Experimental Measurement of Volume Changes on Cement Concrete Depending on the Subsoil

M. Kropacek and R. Cajka

Abstract. The paper describes experimental measurement of volume changes of cement concrete elements depending on the subsoil. Volume changes of cement concrete (including shrinkage and swelling) are theoretically known and at present there are many calculation models to determine the final shrinkage at the time of the design of the concrete or construction. The subsoil beneath the concrete structure has a significant effect on the volume changes of the concrete, and this behaviour must be considered when designing. However, the calculation models do not consider the influence of the subsoil and friction effects. The experiment described in the article includes the behaviour of different concretes on differently defined subsoils. At the defined input conditions, volume changes have been measured over the long term in different climatic conditions. The result of the experiment is the values of volume changes, depending on the concrete-subsoil interaction.

Keywords: VSB – Technical University of Ostrava, Ostrava, Czech Republic

1. Introduction

1.1. Theoretical Knowledge

Volume changes and their influence on concrete structures are theoretically very well described. In terms of composition, it occurs within concrete based on the hydration of cement as a binder. During the hydration of the cement first occurs the swelling, which gradually, depending on the surrounding conditions, and the chosen curing pass through the gradual shrinkage of the concrete. Shrinkage of the concrete is a known phenomenon, which can lead in the extreme case (lack of curing, wrong design of concrete or construction) to cracks. Volume changes are thus based on the composition of the concrete. Ambient climatic conditions significantly affect these volume changes in terms of speed and significance. In terms of volume changes, the influence of temperature and the associated expansion (volume changes due to temperature) of concrete must also be mentioned. All these chemical processes and cement concrete properties are theoretically well described and have been in the past given significant attention. (Aïtcin 2008, Aïtcin & Mindess 2011, Collepardi 2010, Tazawa 1999)

Knowledge and experiments have produced calculation models, that can determine the final shrinkage in the long term at the time of designing the concrete construction. Calculation models are a large amount. The most commonly used is the model in the technical standard Eurocode 2 (CSN EN 1992-1-1 2006), because is in base technical standard for designing concrete structures. Similar principles of calculation are provided by the MC2010 model (FIB 2010), which improves limits of model from Eurocode 2. Currently the most sophisticated calculation model is model B4 (Bazant 2015). This model considers large number of parameters and boundary conditions, thus allowing for any change in the composition of the concrete in the calculation. In addition to the above models, there are many other calculation models with different approaches to calculation. However, there is no model to con-
sider the influence of the subsoil and the friction level on the lower surface of the concrete element or the whole construction.

In the interaction of concrete base-subsoil occurs friction that is caused by many phenomena. An important necessity to consider friction is for example when using prestressed foundations (Sekanina & Cajka 2009). However, friction occurs also in the case of volume changes at the lower surface of the concrete structure in contact with the subsoil, so sliding joints that reduce the shear forces in the base joint need to be considered. In general, sliding joints can be divided into two types. The first one is stack of several materials, e.g. two layers of polyethylene foils with sand interlayer, which then form a sliding joint and the resulting stress depends only on the friction coefficient μ. The second method is to use materials having visco-elastic properties, typically asphalt membranes. When using asphalt membranes, it was found that the horizontal forces at the base were reduced due to shrinkage and creep. (Bradac 1991, Bradac 1996, Cajka 2005, Cajka & Manasek 2005, Janulikova 2014, Sekanina & Cajka 2009)

The general principles for reducing friction include surface treatment at the sliding joint. This is to ensure the smoothest surface of the underlying concrete, the subsoil, the bottom surface of the foundation structure etc. In practice, this can be solved by additional compacting. During the concreting prevent segregation of coarse aggregate fractions at the bottom. After casting the concrete, adjust the surface of the finishing trowel or vibratory bar etc. Another way is to reduce the length of the concrete sections. The above steps can effectively reduce the friction coefficient.

Table 1. Friction coefficient for foundations joints (Schweighofer & Kollegger 2013)

| Base layer             | Sliding joint | Friction coefficient |
|------------------------|---------------|----------------------|
| Gravel                 | No sliding joint | 1.4 – 2.1           |
| Sand                   | No sliding joint | 0.9 – 1.1           |
| Cohesive soil          | No sliding joint | 0.5 – 0.8           |
| Sand                   | No sliding joint | 0.9 – 1.1           |
| Cohesive soil          | No sliding joint | 0.5 – 0.8           |
| Base concrete smooth   | 1 layer PE foil | 0.8 – 1.4           |
| Base concrete smooth   | 2 layers PE foil | 0.6 – 1.0          |
| Base concrete rough    | 2 layers PE foil | max. 2.0 (h = 0.3 m) |
|                        |               | max. 1.3 (h ≥ 1.5 m) |
| Base concrete rough    | 1 or 2 layers avg. 0.45 (h = 0.3 m) | avg. 0.2 (h ≥ 1.5 m) |
|                        | bitumen memb. |                     |

Sliding joint using visco-elastic properties include materials such as asphalt membranes, mastic asphalt, or other similar material. When assessing a suitable material, it is always necessary to assess their properties based on experimental tests based on shear stress. Regarding materials such as asphalt, it is essential to assess the properties based on temperature. (Janulikova et al. 2012)

In an experiment to determine the coefficient of friction of the sliding stack of prestressed floors, it was found that the concrete-concrete contact had such high friction that in practice it would not be sheared off and the stack behaved more like composite element. Furthermore, it was found that the pure foil assembly had a low coefficient of friction and showed low horizontal forces in the shear test. When using the sand assembly, the friction is higher, however, under load there is no loss of contact between the slab and the subsoil. In terms of prestressing, a low friction coefficient of assembly is generally preferable with respect to free deformation and insertion of a higher prestress. (Hornikova et al. 2016)
1.2. Previous Research
This article describes the results of an experiment, which directly follows the previous experiment made by the authors. The previous experiment was based on measurements volume changes of concrete C 30/37 - XC4 on large-dimensional specimens, where was selected as a sliding joint polyethylene foil. The results showed a significant difference between the shrinkage of the specimen in the laboratory and the specimen in the outdoor environment. It was also clearly showing the influence of the sliding joint, when even one layer of PE foil reduced friction and the concrete specimen responded to any changes in temperature and humidity. As a complement, measurements of volume changes were made by using shrinkage drains. This test gives good information about the length shrinkage of the concrete. The experiment was performed as a “zero” in order to obtain input data for further experimental measurements of the volume changes depending on the subsoil. (Kropacek & Cajka 2018E, Kropacek & Cajka 2018M)

2. Experimental Part

2.1. Composition of Concrete
In the experiment was done six large-dimensional specimens. Four specimens were made of steel fiber reinforced concrete C 30/37 - X0 and two specimens were made of concrete C 30/37 - XC4. For the measuring volume changes was intention to eliminate as much of the phenomena as possible in terms of composition of the concrete, so no addition was given to the concrete and no aerated concrete was proposed. Composition of both concretes has been designed in accordance with relevant technical standard, where requirements for the composition are defined (CSN EN 206 2014). The composition of steel fiber reinforced concrete is shown in the Table 2.

Table 2. Composition of steel fiber reinforced concrete C 30/37 – X0

| Component                              | Amount (kg/m³) |
|----------------------------------------|----------------|
| Cement CEM I 42,5 R                    | 340            |
| Fine aggregate 0/2                     | 595            |
| Fine aggregate 0/4                     | 255            |
| Coarse aggregate 4/8                   | 110            |
| Crushed coarse aggregate 8/16          | 495            |
| Crushed coarse aggregate 11/22         | 370            |
| Super plasticizing admixture           | 3.3            |
| Water                                  | 182            |
| W/C                                     | 0.52           |
| Steel fibers – 55 mm length            | 25             |

Steel fibers have a positive effect on reducing concrete volume changes. The strength class has been chosen in view of the frequent use of this strength class in practice and at the same time with a high amount of cement with the assumption of high shrinkage.
Table 3. Composition of concrete C 30/37 – XC4

| Component                             | Amount (kg/m³) |
|---------------------------------------|----------------|
| Cement CEM I 42,5 R                   | 345            |
| Fine aggregate 0/2                    | 570            |
| Fine aggregate 0/4                    | 250            |
| Coarse aggregate 4/8                  | 130            |
| Crushed coarse aggregate 8/16         | 510            |
| Crushed coarse aggregate 11/22        | 335            |
| Super plasticizing admixture          | 2.3            |
| Water                                 | 189            |
| W/C                                   | 0.52           |

The composition of both concretes shows that they have the same water to cement ratio, which is important in terms of shrinkage development (especially drying shrinkage). The super plasticizing admixture has been dosed into the concrete to provide the desired water to cement ratio and S4 (fibre concrete) or S3 (plain concrete) consistency. Concrete was cast into formwork and after this curing of concrete was started immediately at the beginning of setting. In the same time started measurements of volume changes using string strain gauges. For the determination of compressive strength and modulus of elasticity after 7 and 28 days, specimens were taken at a quantity of 6 cylinders for each test. Determination of modulus of elasticity is important parameter for calculating final shrinkage with using calculation model.

2.2. Specimens, Casting and Curing
Large-dimensional specimens were designed in size 150 x 500 x 6000 mm. Three specimens were placed in the laboratory and other three specimens were placed in an outdoor environment where the specimens were exposed to external climatic conditions including precipitation. Concrete were cast into wooden formwork, see Figure 1.

Figure 1. Formwork with asphalt membrane as the sliding joint and with string strain gauges
The bottom of the formworks was covered different materials as the sliding joint for a lower friction. These sliding joints also have the advantage of zero water removal from the bottom surface of the concrete and thus preventing plastic shrinkage. The combination of concrete and sliding joints for the experiment was as follows, the same combination being placed in the laboratory and in the outdoor environment (3 + 3 specimens). First combination was fibre concrete and asphalt membrane. Second combination was fibre concrete and two layers of polyethylene foil with geotextile interlayer. Third combination was plain concrete and asphalt membrane. Asphalt membrane was 4 mm thick modified bitumen (SBS) with sand on the surface and a PE foil on the bottom. Concrete was cast directly from agitating truck by using a through and compacted by a submersible vibrator. After casting and compacting was surface of specimens treated with a finishing trowel. Specimens were immediately covered with geotextile at the beginning of the setting of the concrete and cured with water for 5 days, see Figure 2. Geotextiles were removed after end of curing and lateral stripping was performed. Specimens in the laboratory was kept permanently in an environment having ambient temperature of 20 ± 2 °C and relative humidity of air 55 ± 5 %.

![Figure 2. Specimens in laboratory covered with wet geotextile](image)

### 2.3. Measurement of Volume Changes

For measuring volume changes on specimens were used string strain gauges EDS-20-E. String strain gauges have length 170 mm (active gage length 150 mm), range ±1500 µ-strain, sensitivity 1 µ-strain and thermistor type YSI 44005 (3000 Ohm at 25 °C). Thermistor allows to measure the temperature inside the specimen through the resistance. From the measured resistance values, it is then possible to derive the temperature inside the specimen based on the calibration for the given type of the thermistor. Three string strain gauges were placed in each specimen at 1.5 m apart, counted from the edge of the specimen along the length. Internal string strain gauges were at a height of 50 ± 10 mm from the lower surface of the specimen. The internal string strain gauges were fixed using steel hooks and a binding wire as can be seen in the Figure 3.
Figure 3. Detail on installation of internal string strain gauge

The value readings were performed manually using the Gage GT1174-3 control panel at least once every day since the concrete was cast into the formwork.

3. Evaluation of Results
The experiment was evaluated after 7 weeks from casting the concrete, which is a sufficiently long time for evaluation (technical standards for concrete and concrete structures require as usual 28 days for evaluating), but the measurements continues. Figure 4 and Figure 5 show in graphs the measured results of volume changes using string strain gauges according to the environment. The measured values are already recalculated for correction to the temperature of the string strain gauge. Since the influence of hydration also occurs in the laboratory at rapid temperature changes and these changes in the extensibility of the concrete and the string strain gauge it is necessary to consider. For specimens in the outdoor environment this must be considered for changes in climatic conditions (temperatures). In view of the constant ambient conditions in the laboratory, a specimen placed in the laboratory will be commented on first.

From the Figure 4 can be seen that all three specimens in the laboratory due to high temperature caused by the hydration of cement and the supply of water from the curing began to swell immediately at the beginning of the setting. Swelling is also caused by the creation of new hydrating minerals such as C$_3$A and C$_2$S, but the phenomenon is minimal in concrete and does not form the dominant part of the swelling (in cement mortar is this effect higher) compared to other influences (Kropacek & Safrata, 2015). After 5 days when water curing was ended, the specimens began to shrink by drying. The largest drying shrinkage occurred with plain concrete C 30/37 - XC4 and asphalt membrane, which fulfills the assumption. The smallest drying shrinkage occurred with fibreconcrete C 30/37 - X0 and PE foil + Geotextile + PE foil. This influence can be attributed to the higher friction than the asphalt membrane. The drying shrinkage process was gradual and regular in time, due to constant ambient conditions in the laboratory. For completeness it is necessary to add that autogenous and chemical shrinkage have low significance in concrete with water to cement ratio higher than 0.46 and for this experiment can be neglected (Aïtcin 2008, Aïtcin & Mindess 2011, Holt 2001). Plastic shrinkage has been avoided by timely and adequate curing, so the effect of this shrinkage can also be neglected.
Figure 4. Volume changes of specimens in laboratory. Legend: Dashed line short – Temperature ambient [°C]; Dotted line – Relative air humidity [%]; Dashed line long – Fibreconcrete / Asphalt membrane; Dashed line one dot – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots – Concrete / Asphalt membrane.

For the specimens exposed to climatic conditions, the analysis in the above paragraphs applies, but additional significant influences, variable temperature and relative humidity of air are added, see Figure 5. Specimens in the outdoor environment alternately swell over time and shrink. The drying shrinkage undoubtedly occurring (as will be explained in Figure 6), but shrinkage is denied by other influences such as concrete expansion and water absorption. Important effect on this behaviour also have sliding joint that ensures low friction. Generally, has the subsoil significant role in the volume changes development (prevails shrinkage) especially in industrial floor (Cajka et al. 2017, Janulikova 2014, Janulikova & Stara 2013). Figure 5 illustrates the climate conditions at the time of reading, which are very variable, and it is difficult to evaluate any trend. During the period under review it shows the lowest volume changes specimen fibreconcrete C 30/37 - X0 with PE foil + Geotextile + PE foil. This is again the assumed behavior because the same specimen shows the lowest shrinkage in the laboratory as well. Steel fiber reinforced concrete effectively reduces concrete volume changes. The largest volume changes are shown in the specimen with plain concrete C 30/37-XC4 and asphalt membrane. As can be seen from the previous Figure 4 the largest drying shrinkage has the same specimen, which demonstrates the functioning of the sliding joint and low friction provided by asphalt membrane.
Figure 5. Volume changes of specimens in outdoor environment. Legend: Rhombuses – Temperature ambient [°C]; Crosses – Relative air humidity [%]; Dashed line – Fibreconcrete / Asphalt membrane; Dashed line one dot – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots – Concrete / Asphalt membrane.

The graph in the Figure 6 compares the shrinkage of all specimens. For this graph it was necessary to separate initial swelling and water curing and measured specimens limit only to shrinkage. The specimens began to shrink after ending of curing, which was after 5 days. The highest swelling value was defined zero and the shrinkage began to count from this value. Therefore, the shrinkage values are higher than in Figure 4 and Figure 5. While the final shrinkage values do not differ significantly in specimens stored in the laboratory, specimens stored in the outdoor environment (both fibre concrete specimens) have significantly different shrinkage values from total volume changes.
Figure 6. Comparison of shrinkage of all specimens. Legend: Laboratory: Dashed line – Fibreconcrete / Asphalt membrane; Dashed line one dot – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots – Concrete / Asphalt membrane; Outdoor environment: Dashed line rhombus – Fibreconcrete / Asphalt membrane; Dashed line one dot rhombus – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots rhombus – Concrete / Asphalt membrane

4. Conclusion
The aim of the experiment was to compare the volume changes of different concrete depending on the subsoil and the chosen sliding joint. Although the experiment continues because the long-term behaviour needs to be known, partial conclusions can be drawn. The experiment provided the results of volume changes of different concrete, when steel fibre reinforced concrete has generally lower volume changes then plain concrete. The effect of sliding joint plays significant role in the development of volume changes. From the measured results, especially in the laboratory, it is obvious that in the same concrete the formation PE foil + Geotextile + PE foil have the higher friction that asphalt membrane.

The measured results will be further used for modelling interaction base-subsoil and results will also serve for comparison with results from calculation models for determining final shrinkage. Calculation models do not consider the influence of the subsoil and sliding joint, and the volume changes of real constructions can thus differ significantly from the calculations.

Acknowledgments
The work was supported by the VŠB-TUO Student grant competition. The project registration number is SP2018/153.

References
[1] Aïtcin, P.C. 2008. Binders for durable and sustainable concrete. New York: Taylor & Francis.
[2] Aïtcin, P.C. & Mindess, S. 2011. Sustainability of Concrete. New York: Spon Press.
[3] Bazant, Z. 2015. RILEM draft recommendation: TC-242-MDC multi-decade creep and shrinkage of concrete. Model B4 for creep, drying shrinkage and autogenous shrinkage of normal and high strength concretes with multi-decade applicability. Materials and Structures, Vol. 48, pp 753-770.

[4] Bilcik, J. & Sonnenschein, R. 2018. Measures to Reduce the Formation of Early-Age Through Cracks in Foundations Slabs. Beton TKS, Vol. 18, pp 46-50.

[5] Bradac, J. 1991. Designing of objects in the undermined area. Comment on CSN 73 0039. Prague: Publishing standards.

[6] Bradac, J. 1996. Effects of undermining and protecting buildings. Part One. Ostrava: Technical publishing.

[7] Cajka, R. 2005. Rheological Properties of Bituminous Materials for Slide Joints, Construction Materials. Vancouver, Canada: ConMat '05 and mindessb symposium.

[8] Cajka, R. & Manasek, P. 2005. Effect of friction in the subsoil on the tension of fiber concrete floors. Conference Proceedings of the Conference with International Participation FC 2005 – Fiber concretes, Vol. 3, pp 237-242.

[9] Cajka, R. & Smirakova, M & Vaskova, J. 2017. Experimental testing of shear resistance on SFRC Slab structures. Materials Science Forum, Vol. 893, pp 363-368.

[10] Collepardi, M. 2010. The New Concrete. Italy: Grafiche Tintoretto.

[11] CSN EN 206. 2014. Concrete – Specification, performance, production and conformity. Prague: Czech Office for Standards, Metrology and Testing.

[12] CSN EN 1992-1-1. 2006. Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for building. Prague: Czech standards institute.

[13] Holt, E.E. 2001. Early age autogenous shrinkage of concrete. Finland: VTT Publications.

[14] Hornikova, K. & Foglar, M. & Kolisko, J. & Kolar, J. 2016. Experimental and Numerical Assessment of Slab-on-grade Friction Coefficient. Beton TKS, Vol. 16, pp 42-49.

[15] International Federation for Structural Concrete FIB. 2010. Model code 2010: first complete draft. Lausanne, Switzerland: Fédération Internationale du Béton.

[16] Janulikova, M. 2014. Comparison of the Shear Resistance in the Sliding Joint between Asphalt Belts and Modern PVC Foils. Applied Mechanics and Materials, pp 501-504.

[17] Janulikova, M. & Stara, M. 2013. Reducing the Shear Stress in the Footing Bottom of Concrete and Masonry Structures. Procedia Engineering, Vol. 65, pp 284-289.

[18] Janulikova, M. & Cajka, R. & Mateckova, P. & Stara, M. 2012. Modelling of foundation structures with sliding joint using results of laboratory tests of asphalt belts. Transactions of the VŠB – Technical University of Ostrava, Civil Engineering Series, Vol. 12, pp 5-10.

[19] Kropacek, M. & Cajka, R. 2018. Experimental measurement and calculation of volume changes of concrete specimens. WSEAS Transactions on Applied and Theoretical Mechanics, Vol. 13, pp 29-36.

[20] Kropacek, M. & Cajka, R. 2018. Measurement of Volume Changes of Cement Concrete in Large-Dimensional Samples. Solid State Phenomena, Vol. 272, pp 102-106.

[21] Kropacek, M & Safrata, J. 2015. Volume changes of cements from different locations depending on time. Transactions of the VŠB – Technical University of Ostrava, Civil Engineering Series, Vol. 15, pp 11-20.

[22] Sekanina, D. & Cajka, R. 2009. Interaction between prestressed floor and subsoil. Transactions of the VŠB – Technical University of Ostrava, Civil Engineering Series, Vol. 9, pp 17-24.

[23] Schweighofer, A. & Kollegger, J. 2013. Reibungsfreie Gleitlagerung für vorgespannte Bodenplatten. Beton und Stahlbetonbau, Vol. 108, pp 335-345.

[24] Tazawa, E. 1999. Autogenous Shrinkage of Concrete. New York: E & FN Spon.