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Experimental study on bending behavior of prefabricated dry connection wall

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ABSTRACT

In this paper, a dry connection method for assembly wall is put forward according to the structure form of underground engineering. In this paper, an experimental study of 5 sets of dry connecting specimens for the prefabricated dry connection is carried out. The bending process, failure mode and ultimate bearing capacity of prefabricated dry connection specimens are obtained. The research work of this paper realizes the innovation of assembly technology, and provides guidance for the design of connection nodes of underground assembly wall.

1. INTRODUCTION

With the development of human settlements and urban infrastructure, the development of urban underground space had been paid more and more attention. Vigorously developing the city underground space has become a solution to urban parking, rail transportation, and pipeline layout of the necessary facilities. The underground space structure is also becoming an important field of civil engineering structure development. At the same time, the assembled reinforced concrete structure is a major structural form of the construction industry. As with the concept of the development of the industrial construction on the ground, the assembly construction has more necessity and urgency to develop in the underground space. To ensure the quality of the project, expedite construction speed and reduce the impact on normal urban traffic, its development has become the industry consensus.

The research on the connection of the connection node can be divided into two

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1) Ph.D Professor
2) Graduate student
3) Graduate student

categories in connection form, wet connection and dry connection. Wet connection, as early as 1980s, has a lot of engineering applications practice case of anchor in Japan and New Zealand and other regions, (R. Park 1995, J.estrepo 1995, Yu Z M 1991) while Jiang Hongbin (Jiang H B 2010) proposed a plug-in hole grouting reinforcement Lap connection. Dry connection includes unbonded prestressed connection of bolted connection (Menegotto M. 2008, Wilson J F 2004), posterior prestressed tendon (Y. Kurama 1999) and WALL-SHOES connection used for shear wall (Peikko Group 2006, Vimmr 2009) and other connection methods.

Unlike the ground structure, the wall structure of the underground structure is mainly affected by the circumferential load, such as the side wall of the standard section of the integrated corridor. Because underground structure is generally below the groundwater level, waterproof performance is one of the key elements in design. In the structural limit state design method, it is necessary to increase the limit state of the waterproof performance index. Therefore, according to the structural characteristics of the assembled underground structure and the corresponding waterproof performance requirements, a prefabricated dry connection wall is proposed for the upper and lower wall connection nodes of the assembled underground structure based on the concept of dry connection.

In this paper, the applicability of the connection method and the two-parameter design method based on the structural performance and waterproof performance are studied experimentally. The innovation of the assembly technology is realized and the connection design guidance of the upper and lower wall of the assembled underground structure is provided.

2. SPECIMEN AND TEST PLAN DESIGN

2.1 Prefabricated dry connection wall description

As shown in Figure 1, the fabricated joints are specially made of steel bars, which are manufactured by Finnish Peikko, consisting of three parts: a steel connection box, anchor bars welded with the connection box and connecting bars. In the design of the prefabricated components, the steel bar connection box and the front, behind, up and down of connecting steel are staggered on the splicing surface. The steel connecting box and connecting steel bars in the set position and anchorage fixed, and with the rest of the steel band formation Steel cage. After pouring of concrete, the connection box, connection steel bar and concrete become a monolithic prefabricated part. We put the two pieces of prefabricated components together, stitching with bolts to form the assembly.

2.2 Specimen size and loading program

The loading characteristics of underground structure is bearing circumferential load, bending in cross-section, making the prefabricated wall becoming bending components. In order to examine the feasibility of the assembled connection nodes and their mechanical properties, five sets of test pieces were designed to carry out the bending performance test of the prefabricated dry connector. The basic information of the components is shown in Table 1.

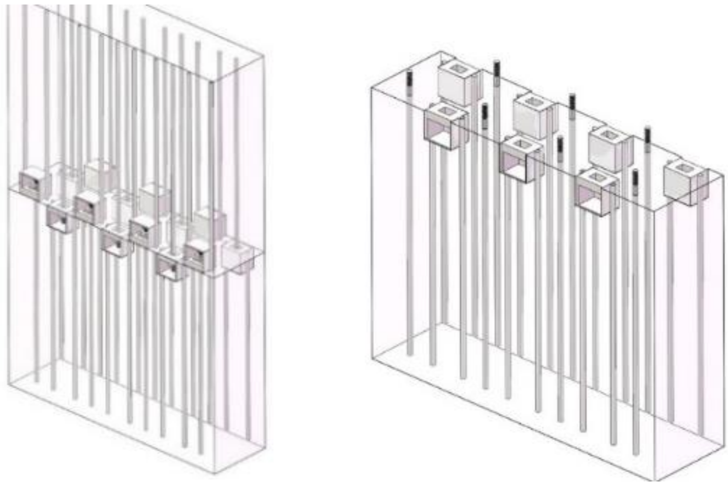

Fig.1 Prefabricated dry connection wall

Table. 1 Component size table

No.	Section Size	Strip	Structure Glue	Reinforcement	Connection Arrangement
L-D-300	300*400*2600	no	smear	1F20/2F16	Unilateral
LJ-D-300	300*400*2600	yes	no	1F20/2F16	Unilateral
L-S-500	500*400*2600	no	smear	1F20+2F16	Bilateral
L-D-600	600*400*2600	no	smear	2F20/4F16	Unilateral
L-S-700	700*400*2600	no	smear	1F20+4F16/2F20+2f16	Bilateral

Note: L is the connecting element, J is the waterproof tape; D is the connector arranging in one side, S is the connector arranging in both side, and the number shows the cross section width.

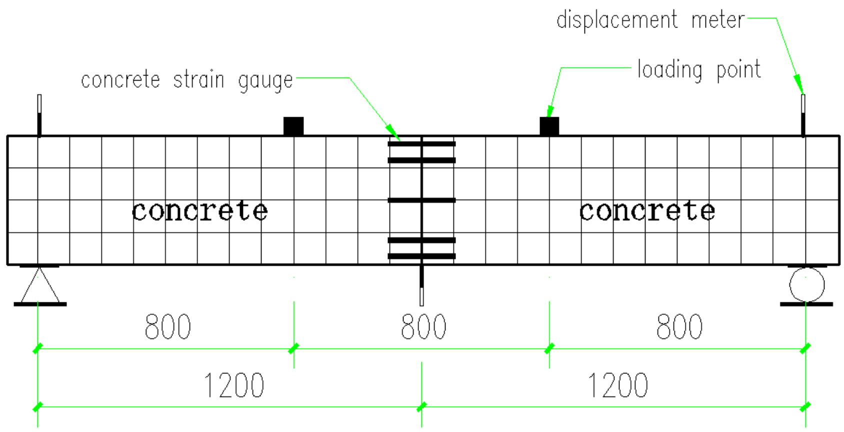

Fig.2 loading device and instrument layout

The loading scheme and the corresponding instrument layout are shown in Fig.2. The loading device is a 50-ton jack combined with a reaction stand. The steel plate and the steel shaft are placed in the width direction at the loading point and the steel shaft is fixed.

2.3 Specimen production

The prefabricated dry connector specimen is made of two 1300mm counter-symmetrical prefabricated members made of bolts, each of which is molded with a steel mold at the end and a side and bottom wood mold. The end of the steel mold in the appropriate location of the precise opening, reinforced joints and connecting steel through bolts in advance fixed on the steel mold as shown in Fig. 3, making the steel joints and connecting steel bars in the concrete components in the error control within 1mm, solving the installation error in the production.

Fig.3 The connector is fixed

Fig. 4 Preform splice

After the completion of the maintenance, the two prefabricated components flip 90 degrees on the steel pipe slide to assemble, as shown in Figure 4. When assembling, you need to apply the structural glue to the seam surface in advance to make the finished construction of the finished glue, the two prefabricated components sliding alignment, connecting the steel through the steel connection box, into the pad, with bolts, Place the specimen of the waterproof tape, tighten the bolt with a wrench, and do not apply additional torque. For the specimen placed in the waterproof strip, control according to the calculate amount of compression, and to ensure that the joint surface parallel.

2.4 Test piece material

Select three groups of steel with the diameter of 16,20mm respectively. Test in the hydraulic universal testing machine, measured the yield strength, tensile strength and the corresponding yield strength and limit strength of steel bars with data shown in Table. 2. C50 commercial concrete is used, the specimen is divided into two times to complete the pouring, each pouring left three sets of test block for the detection of concrete strength. The test block uses 100mm cubic test block and will be converted to the standard value of concrete axial compressive strength. The test results are shown in Table. 3.

Table. 2 steel properties

No.	diameters (mm)	Yield tension (KN)	Limit tension (KN)	Yield strength (MPa)	Ultimate strength (MPa)	Yield strain (micro strain)
1	16	101	130			
2	16	103	131	512	649	2530
3	16	104	131			
4	20	165	202			
5	20	165	201	527	645	2589
6	20	167	202			

Table. 3 Concrete properties

No.	compressive strength of the cube (MPa)	Mean value of axial compressive strength (MPa)
1	51.8	33.5
2	52.2	33.8

3. TEST PHENOMENON

According to the phenomenon of the test, the stress deformation process of the L-D-300 specimen is divided into three stages: the elastic stage before cracking, the cracked work from the cracking to the pre-yield stage and the post-yield stage.

Before the cracking of the elastic section: we can see from the load displacement curve, before the first fracture appears (the external load before 68KN), the specimen load displacement curve is basically a straight line, the specimen stiffness is consistent with the maximum slope in the load displacement curve, where the strain distribution of the concrete along the cross section is basically a straight line distribution, as shown in Figure 5. Until the emergence of cracks, stiffness began to decline gradually.

The second stage: work with cracks before specimen yields. When the external load is loaded to 68KN, the specimen has the first crack, and the location of the crack is at the interface of the mid-span. At this time, the structural adhesive of the interface loses its tensile strength and appears to be brittle cracking (once cracked, it develops upwards sharply), and the interface opening gradually increased. The crack opening trend there is greater than the rest of cracks. When loaded at 85KN, cracks are beginning to appear at other locations in the bend area, and it can be seen that the number of cracks is small as the load increases. Some cracks in the vicinity of the loading point is due to the interface after the opening, the left and right parts of the prefabricated concrete integrity is good, and with the rest of the structural tendons, making the reinforcement ratio greater than the interface of steel bars. It provides a pin bolt action, so that the cracks in the component near the seat are more intensive. When the external load is added to 110KN, it can be seen from the load displacement curve that the stiffness of the structure begins to decrease obviously.

The third stage: after the specimen yields. When the external load increases to 110KN, the specimen begins to yield, after which the stiffness increase of the specimen is very slow, and the mid-displacement increases sharply with the increase of the external load. The crack width is also increasing, but mainly concentrated in the interface seams. The remaining position of the crack width growth is small. At this point the specimen deformation is large, performs as the left and right parts of the prefabricated parts rotates relatively of each other. With the increase of the load, the steel reaches the yield strain, and the concrete in the compression area crushes, and the whole performance is the damaged form of the reinforced beam. The load displacement curve of the specimen is shown in Fig. 6.

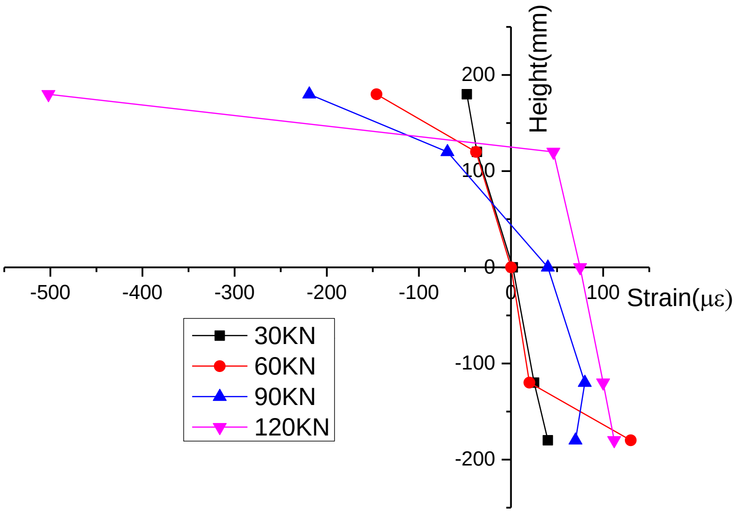

Fig.5 Strain curve of concrete in L-D-300 specimen

LJ-D-300 specimen has 3mm width spacing due to the existence of the tape, so the test is divided into two stages: loading to yield and after yielding. The two stages are described as follows:

Loading to the yield: At the time of loading, since the seams have initial spacing, the load is first brought into contact with each other by means of coagulation in the compression zone, where only the compression force of the strip can be overcome. The component as a whole has an initial rotation and an initial deflection, the external load is small at this point and can be ignored. After the compression zone coagulation contact, the specimen began to show certain stiffness and load rises. There is no crack at the beginning of the load, and the left and right specimens show significant rotation. When loading to 92KN, the first crack at the bottom of the interface appears at loading point. When loaded to 122KN, the fracture of the specimen occurs, and the location

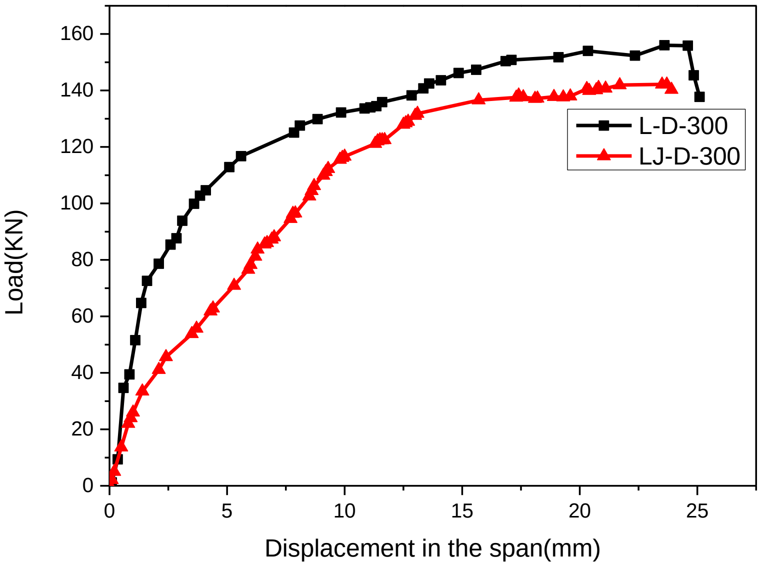

Fig.6 Load displacement curve

of the crack is close to the other four sets of specimen, near the interface and below the loading point. At this time there is a crack in the compression zone of the concrete, the reason for the failure of the concrete is not fracture, but the angle of rotation is relatively large. The interface pressure as part of the friction force in the surface of the concrete pressure zone causes the concrete cracking. From the load-displacement curve, it can be seen that the deflection reaches 13 mm when the specimen is yielded.
After the yielding stage: When loaded to 110KN, the rigidity of the specimen decreases sharply and the deflection increases rapidly. In contrast to the rest of the test pieces, the strengthening section of the specimen after yield is not obvious. After the specimen yielding, the concrete in the compression zone is soon crushed and broken, and the ductility of the specimen is very small.

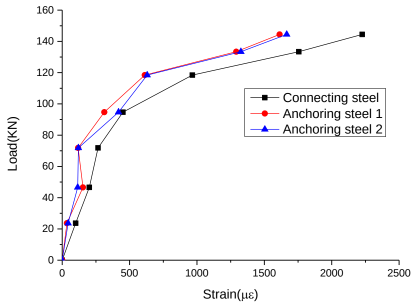

Fig. 7 L-D-300 steel strain

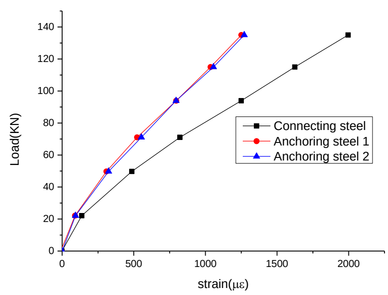

Fig. 8 LJ-D-300 steel strain

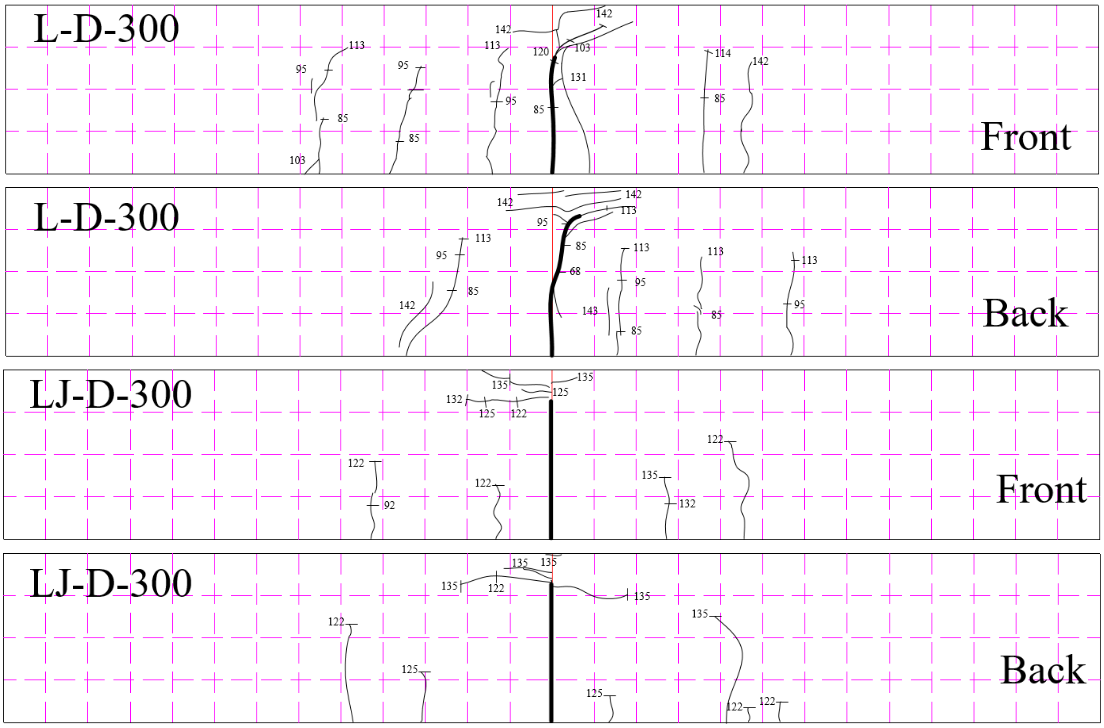

Fig. 9 specimen loading process

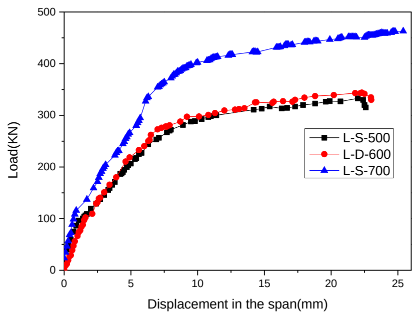

Fig. 10 specimen loading process

Fig. 11 Load-displacement curve

Table. 4 Specimen cracking and yield load

No.	Cracking load (KN)	Yield load (KN)
L-S-500	105	250
L-D-600	122	270
L-S-700	158	350

The experimental phenomena of the other three groups were similar to those of L-D-300, and are summarized in Table. 4. The load-displacement curve is shown in Fig. 9

4. TEST RESULTS AND ANALYSIS

It can be seen from the strain curve, the connecting bar yields earlier than that of the connecting box. The reinforcement area of the connecting bar is smaller than that of the connecting box, but the deformation of the two is basically coordinated. The forces are basically the same and the performance of steel joints work well.

The comparison of the load displacement curves between L-D-300 and LJ-D-300 shows that the yield loads are basically the same, both at 110KN. The former deflection of the middle of the span (5.1mm) is much smaller than that of the latter (9.2mm). The main reasons are three points: 1, the strip of the LJ-D-300 specimen causes the initial spacing at the interface. The load is overcome by the elasticity of the strip to contact the concrete in the compression zone, so that the upper stage is pressed by the upper strip; 2, as the initial spacing exists, there is a certain initial rotation angle. 3, only the contact part of the pressured area of concrete can provide resistance, resulting the height of the pressure zone increases with the load increasing before the yielding load, reducing the stiffness of the structure. So that the deformation due to yield is too large, that is, the normal use of the tape may also lead to insufficient amount of water leakage, and the corresponding structural ductility decreased. It can be seen, however, that the effect of the tape itself on the structure is very small, mainly due to the arrangement of the tape and the initial compression, the seam interface is not completely closed leading to the initial deformation of the structure.

Specimens L-S-500 and L-D-600 were used in the form of two kinds of steel bars, respectively, arranged in both sides and unilateral layout. The double-sided arrangement of the rebar connections can increase the clearance of each side of the connection box so that the reinforcement ratio can be increased without increasing the diameter of the bars. It can be seen from the comparison of the load displacement curve that the initial stiffness, yield load and ultimate bearing capacity of the two specimens are very close, and the L-D-600 is slightly improved by the width. It can be seen that the deflection of the three sets of members is very close to the yield strength, indicating that the rotation angle of the three sets is close to that of the three, and the arrangement does not improve the rotational stiffness of the structure. It is because the reinforcement ratio is determined by the diameter and number of connecting steel bars. It can be seen from the steel members of the structural strain from the seams opening to the second stage of the yielding. The strain load relationship of the rebar is close to the linearity. At this time, the compressive strain of the concrete does not reach the peak strain, the deformation of the component is elastic deformation, and the reinforcement area of the joint interface determines the elastic rotation stiffness. As can be seen from the results, both types of prefabricated dry connector can meet the structural bending performance requirements, which can be selected in design.

It can be seen from the experimental phenomena that the failure modes of each specimen in the test are the yielding of the steel in the tension zone and the crushing of the concrete in the compression zone. The overall performance is the damage form of the reinforced bending member. The ultimate bearing capacity of the cast-in-place concrete specimen under the same reinforcement ratio is close to the ultimate bearing capacity. When the specimen is broken, a large relative rotation occurs between the two prefabricated concrete pieces. Although the rotation effect does not affect the ultimate bearing capacity of the structure, the opening of the interface is large. For the underground structure, it is possible that the use of the structure influenced before the ultimate bearing capacity because of water leakage, which can also be defined as reaching ultimate state and damage.

5. CONCLUSION

Through the experimental study on the bending performance of the prefabricated dry connector, the bending process and the failure mode of the specimen are observed. The main conclusions are as follows:

(1) The deflection of the specimen occurred in the bending process as well as rotational deformation. It can be obviously observed in the results that the rotation of the specimen leads to the opening of the joints significantly. The steel deformation at the connection joints is large. When the specimen is broken, the compression zone of the concrete crushing is also concentrated in the vicinity of the seam. The interface is the most obvious load response section of the prefabricated dry connector.

(2) During the test process, the cracks have a certain law. For the specimen with structural adhesive, with the increase of the load, the structural adhesive connection surface first cracks, leading the cracks along the interface upright, due to the role of steel pin and the reinforcement of the stress transmission. There is also a corresponding crack below the loading point and near the interface.

(3) The test results show that the working performance of the steel bar connector is good in the structure, and the connection of the steel bar and the connecting box steel can work well, which proves that the assembly node has a reliable force transmission path. Because the connection box has high reinforcement ratio and small bar diameter, its control of the crack is better than the connecting steel.

(4) The single and double side arrangement of the connecting member has little effect on the bearing capacity of the structure, and the experimental results show that the bearing capacity of the tension zone after cracking is uniformly supported by the reinforced area of the tension zone, which does not cause eccentricity. The design of the prefabricated dry connector in the case can be arranged with asymmetrical reinforcement and the staggered arrangement of the upper and lower prefabricated members is more consistent. The experiment shows that the crack distribution is relatively symmetrical.

(5) The strip itself has little effect on the basic performance of the structure. However, due to the existence of the strip, the initial spacing of the structural joint decreases the rigidity of the structure by 45%. Although it does not affect the ultimate bearing capacity of the structure, it has excessive effects on normal use due to large

deformation. It is recommended setting the groove to solve the problem of the amount of adhesive and the initial spacing of the strip in the initial design.

6. ACKNOWLEDGEMENT:

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7. REFERENCE

R. Park, (1995), "Perspective on the Seismic Design of Precast Concrete Structures in NewZealand". PCI Journal, 40(3), 40-60.

J.estrepo, R. Park and A. H. Buchanan, (1995), "Design of Connections of Earthquake Resisting recast Reinforced Concrete Perimeter Frames". PCI Journal, 40(5), 68-80.

Yu Z M, (1991), "Sleeve-grouted reinforced steel joint in Japan". Architecture Technology, 2, 50-53.

Jiang H B, (2011), "Quasi-static test of precast reinforced concrete shear wall structure". Journal of Building Structures, 32, 34-40.

Menegotto M. (2008), "Structural Connections for Precast Concrete. Technical Council of Fib", Fib Bulletin, 43(2), 34-37.

Wilson J F, Callis E G, (2004), "The Dynamics of Loosely Jointed Structures". International Journal of Non-Linear Mechanics, 39, 503-514.

Y. Kurama, R. Sause, S. Pessiki and a. L. Lu, (1999), "Lateral Load Behavior. And Seismic Design Of Unbonded Post-Tensioned Precast Concrete Walls", ACI Structural Journal,96(4), 622-632.

Peikko Group. PSK Wall Shoe. Peikko News, (2006).

Vimmr, Zahr SharifKbodaei. Wall Shoes and Field of Application[R]. Peikko News, (2009).