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論文 A Study on the Resistance Mechanism of Spliced Bar Joints for Precast Concrete Shear Walls

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ABSTRACT

Pullout tests of 90 spliced bar joints for precat walls were conducted. Actual contributions of spiral steel and concrete confinement to the maximum tensile load and to the pipe bond resistance are obtained. Based on the values of tensile loads and strains on main bar, lapped bar and spiral steel, the failure processes are categorized into whether the concrete is cracked or uncracked. The modes and step-by-step processes of failure of the bar connection under tension are discussed.

KEYWORDS: winding pipe, grout, spiral steel, precast shear wall, lapped bar, tensile load, bond stress, concrete confinement, pipe bond failure, direct pullout.

1. INTRODUCTION

Previous studies [1, 2] show that the vertical bar connection (see Fig. 1) subjected to pullout load fails in two ways when the main bar used has screw type lugs. These are bond failure on the surface of the winding pipe wherein the main bar, grout and winding pipe act as one, and direct pullout of main bar from the grout. In investigating the seismic behavior of walls [3] with such bar connections, main bars with bamboo type lugs were used. Bamboo-type bar is commonly used in actual construction. Whatever reason there is in using two types of main bars, it is essential to verify the actual performance of both types.

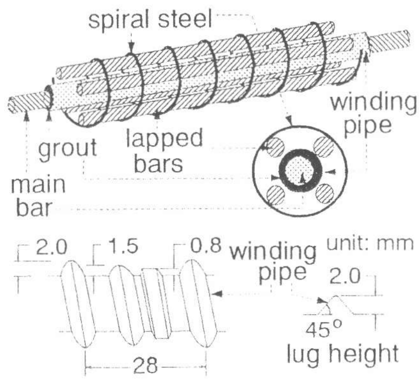

Fig. 1 Details of bar connection.

It was also found out in previous tests that the factors affecting the maximum tensile resistance of the connection are lapped length, size of splice bars, concrete thickness, spacing of main bars, amount of confining reinforcements such as lateral reinforcements and spiral steel, splitting strength of concrete, and winding pipe lug height. Those which have slight effects on the tensile capacity are cyclic loads below yield strength of the bar when the lapped length is 20d (20 times the lapped bar diameter) or more, and winding pipe diameter. When factors such as size of lapped bars and spacing of main bars are varied, there is a change in lapped length and in concrete confinement, respectively. The maximum load increases or decreases not because of the change in size of lapped bar or spacing of main bar but because of the change in lapped length and in concrete confinement, respectively. Therefore, it may be generalized that there are only three major factors which greatly influence the tensile resistance of the joint. These are lapped length, concrete confinement, and amount of confining reinforcement particularly the spiral steel. With the main bar type and these three major influencing factors as principal parameters, a pullout test of the connection was conducted.

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1.1 OBJECTIVES

Thorough analyses of the previous test results led to an additional experiment with the following objectives:

1) to confirm the reason why two types of failures occur,
2) to evaluate the actual contribution of spiral steel and concrete on the tensile resistance and on the average bond stress and to explicate clearly the factors that influence them,
3) to obtain the actual strain distributions on the main bar, lapped bar and spiral steel,
4) to understand the step-by-step failure processes of the bar connection under tension, and
5) to be able to explain the mechanism of each failure process.

2. EXPERIMENTAL METHOD

2.1 SPECIMENS AND PROPERTIES OF MATERIALS

Ninety specimens were subjected to pullout tests (see Fig. 2). These specimens were divided into six groups at 15 specimens per group. In each group, 10d, 15d, 20d, 25d and 30d, five of variations on the lapped length at three specimens per variation were done. The first group which was considered to be the reference group had 200 x 200 mm concrete section, 60-mm spiral steel spacing, D25(SD390) main bar with bamboo type and screw type lugs, 4-D13 (SD680) lapped bars, and 42-mm winding pipe inner diameter with 2.0-mm lug height. Four D13 bars have a total cross sectional area almost equal to that of D25 bar. The changes done in the other five groups were main bars with screw type lugs, without spiral steel, with 30 mm spiral steel spacing, 400 x 400 mm concrete section, and 400 x 400 mm concrete section without spiral steel. The specified strengths of concrete and grout are 300 kgf/cm^2 and 600 kgf/cm^2, respectively. Actual strengths of materials used are shown in Table 1.

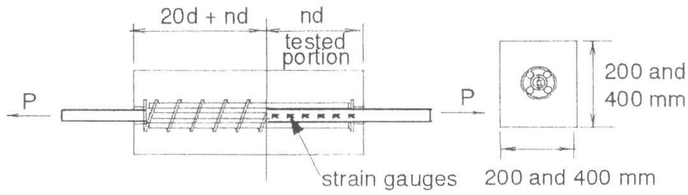


Fig. 2 Sketch of specimen.

Table 1 Strengths of materials.

a) Concrete unit: kgf/cm^2

	28 days	start of exp t	end of exp t
compressive	302	335	379
splitting	27	31	29

b) Grout unit: kgf/cm^2

	7 days	28 days
compressive	630	814

c) Steel unit: tonf/cm^2

Size/Specs.	Actual Yield	Maximum Tensile	Young s Modulus	Remarks
D29(SD390)	4.4	6.3	2010	reaction
D25(SD390)	4.5	6.4	2030	bamboo type
D25(SD390)	4.4	6.2	1960	screw type
D13(SD685)	7.9	10.0	2040	lapped bar
D10(SD295A)	3.8	5.4	1900	lateral bar
6 mm	5.5	6.1	1950	spiral

2.2 LOADING METHOD, DISPLACEMENT TRANSDUCERS AND STRAIN GAUGES

In the previous pullout tests where oil jacks were used, main bars with screw type lugs were adopted for convenience in testing. In this experiment, a 200-tonf testing machine was employed in order to mount bars with either screw type lugs or bamboo type lugs, and to obtain the relations between the load and displacement after the maximum load is reached. A strain gauge was put at every 65 mm interval on main bars and lapped bars and in every turn of spiral steel. The strain distribution on the main bar was obtained using the technique of Nilson [4], where the bar was sawed longitudinally on a diametrical plane and slots for strain gauges were milled along the center line. The displacement within 30 mm portion above and below the abutted ends of main bars (Fig. 3) was monitored using four

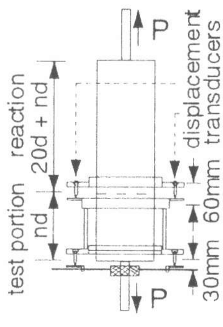
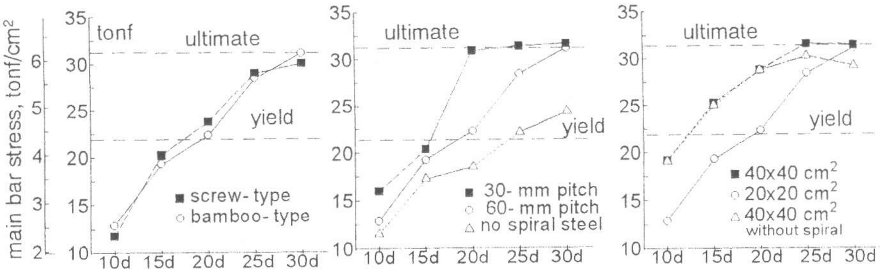


Fig. 3 Gauges.

displacement transducers mounted on four faces of the specimen. The elongation from that portion to 30 mm below the confined end was measured using four transducers. The sum of their averages was assumed to be the total displacement of the tested portion.

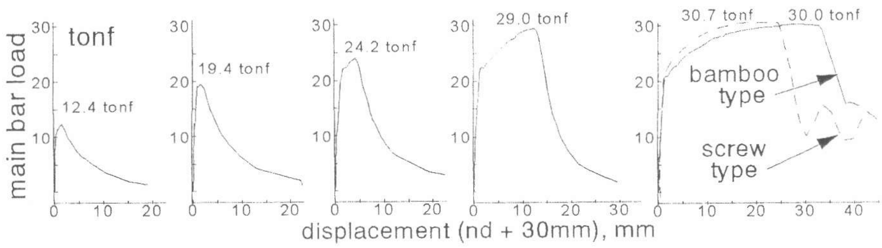
3. DISCUSSIONS AND ANALYSES OF TEST RESULTS

3.1 MAXIMUM TENSILE RESISTANCE AND LOAD - DISPLACEMENT RELATIONS



a) bar type varied b) spiral steel varied c) concrete thickness varied

Fig. 4 Average maximum tensile loads.



a) 10d b) 15d c) 20d d) 25d e) 30d

Fig. 5 Load - displacement relations.

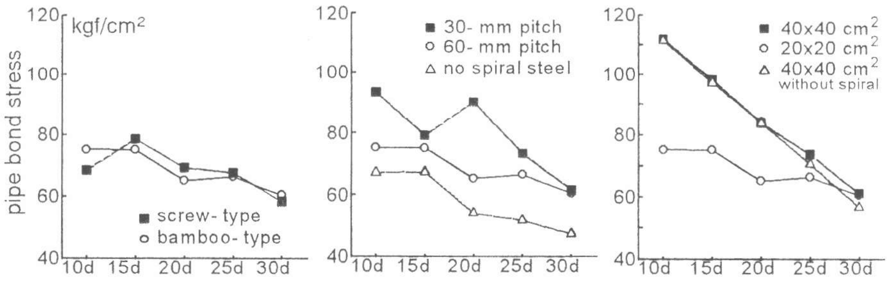
In this pullout test, where only these three major factors were varied, the actual contributions of spiral steel and concrete confinement on the tensile capacity at a wider range of lapped length (10d, 15d, 20d, 25d, and 30d) were obtained. The maximum tensile load when the main bar has screw type lugs is similar to that with bamboo type lugs (see Fig. 4(a)) but there is a different manner of failure when the ultimate strength of bar is reached (see Fig. 5(e)). As shown in Fig. 4(b), when lapped bars are confined to spiral steel with 60 mm pitch, the maximum tensile load increases by approximately 12.0 percent of that without spiral when lapped lengths are 10d and 15d. From 20d to 30d lapped length, the additional load due to spiral steel confinement is about 20 to 30 percent. Confining to 30-mm pitch spiral steel, gives 20 to 40 percent increase on the tensile load when the lapped lengths are 10d and 15d. When the lapped length is 20d, the contribution reaches around 60 percent of the connection without spiral. At 25d and 30d, the connection strength could not be obtained because the main bar collapsed.

Figure 4(c) shows that when the area of the concrete section of specimens with 60 mm spiral pitch was changed from 200x200 mm to 400x400 mm, the maximum tensile capacity increased to about 30 to 50 percent when the lapped length is within 10d and 20d. In higher lapped lengths, the actual contribution of the concrete confinement can not be evaluated because the resistance is more than the ultimate load of the bar. At 400x400 mm concrete section, whether the connection is confined to spiral steel or not, does not make any big difference on its maximum tensile capacity. The load - displacement relations in Fig. 5 show the behavior after the maximum load is reached.

3.2 AVERAGE BOND STRESS ON WINDING PIPE AT MAXIMUM LOAD

Only the average bond stress on the surface of the winding pipe (maximum load/(lapped length x pipe circumference)) is examined because almost all specimens failed in bond on the pipe. In the past pullout tests, where 15d to 30d lapped lengths and utmost 200 mm thickness of concrete were adopted, the average bond stress on the winding pipe at peak load ranges from 60 to 80 kgf/cm^2. This experiment confirms that the average pipe bond stress decreases to 50 kgf/cm^2 when the wall thickness is 200 mm and without spiral steel confinement (see Fig. 6(b)). This bond stress reaches almost 115 kgf/cm^2 when the concrete section is 400x400 mm even without spiral steel (see Fig. 6(c)). These figures show that at 20d to 30d lapped length, the pipe bond stress when confined to 30-

mm pitch spiral steel at 200 mm concrete thickness is the same when the concrete thickness is 400 mm with or without spiral steel. The difference occurs when the lapped lengths are 10d and 15d. The bond stress in specimens with 400 mm thickness increases constantly while that in specimens with 30-mm spiral pitch becomes somewhat constant. This indicates that concrete is the main factor that affects the bond on the pipe. At 400 mm thickness, no crack was noticed when the peak load was reached which means that there was a nearly perfect concrete confinement of the connection. In such a case, the effect of spiral steel on the pipe bond stress is very slight which may be neglected.

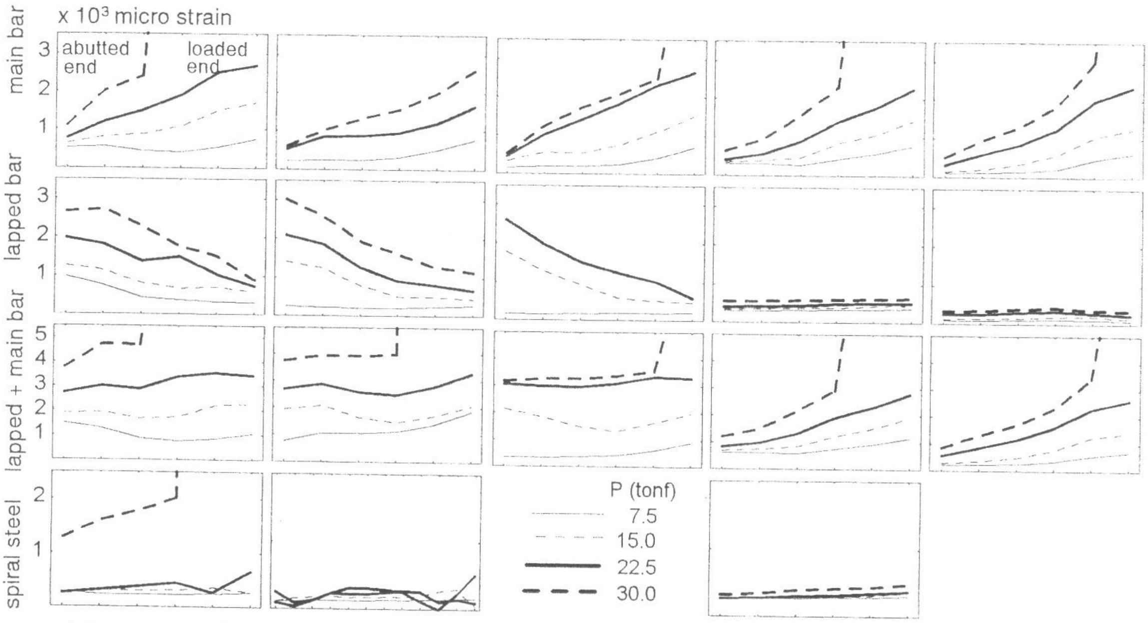


a) bar type varied b) spiral steel varied c) concrete thickness varied

Fig. 6 Pipe bond stresses at maximum load.

It can be concluded from this fact that the main cause of failure for this type of connection is the cracking of concrete. Uncracked concrete together with lapped bars and confining reinforcements act as one solid body which resists the pullout load on the main bar. The component materials of this solid body have no movement relative to each other. They deform together as if each material is a part of a monolithic body. The spiral steel and other reinforcements are activated only after cracking of concrete.

At 200 mm thickness, the contribution of spiral steel with 60 mm pitch to the bond resistance is approximately 12 percent of that without spiral when lapped lengths are 10d and 15d, and 21 to 28 percent when lapped lengths are 20d, 25d and 30d (see Fig. 6(b)). When the spiral pitch is 30 mm, the bond stress increases by 39 percent of that without spiral steel when the lapped length is 10d, 18 percent when the length is 15d, and 67 percent at 20d length (see Fig. 6(c)). At lapped lengths of 25d and 30d, the actual contribution can not be determined because the main bar collapses before the bond stress at maximum possible load is reached.



a) 200x 200 mm² 60 mm spiral pitch
b) 200x 200 mm² 30 mm spiral pitch
c) 200x 200 mm² no spiral
d) 400x 400 mm² 60 mm spiral pitch
e) 400x 400 mm² no spiral

Fig. 7 Strain distributions on main bar, lapped bar and spiral steel at 30d lapped length.

3.3 STRAIN DISTRIBUTION ON MAIN BAR, LAPPED BAR AND SPIRAL STEEL

The actual strain distributions on the component materials of the connection with different parameters are shown in Fig. 7. Only the strain distributions of specimens with 30d lapped length were plotted because they are similar to those in specimens with lower lengths at the same load level. Clear differences can be observed on the strains of lapped bars and of spiral steel especially when the thickness of concrete is changed from 200 mm to 400 mm. The implications of such distributions are discussed in the following section.

3.4 FAILURE PROCESS AND MECHANISM

There are two types of connection failure when subjected to pullout load. These are pipe bond failure and direct pullout of main bar. In specimens with bamboo type bars, all failures are in bond on the pipe. Direct pullout of main bar only occurred in screw type main bars when the maximum load reached the ultimate strength of the main bar. In the other specimens having screw type bars which did not reach the ultimate load, the failure was in bond on the pipe. One reason why direct pullout of main bar happens is that at ultimate load level, the main bar shrinks because of excessive elongation particularly at the end portion of the specimen. The shrinkage somehow decreases the bond between the main bar and the grout. But the main reason is that the spacing of lugs in screw-type bar is 10 mm while that in bamboo-type bar is 15 mm. The lesser the spacing of lugs, the smaller the amount of resisting concrete between lugs.

The abovementioned two types of failure are only after the maximum load is reached. It is also important to know the step-by-step process of failure from the beginning of loading until before the maximum load is reached. In this investigation, two different processes of failure occurred. These processes differ mainly because of the thickness of concrete. In 200 mm thick specimens, the failure starts by cracking of concrete perpendicular to the main bar at portion where main bar ends meet. Just before or after that perpendicular cracking, longitudinal splitting starts at the end of the specimen and develop gradually along the length. Related studies by Tepfers [5], Goto [6], Gambarova et al [7], Orangun et. al [8], and Fujii-Morita [9] explain the manner of occurrence of longitudinal cracks. If there is no spiral steel or reinforcement across the longitudinal cracks, the connection collapses suddenly when the splitting resistance of concrete along the length is exceeded. If there are reinforcements across the longitudinal cracks, more resistance is acquired which results to higher tensile resistance and a ductile failure. However, in 400 mm thick specimens, usually there is no perpendicular or longitudinal cracking on concrete. The load increases until the maximum bond resistance (values shown in Fig. 6(c)) between the surface of winding pipe and the concrete is reached. That is when failure occurs. The resistance against tensile load of main bar is solely done by the concrete together with lapped bars and confining reinforcements which act as one solid body. Lapped bars, lateral reinforcements and spiral steel do not move separately relative to each other or to concrete. Their deformations coordinate with the necessary displacements of parts of a solid body. In other words, when the concrete is uncracked, these component materials do not act against each other, rather, they cooperate with one another by working together in resisting the pulling out load. A good proof is that the strain distribution (see Fig. 7(d) and (e)) on lapped bars remains constant from the beginning of loading until the maximum load. This indicates that there is no bond stress acting on lapped bars and its strain is similar to the strain of concrete. The confinement of spiral steel has a very slight effect on bond stress if the thickness is 400 mm. With and without spiral steel, the maximum tensile resistance is the same when the concrete thickness is 400 mm (see Fig. 4(c)).

The main difference in these two processes is that in uncracked concrete, the concrete, lapped bars, mesh reinforcements and spiral steel act as one monolithic body resisting the main bar together with grout and winding pipe, while in cracked concrete, each component material acts separately. An example is the case of specimens with 200x200 mm concrete section. The splitting strength of concrete, which can be considered to be its tensile strength as well, is 30.3 kgf/cm^2. Multiplying this value by the area of the section transformed to concrete (417 cm^2) gives 12.6 tonf (agrees well with the test results), which is the required tensile load to cause sectional crack perpendicular to the main bars. The sectional crack usually occurs near the location of main bar ends. When this happens, the normal stress, which can be assumed to be uniformly distributed over the section of specimen perpendicular to the main bar, concentrates suddenly to lapped bars because the tensile resistance of concrete on that section is lost completely. It means that the tensile stress carried by both concrete and lapped bars before cracking becomes the load of lapped bars alone after cracking. This statement is testified by the observed sudden increase in the values of strain gauges (see Figs. 7(a), (b) and (c)) of lapped bars near the crack at that load level. Such occurrence caused major changes on the resisting mechanism against pullout load. Instead of concrete, lapped bars and spiral steel against the main bar, the mechanism becomes lapped bars against main bar through the confinement of concrete segment and spiral steel between the pulling end of lapped bar and that of main bar. In such a case, the confinement of concrete and spiral steel prevents not only the main bar from coming out of one end but also the coming out of lapped bars from the other end. This phenomenon is the reason why the strain distribution on lapped bars of 200-mm thick specimens is not constant. If perpendicular cracking does not occur as in the case of 400-mm thick specimens, then the strain distribution on lapped bars is uniform as can be seen in Fig. 7(d) and (e). Perpendicular cracking does not occur in 400-mm thick specimens because the required tensile load to produce that crack is approximately 48.0 tonf but the ultimate load of the main bar is only about 32.0 tonf .

4. CONCLUSIONS

From the foregoing discussions and analyses of test results, the following conclusions are drawn:

1. The three major factors which greatly influence the tensile resistance of the connection are lapped length, concrete confinement and amount of confining reinforcement particularly the spiral steel.
2. The connection always fails in bond on the winding pipe except the case of the main bar with screw type lugs (1.0 mm lug spacing) which reached the ultimate strength level of the bar.
3. The failure process can be categorized into whether the concrete is cracked or uncracked. Since walls usually have small thickness, the failure mechanism will be that of cracked concrete.
4. Cracking of concrete mainly causes the collapse of the connection. It causes separate action of component materials while uncracked concrete together with lapped bars and confining reinforcements act together as one against pullout load on main bar.
5. Spiral steel, lateral reinforcement and lapped bars are greatly activated only after cracking of concrete.
6. Ranges of maximum tensile loads and bond resistance on the winding pipe are established when lapped lengths are within 10d and 30d. Actual contributions of spiral steel and confining concrete are obtained.

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