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Stress-strain state of the precast monolithic bent element

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Abstract. The features of the stress-strain state of a precast monolithic bent element (beam) arising as a result of its phased installation and loading are considered and experimentally investigated. At the first stage, the load is perceived only by the precast part of the beam made of heavy concrete, and at the second stage, monolithic lightweight concrete (expanded clay concrete) is included in the process of deformation and perception of the external load. There were two factors that served as motivation for these experimental studies: − Real precast monolithic structure, mounted on the construction site, in the absence of special structural measures (temporary mounting racks, brackets, etc.) is included in the deformation process in stages, first being the prefabricated part, followed by the monolithic one. This point is in no way reflected in the regulatory documents for design; − Insufficient study of the influence of the phased installation on the stress-strain state of the precast monolithic bent element leads to a biased assessment of its performance. Experimental studies of the stress-strain state of the precast monolithic bent element are performed, taking into account the installation process and the stepwise inclusion of the precast and then monolithic parts in the deformation process. At that, the precast part is made of heavy concrete, and monolithic-of light concrete (expanded clay concrete). The influence of the following factors on the stress-strain state of precast monolithic structures is investigated and studied: the value of pre-loading of the precast part at the first stage; the stages of installation and loading; the height of the monolithic part of the concrete. As a result of conducted research, the new data concerning features of formation of the stress-strain state of the precast monolithic element are received. The positive influence of phase loading and higher height of the monolithic part on the stress-strain state of the precast monolithic structure is revealed. In this case, the insignificant influence of the value of pre-loading of the precast part is determined.

1. Introduction

Ever increasing interest of builders [1–4] has caused the need for a more detailed study of the issues related to the features of the formation of the stress-strain state of precast-monolithic bent elements. Engineers and scientists conduct various studies aimed at identifying the degree of influence of various aspects on the deformation process of composite structures, including structures made of precast-monolithic concrete. For example, in [5, 6] various studies of individual junctions of hollow core slabs with precast-monolithic beams are carried out, as well as the peculiarities of the deformation of junctions of precast beams with columns are studied. As a result, a number of design drawbacks have been revealed that require technical improvements in the structural systems of prefabricated monolithic buildings used in modern construction practice. In [8, 9, 18, 19] the research devoted to studying of joints of plates with beams and beams with columns has also been carried out.

The results of experimental study of the research of precast-monolithic and monolithic slabs are studied in [7]. The data on the bearing capacity, deformability and crack resistance of the slabs are obtained, and the analysis of their stress-strain state is performed.

In addition, one should mention the contributions devoted to the study of individual structural elements, allowing a qualitative assessment of their design features. In [3, 10, 11, 25] experimental studies of precast-

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monolithic slabs are carried out, and in some publications the issue of deformation of multilayer structures [12] is considered, including the issues of deformation of structures with external sheet reinforcement [13, 14] or separate types of impact [15–17].

In [20, 21, 24] the issues of structural reliability of building frames on the whole are shown, with the identification of deformation features of precast-monolithic structures taking into account the stages of their construction.

Along with consideration of questions of constructive reliability both of buildings from precast-monolithic reinforced concrete, and separate constructive elements, questions of feature of technology of their construction are actively considered [22, 23].

Despite the increasing experience of precast-monolithic housing construction and the increasing volume of research materials on this type of construction system, the authors of the article have identified two factors that, in our opinion, are insufficiently studied and require additional research. In particular, a more extensive study of the structural features of the stress-strain state of bent precast-monolithic structures is required, taking into account that:

− The real precast-monolithic structure, mounted on the construction site, in the absence of special structural measures (temporary mounting racks, brackets, etc.) will be included in the deformation process in stages, first the prefabricated part, and then the monolithic one;

− Insufficient study of the influence of the phased installation on the stress-strain state of the precast-monolithic bent element leads to a biased assessment of its performance.

It is these two factors that have prompted the authors of this article to perform experimental studies of the stress-strain state (the subject of research) of precast-monolithic gradually erected and loaded bent elements (the object of research).

The aim of conducted experimental studies is to study the features of forming the stress-strain state of the precast-monolithic bent element, taking into account its phased installation and loading.

2. *Methods*

In order to conduct experimental studies, 6 different series (B1...B6) of samples of hinged beams were manufactured and tested (Fig. 1).

The experimental models were carried out in 2 stages:

− 1st stage. At the plant of reinforced concrete products, precast parts of prototypes made of heavy concrete class B25 with 1700×80×80 (h) mm dimensions were manufactured and reinforced: longitudinal reinforcement-1Ø10A240; transverse reinforcement in the support zone-Ø4B500 with a step of 50 mm in the support zone; transverse reinforcement in the central zone was missing (Fig. 1,*a*,*b*);

− 2nd stage. In laboratory conditions, the precast parts were concreted with light concrete (structural expanded clay concrete of class B12. 5). The height of the grouted part was 60 mm in the samples of series B1...B3, B5 and 100 mm in the samples of series B4 and B6, i.e. the total dimensions of the precast-monolithic experimental samples were 1,700×80×140 (h) mm and 1,700×80×180 (h), respectively ((Fig. 1,*a*,*c*).

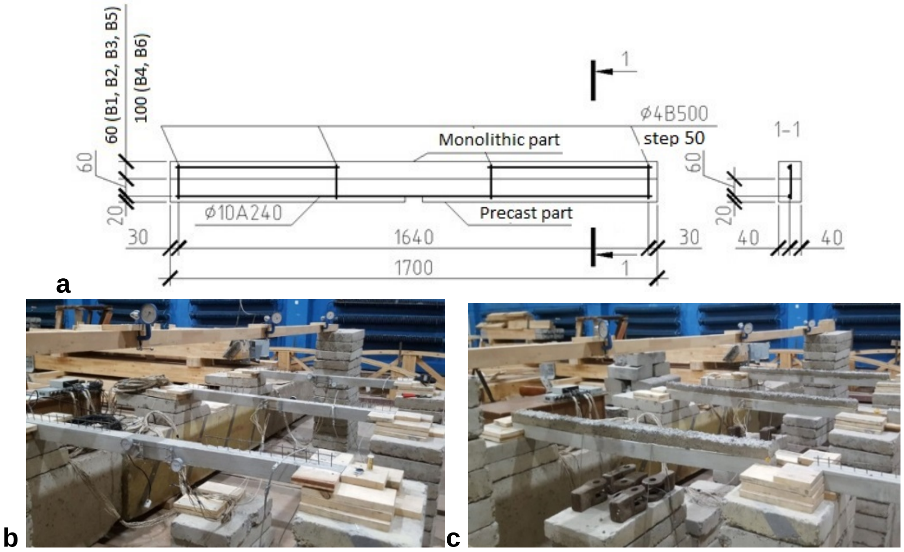

Figure 1. Experimental samples: *a* – drawing; *b* – precast parts (photo); *c* – precast-monolithic samples (photo).

In total, 15 samples were produced and tested: 3 samples in series B1...B3 and 2 samples in series B4...B6.

Series B1...B3 structurally did not differ from each other, the difference between them being in the value of the preload applied to the precast part, which was: B1 – P = 0.83 kN; B2 – P = 1.18 kN; B3 – P = 1.56 kN. The purpose of testing samples of series B1...B3 is to identify the influence of the preload value on the stress-strain state of the precast-monolithic bending element.

The B4 series differed from the B2 series samples in the height of the monolithic part, which was 100 mm. The value of the load previously applied to the precast part was P = 1.18 kN (similar to B2 series samples). The purpose of testing B4 series samples and subsequent comparison with the results of testing B2 series samples is to identify the influence of the height of the monolithic part on the stress-strain state of the precast − monolithic bent element.

Series B5 and B6 are structurally similar to the samples of series B2 and B4, respectively, but with the difference that the monolithic part was arranged without pre-loading of the precast part. Thus, the samples of the B5 and B6 series were loaded in a ready-assembled monolithic execution. The purpose of testing samples of series B5 and B6 and subsequent comparison with the test results of samples of series B2 and B4, respectively-to identify the impact of the fact of phased installation and loading on the stress-strain state of the precast-monolithic bent element.

The experimental setup (Fig. 2) is provided by 2 concrete blocks on which the single-span beam with its subsequent loading by the concrete and metal blocks suspended on flexible cables hinges leans.

Loading of samples B1...B4 was carried out in 2 stages:

− 1st stage (Fig. 2,*a*). Loading of the precast part with a preliminary load simulating the loading of precast elements with a mounting load in real construction (the own weight of the precast element itself and other elements supported on it, the weight of monolithic concrete);

− 2nd stage (Fig. 2,*b*). After the required strength of monolithic concrete, loading of precast monolithic structure took place by the load, simulating additional mounting load (floor structures weight, partitions, curtain walls) and operational load.

Samples of B5 and B6 series were loaded, being in a ready-precast monolithic version.

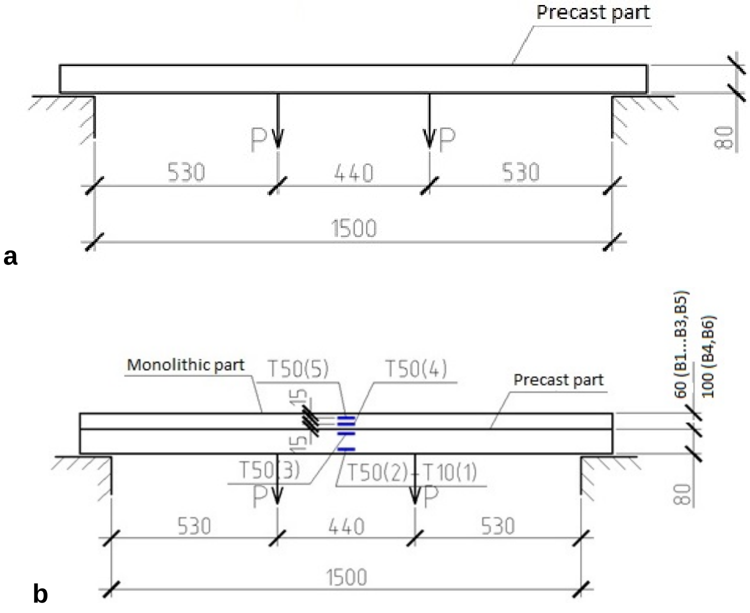

Figure 2. Test scheme:
***a* – 1st loading stage; *b* – 2nd loading stage.**

Strains in concrete and reinforcement were recorded using strain gauges of 10 mm (T10) and 50 mm (T50), respectively. Readings from strain gauges were duplicated (for confirmation) with the help of hour-type indicators (not shown in the Fig.). Deflections were fixed by deflection meters placed in the center of the beam (not shown in the Fig.).

3. Results and Discussion

During the tests, the following points were noted, common to all experimental samples:

− mutual displacement of monolithic and precast parts relative to each other did not happen;

− exhaustion of the bearing capacity of the beams occurred as a result of reaching the flow limit in the longitudinal reinforcement.

The analysis of the obtained deflection values showed the following (Fig. 3):

− at the end of the 2nd stage of loading in the samples of series B1...B3, the greatest deflection is recorded in the sample B3 and, first of all, this difference is caused by the larger value of the deflection accumulated within the 1st stage of loading (in Fig. 3 a red square means the end of the 1st stage of loading). In particular, at load P = 5.1 kN average deflections in samples of series B1 were 8.88 mm, B2-10.17 mm and B3-11.35 mm. At that the difference of deflections after the 1st stage of loading was 4.15 mm between samples of series B1 and B3, and 2.86 mm between samples of series B2 and B3;

− Gradual involvement in the deformation process of precast and monolithic concrete in the result is more profitable than their simultaneous deformation from the first step of loading. This is indicated by the fact that the values of the average deflections at the 2nd stage at a load of P = 4.0 kN in the samples of the B2 series were 8.23 mm, against 9.60 mm in the samples of B5 series. And this is despite the fact that after the 1st stage of loading, i.e. before the inclusion of monolithic concrete in the deformation process, the deflections in B2 series samples are on the contrary greater than the deflections in B5 series samples. Thus, at a certain point in time, the deflections of the simultaneously deformed B5 series samples "overtake" the deflections of B2 series samples gradually involved in the deformation process. Similar results were shown by samples (B4 and B6) with a larger height of the monolithic concrete zone;

− The larger height of the monolithic zone naturally increases the bending stiffness, and at a load of P = 5.1 kN, the average deflection of samples of B2 series was 10.17 mm, and in samples of B4 series – 6.18 mm. A similar pattern is observed in samples with one-stage loading, where the average deflection at a load of P = 3.71 kN in B5 was 8.30 mm, and in B6 – 4.39 mm.

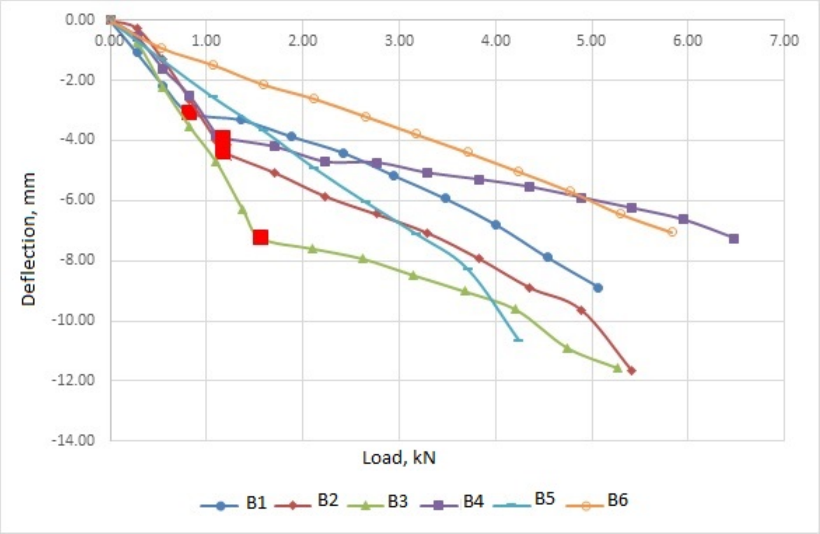

Figure 3. Graphs of averaged deflection values of experimental samples.

In phased loaded samples of series B1...B4 in the middle of the beam span at the 1st stage of loading normal cracks were formed at a load of P = 0.55...0.83 kN. By the end of the first loading stage in all samples recorded cracks had a height of 30...50 mm and a width of disclosure of not more than 0.1 mm.

Within the 2nd stage of loading in samples of series B1...B3 (height of monolithic concrete 60 mm) cracks were formed and developed only in the precast part without transition to monolithic one. In the samples of series B4 (height of in-situ concrete 100 mm) with increasing load the crack from precast concrete penetrated into monolithic concrete at a depth of 50 mm.

The formation of cracks in the samples of series B5 and B6 begins at later loads (1.06...1.59 kN in the samples of series B5 and 2.65 kN-B6) due to the greater bending stiffness of the element. As the load increased, the critical crack completely crossed the precast part; however, it did not pass into monolithic concrete, stopping at the border.

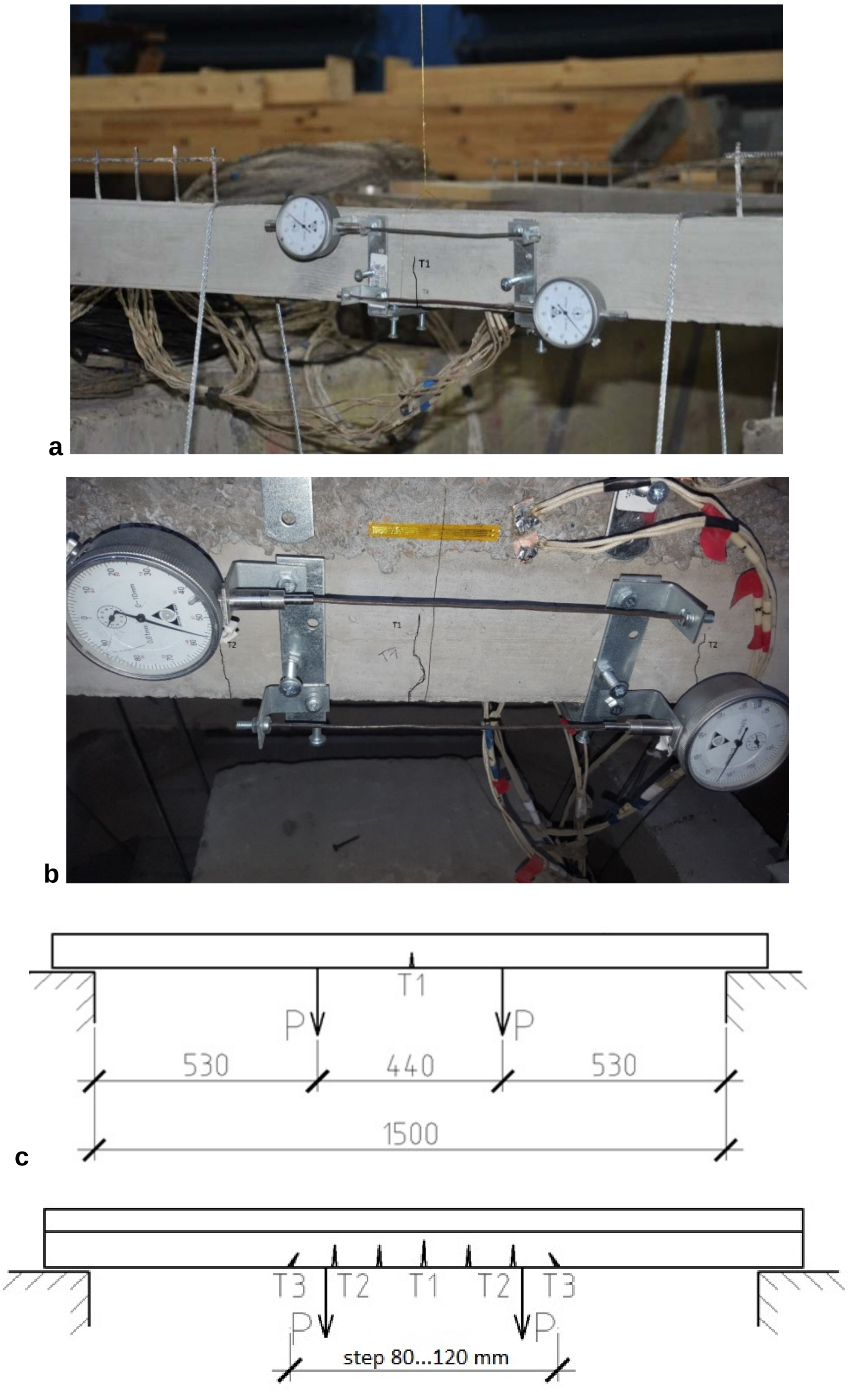

Figure 4. Cracking: *a* – photo of the beam series B1 after the 1st stage of loading; *b* – photo of the beam series B1 at the loading step prior to destruction; *c* – scheme of cracks in samples of series B1...B4 at the 1st stage of loading; *d* – scheme of cracks in samples of series B1...B4 at the 2nd stage of loading.

The analysis of the data obtained by measuring the deformation of the longitudinal reinforcement showed the following (Fig. 5):

− At the end of the 1st stage of loading, the strain of the longitudinal reinforcement was the greater, the higher the value of the applied load. In particular, in the samples of the B1 series, the average strains were 0.000616, B2 – 0.000796, B3 – 0.001079. However, at the end of the 2nd stage of loading with the force preceding the destruction (M = 2.7 kN*m), the values of the strains in the same samples were in the range from 0.001728 to 0.001766, i.e. the values were almost equal;

− Phased inclusion of monolithic concrete in the deformation process eventually led to lower values of reinforcement strains than simultaneous deformation of precast and monolithic concrete from the first loading step. In particular, with the force M = 2.1 kN*m, the average value of strains of sample B5 was 0.002212, which is more than the values in the samples of series B2 that are equal to 0.001433. Similar results were obtained in samples of series B4 and B6, where at M = 2.7 kN*m the average values of strains of longitudinal reinforcement of samples were 0.001287 and 0.001247, respectively;

− The greater height of the monolithic zone leads to a decrease in the values of strains in the longitudinal reinforcement. In particular, the value of strains in the samples of series B2 and B4, approximately equal after the 1st stage (0.000796 and 0.000834, respectively), within the deformation at the 2nd stage (after inclusion in the deformation process of monolithic concrete) becomes significantly different (when the force M = 2.7 kN*m 0.001758 and 0.001287, respectively). A similar pattern is observed in the one-stage loading of the structure, where with the force of M = 1.97 kN*m, the average value of strains in the longitudinal reinforcement of samples of B5 series was 0.002141, and in samples of the B6 series – 0.000860;

− The exhaustion of the bearing capacity of the experimental samples occurred as a result of reaching the yield strength in the longitudinal reinforcement as evidenced by the non-stabilizing growth of deformation of the reinforcement and deflections of the beams at the last step of loading. At the same time, there were no visible signs of destruction and limit values of relative compression strains of concrete.

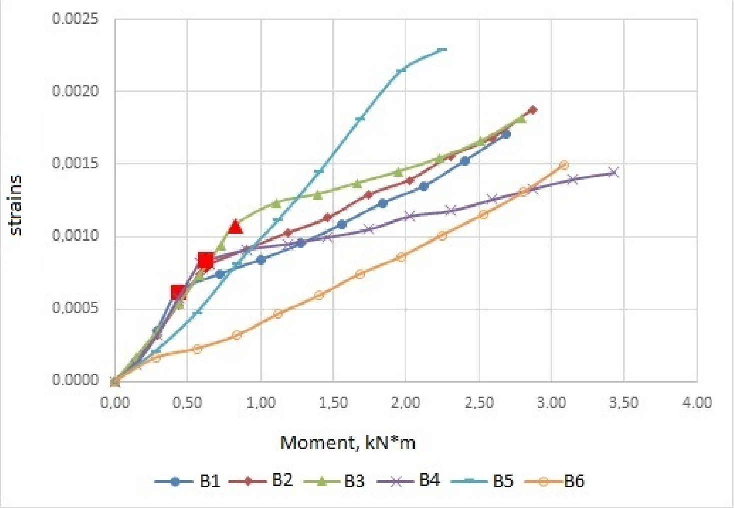

Figure 5. The reinforcement strain average values.

The data obtained from strain gauges located on the concrete are shown in Fig. 6:

− In samples of series B1...B3, an increase in the average strains occurred approximately identically and at the value of the bending moment M = 2.7 kN*m, the compression strains in the samples of series B1 were 0.000499, B2-0.000525 and B3-0.000598. At the same time, within the bending moment equal to 2.5 kN*m, there is a minimal difference in the values of strains;

− A rise in the height of the monolithic zone increases, in turn, the bending stiffness of the transverse section. As a result, the value of compression strains of monolithic concrete is significantly reduced. In particular, at the value of the bending moment force M = 2.7 kN*m, the average strains in the samples of B2 series were 0.000525, and in the samples of the B4 series – 0.000389. Similarly, the samples of series B5 and B6 behave in the same way, where the deformation under the force preceding the destruction amounted to 0.000605 and 0.000265, respectively;

− limiting compressive strains in monolithic and precast concrete have not been achieved.

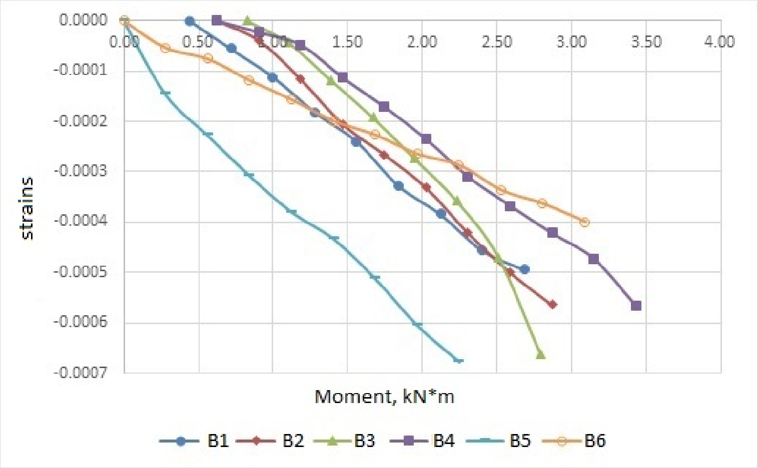

Figure 6. The average values of the monolithic concrete upper part strain.

Tensile strains of precast concrete in the phased loaded samples of series B1...B4 reach the limit values during the 1st stage of loading at the load range of P = 0.55...0.83 kN. Approximately at the same values the formation of cracks occurs in the precast parts.

At the 1st stage of loading in the upper zone of the precast part in the samples of series B1...B4 there arise compression strains not exceeding 0.0007. After a set of the required strength by monolithic concrete and subsequent loading of the structure within the 2nd stage, an increase in compression strains stops and in almost all samples, the value of the strain that occurred earlier even decreases. In the samples of series B5 and B6 strains in the upper zone of precast concrete had, as a rule, insignificant tensile values.

The average value of the bending moment at which the load-bearing capacity was exhausted in the samples of different series is shown in Fig. 7. The analysis of the bearing capacity has shown the following:

− The amount of pre-loading of the precast part did not significantly affect the bearing capacity of the precast-monolithic element. The range of the maximum bending moment perceived by the samples of series B1...B3 was 3.00...3.06 kN * m;

− Separation of the deformation process of the precast-monolithic bent element into 2 stages allows to increase the load-bearing capacity. In particular, the average carrying capacity of the B2 series samples was 3.00 kN*m, and in the B5 series samples – 2.53 kN*m. The same situation is with the samples of the B4 and B6 series, where the values were 3.99 kN*m and 3.37 kN*m, respectively;

− The height of the monolithic concrete significantly affects the load-bearing capacity of the precast-monolithic structure. The average carrying capacity of samples with a monolithic part height of 100 mm was higher than that of the samples with a monolithic part height of 60 mm (B4 – 3.99 kN*m vs. B2 – 3.00 kN*m, and B5 – 2.53 kN*m vs. B6 – 3.37 kN*m).

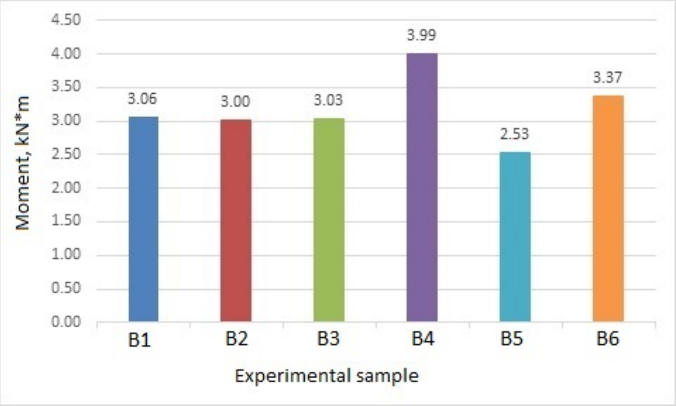

Figure 7. Diagram of the experimental sample carrying capacity averaged values.

The results obtained in the course of experimental studies are quite well correlated with the data defined in other scientific contributions. In particular, the character of stress and strain distribution during the gradual phased involvement of precast and monolithic concrete in the deformation process shown in numerical studies [21] has been confirmed in this experimental research. In addition, similar results are shown in [25], which also confirmed the high shear stiffness of the joint of different-aged concretes performed with transverse reinforcement.

4. Conclusions

On the basis of the conducted research the following conclusions are made:

1. The phased involvement of precast and monolithic concrete in the deformation process significantly changes the picture of stress-strain of precast-monolithic bent element, which makes it mandatory to take this fact into account in design.

2. The value of the pre-loading of the precast part does not significantly affect the subsequent stress-strain state and bearing capacity of the precast-monolithic structure.

3. The gradual inclusion of monolithic concrete in the deformation process has a positive effect on the bearing capacity and the nature of the stress-strain state of the precast monolithic element as a whole, in comparison with the single-staged manufactured and loaded elements. There was a decrease in deflections up to 14 %, a decrease in the strain of longitudinal reinforcement up to 20 % and an increase in the bearing capacity up to 18 %.

4. An increase in the height of monolithic concrete leads to a decrease in deflections up to 40 %, a decrease in the value of strains in concrete and reinforcement and an increase in load-bearing capacity up to 33 %.

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