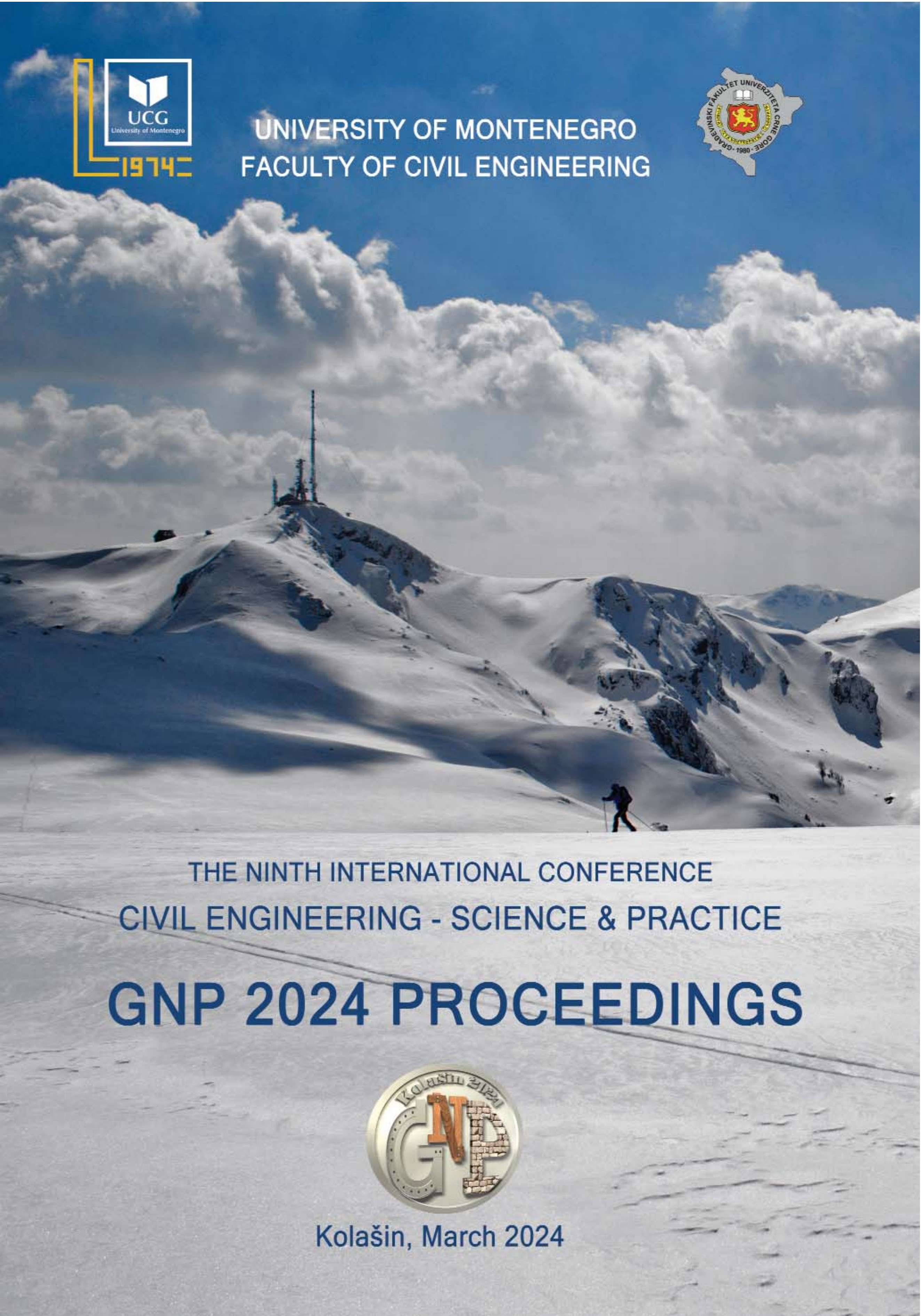

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GNP 2024 PROCEEDINGS

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EXPERIMENTAL INVESTIGATION OF THE CONSTRUCTION JOINT IN CONCRETE GROUND FLOORS

Abstract

Ground floors of industrial buildings, fully supported on the ground or piles, are usually made of several concrete segments connected through free-movement construction joints. These joints should provide shear load transfer of the slab and minimise its vertical displacements while allowing slab horizontal movement to prevent damage due to concrete dry shrinkage. The construction joint "Dilat 08", consisting of round steel dowels and steel formwork, was experimentally tested in a laboratory environment to determine its behaviour to shear load. The experimental double-shear setup consisted of three slabs connecting through the "Dilat 08" join system, with two side slabs fully supported on the base and the middle slab on which the vertical loading was applied. Specimens were formed with a gap of 10 mm between adjacent slabs to simulate the construction joint opening. Two construction joint orientations were investigated introducing the vertical load to the slab with a steel plate on the edge and to the slab with an angle profile on the edge. Experimental testing of both specimens resulted in construction joint failure due to concrete cracking around steel dowels, near the edges of the middle slab. The investigation confirmed that the joint orientation affects the joint shear response, demonstrating larger joint resistance when the steel plate is installed in the slab subjected to failure. Although contributing to the joint bending stiffness before formwork installation on the site, the horizontal leg of the angle profile decreases the joint resistance. Experimentally obtained joint resistance was compared to the design values of resistance according to Technical Report 34 and EN 1992-4, highlighting a considerable difference between the two analytical approaches. The comparison between the "Dilat 08" and three types of free-movement joints available on the construction market showed that "Dilat 08" features larger resistance according to Technical Report 34, but it also weighs more.

Keywords

Construction joint, free-movement joint, steel dowel, dowel bar, industrial floor, concrete slab, shear failure, dowel bending, concrete bearing, punching out

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1. INTRODUCTION

Ground floors of industrial halls and other commercial or industrial buildings are commonly made of concrete slabs due to their durability, strength, and suitability for heavy loads. These slabs are fully supported on the ground or piles, and they are usually divided into several segments (panels) with adequate construction joints provided on their contact. Joints should be designed to resist potential damage induced by vehicles operating in the industrial halls and provide load transfer between two adjacent slabs. They should ensure uniform vertical displacement of adjacent slabs and minimize it. Also, they need to enable concrete dry shrinkage, i.e. avoid slab damage due to shrinkage tensile stresses [1].

The commonly applied construction joint type is a free-movement joint [1], which should allow free horizontal movement of a slab and minimize its vertical movement. These joints are usually formed of steel formwork with installed steel dowels along the slab edges. Different types of joints may be found on the construction market including round and square steel dowels, as well as steel plate dowels of different shapes, as illustrated in Figure 1 [2], [3], [4]. Dowels are directly embedded in one concrete slab and placed in plastic sleeves in the adjacent slab, enabling horizontal movement in the join. While round and square dowels enable slab movement in the direction transverse to the slab edge (Figure 1.c), plate slabs enable certain lateral movement as well (Figure 1.a, 1.b). The construction joints presented in Figure 1 also include steel plates installed on slab edges which are supposed to strengthen the edges when the joint has opened, increasing the edge stiffness and resistance to bending. These plates are anchored into concrete slabs with studs (Figure 1.a, 1.b) or reinforcement bars (Figure 1.c). In the case of the solution with round dowels presented in Figure 1.c, instead of plates on both sides of the joint, the angle profile is used in one slab, to additionally increase the stiffness and avoid joint formwork deformation before installation.

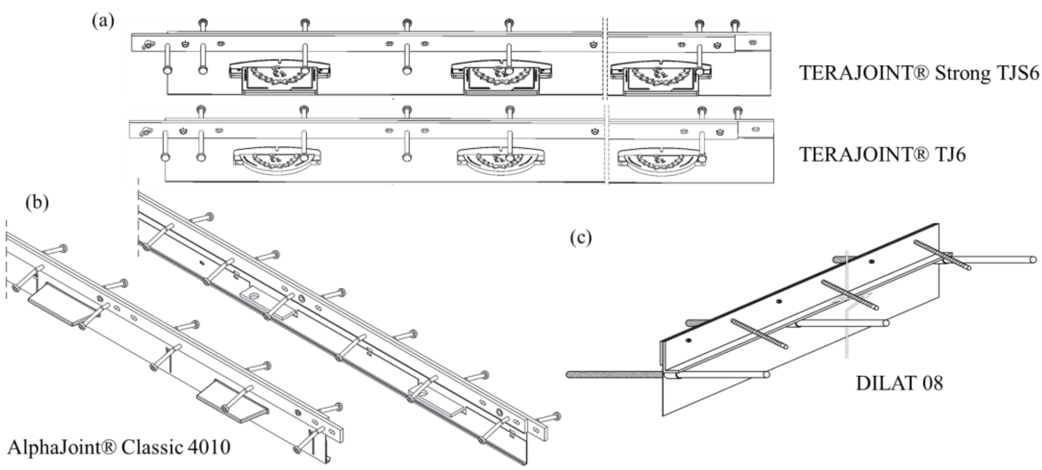

Figure 1. Free-movement joints with different dowel types: (a) rectangular and circular plate dowels [2], (b) rectangular plate dowels [3], (c) round dowels [4]

Certain directions for the design of free-movement joints including recommended dowel size and spacing, depending on the concrete slab depth, are provided in the Americal Concrete Institute Guide for Concrete Floor and Slab Construction [5]. Technical Report 34 [1] published by The Concrete Society, UK, prescribes analytical expressions for obtaining design resistance of joints with round and plate dowels. Producers of construction joints usually provide specific technical manuals for their products including data on the joint shear resistance and directions for selecting the appropriate joint design. To provide such technical specifications for company Rinol d.o.o. and their construction joint "Dilat 08" [4], which has been successfully used in practice over the last 20 years, an experimental campaign has been conducted at the Faculty of Civil Engineering, University of Belgrade.

In this paper, the experimental testing of the construction joint "Dilat 08" (Figure 1.c) performed in order to evaluate its shear behaviour is presented. Comparisons with other free-movement joint solutions are made, discussing the "Dilat 08" potential for optimization.

2. EXPERIMENTAL CAMPAIGN

The investigated construction joint "Dilat 08" consists of round dowels of a diameter of 22 mm and length of 500 mm, placed in the slab mid-depth on a spacing of 330 mm. The shear behaviour of the construction joint was investigated through experimental testing of two possible orientations of the joint, assuming that these orientations affect the joint response. In specimen R1, the construction joint is positioned with a steel plate installed on the edge of the middle (loaded) slab (Figure 2.a), while in specimen R2, the opposite orientation was introduced with an angle profile installed on the middle slab edge (Figure 2.b).

The tested specimens consisted of three concrete slabs, according to Figure 2, with two side slabs that were fully supported on the horizontal base during experimental testing, and the middle (loaded) slab without any support, allowing its vertical displacement, and therefore fulfilling the double shear test conditions. The middle slab was reinforced with mesh reinforcement to avoid bending failure of the slab during the testing. The depth of each slab was 200 mm. The gap between the middle slab and side slabs in a lateral direction was adopted as 10 mm, to simulate the construction joint opening due to dry shrinkage.

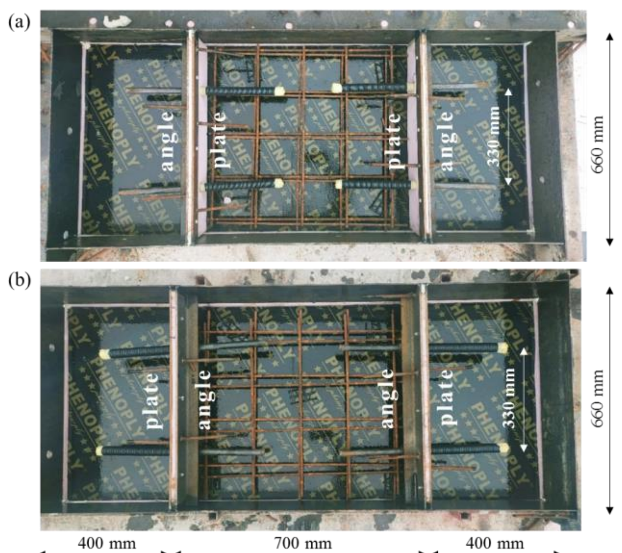

Figure 2. Specimen formwork before concrete casting: (a) specimen R1, (b) specimen R2

The specimens were tested in the Laboratory for Structures of the Faculty of Civil Engineering, University of Belgrade. The hydraulic actuator with a capacity of 300 kN was used for applying the load. The load was introduced to the mid-span of the middle slab along the whole slab length. Two side slabs, which were supported on the horizontal base, were additionally fixed to the base using the U profiles to avoid vertical lifting. For tracking the specimen behaviour during the load application, LVDTs were installed: (1) four LVDTs were used to measure the relative vertical displacement between the middle slab and side slabs at the construction joint, (2) two LVDTs were used to measure the vertical displacement of the middle slab in its mid-span relative to the ground, (3) two LVDTs were used to control the vertical lifting of the side slabs relative to the base.

Figure 3. Experimental setup

Firstly, the specimens were subjected to three load cycles in the range from 5 to 20 kN, applying a uniform loading rate of 0.2 kN/s. After the cycling loading, the load was applied as displacement control with a uniform rate of 0.015 mm/s, ensuring that this loading phase lasted at least 15 minutes before the specimen failure, as recommended for shear connector testing in EN 1994-1-1 [6]. The testing continued until the load dropped by 20% of the ultimate load.

Alongside the main experimental testing, material properties of concrete and steel components were obtained through standardised testing procedures. The mean and characteristic values of the concrete compressive strength, steel yield and tensile strength are listed in Table 1.

Table 1. Material properties

Material	Mean values		Characteristic values	
Concrete	$f_{c,cube}$ = 59.4 MPa		$f_{ck,cube}$ = 54.7 MPa	
Dowel bar	f_y = 333.4 MPa	f_u = 458.8 MPa	f_{yk} = 318.0 MPa	f_{uk} = 458.4 MPa
Angle profile	f_y = 316.1 MPa	f_u = 458.4 MPa	f_{yk} = 273.9 MPa	f_{uk} = 453.2 MPa
Steel plate	f_y = 343.9 MPa	f_u = 482.1 MPa	/	

3. RESULTS AND DISCUSSION

Both tested specimens, R1 and R2, failed due to concrete damage in the area around the steel dowels in the middle slab. During the testing, concrete cracks were detected in the middle slab along the diagonal direction from the slab mid-depth where dowels were installed, up to the concrete slab top surface, as presented in Figure 4.a. After the testing, specimens were demounted to observe the failure modes and deformed shapes of joint components. Certain bending deformation of dowels was observed, as illustrated in Figure 4.b, whereas other steel components remained undeformed.

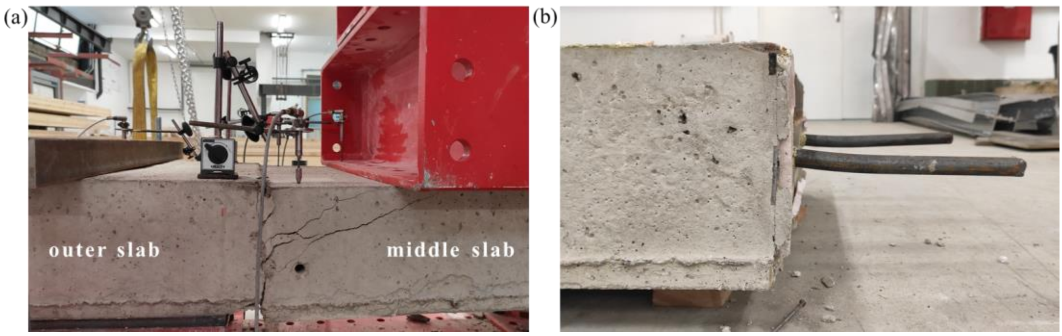

Figure 4. (a) Cracks observed during the testing, (b) Deformed shapes of dowels after the testing

Vertical displacements measured through LVDTs on the side slabs confirmed minimized lifting of those slabs relative to the base. Load as a function of relative vertical displacement at the construction joint between two adjacent slabs is presented in Figure 5 for tested specimens R1 and R2. Both specimens showed similar responses during the initial loading. However, specimen R1 observed a 16% larger resistance (165.7 kN) than specimen R2 (143.1 kN). The vertical slip at the ultimate load was somewhat larger for specimen R2 (3.92 mm) in comparison to specimen R1 (4.84 mm). The difference in the joint post-ultimate behaviour is distinct: the load in specimen R1 rapidly declined after reaching its peak, while specimen R2 featured a gradual load decrease and more ductile response.

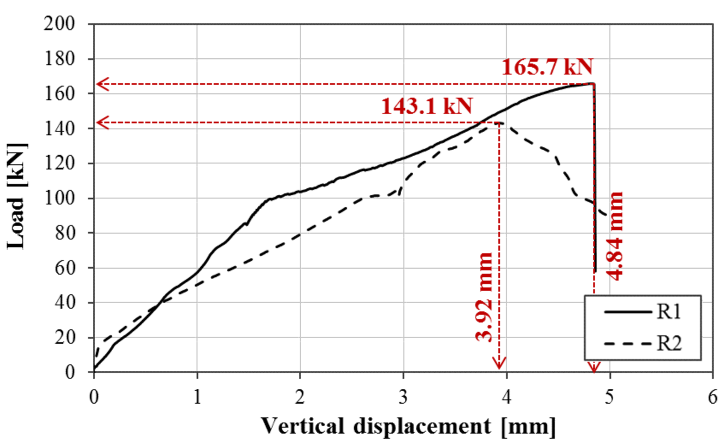

Figure 5. Load-vertical displacement curves.

Experimental testing confirmed the initial assumption that the join orientation affects the joint shear response. The resistance is decreased when the failure occurs in the slab with the angle profile installed on its edge. On the opposite, when the slab with the installed steel plate on the edge is subjected to the loading, the failure is postponed and the ultimate resistance is non-negligibly increased. Differences in joint behaviour depending on its orientation are attributed to the angle horizontal leg which cuts through the concrete slab just above the dowel, reducing the size of the concrete zone participating in the transfer of the shear load. In the case of the slab with a steel plate placed on its edge, horizontal steel components which are continuous along the slab edge such as the angle leg, are not present.

4. COMPARISON WITH OTHER JOINT SYSTEMS

To compare the “Dilat 08” construction joint with other joint systems, the experimentally obtained ultimate loads of tested specimens of 143.1 kN and 165.7 kN are transformed into the joint resistance per meter: 108.4 kN/m and 125.5 kN/m, respectively.

Design resistances of four different free-movement joints presented in Figure 1, including the “Dilat 08”, were obtained following design guidelines provided in Technical Report 34 [1]. A concrete slab depth of 200 mm, a joint opening of 10 mm and concrete class C40/50 were used as input parameters for calculation, corresponding to the experimentally tested specimens. Design procedures in Technical Report 34 are given for both plate and bar dowels, covering four possible failure modes: dowel shear, dowel bending, concrete bearing and dowel bursting/punching out of the concrete slab. Design equations are provided for the first three possible failure modes, while, due to the lack of a more precise prediction model, a calculation model for punching shear provided in EN 1992-1-1 [7] is suggested for obtaining dowel resistance to punching out. In addition to the mentioned procedures, the design resistance of the “Dilat 08”, as the construction joint with round dowels, was also obtained following design expressions for anchor resistance to shear given in EN 1992-4 [8]. Design resistances with relevant failure modes according to Technical Report 34 and corresponding construction joint weight are listed in Table 2.

Table 2. Comparison between different free-movement joint systems (concrete slab depth 200 mm, joint opening 10 mm, concrete class C40/50)

No.	Joint system	Weight [kg/m]	Design resistance [kN/m]	Relevant failure mode accord. to [1]
(1)	TERAJOINT® TJ6	10.8	60.4 (1)	bursting/punching out
(2)	TERAJOINT® Strong TJS6	11.4	71.0 (1)	bursting/punching out
(3)	AlphaJoint® Classic 4010	11.0	58.1 (1)	bursting/punching out
(4)	DILAT 08	15.5	111.0 (1) / 75.2 (2)	bending/bearing

Note: (1) According to Technical Report 34 [1], (2) According to EN 1992-4 [8]

The first three considered construction joints presented in Table 2 (No. 1–3), all including plate dowels, have similar weights in the range of 10.8–11.4 kg/m, whereas the “Dilat 08” weighs 36–44% more. Nevertheless, the “Dilat 08” features considerably higher design resistance according to Technical Report 34 than the other types of construction joints. According to the presented, optimization of the “Dilat 08” joint may be considered to reduce material consumption, while still meeting the design requirements for industrial ground floors.

For the joint “Dilat 08”, a difference of approximately 30% in design resistance prediction according to Technical Report 34 and EN 1992-4 is noticed. When transformed to a characteristic instead of a design value, resistance according to EN 1992-4, 75.2·1.5 = 112.8 kN/m, gets close to the experimentally obtained joint resistance. Considering that the failure occurred in the middle slab which was not base supported, producing the loading effect in dowels similar to the one in anchors subjected to shear, the successful applicability of the EN 1992-4 design predictions is not unexpected. On the opposite, design resistance according to Technical Report 34 is close to the experimental results, questing the safe-sided nature of the analytical prediction model. Nevertheless, none of the design expressions according to Technical Report 23 and EN 1992-4 consider the presence of an angle profile on the slab edge and its negative effect on the construction joint resistance.

5. CONCLUSIONS

The experimental investigation conducted on the free-movement construction join “Dilat 08”, designed for application in the concrete ground floors of industrial halls, is presented in the paper. The obtained results led to the formulation of the following conclusions:

1) The joint orientation affects the joint response to the shear. When the failure occurs in the slab with an angle profile on the edge, the joint resistance is 16% lower than when failure occurs in the slab with the steel plate on the edge.
2) Angle horizontal leg, i.e. continuous horizontal plate along the joint, leads to the decrease of the joint resistance to the shear. However, the angle profile facilitates the joint installation, preventing joint formwork deformation on the construction site, before concrete casting.
3) The experimentally obtained construction joint resistance, considering the less favourable joint orientation, is 108 kN/m. The relative vertical displacement between adjacent slabs at this load is approximately 3.9 mm.

The joint “Dilat 08” is on average 40% heavier than construction joints with plate dowels available on the construction market. To optimize the “Dilat 08”, further experimental and numerical investigations are planned, considering the decrease in dowel diameter and length. A difference of approximately 30% between the joint design resistance according to Technical Report 34 [1] and EN 1992-4 [8] opens up new questions concerning the choice of the adequate design procedure. To provide precise conclusions regarding the suitability of the analytical predictions, experimental work will be complemented with results of the numerical parametric analysis which will cover relevant key parameters on the joint response.

FUNDING

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