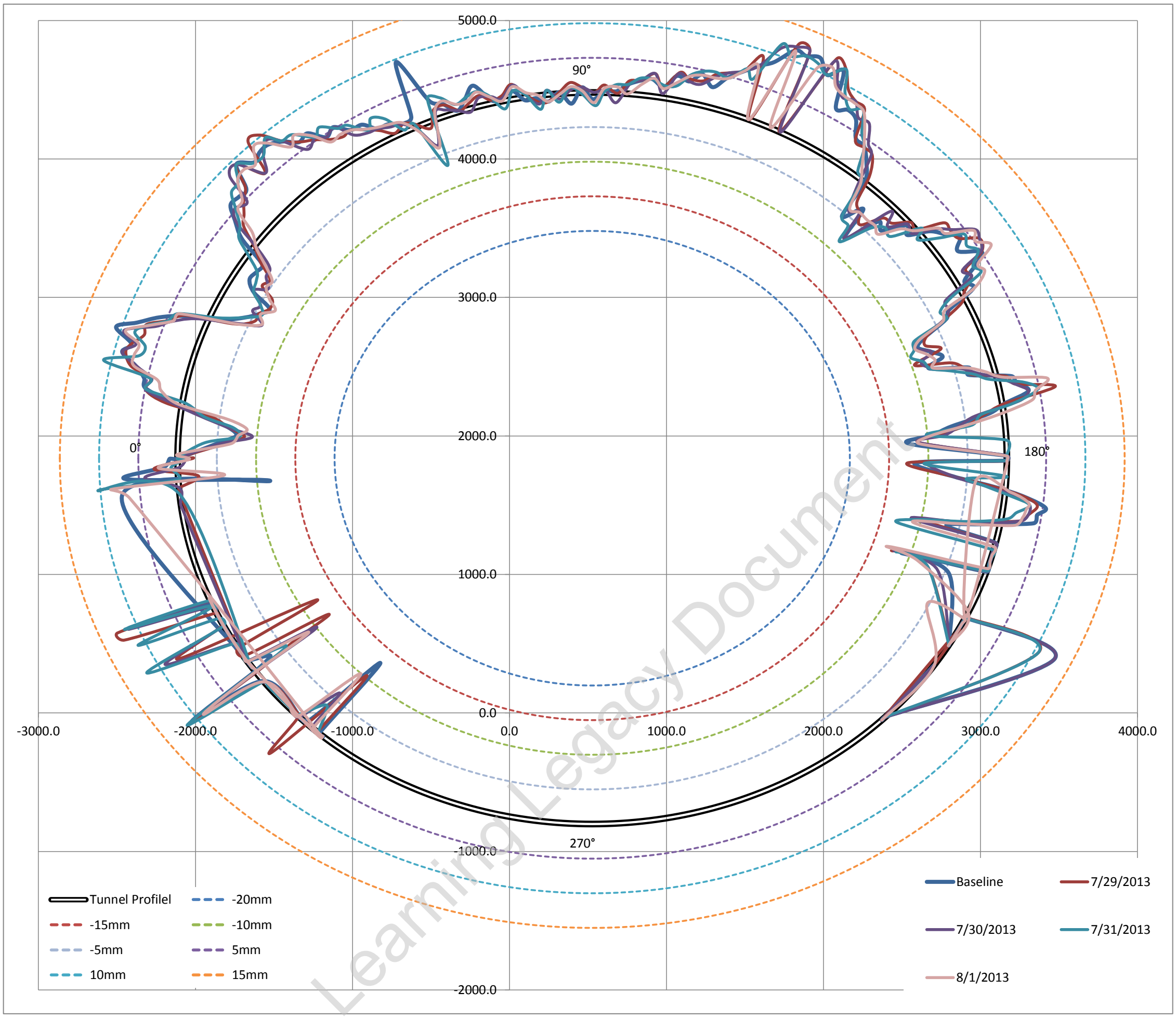
DLR LINE: DN **SECTION: 972**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **972**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.90	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.00184%	

i.e. Average surveyed diameter varies on -0.001% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-12.6**
Max / Min deviation % to estimated dia	**0.47%**	**-0.48%**

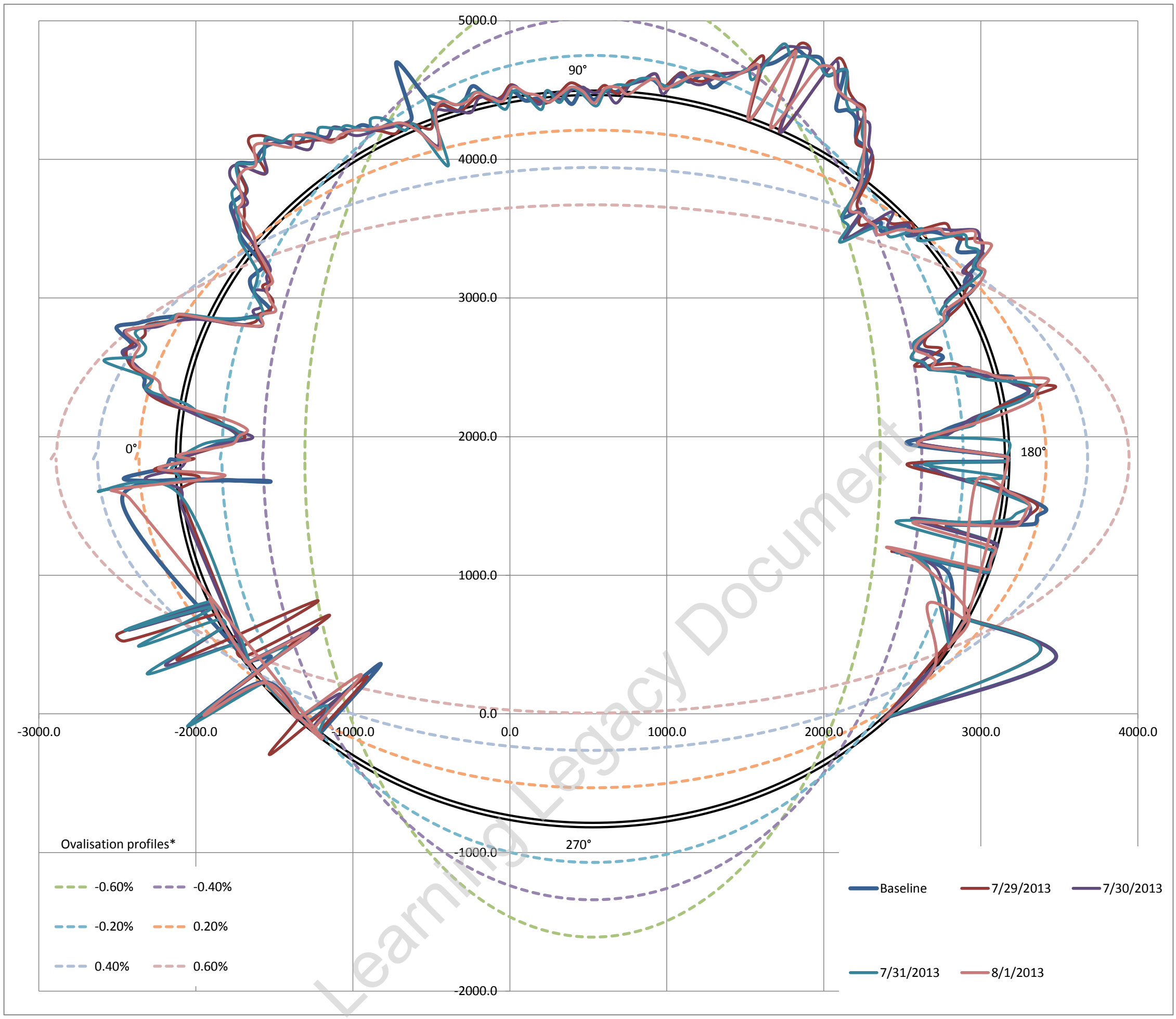
Fitted Circle Coordinates

Axis	X	527
	Y	1839
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **972**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

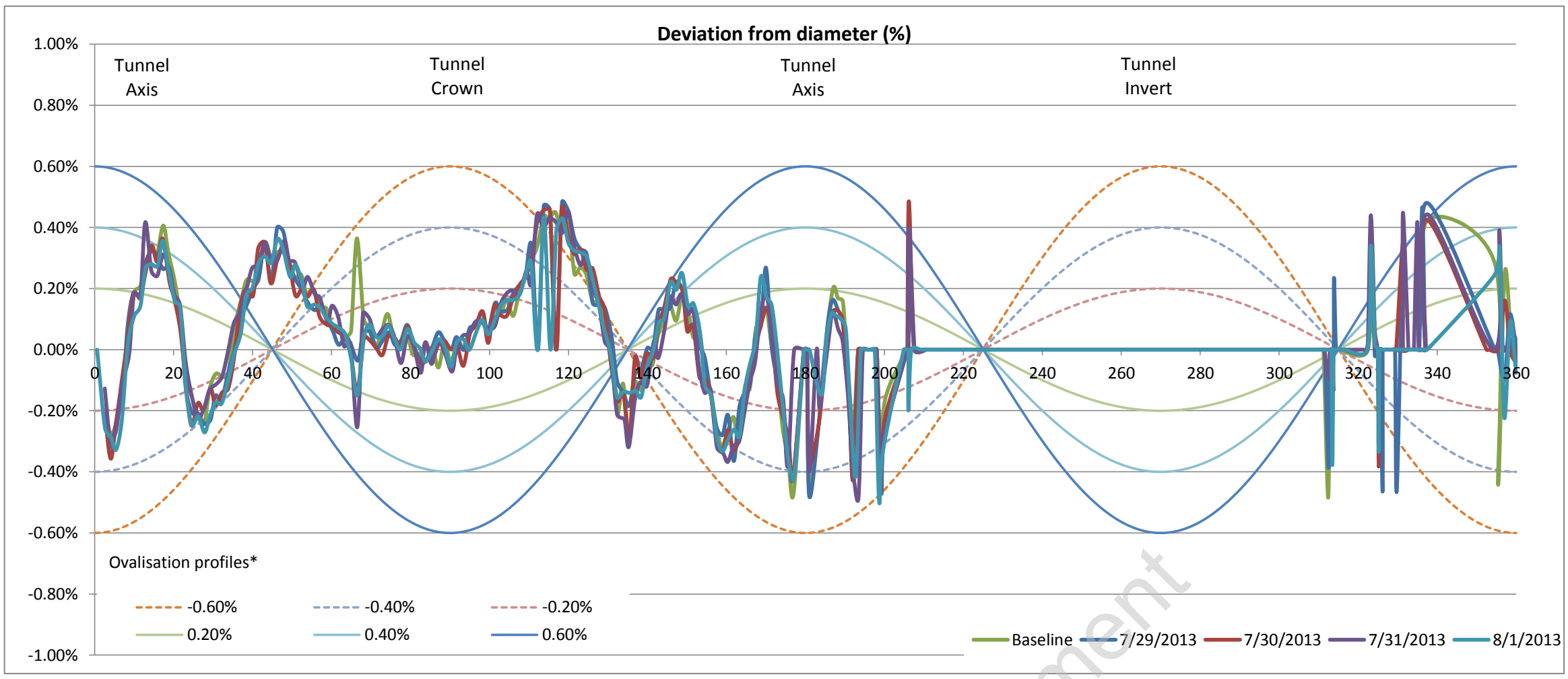
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5265.18	mm
Estimate of vertical diameter at crown, Dv	5282.30	mm
Dh / Dv	0.9968	

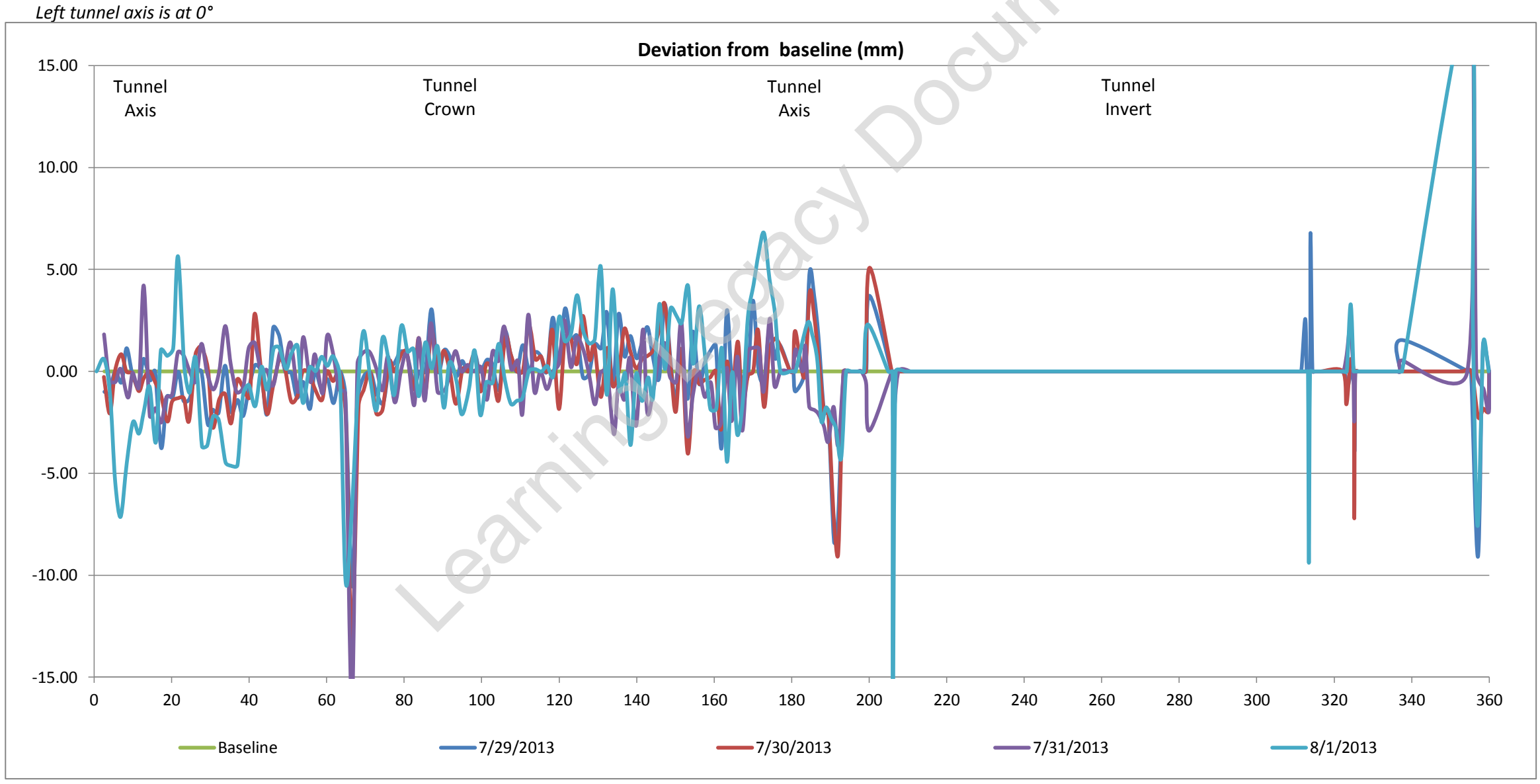
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 972**

Deviation vs Profile

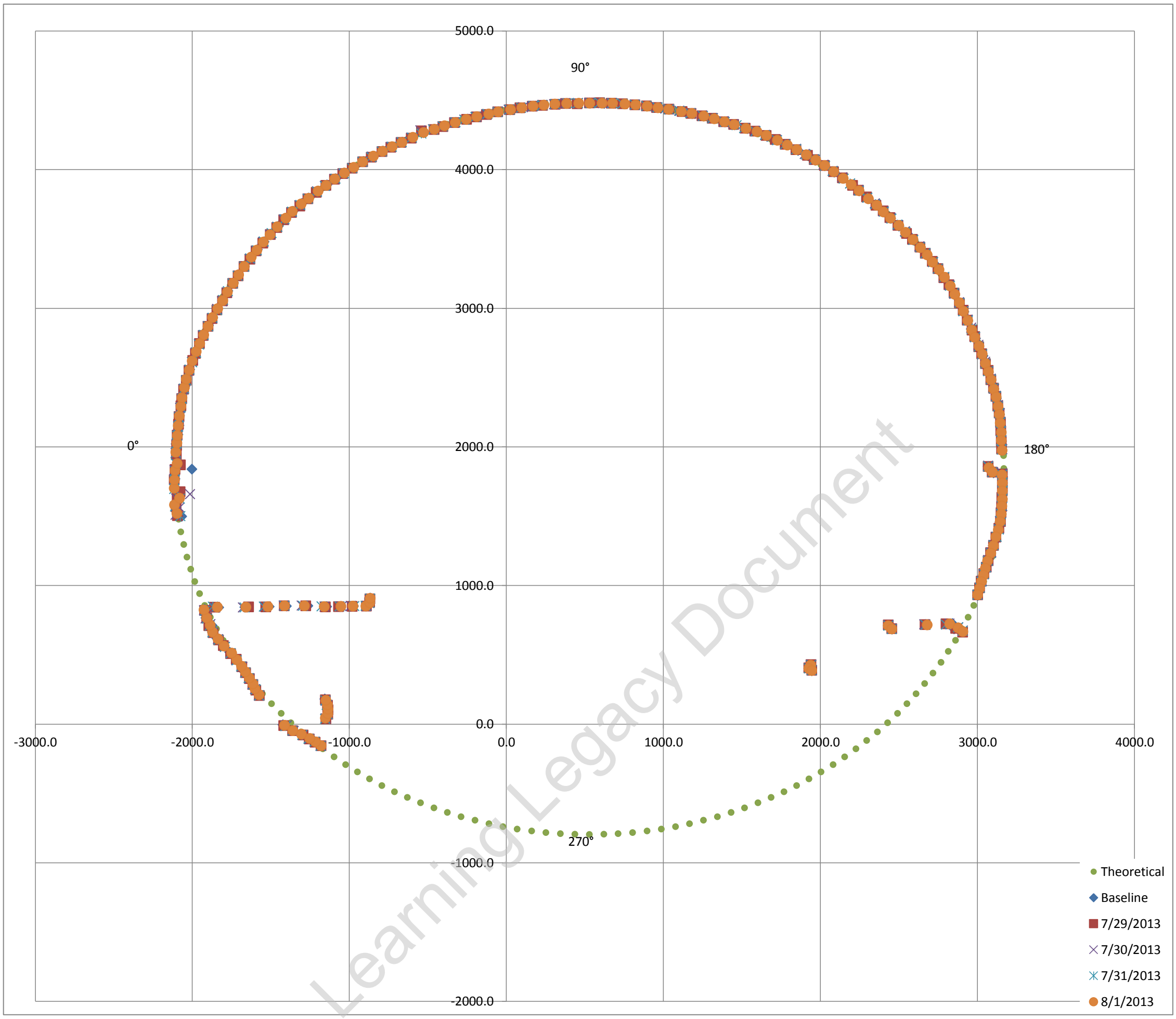


Left tunnel axis is at 0°



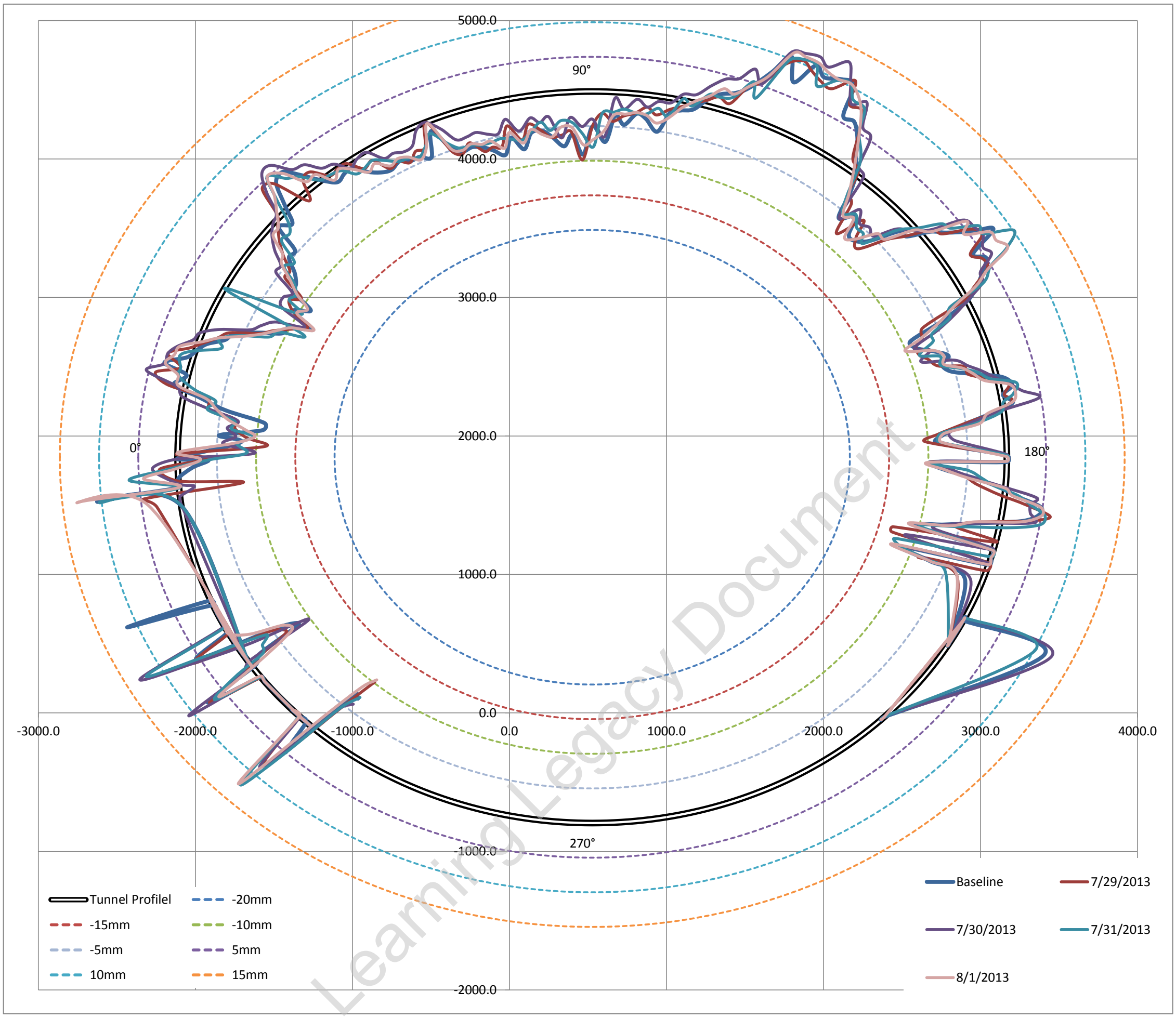
DLR LINE: DN **SECTION: 973**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **973**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5279.87	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.04032%	

i.e. Average surveyed diameter varies on -0.04% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.2**	**-12.5**
Max / Min deviation % to estimated dia	**0.46%**	**-0.48%**

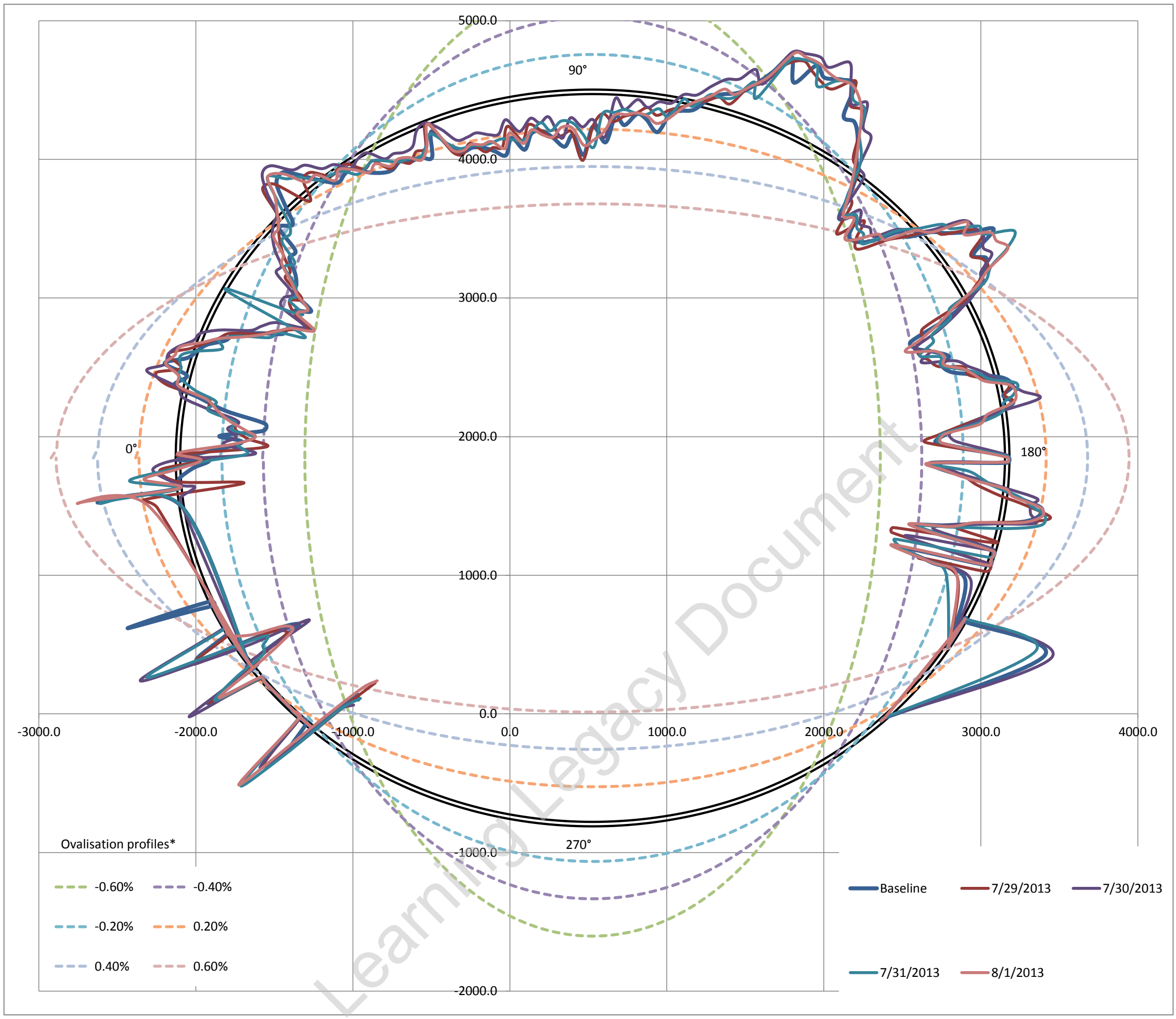
Fitted Circle Coordinates

Axis	X	527
	Y	1846
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **DN** **SECTION:** **973**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

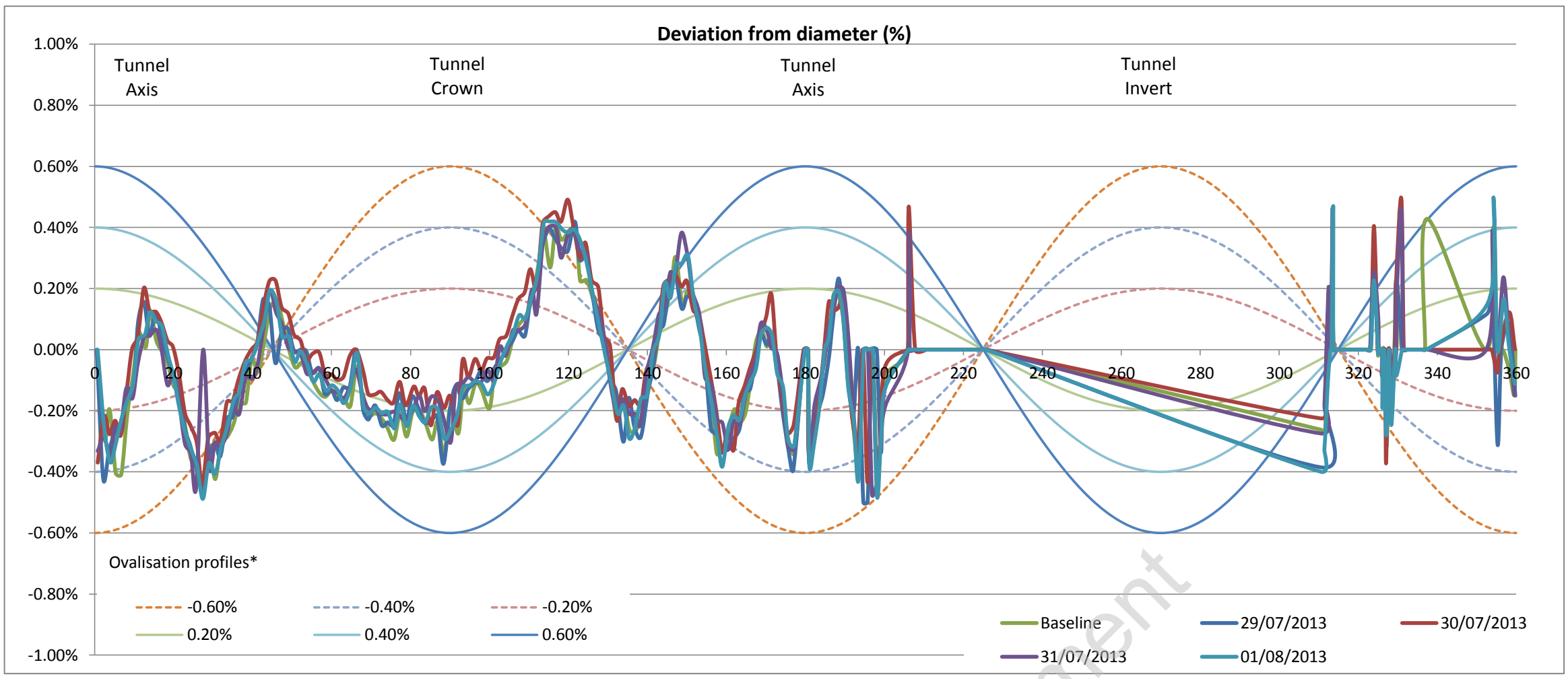
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5266.19 mm
Estimate of vertical diameter at crown, Dv	5274.75 mm
Dh / Dv	0.9984

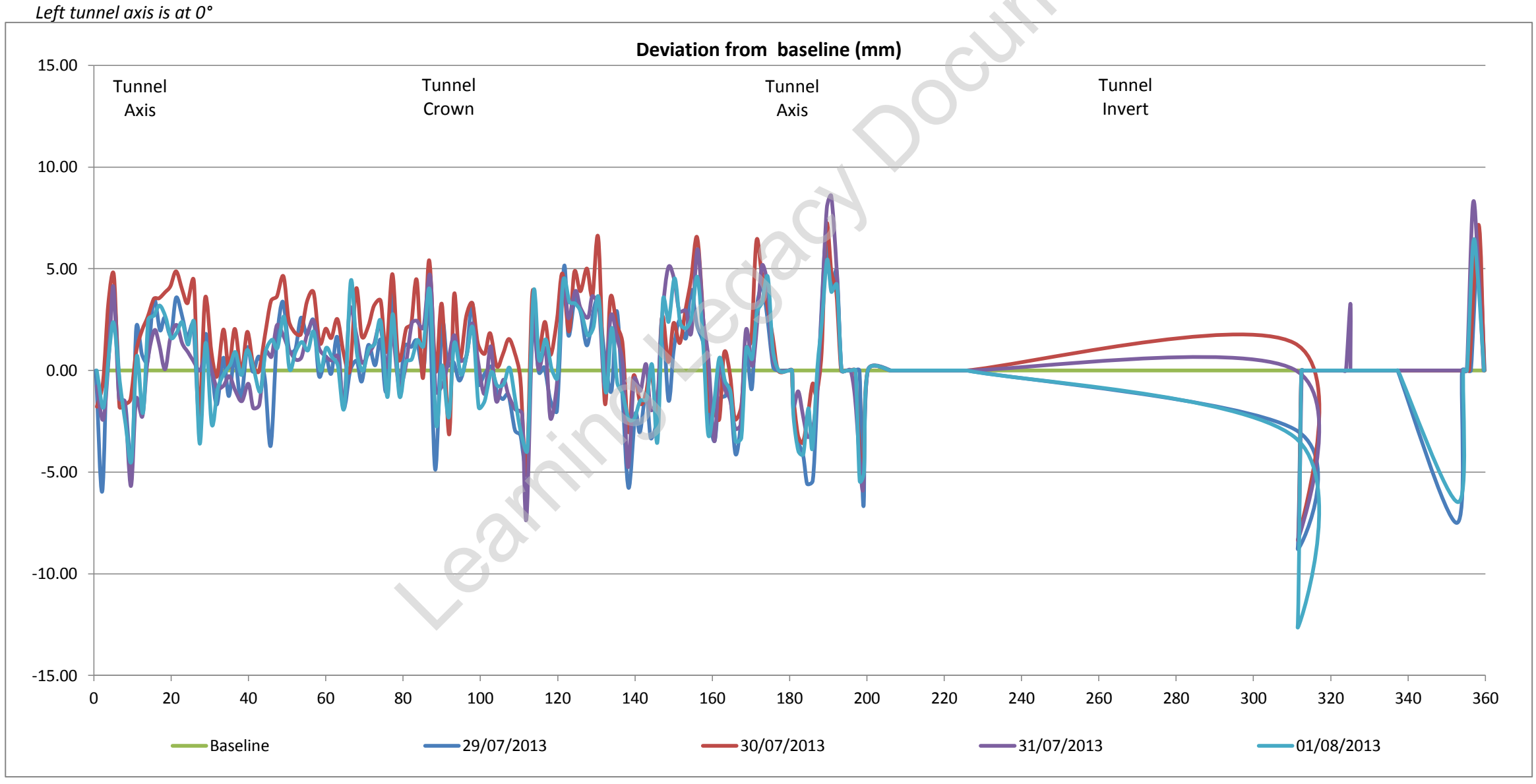
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 973**

Deviation vs Profile

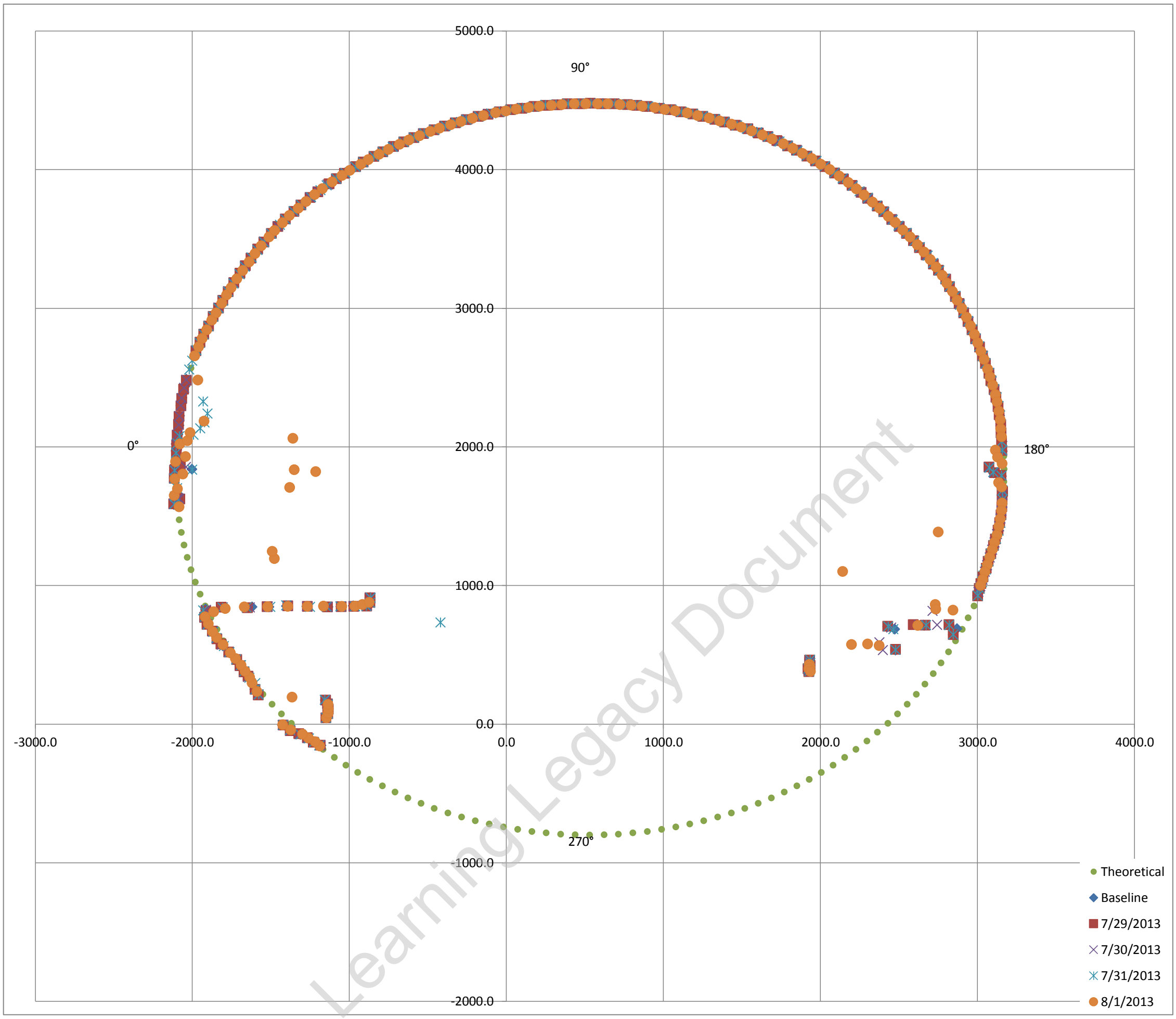


Left tunnel axis is at 0°



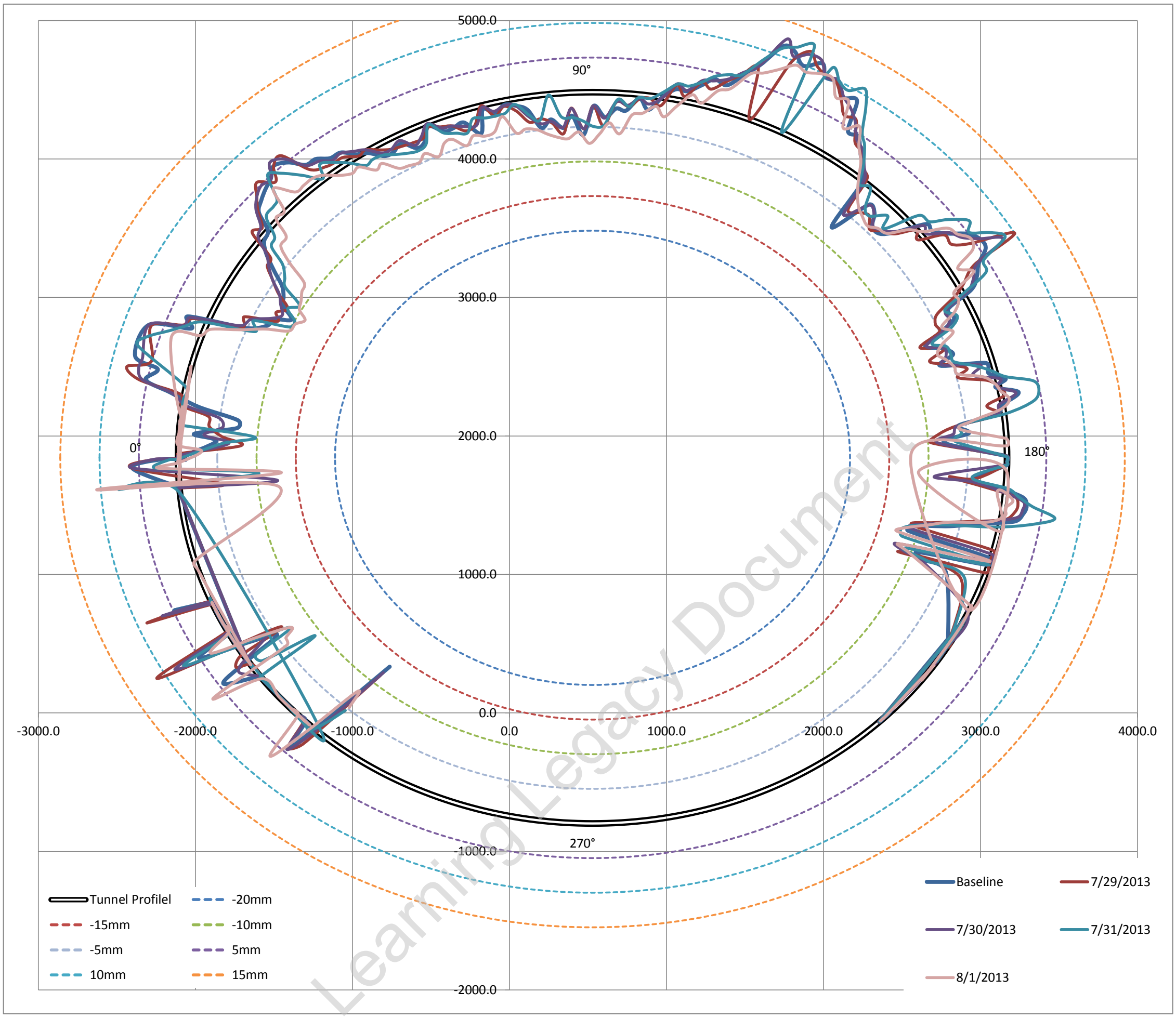
DLR LINE: DN **SECTION: 974**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **974**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5276.91	mm
Estimated best fit as built diameter	**5280.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.05849%	

i.e. Average surveyed diameter varies on -0.058% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.9**	**-12.5**
Max / Min deviation % to estimated dia	**0.45%**	**-0.47%**

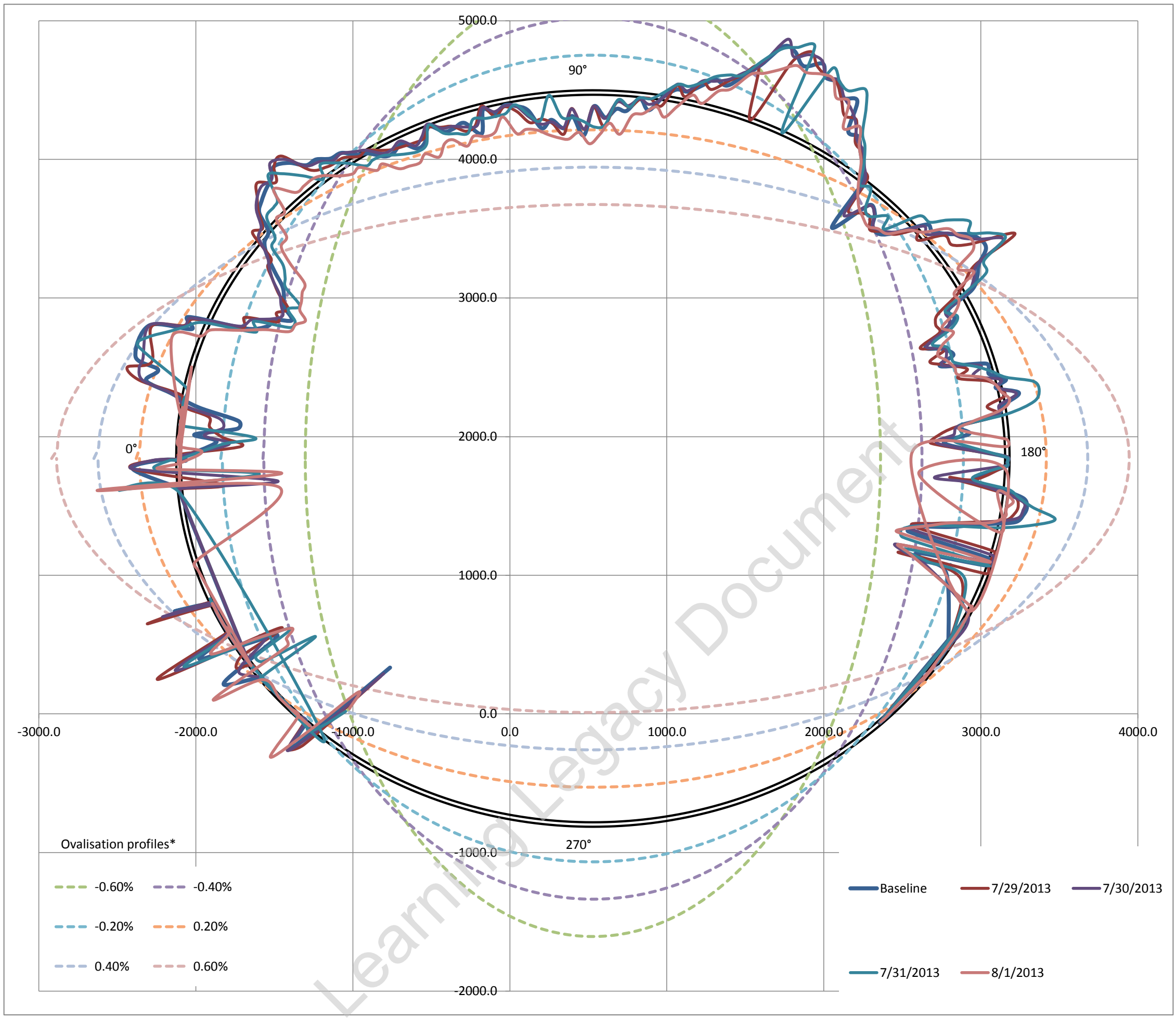
Fitted Circle Coordinates

Axis	X	529
	Y	1842
Radius		2640

Estimated best fit as built diameter	5280	mm
Designed diameter	5300	mm
Average diameter difference	**-20**	mm
Average radial difference	**-10**	mm
Average difference%	**-0.38%**	

DLR LINE: **DN** **SECTION:** **974**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

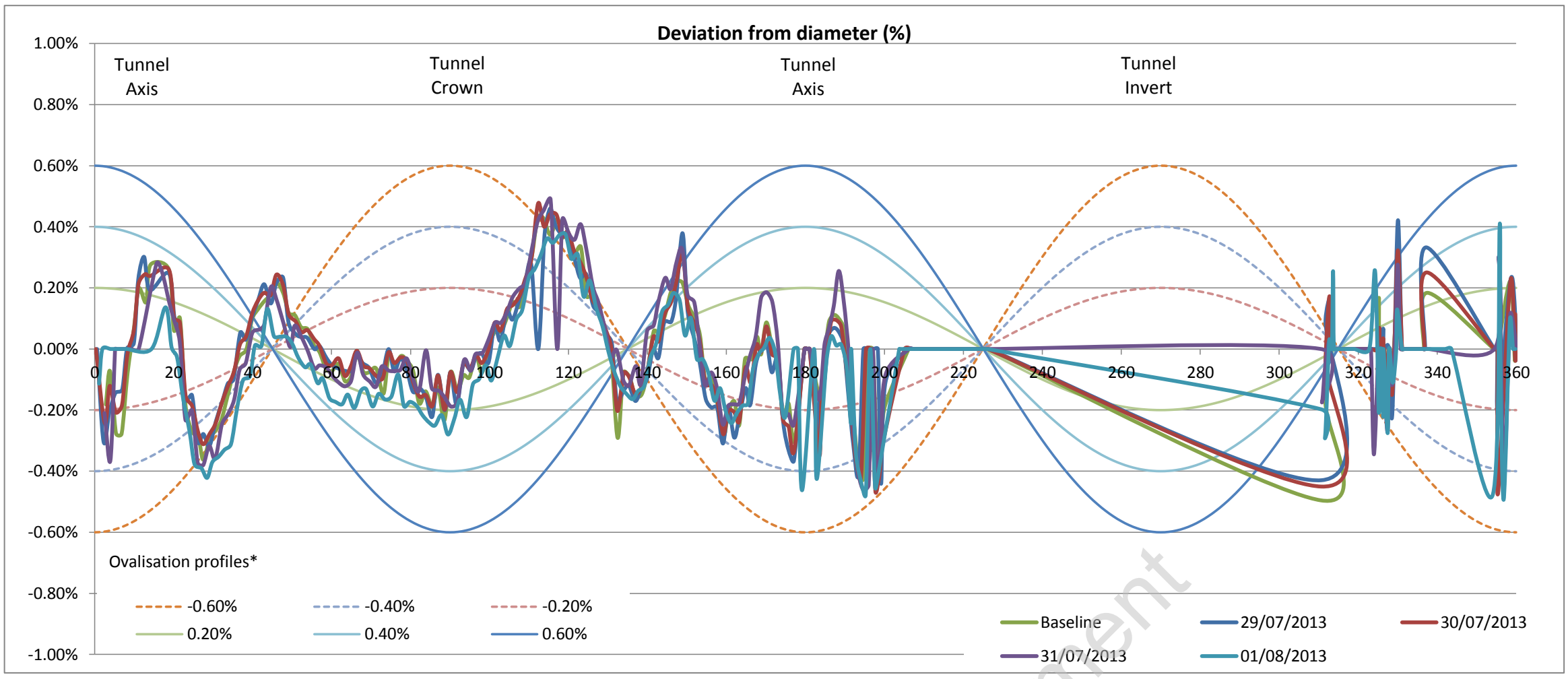
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5276.40	mm
Dh / Dv	#VALUE!	

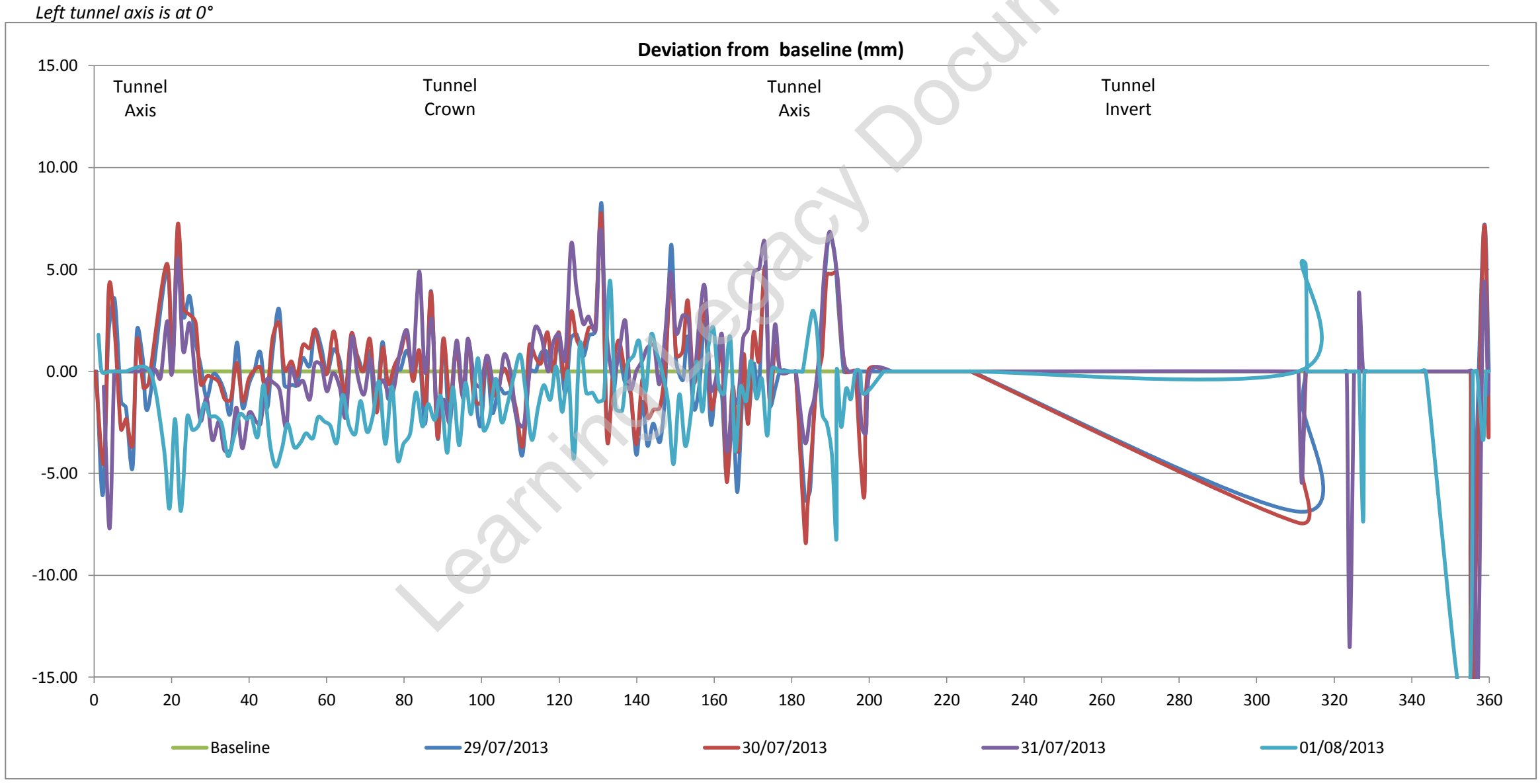
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 974**

Deviation vs Profile

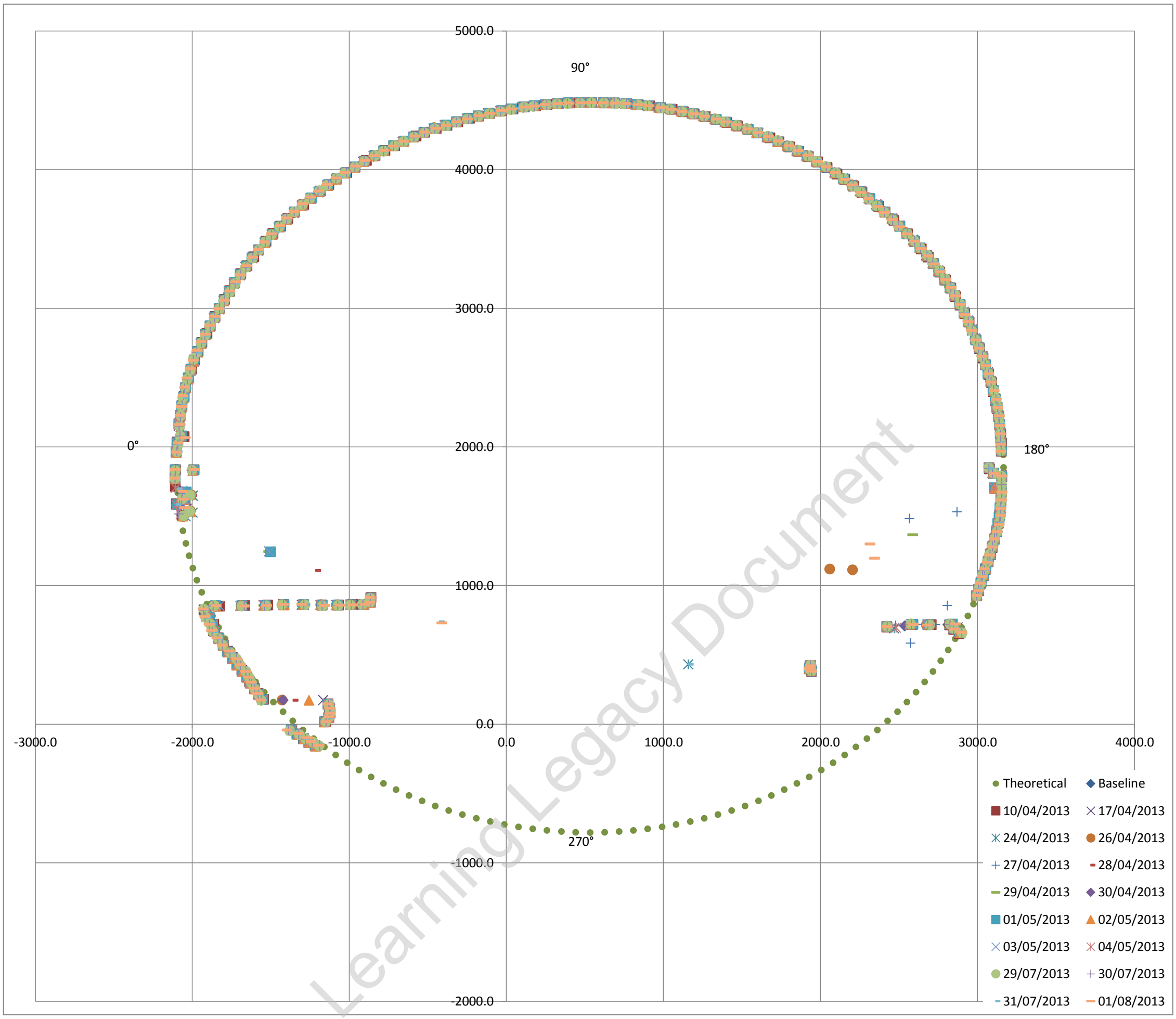


Left tunnel axis is at 0°



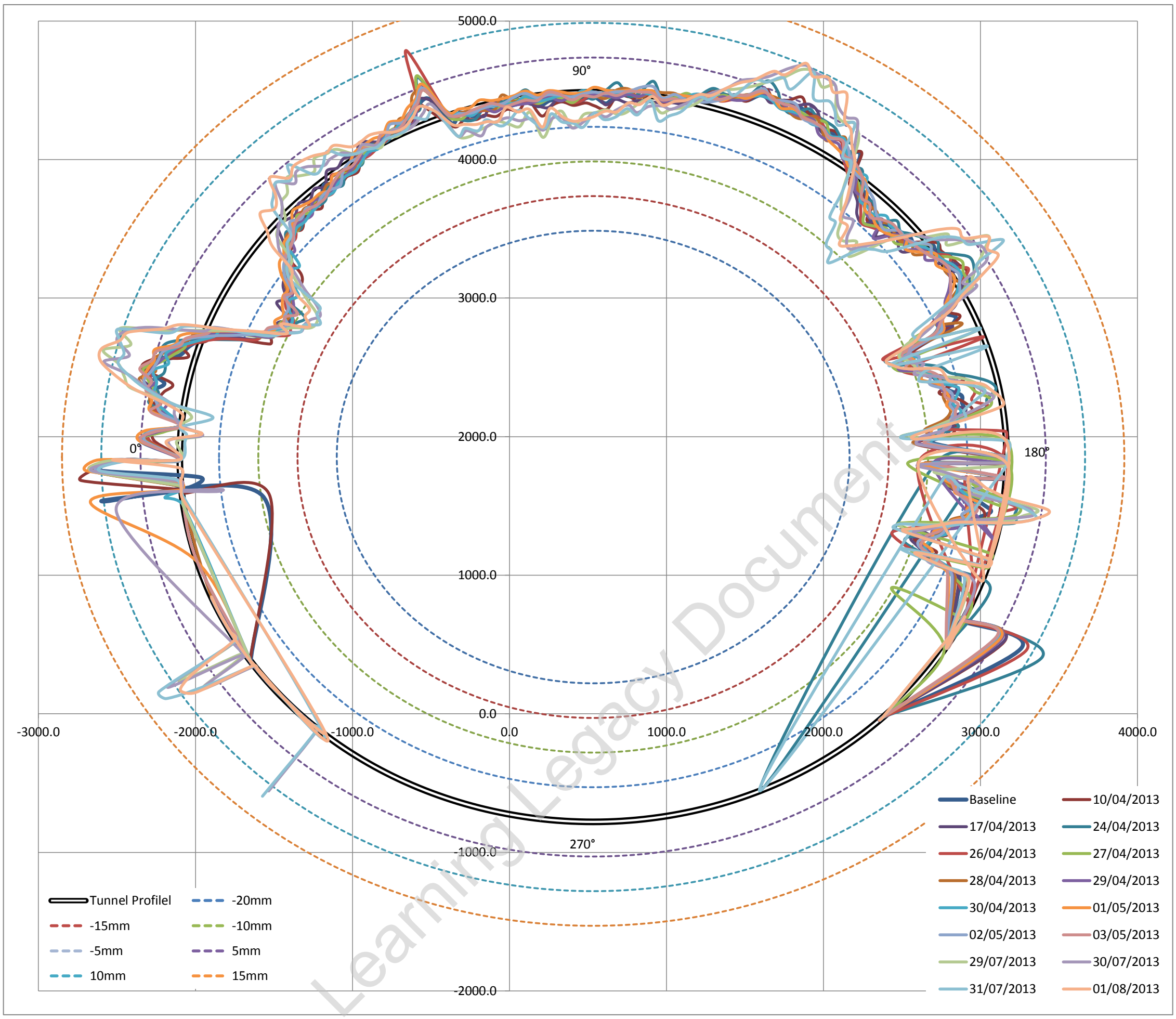
DLR LINE: DN **SECTION: 977**

Tunnel profile from laser scans (raw data)



DLR LINE: **DN** **SECTION:** **977**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5264.30	mm
Estimated best fit as built diameter	**5266.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.03225%	

i.e. Average surveyed diameter varies on -0.032% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.2**	**-11.6**
Max / Min deviation % to estimated dia	**0.43%**	**-0.44%**

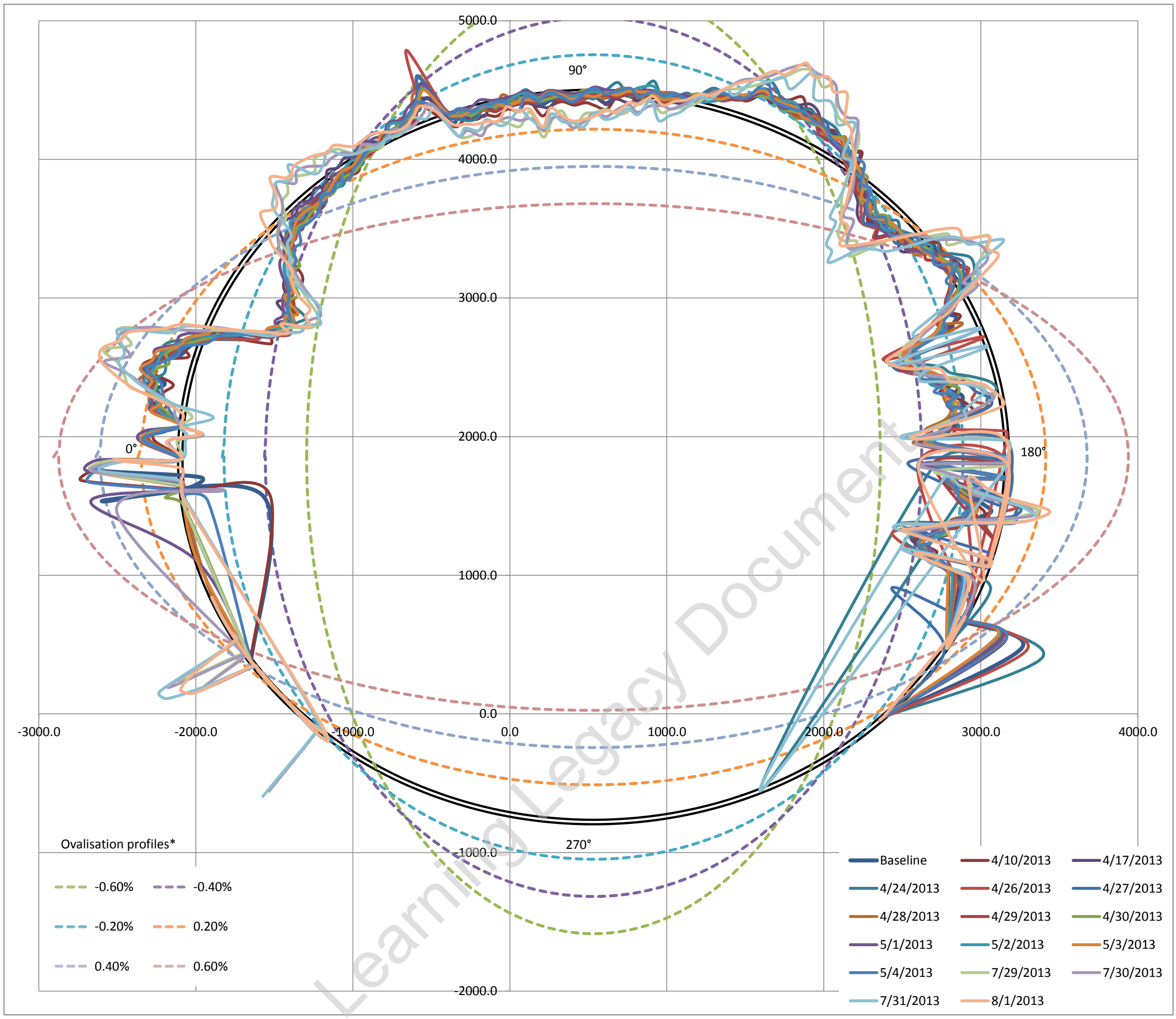
Fitted Circle Coordinates

Axis	X	533
	Y	1853
Radius		2633

Estimated best fit as built diameter	5266	mm
Designed diameter	5300	mm
Average diameter difference	**-34**	mm
Average radial difference	**-17**	mm
Average difference%	**-0.64%**	

DLR LINE: **DN** **SECTION:** **977**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

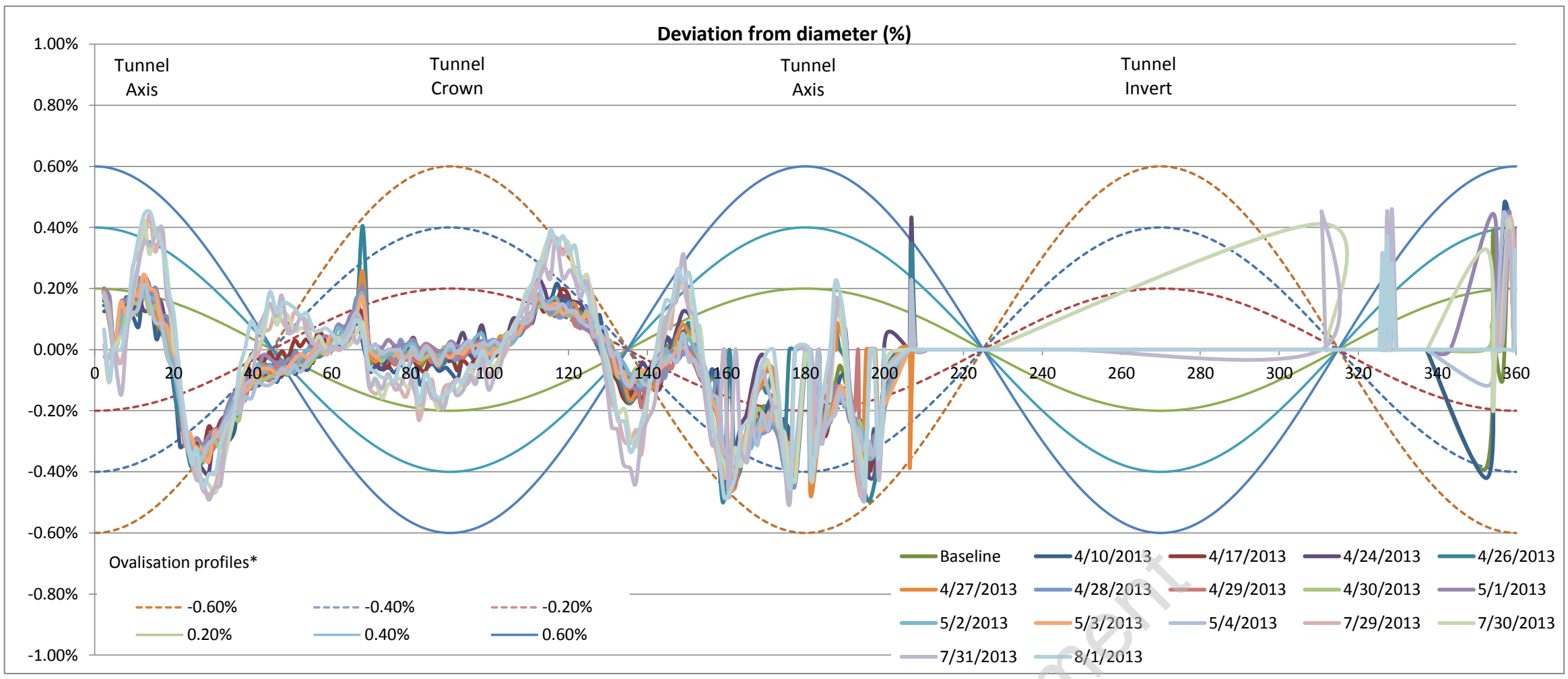
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5261.70 mm
Estimate of vertical diameter at crown, Dv	5264.40 mm
Dh / Dv	0.9995

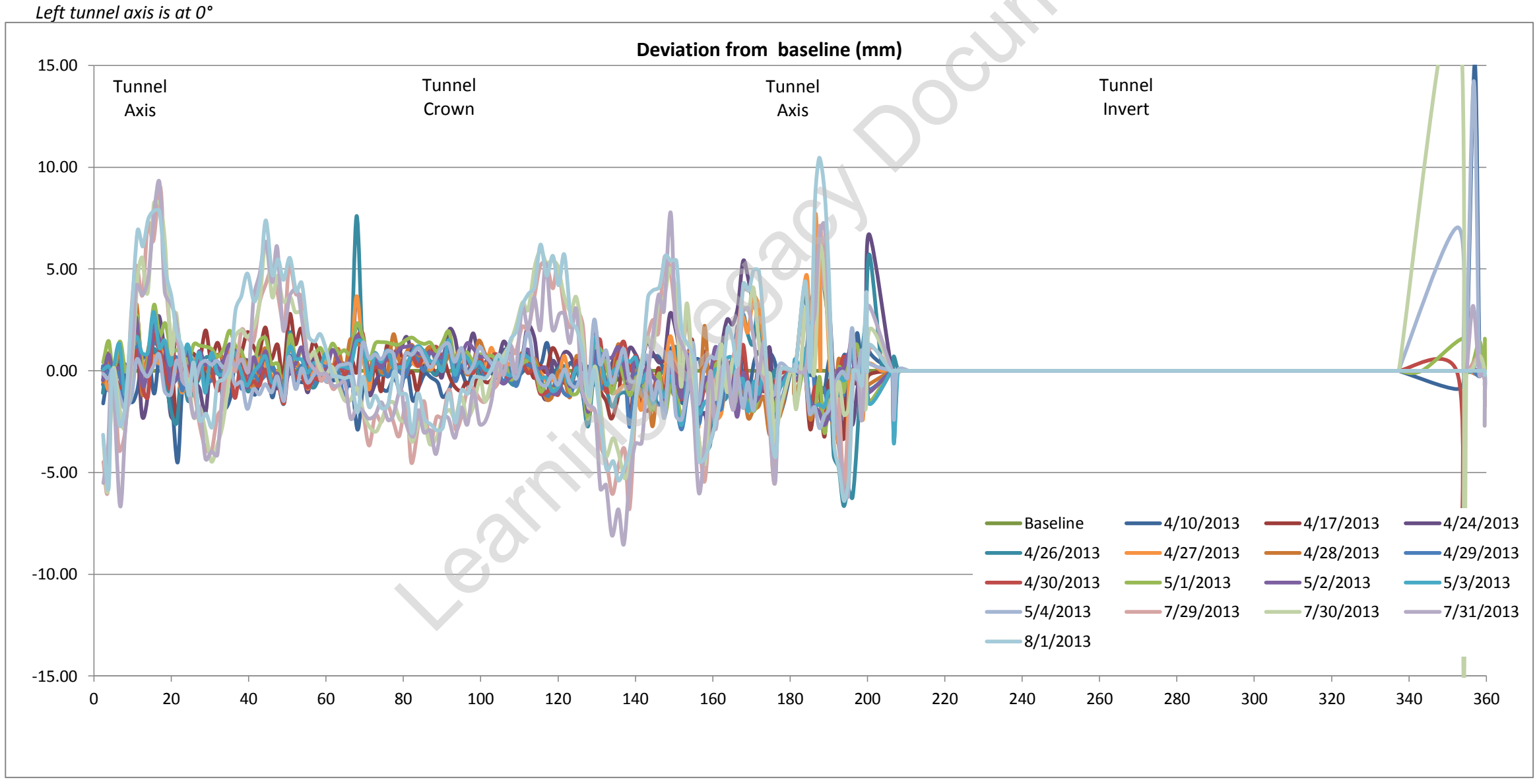
Best fit ovalsation profile: **Neutral**

DLR LINE: DN **SECTION: 977**

Deviation vs Profile

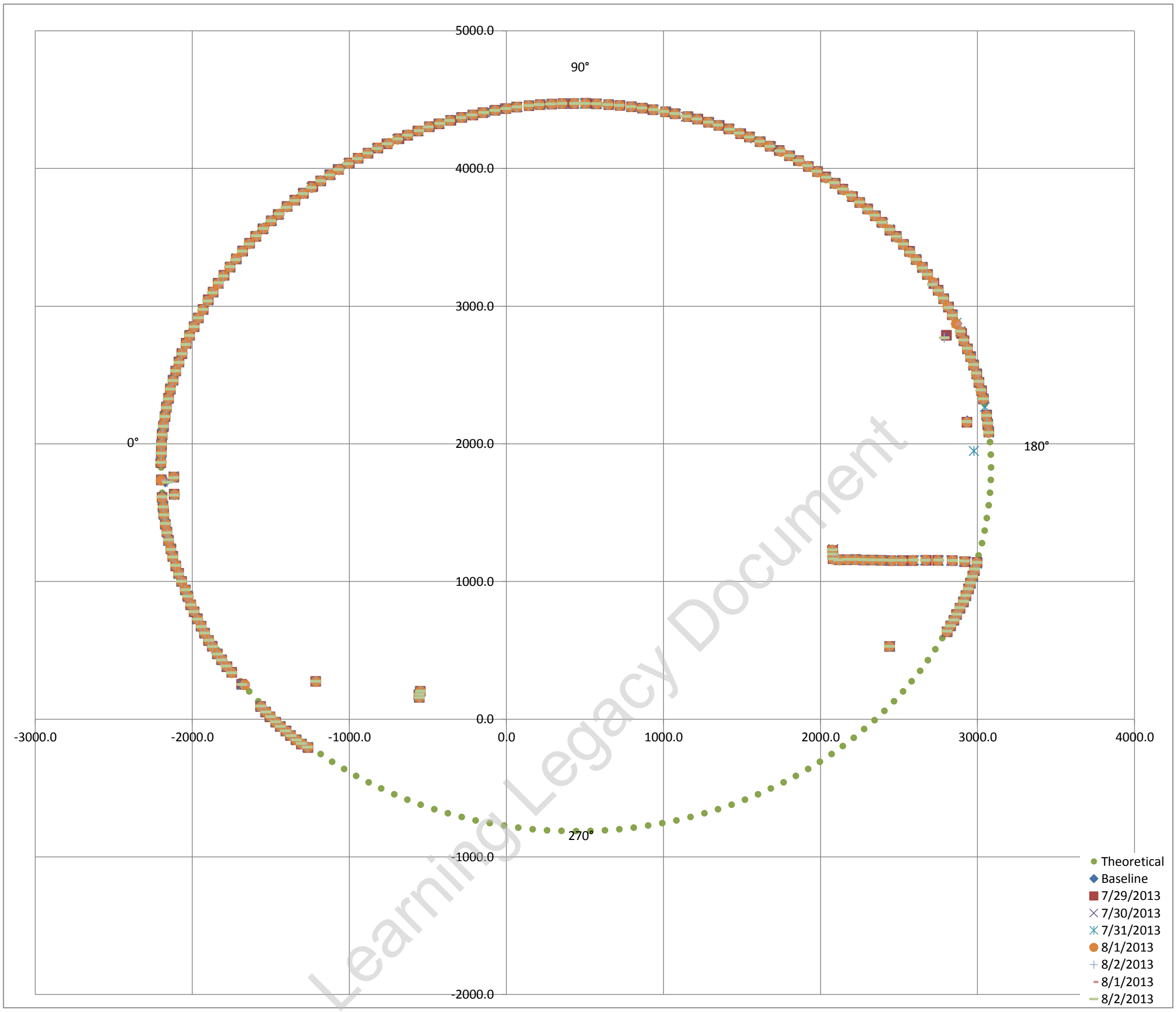


Left tunnel axis is at 0°



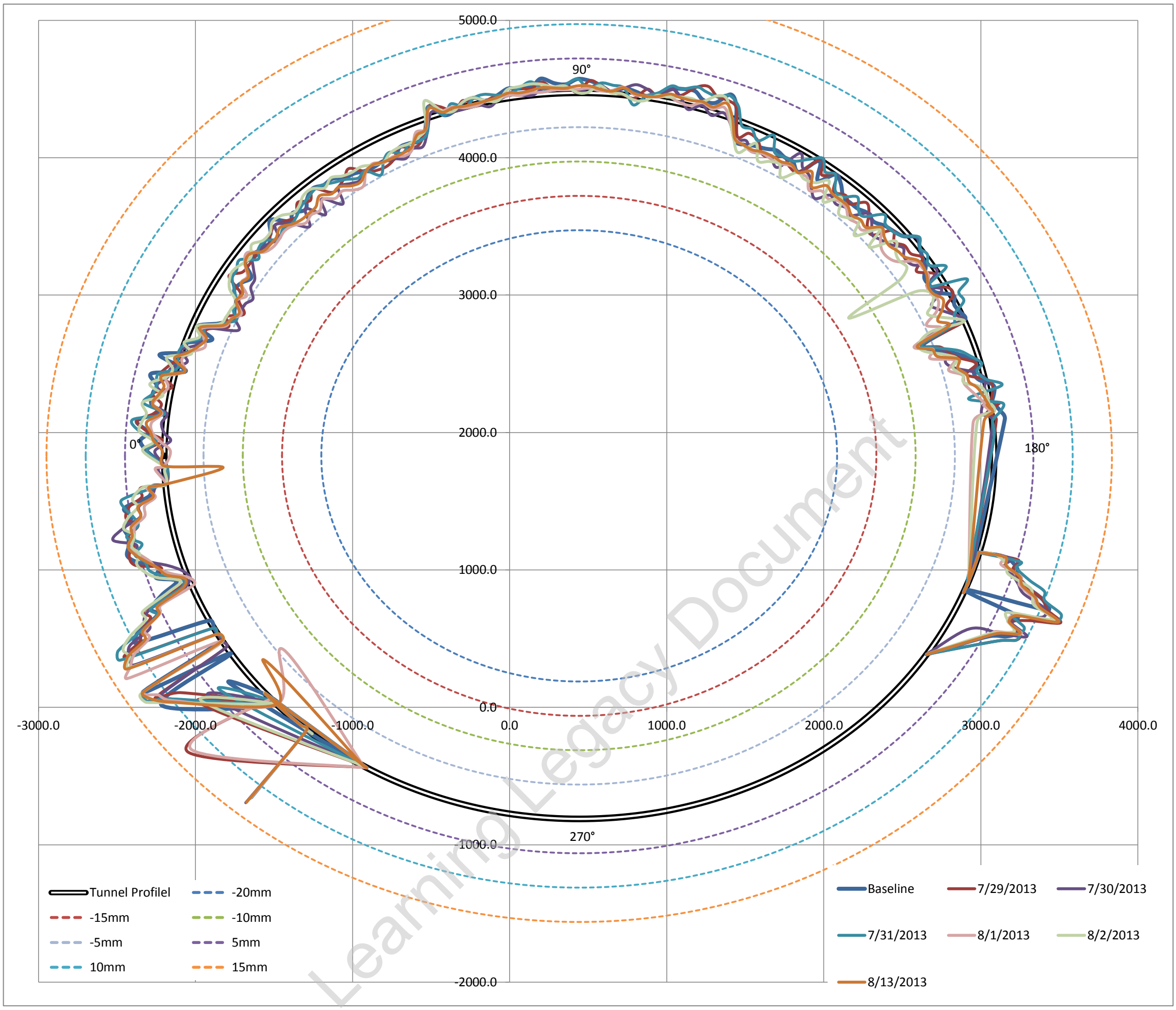
DLR LINE: UP **SECTION: 950**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **950**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5287.68	mm
Estimated best fit as built diameter	**5284.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.06956%	

i.e. Average surveyed diameter varies on 0.069% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**13.0**	**-7.7**
Max / Min deviation % to estimated dia	**0.49%**	**-0.29%**

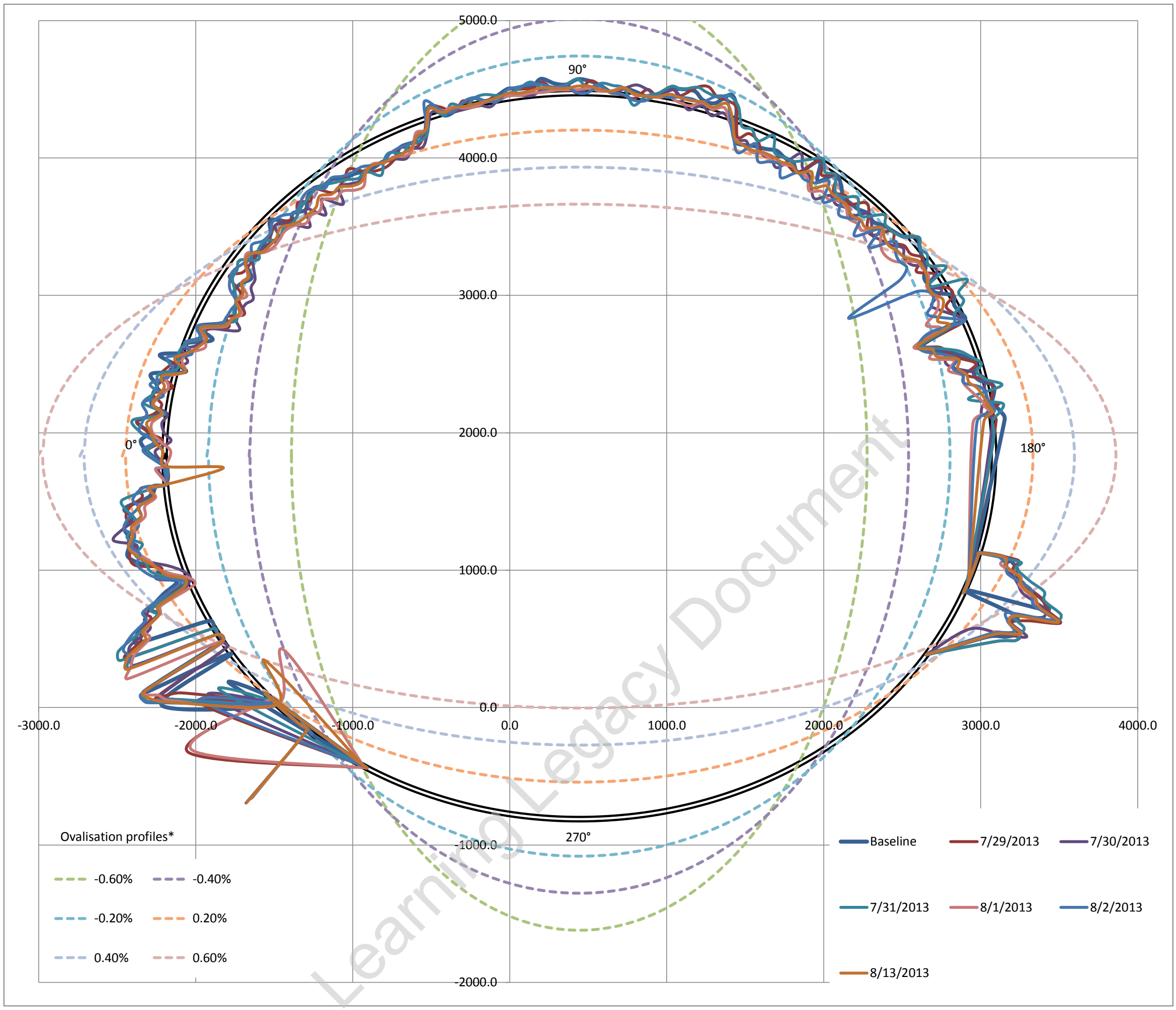
Fitted Circle Coordinates

Axis	X	443
	Y	1830
Radius		2642

Estimated best fit as built diameter	5284	mm
Designed diameter	5300	mm
Average diameter difference	**-16**	mm
Average radial difference	**-8**	mm
Average difference%	**-0.30%**	

DLR LINE: **UP** **SECTION:** **950**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

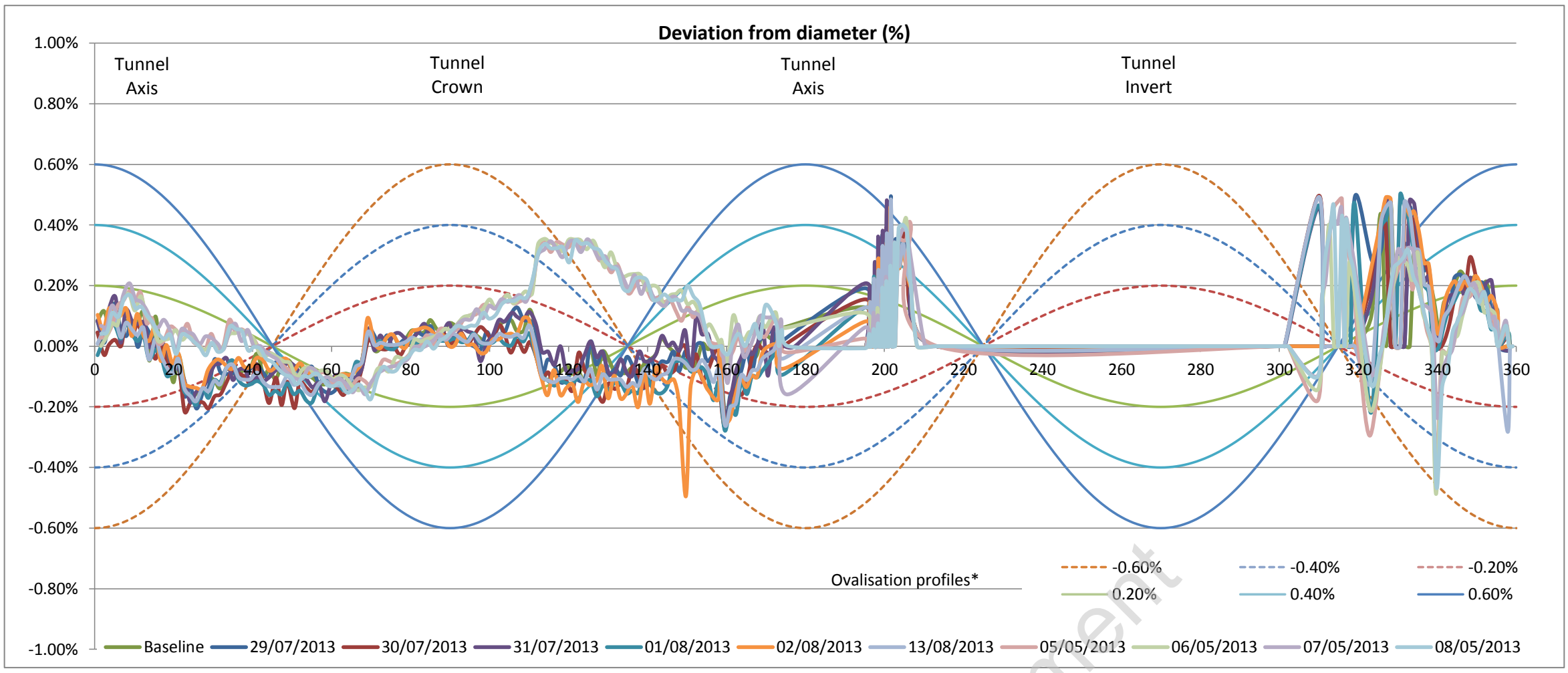
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5289.59 mm
Estimate of vertical diameter at crown, Dv	5285.77 mm
Dh / Dv	1.0007

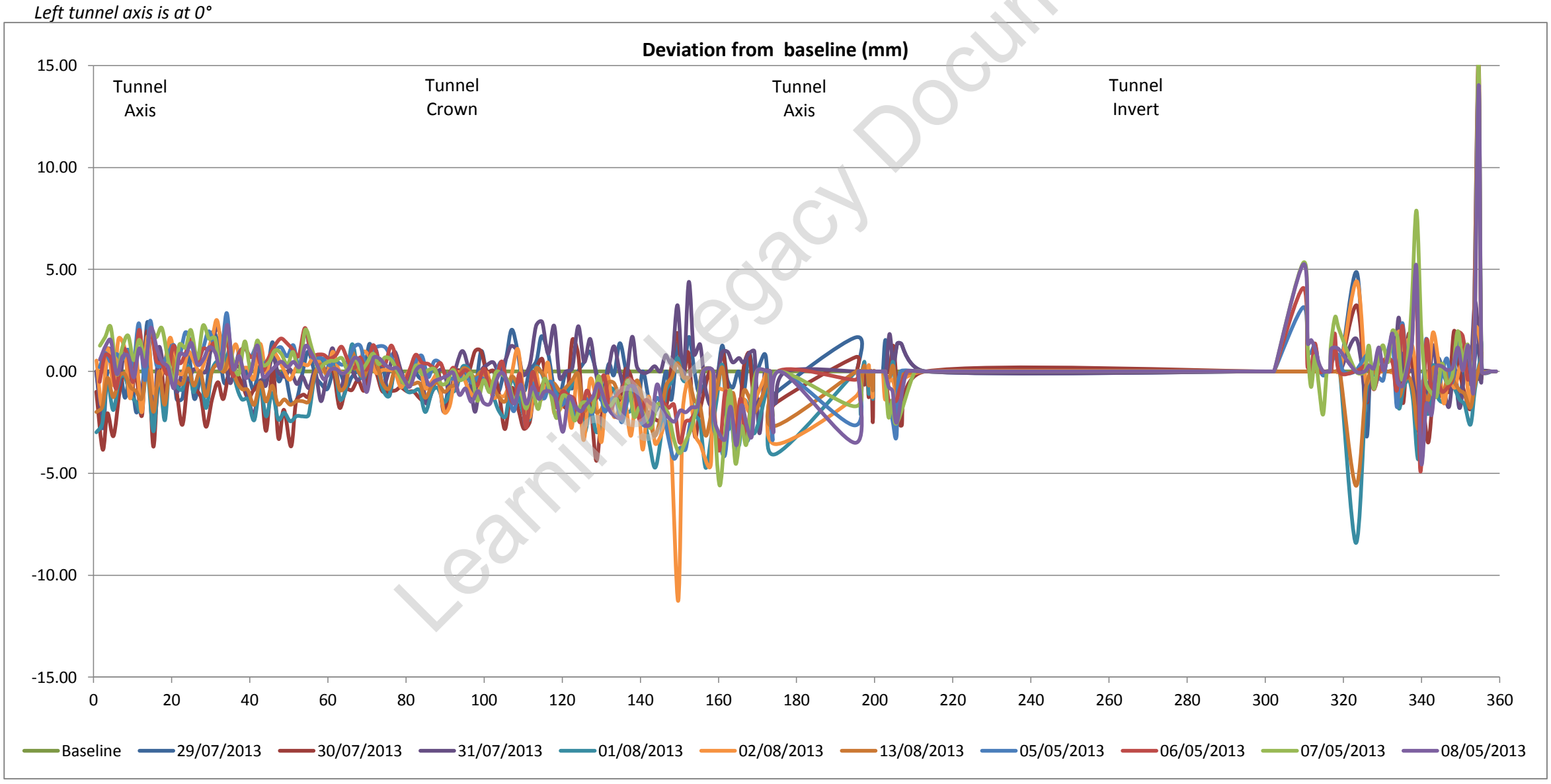
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 950**

Deviation vs Profile

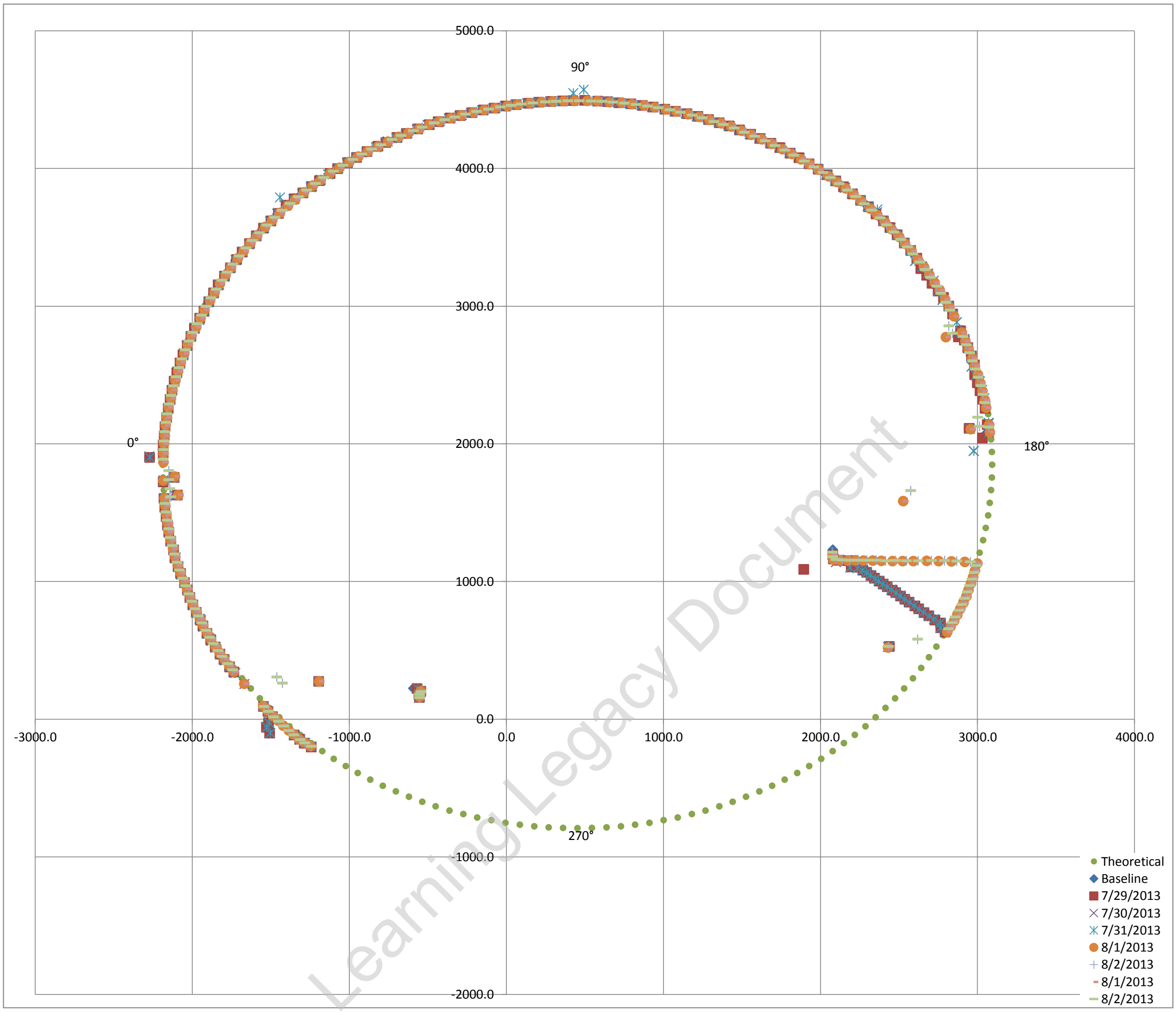


Left tunnel axis is at 0°



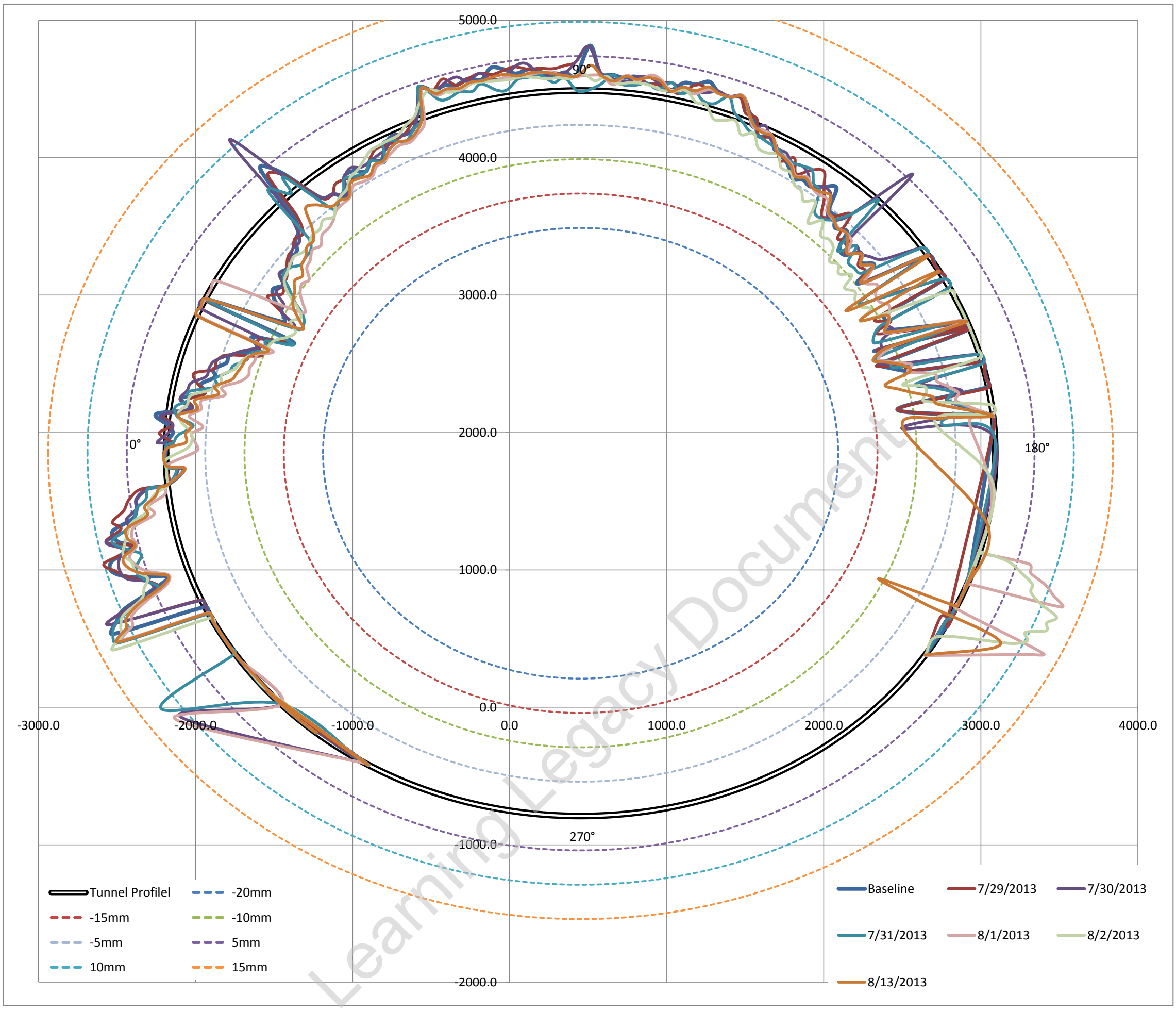
DLR LINE: UP **SECTION: 953**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **953**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5276.04	mm
Estimated best fit as built diameter	**5280.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.07509%	

i.e. Average surveyed diameter varies on -0.075% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.5**	**-12.7**
Max / Min deviation % to estimated dia	**0.47%**	**-0.48%**

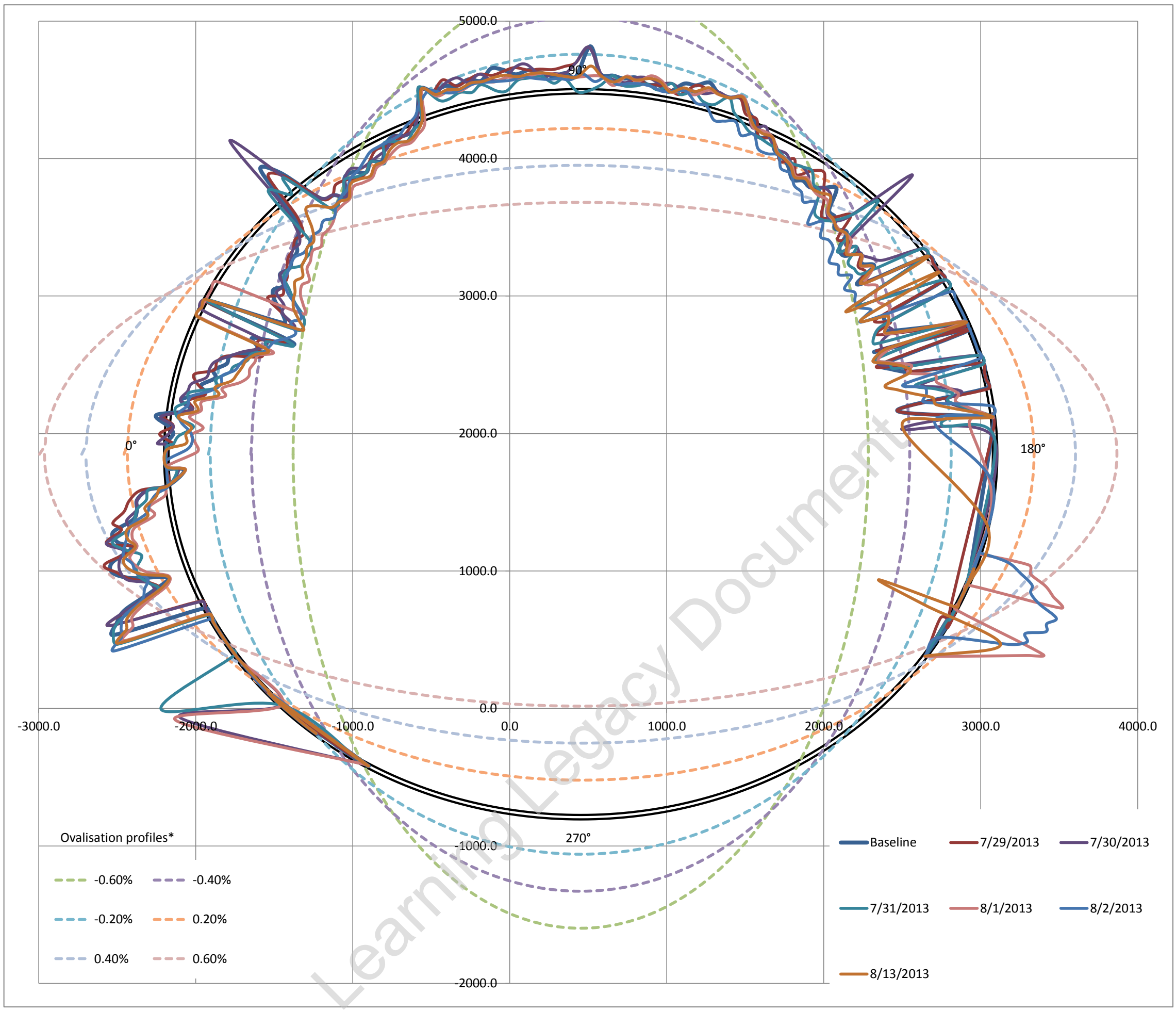
Fitted Circle Coordinates

Axis	X	452
	Y	1849
Radius		2640

Estimated best fit as built diameter	5280	mm
Designed diameter	5300	mm
Average diameter difference	**-20**	mm
Average radial difference	**-10**	mm
Average difference%	**-0.38%**	

DLR LINE: **UP** **SECTION:** **953**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

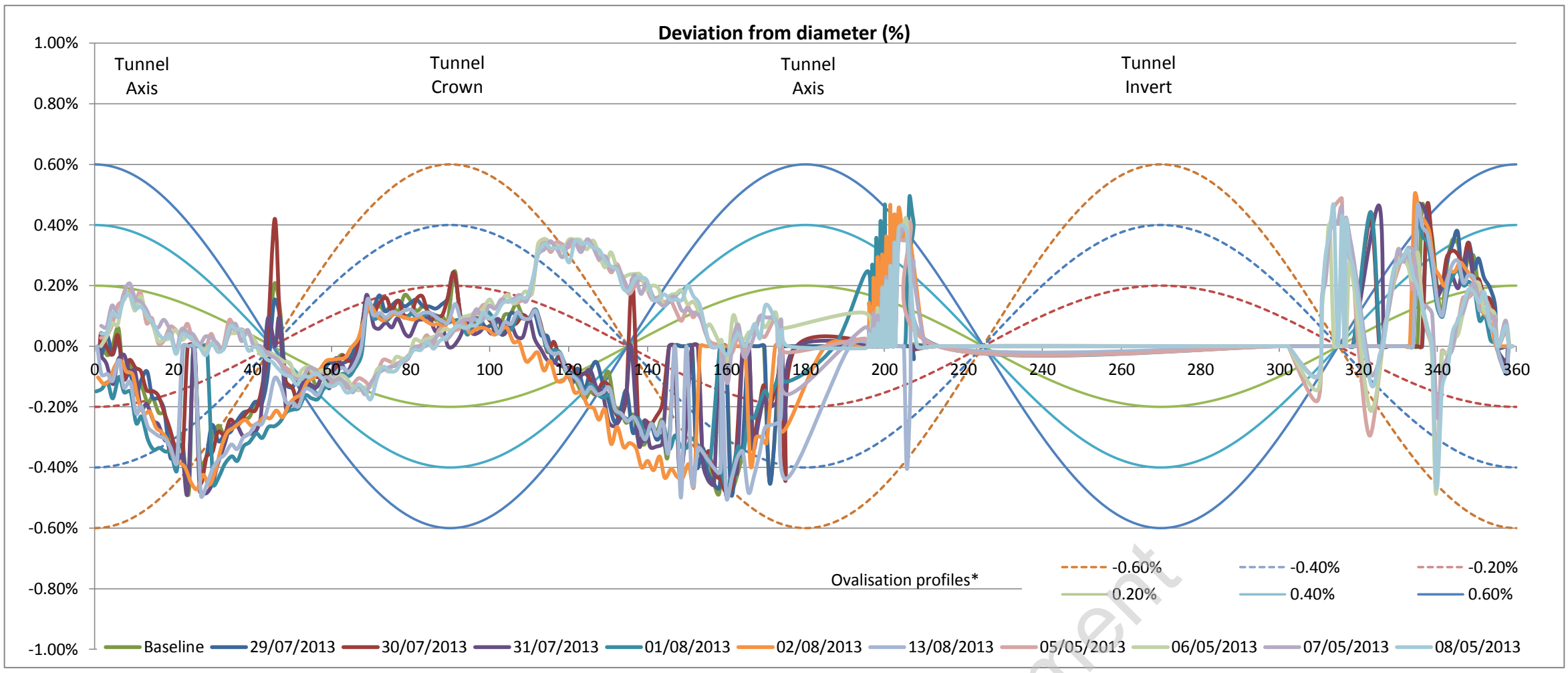
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5286.55	mm
Dh / Dv	#VALUE!	

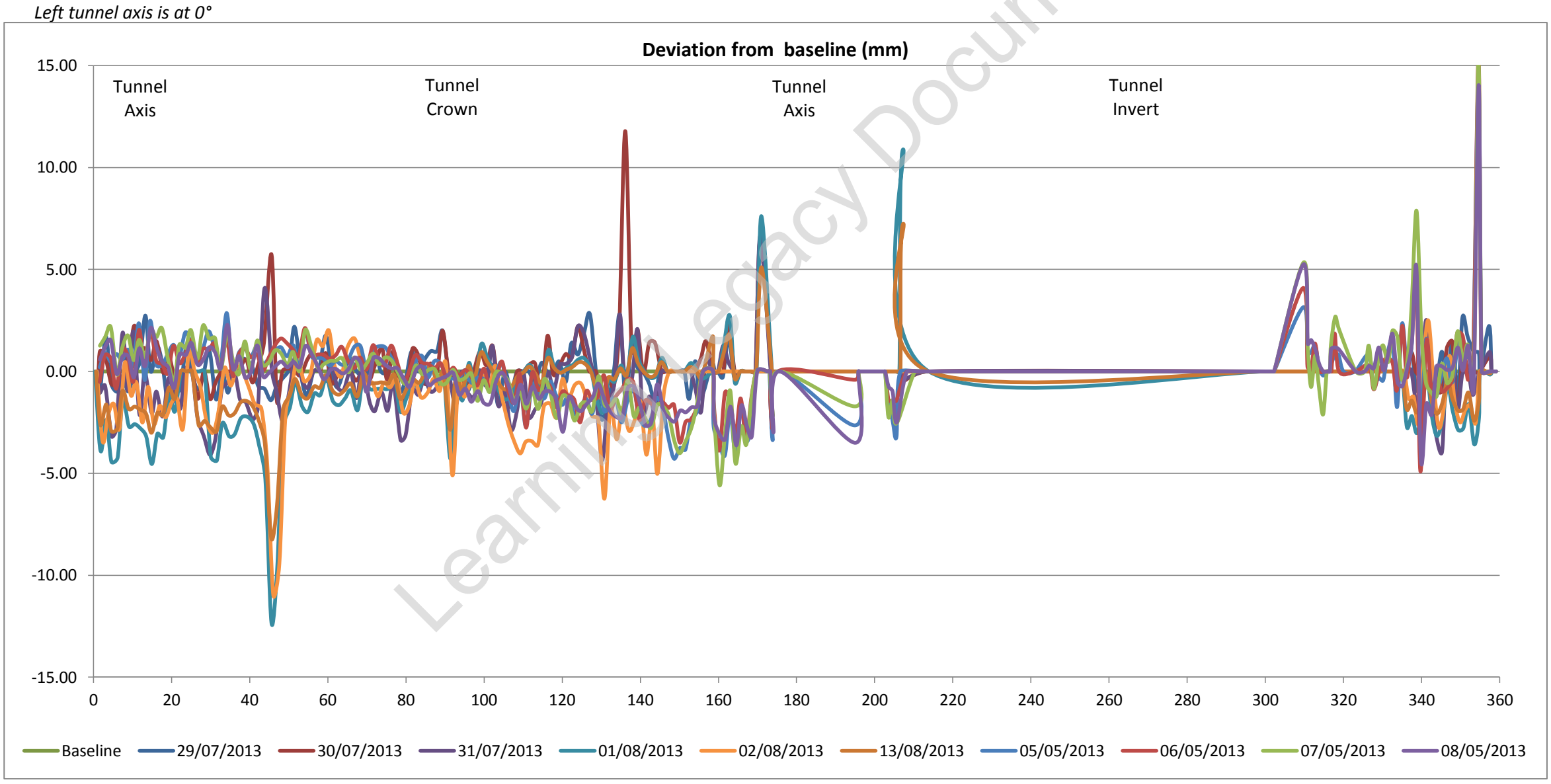
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 953**

Deviation vs Profile

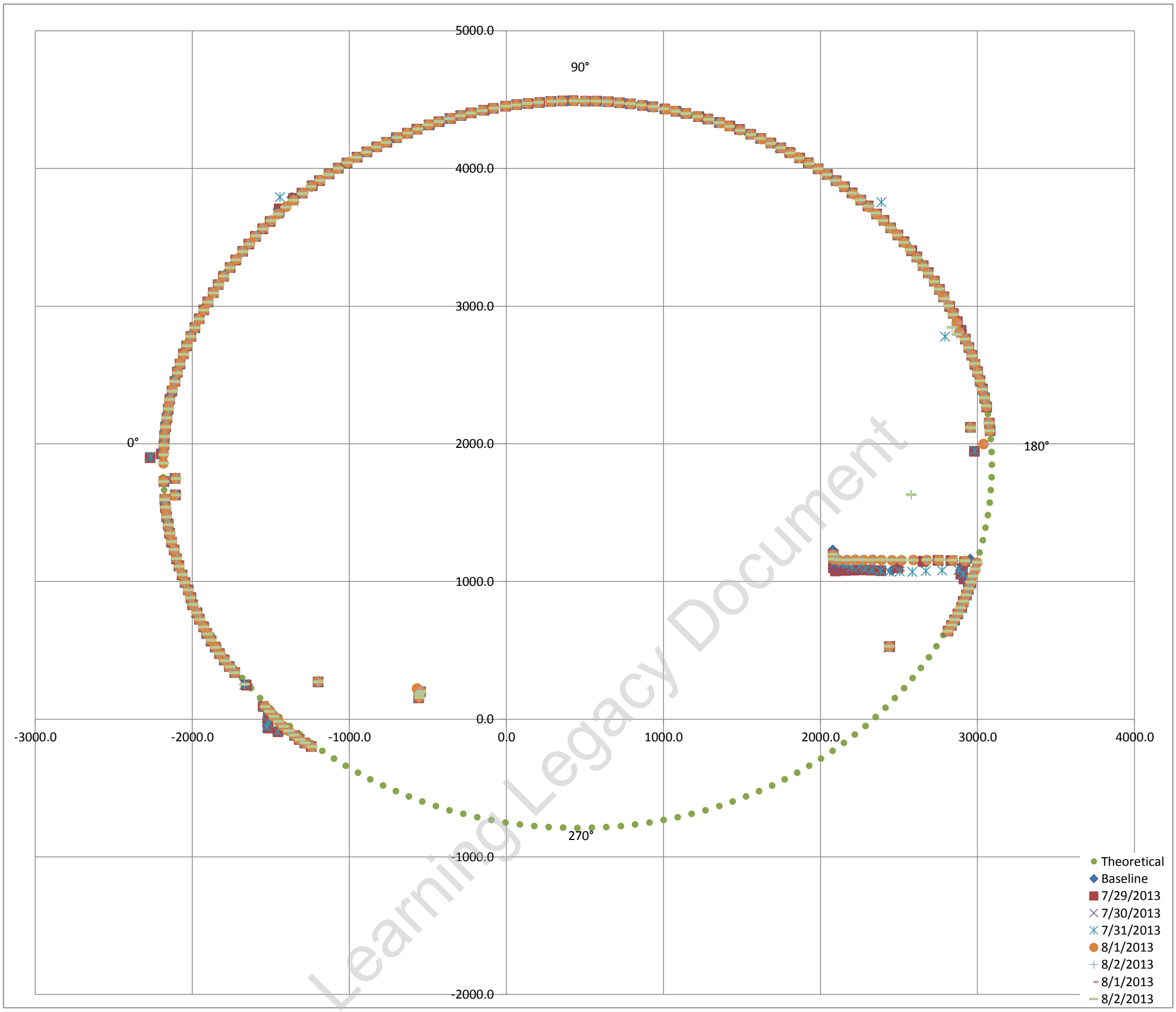


Left tunnel axis is at 0°



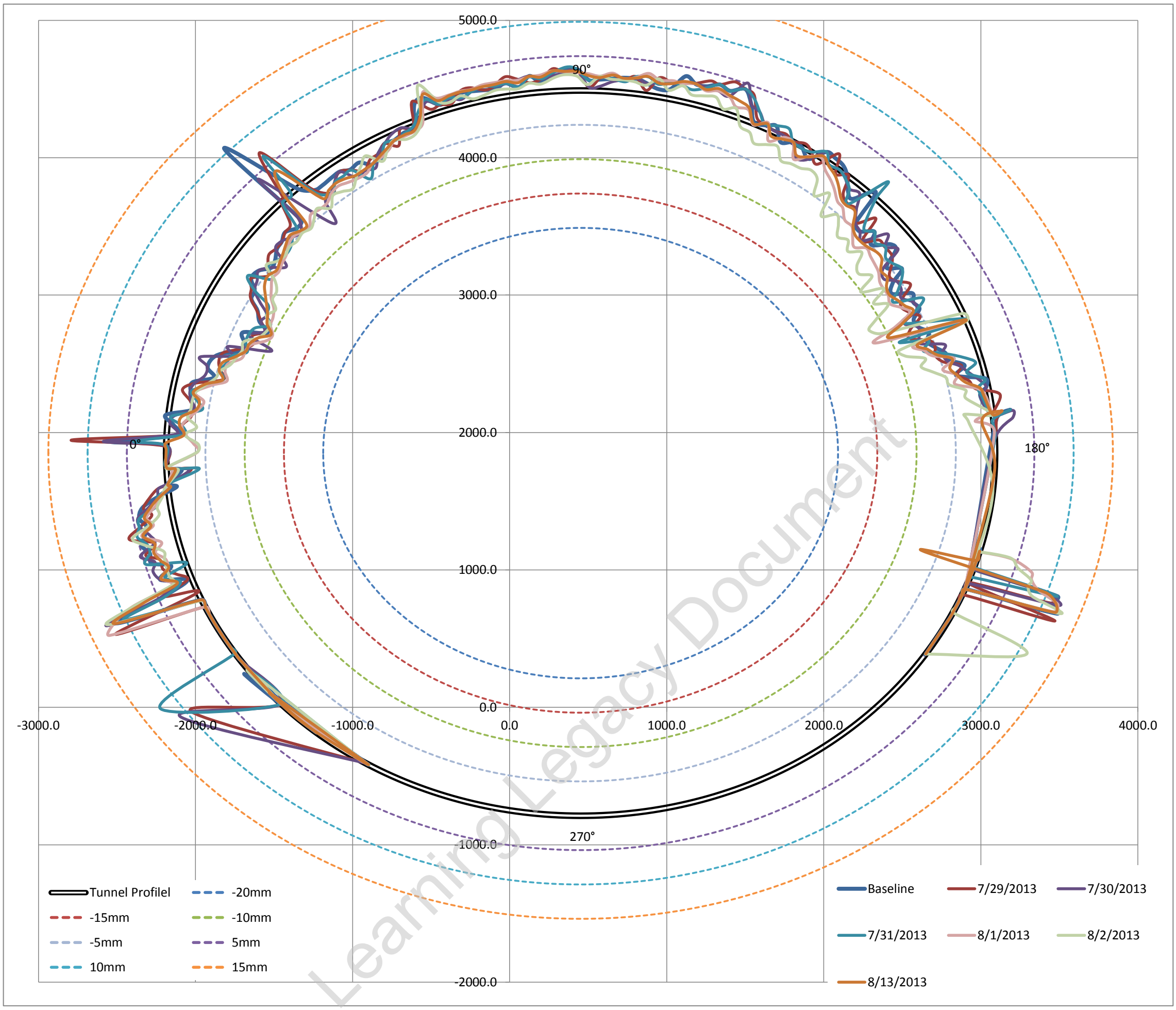
DLR LINE: UP **SECTION: 954**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **954**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5278.20	mm
Estimated best fit as built diameter	**5278.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.00378%	

i.e. Average surveyed diameter varies on 0.003% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-10.2**
Max / Min deviation % to estimated dia	**0.47%**	**-0.39%**

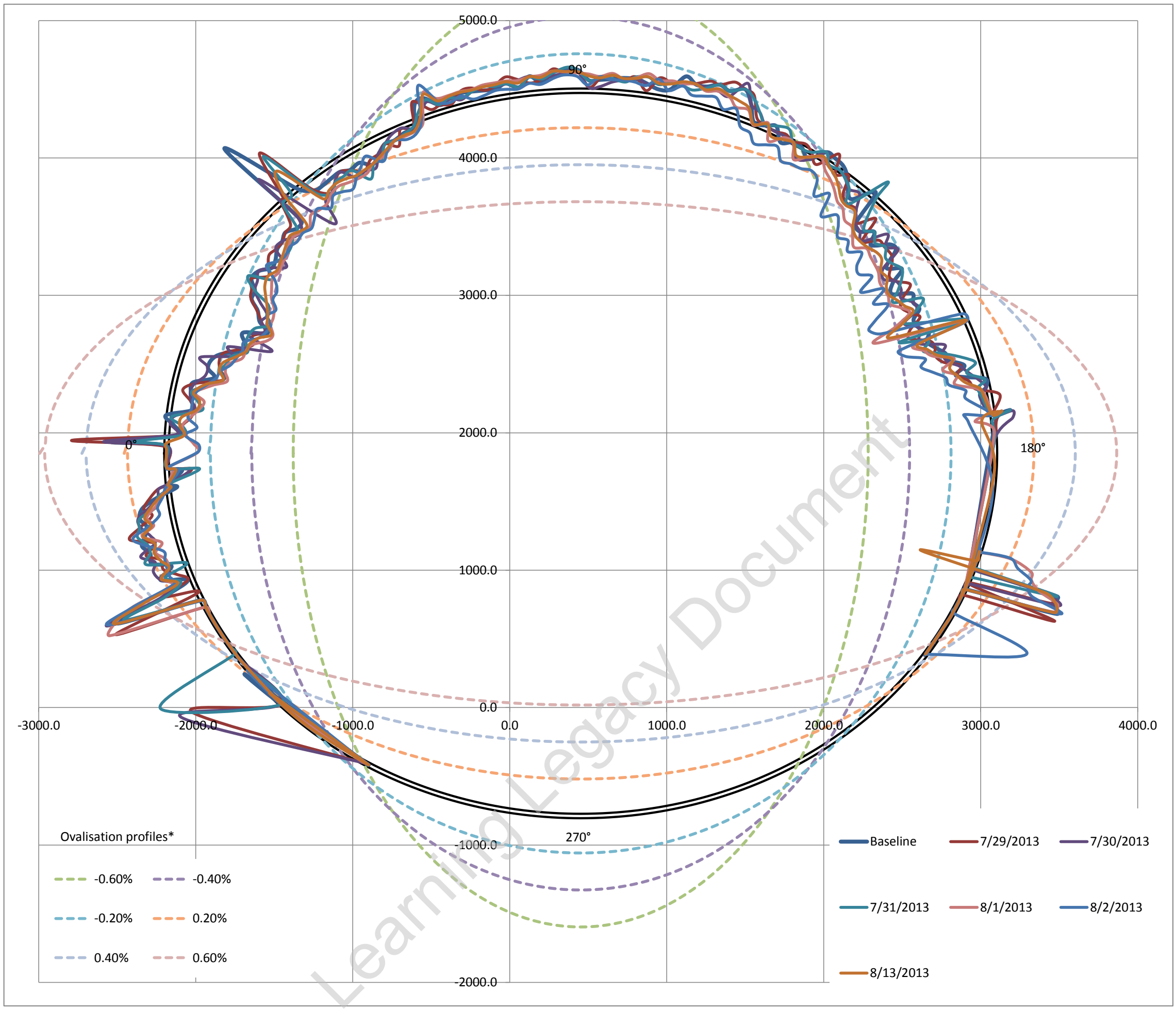
Fitted Circle Coordinates

Axis	X	452
	Y	1850
Radius		2639

Estimated best fit as built diameter	5278	mm
Designed diameter	5300	mm
Average diameter difference	**-22**	mm
Average radial difference	**-11**	mm
Average difference%	**-0.42%**	

DLR LINE: **UP** **SECTION:** **954**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

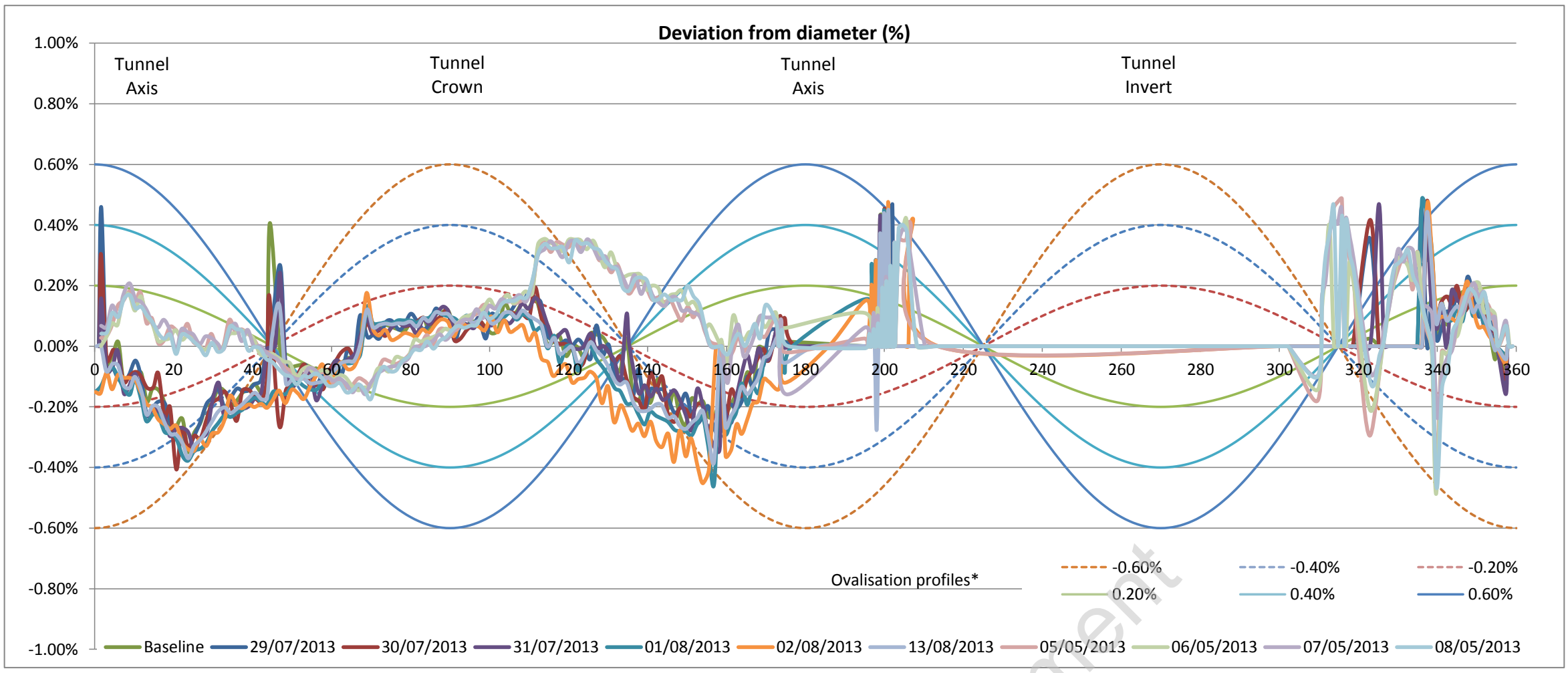
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5279.51	mm
Dh / Dv	#VALUE!	

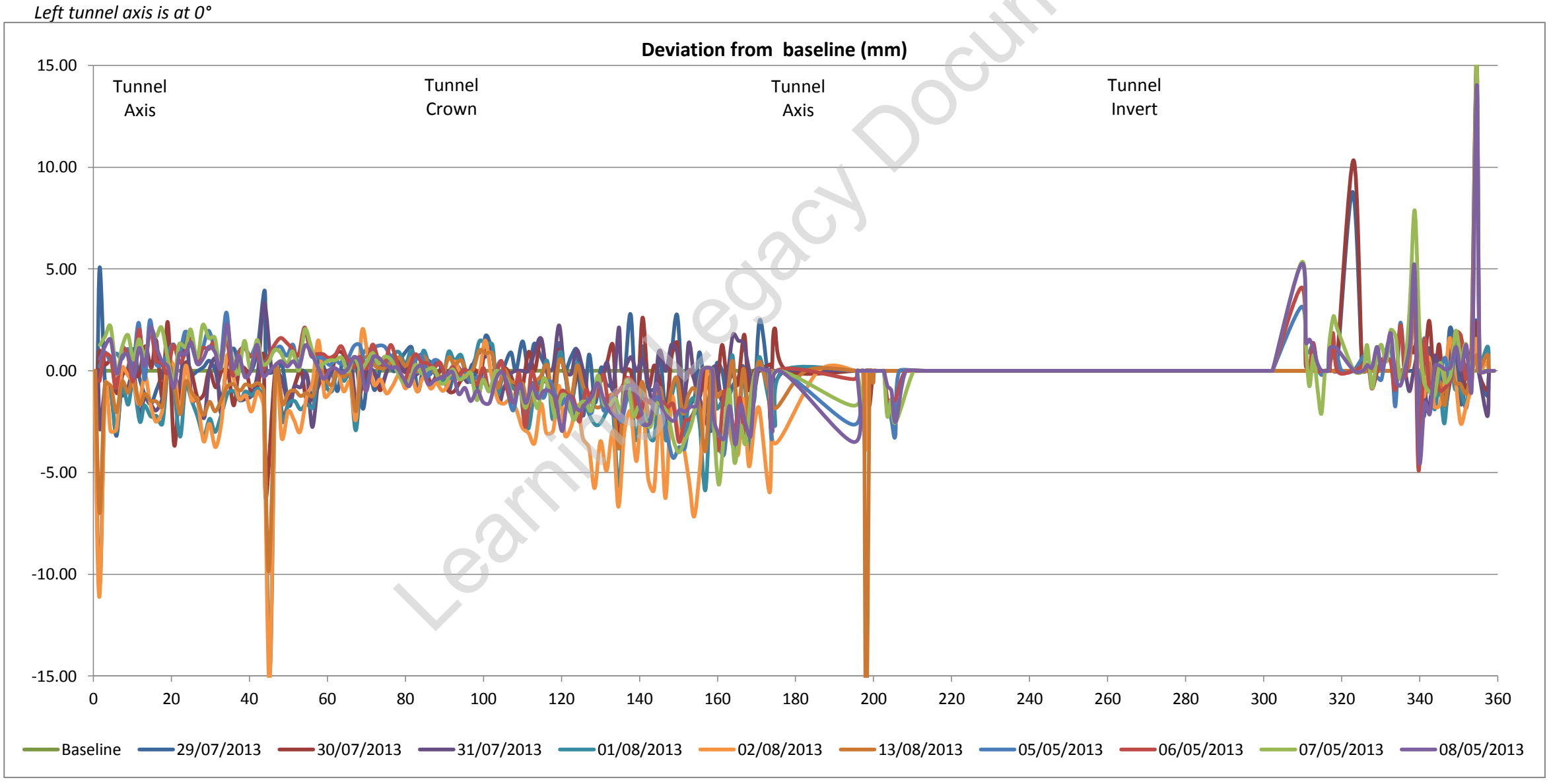
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 954**

Deviation vs Profile

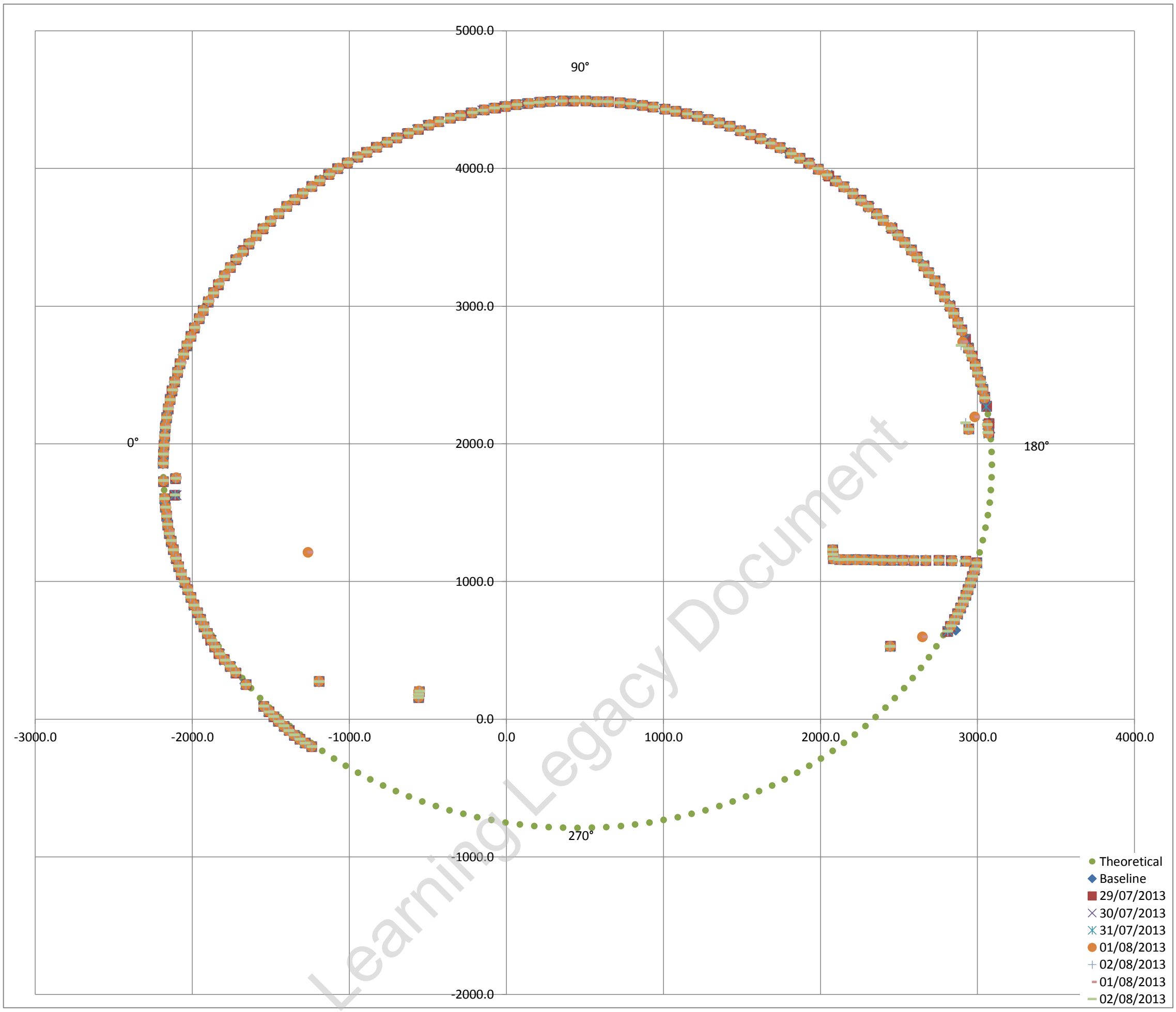


Left tunnel axis is at 0°



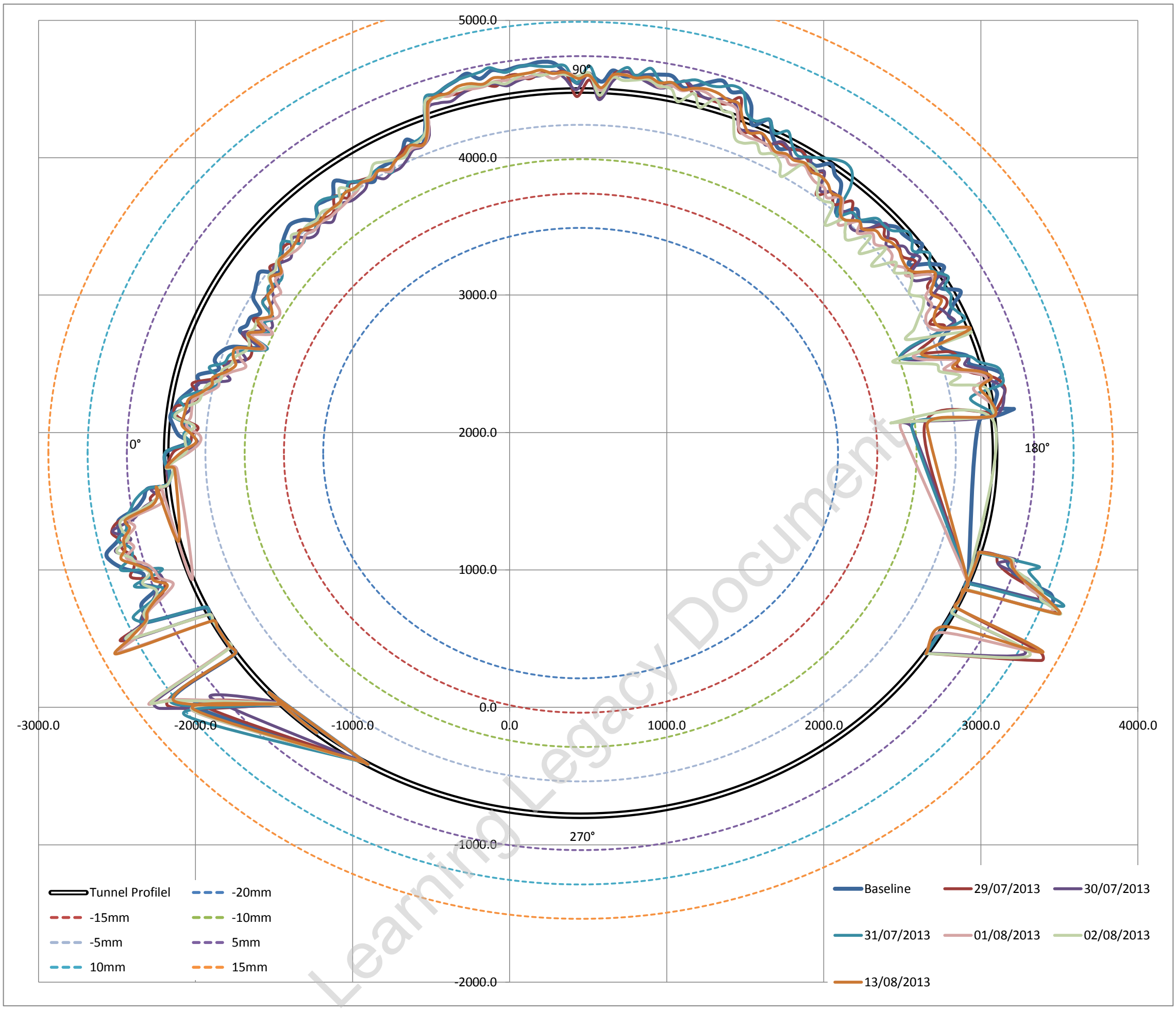
DLR LINE: UP **SECTION: 955**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **955**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5277.36	mm
Estimated best fit as built diameter	**5278.00**	**mm**
Difference between average surveyed diameter and best fit diameter	-0.01207%	

i.e. Average surveyed diameter varies on -0.012% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.5**	**-10.7**
Max / Min deviation % to estimated dia	**0.47%**	**-0.41%**

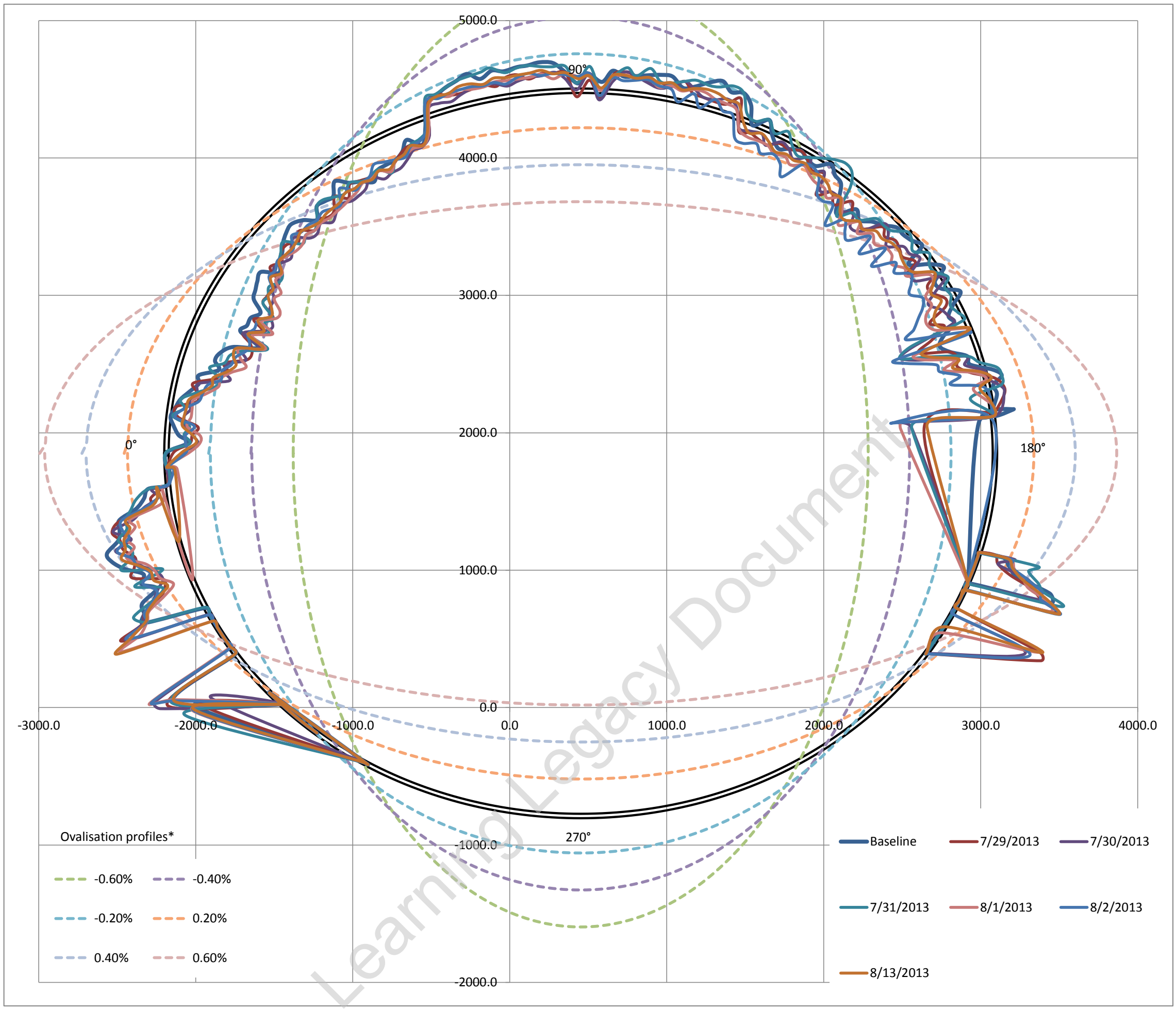
Fitted Circle Coordinates

Axis	X	452
	Y	1850
Radius		2639

Estimated best fit as built diameter	5278	mm
Designed diameter	5300	mm
Average diameter difference	**-22**	mm
Average radial difference	**-11**	mm
Average difference%	**-0.42%**	

DLR LINE: **UP** **SECTION:** **955**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

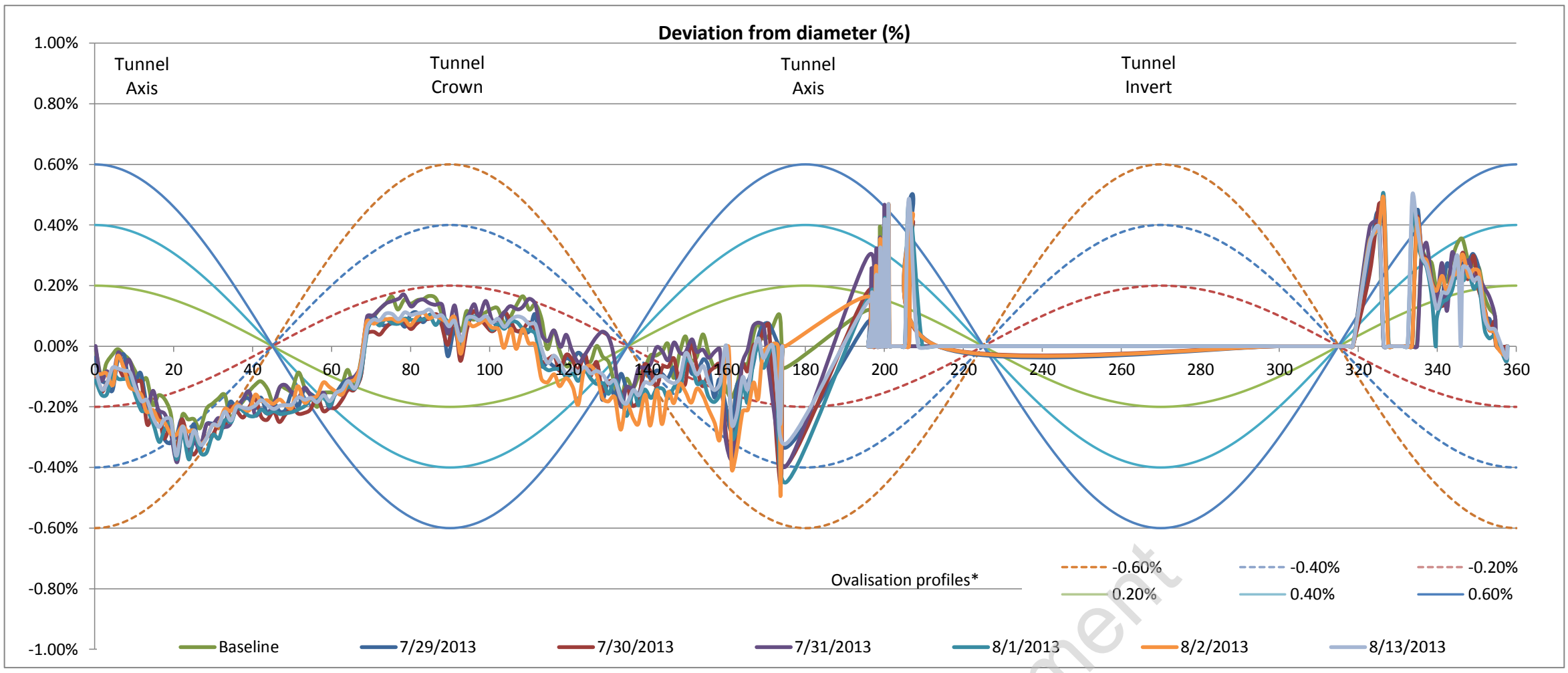
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5281.15 mm
Estimate of vertical diameter at crown, Dv	5280.42 mm
Dh / Dv	1.0001

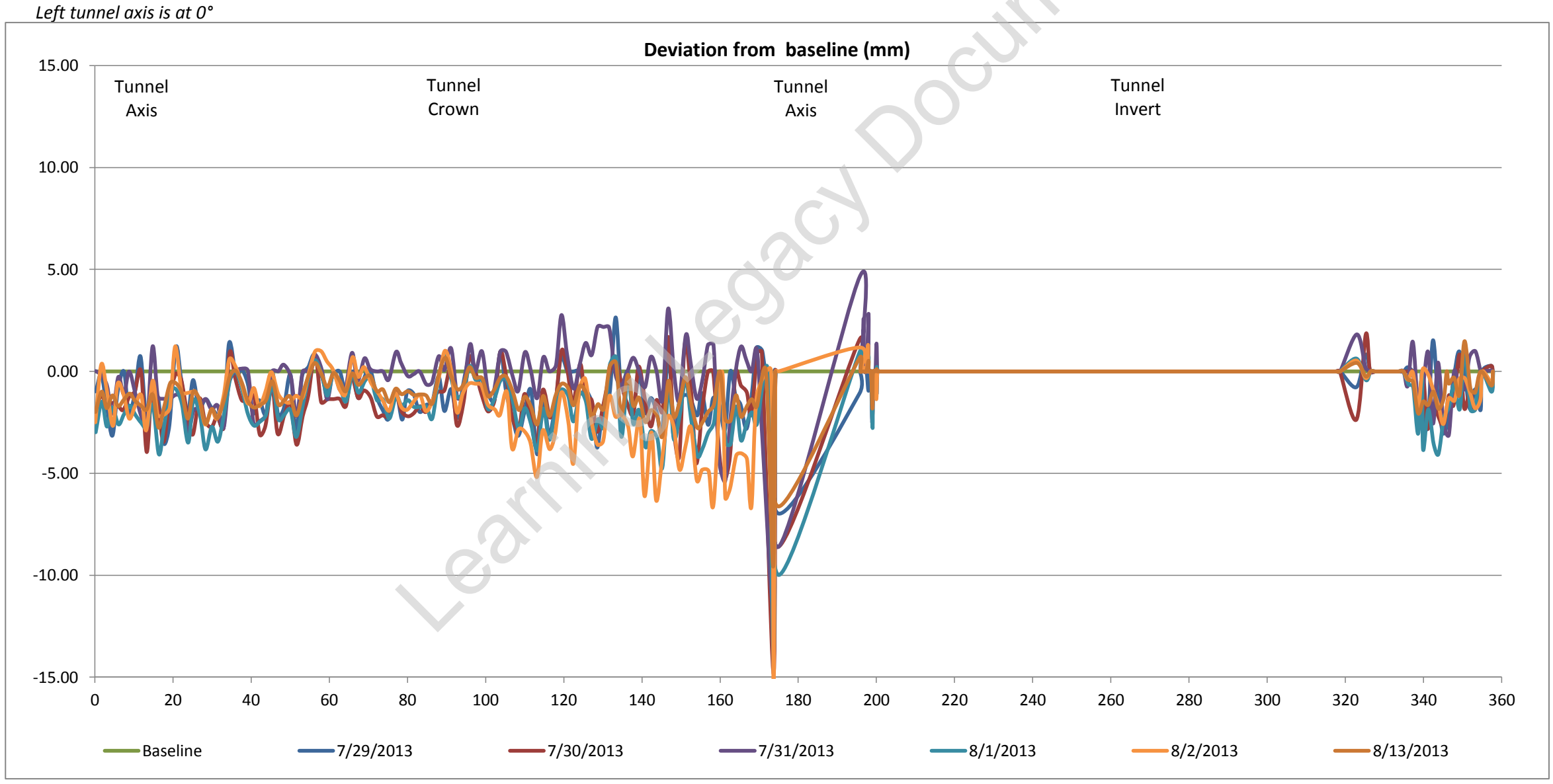
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 955**

Deviation vs Profile

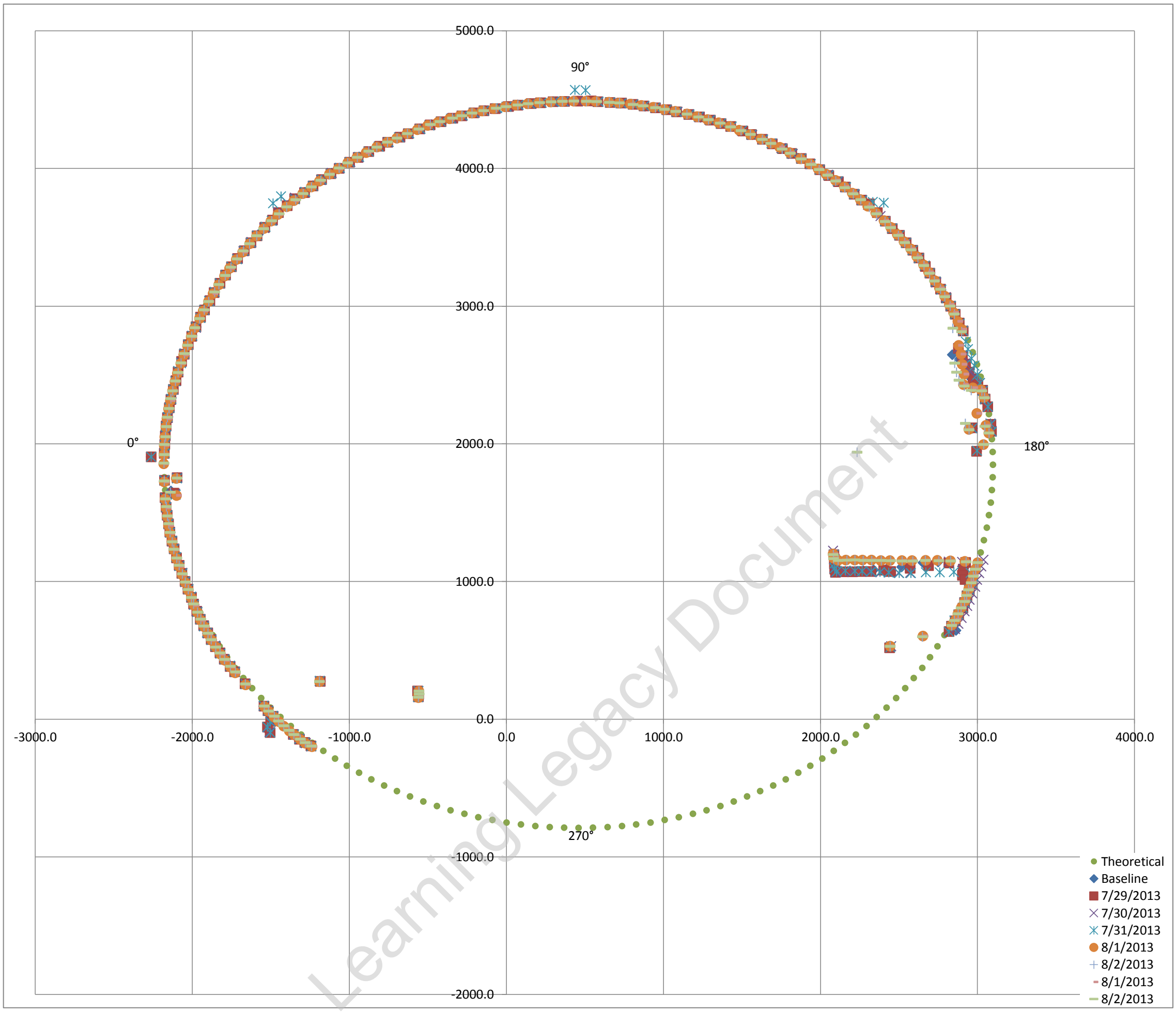


Left tunnel axis is at 0°



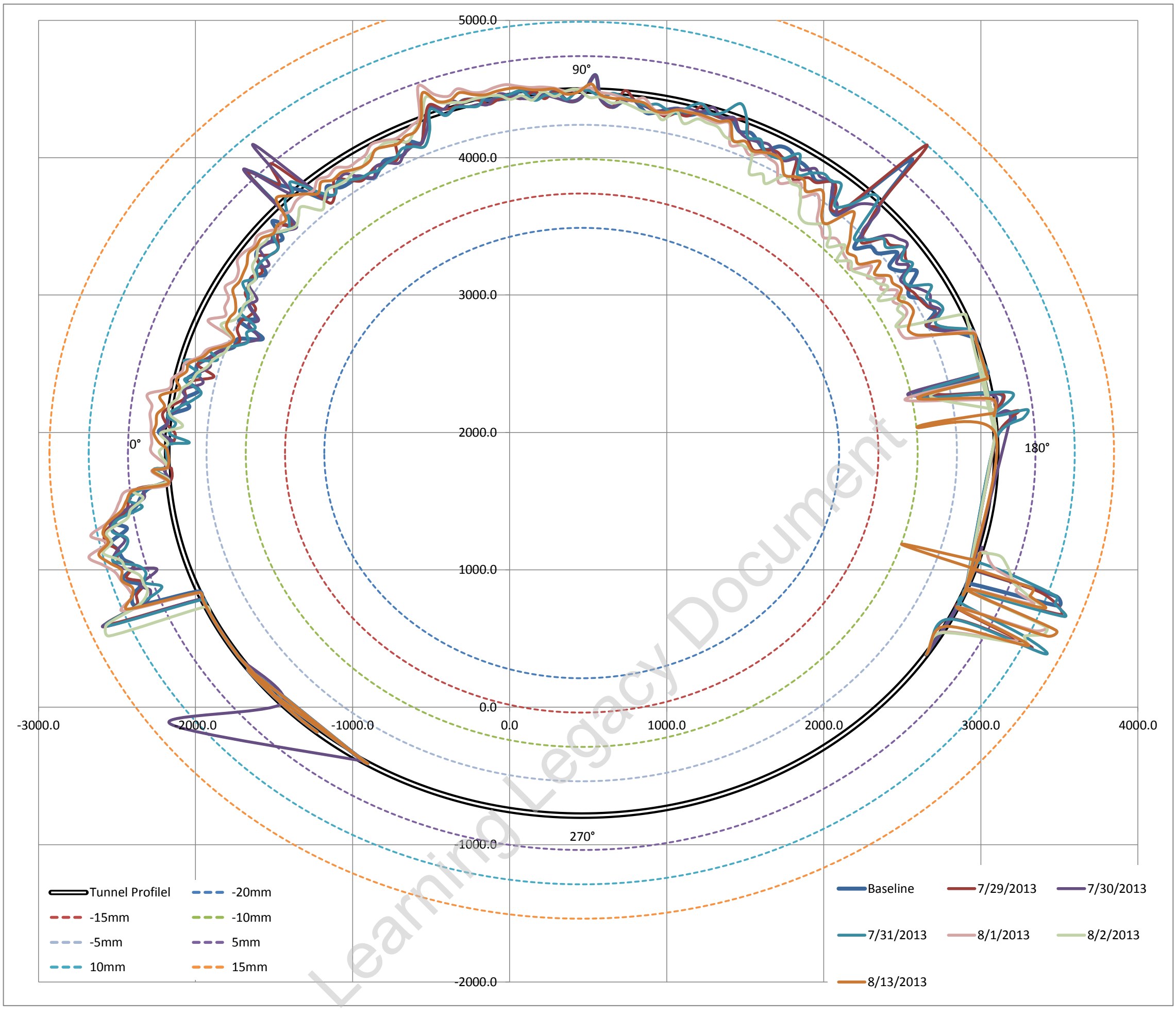
DLR LINE: UP **SECTION: 956**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **956**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5281.82	mm
Estimated best fit as built diameter	**5278.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.07247%	

i.e. Average surveyed diameter varies on 0.072% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.6**	**-9.5**
Max / Min deviation % to estimated dia	**0.48%**	**-0.36%**

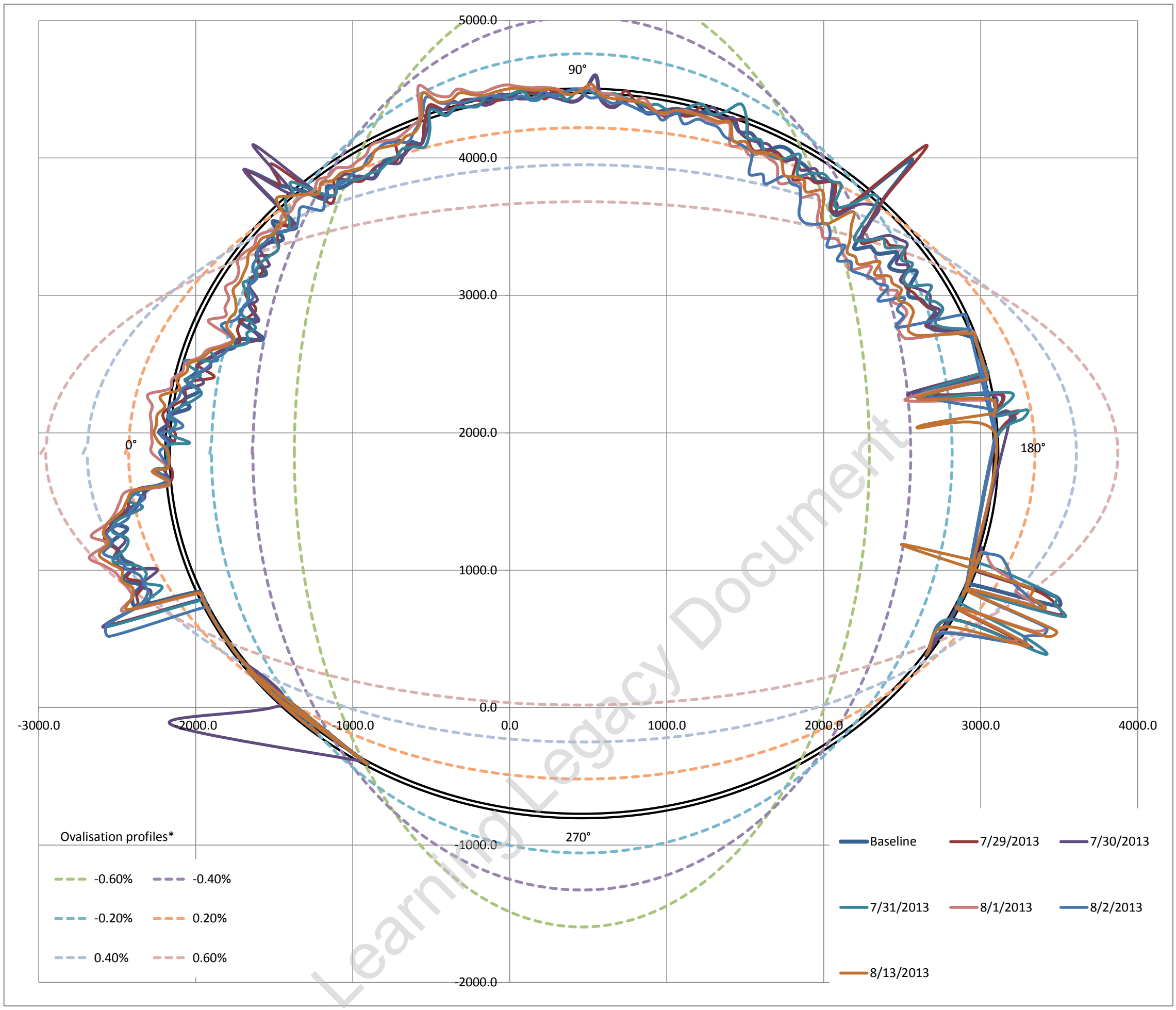
Fitted Circle Coordinates

Axis	X	459
	Y	1850
Radius		2639

Estimated best fit as built diameter	5278	mm
Designed diameter	5300	mm
Average diameter difference	**-22**	mm
Average radial difference	**-11**	mm
Average difference%	**-0.42%**	

DLR LINE: **UP** **SECTION:** **956**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

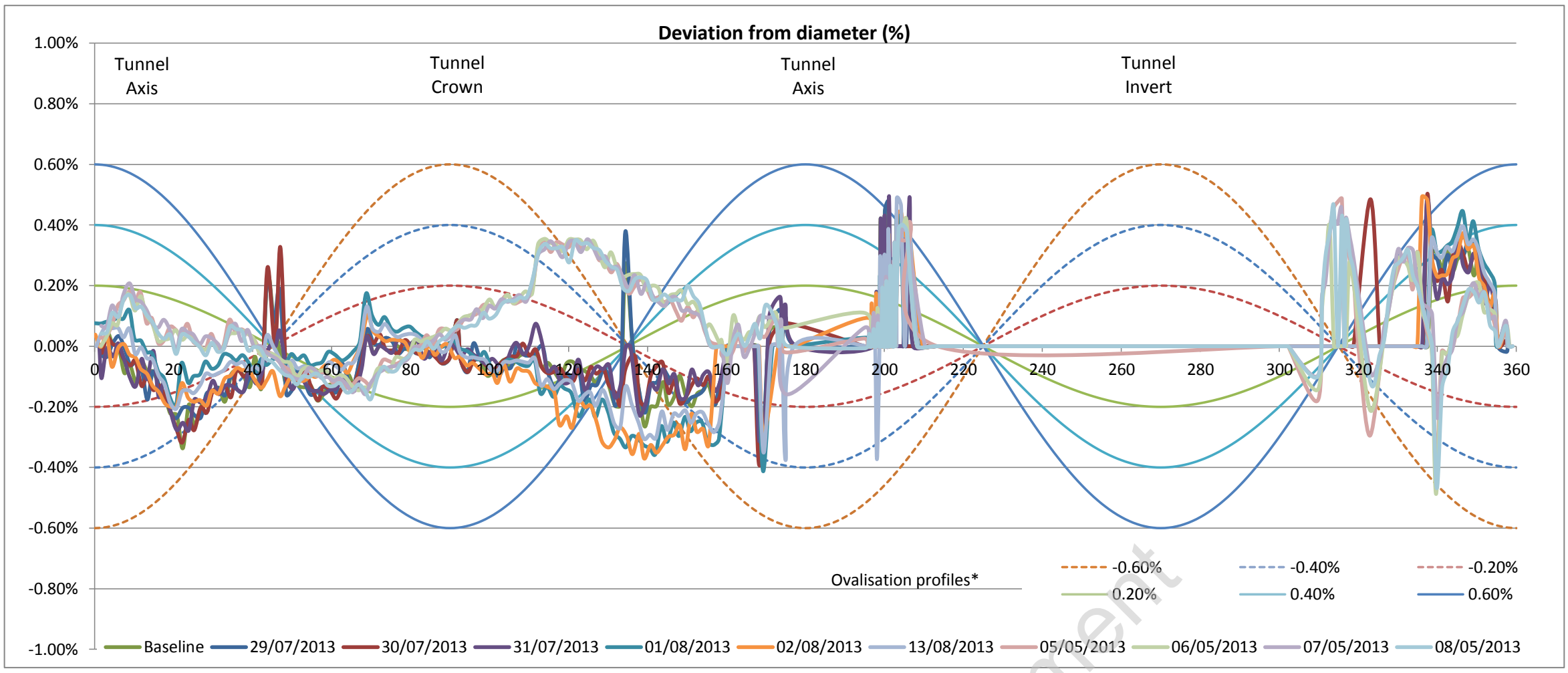
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5280.27	mm
Dh / Dv	#VALUE!	

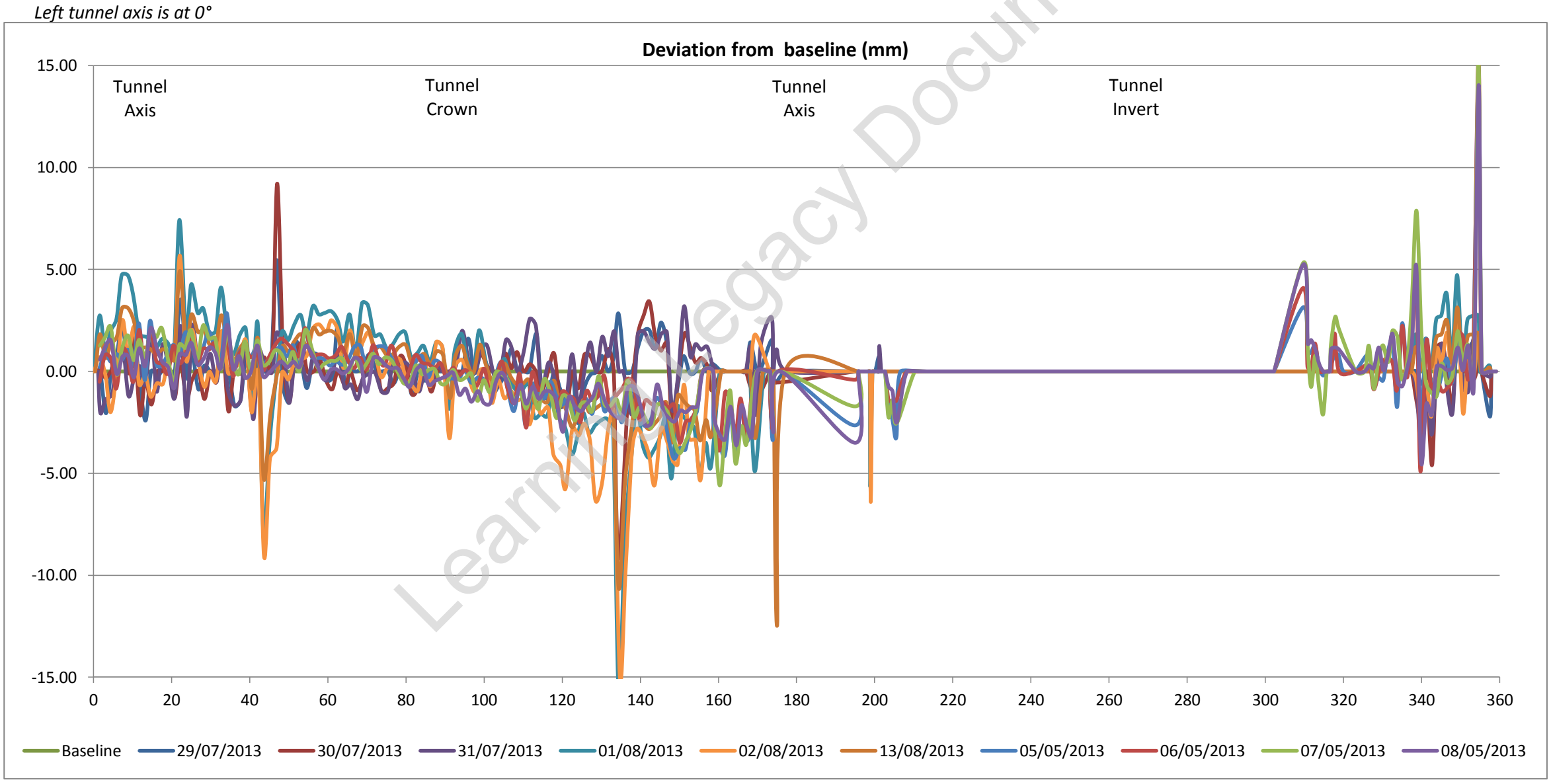
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 956**

Deviation vs Profile

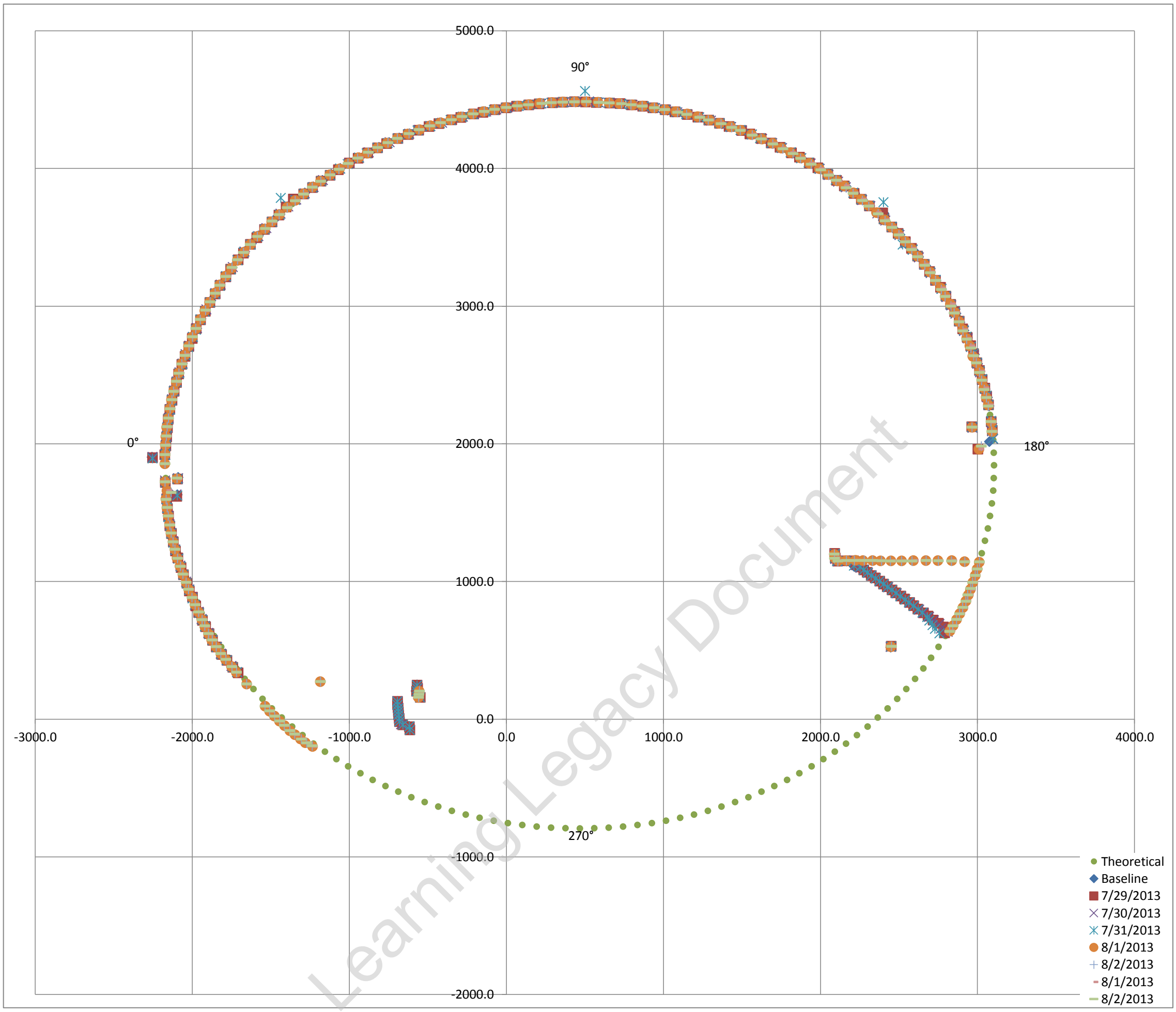


Left tunnel axis is at 0°



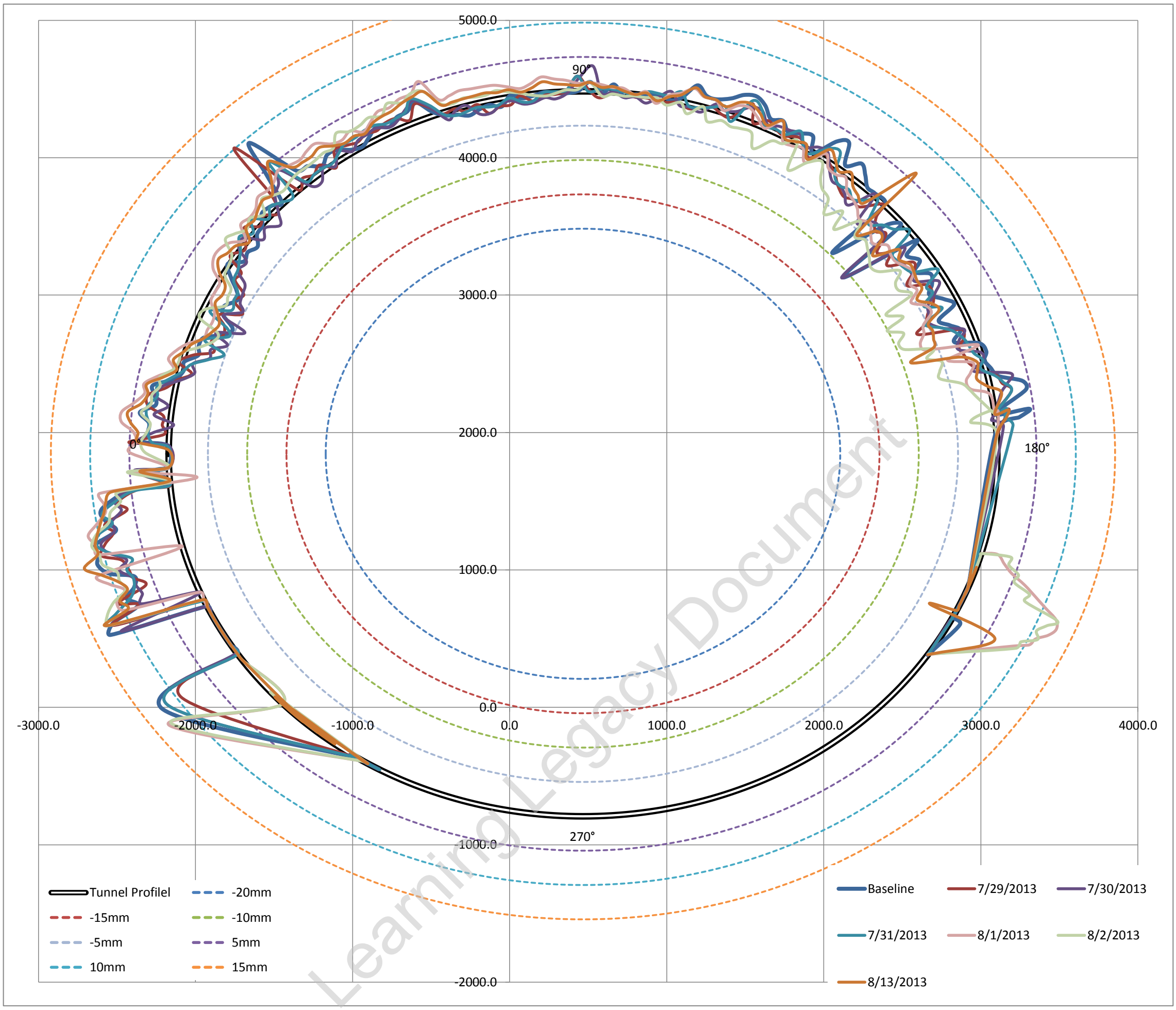
DLR LINE: UP **SECTION: 957**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **957**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5282.79	mm
Estimated best fit as built diameter	**5276.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.12875%	

i.e. Average surveyed diameter varies on 0.128% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.6**	**-8.5**
Max / Min deviation % to estimated dia	**0.48%**	**-0.32%**

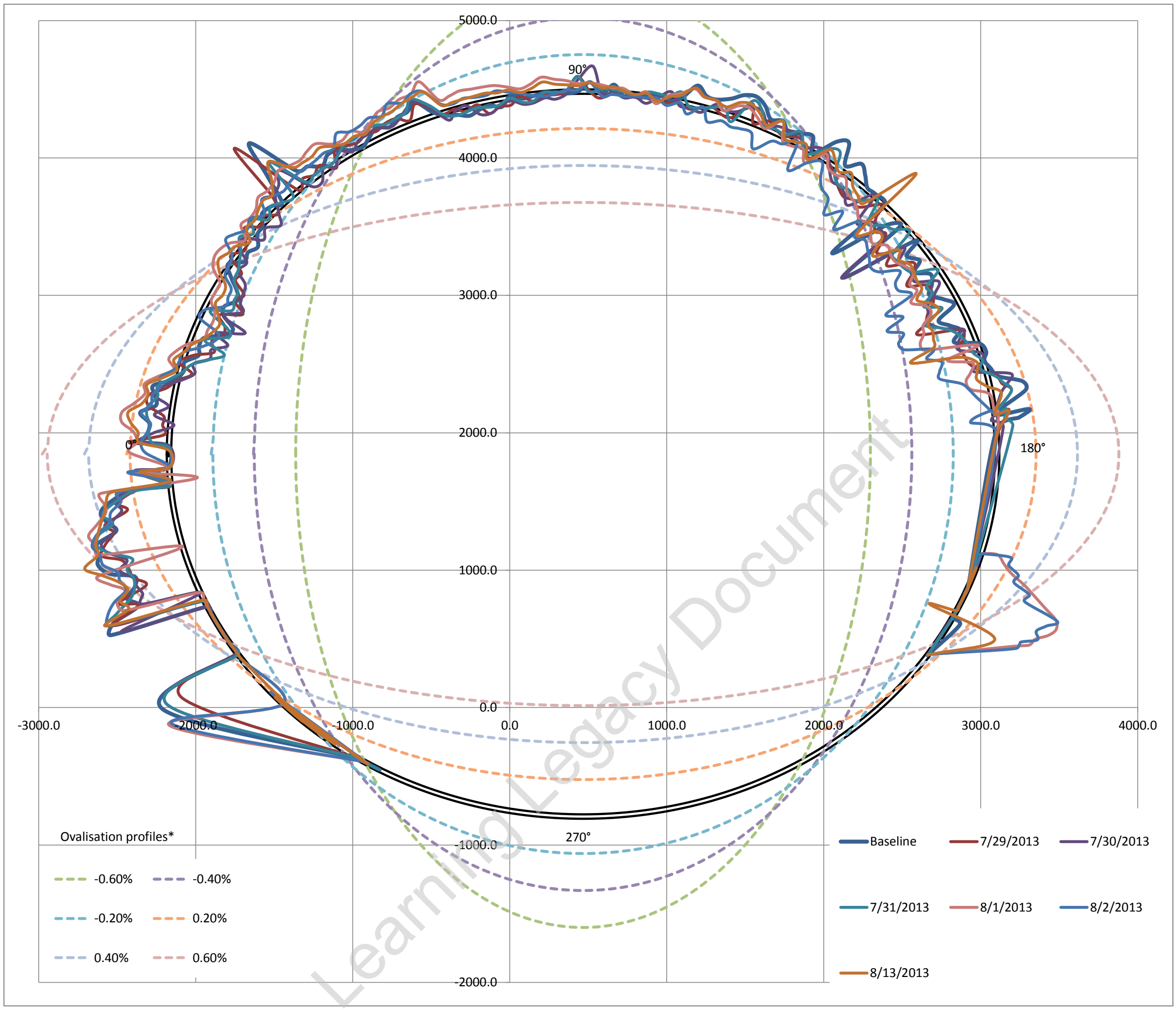
Fitted Circle Coordinates

Axis	X	467
	Y	1845
Radius		2638

Estimated best fit as built diameter	5276	mm
Designed diameter	5300	mm
Average diameter difference	**-24**	mm
Average radial difference	**-12**	mm
Average difference%	**-0.45%**	

DLR LINE: **UP** **SECTION:** **957**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

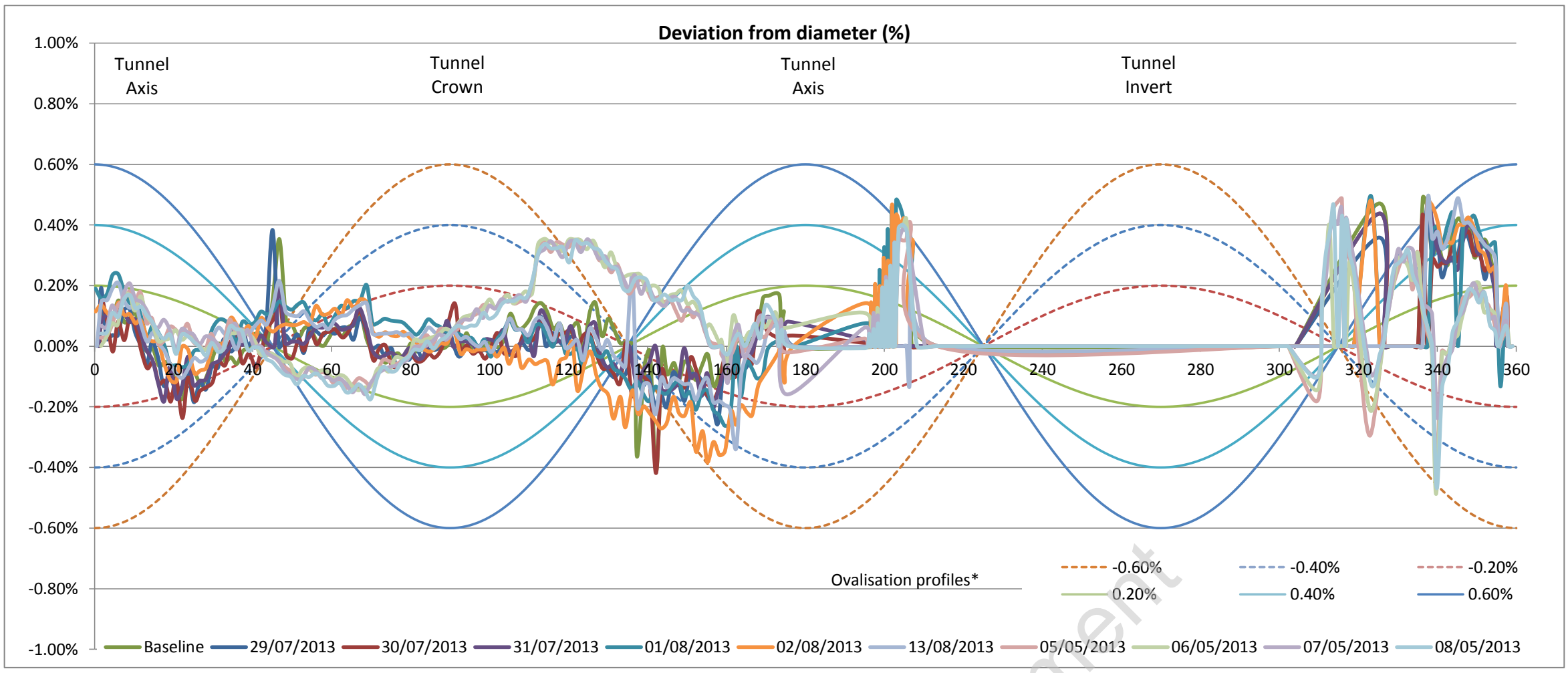
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5277.37	mm
Dh / Dv	#VALUE!	

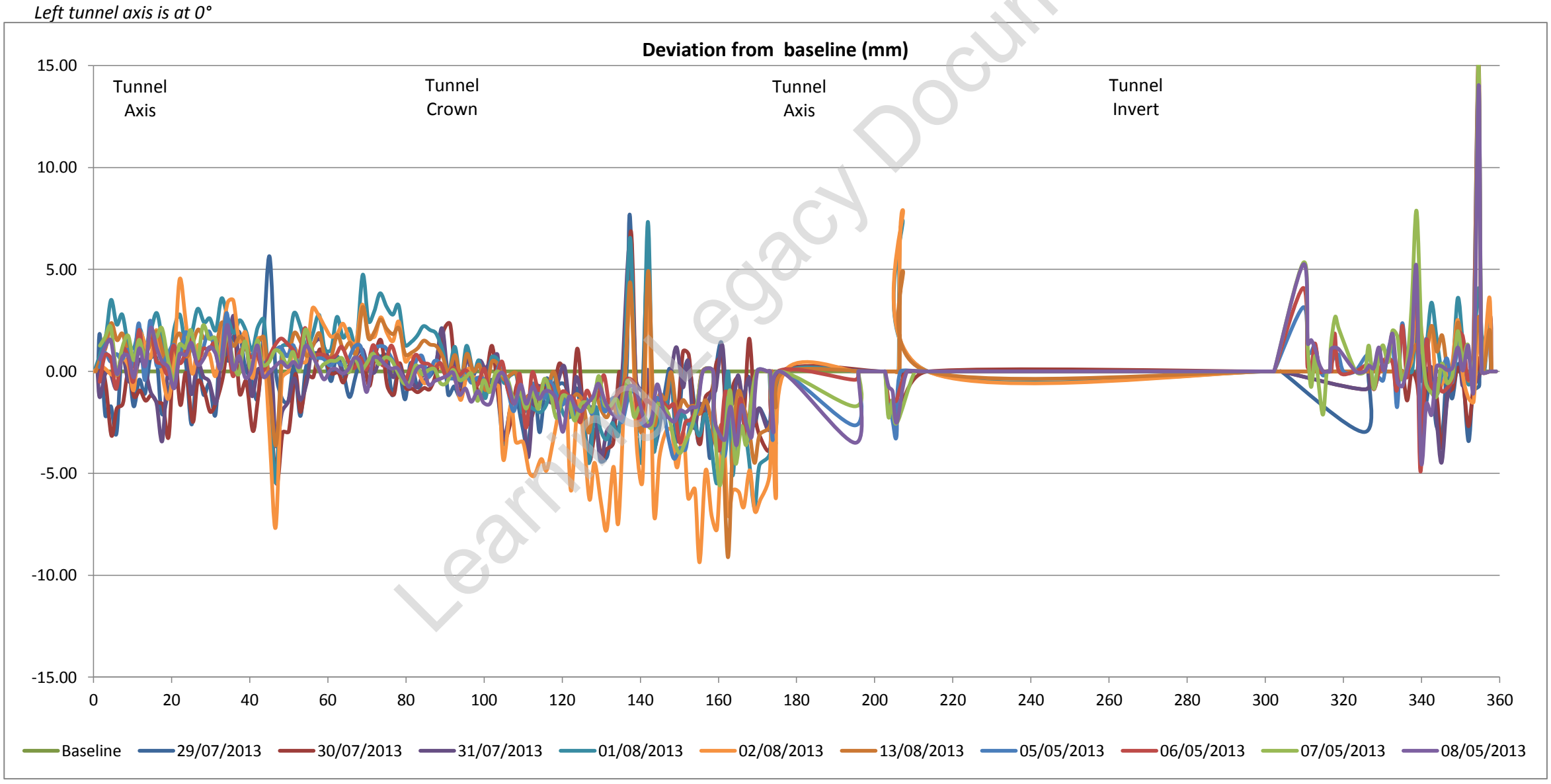
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 957**

Deviation vs Profile

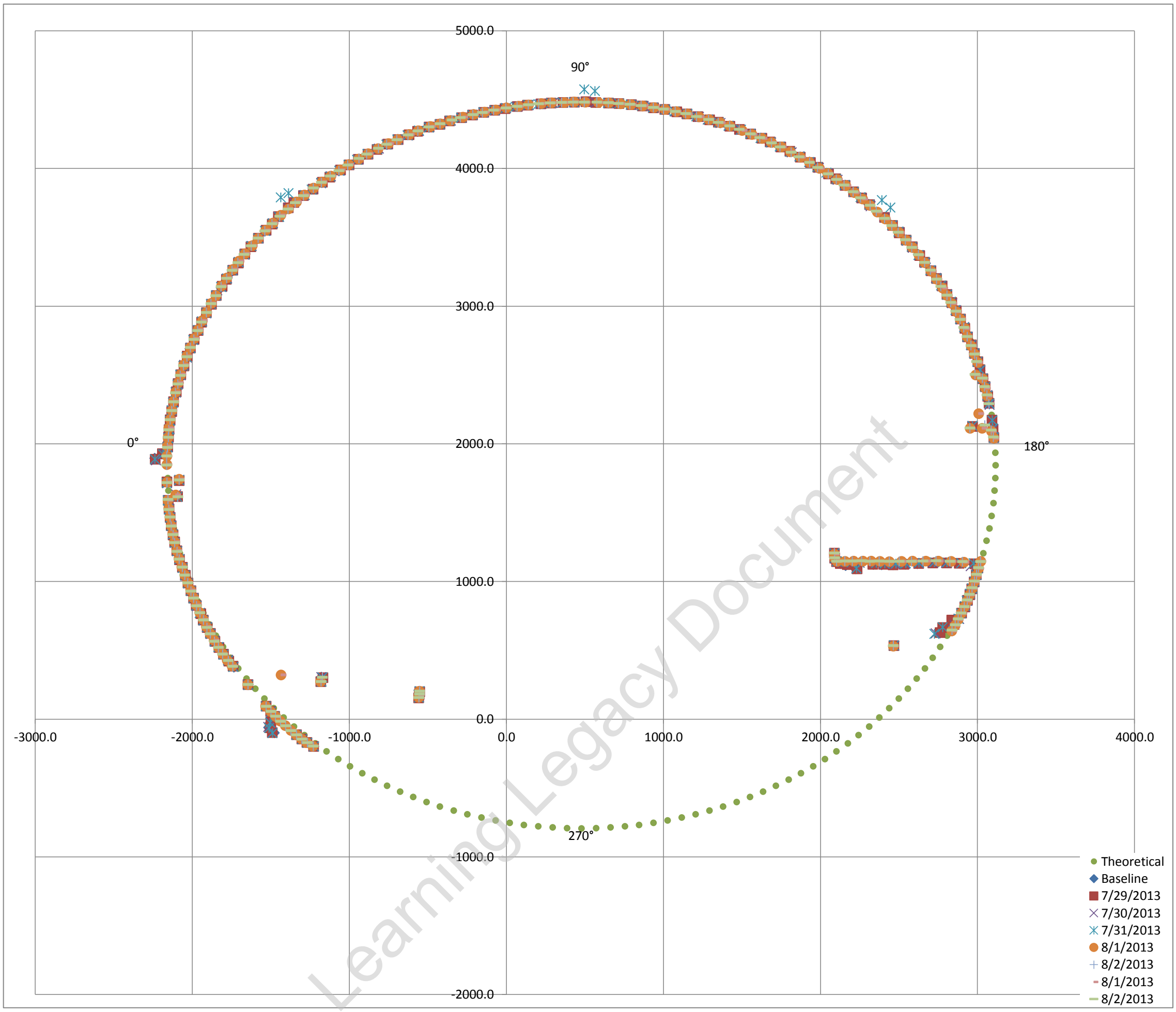


Left tunnel axis is at 0°



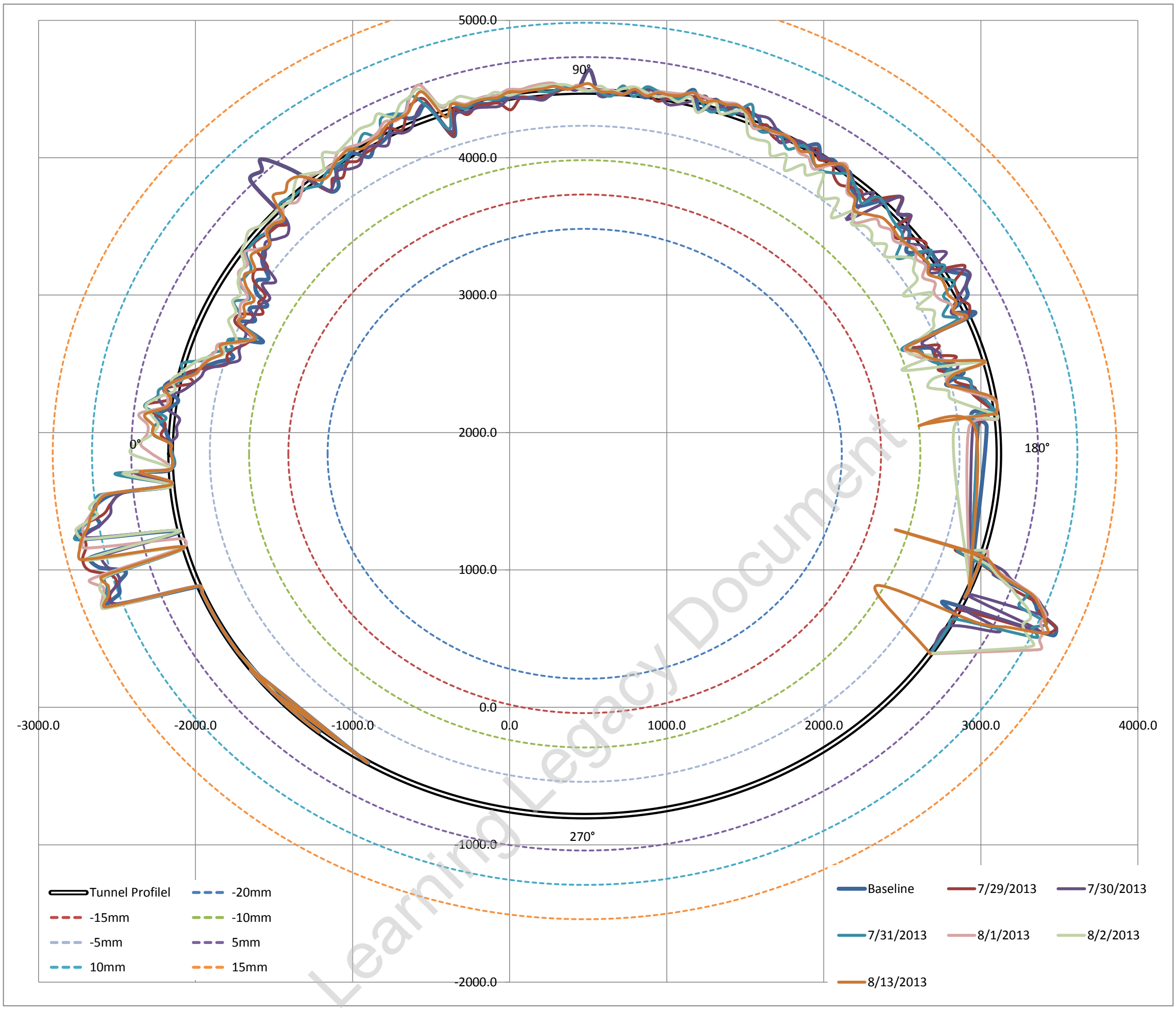
DLR LINE: UP **SECTION: 958**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **958**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5275.68	mm
Estimated best fit as built diameter	**5274.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.03189%	

i.e. Average surveyed diameter varies on 0.031% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.8**	**-9.2**
Max / Min deviation % to estimated dia	**0.49%**	**-0.35%**

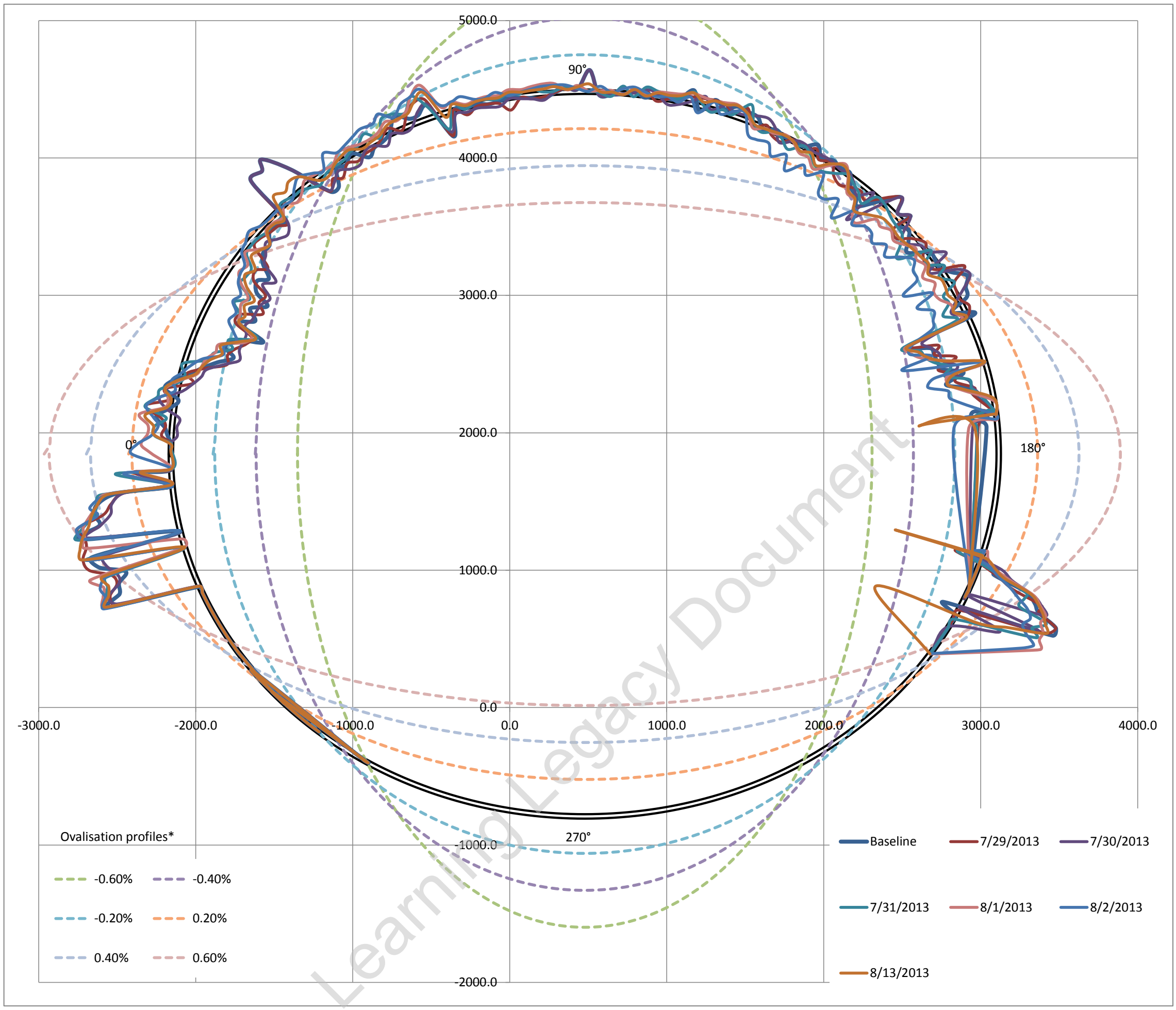
Fitted Circle Coordinates

Axis	X	478
	Y	1845
Radius		2637

Estimated best fit as built diameter	5274	mm
Designed diameter	5300	mm
Average diameter difference	**-26**	mm
Average radial difference	**-13**	mm
Average difference%	**-0.49%**	

DLR LINE: **UP** **SECTION:** **958**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

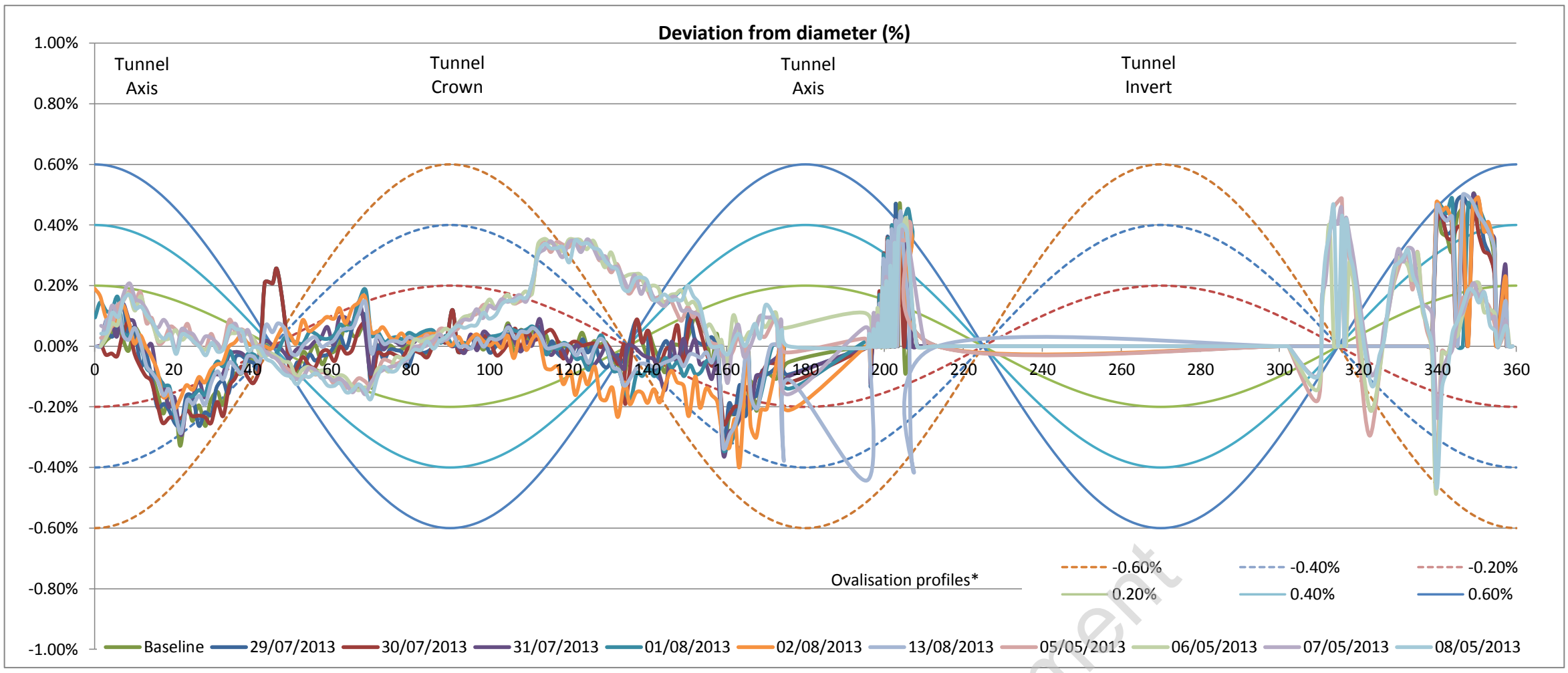
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	#VALUE!	mm
Estimate of vertical diameter at crown, Dv	5273.57	mm
Dh / Dv	#VALUE!	

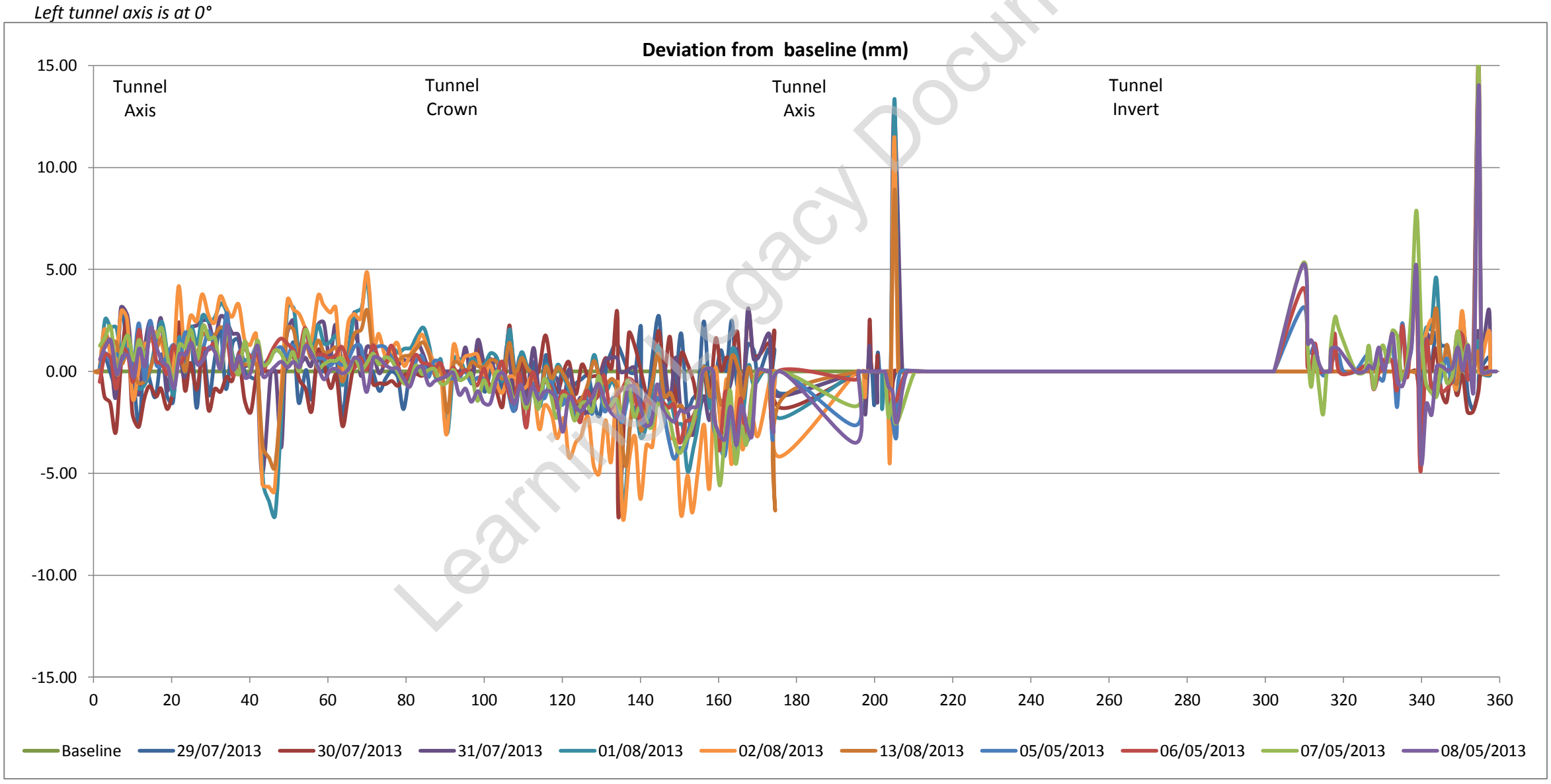
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 958**

Deviation vs Profile

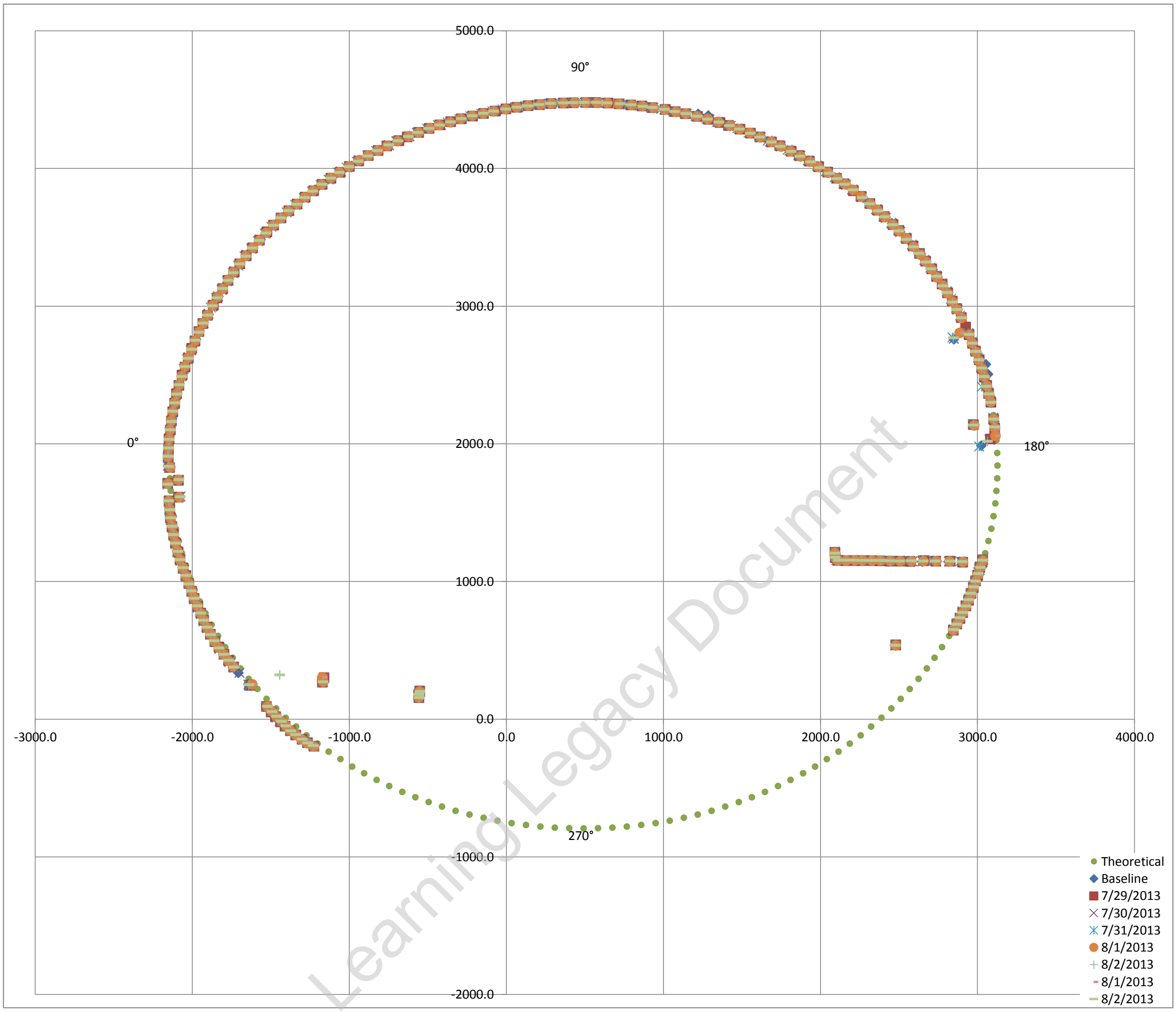


Left tunnel axis is at 0°



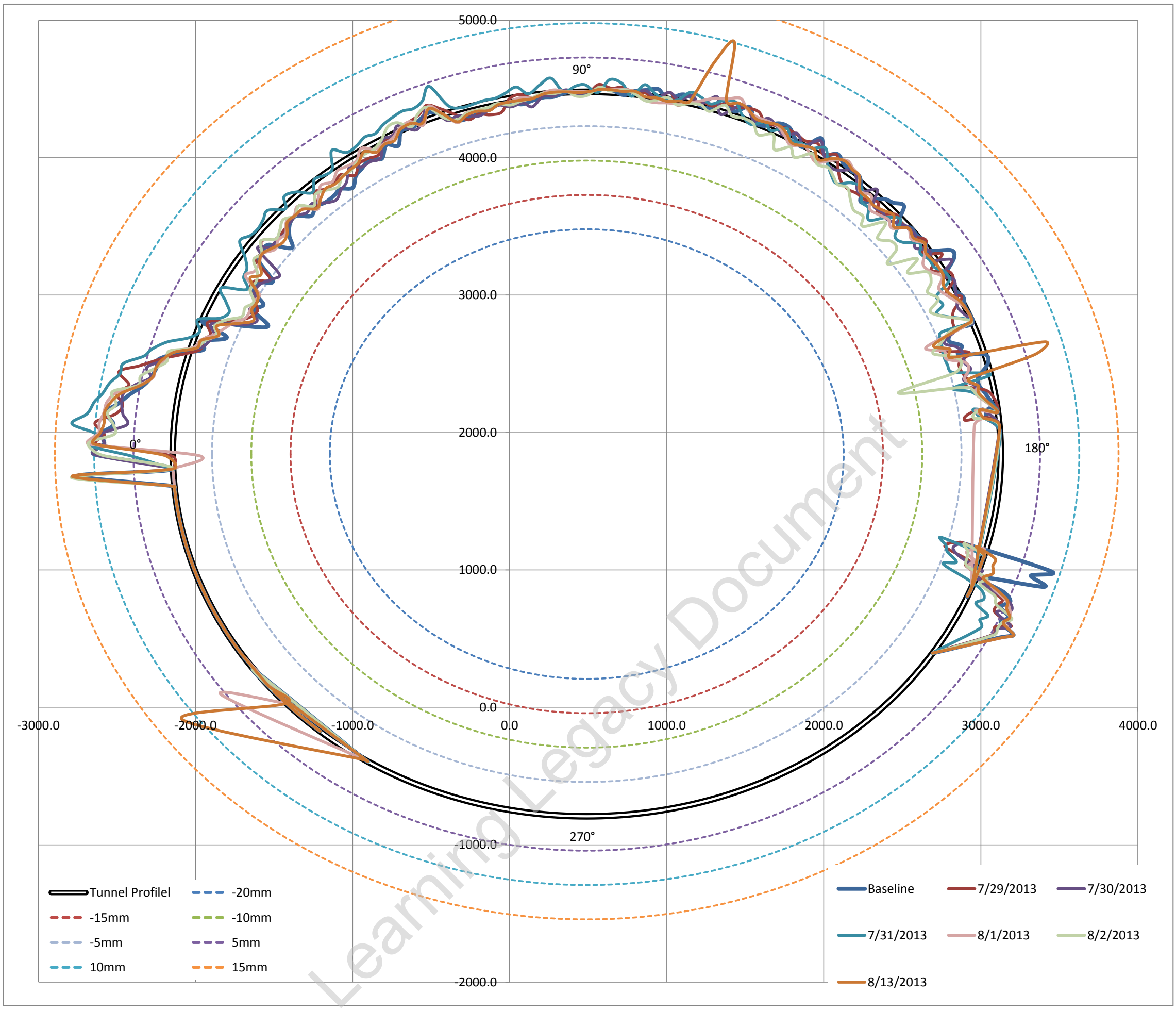
DLR LINE: UP **SECTION: 959**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **959**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5272.88	mm
Estimated best fit as built diameter	**5272.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.01668%	

i.e. Average surveyed diameter varies on 0.016% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**11.7**	**-7.3**
Max / Min deviation % to estimated dia	**0.44%**	**-0.28%**

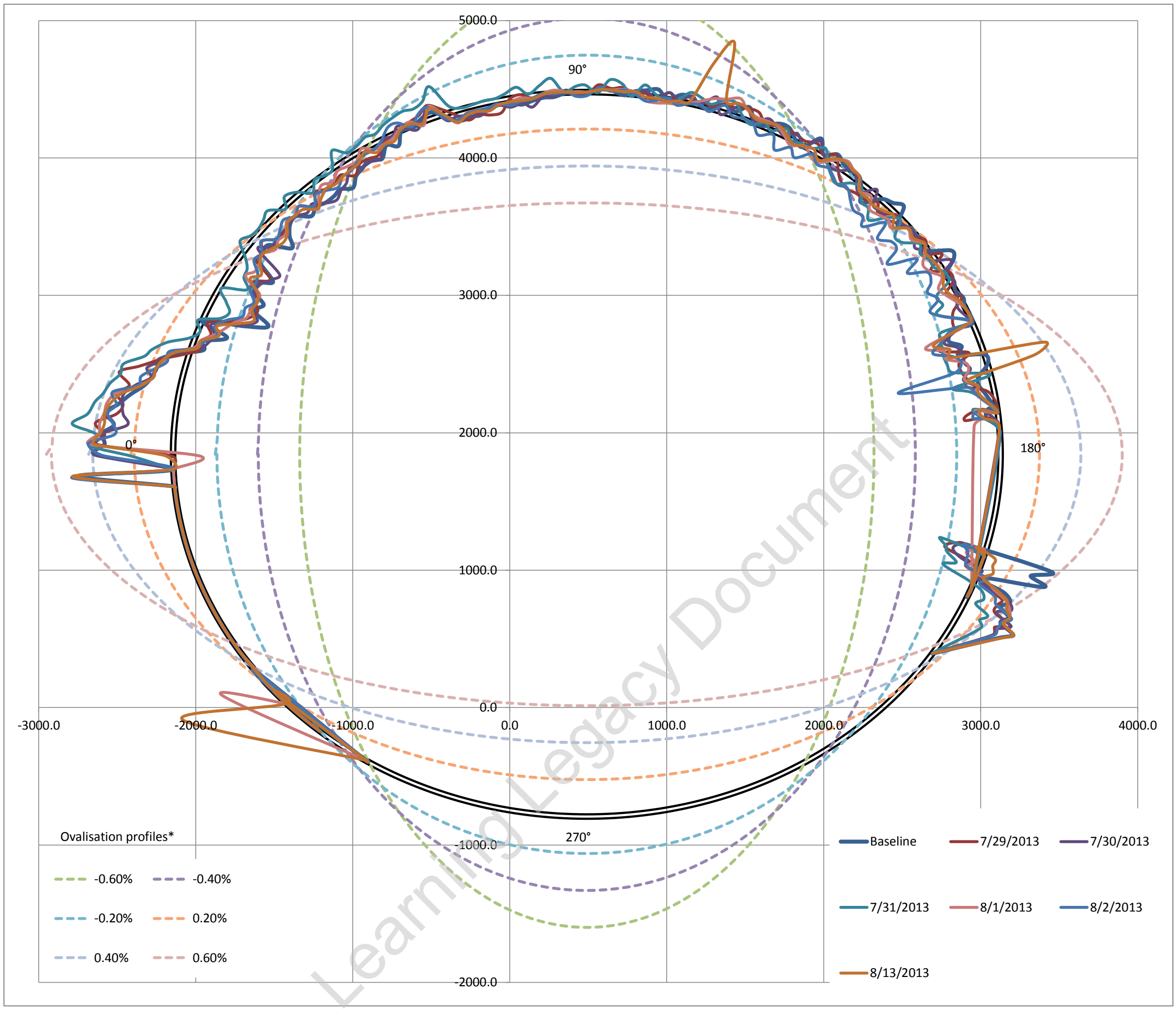
Fitted Circle Coordinates

Axis	X	491
	Y	1843
Radius		2636

Estimated best fit as built diameter	5272	mm
Designed diameter	5300	mm
Average diameter difference	**-28**	mm
Average radial difference	**-14**	mm
Average difference%	**-0.53%**	

DLR LINE: **UP** **SECTION:** **959**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

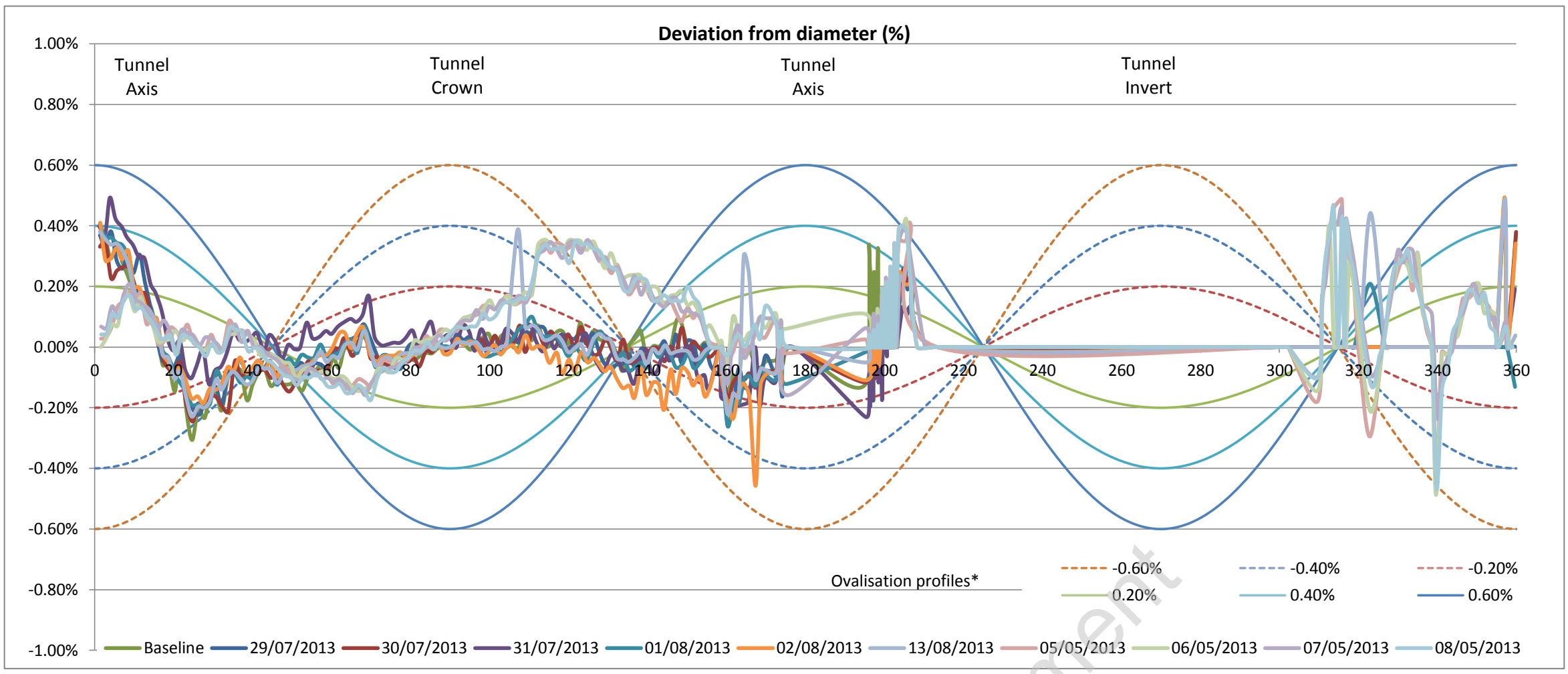
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5277.51 mm
Estimate of vertical diameter at crown, Dv	5272.40 mm
Dh / Dv	1.0010

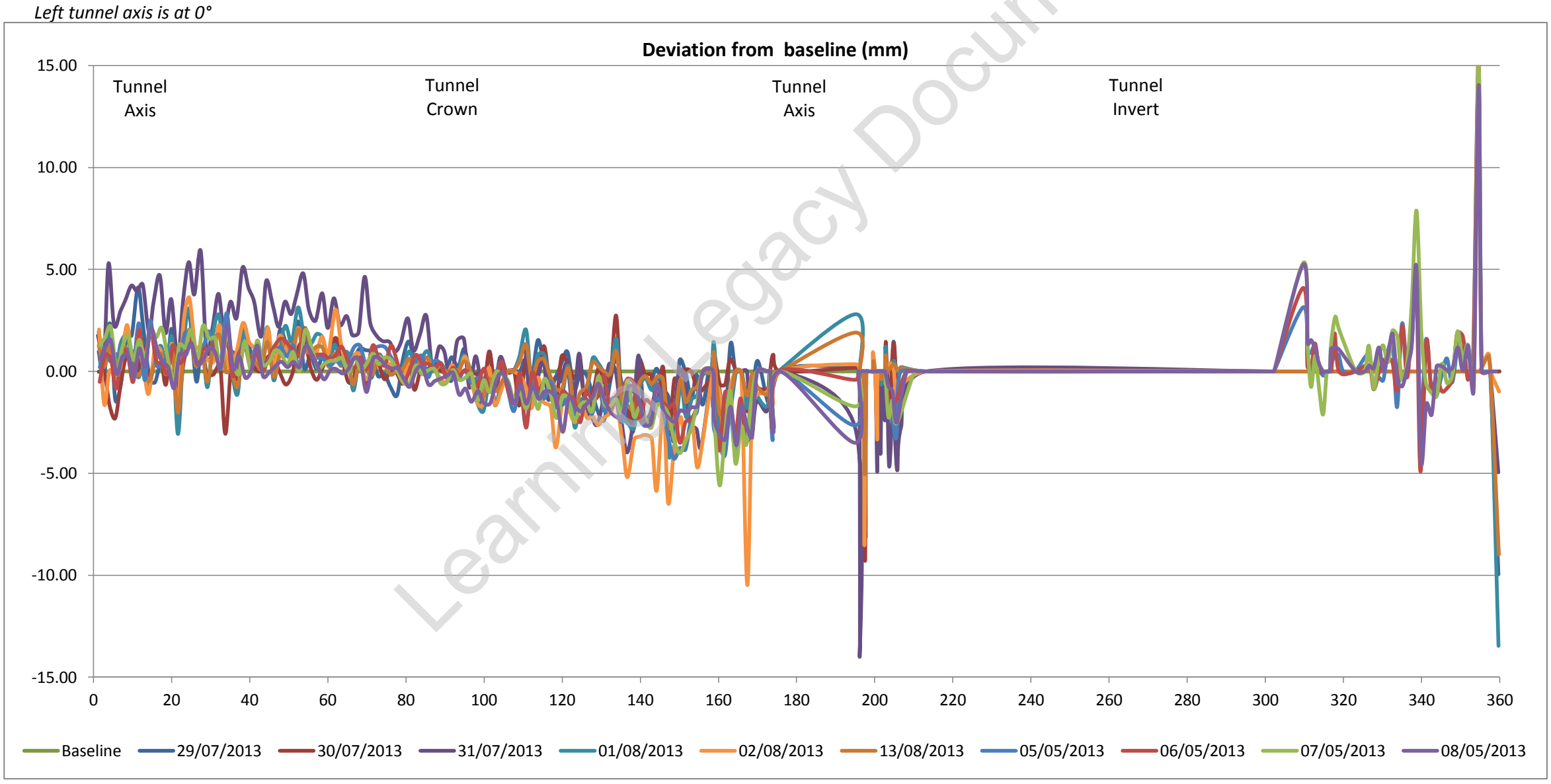
Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 959**

Deviation vs Profile

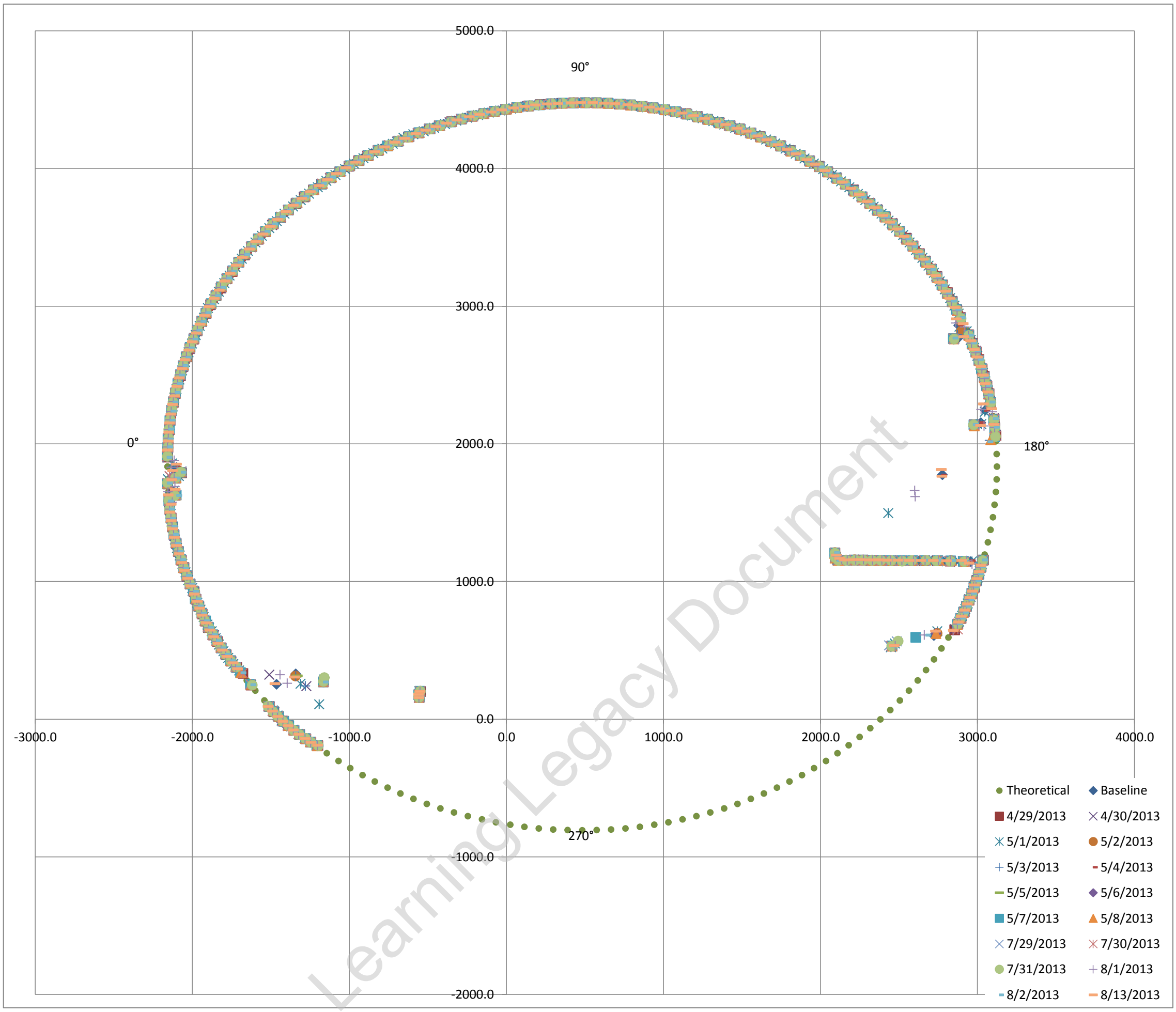


Left tunnel axis is at 0°



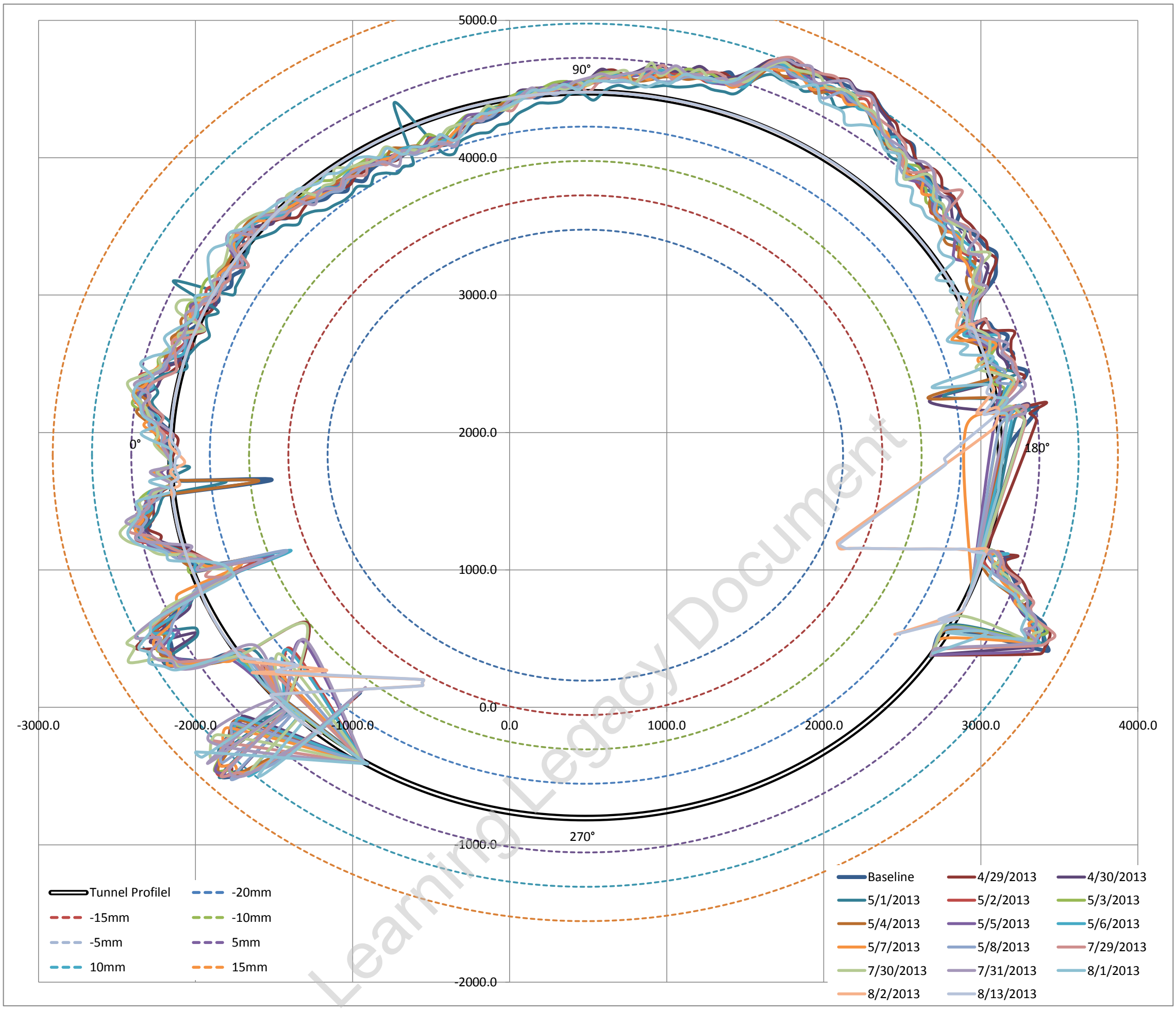
DLR LINE: UP **SECTION: 961**

Tunnel profile from laser scans (raw data)



DLR LINE: **UP** **SECTION:** **961**

Exaggerated tunnel profile from laser scans. Displacement contours indicated



Average surveyed diameter	5288.31	mm
Estimated best fit as built diameter	**5282.00**	**mm**
Difference between average surveyed diameter and best fit diameter	0.11948%	

i.e. Average surveyed diameter varies on 0.119% (ave) from estimated best fit as built diameter

Max radial difference (+ve) / (-ve) (mm)	**12.4**	**-9.3**
Max / Min deviation % to estimated dia	**0.47%**	**-0.35%**

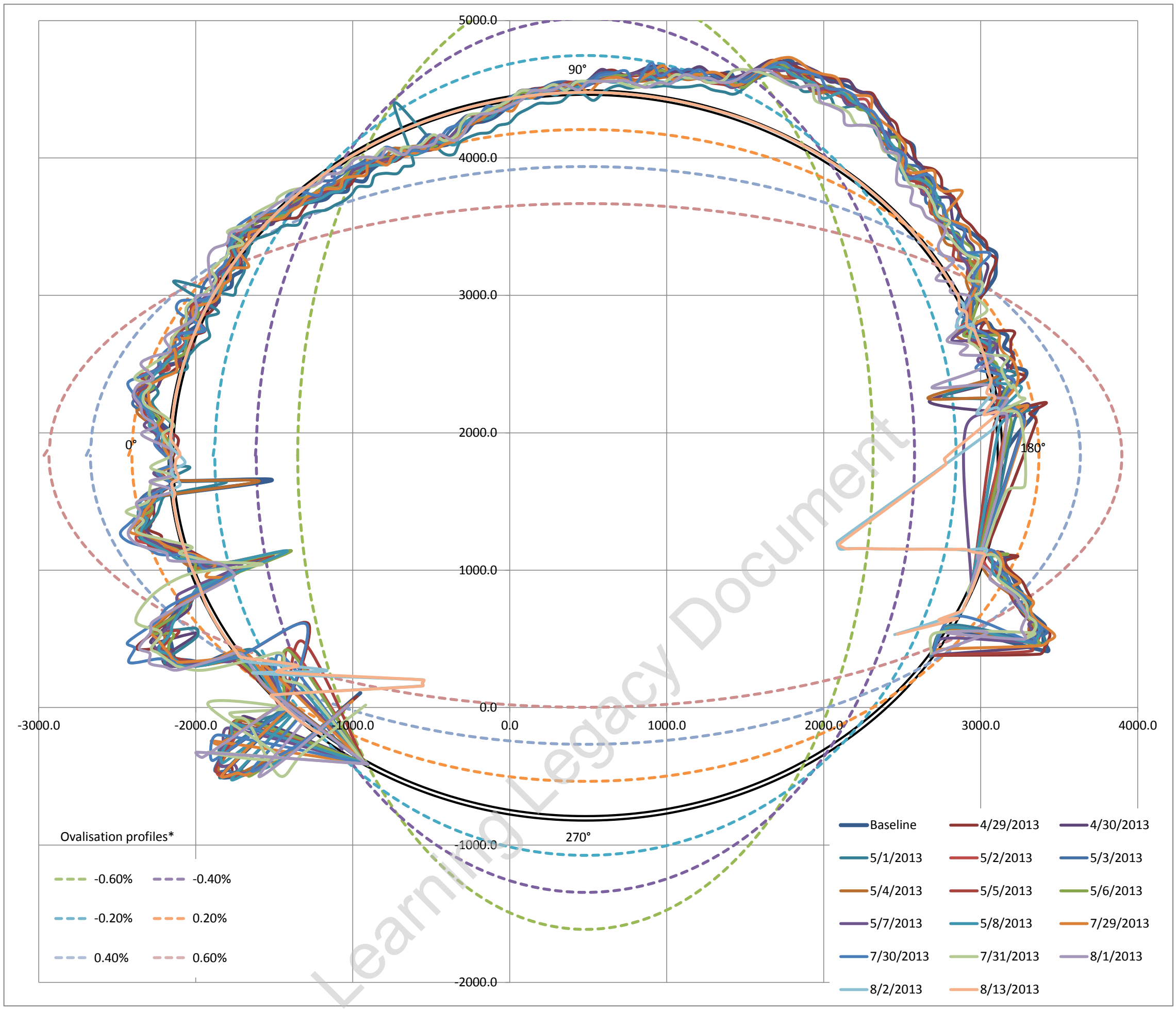
Fitted Circle Coordinates

Axis	X	482
	Y	1835
Radius		2641

Estimated best fit as built diameter	5282	mm
Designed diameter	5300	mm
Average diameter difference	**-18**	mm
Average radial difference	**-9**	mm
Average difference%	**-0.34%**	

DLR LINE: **UP** **SECTION:** **961**

Tunnel profile from laser scans and ovalisation profiles



Ovalisation profile of tunnel

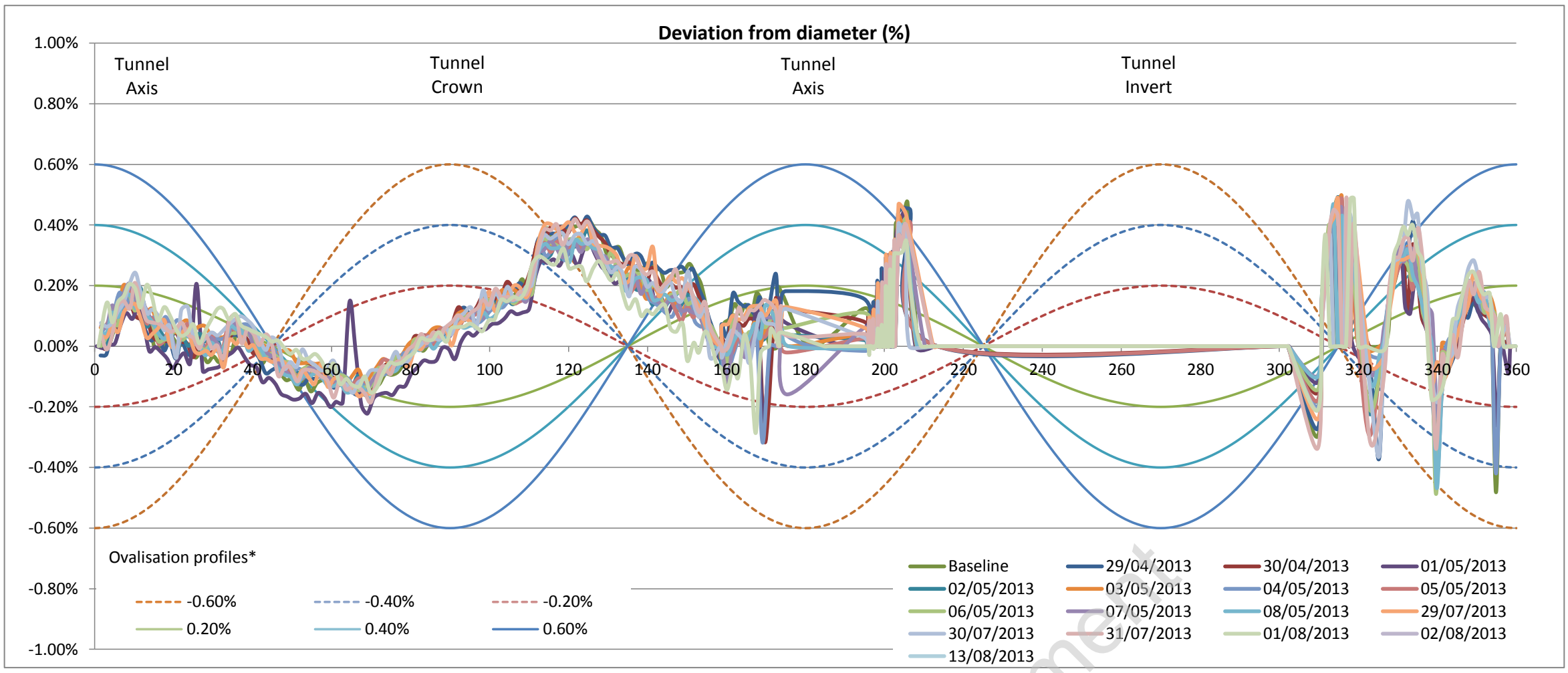
1 Positive ovalisation = diameter at tunnel axis is > diameter at tunnel crown - invert (tunnel squat)
2 Negative ovalisation = diameter at tunnel crown - invert > diameter at tunnel axis ('standing egg')
3 Neutral ovalisation = No discernible tunnel ovalisation

Estimate of horizontal diameter at axis, Dh	5285.84 mm
Estimate of vertical diameter at crown, Dv	5283.86 mm
Dh / Dv	1.0004

Best fit ovalsation profile: **Neutral**

DLR LINE: UP **SECTION: 961**

Deviation vs Profile



Left tunnel axis is at 0°