doi: 10.18720/MCE.84.16

Compatibility of precast heavy and monolithic lightweight concretes deforming

Совместность деформирования сборного тяжёлого и монолитного лёгкого бетонов

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Key words: reinforced concrete structures; precast and monolithic structures; lightweight concrete; connection of monolithic and precast concrete; keyed connection of concretes; shear strength

Ключевые слова: железобетонные конструкции; сборно-монолитные конструкции; лёгкий бетон; сопряжение монолитного и сборного бетонов; шпоночное сопряжение бетонов; сопротивление на сдвиг

Abstract. Safe performance of connecting joint applied to different concrete ages is highly important when joints is placed in composite structures since joint is involved in mutual deformation of precast and monolithic concretes. This experimental study was carried out to determine how type of joint influence on it bearing capacity when perceiving shearing forces. The tests were carried out on a specially manufactured horizontal bench and a vertical press, which provided a shear force in the samples of different ages and with different concrete strength (light monolithic and heavy precast concretes). The following options of the joint were considered: a smooth surface, where the connection is done only by the forces of adhesion and friction; a joint with keys, the spacing of which varied; and a joint with the use of cross reinforcement. This paper determines nuances of the load-bearing capacity exhaustion in a composite structure at shear depending on the type of joint of lightweight monolithic and heavy precast concrete. A comparative analysis of the results obtained in the experimental studies and the data of previous studies has been carried out. The highest bearing capacity under shearing loads was determined in the joint with the cross reinforcement. Moreover, it was noted that keyed connection of concretes let guarantee sufficiently safe performance of connection.

Аннотация. Надёжная работа шва сопряжения бетонов разного возраста наиболее важна, когда он расположен в сборно-монолитных конструкциях, поскольку шов обеспечивает совместное деформирование сборного и монолитного бетонов. С целью изучения влияния вида шва сопряжения на его несущую способность при восприятии сдвигающих усилий авторами проведены экспериментальные исследования. Исследования были выполнены на специально изготовленном горизонтальном стенде и вертикальном прессе, которые обеспечивали создание сдвигающего усилия в образцах с разновозрастными и разно прочными бетонами (лёгкий монолитный и тяжёлый сборный). Были рассмотрены следующие варианты устройства шва сопряжения: гладкая поверхность, где сопряжение обеспечивается только за счёт сил адгезии и трения; шов сопряжения выполняемый со шпонками, шаг которых варьировался; сопряжение, выполняемое с использованием поперечной арматуры. Определены нюансы характера исчерпания несущей способности сборно-монолитной конструкции при сдвиге в зависимости от вида шва сопряжения лёгкого монолитного и тяжёлого сборного стержня. Проведён сопоставительный анализ полученных при экспериментальных исследованиях результатов с данными ранее выполненных исследований. Наибольшую несущую способность на восприятие сдвигающего усилия показал шов сопряжения,

усиленный поперечной арматурой. Вместе с тем, шпоночное сопряжение также позволяет обеспечить достаточную надёжность сопряжения.

1. Introduction

At present, precast and monolithic building is becoming more and more popular, which is manifested by a significant increase in a specific share of this type of construction against the background of the total mass of erected buildings. Such a phenomenon is quite logical and expected because the precast-monolithic frame of a building is deemed as a more flexible construction system. Indeed, the disadvantages, which are well-known and sometimes are quite a challenge, of separately precast or monolithic building systems can be solved easily enough by erecting buildings and structures made from precast and monolithic reinforced concrete. An intensive growth of popularity of such system inevitably led to the need of developing optimal constructive precast and monolithic frameworks and a simultaneous interest in obtaining new experimental data which take into account all the innovations proposed by modern builders. Many researchers conducted various surveys to study the features of the stress-strain behaviour of precast and monolithic structures, moreover, such studies were carried out either on buildings or fragments of buildings and considered the features of deformation of a building as a whole [1, 10, 11, 21, 23–27], and on its individual structural elements [2–4, 9, 12, 13, 20, 29]. In particular, the authors in [1, 9] carried out experimental studies on full-scale samples of the composite monolithic frame of BelNIIS (Belarusian Scientific and Research Institute for Construction) suggested by the Belarusian builders. Moreover, in [9], they tested a single frame floor member which showed its sufficient reliability. When studying the precast and monolithic structures and the structures reinforced by extending their sections with monolithic concrete, in [2], they took into account the loading background of the precast (or reinforced) part of the structure, which is an important factor for the above structures. The influence of the factor of the sequence of assembling and loading the precast-monolithic structure was analysed in the course of numerical studies in [27], and the performance of the precast-monolithic structure exposed to elevated temperatures was studied by the author of [13]. Besides, engineers and scientists are actively developing more and more efficient building systems of precast and monolithic framed buildings [1, 10, 14–17, 19, 20, 28]. The engineering solutions suggesting using lightweight concrete [18, 27] seem to be interesting, because it enables reducing the mass of the structure significantly, and hence, the constant loads. The authors of this paper also carried out surveys (experimental, numerical) to study the stress-strain behaviour of precast and monolithic structures [5, 6, 27], and in addition, proposed various constructive solutions to improve them [7, 8].

After the performed surveys of structures with a precast and monolithic frame, as well as having studied the practices of this type of construction, we concluded that there are relatively few surveys devoted to joint deformation of precast heavy and monolithic lightweight concretes. At the same time, such combination of concretes is quite promising for arranging floors where a precast part of a slab acts as a form until monolithic concrete develops the necessary strength, and after maturing both the parts jointly begin taking the forces caused by external loads. Based on the above, we conceived the purpose of this research as identifying the features of joint deformation of precast heavy and monolithic lightweight concretes depending on the type of their connection surface.

2. Methods

The models were made and tested in two stages to achieve this stated goal: first, precast parts from the heavy concrete of grade B25 were made, which were then poured with lightweight concrete (constructional LECA concrete of grade B12.5). The final overall dimensions were 300×100×140 (h) mm. The samples were divided into 4 series (P1 ... P6), with 5 pieces of identical samples in each series (Figure 1), according to the constructive design of the joint of precast and monolithic concretes:

– P1 is a smooth surface connection;

– P2 is a surface with two keys (the key has a width of 30 mm, depth 10 mm), which corresponds to 150 mm spacing;

– P3 is a surface with 3 keys (the width of 30 mm, the depth of 10 mm), which corresponds to 100 mm spacing;

– P4 is a connection surface with 2 rows of rebars (Ø6A240), which corresponds to 150 mm spacing;

– P5 is a connection surface with 3 rows of rebars (Ø6A240), 100 mm spacing;

– P6 is a connection surface with 5 rows of rebars (Ø6A240), 50 mm spacing.

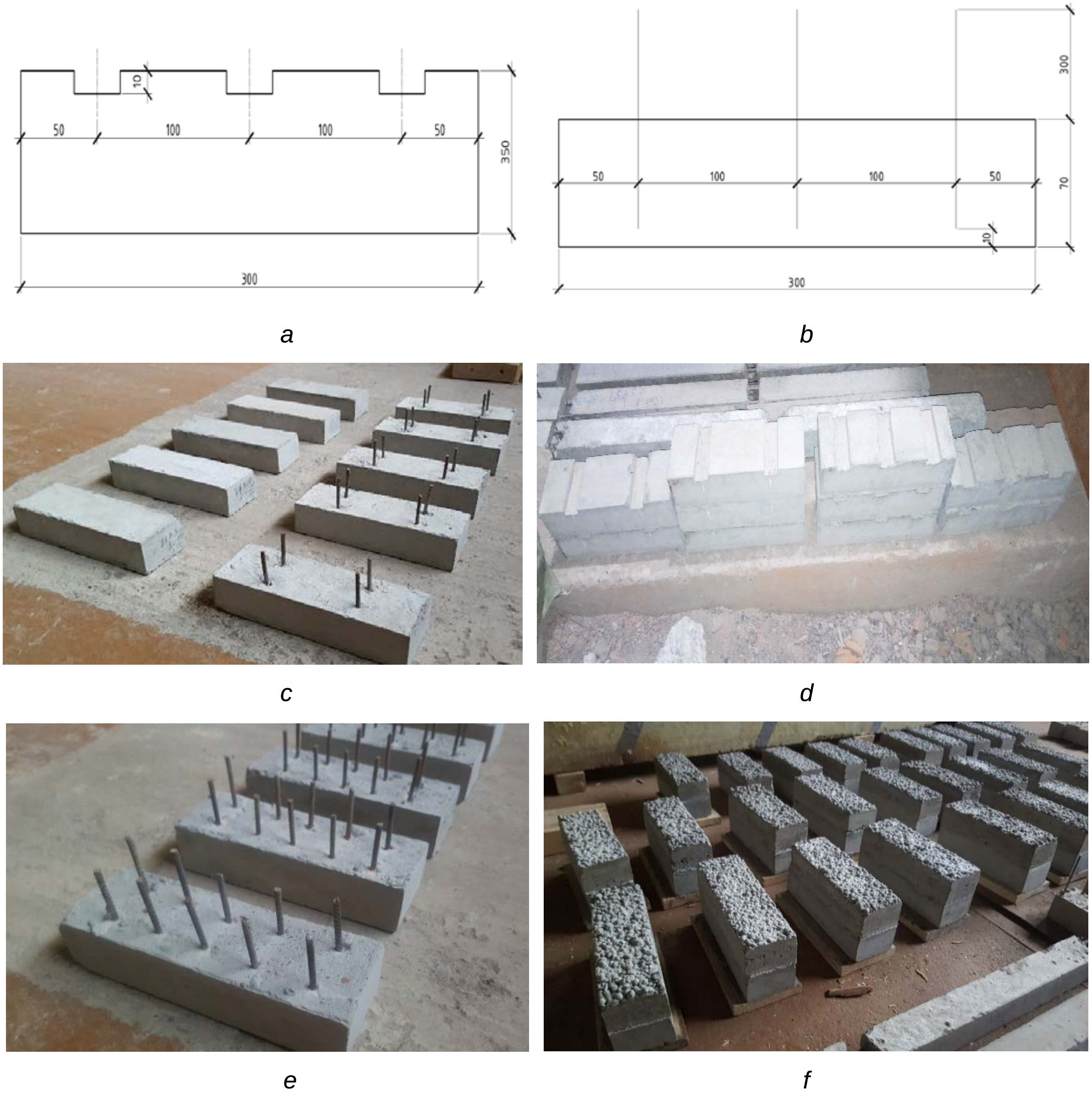
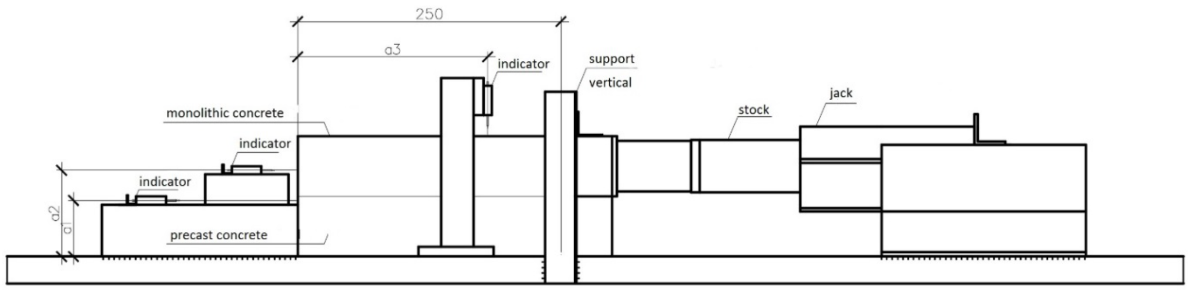


Figure 1. Experimental samples: a, b – drawings of the assembly parts of P3, and P5 samples; c, d – general view of the assembly parts of the samples of P1, P4 and P2, P3 series; e – general view of the assembly parts of the samples of P6 series; f – general view of the ready samples.

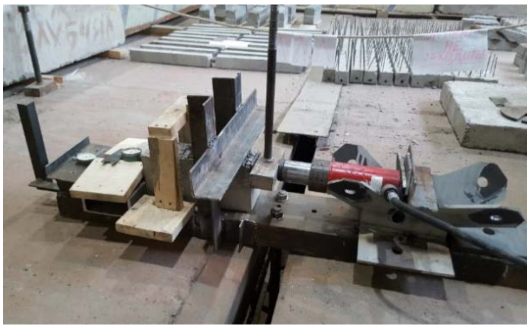
The tests of the samples for P1…P4 were carried out on an experimental bench which enables creating a shearing force of 150 kN (Figure 2), where a precast part laid against a rigid stop of the bench, and the force was applied horizontally to a monolithic section of the sample. Deformations and displacements were recorded by means of horizontally and vertically positioned dial indicators (Dial Indicator 10). The P5 and P6 samples were tested on a powered vertical press (Figure 2).

3. Results and Discussion

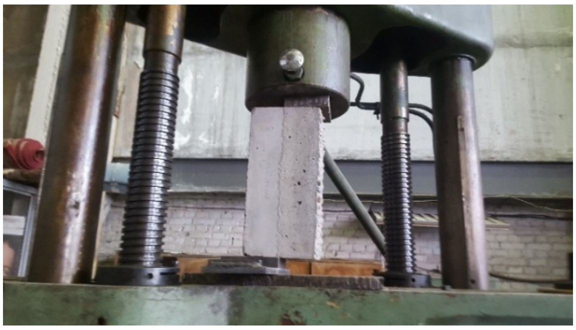
Getting ahead of the detailed analysis, we ascertain that in all the experimental samples there was no mutual move of monolithic and precast concretes observed before the moment of fracturing. Also until this moment, there was no local fracturing of separate sections of precast and monolithic concretes (cracks, crushes, splitting, etc.). At the time of exhaustion of the load-bearing capacity, an abrupt sudden fracturing of the samples occurred without any noticeable increase in deformations at the previous phases. At the same time, the patterns of the samples failure we observed were different and depended on the type of jointing.



a



b



c

Figure 2. Experimental tests: a – a layout of the horizontal experimental bench; b – a photo of the horizontal experimental bench; c – a photo of the powered vertical press.

A more detailed analysis of the research results shows that a uniform pattern of fracturing is observed in the P1 samples, namely, a sudden shear of the monolithic concrete section relatively to the precast one along the smooth joint (Figure 3). However, we did not observe any significant damage to the integrity of individual sections of the samples (at best, we noted splitting of small fragments of precast or monolithic concretes at the time of failure, and partial minor shearing of monolithic concrete). The experimental samples fractured at the following load values: P1-1 – 49.2 kN; P1-2 – 34.5 kN; P1-3 – 29.5 kN; P1-4 – 49.2 kN; P1-5 – 64.0 kN. The average value of the breaking load was 45.28 kN.

a

b

c

d

Figure 3. The photos of fracture of the P1 series samples: *a, b, c, d* – respectively, the photos of the fractured samples P1-1, P1-2, P1-3 and P1-4.

Koyankin, A.A., Mitasov, V.M., Tskhay, T.A. Compatibility of precast heavy and monolithic lightweight concretes deforming. Magazine of Civil Engineering. 2018. 84(8). Pp. 162–172. doi: 10.18720/MCE.84.16.

The fracture patterns which were obtained during the tests of the P1 samples clearly indicate that in the case of using a smooth joint of two concretes of different age, the sections mutually move due to the shear forces exceeding the adhesion and friction forces. Thus, it is absolutely obvious that it is not enough to confine oneself to these forces to ensure a joint deformation, but it is necessary to provide additional technical solutions capable of ensuring a joint load resistance by precast and monolithic concretes.

The fracture pattern is more complex in the samples of P2 series. Due to the use of keys, the joint's load-bearing capacity increased because the existing bearing capacity of the forces of adhesion and friction in the smooth joint was added by the strength of the keyed joint, so there was no clear fracturing along the joint. We observed both exhaustion of the bearing capacity along the smooth part of the joint, a shift in the monolithic part, cutoff of the keys and partial fracture of the individual sections of the P2 series samples. In particular, the pattern of load-bearing capacity exhaustion basically looks as follows: on the part of the element, the shear occurs in the body of the monolithic section (approximately at the level of 0.5 ... 1.0 cm from the joint), while in the smooth joint, a shear along the joint surface or cleavage of precast concrete with cutoff of its keys in the rest of the joint (Figure 4). The ultimate load in the samples of P2 series was: P2-1 – 51.7 kN; P2-2 – 61.5 kN; P2-3 – 71.4 kN; P2-4 – 56.6 kN; P2-5 – 83.7 kN. The average value of the breaking load was 64.98 kN.

a

b

c

d

Figure 4. The fracture photos of the P2 series samples: a, b, c, d – respectively, the photos of the fractured samples P2-2, P2-3, P2-4 and P2-5.

We noted a greater precision of the testing results for the samples with two keys in contrast to the samples with a smooth joint. More specifically, the range of divergence in the ultimate loads is 53.8 % in regard to the maximum value of the force in the P1 samples, while in the P2 samples this divergence amounts to 38.2 %. This signifies that the adhesion and friction factor is scantily predictable, and as a result of the inclusion of a more stable (in terms of providing the shear capacity) technical solution (application of the keys), the specific share of instability reduces, resulting in a greater predictability of the joint performance. In addition, the average ultimate load of the P2 samples exceeded the P1 samples by 43.5 %, which also indicates a significant positive effect of the keys on the bearing capacity of the contact joint.

The testing results for the P3 samples showed that a more dense spacing between the keys makes it possible to significantly increase the load-bearing capacity of the joint of monolithic concrete with precast one. In particular, the ultimate loads ranged from 71.4 kN to 150 kN with an average one of 99.1 kN. At the same time, the load-bearing capacity exhausted due to reaching of the limit of the ultimate compression strength of monolithic lightweight concrete with the joint remained integral (no mutual movement of the samples sections relative to each other was recorded). Thus, it can be summarized that if a certain spacing between the keys is observed, it is possible to secure the required load-bearing capacity, which can guarantee joint deformation of concretes of different age (Figure 5).

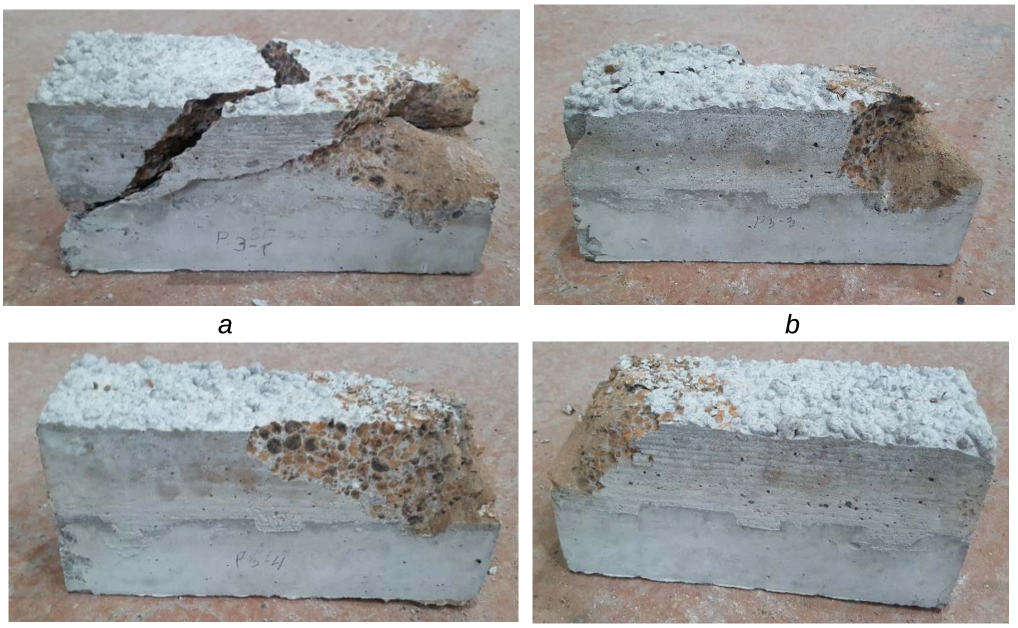


Figure 5. The fracture photos of the P3 series samples: a, b, c, d – respectively, the photos of the fractured samples P3-1, P3-3, P3-4 and P3-5.

Testing the samples with three keys resulted in a precision similar to that of the samples with two keys, which, unlike when using the smooth one, also clearly indicates a more stable joint deformation in the keyed joint. The average ultimate load of P3 samples 2 times exceeded the value of the same load in P1.

The fracture pattern in the P4 samples with transverse reinforcement rebars spaced at intervals of 150 mm is comparable with the general fracturing pattern for the P2 samples, i.e. we see some balancing between the joint's shear strength and compression strength of the materials (precast and monolithic concretes), and, at the same time, there is no clear fracturing along the joint only. However, unlike in P2 series, the P4 samples showed exhaustion of load-bearing capacity resulted from both a shear along the smooth part of the joint and a shear inside the body of the monolithic part with a partial breaking of the separate sections of the samples. Notice that the fracture load here is higher and lies in the range from 81.2 kN to 103.4 kN (Figure 6), with the average of 94.4 kN, which is 2 times higher than the similar value in those samples without any keys and rebars.

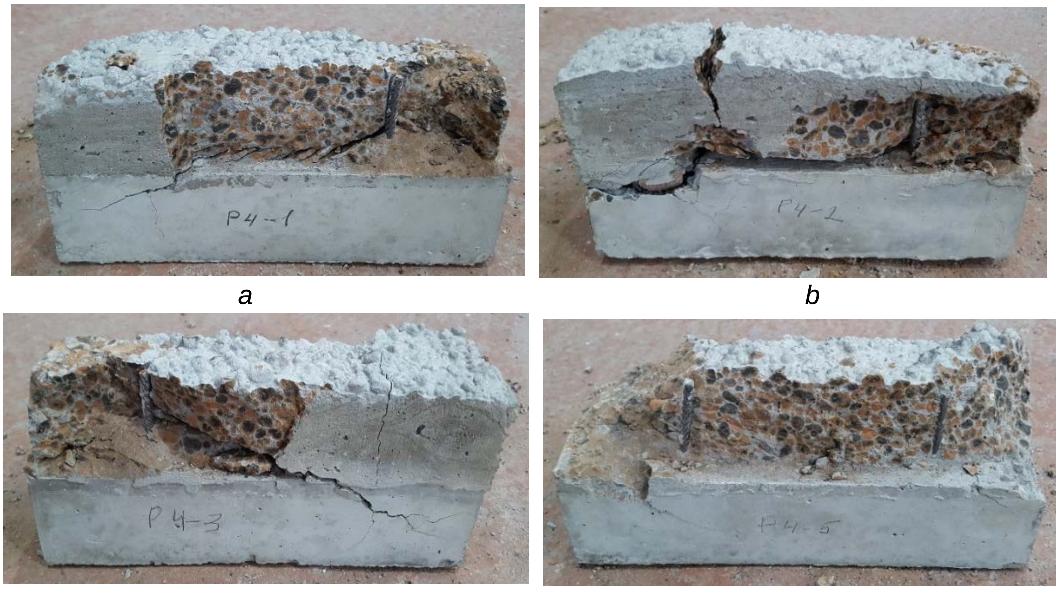


Figure 6. The fracture photos of the P4 series samples: *a, b, c, d* – respectively, the photos of the fractured samples P4-1, P4-2, P4-3 and P4-5.

When testing the samples with two rows of rebars, we noted that the difference between the maximum and minimum results did not exceed 22 %, which manifests a sufficient stability of these results in contrast to the connection at the expense of the adhesion and friction forces, and even compared to the elements where concrete keys were embedded as a reliable joint. It should be pointed out additionally that any noticeable damage (such as rupture, shear or any movements) of the rebars was not detected; we observed only a small incline of the traverse rebars, which is quite natural.

A more dense spacing of the transverse reinforcement bars in the P5 and P6 series samples allowed ensuring the compatibility of deformation of monolithic light and precast heavy concretes, which is manifested in their destruction pattern, precisely, the destruction of monolithic concrete as a compressed element from transverse stretching strains. It should be noted additionally that if previously in the P1 ... P4 samples, we occasionally observed a boundary state in the fracture pattern between the destruction of monolithic concrete and the mutual displacement of parts, but in case of the P5 and P6 samples, a clear picture of their fracture due to exhaustion of the carrying compression capacity of monolithic light (less durable) concrete.

At the same time, we noted an increase in the carrying capacity of samples with transverse reinforcement (series P4 ... P6) on resisting the compression load as the number of rebars increase in the reinforcement, which drove us to the conclusion that traverse reinforcement had a positive effect on the strength of the compressed concrete. This is explained by the fact that the reinforcement bars, located across the compressive load applied, act as an indirect reinforcement and quite effectively perceive the transverse stretching strains occurring in the compressed concrete.

The bearing capacity of the P5 samples was exhausted within the range of loads from 112.5 kN to 128.0 kN (124.6 kN average) due to the fracturing of monolithic concrete; at the same time, there were no significant signs of fracturing, except for small local chips in the precast part (Figure 7). The transverse reinforcement bars slightly deflected. We observe a significant 3-fold exceedance of the average ultimate fracturing value over the samples of P1 series.

a

b

c

d

Figure 7. The fracture photos of the P5 series samples: a, b, c, d – respectively, the photos of the fractured samples P5-1, P5-2, P5-3 and P5-4.

When testing the samples with three rows of rebars, the discrepancy between the maximum and minimum results did not exceed 12%, which indicated the stability of the results compared to the P1 ... P4 samples.

The most typical fracture patterns are in Figure 8.

The carrying capacity of the P6 samples was generally greater than that of the P5 samples, which is, actually, expected, keeping in mind the earlier conclusion about the positive effect of the transverse reinforcement (confinement reinforcement) on the strength of the compressed concrete. The critical load ranged from 178.5 kN to 196 kN. In such case, as it was previously noted, the fracturing occurred due to achieving the ultimate compression strength of monolithic light (less strong) concrete. In four samples of the P6 series, precast concrete retained its integrity, regardless of minor chips, but in one sample, simultaneous fracture of both monolithic and precast concrete occurred. The traverse reinforcement rebars got bare as a result of the fracture of monolithic concrete and slightly inclined, and the rebars that remained in the body of monolithic concrete remained intact.

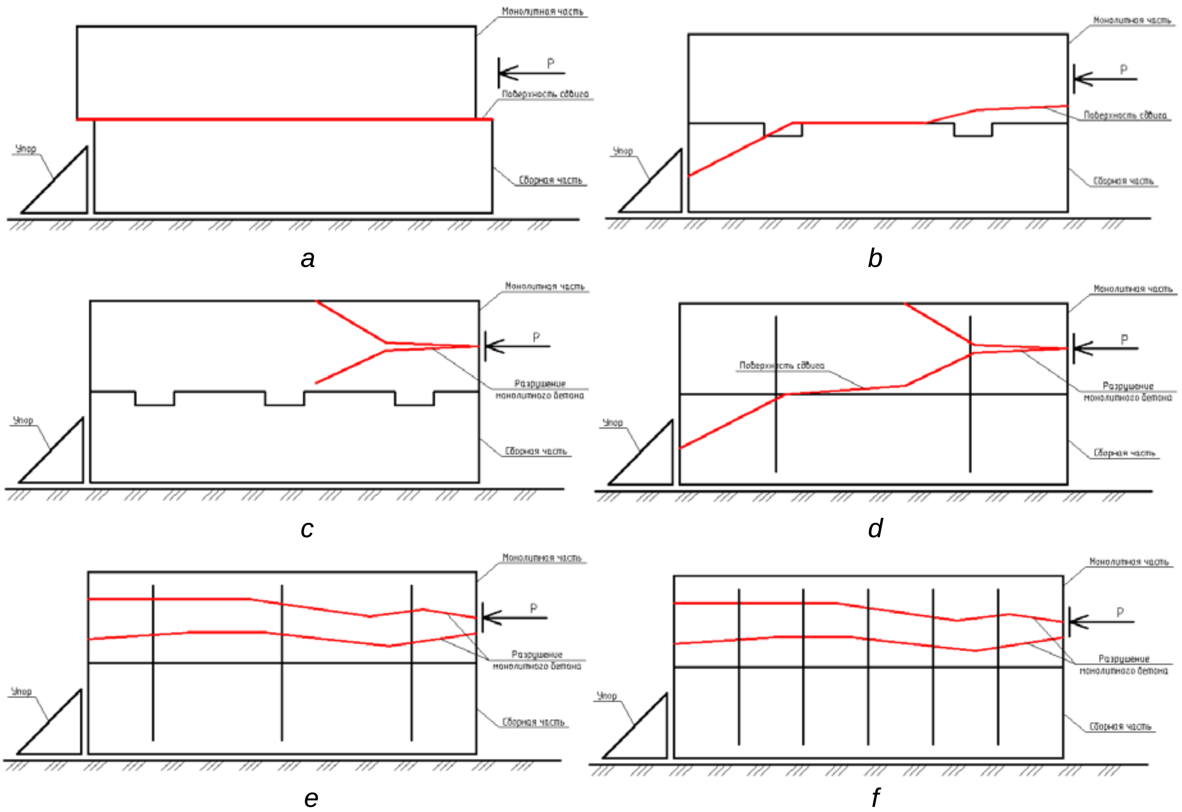


Figure 8. The typical fracture patterns: a – P1 samples; b – P2 samples; c – P3 samples; d – P4 samples.

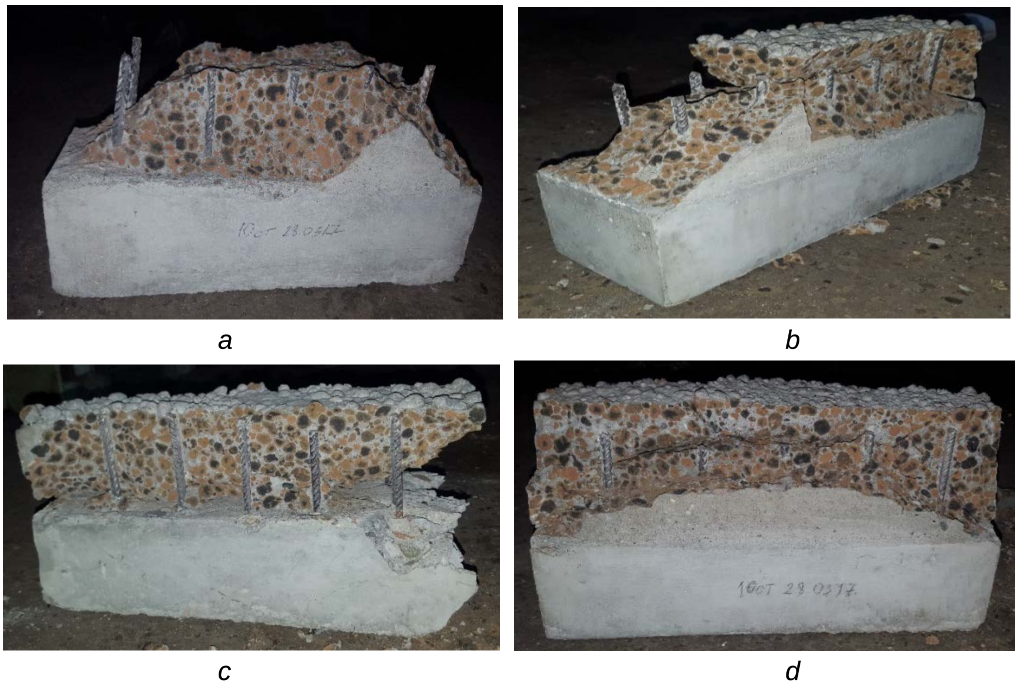


Figure 8. The fracture photos of the P6 series samples: a, b, c, d – respectively, the photos of the fractured samples P6-1, P6-2, P6-3 and P6-4.

The results provided by this paper are in good correlation with the data obtained in earlier surveys conducted by various authors, including the authors of this paper. Particularly, the results of bending tests on precast and monolithic beams in [2] showed a high shear rigidity in the case when transverse reinforcement was used in the joint. Previous works by the authors [5, 6] where, among other things, they tested bendable precast and monolithic transversely reinforced beams showed no mutual movement of the sections of monolithic and precast concrete relative to each other. A similar result was in [1–4, 9–13].

4. Conclusions:

1. The pattern of concrete failure – along the connection joint or along concrete – depends on the type of concretion of the concrete;

2. A smooth surface connection of monolithic light and precast heavy concretes, that provides adhesion only due to the adhesion and friction forces, is inefficient to ensure a joint deformation of two conjugated concretes; the fracturing occurs as a result of mutual displacement of the sections;

3. An efficient and at the same time low-cost method for ensuring a joint deformation of adjacent concretes along the joint is either a keyed joint or a joint with transverse reinforcement;

4. The most reliable is the connection between monolithic and precast concretes with the use of transverse reinforcement which along with increasing the joint's strength also ensures a more reliable result. In addition, this type of joint is simpler when manufacturing precast elements, as well as the subsequent construction and assembly operations on installation of monolithic concrete;

5. Adding transverse reinforcement indirectly increases the compression strength of concrete.

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