Збірник наукових праць. Галузеве машинобудування, будівництво
Academic journal. Industrial Machine Building, Civil Engineering
http://journals.nupp.edu.ua/znp
https://doi.org/10.26906/znp.2022.58.3080

UDC 624.072.2.016

Fundamentals of designing rational slab steel-reinforced concrete structures and elements of floors

Galinska Tatiana[1]*, Ovsii Dmytro[2], Ovsii Oleksandra[3], Ovsii Mykola[4]

[1] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0002-6138-2757
[2] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0001-7007-1857
[3] National University «Yuri Kondratyuk Poltava Polytechnic» https://orcid.org/0000-0001-5833-4757
[4] PE «Budexpertyza» (Poltava)
*Corresponding author E-mail: Galinska@i.ua

The article provides a general methodology for calculating and designing rational (optimal) slab structures and elements of steel-reinforced concrete (SRC) floors, taking into account the ultimate stress-strain state of their elements at the moment of their destruction. The method of rational (optimal) design of slab SRC elements of floors depending on the ultimate stress-strain state at the time of failure of their component parts includes the solution of two problems: the selection of the cross section of the slab SRC element and its reinforcement, which is a direct task of optimization design; checking the bending strength in the calculated cross-sections of the slab SRC element

Keywords: steel-reinforced concrete, slab structures, flexural strength, floors, design

Основи проектування раціональних плитних сталезалізобетонних конструкцій і елементів перекриттів

Галінська Т.А.[1]*, Овсій Д.М.[2], Овсій О.М.[3], Овсій М.О.[4]

[1, 2, 3] Національний університет «Полтавська політехніка імені Юрія Кондратюка»
[4] ПП «БУДЕКСПЕРТИЗА», м. Полтава
*Адреса для листування E-mail: Galinska@i.ua

Плитні сталезалізобетонні (СЗБ) конструкції і елементи різних комбінованих перерізів є, як окремими (збірними) основними несучими елементами перекриттів безкаркасних будівель і споруд, так і частинами балкових і безбалкових (гібридних збірно-монолітних чи чисто монолітних) перекриттів каркасних будівель і споруд. Конструктивні вирішення плитних сталезалізобетонних конструкцій і елементів широко застосовуються на сьогодні в будівництві перекриттів з прогонами L=3…12 м і більше. Значну популярність гібридні сталезалізобетонні плитні конструкції і елементи отримали при будівництві перекриттів в Німеччині, Кореї, Японії, Китаї. В статті наведено загальну методику розрахунку і проектування раціональних (оптимальних) плитних конструкцій і елементів сталезалізобетонних перекриттів з урахуванням граничного напружено-деформованого стану (НДС) їх компонентів в момент їх руйнування. Методика раціонального (оптимального) проектування плитних СЗБ елементів перекриттів залежно від НДС в момент руйнування їх компонентів включає в себе вирішення двох задач: підбору перерізу плитного СЗБ елементу та його армування, яка є прямою задачею оптимізаційного проектування; перевірки міцності на згин в розрахункових перерізах плитного СЗБ елементу. Авторами статті в результаті розрахунків були отримані значення коефіцієнтів оптимального армування поперечних перерізів плитних СЗБ елементів залежно від їх висоти, величин розрахункового прогону плити, міцностних і деформаційних характеристик матеріалів та значень корисного навантаження. Впровадження запропонованої методики в практику проектування дозволить ефективно вирішувати плитні і балкові елементи СЗБ перекриття різних конструктивних типів і видів при будівництві, ремонті та реконструкції будівель і споруд.

Ключові слова: сталь-залізозобетон, плитні конструкції, міцність на згин, перекриття, проектування

Introduction

Today in Ukraine there is an urgent need for capital repair, reconstruction and restoration of buildings and structures of public, residential buildings and industrial enterprises, damaged or destroyed as a result of emergency situations, hostilities and acts of terrorism. A comprehensive solution to this problem requires the development and implementation of effective (rational) constructive solutions, resource-saving construction methods and technologies, while simultaneously ensuring the requirements for their economy and reliability at all stages of the life cycle.

In addition, the current domestic regulatory documents [1-3] on the calculation and design of steel-reinforced concrete structures (elements) that bend do not cover the entire range of combinations, types and types of their main structural solutions and therefore currently require further improvement.

Review of the research sources and publications

The design of cost-effective slab SRC elements of floors is achieved through the implementation of optimal methods of their calculation. The essence of these methods is to determine the rational (optimal) cross-section of the SRC element's and the minimum cross-section of their reinforcement.

Scientists Linfeng Mei and Qian Wang, as a result of the study of 196 publications, conducted in the article [4] a comprehensive analysis of the existing methods of optimizing structures in construction, their general and spatial trends, the optimization process itself by various methods, recommendations on current and future directions of research were summarized. The authors [4] list the main four categories of structure optimization:

1. Size optimization, which determines the boundars (change area) of the cross-section of constructions or structural elements during design;
2. Shape optimization: that is, during design, the configuration of the structure is optimized by changing its nodal coordinates;
3. Topology optimization: when designing an optimal structure, it is necessary to improve the connection of its nodes in order to remove unnecessary (redundant) elements
4. Multi-objective optimization, which simultaneously includes size, shape and topology, is also known as layout optimization: it considers two or more of the above objectives simultaneously during design for better optimization results.

A significant amount of research by scientists is devoted to the optimization of building structures according to the categories listed above. Thus, the following works of scientists are devoted to the optimal design of beam-reinforced concrete structures: Luevanos-Rojas A., Lopez-Chavarria S., Medina-Elizondo M., Kalashnikov V. [5]; Tliouine B., Fedghouche F. [6]; Habibi A., Ghawami F., Shahidsade M.S. [7]; Rahmanian I., Lucet Y., Tesfamariam S. [8]; Singh J., Chutani S. [9]; Guerra A., Kiousis P. [10] and other works of scientists.

In works Kwan A., Ho J. and Pam H. [11-14], Seguirant S. and others [15], Subramanian N. [16], Orozco C. [17], Fayyad T., Lees J.M. [18] theoretical studies were carried out to determine the minimum and maximum limits of the minimum reinforcement of flexural reinforced concrete (RC) elements, its influence on their minimum load-bearing capacity, deformability and nature of destruction depending on the strength of concrete and reinforcement.

Scientific developments in the design of steel-reinforced concrete slab elements can be classified according to different structural cross-sections of the same type, see Fig. 1. Here, for example, the latest publications of scientists, which are devoted to experimental and theoretical research and design of steel-reinforced concrete slab structures and elements with different structural solutions of cross sections: Mafleh W., Kovacs N. [19]; Mohamed S., Shahrizan B., Ahmed W., Azrul A., Emad H. [20]; Duma D., Zaharia R., Pintea D., Both I., Hanus F. [21]; Borghi T., Oliveira L., El Debs A. [22]; Dai X., Lam D., Sheehan T., Yang J., Zhou K. [23]; Furche J., Bauermeister U. [24] and other scientists.

Definition of unsolved aspectsof the problem

The calculation regulations that are currently used in domestic standards [1-3] and in the standards of the leading countries of the world [25-30] do not have a general concept and methodical approach to calculating the strength of various types of cross-sections of steel-reinforced concrete slab structures (elements) of floors. As a result, at the time of their calculation, they do not always fully equate the dependence of their bearing capacity with the stress-strain state at the time of failure (limit state), which leads to the re-reinforcement of their individual sections, i.e. to the use of the strength of their structural metal component not in full.

Problem statement

The aim of the work is to improve the method of calculation of plate structures and elements of steel-reinforced concrete floors, taking into account the ultimate stress-strain state of their elements at the time of their destruction, which allows you to design economically rational resource-saving construction structures due to the joint work of their constituent parts.

Basic material and results

The method of optimal (rational) design of slab SRC elements of floors, depending on the stress-strain state at the time of failure of their components, includes the solution of two problems: selection of the cross-section of the slab SRC element and its reinforcement, which is a direct task of optimization design; checking the bending strength in the calculated cross-sections of the slab SRC element.

The task of selecting the cross-section of the slab SRC element and its optimal reinforcement, and the task of checking its bending strength are based on the following criteria of its limit state:

- the task of choosing the optimal cross-section of the reinforcing bars A_s and the cross-section of the steel element A_a, which are used to reinforce the calculated cross-section of the slab SRC element, is solved on the basis of the following criteria:

$$A(\varepsilon_{cu};\varepsilon_{sy})+A(\varepsilon_{cu};\varepsilon_{ay})= A_s+A_a=min, \quad (1)$$

where: $A_s = A_{sf}+A_{sc}$ – the total area of the optimal cross-section of the reinforcing bars, which consists of the area of the bars located, respectively, in the stretched and compressed parts of the calculated cross-section of the SRC element;

$A_a = 2\times A_f+A_w$ - the optimal cross-sectional area of a steel element in the form of a I-beam, which consists of the sum of the areas of its shelves and rib;

ε_{cu} – the ultimate relative compression deformations in the uppermost fiber of the compressed zone of the concrete of the calculated section of the SRC element, which are taken to be equal to $\varepsilon_{cu} = 0{,}0035$ (at f_{cd}=8...60 MPa) or in accordance with the requirements of the norms [1, 2, 3];

ε_{su} – ultimate relative tensile deformations in the reinforcing bars that reinforce the design cross-section of the slab SRC element, the values of which are taken as equal to $\varepsilon_{cu} \leq 0{,}005$ or according to the given norms [1, 2, 3] depending on their class;

ε_{au} – ultimate relative tensile deformations in the lower stretched fiber of the steel I-beam profile, which is used to strengthen the calculated section of the slab SRC element, the value of which is taken as $\varepsilon_{cu} \leq 0{,}005$ or according to the norms [1, 2, 3] depending on the class of steel.

- the task of checking the bending strength of the slab SRC element is based on the following criteria:

$$M(\varepsilon_{cu};\ \varepsilon_s\geq\varepsilon_{su};\ \varepsilon_a\geq\varepsilon_{au})=max;$$
$$M(\varepsilon_{cu};\ \varepsilon_s\geq\varepsilon_{su};\ \varepsilon_a<\varepsilon_{au})=max; \quad (2)$$
$$M(\varepsilon_{cu};\ \varepsilon_s<\varepsilon_{su};\ \varepsilon_a<\varepsilon_{au})=max.$$

where: M - the maximum value of the bending moment, which can to perceive the estimated reduced section of the SRC element;

ε_a - relative deformations in the lowermost fiber of the stretched zone of the steel element.

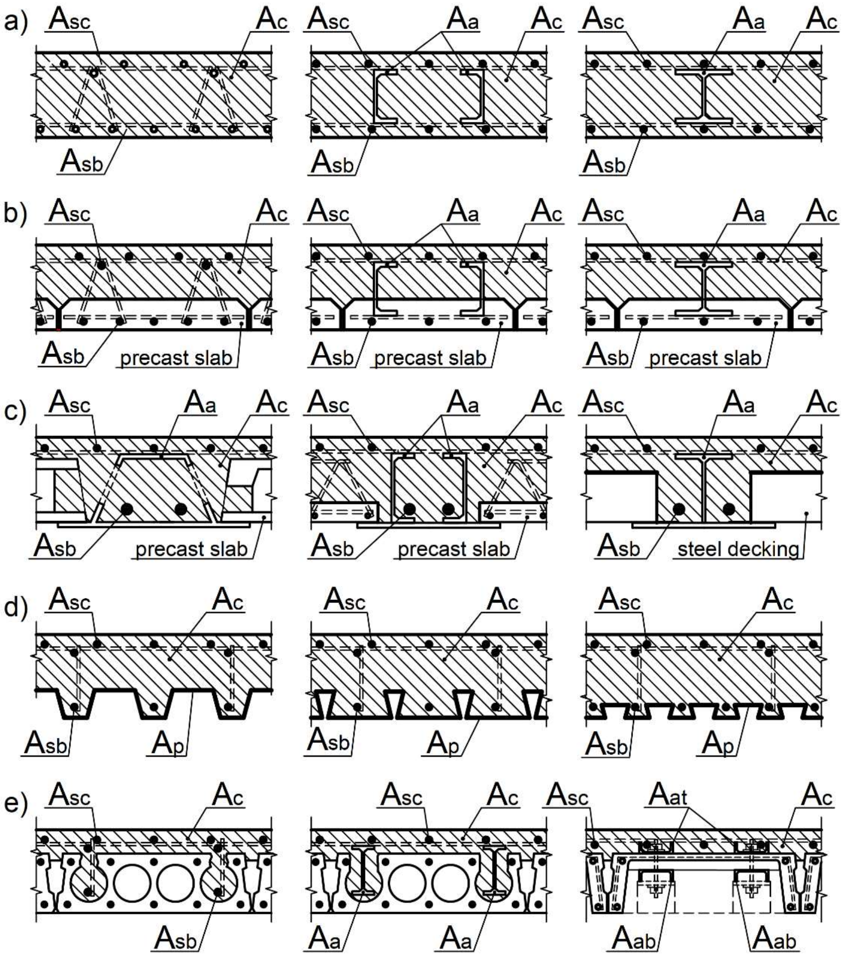

Figure 1 – Different types cross-sections of SRC slab structures:
a) cross-sections of monolithic SRC slab element of floor;
b) hybrid cross-sections prefabricated-monolithic SRC slab element of the floor;
c) hybrid cross-sections prefabricated-monolithic SRC beam element of the slim-floor;
d) cross-sections SRC composite floors from steel sheets of various profiles;
e) hybrid cross-sections of the SRC slab structures after strengthening the floor from prefabricated reinforced concrete elements

Basic prerequisites for calculating and designing a slab SRC structure or element.

The following prerequisites were adopted for the development of a general methodology for the optimal (rational) design of a slab steel-reinforced concrete (SRC) structure or element:

- in the cross-section of slab SRC structures, the steel profile has rigid vertical, inclined or horizontal connections with concrete;
- at the time of failure, the cross-section of a slab SRC structure or element can have three cases of the ultimate stress-strain state, in which:
  case a $M_{plRb}(\varepsilon_{cu}, \varepsilon_a>\varepsilon_{au})=max$ – is the plastic stage;
  case b: $M_{Rb}(\varepsilon_{cu}, \varepsilon_a=\varepsilon_{au})=max$ – the border between plastic stage and elastic-plastic stage;
  case c: $M_{Rb}(\varepsilon_{cu}, \varepsilon_a<\varepsilon_{au})=max$ – elastic-plastic stage;
- the compressive strength of concrete N_c in the cross-section of a slab SRC structure or element is determined as for reinforced concrete, taking into account the percentage of its reinforcement, according to the scientific proposals of D. Kochkaryev and T. Galinska given in works [31];
- the analysis of cross-sections of slab SRC structures (see Fig. 1) showed that most of their cross-sections can be generalized relative to the vertical axis to an equivalent slab section or T-section, see Fig. 2 and Fig. 3;
- depending on the position of the neutral line and the nature of fracture when determining the bening strength, three main boundary cases of the stress-strain state of the cross-section of slab SRC structures are distinguished.

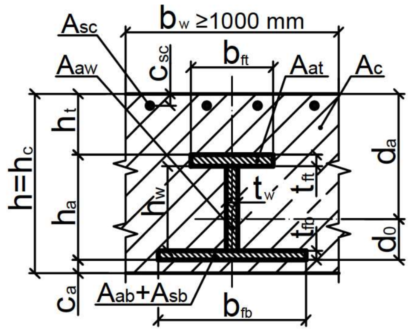

Figure 2 – Equivalent calculated cross-section of the SRC slab structure relative to the vertical axis

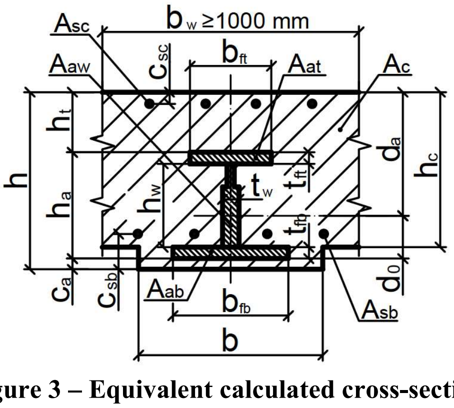

Figure 3 – Equivalent calculated cross-section of the T-shaped SRC slab structure relative to the vertical axis

The foundations of the method of calculating steel-reinforced concrete structures were previously laid in the works of the authors [32, 33].

The sequence of calculation and design of optimal (rational) reinforcement in the calculated cross-section of slab SRC constructions and elements.

We select the cross-section of the plate SRC element and its optimal reinforcement in the following sequence:

– we check the condition of equality:

$$M_{RC,\min} < M \le M_{RC,b}; \quad (3)$$

where: M - external moment in the calculated cross-section of the slab SRC element from the action of the load;
$M_{RC,b}$ - the value of the balance moment, which perceives the calculated cross-section of the slab reinforced concrete (RC) element;
$M_{RC,min}$ – the minimum value of the limiting moment, which perceives the calculated cross-section of the slab reinforced concrete (RC) element:

$$M_{RC,\min} = \alpha\beta k_z f_{cd} b_w x_{c,\min}(h - 0{,}5\alpha x_{c,\min}); \quad (4)$$

$$M_{RC,b} = \alpha\beta k_z f_{cd} b_w x_{c,b}(h - 0{,}5\alpha x_{c,b}); \quad (5)$$

where: α – parameter of eguivalent stress block defming the depth of stress block, the values of which are determined according to norms;
β – parameter of eguivalent stress block defming the average stress, the values of which are determined according to norms;
b_w – the cross-section width of the slab SRC element;
h – the height of the cross-section of the slab SRC element, the value of which is preliminarily taken from the table 2 depending on the value of the total calculated load on the floor ($g_{k,i}$+$q_{k,i}$ [kN/m²]);
x_C – compressed zone of concrete in the design cross-section of the slab SRC element:

$$x_{C,\min} = \frac{A_{s,\min} f_{sd}}{\alpha\beta k_z f_{cd} b_w} \ge \frac{200 b_w d_s}{f_{sd}}; \quad (6)$$

$$A_{s,\min} = 3 b_w d_s \sqrt{f_{cd}} \,/\, f_{sd}; \quad (7)$$

$$d_s = h - c_s; \quad (8)$$

$$x_{C,b} = \frac{A_{s,b} f_{sd}}{\alpha\beta k_z f_{cd} b_w} = \frac{h}{k_z}\left(\frac{E_c \varepsilon_{cu}}{E_c \varepsilon_{cu} + f_{sd}}\right); \quad (9)$$

$$A_{s,b} = \alpha\beta \frac{k_z f_{cd}}{f_{sd}}\left(\frac{E_c \varepsilon_{cu}}{E_c \varepsilon_{cu} + f_{sd}}\right) b_w h; \quad (10)$$

where: f_{cd} - design value of the cylinder compressive strength of concrete;
f_{sd} - design value of the yield strength of reinforcing steel;
d_s - distance between the steel reinforce- ment in tension to the extreme fibre of the composite slab in compression;
c_s - thickness of concrete cover;
k_z – coefficient that takes into account the influence of the percentage of reinforcement (ϖ) of the cross-section

of the slab SRC element on the compressive strength of concrete in its compressed zone, the value of which is determined by the dependencies:

$$\rho_{s,\min} = \frac{A_{s,\min}}{b_w d_s} = 3\frac{\sqrt{f_{cd}}}{f_{sd}} \geq \frac{200}{f_{sd}}; \quad (11)$$

$$\rho_{b0} = \alpha\beta\frac{f_{cd}}{f_{sd}}\left(\frac{E_c\varepsilon_{cu}}{E_c\varepsilon_{cu} + f_{sd}}\right); \quad (12)$$

$$\rho = \rho_t + \rho_c = \frac{A_{st} + A_{sc}}{b_w h}; \quad (13)$$

where: $\rho_{s,min}$ – the minimum reinforcement ratio of the slab section when $\varepsilon_s \geq 0{,}005$ (ε_s - reinforcement deformation at the extreme fiber);
ρ_{b0} – balanced steel ratio of slab section, i.e. tension steel ratio that will lead to balanced failure when $\varepsilon_s = \varepsilon_y$ (ε_y - deformation of reinforcement in the extreme fiber at the yield point);
ρ_c – compression steel ratio ($\rho_c = A_{sc}/(b_w h)$);
ρ_t – tension steel ratio ($\rho_{s,min} < \rho_t \leq \rho_{b0}$);
ε_{cu} – ultimate concrete strain, i.e. value of ε_c (ε_c - concrete strain at extreme fibre) at peak bending moment;
E_c – elastic modulus of concrete;
ϖ - reinforcement mechanical coefficient:
at $\rho_t = \rho_{s,min}$:

$$\varpi = \rho_{s,\min} f_{sd} / f_{cd} = 3\frac{\sqrt{f_{cd}}}{f_{cd}} \geq \frac{200}{f_{cd}}; \quad (14)$$

at $\rho_t = \rho_b$:

$$\varpi = \rho_{b0} f_{sd} / f_{cd} = \alpha\beta\frac{E_c\varepsilon_{cu}}{E_c\varepsilon_{cu} + f_{sd}}; \quad (15)$$

The dependence $k_z = f(\varpi)$ for a flat bend for a rectangular section with single and symmetrical reinforcement is given in Table 1.

Table 1 – Dependence of $k_z = f(\varpi)$ by the flat bend for a rectangular section with single and symmetrical reinforcement [31]

mechanical reinforcement coefficient, ϖ	parameter k_z (single reinforcement), when $\rho = \rho_t$	parameter k_z (symmetrical reinforcement), at $\rho = \rho_t + \rho_c = 2\rho_t$
0,00	0,000	0,000
0,10	0,586	0,292
0,15	0,828	0,429
0,20	1,071	0,565
0,25	1,299	0,700
0,30	1,511	0,834
0,35	1,706	0,967
0,40	1,885	1,100
0,45	2,028	1,232
0,50	2,070	1,360
0,60	2,140	1,630
0,70	2,195	1,888
1,00	2,310	2,660
2,00	2,476	4,850
3,00	2,542	6,671

The value of the coefficient ϖ at $\rho_t < \rho < 2\rho_t$, when $\rho = \rho_t + \rho_c$, is determined by interpolation.

If the condition of equality (3) is satisfied, then the slab structure is designed as a slab reinforced concrete element.

When $M > M_{RC,b}$ the slab structure is designed as a steel-reinforced concrete slab element:

– we determine the value of the bending moment (ΔM), which the steel profile of the slab steel-reinforced concrete element should perceive:

$$\Delta M = M - M_{RC,\min}; \quad (16)$$

– we determine the necessary moment of inertia ($I_{a,red}$) and moment of resistance ($W_{a,red}$) of the steel profile, which reinforces the steel-reinforced concrete plate element:

$$I_{a,red} = \frac{\Delta M}{k_z E_c \varepsilon_{cu}}\frac{h}{2}; \; W_{a,red} = \frac{\Delta M}{k_z E_c \varepsilon_{cu}}; \quad (17)$$

– we determine the optimal height ($h_{a,opt}$) of the equivalent steel I-profile, which is used to reinforce the plate steel-reinforced concrete element:

$$h_{a,opt} = 1{,}1\sqrt[3]{220 W_{a,red}} - 15 \leq h - 2c_a; \quad (18)$$

– we determine the value of the optimal area ($A_{a,opt}$) of the equivalent steel I-profile, which is used to reinforce the slab SRC element:

$$A_{a,opt} = 3W_{a,red} / h_{a,opt}; \quad (19)$$

– we determine the values of the height and thickness of the rib of the equivalent steel I-profile (h_w, t_w), which reinforces the slab SRC element:

$$h_w = h_{a,opt} / 1{,}1; \quad (20)$$

$$t_w = \frac{Q_{\max}}{0{,}56 f_a h_{a,opt}}; \quad (21)$$

$$t_w \geq \frac{h_{a,opt}}{160\sqrt{210 / f_a}}; \quad (22)$$

where: $Q_{\max}$ – the largest value of the transverse force acting in the section along the length of the element;
f_a – calculated value of the yield strength of the structural steel of the equivalend steel I-profile.

The wall thickness of the I-profile (t_w) should be correspondingly greater by the amount determined by the formulas (21), (22).

We determine the moment of inertia of the belts (I_f) of the equivalent steel I-profile, which reinforced the slab SRC element, and their cross-sectional area (A_f):

$$I_f = \frac{h_{a,opt} W_{red}}{2} - \frac{b_w h_w^3}{12}. \quad (23)$$

$$A_f = \frac{W_{red}}{h_{a,opt}} - \frac{b_w h_w^3}{6 h_{a,opt}}; \qquad A_f = \frac{2 I_f}{(h_w + t_f)^2}. \quad (24)$$

We determine the width of the shelf of the upper (b_{ft}) and lower (b_{fb}) belts of the equivalent steel I-profile according to the relevant dependencies:

$$b_{ft} = h_{a,opt} / 5; \quad b_{fb} = h_{a,opt} / 3; \tag{25}$$

The shelf thickness of the upper (t_{ft}) and lower (t_{fb}) belts of the equivalent steel I-beam profile is determined by the formula:

$$t_{ft} = t_{fb} = 4A_f / h_{a,opt}; \tag{26}$$

We check the condition of inequality and specify (if necessary) the optimal dimensions of the equivalent steel I-profile (h_w, t_w, b_{fb}, t_{fb}, b_{ft}, t_{ft}):

$$b_{ft}t_{ft} + h_w b_w + b_{fb}t_{fb} \geq A_{a,opt}. \tag{27}$$

On the basis of the obtained optimal dimensions of the equivalent steel I-beam profile (h_w, t_w, b_{fb}, t_{fb}, b_{ft}, t_{ft}) and the values of the cross-sectional areas of the reinforcement A_{sb}, A_{sc}, we perform the design of the cross section of the slab SRC element at the values of the thickness of the concrete protective layer c_a=20...50 mm and c_s=20...50 mm.

Table 2 – Slab thickness *h* of solid cross-section depending on the amount of full load

<table>
<tr><th rowspan="2">Slab span
L, [m]</th><th colspan="14">Slab thickness h [mm] of solid cross-section depending on the amount of full load
g_{k,i} + q_{k,i} [kN/m²] 1)</th></tr>
<tr><th>1,0</th><th>1,5</th><th>2,0</th><th>2,5</th><th>3,0</th><th>3,5</th><th>4,0</th><th>4,5</th><th>5,0</th><th>7,5</th><th>10,0</th><th>15,0</th><th>20,0</th><th>25,0</th></tr>
<tr><td>3,0</td><td colspan="10">120/140</td><td colspan="2">140/160</td><td colspan="2">160/180</td></tr>
<tr><td>4,0</td><td colspan="10">140/160</td><td colspan="2">160/180</td><td colspan="2">180/200</td></tr>
<tr><td>5,0 2)</td><td colspan="10">180/200</td><td colspan="2">200/220</td><td colspan="2">220/240</td></tr>
<tr><td>6,0 2,3)</td><td colspan="10">220/240</td><td colspan="4">240/260</td></tr>
<tr><td>7,5 2,3)</td><td colspan="6">240/260</td><td colspan="4">260/280</td><td colspan="2">280/300</td><td colspan="2">300/320</td></tr>
<tr><td>10,0 2,3)</td><td colspan="6">260/280</td><td colspan="3">280/300</td><td colspan="2">300/320</td><td colspan="3">340/360</td></tr>
<tr><td>12,5 2,3)</td><td colspan="2">260/280</td><td colspan="2">300/320</td><td colspan="2">340/360</td><td colspan="4">380/400</td><td colspan="4">420/460</td></tr>
</table>

1) In the case of single-span panels, the slab thickness *h* must be increased by approx 15%.
2) When resting vertical partitions on slabs, it is necessary to take additional measures, namely: use partitions that are more resistant to cracks; increase the height of the plate by 15...20%.
3) When designing slabs with a span of L≥6 m, it is necessary to use their section with round or oval through voids to reduce their own weight.

The sequence of calculation of the bending strength of the slab SRC constructions and elements.

When calculating the bending strength of slab SRC structures, the value of the limiting moment $M_{SRC,b}$ is determined and compared with the external moment M from the action of the load:

$$M_{SRC,b} \geq M; \tag{28}$$

To check the strength of slab SRC elements, we accept the values of the strength characteristics of their components and the size of their cross-section, which we preliminarily determine according to the method described above: f_{cd}; f_{yd}; f_{sd}; b_w; h; h_a; b_{ft}; t_{ft}; b_{fb}; t_{fb}; $h_w=h_a-t_{ft}-t_{fb}$; A_{sc}; A_{sb}; $A_a=t_{ft}b_{ft}+h_w t_w+t_{fb}b_{fb}$; $A_C=b_w h$.

At the ultimate stress-strain state in the cross-section of slab SRC structures, which corresponds to case 1a, see Fig. 4.

Next, we determine the position of the neutral horizontal axis in the calculated section of the slab SRC element according to condition (29):

$$0{,}85 f_{cd} b_w h_t + f_{sd} A_{sc} \geq f_{yd} A_a + f_{sd} A_{sb}; \tag{29}$$

If condition (29) is fulfilled, then the neutral horizontal axis in the cross-section of the plate element is located above the cross-section of the steel equivalent profile of the I-beam beam (see case 1a, Fig. 4), then:

$$x \leq h_t; \tag{30}$$

where: *ht* - the distance between the uppermost fiber of the steel equivalent I-profile and the extreme compressed fiber of the composite slab:

$$h_t = h - h_a - c_a; \tag{31}$$

where: c_a - the thickness of the concrete cover between the lower fiber of the steel equivalent I-profile and the extreme stretched fiber of the composite slab.

Then, the height of the concrete compression zone is determined using dependence (32):

$$x = \frac{A_a \cdot f_{yd} + A_{sb} \cdot f_{sb} - A_{sc} \cdot f_{sd}}{0.85 \cdot f_{cd} \cdot b_w}. \tag{32}$$

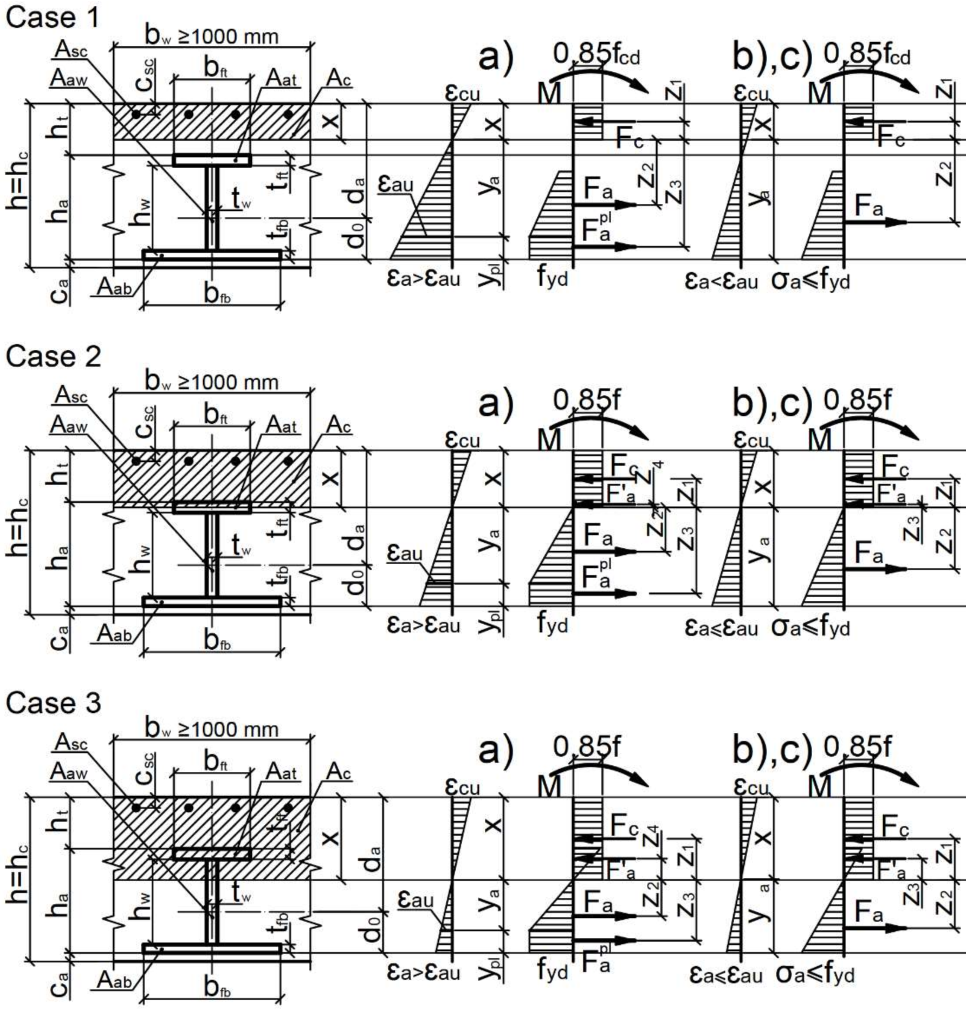

Figure 4– Limiting states of the equivalent cross-section of a slab steel-reinforced concrete structure when determining the bending strength

According to dependence (33) determine the bending strength $M_{SRC,b}$ of the slab SRC structure:

$$M_{SRC,b} = A_a f_{yd}\left(d_a - x/2\right) + A_{sb} f_{sd}(h - c_{sb} - x/2) - A_{sc} f_{sc}(x/2 - c_{sc}); \tag{33}$$

where: d_a - distance between the center of mass of the steel equivalent section and it's bottom surface.

$$d_a = h - d_0 - c_a = h_t + h_a - d_0; \tag{34}$$

where: d_0 - the distance between the center of mass of the steel equivalent section and its lower fiber.

At the ultimate stress-strain state in the calculated cross-section of slab SRC structures, which corresponds to case 2a, see Fig. 4.

If the condition (29) is not met, need to check the condition (35):

$$0{,}85 f_{cd} b_w (h_t + t_{ft}) + f_{sd} A_{sc} + 2 f_{yd} b_{ft} t_{ft} \ge f_{yd} A_a + f_{sd} A_{sb}; \tag{35}$$

If the condition (35) is fulfilled, then the neutral horizontal axis of the element is situated in the upper shelf of the steel I-profile (see case 2a, Fig. 4) within:

$$h_t < x \le h_t + t_{ft}. \tag{36}$$

where: t_{ft} – the width of the top flange of the steel equivalent I-profile.

According to dependence (37), we determine the height (x) of the compressed zone of concrete in the calculated section of the slab SRC element:

$$x = \frac{A_a f_{yd} + A_{sb} f_{sd} - A_{sc} f_{sd} - 2 f_{yd} b_{ft} t_{ft}}{0{,}85 f_{cd} b_w}; \tag{37}$$

We determine the bending strength ($M_{SRC,b}$) of the slab SRC structure according to dependence (38):

$$M_{SRC,b} = A_a f_{yd}\left(d_a - x/2\right) + A_{sb} f_{sd} \times (h - c_{sb} - x/2) - A_{sc} f_{sc} \times (x/2 - c_{sc}) - f_{yd} b_{ft} h_t \times (h_t + t_{ft} - x); \tag{38}$$

At the ultimate stress-strain state in the calculated cross-section of slab SRC structures, which corresponds to case 3a, see Fig. 4.

If condition (35) is not fulfilled, then the neutral horizontal axis of the element crosses the rib of the steel equivalent I-profile (see case 3a, Fig. 4) when:

$$h_t + t_{ft} < x. \quad (39)$$

Then the height (x) of the concrete compression zone in the calculated cross-section of the slab SRC element is determined by dependence (40):

$$x = (A_a f_{yd} + A_{sb} f_{sd} - A_{sc} f_{sd} - \\ - 2 f_{yd} [h_t t_w + t_{ft} (t_w - b_{ft}) \times \\ \times t_w]) / (0{,}85 f_{cd} b_w + 2 f_{yd} t_w). \quad (40)$$

The bending strength ($M_{SRC,b}$) in calculated section the slab SRC structures is determined according to equation (41):

$$M_{SRC,b} = f_{cd} b_w x^2 / 2 + A_{sc} f_{sc} (x - c_{sc}) + \\ + A_a f_{yd} \left(W_{pl} + [d_a - x]^2 \right) + \\ + A_{sb} f_{sd} (h - c_{sb} - x); \quad (41)$$

where: W_{pl} – is the plastic moment of resistance of the section of the steel equivalent I-profile;
c_{sc} - the distance from the center of the cross section of the upper reinforcement Asc to the upper fiber of the concrete cross-section of the slab element;
c_{sb} - the distance from the center of section of the lower reinforcement Asb to the lower fiber of the concrete section of the slab element (see case Fig. 2 and Fig. 3).

The value of the limiting moment ($M_{SRC,b}$), obtained according to one of the dependencies (33), (38), (41), is compared with the value of the moment (M) due to the action of the external load, see inequality conditions (28).

Calculation of the values of the maximum bending moment $M_{RC,b}/(bh^2)$ of the reinforced concrete element depending on the classes of concrete and reinforcing steel and calculation of the coefficients of optimal reinforcement of the cross-sections of the slab SRC elements depending on height, slab span and payload value.

The results of calculating the values of the maximum bending moment $M_{RC,b}/(bh^2)$ of a reinforced concrete element depending on the class of concrete and classes of reinforcing steel A240C (f_s=240MPa) and A400C (f_s=400MPa) are given in the table. 3.

Using the methodology described above for the design of rational slab SRC elements, the authors of the article determined the values of the optimal reinforcement coefficient ρ_a (%) equivalent steel I-profile ($\rho_a = A_{a,opt}/(b_w h)$) for slab SRC elements with a width of b_w=1 m depending on from the values of the span, the class of concrete, the class of longitudinal reinforcement and the uniformly distributed load $q_{k,I}$ (kN/m²), which acts on the slab SRC element.

Calculation results of the steel I-profile reinforcement coefficient ρ_a (%) of slab SRC elements with a width of b_w=1 m for concrete of strength class C20/25 (f_{cd}=13.3 MPa), reinforcement of class A400C (f_{sd}=347.8 MPa).) at $\rho_t = \rho_{b0}$=0,71%, ρ_c=0% are given in the table 4.

Table 3 – Maximum bending moment $M_{RC,b}/(bh^2)$ of a reinforced concrete element depending on the class of concrete and classes of reinforcing steel A240C (f_s=240MPa) and A400C (f_s=400MPa)

Strength class of concrete	Design compressive strength, f_{cd}, MPa	Ultimate concrete strain, ε_{cu}	Compression zone height correction factor, α	Effective strength correction factor, β	$M_{RC,b}/(bh^2)$, MPa	
					f_s = 240 MPa	f_s = 400 MPa
C12/15	8,00	0,0035	0,800	1,000	1,607	1,132
C16/20	10,00	0,0035	0,800	1,000	2,078	1,473
C20/25	13,33	0,0035	0,800	1,000	2,849	2,032
C25/30	16,67	0,0035	0,800	1,000	3,667	2,631
C30/37	20,00	0,0035	0,800	1,000	4,510	3,252
C35/40	23,33	0,0035	0,800	1,000	5,374	3,894
C40/50	26,67	0,0035	0,800	1,000	6,257	4,552
C45/55	30,00	0,0035	0,800	1,000	7,155	5,226
C50/60	33,33	0,0035	0,800	1,000	8,068	5,914
C55/67	36,67	0,0031	0,788	0,975	8,093	5,854
C60/75	40,00	0,0029	0,775	0,950	8,275	5,948
C70/85	46,67	0,0027	0,750	0,900	8,734	6,245
C80/95	53,33	0,0026	0,725	0,850	9,144	6,528
C90/105	60,00	0,0026	0,700	0,800	9,573	6,850

Table 4 –The steel I-profile reinforcement ratio ρ_a for slab SRC elements for concrete of strength class C20/25 (f_{cd}=13,3 MPa), reinforcement of class A400C (f_{sd}=347,8 MPa) when ρ_f=ρ_{b0}=0,71%, ρ_c=0%

Slab span *L*, [m]	The steel profile reinforcement ratio ρ_a, % of solid cross-section slab SRC elements[1,2] depending on the characteristic value of a uniformly distributed load $q_{k,i}$ [kN/m²]													
	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	7,5	10,0	15,0	20,0	25,0
3,0	1,70	1,98	2,24	2,48	2,70	2,30	2,48	2,66	2,83	3,58	4,25	4,60	5,51	5,52
4,0	2,66	2,95	3,23	3,49	3,73	3,41	3,61	3,81	4,00	4,88	5,67	6,23	7,36	7,50
5,0	3,15	3,42	3,68	3,93	4,17	3,95	4,15	4,35	4,54	5,43	6,25	6,99	8,20	8,51
6,0	3,68	3,94	4,19	4,43	4,67	4,50	4,71	4,90	5,10	6,00	6,84	8,35	8,98	10,16
7,5	5,07	5,37	5,65	5,56	5,81	6,05	6,28	6,52	6,32	7,31	8,23	9,30	10,73	11,34
10,0	7,53	7,90	8,26	8,19	8,51	8,81	9,12	9,41	9,21	10,50	11,10	12,50	13,58	15,16
12,5	10,40	10,43	10,42	10,39	10,33	10,26	10,18	10,46	10,35	11,57	12,25	14,28	14,97	16,59
1. Slab width (b_w) accepted as equal 1,0 m, slab height (*h*) according to Table 2..														
2. Calculations made with account the own weight of the slab (unit weight γ =25 kN/m³)														

Conclusions

The article provides a general methodology for calculating and designing rational (optimal) slab structures and elements of steel-reinforced concrete floors, taking into account the ultimate stress-strain state of their elements at the moment of their destruction. The method of rational (optimal) design of slab SRC elements of floors depending on the ultimate stress-strain state at the time of failure of their component parts includes the solution of two problems: the selection of the cross section of the slab SRC element and its reinforcement, which is a direct task of optimization design; checking the bending strength in the calculated cross-sections of the slab SRC element.

Implementation of the proposed methodology in design practice will allow to effectively solve slab and beam SRC overlappings of various structural types and species during the construction, repair and reconstruction of buildings and structures.

References

1. ДБН В.2.6-160:2010 (2011). *Конструкції будинків і споруд. Сталезалізобетонні конструкції. Основні положення*. Київ: Мінрегіонбуд України

2. ДСТУ БВ.2.6-206:2015 (2015). Розрахунок і конструювання згинальних і стиснутих елементів сталезалізобетонних конструкцій будівель та споруд. Київ: Мінрегіонбуд України

3. ДСТУ БВ.2.6-215:2016 (2016). *Розрахунок і конструювання сталезалізобетонних конструкцій з плитами по профільованим настилам*. Київ: Мінрегіонбуд України

4. Mei L., Wang Q. (2021). Structural Optimization in Civil Engineering: A Literature Review. *Buildings 2021, 11, 66* https://doi.org/10.3390/buildings11020066

5. Luevanos-Rojas A., Lopez-Chavarria S., Medina-Elizondo M., Kalashnikov V. (2020). Optimal design of reinforced concrete beams for rectangular sections with straight haunches. *Revista de la Construcción*, 19-1, 90-102 http://dx.doi.org/10.7764/rdlc.19.1.90-102

6. Tlioune B., Fedghouche F. (2010). *Optimal Design of Reinforced Concrete T-Beams under Ultimate Loads.* 2nd International Conference on Engineering Optimization. (September 6 - 9, 2010), Lisbon, Portugal

7. Habibi A., Ghawami F. & Shahidsade M.S. (2016). Development of optimum design curves for reinforced concrete beams based on the INBR9. *Computers and Concrete*, 18(5), 983-998 https://doi.org/10.12989/CAC.2016.18.5.983

8. Rahmanian I., Lucet Y. & Tesfamariam S. (2014). Optimal design of reinforced concrete beams: A review. *Computers and Concrete*, 13(4), 457-482 https://doi.org/10.12989/CAC.2014.13.4.457

1. DBN V.2.6-160:2010 (2011). *Structures of buildings and structures. Steel-reinforced concrete structures. Basic Provisions*. Kyiv, Minregion Ukraine (in Ukrainian)

2. DSTU B V.2.6-206:2015 (2015). *Calculation and design of bending and compression elements of steel-reinforced concrete structures of buildings and structures*. Kyiv, Minregion Ukraine (in Ukrainian)

3. DSTU B V.2.6-215:2016 (2016). *Calculation and construction of steel-reinforced concrete structures with slabs on profiled floors*. Kyiv, Minregion Ukraine (in Ukrainian)

4. Mei L., Wang Q. (2021). Structural Optimization in Civil Engineering: A Literature Review. *Buildings 2021, 11, 66* https://doi.org/10.3390/buildings11020066

5. Luevanos-Rojas A., Lopez-Chavarria S., Medina-Elizondo M., Kalashnikov V. (2020). Optimal design of reinforced concrete beams for rectangular sections with straight haunches. *Revista de la Construcción*, 19-1, 90-102 http://dx.doi.org/10.7764/rdlc.19.1.90-102

6. Tlioune B., Fedghouche F. (2010). *Optimal Design of Reinforced Concrete T-Beams under Ultimate Loads.* 2nd International Conference on Engineering Optimization. (September 6 - 9, 2010), Lisbon, Portugal

7. Habibi A., Ghawami F. & Shahidsade M.S. (2016). Development of optimum design curves for reinforced concrete beams based on the INBR9. *Computers and Concrete*, 18(5), 983-998 https://doi.org/10.12989/CAC.2016.18.5.983

8. Rahmanian I., Lucet Y. & Tesfamariam S. (2014). Optimal design of reinforced concrete beams: A review. *Computers and Concrete*, 13(4), 457-482 https://doi.org/10.12989/CAC.2014.13.4.457

9. Singh J. and Chutani S.A. (2015). Survey of Modern Optimization Techniques for Reinforced Concrete Structural Design. *International Journal of Engineering Science Invention Research & Development*, II(I), 55-62

10. Guerra A. and Kiousis P.D. (2006). Design optimization of reinforced concrete structures. *Computers and Concrete*, 3-5, 313-334
https://doi.org/10.12989/CAC.2006.3.5.313

11. Pam H.J., Kwan A.K.H. and Islam M.S. (2001). Flexural strength and ductility of reinforced normal- and high-strength concrete beams. *Structures & Buildings*, 146-4, 381-389
https://doi.org/10.1680/stbu.2001.146.4.381

12. Kwan A.K.H., Ho J.C.M. and Pam H.J. (2002). Flexural strength and ductility of reinforced concrete beams. *Structures & Buildings*, 152-4, 361-369
https://doi.org/10.1680/stbu.2002.152.4.361

13. Kwan A.K.H., Au F.T.K. and Chau S.L. (2004). Theoretical study on effect of confinement on flexural ductility of normal and high-strength concrete beams. *Magazine of Concrete Research*, 56-5, 299-309
https://doi.org/10.1680/macr.2004.56.5.299

14. Ho J.C.M., Kwan A.K.H. and Pam H.J. (2004). Minimum flexural ductility design of high strength concrete beams. *Magazine of Concrete Research*, 56-1, 13-22
https://doi.org/10.1680/macr.2004.56.1.13

15. Seguirant S.J., Brice R. and Khaleghi B. (2010). Making sense of minimum flexural reinforcement requirements for reinforced concrete memders. *PCI Journal,* Summer, 64-85

16. Subramanian N. (2010). Limiting reinforcement ratios for RC flexural members. *The Indian Concrete Journal,* September, 71-80

17. Orozco C.E. (2015). Strain limits vs. reinforcement ratio limits – A collection ofnew and old formulas for the design of reinforced concretesections. *Case Studies in Structural Engineering*, 4, 1-13
https://doi.org/10.1016/j.csse.2015.05.001

18. Fayyad T.M and Lees J.M. (2015). *Evaluation of a minimum flexural reinforcement ratio using fracture based modelling*. IABSE Conference – Structural Engineering: Providing Solutions to Global Challenges, 2-9

19. Mafleh W. and Kovacs N. (2022). Numerical analysis of composite slim-floor beams. *Pollack Periodica*, 17-2, 81-85
https://doi.org/10.1556/606.2022.00396

20. Mohamed S., Shahrizan B., Ahmed W., Azrul A. and Emad H. (2022). Innovation of Shear Connectors in Slim Floor Beam Construction. *Journal of Engineering*, 2022
https://doi.org/10.1155/2022/2971811

21. Duma D., Zaharia R., Pintea D., Both I., Hanus F. (2022). Analytical Method for the Bending Resistance of Slim Floor Beams with Asymmetric Double-T Steel Section under ISO Fire. *Appl. Sci.*, 12, 574
https://doi.org/10.3390/ app12020574

22. Borghi T.M., Oliveira L.A.M. and El Debs A.L.H.C. (2021). Numerical investigation on slim floors: comparative analysis of ASB and CoSFB typologies. *Rev. IBRACON Estrut. Mater.*, 14-4, e14411
https://doi.org/10.1590/S1983-41952021000400011

23. Dai X., Lam D., Sheehan T., Yang J. and Zhou K. (2020). Effect of dowel shear connector on performance of slim-floor composite shear beams. *Journal of Constructional Steel Research,* 173
https://doi.org/10.1016/j.jcsr.2020.106243

24. Furche J., Bauermeister U. (2020). Ermüdungsnachweis für Elementdecken mit Gitterträgern. *Beton- und Stahlbetonbaum*, 115(1), 26-35
https://doi.org/10.1002/best.201900056

9. Singh J. and Chutani S.A. (2015) Survey of Modern Optimization Techniques for Reinforced Concrete Structural Design. *International Journal of Engineering Science Invention Research & Development*, II(I), 55-62

10. Guerra A. and Kiousis P.D. (2006) Design optimization of reinforced concrete structures. *Computers and Concrete*, 3-5, 313-334
https://doi.org/10.12989/CAC.2006.3.5.313

11. Pam H.J., Kwan A.K.H. and Islam M.S. (2001). Flexural strength and ductility of reinforced normal- and high-strength concrete beams. *Structures & Buildings*, 146-4, 381-389
https://doi.org/10.1680/stbu.2001.146.4.381

12. Kwan A. K. H.; Ho J. C. M. and Pam H. J. (2002). Flexural strength and ductility of reinforced concrete beams // *Structures & Buildings. – 2002, Vol. 152, № 4. – pp. 361–369.* Doi: 10.1680/stbu.2002.152.4.361

13. Kwan A.K.H., Au F.T.K. and Chau S.L. (2004). Theoretical study on effect of confinement on flexural ductility of normal and high-strength concrete beams. *Magazine of Concrete Research*, 56-5, 299-309
https://doi.org/10.1680/macr.2004.56.5.299

14. Ho J. C. M.; Kwan A. K. H. and Pam H. J. (2004). Minimum flexural ductility design of high strength concrete beams // *Magazine of Concrete Research. - 2004, Vol. 56, № 1 .– pp. 13–22*. Doi:10.1680/macr.2004.56.1.13.

15. Seguirant S.J., Brice R. and Khaleghi B. (2010). Making sense of minimum flexural reinforcement requirements for reinforced concrete memders. *PCI Journal,* Summer, 64-85

16. Subramanian N. (2010). Limiting reinforcement ratios for RC flexural members. *The Indian Concrete Journal,* September, 71-80

17. Orozco C.E. (2015). Strain limits vs. reinforcement ratio limits – A collection ofnew and old formulas for the design of reinforced concretesections. *Case Studies in Structural Engineering*, 4, 1-13
https://doi.org/10.1016/j.csse.2015.05.001

18. Fayyad T.M and Lees J.M. (2015). *Evaluation of a minimum flexural reinforcement ratio using fracture based modelling*. IABSE Conference – Structural Engineering: Providing Solutions to Global Challenges, 2-9

19. Mafleh W. and Kovacs N. (2022). Numerical analysis of composite slim-floor beams. *Pollack Periodica*, 17-2, 81-85
https://doi.org/10.1556/606.2022.00396

20. Mohamed S., Shahrizan B., Ahmed W., Azrul A. and Emad H. (2022). Innovation of Shear Connectors in Slim Floor Beam Construction. *Journal of Engineering*, 2022
https://doi.org/10.1155/2022/2971811

21. Duma D., Zaharia R., Pintea D., Both I., Hanus F. (2022). Analytical Method for the Bending Resistance of Slim Floor Beams with Asymmetric Double-T Steel Section under ISO Fire. *Appl. Sci.*, 12, 574
https://doi.org/10.3390/ app12020574

22. Borghi T.M., Oliveira L.A.M. and El Debs A.L.H.C. (2021). Numerical investigation on slim floors: comparative analysis of ASB and CoSFB typologies. *Rev. IBRACON Estrut. Mater.*, 14-4, e14411
https://doi.org/10.1590/S1983-41952021000400011

23. Dai X., Lam D., Sheehan T., Yang J. and Zhou K. (2020). Effect of dowel shear connector on performance of slim-floor composite shear beams. *Journal of Constructional Steel Research,* 173
https://doi.org/10.1016/j.jcsr.2020.106243

24. Furche, J.; Bauermeister, U. Ermüdungsnachweis für Elementdecken mit Gitterträgern. *Beton- und Stahlbetonbaum, 2020, 115 (1), 26–35.*
https://doi.org/10.1002/best.201900056

25. ДСТУ-Н Б EN 1994-1-1: 2010 (2010). *Єврокод 4. Проектування сталезалізобетонних конструкцій. Частина 1-1. Загальні правила і правила для споруд* (EN 1994-1-1:2004, IDT). Київ: ДП "УкрНДНЦ"
26. Comité Européen de Normalisation (CEN), (2004b) *"Eurocode 4: Design of Composite Steel and Concrete Strucures-Part 1-1: General Rules and Rules for Buildings"*, European Standard BS EN 1994-1-1: 1994. European Committee for Standardization (CEN), Brussels, Belgium
27. American Institute of Steel Construction. (2010). Specifications for structural steel buildings, AISC 360-10, Chicago, IL
28. Architectural Institute of Korea (2014). *Korea Building Code (KBC 2014) and Commentary*, Kimoondang, Korea
29. JGJ 138-2016 (2016). *Code for Design of Composite Structures*, China building industry press, Beijing, China
30. Japan Society of Civil Engineers. (2009). *Standard specifications for steel and composite*, Tokyo, Japan
31. Kochkarev D., Galinska T. (2017). Calculation methodology of reinforced concrete elements based on calculated resistance of reinforced concrete. *MATEC Web of Conferences 116*, 02020 https://doi.org/10.1051/matecconf/201711602020
32. Кушнір Ю.О., Пенц В.Ф., Овсій М.О. (2012). Методичні основи розрахунку несучої здатності нормального прямокутного приведеного перерізу сталебетонних балок на основі розрахункової деформаційної моделі. *Ресурсоекономні матеріали, конструкції, будівлі та споруди,* 24, 167-179
33. Galinska T., Ovsii D., Ovsii M. (2018). The combining technique of calculating the sections of reinforced concrete bending elements normal to its longitudinal axis, based on the deformation model. *International Journal of Engineering & Technology (UAE),* 7(3.2), 123-127 https://doi.org/10.14419/ijet.v7i3.2.14387

25. DSTU-N B EN 1994-1-1:2010 (2010). *Eurocode 4. Design of Composite Steel and Concrete Strucures-Part 1-1: General Rules and Rules for Buildings* (EN 1994-1-1:2004, IDT)., Kyiv, Ukraine
26. Comité Européen de Normalisation (CEN), (2004b) *"Eurocode 4: Design of Composite Steel and Concrete Strucures-Part 1-1: General Rules and Rules for Buildings"*, European Standard BS EN 1994-1-1: 1994. European Committee for Standardization (CEN), Brussels, Belgium
27. American Institute of Steel Construction. (2010). Specifications for structural steel buildings, AISC 360-10, Chicago, IL
28. Architectural Institute of Korea (2014). *Korea Building Code (KBC 2014) and Commentary*, Kimoondang, Korea
29. JGJ 138-2016 (2016). *Code for Design of Composite Structures*, China building industry press, Beijing, China
30. Japan Society of Civil Engineers. (2009). *Standard specifications for steel and composite*, Tokyo, Japan
31. Kochkarev D., Galinska T. (2017). Calculation methodology of reinforced concrete elements based on calculated resistance of reinforced concrete. *MATEC Web of Conferences 116*, 02020 https://doi.org/10.1051/matecconf/201711602020
32. Kushnir Y.O., Pents V.F., Ovsii M.O. (2012). Methodical bases for calculating the load-bearing capacity of a normal rectangular reduced cross-section of steel-concrete beams based on the calculated deformation model. *Resource-saving materials, structures, buildings and structures,* 24,167-179.
33. Galinska T., Ovsii D., Ovsii M. (2018). The combining technique of calculating the sections of reinforced concrete bending elements normal to its longitudinal axis, based on the deformation model. *International Journal of Engineering & Technology (UAE),* 7(3.2), 123-127 https://doi.org/10.14419/ijet.v7i3.2.14387