INITIAL DEFORMATION OF THE PETRA III SLAB

Markus Schlösser, DESY, Hamburg

Abstract

During the conversion of PETRA from a pre-accelerator for HERA to a synchrotron radiation source, one eighth (“octant”) of the tunnel ring was excavated and replaced by the new PETRA III experimental hall.

The concrete slab of this hall is a monolithic block with a size of roughly 300x30m² and a thickness of 1m. Movements due to temperature variations and setting of the concrete are discussed. Methods of predicting future movements are developed.

INTRODUCTION

The floor of the PETRA III experimental hall is a monolithic slab made from reinforced concrete with a size of approximately 300m x 30m. It has a thickness of 1m plus an additional concrete bed of another ~1m. It consists of various layers (figure 1), where the bitumen gliding sheet is of special importance. It decouples the movement of the top layer from the base layer. Since for the accelerator installation only the movement on the top layer is important, we can ignore any (horizontal) movements of the base layer.

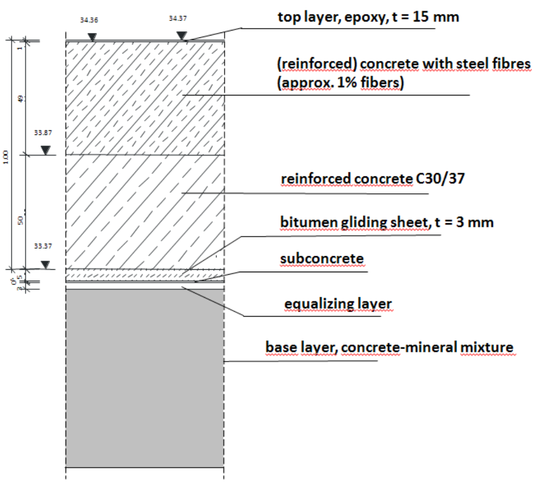

Figure 1: cross section of the PETRA III slab [1]

SETTING OF CONCRETE AND TEMPERATURE VARIATIONS

During the setting time of the concrete, the temperature was recorded at various positions and in different layers. Figure 2 und figure 3 show four temperature measurements from the gliding bed up to 10cm below surface, as well as the air temperature.

During the setting of the concrete a temperature of up to 40°C was measured in the middle of the top layer, named “gliding bed + 50cm” in figure 2 and 3. A daily variation of the air temperature of approx. 1K as well as the activation of air-condition can be seen in figure 3.

Figure 2: Temperature measurement between 12/2007 and 04/2009

Figure 3: Temperature measurement between 05/2008 and 11/2008

Since the installation of accelerator components had to begin well before the activation of the air condition and thus before the final temperature of the concrete was reached, a later movement of the components had to be assumed. A rough calculation with $\alpha_{concrete} = 10 \cdot 10^{-6} / K$, $\Delta T = 6K$ and the length of the slab being $l \approx 300m$ gives a longitudinal expansion of $\Delta l \approx 18mm$. Since the movers for most components have a range of a few mm only, a model for the movement of the slab surface had to be introduced. This should ensure that after the slab reaches the final temperature of 22°C each component is close to its nominal position.

ANALYTICAL MODELS

Model A

The first network measurement was made in May 2008, with a slab temperature of 16.2°C. Since the shape of the slab is in principle a section of an annulus and the top layer is free-floating on its gliding bed, it was assumed that there is a center point in the middle of the slab, which does not move at all and two lines along the two axes of the slab that don't show tangential resp. radial movement.

With this assumption, a thermal expansion coefficient of $\alpha_{concrete} = 10 \cdot 10^{-6} / K$ from literature and (r, φ) being polar coordinates of a point P, a simple linear model was created, so that the radial movement of a point caused by temperature variation is only dependent of its radial coordinate r and the tangential movement is only dependent on its tangential coordinate φ:

$$\Delta r = \eta(r)$$

$$\Delta\varphi = \xi(\varphi)$$

where both η and ξ are linear functions.

Model B

After a second network measurement was completed in July 2008, with a slab temperature of 20.4°C, it became apparent that the first model is not sufficient. A second linear model was introduced where both η and ξ are again linear functions, but with

$$\Delta r = \eta(r, \varphi)$$

$$\Delta\varphi = \xi(r, \varphi)$$

so that the lines of no movement are no longer represented by the axes of the slab.

Model C

The comparison of the values obtained from model B to the measured values showed that most of the movements between the first epoch at 16.2°C and the second epoch at 20.4°C could be explained by this approach. However, some small inconsistencies of up to 1mm remained, while the error ellipses of the adjusted points were usually below 0.2mm. It is assumed that this is caused by the thermal expansion coefficient of concrete varying slightly over the slab.

To improve the second model, a third model was introduced. Each point gets its own functional description of movement, where only points in close proximity are used to determine the weighted model:

$$\Delta r = \eta\eta(r, \varphi)$$

$$\Delta\varphi = \xi\xi(r, \varphi)$$

Within this model, lines of identical movement are no longer parallel.

MEASUREMENT RESULTS

During the early installation phase with only very few obstacles on the slab, the network was measured at three different epochs. Between the third and fourth epoch there were major installations made on the slab so that only a part of the network could be measured during the fourth epoch. The third epoch was therefore considered as reference.

- 1st epoch: May 2008 16.2°C
- 2nd epoch: July 2008 20.4°C
- 3rd epoch: January 2009 22.0°C
- 4th epoch: April 2009 22.0°C

The total length variation of the slab between 1st and 3rd epoch was about 21.5mm and is shown in figure 4. This gives a mean empirical thermal expansion coefficient of $\alpha_{emp} = 12 \cdot 10^{-6} / K$, which is close to the value obtained from literature.

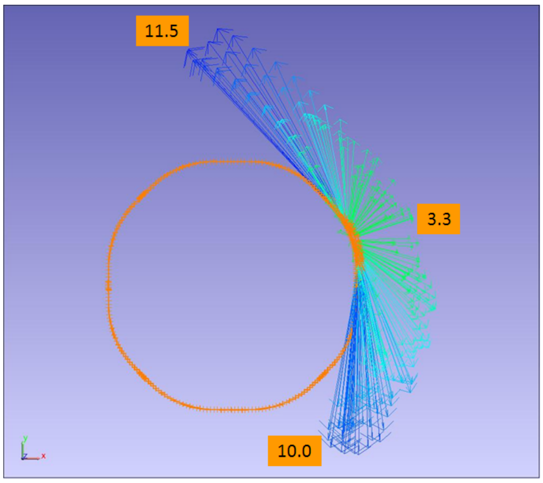

Figure 4: Movement of floor monuments between 1st and 3rd epoch, values in mm

Comparing the predicted coordinates from model A at 22°C with the (a posteriori) knowledge of the third epoch, errors of up to 3.6mm remain, as shown in figure 5. The main part of these remaining errors is pointing in lateral direction and is caused by the fact that the line of no radial movement is not in the geometric middle of the slab, as it was expected, but near to the inner rim.

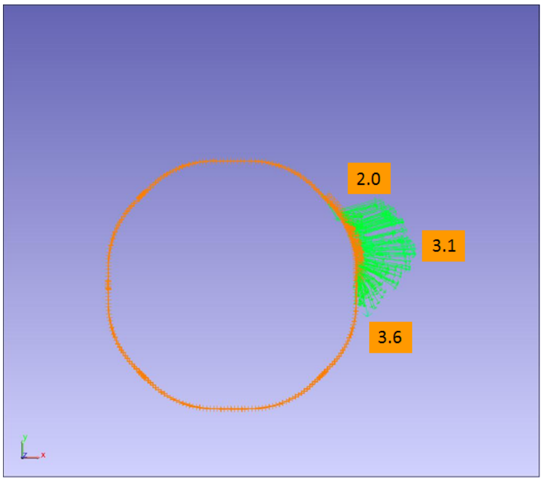

Figure 5: Comparison between prediction of model A and measurements from 3rd epoch, values in mm

The length variation of the slab between 2nd and 3rd epoch was about 5.7mm and is shown in figure 6. The remaining radial movement was about 1mm, again mostly outward from the inner rim of the slab.

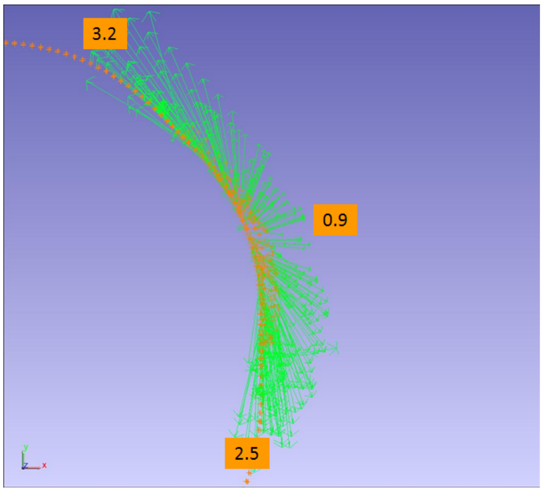

Figure 6: Movement of floor monuments between 2nd and 3rd epoch, values in mm

Comparing the predicted coordinates from model C with the (a posteriori) knowledge of the third epoch, gives remaining errors below 0.8mm, typically below 0.5mm, as shown in figure 7. These remaining errors are distributed randomly over the entire slab. With the limited set of epochs available, a better model does not seem to be possible.

Model C was sufficient for the installation and coarse alignment of all components.

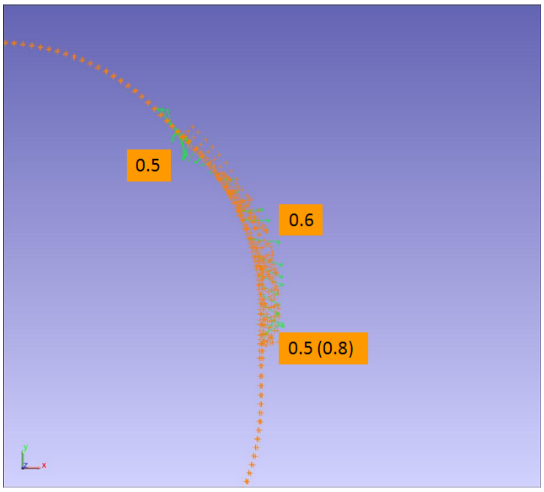

Figure 7: Comparison between prediction of model C and measurements from 3rd epoch, values in mm

Continuing the networks measurements after the slab had reached its final temperature showed unexpected additional movements as shown in figure 8. This was caused by inner tension of the slab that has not been fully released in January 2009. After April 2009 there were no further network measurements possible because of installations in the hall. Therefore it cannot be proven that the movement of the slab has finished after the 4th epoch. The largest movements of floor monuments between 3rd and 4th epoch – both measured at 22°C – were about 1.3mm.

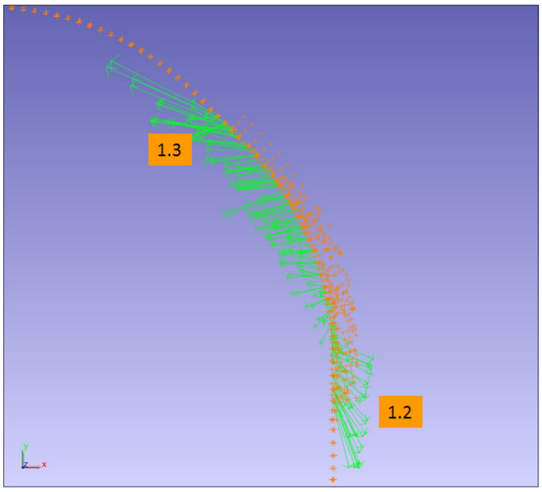

Figure 8: Movement of floor monuments between 3rd and 4th epoch, values in mm

Looking at the height, the floor monuments show variations of up to 1.7mm, typically around 1mm. These movements could only be explained with deformations of the base layer resp. the soil and with the mass of concrete shielding and other installations added to and shifted in the new hall during the installation phase. However, measurements from a hydrostatic leveling system that was installed well after April 2009, indicate that there are no major variations in height any more.

CONCLUSION

The empirical thermal expansion coefficient of the concrete used for the floor slab of the new PETRAIII experimental hall has been estimated to $\alpha_{concrete} = 12 \cdot 10^{-6} / K$. This coefficient is not homogenous over the whole slab, there are some small variations that caused position errors of floor monuments of up to 1mm. An empirical model was introduced to reduce this effect to 0.5mm. This model was sufficient for the installation and coarse alignment of all accelerator components. Even three months after the slab had reached its final temperature, there were still additional movements of up to 1.3mm, caused by the release of inner tensions of the slab.

REFERENCES

[1] Hänisch, Lindemar, „Bau der PETRA III Experimentierhalle“, Presentation, 06.11.07; unpublished