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Original Research Article

The analysis of concreting process impacts on the behaviour of residual liners of cast-in-situ voided slabs

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A B S T R A C T

This article reviews stresses caused by technological processes of concreting making an impact on void liners in reinforced concrete structures, and discusses the principles of void design. Through the application of numerical modelling, the paper considers the stress–strain status of the liners forming plastic residual voids under the loads acting in the floor slab. The authors provide a design solution to the liners forming voids.

1. Introduction

Floor slabs are one of the most important structural elements of the building which divide the structure into separate spaces, transfer arising vertical loads to columns or walls and distribute forces caused by horizontal loads among columns and restraining walls. In this case, floor slabs function as a lateral disc of rigidity. Therefore, slabs must be designed so as to produce their highest rigidity. Cast-in situ concrete flat slabs are widely used in construction industry. The employment of such floor slabs is preconditioned by a simple design solution, a straightforward cross-section, predictable behaviour and plain construction technology. Flat cast-in situ concrete slabs behave in two ways and enable to produce a continuous scheme. Rigidity in floor slabs is often reached by increasing the height of the cross-section, which, however, also means the loads of its own weight and concrete input. To avoid them, ribbed (caisson) slabs can be applied. Such design solution enables to decrease the weight of slabs slightly decreasing their rigidity.

The analysis of projects on buildings demonstrates that to achieve an efficient layout, new structural and technological solutions to increasing spans and decreasing the number of bearing structures and the dead weight of the slab have to be found [1]. The application of fibro-concrete for reinforcing long-span structures seems to be one of the most helpful examples for achieving a complexity of both structural and technological solution [2,3]. At present, more than ever, the issue of sustainable construction has been of an utmost importance [4] and has focused on a decrease in construction materials, recycling and re-using building materials and

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plastic waste. This allows reducing the cost of concrete and cement as well as cutting CO_2 emissions to the environment. The mentioned above indexes must be identified and assessed along with other Critical Success Factors (CSF) for the purpose of defining the efficiency of the project [5].

For making floor slabs lighter, the system of voided slabs of cast-in situ concrete have been introduced worldwide. For residual voids, plastic residual liners of various design solutions: spheres [6,7], ellipsoids [8,9], conical cylinders [10] or rectangular boxes [11–13] are applied. Residual liners produce voids in the cast-in situ concrete slab, and the cross-section in slabs becomes similar to hollow section precast concrete slabs. The like design solutions observed in the slab become environmentally friendly, as the liners forming voids are produced from plastic residues. A decrease in concrete in the floor slab of similar design enables to save energy in the processes of producing concrete and reducing CO_2 emissions.

Residual liners used for the formation of voided cast-in situ concrete slabs are mainly closed-type spacious elements [6]. Voids in the floor slabs of similar design are formed using plastic closed spheres (bubbles). Such liners may reduce the weight of the slab up to 30% producing spaces of up to 20 m span length. The design solution applying bubble liners of closed volumes is quite rational from the points of view of production technology and construction operation. However, the introduced liners are not dissembled and space consuming in transportation operations. Therefore, residual liners consisting of two parts have become available [8,11]. In this case, the volume and transportation expenditures of residual liners are significantly reduced.

A large number of the articles reviewing the operations of voided cast-in situ concrete slabs can be found in research literature. Particular attention is shifted on research into punching shear behaviour [14,15], flexural capacity of the vertical [16,17] and shear capacity of the inclined [18,19] cross-sections of such slabs. In addition, the impact of the form of the void on slab behaviour under operational loads has been investigated [20]. However, the behaviour of the liners forming voids at the stage of producing constructions meanwhile remains insufficiently investigated. As regards concreting operations of voided cast-in situ concrete slabs, the liners forming voids are under the impact of specific technological actions and loadings. Such loads can be assessed by choosing design solutions to the liners of residual voids. The article reviews the stress–strain behaviour of plastic liners forming residual voids under various technological impacts and loading during slab manufacturing. Endeavouring to understand the behaviour of liners under various loads and the impact combinations of technological processes during installation and concreting operations as well as to produce a rational design solution to the liner, numerical modelling under manufacturing loads of slabs has been performed.

2. Concreting technology, problems and impacts

The earlier research applied by the authors on mounting cast-in situ voided slabs equipped with industrial residual liners has identified frequent problems of their strength and rigidity under installation loads and during casting as well as has focused on the stiffness and tightness of liners within the process of compacting concrete.

Prior to concreting, liners are under the impact of heavy installation loads such as the weight of installers or concrete workers, including their equipment. During the concreting, leaners are subjected to additional significant loadings such as pressure of the cast and compacted concrete mixture. To avoid liners coming to the surface, concreting operations at two stages are performed. The thickness of the first concrete layer usually makes up to 1/3–1/2 thickness of the liner. The second layer is cast when the first concrete layer is poured and the liner is not pushed to the surface. Concreting the slab involves a bottom part of the liner under the pressure of the cast and compacted concrete. The pressure of the concrete mix on the liner acts horizontally and most frequently is transferred asymmetrically from two or three sides.

Regarding the concreting operation of the upper layer, loads also make an impact on the top part of the liner. In this case, the entire surface of the bottom part of the liner rests on the compacted concrete of the lower (first) layer. The possible combinations of the above discussed loads and rest cases are given in Table 1.

According to EN1991-1-6 recommendations, the characteristic load of concrete workers, including their equipment, makes $Q_{ca,k} = 1\ \text{kN/m}^2$. According to EN1991-1-1, the density of the unfastened concrete is $25\ \text{kN/m}^3$.

The use of in-depth vibrators for concrete compacting operations increases the pressure of the compacted concrete mix transferred to plastic liners. If the type of the vibrator is unknown, the pressure of compacted concrete p to liners is estimated according to the formula [21]

$$p = 2900\tau \mathrm{h}/k_4(1 - 0.01h) + \rho h^2/2, \quad (1)$$

where τ is a factor to be determined from formula

$$\tau = 0.34(8\eta + 4\eta + \eta^4) \times 10^{-4}\ \ \mathrm{s}^2/\mathrm{cm}, \quad (2)$$

$$\eta = 2nR/l, \quad (3)$$

n is the number of vibrators operating around the liner (possibly, $n = 1$), R – the impact radius of the vibrator, l – the estimated length of the liner (distance between fixing points), k_4 – a factor assessing the impact between the ratio of the thickness of compacted layer h and the length of the head of vibrator h_1, ρ – the density of the unfastened concrete.

The process of concreting voided slabs requires an increased focus on liners and fixing the design position of reinforcement nets. An important point is to ensure the procedure for positioning liners in rows, their position with respect to the top and bottom of the slab, distances between reinforcement bars and the thickness of the protective layers of reinforcement concrete.

For concreting voided slabs, the laid concrete mixture must satisfy the specified requirements. The mobility of the mix is one of the essential obligations, which is very important for fulfilling spaces between liners, the bottom of the liner and the bottom of formworks, reinforcement and the liner and surfaces of formworks. Thus, for concreting, cast concrete mixtures, the mobility mark of which is not less than S3 must