International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:5, No:10, 2011

Sliding Joints and Soil-Structure Interaction

Radim Cajka, Pavlina Mateckova, Martina Janulikova and Marie Stara

Abstract**—**Use of a sliding joint is an effective method to decrease the stress in foundation structure where there is a horizontal deformation of subsoil (areas afflicted with underground mining) or horizontal deformation of a foundation structure (pre-stressed foundations, creep, shrinkage, temperature deformation). A convenient material for a sliding joint is a bitumen asphalt belt. Experiments for different types of bitumen belts were undertaken at the Faculty of Civil Engineering - VSB Technical University of Ostrava in 2008. This year an extension of the 2008 experiments is in progress and the shear resistance of a slide joint is being tested as a function of temperature in a temperature controlled room. In this paper experimental results of temperature dependant shear resistance are presented. The result of the experiments should be the sliding joint shear resistance as a function of deformation velocity and temperature. This relationship is used for numerical analysis of stress/strain relation between foundation structure and subsoil. Using a rheological slide joint could lead to a decrease of the reinforcement amount, and contribute to higher reliability of foundation structure and thus enable design of more durable and sustainable building structures.

Keywords**—**Pre-stressed foundations, sliding joint, soil-structure interaction, subsoil horizontal deformation.

I. 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. One of the reasons is that, through the friction between subsoil and foundations, the foundation structure must resist significant normal forces. The idea of sliding joints between subsoil and foundation structure, which eliminates the friction in footing bottom, comes from the 1970's, Fig. 1. In the beginning there were several materials considered, (e.g. use of cardboard with ash, isinglass, graphite). Finally the bitumen asphalt belt, a widely available and reasonably priced material given its rheological properties, has been proven as an effective material for sliding joints. When the deformation velocity is slow the shear resistance of the bitumen sliding joint is low. Next, when sliding joint is mentioned, bitumen asphalt sliding joint is considered.

Application of a sliding joint is effective also where there is horizontal deformation of foundations due to shrinkage, creep, pre-stressing and temperature variation.

The first sliding joints tests were made in 1980's for the asphalt belt common in that time [1]. Material characteristic of the bitumen belt has been changed significantly since that time and this fact demanded new experiments. At VSB – Technical University of Ostrava unique equipment was designed for shear resistance measurement. Renewed experiments for different types of bitumen belts were undergone in 2008 [2], [3].

One of the important factors which affect shear resistance is temperature. In this way experiments continue with measurement of the shear resistance of a slide joint as a function of temperature in a temperature controlled room.

Though the bitumen sliding joint was successfully applied in a few buildings, sliding joints have not been widely used yet. Ongoing experiments should contribute to a wider utilization of bitumen asphalt belt and thus enable design of more durable and sustainable building structures.

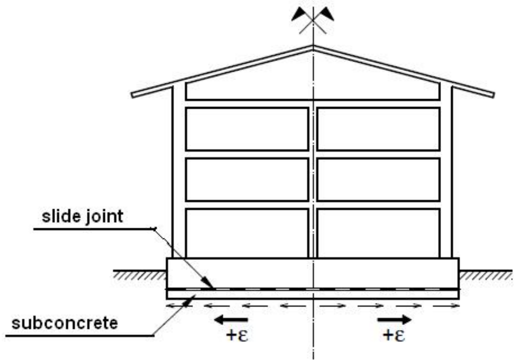

Fig. 1 Schematic drawing of slide joint

II. Sliding Joint Testing

A. Testing Principle

The shear resistance of slide joints is primarily dependant on the deformation rate. As the measurement of shear resistance for particular deformation rate is problematic, it was decided to experimentally appoint the deformation rate 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.

Prof. Radim Cajka is the Head of the Department of Building Structures, VSB-Technical University of Ostrava, Czech Republic (phone: +420 59732 1344; fax: +420 59732 1377; e-mail: radim.cajka@vsb.cz).

Pavlina Mateckova, Martina Janulikova, and Marie Stara are with the Department of Building Structures, VSB-Technical University of Ostrava, Czech Republic (phone: +420 59732 1394; fax: +420 59732 1377; e-mail: pavlina.mateckova@vsb.cz).

This outcome has been achieved with the financial support of the Ministry of Industry and Trade of the Czech Republic, program TIP, project No. FR-TI2/746 Rheological sliding joint with thermo-controlled viscoelastic properties.

B. Primary Testing

Primary sliding joint testing dates from the 1980's and was focused on bitumen asphalt belts common at the time of testing. The scheme of the testing is in Fig. 2, and authors of this experiment were Balcarek and Bradac [1].

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 shear force T. On the basis of experimental data the shear stress as a function of deformation rate was derived.

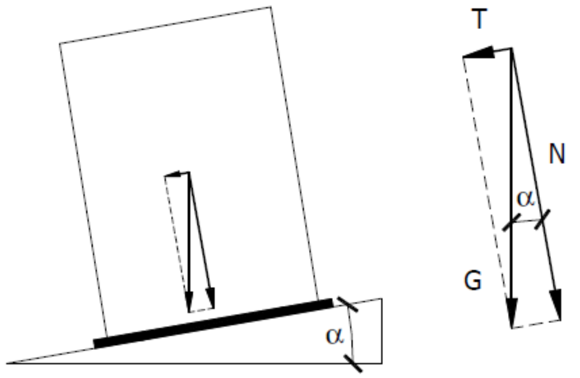

Fig. 2 Slide joint primary testing

C. New Materials and New Testing

At VSB – Technical University of Ostrava unique equipment was designed for slide joint shear resistance testing, Fig. 3.

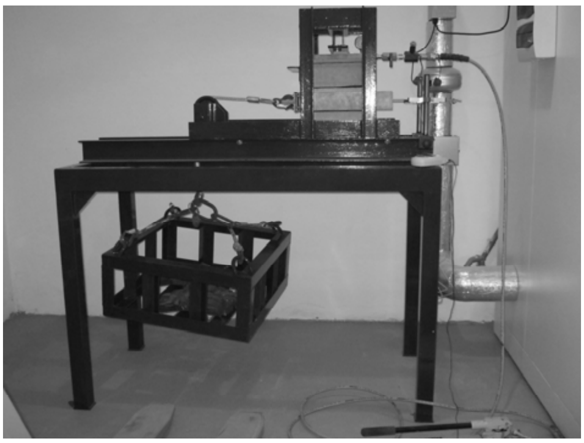

Fig. 3 New testing method of slide joint shear resistance

In between concrete blocks with dimension 300 x 300 x 100 mm 2 asphalt belt specimens are placed, Fig. 4. Specimens are exposed to vertical load and after one day delay a horizontal load is also applied. Displacement *u* of the middle concrete block is measured for 6 days, and sometimes also for more days. Experiments for different types of bitumen belts at laboratory temperature were undergone in 2008, and test results were presented in several papers, e.g. [2], [3].

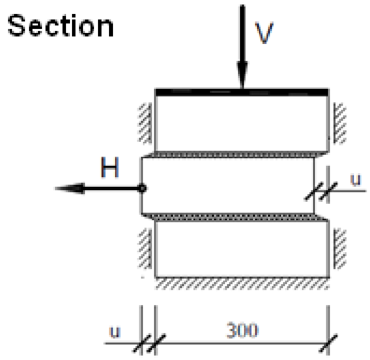

Fig. 4 Schematic drawing of slide joint testing

D. Testing the Temperature Influence

One of the important factors which affect the rheological shear resistance of slide joint is the temperature. For that reason laboratory testing of selected materials continues and rheological shear characteristics are tested by dependence on temperature in a temperature controlled room, Fig. 5. The temperature limit is from -20°C to +40°C. The aim is to determine the slide joint shear resistance for temperatures expected in a footing bottom. There is also the possibility of sliding joint target heating in the case of foundation pre-stressing.

Fig. 5 Testing equipment in a temperature controlled room

III. Test Results

In this paper test results of one common asphalt belt, IPA™, are presented. The experimental results are presented for the temperatures of 20°C and 10°C. The temperature of 20°C represents the laboratory temperature and the temperature of 10°C represents an approximately average temperature in the footing bottom. In the charts in Fig. 6 and Fig. 7, there are measured displacements for vertical load 500 kPa and horizontal force 2.0 kN, 0.95 kN and 0.63 kN.

In the charts, Fig. 6 and Fig. 7 it is possible to mention that after one day the deformation increment became nearly steady. This fact was also proven with a few experiments which lasted 13 days.

Steady deformation rates for selected parameters are in Table 1 and graphically also in the chart, Fig. 8.

Providing the linear regression function it is possible to derive the shear stress of a sliding joint τ as a function of deformation rate v for different temperatures, (1),(2).

For 10°C: $\tau = 4.10^{10}.v + 1.06$ (1)

For 20°C: $\tau = 5.10^{9}.v + 1.91$ (2)

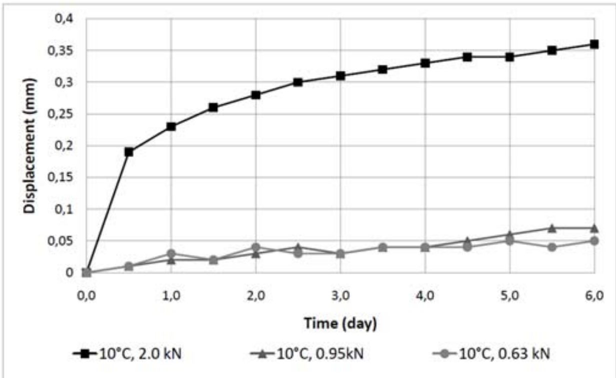

Fig. 6 Measured displacements, 10°C, vertical load 500 kPa

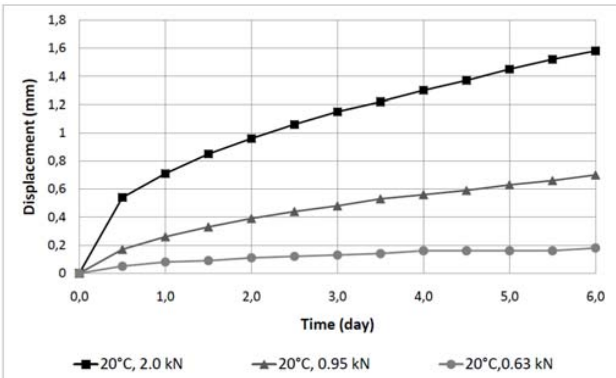

Fig. 7 Measured displacements, 20°C, vertical load 500 kPa

TABLE I
Steady Deformation Rates

	Horizontal force (kN)		
	2.0	0.95	0.63
	Shear stress (kPa)		
	11.11	5.28	3.44
Temperature 20°C			
Deformation rate v (mm.day^{-1})	0.17	0.08	0.02
Deformation rate v (m.s^{-1})	1.97E-09	9.26E-10	2.31E-10
Temperature 10°C			
Deformation rate v (mm.day^{-1})	0.02	0.01	0.004
Deformation rate v (m.s^{-1})	2.32E-10	1.16E-10	4.63E-11

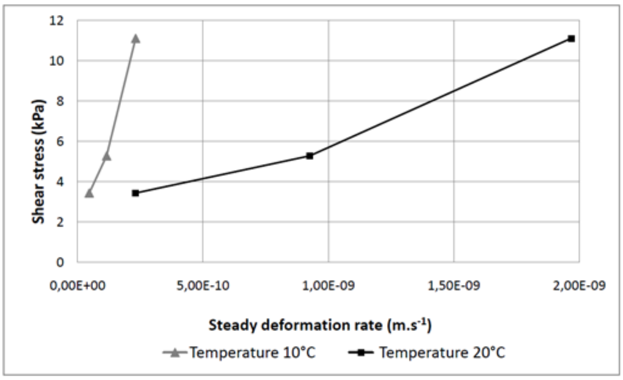

Fig. 8 Shear stress as a function of deformation rate for different temperatures

IV. Application

A. Model Strip Foundation

A sliding joint application is demonstrated in the example of a 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 horizontal terrain deformation is $\varepsilon = \pm 5.10^{-3}$, at first the subsoil is compressed and then expanded, each phase will be lasting 16 months. A detailed description of terrain deformation and time factor can be found in e.g [4], [5].

B. Strip Foundation without Sliding Joint

A simple numerical method for appointing the shear stress in the footing bottom τ_x and consequently the normal force in the foundation structure N_x in case of horizontal subsoil deformation is referenced in Czech code [5]. Shear stress τ_x is settled as a function of horizontal deformation, dimensions of the foundation structure and the oedometric modulus of subsoil. It is also possible to take into account slip in the footing bottom with a limit value of shear stress τ_{max}. Appropriate complex functions are not listed in this paper. Calculation is performed for a symmetrical half of the structure in the Table II.

TABLE II
SHEAR STRESS AND NORMAL FORCE WITHOUT SLIDING JOINT

coordinate	shear stress	slip shear stress	normal force
x (m)	τ_x (kPa)	τ_{max} (kPa)	N_x (kN)
0.0	0.00	312.43	655.7
2.0	8.54	312.43	645.8
4.0	36.16	312.43	588.8
6.0	70.59	312.43	465.2
8.0	106.99	312.43	269.6
10.0	144.09	312.43	0.0

C. Strip Foundation with Sliding Joint

Shear stress in a footing bottom with a sliding joint $\tau_{x,sj}$ is calculated according to (1), the temperature in a footing bottom is supposed as 10°C. Strip deformation is settled for specific dimensions and particular horizontal deformation *u*. Deformation velocity *v* is derived from expected duration of deformation. Simple calculation of shear stress $\tau_{x,sj}$ and respective normal force N_x is performed for a symmetrical half of the structure in Table III.

TABLE III
SHEAR STRESS AND NORMAL FORCE WITH SLIDING JOINT

coordinate	deformation	deformation rate	shear stress	normal force
x (m)	*u* (m)	*v* (m.s^{-1})	$\tau_{x,sj}$ (kPa)	N_x (kN)
0.00	0.000	0	1.06	294.78
2.00	0.010	2.58E-10	11.39	277.16
4.00	0.020	5.17E-10	21.73	238.87
6.00	0.030	7.75E-10	32.06	179.92
8.00	0.040	1.03E-09	42.40	100.29
10.00	0.050	1.29E-09	52.73	0.00

D. Discussion

Calculations in Table II and Table III demonstrate that, providing the deformation velocity is low, a sliding joint significantly reduces shear stress in a footing bottom and consequently normal force in a foundation structure. Shear stresses are compared also in the chart, in Fig. 9.

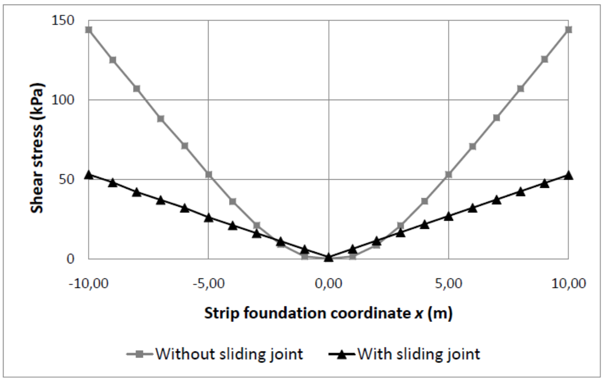

Fig. 9 Shear stress in footing bottom with and without sliding joint

V. FINITE ELEMENT METHOD ANALYSIS

It is also possible to use the test results for finite element method analysis. Considering one parametrical Winkler subsoil model, the slide joint shear resistance could be defined in (3) with parameters C_{1x}, C_{1y}, analogically to vertical parameter C_{1z}, (4), *u* and *v* are horizontal deformations in the *x* and *y* direction, *w* is vertical deformation. Schematic description is in Fig. 10, index 1 indicates one parametrical subsoil model.

$$\sigma_z = C_{1z}.w \tag{3}$$

$$\tau_x = C_{1x}.u\,,\ \tau_y = C_{1y}.v \tag{4}$$

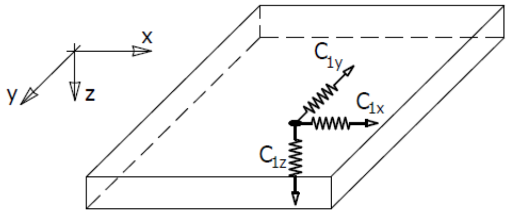

Fig. 10 Schematic description of subsoil parameters

VI. CONCLUSION

In the paper authors present test results of one type of bitumen rheological slide joint shear resistance depending on the temperature. Application of a slide joint is demonstrated in a model strip foundation situated in an area associated with underground mining. Utilization of a slide joint is wider, e.g. crack elimination due to concrete creep and shrinkage, or pre-stressed foundations.

ACKNOWLEDGMENT

Authors thank the designers of ARMING, Ltd., Ostrava, Czech Republic, who within TIP project No. FR-TI2/746 provided helpful comments and valuable suggestions connected with practical design of foundation structures.

REFERENCES

[1] V. Balcarek, J. Bradac: "Utilization of bitumen insulating stripes as sliding joints for buildings on undermined area," *Civil Engineering Journal*, vol. 2, 1982, in Czech.

[2] R. Cajka, P. Manasek: *Application of slide joints for shear stress elimination of prestressed foundation*, in Ninth Pan American Congress of Applied Mechanics, proceedings of conference, Mérida, Yucatán, Mexico, 2006

[3] R. Cajka, P. Manasek: "Laboratory tests and numerical modeling of rheological sliding joints," *journal Roczniki insynierii budowlanej –* vol. 5, 2005, Katowice, Poland.

[4] O. Luetkens: *Bauen im Bergbaugebiet*. Berlin, New York, Wien: Springer-Verlag, 1957

[5] CSN 730039: *Design of building structures at undermined areas. Basic requirements*, Czech code, Prague, 1990, in Czech