

BOND STRESS IN GROUTED SPIRAL CONNECTORS

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Abstract

Grouted connections are defined as the system used to join steel rebars available in precast components by means of grouting the splice sleeve and steel rebars together. The bond between the infill material and the steel bar is the key factor that governs the capacity and the performance of the connection. This study was carried out to investigate the parameters that affect the bond-slip relations in the connection. The variables in this study were the pitch distance of the spiral and reinforcement bar diameter. Altogether, 21 specimens were prepared in which 3 of them were the control specimens. Each splice sleeve utilized a spiral surrounding the main bars and 4Y10 steel splice bars which were welded to the inner surface of the spiral. All the grout filled splices were tested under increasing tensile loading. The experiments examined the bond stress-slip behaviour as well as the failure mode of the splices. The results indicate that by using the spiral without the vertical bars could not increase the bond capacity of the splices significantly. The results also showed that by reducing the bar diameter and the pitch distance of the spiral led to a higher bond strength. The highest bond stress was observed in the specimen with the lowest pitch distance and smaller bar diameter.

Keywords: Grouted splice connection, bond stress, confinement, tensile tests, precast concrete connection

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1.0 INTRODUCTION

In Malaysia, precast concrete building system is one of the Industrialised Building Systems (IBS) that has gained much popularity. The loose prefabricated precast concrete components are joined together using structural connections to make a complete building. Grouted splice sleeve is one of the structural connection widely used in precast concrete systems. It is used to join precast concrete components through the protruding reinforcement bars available in each precast concrete component. The grouted splice connection is popular because it can be embedded completely inside the precast component without the need for any opening to access the splice during erection. Figure 1 shows the various types of grouted sleeve connections available in the market [1, 2].

The grouted connection should be able to provide adequate strength equivalent to the tensile strength of

the connected reinforcement bars. In other words, under the application of tension load, the grouted connection should be able to anchor the rebars embedded in the sleeve from any pullout failure. Subsequently, adequate anchorage in the splice could ensure that the rebar fracture outside the grouted sleeve. This indicates that the grouted splice connection is able to provide full tensile strength of the connected rebars. The connection capacity relies mainly on the anchorage bond mechanisms between the rebars and the surrounding grout.

Bond is defined as 'the adhesion of concrete or mortar to reinforcement or to other surfaces against which it is placed', and bond strength is defined as 'the resistance to separation of mortar and cement from reinforcing steel and other materials with which it is in contact' [3]. Bond describes the total interaction of the reinforcement with the surrounding material. Understanding the mechanism of bonds leads to

understanding the variables that influence the bond strength.

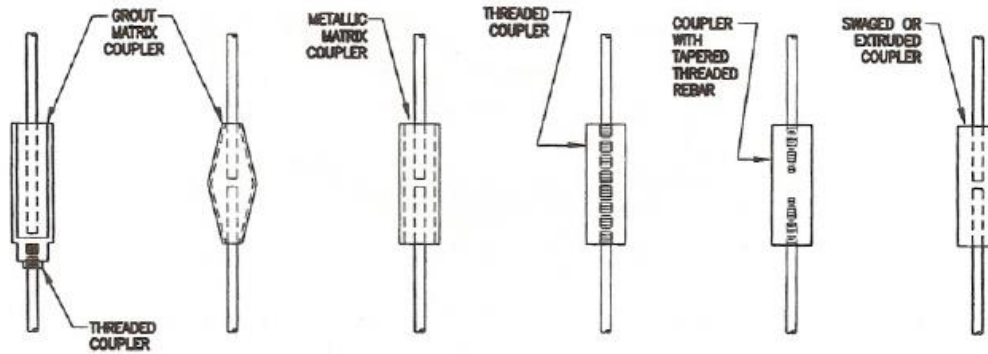


Figure 1 Typical Mechanical Connectors [1]

The three main components which contribute to the bond resistance are: chemical adhesion, frictional resistance, and mechanical interlock between the bar ribs and concrete, which is also termed as the bearing action. These three modes of bonding action may not occur at the same time at any point along the bar. The frictional resistance and bearing action take place only after the adhesion breaks down.

Adhesion occurs due to the chemical bonding between the cement to the bar and the effect of shrinkage stresses that develop during curing [4]. Therefore it should depend on the properties of the material around the bar. According to Malvar [5], chemical adhesion poses a small resisting mechanism for very small values of bond stress of up to 200 psi (≈ 1.38 MPa). The loss of adhesion along the bar increases as the load applied increases.

The bond resistance of ribbed-bars is provided mainly by the mechanical interaction between the bar ribs and the surrounding material. In the early of bond response, the bearing action of the rib onto its surrounding concrete breaks down the adhesion. Later, the bond force is transferred by friction and the mechanical interaction of the ribs with the adjacent concrete. The mechanical interaction dominates the transfer of force as the bar force increases and resulting the force concentrated near the rib faces [5]. According to Hungspreug [6], the bearing action involves crushing of a small portion of confined concrete in front of the rib, bending action of concrete teeth in front of the rib, and the aggregate interlocking when cracks are formed. But how these actions contribute to the bearing resistance is yet to be discovered. Figure 2 shows the bearing of ribs that provide the mechanical interlock.

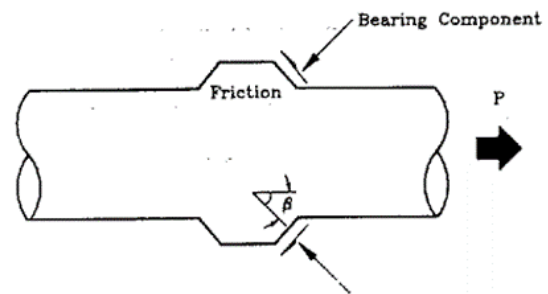


Figure 2 Free body diagram of portion of reinforcing bar embedded in concrete [7]

Soroushian, Choi, Park, and Aslani [9] investigated the effect of confinement on local bond characteristics of deformed bars in reinforced concrete joints. In regards that confinement in joints is normally achieved by closely spaced transverse reinforcement, the authors aim to investigate the influence of the transverse reinforcement to the performance under pullout force. The outcomes of the study show that plain specimens without any vertical and transverse reinforcement as confinement failed by split cracking, which occurred in a brittle manner.

Loh Hsi Yoon [10] conducted 20 grouted splice specimens of various configurations. The experimental test results show that he proposed splice sleeve provided adequate strength to allow continuity between two connected rebars. The splice connection consisted of steel bars with tapered nuts and a simple modified standard steel pipe. The success of the grouted splice is due to good bond provided by the confinement of the steel pipe.

One way of improving the bond strength is through confinement [5, 9, 11, 12, 13]. Confinement can be achieved by means of transverse reinforcement, pressure or cylindrical pipes. Confinement has been proven to be an effective way to enhance the bond between the reinforcement and the surrounding material.

This paper presents a study on 21 steel pipes combined with spiral as a connection to join two reinforcement bars. In this connector, the confinement

is provided by the steel spiral. All the splice specimens were tested under increasing tensile to determine the bond stress between the anchored bars and the surrounding grout.

The objectives of this research are to investigate: (1), the effect of pitch distance of the spiral to the bond stress-slip response, (2), the effect of rebar diameter to the bond stress-slip response.

2.0 EXPERIMENTAL PROGRAMME

2.1 Descriptions of Test Specimens

A total of 21 specimens were tested under pullout load to investigate the effect of different parameters to the behavior and performance of the grouted connection. The parameters considered in this study are pitch distance of the spiral connector and steel rebar size.

Figure 3 shows 3 control specimens where S1 is the lower range of the connection without any spiral. Then specimen S2 comprised a spiral but without splice bars, whereas in specimen S3, a complete grouted spiral connection comprised a steel spiral and 4Y10 splice bars were considered. Further details of the grouted spiral connection are shown in Figures 4 and 5. Descriptions of the specimens are given in Table 1.

In preparing the connection specimen, a spiral with welded splice bars was inserted centrally into the PVC pipe. After that the main reinforcement rebars to be connected were placed at both ends of the spiral splice connection. In order to avoid movement in the connection system, steel wires and wood frames were used to hold the spiral and reinforcement bars firmly in their place. After the specimens were ready to be cast, the bottom end of the specimen was fastened with a small plywood to prevent the flow of grout from the PVC pipe.

As all the specimens were properly placed and arranged, the grout infill material was poured into the PVC pipes and was kept for 28 days until the grout reached the intended strength, see Figure 6. Three cubes for each grout infill were prepared. The infill material was precisely mixed based on the prescribed guide by the grout producer.

The embedment length of connected main rebars was 75 mm for all specimens. This short embedment length was chosen to ensure uniform bond stress along the embedment length so that Equation 1 can be adopted to calculate the bond strength, τ [14].

$$\tau = P / (\pi \times d_b \times L_e) \quad (1)$$

Where

P = Maximum tension load,

d_b = main bar diameter,

L_e = embedment length of connected main bar

2.2 Grout Compressive Strength

Compressive tests on grout cubes of 70 mm x 70 mm x 70 mm were conducted on the day of the test to determine the compressive strength of the grout during pullout. The grout compressive strength is needed as it also plays important role in controlling the anchorage bond between steel reinforcement bar and the grout.

2.3 Direct Pullout Test

All the grouted connections were tested under increasing pullout load using Dartec Universal Testing Machine. In conducting the test, the connected reinforcement bars were fixed between two actuators at top and bottom of the device. Pullout force was applied gradually by the upper actuator while the other one was fixed during the experiment. The loading rate was 0.5 kN per second. All the strain gauges and Low Voltage Displacement Transducer (LVDT) were connected to a data logger and the strain values were printed at every 5 kN of applied load.

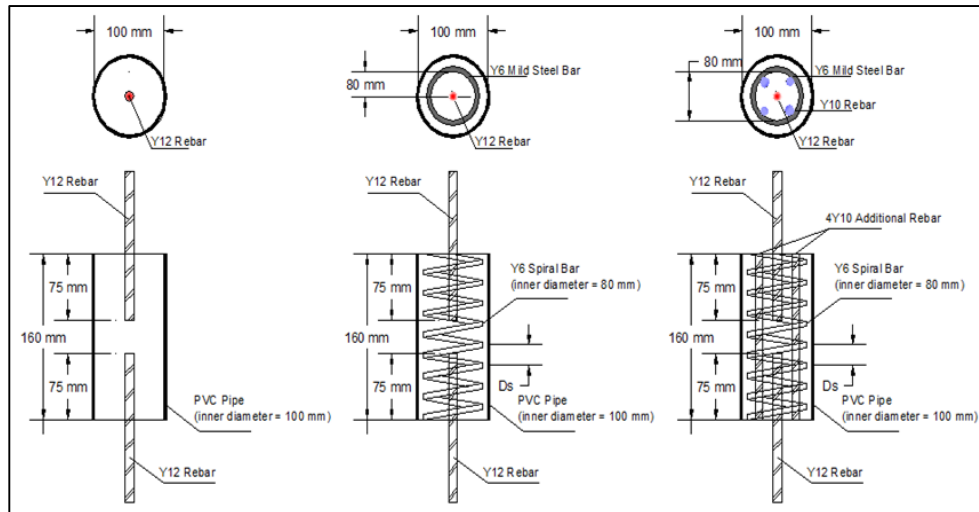


Figure 3 Control specimens S1, S2 and S3

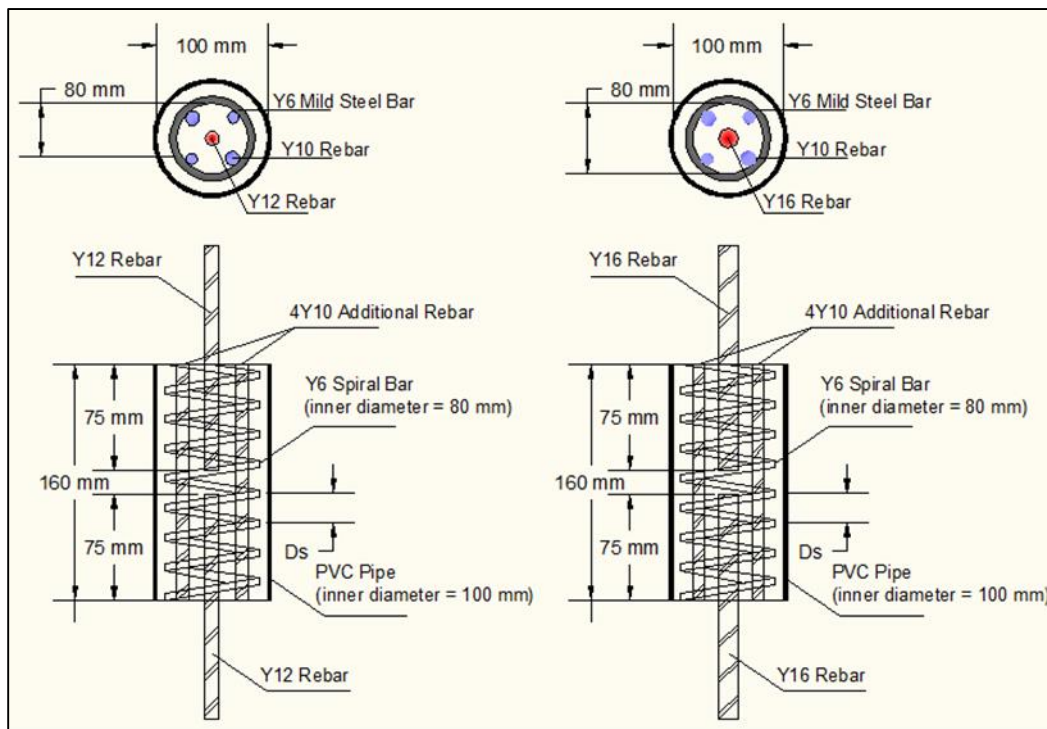


Figure 4 Specimen details



Figure 5 Splice joint with spiral connector and splice bars



Figure 6 Preparation of specimens

Table 1 Descriptions of specimens

Specimen No.	Specimen Specification	Length of specimen (mm)	Embedment length, L_e (mm)	Grout compressive strength, (N/mm ²)	Main rebar diameter (mm)	Pitch distance fo spiral (mm)
S1	Control Specimen				12	No spiral
S2	Control Specimen				12	15
S3	Control Specimen				12	15
S4	Di12 Ds15				12	15
S5	Di12 Ds25				12	25
S6	Di12 Ds35				12	35
S7	Di16 Ds15				16	15
S8	Di16 Ds25				16	25
S9	Di16 Ds35				16	35
S10	Di12 Ds15				12	15
S11	Di12 Ds25	160	75	58.47	12	25
S12	Di12 Ds35				12	35
S13	Di16 Ds15				16	15
S14	Di16 Ds25				16	25
S15	Di16 Ds35				16	35

Specimen No.	Specimen Specification	Length of specimen (mm)	Embedment length, L_e (mm)	Grout compressive strength, (N/mm ²)	Main rebar diameter (mm)	Pitch distance fo spiral (mm)
S16	Di12 Ds15				12	15
S17	Di12 Ds25				12	25
S18	Di12 Ds35				12	35
S19	Di16 Ds15				16	15
S20	Di16 Ds25				16	25
S21	Di16 Ds35				16	35

Where Di = Diameter of main rebar, Ds = Diameter of spiral

3.0 RESULTS AND DISCUSSION

3.1 Response of Control Specimens

Table 2 shows the results of control specimen in terms of bond strength, slip and failure modes. The bond strength, i.e. the maximum bond stress, is calculated using Equation 1.

In the first control specimen S1, the bond strength was 9.57 MPa with the corresponding slip of 33.4 mm. In terms of load transfer mechanism, the ultimate tensile load was applied to the reinforcement bars at both ends. The applied load was transferred from the bars to the grout. Due to strong mechanical interlocking between bar ribs and grout, the grout tended to move as a unit with reinforcement bar,

toward the direction of the pulling force. Similarly, the grout at mid-length had to carry the tensile load to be transferred between the connected main rebars. However, the grout fractured at mid-length because the grout alone was very weak in tension.

The second control specimen, S2 consisted of R6 cylindrical spiral only and without any Y10 splice bars. The ultimate load capacity of this specimen was 27.75 kN, close to the bond strength of specimen S1. The rebar slip at failure was 10.89 mm. This means that the spiral does not improve the performance of the splice significantly although spirals are somewhat effective in restraining the movement of grout. However, spirals have the potential to control the splitting cracks in the splice and prevent deterioration of the connection.

Table 2 Control specimens

Specimen	Grout compressive strength (N/mm ²)	Bar diameter (mm)	Bond strength (MPa)	Slip (mm)	Failure mode
S1	111.3	12	9.57	33.34	Grout broken apart
S2	58.47	12	9.81	10.89	Grout splitting
S3	55.3	12	19.1	6.45	Bar slippage

In specimen S3, the ultimate load capacity was 19.1 kN, the highest as compared to the other two. The slip had reduced significantly to 6.45 mm. This was due to the load applied to the bars was able to be transmitted to the grout and then from the grout to the 4 splice bars along the spiral. Due to the good interlocking mechanism between the main rebars and the spiral, the grout tended to move in the direction of tensile load but the 4 splice bars restrained the grout movement. The splice bars combined with the spiral managed to confine the development of radial cracks in the grout. As a result, the pattern of the failure in this specimen changed from grout split to bar pull-out. This specimen ended up with dislocation of reinforcement bar and the bar slipped out of the grouted sleeve due to excessive tensile force.

Figure 7 shows the corresponding failure modes of control specimens S1, S2 and S3. The response of bond

stress-slip of specimens S1, S2 and S3 is shown in Figure 8. It can be seen that, by introducing spiral without splice bars did not improve the bond strength. However, by attaching 4 splice bars to the spiral, the bond had improved significantly. In brief, it can be observed that the spiral provides the confinement that delays the radial cracks and loss of bond. The spiral is good in providing the confinement but weak in tension as can be seen in specimen S2. The four splice bars welded to the spiral had improved the tension capacity of the joint. The four splice bars had bridged the two connected main reinforcement bars successfully. Figure 8 shows the response of bond stress for S1, S2 and S3. The maximum bond stress achieved by the specimen is defined as the bond strength, τ . The bond stress at any load level, σ is also calculated by using Equation 1.

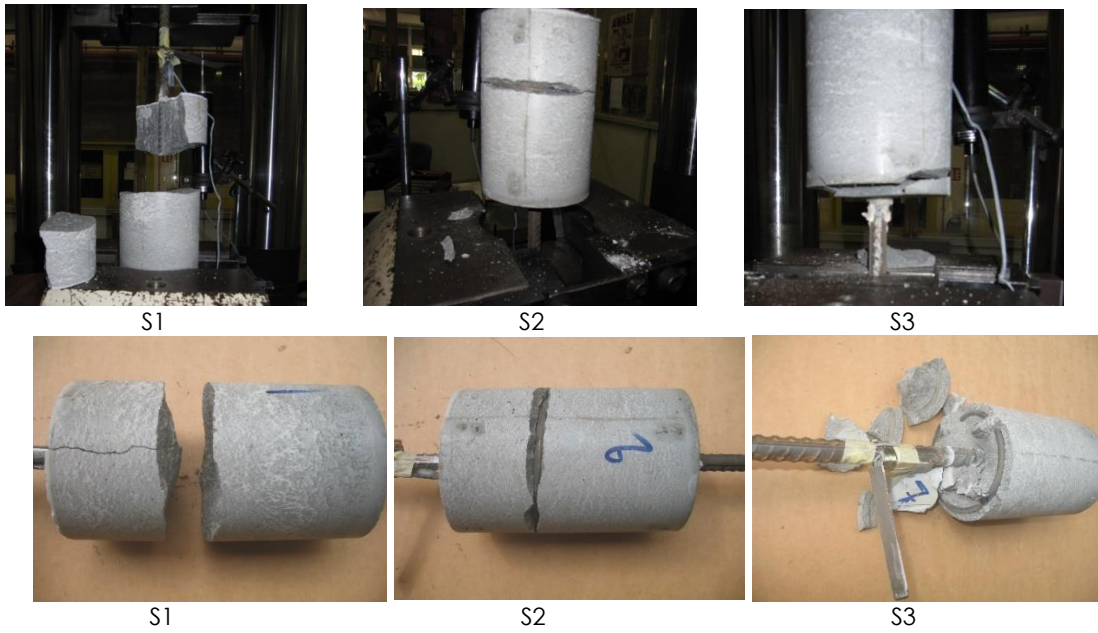


Figure 7 Failure modes of control specimens S1, S2 and S3

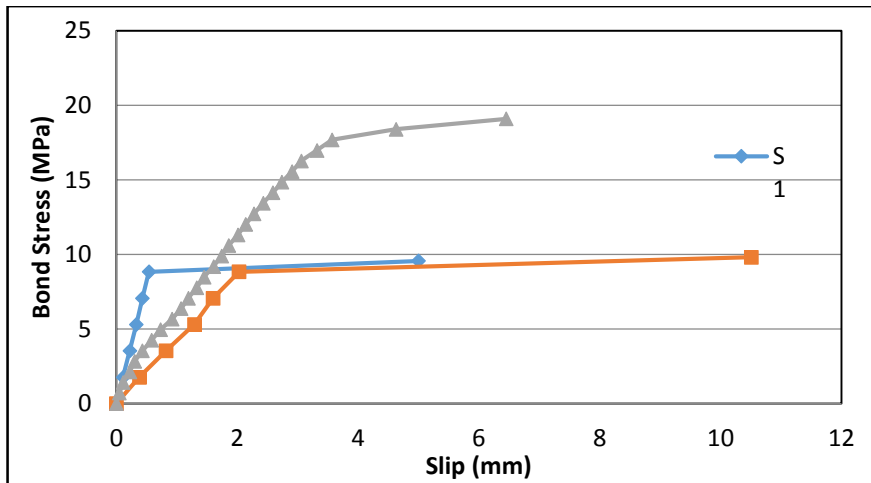


Figure 8 Bond stress-slip response for control specimens S1, S2 and S3

3.2 Effects of Pitch Distance

To study the effect of pitch distance, results of specimens S19, S20 and S21 are considered. From Figure 9 and Table 3, specimen S19 with the smallest pitch distance had the highest bond strength of 16.98 MPa. In the case of pitch distances of 25 mm and 35 mm in specimens S20 and S21 respectively, not much different of bond strength were observed. The bond strength values for pitch distances of 25 mm and 35 mm were 15.07 MPa and 15.12 MPa respectively. This indicates that pitch distances between 25 mm to 35 mm could be the optimum range to give good bond strength of about 15 MPa. Reducing the pitch distance from 25 mm to 15 mm had increased the bond strength by 12.6%.

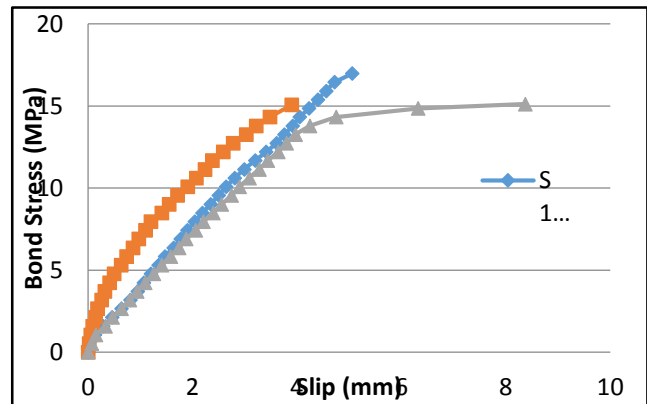


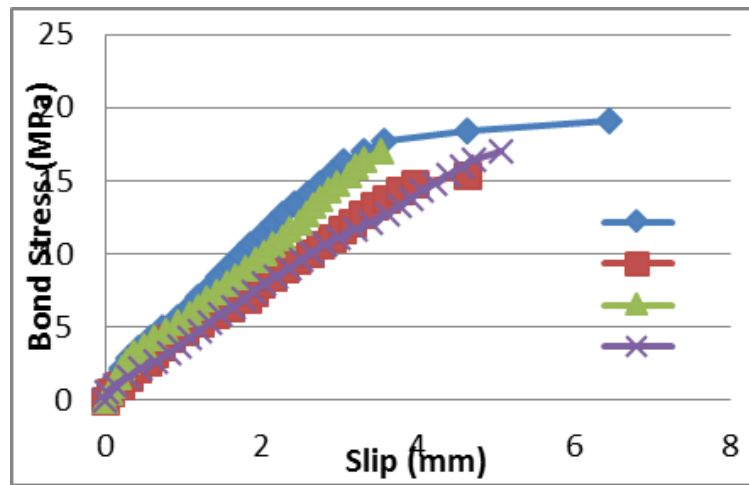
Figure 9 Bond stress-slip response with different pitch distance

Table 3 Bond and slip response with different pitch distance, D_s

Specimen	Specimen Specification	Infill material and grade (MPa)	Bar diameter (mm)	Bond strength (MPa)	Slip (mm)	Failure mode
S19	Di16Ds15	58.47	16	16.98	5.06	Bar slippage
S20	Di16Ds25	58.47	16	15.07	3.9	Bar slippage
S21	Di16Ds35	58.47	16	15.12	8.37	Bar slippage

Figure 10 and Table 4 shows the response of bond stress-slip. The area under the graph represents the bond energy. As can be seen from the figure, S4 has the largest area under its curve indicating it has the largest bond energy as compared to S7, S13 and S19

and therefore able to carry higher tensile load at larger slip.

**Figure 10** Bond stress-slip response with different bar diameter**Table 4** Bond and slip response with different bar diameter

Specimen		Infill material and grade (MPa)	Bar diameter (mm)	Pitch Distance (mm)	Bond strength (MPa)	Slip (mm)	Failure mode
S4	C3-Di12Ds15	58.47	12	15	19.1	6.45	Bar slippage
S7	2(a)-Di16Ds15	58.47	16	15	15.38	4.64	Bar slippage
S13	2(b)-Di16Ds15	58.47	16	15	16.98	3.54	Bar slippage
S19	2@-Di16Ds15	58.7	16	15	16.98	5.06	Bar slippage

4.0 CONCLUSION

Based on the study, the following conclusions are drawn:

1. With the presence of splice bars, the spiral is able to provide the confinement to the surrounding grout that delay the radial cracks which eventually increases the bond strength.
2. Pitch distances between 25 mm to 35 mm could provide the maximum bond strength in the grouted splice connections.
3. Reducing the pitch distance increases the bond strength between the connected main rebars and the surrounding grout. A spirals with smaller pitch distance has better confinement that delay the radial cracks subsequently increases the bond strength.

4. Increasing the diameter of the main reinforcement reduces the bond strength.

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