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TESTS OF FIBER REINFORCED CONCRETE COMPOSITE SLABS ON THE SUBSOIL WITH HORIZONTAL LOAD

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ABSTRACT: Interaction between the soil and the structure is complex problematic. For the better understanding of the behavior of the flat concrete slab in contact with the subsoil series of tests were performed in the Faculty of Civil Engineering in Ostrava in the Czech Republic. This article focuses on the fiber reinforced concrete flat slab with dimensions 2000 x 2000 x 150 mm loaded by vertical and horizontal force. This loading is typical for building in undermined areas. The article describes the course, results, and evaluation of the experimental test, which was performed on special test equipment Stand over a four day period. The slab was exposed to a constant load of 100 kN in the vertical direction and about 50 kN in a horizontal direction. The deformations of the top surface of the slab were monitored by many sensors in both directions. Concrete deformation and cracks was also observed during the experiment. Deformation curves in the selected cross-section of the slab were evaluated from the measured data. Together with the experiment, the laboratory tests were performed from the same dough of concrete like the slab itself. The laboratory results are also present. The slab is compared to the vertically loaded slab with the same characteristics

Keywords: Fiber-reinforced concrete composite, Soil-structure interaction, Vertical and horizontal loading, Sliding joint, Punching

1. INTRODUCTION

This article deals with slab-soil [1-3] using fiber reinforcement concrete (FRC) [4-7]. A specific research task is focusing on horizontal loading with a sliding joint [8]. This problematic is typical for undermined areas and mining activities, which affect the landscape on the surface [9]. As a result of deep mining, terrain deformations gradually occur on the surface. Terrain deformation can be described by the following parameters: slope, curvature, displacement, and horizontal deformation. This is mainly the region Moravian-Silesian in the Czech Republic and Poland. Friction and significant normal forces occur between the foundation structure and the subsoil as a result of deep mining and the terrain deformations.

Possible solutions to this problem include a sliding joint design - sliding joints from an asphalt belt [8], which was used in the present experimental program. The idea of using an asphalt belt as a sliding joint comes from the 1970s. The first experiments have already been implemented by Balcarek and Bradac [8]. However, the number of experiments and horizontal/vertical load configurations was limited. With regard to the development of materials engineering and properties of asphalt belt, the performed experiments give insufficient results for further research.

In the case of concrete structures, it is also necessary to consider the effect of shrinkage (deformation without the effects of loading), mainly due to the drying of concrete. Concrete slabs (foundation, floor) are usually concreted on the concrete base layer, where the individual concrete layers are separated by an impermeable layer (asphalt strip, PE foil, etc.). In this case, the slab dries only on one side (the upper layer does dry/shrinkage, the bottom layer does not dry). This leads to unwanted lifting of the edges, which can break off under the load. In concrete structures where free deformations are allowed, the shrinkage results in a shortening of such a construction and intrinsic stresses (local exceeding of concrete tensile strength), which results in cracks. In cases where these free deformations are limited, the risk is significantly greater. Therefore, it is necessary to reduce the formation of cracks due to shrinkage and it is necessary to take appropriate measures using so-called shrink joints.

The selected composite slab is FRC. FRC has improved mechanical properties compared to plain concrete. FRC belongs to the group of fiber concrete. The fiber concrete group is divided according to the material used, the shape and length of the wire in the concrete mixture [11-13]. An important factor is the dosage amount of fibers in the concrete mixture. The FRC has typically a better tensile strength and toughness. The actual determination of the responsibility and mechanical testing of FRC are dedicated experts in researches and recommendations [14-17]. In particular, there are a number of approaches that differ in the test configuration to determine the tensile strength. The scope of the tests and the description of the mechanical properties are also influenced by the used design procedure. Research in the field of concrete structures and punching of concrete slabs are also related [18-24].

Fig.1 Special testing device Stand

FRC typical applications include the construction of industrial floors and foundations. This also falls within the research area. The slab-subsoil interaction needs to be taken into account while designing industrial floors [25-26]. It is important to use a suitable interaction system between the upper structure, foundation, and subsoil in the computational model of construction when solving a task. Interaction occurs in the interconnection system, where physical, geometric and design nonlinearities are also included in the calculation.

An important aspect of the design and modeling of foundation-soil interaction is that it connects the design of structure and geotechnics areas, where these areas are each other influence. During design and analysis, it is possible to divide the interaction between:

- subsoil (number of layers, soil, groundwater level),
- foundation (belt, foot, slab, grate, pile),
- the bearing structure of the upper construction (columns, walls, floors).

The problem that addresses the influence of subsoil response to the foundation and upper construction by external forces (e.g. earthquakes) is called SSI - Soil-Structure Interaction. This problem is illustrated in Fig. 2. The resulting overall state of stress and, in particular, the total deformation then depends on the stiffness of all said parts. It is therefore important to choose the appropriate detail and dimension of the computational model and boundary conditions. Analytical and numerical methods are used to solve this problem [27-29]. Numerical methods based mainly on the finite element method (FEM) find wider application with the development of computer technologies (Ansys, Scia Engineer). With regard to the extent of the solved tasks and the complexity of the solved problem, there are categories that distinguish the geological conditions and complexity of the building construction. In simple cases, analytical methods or tabulated results can be advantageously used. However, in case of more demanding constructions such as industrial halls, high-rise buildings or complex geological conditions (groundwater level, low-bearing soil, surrounding buildings) it is necessary to use planar and spatial computational models. Many authors is addressing this problem [30-33].

The paper deals with two experiments, which differ mainly due to way of stress of fiber reinforced concrete. Fig. 3 and Fig. 4 show the influence of the change of stress on the deformation of the slab and subsoil. In particular, the stress-strain state of the slab and subsoil differs significantly.

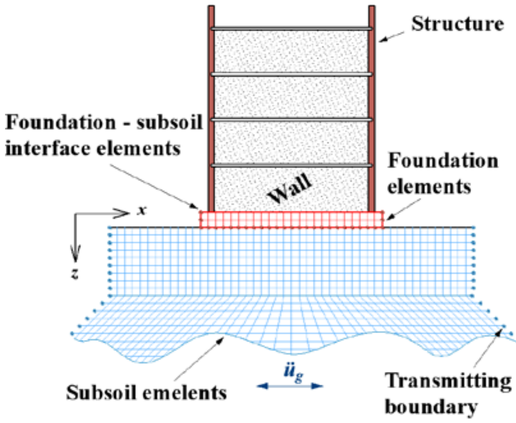

Fig.2 SSI – Soil-Structure Interaction

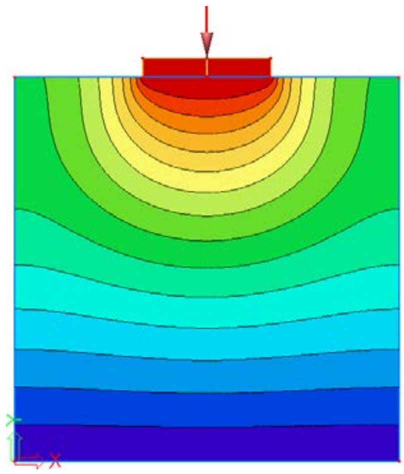

Fig.3 Interaction slabs on the subsoil with vertical load – deformation.

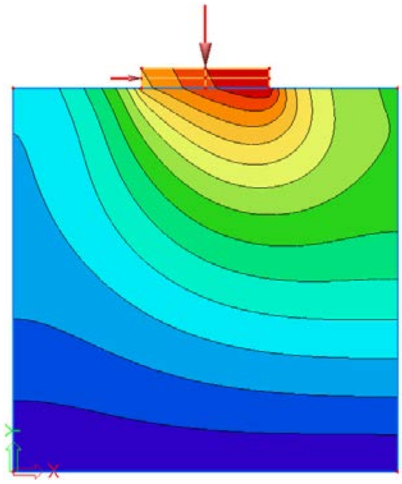

Fig.4 Interaction slabs on the subsoil with horizontal and vertical load – deformation.

2. EXPERIMENTAL PROGRAM

The experimental program involves testing two fiber-concrete slabs interacting with the subsoil. The test variants of the experiments differ in the load character. The experimental tests are performed on a specialized test facility, the so-called Stand [34] shown in Fig. 1.

The plate tests are also supplemented by laboratory testing to determine mechanical properties. Special testing equipment Stand allows testing the interaction of concrete slab with subsoil. The test device can develop a vertical load up to 1000 kN using a hydraulic press [34]. The device was specially modified by adding horizontal hydraulic cylinders to develop a horizontal loading in addition to vertical loading. The improved device can develop a horizontal load of up to 295 kN. The test equipment includes a data logger for evaluating deformations using up to 24 track sensors. The tested slab has dimensions 2000 x 2000 mm with height 150 mm. Used concrete mixture is described in Table 1.

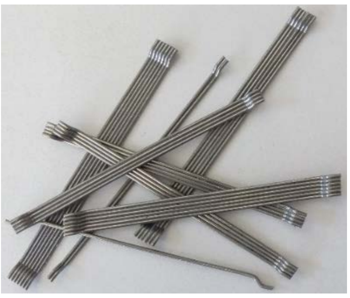

Fig.5 Shape of fibers Dramix® 3D 65/60 BG

Table 1 Material composition of concrete

Description	Type/Amount
Consistency	S3
Maximum grain	CEM I 42.5
Minimal cement content	300 kg
Water Factor: v / c	0,6
Aggregates 0/4	870 kg
Aggregates 4/8	150
Aggregates 8/16	820 kg
Water	189 l
Plasticizer	2.9 l

The Dramix® 3D 65/60 BG fiber type was used in dosage 25 kg/m^3. The basic material characteristics of the fibers are given in Table 2. These fibers end with double bending, their shape is shown in Fig. 5.

The first experiment was focused on tracking the vertical deformation of the slab using the deformation sensors and the load capacity of the slab. The loading of the FRC was in steps of 75 kN/30 min to its maximum bearing capacity. The second part of the experiment attempted to approximate the conditions corresponding to the undermined area. The sliding joint was created between the FRC slab and subsoil using asphalt strips and underlay concrete with thickness 50 mm. A horizontal load was caused by a gradual increase of a horizontal load of about 50 kN with two hydraulic cylinders from one side of the slab. One hydraulic cylinder exerted a load of about 25 kN. This load was kept constant throughout the experiment. Uniform transmission of this load was ensured by a specially designed construction created for this type of experiment. Construction consists of a mounting frame, hydraulic cylinder brackets and support frame.

Table 2 Fiber properties Dramix® 3D 65/60 BG

Description	
Length [mm]	60
Diameter [mm]	0.9
Aspect Ratio	67
Tensile strength [N/mm^2]	1160
Effect on consistency [s]	8
Impact on concrete strength [kg/m^3]	15
Modulus of elasticity [GPa]	200

3. LABORATORY TEST OF FRC

The experimental tests of the slabs are supplemented by laboratory tests. Samples for laboratory tests were performed at the same time as casting slabs from the same batch of mixture. The following characteristics were tested in laboratory: compressive strength on cube ($f_{c,cube}$), compressive strength on cylinder ($f_{c,cyl}$), Modulus of elasticity ($E_{c,cyl}$), splitting tensile strength perpendicular to filling direction ($f_{ct,split,A}$), splitting tensile strength parallel ($f_{ct,plit,B}$), three-point bend test with no cut for a span 500 mm ($f_{c,fl,3B}$) and four-point bend test for span 500 mm ($f_{c,fl,4B}$).

The test scheme is shown in Fig. 6 and Fig. 7. Laboratory test results are given in Table 3 in summary.

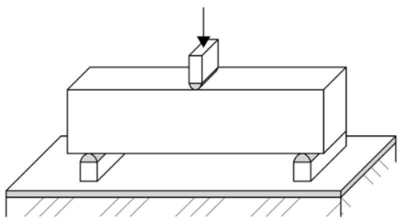

Fig.6 Three-point test scheme

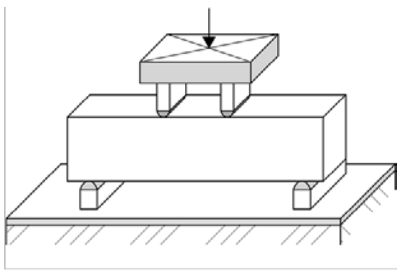

Fig.7 Four-point test scheme

Table 3 Laboratory test results

Notation.	Number samples	Min. value	Max. value	Medium value
$f_{c,cube}$	12	24.5	37.4	30.4
$f_{c,cyl}$	12	20.3	27.9	23.5
$f_{ct,split,A}$	12	2.1	3.2	2.6
$f_{ct,split,B}$	12	1.4	3.3	2.1
$E_{c,cyl}$	6	15.6	24.5	19.3
$f_{c,fl,3B}$	5	4.0	4.4	4.2
$f_{c,fl,4B}$	4	2.6	4.0	3.6

The influence of wire orientation results has showed during the testing. The tensile strength perpendicular to the filling direction was bigger than in a parallel direction. The modulus of elasticity is only 19.3 GPa. With the comparison of bending tests, it is seen that the strength of the four-point test is smaller. The typical course of load-displacement diagrams from performed bending tests is on Fig. 8.

4. FRC SLAB OF EXPERIMENTS

The first performed experiment is a variant with a vertical load. Vertical deformation was observed during the experimental testing using 24 track sensors (Fig. 9). The vertical loading was performed in steps 75 kN/30 min until the maximum bearing capacity reached. The loading process is in Fig. 10.

The vertical deformation in cross-sections and maximum bearing capacity were evaluated based on measured data. The vertical deformation for the selected cross-section are shown in Fig. 11. Maximal measured vertical deformation was 26.72 mm in sensor 09. The lifting of edges occurs at higher load intensities. Maximum lifting was observed in sensor 42 at the amount of 13.06 mm. The maximum bearing capacity of the slab was reached in the 7th loading step under the load of 499.2 kN.

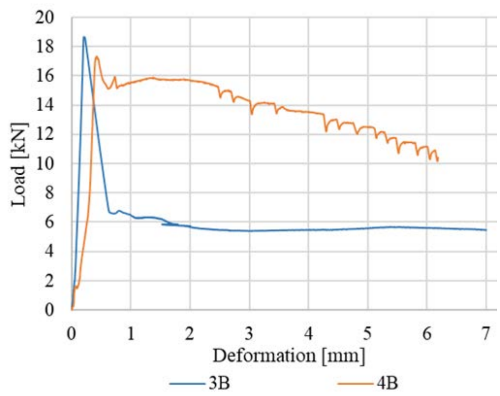

Fig.8 Typical load-displacement diagram for three and four-point bending test

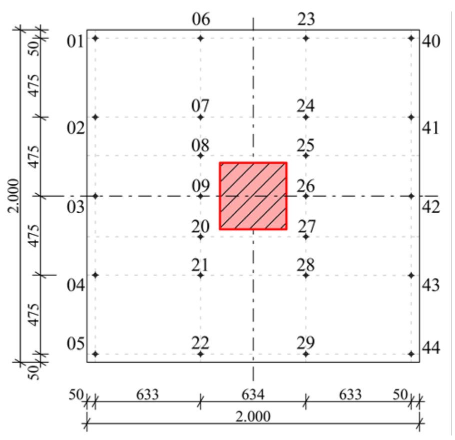

Fig.9 Placement of track sensors for a slab with vertical load

A gradual decrease in bending stiffness is well visible from Fig. 11. The decrease was caused due to the gradual development of cracks in concrete. The cracks in concrete can be seen in Fig. 12 and detail of slab with the crack in Fig. 13.

The second experiment contained a combination of vertical and horizontal loading. The experiment also included the sliding joint created by the asphalt belt and the underlying concrete with thickness 50 mm. The experimental testing scheme is in Fig. 14.

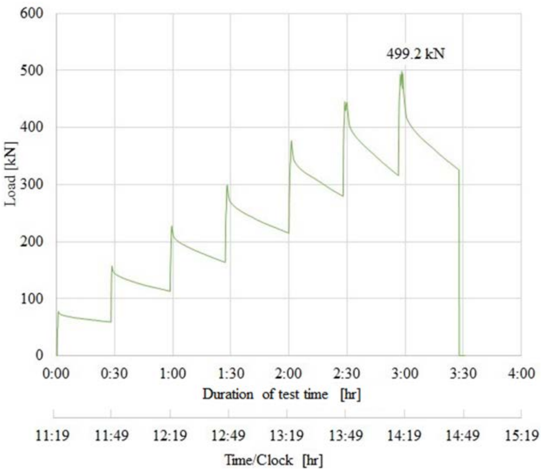

Fig.10 Loading process

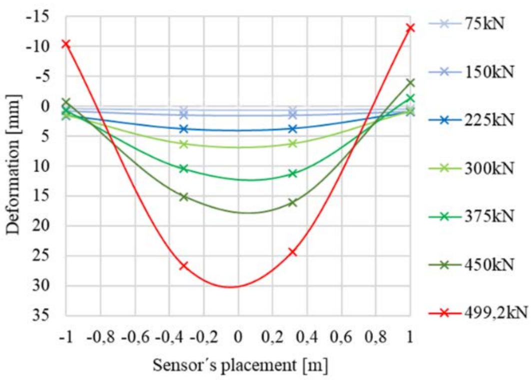

Fig.11 Vertical deformation in cross-section for track sensors 03-42

Fig.12 Deformation of the slab with vertical load

Fig.13 Detail of slab with crack

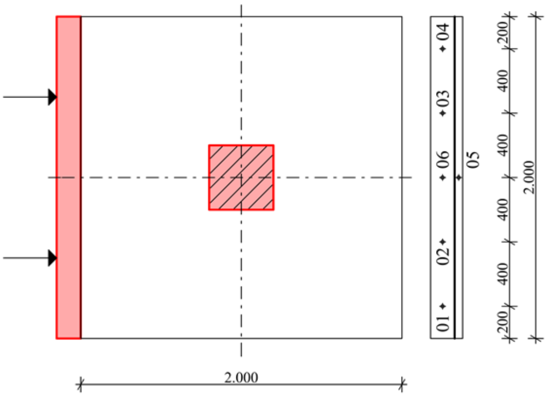

Fig.14 Location of track sensors for a slab with horizontal and vertical load

The constant load of size 100 kN was maintained in the vertical direction using a hydraulic piston. This force represents the load from the upper structure. Furthermore, a horizontal load of about 50 kN was applied from one side of the plate using two hydraulic cylinders. The horizontal load represents the effects caused by undermining. This load was kept constant throughout the experiment. Uniform transmission of this load was ensured by a specially designed construction created for this type of experiment. The horizontal displacement between the concrete bed layer and the FRC was monitored from the other side of the board. The vertical and horizontal deformation was recorded by a data logger every 5 minutes. The experiment is shown in Fig. 15.

Fig.15 Positioning of the track sensors for experiment slab with horizontal and vertical load

The ambient temperature, the temperature in the middle of the slab and temperature at the edge of the slab to verify slab temperature stability were measured every 15 minutes. The ambient temperature was reaching 5-22°C during the experiment. The temperature in the middle of the slab was around 10°C and the temperature at the edge of the slab was slightly higher about 13°C. The experiment took 4 days.

The final horizontal displacements in the middle of the slab (sensor 6) are in Fig. 16. A course of the ambient temperature and the temperature in the middle of the slab are in Fig. 17.

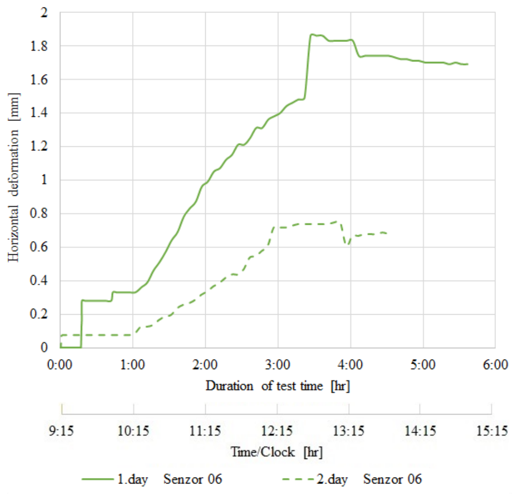

Fig.16 Horizontal deformation (sensor 6) – 1., 2. day

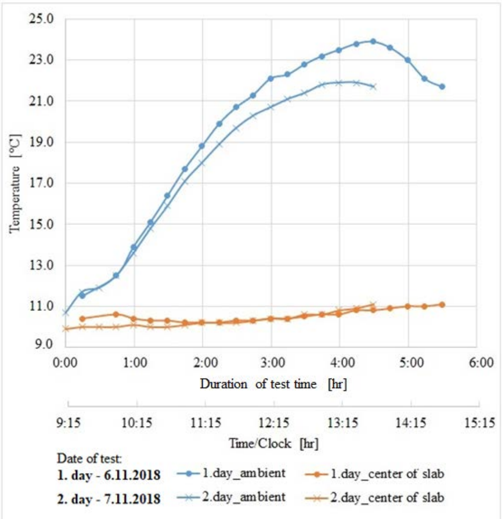

Fig.17 Temperatures course

Based on the measured data, horizontal shifts of the slab for the first and second day were evaluated. Fig. 18 and 19 show horizontal displacements for ½ slabs where the other side deforms very similarly. Sensor 3 describes the deformation at a distance of 400 mm respectively and sensor 4 at a distance of 800 mm from the center of the slab. The sensor 6 indicates the deformation in the center of the slab. The course of horizontal deformation for sensor 3 and 4 are at Fig. 20.

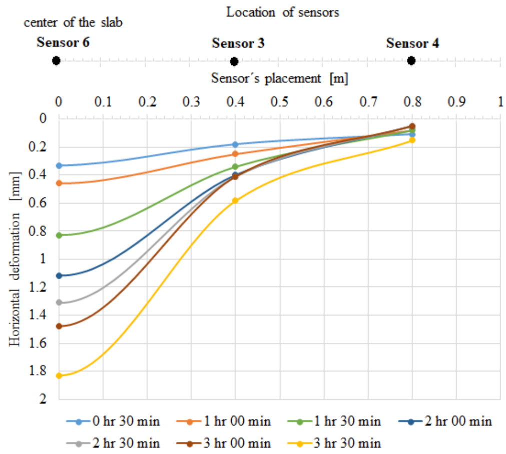

Fig.18 Horizontal deformation of ½ slab – 1. day.

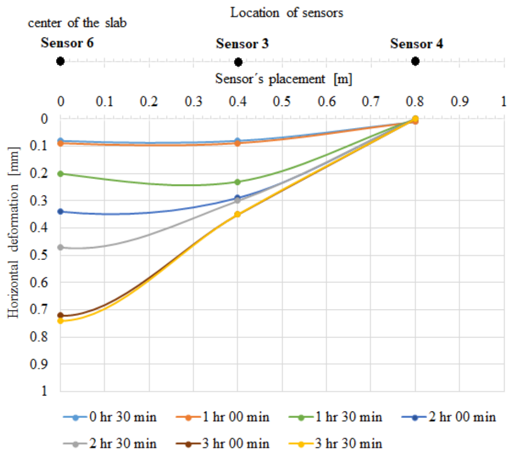

Fig.19 Horizontal deformation of the ½ slab – 2. day.

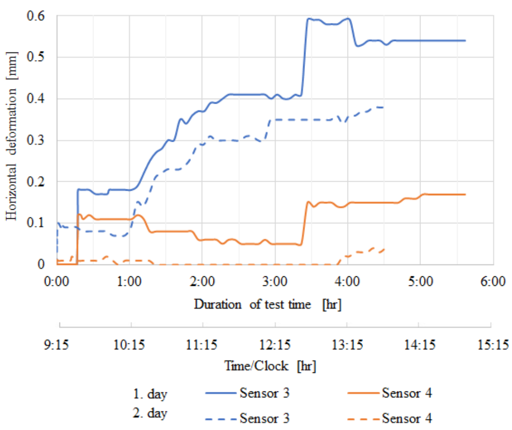

Fig.20 Horizontal deformation (sensor 3, 4) – 1., 2. day

5. CONCLUSION

The article is focused on the interaction of slab and subsoil. The performed experiment focused on the application of FRC for horizontal loading. The experiment was performed on slab with dimension 2000 x 2000 mm and height 150 mm. The special testing equipment Stand was used for testing. The sliding joints were used among the specifics of the experiment. Experimental testing proved an increase of total bearing capacity and ductility of tested slabs already at a dosage of 25 kg/m^3 fibers in previously tested slab [10]. The cracking and destruction of FRC occurred gradually. The use of a sliding joint was confirmed in case of horizontal loading. The laboratory program was also very useful as it allows us to describe in detail the mechanical properties of FRC, which are necessary for follow-up tasks for research like numerical modeling of the task which will be performed in the future by the authors of the article.

6. ACKNOWLEDGMENTS

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