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COMPARISON OF CENTRIC AND ECCENTRIC LOADED FIBRE REINFORCED CONCRETE SLAB

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ABSTRACT

The soil-structure interaction is the crucial part of the stability of all buildings. Understanding this problematic has a huge impact on a structure design. An experimental testing is an opportunity for better understanding of the soil-foundation behaviour. Faculty of Civil Engineering of Ostrava in the Czech Republic made series of test of flat slabs for this purpose. This article focuses on two fibre-reinforced slabs C25/30 with dimension 2000 x 2000 x 150 mm with the fibre content of 25kg/m^3. Both slabs were located on the same subsoil and loaded by the force load in the steps until the maximum bearing capacity reached. First slab was loaded by the centric force but the second one was loaded with a 400 mm eccentricity. Deformation of the top surface of the slab were measured in several points during the test. Deformation of both slabs were compared in the middle cross-section.

Keywords: fibre reinforced concrete, punching, flat slab, experimental testing, soil-structure interaction.

INTRODUCTION

Properly made foundation with respect to the underlying subsoil has an important role to the overall stability of the building. Therefore, interaction between the soil and the structure is an important issue, which many scientists around the world focuses the attention on. Examining this problem leads to a deeper understanding of the behaviour of the subsoil in the contact with the foundation and facilitates the design of the foundation structures.

There are many approaches since it is very complex phenomenon. First approach is experimental testing which is also topic of this paper. Scientists all over the wold create special testing devices to test the concrete with the soil interaction. Small size tests can be performed in the laboratory under optimal conditions. However, this task is difficult to perform in the laboratory due to its size. For this reason it could be performed as in-situ test with additional laboratory tests. Disadvantages of such tests are variable conditions such as temperature or humidity, which can significantly affect test results. Experiment testing is most often used to investigate the stresses in the contact between the soil and the foundation, the bearing capacity of the slab, slab punching behaviour and the stresses in the soil tests (Hrubesova *et al.* 2018), (Ricker & Siburg 2016), (Siburg & Hegger 2014), (Halvonik, & Fillo 2013), (Halvonik, Hanzel & Majtanova 2017), (Halvonik & Majtanova 2018), (Hegger *et al.* 2007), (Hegger, Sherif & Ricker 2014), (Kotsovou, Kotsovos & Vougioukas 2016), (Sucharda *et al.* 2018).

With the expansion of computer technologies large amount of numerical modelling approaches are being developed. Numerical models become more complex and sophisticated and their development and improvement continues to these days (Cajka & Labudkova 2014), Ganasan, Lim & Wijeyesekera 2016), (Ibrahim &Metwally 2014), (Hrubesova *et al.* 2015), (Labudkova & Cajka 2016), (Musmar, Shatnawi, & Shatarat 2017).
For the most accurate results combination of the both mentioned approaches are appropriate (Aboutalebi *et al.* 2014), (Cajka 2014), (Cajka, Labudkova & Mynarcik 2016). In the both cases, it is important to perform these procedures on small scale tests while keeping the most similar conditions with one variable to eliminate a large number of unknowns in order to be able detect the effect of this variable on overall deformations and stresses and apply them to large scale problems in the future.

Faculty of Civil Engineering in Ostrava focuses on this problematic for many years now. Different types of flat slabs made of concrete, reinforced concrete, pre-stressed reinforced concrete and fibre-concrete has been testing during the last years (Cajka 2014), (Cajka, Labudkova & Mynarcik 2016), (Cajka & Labudkova 2014), (Sucharda *et al.* 2017). Tests of fibre-concrete with different amount of fibres has been performed in these days. Comparison of centric and eccentric fibre-reinforce concrete slab is the scope of this paper.

EXPERIMENTAL TESTING

Testing device

Whereas the problematic of interaction between the soil and the structure has been examined in the Faculty of Civil Engineering of Ostrava for a longer period of time, the special testing equipment named Stand was constructed outside the premises of faculty.

Testing equipment consists of massive steel frame anchored by micropiles to the underground. Steel frame serves as support for hydraulic press which allows loading of the slab. The basic principle is clear from the Figure-1, detail see (Cajka, Krivy &Sekanina 2011).

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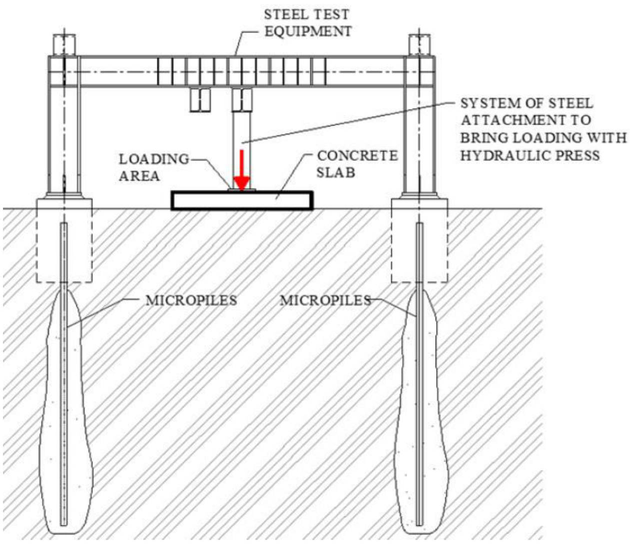

Figure-1. Scheme of testing device.

Figure-2. Testing of centric slab.

Figure-3. Testing of eccentric slab.

Course of the test

Concrete slab is concreted in the middle of the testing area with dimensions of 2000 x 2000 x 150 mm. The test itself is performed after 28 days during one day period. Using a hydraulic press anchored by system of steel attachment to the steel frame the loading force is transmitted to the tested slab trough the transmitting area of 400 x 400 mm. Deformations are measured on the top surface of the slab with potentiometers distributed as shown in the Figure-4 for centric loaded slab (Figure-2). Distribution of sensors on eccentric loaded slab (Figure-3) is shown in Figure-5. The load force is introduced by 75 kN until the maximum bearing capacity is reached or to maximum of 1000 kN which is maximum force the Stand can develop (Figure-8, Figure-11). Time between the individual steps is set to 30 minutes. With this set up, the soil has some opportunity to creep. Creep is very important process under the real foundation. The longer time would be more accurate but this time was selected with regard to feasibility of the test in one day and that the creep of the gravel subsoil is more significant in the at the beginning and with time this phenomenon is less significant.

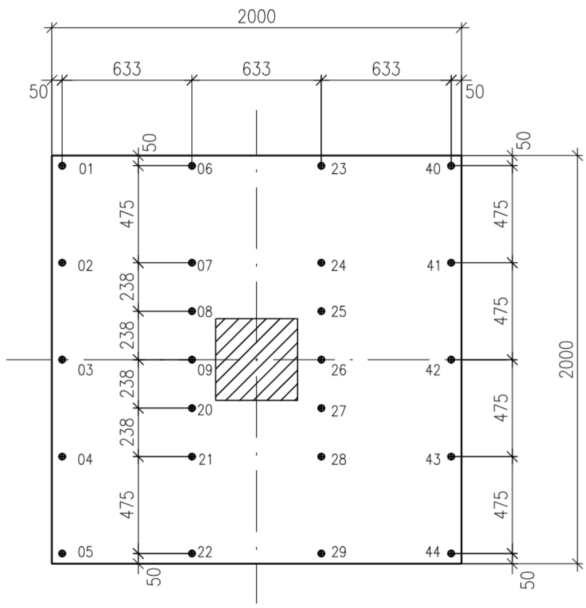

Figure-4. Distribution of sensors on centric loaded slab.

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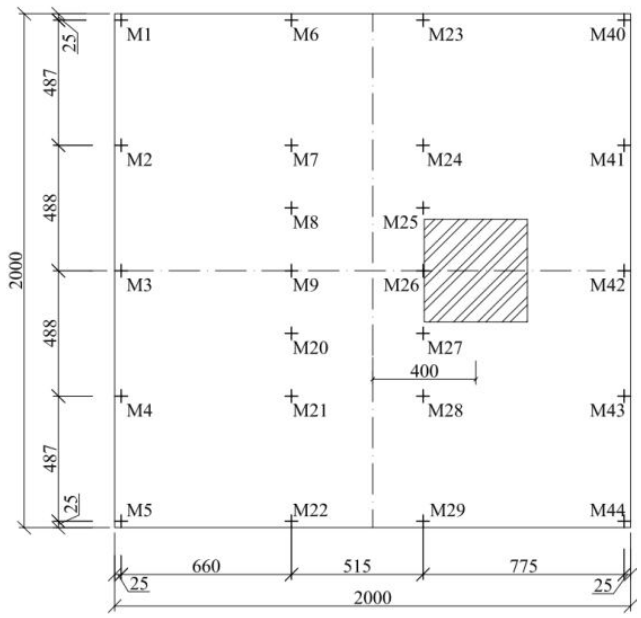

Figure-5. Distribution of sensors on eccentric loaded slab.

Subsoil of the testing area

The slab was located in the middle of the tested area to prevents affecting the results by the foundations strips. The subsoil is classified as sandy clay loam - F4. The static load test was performed before the slab testing. This in-situ test determines the bearing capacity of the soil and describes how the soil reacts to the repeatable loading and unloading. Two cycles of the test were performed and the values of deformation modules were computed (E_{def1} = 16.6 MPa; E_{def2} = 32.6 MPa).

Centric vs. eccentric slab theory

We differentiate between three types of concrete foundations by the load placement - centric loaded, eccentric loaded with small eccentricity and eccentric loaded with large eccentricity. Boundary between the small and large eccentricity is defined by the core section (the kern) (Figure-6). If the force location is placed in this area that means that it is case of small eccentricity. If the load location is outside of this area than it is large eccentricity. Our location of the load is 400 x 400 mm large and it lays directly on the core section.

Main difference between these variants are in the distribution of stress under foundation (Figure-7). In case of centric force, we are simply considering uniform distribution under the rigid foundation. In case of small eccentricity, the whole area in exposed to pressure and the stress distribution has shape of trapezoid. In the large eccentricity there is tensile stress that cannot be transferred by the soil. The only part of the area exposed to the pressure is called effective area. The triangular stress distribution is simplified as rectangular too.

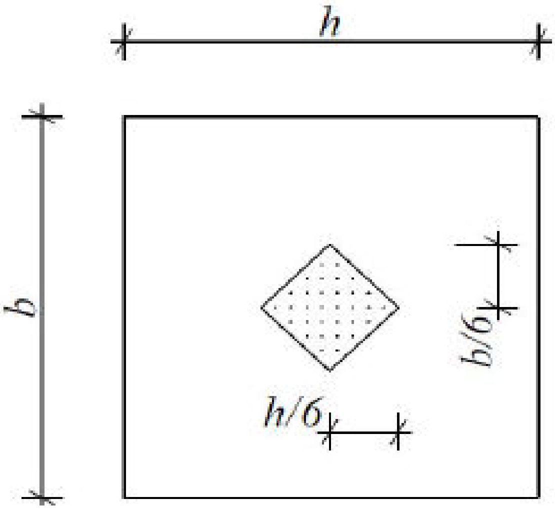

Figure-6. The core section (the kern) on the slab.

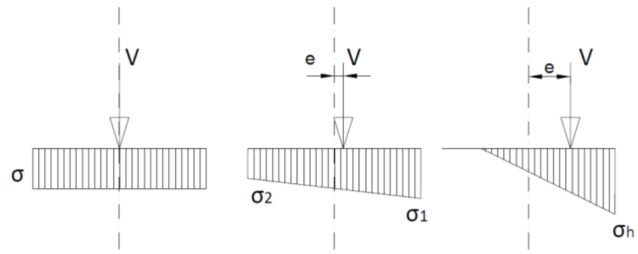

Figure-7. Distribution of stress under the rigid foundation: centric (left); small eccentricity (middle); large eccentricity (right).

RESULTS

Two fibre-reinforced slabs with 25kg/m^3 amount of fibres are observed in this paper. First slab is centric loaded fibre reinforced slab marked as D19_G10. Second one is marked as D20_G11 and this slab is loaded eccentrically with 400 mm eccentricity in one direction. In addition to the eccentric location of the loading area, other inputs were left as similar as possible.

Deformation of top surface of both slabs has been monitored by 24 sensors as described before. The result is deformation of the individual sensors over time as we can see in the Figure-9 for the centric slab and in the Figure-12 for eccentric slab. Distribution of sensors has been mentioned before (Figure-4, Figure-5).

From the measured data, following tables has been plotted trough the centre cross-section of the slab (Table-1, Table-2) since the greatest deformation of the slab is located here. It means section 3-9-26-42 from the Figures 4 and 5. Results from this table has been plotted into graphs (Figure-10, Figure-13). Deformation curve of the beam on the elastic subsoil is described by 4^{th} order differential equation. Deflection curve should be interpolated by the polynomial curve of 4^{th} degree. But since we have only 4 values in this cross section usage of this equation is not possible. Therefore 3^{rd} order polynomial curve has been used to interpolate values and plot graphs.

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Table-1. Deformation of D19_G10 centric slab.

Applied force [kN]	Deformation [mm]			
	sensor 03	sensor 09	sensor 26	sensor 42
77.4	0.41	0.63	0.66	0.48
157.2	0.85	1.5	1.54	0.93
227.6	1.6	3.85	3.79	1.01
299.2	1.48	6.32	6.3	0.82
377.2	0.72	10.48	11.27	-1.37
445.8	-0.6	15.13	16.13	-3.84
499.2	-10.4	26.72	24.36	-13.06

Table-2. Deformation of D20_G11 eccentric slab.

Applied force [kN]	Deformation [mm]			
	sensor 03	sensor 09	sensor 26	sensor 42
71.4	0.11	0.61	0.96	1.43
148	0.27	1.69	2.66	3.58
225.8	-0.57	3.07	5.25	6.6
308	-1.86	4.38	8.02	8.93
373.8	-5.19	5.08	10.83	10.86
451.6	-12.16	6.59	17.06	13.6
477.6	-20.37	6.23	21.84	12.71

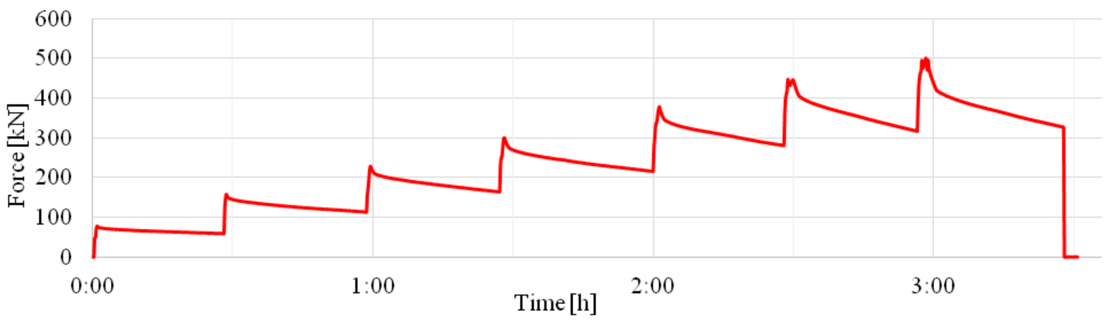

Figure-8. Exerted force in time D19_G10 centric slab.

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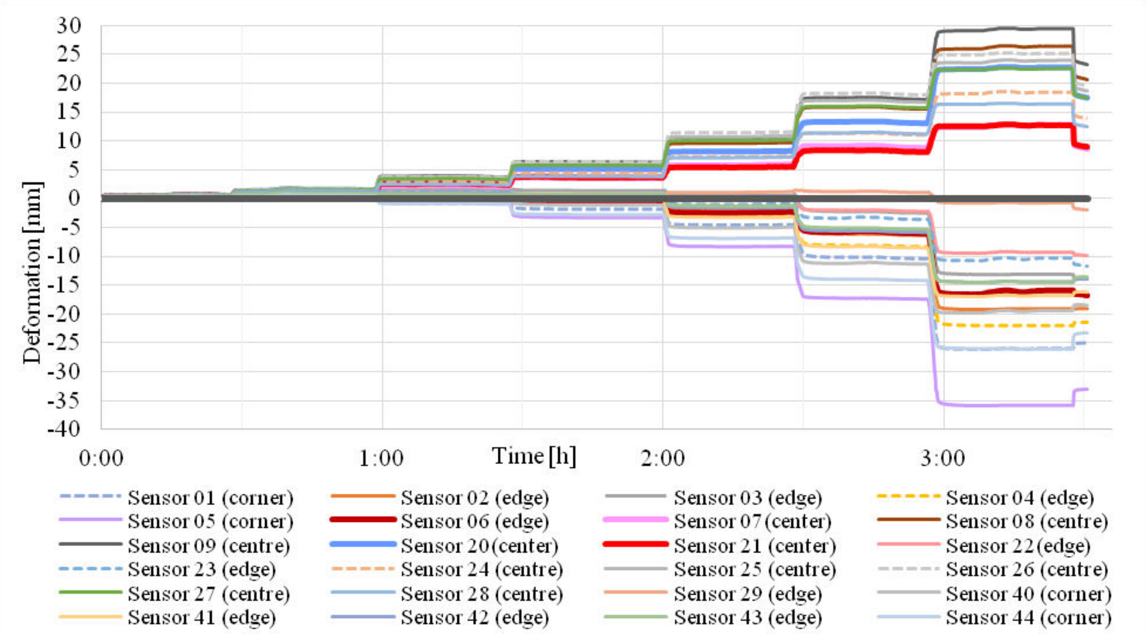

Figure-9. Exerted deformation in time D19_G10 centric slab.

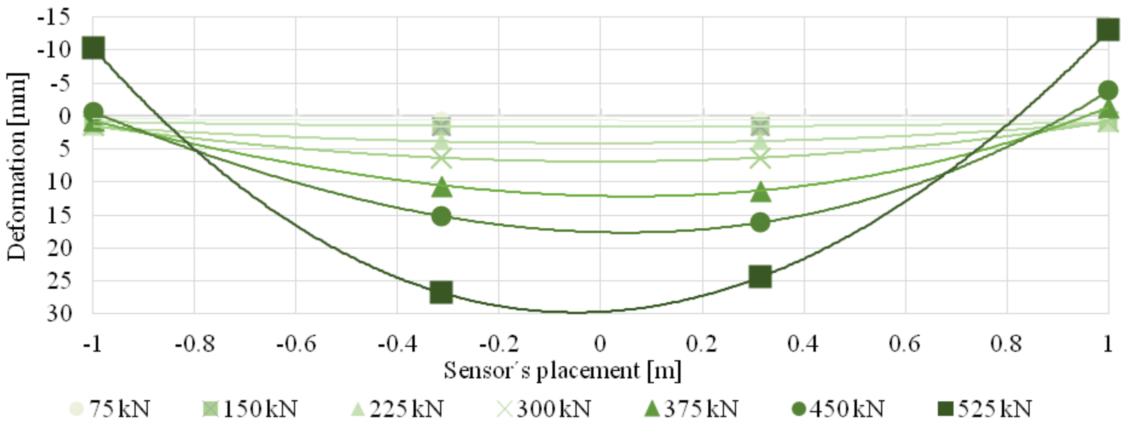

Figure-10. Deformation trough centre cross-section D19_G10 centric slab.

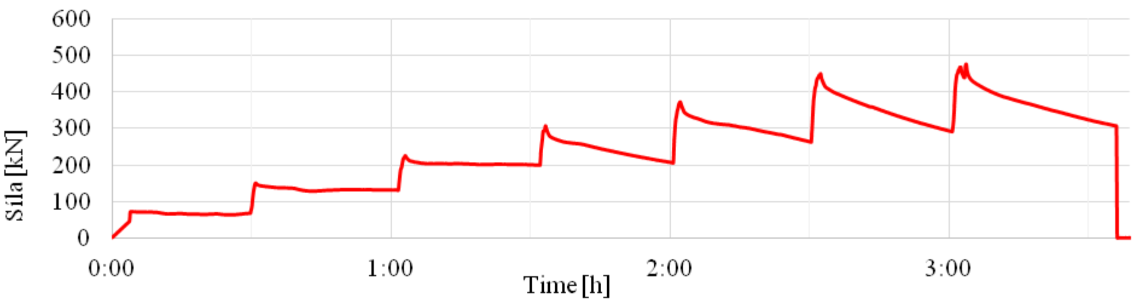

Figure-11. Exerted force in time D20_G11 eccentric slab.

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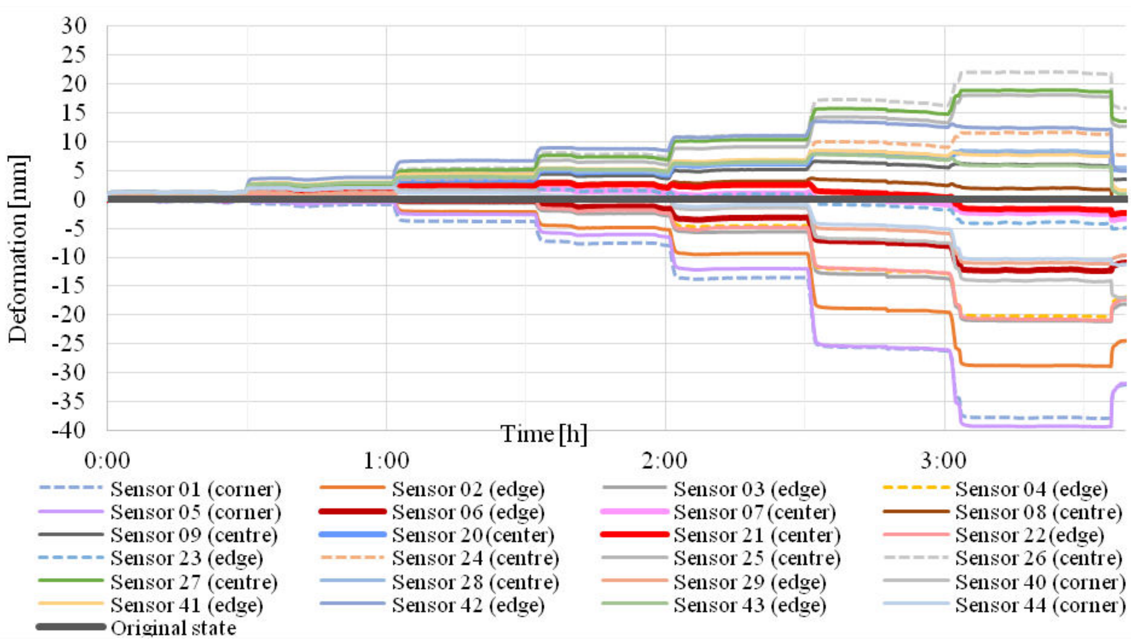

Figure-12. Exerted deformation in time D20_G11 eccentric slab.

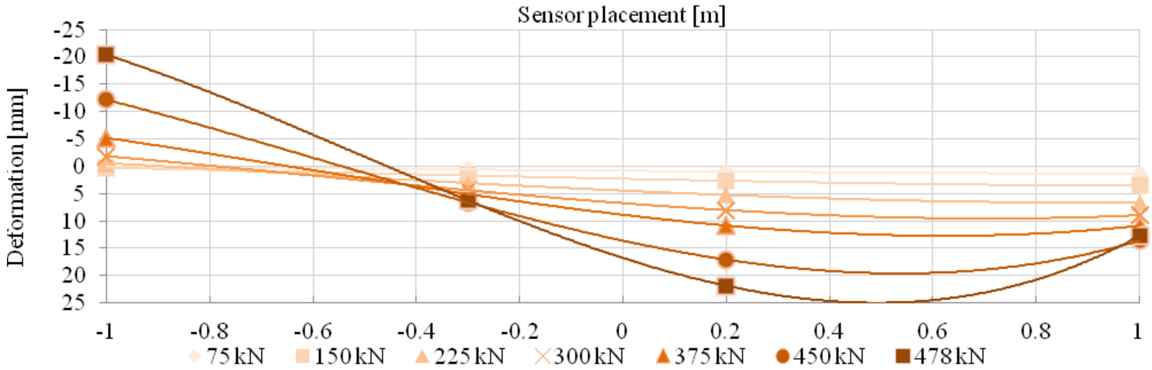

Figure-13. Deformation trough centre cross-sectionD20_G11 eccentric slab.

DISCUSSIONS

Based on the mentioned centric and eccentric theory (Figure-6, Figure-7) the centric slab should not be lifted at all and should be pressed in over the entire surface. Also the lifting of the eccentric slab should be minimal since the loads distribution area lies on the core section of the slab.

It should be noted that assumption of this theory counts with perfectly rigid slab which presumes with total rotation but not deformation. The stress distribution under the foundation is linear based on Euler-Bernoulli-Navier theorem which says that under loading the cross-section of the beam remains straight before and after loading. In general, the deformation of the slab is mathematically described by the Kirchhoff or Mindlin theorem. From the results it obvious that the centre line of the tested slabs were deformed so the assumption of the rigid foundation is not met and the behaviour of the slabs can be described as flexible (Figure-14), (Figure-15). The stress distribution under the flexible foundation is non-linear. On the flexible slab smaller eccentricity is required to generate tensile stresses in the slab. The edges of the slab lifted because the subsoil can only compress but not elongate. For this reason, simplifying assumptions cannot be used and it is eligible to solve this problem as a contact task.

The maximum measured deformation of the centric slab is 26.72 mm and for eccentric slab it is 21.84 mm. The maximum bearing capacity of the centric slab is 499.2 kN and of the eccentric slab it is 477.6 kN. As we can see from the results, the force at which the failure occurs is larger for the centric loaded slab. That corresponds to the eccentric slab theory. As we mentioned before generation of tensile stresses in the soil occurs on a smaller eccentricity in this case. We can compute the effective area of the slab by using the equation (1). That means that the effective area of the eccentric loaded slab is smaller than on the centric loaded slab. And since the effective area of the slab is smaller the transferred load must be also smaller.

$$A_{eff} = A - 2 \cdot e \quad (1)$$

A	=	Foundation area
A_{eff}	=	Effective area of foundation
e	=	Eccentricity

Figure-14. Lifted edge on D20_G11 eccentric slab.

Figure-15. Lifted corners on D19_G10 centric slab.

CONCLUSIONS

The special testing equipment named Stand (Cajka, Krivy & Sekanina 2011) was used to make loading test of two fibre-reinforced slabs with the amount of steel fibres of 25kg/m^3. One slab was centric loaded other eccentric with maximal eccentricity which falls into the kern.

The assumption of the core section placement applies only on the rigid concrete foundation which not corresponds with the tested slab since it exhibits flexible behaviour. In this case, the magnitude of the eccentricity required to form the tensile stresses is much lower than in the case of a rigid base. The subsoil is not able to transfer this tensile stress. For this reason the load on the eccentric slab is distributed by smaller effective area than on the centric slab. Therefore, the eccentrically loaded slab transfers less load.

On the centric slab the load is transmitted in the form of a compressive stress trough the slab but on the edges the tensile stress has occurred. Since the soil cannot transfer tensile stress the edges of the slab lifted. In case of eccentric slab it occurred as the lifting of the unloaded edge.

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REFERENCES

Aboutalebi M., Alani A., Rizzuto J. and Beckett D. 2014. Structural behaviour and deformation patterns in loaded plain concrete ground-supported slabs. Structural Concrete. 15(1): 81-93. DOI:10.1002/suco.201300043

Cajka R. 2014. Comparison of the calculated and experimentally measured values of settlement and stress state of concrete slab on subsoil. Applied Mechanics and Materials, 501-504, pp 867-876. Trans Tech Publications, Switzerland, ISSN: 16609336, ISBN: 978-3-03835-005-7, DOI: 10.4028/www.scientific.net/AMM.501-504.867.

Cajka R., Krivy V. and Sekanina D. 2011. Design and Development of a Testing Device for Experimental Measurements of Foundation Slabs on the Subsoil. Transactions of the VSB - Technical University of Ostrava, Civil Engineering Series. 11(1): 1-5, DOI: 10.2478/v10160-011-0002-2, 2011.

Cajka R. and Labudkova J. 2014. Dependence of deformation of a plate on the subsoil in relation to the parameters of the 3D model. International Journal of Mechanic. pp. 208-215, ISSN: 19984448, 2014.

Cajka R., Labudkova J. and Mynarcik P. 2016. Numerical solution of soil - foundation interaction and comparison of results with experimental measurements. International Journal of GEOMATE. 11(1): 2116-2122.

Ganasan R., Lim A.J.M.S. and Wijeyesekera D.C. 2016. Physical and software modelling for challenging soil structure interaction. ARPN Journal of Engineering and Applied Sciences. 11(6): 3668-3676.

Halvonik R. and Fillo J. 2013. The Maximum Punching Shear Resistance of Flat Slabs. Procedia Engineering. 65, pp. 376-381, ISSN 1877-7058.

Halvonik J., Hanzel J., Majtanova L. 2017. Punching Resistance of Column Basis. Advances and Trends in Engineering Sciences and Technologies II. Pages: 93-98, 2nd International Conference on Engineering Sciences and Technologies (ESaT), Jun 29-Jul 01, Slovakia 2016

Halvonik J., Majtanova L. 2018. Experimental Investigation of the Maximum Punching Resistance of Slab-Column Connections. Slovak Journal of Civil Engineering. 26(3): 22-28, DOI: 10.2478/sjce-2018-0017

Hegger J., Ricker M., Ulke B. and Ziegler M. 2007. Investigations on the punching behaviour of reinforced concrete footings. Engineering Structures. 29, pp. 2233-2241. DOI:doi.org/10.1016/j.engstruct.2006.11.012

Hegger J., Sherif G. A. and Ricker M. 2014. Experimental Investigations on Punching Behaviour of Reinforced Concrete Footings. ACI Structural Journal, pp. 604-613, 2006.

Hrubesova E., Lahuta H., Duris L., Jaafar M. 2015. Mathematical modeling of foundation-subsoil interaction. International Multidisciplinary Scientific Geo Conference Surveying Geology and Mining Ecology Management, SGEM. 2(1): 437-444.

Hrubesova E., Mohyla M., Lahuta H., Bui T.Q., Nguyen P.D. 2018 Experimental analysis of stresses in subsoil below a rectangular fiber concrete slab. Sustainability (Switzerland), 10(7): art. no. 2216, DOI: 10.3390/su10072216

Ibrahim M. and Metwally, I. M. 2014. Three-dimensional finite element analysis of reinforced concrete slabs strengthened with epoxy-bonded steel plates. Advances in Concrete Construction. 2(2): 91-108., DOI:10.12989/acc.2014.2.2.091

Kotsovou M. G., Kotsovos M. G. and Vougioukas E. 2016. Assessment of design methods for punching through numerical experiments. Computers and Concrete. 17(3). DOI:10.12989/cac.2016.17.3.305

Labudkova J. and Cajka R. 2016. Numerical modeling of the subsoil-structure interaction. Key Engineering Materials. 691, pp. 333-343.

Lahuta H., Hrubesova E., Duris L. and Petrasova T. 2015. Behaviour subsoil of slab foundation under loading. International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management. SGEM. 2(1): 119-126., ISSN 1314-2704.

Musmar M., Shatnawi A. and Shatarat N. 2017. Finite element analysis of the behavior Of RC beams during fires. ARPN Journal of Engineering and Applied Sciences. 12(23): 6869-6876.

Ricker M. and Siburg C. 2016. Punching shear strength of flat slabs - critical review of Eurocode 2 and fib Model Code 2010 design provisions. Structural Concrete. 17(3): 457-468.

Siburg C. and Hegger J. 2014. Experimental investigations on the punching behaviour of reinforced concrete footings with structural dimensions. Structural Concrete. 15(3). DOI: 10.1002/suco.201300083.

Sucharda O., Smirakova M., Vaskova J., Mateckova P., Kubosek J., Cajka R. 2018. Punching Shear Failure of Concrete Ground Supported Slab. International Journal of Concrete Structures and Materials. 12(1): art. no. 36.

Sucharda O., Bilek V., Smirakova M., Kubosek J. and Cajka R. 2017 Comparative Evaluation of Mechanical Properties of Fibre-Reinforced Concrete and Approach to Modelling of Bearing Capacity Ground Slab. Periodica Polytechnica Civil Engineering. [S. l.], 61(4): 972-986. ISSN 1587-3773. DOI:10.3311/PPci.10688