Design of foundations with sliding joint at areas affected with underground mining

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Abstract. Underground mining always influences also landscape on surface. If there are buildings on the surface they are affected with terrain deformation which comprises terrain inclination, curvature, shift and horizontal deformation. Ostrava – Karvina region is specific with underground mining very close to densely inhabited area. About 25 years ago there were mines even in the city of Ostrava. Recommendations and rules for design of building structures at areas affected with underground mining have been therefore analysed in long term. This paper is focused on deformation action caused by terrain horizontal deformation - expansion or compression. Through the friction between foundation structure and subsoil in footing bottom the foundation structure has to resist significant normal forces. The idea of sliding joint which eliminates the friction and decreases internal forces comes from the last century. Sliding joint made of asphalt belt has been analysed at Faculty of Civil Engineering, VSB – Technical University of Ostrava in long term. The influence of vertical and horizontal load and the effect of temperature in temperature controlled room have been examined. Testing, design and utilization of sliding joint is presented.

1. Introduction
Building structures in areas affected by underground mining demand specific treatment due to expected terrain deformation. Terrain deformation comprises subsidence, declination, curvature, and horizontal deformation. The most demanding, and also most expensive, are requirements for terrain horizontal deformation. Through the friction between subsoil and foundations, the foundation structure is loaded with significant normal forces. The idea of elimination of this friction with layer of sliding joint and thus decrease the normal forces comes from the 1970’s, figure 1. Several materials for sliding joint between subsoil and foundation were considered in the beginning. The bitumen asphalt belt, given its rheological properties, has been chosen as an effective material for sliding joints.

Primary experiments of asphalt belt sliding joints were realized in the 1980’s and authors of this experiment were Balcarek and Bradac [1]. The scheme of the testing is shown in figure 2. A concrete block weighing 2208 kg was placed on the asphalt belt on an inclined plane, and the displacement was measured for different tilt angles, and consequently different horizontal and vertical force. This primary experiments were carried out for asphalt belts common in time of testing and proved rheological properties of asphalt sliding joint. Though many significant aspects were not taken into account (e.g. influence of a different vertical load) experiment results were the basis for sliding joint design principles mentioned in still valid national code [2] and lead to a linear dependence of shear stress and deformation rate. In simplified way it is also possible to involve the influence of temperature.
Motivation for new testing was mainly wide range of new asphalt belt types in the beginning of new century. With new testing there was effort to take into account the influence of vertical and horizontal load and later also influence of temperature.

The utilization of sliding joints is not limited to areas affected with underground mining, it is valuable instrument in case of horizontal deformation load due to pre – stressing. In the paper [3] it is presented utilization of sliding joint made of plastic foil for decrease of horizontal deformation load in case of pre-stressing of oil tanks. Experiments have been carried out also by Hornikova et al [4] concerning assessment of slab-on-grade friction coefficient for elimination of horizontal deformation load due to shrinkage and pre-stressing of concrete floors.

Though the bitumen sliding joint was successfully applied in a few buildings [5], sliding joints have not been widely used yet. Experiments presented in this paper should contribute to a wider utilization of sliding joint and thus enable design of more durable and sustainable building structures.

2. Sliding joint testing

2.1. Testing principle

Shear resistance is the main material characteristic when using asphalt belt as sliding joint. It was found out that the shear resistance of slide joints is primarily dependant on the deformation velocity. When the deformation velocity is slow the shear resistance of the bitumen sliding joint is low. The terrain deformation velocity could be estimated on the basis of exploitation plan.
However, testing of the shear resistance for particular deformation velocity is problematic. It was decided to appoint experimentally the deformation velocity for different shear stresses. Using linear regression, it is possible to appoint the shear resistance of a slide joint as a function of deformation rate.

2.2. Testing equipment
At VSB – Technical University of Ostrava unique equipment was designed for shear resistance measurement, figure 3. Experiments started in 2008 and have proceeded continuously. Asphalt belt specimens are placed in between concrete blocks with a dimension of 300 x 300 x 100 mm. Specimens are exposed to a vertical load. A horizontal load is applied after a one-day delay. Displacement of the middle concrete block is measured for 6 days, and sometimes also for more days. Selected materials have been tested also for arbitrary temperature when the testing equipment was placed in a temperature controlled room.

![Equipment for sliding joint testing](image)

2.3. Testing results
Primitive asphalt is refined with oxidization or modified with an admixture of polymers. Depending on the type of admixture polymer there are asphalt belts modified with rubber, usually styrene-butadiene-styrene (SBS asphalt) and thermoplastics, mostly amorphous polypropylene (APP asphalt). Oxidized and modified asphalts possess different temperature sensitivity, elasticity and plasticity or adhesiveness also in correlation with the amount of admixture.

A few types of different trademarks bitumen asphalt belts have been tested since the year 2008. The thickness of asphalt belts is between 3-5 mm, and they are predominantly covered with mineral gritting. Four types were oxidized, nine types SBS modified and 1 type APP modified. Six types of asphalt belt were tested with dependence of temperature.

The specimens were exposed to vertical load 100 kPa and 500 kPa. Applied horizontal load is 1.0 kN and 2.0 kN, such that the deformation velocity corresponds with expected terrain deformation velocity.

In the figure 4 there are measured displacements for one type of oxidized asphalt belt and in the figure 5 there are measured displacements for one type of SBS modified asphalt belt, both for the temperature 20 °C.

The testing temperature was 20 °C. Shear resistance of some specimens was tested also for temperature 10 °C, which corresponds better with temperature expected in footing bottom, appropriate test results are published in papers [6], appointing of expected temperature in footing bottom is discussed in the paper [7].
3. Design of sliding joint

3.1. Shear stress in footing bottom
A simple method for appointing the shear stress between a foundation and subsoil without a sliding joint brings forth Czech code [2]. Shear stress between a foundation and subsoil are settled as a function of terrain horizontal deformation \( \varepsilon \), dimensions of the foundation structure and oedometric modulus of subsoil \( E_{\text{oed}} \).

This code includes also simple formulas for appointing the shear stress with a sliding joint. Shear stress between a foundation and subsoil is settled as a function of terrain horizontal deformation rate, temperature is taken into consideration in a simplified way, figure 6. Type of the asphalt belt and vertical load are not taken into consideration.

The advantage of calculating shear stress based on test results is possibility to take into account many parameters, e.g. type of asphalt belt, expected vertical load, temperature in footing bottom and time of deformation duration. Sher stress functions based on experiments are in the figure 6. In the charts it is visible that the formula according to current code for the temperature 10°C, leads to similar shear resistance as tested SBS modified asphalt belt.

Results of asphalt belt testing can be used also for numerical analysis of soil-structure interaction. Shear resistance is defined with parameters \( C_{1x} \), analogically to parameter of vertical resistance defined in Winkler one parametrical model, more details are in the paper [8].

3.2. Pilot example
Stress function is used in model example of strip foundation situated in an area attached to underground mining. The length is 20 m, and width 1.0 m. It is supposed that the strip foundation is exposed to a vertical load 0.5 MPa, laid on gravel. According to the data obtained from mining company it is expected
that relative horizontal terrain deformation is 5 mm/month, at first the subsoil is compressed and then expanded, each phase will be lasting 16 months. Comparison of shear stress between subsoil and strip foundation with and without sliding joint is in the figure 7. In the figure 8 significant decrease of normal force acting on foundation structure when using sliding joint is presented. The decrease is remarkable both for sliding joint made of oxidised asphalt and sliding joint made of SBS asphalt belt.

4. Planned testing
Research at technical university in Ostrava is focused on soil structure interaction, both in the experimental field and in the consecutive mathematical modelling [9]. On the yard of the technical university testing devise was built up for testing of simple model foundation structures, figure 9. It is possible to analyse experimentally foundations up to dimensions 2.0 m x 2.0 m. Vertical mechanical load is applied using a hydraulic press which is placed between the tested structure and steel frame. Limit value of mechanical load is 1000 kN. Since 2012 research team has tested a few slabs made of plain concrete, reinforced concrete, pre-stressed concrete and recently also fiber concrete. In 2018 it is planned to concrete also foundation slab with sliding joint and apply horizontal load together with vertical load. Experiments should complement the small-size laboratory testing of sliding joints.
5. Conclusion
In the paper shear resistance testing of different types of asphalt belt was presented. Obtained data are utilized for design of sliding joint. When the friction in footing bottom is decreased normal forces in foundation structure could be significantly decreased.

Laboratory testing of sliding joints comprises testing of different types of sliding joints exposed to various vertical and horizontal load and influence of temperature. Testing of big-size sliding joint specimen with dimensions 2 x 2 m is planned in 2018.

Sliding joint has been already applied in a few buildings. Experiments which have been carried out at VSB – Technical University of Ostrava should contribute to a wider utilization of sliding joint and thus enable design of more durable and sustainable building structures.

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Acknowledgments
This outcome has been achieved with the financial support of the project GACR No. 16-08937S “State of stress and strain of fiber reinforced composites in interaction with the soil environment”.
