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Peculiarities of Russian Standards Application in Horizontal Formwork Design

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Abstract. The article deals with a typical technological map for the installation and dismantling of the formwork of a German manufacturer, the loads listed in the technological map according to the German regulatory documents are considered. The calculation of the loads acting on the formwork was performed in accordance with the Russian regulatory documents. A table comparing the results is presented from which it can be seen that the loads calculated in accordance with DIN 4421 and GOST R 52085-2003 for the same formwork differ in the values obtained. The conclusion is made that it is necessary to apply the Russian normative documents when calculating and using the formwork in the territory of the Russian Federation. In accordance with the Russian regulations, when calculating the distances between girders and contractions, calculations must be made for the two limiting states - from the strength conditions of the shield according to the carrying capacity and the shield strength by deformation. The distances between girders and contractions calculated in this way will meet the requirements of the normative documents of the Russian Federation. The article proposes a method for determining the distances between girders and contractions in two limiting states and shows the derivation of the formulas used in the calculations.

1. Introduction

At present, erection of a monolithic multi-storey frame of the building is one of the promising directions in the construction of housing, administrative buildings and other structures both in Russia and abroad. Construction of residential and public buildings from monolithic reinforced concrete opens wide prospects not only for creating the architectural expressiveness of the object and its individuality, but also for improving the quality and durability of structures.

In recent years more than one and a half billion cubic meters of concrete have been laid in monolithic structures every year. The volume of production and use of monolithic concrete is much ahead of other types of building materials [1].

Currently, there is a wide variety of removable formwork in the construction industry, a large number of both domestic and foreign formwork manufacturers are represented on the Russian construction market. One of the largest and most famous manufacturers is the German firm Peri. The formwork of this company is used primarily in industrial construction and is characterized by a large number of unified elements, the use of which allows to install prefabricated formwork for various structural elements [2].

This paper considers the compliance of typical technological maps for the installation and dismantling of the PERI "MULTIFLEX" formwork by the Russian GOST.

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2. Comparison of load calculations acting on the formwork, made in accordance with DIN 4421 and GOST R 52085-2003

The process of calculating the formwork using a typical process map is simple and obvious: depending on the required thickness of the overlap, the load per $1m^2$ of formwork is calculated and the permissible distances between the transverse beams and the permissible distances between the longitudinal beams are proposed. In this case, the load calculation was carried out in accordance with the German national standard DIN 4421 "Carcasses. Rules for calculation, design and execution "[3].

Let us compare the method of calculation of loads according to the standards of Germany and Russia:

2.1. *Constant load from reinforcement and concrete mix:*

- according to DIN 4421: concrete layer pressure $P_c = 26 \cdot d$ kN/m^2, where 26 is the average specific weight of the layer for normal conditions (average density of fresh concrete mix 25 kN/m^3 and approximately 100 kg of reinforcement per 1 m^3 of concrete); d is the thickness of the overlap, m;
- according to GOST R 52085-2003, a constant load from the reinforcement and concrete mixture is considered separately [4]. The weight of the concrete mix is assumed: for heavy concrete 25kN/m^3, for other concretes - according to the actual weight. The weight of reinforcement is accepted according to the project and only 100 kg/m^3. can be taken in the absence of design data. Taking into account that the project documentation is always present on the site, the weight of the reinforcement must be taken in accordance with it, which means that it will differ from 100 kg/m^3.

2.2. Proper weight of formwork:

- according to DIN 4421: $P_w = 0{,}40$ kN/m^2. There may be refinements depending on the materials and structures used, but this value is adopted in the considered technological map;
- according to GOST R 52085-2003, the actual weight of the formwork is determined by the drawings.

2.3. Temporary load:

- according to DIN 4421: $P_t = 0{,}2P_c$ kN/m^2. At the same time, the values of the temporary load are limited: 1.5 kN/m ^{2}<P_t< 5 kN/m^2 – in the working area 3x3 m; $P_t = 0{,}75$ kN/m^2 - outside the working area. At the same time, uneven laying of the concrete mix, compaction of the concrete mix, locating the personnel and tools on the formwork is considered a temporary load;
- according to GOST 52085-2003, loads from people and vehicles are taken as 2.50 kN/m^2. In addition, the formwork must be checked for the concentrated load from the technological means in accordance with the actual possible loading of the design of the work.

Comparing the above methods of calculating the load, it is possible to see that the German standard regulates the use of fixed loads, while according to the Russian standard, in most cases it is necessary to take the actual load for calculation. In a typical technological map, concentrated forces are not taken into account in calculating temporary loads, although they could make a significant contribution to the distribution of effort along the cross-section of the formwork, especially outside the working area (for example, the installation of industrial welding machines, bundles of reinforcement etc.). On the other hand, the values of temporary loads, determined by the German standards, may differ from the Russian standards both in large and in smaller directions. In addition, according to DIN 4421, when calculating the formwork elements, only the normative load obtained by adding the above-mentioned permanent and temporary loads is accepted, while the Russian GOST R 52085-2003 provides for the use of safety factors [5].

Consider the calculation from the standard process map for the installation and dismantling of the PERI system formwork "MULTIFLEX" using beams VT 20 [6].

The results of calculations in accordance with DIN 4421 and GOST R 52085-2003 in tabular form are as follows (Table 1):

It can be seen from the table that the loads calculated according to the German and Russian standards differ, the deviation of the reinforcement mass from 100 kg/m2 affects the final design load.

Table 1. Comparison of the loads calculated according to the German and Russian standards.

Thickness of concrete slab, d (cm)	Load calculation according to DIN4421 (kN/m^2)				Load calculation according to GOST R 52085-2003 (kN/m^2)					
	Proper formwork weight, Pw	Constant load from reinforcement and concrete mix, Pc	Temporary load, Pt[1]	Normative load, Pn	Proper formwork weight [2], Pw	Constant load from concrete mix, Pc	Constant load from reinforcement [3], Pr	Temporary load, Pt	Normative load, Pn	Design load, Pd[4]
14	0,4	3,6	0,7	5,5	0,4	3,5	0,11	2,5	6,51	8,02
							0,14		6,54	8,06
							0,17		6,57	8,09
16	0,4	4,2	0,8	6,1	0,4	4	0,13	2,5	7,03	8,64
							0,16		7,06	8,68
							0,19		7,09	8,72
18	0,4	4,7	0,9	6,6	0,4	4,5	0,14	2,5	7,54	9,26
							0,18		7,58	9,31
							0,22		7,62	9,35
20	0,4	5,2	1,0	7,1	0,4	5	0,16	2,5	8,06	9,88
							0,20		8,10	9,93
							0,24		8,14	9,98
22	0,4	5,7	1,1	7,6	0,4	5,5	0,18	2,5	8,58	10,50
							0,22		8,62	10,55
							0,26		8,66	10,61
24	0,4	6,2	1,2	8,1	0,4	6	0,19	2,5	9,09	11,12
							0,24		9,14	11,18
							0,29		9,19	11,24
26	0,4	6,8	1,4	8,7	0,4	6,5	0,21	2,5	9,61	11,74
							0,26		9,66	11,80
							0,31		9,71	11,86
28	0,4	7,3	1,5	9,2	0,4	7	0,22	2,5	10,12	12,36
							0,28		10,18	12,42
							0,34		10,24	12,49
30	0,4	7,8	1,6	9,8	0,4	7,5	0,24	2,5	10,64	12,98
							0,30		10,70	13,05
							0,36		10,76	13,12
35	0,4	9,1	1,8	11,3	0,4	8,8	0,28	2,5	11,93	14,53
							0,35		12,00	14,61
							0,42		12,07	14,69
40	0,4	10,4	2,1	12,9	0,4	10	0,32	2,5	13,22	16,07
							0,40		13,30	16,17
							0,48		13,38	16,27
45	0,4	11,7	2,3	14,4	0,4	11,3	0,36	2,5	14,51	17,62
							0,45		14,60	17,73
							0,54		14,69	17,84
50	0,4	13	2,6	16	0,4	12,5	0,40	2,5	15,80	19,17
							0,50		15,90	19,29
							0,60		16,00	19,41

[1] According to DIN4421, the temporary load is accepted as $1,5 \leq Pt \leq 5,0$, the normative load P_n is calculated taking this condition into account.
[2] The weight of the formwork in the calculations for the two normative documents was adopted the same.
[3] The constant load from the valves in accordance with GOST R 52085-2003 is adopted according to the project; in this calculation, 3 load variants - 80 kg/m^3; 100 80 kg/m^3, 120 80 kg/m^3.
[4] The calculated load is calculated using the safety factors: for the proper weight of the formwork k = 1,1; for the load from the concrete mix and reinforcement k=1,2; - for the temporary load k=1,3

3. Methods of calculating the formwork

Formwork boards are flat elements made of plywood, metal, plastic or wood. To ensure the necessary rigidity there are ribs arranged on the boards. These stiffeners are arranged in two mutually perpendicular directions - a vertical rib, called a girder, is in contact directly with the shield, and a horizontal rib, called a contraction, passes over the run. And tgirder and contraction must be connected to the shields [7].

Thus, girders and contactions play the role not only of the stiffeners, but of the connecting elements that ensure the integration of individual shields into the deck, and in combination with the supporting devices, the geometric invariability of the entire formwork [8].

According to the Russian GOST R 52085-2003, the calculation is carried out according to two limiting states - on bearing capacity and deformations. When calculating the first limiting state, the stock factors to the standard load are taken into account.

In order to determine the distance between girders, the case of a two-span beam is considered. In this case, the maximum bending moment will occur on the support [9].

1. Determination of the distance between girders [10].

- Determination of the distance between girders from the condition of bearing capacity.

The condition of the strength of the shield according to the bearing capacity:

$$\frac{M}{W} \le R_c \tag{1}$$

where M – maximum bending moment in the formwork panel; W- resistance moment; R_c - design resistance to the bending of the formwork panel material, kg/cm^2.

The maximum bending moment in the formwork panel:

$$M = \frac{P_d \cdot L_1^2}{8} \tag{2}$$

P_d – design load acting on the formwork; L_1 – distance between supports.

The moment of resistance W is determined by the formula:

$$W = \frac{b \cdot h^2}{6} \tag{3}$$

Cut the beam of the unit width. Then in the moment of resistance formula: b = 1, h = δ.

Substituting the resulting values into the formula for the strength condition for the load-bearing capacity, we obtain L_1:

$$L_1 = \sqrt{\frac{8 \cdot R_c \cdot \delta^2}{6 \cdot P_d}} \tag{4}$$

- Determination of the distance between girders from the condition of deformation.

The condition for the strength of the shield for deformations for horizontal formwork [11]:

$$f \le \frac{1}{500} L_1 \tag{5}$$

where f - maximum possible deflection of the formwork panel.

At the same time, the ultimate deflection of the shield is determined by the formula [12]:

$$f = 0.00547 \frac{P_n \cdot L_1^4}{E \cdot J} \tag{6}$$

where E - module of elasticity of the formwork material, kg/cm ^{2}; J - moment of inertia of the shield, cm ^{4}.

The moment of inertia of the shield:

$$J = \frac{b \cdot h^3}{12} = \frac{1 \cdot \delta^3}{12} \tag{7}$$

Equating the formulas, it is possible to express the distance between girders:

$$L_1 = \sqrt[3]{\frac{E \cdot \delta^3}{32.82 \cdot P_n}} \tag{8}$$

The final distance between the girders is determined as the smallest, obtained from the conditions of strength and deformation.

2. Distance between contractions.

Distance between contractions (clamps) L_2 is determined from the load collected from the strip with a width equal to the distance between girders (Figure 1).

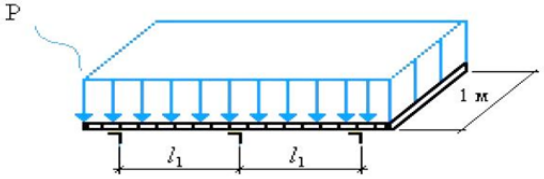


Figure 1. Calculation scheme for determining the load.

Figure 2 shows an example of the reduced section and the geometric scheme of the girder.

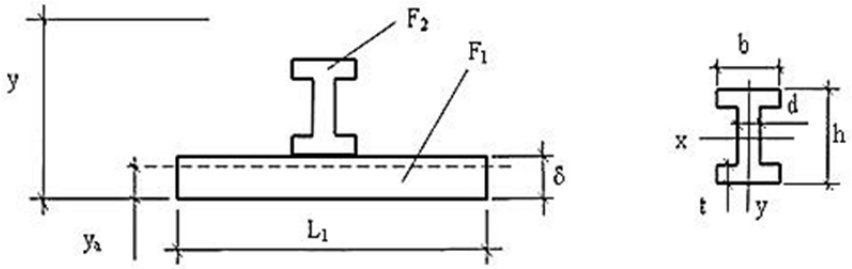


Figure 2. Scheme of the reduced section and geometrical scheme of the girder.

Characteristics of the reduced section [13]:

The coordinate of the center of gravity of the section, cm:

$$y_a = \frac{F_1 \cdot y_1 + F_2 \cdot y_2}{F_1 + F_2} \tag{9}$$

The given moment of inertia of the section, cm ^{4}:

$$J_a = J_1 + (y_a - y_1)^2 \cdot F_1 + \frac{E_2}{E_1} \cdot \left[J_2 + \left(y_a - y_2 \right)^2 \cdot F_2 \right] \tag{10}$$

where E_1, E_2 – respectively, the module of elasticity of the shield and girder material, kg/cm ^{2};

The given moment of section resistance, cm^3:

$$W_a = \frac{J_a}{y_{\max}} \tag{11}$$

y_{max} – maximum value of the cross-sectional dimension with respect to the axis passing through the center of gravity of the section ($y_{max} = y_a$, or $y_{max} = \delta + b - y_a$).

The derivation of formulas for determining the distance between contractions is similar to the derivation of formulas for determining the distance between girders:

- Distance between contractions from the calculation of the bearing capacity:

$$L_2 = \sqrt{\frac{8 \cdot W_a \cdot R}{P_d \cdot L_1}} \tag{12}$$

- Distance between contractions from the calculation of deformations

$$L_2 = \sqrt[3]{\frac{E \cdot J_a}{2.735 \cdot P_n \cdot L_1}} \tag{13}$$

Finally, the distance between contractions is defined as the smallest, obtained from the conditions of strength and deformability.

4. Conclusion

Application in the construction of monolithic buildings and structures of foreign formwork in our country is very common. As it can be seen from the above comparisons and calculations, the normative documentation in the construction of the formwork producing countries and the countries in which this formwork finds application differ both in terms of determining the effective load and in calculating the structural elements of the formwork. In connection with this, when drawing up technological maps for the use of formwork, which, as it is known, is compiled for each customer organization individually, it is necessary to apply the normative documents of the country in which this formwork will be used. In particular, when using foreign formwork systems in the territory of the Russian Federation, it is necessary to use the normative documentation of this country when calculating. The building regulatory documentation of the Russian Federation is freely available on the website of the national information dissemination center [14].

Acknowledgments

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