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A deformed state of the composite frame with phased installation

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Abstract. Experimental studies have been carried out to investigate the features of a composite flat frame deformation that arise in the process of its gradual installation and loading. During the first stage only precast elements (columns and beam precast parts) are assembled, which are further loaded with some weight that simulates its own weight in a real structure, the weight of other precast elements and that of monolithic concrete. Thus, at the first stage of existence the load is perceived only by the precast elements of the flat frame. Subsequently, at the second stage, without removing the previously applied load, the monolithic concrete is laid, which, having gained the required strength is included in the deformation process, taking an additional applied load that simulates the weight of floor structures, partitions, curtain walls and operational load. The motivations for conducting experimental research were as follows: the carcass of a composite building (is simulated by a flat double two-story frame in the experiment) in real conditions is built in stages, which is expressed in serial installation of individual components. These design features lead not only to the inclusion of separate parts of composite elements in the deformation process at different times, but also to a significant change in the design scheme as a whole (the formation of continuous beams and floor slabs, an appearance of a rigid junction of beams with columns, an increase in the degree of static indefinability of the system, and so on). Experimental studies of the stress-strain state of composite flat frames were performed, taking into account the phased installation process and changes in the design scheme. Precast parts of experimental flat frames (columns, beam precast parts) are made of heavy concrete, and monolithic beam parts – of light concrete (expanded- clay concrete). The conducted research allows us to state that the phased installation and involvement in the deformation process of both individual elements of the composite carcass and the constituent parts of the elements significantly change the picture of the carcass deformation.

1. Introduction

Prefabricated-monolithic housing construction is actively developing, which is reflected not only in the increase of volume of this type of construction [1–4], but in the interest of scientists in this structural system. Various scientific (theoretical, numerical, and experimental) studies of various aspects that affect the stress-strain state of individual composite elements, as well as buildings and structures in general, have been carried out. For this reason, a composite carcass was taken to be the subject of research.

For example, the authors of some contributions [5–7] have conducted research on the influence of various design features, as well as the stages of construction on the process of deformation and structural reliability of composite structures.

Of interest is work [8], where experimental studies of composite and monolithic overlappings were conducted with data on load-bearing capacity, deformability and crack resistance. At that, the estimation of

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the stress-strain state was performed. The authors of some publications [1, 9–11] have also conducted a number of experimental studies of composite slabs.

In addition to considering the issues of stress-strain state, reliability and other parameters related directly to structures, scientists and engineers are also interested in the features of the technology of construction of composite structures [12, 13].

The contributions are worth noting that address the issues of load-bearing capacity, deformability and crack resistance of not only buildings and their elements as a whole, also paying attention to the reliability of individual components of the junction elements. For example, the authors of this work have previously conducted research [14], devoted to the study of the features of deformation of the junction nodes of hollow floor slabs with composite beams. In addition, the features of deformation of the junction nodes of composite beams with columns are considered. The data obtained in the course of the research made it possible to identify a number of design flaws that indicate the need for technical improvements in a number of structural systems used in modern construction of prefabricated monolithic buildings. The works of a number of other authors [15–18] are also devoted to research on the study of slab junction nodes with columns.

In addition to the above mentioned studies, various scientists and engineers have considered the problems of deformation of multilayer structures [19], including the issues of deformation of structures with external sheet reinforcement [20, 21], as well as other types of impact [22–24].

Having reviewed the current experience of prefabricated housing construction and studied the research carried out, the authors of this work concluded that a more extensive study of the stress-strain state of the building composite carcasses is required, taking into account the phased installation of both the carcass as a whole and its individual structural elements (slabs, floor beams), where, for example, the precast part is first installed, and then the monolithic one. These design features lead not only to the inclusion of individual parts of composite elements in the deformation process at different times, but also to a significant change in the design scheme as a whole (the formation of non-cut beams and floor slabs, the appearance of a rigid junction of beams with columns, an increase in the degree of static indefinability of the system, and so on).

A rather weak study of the effect of phased installation and loading, both of individual structures and of the building as a whole, on the stress-strain state of the composite carcass leads to an incorrect assessment of its performance.

These circumstances served as a reason for performing experimental studies of the stress-strain state (the subject of study) of composite gradually erected and loaded flat frame carcasses (the object of the study).

The purpose of conducted experimental studies was to study the features of formation of the stress-strain state of a composite flat frame, taking into account its phased installation and loading.

To achieve the goal, the following tasks were determined: development of the method for experimental study of the flat carcass of the composite frame taking into account the phased installation and loading, experimental tests, and analysis of received data.

2. Methods

To perform experimental studies, two flat frames R1 and R2 completely identical to each other, both in terms of design and loading were manufactured and tested.

Experimental models were produced and simultaneously loaded in two stages (Fig. 1):

1. stage 1:

– at the plant of reinforced concrete products precast parts of the frames of heavy concrete class of B25 type were manufactured: 70×70×1.200(h) mm two-storey columns, reinforced with four longitudinal Ø8A400bars and transversal Ø4B500 reinforcement with a 50 mm step; 70×70(h)×1.410 mm beam composite parts, strengthened by lower longitudinal 3Ø3B500 and the shear Ø3B500 reinforcement with a step of 100 mm in 2 rows;

– installation of precast elements of two flat two-storey two-span frames, located opposite each other at a distance of 2.0 m. The overall dimensions of each frame are as follows: 2 spans; 2 floors; a span of 1.500 mm; a floor height of 600 mm. At this stage, the flat frame is a geometrically unchangeable statically indeterminate system with the following boundary conditions: rigid pinching of the columns with the base; hinge coupling of the beam (precast part) with the column;

– loading with a preload that simulates the loading of precast elements with an assembly load in a real structure (the actual weight of the precast element itself and other elements supported on it, as well as the weight of monolithic concrete). The concentrated load was applied by hanging concrete blocks on flexible cables (average weight 0.55 kN). Loading of each beam occurred in 2 steps – 1 block for each step. Thus, at the end of the 1st stage of loading, the load was P = 0.55 kN.

2. stage 2:

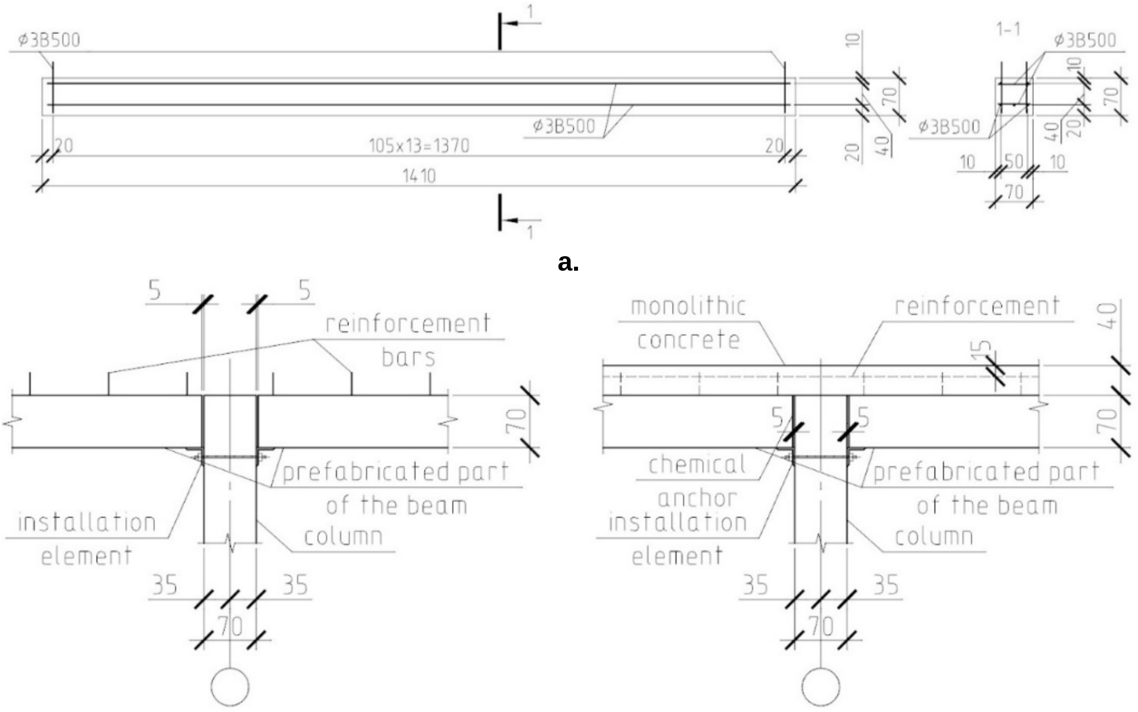
– without removing the pre-load applied during the 1st stage, longitudinal reinforcement was installed in the support zone of the beams and monolithic lightweight concrete was laid (structural expanded-clay concrete of class B12.5). The height of the concreted part of the beams was 40 mm, and the total height of composite beams of flat frames R1 and R2 was 110 mm;

– after a set of solid concrete required strength, the flat frame is a geometrically immutable, statically indefinable system (with a greater degree of indefinability than at the 1st stage) with the following boundary conditions: rigid pinching of the column with the base and the beam with the column;

– after the required strength was set with monolithic concrete, the composite structure was loaded with an additional load that simulates the installation load, such as the weight of floor structures, partitions, curtain walls, etc., and operational loading. To do this, wooden beams were installed between the frames, on which concrete loading blocks were placed. At the same time, the location of the beams was such that the load application within the 2nd stage occurred in exactly the same places as the load application at the 1st stage. Each loading step increased the load P by 0.275 kN.

During the 2nd stage of loading, the maximum force P was: lower – tier beams – 1.65 kN; upper-tier beams – 2.2 kN and 1.925 kN for the right and left spans, respectively.

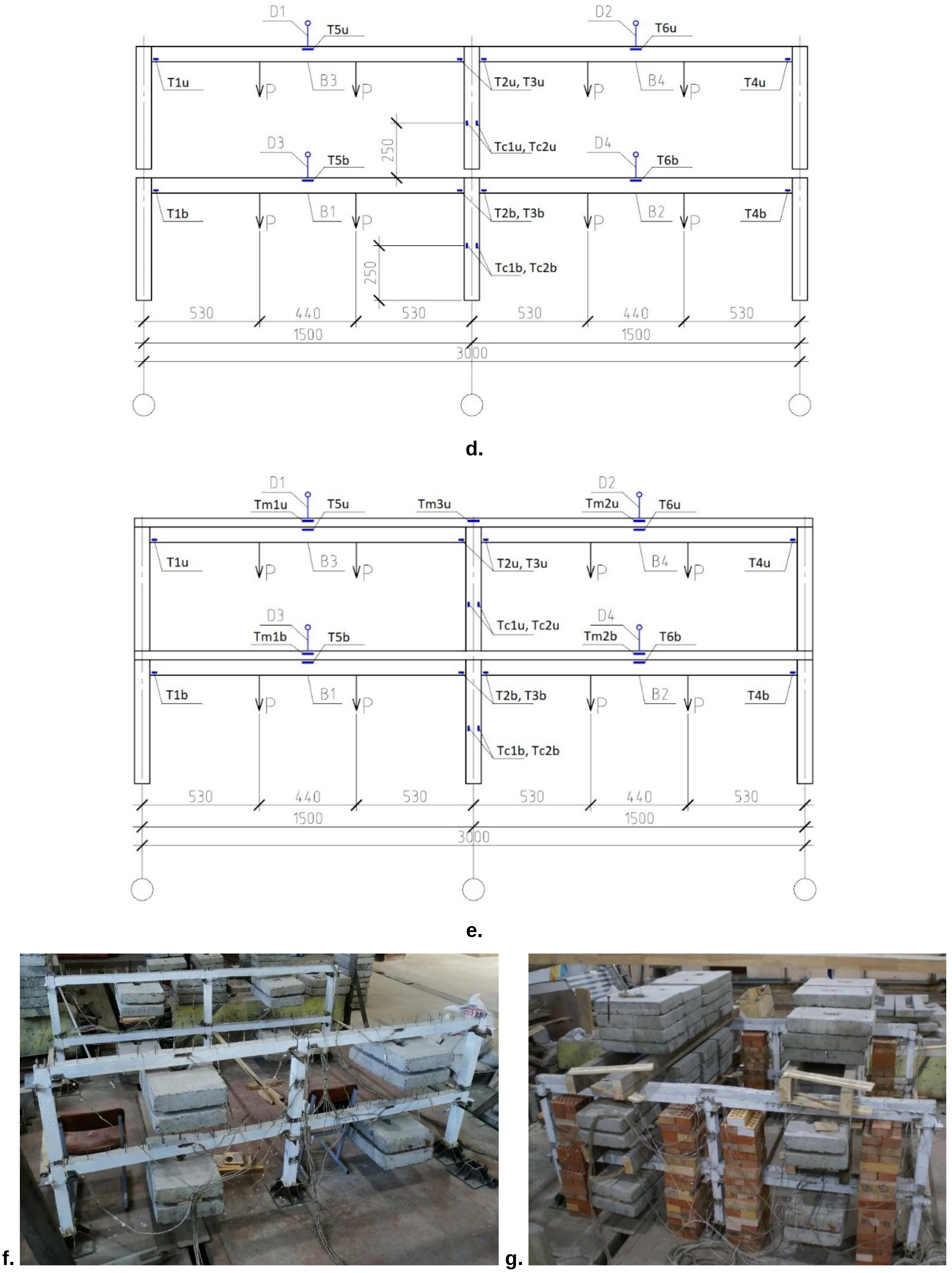
The following order of loading the beams at the 2nd stage was observed: B2, B1, B4 and B3.



a.

b.

c.



d.

e.

f.

g.

Figure 1. Experimental frame: a – the scheme of reinforcement of the combined part of the beams; b – the junction of the crossbar with the column at the 1st stage; c – the junction of the crossbar with the column at the 2nd stage; d – design diagram at the 1st stage; e – design diagram at the 2nd stage; f – frames photo at the 1st stage; g – frames photo at the 2nd stage.

Concrete deformations were recorded by strain gauges with a base of 20, 50 and 60 mm. The bends were fixed by deflectors placed in the center of the beams.

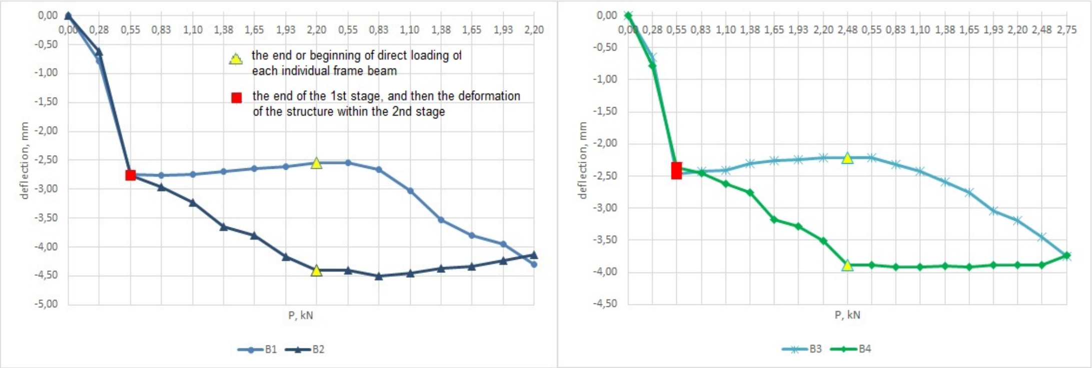
3. Results and Discussion

The analysis of the results of the conducted experimental studies has shown:

- the lack of mutual displacement of the monolithic and precast parts relative to each other, i.e., compatibility of deformation of the monolithic and precast parts was ensured by friction forces at the contact surfaces of the concrete and dowel effect evenly spaced across the length of the beam shear reinforcement;
- the process of deformation of all frames and individual frame elements looks logical, which results in a uniform increase in deflections of beams and deformations of concrete (precast and monolithic) during the entire loading period. Moreover, after a set of monolithic concrete of the required strength, the intensity of the increase in deflections and deformations slows down;
- the formation of the first cracks in the beams of frames R1 and R2 occurred during the 1st stage of loading;
- there was no exhaustion of the load-bearing capacity in any element of the frame. This is evidenced by the absence of visible signs of destruction of compressed concrete, and not reaching the maximum compression deformations in concrete. In addition, the experiment did not record an intensive and non-stabilizing increase in deflections during loading.

The detailed analysis of deflections (Fig. 2) has shown the following:

- there is a different intensity of the increase in deflections at each stage of loading. At the 1st stage, when only the precast part is included in the deformation process, an increase in deflections occurs more intensively than at stage 2, when monolithic concrete has already been included in the deformation process;
- during loading at the 2nd stage, the deflection of the directly loaded beams increases, while the beams in the adjacent span, due to the continuity of the monolithic concrete, experience bending deformations, which is associated with the continuity of the composite beam;
- at the 1st stage, the deflections of the beams in the frames R1 and R2 were in the range of 0.63...0.78 mm when loading P = 0.28 kN and 2.47... 2.77 mm when loading P = 0.55 kN;
- at the 2nd stage, the deflections in the initially loaded beams B2 and B4 were 4.40 mm and 3.89 mm, respectively. After the end of direct loading of beams B2 and B4, and the beginning of loading of adjacent beams B1 and B3, the deflections in beams B2 and B4 decreased slightly, amounting to 4.14 mm and 3.73 mm, respectively, at the last step;
- in beams B1 and B3, on the contrary, at first there is a decrease in the deflection value as the adjacent beams are loaded, but later, from the moment of their direct loading, the deflections were 4.30 mm and 3.75 mm, respectively.



a **b**

Figure 2. Frame beam deflection graph: a – beams B1, B2; b – beams B3, B4.

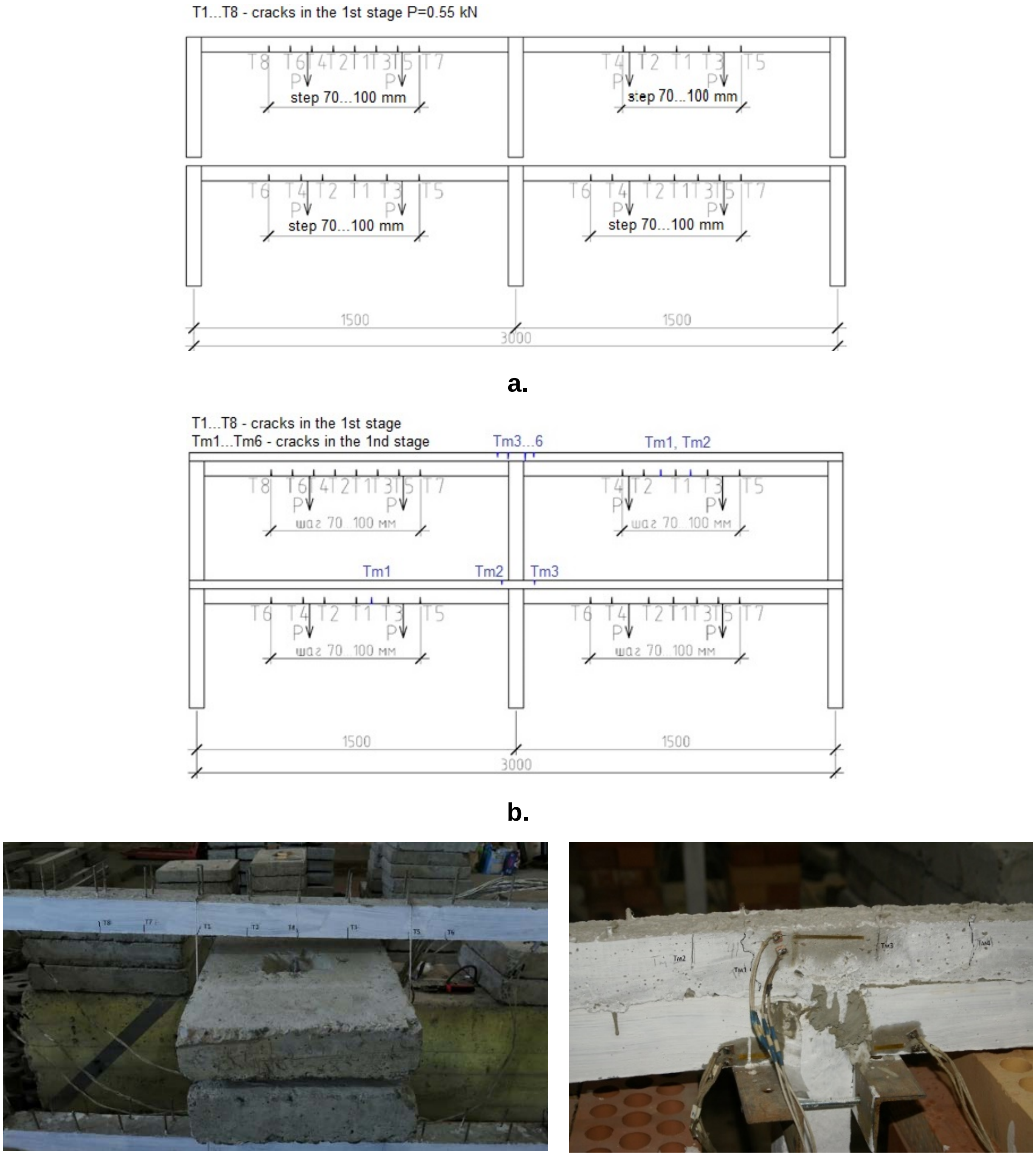
On the graph of the increase in deflections (Fig. 2) a large red square indicates the end of the 1st stage, and then the deformation of the structure within the 2nd stage. The yellow triangle indicates the end or beginning of direct loading of each individual frame beam.

The formation of cracks was recorded in the middle of the span of the precast parts of the beams at the 1st stage of loading (Fig. 3,a), i.e. during the deformation of only the precast part at a load of P = 0.55 kN. The hair cracks formed at the 1st stage had a spreading height of about 20...30 mm, and the width of the opening did not exceed 0.05 mm. The step of the crack arrangement was 70...100 mm.

During the 2nd stage of loading, the opening width of previously formed cracks (Fig. 3,b) was increased without a significant increase in their height. In this case, the cracks of the precast part in the span did not reach the monolithic concrete.

In monolithic concrete, cracks were formed at a load of P = 1.93 kN or more above the middle support. At the same time, some of the cracks on the support at the end of loading of the 2nd stage crossed completely the monolithic part of the concrete, but did not spread to the precast part.

Cracks were not fixed in the columns and beams on the extreme supports, and there were no horizontal cracks, including the seam of the concrete junction.



a.

b.

c.

d.

Figure 3. Crack formation diagram: a – stage 1; b – stage 2; c – prefabricated part at the 1st stage; d – monolithic concrete at the 2nd stage.

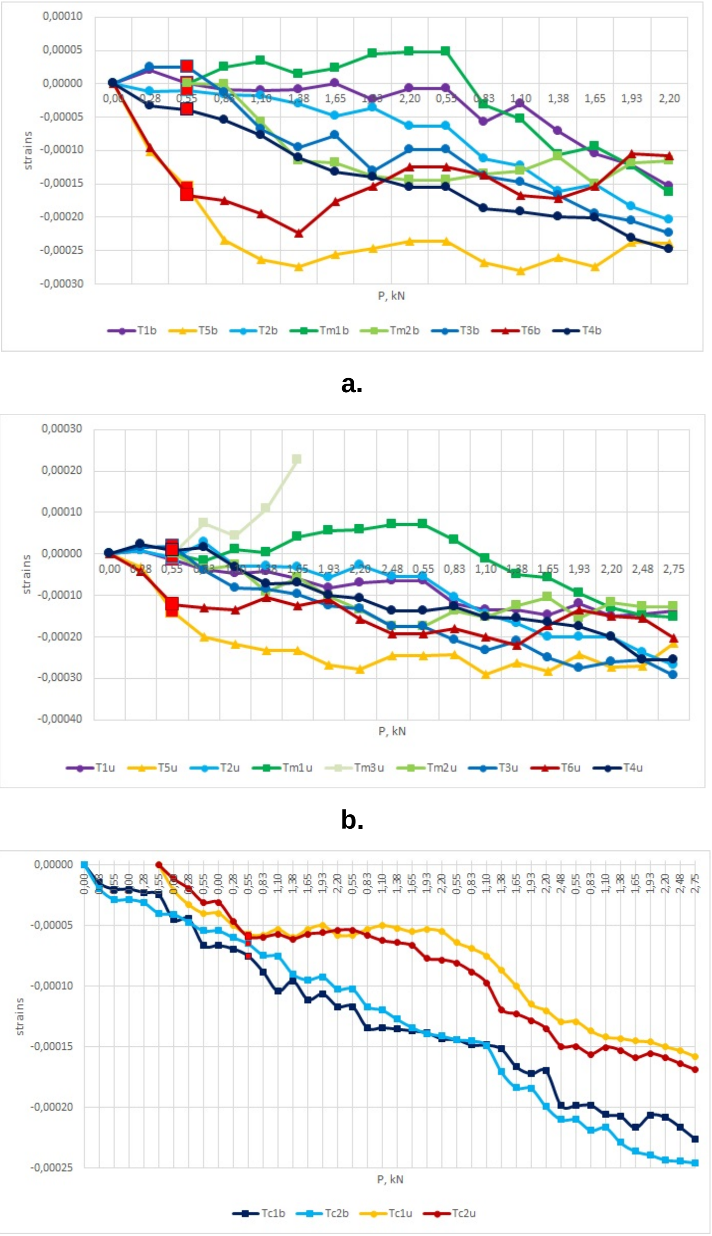
The character of deformation of the beams of experimental frames R1 and R2 is as follows:

- at the 1st stage of loading, the precast parts of the frame beams are deformed as a flexed hinge-supported single-span beam with the appearance of tensile deformations in the lower and compression deformations in the upper zones. Relative compression deformations in the upper zone of the beam precast part in the middle of the span at the end of the 1st stage of loading were 0.000121...0.000168;
- at the 2nd stage of loading, the intensity of growth of compression deformations in the upper zone of the beam precast part in the middle of the span significantly decreases, and in a number of beams, even a decrease in their value was noted. In particular, the lower level beams showed both an increase in compression, deformations from 0.000156 to 0.000239 (left beam) and a decrease from 0.000168 to 0.000108 (right beam). At the same time, on the upper beams, the relative compression deformations of the upper zones of the precast parts only increased from a value of 0.000121 to 0.000203 for the left beam and from 0.000139 to 0.000215 for the right one. Deformations in the lower zone of the beam precast part on the

supports also began to increase, reaching values near the edge column of 0.000154...0.000248, and near the middle column – 0.000204...0.000255;

– the phased loading of the continuous beam at the 2nd stage (after the required strength is set by the monolithic concrete) affects the character of deformation of the monolithic part. In the first loaded beam, compression deformations increase in the monolithic concrete in the middle of the span to values of 0.000145...0.000175. At the same time, tensile deformations occur in the adjacent unloaded beam (values 0.000048...0.000071) in monolithic concrete, which is explained by the bending of the unloaded span. Later, after loading all the beams, final deformations in the monolithic concrete were 0.000115...0.000163;

– monolithic concrete on the support undergoes tensile deformations that reach the maximum values when the load value is more than 1.38 kN. At about the same time, cracks were recorded.



a.

b.

c.

Figure 4. Graphs of relative deformations of precast and monolithic concrete elements of R1 and R2 frames: a – beams of the lower tier; b – beams of the upper tier; c – columns.

In the presented graphs (Fig. 4) relative deformations of the composite concrete, a large red square indicates the end of the 1st stage and further deformation of the structure within the 2nd stage.

Deformation of columns of R1 and R2 frames occurred logically. The lower columns began to be deformed from the first loading step, experiencing compressive deformations that reached values of 0.000065...0.000075 at the end of the 1st loading step. Columns of the upper tier are included in the deformation process after loading the upper tier beams and their deformations reached 0.000057...0.000059 at the end of the 1st stage of loading.

During the 2nd stage of deformation, the columns of the lower tier experience uniform compression. The value of relative deformations was 0.000226...0.000245. In the columns of the upper tier, the relative deformations were 0.000158...0.000169.

The results obtained in the course of experimental studies were compared with the data of other scientific papers and a good convergence was obtained. In particular, the nature of the distribution of deformations in the cross section of the composite element coincides with the data obtained during experimental studies of the hinge-supported beam [25]. In addition, similar results were obtained in [21], where numerical studies of a two-story double span frame were carried out with the phased involvement of composite concrete in the deformation process. Studies carried out in [24] have shown that it is possible to provide high shear stiffness of the joint of different-age concretes by installing transverse reinforcement.

4. Conclusions

Based on the research, the following conclusions are made:

1. Phased involvement of precast and then monolithic concrete in the deformation process significantly changes the picture of the stress-strain state of both the individual composite bent element and the structural system as a whole;

2. The corresponding reinforcement of monolithic concrete on the supports of the composite beam leads to the "transformation" of a series of single-span beams to a single multi-span continuous beam, increase in the rigidity of the beam-column interface nodes, and changes in the design scheme as a whole;

3. Uneven loading of composite beams leads to bending of unloaded beams with the appearance of tensile forces in the middle of the span of the upper zone.

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