



## Experimental and Theoretical Studies of Plug Joints Reinforced Concrete Columns Under Transverse Force

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# Experimental and theoretical studies of plug joints reinforced concrete columns under transverse force

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**Abstract.** The analysis of scientific and technical literature indicates the responsibility of joints of prefabricated elements of buildings for structural safety and reliability under the influence of static loads. According to numerous publications by domestic and foreign authors, in frame buildings, the first signs of destruction appear at the joints of elements due to stress concentration. It is possible that at the operation stage the joints will not meet the requirements of reliability and durability due to a number of reasons: the effect of non-design loads, the presence of defects in the manufacture of the joint and installation (non-design reinforcement, cracks in concrete, incomplete filling of joints, etc.). Therefore, ensuring the structural safety of the building and operational suitability by strengthening joints at minimum cost is an urgent task.

**Key words:** building constructions, reinforced concrete, plug joints, reinforcement, steel cage, reinforced carbon fiber, reinforced stress-strain state, computer simulation, calculated expressions of shear compliance.

In this paper, we consider the strengthening of the plug joint of reinforced concrete columns for the perception of transverse forces as the most dangerous factor. Experimental and theoretical studies of three options for strengthening the plug joint under the action of transverse forces are: external reinforcement with a composite material, a steel cage with and without prestressed clamps.

The results of field examinations have shown that in some cases in existing buildings the plug joints do not meet the regulatory requirements for deformability due to defects in the manufacture of the joint and during installation.

At the operation stage, the joints do not meet the requirements of reliability and durability due to a number of reasons: the effect of non-design loads, the presence of defects in the manufacture of the joint and during installation, non-design

reinforcement, cracks in concrete, poor-quality filling of wells and horizontal seam, etc. This required the development of effective ways to strengthen them.

The theoretical and experimental studies conducted earlier [1, 2, 3, 4,] made it possible to propose some options for strengthening the joint, which increased the bearing capacity and stiffness. The first option is to install a clip from the angle irons with and without prestressed clamps (fig. 1, a). Due to the compression in the area of separation of concrete and the work of the angle irons crossing the seam, crack resistance, load-bearing capacity are increased, and joint compliance is reduced. The second method (Fig. 1, b) is the use of external reinforcement with composite materials based on carbon fibers. The reinforcing effect is achieved due to the operation of carbon fiber tensile in the area of separation of concrete

The study was divided into three stages: computer simulation, physical experiment, development of calculated expressions.

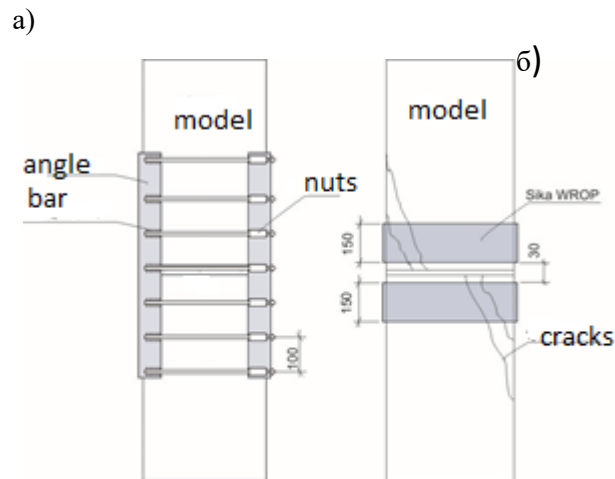


Fig. 1. Methods of reinforcing the plug joint of columns: a - a clip of angle irons and clamps from round ordinary and prestressed reinforcement; b - carbon fiber composite canvas

The purpose of computer modeling of reinforced joints was to assess the deformability of a plug joint reinforced with a steel cage under the action of shear forces with and without prestressing of round rod clamps. An analysis of the effect of the steel cage on the stress-strain state of the joint is presented.

The information scheme of computer modeling of reinforced joints is shown in Figure 2.

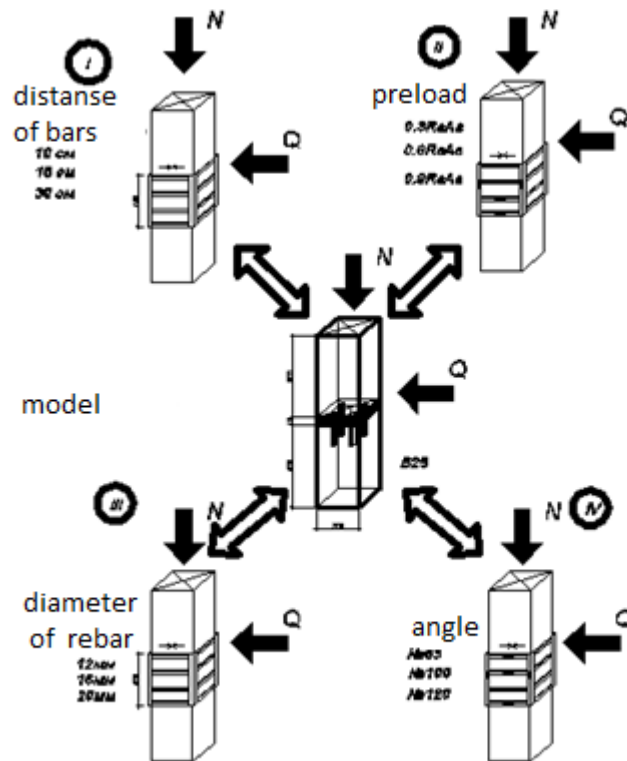


Fig. 2. Information scheme for computer simulation of a plug joint reinforced with a steel clip

The basic model of the design solution [2, 6] of fragments of columns with a plug joint was adopted as the basis. It has the following characteristics:

- cross section 300x300 mm;
- longitudinal reinforcement 4 $\varnothing$ 18 mm of class A400, monolithic in a well with a diameter of  $\varnothing$ 50 mm and a depth of 500 mm, which was framed by a spiral of reinforcement of class B500 with a diameter of 3 mm;
- the length of the longitudinal reinforcement was 480 mm;
- transverse reinforcement  $\varnothing$ 5 mm from steel of class B500 with a pitch of 100 mm. Heavy concrete class B25.

Modeling clips. The holder was modeled by four-node finite elements of the finite element-244 shell with the physicomechanical characteristics of steel. The solution that creates the grip of the cage with the body of the column was modeled in the form of rods finite element-256 working as friction elements. The design model of joints reinforced with a steel cage is shown in Fig. 3.

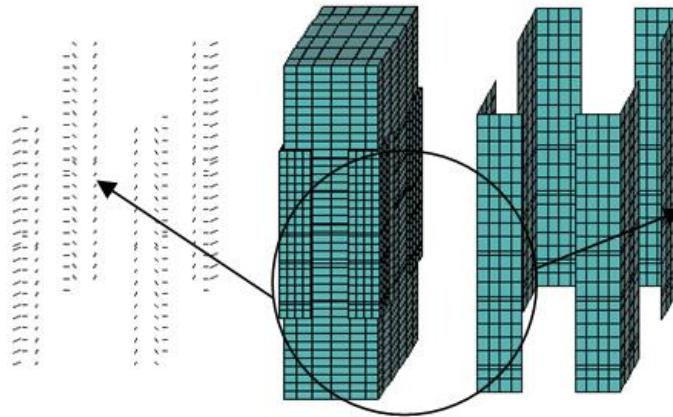


Fig. 3. The calculated model of the plug joint with amplification, performed by the FE method, the scheme of modeling the solution using friction elements

Based on the data obtained during computer modeling of the joints of the design solutions, the “lateral force – strain” relationship was constructed, shown in Figure 4. As can be seen from this diagram, the joints reinforced with a steel cage have deformability of 2.5 times less than the deformability of the plug joints of precast concrete columns not reinforced. Horizontal movement at joints without reinforcement averaged 25 mm, and joints reinforced not more than 13 mm.

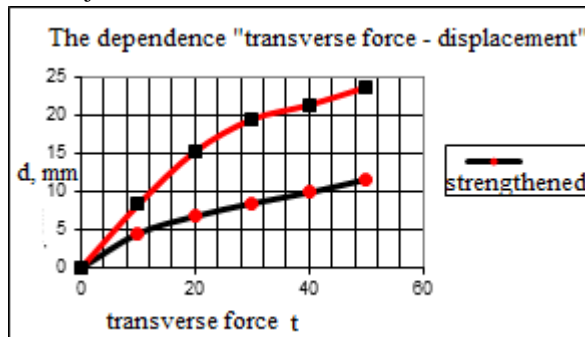


Fig. 4. The diagram "force - deformation" of the plug joints of precast concrete columns

Setting the correct construction of the final model, achieving the compatibility of the concrete structure with the clip is described further. When axial compression in the process of lateral expansion of the joint, the cage was included in the work, since the friction elements transmitted axial forces. Horizontal clamps began to perceive the longitudinal force transmitted to the column, stretched. The following picture was noted: the maximum tension occurred in the middle collar, since the deformability of the element is concentrated in the joint area (results obtained in

previous studies). Here the first deformations took place. The nature of the distribution of forces in the clamps is shown in Figure 5. Based on the above, it can be concluded that the design works reliably. You can proceed to further computer modeling.

In the reinforcement angle iron, maximum stresses appear in the weld zone and at the joints with the clamps, as shown in Figure 6.

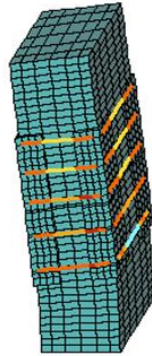


Fig. 5. Mosaic of longitudinal forces arising in clamps

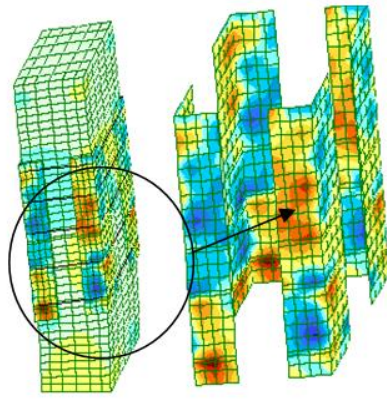


Fig. 6. The distribution of shear stresses on the sample and clip

### **Computer simulation results**

Samples of the first series. Here, the compression by transverse force was taken as a variable parameter; the test was conducted on the effect of horizontal load. The isofields of stresses and horizontal deformations of the finite elements of the joint did not qualitatively differ from those presented above.

Compression efforts were taken in accordance with regulatory documents. With an increase in the compression force, the following picture was observed: displacements with a noticeable step decreased. At the same time, the pitch of the

horizontal clamps was varied. For convenience, we consider the case of prestressing with a step of 30 cm clamps. The load was applied in stages. Figure 7 shows the “strain – shear force” relationship at various compression levels. It is concluded that crimping is effective during the operation of structures reinforced with a steel cage, and prevents the formation of deformations in the early stages of loading. The discrepancy in the numerical equivalent between the crimped and uncompressed joints is about 70%. The average clamp located directly at the level of the plug joint takes maximum effort, then the forces decrease and increase only at the level of the extreme clamps.

From the graphs (Fig. 7) it can be seen that with an increase in prestressing, deformations decrease, the joint is less susceptible to shear.

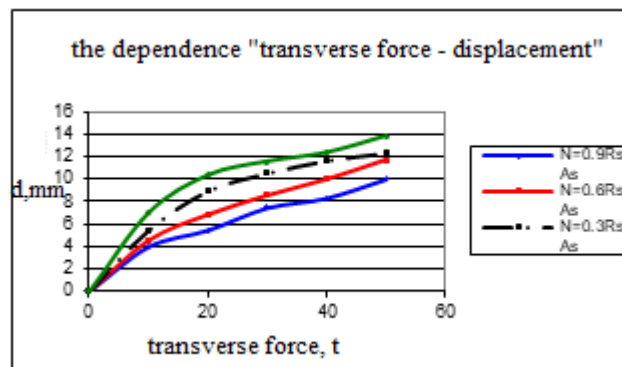


Fig. 7. The dependence "deformation - shear force" at different levels of compression

Samples of the second series. Here, the distance between the clamps, which is determined based on the height of the clip, as well as the values of regulatory documents varying within 10-50 cm, was taken as a variable parameter. A linear relationship is observed. With an increase in the step of the clamps, the forces perceived by one clamp increased up to 1.5 times.

Samples of the third series, varied by the numbers of angle irons, and, consequently, their stiffness. With increasing rigidity, the angle of movement decreased. Based on the results, we decided to take angle No. 100 as having sufficient rigidity.

The picture of the stress-strain state of the angle iron is important in assessing the flexibility of the plug joint, since it is one of the main elements of the construction.

Suppose, that since under the action of the transverse force, the angle iron undergoes a number of deformations (the resistance of the angle iron to shear and the bending of the angle iron between the clamps) taken on the basis of theoretical assumptions. It is necessary to make sure that such construction works correctly.

Figure 8 shows the operation of the angle iron with different compression: with an increase in compression, the stresses in the angle irons decrease. A stress concentration is observed at the locations of the clamps. The maximum work of the angle iron occurs at the joint level, the main stresses are concentrated in this area. By the action of the transverse force, the upper part of the angle iron to which the load was applied begins to resist, trying to stretch, while the lower part, on the contrary, contracts.

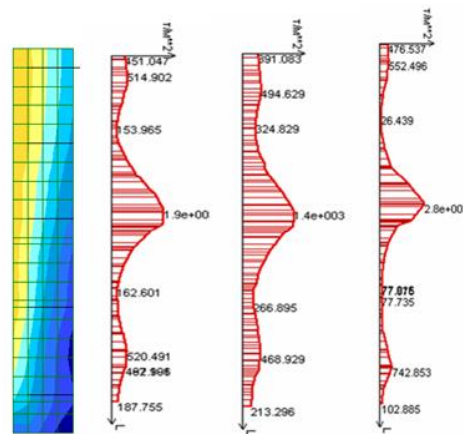


Fig. 8. Distribution of the main normal stresses in the angle iron

When varying the stiffness of the angle of movement at the junction decreased by 30%, it is concluded that the angle iron is only a deterrent and is included in the work, after the clamps reach the yield strength.

Samples of the fourth series. The diameter of the bar rods 12, 16, 20 mm was taken as a variable parameter. The calculation results are not presented, since this factor, in the accepted variable limits, does not affect the displacement at the junction. The differences in movements were insignificant and ranged from 0.5 to 1.8%.

Based on the data obtained, the following conclusions have been made. The results that illustrate the features of the stress-strain state of the joints and necessary for creating the calculated expressions of shear compliance, optimizing the physical experiment are presented.

The main elements of the cage are vertical angles and horizontal clamps with and without prestressing.

- The stress concentration was observed at the joint level, the most included in the work were the clamps installed at the level of the seam, as well as along the edges of the cage.
- It is sufficient to install prestressed clamps in places of stress concentration, if the clamps are not prestressed, they must be installed more often along the entire height of the clip.



- Steel angle irons prevent the separation of the protective layer of concrete; the geometric dimensions of the angle iron are an important factor. According to the results of numerical studies for a physical experiment, angle iron No. 100 was chosen.

### **Experimental research.**

In total, 4 experimental samples were observed, the characteristics of which are similar to the joints considered in computer modeling. Grade of monolithic solution is M600.

The steel clip was made of angle irons No. 100, to which clamps were made of round reinforcement with a diameter of  $\varnothing 16$  mm in increments of 100 mm. The tension of the rods was carried out by tightening the nuts with a torque wrench. The voltage level was additionally controlled by strain gauges.

After a static test of joints reinforced with a steel cage, for 2 samples at the level of the seam, as shown in Fig. 1b, Sika Wrap carbon canvas was glued 15 cm wide in two layers, with preliminary preparation of the concrete surface and further impregnation of the fabric, during gluing, with the SikaDur 330 polymer composition.

The characteristics of the gain elements are shown in Table 1.

Table 1

Model	Strengthening	Parameters	
		tension force	the distance between the bars
PJ-S-1	the steel cage	0t	0,1m
PJ-S-2		1t	0,3m
PJ-S-3		1.5t	0,3m
PJ-S-4		2t	0,3m
PJ-S-2*	external reinforcement	0	0,15m
PJ-S-3*		0	0,15m
Comments: *- previously tested samples			

For a shear test, a power plant with HJ-50 hydraulic jacks was used. Deformation of the joint seam was recorded by dial gauges hour-type indicator-10. The stress-strain state of the steel cage was determined at each stage of loading by load cells mounted on clamps and angle irons as shown in Fig. 9.

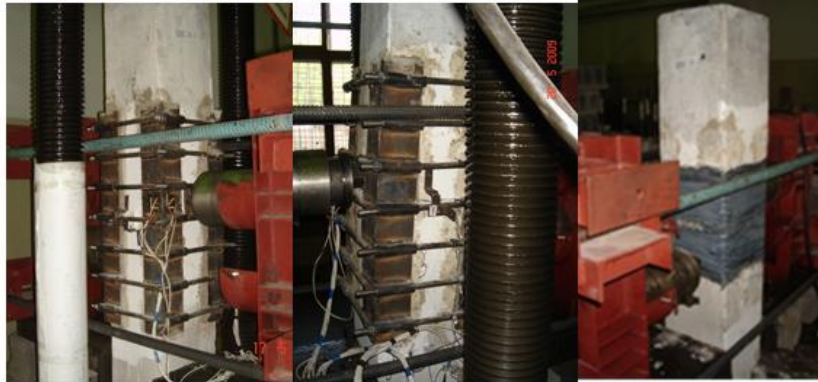


Fig. 9. Types of prototypes prepared for testing

When loading the elements with transverse force, the first crack appeared in the seam. It passed along the surface of the mortar-concrete contact. The load level for all four samples reinforced with a cage was about 140 kH, regardless of the compression force. A further increase in load led to the formation of cracks in the concrete, inclined to the longitudinal axis. One of the important tasks of these experimental studies was to assess the nature of the deformation of the steel cage.

According to the results of the experiment, it was evident that the angle irons, as well as the transverse thrusts, are included in the work after the appearance of cracks in the concrete column. The presence of transverse compression provided an earlier inclusion of the cage in the work during shear. The clamp, which was at the level of the seam, turned out to be the most loaded, which led to significant deformations (Fig. 10) and loss of pre-tension of the strap during unloading of the sample. The lack of symmetry in the strain of the clamps at the extreme points of the ferrule is explained by the formation of cracks and uneven bending of the angle irons.

The nature of the strain of the clamps of the sample PJ-S-1 is shown in Fig. 10 in the form of the dependence “transverse force - relative strain. The view of the destroyed samples is shown in Fig. 11.

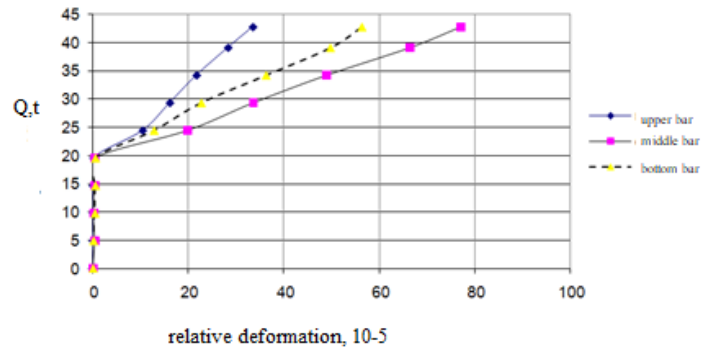


Fig. 10. The graph of the dependence "transverse load - relative strain" in the sample PJ-S-1.

After the test, the PJ-S-2 and PJ-S-3 samples were reinforced by external reinforcement with Sika Wrap carbon cloth, a sheet width of 150 mm and a double layer winding of the column body in the weld area as shown in Fig. 1. The purpose of the test was: to determine the degree of increase in the bearing capacity of the destroyed samples and the impact on the deformability of the joint of the external reinforcement with a composite material.



Fig. 11. Type of destroyed samples after testing

It should be noted that the upper and lower fragment of the column were reinforced to a height of 15 cm of the maximum inclined crack of separation of concrete of the protective layer, the joint itself was not strengthened. Almost immediately after the load was applied, a shift occurred. When the transverse force reached 50 kN, the horizontal displacements in the seam were 3 mm for the first

sample, 1.5 mm for the second. The amplitude of horizontal deformations of the joint reached 3-4 cm during destruction of the samples. A further increase in load led to an increase in displacements, the development of cracks formed during previous tests, and the appearance of new ones. In general, bulging of a web of carbon fiber material was observed due to the high pressure in the concrete of the structural body. Cracking over the entire body of the column, the further development of inclined cracks in the detachment of concrete of the protective layer of the structure occurred under the reinforced elements and amounted to 45 cm in the upper fragment, 25 cm in the lower one.

Destruction of the structure occurred when transverse force of 300 kN was reached, due to the stratification of the fibers of the reinforcing element, rupture in the angle irons of the columns, the stress concentration in the angle irons of the column, the type of destroyed samples is shown in Figure 12. In the two samples, that were tested according to different load-applying schemes, Q was applied in the plane of the previous load, the first sample in the plane perpendicular to the previous load. Despite this, the samples were destroyed in the same way. The only difference was that the deformability of the first sample was 25% higher than the second.

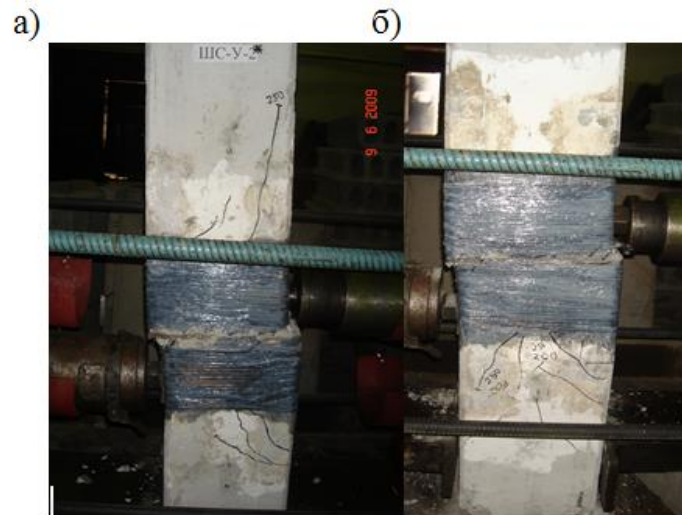


Fig. 12. Type of destroyed samples a) PJ-S-2 \*, b) PJ-S-3 \*

The analysis of the obtained experimental data shows that the plug-in joints reinforced by the presented methods have a two-, three-fold safety margin. However, for each gain option there are advantages depending on the loading mode and operating conditions. Fig. 13 shows the comparison of experimental data for 3 joints.

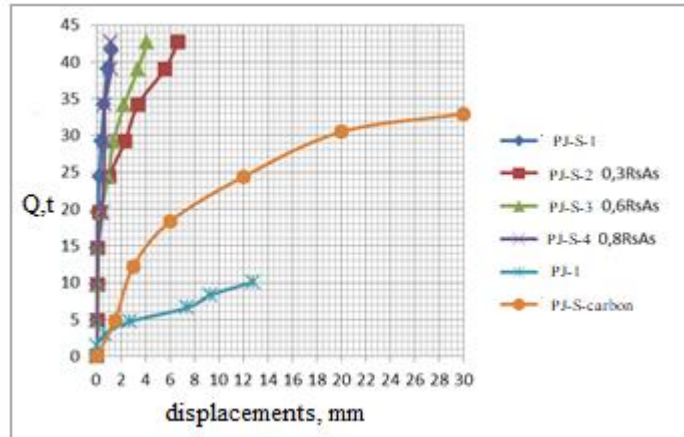


Fig. 13. The dependence "transverse force - displacement" for the joints.

From the graph in Fig. 13 it is seen that the joint reinforced with carbon fiber has the maximum potential energy of destruction, which can positively affect the seismic resistance of the precast-monolithic frame. Given the low complexity of the performance gain, this method becomes the most attractive, but it is worth considering the high cost of the material.

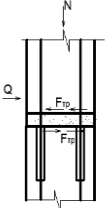
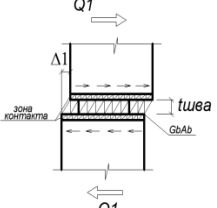
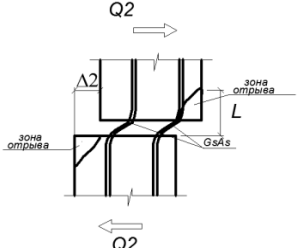
Strengthening the steel cage with clamps without prestressing led to a maximum increase in the bearing capacity of the joint up to 3 times, an increase in crack resistance due to compression of the stretched zone of concrete of the protective layer, and to increased stiffness. Compliance decreased 2.66 times. Since the distance between the clamps and the prestress in them were taken as a variable factor, it was concluded that the bearing capacity and serviceability of the joints with a distance between the clamps of 30 cm and the maximum possible prestressing of them is comparable to samples in which the distance between the clamps was taken to be 10 cm and there was no prestress. Therefore, it is more economical to use a steel cage with prestressed clamps, as this saves steel. Savings for one clip is amounted to 7.1 kg.

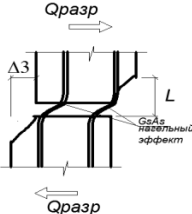
The destruction of samples reinforced by external reinforcement occurred due to the delamination and rupture of the canvas fibers in the angle irons of the columns, the concentration of stresses in these areas due to the destruction of concrete from separation. In this case, horizontal deformations of the joint reached 30 mm at the time of fracture of the samples. The graph shows that the joint, reinforced with carbon fiber canvas, has the maximum potential energy during destruction, which can positively affect the seismic resistance of the frame. Given the low complexity of the performance gain, this is appropriate. The bearing capacity of such samples increased 2.5 times in comparison with the joints of the design solution, however, such

reinforcement was not significantly affected by the flexibility of the joint, since such reinforcement only allowed to prevent separation of the protective layer of concrete, while the shift along the contact surface of the “concrete-mortar” occurred almost from the very beginning of loading.

An analytical description of the calculated expressions of shear compliance of the reinforced plug joints of reinforced concrete columns is given below in Table 2.

Table 2.

stages of stress-strain state	Scheme deformations	Definition displacements, mm	Shear compliance $\frac{1}{C_\gamma}, \frac{mm}{H}$
1 <sup>st</sup> Tough junction work		<p>При <math>Q=Q_{сж}+fN+Q_{пл}</math>  <math>\Delta = 0</math></p>	$\frac{1}{C_{\gamma 0}} = 0$
1. elastic behavior $Q_1 = 0,5Q_{ult}$ $0 < Q \leq Q_1$		$\Delta_1 = \frac{Q_1 \cdot L_y}{k_1 (G_m A_p + G_s A_y + G_s A_s)}$	$\frac{1}{C_{\gamma 1}} = \frac{\Delta_1}{Q_1}$
2. The formation of the first cracks in the concrete of the protective layer $Q_2 = 0,85Q_{ult}$ $Q_1 < Q \leq Q_2$		$\Delta_2 = \frac{L_{ст} = L_y}{k_2 (G_y + G_s + G_{nz}) A_{ред}} Q_2 \cdot (2L + t)$	$\frac{1}{C_{\gamma 2}} = \frac{\Delta_2}{Q_2}$

<p>3. Structural failure <math>Q_3 = Q_{ult}</math> <math>Q_2 &lt; Q \leq Q_3</math></p>		$\Delta_3 = \frac{L_{ст} = L_y \cdot Q_{ult} \cdot (2L + t)}{k_2 (G_y + G_s + nG_{ns}) A_{red}}$	$\frac{1}{C_{\gamma 3}} = \frac{\Delta_3}{Q_3}$
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## References

1. Paal, S. G., Jeon, J. S., Brilakis, I., & DesRoches, R. (2015). Automated damage index estimation of reinforced concrete columns for post-earthquake evaluations. *Journal of Structural Engineering (United States)*, 141(9). [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0001200](https://doi.org/10.1061/(ASCE)ST.1943-541X.0001200)
2. Rimkus, A., & Gribniak, V. (2017). Experimental data of deformation and cracking behaviour of concrete ties reinforced with multiple bars. *Data in Brief*, 13, 223–229. <https://doi.org/10.1016/j.dib.2017.05.038>
3. Yin, S. P., Hu, X. Q., & Peng, C. (2018). Compressive performance of TRC-strengthened column with small eccentricity under chloride-wet-dry cycles. *RILEM Bookseries*, 15, 651–658. [https://doi.org/10.1007/978-94-024-1194-2\\_75](https://doi.org/10.1007/978-94-024-1194-2_75)
4. Vu, N. S., & Li, B. (2017). Seismic performance of reinforced concrete columns in corrosive environment. In *High Tech Concrete: Where Technology and Engineering Meet - Proceedings of the 2017 fib Symposium* (pp. 895–903). Springer International Publishing. <https://doi.org/10.1007/978-3-319-59471-2-104>
5. Kodur, V., Hibner, D., & Agrawal, A. (2017). Residual response of reinforced concrete columns exposed to design fires. In *Procedia Engineering* (Vol. 210, pp. 574–581). Elsevier Ltd. <https://doi.org/10.1016/j.proeng.2017.11.116>
6. Broujerdian, V., Karimpour, H., & Alavikia, S. (2019). Predicting the Shear Behavior of Reinforced Concrete Beams Using Non-linear Fracture Mechanics. *International Journal of Civil Engineering*, 17(5), 597–605. <https://doi.org/10.1007/s40999-018-0336-6>
7. Yu, Q., Muttoni, A., & Ruiz, M. F. (2018). Design of concrete structures using structural optimization based on the stress field method. In *Proceedings of the 12th fib International PhD Symposium in Civil Engineering* (pp. 791–798). Czech Technical University.
8. Gerasimov, E. P. (2019). DETERMINATION OF REGULATORY RELIABILITY FOR DEFORMATION OF REINFORCED-CONCRETE FLEXIBLE STRUCTURES. *Vestnik Tomskogo Gosudarstvennogo*

Arkhitekturno-Stroitel'nogo Universiteta. *JOURNAL of Construction and Architecture*, 21(5), 115–126. <https://doi.org/10.31675/1607-1859-2019-21-5-115-126>

9. Huang, L., Xu, L., Chi, Y., & Xu, H. (2015). Experimental investigation on the seismic performance of steel-polypropylene hybrid fiber reinforced concrete columns. *Construction and Building Materials*, 87, 16–27. <https://doi.org/10.1016/j.conbuildmat.2015.03.073>
10. Raoof, S. M., Koutas, L. N., Bournas, D. A., Harajli, M., ElKhatib, H., San-Jose, J. T., ... Nanni, A. (2018). *Design Procedures for the Use of Composites in Strengthening of Reinforced Concrete Structures. Composites Part B: Engineering* (Vol. 47, p. 406). <https://doi.org/10.1617/s11527-014-0360-1>
11. Oliveira Júnior, L. Á., Araújo, D. D. L., Toledo Filho, R. D., Fairbairn, E. M. R., & Andrade, M. A. S. (2016). <b>Tension stiffening of steel-fiber-reinforced concrete. *Acta Scientiarum. Technology*, 38(4), 455. <https://doi.org/10.4025/actascitechnol.v38i4.28077>
12. Eldho, C. A., Jones, S., Nanayakkara, O., & Xia, J. (2016). Performance of concrete patch repairs: From a durability point of view. In *International Conference on Durability of Concrete Structures, ICDCS 2016* (pp. 66–72). Purdue University. <https://doi.org/10.5703/1288284316112>
13. Silva, R. N. F., Tsuruta, K. M., Rabelo, D. D. S., Neto, R. M. F., & Steffen, V. (2016). The use of electromechanical impedance based structural health monitoring technique in concrete structure. In *8th European Workshop on Structural Health Monitoring, EWSHM 2016*(Vol. 1, pp. 409–421). NDT.net.
14. Abad, B. F., Lantsoght, E. O. L., & Yang, Y. (2019). Shear capacity of steel fibre reinforced concrete beams. In *Proceedings of the fib Symposium 2019: Concrete - Innovations in Materials, Design and Structures* (pp. 1710–1717). International Federation for Structural Concrete.
15. Spinella, N., Colajanni, P., & Recupero, A. (2019). Response behaviour of reinforced concrete beams strengthened in shear with FRP. In *Proceedings of the fib Symposium 2019: Concrete - Innovations in Materials, Design and Structures* (pp. 1601–1608). International Federation for Structural Concrete.
16. Yousef, A. M., Tahwia, A. M., & Marami, N. A. (2018). Minimum shear reinforcement for ultra-high performance fiber reinforced concrete deep beams. *Construction and Building Materials*, 184, 177–185. <https://doi.org/10.1016/j.conbuildmat.2018.06.022>
17. NIST. (2017). Guidelines for Nonlinear Structural Analysis for Design of Buildings; Part IIb – Reinforced Concrete Moment Frames. *NIST GCR 17-917-46v3*, 135. <https://doi.org/10.6028/NIST.GCR.17-917-46v2>
18. Salgado, R. A., & Guner, S. (2017). Modelling beam-column joints for progressive collapse analysis. In *IABSE Conference, Vancouver 2017: Engineering the Future - Report* (pp. 592–599). International Association for Bridge and Structural Engineering (IABSE).
19. Ebrahimkhanlou, A., & Salamone, S. (2017). A probabilistic model for visual inspection of concrete shear walls. In *Sensors and Smart Structures*



*Technologies for Civil, Mechanical, and Aerospace Systems 2017* (Vol. 10168, p. 101680Y). SPIE. <https://doi.org/10.1117/12.2258614>

20. Sagher, A., & Abed, F. (2017). Finite element parametric study of the shear behavior of GFRP-RC short beams. In *2017 7th International Conference on Modeling, Simulation, and Applied Optimization, ICMSAO 2017*. Institute of Electrical and Electronics Engineers Inc. <https://doi.org/10.1109/ICMSAO.2017.7934912>