AIP Conference Proceedings

RESEARCH ARTICLE | FEBRUARY 21 2019

Effect of the pre-stressed reinforcement curvature on the bearing capacity of inclined sections of monolithic beams

Oleksandr Kozak ✉; Oleksandr Zhuravskyi; Mykhaylo Delyavskyy

AIP Conf. Proc. 2077, 020027 (2019)
https://doi.org/10.1063/1.5091888

Effect of the Pre-Stressed Reinforcement Curvature on the Bearing Capacity of Inclined Sections of Monolithic Beams

Oleksandr Kozak[1, a)], Oleksandr Zhuravskyi[2, b)] and Mykhaylo Delyavskyy[3, c)]

[1]*Kyiv National University of Construction and Architecture, Department of reinforced concrete and stone structures, 03680, Povitroflotskyi ave., 31, Kyiv, Ukraine,*
[2]*Kyiv National University of Construction and Architecture, Department of reinforced concrete and stone structures, 03680, Povitroflotskyi ave., 31, Kyiv, Ukraine*
[3]*University of Technology and Life Sciences, Faculty of Civil Engineering, Architecture and Environmental Engineering, ul. prof. S. Kaliskiego 7, 85-768 Bydgoszcz*

[a)]Corresponding author: 130788kozak@gmail.com,
[b)]azhur@ua.fm,
[c)]delyavmv@utp.edu.pl

Abstract. The results of experimental research of the strength of inclined sections of monolithic frames and continuous beams with pre-tensioned (without adhesion to the concrete) curved reinforcement steel with post-tensioning are presented in the article.

INTRODUCTION

Today stress-strain state of inclined sections with post-tensioning is still under-researched. The lack of uniform methods of calculation that would take into account all the factors that affect the performance of cross-sections of reinforced concrete elements under simultaneous action of bending moment, transverse and longitudinal forces confirms this fact.

Tensioned reinforcement steel (both with and without adhesion to the concrete) is the least researched factor, the effect of which on the strength of inclined sections in various governing documents is treated differently.

The initial tension on precast or monolithic (hardened) concrete can be carried out both with the adhesion of the pre-tensioned reinforcement steel to the concrete and without it. The difference of the technology of post-tensioning from the well-known technology of pre-tensioning (carried out under the conditions of concrete products plant), is that tensioned reinforcement steel is tensioned after concreting and gaining by the concrete of enough transmission strength (approximately 70-80% of the nominal strength). To make the tension of reinforcement steel after hardening of the concrete possible, it must have the ability to move freely in the concrete. For this purpose tensioned reinforcement steel is placed into the channels (made of metal or plastic pipes). De-tensioning is performed by using installed anchor devices at the ends of the elements. As a rule, reinforcement steel ropes are used for pre-tensioning, they are pluggable in the designs according to the shape of the bending moment diagrams (the line of main tension forcing). When the ropes are tensioned, there appears the concrete compression tension (from the tension force P, Fig. 1) and discharging effort in the form of a reaction pressure q_{p1} and q_{p2}, which changes its direction on the length between the supports in continuous structures (Fig.1).

Reinforcement steel tension without adhesion to the concrete is widely used in Europe and the USA for the construction of solid floor of civil and residential buildings, parking lots, ware houses and other. The use of curved reinforcement provides increased resistance to shear, punching shear and torsion, and also, due to the discharging effect (reaction pressure) it results in less deflection and disclosure (or even averting) of cracks.

Scientific Session on Applied Mechanics X
AIP Conf. Proc. 2077, 020027-1–020027-7; https://doi.org/10.1063/1.5091888
Published by AIP Publishing. 978-0-7354-1805-9/$30.00

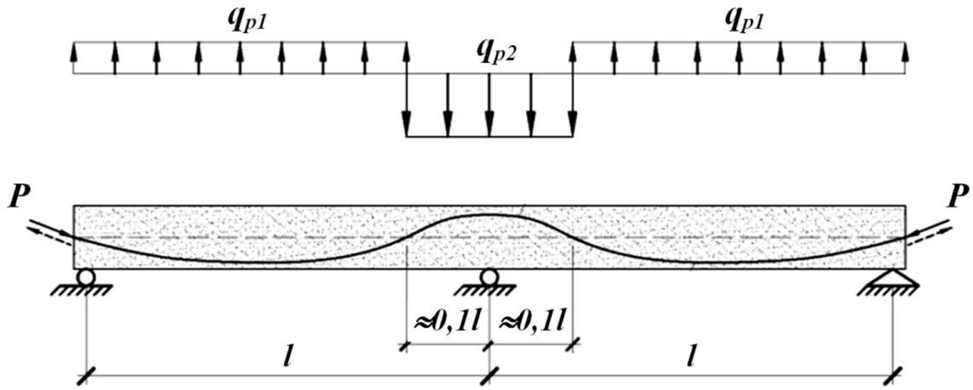

FIGURE 1. The influence of the curved tensioned reinforcement steel on continuous designs.

According to the Ukrainian governing documents DBN C.2.6-98:2009 [1], DSTU B C.2.6-156:2010 [2], DSTU -N EN 1992-1-1:2010 [3] (harmonized with international and European standards EROCODE-2 [4]), when determining the concrete shear resistance $V_{Rd.c}$ (1) the component of the mean stress σ_{cp} from the compression of the concrete cross-section by the strength of reinforcement steel tension is taken into account

$$V_{Rd.c} = \left[C_{Rd.c}k(100\rho_1 f_{ck})^{1/3} + k_1\sigma_{cp}\right]\cdot k_1 \cdot d \tag{1}$$

where: $C_{Rd.c}=0,18/\gamma_c$ – strength concrete shear; γ_c – partial factor for concrete;
$k = 1 + \sqrt{\frac{200}{d}} \leq 2,0$; d – effective depth of a cross-section;
$\rho_1 = \frac{A_{sl}}{b_w d} \leq 0,02$ - reinforcement ratio; A_{sl} – is the area of the tensile reinforcement, which extends ≥ ($l_{bd} + d$) beyond the section considered; b_w – is the smallest width of the cross-section in the tensile area;
$k_1=0,15$;
$\sigma_{cp} = \frac{N_{Ed}}{A_c} < 0,2f_{cd}$; N_{Ed} – is the axial force in the cross-section due to loading or prestressing; A_c – is the area of concrete cross section.

For members with vertical shear reinforcement, the shear resistance, $V_{Rd.s}$ is the smaller value of [2]

$$V_{Rd.s} = \frac{A_{sw}}{s} z f_{ywd} \cot\theta, \tag{2}$$

where: A_{sw} – is the cross-sectional area of the shear reinforcement;
s – is the spacing of the stirrups;
f_{ywd} - is the design yield strength of the shear reinforcement;
$z=0,9d$ – is the inner lever arm;
The magnitude of the angle θ is limited. The recommended limits are given in expression $1 \leq \cot\theta \leq 2,5$.

Normative documents do not consider the effect of curvilinear pre-stressed reinforcement and discharge effort (reactive pressure q_p) when calculating the strength of reinforced concrete elements with transverse force.

These circumstances have prompted the need to conduct experimental studies of stress-strain state of the nodes of continuous beams and monolithic frames with tensioned curved reinforcement steel.

The main aim of the experiment is to study the effect of reaction pressure, tension and canting angle of the pre-tensioned reinforcement steel without adhesion to the concrete on the strength and cracking resistance of inclined sections of reinforced concrete elements.

EXPERIMENTAL SAMPLES AND THE RESEARCH PROGRAM

For the experiment three sets of samples of monolithic reinforced concrete intermediate nodes (two pieces in each set) were produced. Geometrical parameters of the samples with the layout of the pre-tensioned reinforcement steel are indicated in Fig.2.

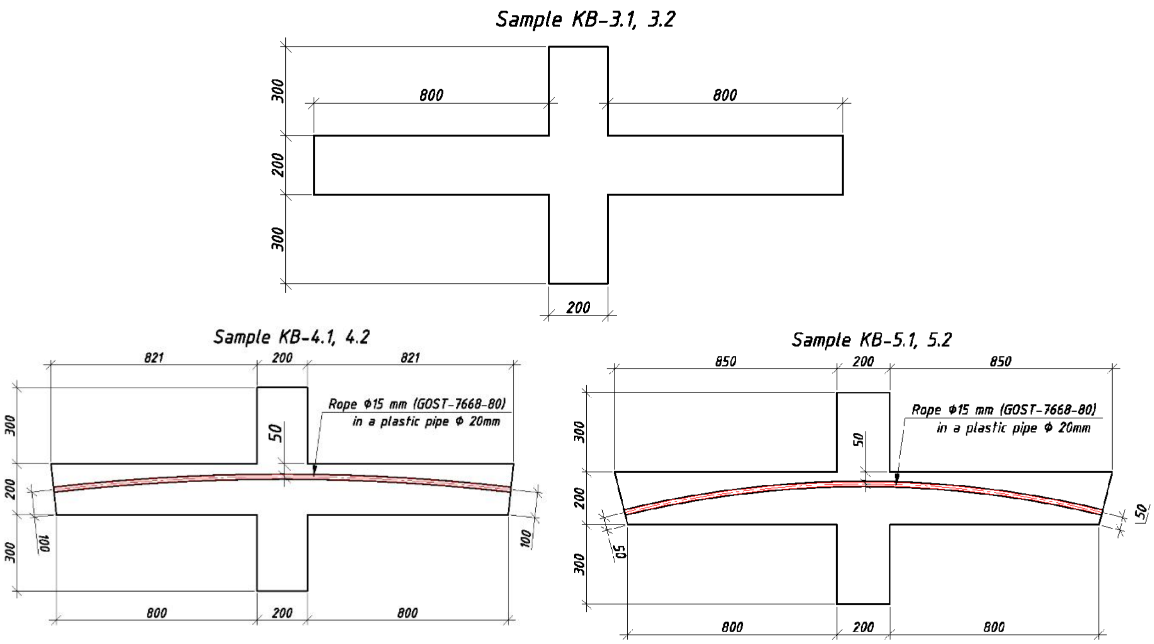

FIG.2. Geometrical parameters (with the placement of pre-tensioned reinforcement steel) of the test samples.

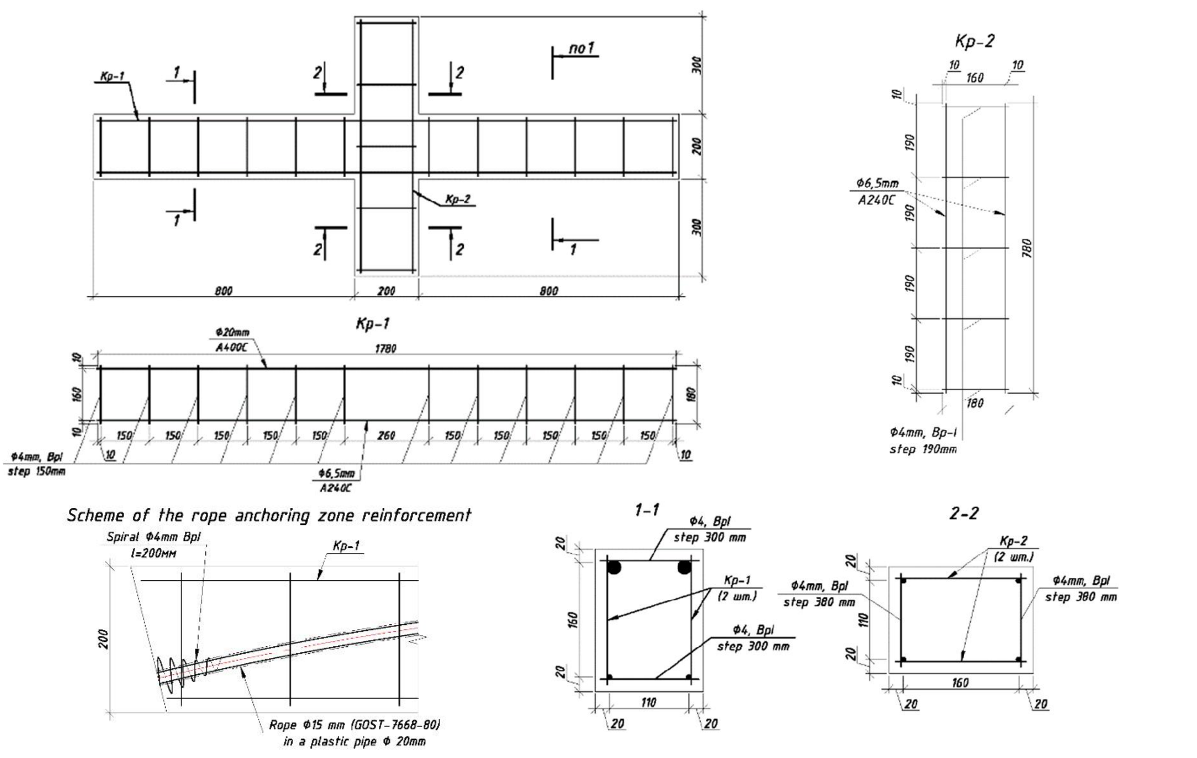

FIGURE 3. The scheme of samples reinforcement with non-tensioned and transverse reinforcement steel.

Reinforcement of all sets of samples with non-tensioned and transverse reinforcement steel is identical (Fig. 3). Spatial frames are formed by two horizontal and two vertical flat frames. All frames are welded and factory fabricated. Ropes Ø15 mm manufactured according to GOST 7668-80 were used as curvilinear pre-tensioned reinforcement steel. The rope was placed into a plastic pipe Ø20 mm, which was plugged before the concreting. Samples of various sets differed as to the canting angle of the ropes.

All sets of experimental samples were factory fabricated from heavy concrete class C25/30. Longitudinal upper (working) reinforcement steel of frames is Ø20 mm (A400C), constructive (bottom) - Ø6 mm (A240C), transverse reinforcement steel is Ø4 mm (Bp-I) with 150 mm spacing.

Experimental studies of reinforced concrete samples were held in two stages:

1) the tension of the curved reinforcement steel before the rated force, which was 63.765 kN (except samples set KB-3);

2) loading of the samples with gradual loading up to their destruction on inclined sections.

During the experiments strains and tension in the compressed and stretched areas, depressions, as well as forcing in the tensioned reinforcement steel were measured. The layout of the measuring equipment is shown in Fig. 4.

Loading on the samples was applied symmetrically on both sides at a distance of 700 mm from the symmetry axis of the sample (Fig.4). The magnitude of the loading range was 3.924 kN (400 kg). Data of the measuring equipment and the development of cracks were recorded at every stage.

The tension on the rope in all the samples sets (except KB-3) was - 63.765 kN (6.5 tons). The tension was provided by a hydraulic jack and during the test it was constantly maintained by it.

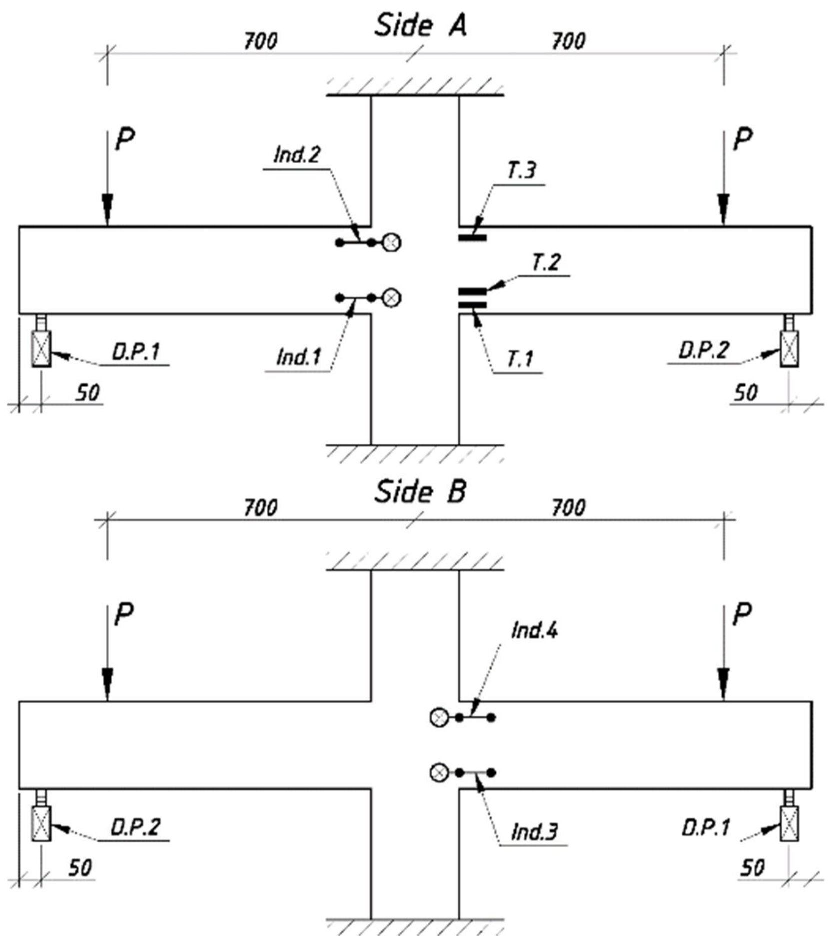

FIGURE 4. The scheme of the measuring equipment layout (Ind.1…4 – dial gauges with a scale division of 0.001 mm, mounted on the base of 50 mm; T1...T3 - resistance strain gages with a base of 50 mm; D. P. 1, 2 - sensor movements).

Testing of all samples was performed up to their destruction with the transverse force. It should be noted that the appearance of the first inclined cracks and destruction of samples of different sets occurred at different stages of loading. The nature of the destruction of samples (according to sets) and the maximum lateral force at fracture are shown in Fig. 5.

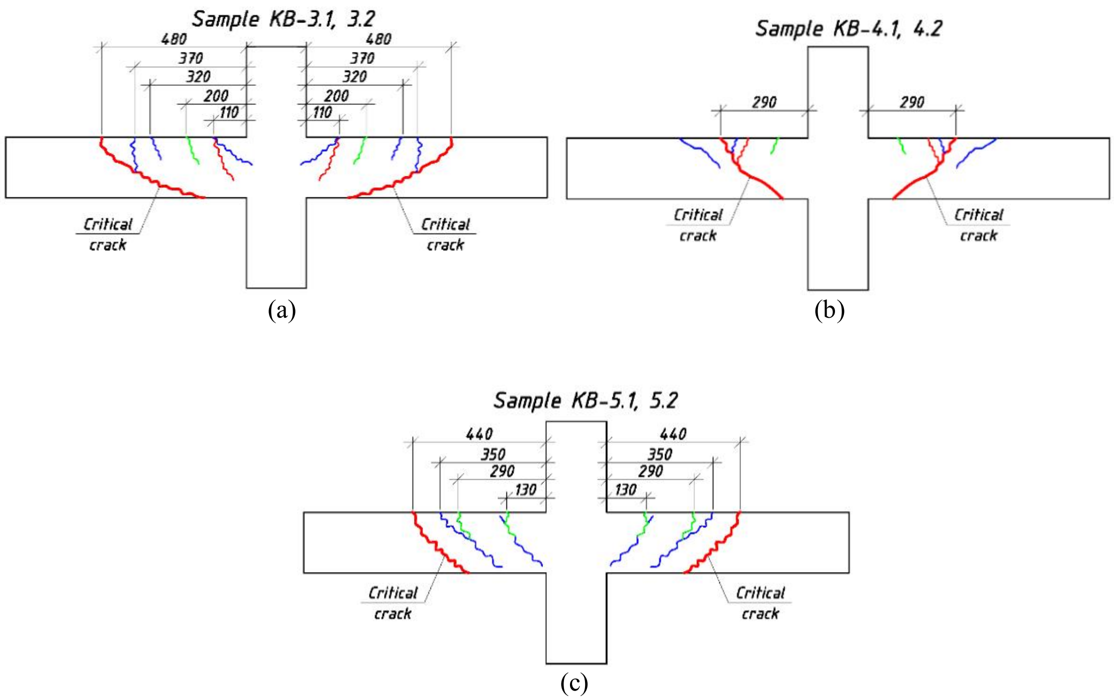

FIGURE 5. The scheme of experimental samples destruction.

When testing the set of samples KB-3, on the 7th stage of loading (2.8 tons at each jack) we could observe the appearance of the first inclined cracks (key. 1, Fig. 5a) that grew and expanded with each stage and at the loading of 5.6 tons (on each jack) resulted in the destruction of the sample at the critical inclined crack (Fig. 5a), the projection of which on the horizontal axis of the sample is 480 mm (about 2.5 d).

In comparison with the samples of KB-3 set during the testing of the set of samples KB-4, a slightly different situation was observed: the first inclined crack appeared on the 15th stage of loading (6.0 tons on each jack), and on the next stage (6,4 tons) the destruction of the sample at the same crack occurred. The projection of the critical crack on the horizontal axis of the sample is 290 mm (about 1.5 d, Fig.5b).

However, the most interesting pattern was observed when testing samples of KB-5 set. The first inclined crack occurred on the 11th stage of the loading (the projection on the horizontal axis - 130 mm, Fig. 5b) and it continued its development up to the 16th stage. With the loading of 6.8 tons (on each jack) 2 other inclined cracks appeared (projections on the horizontal axis - 350 mm and 440 mm) and they continued their developed at later stages of loading. The destruction of the sample occurred at the loading of 7.6 tons at oblique crack with the projection (on the horizontal axis of the sample) of 440 mm (about 2.5 d, Fig. 5c).

It should be noted that the bearing capacity of different sets of samples significantly differs depending on the availability of curved pre-tensioned reinforcement steel and the angle of its inclination. Also there is difference in formation of cracks: the appearance of cracks in the samples with pre-tension occurred at later stages compared with the samples of KB-3 set.

The graphs of the dependence of the average strain of the concrete from the loading have been constructed for the comparative analysis of deformations in the compressed and stretched zones of the samples concrete (Fig.6 and Fig. 7).

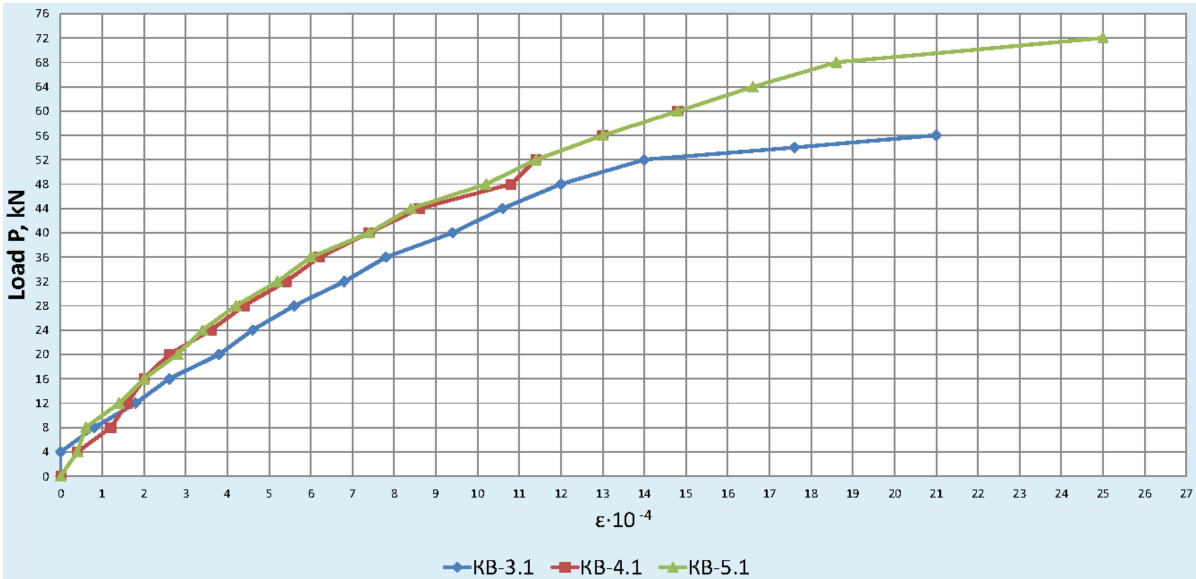

FIGURE 6. Graph of the dependence of the average strain of the concrete from the loading in the compressed zone.

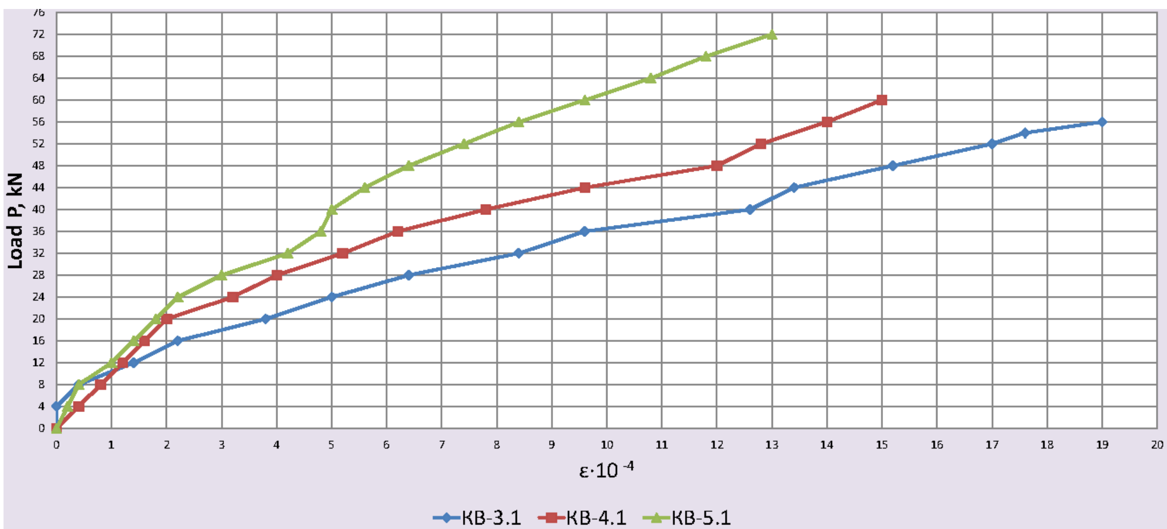

FIGURE 7. Graph of the dependence of the average strain of the concrete from the loading in the stretched zone .

For the comparison of the obtained experimental data of the bearing capacity of inclined sections of the test samples with theoretical ones, its verifying calculation has been made in accordance with the current national governing documents [1, 2].

In determining the total bearing capacity for transverse force, the unloading vertical force V_{dis}, which occurs at the ends of the elements in the anchoring points of the tight fittings, was taken into account. Its value is determined

$$V_{dis} = N_{Ed} \sin \alpha, \quad (3)$$

where: α is the angle of inclination of the prestressed reinforcing bar to the horizontal axis of the element (for samples of the KB-4 series $\alpha=5°$, and for samples of the KB-5 series $\alpha=10°$).

Comparison of the experimental and theoretical bearing capacity is given in table 1.

TABLE 1. Comparison of the experimental and theoretical bearing capacity of the test samples as to transverse force.

Set	Bearing capacity as to transverse force of samples [1, 2, 3]		Unloading vertical force, V_{dis}, kN	Total bearing capacity as to transverse force of samples, V_{Rd}, kN	Experimental bearing capacity (destructive force) $V_{Ed.}$, kN
	Concrete bearing capacity, $V_{Rd.c}$, kN	Transverse reinforcement steel bearing capacity, $V_{Rd.w}$, kN			
KB-3	35,52	15,66	-	51,18	54,936
KB-4	42,76	15,66	5,58	64,00	63,765
KB-5	42,66	15,66	11,11	69,43	74,556

CONCLUSION

The results of experimental studies of the nodes of monolithic continuous beams (frames) confirmed the fact of pre-tension influence (tensioning without adhesion to the concrete) on the strength of the inclined sections and the crack resistance of the reinforced concrete elements, as well as reflected their dependence (bearing capacity as to transverse strength and crack resistance) on the angle of inclination of the curved tensioned reinforcement steel on the concrete (without adhesion to the concrete).

The results of experimental research, that differ significantly from the theoretical ones, calculated according to the current governing documents of our state, proved the necessity of a detailed study and improvement of the methods of the inclined sections strength calculating.

REFERENCES

1. *DBN C.2.6.-98:2009. Designs of buildings and structures. Concrete and reinforced concrete constructions.* Main principles (in Ukraine).
2. *DSTU B C.2.6.-156:2010. Designs of houses and buildings. Concrete and reinforced concrete constructions from heavy concrete. Design rules.* The ministry of regional development of Ukraine. K:2011 (in Ukraine).
3. *DSTU -N EN 1992-1-1:2010. Design of reinforced concrete structures. Substantive provisions. General design rules.* The ministry of regional development of Ukraine. K:2011 (in Ukraine).
4. *EN 1992-1-1-2004: Eurocode 2: Design of concrete structures.*-Part 1-1: General rules and rules for buildings.
5. O.V. Panchenko, Ya.L. Ivanitsky, P.S. Kun and O.D. Zhuravsky, *Determination of durability of reinforced concrete bridge beams reinforced with composite strips* // Physical-chemical mechanics of materials: International scientific and technical journal. -Lviv, FMI them G.V.Karpenko, National Academy of Sciences of Ukraine, Volume 53, No. 5, 2017, p.73-77 (in Ukraine).
6. O. Kozak, and O.Zhuravskyi, *Experimental research of the influence of curved reinforcement steel without adhesion to the concrete on the bearing capacity of inclined sections at post-tensioning* // USEFUL (SCIENTIFIC JOURNAL, 2018 - #2).
7. V.A. Bazhenov and O.P. Krivenko, *Application of techniques for predicting elastic properties of the composite material in the finite element model of the shell with inhomogeneous structure* // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2017. – Issue 98. – P.3-15. (in Ukraine).
8. V.Z. Klimenko, *Strength of materials in the calculation of building structures* // Strength of Materials and Theory of Structures: Scientific-and-technical collected articles – Kyiv: KNUBA, 2017. – Issue 98. – P. 43-55. (in Ukraine).