https://doi.org/10.26906/znp.2018.50.1083

UDC 69.059.3

***Molodid O.S.**, PhD, Associate Professor*
ORCID 0000-0001-8781-6579 molodid2005@ukr.net
Kyiv National University of Construction and Architecture

INDICATORS OF FLOOR SLABS REINFORCEMENT TECHNICAL AND ECONOMIC INVESTIGATION BY DIFFERENT TECHNOLOGIES

The paper presents the results of technical and economic indicators study of reinforcing monolithic reinforced concrete slab various methods, namely: the supply of metal beams with the installation of additional supports, external reinforcement of stretched zones using MAPEI technology, adhesion of metal plates and carbon fiber to the developed technology. There is established that the highest indicators of the materials cost, labor intensity and wages for the execution of works relate to the option of reinforcing the floor slab by supplying metal structures, and the lowest indicators have options for reinforcing the floor slabs using MAPEI technology and bonding carbon fiber under the developed technology. The cost of materials for reinforcing the plate in the developed technology with the adhesion of steel plates is the lowest, but complexity, wages and the duration of the work on this technology are much higher than other studied technologies of external reinforcement.

***Key words:** reinforcement of floor slab, external reinforcement, carbon fiber, technical and economic indicators.*

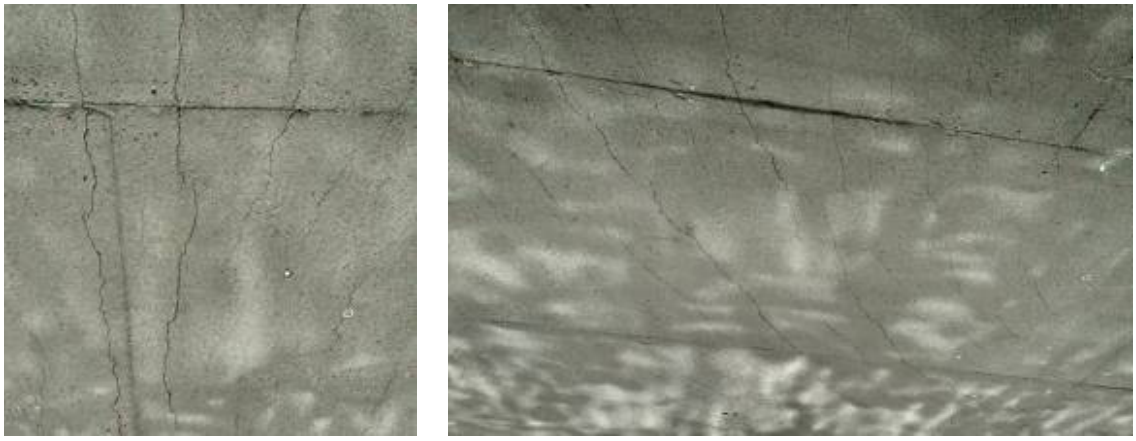
***Молодід О.С.**, к.т.н., доцент*
Київський національний університет будівництва та архітектури

ДОСЛІДЖЕННЯ ТЕХНІКО-ЕКОНОМІЧНИХ ПОКАЗНИКІВ ПІДСИЛЕННЯ ПЛИТ ПЕРЕКРИТТЯ ЗА РІЗНИМИ ТЕХНОЛОГІЯМИ

Наведено результати дослідження техніко-економічних показників різних методів підсилення монолітної залізобетонної плити перекриття, а саме: підведенням металевих балок з установленням додаткових опор, зовнішнім армуванням розтягнутих зон за технологією «МАПЕІ», приклеюванням металевих пластин і вуглецевого волокна за розробленою технологією. Установлено, що найвищі показники вартості матеріалів, трудомісткості та заробітної плати на виконання робіт має варіант підсилення плити перекриття підведенням металевих конструкцій, а найнижчі – варіанти підсилення плити перекриття за технологією «МАПЕІ» й приклеюванням вуглецевого волокна за розробленою технологією. З'ясовано, що вартість матеріалів на підсилення плити в розробленій технології з приклеюванням сталевих пластин найнижча, але трудомісткість, заробітна плата та тривалість виконання робіт за такою технологією значно вищі за інші досліджувані технології підсилення зовнішнім армуванням.

***Ключові слова:** підсилення плити перекриття, зовнішнє армування, вуглецеве волокно, техніко-економічні показники.*

Introduction. During the inspection of a building in Kyiv, a number of damages and defects in inter-floor overlapping structures were detected. The building is 5-storey, frame-monolithic. For floor slabs reinforced concrete was used. On their surface numerous damages were found in the form of cracks, located in stretched areas (Fig. 1). It was found that damage was caused by the influence of constructive, technological and operational factors, in particular: insufficient reinforcement of stretched zones; overload of constructions; discrepancy of the protective layer thickness with the design decision and regulatory requirements; strength of concrete is lower than specified in the project; the thickness of the floor slab, in some places, is less than the design; probable early unpacking.



a) b)

Figure 1 − Longitudinal (a) and bending (b) cracks on the surface of the floor slab

As a result of the visual-instrumental inspection and checking calculations of the overlap pings it was established that the technical condition of the structures does not provide sufficient load bearing capacity for their normal and safe operation according to their intended purpose. Therefore, it is recommended to perform their enhancement.

Analysis of recent research and publications. The analysis of normative and technical literature has established that in practice, in order to reinforce the slabs, the following structural and technological solutions are used: increasing the cross-section due to the build-up; change of the static scheme of work due to the installation of protrusions, slippers, racks, etc. [1 − 3]. However, in this case, the installation of additional reinforcement structures will reduce the inter-floor space, or change the structural and planning decisions of the interior space of the building. In addition, the load on the supports and foundations is significantly increased, or even the need arises for the installation of additional foundations for new supports.

Selection of previously unsettled items of the general problem. Considering the above mentioned, one of the excellent methods of reinforcing structures is external reinforcement (gluing using special adhesives on the surface of high-strength canvases, plates or strips (lamellae) structures. Materials and technologies of foreign production are now used in domestic building practice [4 − 6]. For the purpose of structures enhancement by external reinforcement, metal and composite materials based on carbon fibers, fiberglass and plastics can be used [7 − 10]. On the basis of SE «Research institute of building production» (Kyiv) a number of experimental studies were carried out. Based on the results of these studies constructive and technological solutions for amplification of beam structures with external reinforcement using domestic materials were developed [11 − 13]. However, before providing recommendations for using specific amplification technology in construction, its techno-economic feasibility should be established.

Thus, the **aim** of this publication is the study of technical and economic performance (TEP) of various technologies for reinforcement of overlap slabs.

Main material and results. In order to assess the economic feasibility of a certain method of slabs enhancement, it was decided to compare the following methods of amplification: supply of metal beams with the installation of additional supports, external amplification under the «MAPEI» technology and external reinforcement under the previously researched and proposed technologies. Provided research and comparison of technical and economic indicators for overlapping with area of 250 m², where outer loop is based on the piers and columns support it in the middle (Fig. 2, 3).

The main technical and economic performance indicators (TEP) selected for comparison: cost of materials for amplification, complexity, wages and performance duration.

By the *first method*, the reinforcement of the floor slab is provided by the supply of metal beams with the installation of additional supports (columns) (Fig. 2). Since, when performing amplification by the indicated method, the height of the room is significantly reduced, but in this case it is not acceptable, therefore this method is considered only for the purpose of the TEP comparison.

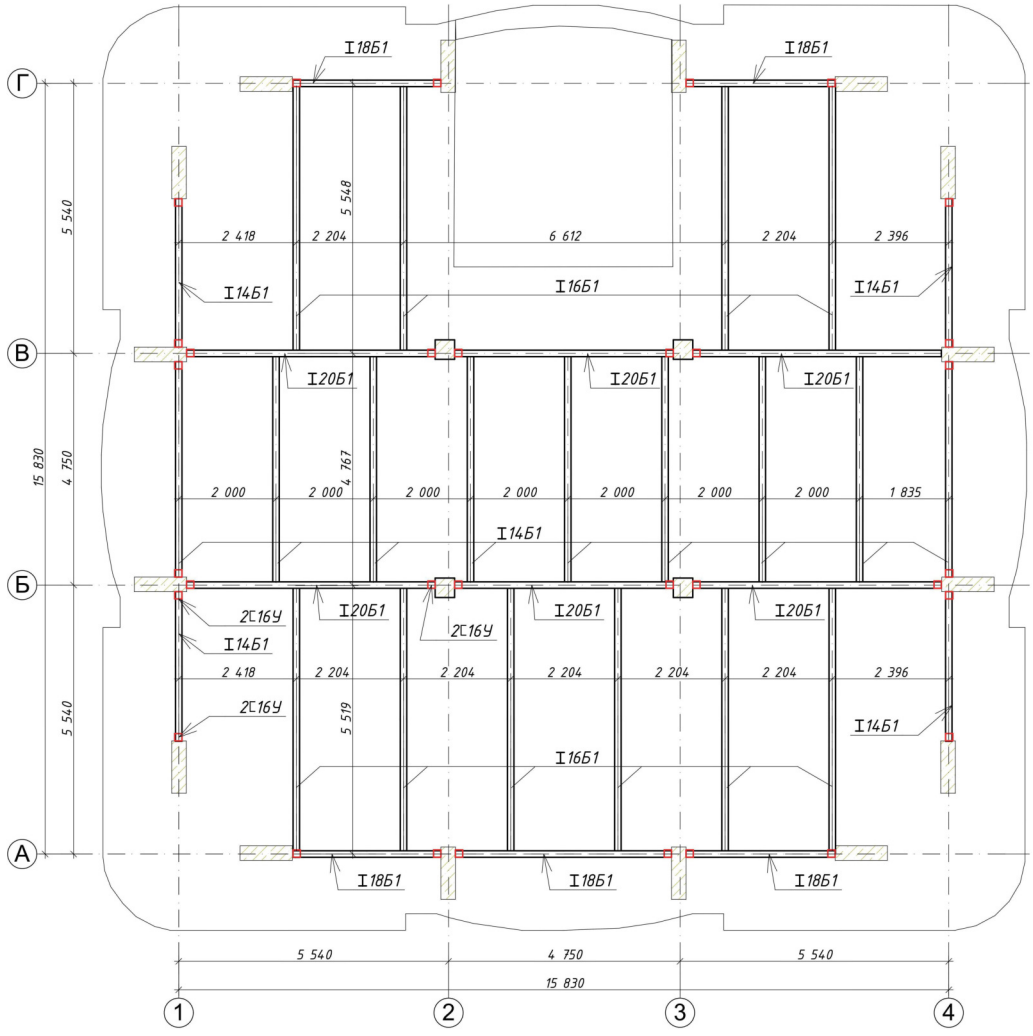


Figure 2 − Scheme of reinforcing elements of the floor slab according to the method of supplying steel beams with the installation of additional columns

The project provides for the installation of rigidly fixed metal columns (two 16U wires welded in a box) to existing reinforced concrete vertical structures in the areas shown in Fig. 2. On the columns longitudinal double T-beams 18B1 and 20B1 on the lower shelves are laid and welded; through their inserts (if necessary) transverse double T-beams 14B1 and 16B1 are laid and welded.

The following methods provide external reinforcement of slabs made of reinforced concrete, such as bonding metal plates or carbon fiber on the stretched zones. It allows increasing bearing capacity of the plate and reducing deflection. The areas for adhesion of strips for external reinforcement are shown in the schematic of the reinforcement elements (Fig. 3).

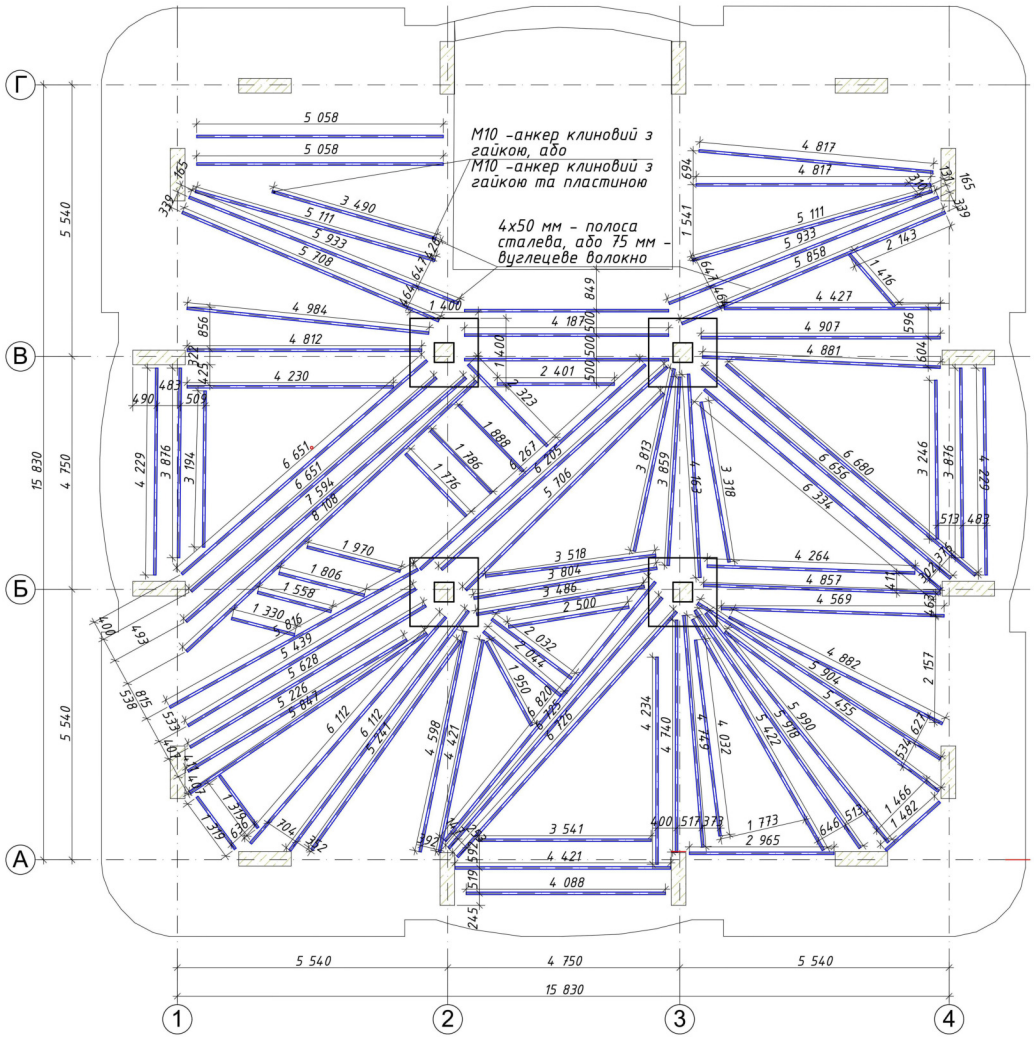


Figure 3 − The layout of the floor slab reinforcement elements with the method of external amplification (MAPEI technology, metal plates, or carbon fiber under developed technology)

By the *second method*, the reinforcement of the floor slab is performed according to the technology of the «MAPEI» company. Prior to the beginning of the reinforcement work, future carbon fiber bonding sites should be cleaned from the «glossy» surface using a sandblasting device, or a grinding machine with a special disk to clear concrete surfaces. This technology provides for priming the concrete surface to strengthen the foundations with composition MapeWrap Primer 1, bonding unidirectional carbon fiber MapeWrap C UNI-AX with adhesive MapeWrap 21. The ends of the carbon fiber strips are mechanically fixed with metal plates and bolts M10.

In the *third method* is scheduled to perform enhancement of the plate by sticking metal plates to its stretched areas. Firstly, the cleaning of the places for gluing plates is carried out according to the technology described above. Subsequently, the place of gluing the plates and 10 mm on each side outside each plate is impregnated with the composite grounding foundation «Consolid 1» manufactured by LLC «COMPOSIT". At least 24 hours later bonding of metal plates (4 x 50 mm) is executed on an epoxy based adhesive «EDMOK» produced by LLC «COMPOSIT». At the ends the plates are fixed with wedge anchors M10. Plates are pre-wiped to shine and degreased.

By the *fourth method*, the reinforcement is performed by gluing of of unidirectional carbon fiber stripes on the stretched zones. Before the beginning of the gluing work, place intended for bonding the fiber is prepared, namely, the surface is cleaned and «Consolid 1» foundation is applied as described in the previous method. After 24 hours «EDMOK» adhesive is applied on the prepared surface and strips of carbon fiber are «drown» in it with a spatula. In 5-10 minutes, another layer of «EDMOC» adhesive is applied to the surface of the fiber so that it completely percolates the fiber and remains on the surface. The ends of carbon fiber strips are mechanically fixed with metal plates and bolts M10.

First of all, there should be established the cost of the materials necessary for the work on reinforcing the floor slab for each described technology. The total cost of materials and equipment is determined by the formula (1):

$$P_M = \sum_{i=1}^{n} (\rho_{мп} \cdot Q_{мп}),$$

where $\rho_{мп}$ – total value of the products of each individual material;

$Q_{мп}$ – the volume of each individual material..

For the *first method* is defined the overall length of each type of steel elements and multiplied by its density, double T-beams 14B1 = 571,41 kg, 16B1= 698,5 kg, 18B1 = 256,41 kg, 20B1 = 659,2 kg; Channel for columns 16U = 2905,32 kg.

Consequently, the total cost of metal elements is:

$$P_M = 23{,}2\ ^{\text{UAH}}/_{\text{kg}}\ (571{,}4\text{kg} + 698{,}5\text{kg} + 256{,}4\text{kg} + 659{,}2\text{kg} + 2905{,}3\text{kg}) = 118\ 106{,}5\ \text{UAH},$$

where 23,2 is the cost of one kilogram of steel constructions.

For the *second method* it is established that in order to strengthen the stretched zones of the slab floor, 376 rm of carbon fiber MapeWrap C UNI-AX 300/10 is required, which, with a strip width of 10 cm has a density of 300 g/m. The cost of such carbon fiber is 154,7 $^{\text{UAH}}/_{\text{rm}}$.

Thus, the cost of fiber needed to strengthen the entire plate is:

$$P_M = 154{,}7\ ^{\text{UAH}}/_{\text{rm}} \times 376{,}0\ \text{rm} = 58\ 167{,}2\ \text{UAH}.$$

The MapeWrap Primer 1 priming fluid consumption is 11.28 kg. With the price of 1 kg of grounding 740,76 $^{\text{UAH}}/_{\text{kg}}$, its total cost is:

$$P_M = 740{,}7\ ^{\text{UAH}}/_{\text{kg}} \times 11{,}28\ \text{kg} = 8\ 355{,}7\ \text{UAH}.$$

For adhesion of carbon fiber, adhesive MapeWrap 21 is used with a total consumption for an overlapping amounting 37,6 kg. The price of glue is 553,97 $^{\text{UAH}}/_{\text{kg}}$, so its total cost is:

$$P_M = 553{,}9\ ^{\text{UAH}}/_{\text{kg}} \times 37{,}6\ \text{kg} = 20\ 829{,}2\ \text{UAH}.$$

For the *third method* of amplification, analyzed in this article, 581.0 kg of steel stripe 4x50 mm are needed at its price of 23,2 $^{\text{UAH}}/_{\text{kg}}$. Consequently, the total cost of the steel strip for reinforcing the plate is:

$$P_M = 23{,}2\ ^{\text{UAH}}/_{\text{kg}} \times 581{,}0\ \text{kg} = 13\ 479{,}2\ \text{UAH}.$$

The total cost of the grounding «Consolid 1» is:

$$P_M = 227\ ^{\text{UAH}}/_{\text{l}} \times 9{,}5\text{l} = 2\ 156{,}5\ \text{UAH}$$

with its need amounting 9.5 liters and a price of 227 UAH/liter.

The total cost of adhesive «EDMOC», which is used when amplifying the plate according to this technology, is:

$$P_M = 288{,}0\ ^{\text{UAH}}/_{\text{kg}} \times 28{,}2\ \text{kg} = 8\ 121{,}6\ \text{UAH}$$

at its price 288 UAH/kg and need 28.2 kg.

For the *fourth method* of amplification 376.0 rm of unidirectional carbon fiber with density of 300 g/rm and a width of a strip of 10 cm a required, as indicated above, at a price of 125.0 UAH/m. Under these conditions, the total cost of fiber for the plate reinforcement is:

$$P_M = 125{,}0\ ^{\text{UAH}}/_{\text{rm}} \times 376{,}0\ \text{rm} = 47\ 000{,}0\ \text{UAH}.$$

The total cost of the grounding «Consolid 1» is:

$$P_M = 227{,}0\ ^{\text{UAH}}/_{\text{l}} \times 15{,}7\ \text{l} = 3\ 564{,}0\ \text{UAH}$$

with its need for 15.7 liters and a price of 227.0 UAH/liter.

The total cost of adhesive «EDMOC», used when amplifying the plate according to this technology, is:

$$P_M = 288{,}0\ ^{\text{UAH}}/_{\text{kg}} \times 75{,}2\ \text{kg} = 21\ 657{,}6\ \text{UAH}$$

As the need for glue «EDMOC» is 75.2 kg, and its price – 288 $^{\text{UAH}}/_{\text{kg}}$.

The calculation of the cost of materials needed to reinforce the floor slab is given in Table 1 and in Fig. 4.

Table 1 – Cost of materials for reinforcement of floor slab by different methods

Name of material	Cost of materials, UAH			
	supply of metal beams	«MAPEI» technology	gluing metal plates	gluing carbon fiber
Metal beams and columns	118106,5	-	-	-
MapeWrap C UNI-AX 300/10	-	58167,2	-	-
MapeWrap Primer 1	-	8355,7	-	-
MapeWrap 21	-	20829,2	-	-
Steel strip 50×4	-	-	13479,2	-
Consolid	-	-	2156,5	3564,0
EDMOK	-	-	8121,6	21657,6
Carbon fiber 300/10	-	-	-	47000,0
Anchor M10	-	516	516	516
Steel strip for mechanical fastening	-	345	-	345
Total cost	**118106,5**	**88213,1**	**23757,3**	**73082,6**

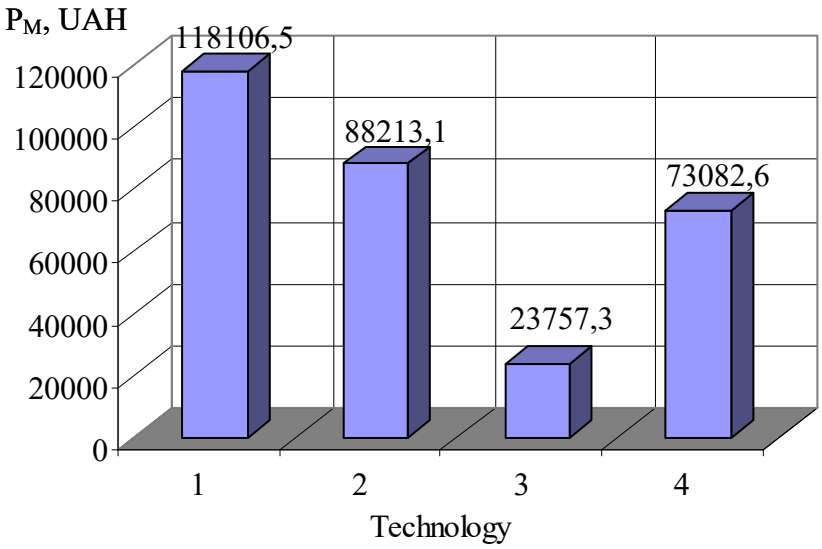


Figure 4 – Cost of materials for reinforcement of floor slab:
1 – supply of metal beams; 2 – «MAPEI» technology;
3 – gluing of metal plates; 4 – gluing carbon fiber

The second phase of the study TEP provides establishment of complexity and amount of wages for performed work at strengthening plates with different technologies. The complexity is determined by the normative values in accordance with the DBN, SGS, DSTU and Unified Norms and Prices, as well as by the values obtained by the results of their own timing. All labor complexity values are summarized in Table 2.

Table 2 – Calculation of labor complexity of reinforcing overlapping slabs by different methods and wages for these works

Working operation	The complexity and wages to enhance the floor slab according to the appropriate technology							
	supply of metal beams		«MAPEI» technology		gluing metal plates		gluing carbon fiber	
	Complexity, man/hour	Wages, UAH	Complexity, man/hour	Wages, UAH	Complexity, man/hour	Wages, UAH	Complexity, man/hour	Wages, UAH
Painting of metal elements	28,5	584,2	-	-	-	-	-	-
Cutting, assembly and welding	478,2	9803,1	-	-	-	-	-	-
Cleaning the surface	-	-	8,8	180,4	8,6	176,3	8,8	180,4
Priming the surface	-	-	10,2	209,1	9,6	196,8	10,2	209,1
Technological break	–				24 hours			
Gluing Carbon Fiber / Metal Plates	-	-	55,4	1135,7	336,3	6894,1	55,4	1135,7
Fixing ends of stripes with anchors	-	-	19,2	393,6	17,6	360,8	19,2	393,6
Total	**506,7**	**10387,3**	**93,6**	**1918,8**	**372,1**	**7628,0**	**93,6**	**1918,8**

Wages, salaries of workers performing amplification are defined in UAH based on the data book «Pricing in construction». The indicated costs are 20.5 UAH/hour for the worker with a grade of 3.8. The calculation of labor and wages is shown in Table 2. The histogram of labor intensity (Fig. 5) and wages (Fig. 6) on the reinforcement of the plate by different technologies is constructed according to the data of Table 2.

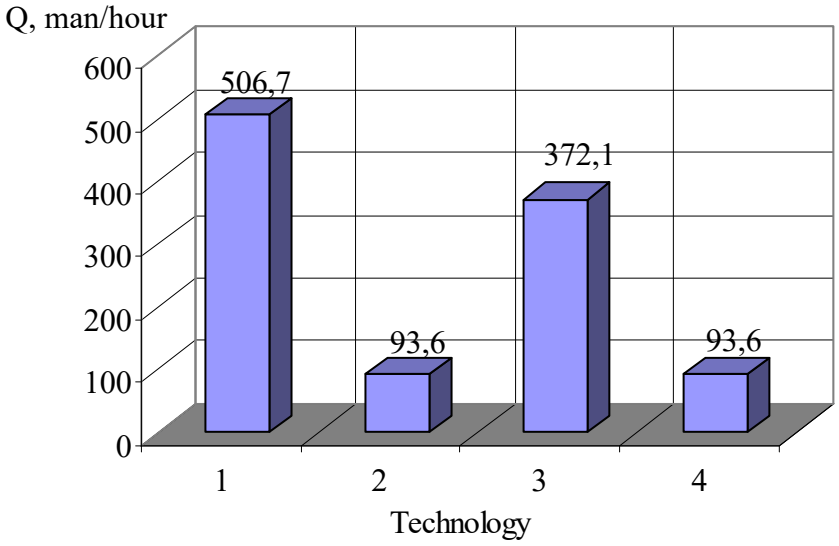


Figure 5 – The work complexity on reinforcement of the floor slab:
1 – supply of metal beams; 2 – «MAPEI» technology;
3 – gluing of metal plates; 4 – gluing carbon fiber

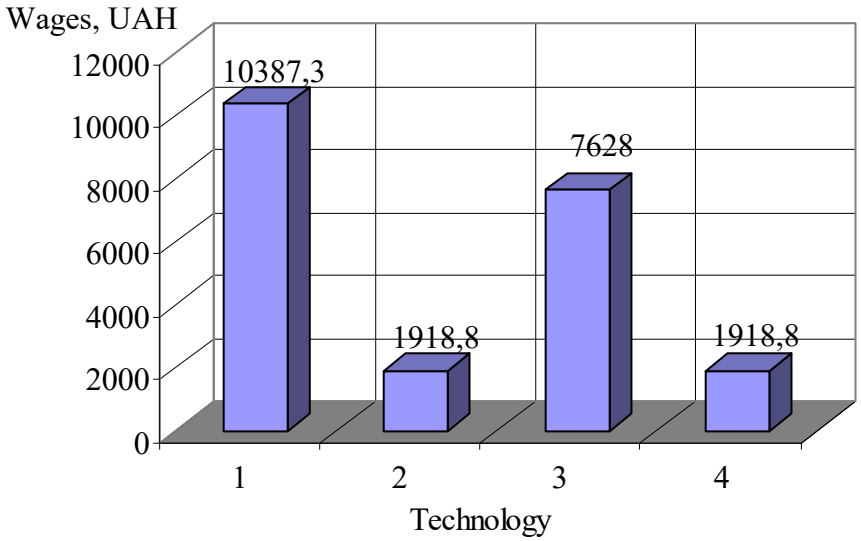


Figure 6 – Wages for strengthening slabs:
1 – supply of metal beams; 2 – «MAPEI» technology;
3 – gluing of metal plates; 4 – gluing carbon fiber

The duration of the floor slab reinforcing process (Fig. 7) is determined by adding the duration of the work operations with the length of the technological breaks between them according to the Table 2. It is considered that the painting of metal constructions and surface cleaning is carried out by one worker, the assembly and welding work is carried out by three workers, and all other processes are performed by two workers.

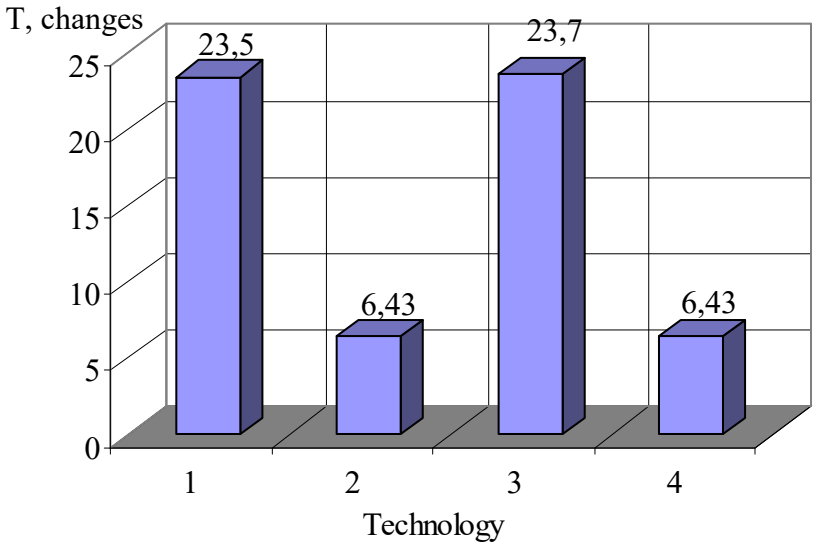


Figure 7 – Work duration on floor slabs reinforcement:
1 – supply of metal beams; 2 – «MAPEI» technology;
3 – gluing of metal plates; 4 – gluing carbon fiber

Conclusions. According to the study of technical and economic performance of different amplification technologies applied to the same floor slab, it was found that the cost of materials, complexity and wages for performing such works on reinforcing floor slab with the amplification method of metal structures supply is the highest. At the same time, labor intensity, wages and the duration of work execution are the lowest with the reinforcement of the floor slabs by the technology of the company MAPEI and the bonding of carbon fiber by the developed technology. The cost of materials for reinforcing the slab by the developed technology, namely, bonding of steel plates is the lowest, but the complexity, wages and length of work under such technology is much higher than other investigated technologies of reinforcement by external enhancement.

The research results are a strong argument in choosing a particular way of structures strengthening, one of the decisions of feasible study

References

1. *ДСТУ Б В.3.1-2:2016. Ремонт і підсилення несучих і огороджувальних будівельних конструкцій та основ будівель і споруд [Чинний від 2017-04-01]. – К. : ДП «УкрНДНЦ», 2017. – 72 с.*
2. *Шагин А. Л. Реконструкция зданий и сооружений / А. Л. Шагин, Ю. В. Бондаренко, Д. Ф. Гончаренко. – М.: Высш. шк., 1991. – 352 с.*
3. *Савйовский В. В. Ремонт и реконструкция гражданских зданий / В. В. Савйовский, О. Н. Болотских. – Х.: Ватерпас, 1999. – 288 с.*
4. *Савйовський В. В. Реконструкція будівель і споруд / В. В. Савйовський. – К.: Вид-во Ліра-К, 2018. – 320 с.*
   ISBN 978-617-7507-70-2
5. *Klebearmierung [Електронний ресурс]. – Режим доступу: http://www.diamont-ag.ch.*
6. *Mapewrap C UNI-AX. Покрытие углеволоконное высокопрочное однонаправленное. [Електронний ресурс]. – Режим доступу: http://rosmax.com.ua*
7. *Minnaugh P. L. The experimental behavior of steel fiber reinforced polymer retrofit measures: thesis master of Science / Patrick Lucien Minnaugh; University of Pittsburgh school of engineering. – Pittsburgh, 2006 – 113 p.*

8. Шилин А. А.. Усиление железобетонных конструкций композиционными материалами/ А. А. Шилин, В. А. Пшеничный, Д. В. Картузов. – М.: ОАО «Издательство «Стройиздат», 2004 – 144 с.
9. Ігнатова І. В. Підсилення бетонних конструкцій за допомогою полімерсилікатної композиції / І. В. Ігнатова // Будівельні конструкції: зб. наук. праць. – К. : ДП НДІБК, 2011. – Вип. 75, Кн. 2. – С. 614 – 621.
10. Obaidat Y. T. Structural retrofitting of reinforced concrete beams using carbon fibre reinforced polymer: Licentiate Dissertation / Yasmeen Taleb Obaidat; Division of Structural Mechanics, LTH, Lund University. - Sweden, May, 2010 – 88 p.
ISSN 0281-6679
11. Технологическая карта на выполнение работ по восстановлению кирпичных, железобетонных конструкций и их защите / ООО «Композит». – К., 2009. – 7 с.
12. Григоровський П. Є. Підсилення балочних конструкцій зовнішнім армуванням методом наклеювання високоміцних тканин / П. Є. Григоровський, О. С. Молодід, Р. О. Плохута // Будівельне виробництво. – 2016. – №61/1. – С. 13 – 18.
13. Савйовський В. В. Підсилення залізобетонних балочних конструкцій зовнішнім армуванням/ В. В. Савйовський, О. С. Молодід, Н. О. Малець // Управління розвитком складних систем. – 2017. – №29. – С. 198 – 204.