Source: Shcherbach A., Sas S. Composite Multi-Ribbed Slabs. Design Peculiarities. Contemporary Issues of Concrete and Reinforced Concrete: Collected Research Papers. Minsk. Institute BelNIIS. Vol. 7. 2015. pp. 229-243.

Alexander Shcherbach, PhD in Engineering Science, head of the research and scientific laboratory, «Institute BelNIIS», RUE, Minsk (Belarus)
Sergei Sas, Master of Engineering, head of the technical department, «Rector Poland», Limited Liability Company, Warsaw (Poland)

COMPOSITE MULTI-RIBBED SLABS. DESIGN PECULIARITIES

ABSTRACT

This article shows the main features of design process of a new (for the Republic of Belarus) type of reinforced concrete inserted floors – composite multi-ribbed slabs. The above-mentioned type of a composite slab is frequently applied in European countries while constructing low-story municipal and residential buildings owing to its simplicity, high speed of erecting, ability to cover up to 10 m span, possibility to create a cantilever, low need for application of powerful hoisting cranes and mechanisms, and also low need for highly qualified personnel on a building site. The information about the basic types of existing composite multi-ribbed slabs with precast reinforced concrete beams, and also various versions of structural solutions of slabs with cantilevers is provided in this article. The article also contains the graphic illustrations of above-mentioned structural solutions. General instructions for the design of composite multi-ribbed slabs and, according to authors' opinion, the most important stages of a design process are provided – the design of resistance to shear, both for the construction stage and for the functional stage of a finished structure. The requirements imposed to the stiffening ribs of slabs are also provided. Special attention is paid to the design of precast beam and monolithic concrete interface – detailed instructions of determination of an interface design length while applying various types of hollow blocks are provided. Besides, the issue of the design of continuous composite slab, consisting of the determination of maximum values of the bending moment as a fraction of a maximum value of the bending moment at the so-called comparable flight of a single-span beam is taken up.

Keywords: multi-ribbed composite slabs, hollow blocks, stiffening rib, interface

INTRODUCTION

During the several recent years, the offers arose in the territory of the Republic of Belarus for the delivery of products and services type of reinforced concrete slabs for construction of multi-ribbed composite slabs that are new for our market of construction products and services.

Due to its simplicity, high speed of erecting and low cost, this type of floor slabs gained special popularity in construction of low-story residential and municipal buildings in the countries of Western Europe (Figure 1).

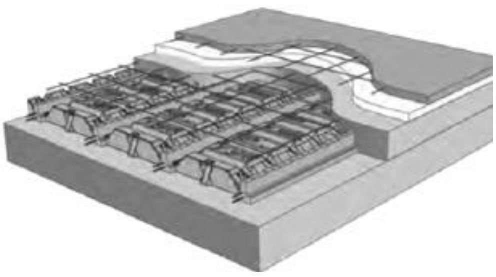


Figure 1. Element of a multi-ribbed composite slab

Multi-ribbed composite floor slabs have several advantages when compared with other types of slabs.

The following advantages shall be considered as the most important ones:

– improved technical and economic characteristics including reduction of materials expenditure if compared with ordinary reinforced concrete composite constructers;
– suitability for construction of large spans with the requirements observed in terms of slab stiffness (up to 10 m). Also, larger sizes of spans allow more flexibility in the slab space layout;
– high speed of erecting;

– in most cases, there is no need to use hoisting mechanisms.

The Recommendations [4] on the design of reinforced concrete multi-ribbed composite slabs have been prepared by the "Institute BelNIIS" RUE, describing in details all the stages of the design of multi-ribbed composite slabs with the prestressed precast beams, starting from general instructions for the design of various types of composite ribbed slabs to the special requirements for the design. Also, the recommendation [4] contain provisions for:

– rules for the design of slab support;
– calculation of resistance to concentrated loads;
– implementation of a seismic stability;
– consideration the diaphragm effect.

Further, we shall discuss in details the most important, in our opinion, stages of design of multi-ribbed composite slabs.

BASIC TYPES OF MULTI-RIBBED COMPOSITE FLOOR SLABS

In accordance with the international practices of design of multi-ribbed composite slabs [1-3], application of these slabs is reasonable for spans not exceeding 10 m and subject to the following additional restrictions:

– the pitch of precast beams (ribs) does not exceed 750 mm;
– floor slabs take predominantly static loads, preventing the risk of onset of repeated or significant dynamic impacts as well as loads that can result in material failure due to fatigue;
– floor slabs are protected against unfavourable atmospheric effects and not exposed to aggressive environments;
– floor slabs take loads from moving objects (such as light-weight vehicles and hoisting machinery with loads on axle not exceeding 30 kN).

It should be noted that multi-ribbed slabs are applicable in seismic regions also.

The following basic types can be distinguished among the lot of various structural solutions for multi-ribbed composite slabs:

– with the continuous composite concrete footing built up by concrete laying on high-strength hollow blocks[1] (Figure 2) or simple hollow blocks[2];

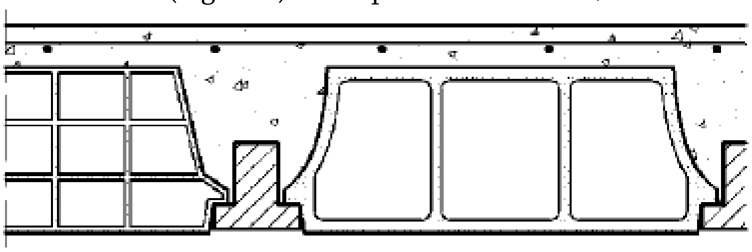


Figure 2. Structural solution for a floor slab with high-strength hollow blocks

– with the "discontinuous" concrete footing on load-carrying hollow blocks[3] – composite concrete is applied only between hollow blocks (Figure 3);

[1] Hollow blocks for arrangement of non-removable formwork made of concrete or ceramics and taken into consideration during the design of floor slabs by two groups of limit states.
[2] Hollow blocks for arrangement of non-removable formwork, not taken into consideration in calculations of floor slab section resistance.
[3] Concrete or ceramic hollow blocks that, due to their shape and mechanical characteristics, redistribute all operational loads on beams and provide resistance to local loads; as a result, arrangement of a distributing concrete footing becomes unnecessary.

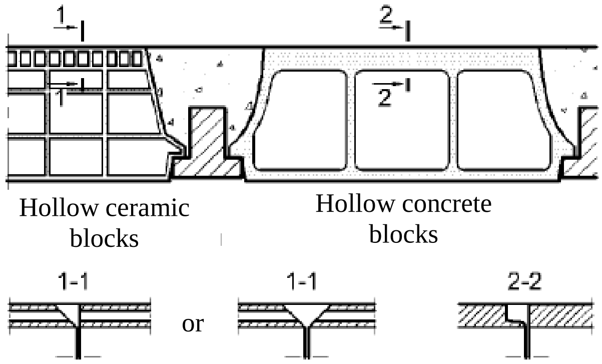


Figure 3. Structural solution for a floor slab with “discontinuous” concrete footing

– with the continuous “independent” composite concrete footing – composite concrete is applied throughout the whole slab surface on the insulating material layer (e.g. throughout foamed polystyrene slabs) (Figure 4);

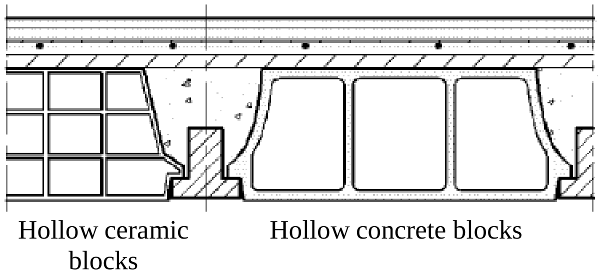


Figure 4. Structural solution for a floor slab with “independent” concrete footing

– floor slabs with high-strength hollow blocks (if used as a deck or as an attic floor) with or without an “independent” concrete footing;
– floor slabs with load-carrying beams: these are floor slabs where resistance to the existing loads is provided by beams, while the link between beams and laid composite concrete is not mandatory (Figure 5).

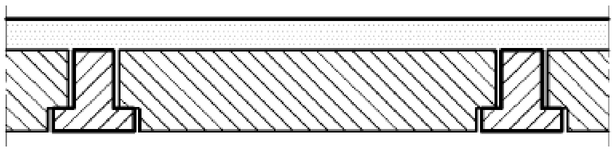


Figure 5. Structural solution for a floor slab with load-carrying beams

Structural solutions for composite multi-ribbed slabs are also suitable to make cantilever elements.

The following structural solutions for multi-ribbed composite slabs with cantilever parts shall be considered:

– application of cantilevering precast beams (Figure 6);

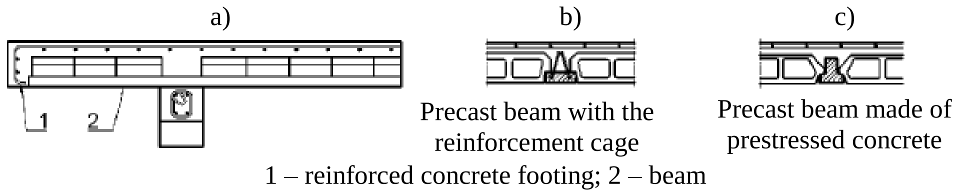


Figure 6. Structural solution for a cantilever overhead of a slab with precast prestressed girders protruding as cantilevers:
a) cantilever overhead of a slab;
b) lightened beam;
c) prestressed beam.

- application of flushing (shortened) precast beams (Figure 7). These beams must be set along the axis of precast beams for a floor slab;

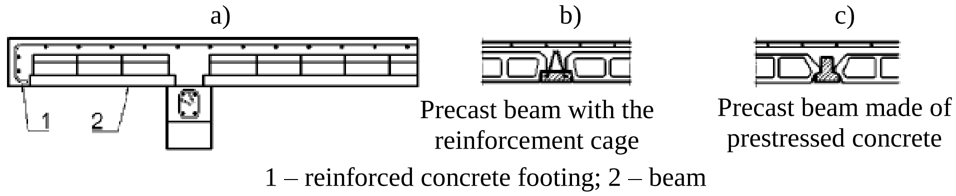


Figure 7. Structural solution for a cantilever overhead of a slab with flushing precast beams:
a) cantilever overhead of a slab;
b) lightened beam;
c) prestressed beam.

- application of short (high quality) beams used as non-removable formwork (Figure 8). The cantilever resistance to the existing loads is provided by the concrete footing;

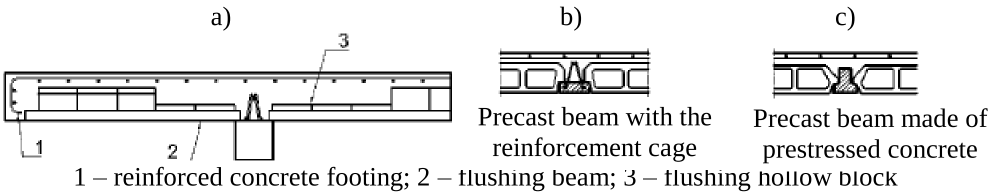


Figure 8. Structural solution for a cantilever overhead of a slab with flushing beams used as non-removable formwork

- application of the structural solution implemented as the arrangement of a composite reinforced-concrete cantilever slab (Figure 9).

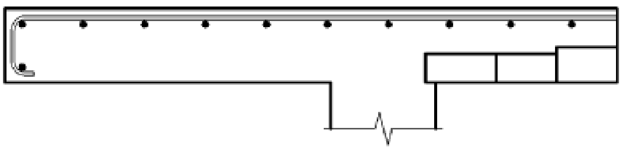


Figure 9. Structural solution for a composite cantilever overhead of a slab

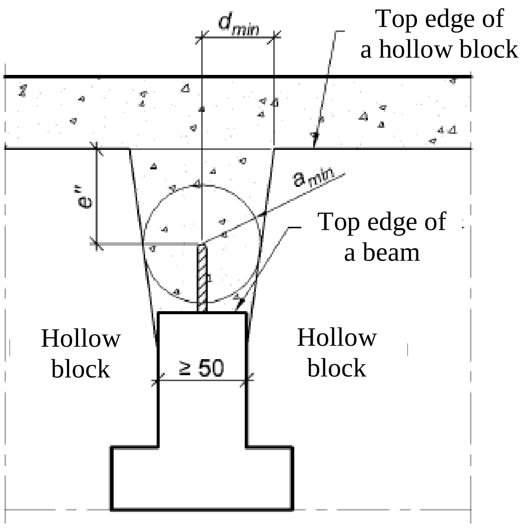
REQUIREMENTS IMPOSED ON THE STIFFENING RIBS OF SLABS

When sizing section of the stiffening ribs, the following requirements [4] shall be met (Figure 10):

- stiffening rib width on the top level of a beam must be at least 50 mm;
- the distances, a and d, must meet the conditions: $a \geq a_{min}$, $d \geq d_{min}$, where

$$a_{min} = max(35;30 + \frac{e''}{8}) \text{, mm,} \tag{1}$$

$$d_{min} = max(a;a_{min} + 0{,}2e'') \text{, mm,} \tag{2}$$



a_{min} is the minimal distance between the top of reinforcement loops and the side edge of a hollow block; e'' and d_{min} are the distances between the top of reinforcement loops and the top edge of a hollow block measured in vertical and horizontal direction respectively

Figure 10. Primary parameters of a composite part in a stiffening rib

FLOOR SLAB DESIGN RULES

The design of multi-ribbed composite slabs shall be carried out for two stages:

- for erection stage;
- for finished slab stage.

The design at the erection stage shall be carried out for elements mounted with or without intermediate temporary supports.

For the slab design at the erection stage according to limit states of the load-carrying capacity, the following conditions shall be met:

$$M_{Ed,\,prov} \leq M_{Rd\,7}\,, \tag{3}$$

where $M_{Ed,\,prov}$ is the bending moment in the design section resulting from an external load, kN·m;

$M_{Ed,\,7}$ is the limit value of the bending moment taken by the section of a precast beam, minimum at 7 days.

$$V_{Ed,\,prov} \leq V_{Rd,\,c}\,,\ V_{Ed,prov} \leq V_{Rd,c}$$

where $V_{Ed,\,prov}$ is the lateral force in the design section resulting from an external load, kN·m;

$V_{Rd,\,c}$ is the limit value of the lateral force taken by the section of a precast beam at the age of at least 7 days.

For the design at the erection stage, the design of beam resistance to the lateral force is especially important. The formula [6] (6.4) shall be used to calculate the lateral force $V_{Rd,\,c}$, kN, taken by concrete in a beam, with consideration of the beam concrete at 7 days:

$$V_{Rd,c} = \frac{I_b \cdot b_w}{S_b}\sqrt{f_{ctd}^2 + \alpha_1 \cdot \sigma_{cp} \cdot f_{ctd}}\,, \tag{4}$$

where f_{ctd} is the design value of tensile strength of concrete, MPa, calculated as follows:

$$V_{Rd,c} = \frac{I_b \cdot b_w}{S_b}\sqrt{f_{ctd}^2 + \alpha_1 \cdot \sigma_{cp} \cdot f_{ctd}}\,, \tag{5}$$

here, γ_C is the partial safety factor for concrete, assumed to be $\gamma_C = 1.3$ [4], [6] (A.2.3);

$f_{ck,7}$ is the characteristic value of tensile strength of concrete in precast beams at 7 days, MPa.

For the slab design at the erection stage according to limits states of serviceability, deflection and cracking shall be controlled:

$$a_{max} \leq \frac{L_{er}}{n_f}\,, \tag{6}$$

where L_{er} is the structure span, kN·m;

n_j is the coefficient assumed to be n_j = 200 for floor slabs constructed without temporary supports and not covered by any aesthetic and psychological requirements (e.g. basements used for technical purposes); n_j = 500 in any other cases.

$$M_{Ed} \leq M_{cr,\,7}\,, \tag{7}$$

where $M_{Ed,}$ is the bending moment in the design section resulting from an external load, kN·m;

$M_{cr,\,7}$ is the moment of cracking for the precast beam at least7 days.

The finished slab shall be designed in accordance with the rules as follows:

- for reinforced-concrete floor slabs, resistance to loads shall be calculated by limit states of the load-carrying capacity with regard to the major combinations of loads according to the requirements listed in [4];
- the design according to limit states of serviceability shall be carried out with regard to the almost constant and frequently occurring combination of loads. The design by limit states of serviceability is focused on the control of deflections and crack initiation and opening processes in accordance with the requirements listed in [6] (7.2, 7.3).

Similar to the design of slab constructers, the calculation of stiffening rib resistance to lateral forces is worthy of special attention at the erection stage.

The following types of calculations shall be carried out:

- calculation of resistance in the interface between the precast beam concrete and composite concrete of the stiffening rib;
- calculation of stiffening rib resistance to shear;
- calculation of resistance to shear from the concrete footing layer along the nominal edge of connection with composite concrete of the stiffening rib.

The interface resistance shall be calculated in accordance with the requirements listed in [6] (6.2.5).

The interface resistance in the combined section shall be checked using the formula:

$$v_{Edi} \leq v_{Rdi}\,, \tag{8}$$

where v_{Edi} is the design value of the shear stress along the interface, MPa, resulting from existing loads and calculated according to the formula (6.24) [6];

v_{Rdi} is the interface resistance to shear, MPa, calculated according to the formula (6.25) [6].

The specific point in calculation of resistance of the interface of precast beam concrete and composite concrete in a multi-ribbed composite slab is the calculation of the design length of the interface which is extremely difficult if only known norms of design of reinforced-concrete structures are used.

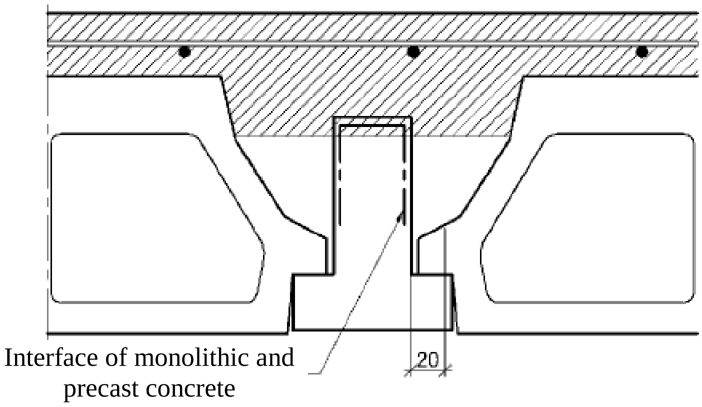


Figure 11. Design length of the interface

The design length of the interface of two concrete surfaces can be conditionally calculated without any consideration of inclinations of side surfaces of beams. This length must be calculated with the preconditions as follows:

- for high-strength hollow blocks or load-bearing hollow blocks with longitudinal cavities, the interface length shall be measured from the level where the width between the beams and hollow blocks, measured horizontally, is 20 mm (Figure 11);
- for simple hollow blocks and composite hollow blocks: by consideration of positions of points A and C or B and C, depending on the shape of blocks.

The positions of points A, B, C shall be defined as follows (Figure 12):

1) A – the top edge of the shelf in a hollow block, if tg $\beta \leq 1/3$;

2) B – the level by height where the width between the beam and the hollow block is 2 cm, if tg $\beta > 1/3$;

3) C – the level produced by intersection of the beam side edge with the inclined plane at an angle 45° tangentially to the outer contour of a hollow block.

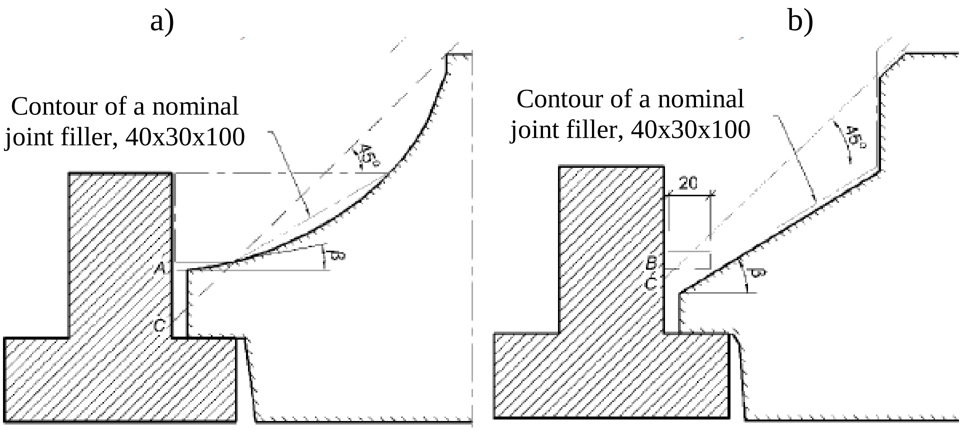


Figure 12. For calculation of the design length of the interface:
a) in case of a curved edge of a hollow block;
b) in case of a straight edge of a hollow block.

Composite concrete footing shear along the edge of a composite stiffening rib

Resistance to shear between the parts of a composite concrete footing located left and right of the stiffening rib and the stiffening rib itself shall be calculated in accordance with the requirements listed in [6] (6.2.4).

In this calculation, the composite concrete layer of thickness shall be taken into consideration, nominally increased by u=1 cm, if standard heavy-concrete or ceramic hollow blocks are used, or by u=0.5 cm, if high-strength hollow blocks made of light-aggregate concrete are used.

See Figure 13 for the vertical section *x-x* that must be checked in terms of resistance to shear.

If all requirements for the floor slab load-carrying capacity and deformability are met and confirmed by calculations carried out for stiffening ribs only, then there is no need to check the section *x-x* in terms of shear.

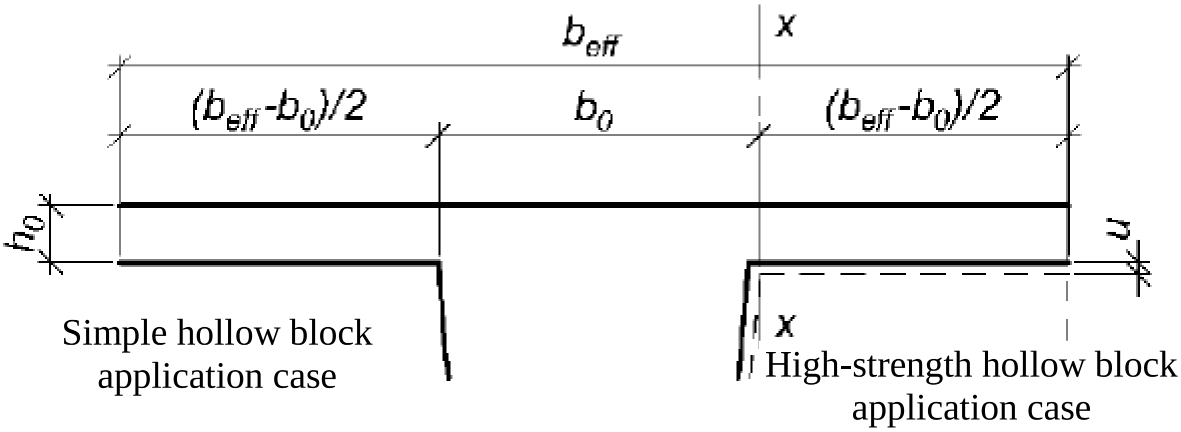


Figure 13. Position of the shear plane *x-x*

CONSIDERATING THE STATIC INDETERMINATENESS IN THE DESIGN OF FLOOR SLABS

Taking the continuity into consideration is the standard method for choosing the cross-section of a multi-ribbed composite slab during the design of middle spans. The similar situation is the case for outermost spans if the required anchorage length for the principal reinforcement can be calculated and taken into consideration.

Meanwhile, the longitudinal reinforcement must be provided on an outermost support; this reinforcement must be installed in the top zone of the section and must be capable to take the bending moment of $0.15M_t$ (here, M_t is the maximum bending moment in a beam to be designed).

In accordance with the provisions of [4], the design of continuous floor slabs may be carried out as for discontinuous ones in cases as follows:

- if cracking on supports poses no threat for strength and stability of structures supported by the slab;
- if it is possible to demonstrate that no cracks arise as a result of growth of constant loads due to incomplete variable loads where part of these loads can be considered as a long-term load.

The core of the design method for continuous slabs is the calculation of maximum values of bending moments in spans and on supports as fractions of the maximum value of the bending moment $M_{ED,0}$ in the so-called "comparable span" for the statically determinable floor slab exposed to the same loads. These values are pre-limited.

For the floor slab to be designed, the effective span length is *L*. It is exposed to the combination of constant loads *G* and the variable load Q_R. The maximum bending moment $M_{ed,0}$, kN·m, in the so-called "comparable span", corresponds to these loads; this moment shall be calculated in accordance with the formula:

$$M_{Ed,0} = \frac{(1.35G + 1.5Q_b) \cdot \chi \cdot L^2}{8}, \tag{10}$$

where χ is the pitch of beams.

The moments on supports, $M_{Rd,w}$ and $M_{Rd,e}$ (Figure 14), shall be calculated as a function of the moment M'_0 that takes the conditions of installation of stands into consideration. The purpose of this calculation is to find the "comparable span" for an imaginable floor slab capable to take the loads $G+Q_R$ and to take the bending moment in the span $M_{Rd,t}$, kN·m, equivalent by value, calculated in accordance with the formula:

$$M_{Rd,t} = \frac{(1.35G + 1.5Q_B) \cdot \chi \cdot L_f^2}{8}. \tag{11}$$

The absolute values of support moments taken on intermediate supports, $M_{Rd,w}$ and $M_{Rd,e}$, must not be less than the values listed in Table 1.

Table 1

Minimal values of support moments taken on intermediate supports

Intermediate support type	Slab with prestressed beams
Floor slab with two spans	0.55·M'_0
The first intermediate support in the slab with the number of spans more than 2	0.50·M'_0
The second and subsequent intermediate supports in the slab with the number of spans more than 3 0.40·M'_0	

For floor slabs mounted with temporary supports, $M'_0 = M_{ed,0}$ shall be assumed.

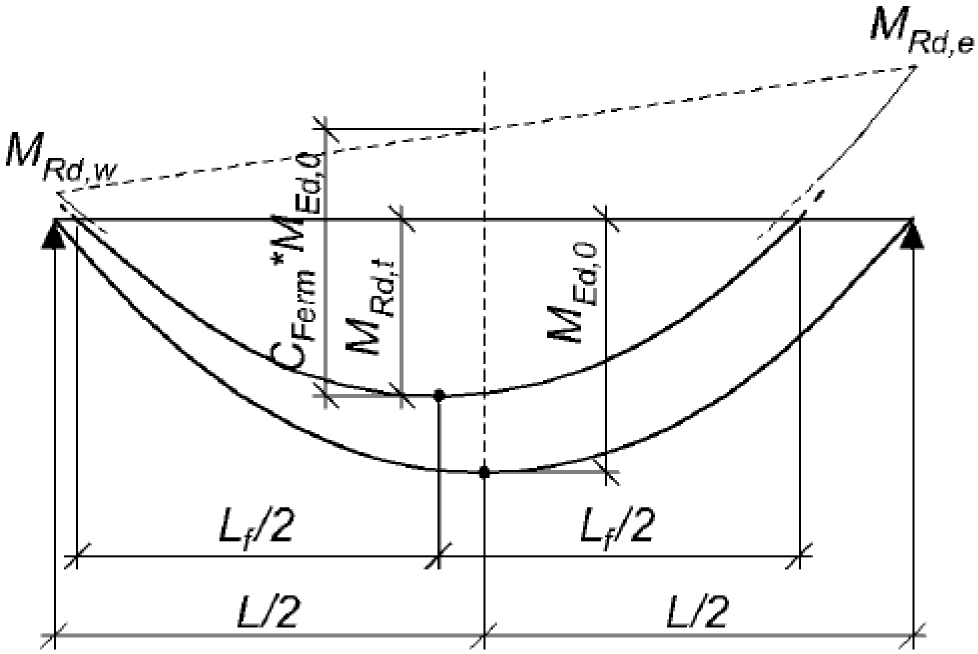


Figure 14. The “comparable span” for the imaginable floor slab

CONCLUSION

Multi-ribbed composite floor (deck) slabs have several advantages, resulting in their sizable proportion in the foreign practice of design and construction of floors for low-story buildings.

The recommendations for the design of ribbed composite slabs, prepared by Institute BelNIIS RUE, make it possible to ease significantly the designer’s work for the design of this type of slabs.

There are several differences between the design of a multi-ribbed composite slab and commonly-used composite slabs, and special rules, not given in the norms being in force for the design of reinforced-concrete structures, must be used in the former case.

REFERENCES

1. Dzięgielewski A. *Engineer in Construction.* 2014. No 5. pp. 71 – 76. (pl)

2. Drobiec L., Pajac Z. *Stropy z drobnowymiarowych elementow* – Gliwice: Wydawnictwo Politechiki Slaskiej, 2010. (pl)

3. *Planchers nervures a poutrelles prefabriquees associees a du beton coule en oeuvre ou associees a d’autres constituants prefabriques par du beton coule en oeuvre* – CSTB, 2012. (fr)

4. R 5.03.148-2015 *Rekomendatsii po raschetu i proyektirovaniyu zhelezobetonnyykh sborno-monolitnykh rebristykh perekrytiy s primeneniyem razlichnykh elementov mezhbalochnogo zapolneniya* [Recommendations on the design of reinforced concrete composite ribbed slabs with the use of various elements for bean filling]. Minsk : RUP ≪Institut BelNIIS≫, 2015. (rus)
5. *Evrokod. Osnovy proyektirovaniya stroitelnykh konstruktsiy* [Eurocode. Principles of design of building structures] : TKP EN 1990-2011. Vved. 01.07.12. Minsk: Minstroyarkhitektury RB, 2012. 70 p. (rus)
6. *Evrokod 2. Proyektirovaniye zhelezobetonnykh konstruktsiy. Chast 1-1. Obshchiye pravila i pravila dlya zdaniy* [Eurocode 2. Design of reinforced concrete structures. Part 1-1. General rules and rules for buildings]: TKP EN 1992–1–1–2009*. Vved. 01.01.10. Minsk : Minstroyarkhitektury RB, 2015. 206 p. (rus)

The article was submitted to the Editorial Board on 11.11.2015