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***Chekanovych M.G.**, PhD, Pofessor*
ORCID 0000-0002-9110-4109 chekanovych@mail.ru
***Romanenko S.M.**, senior lecturer*
ORCID 0000-0002-0443-3896
***Andrievska Y.P.**, post-graduate*
ORCID 0000-0003-3052-2515 Yana Andrievska @ yandex.ua
Kherson State Agricultural University, Kherson

AN EFFECTIVE STRUCTURE FOR STRENGTHENING REINFORCED CONCRETE BEAMS

The study presents a new system of strengthening reinforced concrete beams. The system includes strengthening bars acting on the beam through other strained flexible elements. It operates in a conditionally paradoxical way. It does not compress but strains directly the upper beam zone compressed under the load. Additional flexible elements are made in the form of rods placed obliquely. The study provides the results of determining the most efficient angle of inclination of transverse bars for the external system of strengthening. The paper calculates an efficient angle of inclination of transverse bars that are to unload the beam by the moment reverse in sign of the moment from external load. It also analyzes the results obtained after examining the strengthening by means of a longitudinal-transverse external system and building the diagrams of moments.

***Keywords:** bars, cross-section, stress, strain, strength, rigidity, span.*

***Чеканович М.Г.**, к.т.н., професор*
***Романенко С.М.**, ст. викладач*
***Андрієвська Я.П.**, аспірант*
Херсонський державний аграрний університет

ЕФЕКТИВНА СХЕМА ПІДСИЛЕННЯ ЗАЛІЗОБЕТОННИХ БАЛОК

Запропоновано нову конструктивну систему підсилення залізобетонних балок, яка включає затяжку, що діє на балку через інші гнучкі розтягнуті елементи; вона працює умовно парадоксально – не стискає, а розтягує безпосередньо верхню стиснуту під навантаженням зону балки. Додаткові гнучкі елементи виконано у вигляді похило розташованих срижнів. Наведено результати пошуку найбільш ефективного кута нахилу поперечних стрижнів для зовнішньої системи підсилення балки. Визначено раціональний кут нахилу поперечних стрижнів, які мають розвантажувати балку моментом, зворотним по знаку до моменту від зовнішнього навантаження. Проаналізовано результати, отримані після дослідження підсилення поздовжньо-поперечною зовнішньою системою та побудовано епюри моментів.

***Ключові слова:** затяжка, переріз, напруження, деформації, міцність, жорсткість, проліт.*

Recent sources of rresearch and publications analysis. Strengthening of reinforced concrete elements such as beams and slabs is widely used in construction practice. In recent years, reinforcement application has increased due to a significant increase in the share of reconstruction in construction. This is the result of changes in stress, physical deterioration of existing buildings because of their poor maintenance and other factors, which leads to bearing capacity loss; thus structures need to be strengthened to ensure sufficient performance under normal maintenance and reliability. [1, 2].

Different methods of strengthening bending concrete elements were developed [3-14]. The findings of national and foreign authors, such as E.M. Babich, A.M. Bambura, G.I. Berdichevsky, V.A. Roach, A.A. Gvozdev, A.B. Golyshev, E.A. Hrynevych, F.S. Zamaliyev, M.Y. Izbash, V.G. Kvasha, F.E. Klimenko, F. Leonhardt, E.A. Luchkovskyy V.V. Mikhailov, N.M. Onufriev, S.F. Pichugin, E.G. Ratts, L.I. Storozhenko, L.N. Fomytsya, E. Freyssinet, Jiang De, A.L. Shahin, Richard W. Plavidal, Thomas Keller and others make the scientific, design and technological basis for using reinforced structures in construction. The variety of mentioned methods can be divided into 3 groups: strengthening with a change in the constructive and design scheme of a reinforced concrete member; strengthening without changing the work pattern of structures by building up their cross-sections with additional external reinforcement; strengthening by prestressing beams with horizontal ties.

There can be three types of tie bars: horizontal, sprengel and combined ones. When applying prestressed tie bars, the strengthened elements change their original constructive scheme because they turn into a combined system. Due to this fact, conventional bending elements are compressed noncentrally, and with their supports additional bending moments are created, which in turn influence the initial span moments. In this case, in all the variants of reinforcing beams with tie bars there are still significant reserves of increasing carrying capacity.

Specifying aspects of the problem unsolved before. After considering many schemes of reinforcement it can be concluded that their disadvantage is the inability to effectively unload the compressed zone of concrete beam effectively, which greatly affects rigidity and bearing capacity.

Setting objectives. The aim is to study the most efficient inclination angle for placing cross bars of the reinforcement system. The angle is to meet the following requirement: maximum unloading of the beam by the moment reverse in sign to the moment of external load.

Research objectives:

– to conduct research setting different angles for the inclined transverse reinforcing bars;
– to identify relative and absolute elongation, tensile value in the bars;
– to analyze the results obtained after examining the reinforcement with a longitudinal-transverse external system, and build diagrams of moments, to choose the most efficient inclination angle;
– to evaluate the results of experimental studies;
– to determine the effectiveness of strengthening reinforced concrete beams with a longitudinal-transverse external system of reinforcing bars.

Basic material and results. For experimental studies three series of reinforced samples of reinforced concrete beams were conducted. Reinforced concrete beams were 2.1 m long, had a cross-section of 100×200 mm and were made of concrete of class C45/55. They were reinforced with frames made of rebar of nominal diameter Ø 6 A240S. The БПП beams series were strengthened according to the patent. [15] Three options for the location of inclined bars at different angles such as 30°, 45° and 60° were considered. The external reinforcement system is presented in Fig. 1. It is proposed a design solution of a stressed-regulated beam containing a reinforced concrete body and tie, mounted at the ends onto the beam interacting in the middle with the stressing element contacting the lower part of the beam, and lateral external reinforcement interacting at the ends of the beam with its upper and lower parts, and interacting with the tie in its middle part. Transverse reinforcement bars are strained, flexible and placed symmetrically in the area near the supports of the beam with an inclination to the longitudinal axis of the beam.

Figure 1 – Scheme of strengthening БПП-ІІІ-1 beam with external longitudinal and transverse rebar

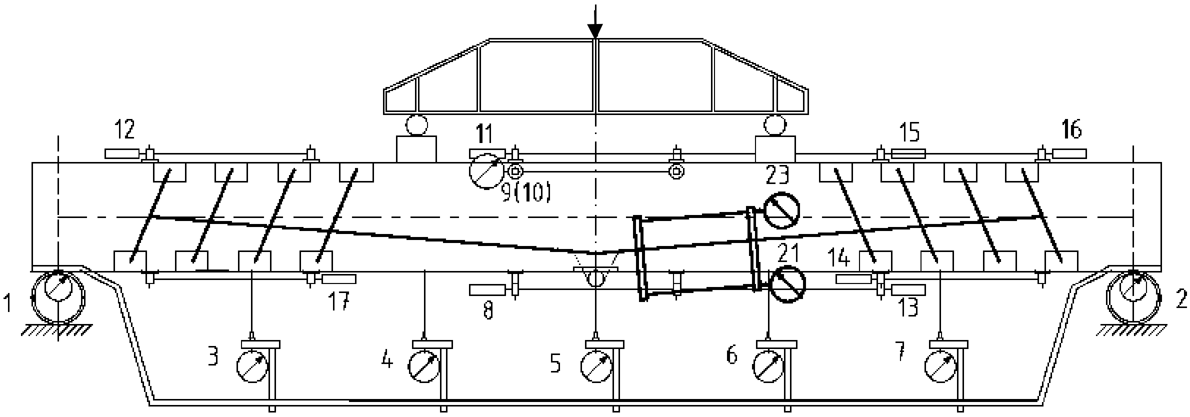
Inclined strands are composed of identical reinforcing bars that are connected with the tie by welding. When external force is applied, inclined bars deform and bend. Fig. 2 shows the initial position of the inclined bar at an angle of 30 °.

The work of the strengthening system was examined at the level of load η =0,9. The force in the tie was fixed in all experiments.

Figure 2 – Starting position of the inclined bar at an angle of 30°, before load application.

When placing the bars at an angle of 30 ° the design scheme the following form is obtained, shown in Fig. 4.

To build a diagram of deformations, it is used the solution proposed by Timoshenko S.P., James M. Gere. [16]. The diagram shows the deformations schematically in Fig. 5.



Figrку 3 – Scheme of testing a strengthened beam of БПП-III series:
1, 2 – force meter; 3-7 – flexometer with a value of a division of 0.01 mm
to measure beam deflection;
8-17 – indicators with a value of a division of 0.001 mm
to measure the deformation of concrete

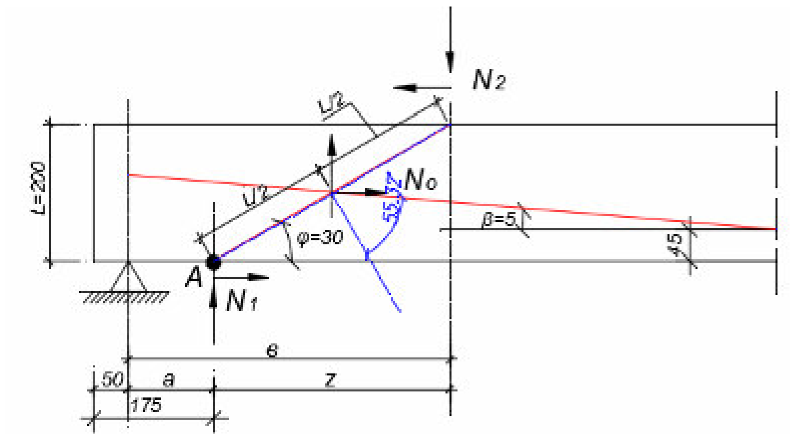


Figure 4 – Scheme of bar placement at an angle of 30 °

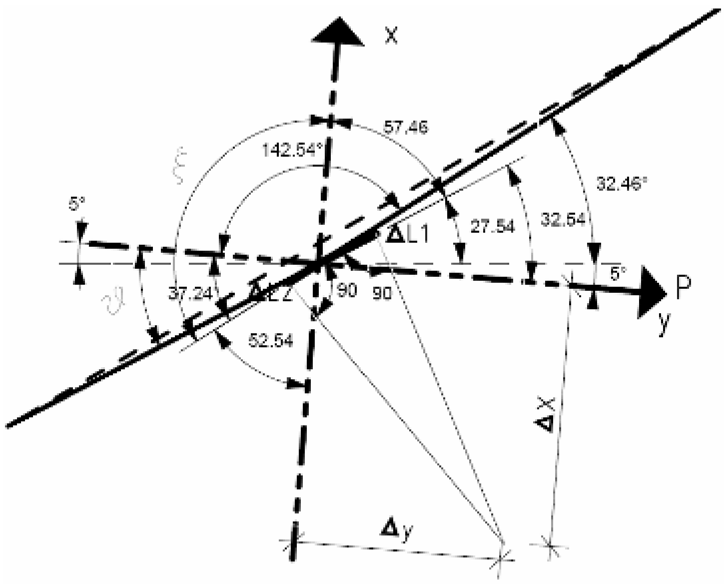


Figure 5 – Estimated diagram to determine the elongation of bars

After applying the load onto the deviation angle of the inclined bar was 1.54 °, and the vertical deformation was 4.88 mm; the data are presented at an angle of inclination of 30 ° for transverse bars.

The forces acting in the upper and lower parts of the cross rod can be expressed by the theorem of sines:

$$N_1 = \frac{P\sin\ \xi}{\sin\left(180 - (\vartheta + \xi)\right)}\ , \tag{1}$$

$$N_2 = \frac{P\sin\ \vartheta}{\sin\left(180 - (\vartheta + \xi)\right)}\ , \tag{2}$$

where: $\gamma = 180 - (\vartheta + \xi)$,

Absolute elongation of bars is:

$$\Delta L_1 = \frac{N_1 \cdot L_1}{E \cdot A}\ , \tag{3}$$

$$\Delta L_2 = \frac{N_2 \cdot L_2}{E \cdot A}\ . \tag{4}$$

To determine the displacement of the point of maximum deformation of the inclined transverse cross bar, it is obtained the crossing of radii $L_1 + \Delta L_1$ and $L_2 + \Delta L_2$. Due to the small value of deformations, it can be added the value of every elongation and drawn a perpendicular from the point obtained to the direction of the bar. The diagram of the elongation of bars is shown in Figure 5. The diagram shows that ΔL_1 is the algebraic sum of the projections of horizontal Δ_x and vertical sΔ_y displacement of the specified point in the direction of the 1st bar, but ΔL_2 is equal to the sum of the projections Δ_x and Δ_y in the direction of the 2nd bar. The position of the maximum displacement is determined by the system of equations:

$$\begin{cases} \Delta L_1 = -\Delta_x cos\theta + \Delta_y sin\theta \\ \Delta L_2 = \Delta_x cos\varphi - \Delta_y sin\varphi \end{cases}\ . \tag{5}$$

After calculating the forces in each bar at different angles of inclination, it is obtained diagrams of moments of external loads and from the strengthening system for getting maximum efficiency and the most efficient angle of inclination. For beams with a 30 ° angle of inclination of transverse bars, the angles were θ = 57.46 °; φ = 52.54 ° under the load η = 0.9.

Research results. Fig. 5, 6, 7 show the diagrams of moments at different angles of inclination under the level of load η = 0.9 on the strengthened beam.

Stress-strain state of each cross-section of reinforced beams can be determined under the equilibrium of the bending moment and longitudinal forces in the cross-section:

$$\sum M = 0 \qquad M_{зов} = \int_A \sigma_c h\, d\, A_c + \sum_{i=1}^{n} \sigma_s A_s h_i + M_{nX} + M_{nY}\ , \tag{6}$$

$$\sum N = 0 \qquad N_{nX} = \int_A \sigma_c d\, A_c + \sum_{i=1}^{n} \sigma_s A_s\ , \tag{7}$$

where σ_c – compressive stress in concrete;

σ_s – stress strain in reinforcement;

A_c – cross-section area;

A_s – cross-section area of steel;

M_{nX}, M_{nY} – moments under strengthening.

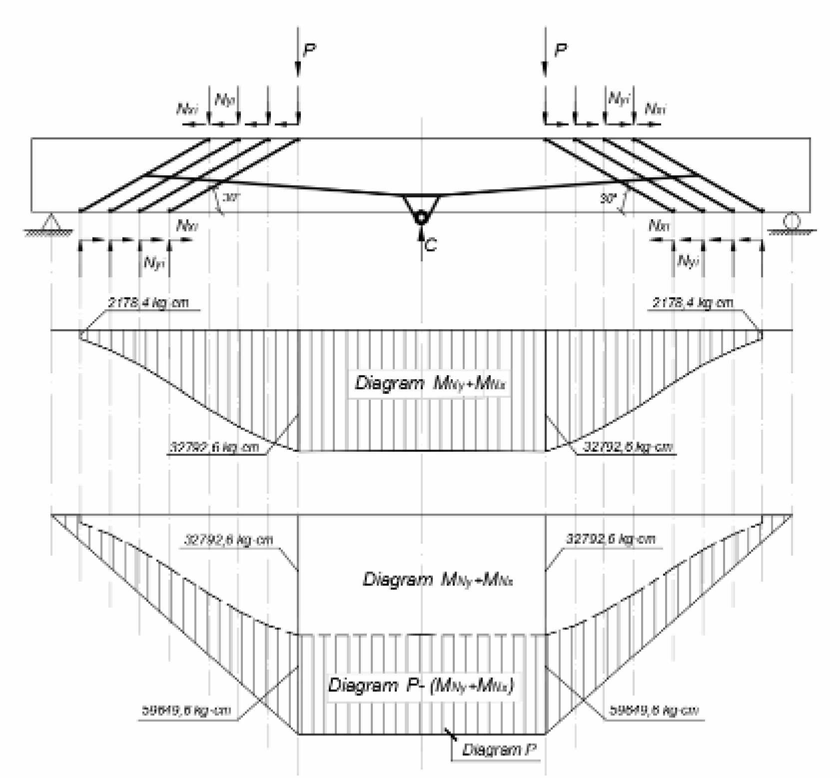


Figure 6 – Diagrams of moments considering strengthening at a 30° angle of inclination of transverse bars

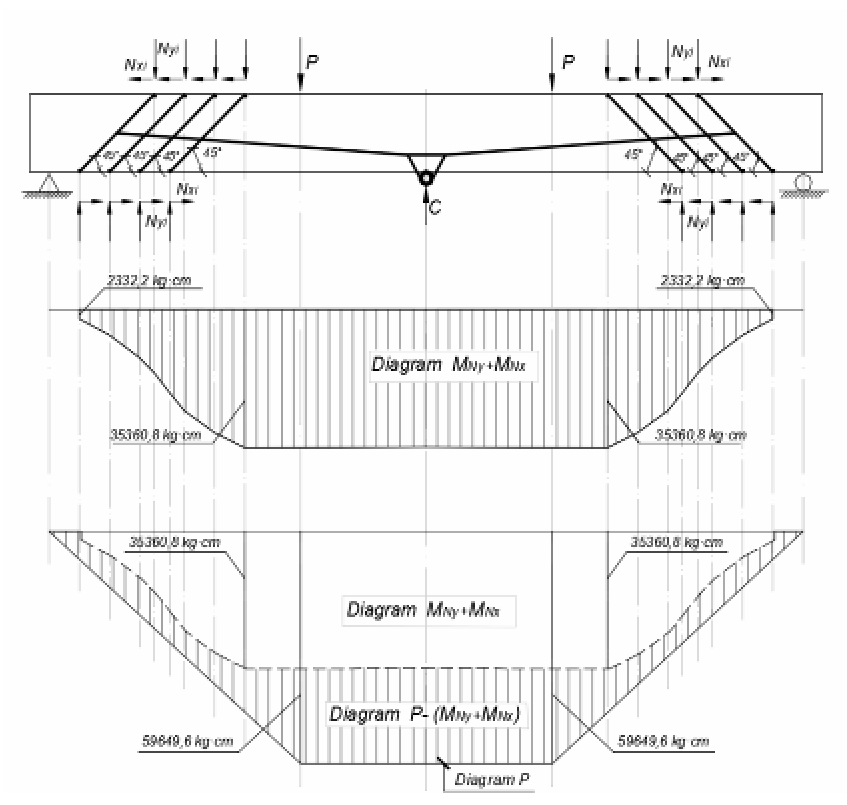


Figure 7 – Diagrams of moments taking into account strengthening at a 45° angle of inclination of transverse bars

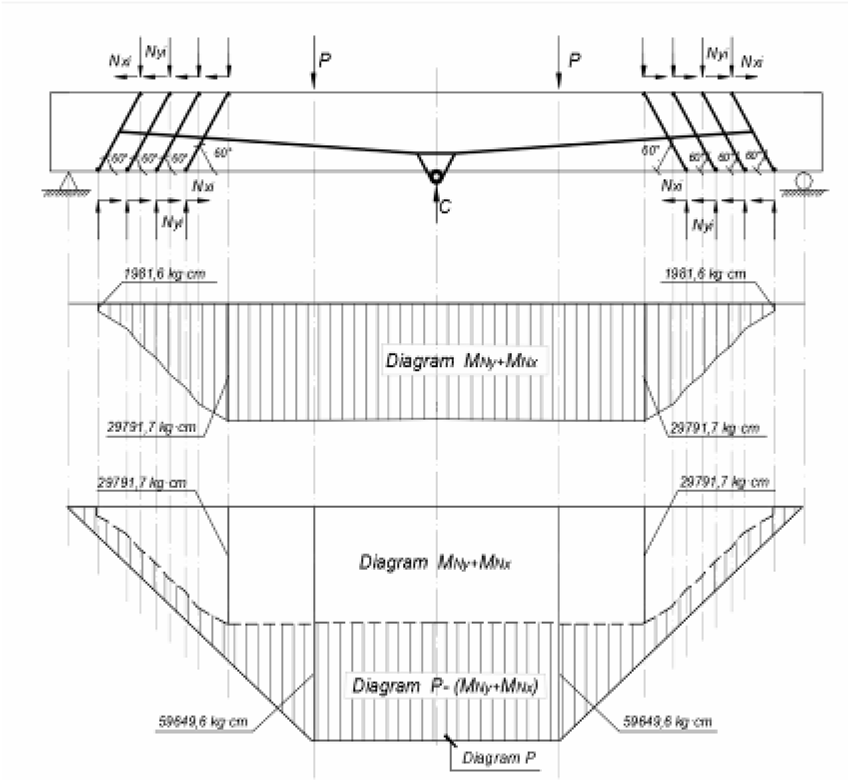


Figure 8 – Diagrams of moments considering strengthening at a 60° angle of inclination of transverse bars

Depending on the angle of inclination of transverse bars near the supports of the beam, the values of the moment were obtained. The most efficient angle for placing the inclined bars was 45° under the level of load η =0.9. The efficiency of strengthening is 59,28%, which is by 4,31% more than for the angle of 30 ° and by 9,34% higher than for the angle of 60°. The main research results are shown in the table.

Table of results

№	Inclination angle of the bars of the strengthening system, α	M_{Nx}+ M_{Ny}, kg·cm	M_{Σ}, kg·cm	$\frac{M_p}{M_{Nx}+M_{Ny}}$	Effect, %
1	30°	32792,8	26856,8	1,81	54,97
2	45°	35360,72	24288,88	1,68	59,28
3	60°	29791,6	29858	2,00	49,94

Conclusions. The findings proves that the effect of the application of the developed system of strengthening reinforced concrete beams is within 49-60%. The most efficient angle of inclination of transverse bars of the external reinforcement is 45°.

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