Geodetic Deformation Measurement and Analysis of the ATLAS Experimental Cavern at CERN

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1. Introduction
   Main subject
   Monitoring and research motivation

2. Object
   Introduction of objet
   Floor presentation
   Walls presentation

3. Methodology
   Introduction of the measurement technique
   Equipment
   Survey monuments
   Network

4. Measurement
   Data extend
   Floor deformation
   Walls deformation
   Systematic of movement

5. Conclusion

Designs in presentation are coming from www.cern.ch or own sources. Otherwise, it is explicitly marked.
The project takes into consideration the following topic:

- Geometrical behaviour of the ATLAS cavern from July 2003 to Dec 2019
- Relationship between the cavern deformation and position of the experiment
- Movement causing factors, their direction and characteristic
- Conclusions concerning the ATLAS experiments and other underground facilities with high precision alignment demands
Why is the monitoring going on?

- The high alignment requirements for the ATLAS experiment
- The scale of the LHC accelerator complex
- Underground constructions instability
- Influence of the cavern deformation on the detector position

In this context it should be considered that the civil engineering specification of the ATLAS experimental cavern did not include any limits for the deformation of the cavern.
Why is it relevant for future?
ATLAS cavern region – geology

sandstone

marl

https://en.wikipedia.org/wiki/
LEP and LHC upgrade
ATLAS cavern - geometry

\[ ~100 \text{ m} \]
Overview of the ATLAS cavern

Measurements of USA and US wall in the perpendicular direction to the wall plane

Measurements of the base slab in 3D. Analysis separately for 1D (vertical) and 2D (horizontal) direction
Base slab – the floor

Position of the survey points on the base slab

https://www.google.com/maps
USA wall – survey network

Area of connection of USA and US wall by direct measurement Side A

Not all points are presented Design only for illustrative purpose

Area of connection of USA and US wall by direct measurement Side C

Position of the survey points on the USA wall
USA wall – survey network

Survey gallery on level 4 A-side

Level 6

Level 4

Level 0

Survey gallery on level 4 C-side

Position of the survey points on the USA wall

Not all points are presented
Design only for illustrative purpose
US wall – survey network

Area of connection of USA and US wall by direct measurement Side C

Level 6

Level 4

Level 0

Position of the survey points on the US wall

Area of connection of USA and US wall by direct measurement Side A
ATLAS cavern stability prediction

The civil engineering predictions for the ATLAS base slab:

- 2.0 mm down before ATLAS installation
- 5.5 mm down due to ATLAS installation
- 1.0 mm/year up caused by ground pressure
- < 1.0 mm/year up to stabilisation period
Detector position requirements

- Internal accuracy of the assembly required 0.0X mm for the pixel detector.
- Internal accuracy of the assembly required 0.X mm for outer muon chambers.
- Relative 0.5 – 1.0 mm with respect to the accelerator.
Vertical reference
Horizontal reference

Horizontal reference (WPS)

UPS 14

USA wall

Base slab

US wall

SIDE A

SIDE C

UX 15

UPS 16

Beam line

Horizontal reference (WPS)
HLS and WPS system

**WPS**: Monitoring a 'long' direction, 2D measurements
  - conducting stretched wire (carbon peek)

**HLS**: Monitoring a 'large' plane
  - water surface (communicating vessels)
HLS bedplates monitoring

HLS Bedplate System

Old picture

TAUSA

TCUSA

Trench C

USA

BCUSA

BMUSA

BMUS

BCUS

BAUSA

BAUS
Coordinate system

The most important factors taken into account during network calculation

- Local geoid model
- Curvature of Earth
- Difference Ellipsoid to Geoid
  - up to 100 mm due to Jura and lake
Measurement principle – 3D polar trigonometry

Measurement of:
- Horizontal angle $\alpha$
- Vertical angle $\beta$
- 3D distance $d$

Allows to find:
- Coordinate difference $\Delta X$
- Coordinate difference $\Delta Y$
- Coordinate difference $\Delta Z$
Measurement principle – optical levelling

Measurement of:
- Height of point $H_1$
- Height of point $H_2$

Allows to find:
- The height difference $\Delta H$
Measurement equipment

- **Wild NA2**
  - Standard deviation for 1km double run levelling ±0.2 mm

- **Wild TC2002**
  - Angle (Hz, Vz) ± 1.5 cc
  - Distance ± 1 mm + 1 ppm
  - After 150 µm calibration for the indoor measurements

- **Leica AT401**
  - Angle (Hz, Vz) ± 1.5 cc
  - Distance ± 10 µm
  - Distances measure up to 80 m

https://shop.wild-heerbrugg.com/
Survey monuments
Survey monuments
Data extend and sorting

Overview of the measurement epochs in the time for the floor and the walls
Displacement of the base slab points 1D (I)

- Heave detected for majority of epochs (exceptions in period 2003-2009)
- Maximum vertical deformation $4.9 \text{ mm}$
- Average accuracy of points $\pm 0.09 \text{ mm}$ (period 2006-2019)
- Average accuracy of points $\pm 0.18 \text{ mm}$ (period 2003-2005)
- Average accuracy of points $\pm 0.35 \text{ mm}$ (July 2003)
- Largest deformation in central part
- Relatively stable areas in the corners
Displacement of the base slab points 1D (II)

- The base slab deformation has a significant influence on the experiment position
- The centre of the floor is the most interesting due to proximity of ATLAS feet
- The cluttered area of the measurement in certain periods
- Influence of asymmetric layout of trenches
- ATLAS feet shifted towards US wall
Displacement of the base slab points 1D (III)

Vertical displacement of chosen points on the base slab in the period Aug03 - Feb20
Displacement of the base slab points 1D (IV)

- Three phases of ATLAS monitoring
  a) Concrete setting
  b) Detector construction
  c) Operation period

- Three different phenomena have impact on the cavern floor deformation
  a) Concrete setting
  b) Upward earth-pressure
  c) Experiment load
Displacement of the base slab points 1D (V)

Vertical displacement with respect to a previous epoch (mm)

Concrete setting phase
Experiment construction phase
Operation phase

Time

12/13/2021
Witold NIEWIEM | ATLAS Cavern Deformation
Displacement 2D of the base slab points (I)

- Maximum movement not exceeding 1.4 mm excluding Aug 2003
- Average movement 0.3 mm in the period from 2004 to 2019 near ATLAS feet
- A-side and C-side tend to move towards the US wall and the centre
- Radial alignment more important than along the beam
The most important part - centre is stable

Movement of points on A and C sides in the direction of the US lateral wall

Scaling factor observed 2005 – 2008

Poor measurement conditions during ATLAS construction

Progress in the measurement techniques
Displacement of the USA wall

• Deformation is larger on USA wall
• Access to points only from platforms
• Fewer points on the walls than on the floor
• Maximum deformation on USA wall 14.5 mm
• Direction of vector towards the cavern centre
• Displacement higher in the centre than in the corners
Displacement of the US wall

Y-direction displacement on the US wall diff = DEC18 - DEC17
Statistic (mm): Min = -0.48, Max = 0.07, Mean = -0.11

- Deformation is smaller on US wall
- Access to points only from platforms
- Fewer points on the walls than on the floor
- Maximum deformation on USA wall 10.1 mm
- Direction of vector towards the cavern centre
- Displacement higher in the centre than in the corners
Conclusion (I)

• Maximum floor deformation is 4.9 mm towards the centre of the cavern
• Maximum deformation US wall 14 mm
• Maximum deformation USA wall 10 mm
• Wall deformation 3 times higher than the base slab
• Maximum deformation in the center
• Geometrical asymmetry of deformation
• Constant direction of the movement *
• Accelerator and experiment move up
Conclusion (II)

- Floor stability fundamental for ATLAS
- 3 main phases of the base slab movement
- Vertical deformation lower than the forecast
- The predicted vertical heave of 1 mm/year has never been reached
- The highest average heave since beam start has been 0.33 mm/year
- Horizontal stability of the floor in operation phase
- Maximum horizontal deformation in the floor centre 0.3 mm
- Asymmetry of the heave could provoke the radial displacement of the detector
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