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CONCRETE STRUCTURES INTERACTING WITH SUBSOIL DEPENDING ON THE USE OF SLIDING JOINT

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ABSTRACT: Article describes the interaction of concrete structure (usually foundation structure or industrial floor) with subsoil, where unwanted friction occurs. Friction can be reduced with sliding joint. This generally known assumption is followed by research described in the article, which determines the effectiveness of sliding joints with respect to concrete volume changes on large-dimensional specimens. Large-dimensional specimens with dimension of 150 x 500 x 6000 mm were placed in the laboratory and outdoor environment, defining different boundary conditions. The research included various concretes in the same strength class and various sliding joints that respect the requirements of construction practice. The paper also describes the comparison of measured results with calculation models from technical standards and regulations, which allow calculation of volume changes on concrete structures. Regarding the subsoil and the sliding joint, this is one of the main long-term goals of the research, since the calculation models do not take these two parameters into account. Deformations from volume changes then deviate significantly from theoretical calculations, as friction in the sliding joint area affects the magnitude and course of volume changes. Practical results show that the steel fibres mixed into concrete have a positive effect on reducing volume changes in early stages of setting and hardening of concrete. Regarding the use of the sliding joint, the most important finding is that there are no significant differences from the selected sliding joints in the experimental part. In connection with friction, the use of the sliding joint itself has a significant effect.

Keywords: Concrete, Foundation, Subsoil, Sliding Joint, Volume changes

1. INTRODUCTION

When designing concrete structures, usually flat foundations and industrial floors, the subsoil has a major impact on the behavior of these structures. This is a well-known phenomenon and is also based on the regulations used to design these structures. In conjunction with the subsoil, a sliding joint is used on the footing bottom to reduce friction (for example, in connection with undermining, prestressing, etc.). The use of sliding joints is a long-term scientific topic of the Faculty of civil engineering, VSB – Technical University of Ostrava. In the context of problem-solving tasks were solved topics related to the interaction of foundation with sliding joint, topic of parameters and comparison of sliding joints, interaction of prestressed structures in contact with subsoil, prestressed industrial substrates and finite element method for foundation-subsoil interaction. Sliding joints are verified by experiments calculations for various types of concrete structures and sliding joints. Various boundary conditions and load methods enter to these calculations. [9-13, 15-19, 23, 32, 37-38]

One of the branches of this research is the use of sliding joint in interaction with volume changes of concrete. From the perspective of concrete structures, volume changes cause unwanted friction on the base-subsoil. Volume changes are usually caused by several processes, but the first significant area is cement hydration. In concrete whose binder is cement, there may by several types of shrinkage that differ in nature and their impact varies depending on the concrete composition. The basic types of shrinkage include plastic shrinkage, autogenous shrinkage (contains autogenous and chemical shrinkage), drying shrinkage and carbonation shrinkage. The second important area is the environment and especially temperature. The effect of temperature is closely related to the mentioned types of shrinkage also with regard to the exothermic reaction during the hydration of concrete, therefore the temperature is often referred to as another type of shrinkage. However, temperature itself also affects the expansion of the concrete element and temperature change has a major effect on volume changes ever after complete hydration of the cementitious composite. These volume changes caused by hydration of cement or also by the ambient temperature lead to stress that can lead to undesirable cracks. [1-2, 4-5, 30-31, 33-35]

For this reason, a sliding joint is used which allows friction to be reduced on this footing bottom. The sliding joint can also be understood as a simple treatment of the footing bottom, as evidenced by the friction coefficients in Tab. 1, where various subsoils and sliding joints are simulated. Values in Tab. 1 are based on experimental shear tests. Mostly, however, the sliding joint is understood as an interlayer composed of one or more layers of different materials providing lower friction. The first option is a composition, where one or more layers are made of foil (PE, PVC) and between them can be, for example, sand or geotextile. The second option is to use asphalt membranes of different thickness and compositon, where viscoelastic properties of asphalt are used. In connection with the use of aphalt membranes, it is necessary to mention that the ambient temperature affects the deformation of the sliding joint and this boundary condition must be taken into account when designing the sliding joint of a material with viscoelastic properties. [7-8, 14, 19, 22, 26, 36]

Table 1 Friction coefficient for subsoil [36]

Base layer	Sliding joint	Friction coefficient
Gravel	No	1,4 – 2,1
Sand	No	0,9 – 1,1
Cohesive soil	No	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=0,3m) max. 1,3 (h≥1,5m)
Base concrete rough	1 or 2 layers bitumen membr.	avg. 0,45 (h=0,3m) avg. 0,2 (h≥1,5m)

Note: h – thickness of foundation slab

The long-term intention of the author's research is to determine the volume changes of concrete in interaction with the use of sliding joint. Several practical experiments were conducted on this subject, and the results were further used as a basis for comparison by calculation models. From experiments performed on large-dimensional specimens, it was found that even one layer of PE foil can serve as an effective sliding joint (depending on the subsoil) and thus significantly different volume changes of concrete were measured in the laboratory and outdoor environment. The results also differ considerably from calculation models, which are currently the most widely used [24]. It is calculation model from the technical standard EN 1992-1-1 [20], a refined model of regulation Model Code 2010 [25], the American model ACI 209R-92 [3], and the most detailed model of a team Professor Bazant model B4 [6]. All these listed calculation models for determining final concrete shrinkage have the following drawbacks. The calculation models do not allow to work with concretes using dispersed reinforcement, which has, among other things, a demonstrably positive effect on the reduction of volume changes in the early stages of setting and hardening of concrete. Another significant drawback is related to the principle of the calculation models themselves. These focus on the technology of concrete, but do not take into account at all the influence of the subsoil and the associated friction that occurs at the level of the footing bottom. [27-29]

2. EXPERIMENTAL PART

The main part of the experiment was the production of six large-dimensional specimens, which were made of two types of concrete. The first concrete was steel fiber reinforced concrete in strength class C 30/37-X0 and the second concrete was plain concrete in the same strength class C 30/37-XC4. Both concretes have been designed fully in accordance with technical standard EN 206 [21], with the intention that both concretes have the same composition. Minor variations in the composition of the concrete components are caused using steel fibers. This made it possible to directly compare the effect of dispersed reinforcement.

Six large-dimensional specimens with dimensions of 150 x 500 x 6000 mm were made with the emphasis on building practices, where laboratory results on small specimens need to be verified. The dimensions of the specimens simulate the dilatation unit and correspond proportionally to the real structure. Of the total number of specimens, three specimens were placed in a test hall simulating laboratory conditions (hereafter referred to as laboratory) and three specimens were placed in outdoor environment. Two types of sliding joints were chosen for this experiment and the combination with the proposed concrete was as follows. Three combinations were chosen for laboratory and outdoor environments. The first pair of specimens was a combination of fibreconcrete and sliding joint from the asphalt membrane. The second pair of specimens was composed of fibreconcrete and two layers of PE foil with an intermediate layer of geotextile. The last pair of specimens consisted of plain concrete and the same type of asphalt membrane as in the first pair of specimens. The asphalt membrane was selected with a thickness of 4 mm based on modified asphalt (SBS) with sand on the strip surface and PE foil on the bottom. Volume changes, including temperature sensing, were measured inside of specimens using the EDS-20-E string strain gauges. Three string strain gauges were fitted in each specimen at a spacing of 1,5 m from the specimen edge along the length. The strain gauges were at a height of 50 ± 10 mm from the bottom of the specimen, see Fig. 1, where the location of the strain gauges can be seen together with the sliding joint from the asphalt membrane and the prepared formwork.

Fig. 1 Installation of string strain gauges

The detail of the anchoring of the string strain gauges can be seen in Fig. 2. String strain gauges were fixed using steel hooks and a binding wire.

Fig. 2 Detail on installation of string strain gauges

The concrete was cast into the prepared formworks directly from the truck mixer using a trough and compacted by submersible vibrators. After the concrete was casted, the curing was started immediately. Curing of concrete was performed for 5 days by spraying with water on specimens that were covered with geotextile, see Fig. 3.

Fig. 3 Large-dimensional specimens in laboratory during concrete curing

At the end of the curing, the specimens in laboratory were exposed to conditions with temperature of 20 ± 2 °C and relative humidity of air 55 ± 5 %, the specimens stored outside the laboratory were fully exposed to ambient conditions.

3. EVALUATION OF RESULTS

The results were continuously evaluated at time 100 days, which is a sufficiently long period since concrete is usually evaluated in accordance with the regulations for a 28-day period. Since the article describes the interaction of concrete with subsoil, it is not an object to describe in depth concrete technology and processes occurring in concrete during hydration. That is why only graphs showing the comparison of volume changes (shrinkage) of concrete with calculation models are presented in the article and there are no detailed results of individual specimens with boundary conditions. A more detailed evaluation focused on concrete technology will be the subject of another article, but it is certain that specimens in the laboratory undergo different volume changes than specimens in the outdoor environment.

Specimens swell at the start of setting and hardening, and no shrinkage occurs during the curing period. However, since the calculation models do not consider initial swelling, the measured results from the experiment had to be customized. Specimens began to shrink after the end of the curing, which was the time defined as "zero" value, and from that time the volume changes read from the string strain gauges were further measured. The following calculation models were used for comparison with experimental results. Calculation model from EN 1992-1-1 [20], Model Code 2010 [25], ACI 209R-92 [3] and Model B4 [6].

Because of the stable conditions and thus the limitation of the external influences, it is advantageous to evaluate the results separately for the specimens placed in the laboratory and specimens placed in the outdoor environment. Figure 4 shows a graph of the comparison of the results on the specimens in the laboratory with the results of the calculation model. As mentioned above, drying shrinkage occurs in the laboratory after the curing is finished. All other volume changes can be neglected or cannot occur in a laboratory environment. For this reason, the shrinkage curves are continuous and have a regular course. This is important for comparing specimens to each other and for comparison to specimens placed in outdoor environment where more influences enter the experiment and it is not easy (or even possible) to accurately evaluate the volume changes or behavior of the specimens interacting with the subsoil. It can be seen from the graph in Fig. 4 that the combination of plain concrete and sliding joint from the asphalt membrane has the largest shrinkage. This result corresponds to the assumption, since the plain concrete without dispersed reinforcement is to generate the largest shrinkage and the asphalt membrane provides low friction. From the graph describing only shrinkage, the results of fibreconcrete is identical regardless of the sliding joint used. The results show that steel fibers in concrete regulate concrete shrinkage. Compared to calculation models, the measured results are comparable to the model assumptions of the technical standard EN 1992-1-1 [20], which is in line with the requirements of a safe design. In contrast, the measured results differ significantly from the assumption of model B4 [6]. The other two models also differ. The results confirm considerably different behavior when using sliding joint.

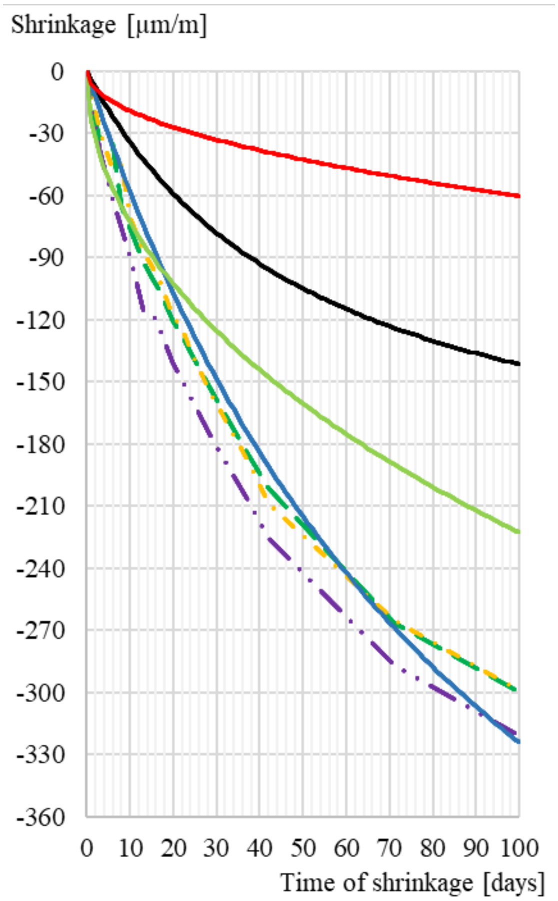

Fig. 4 Comparison of specimens from laboratory with calculation models. Legend: Dashed line – Fibreconcrete / Asphalt membrane; Dashed line one dot – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots – Concrete / Asphalt membrane; Blue line – EN 1992-1-1; Green line – MC 2010; Black line – ACI 209R-92; Red line – Model B4

When evaluating specimens from the outdoor environment, the situation is more complicated. Other boundary conditions, such as varying temperature, relative humidity of air and possibly precipitation, affect the measurement. In addition to drying shrinkage, thermal expansion also affects the volume changes. Since the specimens are in outdoor environment, they can be constantly doped with water and the average higher relative humidity of air also ensures a slower shrinkage of the concrete specimens. Thus, it can be seen from the graph of Fig. 5 that the specimens alternately shrink and swell over time. The shrinkage of concrete is undoubtedly continuous, but shrinkage is outweighed by the expansion of the concrete due to changes in temperature and water supply. An important role is played by the use of a sliding joint that reduces friction and allows the specimen to move horizontally. For the reasons given above, it is very difficult to evaluate any trend, but the largest shrinkage again generates plain concrete in combination with the asphalt membrane sliding joint. The lowest shrinkage (but the largest volume changes) has a specimen of fibreconrete with a sliding joint from the PE foil + geotextile + PE foil. This finding again confirms the trend of laboratory results and the need to use dispersed reinforcement to control concrete shrinkage.

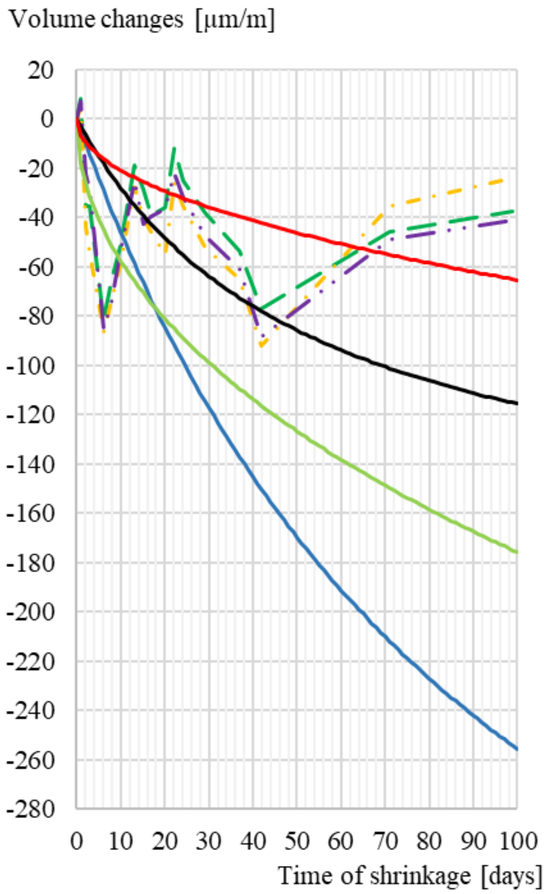

Fig. 5 Comparison of specimens from outdoor environment with calculation models. Legend: Dashed line – Fibreconcrete / Asphalt membrane; Dashed line one dot – Fibreconcrete / (PE foil + Geotextile + PE foil); Dashed line two dots – Concrete / Asphalt membrane; Blue line – EN 1992-1-1; Green line – MC 2010; Black line – ACI 209R-92; Red line – Model B4

Comparison of results with calculation models is significantly different from specimens in the laboratory. Regarding the different behavior of specimens in an outdoor environment, the B4 model [6] is closest to the measured results. Calculation model from technical standard EN 1992-1-1 [20] provides significantly oversized results, but the results are consistent with safe design of concrete structure. These results demonstrate that calculation models do not reflect the effect of sliding joint, which reduces friction and allows the concrete specimen to make volume changes easier.

4. CONCLUSION

An experiment dealing with the interaction of the sliding joint with the concrete specimen provides unique results in several areas. When designing concrete foundations as well as industrial floors, it is always necessary to consider and assess the influence of horizontal forces resulting from the load. However, horizontal forces also arise within the concrete structure through volume changes from hydration or climatic conditions. Large volume changes and high friction at the footing bottom result in high stress inside the structure, which can lead to cracks and weaken the durability of concrete. For this reason, sliding joints are designed in the footing bottom to reduce friction and allow concrete “free” volume changes. The results from experiment show that when using dispersed reinforcement in concrete, the volume changes of fibreconcrete compared to plain concrete are reduced. Steel fibres mixed into concrete have a positive effect on reducing volume changes (mainly shrinkage) in early stages of setting and hardening of concrete. This is particularly evident in laboratory specimens where only drying shrinkage occurs. As mentioned above, the use of sliding joints has its clear reason and importance. In direct comparison of selected sliding joint (and recalculation of results for use with calculation models), the actual use of sliding joint is particularly important. 4 mm thick asphalt membrane and formation of PE foil – geotextile – PE foil do not offer significant differences in friction coefficient.

Comparison of results with calculation models is another separate area to which the author has long focused. Calculation models allow to determine long-term final shrinkage of concrete. The lack of all current models is that they do not reflect initial swelling of concrete during the curing, do not reflect effect of dispersed reinforcement and, above all, do not reflect the influence of subsoil and sliding joint. There are only theoretical sub-calculations that work with a coefficient of friction, but these are not included in calculation models together with other effects such as concrete composition, temperature, relative humidity and time. The results point to the fact that large-dimensional concrete specimens behave very differently from the assumption of calculation models, especially in real conditions of concrete casting and construction conditions. The research of the volume changes of concrete in interaction with the sliding joint is further focused on high performance and high strength concrete. The results will be further compared with calculation models with an emphasis on friction.

5. ACKNOWLEDGMENTS

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