

High resolution terrestrial laser scanning for tunnel deformation measurements

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Outline

- Introduction – Diabolo project
- Surveying instruments
- Deformation measurements
- Processing scan data
- Analysis cross-section
- Conclusions
- Future research



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Introduction

Diabolo project (Brussels National Airport)

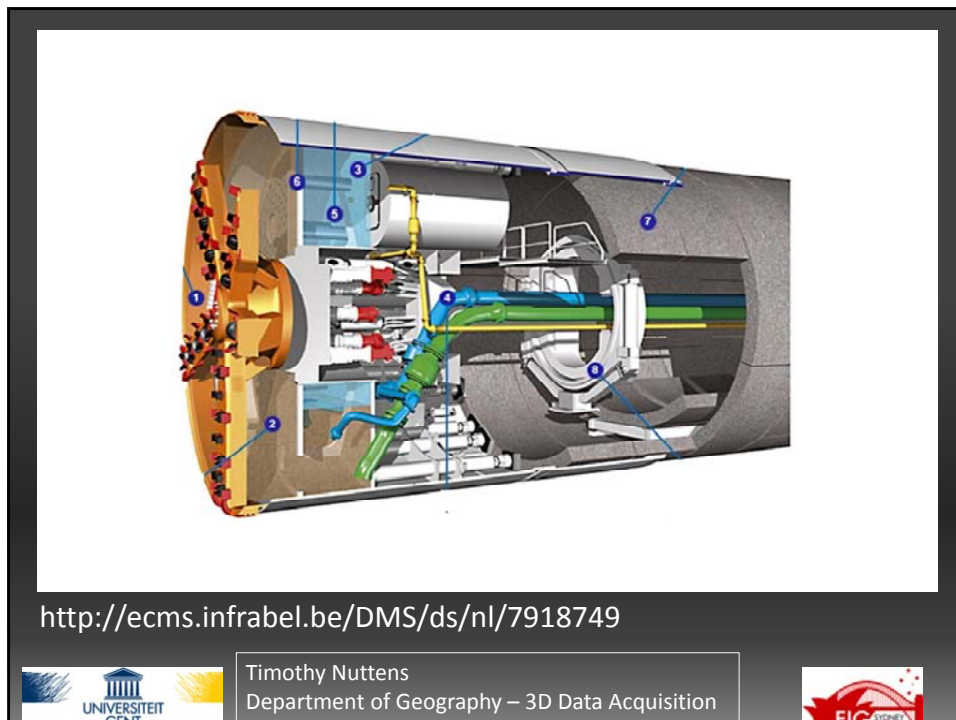
2 tunnels (1.07 km long)

12 sections to monitor

Simultaneous tension measurements

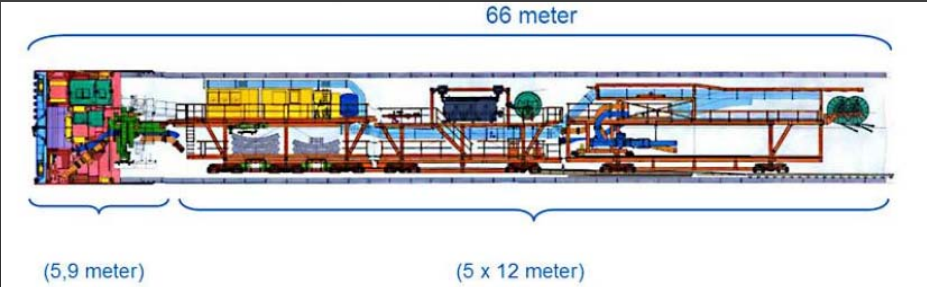


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66 meter

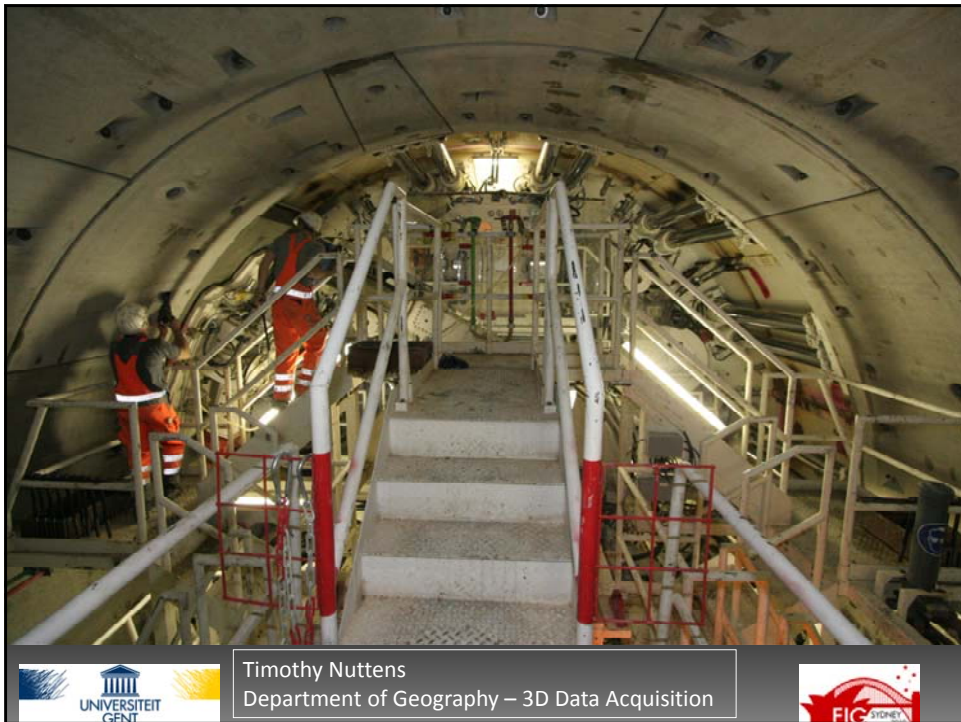
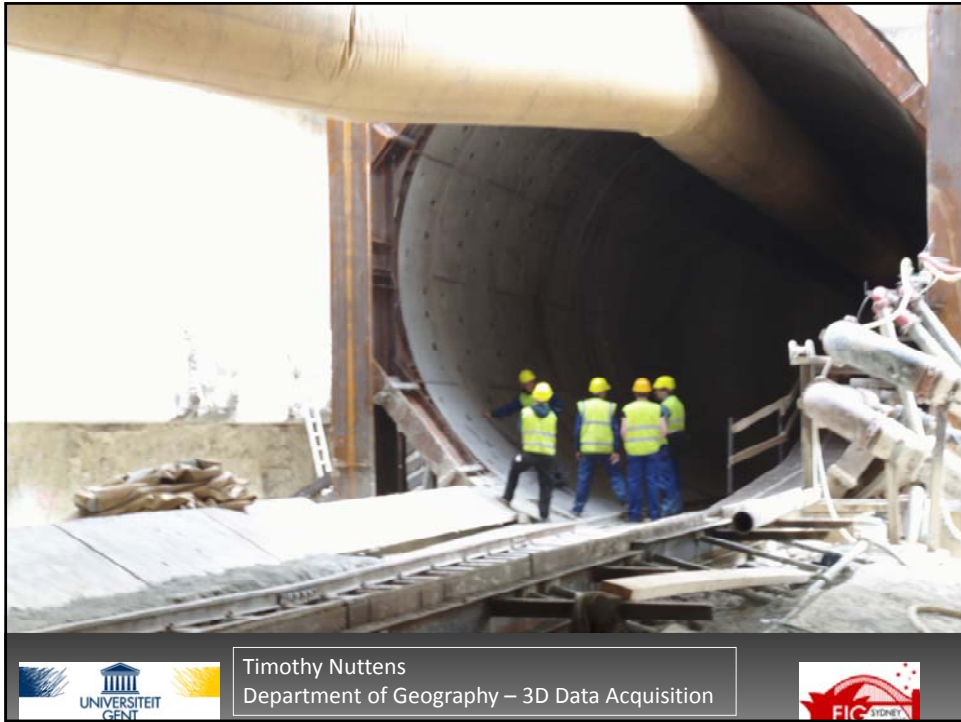
(5,9 meter) (5 x 12 meter)

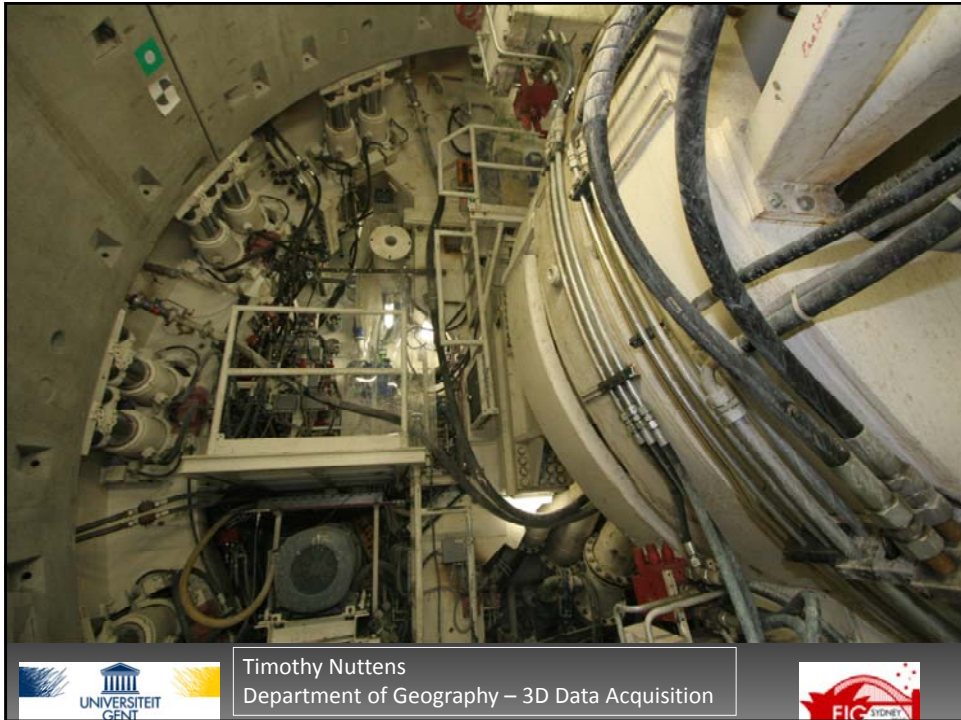
<http://ecms.infrabel.be/DMS/ds/nl/7896402>

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Introduction

Monitoring:
7 measurements per section

- After placement (Measurement 0)
- Every week (1st month) (1 – 4)
- After 2 months (5)
- After 3 months (6)



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Surveying instruments

Laserscanning?

Accurate 3D data (mm-order)

Difficult site measurement conditions

Very high point density (5 mm resolution)

Short time frame (3 – 30 min)



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Surveying instruments

Leica ScanStation 2

Time-of-Flight
Pulse-based

Up to 50 000 pts/sec



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Surveying instruments

Leica HDS 6100

Phase-based

Up to 500 000 pts/sec



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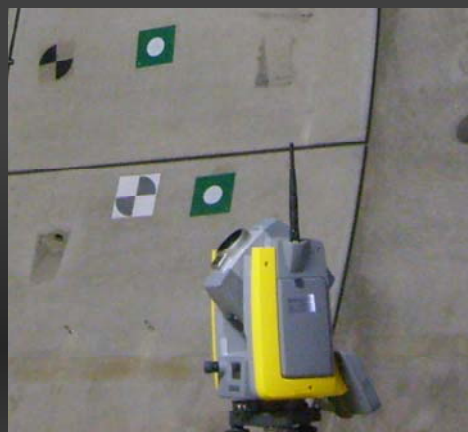


Surveying instruments

Trimble S6

Robotic Total Station
with scan function

1 pt/sec



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Surveying instruments

Experimental standard deviation

| Scanning instrument | Experimental Standard Deviation (mm) |
|--|--------------------------------------|
| Leica ScanStation 2 Pulse-based Laser scanner | 1,6 |
| Leica HDS6100 Phase-based Laser scanner | 0,4 |
| Trimble S6 Robotic Total Station | 0,8 |

(When using 5 gon smoothing)



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Deformation measurements

Scanning positions:

- Left / Right tunnel bracket
- Central position on tripod

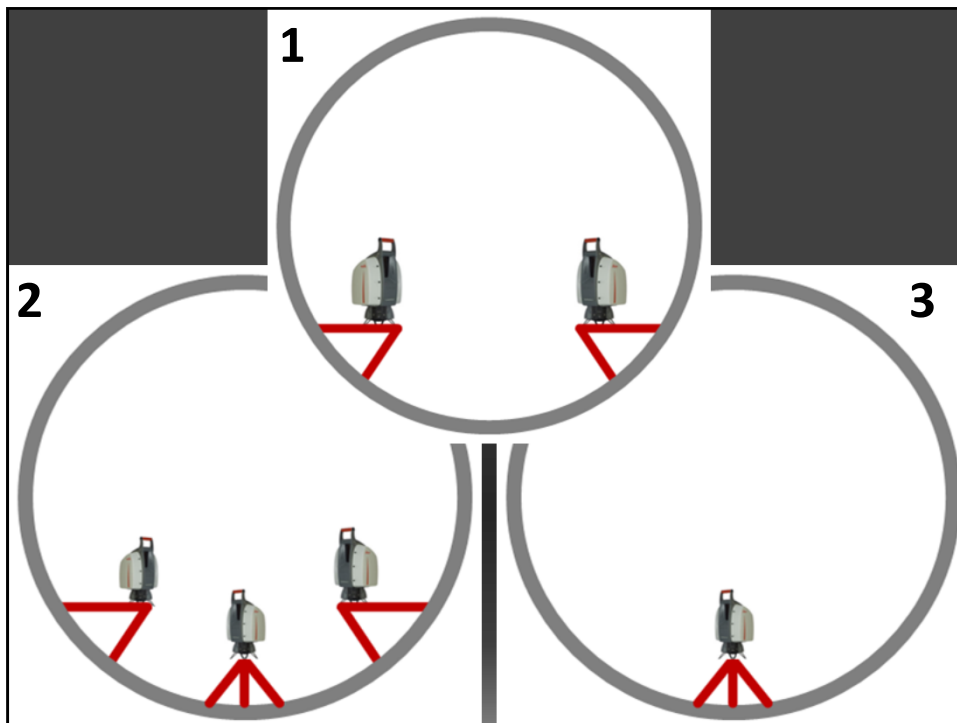
Depending on site conditions

Resolution = 5 mm or higher



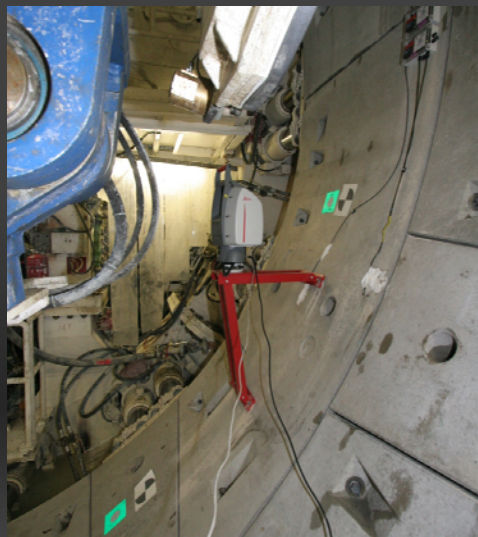
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Deformation measurements

Targets



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Processing scan data

- Filtering point cloud

Laserscanning:

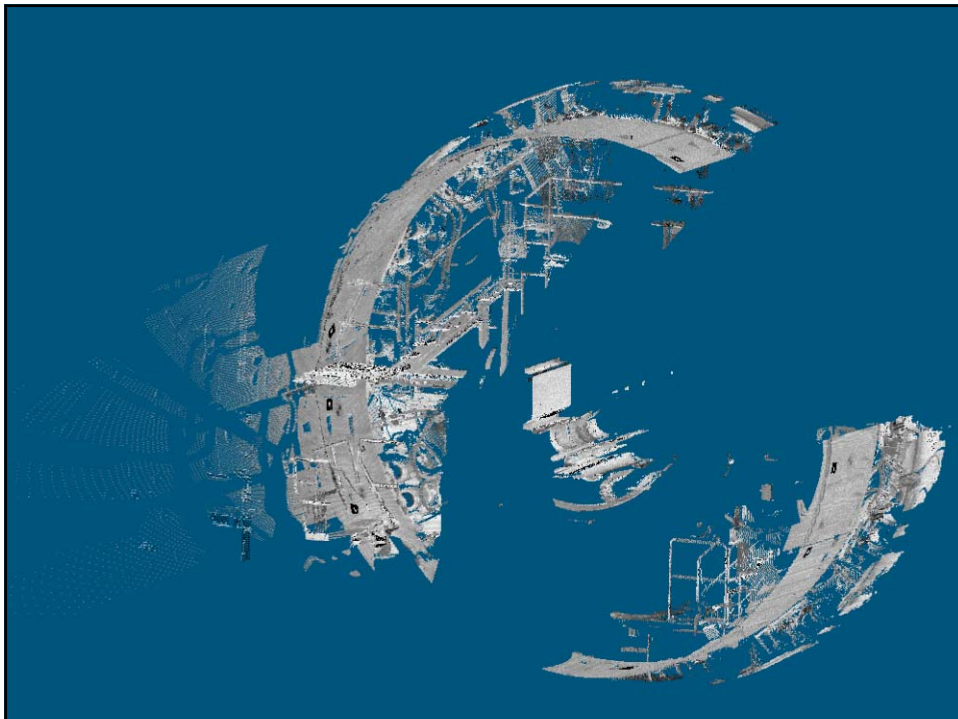
1.7 – 20.4 million ---> 1.0 – 6.7 million

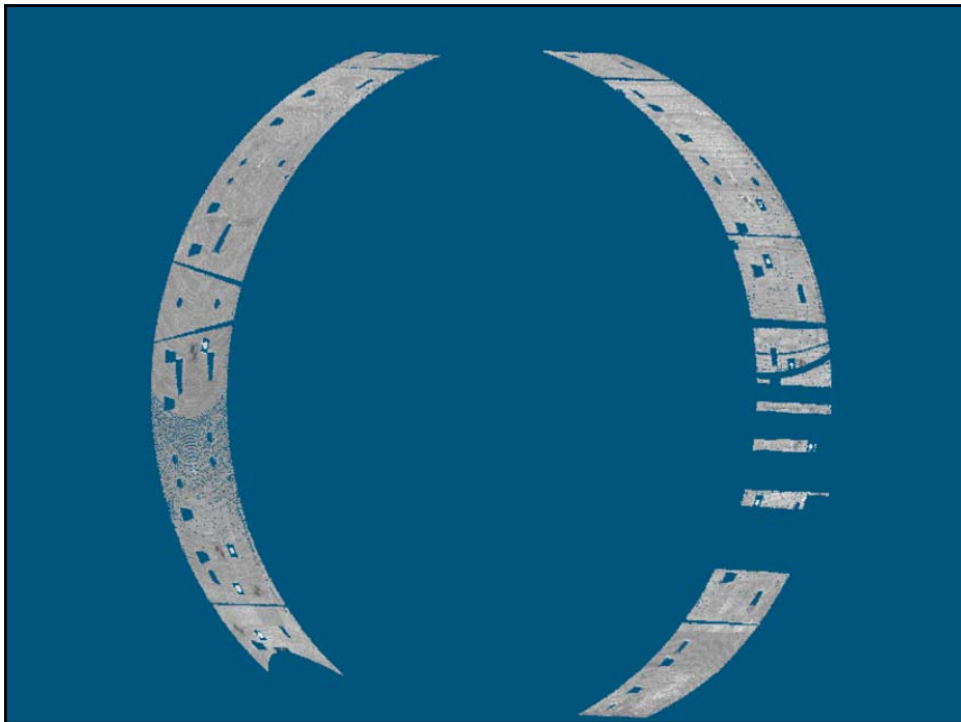
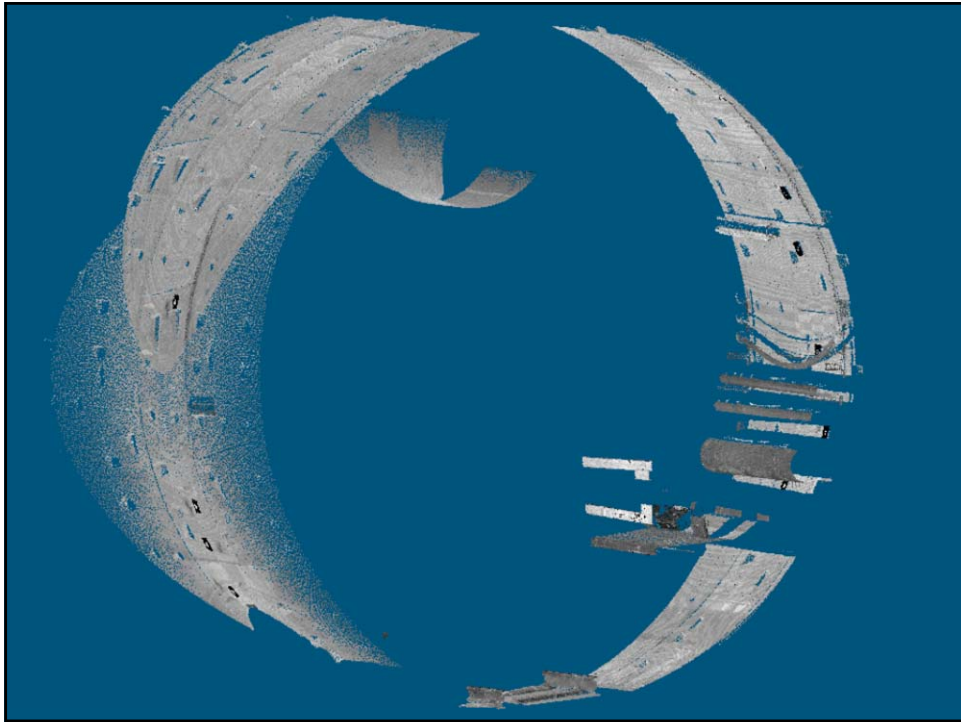
Robotic total station:

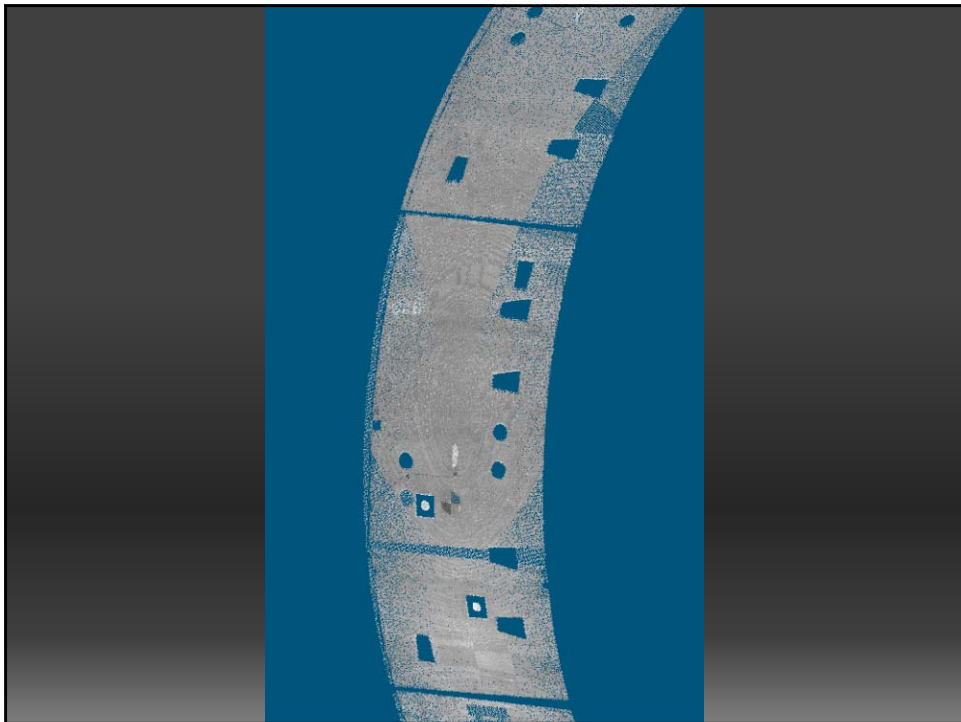
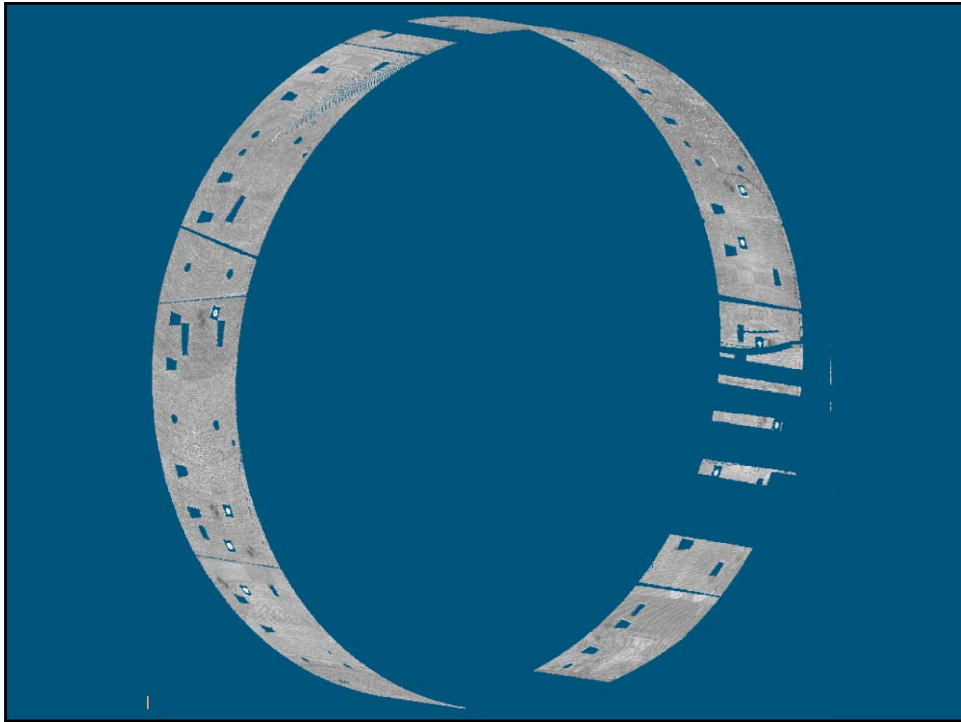
360 – 720 points



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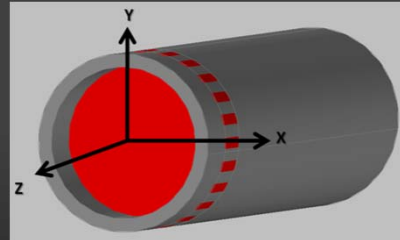


Processing scan data

- Best-fit cylinder

- Mesh

- Cross-section using Master Reference Target



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Analysis cross-section

Radius every 0.1 grad

Smoothing (5 grad)

no excessive noise

minimal difference standard
deviation

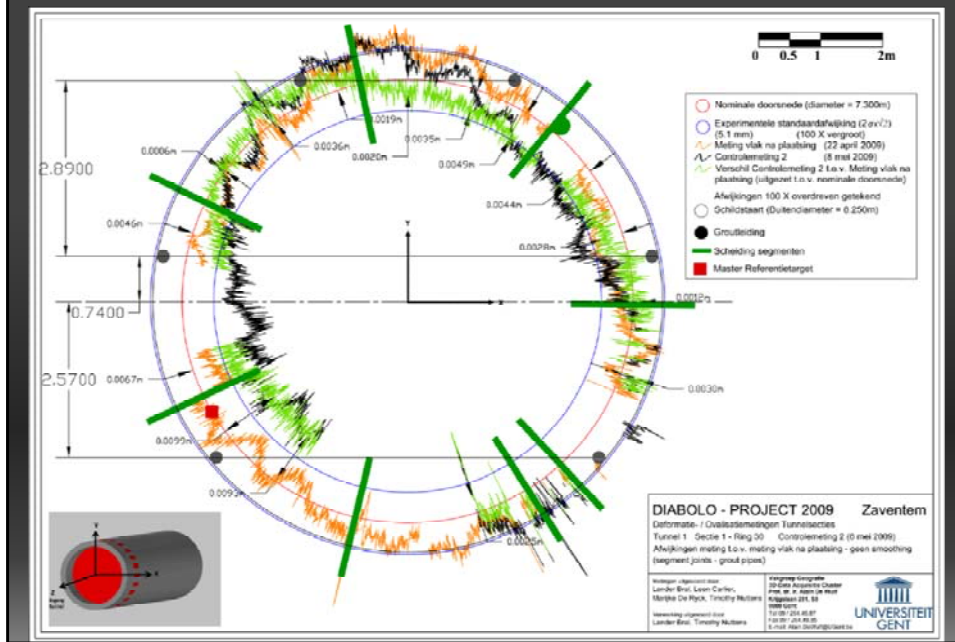
significance of displacements does
not alter substantially



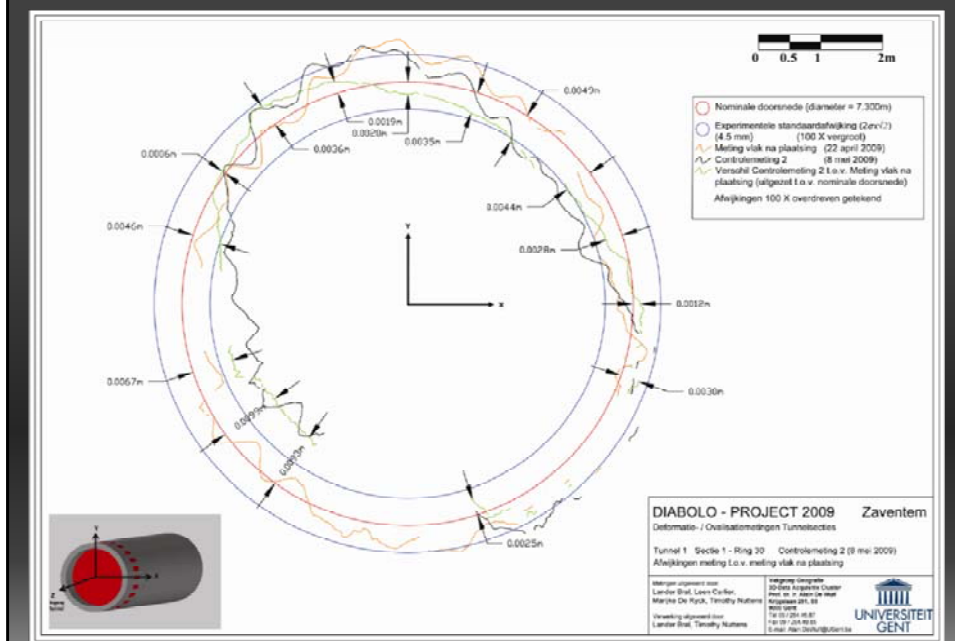
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Non-smoothed



Smoothed



Analysis cross-section

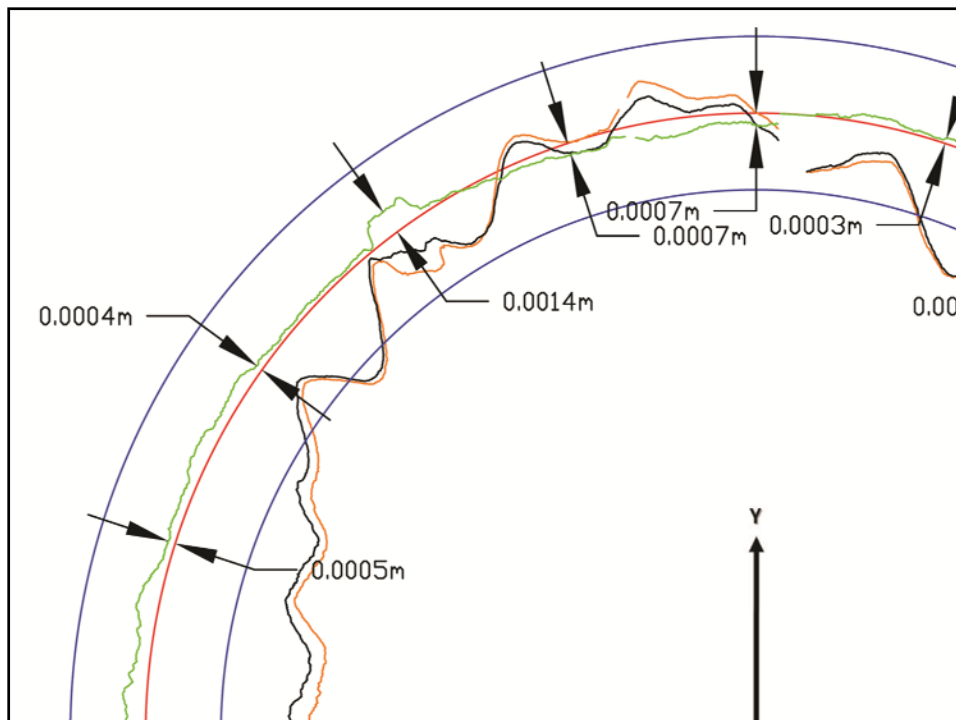
Cross-section drawings
Measurement i compared to:

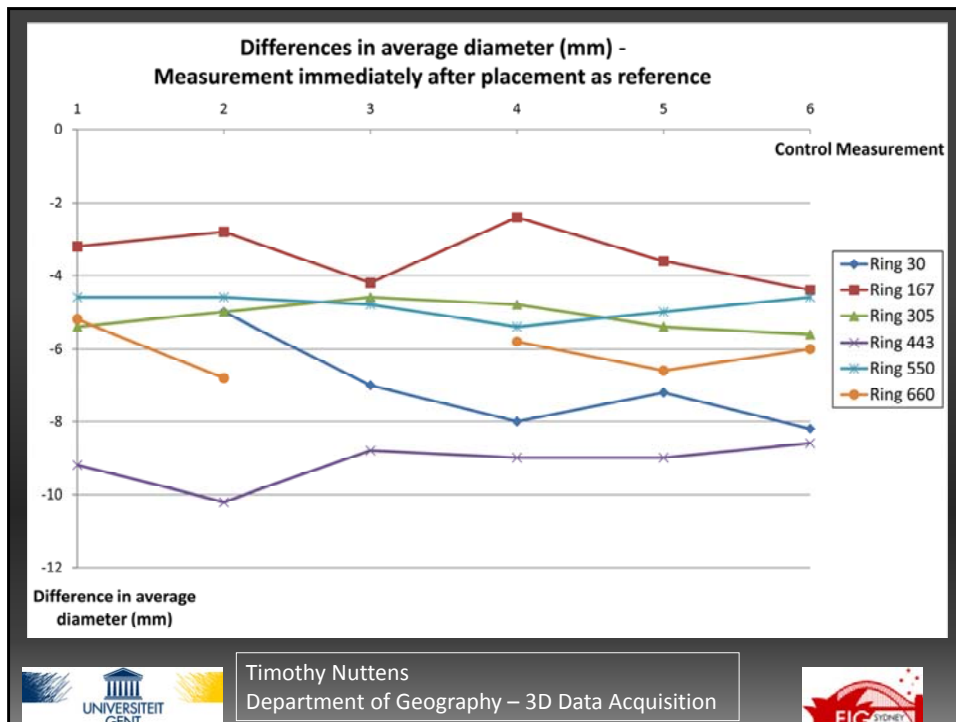
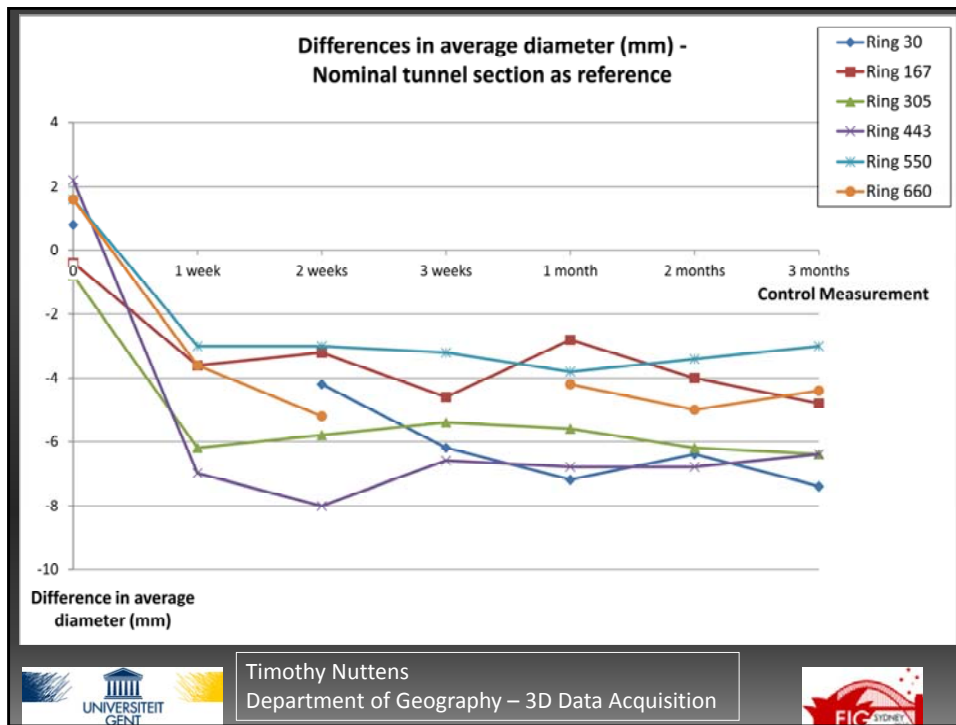
- Design (radius 3.650 m)
- Measurement 0
- Measurement $i-1$

2 sigma intervals (depending on instrument)



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Conclusions

- High accuracy in difficult site conditions (mm order)
- Phase-based scanner best results
- Workflow to process scan data
- Determination of the deviations of the cross-sections
- Stabilization after 1 – 2 week(s)



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Future research

- Optimization workflow
- Correlation with tension measurements
- Best-fit segments
- General trends in movement tunnel

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