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Punching Shear Resistance of Concrete Foundation Slabs without Shear Reinforcement

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Abstract. This paper addresses punching shear analysis and maximum punching resistance defined from the crushing of concrete struts at the perimeter of a column. Number of experimental tests of concrete foundation slabs were carried out at the Faculty of Civil Engineering VŠB – Technical University of Ostrava. Classically reinforced, pre-stressed and FRC slabs were tested but slabs were not reinforced with shear reinforcement. During the experiment, the interaction between the concrete foundation and the subsoil was monitored. The slab was mostly disrupted by punching shear. Results from the experiment and results according to design methods used in EC2 are compared in this paper. The maximum shear design force according to EC2 was more than five times lower than the one from the experiment.

Keywords: punching shear analysis; punching; shear resistance; soil–foundation interaction experiment; ground-supported slab; concrete foundation slab

1. Introduction

The punching share resistance of reinforced concrete slabs-on-ground represents a large category of concrete structure and subsoil interaction problems. Scientific research on the theme of interaction between concrete foundation structures and subsoil is already a long-term scientific direction.

The first theories were put forth by Westergaard (1939) approximately 90 years ago. Westergaard's theory is based on the Winkler foundation model, a traditional method preferred for the design of slabs-on-ground. Many researchers started solving these problems in the following years. Meyenhhof (1962) was one of the leading researchers. They came up with the theory of bearing capacity. It was developed on the basis of plastic theory by extending the previous analysis for surface footings to shallow and deep foundations in a uniform cohesive material with internal friction. The theoretical results were represented by bearing capacity factors in terms of the mechanical properties of the soil and the physical characteristics of the foundation.

Except for Meyenhof, the problems of the ideal foundation model were solved by scientists around the world in the following years. Examples include: R.A. Baumann and F.E. Weisgerber (1983 USA), Timoshenko, S., Woinowsky-Krieger, S. (1959 USA), Johansen, K. W. (1962 UK), Prof. P.A. Konovalova and F. Tugajenka (SSSR), V.N. Golubkov (Ukraina), V. Kolar and I. Nemec (1989). The next important step was realized by Chou (1984). He used the finite element method (FEM) to

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demonstrate that the size of slab panel has an important effect on the build-up of stresses and also the settlement of the slab. However, despite the large number of conducted experimental and theoretical research studies, the results were not conclusive. The result was an interesting clash in the works of J. Irving (1999) and Kearslye (2003). Irving presented the assertion that increasing the compaction effort gives a slab an increased first cracking load and an increased failure load. He also deduced from this experimental works that “an increase in k factor results in improved post-cracking ground slab behaviour.” Opposing that, Kearsley deducted that the incremente in ductility of fibre-reinforced concrete foundation slabs is more intresting if the supporting soil is not so solid.

Alani and Aboutalebi (2014) observed the effect of the carrier substrate stiffness on the mechanical behaviour of concrete slabs. This research team realized a series of experiments on large-scale experimental slabs with dimensions of 3.0 x 3.0 x 0.2 m and 6.0 x 6.0 x 0.15 m and different types of concrete, including samples from reinforced concrete and fibre-reinforced concrete. A Portuguese research team led by António Pinho Ramos focused their research on the influence of pre-stressing to eliminate the punching share effect in concrete slabs - Clément (2014). Ramos et al. based their work on “The Critical Shear Crack Theory” and used it as a consistent frame for investigation of the pre-stressing effects in the punching behaviour of concrete slabs, and they introduced physical models that could be used to estimate the load–rotation behaviour and assess the influence of in-plane stresses on the punching resistance at a given deformation level. The Vietnam-Slovak research team of Nguyen-Minh and Rovnak (2012) examined the punching shear resistance of steel fibre-reinforced concrete flat slabs. They proposed a new formula for more accurate estimation of punching shear resistance of steel fibre-reinforced concrete slabs, in which the effect of the length, shape and ratio of the length and diameter of fibres, as well as the contribution of the dowel action of the tensile reinforcement, should be considered.

A model for the prediction of the punching shear resistance was solved from Moraes Neto et. al (2013). Another view on this problem was given in the work of the Slovak team of Fillo and Halvonik (2013), which pointed to the inaccurate access of Eurocode 2 and offered experimental results.

The science team in this article compared the actual results of the static load test reinforced concrete slab foundation model with the current design theory included in the European standard Eurocode 2. The difference between the experimental results and the theoretical procedure described in the standard Eurocode 2 are large, and there is an open field for research into the effects of the punching shear influence circuits that are not included in Eurocode 2.

Research teams from various countries of the world deal with the analysis of punching shear according to different standards and their comparison with experiments. German researcher Siburg, Ricker, Hegger (2006-2014) were carried out a lot of interesting experiments. Comparison of different experimental test of concrete slabs supported on the ground or as floor slab from around the world are presented in their papers. Zabulionis et. al (2006), Aboutalebi (2014), Kotsovou (2016) or Kurtoğlu (2016) deal with structural behavior of concrete slab and their punching resistance.

Testing equipment, called Stand, was constructed at the Faculty of Civil Engineering, VŠB – Technical University of Ostrava in 2010 – Cajka (2011). The experimental equipment is used during the load testing. The experimental equipment measures deformation and also monitors interactional relationships between stress and deformation. During the experiments, subsoil-slab interaction was observed. In 2012, the stand was used for the first experiment Cajka (2014). Further experimental measurements proceeded at the Faculty of Civil Engineering VŠB – Technical University of Ostrava. In November 2013, load testing of a steel fibre-reinforced concrete foundation slab model with dimensions of 2000 x 2000 x 170 mm was conducted – Mynarcik (2014) and Cajka (2014). In article (Cajka, 2014) a comparison of values measured during the load tests and values calculated by interaction models based on FEM calculations was published.

In May 2014, load testing of a reinforced concrete slab was carried out. Its dimensions were also 2000 x 1950 x 120 mm. This slab was corrupted by punching shear. Punching shear may result from a concentrated load or reaction acting on a relatively small area. This area is called the loaded area, A_{load}, of a slab or foundation. To check punching failure at the ultimate limit, a state verification model is given in