Budownictwo o Zoptymalizowanym Potencjale Energetycznym **Vol. 7, Nr 2/2018, s. 9-17**
DOI: 10.17512/bozpe.2018.2.01

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METHODS FOR IN-SITU REINFORCING OF CONCRETE BUILDING STRUCTURES WITH EXTERNAL REINFORCEMENT BASED ON CARBON FIBER TO RESTORE THEIR SERVICEABLE TECHNICAL STATE

In this article, a method is proposed for calculating the reinforcement of concrete ceiling slabs with carbon composite materials based on the finite element model in the computer program SCAD Office PC. This method allows the most complete and accurate representation to be obtained of the structure stress-strain state before and after reinforcement with composite materials. Therefore, it allows high-quality designing and reduces the cost conducting calculations and tests on a large scale. The design values are taken from the initial data, and include conclusions based on the results of analysis of the technical state of the structures and drawings from the calculation section of the CS (reinforced concrete structures).

Keywords: **carbon fiber reinforcement, composite materials, limit-state design, stress-strain analysis**

INTRODUCTION

Nowadays, both Russian and foreign researchers pay considerable attention to the problem of ensuring the reliability of building structures at all stages of their construction and maintenance, especially in the case of their repair and strengthening [1-3]. This is due to the growing need to ensure reliable operation of unique, expensive and historically significant structures, the dismantling and replacement of which is much more expensive than repair or completely impossible. Reinforced concrete structures damages, as a rule, is associated with corrosion, the overloading of separate elements and improper operation, as well as design and production errors. Strengthening of building structures with composite materials is by far the most "careful" method of restoring and improving the operational characteristics of building structures [4-7].

The most common solution for strengthening reinforced concrete structures with the use of carbon fiber is the location of the external reinforcement element from the side of the most stretched fiber in the span of bent structures, although there has been a successful attempt of strengthening the compressed zone. Both tapes and canvases can be installed in the area of the fly-by moments. Recently there has been a trend of wide use of canvases. This is due to their higher mechanical characteristics, simplicity of installation and reliability of anchoring [8, 9].

An important area of applying external reinforcement elements is strengthening pricked sections in the shear forces action zone. In these zones, as a rule, coal coils are located along the line of principal tensile stresses [10]. They can be glued in several layers and form any sections needed for calculation.

1. MATERIALS AND METHODS

The design values are taken from the initial data, and include a technical conclusion based on the analysis results of the technical state of the structures and drawings from the calculation section of the CS project (reinforced concrete structures). In the calculation, the slab is considered at –8,100.

The thickness of the slab is 300 mm. In the technical conclusion, based on the results of the analysis the minimum class of concrete for durability in compression is B22,5. Because there is no this class in Norms 63.13330.2012 [11], the concrete strength class - B20 is adopted. The reinforcement of the lower zones of the slab section is taken from the technical conclusions from the analysis:

- Along letter axes - Ø16A400 GOST 5781-82 * step 245 mm ($As = 2.011 \cdot 4 = 8.044$ cm^2);
- Along the numerical axes - Ø16A400 GOST 5781-82 * step 240 mm ($As = 2.011 \cdot 4 = 8.044$ cm^2).

The protective layer is 45 mm (the bottom is the reinforcement along the letter axes).

Loads

The load from the weight of the partitions is calculated taken from Norms 20.13330.2011 [12]. The temporary load was calculated taken from the technical conclusion.

Because there are no data on the actual structures of the floors, the explication of the premises or the presence and location of equipment in the original documentation of the architectural section, the uniformly distributed loads in Table 1 are taken into account.

Table 1. **Loads on slab**

No.	Construction element	Specific gravity [t/m^3]	Layer thickness [m]	Specified characteristic load [t/m^3]	Partial safety coefficient	Calculated load [t/m^3]
Constant						
1	In-situ concrete slab	2.5	0.3	0.75	1.1	0.825
2	Leveling screed (20÷110 mm)*	1.8	0.11	0.198	1.3	0.257
3	Concretefooting	1.8	0.07	0.126	1.3	0.164
4	Partition weight	-	-	0.05	1.3	0.065
TOTAL				1.124		1.311
Temporary						
5	Loads for subterranean parking			0.35	1.2	0.42
In all (constant + temporary)				1.434		1.731

* - to compensate for excessive deflection of slab area

2. RESULTS AND DISCUSSION

Calculation of non-reinforced slab

The model is calculated by means SCAD Office 11.5 software. To more accurately determine the stress-strain state of the modeling slab, a calculation section of the slab was taken, which exceeds the area considered (requiring repair and reinforcement) by two column spacing on both sides [13, 14]. The slab model is shown in Figure 1.

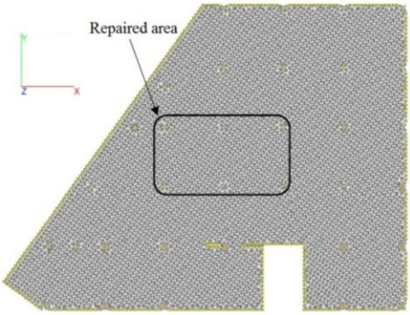


Fig. 1. Finite element model

The isopoles of the calculated bending moments M_x and M_y are shown in Figures 2 and 3, respectively. The maximum bending moments in the section of the overlap plate for the different calculation stages are shown in Table 2.

Determination internal efforts and deficit limits

The calculation was carried out for the first limiting state in order to determine the carrying capacity. The limiting internal forces are determined by the deformation model of reinforced concrete in accordance with the instructions Norms 63.13330.2012 [11]. The calculated diagram of the compressed concrete state is assumed to be trilinear [10].

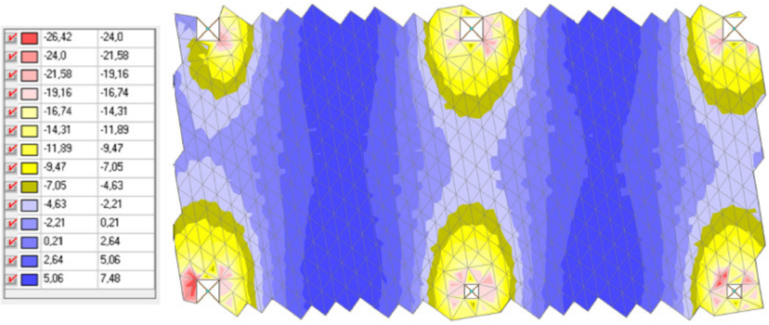


Fig. 2. Isopole of bending moments M_x

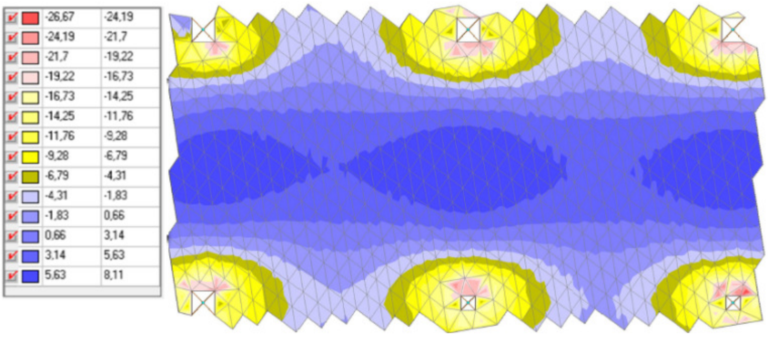


Fig. 3. Isopole of bending moments M_y

Table 2. **Standard and calculated values of internal forces in lower (transit) zone of slab section**

No.	Value	M_x [t/m]	M_y [t/m]
	Non reinforced construction		
1	Standard value	6.3	6.82
2	Calculated value	7.48	8.11
	Non reinforced construction at the moment of enforcement*		
3	Regulation value	2.85	2.95
4	Calculated value	3.13	3.24

* - only weight of reinforced concrete slab is taken into account

Determining $M_{x, ult}$

Table 2.1 presents the calculation results of stresses in the cross section. There are occupation coefficients (deformation) in Table 2.2.

Table 2.1. **Stresses**

No.	Parameter	Value [MPa]	Utilization factor [dimensionless quantity]
1	Stress $\sigma_{b,max}$	–0.75	0.65
2	Stress σ_{s1}	35.5	1

Table 2.2. **Occupation coefficient (deformation)**

1	Compressed concrete	0.1364
2	Tensile reinforcement	0.9999
3	Reinforcement material	-

Stress pattern in cross-section

$$\xi = \frac{5.31}{30-5.3} = 0.218 \le \xi_R = \frac{0.8}{1+\frac{0.001775}{0.0035}} = 0.53$$

Determining $\mathbf{M}_{\mathbf{y,\ ult}}$

Table 2.3 presents the calculation results of stresses in the cross section. There are occupation coefficients (deformation) in Table 2.4.

$$\xi = \frac{5.38}{30-6.1} = 0.225 \le \xi_R = \frac{0.8}{1+\frac{0.001775}{0.0035}} = 0.53$$

Table 2.3. **Stresses**

No.	Parameter	Value [MPa]	Utilization factor [dimensionless quantity]
1	Stress $\sigma_{b,max}$	–0.754	0.66
2	Stress σ_{s1}	35.5	1

Table 2.4. **Occupation coefficient (deformation)**

1	Compressed concrete	0.1401
2	Tensile reinforcement	1
3	Reinforcement material	-

Stress pattern in cross-section

Determining bearing capacity deficits

The limit values of the internal forces and carrier deficits of the bearing capacity are shown in Table 3.

Table 3. **Deficits of the bearing capacity**

No.	Type of value	M_x [t/m]	M_y [t/m]
1	Current value	7.48	8.11
2	Limiting value	6.58	6.36
	Deficits [%]	13.7	27.5

Calculation of reinforced slab

The carbon tape FibArm 530/300 is used as the material for the reinforcing elements. The standard composite design resistance: $R_{f,n}$ = 1100 MPa. The limiting bending moments and the crack opening in the reinforced section are determined by the deformation model of reinforced concrete in accordance with the instructions in Norms 164.1325800.2014 [15]. The calculated diagram of the state of compressed concrete is assumed to be trilinear [10]. The efforts in the section at the time of strengthening work are indicated in Table 2.

Calculating reinforced slab portion according to first limit state

The calculated value of resistance of the first layer of the composite is: R_f = 320.7 MPa.

The width of the composite is 300 mm/m; the thickness is 1 mm. The composite area is: A_f = 3 cm/m^2.

Determining $\mathbf{M_{x,\,ult}}$ and $\mathbf{M_{y,\,ult}}$

The results of calculating the stress-strain state are shown in Figure 4. Table 3.1 presents the calculation results of stresses in the cross section. There are relative deformations in Table 3.2.

For $M_{x,\,ult}$:

$$\xi = \frac{5.51}{30} = 0.184 < \xi_{Rf}\,\frac{0.8}{1+\frac{0.00465+0{,}00103}{0.0035}} = 0.305$$

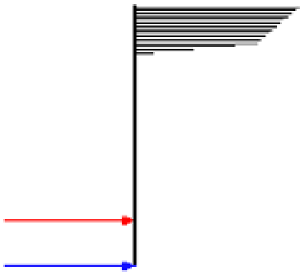
For $M_{y,\,ult}$:

$$\xi = \frac{5.51}{30} = 0.184 < \xi_{Rf}\,\frac{0.8}{1+\frac{0.00465+0{,}00116}{0.0035}} = 0.301$$

Table 3.1. **Stresses**

No.	Parameter	Value [MPa]	Utilization factor [dimensionless quantity]
1	Stress $\sigma_{b,max}$	–0.95	0.83
2	Stress σ_{s1}	35.5	1
3	Stress σ_f	32.07	1

Stress pattern in cross-section



Height of compression zone x = 5,51 cm

Fig. 4. Calculation results $M_{x,ult}$ and $M_{y,ult}$

Table 3.2. **Relative deformations**

No.	Parameter	Value [dimensionless quantity]	Utilization factor [dimensionless quantity]
1	Deformation $\varepsilon_{b,max}$	–0.00124	0.35
2	Deformation ε_{s1}	0.00446	2.51
3	Deformation ε_f	0.00465	1

Stress pattern in cross-section

Table 3.3 presents the calculation results of stresses in the cross section. There are relative deformations in Table 3.4.

Table 3.3. **Stresses**

No.	Parameter	Value [MPa]	Utilization factor [dimensionless quantity]
1	Stress $\sigma_{b,max}$	–0.96	0.83
2	Stress σ_{s1}	35.5	1
3	Stress σ_f	32.07	1

Table 3.4. **Relative deformations**

No.	Parameter	Value [dimensionless quantity]	Utilization factor [dimensionless quantity]
1	Deformation $\varepsilon_{b,max}$	–0.00127	0.36
2	Deformation ε_{s1}	0.00437	2.46
3	Deformation ε_f	0.00465	1

The limit values of internal forces and load-bearing capacity are shown in Table 4.

Table 4. **Reserves of bearing capacity**

No.	Type of value	M_x [t/m]	M_y [t/m]
1	Current value	7.48	8.11
2	Limiting value	9.83	9.67
	***Reserve* [%]**	31.4	19.2

Calculating reinforced slab by service limit state

Calculation of the crack opening width with the selected gain is performed. The calculated value of resistance of the first composite layer is: $R_f = 366.2$ MPa.

The limit values of internal forces reserves for crack resistance are shown in Table 5.

Table 5. **Reserves for crack resistance***

No.	Type of value	Crack width from M_x [mm]	Crack width from M_y [mm]
1	Current value	0.201	0.24
2	Limiting value	0.3	0.3
	***Reserve* [%]**	33	20

* Note: crack width is calculated using design values of bending moments from Table 2

CONCLUSIONS

The method of reinforced calculating concrete structures (overlapping slabs) allows one to obtain a more accurate picture of the stress-strain state in the structure before strengthening and after it, in contrast to traditional manual calculation [16]. Based on the results of the calculation, it is possible to select a more adequate strengthening scheme - by changing the geometry or stiffness characteristics of the carbon fiber reinforced polymer (CFRP). It is shown that applying of the calculation technique allows one to improve the quality of the reinforcement design of concrete slabs, to reduce the costs of carrying out experimental design work and full-scale testing.

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METODA POSTĘPOWANIA W PRZYPADKU KONIECZNOŚCI WZMOCNIENIA I PRZYWRÓCENIA ZAKŁADANEGO STANU TECHNICZNEGO KONSTRUKCJI BETONOWEJ BUDYNKU W WARUNKACH IN SITU - Z ZASTOSOWANIEM ZEWNĘTRZNEGO WZMOCNIENIA Z WŁÓKIEN WĘGLOWYCH

W artykule zaprezentowano metodę obliczania stropów betonowych zbrojonych kompozytami węglowymi, wykorzystując metodę elementów skończonych, w programie komputerowym SCAD Office PC. Metoda ta pozwala uzyskać kompletny i dokładny obraz stanu naprężenia i odkształcenia struktury przed i po zbrojeniu materiałami kompozytowymi. Dzięki tej metodzie można projektować z zapewnieniem wysokiej jakości i przy zmniejszeniu kosztów prowadzenia obliczeń i testów na dużą skalę. Wartości projektowe pochodzą z danych początkowych i zawierają wnioski oparte na wynikach analizy stanu technicznego konstrukcji i rysunkach z sekcji obliczeniowej projektu CS (konstrukcje żelbetowe).

Słowa kluczowe: **wzmocnienie włóknami węglowymi, materiały kompozytowe, projektowanie stanu granicznego, analiza naprężeń i odkształceń**