WARSAW UNIVERSITY OF TECHNOLOGY Index 351733
FACULTY OF CIVIL ENGINEERING
COMMITTEE FOR CIVIL AND WATER ENGINEERING
POLISH ACADEMY OF SCIENCES ISSN 1230-2945

DOI: 10.24425/ace.2023.145285

ARCHIVES OF CIVIL ENGINEERING

Vol. LXIX ISSUE 2 2023

 pp. 571 –582

Research paper

Industrial floor faults caused by volume changes in concrete and subsoil: case study

Radim Cajka[1], Jana Vaskova[2], Martina Smirakova[3], Kamil Burkovic[4], Zdenka Neuwirthova[5]

Abstract: Large floors of industrial enterprises, warehouses, stores, and shopping centres are quite heavily loaded with production technologies, transport mechanisms, stored material or shelf stackers. Regarding simple reinforcement and construction, industrial floors have been used in recent decades mainly reinforced with fibres from so-called fibre-reinforced concrete. Most slab failures are caused by extreme loads on the unbearable subsoil, a small amount of fibres, or by the shrinkage of concrete due to insufficient structural design of sliding, shrinking and expansion joints. Recently, however, in several constructions, structural failures have occurred caused by a volume-unstable subsoil in the form of a mixture of slag or metallurgical debris. The article deals with some failures of fibre concrete floors in practice, their methods of diagnostics and laboratory analysis of samples. The results are supplemented by practical examples of floor failures with respect to their origin.

Keywords: case study, failure, fiber concrete, industrial floor, volume changes in concrete

[1]Prof., Eng., CSc., VSB Technical University of Ostrava, Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic, e-mail: radim.cajka@vsb.cz, ORCID: 0000-0002-2346-062X
[2]Eng., PhD., VSB Technical University of Ostrava, Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic, e-mail: jana.vaskova@vsb.cz, ORCID: 0000-0003-0562-0842
[3]Eng., PhD., VSB Technical University of Ostrava, Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic, e-mail: martina.smirakova@vsb.cz, ORCID: 0000-0002-5988-0204
[4]Eng., PhD., VSB Technical University of Ostrava, Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic, e-mail: kamil.burkovic@vsb.cz, ORCID: 0000-0002-8639-0630
[5]Eng., VSB Technical University of Ostrava, Faculty of Civil Engineering, Ludvíka Podéště 1875/17, 708 00 Ostrava-Poruba, Czech Republic, e-mail: zdenka.neuwirthova@vsb.cz, ORCID: 0000-0001-9560-0604

1. Introduction

Using a fibre reinforced concrete for as an industrial floor solution is a quite popular approach. Standard concrete with no reinforcement is quite brittle with a very low tensile strength and strain capacity. During setting and hardening of the concrete tensile forces occurs as the moisture level of the water in the concrete changes and evaporate from the concrete mixture. Not reinforced concrete is very prone to cracking. That can be preventing by dividing floor to smaller segments, by reinforcing the concrete so it better bear this forces or due to a combination. Cracking may also occur even during a lifetime due to a load stress.

Adding any type of reinforcement increases its durability and ability to resist tensile forces from the shrinkage and due to a stress load. Modern and popular way of reinforcing a concrete against of shrinkage cracks is in a way of short steel fibers [1, 2]. Fibers helps to prevent and limit the cracks from shrinkage [3], help to limit cracks during a construction [4] and prevent failure from load [5]. Steel fibers also improves the durability and toughness performance of such concrete floor [6]. Disadvantage of using a fiber-reinforced concrete is that a proper amount needs to be used to work as expected and proper workability is needed for an even distribution of fibers. Another popular approach is to reinforce industrial floor with a mesh reinforcement. Whether to choose one or another really depends on available technology, expected life of the structure or a price costs. In a very specific cases may be industrial floors even reinforced by a steel bars [7]. But due to higher complexity of execution and increased costs its used only in areas with a very high load. This article is focused on a steel fiber reinforced concrete industrial floor with comparison to a floor reinforce by a net.

Fiber-reinforced concrete is defined as a composite material, principally based on concrete. In addition, it is supplemented by randomly scattered fibers. These fibers are distributed in the fiber concrete completely randomly and evenly in an ideal state. The most commonly used fibers are steel fibers, glass fibers, synthetic fibers and a certain group consists of organic fibers. Scattered reinforcement reduces the formation of micro cracks and cracks, which develop due to shrinkage of concrete or the effects of temperature. The fibers absorb local tensile stresses caused by spatial stress in the area between the aggregate grains. In this way, they significantly increase the tensile strength of concrete and, to a certain extent, also increase the compressive strength [8, 9]. Certain types of fibers have the effect of increasing the toughness of concrete, which is associated with resistance to impact, dynamic loading, abrasion and cavitation. The influence of fibers on the properties of concrete is also discussed in [10–12]. Fiber-reinforced concrete shows a certain residual strength even after failure by brittle fracture [13–15].

Recently, however, in several constructions, structural failures have occurred caused by a volume-unstable subsoil in the form of a mixture of slag or metallurgical debris. Changes in volume of the subsoil affects the whole upper structure and especially floors, pavements and other direct construction [16].

2. Industrial building floor faults

Recently several floors failure occurred. It is important to analyze and establish reason of these failures to prevent similar failures in the future with possibility to improve a possible design flaws, decrease repair costs and to reduce environmental demands [17].

Therefore, several floor faults were analysed by available technology and inspected so that caused these faults can be determined. All the selected cases have an industrial floor reinforced by a steel fibres. As there was no access to a non-invasive methods invasive method of analyses were used. Several floor samples were collected and analyzed in a laboratory of Building Materials of the Faculty of Civil Engineering, VŠB–TU Ostrava.

The scope of diagnostic and laboratory work necessary to determine the cause of the failure include: drill hole location and preparation for analysis, determination of bulk density, verification of the strength of fibre concrete in compression, crushing of test specimens in a jaw crusher, magnetic separation of concrete chips, analysing data (characteristic compressive strength of fibre concrete, verification of fibre dosing), visual analysis of floor compositions, including backfill and final analysis of the data and conclusion.

2.1. Production hall in Ostrava–Vítkovice

The first assessed industrial floor construction is located in the production hall in Ostrava–Vítkovice. It is a single-nave building. Floor plan measures 90.8 × 42.8 m with an attic height of 8.55 m above the level of the terrain landscape. The building is sheathed with sandwich sheet metal panels laid horizontally in modular axes of 6 m (Fig. 1). Based on the calculation, a fiber-reinforced concrete slab made of concrete of strength class B 30 in thickness 200 mm, reinforced with Dramix RL 45/50 BN fibers in the amount of 20 kg/m^3. The floor slab was placed on PE foil, provided with Panbex F2 filling – natural and cut in a 6 × 6 m grid.

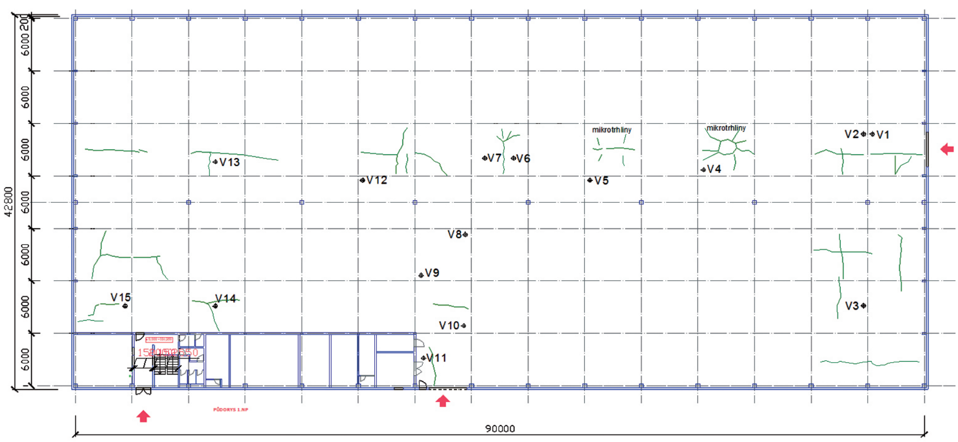

Fig. 1. Scheme of cracks and sampling points of the industrial floor of the production hall in Ostrava–Vítkovice

With regard to the operating conditions (operation in the hall with machine tools could not be interrupted), the actual area was divided into the reference section with the highest incidence of faults (Fig. 2). 15 samples were taken in this reference section. In Fig. 1, the locations of the samples taken (V1 to V15) are marked and numbered.

Fig. 2. Cracks of the industrial floor near the entrance to the production hall

2.2. Production hall in Frýdek–Místek

The second subject of the assessment was the assessment of floor defects, the proposal of an optimal solution for the elimination of defects, the quantification of the reduced utility value of the hall due to floor surface defects and the elaboration of a forecast of defect development over a two-year horizon. The assessed fiber concrete floor is located in the hall in Frýdek–Místek. It is a light steel storage hall based on footings and strips. Fibre-reinforced concrete floor with infill is intended for storage and travel by forklifts. The external floor plan dimensions of the hall are 30.41×16.66 m. The total floor area related to the external dimensions is 506.6 m^2, the internal floor area is 474.3 m^2. After commissioning, after approximately one year, faults in the floorboard were found, consisting of microcracks (cobwebs) and visible cracks, the positions and lengths of which were recorded in the diagram below in the Fig. 3.

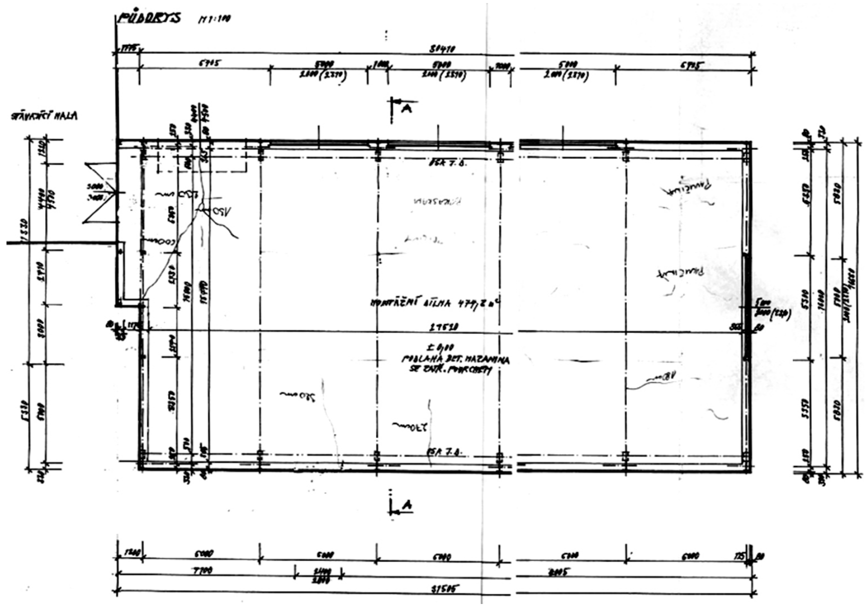

Fig. 3. Scheme of cracks in the floor of the storage hall in Frýdek–Místek

2.3. Sport hall in Ostrava–Dubina

The final subject of assessment was construction and technical survey and assessment of the occurrence of cracks in the object of the indoor sports field. The scope was to make a survey of the current state of the scope, verify slag underfills and assessment of constructions and proposal of measures. The concrete floor under consideration is located in the Ostrava–Dubina sports hall. It is a closed sports hall for collective ball games or tennis, which is roofed using arched steel lattice trusses. A section with operational, social and technical facilities is associated with the playing area. The 2nd floor includes a grandstand with sanitary facilities and technical facilities. Mobile retractable stands are located under the cantilevered overhang of the fixed stand on the 2nd floor. According to the project documentation, the floor structure is designed in the following composition: a layer of underlying concrete with a thickness of 150 mm, reinforced with a 5/150/150 mm net, dilated over a distance of a maximum of 6×6 m and the joints filled with foam polystyrene tape with a thickness of 10 mm or expansion PVC profiles. Waterproofing and individual floor layers with a total thickness of 170 mm are placed on the underlying concrete. After commissioning, construction defects and malfunctions were repeatedly found (Fig. 4) practically from the beginning of use, especially in connection with floor structures (cracks, height differences), which further cause problems with subsequent structures.

Fig. 4. Threshold failure caused by floor slab lift (left); Visible swelling of the floor with ceramic tiles (right)

3. Determining reasons for cracks

Drill holes were tested to determine the quality and strength of concrete, including the analysis of the amount of fibers in individual samples.

3.1. Production hall in Ostrava–Vítkovice

Drilling of laboratory samples was performed based on the selection of accessible places with the largest number of failures (marked in Fig. 1). A total of 15 drill holes were removed (Fig. 5). Statistical evaluation of the set of results of fiber concrete compressive strength was performed according to the conformity criteria ČSN EN 13 822 (Principles of structural design – Evaluation of existing structures). The average compressive strength

Fig. 5. Laboratory samples from the industrial floor of the production hall in Ostrava–Vítkovice

of concrete is 37.15 MPa. The resulting characteristic (cubic) compressive strength of concrete is 30.23 MPa, the concrete corresponds to strength class C 25/30.

The content of fibers in individual core boreholes was determined (Fig. 6). Fiber-concrete test specimens were crushed in a jaw crusher after determining the compressive strength. The method of magnetic separation of scattered steel reinforcement was used to separate the steel fibers from the crushed concrete mixture.

Fig. 6. Determination of the number of fibers in individual samples (Industrial floor of the production hall in Ostrava–Vítkovice)

The weights of the fibers in the individual tested bodies were recalculated for dosing in 1 m^3 of concrete mixture. The final content of fibers in 1 m^3 of concrete mixture is shown in Table 1.

Table 1. Weight of fibers in individual laboratory samples (Industrial floor of the production hall in Ostrava–Vítkovice)

Sample number	Fiber content [kg/m^3]	Sample number	Fiber content [kg/m^3]
1	6.39	9	17.01
2	14.43	10	26.05
3	21.34	11	20.43
4	26.77	12	9.48
5	25.97	13	13.09
6	16.92	14	13.54
7	13.72	15	15.92
8	11.58	Average 1–15	16.84

The dispersion of fiber content is in the range of 6.39 to 26.77 kg of fibers in 1 m^3 of concrete (on average 16.84 kg of fibers / 1 m^3 of concrete). The dimensions and shape of the fibers correspond to the Dramix RL – 45 / 50BN type.

3.2. Storage hall in Frýdek–Místek

Core boreholes taken from the industrial floor of the storage hall in Frýdek–Místek are shown in Fig. 7. Samples suitable for testing the compressive strength of concrete were cut from the core bores. Fiber-concrete samples were marked with the letter A and the base concrete samples were marked with the letter B. Statistical evaluation of concrete compressive strength of fiber-reinforced concrete layer of floor structure was performed according to conformity criteria ČSN ISO 13 822: 2005 (Principles of structural design – Evaluation of existing structures). The average compressive strength of concrete is 40.40 MPa. The resulting characteristic (cubic) compressive strength of concrete in the fiber-reinforced concrete floor layer is 32.8 MPa.

Fig. 7. Laboratory samples from the industrial floor of the storage hall in Frýdek–Místek

In Fig. 8 the locations of the samples taken are marked and numbered. The content of fibers was determined for individual core boreholes. Fiber-concrete test specimens were crushed in a jaw crusher after determining the compressive strength. The method of magnetic separation of scattered steel reinforcement was used to separate the steel fibers from the crushed concrete mixture. The final dosing of fibers in 1 m^3 of concrete mixture is shown in the Table 2. The dispersion of dosing ranges from 12.3 to 18.5 kg of fibers in

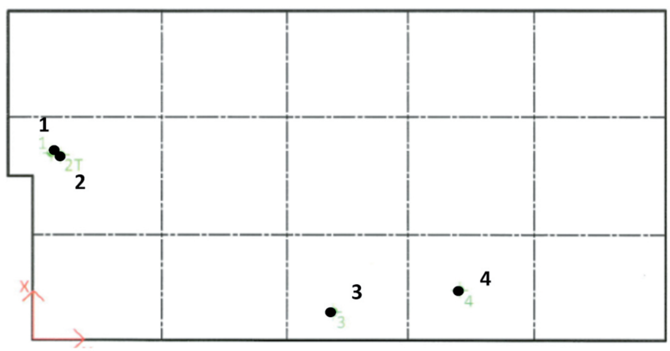

Fig. 8. Scheme of cracks of industrial floor and table of weight of fibers in individual laboratory samples (industrial floor of storage hall in Frýdek–Místek)

1 m^3 of concrete (average 16.3 kg of fibers / 1 m^3 of concrete). The dimensions and shape of the fibers correspond to the Dramix RL – 45 / 50BN type.

Table 2. Measured dispersion of dosing

Sample number	Fiber content [kg/m^3]
1A	18.3
2A	–*
3A	12.2
4A	18.5
Average 1a–4a	16.3

* Sample was not suitable for a test

3.3. Production hall in Ostrava–Vítkovice

The third case is a production hall in Ostrava–Vítkovice (Fig. 9). In this case the floor is not reinforced by fibres at all. The floor is reinforced by a net. This case is included for diversity why each crack may occur. The construction diaries show problems during the

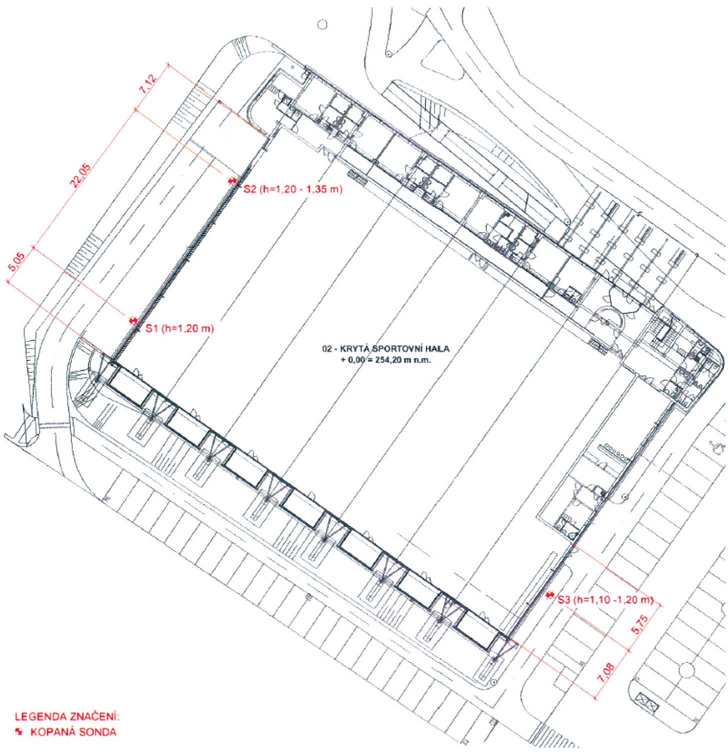

Fig. 9. Scheme and location of test sites

implementation of slag embankments – interruption of work due to frozen layers of water between the plain and slag, removal of slag and re-filling with slag. There is also a mention of wetting the subsoil from an undrawn pipeline. The subject of this analysis was the determination of the material composition of three samples of backfill material and a prognostic assessment of the susceptibility of samples of backfill material to volume changes based on the mineralogical and petrographic analysis of the delivered samples. Excavated probes that were carried out in the vicinity of the assessed object were marked with the description S1 to S3 (Fig. 10). Examination shows that in three supplied samples, therefore, stable pieces of mass of various origins and potentially unstable grains of slag from various metallurgical technologies are dominantly present. Coarse grains are cemented with a sandy-dusty mass of grains of steel slag, grains of sand from rocks and quartz, grains of tailings and ceramics incl. smelter of ceramics and bricks. Individual samples differ primarily in the relative representation of individual components. This is waste that is extremely unsorted, poly-component and materially heterogeneous – an extreme case of materials from the so-called "cold roll". Further examination also shows that hydration and carbonation reactions and the volume changes of reactive components caused by them have not yet been completed.

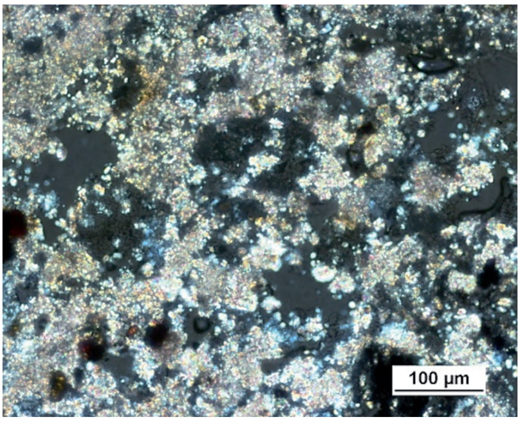

Fig. 10. An example of the secondary transformation of dust and sand grains from steel slag leading to the formation of variously intensely cemented masses referred to in the text as "slag agglomerates". Intense carbonation associated with the formation of carbonate and uneven hydration of the starting silicates of steel slag

4. Conclusions

In this article causes of failure in a form of cracking were examined on a three industrial floorings examples. Two of them were reinforced by steel fibers reinforcement and one by a net. All three floors were invasticated by considering avaiable testing methods. Selected were destructive methods using drill holes close to the cracks.

The results of diagnostics and laboratory analyzes show that failures of both industrial floors were caused by an insufficient amount of reinforcement – DRAMIX fibers. The proper amount of steel fibres and sufficient and even mixing is crutial so the concrete mixture works properly and resists shrinkage and volume changes without cracking. The result is even more durable in a long term. Compared to the required amount of 20 kg/m^3, the average amount of only 16.84 kg/m^3 was found in the industrial floor of the production hall in Ostrava–Vítkovice and only 16.3 kg/m^3 in the industrial floor of the storage hall in Frýdek–Místek. Due to shrinkage, the resulting tensile stresses exceeded the tensile strength of the concrete and cracks occurred. The cracks occurrence could also be influenced by other effects, such as insufficient treatment of concrete, uneven surface of the subsoil before concreting (higher effects of frictional forces leading to the formation of cracks) or delayed cutting time of so-called shrinkage cracks. The macroscopic analysis of the subsoil samples taken shows that the volume changes of the slag in the subsoil were not proven, which does not correspond to the nature of the cracks found. Using an unsufficient amout of fibres may save a little money during a construction but it will result into an expensive repair in the future not to mention ecological aspect.

In the third case industrial floor reinforced by net was inspected. From the results of the performed diagnostics and laboratory analyses, it follows that the cause of the malfunctions are not the volume changes in the concrete mixture itself as in the two previous cases. Cracks were caused by volume changes of the subsoil formed for the most part from the so-called “cold dump”. As a result of these changes in volume, tensile stresses in the concrete floor exceed the tensile strength of the concrete, causing cracks and weaving of the floor. This problem needs to be approached at a design phase as a suitable backfill material for the subsoil needs to be used, more proper use for a subsoil fill would be a blast furnace slag instead of a steel slag. These are two most common slags used in a civil engineering. Blast furnace slag, which is produced during the production of pig iron in blast furnaces, is mainly used in the construction industry today. Steel slag, which is produced during the production of steel, can also sometimes be used in the construction industry, however, this slag often exhibits undesirable volume changes.

From all three cases it’s obvious that there are different reasons that appears with cracks. In this cases it was usefull to take drill wells, make a diagnosis and inspect both – the floor itself and underground. To prevent similar failures in the future it is really important to make a proper design but more importantly supervision during construction and proper implementation of the design is essential.

Acknowledgements

This result was obtained with the financial support of the contribution of the conceptual development of science, research and innovation for 2023 VŠB – Technical University of Ostrava.

References

[1] Z. Kos, S. Kroviakov, V. Kryzhanovskyi, and D. Hedulian, “Strength, frost resistance, and resistance to acid attacks on fiber-reinforced concrete for industrial floors and road pavements with steel and polypropylene fibers”, *Materials*, vol. 15, no. 23, pp. 1996–1944, 2022, doi: 10.3390/ma15238339.

[2] M. Brodnan, P. Kotes, and V. Zimen, "Application of fibre concrete by realization of industrial floor construction", in *Fibre Concrete 2011: technology, design, application*. Prague, 2011, pp. 95–100.

[3] Y. Sun and Y.J. Guo, "Analysis of temperature-field and stress-field of steel plate concrete composite shear wall in early stage of construction", *Archives of Civil Engineering*, vol. 67, no. 1, pp. 351–366, 2021, doi: 10.24425/ace.2021.136477.

[4] J. Jasiczak, "The influence of micro cracks appearing during concreting of road viaducts and their impact on a frost-thaw resistance", *Archives of Civil Engineering*, vol. 66, no. 4, pp. 221–236, 2020, doi: 10.24425/ace.2020.135218.

[5] M.M. Moein, A. Saradar, K. Rahmati, A.H. Shirkouh, I. Sadrinejad, V. Aramali, and M. Karakouzian, "Investigation of impact resistance of high-strength portland cement concrete containing steel fibers", *Materials*, vol. 15, no. 20, 2022, doi: 10.3390/ma15207157.

[6] L. Liu and H.M. An, "Experimental study of compressive failure of concrete under static and dynamic loads", *Archives of Civil Engineering*, vol. 66, no. 3, pp. 427–441, 2020, doi: 10.24425/ace.2020.134406.

[7] M. Niedospial, "Assessment of stresses in reinforcement in the area of joints in composite steel-concrete slabs", *Archives of Civil Engineering*, vol. 67, no. 4, pp. 403–414, 2021, doi: 10.24425/ace.2021.138508.

[8] D. Beckett, "Concrete industrial ground floors – aspects of crack control", *Concrete*, vol. 37, no. 8, pp. 14–16, 2003.

[9] B. Leporace-Guimil, A. Mudadu, A. Conforti, and G.A. Plizzari, "Influence of fiber orientation and structural-integrity reinforcement on the flexural behavior of elevated slabs", *Engineering Structures*, vol. 252, no. 1, 2022, doi: 10.1016/j.engstruct.2021.113583.

[10] R. Cajka, Z. Marcalikova, M. Kozielova, P. Mateckova, and O. Sucharda, "Experiments on fiber concrete foundation slabs in interaction with the subsoil", *Sustainability*, vol. 12, no. 9, 2020, doi: 10.3390/su12093939.

[11] R. Cajka, J. Labudkova, and P. Mynarcik, "Numerical solution of soil – foundation interaction and comparison of results with experimental measurements", *International Journal of GEOMATE*, vol. 11, pp. 2116–2122, 2016, doi: 10.21660/2016.23.1208.

[12] K. Aldossari, W.A. Elsaigh, and M.J. Alshannag, "High-strength steel-fibre-reinforced concrete: potential use for ground slabs applications", *Proceedings of the Institution of Civil Engineers: Transport*, vol. 171, no. 3, pp. 156–165, 2018, doi: 10.1680/jtran.15.00118.

[13] P. Mynarcik, J. Labudkova, and J. Koktan, "Experimental and numerical analysis of interaction between subsoil and post-ensioned slab-on-ground", *Jurnal Teknologi*, vol. 78, no. 5-4, pp. 23–27, 2016, doi: 10.11113/jt.v78.8530.

[14] P. Mynarcik and R. Cajka, "Experimental testing of post-tensioned concrete industrial floor model – Subsidence analysis", *International Journal of Mechanics*, vol. 10, pp. 33–38, 2016.

[15] R. Cajka, P. Mynarcik, Z. Neuwirthova, Z. Marcalikova, and M. Kropacek, "Tests of fiber reinforced concrete composite slabs on the subsoil with horizontal load", *International Journal of GEOMATE*, vol. 18, no.69, pp. 143–150, 2020, doi: 10.21660/2020.69.9461.

[16] I.S. Ünver, M.A. Lav, E. Cxokcxa, and G. Baykal, "Evaluation of the curing time effect on the swelling, unconfined strength and resilient modulus of an expansive soil improved with hydrated lime", *Transportation Research Record*, vol. 2676, no. 4, pp. 76–89, 2022, doi: 10.1177/03611981211057053.

[17] J.L. Silfwerbrand and A.A. Farhang, "Reducing crack risk in industrial concrete floors", *ACI Materials Journal*, vol. 111, no. 6, pp. 681–689, 2014, doi: 10.14359/51686833.

Received: 2022-12-05, Revised: 2023-03-14

CONTENTS – SPIS TREŚCI