Experimental and Numerical Research on Tensile Performance of Inter-Panel Fastener Joints of Large-Panel Buildings

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Abstract. When designing large-panel buildings, it is necessary to take into account the work of wall panel joints. In addition to welded joints, monolithic joints in the form of pinned joints of the loop releases of adjacent wall panels are widely used. The main characteristics of a joint in the design scheme are its rigidity and bearing capacity under the action of shear and tensile (compressive) forces. This paper studies a new type of an inter-panel joint in the form of a fastener junction of wall panels made using a bracket of reinforcing steel and a metal plate joining the ends of the bracket. Due to the creation of a closed loop of voltages in the node, its high load-bearing capacity is assumed as well as the possibility of using this connection under dynamic effects on the building. An experimental study of the strength and rigidity of the joint at tensile loading along the joint axis was carried out, the breakdown of the joint, the stiffness characteristics and the bearing capacity of the samples were determined. The numerical modeling of the joint's work on stretching to the formation of cracks is carried out.

1. Introduction
In 2014, a new design for the joint of wall panels was developed at JSC "Central Research Institute of Residential and Public Buildings (Central Research Institute of Housing)". The node is a prefabricated monolithic well joint. The connection was made through the loop outlets on the end faces of the panels joined by a lock consisting of a connecting bracket and a steel plate.

Also, this joint was tested for shear and a significant increase in the strength and rigidity of the joint was obtained in comparison with the currently used weldless joints of wall panels [1].

The advantages of this joint are its high bearing capacity and the possibility of its application both as a vertical and as a horizontal joint [2]. In addition, a two-stage operation of the joint is envisaged, including the operation of a unit with high rigidity to local destruction of the concrete of the node and with a much lower after it. Thus, the use of a fastener joint is capable of providing high stiffness and strength characteristics of a building under standard design situations, and at the same time allows the building to be adapted to seismic action by reducing the rigidity of the units and the building as a whole, thereby reducing the dynamic seismic load factor [3].

At the present time, the task is to further study the feasibility of using the compound in large-panel housing construction, including in seismic regions.

Vertical joints work mainly on shearing forces, but they also generate tensile forces from uneven deformations of the substrate, from temperature-humidity influences, from the action of the forces of
expansion caused by the displacement of the keyed wall joints [4], in addition tensile stresses arise from uneven loading adjacent panels from the effect of wind load [5] as well. Also, significant tensile forces can occur with seismic action.

2. Vertical interpanel joints of large-panel buildings

Vertical joints in large-panel buildings serve for the perception of shearing, stretching and compression. In accordance with the normative documents [6,7] in vertical joints it is recommended to install metal bonds.

In addition to the standard types of joints [5], monolithic keyed joints with cable loops are now widely used [8]. The drawbacks of existing joint designs require the development of new types of joints.

Simulation of the work of joints is made in accordance with the provisions of [9-12], using finite elements of the elastic coupling between nodes, which need to specify the numerical value of the rigidity of the connection.

The fastener junction proposed by the Central Research Institute for Housing is shown in Figure 1. It is a loop-like outlet on the end faces of panels, connected by a curved U-shaped bracket made of A500 reinforcement. To make the unit more stiff and durable, and also to prevent the loop from loosening and further breaking the joint due to puncturing the concrete, the ends of the bracket are connected by a steel plate with holes. The plate is brought to the loop outlets and, to prevent separation during concreting, binds to the bracket with knitting wire.

3. Experimental study of tensile performance of fastener joints of wall panels

In the course of studying the characteristics of the strength and rigidity of the joint, tensile tests were carried out for specimens simulating the joint.

3.1. Design of prototypes

For the tests, six prototypes were made: three from concrete with a design class of compressive strength B20, three from concrete B30.

The samples are made of two steel plates with thickness of 20 mm, to which, on the one hand, loops of 16 mm in diameter from A500C reinforcing bars imitating loop outlets from the reinforced concrete wall panel were welded, on the other hand, a reinforcing bar with diameter of 28 mm was fastened to the plate by welding and additional steel plates, designed to fix the sample in the test machine and transfer tensile load to it. The bracket connecting the loops in the sample was made of A500C reinforcement with diameter of 10 mm, the steel plate of 6x50 mm section was made of steel C245. A three-dimensional image of the sample is shown in Figure 2 (concrete is not shown conditionally).

3.2. Test scheme
The tests were carried out in the test machine in an upright position. On the edge of the plate, clock-type indicators (with a 0.01 mm dividing point) were installed at the corners of the sample to determine the displacement under load of the opposite sides of the unit. Indicators of the clock-type (with a division point of 0.001 mm) were also installed in the center of the sample directly on the concrete of the unit for determining concrete deformations. The sample before the tests is shown in Figure 3.

Loading of the sample was carried out in steps of 5 kN before the appearance of cracks, 10 kN - after the appearance of the first cracks. At the load of 60-70 kN from the sample indicators were taken, then the sample was brought to destruction.

On the day of testing, the actual compressive strength of the concrete of the sample was also determined by breaking the sample cubes made in the production of samples.

3.3. Results of testing samples
The general view of the sample after destruction is shown in Figure 4.

Figure 2. A three-dimensional model of the sample (concrete is not shown conditionally).

Figure 3. General view of the sample prior to testing.

Figure 4. General view of the sample after destruction.

Figure 5. Test chart of sample P-30 (1).
Based on the test results, graphs were plotted for the displacement of the ends of the sample from the applied load (Figure 5). According to these data, direct regression lines were constructed, approximating the graph before the cracks appeared in the sample and after. The angular coefficients of these lines determined the stiffness of the joint at each stage.

The test results are given in Table 1.

| Table 1. The results of the experimental study of the fastener joint. |
|-------------------------------------------------|
|                                              | P-20 (1) | P-20 (2) | P-20 (3) | P-30 (1) | P-30 (2) | P-30 (3) |
| Design concrete compression class             | B20      | B20      | B20      | B30      | B30      | B30      |
| Actual concrete compression class             | B28,81   | B29,16   | B30,05   | B39,85   | B37,83   | B43,39   |
| Average prismatic concrete compression strength (MPa) | 27,75    | 28,09    | 28,94    | 38,39    | 36,44    | 41,80    |
| Average concrete tension strength (MPa)       | 2,26     | 2,27     | 2,31     | 2,66     | 2,60     | 2,77     |
| Load before cracking (kN)                     | 15       | 25       | 25       | 35       | 35       | 35       |
| Stiffness before cracking (kN mm⁻¹)           | 151,1    | 98,0     | 222,2    | 255,9    | 279,9    | 256,3    |
| Stiffness after cracking (kN mm⁻¹)            | 16,3     | 10,4     | 11,4     | 12,6     | 15,8     | 9,8      |
| Breaking load (kN)                            | 88,0     | 76,0     | 78,0     | 82,5     | 88,5     | 74,5     |
| Type of destruction                           | Cutting  | Breaking  | Breaking-cut | Loop-cutting | Breaking-cut | Loop-cutting |

As a result of the experimental study, the following was revealed:

- The destruction of all samples occurred as a result of the destruction of the bracket in places close to the connection with the loop at the load of 74.5 kN to 88.5 kN.
- The destruction of the bracket was due to cutting it by the plate, from the extension and cutting the bracket by the loop, from the rupture at the beginning of the bend of the bracket.
- In the upper and lower part of the sample, at the distance of about 55 mm from the plate (at the junction of the bracket and the loop, at the point of future failure), cracks formed developing with further loading along the perimeter of the sample section, after which the cracks became through ones.
- In the middle part of the sample (between the main cracks), according to the indicators, the displacements did not exceed 0.025 mm.
- The occurrence of cracks occurred at the load of less than 50% of the load capacity of the sample.
- The work of the sample under load can be conditionally divided into two stages: before the formation of cracks in the place of sample destruction and after the formation of cracks.
- The rigidity of the unit prior to cracking is much higher than the rigidity after the formation of cracks.
- The loading of cracks in concrete samples of the design strength class B30 was higher than that of concrete B20.
- The stiffness of the samples before the formation of samples from concrete of the design class B30 is higher than that of concrete B20;
- The strength and rigidity of the unit after the formation of cracks does not depend on the strength of the concrete in the sample.

The actual class of concrete was determined on the basis of the compression test of concrete cubes on the day of testing the samples. The class of concrete and the prismatic strength of concrete for compression were determined according to the formulas of [13], the strength of concrete for stretching - according to [14].

4. Numerical study of the tensile performance on the joint

Numerical research was carried out in the Lira-SAPR software complex. A flat design scheme was adopted in which looped outlets, a bracket and a plate were modeled by rod finite elements, concrete - shells. The cross-section of the loop outlets was taken to be rectangular equivalent rigidity to tension and bending.

The edge of the wall panel (the metal plate in the experiment) was modeled by an infinitely rigid body. Contact concrete panel and concrete joint was modeled by elastic bonds with ultimate effort; characteristics of the bonds were taken in accordance with the methodology [15].

Elastic connections with the ultimate force also simulated the contact of reinforcing bars with concrete. The rigidity of the elastic bonds was determined depending on the strength of the concrete of the sample on the basis of the study [16], but was corrected for the difference in the profile of reinforcement A500C [17,18], taking into account the relative area of the crumpling of the transverse edges of the profile \( f_{x} \) [19]. Limiting efforts were taken depending on the strength of the concrete for tension and compression.

The calculation was made in a non-linear setting, the concrete deformation diagram was taken as three-linear in SP 63.13330.2012 [20], the diagram of the loop and staple deformation was taken as a five-line diagram with a yield pad and hardening of the steel to the time resistance with tear tests of the brackets and the study extracted from the sample [18], for connecting the plate was taken as a two-line diagram according to the Prandtl diagram.

The joint with characteristics of the sample P-30 (1) was modeled.

In accordance with the calculation before the connection between the concrete and the panel is disconnected, cracks in the sample are not formed, after switching off the linking elements, the load transfer occurs more unevenly and at a load of 3.8 to 4 tons (38 to 40 kN) in the concrete, cracks appear in the loop area.

![Figure 6. Isopoles of principal tensile stresses.](image-url)
The distribution of the main normal stresses $\sigma_2$ in the concrete of the sample is shown in Figure 6. Also in the figure are the directions of the main stress $\sigma_3$, from which one can judge the direction of the development of cracks.

Figure 6 allows to conclude that the nature of the destruction in the numerical model coincides with the test results.

5. Conclusion
The performed investigations made it possible to determine the bearing capacity of the fastener joint and its rigidity in tension, the nature of the joint destruction was determined, and the results of the work could be used in the design of large-panel buildings.

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