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# EXPERIMENTAL STUDIES OF WELDED JOINTS OF PRECAST BUILDINGS FOR SHEAR AND TORSION

**Valery Lyublinskiy[1], Vladislav Struchkov[2]**

[1,2] Department of Reinforced Concrete & Masonry Structures, Moscow State University of Civil Engineering, Moscow, Russia.

Email: [1]lva_55@mail.ru

Corresponding Author: **Valery Lyublinskiy**

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**Abstract**

*The spatial rigidity and strength of precast multi-story buildings are largely determined by the rigidity of the shear bonds connecting the vertical load-bearing reinforced concrete structures. When a horizontal load is applied in asymmetrical in-plan load-bearing systems of multi-story buildings, torsion occurs. In vertical shear bonds, especially those located furthest from the center of rigidity, a torque appears. This article presents the results of experimental studies of welded joints of precast buildings under the action of shear and torsion. The research study has been conducted using full-scale samples of shear bonds. The samples have been loaded with a static load vertical shear force and horizontal torsion moment. Various loading conditions are considered. Deformation diagrams of shear bonds were obtained. The limit state of a welded joint under shear and shear with torsion is described. The obtained experimental data on the rigidity of shear connections can be used in mathematical models for determining the stress-strain state of load-bearing systems of panel multi-story buildings.*

**Keywords:** Welded joints, Shear bonds, Torsion, Panel buildings, Stress-strain state

## I. Introduction

The precast technology construction of multi-story buildings has several advantages over monolithic construction [XV]. There is a reduction in the cost of construction in mass production. The terms of the erection of load-bearing systems of multi-storey buildings are reduced. The quality of construction projects increases due to the factory production of load-bearing elements of multi-storey buildings. The main forces arising in vertical joints of large-panel buildings and frame-panel structures are bending, stretching, compression, and shear forces [VI]. Vertical and horizontal connections ensure the joint work of load-bearing elements of the building. Shear connections are the most stressed elements of the load-bearing system of multi-storey buildings [XII] and act as regulators in the redistribution of forces, taking into account the nonlinear operation of reinforced concrete. One of the frequently used joints of wall panels in existing large-panel buildings is a welded joint. A large number of studies have been carried out on vertical panel joints [VIII, XX], but the experimental data on welded joints are limited. In work, [XIII] test welded joints were carried out only for shear. The stress-strain state of the shear bonds was analyzed and the dependence of the weld joints strain on the applied load was obtained.

In asymmetric buildings in plan, under the action of horizontal load, torsion occurs. Seismic action is the most intense and complex, but some aspects of torsion are also valid when a wind load is applied to tall buildings. The main causes of torsion are the appearance of eccentricity between the center of rigidity and the center of mass, the appearance of eccentricity in the distribution of strength and deformability in the building plan under the action of a high level of stress, and much more. Compression, tension, and shear acting in the connections of a prefabricated building can be supplemented by torsional forces. The studies of the torsion of buildings and the reviews given are associated with the action only of the seismic load [XXII- XXIV].

Some interesting scientific studies of the torsion of buildings under the action of horizontal loads are given in papers [V, VII, XVI, XVIII]. Significant horizontal loads, leading to the appearance of torsional modes of the building, arise mainly due to wind and seismic influences [II, XI]. But by themselves, horizontal loads would not lead to dangerous torsion of the building if there were no such factors as the asymmetry of buildings in plan or height. Torsion of precast buildings can be a critical factor that can destroy single load-bearing elements and the entire load-bearing system. Due to the lack of symmetry between the centers of stiffness and mass, significant torques occur in the edge elements of buildings [I, IV, IX-X]. In such conditions, the vertical joints in the panels experience a complex stress-strain state. With significant seismic loads, as well as progressive destruction, shear bonds can go into plastic work [**Error! Reference source not found.**, XXI].

In an experimental investigation [**Error! Reference source not found.**I], a reinforced concrete structure consisting of four columns anchored in the foundation and floors was considered. The structure was subjected to dynamic loading up to destruction. Although the design was symmetrical, the reaction to torsion was observed. This is due to the different values of the pliability of the structural elements. Since the article considered a small eccentricity, it was noted that at low levels of horizontal load, the operability of the structure would not be impaired. In study [**Error! Reference source not found.**], a full-fledged asymmetric three-storey reinforced concrete building was considered. The so-called PsD method was used in the experiment. The essence of the method is the simultaneous effect of the longitudinal and transverse components of the seismic load. The tests highlighted the strong effects of torsional irregularity on the column drifts, even for a limited level of plan eccentricity and relatively low loading levels [**Error! Reference source not found.**].

To date, there are many works devoted to the operation of various vertical joints of elements for shear in the conditions of normal operation of the building. One of the industrial solutions is the use of a metal plate welded to embedded parts inside reinforced concrete panels as a shear bond. This topic was discussed in the articles [XI, XIII]. This study aims to investigate the behavior of the welded bond, considering shear forces, torsional effect, and material nonlinearity. See Fig. 1.

Pacifically, the study includes the evaluation of the strength and deformability of the joint under simultaneous shear and torsion. Torsional effects are assumed to reduce the strength of the joint due to additional forces in the reinforced concrete element.

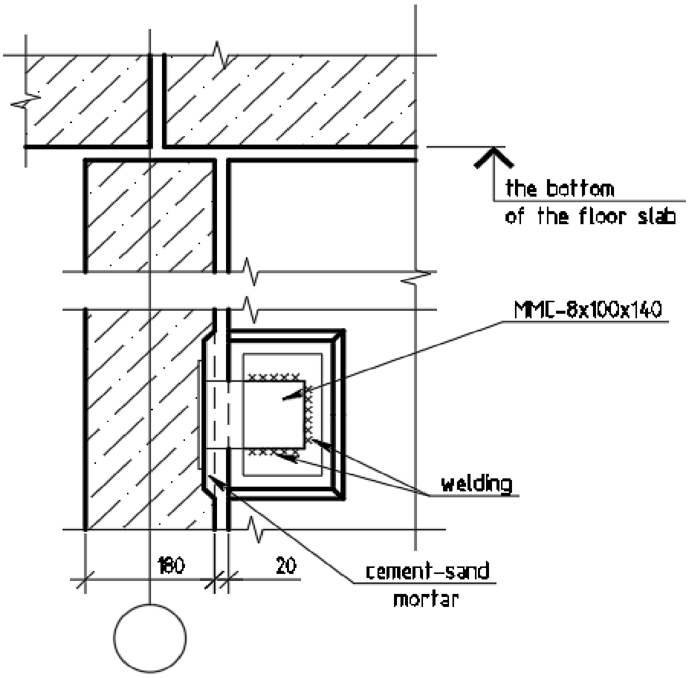


**Fig. 1.** Mounting unit for internal panels (side view)

## II. Materials and Methods

### Material, and Experimental Methods

In this work, an experimental study was conducted of the fragment of the connection of internal wall panels using welded vertical connections for loading vertical and horizontal torsion loads. The specimens consisted of two 180mm thick panels, which are interconnected by an 8x100x140mm metal plate on welding. The plate was welded to the embedded parts installed in each panel. The total height of the specimen was 550 mm. Concrete reinforced concrete panels – B20. C255 steel was used for metal bonds. For a general view of the test specimen, see Fig. 2.

Sensors were glued to the specimens to measure the relative deformations. In the specimens, 32 sensors were involved in the work, which were located vertically and horizontally. Sensors with a base of 5mm were installed on metal, and sensors with a base of 60 mm were installed on concrete. Four linear strain gauges were used to record the movements of one panel relative to the other. Sensors were installed on both sides of the loaded panel. Two sensors registered the vertical movement of the left panel, and the other two sensors registered the rotation of the panel due to the action of torque.

**Fig. 2.** General view of the sample during testing

The shear of the left panel relative to the right was performed using a hydraulic piston. The load created by the piston was fixed by a force meter modification M 70-10-S 3. Uniform load distribution over the area of the panel was provided using distribution metal plates. The torque was created by mechanical jacks that rested against the frame. A step-by-step loading of the specimens was performed with an exposure time of 5 minutes after each step.

It was previously supposed to perform ten stages of load application. To be able to compare the effect of torque on the operation of vertical shear bonds, the following sequence of specimen tests was performed; the first two specimens were tested only for shear (specimens No. 1, No. 2), the next two specimens were tested for shear and torque (specimens No. 3, No. 4), and torque was created from the first the loading step. The last two specimens were also tested for shear and torque, torsion was created starting from the sixth step (specimens No. 5, No. 6). The appearance and development of cracks in concrete were monitored at all stages of loading. At all stages of loading, the total deformation of the welded joint elements was recorded using instruments.

## III. Results

### Mechanical Properties, and Failure Mechanism

According to the results of experimental studies, the stress-strain state of vertical shear bonds under the influence of shear and torque, the "shear-displacement" diagram, diagram of the dependence of the joint pliability on load were obtained. The magnitude of the destructive load is determined for cases when only shear is affected and when torsion is added.

The same pattern of specimen destruction was observed in all specimens except the last one. In shear tests, an inclined crack formed on the right panel on the left at the eighth step of the load application. The crack developed from the middle of the embedded part upwards (see Fig. 3). At the ninth step, at a load of 87.1kN avalanche cracking of concrete occurs from above and below the embedded parts and the specimen ceases to hold the load. Analyzing the sensor readings, it can be seen that the metal plates worked the plastic stage. There was no visible rupture of the plates. In the stage of destruction, there was a rotation of the connecting plate of the welded joint.

In the torsion shear tests of samples No. 3 and No. 4, a crack of a similar nature was also formed, but already at the fifth loading step. The sixth step of applying the load is considered to be the destruction of the specimen since the crack from the mortgage has already opened more than 2.5 mm.

When testing specimens No. 5 and No. 6 a different picture of destruction was obtained. The nature of the destruction of specimen No. 5 is the same as in the previous ones, but in specimen No. 6 there was no development of an inclined crack. In the ninth loading step the mortgage in the left panel was torn off. At the same time, the maximum shear force was 87.9 kN and the maximum torque moment was 10.4 kN*m.

**Fig. 3.** Destruction of the sample during shear tests

Based on the shear-displacement relationships obtained, it can be noted that the specimens in which torque was present do not have an obvious stage of plastic deformation, unlike specimens tested only in shear (see Fig. 4). The failure occurs suddenly. This should be taken into account when resisting prefabricated buildings to torsional loading during an earthquake.

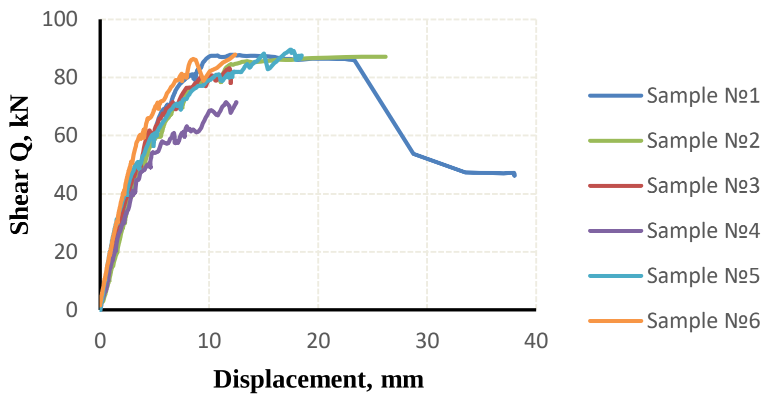


**Fig. 4.** Experimental diagrams of the "shear-displacement" of the welded joint

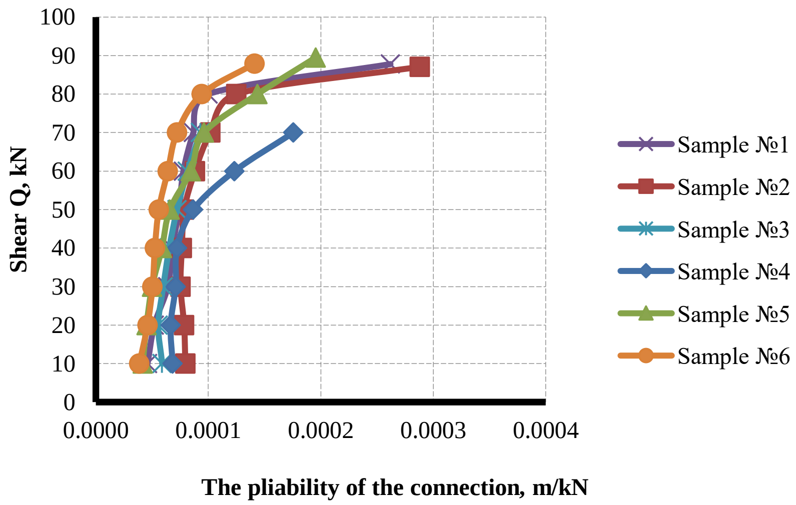


**Fig. 5** Diagram of the dependence of the joint pliability on the shear

## IV. Discussion

One of the important results of the experiment was to obtain data to determine the pliability of the joint during shear tests and separately for shear torsion. Firstly, the joint stiffness was determined by dividing the load by the displacement for each step of the load application. Next, a transition was made from rigidity to pliability, according to [XX]. Pliability was determined separately for forces Q and M. In general, there is an increase in pliability with increasing load, see Fig. 6.

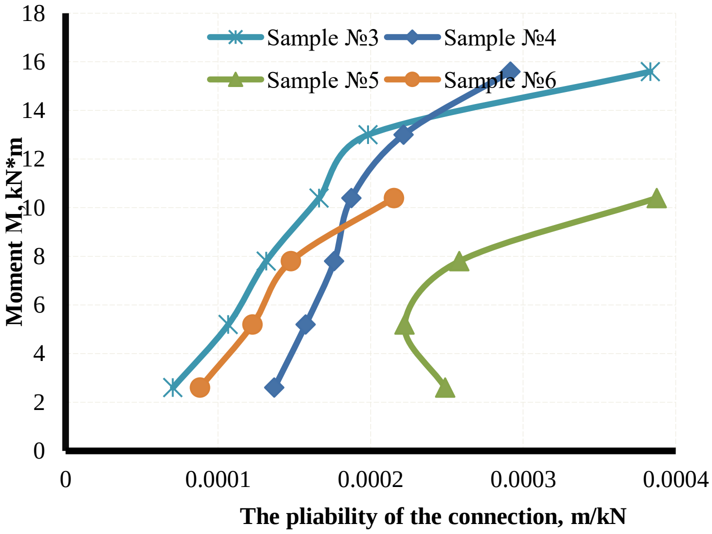


**Fig. 6.** Diagram of the dependence of the joint pliability on the torque moment

A comparison of the strain sensor readings for all six specimens was also carried out. When comparing the results, a transition was made from relative deformations to shear stresses. Sensor No. 13 was used for monitoring, which recorded shear deformations. The sensor was positioned vertically on the right side of the connecting plate, between two panels. This position of the sensor was determined by the fact that, according to the results of previous experiments destruction was assumed by metal in this place [XIII]. The results of our experimental studies of this welded joint have shown a nature of destruction different from previous tests. This section of the connection is experiencing significant shear stresses. The diagram shows that according to the shear stresses in specimens No. 5 and No. 6, the metal in this place experienced much greater stresses than other specimens. For a diagram of the shear stress dependence, see Fig. 7. According to the obtained "shear-displacement" diagrams, trend lines were constructed and a mathematical description of the function was proposed (see Table 1).

**Table 1: Description of the «shear-displacement» curves using the function**

| № samples | Function |
|---|---|
| 4 | y=6,75x+12,09 |

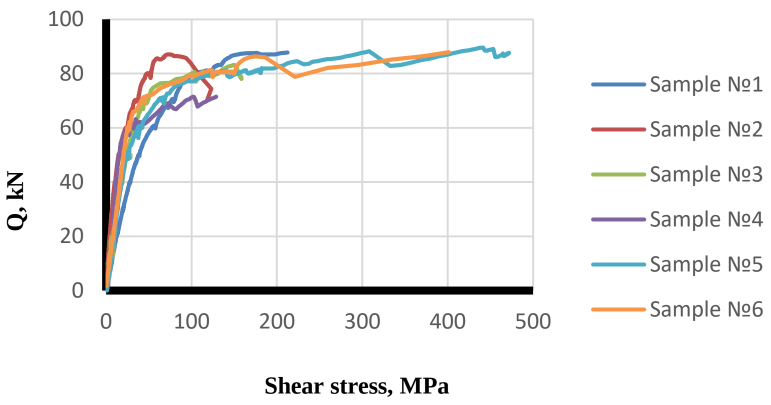


**Fig. 7.** Diagram of the dependence of shear stresses on shear

## V. Conclusion

The purpose of this experimental study was to investigate the behavior of the welded joint considering shear forces, and torsional moment.

The following results are obtained.

The deformation diagrams of the investigated connection under different loading regimes remained approximately the same. At torsion, the plasticity zone disappeared. The bearing capacity of the butt joint decreased. Loading to the exhaustion of bearing capacity in all specimens was carried out by shear force, the torsion value reached a predetermined fixed value of 30.0 kN per jack.

Failure of a fragment of a full-scale panel connection under the combined action of shear and torsion began at the 5th stage of loading out of 10. The maximum vertical load during the torsion shear tests of samples No. 3, and No. 4 was 60.0 kN. When shear alone was applied, failure began later, at stage 8. The maximum destructive load during shear tests of samples No. 1, and No. 2 was 87.1 kN. Earlier experimental tests of similar joint designs recorded metal failure. In the samples under consideration, the joint failure occurred in concrete.

The obtained experimental data on the stiffness of shear joints can be used in the FEM to determine the stress-strain state of load-bearing systems of panel asymmetric multistory buildings, taking into account the reduced strength of the joint, the lack of plasticity zone and possible brittle fracture.

## Conflict of Intrest

There is no conflict of interest regarding this article.

## References

I. Ajay T., Parthasarathi N., Prakash M., : ‘Effect of planar irregularity of linear static and dynamic analysis’. *Materials Today: Proceedings*. Vol. 40, 2020. 10.1016/j.matpr.2020.03.499

II. Benaied B., Hemsas M., Benanane A., Hentri M., : 'Seismic analysis of RC building frames with vertical mass and stiffness irregularities using adaptive pushover analysis'. *Revista De La Construcción*. Vol. 22(3), pp. 597–612, 2023. 10.7764/RDLC.22.2.597

III. Benavent-Climent A., Morillas L., Escolano-Margarit D., : 'Inelastic torsional seismic response of nominally symmetric reinforced concrete frame structures: Shaking table tests'. *Engineering Structures.* Vol. 80, pp. 109–117, 2014. 10.1016/j.engstruct.2014.08.047

IV. Botis M., Cerbu C. A., : 'Method for Reducing of the Overall Torsion for Reinforced Concrete Multi-Storey Irregular Structures'. *Applied Sciences*. Vol. 10, 5555, 2020. 10.3390/app10165555

V. De Stefano M., Pintucchi B., :'A review of research on seismic behaviour of irregular building structures since 2002'. *Bull Earthquake Eng*. Vol. 6, pp. 285–308, 2008. 0.1007/s10518-007-9052-3

VI. Drozdov P., : 'Design and Calculation of Load-bearing Systems of Multistorey Buildings and their Elements'. *Moscow*. *Stroyizdat*, 1977.

VII. Hussein G., Eid N., Khaled H., : 'Torsional Behavior of Irregular Structures during Earthquakes'. *Journal of Mechanical and Civil Engineering*. Vol. 16, pp. 40-55, 2019. 10.9790/1684-1605044055

VIII. Karyakin A.A., Derbentsev I.S., Tarasov M.V., : 'Experimental and Numerical Research on Tensile Performance of Inter-Panel Fastener Joints of Large-Panel Buildings'. *IOP Conf. Ser.: Mater. Sci. Eng.* Vol. 262, 2017. 10.1088/1757-899X/262/1/012046

IX. Khatiwada P., Lumantarna E., : 'Simplified Method of Determining Torsional Stability of the Multi-Storey Reinforced Concrete Buildings'. *Civil Eng.* Vol. 2, pp. 290–308, 2021. 10.3390/civileng2020016

X. Lim H., Kang J. W., Pak H., Chi H., Lee Y. and Kim J., : 'Seismic Response of a Three-Dimensional Asymmetric Multi-Storey Reinforced Concrete Structure'. *Applied Sciences*. Vol. 8(4), 479, 2018. 10.3390/app8040479

XI. Lyublinskiy V., Struchkov V., : 'Resistance of Vertical Joints During Torsion of Multistorey Buildings', *Proceedings of FORM 2022, LNCE, Springer.* Vol. 282, pp. 407-415, 2023. 10.1007/978-3-031-10853-2_38

XII. Lyublinskiy V.A., : 'To the question of redistribution of stress in Vertical bearing rc structures multi-story buildings'. *Building structures.* Vol. 2 (94), pp. 39-45, 2021. 10.33979/2073-7416-2021-94-2-39-45

XIII. Lyublinskiy V.A., Tomina M.V., : 'Experimental study of the strength and suppleness of a vertical welded joint'. *Syst. Meth.Techn*. Vol. 3(39), pp. 154-158, 2018. 10.18324/2077-5415-2018-3-154-158

XIV. Manual for the calculation of large-panel buildings Issue 1 Characteristics of the rigidity of walls, elements and joints of large-panel buildings. *Moscow*. *Stroyizdat*, 1974.

XV. Nabila Rossley, Farah Nora Aznieta Abdul Aziz, Heng Chiang Chew, Nima Farzadnia., : 'Behaviour of vertical loop bar connection in precast wall subjected to shear load'. Aust. J. Basic & Appl. Sci. Vol. 8(1), pp. 370-380, 2014.

XVI. Naresh kumar B. G., Punith N., Bhyrav R.B., Arpitha T. P., : 'Assessment of Location of Centre of Mass and Centre of Rigidity for Different Setback Buildings'. *International Journal of Engineering Research & Technology*. Vol. 6, Issue 5, pp. 801-804, 2017. 10.17577/IJERTV6IS050488

XVII. Negro P., Mola E., Molina F.J., Magonette G., : 'Full-scale PsD testing of a torsionally unbalanced three-storey non-seismic RC frame'. *Proceedings of 13th world conference on earthquake engineering*, Vancouver, Canada; 2004.

XVIII. Satheesh A.J., Jayalekshmi B.R., Venkataramana Ka., : 'Effect of in-plan eccentricity on vertically stiffness irregular buildings under earthquake loading'. *Soil Dynamics and Earthquake Engineering*. Vol. 137, 106251, 2020. 10.1016/j.soildyn.2020.106251

XIX. Sharma J., Singh A., Sehgal R., : 'Torsional Reduction Techniques in High Rise Structures'. *International Journal of Engineering Research & Technology (IJERT).* Vol. 3, Issue 10, 2015. 10.17577/IJERTCONV3IS10013

XX. Shen S.D., Pan P., Miao Q.S., Li W.F., Gong R.H., : 'Test and analysis of reinforced concrete (RC) precast shear wall assembled using steel shear key (SSK)'. *Earthq. Eng. Struct. Dyn.* Vol. 48, pp. 1595–1612, 2019. 10.1002/eqe.3215

XXI. Shuvalov A., Gorbunov I., Kovalev M., Faizova A., : 'Experimental studies of compliance of vertical joints used in construction of high-rise panel buildings', *MATEC Web of Conferences*, Vol. 196, 02049, 2018. 10.1051/matecconf/201819602049

XXII. Singhal S., Chourasia A., Chellappa S., Parashar J., : 'Precast reinforced concrete shear walls: State of the art review'. *Struct. Concr*. Vol. 20, pp. 886–898, 2019. 10.1002/suco.201800129

XXIII. Sritharan S., Aaleti S., Henry R.S., Liu K.Y., Tsai K.C., : 'Precast concrete wall with end columns (PreWEC) for earthquake resistant design'. Earthq. *Eng. Struct. Dyn*. Vol. 44, pp. 2075–2092, 2015. 10.1002/eqe.2576

XXIV. Yang, J.; Yang, Y.; Deng, L.; Sun, B.; Gu, Z.; Zeng, L.; Zhao, S., : 'Seismic Behaviors of Prefabricated Reinforced Concrete Shear Walls Assembled with a Cast-in-Place Vertical Joint'. *Buildings*. Vol. 13, 2023. 10.3390/buildings13123013